MURB *Electrification* Retrofits

Phase 2: Understanding Electrification Retrofit Opportunities and Challenges in BC Apartment Buildings

For:

LandlordBC

BC Hydro

March 2023

FRESCo
Building Efficiency

info@frescoltd.com

www.frescoltd.com

A Message from the CEO of LandlordBC

Building electrification, or fossil fuel to electricity for space and water heating, is a topic of growing importance of the rental housing sector in BC. This importance is driven by environmental, regulatory and occupant comfort and live-safety imperatives.

The environmental imperative: It is widely accepted that climate change, through greenhouse gases (GHGs) emissions, is having serious negative impacts that threaten our health, environment, and economy. Like all Canadians, the residential rental housing sector is committed to playing its part in reducing energy consumption in buildings and using efficient and climate-friendly technologies.

The regulatory imperative: The Province commits, in the CleanBC Roadmap to 2030, to requiring that all space and water heating equipment sold and installed in BC after 2030 is to meet or exceed 100% efficiency (i.e., conventional natural gas combustion equipment may no longer be installed). As a result, the rental housing sector needs to be provided with viable, reliable, and cost-effective building electrification options for existing rental housing and for new rental construction as a pathway for meeting the coming regulations.

The occupant comfort and life-safety imperative: Since the 2021 heat wave and the realization that BC will continue to experience hotter weather, demand for air conditioning has greatly increased in the province. In addition to general interest in accessing air conditioning for improving home comfort, cooling has been identified as an important life safety building upgrade. The BC Coroners Service (BCCS) confirmed the heat related deaths of 619 people who died because of the extreme heat event that occurred within one week, June 25–July 1, 2021.[1] Key recommendations of the BCCS include the implementation of extreme heat prevention and long-term risk mitigation strategies that include improving access to active cooling measures (such as installing heat pumps) and passive cooling measures (such as upgrading building enclosures).

Building electrification is a key solution to addressing these important environmental, regulatory and occupant comfort and life-safety imperatives. On the other side of the coin, it is equally important that BC maintain and grow the stock of rental housing in the province and that this housing remains affordable to build, maintain and operate.

In 2021, LandlordBC supported the development of the report *Electrification of Multi-Unit Residential Buildings* report, that highlighted electrification opportunities, the general considerations and approaches for building electrification, and the education and engagement efforts needed for the rental housing industry. Phase two of this work is presented in this report *Electrification of Multi-Unit Residential Buildings – Understanding Electrification Opportunities and Challenges in BC Apartment Buildings,* which digs deeper into the information needed to operationalize building electrification. Specifically, the report starts by investigating the financial considerations (how much will it cost and what are the factors contributing to higher and lower costs) and the technical considerations (what technologies are already available and emerging and what are the benefits and technical installation considerations of each building electrification option). The report then

[1] "Extreme Heat and Human Mortality: A Review of Heat-Related Deaths in B.C.in Summer 2021.", June 7, 2022, https://www2.gov.bc.ca/assets/gov/birth-adoption-death-marriage-and-divorce/deaths/coroners-service/death-review-panel/extreme_heat_death_review_panel_report.pdf

identifies the key program, policy and industry capacity building considerations that are essential to scaling up and accelerating building electrification.

As the leader in the rental housing sector in BC, LandlordBC aims to continue to support both research and practical projects that advance and accelerate building electrification in the province. The information in this report fills some critical gaps in knowledge and identifies practical next steps for introducing programs, policies and industry capacity building for enabling building electrification. Our organization hopes you find this report informative. We will be using the findings to inform our membership and continue to take a leadership role in advocating for support for improving rental housing, reducing greenhouse gas emissions from the sector, and maintaining housing affordability.

Sincerely,

D. Hutniak

David Hutniak
Chief Executive Officer
LandlordBC

Table of Contents

TABLE OF TABLES

1: Executive Summary

British Columbia's Building Electrification Road Map (BERM) envisions that by 2030, most replacement domestic hot water and heating systems in BC homes and buildings will be high-efficiency electric. The electrification of multi-unit residential buildings (MURBs) in British Columbia[2], has been identified as more challenging technically, financially and from a program and policy perspective than the electrification of single-family residential homes. For this reason, this report has been commissioned by LandlordBC, with funding from BC Hydro and the Province of BC, to:

1. Provide a deeper understanding of financial and technical considerations of building electrification of water and space heating in MURBs.
2. Explore the high-level considerations of the relationship between:
    - MURBs electrifying their building mechanical systems and adding Electric Vehicle Supply Equipment (EVSE).
    - Other building upgrades that can interact with electrification retrofits (e.g., structural upgrades, hazardous materials, remediation, enclosure renewals, and other building energy retrofits).
3. Increase understanding of key considerations that can inform strategies that enable a scaling up and acceleration of building electrification. This includes a high-level identification of:
    - Program considerations
    - Policy considerations
    - Contractor and industry readiness and capacity to implement electrification of MURBs

While this report has a specific focus on rental apartment buildings, many of the financial and technical considerations of electrifying MURBs are similar whether the building is a rental (private, non-profit, or co-op) or strata condominium. Given the limited data available on MURB electrification in the rental market sector, the scope of data collection for this project expanded to include electrification in new construction, electrification retrofits of various types of MURBs, and the retrofits of buildings with electric baseboards to heat pump technologies.

The findings of this report highlight:

- **Financial Considerations:** Although there is a wide range of capital costs associated with electrifying MURBs and a multitude of factors influencing costs, building electrification is already

[2] For the purposes of this document, multi-unit residential building is defined as the broad range of buildings that are not single family detached buildings, but the focus of the analysis and recommendations is on apartment style MURBs

being cost-effectively undertaken. To accelerate building electrification, additional work must be invested in finding innovative ways to reduce costs. More accurate and cost-effective analysis of building electrification could be achieved if stakeholders collaborated to define a standard set of data points for tracking and reporting on electrification projects.

- **Technical Considerations:** Stakeholder understanding of MURB electrification technology options is still relatively low. For stakeholders to be able to identify the most appropriate electrification technology for any given building it is important to have summarized information on each option to determine the: a) appropriateness of the technology for the building type and type of system it is replacing, b) benefits and technical considerations of using the technology compared to other options, and c) cost-effectiveness of the technology (product and installation) compared to other options. The FRESCo MURB Electrification Technologies Fact Sheets, developed for this report, represent a building block for the type of information that is needed to advance stakeholder understanding of the technical considerations for MURB electrification. Versions of these types of fact sheets could be developed for the various stakeholders, including building owners and managers, mechanical designer and installation contractors.

- **High-Level Program and Policy Considerations:** There are a wide range of program and policy considerations and strategies that must be considered if there will be a scaling up and acceleration of MURB electrification. The program and policy considerations, and the associated recommendations, identified in this report warrant more investigation, dialogue and stakeholder consultation.

    - Program considerations identified include:

        - Expand and improve rebates and incentives for MURB electrification
        - Make it easier to access MURB retrofit incentive programs
        - Provide more electrification retrofit planning and implementation support
        - Integrate or align EVSE and building electrification rebates and programs
        - Streamline electrical capacity calculations to reduce time, cost and complexities
        - Staging (and bundling) building enclosure and electrification retrofits
        - Validate MURB electrification post-retrofit performance and savings
        - Introduce industry training for MURB electrification

    - Policy considerations identified include:

        - Provide building owners and industry with access to energy (electric/gas) data to enable MURB electrification

    - Valuation of life safety and non-energy benefits
    - Mechanical and other end-of-life replacements as a regulated "electrification trigger"
    - Streamlining and standardizing permits/bylaws MURB for electrification
    - Addressing heat pump refrigerant leakage and high global warming potential refrigerants
- **Contractor Capacity:** As of fall 2022, there is a moderately low level of contractor experience and capacity with MURB electrification retrofits in BC. However, contractor capacity could be dramatically increased with the introduction of the right supports, including: introducing more incentive offers for MURB electrification measures, introduction of installer training for MURB electrification, and enhancing consumer and industry awareness on the new technologies available for, and benefits of, MURB electrification.

The transition to low carbon buildings in BC is happening at the same time as there is a critical need to protect and expand critical rental housing for a growing population. With this report, LandlordBC, the key industry representative, aims to continue to support the industry and other stakeholders to understand the financial, technical, program, policy and industry capacity building considerations for accelerating the decarbonization and electrification of the MURB sector.

2: Key Findings

2.1 KEY FINDINGS: POTENTIAL BUILDING UPGRADES AND TRIGGERS TO ENABLE MURB ELECTRIFICATION

There are a variety of different building upgrades and other triggers that could enable and motivate MURB electrification. However, it is important to note that these upgrades and triggers will only enable electrification if the contractors, engineers, and other stakeholders involved are educated on electrification opportunities, have the experience and capacity to make informed recommendations, and are motivated to make such recommendations. Key upgrades and triggers include:

- **Increased Demand for Cooling:** Since the British Columbia 2021 heat wave and the realization that BC will continue to experience hotter weather, demand for air conditioning has greatly increased in the province.
- **Mechanical System End-of-Life:** Mechanical system end-of-life upgrades is the most common, and cost-effective trigger of electrification. However, capital planning and pro-actively replacing equipment is recommended as emergency replacement of equipment as it fails is very common, and electrification is extremely difficult to implement under short time constraints.
- **Financial Incentives and Rebates:** Financial incentives from utilities and government are often a major factor in decision making for electrification, in combination with all the other factors listed above.
- **Enclosure Renewals and Building Energy Retrofits:** While enclosure renewals often do not include mechanical upgrades, they indirectly provide an opportunity to trigger building electrification and there can be many benefits to aligning enclosure renewals and other energy retrofits and electrification.
- **EV-Charging Infrastructure is Being Installed or Considered:** When changes are being made to a building that will involve an electrical capacity assessment and/or upgrades to the electrical infrastructure for the installation of Electric Vehicle (EV) charging infrastructure, efforts should be invested in considering the future electrification of space heating and cooling and domestic hot water.
- **General Building Renovations and Modernization:** Any time a MURB is going through a general renovation to improve or modernize the building, or a suite within the building, is an opportunity for electrification. Examples of renovations/modernization of buildings that could include: appliance upgrades, adding ventilation or cooling, tenant turn-over of suites, whole-building renovation, electrical upgrades for safety or maintenance, and alignment with other renovations.
- **Structural Upgrades:** There were no specific reports within the data collected of structural upgrades directly triggering electrification. Desires to improve structural (earthquake proofing)

could trigger a quest to access government incentives, which in turn could trigger an exploration of electrification. Small structural upgrades, rather than *triggering* electrification, are far more likely to be *required for* electrification, in particular for rooftop heat pumps.

Other supporting mechanisms that could become a trigger for electrification, include:

- **Building Condition Assessments, Depreciation Reports, and other Facilities Assessments:** While not common, it would be beneficial for any building assessment or depreciation report to identify and assess the remaining life of mechanical systems and infrastructure and to identify the technology options for meeting the CleanBC Roadmap requirement that all space and water heating equipment sold and installed in BC after 2030 is to meet or exceed 100% efficiency.
- **Environmental, Social and Governance (ESG) Plans:** ESG Plans for major corporate building owners are a major driver of interest in electrification in the private sector.

2.2 KEY FINDINGS: FINANCIAL CONSIDERATIONS

1. **MURB Electrification Capital Cost Data:** Electrification of MURBs is still in its infancy and limited cost data is available. The earliest project data compiled within this study was completed in 2019. Since 2019, there has been significant inflation, supply shortages, greatly increased costs across the construction and renovation sectors, and strong demand for heat pumps.

   To estimate average retrofit costs per suite, investigation of various types of MURBs was undertaken. The most detailed and accessible data was from the non-profit housing projects. Working with available data to inform average costs, new construction, electric baseboard to heat pump retrofits and other consultant studies were also included.[3]

2. **Range of Costs for Electrification:** As with any retrofit project, the capital costs for MURB electrification can be highly variable. This report highlights data for a high, average, and low range of costs for MURB electrification per suite, while acknowledging that the data in this report may not fully reflect the full range of potential costs. For example, with data available for this report the cost ranges for MURB space heating electrification per suite (fuel switching) were identified as low ($11,000), average ($13,250) and high ($22,000). As benchmark costs, electric space heating system installations in new construction and upgrades from electric baseboards to heat pumps demonstrate a range between $2,800 to $6,000 per suite. It is expected that the average range costs for MURB electrification will go down as the market matures, mechanical design engineers and contractors gain experience and specialize in MURB electrification and as new technologies are introduced into the market.

