THE BRETON LAW GROUP

James R. Gogan
Direct Dial: (902) 563-5920
E-Mail: jim@bretonlawgroup.com

File No. 41736-72

October 15, 2019

Nova Scotia Utility & Review Board
PO Box 1692, Unit "M"
Halifax, Nova Scotia
B3J 3S3

Attention: Doreen Friis, Regulatory Affairs Officer / Clerk

Dear Ms. Friis:

Re: M09096 – EfficiencyOne Application for Approval of Supply Agreement for Electricity Efficiency and Conservation Activities between E1 and Nova Scotia Power (NS Power), the establishment of a final agreement between the parties, and approval of a 2020 – 2022 Demand Side Management Resource (DSM) Plan

Multi Unit Residential Buildings Study Report

In the course of the proceedings in this matter, EfficiencyOne and Heritage Gas entered into a Settlement Agreement, which was filed with the Board on June 6, 2019. In its decision dated August 2, 2019, the Board approved the Settlement Agreement between EfficiencyOne and Heritage Gas. The Board further incorporated the Settlement Agreement in its Order issued September 16, 2019, directing inter alia that the study report regarding new construction Multi-unit Residential Buildings referred to in the Settlement Agreement, and any recommendations arising from it, be presented to the Board by October 15, 2019.

Dunsky Energy Consulting – VRF Program Review

EfficiencyOne and Heritage Gas engaged Dunsky Energy Consulting ("Dunsky") to study the program design and operation of the Custom Incentives Program related to Variable Refrigerant Flow (VRF) electric heat pump measures in multi-unit residential buildings (MURBs) in areas where natural gas is available. Dunsky's **VRF Program Review** report is included herein for filing with the Board.

Agreement between EfficiencyOne and Heritage Gas

Dunsky's study aimed to determine how E1's baseline energy building model should be determined for new construction MURBs where natural gas is available. Dunsky found that the current baseline for VRF heat pumps does not reflect the local market for new construction multi-unit residential buildings where natural gas is available.

Therefore, Dunsky recommends that the baseline definition should be modified as set out in its VRF Program Review.

Subject of course to the Board's review of the Dunsky report, and any process which may follow, EfficiencyOne and Heritage Gas have agreed to incorporate Dunsky's recommended changes to the existing New Construction service in the Custom Incentives Program as follows:

1. **Modification of Baseline Definition**

   EfficiencyOne will modify the requirements of the Custom Incentives New Construction service to redefine the baseline Heating, Ventilation and Air Conditioning (HVAC) system operation for a proposed VRF heat pump system. The baseline definition will use the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) 90.1-2013's prescriptive minimum VRF equipment efficiencies, keeping all other National Energy Code of Canada for Buildings (NECB) modeling specifications.

   The baseline will incorporate ASHRAE 90.1-2013's Table 6.8 1-9, with the following energy efficiency requirements:
   - Energy Efficiency Ratio (EER) of 9.3 – 11; and
   - Coefficient of Performance (COP) of 3.2 – 3.3.

   Part-load operation will incorporate performance curves from NECB 8.4.4.21.-E (Electric Air-Source Heat Pump Equipment Part-Load Performance) and will operate between -10°C and -18°C.

   All other NECB performance path modeling requirements and specifications will follow NECB-2015 Part 8.

2. **Geographical Coverage – Areas Where Natural Gas is Available**

   Natural gas service is available to a building where:

   1. A service line can be installed to the building from a natural gas main located in front of the property or from a nearby building, or

2. It is economically feasible to construct a natural gas main to provide the building with natural gas service, as determined by the Economic Feasibility Test[1] thresholds that have been approved by the Nova Scotia Utility And Review Board.

   To determine the baseline HVAC system required for energy modeling of a proposed new MURB, EfficiencyOne will contact Heritage Gas to determine the availability of natural gas to the proposed building. Within 15 working days, Heritage Gas will determine if natural gas service is available to the building and notify EfficiencyOne and the building developer.

3. **Incentive Estimates for Projects that Include VRF Technology**

   Marketing and communication activities related to VRF technology, including the provision of incentive estimates for projects that include VRF technology, will state that the incentives are based upon total eligible electrical energy savings versus the baseline building performance due to the combined technologies and strategies implemented on the project and not strictly due to the inclusion of VRF in the design. The technologies contributing to the eligible electrical energy savings will be referenced with the incentive estimate.

EfficiencyOne is confident this change will not impact its ability to meet its approved 2020-2022 DSM targets.

EfficiencyOne thanks Heritage Gas for its collaborative support in addressing the concerns it has raised in the course of these proceedings.

EfficiencyOne respectfully submits this Study and agreement it has reached with Heritage Gas to the Board for its approval. EfficiencyOne proposes to adopt the amendments reached through this study and agreement upon Board confirmation of acceptance of the Dunsky Report.

---

[1] The acceptance criteria to provide natural gas service to a customer without customer contribution requirement is a NPV profitability ratio (NPV of the revenue stream for 25 years divided by the NPV of the revenue requirement stream for 25 years) of 1.00 or greater and a year seven profitability ratio (revenue divided by the revenue requirement) of 1.00 or greater. Utilizing the following criteria a net present value for the project will be calculated:

- An estimate of the total incremental capital costs of providing service;
- An estimate of the total annual incremental operating costs of providing service;
- The Board approved return on common equity, interest rates, amortization (depreciation) rates, income taxes and capital structure; and
- An estimate of the expected incremental net revenue that will result from the addition of the service.

Individual projects are required to meet both of the following thresholds to be considered “Feasible”:

- Profitability Ratio in Year 7, PR (Yr7), must exceed 1.
  - PR (Yr7) = Revenue in year 7 of the project divided by Revenue Requirement in year 7.
- Net Present Value Ratio, PR (NPV), must exceed 1.
  - PR (NPV) = NPV of Revenue over 25 years divided by NPV of Revenue Requirement over 25 years.

I confirm 6 hard copies will be filed with the Board.

Yours very truly,

THE BRETON LAW GROUP

James R. Gogan

cc. M09096 Participants

VRF Program Review

Prepared for:

Efficiency One & Heritage Gas

Submitted to:

Efficiency One
Sarah Chiasson
Director, Efficiency Services

Heritage Gas
Derek Estabrook
Vice President, Business Development

Prepared by:

Dunsky Energy Consulting
50 Ste-Catherine St. West, suite 420
Montreal, QC, H2X 3V4

www.dunsky.com
info@dunsky.com
+ 1 514 504 9030

About Dunsky

Dunsky provides strategic analysis and counsel in the areas of energy efficiency, renewable energy and clean mobility. We support our clients – governments, utilities and others across North America – by assessing opportunities (technical, economic, market); designing strategies (programs, plans, policies); and evaluating performance (with a view to continuous improvement)

Dunsky's 30+ experts are wholly dedicated to helping our clients accelerate the clean energy transition.

EXECUTIVE SUMMARY

Efficiency One (E1) and Heritage Gas have agreed to engage in a collaborative study of the program design and operation of the Custom Incentive Program related to Variable Refrigerant Flow (VRF) electric heat pump measures in multi-unit residential buildings (MURBs) in areas where natural gas is available.

The current study provides best practices in program design and appropriate incentives to be offered in the Custom Incentives Program to avoid the risk of offering incentives that create the unintended and counterproductive effect of increasing electricity usage and demand where natural gas is available.

The study aims to answer the following main question: **How should E1's baseline energy building model be determined for new construction MURBs where natural gas is available?**

Interviews with local market actors show that the current adoption of VRF heat pumps seems both technology- and incentive-driven.

A scan of relevant jurisdictions show that new construction custom programs use the local energy code as baseline (NECB and/or ASHRAE 90.1), and prescriptive programs use ASHRAE 90.1's prescriptive minimum VRF equipment efficiencies as baseline.

Finally, a comparison of the operational and capital costs for five heating systems in a single building archetype show that VRF heat pump systems are more cost-effective than a hybrid natural gas system, but require more upfront capital.

