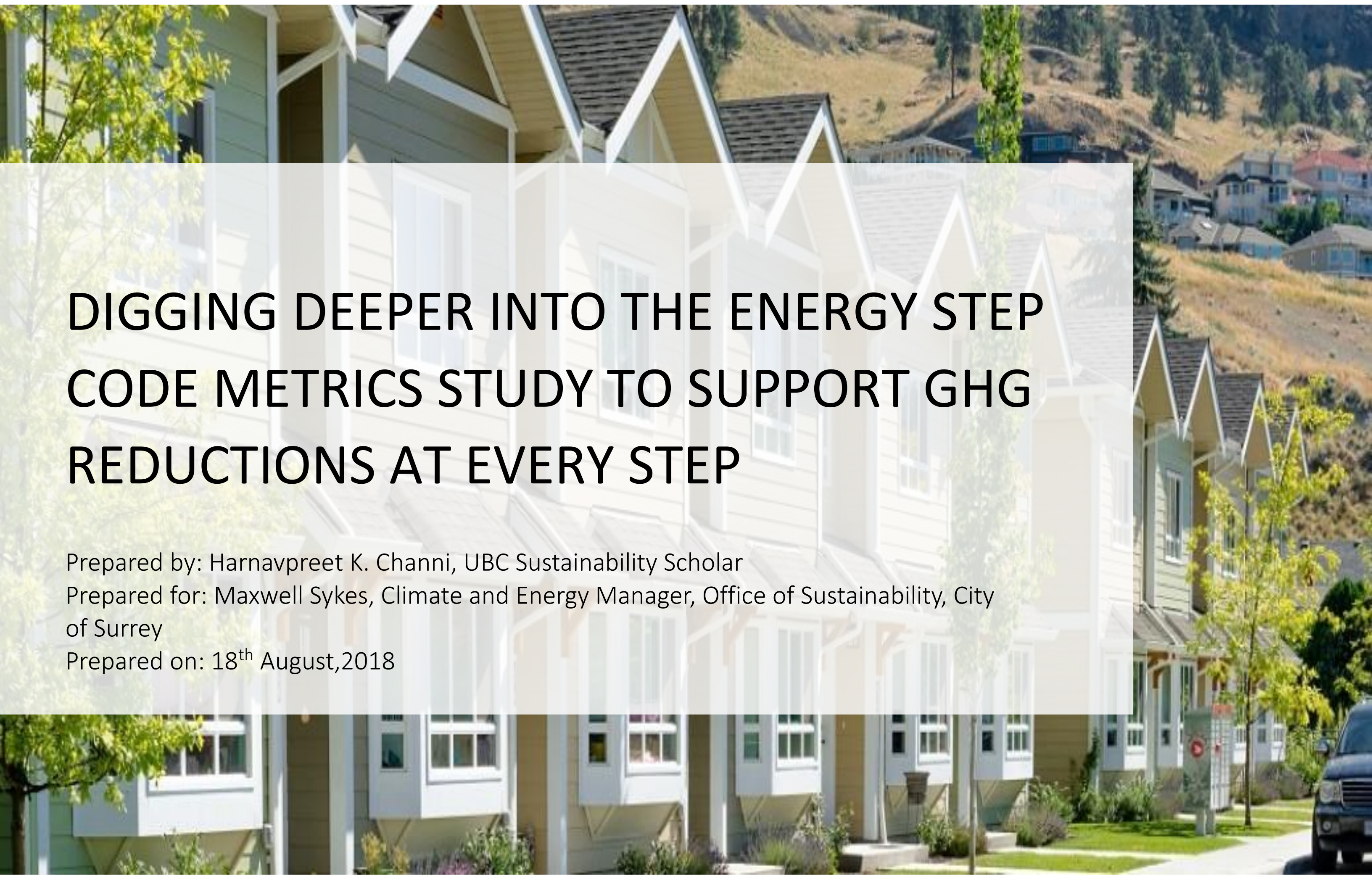

DIGGING DEEPER INTO THE ENERGY STEP CODE METRICS STUDY TO SUPPORT GHG REDUCTIONS AT EVERY STEP

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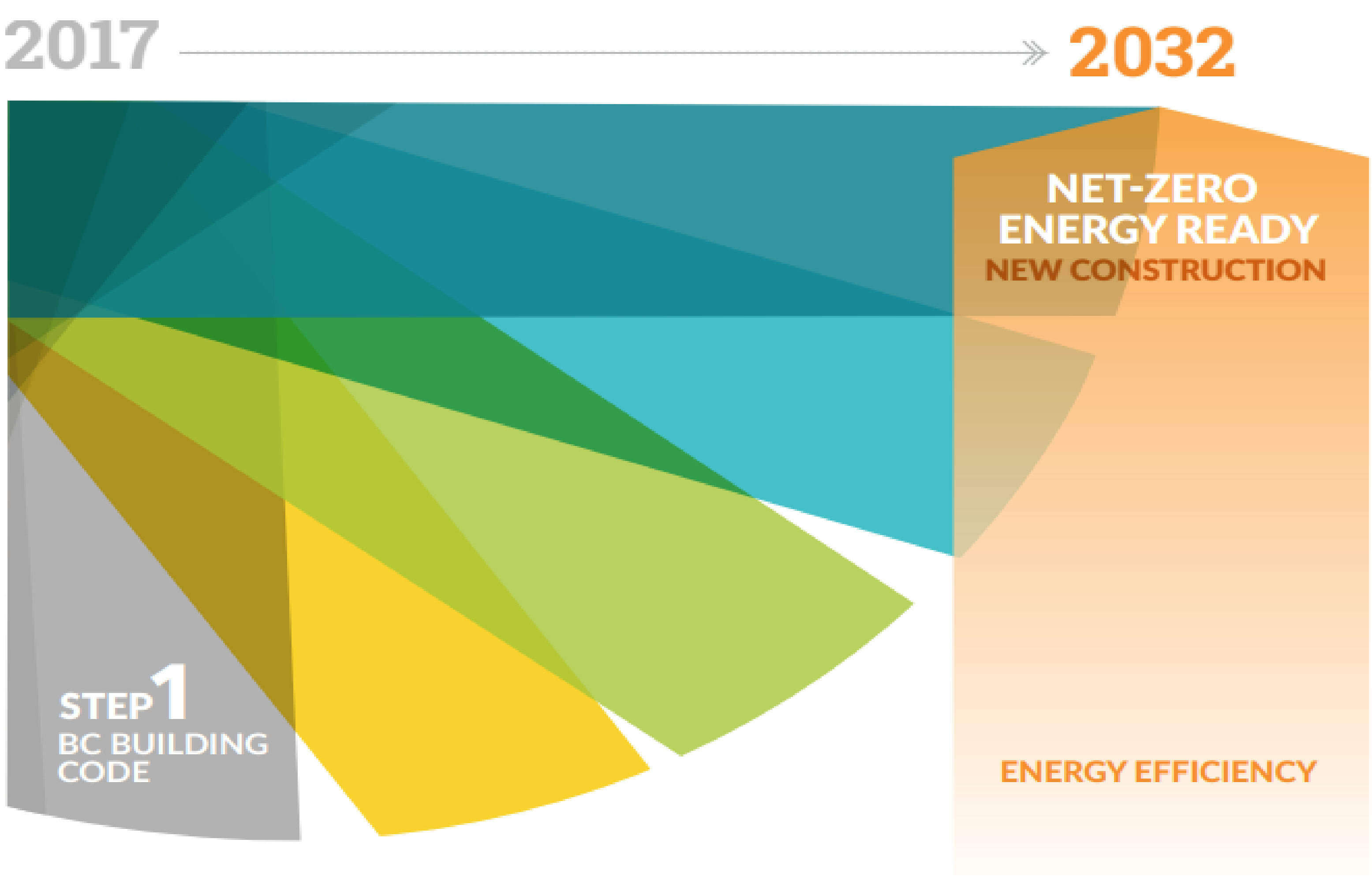

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Introduction

The BC Energy Step Code (Step Code), British Columbia's recently enacted building energy code, is a performance-based standard that establishes a set of Steps, using measurable requirements to achieve incremental improvements in the energy efficiency of new buildings**.**

Developed through a consensus of key stakeholders, the Step Code's goal is to standardize stretch code requirements across the province, help bridge the energy performance gap between today's BC Building Code (BCBC) and the performance of some of today's highest performing buildings. It involves measured steps in reaching the goal of all new construction across the province to be "net-zero energy ready" by 2032 (net-zero energy ready buildings are explained in the Figure 1 below). The Step Code seeks to accomplish this by establishing a series of measurable, performance-based energy-efficiency requirements for construction that local governments may choose to adopt for their communities.[3]

The path to net-zero energy ready buildings is set out through a series of Steps with increasingly stringent performance requirements. Specific metrics and requirements vary by building type (as explained in the Methods chapter), but, in general, builders need to continually improve:

- **Energy Use Intensity (EUI)**: measures overall building energy efficiency by calculating the annual energy consumed by a building per square foot ($kWh/ft^2/yr$)
- **Thermal Energy Demand Intensity (TEDI):** measures building thermal efficiency, which is primarily influenced by the insulating performance of a building's envelope/enclosure, calculated as annual energy required to meet thermal comfort needs per square foot ($kW/ft^2/yr$)
- **Airtightness:** measures energy lost through leakage in the building envelope/enclosure and ventilation system, which affects both EUI and TEDI (ACH@50kPA).

The Step Code provides local governments an important tool to achieve certain policy objectives, while also providing the construction industry with a single set of consistent standards for building energy efficiency across the province. Notably, however, the Step Code is purely an energy-focused regulation. It does not directly target reductions in a building's greenhouse gas (GHG) emissions, nor prioritize any given fuel. While this supports cost-effectiveness and innovation in improving building energy performance, this design approach does not guarantee GHG reductions. As such, local governments, the Province, and other key actors are seeking ways to use the Step Code as a strong climate change mitigation tool.

