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

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» **2032**

NET-ZERO ENERGY READY NEW CONSTRUCTION

STEP BC BUILDING CODE

2017

ENERGY EFFICIENCY

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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/ft²/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/ft²/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.

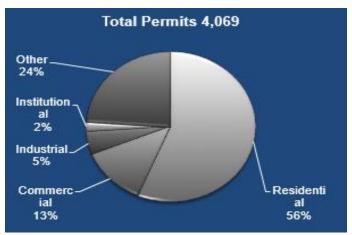


Figure 1 Permits issued for construction in 2017 for the City of Surrey

What is a Net-Zero Energy Ready Building?

Net-zero energy buildings produce as much clean energy as they consume. They are up to 80 percent more energy efficient than a typical new building, and use on-site (or near-site) renewable energy systems to produce the remaining energy they need. A net-zero energy ready building is one that has been designed and built to a level of performance such that it could, with the addition of solar panels or other renewable energy technologies, achieve net-zero energy performance.



Highly energy-efficient home currently under construction in Kelowna BC (Part 9, Step 5).



The Heights, a highly energy efficient wood-frame residential building under construction in Vancouver BC (Part 3, Step 4).

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.

Building Type	Building permit application filed on or afterApr 1, 2019Jan 1, 2021				
Single Family Home (≥1200ft²/111.5m²)	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 <u>or</u> satisfy low-carbon energy reqs				
Large Concrete Residential Apartments	Step 3 or Step 2, if connected to Surrey City Energy <u>or</u> 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 600m² 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.

What are "Part 9" and "Part 3" Buildings?



Photos: Top: Townhome in Township of Langley BC. Bottom: 10-storey residential building in Vancouver BC, photo by Derek Lepper Photography. Part 9 – Houses and small buildings.

These buildings are three storeys or less and have a building area or "footprint" no more than 600 square metres (approximately 6,500 square feet). This category includes single-family homes, duplexes, townhomes, small apartment buildings, and small stores, offices, and industrial shops.

Part 3 - Large and complex buildings.

These buildings are four storeys and taller and greater than 600 square metres in building area or "footprint". This category includes larger apartment buildings, condos, shopping malls, office buildings, hospitals, care facilities, schools, churches, theatres, and restaurants.

These definitions are simplified for the purpose of understanding the content of this guide. The official definition of Part 9 and Part 3 buildings can be found in the **BC Building Code**.

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:

Archety	/pe	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

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

Figure 7 Modelling Part 9 buildings^[3]

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



Figure 13: Example of a Large SFD (Source: bm2dev)



Figure 16: Example of a Small SFD (Source: Smallworks)

Figure 12: Example of a Medium SFD (Source: realspace)





Quadplex (Source: Core Development)

Figure 17: Example of a



Figure 15: Example of a 10-Unit MURB (Source: blue host)



Figure 14: Example of a 6-Unit Row House (Source: House Plans)

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, kgCO₂e/m²/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, \$/m²/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]

Archetype	Step	GHGI ECI (\$/m (kgCO2e/m2/yr)		ICC (%)
	1	<=6	<=7.5	<=3
	3	<=6	<=7.5	<=3
Medium SFD	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 2: The standards defined with the archetype (medium SFD)

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.

	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	

Table 3: Compilation of selected Step 1 and 2 results

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.

	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	

Table 4: Compilation of selected Step 3 results

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 A: Compilation	of selected Step 4 and Step 5 results
Tuble 4. Compliation	of selected step 4 and step 5 results

Step 4 and 5						
	Medium SFD	Large SFD	Townhouse s	MURB	HighRise_MUR B	LowRise_MUR B
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
Domesti c hot water	72% weightage to 86% for GHG<3 HPHotWater; Domestic heat water recovery <=30%	for GHG<3, there is a shift from GasInstantaneou s (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
Envelop e	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.
Window s	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 importance of heat pumps for achieving cost-effective (near) decarbonization of townhome space heating, and suggests this as a priority for Surrey and other cities seeking such buildings.

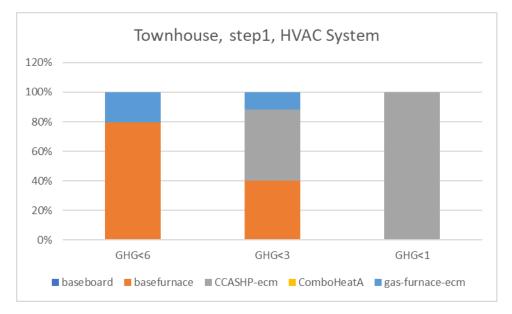


Figure 9: Archetype: Townhouse; Step1; HVAC system; with GHG limitations

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

<u>Heat recovery system</u>: 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

<u>Heat recovery system</u>: 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.

<u>Envelope R-values</u>: 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

<u>Envelope R-values</u>: 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

<u>Space heating and cooling</u>: 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.

Archetype	Step	GHGI (kgCO2e/m2/yr)	ECI (\$/m²/yr)	ICC (%)
	1	<=6	<=7.5	<=3
	3	<=6	<=7.5	<=3
MEDIUM SFD	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 5: The standards defined with the archetype (medium 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	1	<=5	<=10	<=2
(Mid occupancy)	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	1	<=5	<=10	<=2
(Mid occupancy)	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.

/ledium SF	D														
Step 1															
GHGI ≤6	ICC ≤3%	ECI ≤\$7.5													
Space Heati	ng and	Cooling	,	Domestic	Hot W	ater		Fn	velope	R-Val	Jes	Win	dows		
HVAC		HF		DHW System		DW	/HR		all		of	Pane and Gla	ze	U-v	alue
baseboard	52%	0%	25%	BaseDHW	20%	0%	57%	16	39%	40	31%	HG-avg-Triple	18%	0.8	19
basefurnace	29%	60%	21%	Combo	0%	30%	23%	18	25%	50	19%	HG-HP-Triple	1%	1.0	19
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%														
Space Heati	ng and	Cooling	ł	Domestic	Hot W	ater		En	velope	R-Val	ues	Win	dows		
HVAC		HF	RV	DHW System		DW	/HR	w	'all	Ro	of	Pane and Gla	ze	U-v	alue
baseboard	56%	0%	50%	BaseDHW	0%	0%	78%	16	39%	40	28%	HG-avg-Triple	33%	0.8	09
basefurnace	0%	60%	17%	Combo	0%	30%	6%	18	11%	50	22%	HG-HP-Triple	0%	1.0	09
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