Our recommendation is to keep NECB's modeling specifications but use ASHRAE 90.1-2013's prescriptive minimum VRF heat pump equipment efficiencies as baseline, which would limit equipment-related incentives to the incremental savings between a standard efficiency and a higher efficiency VRF system.

dunsky

Table of Contents

Introduction

Context

Efficiency One (E1) and Heritage Gas have agreed to engage in a collaborative study of the program design and operation of E1's Custom Incentive Program related to VRF electric heat pump measures in multi unit residential buildings (MURBs) in areas where natural gas is available.

Variable Refrigerant Flow (VRF) systems are commercial multi-split air-conditioners or heat pumps which modulate the flow of refrigerant between the outdoor compressor unit and the multiple indoor units it supplies based on the varying load conditions in each zone. Refrigerant is therefore used as a heat transfer medium throughout the building instead of air or water. VRF systems can be air- or water-source and some models can simultaneously heat and cool different zones.

Objectives

The study aims to provide best practices in program design and appropriate incentives to avoid the unintended effect of increasing electricity usage in new construction MURBs where natural gas is available.

The central question is the following:

> How should E1's baseline energy building model be determined where natural gas is available?

The following items will be analysed in that regard:

- How do developers choose their primary heating systems, both when they are offered incentives and when they are not?
- How is this issue addressed in other relevant jurisdictions?
- What are the differences in capital and energy costs between VRF heat pump systems and natural gas primary heating systems?

Limits of our assessments

The current study's scope is limited to a delimited portion of the market:

Multi-unit residential buildings (MURBs)

Where natural gas is available

New construction projects

In the context of this study, it was agreed between E1 and Heritage Gas to define the availability of natural gas as any project which has confirmation from Heritage Gas that natural gas will be available.

The Table 1 below highlights this specific portion of the market that is included in the study scope based on the items above.

Table 1 Study scope

MURBs	New Construction	Existing Buildings
Where Natural Gas **Is Available**		
Where Natural Gas **Is Not Available**		

Additionally, the market actor interviews are not meant as in-depth interviews for program evaluation, but as discussions with a range of market actors in order to acquire information on the current market transformation. Conclusions and recommendations are drawn from the other research activities as part of this project, along with Dunsky's professional judgement and experience in program design, evaluation and benchmarking.

Furthermore, the jurisdictional scan focused on local energy efficiency programs and not on the local market context or recent market transformation.

Finally, the energy modeling and cost analyses are at a higher level than the hourly building energy simulations that are required for participating in E1's Custom program. Results from energy simulations using different models or simulation software are only barely comparable, as the assumptions, inclusions and end-use allocations can differ. Moreover, building energy simulations are estimates that are not predictions of actual energy consumptions or costs – being at a higher level, the current study's energy modeling and cost estimates are only meant to compare the relative performance of five heating system types for a single building archetype, in order to inform the analysis and recommendations.

1 MARKET ACTOR INTERVIEWS

This chapter describes the methodology used for the market actor interviews and the insights they provided.

The objective of this part of the study is primarily to answer the following question:

How do developers choose their primary heating systems, both when they are offered incentives and when they are not?

1.1 – Methodology

1.1.1 – Objectives

The market actor interviews are meant to provide an understanding of the local context in Nova Scotia where new MURBs are planned.

The discussions focused on typical heating systems in new construction MURBs, both in recent years and current projects under construction, how the primary heating system is chosen, and recent market transformation related to heating systems, specifically on the use of VRF heat pumps in MURBs.

An interview guide was developed and agreed upon by E1 and Heritage Gas. The interviews were qualitative in nature and semi-structured (they did not follow a set script). Rather, we used our expertise to adjust the questions and pacing in a manner that allowed us to gain insights into various perspectives and needs of the sector.

1.1.2 – Interviewees

The interviewees were identified by E1 and Heritage Gas together in order to get a fair and diverse representation of the HRM MURB market.

We interviewed five local market actors, including an energy consultant, two engineering firms, one developer and a large HVAC distributor.

1.2 – Findings

The results from the interviews are described in this section.

The market actor interviews are not meant as in-depth interviews for program evaluation, but as discussions with a range of market actors in order to acquire information on the current market transformation. While the findings do not have statistical significance, the high level of agreement in the responses we received leads us to believe they do offer a fair representation of the local context.

1.2.1 – Market Insights

Gas HVAC systems are common   Buildings currently under construction typically use natural gas boilers with hydronic baseboards, fan-coils or infloor heating, and that has been the case for at least the past 5 years. There are also developers installing hybrid systems of distributed water-loop heat pumps coupled with a supplemental gas boiler. Natural gas (and before that oil) fired boilers are commonly installed, so there is a large knowledge base within the developer community regarding reasonable costs for the equipment, the associated plumbing work, and the availability of technicians who can service the system.

The Nova Scotia climate is ideal for electric VRF heat pumps Given Nova Scotia's mid-temperate climate, VRF heat pumps available on the market today are able to meet the typical heating load of a newly constructed building. In some cases, VRF systems are installed without the need for auxiliary backup heating systems.

Nova Scotia's new construction market is dominated by rentals Many of the recently built MURBs in Nova Scotia are for the rental market instead of being sold as condos. This means building developers often operate the building after construction, and therefore are influenced not just by the upfront capital costs but also the operating and maintenance costs associated with the building.

It's typical for heat and hot water to be included in the rent Due to heating being included in rents, electric baseboard heating is uncommon. Even though electric baseboard heating has a modest install cost, it is more expensive to operate than a central gas fired boiler system. Since the landlord is often responsible for providing heat, building owners tend to prefer the lower operating costs.

Cooling is increasing in importance Traditionally cooling hasn't been included in rent, however recent trends in the higher end of the market have shown a tendency to do so. Older buildings were often constructed without cooling while newer buildings use central systems sparingly and more often use systems connected to the rental unit's meter. Nova Scotia's mild summers mean that the cost of cooling is minimal compared to heating. Building owners can command a premium in the rent by including cooling without necessarily incurring a large expense which leads to enhanced profit margins.

The higher end of the market values balcony space and sound comfort In the low to mid end of the market, ductless mini-split heat pumps (DMSHP) are common, where the renter is responsible for the cost of operation. In the high end of the market there is a move away from DMSHPs due to clients not wanting to give up balcony space to house the outdoor unit and its associated noise while running. In their place developers are installing CGC Bulldog heat pumps or VRF heat pumps.

Developers are capital cost driven Developers are influenced by multiple criteria when selecting which HVAC system to install, but the most pressing concern is the total installed cost. Due to heating often being included in the rent, developers also look at the cost of operation and maintenance. If the developer has access to inexpensive capital then the value placed on operating costs might increase, especially if the developer will manage the building post construction. Since developers are primarily influenced by the capital cost, incentives offered can have an effect on system choice.

Growing familiarity with VRF With the rapid uptake in DMSHPs, there is a larger awareness with heat pumps as a heating and cooling technology. In addition, Nova Scotia Power (NSPI) has a sales team which approaches developers and highlights VRF's which contributes to the greater levels of awareness.

Concern regarding VRF supply chain With VRF heat pumps being a relatively recent technology introduced to the market, there is a perceived lack of refrigeration technicians and little experience with appropriate costs for installing the system. Developers find it difficult to get a sense of the right pricing levels for VRF and concern that the promised savings will be there.

Market for VRF will continue to grow Developers are in competition with each other for renters, especially in the high end of the market, and including cooling in the rent nudges developers towards VRF, with it being a single system which provides both heating and cooling. As developers gain experience in installing and operating VRF's, the first-adopter risk is being reduced.

1.2.2 – Heating System Selection

In short, while the selection of the primary heating system is complex, it appears to be mainly driven by capital cost, but also on operating cost, developer comfort with a technology, and additional revenue opportunities.