[3] The figures presented in the report are intended to be high level estimates and are not expected to have as high accuracy as analysis carried out in building-specific studies. Such studies should be carried out for any specific building where electrification is being considered.

3. **Factors Contributing to High and Low Costs of Building Electrification:** Identifying factors that may have contributed to higher and lower costs for building electrification and installing electric heating systems helps stakeholders to understand how to enable more cost-effective electrification strategies.

   Factors Contributing to Higher Costs:

   - **Contractors and Suppliers Lack of Familiarity, Interest and Risk Adversity to Building Electrification:** When there is a lack of competition, fear of unknown potential problems, a learning curve and lack of interest in electrification, bidders may increase prices. FRESCo is aware of several projects where bids were more than double that of costs based on supplier quotes and projected labour hours.
   - **Engineers and Project Managers Lack of Familiarity with Building Electrification and Best Practices of System Design:** Has led to specifications for less cost-effective equipment, oversizing, over-emphasis on auxiliary heating and other design issues. These aspects can be compounded by installation issues, controls and commissioning issues, noise complaints and other operational problems requiring remediation.
   - **Electrical Upgrade Costs:** The costs for building and suite electrical service upgrades are beyond the scope of this study, however, it is noted that these costs are variable and can be very significant. Significant effort should be invested in developing mechanical engineering design and retrofit design strategies to minimize the need for, and financial impacts of, electrical upgrades.
   - **Access to Energy Data to Enable MURB Electrification:** Challenging access to whole-building electrical demand data is a critical barrier to building electrification. Delays in access to electric consumption data from the electrical utility, particularly peak demand, can increase costs for electrification projects and in many cases creates a time delay that results in a building electrification project not proceeding. Challenges in accessing data on gas consumption from the gas utility can limit the ability of the consultants to accurately quantify the potential greenhouse gas emission from the project.
   - **Electrical Capacity Calculation:** The considerable challenges and complexities of accessing utility data for performing electrical capacity calculations leads to professionals doing electrical capacity calculations in different ways, with different levels of effort and cost (and likely accuracy). Consistency, clarity and accuracy of electrical capacity calculations can be enhanced by Technical Safety BC (and/or other appropriate authority) issuing a bulletin on the acceptable calculation methods and procedures. This will save time for both professionals doing the calculations and for those who review them (utilities, inspectors, municipalities, etc.).
   - **Supply Shortages:** Due to high demand as well as global supply chain problems, the cost for heat pumps, mechanical components and controls have increased recently. These cost

increases impact all retrofit mechanical equipment. For example, FRESCo has seen that routine boiler upgrade costs have increased on order of 50% within the last few years.

- **Building Size:** All jobs require overhead for sales, project management, labour mobilization, familiarization and site set up. For very small jobs, this becomes a larger percentage of the total cost. Economies of scale, providing a lower cost per MURB suite, can potentially be achieved for larger buildings. This is also the case with other types of heating equipment (i.e., boilers).

- **Client and Expectations:** Some contractors indicated that jobs for government affiliated organizations may cost more as there are more complex procurement processes, higher standards, more administrative demands, and the understanding that higher prices are accepted.

- **Asbestos:** Due to the era of construction, asbestos is present in many of the MURBs where energy retrofits, or renovations of any kind are planned. Abatement and work procedures are well known and established in BC, but add significant cost to interior modifications, such as boxing drywall for ductwork, linesets or electrical.

Factors Contributing to Lower Costs:

- **Choice of Electrification Technology:** Newer technologies and innovations offer the potential to lower electrification costs. For example, CO_2 modular heat pumps for domestic hot water and mini-splits for space heating are both widely accepted to be high efficiency, high reliability and relatively low cost when compared with alternatives. The enhancements in cold climate heat pump technologies is increasing the ability for use of heat pumps in regions across BC. The introduction of new heat pump technologies (e.g., all-in-one heat pumps) is providing new opportunities for in-suite electrification.

- **Electrical Load Management and Load Reduction:** Untapped opportunities exist to minimize electrical upgrades and associated costs through electrical load sharing and load reduction. This may reduce capital mitigating costs of electrical service upgrades to suites and main building.

- **Business Model – Bulk Installations:** Companies specializing in installing heat pumps in multi-unit residential buildings have demonstrated they can reduce capital and installations costs by handling the import of heat pump units directly from the manufacturer and pricing for bulk installations.

- **Business Model – General Heat Pump Contactor:** One of the most active contractors in the Ontario market converting electric baseboard MURBs to heat pumps prefers to rely primarily on lower cost trades and labour for most of the work, since higher skilled and higher paid refrigeration technicians are only required to make the final connections.

- **Alternative Ducting Solutions:** For projects that require ducting, drywall work to new hide ducting can be a significant added cost. Exploring approaches that either allow for more cost-effective ways to utilized existing ducting (if available) or for new ducting installations to either to hide ducting or use strategies that make exposed ducting aesthetically pleasing enough to be acceptable (as is common in commercial applications).

- **Design Strategies to Reduce Impact of Rates and Peak Electrical Demand Charges:** Best practices for MURB electrification should highlight the importance of mechanical design strategies to reduce the financial impact of rates and peak electrical demand charges. DHW systems, for example, should operate at low average power and avoid coincident operation with peak space heating, but poor design or controls commissioning can cause unnecessary peaks. Industry awareness of pending changes to rate structures will allow for future proofing of the affordability of MURB electrification retrofits. For example, there is currently no incentive for buildings to control equipment to mitigate consumption during peak hours. If it is likely that time of use rates will be introduced, system design should account for the ability to shift consumption to off-peak times where feasible.

2.3 KEY FINDINGS: TECHNICAL CONSIDERATIONS

Limited Information Available to Compare MURB Electrification Technology Options: There are many considerations for each technology that could be used for a building electrification retrofit. For stakeholders to be able to identify the most appropriate electrification technology for any given building it is important to have summarized information on each technology to determine:

- The appropriateness of the technology for the building type and type of system it is replacing.
- The cost effectiveness of the technology (product and installation) compared to other options.
- The benefits and challenges associated with the technology compared to other options.

To help address this objective of this project (to deepen stakeholder understanding of MURB electrification options), FRESCo has developed a series of *MURB Electrification Technology Fact Sheets*.

Key Technical Consideration Learnings

- **Northern climate** electrification retrofits are already and currently functioning without use of auxiliary heating.
- **Over-use of auxiliary heating in hybrid heat pumps systems** was reported in multiple sites, not meeting the decarbonization intent and GHG savings expected of the retrofit. Hybrid heat pump make up air units, central domestic hot water and central space heating systems are all susceptible to this issue. One engineering firm reported in an interview: *"The majority of these hybrid systems are not working [on the heat pump]. We recommissioned many systems and found the heat pumps tripped out; no-one knows for how long, and the system was running only on gas. Hybrid is harder to operate; we need to plan for ongoing operations."* The reasons for falling back on gas are various, but most were from complications in control setups. Having two pieces of heating equipment with very different operating characteristics work together by controlling pumps, mixing valves, setpoints and schedules is difficult. Control software is vulnerable to changes from upgrades, code modifications

and manual interventions typically by personnel from multiple organizations involved in projects. These problems are very common in any complex mechanical project. Sacrificing efficiency to quell comfort complaints by defaulting to the simplest and quickest solution (in this case running only on gas) is a very common practice in the world of building control systems. None of these problems were reported to be due to failed or low-quality heat pumps.

- **Engineers reported reluctance** and trepidation in designing systems with heat pumps as primary equipment and reported intentional over-design and reliance on auxiliary heating, which can reduce performance and increase cost. In some cases, there was evidence that mechanical design issues contributed to higher-than-expected utility costs.
- **Education of mechanical engineers** specific to heat pumps in retrofit applications is needed. Best practices for mechanical system design for MURB electrification, informed by completed projects, should be developed, and disseminated. Complementary materials should be provided for owners so they can ask the right questions to identify knowledgeable engineers to work with.
- **In-suite heating solutions** is an emerging opportunity for more cost-effective MURB electrification. There are already numerous options that achieve this, though more variety of equipment (e.g., smaller capacity units) would be beneficial and expand the viability of in-suite electrification options.
- **Electrical upgrade costs** to enable electrification can be high and may be difficult to predict and budget for. Avoiding electrical upgrade costs is a major driver for the use of hybrid systems. The pending BC Hydro Connection Tariff Review (summer or fall of 2023) will provide insights into how this issue can be addressed.
- **Higher electric bills** than expected were reported in some projects. Higher consumption in general and higher consumption during peak demand periods can trigger rate changes and demand charges, which was not always predicted by the original business case. Knowledge of mechanical design strategies to minimize peak demand charges are not widespread among contractors or engineers. There is a lack of awareness of electrical demand response, load sharing, and design strategies to minimize peak demand charges. Increasing awareness and understanding in the industry is required.
- **Displacement of tenants** was not reported in the projects explored. Electrification without displacing tenants is possible, although can be more challenging in some circumstances.
- **Noise complaints** and remediation were reported with some electrification projects, mostly with make-up air units (MUA's) installed on the roof. Residents located above the MUA in adjacent buildings and parts of the same building were affected by noise (from fans and compressors), and in some cases residents located beneath the equipment were affected by vibration through the roof. Equipment selection, mechanical design solutions (quieter units, addition of sound baffles, and improved vibration isolation mounts) and other installation best practices exist to achieve quieter operation for all types of heat pump applications. Noise concerns have also been an issue in recent gas absorption heat pump (GAHP) projects.

- **New contractor business models** offer the potential to accelerate MURB electrification and reduce per suite MURB electrification costs. Examples of this include the potential for contractors specializing in lower cost products and are easier to install (e.g., all-in-one-heat pumps or window mounted technologies), contactors specializing in bulk installations and reducing costs through direct import and economies of scale (e.g., as at least one contractor in BC is already operating), and general contractors installing heat pumps with lower cost labour with refrigeration mechanics only used for refrigerant connections (e.g., as at least one contactor in Ontario is already operating).
- **Lower global warming potential refrigerant** product options are available for space and hot water heat pumps. For example, CO_2 domestic hot water heat pump technologies are a leading hot water electrification option based on capital installation costs, cold climate functionality, low global warming potential refrigerant and superior energy performance. Other systems less prone to leaks and with small amounts of refrigerant include All-In-One space heat pumps (see the "All-In-One" Fact Sheet in this report for more detail). Low GWP refrigerant products (such as R290) for space heating/cooling are available but restricted due to hesitancy in industry and a lack of progress and clarity in regulations.
- **High global warming potential refrigerants** with inherently high leakage risk technologies are widely promoted and installed (e.g., Variable Refrigerant Flow Heat Pumps).
- **Tenant comfort** was not examined in depth in this study, but the interviewees who were asked, and many literature references, reported high tenant satisfaction with heat pump space heating and cooling. The ability to add cooling to BC MURBs, which rarely have cooling, not only improves comfort but also improves life safety. The over 600 deaths caused by BC's 2021 heat dome event is a reminder of the value of cooling, particularly for more vulnerable populations.

2.4 PROGRAM AND POLICY CONSIDERATIONS TO SCALE UP AND ACCELERATE MURB ELECTRIFICATION

There are a wide range of program and policy considerations and strategies that can be used to enable a scaling up and acceleration of multi-unit residential building electrification. FRESCo has provided a summary of each of these considerations and a corresponding actionable recommendation in sections *7 Strategies – Scaling Up Building Electrification and 8 Summary of Recommendations.*

Table 1: Program and Policy Considerations

Program Considerations	Policy Considerations
▪ Expand and improve rebates and incentives for MURB electrification ▪ Make it easier to access MURB retrofit incentive programs ▪ Provide more electrification retrofit planning and implementation support ▪ Integrate or align EVSE and building electrification rebates and programs ▪ Streamline electrical capacity calculations to reduce time, cost and complexities ▪ Staging (and bundling) building enclosure and electrification retrofits ▪ Validate MURB electrification post-retrofit performance and savings ▪ Introduce comprehensive program requirements to ensure hybrid systems deliver anticipated GHG emission reductions ▪ Introduce industry training for MURB electrification	▪ Provide building owners and industry with access to energy (electrical capacity) data to enable MURB electrification ▪ Valuation of life safety and non-energy benefits ▪ Mechanical and other end-of-life replacements as a regulated "electrification trigger" ▪ Streamlining and standardizing permits/bylaws MURB for electrification ▪ More provincial action on addressing heat pump refrigerant leakage and high global warming potential refrigerants

Industry Capacity for MURB Electrification Retrofits

As of fall 2022, there is a moderately low level of contractor experience and capacity with MURB electrification retrofits in BC. However, contractor capacity could be dramatically increased with the introduction of the right supports, including:

- Introducing more incentive offers for MURB electrification measures
- Introduction of installer training for MURB electrification, and
- Enhancing consumer and industry awareness on the new technologies available for, and benefits of, MURB electrification.