As one of the fastest growing cities in Canada, the City of Surrey is experiencing a boom in construction. In 2017, for example, the City issued permits for 1118 single family dwelling units, 300 townhouses, and11 low rise apartments, in addition to non-residential building permits (See Figure 3). Population growth, and associated growth in building construction, is projected to last for several decades. With so much growth, GHG emissions from the City will increase significantly, absent policy action to reduce GHG emissions from new buildings.

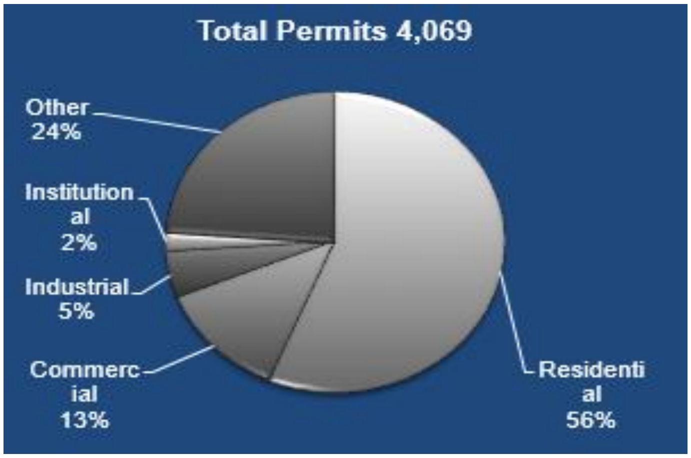

Figure 1 Permits issued for construction in 2017 for the City of Surrey

Figure 2: Net-Zero Buildings[3]

Purpose

The purpose of this study is to conduct quantitative analyses to determine the energy conservation measures (ECMs) that tend to drive the most cost-effective approaches to minimizing GHG emissions from new buildings. More specifically, this study seeks to identify, summarize, and draw conclusions from the set of ECM combinations that appear buildings with low-to-very low GHG emissions, low incremental capital costs (borne by developer and homebuyer), and affordable energy costs (borne by occupant and strata), and therefore lower carbon abatement costs (borne by society). I use a subset of building energy model datasets of climate zone 4 buildings previously modelled for the BC Housing's 2017 BC Energy Step Code Metrics Study. These findings will help to identify what ECMs are important and which are not for each archetype, and consider implications for industry capacity building and government policy, including training, incentives, and similar programs.

This study will enable the City of Surrey to provide builders and other stakeholders a clear picture of what they should focus on (that is, which ECM options to prioritize) in order to achieve greater GHG emissions reductions. The results are relevant to other local governments building in climate zone 4, as well. The results can be expanded and extended to include other building types and

Background

Achieving the Steps

The BC Energy Step Code groups energy-efficiency requirements into a series of “Steps”. The Province has committed to taking these incremental steps as a part of its overarching commitments to improving energy efficiency in the built environment.[3] Figure 4 below depicts the different steps that can be achieved for the different type of buildings (Part 3 or part 9, covered further in the chapter).

To achieve Step 1, builders need to use a whole-building energy model to calculate the energy use of the building and conduct an airtightness test, but the performance of the building only needs to be as good as the base BCBC requirements for energy efficiency. The purpose of Step 1 is to familiarize builders with a new way of measuring and designing for energy efficiency during the construction process, although the actual construction of the building can remain the same as conventional construction.[3]

To achieve the Lower Steps, building and design professionals and trades can rely on conventional building designs with careful air-sealing practices and some incremental improvements incorporated into key elements in the design, building envelope, and equipment and systems. Builders and designers are advised to collaborate with a building energy modeller to select the most cost-effective way to meet the requirements. These Lower Steps give builders new flexibility in how to achieve modest gains in efficiency.

To achieve the Upper Steps, builders and designers will need to adopt a more integrated approach to building design and may need to incorporate more substantial changes in building design, layout, framing techniques, system selection, and materials. These techniques and materials will be more costly and challenging without additional training and experience.

Figure 3: The number of steps with the type of buildings (Part 3 & Part 9 explained further)[4]

As a technical regulation, local governments have the option to voluntarily adopt Steps (performance requirements) to set higher energy compliance standards for builders working locally. Local governments, like the City of Surrey, cannot set their own standards, but can reference the standards set out in the Energy Step Code.

On July 23, 2018, the City of Surrey adopted the Step Code requirements summarized in Table 1 below.

Table 1: Adopted Steps from the Step Code by City of Surrey

Building Type	**Building permit application filed on or after** Apr 1, 2019	Jan 1, 2021
Single Family Home ($\geq$1200ft^2/111.5m^2)	Step 1	Step 3
Small Single Family Home (<1200ft^2/111.5m^2)	Step 1	Step 2
Townhouses and Small Apartments	Step 1	Step 3
Large Wood Frame Residential Apartments	Step 3 ***or*** Step 2, if connected to Surrey City Energy or satisfy low-carbon energy reqs	
Large Concrete Residential Apartments	Step 3 ***or*** Step 2, if connected to Surrey City Energy or satisfy low-carbon energy reqs	
Commercial Office and Mercantile	Step 2	

Building Types

The BCBC, and Energy Step Code, separates all buildings into two basic categories: Part 9 and Part 3. Part 9 buildings are any building less than or equal to 600m^2 and three storeys, while Part 3 buildings are anything larger. Each category of building can have both residential and commercial buildings. They are also explained in the figure below (fig 2).

This study covers the Step Code application to the new construction of Part 9 residential buildings, Part 3 residential buildings, and Part 3 commercial buildings. Performance requirements vary by building types and climate zone, with more stringent requirements for milder climates. This study is limited to Climate Zone 4, which encompasses all of Metro Vancouver, including the City Surrey.

Figure 4: Part 3 and Part 9 buildings[3]

The different types of buildings are further modelled into different types which are explained below:

Modelling Part 3 Buildings:

Archetype	Details
• Low-Rise MURB	Variable characteristics to represent the range of MURBs in the marketplace (see below for more detail), 90% suites, 10% common area
• High-Rise MURB	Variable characteristics to represent the range of MURBs in the marketplace (see below for more detail), 90% suites, 10% common area
• Office	Market, 18,200m^2, 10 storeys, 790 people, 155 parking spaces
• Retail (big box)	Market, 4,500m^2, 1 storey, 150 people

**MURB Multi unit residential building*

Figure 5: Modelling Part-3 buildings[3]

The figures below show the different building structures for Part-3.

Figure 2: Example of a Low-Rise MURB
(Source: Cor)

Figure 3: Example of a High-Rise MURB
(Source: KPF)

Figure 4: Example of a Commercial Office Building
(Source: MGA)

Figure 5: Example of a Retail Building
(Source: REA)

Figure 6: Part 3 buildings Examples[3]

Modelling Part 9 Buildings

Archetype	Details
• MURB (10 units)	Market, 1,654m², 1,780ft²/unit, 3 storey over underground parkade
• Row House (6 units)	Market, 957m², 1,720ft²/unit, 3 storey over underground parkade
• Quadplex	Market, 513m², 1,382ft²/unit, 3 storey over underground parkade
• Large SFD	Market, 511m², 2 storey with basement
• Medium SFD	Market, 237m², 2 storey with basement
• Small SFD*	Market, 102m², single storey on heated crawlspace

**single family dwelling*

Figure 7 Modelling Part 9 buildings[3]

The figures below show the different building structures for Part-9.

Figure 8: Part 9 buildings Examples[3]

The type of building prioritized for this study are:

Part 9 buildings

- Medium SFD
- Large SFD
- Townhouse
- Small SFD
- MURB

Part 3 buildings

- Retail
- Office
- HighRise MURB
- Low Rise MURB

Methods

Building Energy Model Datasets

As discussed in the Introduction, the major aim of this study is to identify combinations of energy conservation measures (ECMs) that building energy modelling has identified as providing significant GHG reductions with affordable energy and capital costs. The strategy used was to filter results based on

GHGs, incremental capital costs, and energy costs. It is to be noted that different thresholds were set for each archetype and these thresholds were determined through a process of iteratively reviewing and filtering datasets.

More specifically, relevant datasets from the Metrics Study that were filtered:

- Greenhouse gas intensity (GHGI, $kgCO_2e/m^2/yr$; GHGI was initially informed in part by the City of Vancouver's Zero Emissions Building Strategy.
  Building scale greenhouse gas emissions are measured in kg CO2e/m2 per year, since these are emissions per unit area they are referred to as emissions intensity or GHGI),
- energy cost intensity (ECI, $\$/m^2/yr$; Energy cost Intensity can be defined as the measurement of a building's annual energy cost relative to its gross square footage per year),
- incremental capital costs (ICC, % of $; the average cost incurred to issue one additional unit of debt or equity) for different archetypes.

For example for medium SFD, the standards used are shown in the table 2 below. Further after setting standards and limitations, it results in a combination of different ECMs and the percentage weightage of each ECM enables to observe which of them would help achieve the desired set targets. All values used to filter GHGI, ECI, and ICC into potential results for analysis are summarized in the Appendix.[1]

Table 2: The standards defined with the archetype (medium SFD)

Archetype	**Step**	**GHGI (kgCO2e/m2/yr)**	**ECI ($\$/m^2/yr$)**	**ICC (%)**
Medium SFD	1	<=6	<=7.5	<=3
	3	<=6	<=7.5	<=3
	4 & 5	<=6	<=7.5	<=3
	1	<=3	<=7.5	<=3
	3	<=3	<=7.5	<=3
	4 & 5	<=3	<=7.5	<=3
	3	<=1	<=7.5	<=3
	4 & 5	<=1	<=7.5	<=3

Energy Conservation Measures Reviewed in this Study

Below I summarize the major ECM categories covered by this study and provide short descriptions of each ECM option within each ECM category.
An Energy conservation measure (ECM) is any type of project conducted, or technology implemented, to reduce the consumption of energy in a building. ECM measures are for example HVAC systems, lighting systems, high R-value, low-emissivity glazing for windows etc

While all ECMs were included in the analysis, an organized sampling of the key ECM findings is presented in this report. Four categories of ECMs were reviewed for this study: space-heating and cooling, domestic hot water, envelop insulation, and window type and insulation. These ECM options were chosen because they have a huge impact on the enrgy performance. Each ECM category includes two ECMs used as indicators to determine what would be necessary to achieve the new buildings requirements. Each ECM has multiple options that can be used in the building. The choice of ECMs drives the energy and emissions resulting from building operations. Note that airtightness is not included as an ECM. Airtightness is known to be one of the most cost-effective ways to reduce energy consumption, but is directly targeted through Part 9 performance requirements and indirectly targeted through Part 3 performance requirements. Future studies could examine the role of airtightness to provide stakeholders further information with which to develop policy and programs.