The Market Actor Interviews shows that the value proposition of VRF heat pumps currently appeals especially to new construction MURBs that are:

- Rental buildings
- Higher-end tier

That can be explained by the fact that mid and low-end projects are even more concerned with capital costs and have less of an opportunity to distinguish themselves in a market mainly driven by the rental prices. In the higher-end tier of the market, however, it appears some developers see VRF systems as an opportunity to lower their long-term maintenance costs, use a single central system for both cooling and heating and possibly command a rent premium.

1.3 – Summary

The market actor interviews aimed at answering the following question:

> How do developers choose their primary heating systems, both when they are offered incentives and when they are not?

In summary, developers are familiar with and commonly install natural gas fired boiler systems to heat their buildings. In Nova Scotia heating and hot water are often included within the rent and now because of competition in the high-end market, developers are looking to include cooling as well. While capital cost is the main driver for project developers, a VRF heat pump is seen as a promising option to provide both heating and cooling with a single system and is therefore starting to compete with the natural gas hybrid system in the high-end rental market.

2 JURISDICTIONAL SCAN

This chapter describes the methodology used for the jurisdictional scan of similar programs and the insights they provided.

The objective of this part of the study is primarily to answer the following question:

How is this issue addressed in other relevant jurisdictions?

Jurisdictional Scan

2.1 – Methodology

The jurisdictional scan focused on local energy efficiency programs and not on the local market context or recent market transformation.

The following criteria were initially set by Dunsky, E1 and Heritage Gas to identify relevant incentive programs for the current study:

Program administrator is limited to electricity savings

Custom program for new construction

Incentives for VRF heat pumps

Natural gas is available

Comparable weather

However, an initial desktop review resulted in a limited number of jurisdictions which corresponded to all of the above criteria, mainly because VRF programs are still relatively new and few, and because U.S. program administrators often have all fuels as part of their mandate. We therefore broadened the filters in order to get the 7 jurisdictions identified in the Table 2, which correspond to many if not all of the above criteria.

Three types of programs have been identified which included incentives for VRF heat pumps: prescriptive programs, new construction custom programs, and GHG-reduction-focused programs.

We examined those programs through a desktop review and contacted some program administrators to get direct inputs in order to get a better understanding of how they deal with unintended fuel-switching.

It should be added that the low number of programs which fit the above criteria does not allow us to recognize the findings detailed below as *best* practices, but rather as *common* practices.

2.2 – Findings

The Table 2 summarizes the different programs in the relevant jurisdictions, highlighting the baseline definitions used for each. Findings for each program type are described in the following sub-sections.

It is to be noted that while energy commodity costs could have been an interesting avenue to explain the presence and structure of VRF incentive programs, it appears the baselines in new construction custom programs are all very similar and therefore cannot be linked to commodity costs, and the limited presence of VRF prescriptive incentives prevent the identification of any link with local commodity costs.

Table 2 Jurisdictional scan summary: programs which include VRF heat pumps and their baselines

Jurisdiction	Mandate	New Construction	Prescriptive	GHG reduction
Nova Scotia		*NECB baseline:* Packaged Terminal Heat Pumps (PTHP) + electric	Incentive per ton (must off-set electric resistance)	-
British Columbia	Electricity	NECB or ASHRAE 90.1 baseline: PTHP + electric	-	Fuel-switching goal
Ontario *	Electricity	NECB or ASHRAE 90.1 baseline: PTHP + electric	-	-
New Brunswick	All fuels	-	-	-
New York	All fuels	ASHRAE 90.1 baseline: PTHP + electric	ASHRAE 90.1: standard VRF	-
Vermont	All fuels	ASHRAE 90.1 baseline: PTHP + electric	-	-
Massachusetts	All fuels	ASHRAE 90.1 baseline: PTHP + electric	ASHRAE 90.1: standard VRF	Fuel-switching goal
Maine	All fuels	ASHRAE 90.1 baseline: PTHP + electric	ASHRAE 90.1: standard VRF	-

** The High Performance New Construction program was discontinued and closed to new applicants as of April 2019*

2.2.1 – New Construction Programs

All of the New Construction custom programs use the State or Province's building energy code to define baselines. E1 also uses the Nova Scotia Building Code (NECB-2015) for baseline definitions in its new construction program since 2017.

Two standards are referenced by jurisdictions in their codes: NECB in Canada and ASHRAE 90.1 in the U.S., with the exception of Ontario and British Columbia where both can be used as performance paths.

The following sub-sections detail the specific baselines for each building energy standard.

2.2.1.1 – National Energy Code of Canada for Buildings (NECB)

The NECB is published by National Research Council Canada, but adoption and enforcement are the responsibility of the provincial governments. For example, NECB version 2015 is currently adopted in Nova Scotia.

The NECB incorporates prescriptive requirements and an optional performance path. Division B – Part 8 of the NECB lists modeling specifications to use the performance path and ensure that the proposed building is at least as performing as it would have if the prescriptive requirements had been used.

The baseline definitions for VRF air-source heat pumps in MURBs in NECB-2015 are the following (the term *Reference* is used instead of baseline):

HVAC SYSTEM SELECTION

"(…) the reference building or space's HVAC system shall be modeled as being identical to that of the proposed building or space; otherwise, the reference building or space shall use through-the-wall systems."

NECB 2015, Table 8.4.4.7

AUXILIARY HEATING

"(…) the energy type of the heat pump's terminal heating or auxiliary heating shall be, for an air-source heat-pump, the energy type used for terminal or auxiliary heating of the thermal blocks of the proposed building (…)"

NECB 2015, Clause 8.4.4.13 2) g)

In summary, according to NECB's specifications, the baseline HVAC system of a proposed VRF air-source heat pump would be mini-split or packaged-terminal heat pumps (PTHP) and the auxiliary heating source would be electricity.

2.2.1.2 – ASHRAE 90.1 Energy Standard for Buildings

ANSI/ASHRAE/IES Standard 90.1 – Energy Standard for Buildings except Low-Rise Residential Buildings is mostly used in the United States. It lists minimum equipment efficiency tables which are aligned with the International Energy Conservation Code (IECC).

VRF heat pump **minimum equipment efficiencies** were added to version 2007 of the standard through an addendum that was published in 2010. VRF efficiency levels were raised starting in 2012, and the 2016 version of the standard updated efficiencies starting in 2017. The efficiencies are provided in terms of EER and IEER in cooling, and COP at 17°F (-8.3°C) and 47°F (8.3°C) in heating.

ASHRAE Standard 90.1 also includes an Energy Cost Budget method (Section 11) that should be used to demonstrate equivalent minimum performance compliance, and a Performance Rating Method (Appendix G) to quantify a performance that exceeds the minimum requirements. The **Performance Rating Method** incorporates a table that lists the modeling specifications for calculating proposed and baseline building performance, including 13 baseline system descriptions and their applicability for different proposed building types. In the case of a proposed electrically heated VRF system in a MURB, the baseline system for the apartments would be a PTHP with electrical auxiliary heating, similar to the NECB specifications.

2.2.2 – Prescriptive Programs

Some jurisdictions offer prescriptive programs for VRF heat pumps. These programs are mainly targeted at, but not limited to, retrofit projects.

Prescriptive programs usually use a Technical Reference Manual (TRM) to detail the calculations that should be used to determine the energy and demand savings for each measure. In the case of VRF heat pumps, all prescriptive VRF heat pump measures were in U.S. jurisdictions and use a standard-efficiency heat pump according to ASHRAE 90.1 as baseline (refer to section 2.2.1.2 – above).

The TRMs use simplified equations to determine equipment savings, using their nominal capacities, average efficiency levels for both the proposed and the baseline equipment, and equivalent full-load hours (EFLH) of operation. Proposed equipment use either the actual equipment's performance data, or alternatively a pre-defined performance level (ex: IEER of 17 or greater).

2.2.3 – Other Programs: GHG emissions reduction

While GHG emissions were not part of this study's scope, the main issue relates to unintended fuel switching. It is therefore interesting to note that VRF heat pump systems are being offered in programs that specifically target fuel-switching.