To accelerate training and industry capacity there is potential to streamline training and qualifications for focused MURB electrification applications. For example, focused best practices installation training could be developed for in-suite mini-split heat pump systems, all-in-one heat pump systems, window mounted heat pump systems, CO_2 domestic hot water heat pump systems, and other specific applications. Industry training should be as flexible as possible with resources and support to rapidly deploy training opportunities to address common installation issues with heat pump technologies.

2.5 SUMMARY AND STATUS OF MURB ELECTRIFICATION SOLUTIONS

The following chart provides a snapshot of the feasibility and economics, the prevalence of installations in BC, the typical hurdles and risks and product availability. For all technologies a common factor, not identified in the chart, is the need for consumer awareness building about the products and industry (engineer and installation contactor) training on the design and installation of systems.

Major End Use Category	Feasibility (Varies)	Prevalence Installations in BC	Hurdles and Risks	Product Availability
Domestic Hot Water	Very feasible	Several	• Dependant on site conditions (e.g., space, location of outdoor units relative to storage) • Electrical capacity • Gas backup overuse risk if hybrid solutions are used	• Only 3 best class products (CO_2) in the market in spring 2023. • Many new products will be in the market in the near future.
Make Up Air	Very feasible	Many	• Electrical capacity • Structural capacity • Gas backup overuse common with hybrid solutions	• Many products available.
Space Heating: In-Suite	Feasible	Few	• Regulatory (switching utility costs onto tenant meter) • Electrical capacity • Will gas backup eliminated? • Heat load/sizing	• Many products available. • Smaller apartment sized units needed.
Space Heating: Central Hydronics	Difficult	One (unicorn building)	• Existing pipe leaks and incompatibility • High complexity, design risk, maintenance costs • Gas backup overuse risk • Portion of load being served by electric v. gas is a major factor in cost, complexity, etc.	• Small selection for central outdoor heat pump. • Potential products for in-suite.

3: Project Approach

3.1 FORMAL AND INFORMAL INTERVIEWS AND INPUT

The findings of this report were informed by stakeholders directly involved in MURB electrification. This included formal interviews with 25 stakeholders and informal input provided by dozens of stakeholders representing equipment suppliers, contractors, cost consultants, government, private owners, social housing operators, and consultants (engineers, designers, etc.). Interviewees provided valuable information on costing and technical considerations and key insights on the program, policy, and industry (engineer/contractor) capacity considerations needed to accelerate MURB electrification.

Individuals to be interviewed were identified primarily by their involvement in actual projects. To save time, and to improve results, a lengthy fixed set of repetitive questions was not used. Questions were custom formulated for individuals to specific aspects of the previously obtained project data (such as very high or low cost, low savings claims, very successful or problematic projects or missing information). Excursions on illuminating project details, market aspects and personal perspectives which could not be predicted before the interview were encouraged. Questions were in the general categories of:

- Resident reception, comfort, adequacy of heating capacity and water temperature.
- Rationale of mechanical design including system type, hybrid, sizing, siting of equipment.
- Startup problems, reliability, auxiliary heating control, maintenance experience and/or expectations.
- Electrical capacity considerations and cost.
- Utility costs post-operation.
- Capital breakdown including hardware cost vs labour, unexpected costs, electrical upgrades.
- Perspectives and knowledge about heat pump design and operation.

Interviews were between ½ hour and 1 hour, often with preceding questions and/or post-interview email follow up.

BC Housing staff have been involved in the most projects and are strongly invested in converging good solutions on behalf of people they serve. They were very forthcoming with information despite being extremely busy. They gave unvarnished information on problems as well as solutions and connected FRESCo with Engineers involved in projects after gaining permission.

3.2 DATA COLLECTION AND ANALYSIS

Data on capital costs was acquired through multiple databases and study sources, including:

- FRESCo: Projects database
- CleanBC: CleanBC Small Buildings database of projects receiving rebates
- BC Non-Profit Housing Association (BCNPHA): SHRSP Energy study database
- Metro Vancouver: Retrofit database
- Pembina Institute: Reframed Project
- MURB Electrification Studies and Reports: Various

Although all the data was informative, it was identified that cost statistics from actually completed retrofits in BC would be the most valuable. Also, it was identified that cost comparison per suite per end use, (or of sites with all end uses retrofitted) would be most informative. However, only a small subset of the data provided this.

The various data sources were compiled into a master database and analyzed for comparability of the data. The information items (total of 133) included pre-and post-fuel types per end use (space heating, domestic hot water and outdoor air ventilation), auxiliary fuel type, equipment model, building type, age, size, region, ownership type, project capital, electric service cost (if available), energy savings, and derived results such as cost per suite. Some buildings appeared in multiple databases which needed to be identified and consolidated as one record. Some databases did not include the number of suites which needed to be obtained, or clear indication of whether the project went ahead. Most buildings did not have data for all parameters, and much of it was not comparable; see Section 5.1 Costing Data Limitations and Recommended Standardized Building Electrification Database for details on the collected data.

3.3 RESEARCH

The interviews and data analysis portions of this project were complemented by extensive investigation into the financial and technical considerations of MURB electrification, including:

- Conversations with equipment suppliers, manufacturers, and project engineers
- Case studies, analysis reports, studies, and project summaries
- Technical forums and articles on electrification and heat pump technologies
- Presentations
- Equipment installation guidelines
- Best practices installation guides
- Manufacturer and supplier websites

04

4: Building Upgrades and Triggers That Can Enable MURB Electrification

There are a variety of different building upgrades and other triggers that can enable and motivate MURB electrification. However, it is important to note that these upgrades and triggers will only enable electrification if the contractors, engineers, and other stakeholders involved are educated on the electrification opportunities, have the experience and capacity to make informed recommendations and are motivated to make the recommendations.

Increased Demand for Cooling

Since the British Columbia 2021 heat wave and the realization that BC will continue to experience hotter weather, demand for air conditioning has greatly increased in the province. In addition to general interest in accessing air conditioning for improving home comfort, cooling has been identified as an important life safety building upgrade. The British Columbia Coroners Service (BCCS) confirmed the heat related deaths of 619 people who died because of the extreme heat event that occurred within one week, June 25–July 1, 2021.[4] Key recommendations of the BCCS include the implementation of extreme heat prevention and long-term risk mitigation strategies that include improving access to active cooling measures (like heat pumps) and passive cooling measures (improving building envelope).

The building code will likely incorporate increased requirements for cooling based on future climate projections files that have been generated for the next 30-year period. BC Housing now requires cooling demand be recognized in all current projects based on projections, not just historical data. Mechanical equipment is typically expected to last ~15 to 25 years and a significant increase in cooling demand is expected over the lifetime of equipment installed today. New construction projects today typically consider air conditioning. Strata condos often offer options for built-in or roughed-in (electrical connections and enclosure penetrations are prepared) for cooling. Higher end private rentals sometimes include air conditioning.

Retrofitting air conditioning to existing MURBs is a topic on many owner's minds, but not a common practice yet. While air conditioning has been common in MURBs in the Okanagan since the 1960's, many of the systems are older and relatively inefficient. In the lower mainland and Vancouver Island, virtually all older buildings were built without air conditioning.

[4] "Extreme Heat and Human Mortality: A Review of Heat-Related Deaths in B.C.in Summer 2021.", June 7, 2022, https://www2.gov.bc.ca/assets/gov/birth-adoption-death-marriage-and-divorce/deaths/coroners-service/death-review-panel/extreme_heat_death_review_panel_report.pdf

Capital spent on adding air conditioning as a separate system could be less economical option when a heat pump system can provide both heating and cooling and may reduce long term overall capital, maintenance, and utility costs.

For buildings that use electric baseboard heating or have lower efficiency air conditioning equipment, air source heat pumps offer the opportunity to reduce both electric heating and cooling loads, potentially freeing up electrical capacity for the addition of electric vehicle charging infrastructure.

Private rental owners are interested in recovering costs by providing improved comfort. Larger owners, including REITs are looking at longer term options. One owner representative indicated in the Toronto market they expect a market rent increase of $50-$100 per month when upgrading to air conditioning.

Mechanical System End-of-Life

Mechanical system end-of-life upgrades is the most common, and cost-effective trigger of electrification. Space heating boilers, hydronic pipes, gas water heaters, or make up air units and existing air conditioners have limited lifespan even with the best maintenance, and maintenance levels in MURBs is typically far lower than other commercial building types. Emergency replacement of equipment as it fails is very common, and electrification is extremely difficult, and sometimes impossible, to implement under short time constraints.

Hydronic pipe leaks were cited as electrification triggers in two of the sites involved in this research, and in-suite heat pumps were assessed as lower cost than replacing the pipes. Failed or end of life gas fired mechanical systems was cited as the main trigger for all the other electrification projects where this was specifically asked.

Mechanical system end-of-life is a key trigger point for MURB electrification because:

- **The decision-making process** has been initiated; they will allocate capital to *something* to replace the existing failing heating, hot water and/or air conditioning system and are already considering options.
- **Pipe leaks, air locks** and other equipment failures result in expensive ongoing maintenance and repair which creates pressure to force a capital replacement decision. Pipe and hydronic radiator replacement requires expensive and disruptive work in suites and throughout the building. It includes extensive drywall work which is complicated by the presence of asbestos in most buildings. Switching to an in-suite heat pump system can be much less costly and disruptive.
- **Tenant complaints** can result from failure of heating, hot water, and air conditioning. Complaints are very stressful to property management staff and owners. This can include Residential Tenancies Board (RTB) cases, financial penalties, and warnings from municipal staff.
- **Air conditioning** needs are increasing, and owners are looking for options. If the building is in the Okanagan or other hot summer area, it likely has an obsolete and underpowered system, including

evaporative “swamp” MUA coolers, and small ineffective through wall AC units. If the building is in the lower mainland or Vancouver Island, it likely lacks air conditioning.

Enclosure Renewals and Energy Retrofits

Enclosure renewals and other energy retrofits are an opportunity trigger for building electrification. Enclosure renewals can include, addressing moisture issues (i.e., leaky condo), replacing cladding due to age, adding insulation, upgrading windows, air sealing and painting. While enclosure renewals often do not include mechanical upgrades, they indirectly provide an opportunity to trigger building electrification. An enclosure upgrade that improves the efficiency of the building can allow for a smaller sized heat pump system to be installed. There are multiple other benefits to combining the building improvement work with heat pump installations. For example, having a general contractor coordinate enclosure renewals and heat pump upgrades at the same time can provide options for:

- **Window upgrades** are very frequent in older buildings due to mechanical failure/ safety, poor comfort from drafts, and condensation/ mildew on windowsills. Window replacement is an ideal time to consider electrification. FRESCo projects in process have proposed use of window penetrations for line-sets, direct heat pump air exchange and HRV mounting. This reduces enclosure penetration cost very significantly. Window size on older MURBs is often much larger than really required, and owners have expressed interest in this option.
- **Aesthetics** of lineset and outdoor unit covers should be integrated into the enclosure renewal design. Lineset and outdoor unit covers can be purchased colour matched or painted on site. Painting can be planned for after lineset installation so that all fasteners into the envelope are sealed and linesets are painted to match the building.
- **Penetrations** of envelope components for heat pump lines (refrigerant, electrical, condensation) are effectively sealed and integrated into the cladding and/or roofing.
- **Construction sequence** considerations for installation of heat pump outdoor units on decks, balconies, or roofs. Attachment points of outdoor units should be integrated into balcony railing and waterproofing membrane renewal design. Sleeper structural supports for roof mounted outdoor units and roof penetrations need to be coordinated with roofing specification.

Additionally, it is common practice in Part 9 and Part 3 buildings for heat pumps to be installed in relatively inefficient homes and buildings that do not receive building envelope upgrades. Best practices for building energy improvements would encourage that all homes and building energy retrofit projects include an investigation on how to reduce the heating and cooling load prior, or at the same time, as a heat pump upgrade is planned. At the minimum, an investigation and implementation of air sealing to reduce heat loss in winter and heat gain in summer should occur in all homes and buildings prior to a heat pump retrofit. Window upgrades and exterior shades should be explored, costed, and integrated into the retrofit.