The covered ECMs are described below.

Space Heating and Cooling

Heating, Ventilation, and Air Conditioning (HVAC) System

An HVAC system is designed to control the thermal comfort and air quality of the environment in which it works. It achieves this by controlling the temperature of a room through heating and cooling. It also controls the humidity level.

- **Baseboard**: electric baseboard heaters heat the room through convection (usually without help of a fan). [5]
- **Base-furnace**: This type of heating system is called a ducted warm-air or forced warm-air distribution system. It can be powered by electricity and natural gas. [6]
- **Cold Climate Air Source Heat Pump (CCASHP):** A heat pump is a device that transfers heat energy from a heat source to a heat sink. [7]
- **Combo heat**: Combo or integrated heating systems provide space heating from a single hot water tank.
- **Gas-furnace**: This type of heating system is called a ducted warm-air or forced warm-air distribution system. It can be powered by natural gas. [8]

Heat Recovery Ventilation

A heat-recovery ventilator (HRV) uses the heat in the outgoing stale air to warm up the fresh air. Heat recovery ventilation works by constantly removing stale, moist air from a building's wet rooms. While this occurs, filtered, fresh air is delivered to habitable rooms, such as living rooms, bedrooms, and dining rooms. The core transfers heat from the outgoing stream to the incoming stream, the percentages mentioned signify the proportion of heat recovery. The heat recovery ventilation options included in the Metrics Study analysis are 0%, 60%, 70%, 75%, and 84%.

Domestic Hot Water

Domestic hot water system

The domestic hot water system (DHW) is used to provide hot water for the kitchen and bathroom sinks, tubs and other appliances. The same boiler can provide both water systems as long as both water systems do not mix. That is the water that circulate through the heating system cannot be circulated through the domestic hot water system.

- **Heat Pump HotWater**: Small mechanical tool installed on central heating system that is used to speed up the process of circulating hot water from boiler to radiators and back to the boiler.
- **Gas (GasInst_Low)**: Gas-fired hot water system**.**
- **Electric (Electric storage)**: Electric immersion heater.
- **Base DHW**: the water is heated directly from the heat source either by an immersion heater or by the boiler.

- **Combo:** Combination boilers that combine the central heating with domestic hot water (DHW) in one device. When DHW is used, a combination boiler stops pumping water to the heating circuit and diverts all the boiler's power to heating DHW. Some combo systems have small internal water storage vessels combining the energy of the stored water and the gas or oil burner to give faster DHW at the taps or to increase the DHW flow rate. [10]
- **Gas-Instantaneous:** This method involves using gas to heat the water to a useable temperature without the need to store the water. The electric versions use a coiled heating element to heat the water rapidly in a similar way to a kettle or immersion heater.

Drain Water Heat recovery

Drain-water heat recovery technology works well with all types of water heaters, especially with demand and solar water heaters. Drain-water heat exchangers can recover heat from the hot water used in showers, bathtubs, sinks, dishwashers, and clothes washers. They generally have the ability to store recovered heat for later use. [11]

Envelope Insulation Performance

Insulation is rated based on a measurement of resistance the material has to the movement of heat. This is most commonly referred to as an R-value. The higher the R-value, the more effective the insulation.

Wall Insulation

Included R-values: 16, 18, 22, 24, 30, 40, 50, and 60.

Roof Insulation

Included R-values: 40, 50, 60, 70, 80, and 100

Window Insulation Performance

Window performance is important because windows let light and heat in from outside of the building.

Window Type and Glazing

Glazing, which derives from the Middle English for 'glass', is a part of a wall or window, made of glass. The two types of glazing covered in this study are discussed as follows:

Double glazed vs triple glazed: double glazed window is made up of two panes of glass with argon gas in the middle. Triple glazing is the same, except there is an additional pane of glass. This means that the triple glazed window has two separate argon gas filled areas. [12]

Window Insulation

Window U-Value also known as the U-factor or coefficient of heat transmission, a measure of the rate of non-solar heat loss or gain through a material or assembly. U-Values gauge how well a material allows heat to pass through. Lower U-values indicated higher performing windows.

Included U-values: 0.8, 1.2, 1.6, 2, 2.5

Results

By setting limits to GHGI, ECI and ICC, I identified combinations of ECMs which could help achieve the desired low-emission buildings at affordable costs for all Steps and building types. The final results for selected archetypes are summarized below. Those seeking more information can find the detailed full results in Appendix.[1][2][3][4]

Based on the City's adopted Step Code approach, Surrey's new construction can be divided into short-term and long-term priorities.

Short-term / 2018-2022

- Step 1 for all Part 9
- Step 2 and 3 for Residential Part 3
- Step 2 for Commercial Part 3

Long-term / 2023 onward

- Step 3+ for all Part 9
- Step 4 for Residential Part 3
- Step 3 for Commercial Part 3

Given these timelines and priorities, the results are presented under three headings:

Step 1 and 2,

Step 3 and

Step 4 and 5.

It should be noted that this study has certainly not identified all useful findings and takeaways, and the City of Surrey should pursue further analysis of the newly- developed datasets to generate further insights.

Ideas for future work and extensions of the current study are provided in the Discussion and Conclusions chapter.

Step 1 and 2

Table 3 below summarizes key findings regarding ECM options for Surrey's high priority archetypes. These findings are based on the subset of results for each archetype when filtered according to the thresholds summarized in the Appendix[2].

The results in the table include some of the major takeaways from the analysis. Below Table 3, I have summarized some of the key takeaways for each archetype.

Table 3: Compilation of selected Step 1 and 2 results

Step 1 and 2						
	Medium SFD	**Large SFD**	**Townhouses**	**MURB**	**HighRise_MURB**	**LowRise_MURB**
Space heating & cooling	>50% electric baseboard; furnaces possible at GHGI<6; ASHPs and baseboard only for GHGI<3	>85% results are electric baseboard for both scenarios	79% basefurnace but for lower GHG targets there is a shift towards 100% ASHP; HRV 60% recovery dominates for GHG<1	88% electric baseboard	100% results are condensing	100% results are condensing
Domestic hot water	HPHotWater for GHG<=3	HPHotWater	Electric Storage to HPHot Water	HPHotWater	100% results are 40	100% results are 40
Envelope	equally distributed, with most of the results <18 gor GHG<6, there is a shift towards higher R value for GHG<3	equally distributed	equally distributed with low R values dominating	equally distributed with low R values dominating	equally distributed	equally distributed
Windows	shift from double glazed to triple glazed	double glazed	shift from triple glazed (66%) to double glazed for lower GHG.	>50% of the results are double glazed and the rest are equally distributed	For GHG<1, maximum results are 2.5 for windows USI value, rest are equally distributed	100% results are 2.5 for windows USI value, rest are equally distributed

Medium SFD

Space heating and cooling

- 52% of the results are electric baseboard for GHG<6 with the remainder mostly divided among natural gas options and
- 44% of the results for GHG<3 are CCASHP.
- When there is a shift from GHG<6 to GHG<3, the results shift from baseboard to ASHP.
- For HRV, the results evenly distributed at GHG<3 (implying that none of the result majorly dominates), but for GHG<6 half of the buildings had 0% HRV.

Domestic hot water

- With baseDHW & HpHotwater dominating for GHG<=6, there is a shift towards HpHotWater for GHG<=3.

Envelope

- For GHG<6, it is equally distributed, with most results between R18 and R60, further there is a shift towards higher R value for GHG<3.

Windows

- There is shift in double glazed glass percentage weightage from 78% of the results for GHG<6 to 67% of the results for GHG<=3.

Large SFD

Space heating and cooling

- 89% of the results are electric ASHP for GHG<3
- 86% is for ASHP for GHG<1.

Domestic hot water

- For lower GHG targets (ie GHG<1),HPHotWater results are 79%
- For GHG<3, 21% of the results are HPHotwater.
- Domestic hot water recovery is 0% for maximum results for GHG<3 (74% of the results) and for GHG<1, Domestic hot water recovery is 0% for 61% of the results.

Envelope

- For both GHGI<3 and GHGI<6, builders can continue to use more common, lower performing envelope systems (R-16 to R-24) for walls and R-40 to R-70 for roof.

Windows

- Pane and glaze, the windows are double glazed for GHG<3 and for GHG<1, the percentage weightage is almost evenly distributed with double glazed still dominating.

Townhouse

Space heating and cooling

- For HVAC, 79% of the results are basefurnace. In order to achieve lower GHG targets there is a shift towards ASHP.
- For targets GHG<1, 100% of the results are ASHP.
- Heat recovery system, a direct relationship cannot be interpreted but 0% recovery dominates for GHG<6,
- As there is shift to lower GHG values, 60% recovery dominates for GHG<1 (that is 34% of the results), rest 66% is evenly distributed.

Domestic hot water

- From 65% of the results are electric storage for GHG<6, there is a shift towards HPHotWater (92% of the results) for GHG<1.