C1 4													
Step 1													
GHGI	ICC	ECI											
≤3	≤2%	≤\$6											
Space Heating and	Cooling	Dom	estic Hot Water			En	velope	R-Val	ues		Windo	ws	
HVAC		DHW Syste	em	DWH	2	W	all	Ro	of	Pane and Gla	ze	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	05
CCASHP-ecm	89%	GasInstantaneous	26%	42%	16%	22	0%	60	11%	HG-i89-Triple-B	0%	1.2	119
ComboHeatA	0%	HPHotWater	21%	55%	0%	24	5%	70	21%	LG-avg-Double	68%	1.4	- 55
gas-furnace-ecm	0%	ElectricStorage	0%			30	0%	80	11%	LG-avg-Triple	0%	1.6	165
		GasInst_Low	26%			40	0%	100	5%	MG-HP-Double	5%	1.8	689
						50	0%			MG-i89-Double	16%		
						60	0%						
GHGI	ICC	ECI											
≤1	≤2%	≤\$6											
Space Heating and	Cooling	Dom	estic Hot Water			En	velope	R-Val	ues		Windo	ws	
HVAC		DHW Syste	em	DWH	۲	W	all	Ro	of	Pane and Gla	ze	U-value	
baseboard	14%	BaseDHW	0%	0%	61%	16	39%	40	39%	HG-avg-Triple	25%	0.8	05
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	255
ComboHeatA	0%	HPHotWater	79%	55%	18%	24	14%	70	25%	LG-avg-Double	46%	1.4	119
gas-furnace-ecm	0%	ElectricStorage	21%			30	11%	80	0%	LG-avg-Triple	0%	1.6	185
Dee lainage celli													
0 rumace com		GasInst_Low	0%			40	11%	100	14%	MG-HP-Double	11%	1.8	469
out ramate com		GasInst_Low	0%			40 50	11% 0% 0%	100	14%	MG-HP-Double MG-i89-Double	11% 18%	1.8	469

Figure 11: Large SFD step 1 results

Step 1															
GHGI	ICC	ECI													
≤6	≤2%	≤\$10													
	Heating ar					lot Water	10		nvelope R			David and	Window		
HVAC baseboard	0%	HRV 0%	48%	DHW Sy BaseDHW	stem 0%	DWH 0%	нк 75%	Wall 16	52%	Roof 40	45%	Pane and HG-avg-Tr	Glaze 1%	U-value 0.8	e 0%
basefurnace	79%	60%	27%	Combo	0%	30%	9%	18	25%	50		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%	HPHotWa	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_L	0%			40	0%	100	16%	MG-HP-Do	10%	1.8	73%
								50	0%			MG-i89-D	15%		
								60	0%						
HVAC baseboard	Heating ar	HRV 0%	10%	DHW Sy BaseDHW		lot Water DWI 0%	HR 0%	Wall 16	nvelope R 13%	Roof	23%	Pane and HG-avg-Tr	Windov Glaze 21%	U-value 0.8	45%
basefurnace	40%	60%		Combo	0%	30%	40%		6%			0			4370
CCASHP-ecm	400/	700/			0/0	30/0		18	0%	50	21%	HG-HP-Tri	6%	1	43%
contorni conti	48%	70%	11%	GasInstan	0%	42%	18%	18 22	2%	50 60		HG-HP-Tri HG-i89-Tri	6% 45%	1 1.2	
	48% 0%	70%		GasInstan HPHotWa							15%				6%
ComboHeatA			15%		0%	42%	18%	22	2%	60	15% 7%	HG-i89-Tri	45%	1.2	6% 23%
ComboHeatA	0%	75%	15% 37%	HPHotWa	0% 60%	42%	18%	22 24	2% 5%	60 70	15% 7% 7%	HG-i89-Tri LG-avg-Dc	45% 9%	1.2 1.4	6% 23% 3%
ComboHeatA	0%	75%	15% 37%	HPHotWa ElectricSto	0% 60% 40%	42%	18%	22 24 30 40 50	2% 5% 4% 23% 23%	60 70 80	15% 7% 7% 26%	HG-i89-Tri LG-avg-Dc LG-avg-Tri	45% 9% 2%	1.2 1.4 1.6	6% 23% 3% 14%
ComboHeatA gas-furnace-	0%	75%	15% 37%	HPHotWa ElectricSto	0% 60% 40%	42%	18%	22 24 30 40	2% 5% 4% 23%	60 70 80	15% 7% 7% 26%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc	45% 9% 2% 3%	1.2 1.4 1.6	6% 23% 3% 14%
ComboHeatA gas-furnace-€ GHGI ≤1	0% 12% ICC ≤5%	75% 84% ECI ≤\$10	15% 37%	HPHotWa ElectricStc GasInst_Lc	0% 60% 40% 0%	42% 55%	18%	22 24 30 40 50 60	2% 5% 4% 23% 23% 24%	60 70 80 100	15% 7% 7% 26%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc	45% 9% 2% 3% 14%	1.2 1.4 1.6 1.8	6% 23% 3% 14%
ComboHeatA gas-furnace-∢ GHGI ≤1 Space	0% 12% ICC ≤5% Heating ar	75% 84% ECI ≤\$10 ad Cooling	15% 37%	HPHotWa ElectricStc GasInst_Lc	0% 60% 40% 0%	42% 55%	18% 42%	22 24 30 40 50 60	2% 5% 4% 23% 23% 24%	60 70 80 100	15% 7% 7% 26%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-Do	45% 9% 2% 3% 14%	1.2 1.4 1.6 1.8	6% 23% 3% 14% 9%
ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC	0% 12% ICC ≤5% Heating ar	75% 84% ≤\$10 HRV	15% 37%	HPHotWa ElectricStc GasInst_Lc DHW Sy	0% 60% 40% 0% Domestic H	42% 55% lot Water DWH	18% 42%	22 24 30 40 50 60 E Wall	2% 5% 4% 23% 23% 24%	60 70 80 100 -Values Roof	15% 7% 26%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-D(Pane and	45% 9% 2% 3% 14% Glaze	1.2 1.4 1.6 1.8 ws	6% 23% 3% 14% 9%
ComboHeatA gas-furnace-€ GHGI ≤1 Space HVAC baseboard	0% 12% ICC ≤5% Heating ar	75% 84% ECI ≤\$10 ad Cooling	15% 37% 15%	HPHotWa ElectricStc GasInst_Lc	0% 60% 40% 0%	42% 55%	18% 42%	22 24 30 40 50 60	2% 5% 4% 23% 23% 24%	60 70 80 100	15% 7% 26% 27%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-Do	45% 9% 2% 3% 14%	1.2 1.4 1.6 1.8	6% 23% 3% 14% 9%
ComboHeatA gas-furnace-€ GHGI ≤1 Space HVAC baseboard basefurnace	0% 12% ICC ≤5% Heating ar	75% 84% ≤\$10 HRV 0%	15% 37% 15% 34%	HPHotWa ElectricStc GasInst_L DHW Sy BaseDHW	0% 60% 40% 0% Domestic H	42% 55% łot Water DWł	18% 42% HR 8%	22 24 30 40 50 60 8 Wall 16	2% 5% 4% 23% 23% 24%	60 70 80 100 -Values Roof 40	15% 7% 26% 27% 27%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-Dc MG-i89-Dc HG-avg-Tr	45% 9% 2% 3% 14% Glaze 8%	1.2 1.4 1.6 1.8 WS U-valut 0.8	6% 23% 3% 14% 9%
ComboHeatA gas-furnace-€ GHGI ≤1 Space HVAC baseboard basefurnace CCASHP-ecm	0% 12% ICC ≤5% Heating ar 0% 0%	75% 84% ≤\$10 hd Cooling HRV 0% 60%	15% 37% 15% 34% 10%	HPHotWa ElectricSt(GasInst_L(DHW Sy BaseDHW Combo	0% 60% 40% 0% 0%	42% 55% łot Water DWł 0% 30%	18% 42% HR 8% 34%	22 24 30 40 50 60 Wall 16 18	2% 5% 4% 23% 23% 24% nvelope R 27% 10%	60 70 80 100 -Values Roof 40 50	15% 7% 26% 26% 27% 27% 20%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-Dc MG-i89-Dc HG-avg-Tr HG-HP-Tri	45% 9% 2% 3% 14% Slaze 8% 10%	1.2 1.4 1.6 1.8 U-valut 0.8 1	6% 23% 3% 14% 9%
ComboHeatA gas-furnace-€ GHGI ≤1 Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA	0% 12% ICC ≤5% Heating ar 0% 0% 100%	75% 84% ≤\$10 d Cooling HRV 0% 60% 70%	15% 37% 15% 34% 10% 19%	HPHotWa ElectricStc GasInst_Lt DHW Sy BaseDHW Combo GasInstan	0% 60% 40% 0% 0% 500mestic F stem 0% 0% 0%	42% 55% Hot Water DWH 0% 30% 42%	18% 42% 42%	22 24 30 40 50 60 Wall 16 18 22	2% 5% 4% 23% 23% 24% nvelope R 27% 10% 3%	60 70 80 100 -Values Roof 40 50 60	15% 7% 26% 26% 27% 27% 27% 20% 5%	HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-D(MG-i89-D(HG-avg-Tr HG-HP-Tri HG-HP-Tri HG-i89-Tri	45% 9% 2% 3% 14% Glaze 8% 10% 22%	1.2 1.4 1.6 1.8 U-valut 0.8 1 1.2	6% 23% 3% 14% 9% 2% 22% 10% 12%
ComboHeatA gas-furnace-€ GHGI ≤1 Space	0% 12% ICC ≤5% Heating ar 0% 0% 100% 0%	75% 84% ≤\$10 Md Cooling HRV 0% 60% 70% 75%	15% 37% 15% 34% 10% 19% 22%	HPHotWa ElectricStc GasInst_Lc DHW Sy BaseDHW Combo GasInstan HPHotWa	0% 60% 40% 0% 0% bomestic H stem 0% 0% 0% 92%	42% 55% Hot Water DWH 0% 30% 42%	18% 42% 42%	22 24 30 40 50 60 Wall 16 18 22 24	22% 5% 4% 23% 23% 24% 	-Values Reof 40 50 60 70	15% 7% 26% 26% 27% 27% 20% 5% 8%	HG-i89-Tri LG-avg-Tc LG-avg-Tri MG-HP-Dc MG-i89-Dc MG-i89-Dc HG-avg-Tri HG-HP-Tri HG-i89-Tri LG-avg-Dc	45% 9% 2% 3% 14% Glaze 8% 10% 22% 22%	1.2 1.4 1.6 1.8 U-valut 0.8 1 1.2 1.4	6% 23% 3% 14% 9% 2% 22% 10% 12% 8%
ComboHeatA gas-furnace-€ GHGI ≤1 Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA	0% 12% ICC ≤5% Heating ar 0% 0% 100% 0%	75% 84% ≤\$10 Md Cooling HRV 0% 60% 70% 75%	15% 37% 15% 34% 10% 19% 22%	HPHotWa ElectricStc GasInst_Lc DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc	0% 60% 40% 0% 0% 0% 0% 92% 8%	42% 55% Hot Water DWH 0% 30% 42%	18% 42% 42%	22 24 30 50 60 	2% 5% 4% 23% 23% 24% 7% 7% 10% 3% 10% 3%	-Values Roof 40 50 60 70 80	15% 7% 26% 26% 27% 27% 20% 5% 8% 12%	HG-i89-Tri LG-avg-Tri MG-HP-Dc MG-i89-Dc HG-avg-Tri HG-HP-Tri HG-HP-Tri LG-avg-Tc LG-avg-Tr	45% 9% 2% 3% 14% Glaze 6laze 8% 10% 22% 22% 3%	1.2 1.4 1.6 1.8 U-valut 0.8 1 1.2 1.2 1.4 1.6	6% 23% 3% 14% 9% 22% 10% 12% 8% 25%