These programs specifically target greenhouse gas (GHG) emissions reductions - in other words, they are mainly aimed at existing buildings who use fossil fuel heating systems. In both cases, VRF heat pumps were included as eligible GHG-reducing technologies.

- In British Columbia, the Clean BC custom program is administered by BC Hydro but is funded by the provincial and federal governments
- In Massachusetts, the Massachusetts Clean Energy Center (MassCEC) offered a VRF-specific pilot program between 2017 and June 2019 to retrofit fossil fuel heated buildings. The program was halted due to an exhausted pool of funds. MassCEC is funded by a systems benefit charge paid by electric ratepayers of investor-owned utilities in Massachusetts, as well as the five municipal electric departments that have joined the fund.

2.3 – Summary

The jurisdictional scan aimed at answering the following question:

> How is this issue addressed in other relevant jurisdictions?

In summary, the relevant jurisdictions use the modeling specifications in their building energy code - NECB or ASHRAE 90.1. Both dictate the use of packaged terminal heat pumps with electric auxiliary heating as baseline for VRF heat pumps. However, ASHRAE 90.1 also provides minimum equipment efficiencies for VRF systems that are often used as baseline in prescriptive programs.

3 HEATING SYSTEM COST COMPARISON

This chapter describes the methodology used for the heating system cost comparison and the insights which can be drawn from the results.

The objective of this part of the study is mainly to answer the following question:

What are the differences in capital and energy costs between VRF heat pump systems and natural gas primary heating systems?

3.1 – Methodology

This section describes the methodology used to compare the five heating system's costs, including energy, maintenance and capital costs.

3.1.1 – Building Energy Modeling

First of all, it is important to note that the current study's energy modeling is not meant to be as precise as the hourly simulations that are required for a project's participation in most custom programs. The energy modeling methodology used in the current study is at a higher level and is meant to compare the *relative* performance of five heating system types for a single building archetype in order to inform the analysis and recommendations.

The temperature-bin methodology was used in order to focus effort on what is most relevant for this study: the HVAC systems. The use of aggregated 3°C temperature-bins simulates all 8760 hours of a typical year, while keeping the model simple, transparent and customizable in order to reflect the real-world performance of the systems that are compared in the present study.

Since a portion of the heating and cooling loads is not directly related to the outdoor air temperature, like solar and internal heat gains, and since two of the modeled heating systems are able to recover heat from the cooling zones and transfer it to the heating zones, the Dunsky team undertook three tasks:

1. hourly simulations to assess the building's heating and cooling loads
2. aggregation of the hourly heating and cooling loads into the temperature-bins
3. modeling of five heating and cooling systems using a temperature-bin methodology

The energy modeling and cost analysis are at a higher level than the hourly building energy simulations that are required for participating in E1's Custom program. Results from energy simulations using different models or simulation software are only barely comparable, as the assumptions, inclusions and end-use allocations can differ. Moreover, hourly building energy simulations are estimates that are not predictions of actual energy consumptions or costs – being at a higher level, the current study's energy modeling and cost estimates are only meant to compare the relative performance of five heating system types for a single building archetype in order to inform the analysis and recommendations. As such, the building systems do not follow all of the modeling specifications included in Division B - Part 8 of the NECB.

3.1.1.1 – Hourly Simulations

The first step of the analysis focused on gathering typical hourly heating and cooling loads for a MURB in Nova Scotia. As part of this process, our team used the Natural Resources Canada software (CAN-QUEST version 1.2) to model the building. This software is an adaptation of the eQUEST 3.62 tool.

The assessment was based on the new construction of a multi-apartment building located in Halifax, Nova Scotia. The key building characteristics used in our simplified modeling version are included in the Table 3 below (more details are provided in the Appendix).

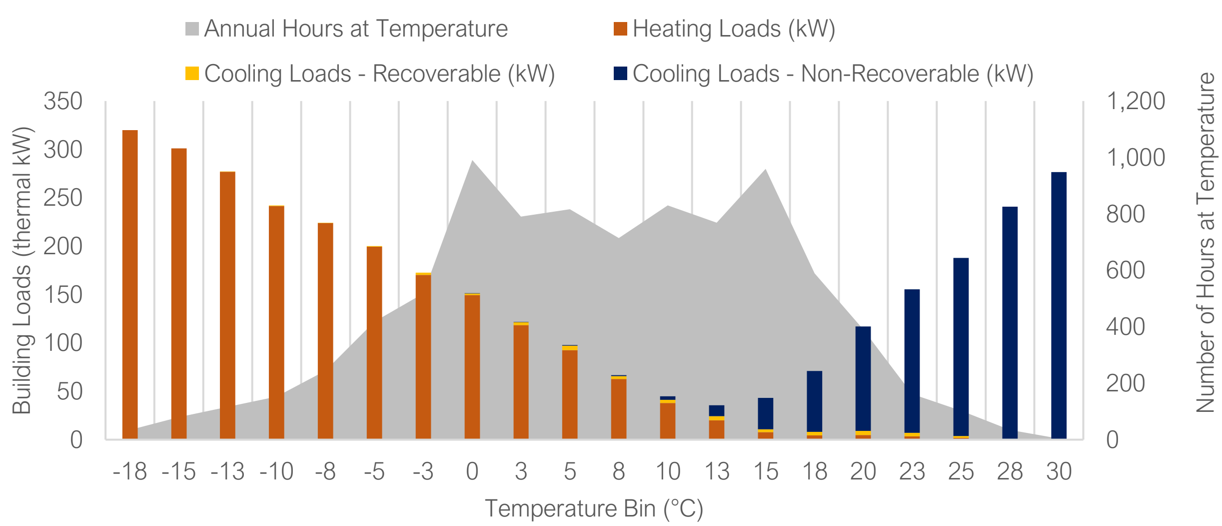
Table 3: Key Building Characteristics

Weather Data	Shearwater Airport, Halifax, Nova Scotia
Conditioned Area (ft²)	13,246 m²
Underground Parking	Yes
Above-ground Levels	6
Number of Units	88
Envelope Performance	NECB Baseline Insulation Levels
Thermostat Setpoints	Cooling setpoints: 23°C Heating setpoints: 20°C

3.1.1.2 – Temperature-Bin Modeling

Once the building heating and cooling loads were extracted, our analysis consisted of modeling each selected HVAC system to assess the overall impact of these systems on the energy consumption of our building. This second part of the modeling, performed in Excel, leverages the building load outputs from CAN-QUEST and contains the detailed energy calculations of the different systems. The Figure 1 below displays the number of hours (representing the Halifax weather) and the building heating and cooling loads resulting from our 8,760-hourly simulation within each aggregated 3°C temperature-bin.

Figure 1: Annual Hours and Building Loads for each Temperature-Bin



The recoverable cooling loads presented in the Figure 1 above were directly calculated in our Excel modeling. They represent the recovery heat that is extracted from the cooling zones and transferred to the heating zones when heating and cooling happens simultaneously. Only two of the modeled heating systems were able to recover this heat and thus to improve the system overall efficiency: the Hybrid Natural Gas system and the efficient VRF system.

The temperature-bin method allowed us to adjust the performance of the systems to the outdoor air's temperature. The Dunsky team used manufacturer performance tables to develop the performance curves of each system. Some adjustments were made to the curves, for instance the impact of the defrost cycle on the VRF and heat pump efficiencies when the outdoor temperature is below 5°C.

All the other buildings loads associated with the different HVAC systems were also evaluated.

3.1.2 – Heating System Descriptions

The five following systems have been analyzed for the same building archetype described in the Table 3 above. Our selection was based on the results of our jurisdictional scan and the interviews of key stakeholders, with inputs and agreement from E1 and Heritage Gas.

3.1.2.1 – Standard Natural Gas System

This system uses a standard heating water loop supplying hydronic radiators, the loop being heated by a condensing boiler. Mini-split heat-pumps are used for cooling and are considered to only be used for cooling as heating from the radiators would be included in the rents.