Envelope

- There are Low R values of R-16 & R-18 are observed in the cases for GHG<6.
- There is a shift towards higher R value (between R-40 to R-60) for GHG<3,
- But for GHG<1 the shift is back to lower R values (between R-16 to R-24).

Windows

- Pane and glaze, for GHG<6 it is LG-avg-DOUBLE glazed (73% of the results).

- For GHG<3, there is a shift towards HG-i89-Triple glazed (45% of the results) and 21% of the results are HG-avg-triple, that is triple glazed dominates.
- For GHG<1, the percentage weightage is almost equally distributed among double and triple glazed, with double glazed still dominating.

MURB

Space heating and cooling

- For HVAC, 88% of the results are electric baseboard.

Domestic hot water

- 69% of the results are HPHotWater for GHG<1.

Envelope

- R values vary from R-16 to R-24 for wall R value and 50% of the results are R-40 for roof R value.

Windows

- Pane and glaze, >50% of the results are double glazed.

Highrise_MURB

Space heating and cooling

- For heating efficiency, 100% of the results are condensing for step 1 & 2.
- Vent heat recovery, 73% of the results have 60% heat recovery for GHG<5, step1.
- Step2, GHG<5, 55% of the results have 60% heat recovery & rest is 80% HRV.

Domestic hot water

- 100% of the results are 40% DHW savings.

Envelope

- For wall R values, the results vary between R-4 to R-10.
- For roof R values, the results are majorly R-20.

Windows

- Pane and glaze, for 100% of the results are 2.5 for step 1,
- For step 2, 81% of results are window USI value >=2.

Lowrise_MURB

Space heating and cooling

- For heating efficiency, 100% of the results are condensing for step 1 & 2.
- Vent heat recovery, 73% of the results have 60% heat recovery for GHG<5, step1.
- For step2, GHG<5, 55% of the results have 60% heat recovery & rest is 80% HRV.

Domestic hot water

- 100% of the results are 40% DHW savings.

Envelope

- For wall R values, the results vary between R-4 to R-20.
- For roof R values, the results are majorly R-20.

Windows

- Pane and glaze, for 100% of the results are window USI value 2.5.

Step 3

Table 4 below summarizes key findings regarding ECM options for Surrey's high priority archetypes. These findings are based on the subset of results for each archetype when filtered according to the thresholds summarized in the Appendix[3]. The results in the table include some of the major takeaways from the analysis. Below Table 4, I have summarized some of the key takeaways for each archetype.

Table 4: Compilation of selected Step 3 results

Step 3						
	Medium SFD	**Large SFD**	**Townhouses**	**MURB**	**HighRise_MURB**	**LowRise_MURB**
Space heating & cooling	48% electric baseboard; 33% are basefurnace but for GHG<3 90% results are baseboard; 84%HRV is required for both GHG<6 And GHG<3	83% electric baseboard	88% basefurnace but for lower GHG targets there is a shift towards 100% ASHP; For HRV 86% of the results are <=70%HRV for lower GHG <=60% HRV	100% electric baseboard; no HRV (68% of results)	91% results are condensing; 60% HRV required	91% results are condensing; 100% HRV required
Domestic hot water	for GHG<3, HPHotWater; DHWR 83% of results are <=30%DHWR	HPHotWater; 90% of results are <=30% DWHR	Electric Storage(52%) for GHG<6 to HPHot Water for GHG<1	HPHotWater; 66% of the results <=30% HRV	100% results are 40	100% results are 40
Envelope	equally distributed, low R values dominating	equally distributed, low R values dominating	equally distributed with low R values dominating	equally distributed with low R values dominating	equally distributed, low R values dominating	equally distributed, low R values dominating
Windows	shift from double glazed to triple glazed	double glazed for GHG<3	shift from double glazed to triple glazed for lower GHG, but double glazed still dominates	66% of the results are double glazed	86% results are >=1.6 for windows USI value	91% results are >=1.6 for windows USI value

Medium SFD

Space heating and cooling

- For HVAC, 48% of the results are electric baseboard and 33% are Basefurnace for GHG<6.
- But for lower GHG targets GHG<1, 90% of the results are electric baseboard.
- For HRV, evenly distributed at GHG<6 with 84% HRV dominating (29% of the results)
- For HRV, for GHG<3 & GHG<1, the results are evenly distributed amongst values 0%, 60%, 70%, 75%, 84%HRV.
- For GHG<3, 40% of buildings require 84% HRV.

Domestic hot water

- In order to achieve better GHG minimization target, there is a shift from 29% weightage of HPHotwater for GHG<6 to 90% of HPHotWater for GHG<3.

- Domestic water heat recovery, for GHG<6, 83% of the results are <=30% DWHR and it remains same for GHG<3.

Envelope

- There are Low R values (R-16 to R-24) observed in the cases, GHG<6.
- There is a shift towards higher R value (R-16 to R -40) for GHG<3.

Windows

- For GHG<=6 there is shift from double glazed (41%) to triple glazed (50%) for GHG<=3.

Large SFD

Space heating and cooling

- For HVAC, 83% of the results are baseboard.

Domestic hot water

- For GHG targets of (ie GHG<3), it is BaseDHW.
- 90% of the results require <=30% DWHR

Envelope

- There R values are equally distributed, with lower R values (R-16 to R -24 for wall R value) & for roof R value it is R-40 to R-50 dominates.

Windows

- Pane and glaze, the windows are double glazed for GHG<3.

Townhouse

Space heating and cooling

- For HVAC, 88% of the results are basefurnace.
- For targets GHG<1, 100% of the results are ASHP.
- For heat vent recovery, GHG<6, 86% of the results are <=70% HRV,
- But for GHG<3, there is a shift towards high vent heat recovery values that is >=60%.
- For GHG<1, again 76% of the results are less than 60% HRV.

Domestic hot water

- From 52% weightage of electric storage for GHG<6,
- there is a shift towards 100% of the results for electric storage for GHG<3 and
- Further 100 % of the results are HPHotWater for GHG<1.

Envelope

- There are Low R values are observed for GHG<6, that is 77% of the results are for R<=18.
- For GHG<3, there is an shift towards high R value (between R-22 to R-40) but for GHG<1, again there is a shift towards <=18 R value.

Windows

- Pane and glaze, for GHG<6 it is LG-avg-DOUBLE glazed.
- For GHG<3, there is a shift towards MG-i89-Triple glazed.
- For GHG<1, the percentage weightage is again LG-avg-DOUBLE glazed.

MURB

Space heating and cooling

- For HVAC, 100% of the results are electric baseboard.
- 68% of the results say that no Heat vent recovery is required.

Domestic hot water

- From 52% of the results are HPHotWater for GHG<1.
- There is an equal distribution of results amongst the available options (0%, 30%, 42%, 55%) for DWHR, still 66% of the results are <=30%HRV.

Envelope R-values-

- A lower R value is observed in most cases. For wall R value R-16 to R-22 and for roof R value it varies between R-40 to R-50.

Windows

- Pane and glaze, for 66% of the results it is LG-avg-DOUBLE glazed.

Highrise_MURB

Space heating and cooling

- For heating efficiency, 91% of the results are condensing for step 3.
- A 60% HRV is required.

Domestic hot water

- 100% of the results are 40% DHW savings

Envelope

- There is an equal distribution of R values that is between R-7 to R-20, dominating the scenario for wall R value case but for roof R value it is R-20.

Windows

- Pane and glaze, for 86% of the results are window USI value >=1.6.

Lowrise_MURB

Space heating and cooling

- For heating efficiency, 91% of the results are condensing for step 3.

Domestic hot water

- 100% of the results are 40% DHW savings.

Envelope

- There is an equal distribution of R values that is between R-7 to R-20, dominating the scenario for wall R value case but for roof R value it is R-20.

Windows

- Pane and glaze, for 91% of the results are window USI value >=2 for step 3.

Step 4 and 5

Table 5 below summarizes key findings regarding ECM options for Surrey's high priority archetypes. These findings are based on the subset of results for each archetype when filtered according to the thresholds summarized in the Appendix[4]. The results in the table include some of the major takeaways from the analysis. Below Table 5, I have summarized some of the key takeaways for each archetype.

Table 4: Compilation of selected Step 4 and Step 5 results

Step 4 and 5						
	Medium SFD	**Large SFD**	**Townhouses**	**MURB**	**HighRise_MURB**	**LowRise_MURB**
Space heating & cooling	71% of results are electric & 26% basefurnace, for GHG<3 100% results are baseboard; for GHG<6 <=60%HRV(59 % of results) and for GHG<3 there is an equal distribution	CCASHP-ecm	89% basefurnace but for lower GHG targets there is a shift towards 100% ASHP; for HRV most results are <=60%HRV (all scenarios)	100% electric baseboard; no HRV (68% of results)	55% results are condensing	55% results are condensing
Domestic hot water	72% weightage to 86% for GHG<3 HPHotWater; Domestic heat water recovery <=30%	for GHG<3, there is a shift from GasInstantaneous (45%) , electric storage (17%) to HPHotWater (55%) & electric storage (45%) for GHG<1	100% electric storage for GHG<3 to 91% HPHot Water for GHG<1	HPHotWater ; 66% of the results <=30% HRV	100% results are 40	100% results are 40
Envelope	equally distributed, low R values dominating	equally distributed, low R values dominating	equally distributed with low R values dominating	equally distributed with low R values dominating	equally distributed,	83% of results have wall R value of 20.
Windows	shift from 60% to 78% double glazed for GHG<3	double glazed	shift from double glazed to triple glazed for lower GHG, but double glazed still dominates	66% of the results are double glazed	26% results are 2.5 for windows USI value, rest are equally distributed	39% results are 2.5 for windows USI value, rest are equally distributed

Medium SFD

Space heating and cooling

- 71% of the results are electric baseboard and 26% are basefurnace for GHG<6 with the shift to a weightage of 100% baseboard for GHG<3 and GHG<1 target.
- For HRV, 59% of the results are <=60% HRV for GHG<=6 and for GHG<=3, there is an equal distribution of HRV percentages of 0%, 60%, 70%, 75%, 84% HRV.