Figure 12: Townhouse Step 1 results

Step 1															
GHGI ≤1	ICC ≤2%	ECI ≤\$10													
		and Cooling		D	omestic He	ot Water		E	nvelope	R-Values			Window	ws	
HVAG	2	HRV		DHW Sy	stem	DWH	IR	Wall		Roof		Pane and	Glaze	U-valu	е
baseboard	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
Dasciullia	0,0														
CCASHP-e	13%	70%	19%	GasInstan	0%	42%	6%	22	0%	60	0%	HG-i89-Tri	0%	1.2	6
		70% 75%		GasInstan HPHotWa	0% 69%	42% 55%	6% 25%	22 24	0% 31%	60 70		HG-i89-Tri LG-avg-Dc	0% 50%	1.2 1.4	
CCASHP-e	13%		13%								0%				25%
CCASHP-e ComboHe	13% 0%	75%	13% 19%	HPHotWa	69%			24	31%	70	0% 6%	LG-avg-Dc	50%	1.4	259 199
CCASHP-e ComboHe	13% 0%	75%	13% 19%	HPHotWa ElectricSto	69% 31%			24 30	31% 0%	70 80	0% 6% 25%	LG-avg-Dc LG-avg-Tri	50% 0%	1.4 1.6	6% 25% 19% 50%

Figure 13: MURB Step 1 results

Step 1											
GHGI	ICC	ECI									
≤5	≤2%	≤\$10									
Spa	ce Heating	and Cooling	2	Domestic I	Hot Water		Envelope	R-Values		Window	vs USI
Heating ef		HRV		DHW S		Wa		Roof		Pane and	
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%
Stop 2											
Step 2 GHGI ≤5 Spaa	ICC ≤2% ce Heating	ECI ≤\$10 and Cooling	2	Domestic I	Hot Water		Envelope	R-Values		Window	rs USI
GHGI ≤5	≤2% ce Heating	-		Domestic F DHW S		Wa	Envelope II	R-Values Roof		Window Pane and	
GHGI ≤5 Spa	≤2% ce Heating	≤\$10 and Cooling							52%		Glaze
GHGI ≤5 Spac Heating ef	≤2% ce Heating fficiency	≤\$10 and Cooling HRV	-	DHW S	avings	Wa		Roof		Pane and	Glaze 55%
GHGI ≤5 Spa Heating ef Condensi	≤2% ce Heating fficiency 100%	≤\$10 and Cooling HRV 0	0%	DHW S	avings	Wa 4	ll 34%	Roof 20	52%	Pane and 2.5	Glaze 55% 26%
GHGI ≤5 Spa Heating ef Condensi	≤2% ce Heating fficiency 100%	≤\$10 and Cooling HRV 0 60%	0% 55%	DHW S	avings	Wa 4 7	II 34% 28%	Roof 20 30	52% 0%	Pane and 2.5 2	