3.1.2.2 – Hybrid Natural Gas System

The higher-efficiency natural gas-based system is a hybrid packaged heat pump system that incorporates a hot water coil and a water-to-air air-conditioner which rejects heat to the heating loop. That heating loop is therefore kept at a higher temperature compared to a mitigated loop and is also heated by a condensing boiler. These hybrid heat pumps are often identified as the CGC or Bulldog system, respectively one manufacturer and their system's brand.

3.1.2.3 – Standard Electric System

The standard electric system is based on the current modeling specifications from NECB and ASHRAE 90.1, which is an air-source mini-split heat pumps with electric resistance auxiliary heating. Heat pump efficiencies reflect NECB-2015's minimum equipment efficiencies for new construction packaged terminal heat pumps (PTHP).

However, the energy modeling is not meant to reflect all of the modeling specifications in NECB and professional judgement was used in order to reflect a typical operation of such system.

As in the five modeled systems, ventilation is provided by heat-recovery ventilators (HRV), with gas-fired make-up air units supplying the corridor. Domestic hot water is also gas-fired.

3.1.2.4 – Standard VRF System

The standard version of the VRF heat pump system is an air-source VRF that reflects the prescriptive minimum efficiencies in ASHRAE 90.1-2013. The indoor units in each apartment use an electric resistance as auxiliary heating.

As in the five modeled systems, ventilation is provided by heat-recovery ventilators (HRV), with gas-fired make-up air units supplying the corridor. Domestic hot water is also gas-fired.

3.1.2.5 – Efficient VRF System

The efficient version of the electricity-based system is an efficient air-source VRF with heat recovery capabilities. The indoor units in each apartment use an electric resistance as auxiliary heating.

As in the five modeled systems, ventilation is provided by heat-recovery ventilators (HRV), with gas-fired make-up air units supplying the corridor. Domestic hot water is also gas-fired.

3.1.2.6 – Systems Summary

The Table 4 summarizes the main details of the five compared heating systems:

Table 4 HVAC systems comparison

	Standard Natural Gas	Hybrid Natural Gas	Standard Electric	Standard VRF	Efficient VRF
Terminal Heating	Hydronic radiators	CGC hybrid ducted units	Mini-split heat pumps	VRF ducted indoor units	
Auxiliary terminal heating	Mini-split heat pumps	-	Electric baseboards	Resistive	
Terminal Cooling	Mini-split heat pumps	CGC hybrid ducted units	Mini-split heat pumps	VRF indoor units	
Central Heating	Condensing boiler		-	Air-source VRF outdoor units	
Ventilation	In-unit HRVs Gas-fired MUA				
DHW	Gas-fired storage				

3.1.3 – Cost Analysis

The energy consumption results are used to determine monthly energy costs, which are coupled with maintenance and capital cost estimates in order to compare the five heating systems.

3.1.3.1 – Operating Costs

The operating costs consist of energy and maintenance costs.

Energy Costs: Monthly results from the building energy modeling are coupled with energy rates in order to get monthly energy costs for the five systems. The following rates were provided by Heritage Gas and E1:

- Natural Gas: $14.66/GJ (summer), $16.64/GJ (shoulder months), $17.54/GJ (winter)
- Central electrical meter: $10.497/kW, $0.1201/kWh (first 200 kWh per peak kW), $0.0873/kWh (rest)
- Apartment electrical meters: $0.156 per kWh

Maintenance Costs: Maintenance, preventive maintenance and end of life cycle replacement were estimated using EIA's *Updated Buildings sector Appliance and Equipment Costs and Efficiencies*, a Pacific Northwest National Laboratory study on VRF heat pumps, and professional judgment.

3.1.3.2 – Capital Costs

The capital cost analysis focused mainly on the differences between the five studied systems. The objective was to develop a high-level assessment of each system's capital costs in order to better understand its impact on a project developer's heating system choice.

Capital costs were estimated for the modeled building described in section 3.1.1.1 – a new construction MURB of 88 units, in Halifax, Nova Scotia. The information was sourced mainly from the construction cost estimates software RSMeans and inputs from HVAC distributors. Where data was missing, internal modelling, energy modelling reports provided by E1 and Heritage Gas, and professional judgment was used.

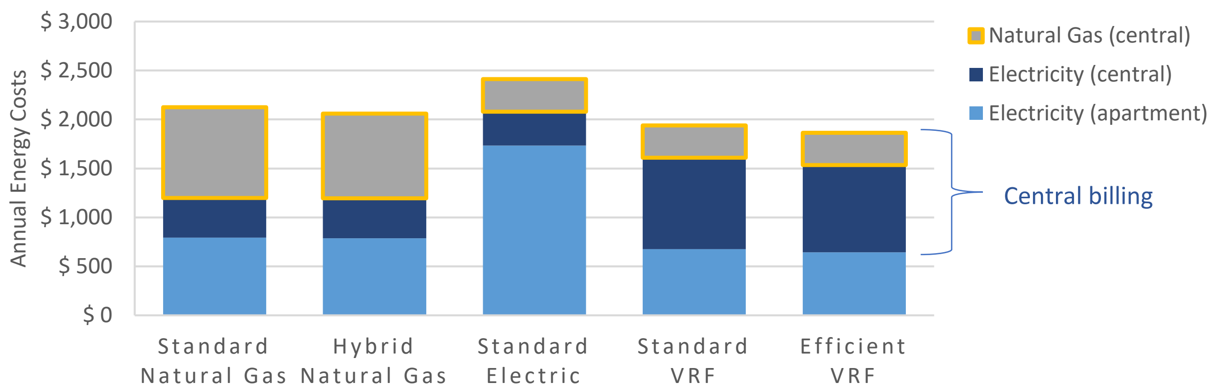
Detailed cost estimates for the five modeled systems are provided in the Appendix.

3.2 – Results

The results that follow highlight the annual energy and maintenance costs of operating a typical new construction MURB as well as the upfront costs for each system. All costs presented in this section are not actual costs but high-level estimates with the exclusive goal of guiding our final recommendations.

Estimated annual energy costs per system are presented in the Figure 2 below. These annual costs represent all energy costs for the building including heating, cooling, fans, pumps, lighting and all other miscellaneous equipment consumption. The distinction between the in-unit consumption and the common areas equipment is displayed as well.

Figure 2: Annual Energy Costs per Apartment



Detailed annual costs for all systems along with capital costs are summarized in the Table 5 below. From these results, the following observations can be made:

- **The VRF systems have the lowest operating costs** compared to the three other modeled systems, ranging from 10% to 22% annual savings;
- **The VRF systems are the most expensive options,** with a standard-efficiency VRF being slightly more expensive than a hybrid natural gas system in terms of capital costs ($76 per apartment);
- **The VRF heat pump systems are more cost-effective** than a hybrid natural gas system, with a payback period between 17 months and 9 years depending on the VRF system's efficiency.

Table 5: Annual Energy and Operating Costs and Capital Costs per Apartment

		Standard Natural Gas	Hybrid Natural Gas	Standard Electric	Standard VRF	Efficient VRF
Operating Costs						
Energy	Electricity (apartment)	$ 795	$ 786	$ 1 733	$ 677	$ 643
	Electricity (central)	$ 404	$ 405	$ 347	$ 932	$ 890
	Natural Gas (central)	$ 925	$ 866	$ 331	$ 331	$ 331
	Total	**$ 2 124**	**$ 2 060**	**$ 2 412**	**$ 1 940**	**$ 1 864**
	Maintenance	$ 241	$ 192	$ 200	$ 154	$ 154
	Total	**$ 2 365**	**$ 2 252**	**$ 2 612**	**$ 2 094**	**$ 2 018**
	Operating Savings	$ 247	$ 360	-	$ 518	$ 594
Capital Costs						
	Capital	$ 10 017	$ 14 111	$ 6 861	$ 14 332	$ 16 133
	Incremental	$ 3 156	$ 7 250	-	$ 7 471	$ 9 272
Simple Payback Period						
	Without Incentives	13 years	20 years	-	14 years	16 years

For comparison purposes, it is to be noted that the energy modeling is not meant to reflect all of the modeling specifications in NECB that program participants must follow and professional judgement was used in order to reflect typical operations of such systems. The calculated incentive amounts are therefore approximations and complete hourly simulations following all of NECB-2015's modeling specifications would be required for a more accurate assessment of the incentives.