Domestic hot water

- In order to achieve better GHG minimization target, there is a shift from 72% weightage of HPHotwater for GHG<6 to 86%of the results for GHG<1 as well as GHG<3 for HPHotWater.
- For DWHR, the results are almost same for both the scenarios that is <=30% DWHR.

Envelope

- An equal distribution of R values with the bent towards a lower R value from R-16 to R-24.

Windows

- For GHG<=6 there is shift from 60% to 78% double glazed for GHG<=1.

Large SFD

Space heating and cooling

- 76% of the results of GHG<3 are CCASHP-ecm
- 69% of the results for CCASHP-ecm for GHG<1.

Domestic hot water

- For GHG targets (ie GHG<3), it is GasInstantaneous (45% of the results) , electric storage (17% of the results)
- For GHG <1, it is HPHotWater (55% of the results) & electric storage (45% of the results).

Envelope

- There are lower R values (R-16 to R-24) are equally distributed for GHG<=3 and for GHG<=1 it varies between R-16 to R-40.

Windows

- Pane and glaze, the windows are LG-avg-double glazed for GHG<3 & for GHG<1.

Townhouse

Space heating and cooling

- For HVAC, for GHG<6, 89% of the results are basefurnace.
- For targets GHG<3 & GHG<1, 100% of the results are CCASHP.
- For HRV, the results are <=60%HRV, for all the scenarios

Domestic hot water

- From 93% weightage of HPHotWater for GHG<6,
- there is a shift towards 100% of the results being electric storage for GHG<3,

- 91% of results HPHotWater for GHG<1.

Envelope

- There are Low R values (R-16 to R -24) are observed in almost all the cases.

Windows

- Pane and glaze, for GHG<6 it is MG-i89-DOUBLE glazed.
- For GHG<3, there is a shift towards 100% HG-avg-Triple glazed.
- For GHG<1, 77% of the results are LG-avg-double.

MURB

Space heating and cooling

- 95% of the results are electric baseboard for GHG<1.

Domestic hot water

- 54% of the results say HPHotwater system for GHG<1.
- 52% of the results require 0% DHW savings for GHG<1.

Envelope

- Lower R value dominates that is R<=24 for wall R value value for GHG<1.
- Lower R value dominates that is R<=70 for roof R value value for GHG<1.

Windows

- 65% of the results are LG-avg-Double for GHG<1.
- 65% of the results have a window U value of 1.8 for GHG<1.

Highrise_MURB

Space heating and cooling

- For heating efficiency, 55% of the results are condensing.

Domestic hot water

- 100% of the results are 40% DHW savings

Envelope

- There is an equal distribution that is for wall R value R-7 to R-20 and for roof R value it is equally distributed between R-20 and R-40.

Windows

- Pane and glaze, for 26% of the windows USI results are 2.5.

Lowrise_MURB

Space heating and cooling

- For heating efficiency, 55% of the results are condensing for step 3.

Domestic hot water

- 100% of the results are 40% DHW savings

Envelope

- 83% of the results have an wall R value of 20.

Windows

- Pane and glaze, for 39% of the windows USI results are 2.5.

Discussion and Conclusions

Recommendations

The Province and local governments can use several policy tools to pursue the low-emission, affordable buildings investigated in this study. For example, education, awareness, and capacity building can be applied to simply encourage builders to use the identified ECM approaches, or governments could provide incentives for certain ECMs to increase their uptake. Local governments, in conjuction with the Province and utilities, can work with industry stakeholders to select the tool(s) that are most suitable to their circumstances.

From the study completed there are some valuable take-aways and visual representation of the findings, which can be developed to better communicate the study findings to key stakeholders. One of which is from Step 1 results, Townhouse archetype, space heating and cooling system:

The space heating cooling system for townhouses is shown in Figure 7 below for GHG<6, GHG<3 and GHG<1 with the ECM options displayed in the bar graph representing that for lower GHG targets that is GHG<1 the results are 100% CCASHP.

This indicates the importanvce of heat pumps for achieving cost-effective (near) decarbonization of townhome space heating, and suggests this as a prioirity for Surrey and other cities seeking such buildings.

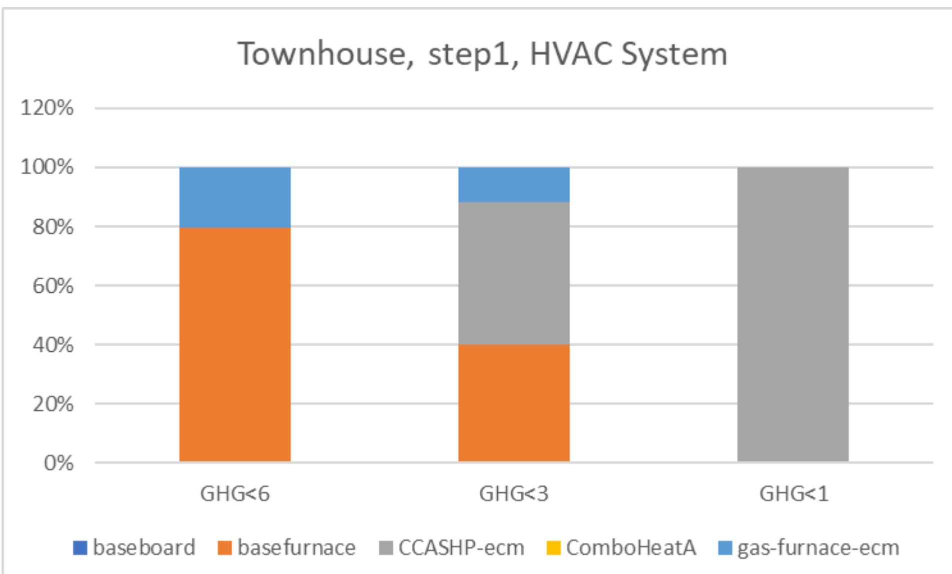

Figure 9: Archetype: Townhouse; Step1; HVAC system; with GHG limitations

As a next step, findings like these can be identified and translated to more visual representation for communication to industry and other important stakeholders.

Ideas for future work

Moving forward, the City can learn from the relevant results described above to design and implement policies and programs to address their respective short- and long-term approaches. The City should also consider the following points in designing any follow-up analysis:

Medium SFD, Step 1

Heat recovery system: 55% of the results say that HRV should be >=70%, at GHG<3, but for GHG<6 half of the buildings had 0% HRV. So more research can be done to understand HRV for these scenarios in order to understand that relation that for GHG<3 why >=70% heat vent recovery is required and for lower GHG target no heat vent recovery is required.

Townhouse, Step 1

Heat recovery system: A direct relationship can not be interpreted but 0% recovery dominates for GHG<6, and as there is shift to lower GHG values, 60% recovery dominates for GHG<1 (that is 34%). Rest 66% of data is evenly distributed. So further research can be done in order to understand HRV relationship that is there a vent heat recovery required or 0% is a good enough.

Envelope R-values: There are Low R values (between R-16 to R-24) are observed in the cases, GHG<6. There is a shift towards higher R value for GHG<3, but for GHG<1 there is an equal distribution among all the R values so no proper answer is obtained as to which R value will be beneficial as it varies from R-16 to R-60 with none of the results dominating. Further investigation can be done in order to understand that is envelope R value an important factor in order to achieve lower GHG targets or not.

Townhouse, Step 3

Envelope R-values: There are Low R values are observed for GHG<6, that is 77% of the results are <=18.For GHG<3, there is an shift towards high R value but for GHG<1, again there is a shift towards <=18 R value. Further study can be done in order to understand that in order to achieve lower GHG targets a higher R value is the answer or a lower R value.

Large SFD, Step 4 and 5

Space heating and cooling: For HVAC, 76% of the results of GHG<3 drop to 69% CCASHP-ecm. Further investigation can be done in order to understand that is ASHP a good enough option to achieve lower GHG targets or not.

Commercial buildings (Part 3)

The methods described in this paper were also applied to non-residential buildings. However, there was not enough time to review and draw conclusions from all the results. The analysed data could be looked into further and the study can be expanded to include other archetypes. And it can be noted that the data is ready for another person to start that analysis.

Appendix 1: Scenario Conditions

The tables below summarize the thresholds used for identify the desired buildings for each priority archetype and Step.

Table 5: The standards defined with the archetype (medium SFD)

Archetype	Step	GHGI (kgCO2e/m2/yr)	ECI ($/m²/yr)	ICC (%)
MEDIUM SFD	1	<=6	<=7.5	<=3
	3	<=6	<=7.5	<=3
	4 & 5	<=6	<=7.5	<=3
	1	<=3	<=7.5	<=3
	3	<=3	<=7.5	<=3
	4 & 5	<=3	<=7.5	<=3
	3	<=1	<=7.5	<=3
	4 & 5	<=1	<=7.5	<=3

Table 6: The standards defined with the archetype (Large SFD)

Archetype	Step	GHGI	ECI	ICC
Large SFD	1	<=3	<=6	<=2
	3	<=3	<=6	<=2
	4&5	<=3	<=6	<=2
	1	<=1	<=6	<=3
	3	<=1	<=6	<=3

Table 7: The standards defined with the archetype (Townhouse)

Archetype	Step	GHGI	ECI	ICC
Townhouse	1	<=6	<=10	<=2
	3	<=6	<=10	<=2
	4&5	<=6	<=10	<=3
	1	<=3	<=10	<=3
	3	<=3	<=10	<=3
	4&5	<=3	<=10	<=3
	1	<=1	<=10	<=5
	3	<=1	<=10	<=5
	4&5	<=1	<=10	<=5

Table 8: The standards defined with the archetype (MURB)

Archetype	Step	GHGI	ECI	ICC
MURB	1	<=1	<=10	<=2
	3	<=1	<=10	<=2
	4&5	<=1	<=10	<=2

Table 9: The standard defined with the archetype (low rise MURB (mid occupancy))

Archetype	Step	GHGI	ECI	ICC
Low rise MURB (Mid occupancy)	1	<=5	<=10	<=2
	2	<=5	<=10	<=2
	3	<=5	<=8	<=2
	4	<=5	<=8	<=2

Table 10: The standards defined with the archetype (High rise MURB (mid occupancy))

Archetype	Step	GHGI	ECI	ICC
High rise MURB (Mid occupancy)	1	<=5	<=10	<=2
	2	<=5	<=10	<=2
	3	<=5	<=8	<=2
	4	<=5	<=8	<=2

Appendix 2: Full Step 1 and 2 Results

The figures below present screenshots from modelled building datasets developed for this study. These results offer opportunities for further analysis, and no doubt can be used to generate additional takeaways for government policies and programs.