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

LowRiseMURB_Midoccupancy

Step 1

GHGI	ICC	ECI									
≤5	≤2%	≤\$10									
Spa	ce Heating	and Cooling	g	Domestic I	Hot Water		Envelope	R-Values		Windo	ws USI
Heating ef	ficiency	HRV	r.	DHW S		w		Roo	of	Pane an	d Glaze
Condensir	100%	0	0%	40	100%	4	47%	20	53%	2.5	1009
standard	0%	60%	73%			7	13%	30	0%	2	05
		80%	27%			10		40	47%	1.6	05
						20	13%			1.2	09
										0.8	05
Step 2											
GHGI	ICC	ECI									
	ICC ≤2%	ECI ≤\$10									
GHGI ≤5	≤2%	-	g	Domestic I	Hot Water		Envelope	R-Values		Windo	ws USI
GHGI ≤5 Spa Heating ef	≤2% ce Heating	≤\$10	, ,	DHW S	avings		all	Roo		Pane an	d Glaze
GHGI ≤5 Spa Heating ef Condensir	≤2% ce Heating fficiency 100%	≤\$10 and Cooling HRV 0	0%	DHW S 40	avings	W 4	all 20%	Roo 20	54%	Pane an 2.5	d Glaze 879
GHGI ≤5 Spa Heating ef	≤2% ce Heating	≤\$10 and Cooling HRV 0 60%	0% 55%	DHW S 40	avings	W 4 7	all 20% 27%	Roo 20 30	54% 0%	Pane an 2.5 2	d Glaze 879 99
GHGI ≤5 Spa Heating ef Condensir	≤2% ce Heating fficiency 100%	≤\$10 and Cooling HRV 0	0%	DHW S 40	avings	W 4 7 10	all 20% 27% 23%	Roo 20	54%	Pane an 2.5 2 1.6	d Glaze 879 99
GHGI ≤5 Spa Heating ef Condensir	≤2% ce Heating fficiency 100%	≤\$10 and Cooling HRV 0 60%	0% 55%	DHW S 40	avings	W 4 7 10 20	all 20% 27% 23% 20%	Roo 20 30	54% 0%	Pane an 2.5 2 1.6 1.2	d Glaze 879 99 39 19
GHGI ≤5 Spa Heating ef Condensir	≤2% ce Heating fficiency 100%	≤\$10 and Cooling HRV 0 60%	0% 55%	DHW S 40	avings	W 4 7 10	all 20% 27% 23% 20%	Roo 20 30	54% 0%	Pane an 2.5 2 1.6	

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.

Vledium SF	D														
Step 3															
GHGI ≤6	ICC ≤3%	ECI ≤\$7.5													
Space Heati	ng and	Cooling		Domestic	Hot Wa	ater		En	velope	R-Val	ues	Win	dows		
HVAC		HR	v	DHW System		DW	'HR	w	all	Rc	of	Pane and Glaz	e	U-v	alue
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 Heati	ng and	Cooling		Domestic	Hot Wa	ater		En	velope	R-Val	ues	Win	dows		
HVAC		HR	v	DHW System		DW	HR	w	all	Rc	of	Pane and Glaz	2e	U-v	alue
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

arge SFD													
Step 3													
GHGI	ICC	ECI											
≤3	≤2%	≤\$6											
Space Heating and	Cooling	Dor	nestic Hot Water			En	velope	R-Valu	ues		Windo	ws	
HVAC		DHW Syst	em	DWH	R	w	all	Ro	of	Pane and Gla	ze	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%
CCASHP-ecm			0%	55%	8%	24	15%	70	15%	LG-avg-Double	31%	1.4	19%
ComboHeatA	0%	HPHotWater	0%	33/0									
	0% 0%	ElectricStorage	2%	33/0		30	2%	80	8%	LG-avg-Triple	2%	1.6	33%
ComboHeatA				3370		30 40	2% 4%	80 100	8% 17%	LG-avg-Triple MG-HP-Double	2% 19%	1.6 1.8	33% 31%