EV Charging Infrastructure is Being Installed or Considered

When changes are being made to a building that will involve an electrical capacity assessment and/or upgrades to the electrical infrastructure, such as the installation of Electric Vehicle (EV) charging infrastructure, efforts should be invested in considering the future electrification of space heating and cooling and domestic hot water. By the same token, building mechanical upgrades should consider the future electrical capacity needs of EV-charging. See *Section 7 – Integrating or Aligning EVSE and Building Electrification Rebates and Programs.*

General Building Renovations and Modernization

Any time a MURB is going through a general renovation to improve or modernize the building, or a suite within the building, is an opportunity for electrification. For example:

- **Appliance upgrades** are often desired, especially by private building owners. Electrical upgrades required to add in-suite laundry and improved kitchen appliances triggered FRESCo's first completed electrification and has been a consideration in most of our projects with private owners.

  An electrician interviewed commented that adding laundry driers was a common threat to overload the main building service on many sites he had seen. Heat pump driers (half the power demand), and load sharing devices at both the suite and building level are solutions to reduce electrical upgrade costs.

- **Ventilation and cooling** is missing or ineffective in most older MURBs in BC. Most buildings in the Okanagan and other regions with hot weather do have cooling, but typically the systems are very low efficiency, low capacity and loud window or through-wall units. Electrification offers the opportunity to cost effectively add or improve cooling and potentially air filtration, improve system efficiency, and reduce operational costs.

- **Turn-over of suites** between tenants offers the potential opportunity to electrify one suite at a time, but there are technical difficulties in a "gradual retirement" of gas systems. Additionally, electrification would happen extremely slowly and not meet CleanBC timelines due to the current very low turn-over rates in a constrained housing market.

- **Whole-building renovation:** Occasionally entire buildings receive an interior renovation, especially following a fire or flooding. This may include removal of drywall, existing heating systems and exterior remediation. This makes electrical upgrades far simpler and allows more flexibility for changes in ventilation and mechanical system replacement for suites and common areas.

  Cases of emptying a building of occupants for the sole purpose of electrification was not encountered in the data. This would result in a loss of revenue to the owner, as well as being challenging to due to the shortage of rental housing.

- **Electrical upgrades for safety or maintenance:** Older buildings occasionally have maintenance or safety problems such as very old panels with obsolete or failing breakers, aluminum wiring, transformers failing or leaking toxic PCB's. This is an ideal time to consider electrification. Panel replacement due to obsolete breakers is regularly encountered by FRESCo. Aluminum wiring is not inherently dangerous, but in some cases improper connections between dissimilar metals was made, and in a small number of buildings this was never corrected.

- **Alignment with other renovations** should be considered for heat pumps which require in-suite ducting, or other modifications.

Hazardous Materials Remediation

- **Asbestos remediation** as a goal was not reported to be a trigger for electrification in any project within the data collected for this project. Nor has this concept ever been encountered by FRESCo. Asbestos is present in almost all older MURBs (~1950's through ~1985), but it is simply left within the building undisturbed, as it is not considered a hazard unless cut into. Hazmat procedures for asbestos are well established and routine but it does add cost to electrification (or any other building upgrade which requires cutting drywall or enclosure penetrations). Quantifying the "extra cost" is difficult. The work area must be sealed off, and all penetration work must be carried out through an additional sealed glove bag. A hazmat company must be present to verify the work procedure and test for asbestos after cleanup. FRESCo estimated that for in-suite ductwork addition, at least $900/suite would be required just to pay for the presence of the hazmat contractors. Running refrigerant linesets, electrical upgrades into suites, adding penetrations for in-suite HRV's or AIO heat pumps, and adding interior ductwork are all examples where the presence of asbestos adds cost to electrification. One interviewee estimated $30k cost for adding ductwork in a suite, including asbestos remediation. FRESCo has been actively searching for a simple to mount lightweight pre-finished ductwork system which could avoid large amounts of drywall and anchoring work in the suite.

- **PCBs** are present in many liquid cooled older transformers, commonly found outdoors on older building sites. These are legally obligated to be replaced if they are found to be leaking. This is also a good time to consider whole-site electrification options. FRESCo is not aware of the presence of PCB's "triggering electrification" to date.

Structural Upgrades

There were no specific reports within the data collected of structural upgrades directly triggering electrification. Desires to improve structural (earthquake proofing) could trigger a quest to access government incentives, which in turn could trigger an exploration of electrification.

Small structural upgrades, rather than *triggering* electrification, are far more likely to be *required for* electrification. Heat-pump make up air units are almost always heavier than the gas units they replace, and structural studies to verify a roof's capacity to support heat pumps, hot water tanks and ventilation units are routine. Upgrades beyond support sleepers are seldom required for concrete structures. No major structural upgrades were required on any sites where FRESCo has been involved or has information about structural studies.

Building Condition Assessments, Strata Depreciation Reports, and other Facilities Assessments

The Province commits, in the CleanBC Roadmap to 2030, to requiring that all space and water heating equipment sold and installed in BC after 2030 is to meet or exceed 100% efficiency (i.e., conventional combustion equipment may no longer be installed). As a result, it would be beneficial for any building assessment or depreciation report to identify and assess the remaining life of natural gas mechanical systems and infrastructure and to identify the technology options for meeting the 100% efficiency equipment requirement.

Energy Studies commissioned by private owners and social housing and co-ops have been prominent triggers for electrification projects by FRESCo and other consultants.

Incentives and Rebates

Financial incentives from utilities and government are often a major factor in decision making for electrification, in combination with all the other factors listed above. This is especially prevalent in the social housing and co-operative sectors where basically all available funding sources have energy performance targets. In FRESCo's experience the primary goals of housing societies and boards is typically enclosure renewal or air conditioning, but they may be persuaded to incorporate heat pumps and efficiency upgrades to secure capital. This is also true of private owners but to a lesser degree due to lower incentive levels.

Environmental, Social and Governance (ESG) Plans

ESG Plans for major corporate building owners are a major driver of interest in electrification in the private sector. There has been a significant increase in the pressure that institutional investors are placing on building owners/operators. Numerous larger companies now have staff specifically tasked to produce plans to achieve increasingly aggressive GHG reduction targets.

5: Financial Considerations of Building Electrification Retrofits

5.1 COSTING DATA LIMITATIONS AND RECOMMENDED STANDARDIZED BUILDING ELECTRIFICATION DATABASE

At the onset of this research project the authors were provided access with data from multiple retrofit databases, which included retrofit costing information. When compiling the information it became apparent that the costing information within the databases was limited and tracked in a way that made it difficult to compile and determine average electrification costs. Limitations of the databases included:

- Most was data from renovation projects, and projects naturally included a bundle of renovation and energy retrofit measures. Typically cost and savings of individual electrification measures could not be isolated. Many jobs included heat recovery ventilation, some may have included enclosure upgrades or other general maintenance upgrades which were not specified. For many retrofits it was not clear if electrical upgrades had been undertaken and if the costs had, or had not, been included in the presented cost.
- Some of the databases were made up of consultants estimates and information from energy studies, rather than actual retrofit costing. The estimates were provided for a wide range of retrofit opportunities, large differences in prices estimates and over a multiple year period with pricing that would no longer reflect current market realities. As a result, this information was not included in the financial analysis of the report. For example, see *Appendix B: BCNPHA Summary of Costs from Energy Studies.*
- There was no consistency between the databases in capturing and/or isolating soft costs (engineering or general contractor fees).
- Some records were by building, some were by project/ end use, some buildings had multiple separate projects listed, others combined multiple end uses in one set of costs.
- How many end uses (space and water heating and outdoor air heating) were electrified, and whether HRV's were added was not always clearly identified.
- The existence and capacity of gas or electric auxiliary heating was not always clear. For example, details were not provided to determine if the full building, or full suite, had been electrified or if the installed heat pump(s) had the capacity to heat the full building/suite, or if it was installed as a supplementation heating system to complement existing building/suite heating.
- Basic building data was reported differently. For example, building construction data sometimes listed the year of building construction (the preferred data point) and sometimes the current age of the building (not recommended).

- Due to database omissions and concerns for confidentiality of suite-level energy consumption data – critical aspects, such as number of suites in the building, were not included in some databases. Without information on number of suites in a building there are large analysis limitations.

As a result, after data cleaning the actual sample size of retrofits was smaller than ideal to be able to determine a representative average MURB electrification cost. However, the compilation of other electric heating system installation data, including electric system installation in non-profit buildings, new construction, electric baseboard to heat pump installations, and integration of data from costing studies allowed for a reasonable estimate of the average cost ranges of MURB electrification.

Recommendation: To streamline future analysis of the technical and financial aspects of building electrification projects, FRESCo recommends that stakeholders collaborate to define a standard set of data points for tracking and reporting on electrification projects. This would facilitate more accurate and cost-effective analysis. Data points could include defined building characteristics, fuel types per end use before and after, auxiliary heating fuel types, original utility rates, capacity of heat pump systems, emitter types, mechanical costs, electrical costs, service upgrade costs. This work could also explore how confidentiality can be protected while tracking and reporting on building and/or suite-level energy consumption.

5.2 INTRODUCTION TO CAPITAL COSTING TABLES

The capital costs for building electrification is provided for electric space heating (Tables 2 and 3), electric water heating (Table 4), electrification of ventilation (Table 5) and electrical upgrades (Table 6). This compilation of costing information was sourced from a variety of different external databases, FRESCo's internal database and interviews. To provide more depth of understanding on the range of costs for electrification a range is provided with low costs, average costs and high costs per suite. Because of the limited amount of building electrification (fuel switching) costing data available, where possible costing benchmarks have been provided for other types of non-fuel switching retrofits. In Tables 2 to 6 the blue rows represent costs for actual *completed fuel switching retrofits in MURBs* and the grey rows represent benchmark costs for other data points (new construction, existing electric to heat pump retrofits, studies).

An example extract from the database used for this project, and description of the data used is included in Appendix D.

5.3 CAPITAL COSTS AVERAGE RANGE AND BENCHMARKS: ELECTRIC SPACE HEATING

An assessment of the costing data highlighted a wide range of capital costs for electrifying, or installing electric space heating equipment, in MURB buildings. As identified in Tables 2 and 3, the retrofit capital costs for electric spacing heating systems assessed in this research have a range between $2,800 to $22,000 per suite.

Table 2: Capital Costs for Heat Pump Space Heating Systems (Various)

Heat Pump Space Heating Systems Per Suite (Various)	Low	Average	High
MURB Electrification Fuel Switch Retrofit (Various Space Heating Types)	$11,000	$13,250	$22,000
Benchmark Cost: Electric Baseboard to Heat Pump Upgrades	*$2,800*	*$5,500*	*$7,300*
Benchmark Cost: New Construction Central Electric (Variable Refrigerant Flow Heat Pump Systems)	*$11,000*	*$13,000*	*$15,000*
Benchmark Cost: Electrification Retrofit: 2022 RDH Existing Home Archetype and ERM Costing Research Report[5]	*$9,200*	*/*	*$15,400*

Table 3: Capital Costs for Mini-Split Air-Source Heat Pump, Per Suite

Mini Split Heat Pump System Per Suite	Low	Average	High
MURB Electrification Fuel Switch (Mini-Split ASHP) Retrofit	$11,000	$16,000	$22,000
Benchmark Cost: New Construction (Mini-Split, no electrical upgrade, efficient building envelope)	*/*	*$10,000*	*/*
Benchmark Cost: HW. Flesher Co-op Electric Baseboard to Mini-Split Retrofit in 100-unit building retrofit (No electrical upgrade, inefficient building envelope)	*/*	*$4,200*	*/*
Benchmark Cost: Fall 2022 Mini-Split Wholesale Cost to Contractor	*$2,000*	*$3,000*	*$4,000*

Although new construction capital costs are not the same as retrofit costs (and are out of scope for this report) they do provide a useful benchmark capital cost for the following reasons:

- New construction installation costs represent the installation costs in a building/suite that does not include electrical capacity upgrade costs.
- The building envelope of the building/suite would represent a built to code or better.

5.4 CAPITAL COSTS AND BENCHMARKS: ELECTRIC WATER HEATING, VENTILATION AND ELECTRICAL UPGRADES

The average retrofit capital costs for the most cost-effective electric water heating systems with data from actual installations is $2,500 per suite ($CO_2$ air source heat pump) with integrated domestic hot water air source heat pumps (R410A) costing $3,200 per suite.

[5] "Existing Home Archetype and ERM Costing Research Report." RDH, 2022.The space heating system proposed for $15,400 is a central hydronic heat pump with in-suite hydronic fan-coil retrofit to replace existing baseboard heaters in Vancouver. The system proposed for $9,200 was a mini-split. These costs may include electrical upgrades of different unknown levels due to the sequential additive approach of this study.