Table 6 below includes the cost differences between the efficient VRF system and the other systems. The resulting payback periods with and without incentives are displayed – incentives for an efficient VRF system if the standard electric system is the baseline (current E1 incentive) and if the standard VRF system is the baseline.

Table 6: Incentive, cost and payback period analysis compared the efficient VRF system (per apartment)

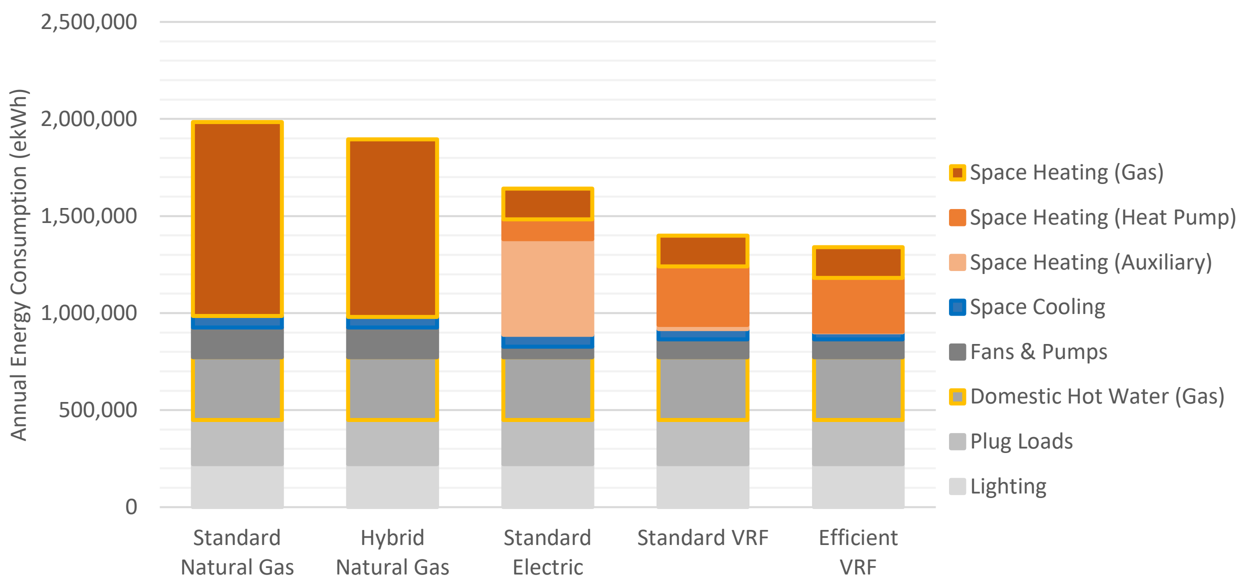
	Efficient VRF system…			
	...vs Standard Natural Gas	…vs Hybrid Natural Gas	...vs Standard Electric	...vs Standard VRF
Incentive				
Electricity savings	-	-	3 422 kWh	666 kWh
Potential VRF incentive	-	-	$ 342 (current baseline)	$ 67
Cost comparison				
Incremental Cost	$ 6 116	$ 2 022	$ 9 272	$ 1 801
Operating Savings	$ 347	$ 234	$ 594	$ 76
Simple payback period				
Without incentive	17.6 years	8.6 years	15.6 years	23.6 years
With $342 incentive (current baseline)	16.6 years	7.2 years	15.0 years	19.1 years
With $67 incentive (Standard VRF as baseline)	17.4 years	8.3 years	15.5 years	22.7 years

The current incentive for E1's new construction program is $0.10 per kWh saved compared to the baseline. It should be noted, however, that because the baseline is an electric system, other building upgrades that impact the heating and cooling demands can also yield electrical savings which can be incentivized through the new construction custom program, which would not be the case (or significantly less) for natural gas-based heating systems. It was not in the scope of this study to estimate these savings, but E1 noted on their website page that the total custom incentive for a MURB including a VRF heat pump system may range from $700 to $1,100 per apartment.

When assessing differences in terms of annual energy consumption, the results show that the VRF systems are the most efficient of all studied systems. The differences in energy consumption between systems match what would be expected based on the overall average efficiency of each configuration over the heating and cooling seasons. The efficient VRF system has the highest efficiency, with an annual heating system average COP of 2.7, compared to 0.91 for the standard natural gas system.

These findings are shown in the Figure 3 below, and more details are provided in the Appendix.

Figure 3: Annual Energy Consumption by End-Use (eKWh)



3.3 – Summary

The heating system cost comparison aimed at answering the following question:

> What are the differences in capital and energy costs between VRF heat pump systems and natural gas primary heating systems?

In summary, VRF heat pump systems are more cost-effective than the three other modeled systems, including the hybrid natural gas system. They offer the lowest operating costs but also required more upfront capital.

4 RECOMMENDATION

The current study aimed at answering the following main question:

How should E1's baseline energy building model be determined where natural gas is available?

Recommendation

The recommended approach to VRF heat pump baseline definition is based on the three tasks that were described in the previous chapters of this report. The main conclusions are the following:

- The current VRF adoption has been both technology- and incentive-driven and most of the current adoption comes from the higher-end of rental MURBs, where long-term operating costs have a heavier weight in an otherwise capital-cost driven market;
- New construction custom programs from the scanned relevant jurisdictions all use the modeling specifications in the performance path of their local building standard (NECB and/or ASHRAE 90.1), but the baseline system for VRF heat pumps, which relies on apartment-metered electric resistance backup, does not reflect the local rental-based market for new construction MURBs where natural gas is available;
- VRF heat pump systems are more cost-effective than a hybrid natural gas system but require more upfront capital.

The modeling results are therefore in line with the insights provided by the market actor interviews: some developers who value long-term operating costs can see VRF heat pump systems as a cost-effective investment, and the potential rent premium can overcome the risk associated with this relatively new technology and supply chain. In other words, even in areas where natural gas is available, it is expected that some new construction MURBs would choose an electrical VRF heat-pump system, but its adoption, especially of higher-efficiency models, would be limited by their higher capital costs.

However, the current baseline's use of apartment-metered heat pumps and electric auxiliary heating does not reflect the local rental-based market for new construction MURBs where natural gas is available. **We therefore recommend that the baseline definition should be modified to use ASHRAE 90.1-2013's prescriptive minimum VRF equipment efficiencies, keeping all other NECB modeling specifications**, as shown in the Table 7 below. The program would therefore assume that a project developer would already have made the decision to go with a VRF heat pump system, and would only incentivize the incremental savings of higher-efficiency VRF systems compared to the standard efficiencies, in line with E1's electrical savings mandate. It is to be noted that it is not in the current study's scope to determine if this recommendation should also be applied where natural gas is not available.

Table 7 Recommended baseline for VRF heat pump systems in new construction MURBs where natural gas is available

	Current Definition	Recommended modification
Baseline HVAC system and ARI-rated performance	**PTHP** from NECB-2015 (Table 5.2.12.1) EER: 8.4-9.7 COP: 2.7-2.9	**VRF** from ASHRAE 90.1-2013 (Table 6.8.1-9) EER: 9.3-11 COP: 3.2-3.3
Part-load operation applied on the rated performance above	Performance curves from NECB Table 8.4.4.21.-E (Electric Air-Source Heat Pump Equipment Part-Load Performance)	
	No operation below -10°C	Operation below -10°C

Other modeling specifications	NECB-2015 Part 8

REFERENCES

References

AINSI/ASHRAE/IES. 2013. “Standard 90.1-2013 Energy Standard for Buildings Except Low-Rise Residential Buildings”. https://ashrae.iwrapper.com/ViewOnline/Standard_90.1-2013_I-P

CGC Group. 2018. “Bulldog Heat Pump Vertical Stack Performance Data”. https://bulldogheatpump.com/wp-content/uploads/2019/05/IKV-HKV-General-Performance-May-2019.pdf

Codes Canada. 2015. “National Energy Code of Canada for Buildings 2015”.