Figure 17: Large SFD occupancy step 3 results

Step 3															
GHGI	ICC	ECI													
≤6	≤2%	≤\$10													
Space	Heating an	nd Cooling			Domestic H	ot Water		En	nvelope	R-Values			Windov	NS	
HVAC		HRV		DHW Sy	stem	DWHR		Wall		Roof		Pane and	Glaze	U-value	е
baseboard	0%	0%	43%	BaseDHW	0%	0%	65%	16	54%	40	45%	HG-avg-Tr	2%	0.8	C
basefurnace	88%	60%		Combo	0%	30%	12%	18	23%	50		HG-HP-Tri	0%	1	0
CCASHP-ecm	0%	70%	14%	GasInstan	0%	42%	14%	22	5%	60		HG-i89-Tri	0%	1.2	2
ComboHeatA	0%	75%	9%	HPHotWa	48%	55%	9%	24	17%	70	6%	LG-avg-Dc	71%	1.4	11
gas-furnace-	12%	84%		ElectricSto	52%		1	30	2%	80		LG-avg-Tri	0%	1.6	17
				GasInst_L	0%			40	0%	100		MG-HP-Do	11%	1.8	71
		1						50	0%			MG-i89-De	17%		
								60	0%						
	≤3% Heating an				Domestic H				nvelope	R-Values Roof		Pane and	Windov		•
Space HVAC	Heating an	nd Cooling HRV		DHW Sy	stem	DWHR		Wall		Roof		Pane and	Glaze	U-value	-
Space HVAC baseboard	Heating an	nd Cooling HRV 0%		DHW Sy BaseDHW	ostem 0%	DWHR 0%	25%	Wall 16	25%	Roof 40		HG-avg-Tr	Glaze 13%	U-value 0.8	0
Space HVAC baseboard basefurnace	Heating an 0% 88%	nd Cooling HRV 0% 60%	75%	DHW Sy BaseDHW Combo	ostem 0% 0%	DWHR 0% 30%	25% 25%	Wall 16 18	25% 38%	Roof 40 50	38%	HG-avg-Tr HG-HP-Tri	Glaze 13% 0%	U-value 0.8 1	0
Space HVAC baseboard basefurnace CCASHP-ecm	Heating an 0% 88% 0%	nd Cooling HRV 0% 60% 70%	75% 13%	DHW Sy BaseDHW Combo GasInstan	ostem 0% 0% 0%	DWHR 0% 30% 42%	25% 25% 13%	Wall 16 18 22	25% 38% 13%	Roof 40 50 60	38% 0%	HG-avg-Tr HG-HP-Tri HG-i89-Tri	Glaze 13% 0% 0%	U-value 0.8 1 1.2	0 0 13
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0% 0%	nd Cooling HRV 0% 60% 70% 75%	75% 13% 13%	DHW Sy BaseDHW Combo GasInstan HPHotWa	ostem 0% 0% 0%	DWHR 0% 30%	25% 25%	Wall 16 18 22 24	25% 38% 13% 0%	Roof 40 50 60 70	38% 0% 25%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc	Glaze 13% 0% 0%	U-value 0.8 1 1.2 1.4	0 0 13 38
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0%	nd Cooling HRV 0% 60% 70%	75% 13% 13%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricSto	ostem 0% 0% 0% 0%	DWHR 0% 30% 42%	25% 25% 13%	Wall 16 18 22 24 30	25% 38% 13% 0% 13%	Roof 40 50 60 70 80	38% 0% 25% 0%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri	Glaze 13% 0% 0% 0% 0% 0%	U-value 0.8 1 1.2 1.4 1.6	0 0 13 38 50
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0% 0%	nd Cooling HRV 0% 60% 70% 75%	75% 13% 13%	DHW Sy BaseDHW Combo GasInstan HPHotWa	ostem 0% 0% 0%	DWHR 0% 30% 42%	25% 25% 13%	Wall 16 18 22 24 30 40	25% 38% 13% 0% 13% 13%	Roof 40 50 60 70	38% 0% 25% 0%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc	Glaze 13% 0% 0% 0% 0% 38%	U-value 0.8 1 1.2 1.4	0 0 13 38 50
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0% 0%	nd Cooling HRV 0% 60% 70% 75%	75% 13% 13%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricSto	ostem 0% 0% 0% 0% 100%	DWHR 0% 30% 42%	25% 25% 13%	Wall 16 18 22 24 30	25% 38% 13% 0% 13%	Roof 40 50 60 70 80	38% 0% 25% 0%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri	Glaze 13% 0% 0% 0% 0% 0%	U-value 0.8 1 1.2 1.4 1.6	0 0 13 38 50
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1	Heating an 0% 88% 0% 0% 13% ICC ≤5%	Ad Cooling HRV 0% 60% 70% 75% 84% 84% ECI ≤\$10	75% 13% 13%	DHW Sy Base DHW Combo GasInstan HPHotWa ElectricStc GasInst_L(stem 0% 0% 0% 0%	DW HR 0% 30% 42% 55%	25% 25% 13%	Wall 16 18 22 24 30 40 50 60	25% 38% 13% 0% 13% 13% 0% 0%	Roof 40 50 60 70 80 100	38% 0% 25% 0%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc	Glaze 13% 0% 0% 0% 0% 38% 50%	U-value 0.8 1 1.2 1.4 1.6 1.8	e 0' 13' 38' 50' 0'
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space	Heating an 0% 88% 0% 0% 13% ICC ≤5% Heating an	ed Cooling HRV 0% 60% 70% 75% 84% 84% ≤\$10	75% 13% 13%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc GasInst_Lo	stem 0% 0% 0% 100% 0%	DWHR 0% 30% 42% 55%	25% 25% 13% 38%	Wall 16 18 22 24 30 40 50 60	25% 38% 13% 0% 13% 13% 0% 0%	Roof 40 50 60 70 80 100 80	38% 0% 25% 0%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-Do	Glaze 13% 0% 0% 0% 38% 50% Windov	U-valut 0.8 1 1.2 1.4 1.6 1.8	0 0 13 38 50 0
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC	Heating an 0% 88% 0% 0% 13% 13% ICC ≤5% Heating an	ed Cooling HRV 0% 60% 70% 75% 84% 84% ECI ≤\$10 ad Cooling HRV	75% 13% 13% 0%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc GasInst_Lc DHW Sy	stem 0% 0% 0% 100% 0% 0%	DWHR 0% 30% 42% 55%	25% 25% 13% 38%	Wall 16 18 22 24 30 40 50 60 60 En Wall	25% 38% 13% 0% 13% 0% 0%	Roof 40 50 60 70 80 100 Roof	38% 0% 25% 0% 25%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-i89-Dc	Glaze 13% 0% 0% 0% 38% 50% \$50% Window Glaze	U-value 0.8 1 1.2 1.4 1.6 1.8 1.8 8 WS	0 0 13 38 50 0
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC baseboard	Heating an 0% 88% 0% 0% 13% ICC ≤5% Heating an 0%	e Cooling HRV 0% 60% 70% 75% 84% 84% ECI ≤\$10 HRV 0%	75% 13% 13% 0%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc GasInst_Lt DHW Sy BaseDHW	stem 0% 0% 0% 100% 0% Domestic H stem 0%	DWHR 0% 30% 42% 55% ot Water DWHR 0%	25% 25% 13% 38%	Wall 16 18 22 24 30 40 50 60	25% 38% 13% 0% 13% 0% 0%	Roof 40 50 60 70 80 100 R-Values Roof 40	38% 0% 25% 25% 25%	HG-avg-Tr HG-HP-Tri HG-189-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-189-Dc MG-189-Dc HG-avg-Tr	Glaze 13% 0% 0% 0% 38% 50% 50% Window Glaze 0%	U-valut 0.8 1 1.2 1.4 1.6 1.8 1.8 V-valut 0.8	0'0'0'13' 38'50'0'0'
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC baseboard basefurnace	Heating an 0% 88% 0% 0% 13% ICC ≤5% Heating an 0% 0%	ed Cooling HRV 0% 60% 70% 75% 84% 84% 84% 55% 84% 84% 84% 84% 84% 84% 84% 84% 84% 84	75% 13% 13% 0% 41% 35%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc GasInst_L(DHW Sy BaseDHW Combo	stem 0% 0% 0% 100% 0% 0% 0%	DWHR 0% 30% 42% 55% 00 Vot Water DWHR 0% 30%	25% 25% 13% 38% 47% 29%	Wall 16 18 22 24 30 40 50 60 En Wall 16 18	25% 38% 13% 0% 13% 0% 0% 0%	Roof 40 50 60 70 80 100 Revalues Roof 40 50	38% 0% 25% 25% 25% 22%	HG-avg-Tr HG-HP-Tri HG-189-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-189-Dc MG-189-Dc HG-avg-Tr HG-HP-Tri	Glaze 13% 0% 0% 0% 38% 50% Window Glaze 0% 0%	U-valut 0.8 1 1.2 1.4 1.6 1.8 8 U-valut 0.8 1	0 0 13 38 50 0
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC baseboard basefurnace CCASHP-ecm	Heating an 0% 88% 0% 0% 13% 13% Figure 25% Heating an 0% 0% 100%	d Cooling HRV 0% 60% 70% 75% 84% 84% ≤\$10 cooling HRV 0% 60% 60%	75% 13% 13% 0% 41% 35% 6%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectriGSt ElectriGSt GasInst_L(DHW Sy BaseDHW Combo GasInstan	stem 0% 0% 0% 100% 0% 0% 0% 0% 0%	DWHR 0% 30% 42% 55% ot Water DWHR 0% 30% 42%	25% 25% 13% 38% 47% 29% 6%	Wall 16 18 22 24 30 40 50 60 En Wall 16 18 22	25% 38% 13% 0% 13% 0% 0% 0%	Roof 40 50 60 70 80 100 80 100 80 100 80 100 80 100 80 100 80 100	38% 0% 25% 25% 25% 24% 29% 0%	HG-avg-Tr HG-HP-Tri HG-189-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-189-Dc HG-avg-Tr HG-HP-Tri HG-HP-Tri HG-189-Tri	Glaze 13% 0% 0% 0% 38% 50% Window Glaze 0% 0% 0%	U-valut 0.8 1 1.2 1.4 1.6 1.8 1.8 U-valut 0.8 1 1.2	0 0 13 38 50 0 0
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0% 0% 13% 13% ICC ≤5% Heating an 0% 0% 0%	d Cooling HRV 0% 60% 70% 75% 84% 84% 84% 84% 84% 84% 84% 84% 84% 84	75% 13% 13% 0% 41% 35% 6% 6%	DHW Sy BaseDHW Combo Gasinstan HPHotWa ElectricSt Gasinst_L(DHW Sy BaseDHW Combo Gasinstan HPHotWa	stem 0% 0% 0% 100% 0% 0% 0% 0% 0% 0% 0% 100%	DWHR 0% 30% 42% 55% 00 Vot Water DWHR 0% 30%	25% 25% 13% 38% 47% 29%	Wall 16 18 22 24 30 40 50 60 60 En Wall 16 18 22 24	25% 38% 13% 0% 13% 0% 0%	Roof 40 50 60 70 80 100 80 Roof 40 50 60 60 70	38% 0% 25% 25% 25% 25% 24% 29% 0% 18%	HG-avg-Tr HG-HP-Tri HG-189-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-189-Dc MG-189-Dc HG-avg-Tr HG-HP-Tri HG-189-Tri LG-avg-Dc	Glaze 13% 0% 0% 0% 38% 50% S0% Window Glaze 0% 0% 0% 0% 71%	U-value 0.8 1 1.2 1.4 1.6 1.8	0 0 13 38 50 0 0 0 0 0 0 0 12 6
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0% 0% 13% 13% Figure 25% Heating an 0% 0% 100%	d Cooling HRV 0% 60% 70% 75% 84% 84% ≤\$10 cooling HRV 0% 60% 60%	75% 13% 13% 0% 41% 35% 6% 6%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc GasInst_L DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc	stem 0% 0% 100% 100% 0% 0% 0% 0% 0%	DWHR 0% 30% 42% 55% ot Water DWHR 0% 30% 42%	25% 25% 13% 38% 47% 29% 6%	Wall 16 18 22 24 30 40 50 60 60 60 60 61 16 18 22 24 30 30 30	25% 38% 13% 0% 13% 0% 0%	Roof 40 50 60 70 80 100 80 100 80 100 60 60 60 60 60 60 70 80	38% 0% 25% 25% 25% 22% 24% 29% 0% 18% 12%	HG-avg-Tr HG-HP-Tri HG-I89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-I89-Dc HG-avg-Tri HG-HP-Tri HG-HP-Tri HG-HP-Tri LG-avg-Dc LG-avg-Tri	Glaze 13% 0% 0% 0% 33% 50% 50% Glaze 0% 0% 0% 0% 0% 12%	U-valut 0.8 1 1.2 1.4 1.6 1.8 U-valut 0.8 1 1 1.2 1.4 1.6	0 0 13' 38' 50' 0' 0' 0' 2' 6' 12'
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space HVAC basefurnace CCASHP-ecm ComboHeatA	Heating an 0% 88% 0% 0% 13% 13% ICC ≤5% Heating an 0% 0% 0%	d Cooling HRV 0% 60% 70% 75% 84% 84% 84% 84% 84% 84% 84% 84% 84% 84	75% 13% 13% 0% 41% 35% 6% 6%	DHW Sy BaseDHW Combo Gasinstan HPHotWa ElectricSt Gasinst_L(DHW Sy BaseDHW Combo Gasinstan HPHotWa	stem 0% 0% 0% 100% 0% 0% 0% 0% 0% 0% 0% 100%	DWHR 0% 30% 42% 55% ot Water DWHR 0% 30% 42%	25% 25% 13% 38% 47% 29% 6%	Wall 16 18 22 24 30 40 50 60 60	25% 38% 13% 13% 13% 0% 0% 0%	Roof 40 50 60 70 80 100 80 Roof 40 50 60 60 70	38% 0% 25% 25% 25% 25% 24% 29% 0% 18%	HG-avg-Tr HG-HP-Tri HG-189-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-189-Dc MG-189-Dc HG-avg-Tri HG-HP-Tri HG-189-Tri LG-avg-Tri LG-avg-Tri MG-HP-Dc	Glaze 13% 0% 0% 0% 38% 50% 50% Glaze 0% Glaze 0% 0% 0% 0% 0% 6%	U-value 0.8 1 1.2 1.4 1.6 1.8	0 0 13' 38' 50' 0' 0' 0' 0' 0' 12' 6'
Space HVAC baseboard basefurnace CCASHP-ecm ComboHeatA gas-furnace-(GHGI ≤1 Space	Heating an 0% 88% 0% 0% 13% 13% ICC ≤5% Heating an 0% 0% 0%	d Cooling HRV 0% 60% 70% 75% 84% 84% 84% 84% 84% 84% 84% 84% 84% 84	75% 13% 13% 0% 41% 35% 6% 6%	DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc GasInst_L DHW Sy BaseDHW Combo GasInstan HPHotWa ElectricStc	stem 0% 0% 100% 100% 0% 0% 0% 0% 0%	DWHR 0% 30% 42% 55% ot Water DWHR 0% 30% 42%	25% 25% 13% 38% 47% 29% 6%	Wall 16 18 22 24 30 40 50 60 60 60 60 61 16 18 22 24 30 30 30	25% 38% 13% 0% 13% 0% 0%	Roof 40 50 60 70 80 100 80 100 80 100 60 60 60 60 60 60 70 80	38% 0% 25% 25% 25% 22% 24% 29% 0% 18% 12%	HG-avg-Tr HG-HP-Tri HG-I89-Tri LG-avg-Dc LG-avg-Tri MG-HP-Dc MG-I89-Dc HG-avg-Tri HG-HP-Tri HG-HP-Tri HG-HP-Tri LG-avg-Dc LG-avg-Tri	Glaze 13% 0% 0% 0% 33% 50% 50% Glaze 0% 0% 0% 0% 0% 12%	U-valut 0.8 1 1.2 1.4 1.6 1.8 U-valut 0.8 1 1 1.2 1.4 1.6	0 0 13 38 50 0 0 0 12 6 12