Table 4: Capital Costs for Water Heating Electrification Per Suite

Various Domestic Water Heating Systems Per Suite	Low	Average	High
CO_2 DHW Air Source Heat Pump	$2,200	$2,500	$4,800
DHW Air Source Heat Pump – R410A	/	$3,200	/
Benchmark Cost: 2022 RDH Existing Home Archetype and ERM Costing Research Report (SANCO2 Waterdrop Array)[6]		*$7,000*	
Benchmark Cost: Fall 2022, CO_2 DHW Air Source Heat Pump System Wholesale Costs (Capacity of one system to provide hot water for 10 people, multiple suites)		*$3,300*	

5.5 CAPITAL COSTS AND BENCHMARKS: VENTILATION

Costing data for 11 hybrid heat pump make up air projects identified an average cost of $1,900 per unit. No data was available for heat or energy recovery ventilators.

Table 5: Capital Costs for Ventilation Electrification Per Suite

Ventilation: Various System Types Per Suite	Low	Average	High
Heat Pump Make Up Air (hybrid gas auxiliary heating)	/	$1,900	/
*Benchmark Cost: Ventilation, Heat Pump Make Up Air: 2022 RDH Existing Home Archetype and ERM Costing Research Report***Error! Bookmark not defined.**	*$800*	/	*$1,100*
Benchmark Cost: Ventilation, In-Suite ERV's and downsize Make Up Air, 2022 RDH Existing Home Archetype and ERM Costing Research Report.[7]	*$4,800*	/	*$10,700*

[6] The 2022 RDH "Existing Home Archetype and ERM costing Research Report" assessed a cost of $7,000 per suite for DHW systems, which may include part of the electrical upgrade cost. The RDH report based the cost on the recently available pre-plumbed SANCO2 Waterdrop array of Sanden CO_2 heat pump modules. While a pre-plumbed array is expected to reduce field labour and engineering errors with these systems, previous systems were installed with lower cost. Reasons for differences in costs could include differences in how electrical upgrade were included in total cost, the time frame systems were installed (given increases in costs in more recent years) and how many suites each heat pump provided hot water for (which can reduce per suite costs). The use of generic storage tanks was also reported as a way of significantly reducing project costs by interviewees.

[7] For ventilation, the 2022 RDH Existing Home Archetype and ERM Costing Research Report estimated $4,800 per suite for "through wall Energy Recovery Ventilators (ERV's)" (most likely alternating flow units such as Lunos). The $10,700 per suite figure is for "central ERV", but no details are included.

5.6 CAPITAL COSTS AND BENCHMARKS: ELECTRICAL UPGRADES

The capital costs for electrical upgrades for MURB electrification can be highly variable. The range of costs for three completed projects ranges from $812 to $6,200 per suite.

Table 6: Capital Costs for Electrical Upgrades

Electrical Upgrades	Per Suite Cost	Main Service	Total
75 Unit Building Electrical Upgrade (main service only)	$3,706	$278,000	$278,000
31 Unit Townhome Electrical Upgrade (in-suite and main service upgrade)	$6,200 (x 31 units)	$139,000	$331,000
32 Unit Building Electrical Upgrade (main service only)	$812 (x 32 units)	$26,000	$26,000
Benchmark Cost: 255 Unit Electrical Upgrade – Electrical Engineer estimate for 2022 FRESCo design	*$4,000-$4,500 (x 255 units)*		*$1,0200,00- $1,147,500*
Benchmark Cost: Average cost of electrical upgrades in single family residential homes undertaking fuel switching[8]		*$5,500*	*$5,500*

5.7 CAPITAL COSTS SUMMARY OF COMPLETED FUEL SWITCH RETROFITS

The data in tables 7 and 8 is extracted from the BC data sets for completed retrofit, and new construction projects respectively. The "BENCHMARK" tables presented previously compared different types of data and from different sources. Tables 7 and 8 only include actual completed projects and only fuel switching.

Table 7 highlights capital metrics for different retrofit types per suite, per area and per lifetime tonne of GHG. The limited number of completed retrofits of each type is shown. The metrics are:

- **Capital/ ltGHG:** Total capital spent on the measure per lifetime GHG savings expected. If there is no base case (e.g., if the existing boiler is brand-new and would otherwise be replaced), this represents the full cost of GHG reduction. If the boiler *is* going to be replaced, normally the incremental ltGHG metric would be used instead because it does include an estimated cost of boiler replacement.
- **$Capital/Suite**: Average capital cost per suite.
- **$Capital/ft²**: Average capital cost per square foot.
- **$Incr/ltGHG**: Incremental cost per lifetime GHG savings. Incremental cost is the difference between a theoretical "base case" (e.g., a new gas boiler) and the proposed case (heat pump). The "base case" costs reported in the databases for this project came from various consultants and their assumptions are not available, thus some caution should be used when applying these results.

[8] Chris Higgins, City of Vancouver. Average cost for 18 months ending 2022-10-04 for installations that received a rebate, including central ducted and mini and multi split heat pumps.

Lifetime GHG savings (ltGHG) are the estimated GHG savings over the estimated lifetime of the new equipment compared to the base case,

Table 7: Capital Cost Summary – Completed Fuel Switch Retrofits

Completed Fuel Switch Retrofits		Projects Completed	$Capital /ltGHG	$Capital/ Suite	$Capital/ ft2 (Retrofit Measures)	$incr/ ltGHG	Notes
Ventilation	MUA HP	11	$224	$1.9k	$2.4	-	High risk of poor GHG savings persistance with NG backup
SH	Central A2W	2	$753	$13k	$12	-	One is radiant slab
SH	VRF (Variable Refrigerant Flow)	1	$317	$12k	$13	-	-
SH	Minisplit	3	$1,684	$16k	$38	-	-
SH	AIO (All-In-One)	1	$1,581	$11k	$33	$110	-
DHW	A2W R410a	2	$1,052	$12k	$21	$382	Requires backup
DHW	CO2	3	$293	$2.5k	$3.6	$272	-
DHW	Cooling Heat Recovery Through W2W HP	1	$82	$1.2k	$0.6	$82	Not widespread applicabilty

The information in Table 7 highlights:

- Only a limited number of fuel switch retrofits have been completed, therefore there is a limited number of each type available with costing data. The number of projects with costing data available per technology ranges from 1 project to 11 projects.
- Ventilation: The only costing information available for ventilation is for hybrid heat pump/gas make up air units (MUA HP). Costing data was available from 11 projects with an average cost of $1,900 per suite. Interviews with owners identified that due to installation, or operational, issues there may be high risk of poor GHG savings persistence due to over reliance on gas system auxiliary heating.
- Space heating (SH): Costing was available from 7 retrofit projects for 4 types of space heating electrification options, including: central air to water heat pump (Central A2W), variable refrigerant flow heat pump (VRF), mini-split heat pump (mini-split), and all-in-one heat pump (AIO). Each of these space heating technologies has specific technical considerations outlined in the technology fact sheets. While some options are less expensive per suite and per square foot (Central A2W and VRF), Central A2W systems may not be applicable for most MURBs in BC and VRF systems utilize a large amount of refrigerant. AIO systems show promise for cost-effective per suite installation, but additional costs may be incurred for heating multiple zones of apartments. The average costs for

mini-splits ($16,000/per suite) are higher than the average costs seen for installation of mini-splits in other sectors (new construction, installation in electric buildings and installation in single family homes). More investigation is needed to determine how costs for MURB electrification with mini-splits can be reduced.

- Domestic hot water (DHW): Costing was available for 6 domestic hot water projects and three technologies including: air to water heat pump with R410A refrigerant (A2W R410A), CO_2 heat pump hot water (CO_2), and cooling heat recovery through water-to-water heat pump (Cooling Heat Recovery Through W2W HP). The most promising technology, based on cost-effectiveness, replicability and low global warming potential refrigerant is the CO_2 system.

Table 8: Capital Cost Summary – Completed New Construction with Mechanical Equipment

SH	Central Vent (MUA)	DHW	Central HRV	In-Suite HRV?	$Capital /ltGHG	$Capital/ Suite	$Capital/ ft2 (Retrofit Measures)	$Incr/ ltGHG	Site Code
In-Suite Heat pumps					**$263**	**$6.8k**	**$7**	**$134**	
Mini-Split	HPMUA With Resistance Backup	Electric Resistance	Y	Y	$114	$9.8k	$4	$72	31
AIO	-	Distributed Resistance Tanks	Y	Y	$388	$6.0k	$11	$243	42
PTHP	-	-	N	-	$287	$4.6k	$6	$87	35
VRF					**$543**	**$12.7k**	**$14**	**$274**	
VRF	Resistance MUA	-	-	-	$596	$10.9k	$6	$519	29
VRF	-	-	Y	Y	$505	$12.5k	$18	$120	37
VRF	-	A2W	-	Y	$529	$14.6k	$17	$182	38
Misc					**$372**	**$3.1k**	**$6**	**$179**	
Central A2W to radiant floors	-	Central ASHP + In-Suite Resistance Tanks	Y	-	$223	$1.8k	$7	$112	33
Gas Boiler Central Loop to In-Suite W2A HP	-	Gas to W2W HP	Y	Y	$609	$4.2k	$9	$85	30
-	-	Sewage Heat Recovery	-	-	$400	$4.6k	$4	$340	41
-	-	Sewage Heat Recovery	-	-	$257	$1.9k	$4	$181	32

Data in Table 8 is taken from the New Construction projects from the CleanBC incentive data. The projects are listed on different lines to illustrate they vary and include different components. Despite these differences, they are grouped into categories by main end use (In-suite heat pumps and VRF), and highlighted rows show average values within each category. Even though the categories include other components space heating is anticipated to be the largest component of cost.

Costs for the incremental lifetime tonne of GHG is relative to various assumed base cases such as condensing boilers or electric baseboards.

The information in Table 8 highlights:

- Capital per suite for VRF systems ($12.7k) is almost double that of In-Suite heat pumps ($6.8k). Incremental cost per lifetime tonne of GHG of VRF ($274) is also almost double that of In-suite heat pumps ($134).

- For VRF, new construction (Table 8) costs per suite are very close to retrofit (Table 7).
- For In-suite heat pumps, new construction (Table 8) costs per suite are significantly lower ($6.8k) compared to retrofit (Table 7), where mini-splits averaged $16k, and the All-in-one was $11k.

5.8 EXAMPLES OF FULL SUITE ELECTRIFICATION

Three buildings, with costing data available, have been identified as having undertaken what can be classified as full, or near full, building electrification of space heating, water heating and ventilation. The average costs per suite for three projects was approximately $18,900.

Clinton (14 Suites): $19,000/suite

- Building type: Low-Rise MURB
- Space heating: Mini-split air source heat pump, no auxiliary heating
- Domestic Hot water: Electric resistance
- Ventilation: No Change (windows and bathroom fans)

Vancouver (29 Suites): $21,500/suite

- Building type: Low-Rise MURB
- Space heating: Central air source heat pump for radiant floor system, without gas auxiliary
- Domestic Hot water: Supplied by the same central ASHP
- Ventilation: Heat Pump make up air, with gas auxiliary heating for peak

Surrey (31 Suites): $16,200/suite

- Building type: Townhouse
- Space heating: Central ducted air source heat pump (was gas furnace)
- Domestic Hot Water: Tank style air source heat pump hot water (was gas fired tank type)
- Ventilation: No Change (windows and bathroom fans)

While these three buildings do not necessarily provide representative average costing for MURB electrification projects, they are informative as examples that highlight:

- Full (or near full) building electrification can be achieved at costs averaging under $20,000 per suite.
- These costs have been achieved before MURB electrification has been occurring at scale and there may be opportunities for cost reductions. For example, different combinations of electrification technologies may allow for lower costs per suite (e.g., incorporating CO_2 domestic hot water air source heat pumps).
- The Clinton example demonstrates that heat pumps can function sufficiently to provide heating in cold climates without auxiliary heating.