Medium SFD

Step 1

GHGI	ICC	ECI
≤6	≤3%	≤$7.5

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	52%	**0%**	25%	**BaseDHW**	20%	**0%**	57%	**16**	39%	**40**	31%	**HG-avg-Triple**	18%	**0.8**	1%
basefurnace	29%	**60%**	21%	**Combo**	0%	**30%**	23%	**18**	25%	**50**	19%	**HG-HP-Triple**	1%	**1.0**	1%
CCASHP-ecm	7%	**70%**	14%	**GasInstantaneous**	18%	**42%**	9%	**22**	9%	**60**	13%	**HG-i89-Triple-B**	1%	**1.2**	22%
ComboHeatA	0%	**75%**	14%	**HPHotWater**	28%	**55%**	11%	**24**	15%	**70**	12%	**LG-avg-Double**	41%	**1.4**	10%
gas-furnace-ecm	11%	**84%**	27%	**ElectricStorage**	22%			**30**	5%	**80**	6%	**LG-avg-Triple**	4%	**1.6**	27%
				GasInst_Low	12%			**40**	8%	**100**	20%	**MG-HP-Double**	10%	**1.8**	41%
								50	0%			**MG-i89-Double**	27%		
								60	0%						

GHGI	ICC	ECI
≤3	≤3%	≤$7.5

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	56%	**0%**	50%	**BaseDHW**	0%	**0%**	78%	**16**	39%	**40**	28%	**HG-avg-Triple**	33%	**0.8**	0%
basefurnace	0%	**60%**	17%	**Combo**	0%	**30%**	6%	**18**	11%	**50**	22%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	44%	**70%**	11%	**GasInstantaneous**	0%	**42%**	0%	**22**	11%	**60**	6%	**HG-i89-Triple-B**	0%	**1.2**	33%
ComboHeatA	0%	**75%**	11%	**HPHotWater**	94%	**55%**	17%	**24**	11%	**70**	11%	**LG-avg-Double**	33%	**1.4**	17%
gas-furnace-ecm	0%	**84%**	11%	**ElectricStorage**	6%			**30**	6%	**80**	11%	**LG-avg-Triple**	0%	**1.6**	17%
				GasInst_Low	0%			**40**	22%	**100**	22%	**MG-HP-Double**	17%	**1.8**	33%
								50	0%			**MG-i89-Double**	17%		
								60	0%						

Figure 10: Medium SFD Step 1 results

Large SFD

Step 1

GHGI	ICC	ECI
≤3	≤2%	≤$6

Space Heating and Cooling		Domestic Hot Water				Envelope R-Values				Windows			
HVAC		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	11%	**BaseDHW**	26%	**0%**	74%	**16**	58%	**40**	37%	**HG-avg-Triple**	11%	**0.8**	0%
basefurnace	0%	**Combo**	0%	**30%**	11%	**18**	37%	**50**	16%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	89%	**GasInstantaneous**	26%	**42%**	16%	**22**	0%	**60**	11%	**HG-i89-Triple-B**	0%	**1.2**	11%
ComboHeatA	0%	**HPHotWater**	21%	**55%**	0%	**24**	5%	**70**	21%	**LG-avg-Double**	68%	**1.4**	5%
gas-furnace-ecm	0%	**ElectricStorage**	0%			**30**	0%	**80**	11%	**LG-avg-Triple**	0%	**1.6**	16%
		GasInst_Low	26%			**40**	0%	**100**	5%	**MG-HP-Double**	5%	**1.8**	68%
						50	0%			**MG-i89-Double**	16%		
						60	0%						

GHGI	ICC	ECI
≤1	≤2%	≤$6

Space Heating and Cooling		Domestic Hot Water				Envelope R-Values				Windows			
HVAC		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	14%	**BaseDHW**	0%	**0%**	61%	**16**	39%	**40**	39%	**HG-avg-Triple**	25%	**0.8**	0%
basefurnace	0%	**Combo**	0%	**30%**	18%	**18**	18%	**50**	11%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	86%	**GasInstantaneous**	0%	**42%**	4%	**22**	7%	**60**	11%	**HG-i89-Triple-B**	0%	**1.2**	25%
ComboHeatA	0%	**HPHotWater**	79%	**55%**	18%	**24**	14%	**70**	25%	**LG-avg-Double**	46%	**1.4**	11%
gas-furnace-ecm	0%	**ElectricStorage**	21%			**30**	11%	**80**	0%	**LG-avg-Triple**	0%	**1.6**	18%
		GasInst_Low	0%			**40**	11%	**100**	14%	**MG-HP-Double**	11%	**1.8**	46%
						50	0%			**MG-i89-Double**	18%		
						60	0%						

Figure 11: Large SFD step 1 results

Townhouses

Step 1

GHGI	ICC	ECI
≤6	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	48%	BaseDHW	0%	0%	75%	16	52%	40	45%	HG-avg-Tr	1%	0.8	0%
basefurnace	79%	60%	27%	Combo	0%	30%	9%	18	25%	50	22%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	0%	70%	12%	GasInstan	0%	42%	10%	22	5%	60	8%	HG-i89-Tri	0%	1.2	2%
ComboHeatA	0%	75%	8%	HPHotWat	35%	55%	7%	24	15%	70	7%	LG-avg-Dc	73%	1.4	10%
gas-furnace-	21%	84%	5%	ElectricSto	65%			30	2%	80	3%	LG-avg-Tri	1%	1.6	15%
				GasInst_Lo	0%			40	0%	100	16%	MG-HP-Dc	10%	1.8	73%
								50	0%			MG-i89-Dc	15%		
								60	0%						

GHGI	ICC	ECI
≤3	≤3%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	10%	BaseDHW	0%	0%	0%	16	13%	40	23%	HG-avg-Tr	21%	0.8	45%
basefurnace	40%	60%	28%	Combo	0%	30%	40%	18	6%	50	21%	HG-HP-Tri	6%	1	6%
CCASHP-ecm	48%	70%	11%	GasInstan	0%	42%	18%	22	2%	60	15%	HG-i89-Tri	45%	1.2	23%
ComboHeatA	0%	75%	15%	HPHotWat	60%	55%	42%	24	5%	70	7%	LG-avg-Dc	9%	1.4	3%
gas-furnace-	12%	84%	37%	ElectricSto	40%			30	4%	80	7%	LG-avg-Tri	2%	1.6	14%
				GasInst_Lo	0%			40	23%	100	26%	MG-HP-Dc	3%	1.8	9%
								50	23%			MG-i89-Dc	14%		
								60	24%						

GHGI	ICC	ECI
≤1	≤5%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	15%	BaseDHW	0%	0%	8%	16	27%	40	27%	HG-avg-Tr	8%	0.8	22%
basefurnace	0%	60%	34%	Combo	0%	30%	34%	18	10%	50	27%	HG-HP-Tri	10%	1	10%
CCASHP-ecm	100%	70%	10%	GasInstan	0%	42%	22%	22	3%	60	20%	HG-i89-Tri	22%	1.2	12%
ComboHeatA	0%	75%	19%	HPHotWat	92%	55%	36%	24	10%	70	5%	LG-avg-Dc	22%	1.4	8%
gas-furnace-	0%	84%	22%	ElectricSto	8%			30	3%	80	8%	LG-avg-Tri	3%	1.6	25%
				GasInst_Lo	0%			40	15%	100	12%	MG-HP-Dc	8%	1.8	22%
								50	15%			MG-i89-Dc	25%		
								60	15%						

Figure 12: Townhouse Step 1 results

MURB

Step 1

GHGI	ICC	ECI
≤1	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboarc	0%	0%	13%	BaseDHW	0%	0%	50%	16	25%	40	50%	HG-avg-Tr	6%	0.8	0%
basefurna	0%	60%	38%	Combo	0%	30%	19%	18	13%	50	19%	HG-HP-Tri	0%	1	0%
CCASHP-e	13%	70%	19%	GasInstan	0%	42%	6%	22	0%	60	0%	HG-i89-Tri	0%	1.2	6%
ComboHe	0%	75%	13%	HPHotWat	69%	55%	25%	24	31%	70	0%	LG-avg-Dc	50%	1.4	25%
elec-base	88%	84%	19%	ElectricStc	31%			30	0%	80	6%	LG-avg-Tri	0%	1.6	19%
				GasInst_Lc	0%			40	13%	100	25%	MG-HP-Dc	25%	1.8	50%
								50	13%			MG-i89-Dc	19%		
								60	6%						

Figure 13: MURB Step 1 results

HighRiseMURB_Midoccupancy

Step 1

GHGI	ICC	ECI
≤5	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensir	100%	0	0%	40	100%	4	47%	20	53%	2.5	100%
standard	0%	60%	73%			7	13%	30	0%	2	0%
		80%	27%			10	27%	40	47%	1.6	0%
						20	13%			1.2	0%
										0.8	0%

Step 2

GHGI	ICC	ECI
≤5	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensir	100%	0	0%	40	100%	4	34%	20	52%	2.5	55%
standard	0%	60%	55%			7	28%	30	0%	2	26%
		80%	45%			10	24%	40	48%	1.6	11%
						20	13%			1.2	6%
										0.8	2%

Figure 14: High Rise MURB Mid occupancy step 1 & 2 results

LowRiseMURB_Midoccupancy

Step 1

GHGI	ICC	ECI
≤5	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensir	100%	0	0%	40	100%	4	47%	20	53%	2.5	100%
standard	0%	60%	73%			7	13%	30	0%	2	0%
		80%	27%			10	27%	40	47%	1.6	0%
						20	13%			1.2	0%
										0.8	0%

Step 2

GHGI	ICC	ECI
≤5	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensir	100%	0	0%	40	100%	4	20%	20	54%	2.5	87%
standard	0%	60%	55%			7	27%	30	0%	2	9%
		80%	45%			10	23%	40	46%	1.6	3%
						20	20%			1.2	1%
						40	9%			0.8	0%

Figure 15: Low Rise MURB Mid occupancy Step 1 & 2 results

Appendix 3: Full Step 3 Results

The figures below present screenshots from modelled building datasets developed for this study. These results offer opportunities for further analysis, and no doubt can be used to generate additional takeaways for government policies and programs.