Figure 18: Townhouse occupancy step 3 results

В															
Step 3															
GHGI ≤1	ICC ≤2%	ECI ≤\$10 and Cooling			Domestic H	ot Water		F	nvelope F	2.Values			Windov	NG	
	•	HRV		DHW S		DWH									
HVA	L						IK	Wali		Roof		Pane and	Glaze	U-valu	e
baseboard	100%	0%	68%	BaseDHW	0%	0%	1R 36%	Wall 16	43%	Roof 40	45%	Pane and HG-avg-Tr	l Glaze 0%	U-valu 0.8	ie 09
	-							-							-
baseboard	100%	0%	16%	BaseDHW	0%	0%	36%	16	43%	40	16%	HG-avg-Tr	0%		0%
baseboarc basefurna	100% 0%	0% 60%	16% 5%	BaseDHW Combo	0% 0%	0% 30%	36% 30%	16 18	43% 9%	40 50	16% 7%	HG-avg-Tr HG-HP-Tri	0% 0%	0.8 1	09 09
baseboarc basefurna CCASHP-e	100% 0% 0%	0% 60% 70%	16% 5% 5%	BaseDHW Combo GasInstan	0% 0% 0% 52%	0% 30% 42%	36% 30% 14%	16 18 22	43% 9% 7%	40 50 60	16% 7% 7%	HG-avg-Tr HG-HP-Tri HG-i89-Tri	0% 0% 0%	0.8 1 1.2	0% 0% 7%
baseboarc basefurna CCASHP-e ComboHe	100% 0% 0%	0% 60% 70% 75%	16% 5% 5% 7%	BaseDHW Combo GasInstan HPHotWa	0% 0% 0% 52%	0% 30% 42%	36% 30% 14%	16 18 22 24	43% 9% 7% 9%	40 50 60 70	16% 7% 7% 7%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc	0% 0% 0% 66%	0.8 1 1.2 1.4	09 09 79 59
baseboarc basefurna CCASHP-e ComboHe	100% 0% 0%	0% 60% 70% 75%	16% 5% 5% 7%	BaseDHW Combo GasInstan HPHotWat ElectricSto	0% 0% 0% 52% 48%	0% 30% 42%	36% 30% 14%	16 18 22 24 30	43% 9% 7% 9% 5%	40 50 60 70 80	16% 7% 7% 7%	HG-avg-Tr HG-HP-Tri HG-i89-Tri LG-avg-Dc LG-avg-Tri	0% 0% 66% 7%	0.8 1 1.2 1.4 1.6	09 09 79 59 239