Electrification: A Cautionary Tale and Lessons Learned

Toronto Atmospheric Fund (TAF) Case Study 2022: Lessons from a VRF Heat Pump Retrofit City Housing Hamilton
A 2022 case study showcased a Variable Refrigerant Flow (VRF) heat pump retrofit in an electric baseboard apartment building. It highlighted the significant risk of oversizing systems and the importance of good mechanical design; analysis showed ***higher consumption after the retrofit than before.***   A 6-Ton Heat Recovery VRF Unit was installed to service just 3 suites. One suite was a 1-bedroom 595ft^2, which received two indoor 10.5MBH[9] heads. The other two were two-bedroom 666ft^2 suites and received a 10.5 and two 8.5MBH heads. The outdoor unit is rated for 81MBH nominal heating with a minimum temp of -25C. The total cost per suite was $18,916, included $2,000 for instrumentation.   Key Lessons: • The VRF system was sized to match the capacity of the original electric baseboards. This is poor practice; electric baseboards are often oversized by a factor of 2 to 4 times due to their low cost.   • Oversizing caused the heat pump to short cycle, drastically reducing performance.   • Post-installation analysis found consumption was significantly higher compared to the pre-retrofit electric baseboards.   • A much smaller, and possibly lower cost, VRF system would have met the heating and cooling demand for the three suites or the existing VRF system could have been used for a higher number of suites. In short, an appropriate mechanical design could have reduced the cost and improved the functionality of the system.   • Indoor heads are typically 9MBH minimum, with a limited number of 6MBH available. Bedroom loads are often much lower, sometimes the range of 2 to 4MBH. Smaller capacity heat pump products may be available in the future which will improve the ability for industry to right-size systems for apartments and bedrooms.

5.9 FACTORS INFLUENCING MURB ELECTRIFICATION CAPITAL COSTS

To more fully understand the capital cost range of MURB electrification it is useful to outline some of the technical and other considerations that may impact the installed cost and ongoing operational costs:

Factors Influencing Lower Costs

- **Choice of Electrification Technology:** Newer technologies and innovations offer the potential to lower electrification costs. For example, CO_2 domestic hot water heat pumps, a relatively new technology in BC, have demonstrated proof in actual installations of being a least cost domestic hot water retrofit option for some MURB electrification applications.

[9] MBH = A 1000 British Thermal Units (BTU) per hour.   It is a measure of the size of a heat pump system in the traditional Imperial System of measurements.

- **Load Management and Load Reduction:** Untapped opportunities exist to minimize electrical upgrades costs by:
  - Load sharing between appliances, for example limiting the dryer and cooking range from operating at the same time. Not many products are readily available in BC for MURB applications, but it is a growing industry as well as some products for detached homes could potentially be used in MURBs.
  - At time of replacement of appliances, purchase smaller, more efficient appliances that use less energy such as electric cooking (e.g., induction) and laundry appliances (e.g., heat pump clothes dryers).
- **Design Strategies to Reduce Impact of Rates and Peak Electrical Demand Charges:** Best practices for MURB electrification (to be created) should highlight the importance of mechanical design strategies to reduce the financial impact of rates and peak electrical demand charges. Industry awareness of pending changes to rates will allow for future proofing the affordability of MURB electrification retrofits.
- **Business Model – Bulk Purchase and Installations:** Companies specializing in installing heat pumps in multi-unit residential buildings have demonstrated they can reduce capital and installations costs by handling the import of heat pump units directly from the manufacturer and pricing for bulk installations. For example, the HW Flesher Coop case study highlights an average cost of $4,200 per suite for the installation of mini-split air source heat pumps for a 100 unit, previously electric baseboard heated, building complex installation in 2021.[10]
- **Business Model – General Heat Pump Contactor:** One of the most active contractors in the Ontario market converting electric baseboard MURBs to heat pumps prefers to rely primarily on lower cost trades and labour for much of the work, since refrigeration technicians are only required to make the final connections. This type of business model, in particular for All-in-One and windowsill type heat pump systems, which are simpler to install, offers potential to significantly reduce installation costs for MURB electrification retrofits.
- **Alternative Ducting Solutions:** When new ducting is required in suites (ducted All-in-One or ducted mini-split heat pump systems) there can be significant additional cost associated with the ducting and constructing drywall bulkheads to conceal it. Exposed ducting has become common, accepted, and even preferred in many commercial applications and residential loft style apartments and may represent an opportunity to significantly reduce costs for ducted heat pump applications in MURB suites.
- **Gas Auxiliary Heating:** Two projects avoided the cost of an electrical upgrade by limiting the size of the heat pumps. They used gas auxiliary heating for the remainder of the load. Although this avoided this major cost, there were many problems with the complex control systems starting up. Many others (particularly make up air units) used gas auxiliary heating to reduce the heat pump

[10] "H.W. Flesher Housing Co-op Case Study – 3545 East 43rd Ave, Vancouver." https://bringithome4climate.ca/wp-content/uploads/2022/03/HWFlesher_HeatPump_CaseStudy-FINAL.pdf

capacity required, therefore reducing cost of heat pump equipment and/or structural roof upgrades.

Factors Influencing Higher Costs

Cost Escalation: A variety of factors have contributed to cost escalation in all sectors related to construction and renovation, including impacting the cost of energy retrofits generally and building electrification. Factors influencing the cost escalation include:

- **COVID Pandemic:** The pandemic "has had major global and local impacts including supply chain issues, material shortages, and labour shortages, which led to increases in both material costs and labour."[11]
- **Rising Interest Rates:** Has made it more expensive for contactors to borrow funds for purchasing equipment.
- **Inflation:** Inflation is a general increase in price and the fall of the purchasing value of money. The cost of the materials that create all electrification retrofit system components has gone up in price, and all the associated costs of transporting and manufacturing a product.
- **High Demand:** A rising demand for heat pump has resulted in more consumer demand than supply of contractors to install heat pumps. It is a fundamental economic principle, that when there is higher demand for a product, prices typically increase. When consumers are competing to secure a contractor there is less need for contractors to provide their most competitive pricing and this results in increased prices. Factors impacting high demand include:
  - 2021 heat dome and consumer demand for equipment that can provide heating and cooling.
  - Availability of high value rebates for heat pumps, and high demand for contractor services, may be contributing to higher quoted costs.
  - Increased program marketing and consumer awareness about heat pumps and available rebates.
  - General consumer awareness about the benefits of heat pumps and electrification.
- **Supply of Skilled Labour:** With high demand for heat pump installations, and low supply of skilled labour to install heat pumps it has become more expensive for contractors to hire, train, and keep employees. These challenges impact the companies that manufacture, supply and transport heat pump products. Industry has highlighted that increased labour costs trickles down to higher costs for heat pump systems.
- **Electrical Upgrade Costs & Complexities:** Since electrification aims to switch building systems from fossil fuels to electricity, any electrification retrofit will consume more electricity that the system that it is replacing. For most electrification retrofits, the new electrical equipment requires

[11] Pablo, Carlito, "Metro Vancouver report says rising construction costs "impacting new affordable rental housing"." The Georgia Straight, May 25, 2022, https://www.straight.com/news/metro-vancouver-report-says-rising-construction-costs-impacting-new-affordable-rental-housing#:~:text=While%20costs%20in%20B.C.%20have,constructed%20homes%20for%20private%20ownership

higher electrical capacity than what the existing electrical infrastructure was designed to provide meaning that electrical upgrades, to different extents, will be required. Any electrical upgrades will increase the cost of a MURB electrification retrofit.

5.10 ELECTRICITY RATE STRUCTURE IMPACT ON OPERATIONAL COSTS

The long-term operational costs of mechanical equipment is an important consideration.

High electric utility operational costs can discourage electrification. Some owners interviewed indicated that post fuel-switch, buildings moved onto a rate that now included demand charges *(see **Meters** bullet below)* resulting in effective 'doubling' of electrical cost per kWh.[12] The potential for high demand charges may push decision makers to avoid complete electrification and retain gas for peak power.

Influencing factors include:

- **Meters** - whether the heat pump is on a suite or a central meter:
    - Central heat pumps on common meters would typically go from a residential or Small General Service Rate (SGS) (which do not charge for kW demand) to Medium or Large General Service Rates which incur demand charges.
    - In-suite heat pumps on suite meters stay on residential rates.
- **Facility type, enclosure efficiency** (pre-electrification baseload):
    - A newer, more efficient building with a large baseload (e.g., care homes with central kitchens, laundries & amenities), may see a much smaller percentage increase in demand, and therefor lower demand charge increases, than older MURBs with lower baseloads.
- **Building size**:
    - A small and efficient building may stay on SGS and avoid demand service charges.
- **Co-incident efficiency improvements:**
    - Electrification often is accompanied by other major capital upgrades such as windows and cladding/ insulation upgrades, HRV and LED lighting which will reduce the demand and consumption.
- **Auxiliary fuel type**:
    - Buildings with electric resistance auxiliary heating are at high risk for high demand charges.
    - Buildings with gas auxiliary heating have lower risk of high demand charges on electricity bills.
- **Auxiliary controls**:

[12] Tony Ogbonna, BC Housing, Input during consultation, October 2022.

- Controls are easily set (intentionally or unintentionally) to use full auxiliary heating. With gas auxiliary heating this will eliminate expected GHG savings. With electric auxiliary heating this may result in more than double expected costs.

- **Mechanical design**:
    - The type of system proposed, and the design of the system can impact demand charges. For example, the design of domestic hot water systems with larger storage tank capacity can minimize peak demand charges when high hot water consumption in the building matches peak demand periods.

Table 9 shows a summary of different electricity rates in BC. The following rates, shown in the table, may discourage electrification:

- **Step 2 residential rates:** While most apartments use less electricity to put them into Step 2, there is potential that some high heat load apartments could be pushed into Step 2 rates by fuel switching. Originally designed to encourage electricity conservation by charging higher rates (10-48% higher) for consumption past a set kWh consumption threshold, Step 2 rates may now discourage electrification as fuel-switching from gas to a heat pump may result in Step 2 charges being applied for some residential rate payers using heat pumps. Conversely, not fuel switching, and continuing to heat with gas, may allow a homeowner to avoid paying Step 2 rates.

- **Demand charges:** Once common meters surpass a maximum kW demand (35-40 kW) they will be moved to a BC Hydro Medium General rate or a FortisBC Large Commercial rate where demand charges will begin to be charged. This discourages electrification as fuel-switching can potentially push a building to start paying for demand charger or start paying higher demand charges (if switched from BC Hydro Medium General to Large General service rate).

Table 9: Summary of Electricity Rates – BC Hydro and FortisBC Electric (SST)

	BC Hydro				FortisBC Electric SST		
Rate:	**Residential Conservation**	**SGS (Small General Service)**	**MGS (Medium General Service)**	**LGS (Large General Service)**	**Residential**	**Small Commercial**	**Large Commercial**
Max Demand	-	35 kW	150 kW	-	-	40 kW	-
Max Consumption	-	-	550,000 kWh	-	-	-	-
Step 1 ($/kWh)	$0.0950	$0.1253	$0.0968	$0.0606	$0.1237	$0.1091	$0.0753
Step 2 ($/kWh)	$0.1408	-	-	-	$0.1371	-	-
Step 1 Threshold	<1,350 kWh	-	-	-	<1,600 kWh	-	-
Demand Charge ($/kW)	-	-	$5.41	$12.34	-	-	$12.39

Changes to rate structures are being considered that may help to encourage (or least not discourage) electrification. Complementary programs and rebates introduced to support reducing energy consumption in buildings can also be used to reduce the impacts of rates on operational costs.

Technical Design Considerations to Minimize Utility Costs

Although very little post occupancy measurement & verification was available for this report, input from interviewees and observations by the FRESCo team identified that professionals involved in the mechanical design of MURB electrification were not always considering the impact of electrical demand and rates into their designs. Five examples are provided:

- **Example Demand Increase Due to Design:** A building representative interviewed for the project, identified that the utility operational costs for a building almost doubled due to high demand charges after a water heating system electrification retrofit. Examination of the bills however, revealed that this was likely due to a poor mechanical design for the water heater which could turn on briefly and demand approximately 40kW, when 3kW would suffice. This issue could be rectified by a small change in design that would include sizing by actual average existing hot water usage. A sufficiently large storage tank can use a low power element sized to handle the average power required plus a modest extra amount for the highest peak use found.
- **Average Domestic Hot Water (DHW) Production:** Peak DHW use occurs during morning showers, and evening dishwashing (with peak strength heavily dependent on demographics). But the heating device does not need to follow this demand curve. Mechanical engineers and contractors who are aware of this can ensure the hot water storage is sufficiently sized so that peak power demand can be minimized. In buildings where the domestic hot water is not on the same demand meter as the space heating (for example if space heating is on suite meters), or in buildings with minimal heating, can also bring the cost of electricity on a demand rate down below a typical residential rate. Billing analysis cannot reveal peak profile. Data logging the domestic hot water use for a week can reveal the profile, and dedicated loggers are inexpensive. Most MURBs do not have DDC systems, and the few which do seldom monitor DHW.
- **Space Heat vs DHW Peak Shifting:** Space heating demand typically peaks just before dawn, and air conditioning in late afternoon. To reduce demand charges, domestic hot water production can be shifted to avoid these times. This requires mechanical engineers to design for larger storage tank volume, a higher capacity heat pump and appropriate controls, which increases capital costs but will allow for reduced long term operational costs. This concept is currently being heavily promoted in the US for detached homes and should be incorporated into MURB electrification best practices in BC, and Canada.
- **ASHRAE/ASPE "Recovery Rate" Sizing Methodology** for domestic hot water gas heaters does not take rates and peak power into account. As a result, domestic hot water heat pumps sized by engineers and contractors without heat pump training are often dramatically oversized, resulting in increased capital costs by a factor of two to four, consumption costs on the order of double, and potentially reduced equipment lifespan.
- **Electrical Backup/Auxiliary Heating Over-Consumption Risk:** MURBs electrification retrofits that retain electric resistance for heating (space, water, ventilation) have the potential to over rely on the electric resistance. This can be caused by a variety of factors including occupant use patterns, system design flaws or installation errors. Two examples are provided:
    - An All-in-One in-suite installation in a Toronto MURB included only one heat pump per suite, with all electric baseboards retained in the suites. A building representative interviewed reported that average savings was only 8% indicating, that the occupants were still relying on the baseboards, rather than the heat pump as the primary heating system and/or the occupants were heavily using the air conditioning.