Medium SFD

Step 3

GHGI	ICC	ECI
≤6	≤3%	≤$7.5

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	48%	**0%**	24%	**BaseDHW**	14%	**0%**	55%	**16**	39%	**40**	31%	**HG-avg-Triple**	16%	**0.8**	0%
basefurnace	33%	**60%**	20%	**Combo**	0%	**30%**	23%	**18**	26%	**50**	18%	**HG-HP-Triple**	1%	**1.0**	1%
CCASHP-ecm	5%	**70%**	14%	**GasInstantaneous**	21%	**42%**	11%	**22**	9%	**60**	13%	**HG-i89-Triple-B**	0%	**1.2**	20%
ComboHeatA	0%	**75%**	13%	**HPHotWater**	29%	**55%**	11%	**24**	17%	**70**	11%	**LG-avg-Double**	41%	**1.4**	10%
gas-furnace-ecm	14%	**84%**	29%	**ElectricStorage**	20%			**30**	4%	**80**	7%	**LG-avg-Triple**	4%	**1.6**	28%
				GasInst_Low	16%			**40**	6%	**100**	20%	**MG-HP-Double**	10%	**1.8**	41%
								50	0%			**MG-i89-Double**	28%		
								60	0%						

GHGI	ICC	ECI
≤3	≤3%	≤$7.5

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	90%	**0%**	0%	**BaseDHW**	0%	**0%**	60%	**16**	30%	**40**	20%	**HG-avg-Triple**	50%	**0.8**	0%
basefurnace	0%	**60%**	20%	**Combo**	0%	**30%**	20%	**18**	30%	**50**	0%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	10%	**70%**	30%	**GasInstantaneous**	0%	**42%**	0%	**22**	10%	**60**	10%	**HG-i89-Triple-B**	0%	**1.2**	50%
ComboHeatA	0%	**75%**	10%	**HPHotWater**	90%	**55%**	20%	**24**	20%	**70**	20%	**LG-avg-Double**	20%	**1.4**	10%
gas-furnace-ecm	0%	**84%**	40%	**ElectricStorage**	10%			**30**	0%	**80**	0%	**LG-avg-Triple**	0%	**1.6**	20%
				GasInst_Low	0%			**40**	10%	**100**	50%	**MG-HP-Double**	10%	**1.8**	20%
								50	0%			**MG-i89-Double**	20%		
								60	0%						

Figure 16: Medium SFD occupancy step 3 results

Large SFD

Step 3

GHGI	ICC	ECI
≤3	≤2%	≤$6

Space Heating and Cooling		Domestic Hot Water				Envelope R-Values				Windows			
HVAC		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	83%	**BaseDHW**	33%	**0%**	60%	**16**	44%	**40**	40%	**HG-avg-Triple**	15%	**0.8**	0%
basefurnace	0%	**Combo**	0%	**30%**	25%	**18**	21%	**50**	8%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	17%	**GasInstantaneous**	27%	**42%**	6%	**22**	15%	**60**	13%	**HG-i89-Triple-B**	0%	**1.2**	17%
ComboHeatA	0%	**HPHotWater**	0%	**55%**	8%	**24**	15%	**70**	15%	**LG-avg-Double**	31%	**1.4**	19%
gas-furnace-ecm	0%	**ElectricStorage**	2%			**30**	2%	**80**	8%	**LG-avg-Triple**	2%	**1.6**	33%
		GasInst_Low	38%			**40**	4%	**100**	17%	**MG-HP-Double**	19%	**1.8**	31%
						50	0%			**MG-i89-Double**	33%		
						60	0%						

Figure 17: Large SFD occupancy step 3 results

Townhouses

Step 3

GHGI	ICC	ECI
≤6	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	43%	BaseDHW	0%	0%	65%	16	54%	40	45%	HG-avg-Tr	2%	0.8	0%
basefurnace	88%	60%	29%	Combo	0%	30%	12%	18	23%	50	25%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	0%	70%	14%	GasInstan	0%	42%	14%	22	5%	60	6%	HG-i89-Tri	0%	1.2	2%
ComboHeatA	0%	75%	9%	HPHotWat	48%	55%	9%	24	17%	70	6%	LG-avg-Do	71%	1.4	11%
gas-furnace-	12%	84%	5%	ElectricSto	52%			30	2%	80	5%	LG-avg-Tri	0%	1.6	17%
				GasInst_Lo	0%			40	0%	100	14%	MG-HP-Do	11%	1.8	71%
								50	0%			MG-i89-Do	17%		
								60	0%						

GHGI	ICC	ECI
≤3	≤3%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	0%	BaseDHW	0%	0%	25%	16	25%	40	13%	HG-avg-Tr	13%	0.8	0%
basefurnace	88%	60%	75%	Combo	0%	30%	25%	18	38%	50	38%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	0%	70%	13%	GasInstan	0%	42%	13%	22	13%	60	0%	HG-i89-Tri	0%	1.2	13%
ComboHeatA	0%	75%	13%	HPHotWat	0%	55%	38%	24	0%	70	25%	LG-avg-Do	0%	1.4	38%
gas-furnace-	13%	84%	0%	ElectricSto	100%			30	13%	80	0%	LG-avg-Tri	0%	1.6	50%
				GasInst_Lo	0%			40	13%	100	25%	MG-HP-Do	38%	1.8	0%
								50	0%			MG-i89-Do	50%		
								60	0%						

GHGI	ICC	ECI
≤1	≤5%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	41%	BaseDHW	0%	0%	47%	16	65%	40	24%	HG-avg-Tr	0%	0.8	0%
basefurnace	0%	60%	35%	Combo	0%	30%	29%	18	24%	50	29%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	100%	70%	6%	GasInstan	0%	42%	6%	22	12%	60	0%	HG-i89-Tri	0%	1.2	12%
ComboHeatA	0%	75%	6%	HPHotWat	100%	55%	18%	24	0%	70	18%	LG-avg-Do	71%	1.4	6%
gas-furnace-	0%	84%	12%	ElectricSto	0%			30	0%	80	12%	LG-avg-Tri	12%	1.6	12%
				GasInst_Lo	0%			40	0%	100	18%	MG-HP-Do	6%	1.8	71%
								50	0%			MG-i89-Do	12%		
								60	0%						

Figure 18: Townhouse occupancy step 3 results

MURB

Step 3

GHGI	ICC	ECI
≤1	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboarc	100%	0%	68%	BaseDHW	0%	0%	36%	16	43%	40	45%	HG-avg-Tr	0%	0.8	0%
basefurna	0%	60%	16%	Combo	0%	30%	30%	18	9%	50	16%	HG-HP-Tri	0%	1	0%
CCASHP-e	0%	70%	5%	GasInstan	0%	42%	14%	22	7%	60	7%	HG-i89-Tri	0%	1.2	7%
ComboHe	0%	75%	5%	HPHotWat	52%	55%	20%	24	9%	70	7%	LG-avg-Do	66%	1.4	5%
elec-base	0%	84%	7%	ElectricSto	48%			30	5%	80	7%	LG-avg-Tri	7%	1.6	23%
				GasInst_Lo	0%			40	11%	100	18%	MG-HP-Do	5%	1.8	66%
								50	9%			MG-i89-Do	23%		
								60	7%						

Figure 19: MURB occupancy step 3 results

HighRiseMURB_Midoccupancy

Step 3

GHGI	ICC	ECI
≤5	≤2%	≤$8

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensir	91%	0	0%	40	100%	4	2%	20	52%	2.5	39%
standard	9%	60%	57%			7	38%	30	0%	2	27%
		80%	43%			10	42%	40	48%	1.6	20%
						20	17%			1.2	9%
										0.8	5%

Figure 20: High Rise MURB Mid occupancy step 3 results

LowRiseMURB_Midoccupancy

Step 3

GHGI	ICC	ECI
≤5	≤2%	≤$8

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensir	91%	0	0%	40	100%	4	0%	20	56%	2.5	69%
standard	9%	60%	57%			7	21%	30	0%	2	22%
		80%	43%			10	37%	40	44%	1.6	8%
						20	40%			1.2	1%
						40	3%			0.8	0%

Figure 21: Low Rise MURB Mid occupancy step 3 results

Appendix 4: Full Step 4 and 5 Results

The figures below present screenshots from modelled building datasets developed for this study. These results offer opportunities for further analysis, and no doubt can be used to generate additional takeaways for government policies and programs.