Figure 19: MURB occupancy step 3 results

HighRiseMURB_Midoccupancy

GHGI	ICC	ECI									
≤5	≤2%	≤\$8									
Spa	ce Heating	and Coolir	ng	Domestic I	Hot Water		Envelope	R-Values		Window	vs USI
Heating ef	ficiency	HR\	/	DHW S	avings	w	all	Ro	of	Pane and	l Glaze
Condensir	91%	0	0%	40	100%	4	2%	20	52%	2.5	39%
standard	9%	60%	57%			7	38%	30	0%	2	279
		80%	43%			10	42%	40	48%	1.6	209
						20	17%			1.2	99

Figure 20: High Rise MURB Mid occupancy step 3 results

Step 3											
GHGI ≤5	ICC ≤2%	ECI ≤\$8									
	-	and Cooling		Domestic I			Envelope R- 			Window	
Heating ef	ficiency	HRV		DHW S	avings	Wa		Roo		Pane and	Glaze
Heating eff Condensir	ficiency 91%	HRV 0	0%	DHW S 40		Wa 4	II 0%	Roo ⁻ 20	56%	Pane and 2.5	Glaze 69%
Heating ef	ficiency	HRV		DHW S 40	avings	Wa		Roo		Pane and	Glaze
Heating eff Condensir	ficiency 91%	HRV 0	0%	DHW S 40	avings	Wa 4	II 0%	Roo ⁻ 20	56%	Pane and 2.5	Glaze 69%
Heating eff Condensir	ficiency 91%	HRV 0 60%	0% 57%	DHW S 40	avings	Wa 4 7	II 0% 21%	Roo ⁻ 20 30	56% 0%	Pane and 2.5 2	Glaze 69% 22%

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 SF	D														
Step 4 and 5															
GHGI ≤6	ICC ≤3%	ECI ≤\$7.5	I												
Space Heati	ng and	Cooling		Domestic	Hot Wa	ater		En	velope	R-Val	ues	Win	dows		
HVAC		HR	v	DHW System		DW	/HR		all		oof	Pane and Glaz	e	U-va	alue
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%	-													
Space Heati	ng and	Cooling		Domestic	Hot Wa	ater		En	velope	R-Val	ues	Win	dows		
HVAC		HR	v	DHW System		DW	/HR	w	all .	Rc	oof	Pane and Glaz	e	U-va	alue
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

tep 4 and 5													
GHGI	ICC	ECI											
≤3	≤2%	≤\$6											
bace Heating and C	Cooling	Domes	stic Hot Water			En	velope	R-Valı	ues		Window	'S	
HVAC		DHW Systen	n	DWH	IR _	w	all	Rc	of	Pane and GI	aze	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%
	00/	HPHotWater	14%	55%	3%	24	0%	70	7%	LG-avg-Double	66%	1.4	0%
ComboHeatA	0%	in notivater											
	0%	ElectricStorage	17%			30	0%	80	0%	LG-avg-Triple	0%	1.6	14%
			17% 21%			30 40	0% 0%	80 100	0% 7%	LG-avg-Triple MG-HP-Double		1.6 1.8	14% 66%
		ElectricStorage								• •	0%		
as-furnace-ecm	0%	ElectricStorage				40 50	0% 0%			MG-HP-Double	0%		
as-furnace-ecm	0%	ElectricStorage				40 50	0% 0%			MG-HP-Double	0%		
as-furnace-ecm tep 3,4 and 5 GHGI	0%	ElectricStorage GasInst_Low ECI				40 50	0% 0%			MG-HP-Double	0%		
as-furnace-ecm	0%	ElectricStorage GasInst_Low				40 50	0% 0%			MG-HP-Double	0%		
tep 3,4 and 5 GHGI ≤1	0% ICC ≤3%	ElectricStorage GasInst_Low ECI ≤\$6				40 50 60	0% 0%	100	7%	MG-HP-Double	0%	1.8	
tep 3,4 and 5 GHGI ≤1	0% ICC ≤3%	ElectricStorage GasInst_Low ECI ≤\$6	21%	DWH	 R	40 50 60	0% 0% 0%	100 R-Valu	7%	MG-HP-Double	0% 14% Window	1.8	
tep 3,4 and 5 GHGI ≤1 pace Heating and C	0% ICC ≤3%	ElectricStorage GasInst_Low ECI ≤\$6 Dome:	21%	DWH 0%	IR 54%	40 50 60	0% 0% 0%	100 R-Valu	7%	MG-HP-Double MG-i89-Double	0% 14% Window	1.8	
as-furnace-ecm tep 3,4 and 5 GHGI ≤1 bace Heating and C HVAC	0% ICC ≤3% Cooling	ElectricStorage GasInst_Low ECI ≤\$6 Dome: DHW System	21% stic Hot Water		_	40 50 60 En W	0% 0% 0% velope fall	100 R-Valu Rc	7%	MG-HP-Double MG-i89-Double Pane and Gl	0% 14% Window aze	1.8 rs U-value	66%
as-furnace-ecm tep 3,4 and 5 GHGI ≤1 bace Heating and C HVAC baseboard	0% ICC ≤3% Cooling 31%	ElectricStorage GasInst_Low ECI ≤\$6 Dome: DHW System BaseDHW	21% stic Hot Water n 0%	0%	54%	40 50 60 En W 16	0% 0% 0% (all 50%	100 R-Vali Ro 40	7% pof 41%	MG-HP-Double MG-i89-Double Pane and GI HG-avg-Triple	0% 14% Window aze 20% 1%	1.8 U-value 0.8	66%
as-furnace-ecm tep 3,4 and 5 GHGI ≤1 base Heating and C HVAC baseboard basefurnace	0% ICC ≤3% 31% 0%	ElectricStorage GasInst_Low ECI ≤\$6 Dome: DHW Systen BaseDHW Combo	21% stic Hot Water n 0% 0%	0% 30%	54% 22%	40 50 60 En W 16 18	0% 0% 0% (all 50% 19%	100 R-Valu Rc 40 50	7% 200f 41% 16%	MG-HP-Double MG-i89-Double Pane and Gi HG-avg-Triple HG-HP-Triple	0% 14% Window aze 20% 1% 1%	1.8 U-value 0.8 1.0	66%
tep 3,4 and 5 GHGI ≤1 bace Heating and C HVAC baseboard basefurnace CCASHP-ecm	0% ICC ≤3% 31% 0% 69%	ElectricStorage GasInst_Low ECI ≤\$6 DHW Systen BaseDHW Combo GasInstantaneous	21% stic Hot Water n 0% 0% 0%	0% 30% 42%	54% 22% 12%	40 50 60 60 En W 16 18 22	0% 0% 0% /all 50% 19% 7%	100 100 R-Valu Rc 40 50 60	7% 200f 41% 16% 6%	MG-HP-Double MG-i89-Double Pane and Gl HG-avg-Triple HG-HP-Triple HG-i89-Triple-B	0% 14% Window aze 20% 1% 1%	1.8 1.8 U-value 0.8 1.0 1.2	66% 1% 1% 20%