- A central DHW heat pump with electric resistance auxiliary heat was found to be running fully on electric resistance since an electrical breaker installation error was disabling the heat pump. The error was caught before the project sign off, highlighting the importance of system commissioning. If this happened in regular operation, it could take a while for the building operator to notice the increase in operating costs and realize the electrical breaker issue was the cause.

These examples illustrate the need to educate mechanical engineers on best practices for mechanical design for building electrification.

6: Technical Considerations of Building Electrification Retrofits

There are many technical considerations for each technology for building electrification retrofits. For stakeholders to be able to identify the most appropriate electrification technology for any given building it is important to have summarized information on each technology to determine the:

- Appropriateness of the technology for the building type and type of system it is replacing
- Cost effectiveness of the technology (product and installation) compared to other options
- Benefits of the technology compared to other options

To enhance stakeholder understanding of the specific technical considerations for key electrification technologies FRESCo has created a series of summary MURB Electrification Technologies Fact Sheets for the following technologies:

- **Space Heating:** All-in-One (AIO) Air Source Heat Pumps, Ducted All-in-One Heat Pumps, Ductless Mini-Split Air Source Heat Pumps, Window Mounted Heat Pumps, Central Hydronic Systems, and Variable Refrigerant Flow (VRF) Heat Pumps.
- **Water Heating:** Modular CO_2 Air Source Heat Pump Water Heater, Large Central Air Source Domestic Hot Water Heat Pumps, and Integrated Air Source Heat Pump and Water Tank.
- **Ventilation:** Central Make Up Air (MUA) and Heat Recovery Ventilation (HRV).
- **Hybrid Systems:** Hybrid Heat Pump Systems (for all applications).

Each technology fact sheet will include:

a) **System Description:** Summary description of technology.
b) **Application:** Types of buildings the technology is ideally suited for and key installation considerations.
c) **System Benefits:** Summary of general and specific benefits of the technology
d) **Retrofit Technical Considerations:** Identification of specific product features and installation considerations that should be considered prior to selection for a MURB electrification retrofit.
e) **Availability in BC:** Overview of accessibility of product and access to qualified contractors in BC.
f) **Cost Range Per Suite:** Summary from available data.

MURB ELECTRIFICATION TECHNOLOGY FACT SHEETS

Space Heating and Cooling Systems

All-in-One Air Source Heat Pump

Ducted All-in-One Heat Pump

Ductless Mini-Split Air Source Heat Pump

Window Mounted Heat Pump

Central Hydronic Systems

Variable Refrigerant Flow (VRF)

Space Heating and Cooling:
All-in-One Air Source Heat Pump

Photo Source: Norm's Plumbing and Heating

Description: All-in-One (AIO) systems are high efficiency air-source heat pumps in a single-package design with no outdoor unit. The indoor unit is mounted on an interior wall and sealed to two small vents that pass through penetrations in an exterior wall. Each indoor unit directly distributes heat into the room/zone where it is placed.

Note: This product type is sometimes categorized as a "PTHP" (Packaged Terminal Heat Pump), a term more typically used for a very different product class; noisy and low performance older designs mounted in a very large rectangular hole through the enclosure.

Application: Can meet the heating and cooling needs of an office, hotel room, apartment, or small dwelling. Ideal for smaller sized open space areas. Multiple systems can be installed for full suite or home heating and cooling.

System Benefits:

- **No Outdoor Unit:** With no outdoor unit, AIO systems provide flexibility for installations in a variety of different types of buildings.
- **Simple Installation:** Simple to install (for most applications). However, consideration must be given to proper placement, effectively sealing wall penetrations and dealing with condensation.
- **Low Risk of Refrigerant Leakage:** AIO systems have a sealed refrigerant system which means the installers do not need to make connections in refrigerant lines or vacuum or pressure test the lines after installation. With small amounts of refrigerant contained in a sealed system there is very low chance of refrigerant leakage.
- **Aesthetics and Choice of Models:** AIO systems have a compact design and footprint and use little interior space. Depending on the building and the preferences of the consumer there are various models available, wall mounted vertical, wall mounted horizontal, or ceiling suspended. Some models can be painted to match décor of room.
- **Cold Climate Models Available:** Models are available for temperatures down to -15C, with built in auxiliary resistance heating for colder temperatures. Auxiliary heat is controlled by the heat pump's built-in controls.
- **Multiple Functions:** AIO system models are in development with integrated Energy Recovery Ventilator (ERV), MERV 13 filters and bathroom exhaust. The multiple functions of the systems reduce mechanical systems needed, may reduce product and installation costs by replacing multiple products with one system and reduce penetrations in the building envelope.

Technical Considerations:

- **Envelope Penetrations:**
  - Requires two 8" holes to be drilled/cored through the exterior wall.
  - Depending on the building construction wall penetrations can be more complicated and/or may not be recommended.

    - If the suite is not ground orientated or if there are no balconies or walkways below the enclosure penetration, the installers need to utilize a means to access the exterior to drill or catch falling debris and for installation of exterior vent cap.
    - The installers need to mitigate the risk of asbestos in the drywall or building envelope.
    - Requires effective sealing to eliminate risk of air leakage and water ingress through envelope penetration.
- **Indoor Unit Placement:**
    - Indoor unit must be mounted in a location with space on an interior wall. Indoor unit should also be placed in a location that will allow the system to distribute heat through the room/zone and where air flow will not be blocked by furniture. Depending on the layout of the suite and the window to wall ratio there may be limited wall space to install the indoor unit.
    - Multiple systems may be needed to heat multiple rooms/zones in a suite.
- **Condensate Drainage:**
    - AIO systems produce water in both cooling and heating modes that must be appropriately drained. The end point of the drainage must be properly located so that released water does not freeze on walkways creating a slipping hazard. Options for water drainage include: a) drained outdoors onto the balcony or into drainage stacks; b) drained into bathroom or kitchen plumbing drains; c) drained into an electrically heated condensate pan designed to evaporate the moisture. Condensate pans are the less preferred option as there is additional cost, additional electrical load and it needs to be placed in a suitable location. Some models can evaporate the summer condensate on the outdoor coil and blow it outside. A lower consumption piezo-electric option for winter condensate was available briefly but at the time of this writing is being redesigned and is not available. Several installs in BC reported satisfactory results simply by allowing evaporation on the balcony surface under pavers.
- **Efficiency:** AIO systems have lower efficiency than mini-split heat pump systems. For example, the efficiency of a mini-split system (COP -15 °C at maximum capacity) is in the range of 1.8 to 3.7 for a ducted all-in-one system it is 1.6. Additionally, the longer ducting runs and more curves in the ducting will impact the operational efficiency of the system.
- **Sound:** AIO indoor units are louder than mini-split indoor heads because the indoor unit functions like the indoor and outdoor unit of a mini-split heat pump system. The noise range of the all-in-one indoor units ranges between 27 to 43 decibels (dB) and with a mini-split heat pump the noise range is between 18 to 30 dB.
- **Electrical Installed Capacity:** Units are available which can fit on one 15A 120V breaker, and higher-powered ones which can use 208V. Even at lower power levels however, multiple units in bedrooms and living rooms can require an electrical service upgrade to the suite service and panel.
- **Maintenance and Reliability:** All-in-one heat pumps are known to be reliable. Like all heat pump systems annual maintenance is recommended.

Availability and Use in BC (2022):

- In 2022, only two brands of AIO heat pumps are available in BC, Innova and Maestro, both made in Italy.
- AIO systems have been manufactured for approximately 12 years and available in the BC market for 5 years.
- Used in 10+ new construction projects in BC for social housing, private rentals and most commonly as air conditioning for condos.
- Only one known example of a whole building retrofit utilizing AIO system in BC.
- More products in this niche are anticipated in the future.

Average Cost Range Per Suite: $6,000 to $11,000.

Space Heating and Cooling: Ducted All-in-One Heat Pump

Description: Ducted All-in-One (Ducted AOI) systems are high efficiency air-source heat pumps with no outdoor unit and attached to an interior ducting system to distribute heat through multiple diffusers in multiple rooms. The indoor unit is attached to two external vents and is typically ceiling mounted.

Application: Can meet the heating and cooling needs of multiple rooms or zones within an office, hotel room, or apartment. This technology is best suited for retrofit applications where there is sufficient ceiling high for framed-in ducting or where exposed ducting is aesthetically acceptable (i.e., loft apartments).

Photo source: EPHOCA Website

System Benefits:

- **No Outdoor Unit:** With no outdoor unit, AIO systems provide flexibility for installations in a variety of different types of buildings.
- **Ducted Full Suite Solution:** Capability to connect to ducting allows for one AIO unit to heat multiple rooms or zones within a MURB apartment.
- **Low Risk of Refrigerant Leakage:** AIO systems have a sealed refrigerant system which means the installers do not need to make connections in refrigerant lines or vacuum or pressure test the lines after installation. With small amounts of refrigerant contained in a sealed system there is very low chance of refrigerant leakage.
- **Cold Climate Models Available:** Down to -15C and models available with built in auxiliary resistance heating. Auxiliary heat is controlled by the heat pump's built-in controls.
- **Multiple Functions:** AIO system models in development with integrated Energy Recovery Ventilator (ERV), MERV 13 filters and bathroom exhaust. The multiple functions of the systems reduce mechanical systems needed, may reduce product and installation costs by replacing multiple products with one system and reduce penetrations in the building envelope.

Technical Considerations:

- **Envelope Penetrations:**
  - Requires two 8" holes to be drilled/cored through the exterior wall.
  - Depending on the building construction wall penetrations can be more complicated and/or may not be recommended.
  - If the suite is not ground orientated or if there are no balconies or walkways below the enclosure penetration, the installers need to utilize a means to access the exterior to drill or catch falling debris and for installation of exterior cap.
  - The installers need to mitigate the risk of asbestos in the drywall or building envelope.
  - Requires effective sealing to eliminate risk of air leakage and water ingress through envelope penetration.
- **Indoor Unit Placement:**

- Indoor unit to be mounted near an exterior wall in the ceiling. Depending on the layout of the suite and the window-to-wall ratio there may be limited wall space to install the indoor unit. The unit is roughly 40" wide by 40" long and 11" deep.