EcoSmart Building Energy Solutions. 2019. “Energy Performance of Variable Refrigerant Flow vs. Natural Gas Heating Systems in Multi-Unit Residential Buildings in Nova Scotia”

Efficiency One, 2019. “Variable Refrigerant Flow”. https://www.efficiencyns.ca/variable-refrigerant-flow. Accessed on September 16, 2019.

EIA. 2018. “Updated Buildings Sector Appliance and Equipment Costs and Efficiencies.”

Gordian. 2019 RSMeans Construction Cost Data Books.

LG Canada. 2018. “Multi V 5 Performance Data Manual 575V”. https://www.lgvrf.ca/en/multi-v-5-575v.aspx/Download?filename=MultiV5_575V_Performance_Table_20181030.pdf&id=1864&inline=True

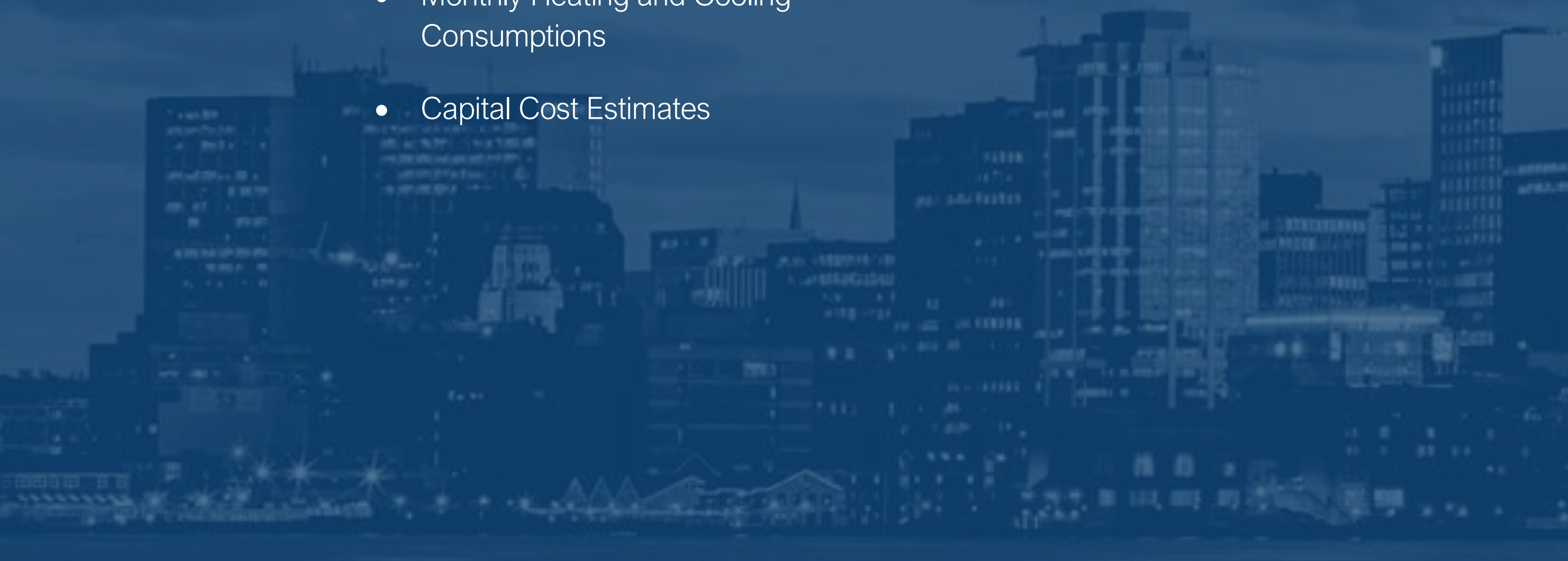
M&R Engineering. 2019. “Multi-Unit Residential Building HVAC Study, revision 3”.

QSolv. 2019. “10 Storey, 100 Unit, Generic Residential Building.”

Thornton, Brian, and Anne Wagner. 2012. Variable Refrigerant Flow Systems. Pacific Northwest National Laboratory.

APPENDIX

- Building Modeling Assumptions
- Annual Consumption by End-Use
- System Performance Metrics
- Monthly Heating and Cooling Consumptions
- Capital Cost Estimates



Appendix

Building Modeling Assumptions Table

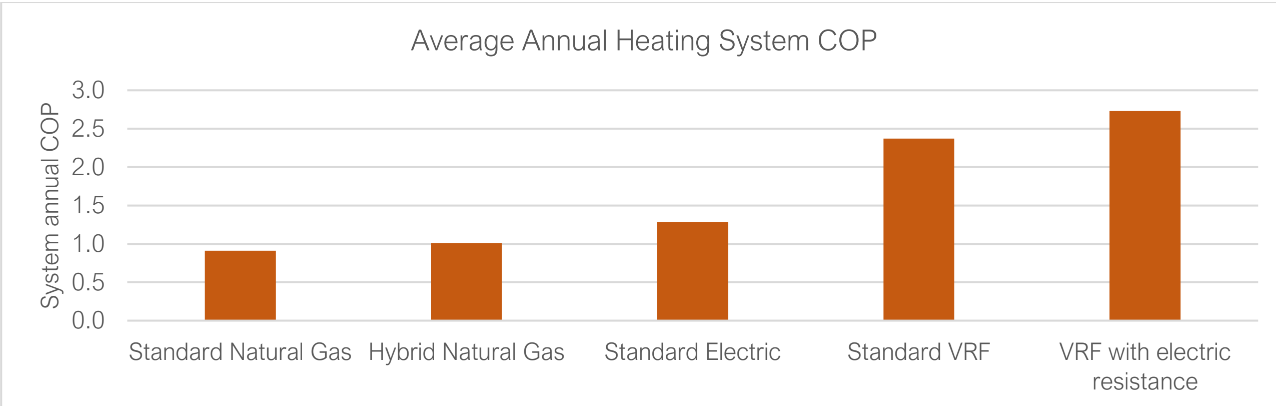
The table below highlights additional key inputs of our building energy modeling.

	Key Building Characteristic
Weather Data	Shearwater Airport, Halifax, Nova Scotia
Envelope Performance	NECB Baseline Insulation Level Above-ground walls: R-23 Underground walls: R-15 Roof: R-31 Fenestration and Doors : R-2.6 Floors: R-3.16
Window to Wall Ratio	24.3%
Thermostat Setpoints	Cooling setpoints : 23°C Heating setpoints : 20°C
Internal Loads	Average interior lighting In-suite: 5 W/m^2 Corridors: 7.1 W/ m^2 Parking: 1.5 W/m^2 Miscellaneous Equipment: 2.6W/m^2

Annual Consumption by End-Use (ekWh)

End-use (system)	Standard Natural Gas	Hybrid Natural Gas	Standard Electric	Standard VRF	Efficient VRF
Space Heating (Heat Pump)	0	0	102 078	300 853	277 512
Space Heating (Auxiliary)	0	0	493 706	22 298	3 290
Space Heating (Gas)	999 029	914 727	157 742	157 742	157 742
Space Cooling	59 824	54 705	59 958	52 872	36 438
Domestic Hot Water (Gas)	322 232	322 232	322 232	322 232	322 232
Fans & Pumps	153 366	153 366	55 473	92 475	92 475
Plug Loads	227 460	227 460	227 460	227 460	227 460
Lighting	222 177	222 177	222 177	222 177	222 177
Total	1 984 087	1 894 666	1 640 826	1 398 110	1 339 327

System Performance Metrics



Monthly Heating and Cooling Consumptions – Standard Natural Gas System (ekWh)