Figure 23: Large SFD occupancy step 4 & 5 results

Townhouses

Step 4 and 5

GHGI		FCI
≤6	≤3%	≤\$10

Space	Heating a	nd Cooling			Domestic	Hot Water			Envelope	R-Values			Wind	lows	
HVAC		HR	v	DHW S	ystem	DW	HR	Wa	all	Ro	of	Pane an	d Glaze	U-va	lue
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%	HPHotWa	93%	55%	9%	24	18%	70	24%	LG-avg-Dc	36%	1.4	14%
gas-furnace-	11%	84%	11%	ElectricSto	8%			30	6%	80	5%	LG-avg-Tri	3%	1.6	39%
				GasInst_L	0%			40	1%	100	8%	MG-HP-Do	14%	1.8	36%
								50	1%			MG-i89-D	39%		
								60	0%						

ghgi icc eci

≤3 ≤3% ≤\$10

Spac	e Heating a	nd Cooling			Domestic I	Hot Water			Envelope	R-Values			Wind	dows	
HVA	с	HR	v	DHW S	ystem	DW	/HR	w	all	Ro	of	Pane and	d Glaze	U-val	ue
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%	HPHotWa	0%	55%	0%	24	0%	70	0%	LG-avg-Dc	0%	1.4	0%
gas-furnace-e	0%	84%	0%	ElectricSto	100%			30	0%	80	0%	LG-avg-Tri	0%	1.6	0%
				GasInst_L	0%			40	67%	100	0%	MG-HP-Do	0%	1.8	0%
								50	33%			MG-i89-De	0%		
								60	33%						

GHGI ICC ECI ≤1 ≤5% ≤\$10

Space I	Heating an	d Cooling		0	Domestic H	lot Water		E	Invelope	R-Values			Wind	ows		
HVAC		HRV		DHW Sy	stem	DW	HR	Wal	I	Roo	f	Pane and Glaze U		U-val	-value	
baseboard	0%	0%	50%	BaseDHW	0%	0%	59%	16	59%	40	41%	HG-avg-Tr	5%	0.8	C	
basefurnace	0%	60%	36%	Combo	0%	30%	23%	18	23%	50	41%	HG-HP-Tri	0%	1	C	
CCASHP-ecm	100%	70%	0%	GasInstan	0%	42%	9%	22	9%	60	0%	HG-i89-Tri	0%	1.2	5	
ComboHeatA	0%	75%	14%	HPHotWa	91%	55%	9%	24	9%	70	9%	LG-avg-Dc	77%	1.4	9	
gas-furnace-(0%	84%	0%	ElectricSto	9%			30	0%	80	0%	LG-avg-Tri	0%	1.6	ç	
				GasInst_L	0%			40	0%	100	9%	MG-HP-Do	9%	1.8	77	
								50	0%			MG-i89-De	9%			
								60	0%							

Figure 24: Townhouse occupancy step 4 & 5 results

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-HP-Tri 0% 1.2 28 ComboHe 0% 75% 10% HPHotWa 54% 55% 17% 24 15% 70 14% LG-avg-Dc 65% 1.4 28 elec-base 0% 84% 26% ElectricStc 46% 30 3% 80 6% LG-avg-Tri 3% 1.6 20																
Space Heating and Cooling HVAC Domestic Hot Water Envelope R-Values Windows baseboard DHW System DWHR Wall Roof Pane and Glaze U-value baseboard 95% 0% 15% BaseDHW 0% 52% 16 35% 40 27% HG-avg-Tr 5% 0.8 00 basefurna 0% 60% 38% Combo 0% 30% 22% 18 15% 50 22% HG-H9-Tri 0% 1 00 CCASHP-e 5% 70% 11% GasInstan 0% 42% 10% 22 9% 60 12% HG-189-Tri 0% 1.2 8 ComboHe 0% 75% 10% HPHotWa 54% 5% 17% 24 15% 70 14% LG-avg-Dc 65% 1.4 24 elec-base 0% 84% 26% ElectricStc 46% 30 33 80 6% LG-avg-Tri 3%	GHGI	ICC	ECI													
HVAC HRV DHW System DWHR Wall Roof Pane and Glaze U-value baseboard 95% 0% 15% BaseDHW 0% 0% 52% 16 35% 40 27% HG-avg-Tr 5% 0.8 0 baseburn 0% 60% 33% 0% 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-HP-Tri 0% 1.2 E ComboHe 0% 75% 10% HPhotWa 54% 55% 17% 24 15% 70 14% LG-avg-Dc 655% 1.4 45% elec-base 0% 84% 26% Electricitic 46% 30 3% 80 6% LG-avg-Tri 3% 1.6 20%	≤1	≤2%	≤\$10													
baseboard 95% 0% 15% BaseDHW 0% 0% 52% 16 35% 40 27% HG-avg-Tr 5% 0.8 00 basefurna 0% 60% 38% Combo 0% 30% 22% 18 15% 50 20% HG-avg-Tr 5% 0.8 0 CASHP-e 5% 70% 11% GasInstan 0% 42% 10% 22 9% 60 12% HG-avg-Tr 0% 1.2 28 ComboHe 0% 75% 10% HPHotWa 54% 55% 17% 24 15% 70 14% LG-avg-Dc 655% 1.4 28 elec-base 0% 84% 26% ElectricStc 46% 30 3% 80 6% LG-avg-Tri 3% 1.6 20	Spac	ce Heating	and Cooling		[Domestic H	lot Water		E	nvelope	R-Values			Windo	NS	
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-HP-Tri 0% 1.2 28 ComboHe 0% 75% 10% HPHotWa 54% 55% 17% 24 15% 70 14% LG-avg-Dc 65% 1.4 28 elec-base 0% 84% 26% ElectricStc 46% 30 3% 80 6% LG-avg-Tri 3% 1.6 20	HVA	NC .	HRV		DHW Sy	/stem	DWH	IR	Wall		Roof		Pane and	d Glaze	U-valu	e
CCASHP-e 5% 70% 11% GasInstan 0% 42% 10% 22 9% 60 12% HG-i89-Tri 0% 1.2 8 ComboHe 0% 75% 10% HPHotWa 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	baseboard	95%	0%	15%	BaseDHW	0%	0%	52%	16	35%	40	27%	HG-avg-Tr	5%	0.8	0%
ComboHe 0% 75% 10% HPHotWa 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	basefurna	0%	60%	38%	Combo	0%	30%	22%	18	15%	50	20%	HG-HP-Tri	0%	1	09
elec-base 0% 84% 26% ElectricSt(46% 30 3% 80 6% LG-avg-Tri 3% 1.6 20		E0/	70%	11%	GasInstan	0%	42%	10%	22	9%	60	12%	HG-i89-Tri	0%	1.2	89
	CCASHP-e	5%		100/	HPHot Wat	54%	55%	17%	24	15%	70	14%	LG-avg-Dc	65%	1.4	89
Gasinst L(0% 40 8% 100 20% MG-HP-D(8% 1.8 65			75%	10%							00	£0/	IC ava Tri	20/	16	209
	ComboHe	0%				46%			30	3%	80	0/0	LG-avg-III	3/0	1.0	
	ComboHe	0%		26%	ElectricSto							20%				65%

Figure 25: MURB occupancy Step 4 & 5 results

HighRiseMURB_Midoccupancy

Step 4												
GHGI	ICC	ECI										
≤5	≤2%	≤\$8										
Spa	ce Heating	and Cooli	ng	Domestic I	Hot Water		Envelope	R-Values		Windo	ws USI	
Heating ef	ficiency	HRV		DHW Savings		Wall		Ro	Roof		Pane and Glaze	
Condensir	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

GHGI ICC ECI ≤5 ≤2% ≤\$8		
≤5 ≤2% ≤\$8		
Space Heating and Cooling Domestic Hot Water Envelope R-Valu	es	Windows USI
Heating efficiency HRV DHW Savings Wall	Roof	Pane and Glaze
Condensir 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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