Medium SFD

Step 4 and 5

GHGI	ICC	ECI
≤6	≤3%	≤$7.5

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	71%	**0%**	28%	**BaseDHW**	0%	**0%**	69%	**16**	32%	**40**	28%	**HG-avg-Triple**	40%	**0.8**	0%
basefurnace	26%	**60%**	31%	**Combo**	0%	**30%**	18%	**18**	21%	**50**	13%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	0%	**70%**	15%	**GasInstantaneous**	19%	**42%**	11%	**22**	14%	**60**	14%	**HG-i89-Triple-B**	0%	**1.2**	40%
ComboHeatA	0%	**75%**	8%	**HPHotWater**	72%	**55%**	1%	**24**	21%	**70**	19%	**LG-avg-Double**	19%	**1.4**	11%
gas-furnace-ecm	3%	**84%**	18%	**ElectricStorage**	8%			**30**	8%	**80**	4%	**LG-avg-Triple**	0%	**1.6**	29%
				GasInst_Low	0%			**40**	4%	**100**	22%	**MG-HP-Double**	11%	**1.8**	19%
								50	0%			**MG-i89-Double**	29%		
								60	0%						

GHGI	ICC	ECI
≤3	≤3%	≤$7.5

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	100%	**0%**	22%	**BaseDHW**	0%	**0%**	62%	**16**	35%	**40**	38%	**HG-avg-Triple**	22%	**0.8**	0%
basefurnace	0%	**60%**	30%	**Combo**	0%	**30%**	24%	**18**	8%	**50**	5%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	0%	**70%**	19%	**GasInstantaneous**	0%	**42%**	11%	**22**	14%	**60**	16%	**HG-i89-Triple-B**	0%	**1.2**	22%
ComboHeatA	0%	**75%**	11%	**HPHotWater**	86%	**55%**	3%	**24**	27%	**70**	16%	**LG-avg-Double**	32%	**1.4**	11%
gas-furnace-ecm	0%	**84%**	19%	**ElectricStorage**	14%			**30**	11%	**80**	8%	**LG-avg-Triple**	0%	**1.6**	35%
				GasInst_Low	0%			**40**	5%	**100**	16%	**MG-HP-Double**	11%	**1.8**	32%
								50	0%			**MG-i89-Double**	35%		
								60	0%						

Figure 22: Medium SFD occupancy step 4 & 5 results

Large SFD

Step 4 and 5

GHGI	ICC	ECI
≤3	≤2%	≤$6

Space Heating and Cooling		Domestic Hot Water				Envelope R-Values				Windows			
HVAC		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	24%	**BaseDHW**	24%	**0%**	72%	**16**	66%	**40**	62%	**HG-avg-Triple**	21%	**0.8**	0%
basefurnace	0%	**Combo**	0%	**30%**	14%	**18**	17%	**50**	17%	**HG-HP-Triple**	0%	**1.0**	0%
CCASHP-ecm	76%	**GasInstantaneous**	24%	**42%**	10%	**22**	17%	**60**	7%	**HG-i89-Triple-B**	0%	**1.2**	21%
ComboHeatA	0%	**HPHotWater**	14%	**55%**	3%	**24**	0%	**70**	7%	**LG-avg-Double**	66%	**1.4**	0%
gas-furnace-ecm	0%	**ElectricStorage**	17%			**30**	0%	**80**	0%	**LG-avg-Triple**	0%	**1.6**	14%
		GasInst_Low	21%			**40**	0%	**100**	7%	**MG-HP-Double**	0%	**1.8**	66%
						50	0%			**MG-i89-Double**	14%		
						60	0%						

Step 3,4 and 5

GHGI	ICC	ECI
≤1	≤3%	≤$6

Space Heating and Cooling		Domestic Hot Water				Envelope R-Values				Windows			
HVAC		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	31%	**BaseDHW**	0%	**0%**	54%	**16**	50%	**40**	41%	**HG-avg-Triple**	20%	**0.8**	1%
basefurnace	0%	**Combo**	0%	**30%**	22%	**18**	19%	**50**	16%	**HG-HP-Triple**	1%	**1.0**	1%
CCASHP-ecm	69%	**GasInstantaneous**	0%	**42%**	12%	**22**	7%	**60**	6%	**HG-i89-Triple-B**	1%	**1.2**	20%
ComboHeatA	0%	**HPHotWater**	55%	**55%**	12%	**24**	13%	**70**	13%	**LG-avg-Double**	51%	**1.4**	8%
gas-furnace-ecm	0%	**ElectricStorage**	45%			**30**	4%	**80**	6%	**LG-avg-Triple**	1%	**1.6**	20%
		GasInst_Low	0%			**40**	7%	**100**	19%	**MG-HP-Double**	8%	**1.8**	51%
						50	0%			**MG-i89-Double**	20%		
						60	0%						

Figure 23: Large SFD occupancy step 4 & 5 results

Townhouses

Step 4 and 5

GHGI	ICC	ECI
≤6	≤3%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	33%	BaseDHW	0%	0%	59%	16	40%	40	31%	HG-avg-Tr	9%	0.8	0%
basefurnace	89%	60%	26%	Combo	0%	30%	23%	18	29%	50	19%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	0%	70%	6%	GasInstan	0%	42%	10%	22	5%	60	14%	HG-i89-Tri	0%	1.2	11%
ComboHeatA	0%	75%	24%	HPHotWat	93%	55%	9%	24	18%	70	24%	LG-avg-Dc	36%	1.4	14%
gas-furnace-	11%	84%	11%	ElectricStc	8%			30	6%	80	5%	LG-avg-Tri	3%	1.6	39%
				GasInst_Lc	0%			40	1%	100	8%	MG-HP-Dc	14%	1.8	36%
								50	1%			MG-i89-Dc	39%		
								60	0%						

GHGI	ICC	ECI
≤3	≤3%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	50%	BaseDHW	0%	0%	83%	16	83%	40	33%	HG-avg-Tr	100%	0.8	0%
basefurnace	100%	60%	33%	Combo	0%	30%	17%	18	17%	50	33%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	0%	70%	0%	GasInstan	0%	42%	0%	22	0%	60	33%	HG-i89-Tri	0%	1.2	100%
ComboHeatA	0%	75%	17%	HPHotWat	0%	55%	0%	24	0%	70	0%	LG-avg-Dc	0%	1.4	0%
gas-furnace-	0%	84%	0%	ElectricStc	100%			30	0%	80	0%	LG-avg-Tri	0%	1.6	0%
				GasInst_Lc	0%			40	67%	100	0%	MG-HP-Dc	0%	1.8	0%
								50	33%			MG-i89-Dc	0%		
								60	33%						

GHGI	ICC	ECI
≤1	≤5%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboard	0%	0%	50%	BaseDHW	0%	0%	59%	16	59%	40	41%	HG-avg-Tr	5%	0.8	0%
basefurnace	0%	60%	36%	Combo	0%	30%	23%	18	23%	50	41%	HG-HP-Tri	0%	1	0%
CCASHP-ecm	100%	70%	0%	GasInstan	0%	42%	9%	22	9%	60	0%	HG-i89-Tri	0%	1.2	5%
ComboHeatA	0%	75%	14%	HPHotWat	91%	55%	9%	24	9%	70	9%	LG-avg-Dc	77%	1.4	9%
gas-furnace-	0%	84%	0%	ElectricStc	9%			30	0%	80	0%	LG-avg-Tri	0%	1.6	9%
				GasInst_Lc	0%			40	0%	100	9%	MG-HP-Dc	9%	1.8	77%
								50	0%			MG-i89-Dc	9%		
								60	0%						

Figure 24: Townhouse occupancy step 4 & 5 results

MURB

Step 4&5

GHGI	ICC	ECI
≤1	≤2%	≤$10

Space Heating and Cooling				Domestic Hot Water				Envelope R-Values				Windows			
HVAC		HRV		DHW System		DWHR		Wall		Roof		Pane and Glaze		U-value	
baseboarc	95%	0%	15%	BaseDHW	0%	0%	52%	16	35%	40	27%	HG-avg-Tr	5%	0.8	0%
basefurna	0%	60%	38%	Combo	0%	30%	22%	18	15%	50	20%	HG-HP-Tri	0%	1	0%
CCASHP-e	5%	70%	11%	GasInstan	0%	42%	10%	22	9%	60	12%	HG-i89-Tri	0%	1.2	8%
ComboHe	0%	75%	10%	HPHotWat	54%	55%	17%	24	15%	70	14%	LG-avg-Dc	65%	1.4	8%
elec-base	0%	84%	26%	ElectricStc	46%			30	3%	80	6%	LG-avg-Tri	3%	1.6	20%
				GasInst_Lc	0%			40	8%	100	20%	MG-HP-Dc	8%	1.8	65%
								50	8%			MG-i89-Dc	20%		
								60	6%						

Figure 25: MURB occupancy Step 4 & 5 results

HighRiseMURB_Midoccupancy

Step 4

GHGI	ICC	ECI
≤5	≤2%	≤$8

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensin	55%	0	0%	40	100%	4	0%	20	50%	2.5	26%
standard	45%	60%	45%			7	13%	30	0%	2	16%
		80%	55%			10	63%	40	50%	1.6	23%
						20	23%			1.2	20%
										0.8	15%

Figure 26: High Rise MURB Mid occupancy step 4 & 5 results

LowRiseMURB_Midoccupancy

Step 4

GHGI	ICC	ECI
≤5	≤2%	≤$8

Space Heating and Cooling				Domestic Hot Water		Envelope R-Values				Windows USI	
Heating efficiency		HRV		DHW Savings		Wall		Roof		Pane and Glaze	
Condensin	55%	0	0%	40	100%	4	0%	20	58%	2.5	49%
standard	45%	60%	60%			7	0%	30	0%	2	29%
		80%	40%			10	17%	40	42%	1.6	18%
						20	83%			1.2	4%
						40	0%			0.8	0%

Figure 27: Low Rise MURB Mid occupancy step 4 & 5 results

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