	Annual	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Space Heating - Natural Gas	999 029	181 352	159 766	147 811	100 728	57 565	23 427	9 099	7 036	18 555	50 998	87 867	154 825
Space Cooling	59 824	499	376	988	1 112	2 889	8 549	15 515	16 298	9 182	2 723	1 386	303

Monthly Heating and Cooling Consumptions – Hybrid Natural Gas System (ekWh)

	Annual	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Space Heating - Natural Gas	914 727	169 183	149 342	136 132	92 280	51 217	18 627	6 236	5 542	16 334	45 301	79 834	145 039
Space Cooling - Electric	54 705	515	411	1 000	1 059	2 627	7 766	14 074	14 811	8 310	2 488	1 327	318

Monthly Heating and Cooling Consumptions – Standard Electric System (ekWh)

	Annual	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Space Heating - Natural Gas	157 742	24 057	21 777	20 755	15 696	11 211	5 992	2 895	2 715	5 358	10 683	14 747	21 858
Space Heating – Heat-pump	102 078	7 034	5 436	8 176	19 729	15 503	5 408	1 793	1 259	4 119	12 520	12 776	8 326
Space Heating – Auxiliary	493 706	124 658	111 318	94 862	27 580	0	0	0	0	0	2 604	33 055	99 628
Space Cooling	59 958	499	376	988	1 112	2 889	8 577	15 555	16 369	9 182	2 723	1 386	303

Monthly Heating and Cooling Consumptions – Standard VRF System (ekWh)

	Annual	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Space Heating - Natural Gas	157 742	24 057	21 777	20 755	15 696	11 211	5 992	2 895	2 715	5 358	10 683	14 747	21 858
Space Heating - VRF	300 853	62 691	52 297	46 844	27 567	13 624	4 752	1 576	1 107	3 619	11 964	23 920	50 546
Space Heating - Auxiliary	22 298	9 688	11 232	1 021	0	0	0	0	0	0	0	0	943
Space Cooling	59 958	499	376	988	1 112	2 889	8 577	15 555	16 369	9 182	2 723	1 386	303

Monthly Heating and Cooling Consumptions – Efficient VRF System (ekWh)

	Annual	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Space Heating - Natural Gas	157 742	24 057	21 777	20 755	15 696	11 211	5 992	2 895	2 715	5 358	10 683	14 747	21 858
Space Heating - VRF	277 512	57 506	49 501	43 662	25 621	12 037	3 590	884	740	3 079	10 543	22 191	47 943
Space Heating - Auxiliary	3 290	774	2 516	0	0	0	0	0	0	0	0	0	0
Space Cooling	36 438	240	172	485	582	1 665	5 250	9 786	10 305	5 553	1 528	726	144

Capital Cost Estimate - Standard Natural Gas System

Element	Quantities	Unit Rates	Sub-totals
HVAC Equipment			
Cast-iron gas boiler (1250 MBH)	2	$ 16 250.00	$ 32 500.00
Hydronic baseboard - 4x 4ft. per housing unit	1408	$ 74.70	$ 105 177.60
Mini split heat pump	176	$ 2 090.00	$ 367 840.00
HVAC Other			
Pump - 7.5 hp	2	$ 8 000.00	$ 16 000.00
Piping - Boiler Room	100	$ 300.00	$ 30 000.00
Water Makeup	1	$ 3 500.00	$ 3 500.00
Housekeeping Slab	1	$ 3 000.00	$ 3 000.00
Piping - Distribution 4"	1100	$ 111.80	$ 122 980.00
Piping - Distribution 2"	432	$ 38.22	$ 16 511.04
Wall Sleeves, grilles, drain kit	176	$ 200.00	$ 35 200.00
Controls & Connections			
Electrical connection - Boilers	2	$ 500.00	$ 1 000.00
Electrical connection - Pumps	2	$ 3 000.00	$ 6 000.00
Electrical connection - Heat pumps	176	$ 500.00	$ 88 000.00
Controls - Boilers	13	$ 750.00	$ 9 750.00
Controls - Heat pumps	176	$ 250.00	$ 44 000.00
Grand Total			$ 881 458.64

Capital Cost Estimate - Hybrid Natural Gas System

Element	Quantities	Unit Rates	Sub-totals
HVAC Equipment			
Cast-iron gas boiler (1250 MBH)	2	$ 16 250.00	$ 32 500.00
CGC Heat Pump	88	$ 4 112.50	$ 361 900.00
Cooling Tower (125 tons)	1	$ 32 281.25	$ 32 281.25
HVAC Other			
Pump - VFDs - 7.5 hp	2	$ 10 000.00	$ 20 000.00
Piping - Boiler Room	100	$ 300.00	$ 30 000.00
Water Makeup	1	$ 3 500.00	$ 3 500.00
Chemical System	1	$ 5 500.00	$ 5 500.00
Housekeeping Slab	1	$ 3 000.00	$ 3 000.00
Piping - Distribution 4"	1100	$ 111.80	$ 122 980.00
Piping - Distribution 2"	432	$ 38.22	$ 16 511.04
Ductwork - 4" - 26 gauge	88	$ 4 500.00	$ 396 000.00
Extra drywall - Ductwork	88	$ 500.00	$ 44 000.00
Wall Sleeves, grilles, drain kit	88	$ 200.00	$ 17 600.00
Controls & Connections			
Electrical connection - Boilers	2	$ 500.00	$ 1 000.00
Electrical connection - Pumps	2	$ 3 000.00	$ 6 000.00
Electrical connection - Cooling Tower	1	$ 5 000.00	$ 5 000.00
Electrical connection - Heat pumps	88	$ 750.00	$ 66 000.00
Controls - Boilers & Heat pumps	104	$ 750.00	$ 78 000.00
Grand Total			**$ 1 241 772.29**

Capital Cost Estimate - Standard Electric System

Element	Quantities	Unit Rates	Sub-totals
HVAC Equipment			
Mini split heat pump	176	$ 2 090.00	$ 367 840.00
Electric baseboard	352	$ 110.00	$ 38 720.00
HVAC Other			
Wall Sleeves, grilles, drain kit	176	$ 200.00	$ 35 200.00
Controls & Connections			
Increase service entrance and main panel for electric load	1	$ 30 000.00	$ 30 000.00
Electrical connection - Heat pump	176	$ 500.00	$ 88 000.00
Controls	176	$ 250.00	$ 44 000.00
Grand Total			$ 603 760.00

Capital Cost Estimate - Standard VRF System

Element	Quantities	Unit Rates	Sub-totals
HVAC Equipment			
Equipment (Condenser + Evaporator - 176 tons)	176	$ 2 250.00	$ 396 000.00
Installation - Evaporator	264	$ 1 250.00	$ 330 000.00
Installation - Condenser	9	$ 2 500.00	$ 22 500.00
Duct Heater	88	$ 100.00	$ 8 800.00
HVAC Other			
Ductwork - 4" - 26 gauge	88	$ 4 500.00	$ 396 000.00
Extra drywall - Ductwork	88	$ 500.00	$ 44 000.00
Piping - Condensing pipes	1760	$ 13.80	$ 24 288.00
Controls & Connections			
Electrical connections	176	$ 225.00	$ 39 600.00
Grand Total			$ 1 261 188.00

Capital Cost Estimate - Efficient VRF System

Element	Quantities	Unit Rates	Sub-totals
HVAC Equipment			
Equipment (Condenser + Evaporator - 176 tons)	176	$ 2 750.00	$ 484 000.00
Installation - Evaporator	264	$ 1 500.00	$ 396 000.00
Installation - Condenser	9	$ 3 000.00	$ 27 000.00
Duct Heater	88	$ 100.00	$ 8 800.00
HVAC Other			
Ductwork - 4" - 26 gauge	88	$ 4 500.00	$ 396 000.00
Extra drywall - Ductwork	88	$ 500.00	$ 44 000.00
Piping - Condensing pipes	1760	$ 13.80	$ 24 288.00
Controls & Connections			
Electrical connections	176	$ 225.00	$ 39 600.00
Grand Total			$ 1 419 688.00