- **Requirement for Concealing Ducting or Alternative:**
    - Consideration must be made for how and where the AIO ducting will be run. Depending on ceiling height and the layout of the suite some buildings may be more suited to this type of system than others.
    - Traditionally ducting within suites has been concealed in ceilings or bulkheads. The task of constructing a bulkhead can be variable and would require a contactor with skills in sheet metal, carpentry, drywall, painting, and potentially asbestos remediation. Constructing bulkheads to cover AIO system ducting in a MURB electrification retrofit in BC was estimated by one source to cost up to $30k per suite, more than double the cost of the heat pump itself.
    - To reduce system costs, some stakeholders in BC are exploring options for system designs where ducted AIO systems would use exposed ducting. The ducting could be painted to match the ceiling or walls or a different colour to make it stand out like an architectural feature. Exposed ducting has become common, and preferred, in many commercial applications and residential loft style apartments and may represent an opportunity to significantly reduce costs for ducted heat pump applications in MURB suites.
- **Condensate Drainage:** AIO systems produce water in both cooling and heating modes that must be appropriately drained. Since these units are often proposed to be in bathroom drop ceilings, connecting into the bathroom drain stacks would likely be the most convenient method, otherwise the drain would need to be routed or pumped to the nearest indoor or outdoor drain.
- **Efficiency:** AIO systems have lower efficiency than mini-split heat pump systems. For example, the efficiency of a mini-split system (COP -15 °C at maximum capacity) is in the range of 1.8 to 3.7 for a ducted all-in-one system it is 1.6. Additionally, the longer ducting runs and more curves in the ducting will impact the operational efficiency of the system.
- **Sound:** AIO indoor units are louder than mini-split indoor heads because the indoor unit functions like the indoor and outdoor unit of a mini-split heat pump system. The noise range of the all-in-one indoor units ranges between 27 to 43 decibels (dB) and with a mini-split heat pump the noise range is between 18 to 30 dB.
- **Electrical Installed Capacity:** Each ducted unit requires 208-240V, 15-20 amps. Each ducted unit requires its own dedicated connection.
- **Service:** These systems are installed in areas of suites which sometimes are difficult to access. Particularly large ceiling mounted models which are typically installed in bathroom drop ceilings, requiring access though a drywall hatch, and working with hands over one's head

Application in BC (2022):

- There is strong and growing interest in ducted AIO systems in BC, which will hopefully attract more products from Europe and elsewhere.
- Only 2 brands are currently available in BC:
    - Minotair brand is quite boxy in form, less suitable for apartments and more suitable for applications with drop ceilings with sufficient space for larger mechanical systems.
    - Innova HRAi brand is aimed at apartments and slim models which can fit in a 1-foot ceiling drop or vertically against a wall. This brand has only been manufactured for 4 years, with no known installations in BC, although it has been specified for at least one BC Housing installation.

- Several models are available which incorporate a heat recovery ventilation system, with no additional work or penetrations.

Average Cost Range Per Suite: Research for this report identified costs of $11,000 per suite for retrofit applications and $6,000 per suite for new construction. However with limited data available no average or representative costing is available.

Space Heating and Cooling:
Ductless Mini-Split Air Source Heat Pump

Photo Source: Daikin Comfort

Photo Source: FRESCo

Description: A mini-split air source heat pump system (mini-split) has an outdoor heat pump unit and one or more indoor units (indoor head) that are connected by refrigerant lines. Each indoor mini-split unit has its own fan and evaporator coil and will independently service a single room or zone. Both ductless and ducted versions of multi-zone or multi-split systems are available to provide conditioned air to multiple rooms/zones by providing an indoor unit in each zone. Some systems will allow up to eight rooms/zones to be heated by one outdoor unit, but typically only two to four indoor units are installed on each outdoor unit split system.

Application: Mini-split systems are very versatile and can be installed in a wide variety of MURBs. Key technical considerations that can be used to determine if mini-split systems are the best option for a suite or for a whole building electrification retrofit include electrical capacity, placement options for indoor and outdoor unit, appropriately sized systems (small enough) for small suites and bedroom, placement of refrigerant lines, and addressing condensation disposal.

System Benefits:

- **Maximum Efficiency/Cold Climate:** Mini-split systems come in brands and models with the highest level of energy efficiency. Many cold climate heat pump systems are available. The ductless design of mini-split systems means they are not subject to the energy losses common to ducted heating systems.
- **Zonal Heating and Cooling Controls:** Mini-splits provide highly effective, responsive, and efficient occupant controlled zonal heating/cooling. The placement of individual indoor heads in different room allows for occupants to heat/cool individual zones to their preference, improving home comfort and reducing energy bills by not needing to heat/cool an entire apartment.
- **Flexibility and Options for Indoor Unit:** With many different brands and models available there is flexibility for indoor unit placement options. Indoor units come in models that can be mounted on the wall, suspended from a ceiling, mounted into drop ceilings, or floor mounted.
- **Operational Capacity of One Outdoor Unit:** Depending on the efficiency and capacity of the system installed, one outdoor unit can be connected to multiple indoor heads in one apartment or multiple indoor heads in several different apartments. However, if multiple indoor heads are running off a single outdoor unit, all rooms/apartments need to either be in heating or cooling mode as one outdoor unit cannot heat and cool at the same time. Additionally, adding multiple indoor heads onto one outdoor unit can impact the operational efficiency of the system.
- **Low Electrical Capacity Models:** Small capacity single head mini-split systems are available in 120V, 15A models which can be connected to a typical suite panel breaker.

Technical Considerations:

- **Capacity of Indoor Heads:** The smallest capacity of indoor head commonly available in the BC market is ¾ ton (or 9,500 BTU). This is much larger than what is typically needed for a bedroom, or small zone, within an apartment. Oversizing of indoor units can result in reduced efficiency, higher operation costs, higher electrical load (contributing to additional need and costs for electrical upgrades), larger physical size of indoor head and short cycling which can lead to the reduced life of the system.
- **Placement of Outdoor Unit:** Outdoor units can be placed on the ground, on a rooftop, on a balcony or deck or attached, with specially designed mounting hardware, to an exterior wall. The outdoor unit must be level and needs ample airflow to operate properly and should not be placed too close to shrubbery or other obstructions to air flow. For multi-unit residential buildings higher than four floors without sufficiently sized balconies there may be limited space available for the installation of the outdoor units.
- **Placement of Indoor Unit:** On average indoor units are 32" wide, 12" tall and 9" deep. Generally, an ideal placement location for the indoor unit is on an exterior wall closer to where the outdoor unit is located. However, other important placement considerations include: in a location on a wall where there is sufficient space for the system to be mounted; the placement of the unit allows for sufficient air distribution through the room/zone; where there is convenient access to the air filter for regular cleaning (not too high); where it allows easy installation of the condensate drain; where it is aesthetically acceptable to the occupant, and; where conditioned air from the unit is ideally not blown directly onto the body of a person sitting or sleeping. If wall mounted, indoor heads are recommended to be installed 6 to 7 feet above the floor and at least 8" from the ceiling.
- **Capacity to Heat Multiple Rooms:** The potential for one indoor unit to heat multiple rooms depends on the capacity of the indoor unit, the layout of the suite and whether doors between rooms will be kept open. With the right layout one larger sized indoor unit can heat multiple rooms (living room, kitchen, bedroom, and bathroom). However, for more consistent temperatures in the suite, multiple smaller indoor units may be more comfortable and practical. Both ductless and ducted mini-splits can be used to heat multiple rooms in a MURB suite, with considerations needed for how, to conceal refrigerant lines and ducting.
- **Placement and Length of Refrigerant Lines:** Mini-splits have minimum and maximum refrigerant line lengths which can limit placement options in some buildings. The longer the refrigerant line the less efficient the system will operate. In general, refrigerant lines should be as short and as straight as possible while allowing for optimal placement of the outdoor and indoor unit. Installations must follow the minimum and maximum line length requirements provided by the manufacturer.
- **Condensate and Defrost Drainage:** Mini-splits produce water in both cooling and heating modes that must be appropriately drained. Water is produced at the indoor head, which can either be brought outside, or drained indoors in a plumbing drain stack. Routing indoors through drywall and wall studs can be difficult and expensive. Routing through bulk heads is possible if they exist, but a slope must be maintained, or a small condensate pump can be added. Routing outdoors to a balcony is the most common solution. The end point of the outdoor drainage must be located so the water does not freeze creating a slipping hazard. Short drain spouts have been used successfully in Toronto and BC, and simply draining onto the balcony and allowing evaporation under pavers has also been successful. New construction often features aesthetically integrated drain stacks.
- **Coring Through Wall:** Running refrigerant, condensate and electrical lines will require the coring or sleeving a penetration through the exterior wall. The complexity and cost of this task can be variable depending on the type of exterior wall in a building.

- **Operating Noise:** Heat pumps make some noise. Outdoor noise considerations are particularly important for mini-split installations on MURBs as more units may be installed near occupants (e.g., on a balcony). There are a wide range of mini-split systems available and systems with the lowest range of noise rating (decibel rating) should always be selected for MURB installations.
- **Need for Auxiliary Heating:** In moderately efficient buildings, the installation of high efficiency or cold climate heat pumps can allow in-suite heat pumps to operate without auxiliary heating. In BC, there are many mini-split heat pumps operating in cold climates without auxiliary heating. If auxiliary heating is used with mini-splits is normally in the form of electric baseboards. Mini-splits do not normally have built-in electric resistance heat available; FRESCo is not aware of any products available today with this option but has seen it on a model many years ago.
- **Refrigerant:** Mini-split systems use more refrigerant than All-in-One (AIO) systems and because they are not sealed units (like AIO systems) there is a higher chance the poor installation practices can result in refrigerant leakage. A typical location for refrigerant leakage is at the flare nut connections between the indoor and outdoor unit.
- **Aesthetics:** Mini-split systems require the use of refrigerant, electrical and condensation lines that need to run exposed on the surface of the exterior of the building and, depending on the indoor head location, possibly on the interior walls. The visibility of these lines may lead to lower consumer acceptance and requires additional cost to have the lines covered to improve aesthetics (and to protect the lines from the elements). Contractors can use plastic lineset covers, which can be painted to match the exterior paint, or custom-built wood covers, which can be constructed and painted to match the exterior of the building. Installing factory linesets or constructing and painting covers will result in an additional cost to the installation.
- **No Advanced Filtration:** Mini-split systems, especially ductless systems generally don't have high performance filters. Typically, mini-split filters are designed to only prevent dust from entering the indoor unit and being distributed through the room. Most of the time, mini-split filters are meant to capture dust to prevent the cooling coil from choking up.
- **Electrical Installed Capacity:** Each mini-split outdoor unit typically requires 208-240V, 20 amps, rating can be higher for increased capacity or for multi-head systems. Each outdoor unit requires its own dedicated connection, the indoor heads will be powered off the main outdoor unit.
- **Service:** These systems are installed in suites which sometimes are difficult to access. However, they are typically very reliable. Owners have reported only requiring filter cleaning only once or twice per year, which can be done extremely rapidly. Filters should be cleaned more often for homes with a dog or cat or when the systems are used more frequently. The outdoor unit requires balcony access, typically these units require annual servicing.

Availability in BC:

- **Equipment:** While there are many models of mini-splits available in BC, there is a limited selection of models with smaller size suitable for bachelor suite or bedrooms within suites.
- **Contactor Capacity:** While there are large numbers of contactors installing mini-split systems to the single-family residential market, there are limited number of contractors that have received training and have experience in designing and installing mini-split systems for suites in multi-unit residential buildings.

Average Cost Range per Suite:

- Low: $4,200 (no electrical upgrade)
- Average: $16,000 (includes electrical upgrade)
- High: $22,000 (includes electrical upgrade)

Space Heating and Cooling: Window Mounted Heat Pump

Photo source: Gradient Website

Context: The New York State Energy Research and Development Authority (NYSERDA) is holding a design competition which is expected to rapidly produce a new heat pump product niche applicable to apartment buildings in cold climates such as BC. The goal of the program is to replace existing window mounted air conditioners in older buildings with simple 120V plug in heat pumps. The entrants are Midea from China, one of the two largest heat pump manufacturers in the world, and Gradient, a US startup company. As of December 2022, the Gradient has not yet started shipping (are taking pre-order deposits) and the Midea model has not been released.

Description: Window mounted heat pumps are a new heat pump product designed to be mounted over a windowsill to provide air conditioning and meet some, or all, of an apartment heating loads, depending on the climate. The systems are designed to be simple to install, requiring no building envelope penetrations and designed to be plugged into a standard 120-volt electrical outlet.

Application: Unfortunately, the Gradient models shown so far are only applicable to a small portion of BC apartment buildings because they require a vertical sliding window. These are typically only found in 1910-1950's buildings. It is hoped that variants will be developed in the future which would work with tilt-out or horizontal sliding windows and spandrel panels.

The Gradient system requires the window to open at least 15" in height, be no less than 24" wide, have a depth of between 6" and 16" and have 24" clearance below the window on both sides of the wall. The window mounted systems are the ideal replacement or alternative for 'window shaker' style air conditioning units and may be a viable cooling and heating alternative for locations that do not have space for outside heat pump units. These systems could be appropriate for multiple different types of buildings – single family residential, ground orientated attached, multi-unit residential buildings. Window mounting in each space avoids enclosure penetrations. Sizing to very small individual spaces solves the problem of minimum size in mini-split offerings. 120V power adds electrical flexibility, and if the unit amperage ratings are low, could, in some cases, reduce the requirement to upgrade power.

System Benefits:

- **Simple Installation:** Window mounted systems are designed to be simple to install. It is a packaged and sealed unit with no refrigerant line connections to be made. By sitting over a windowsill the systems require no drilling or penetrations in the building envelope. The system plugs into 120-volt electrical outlet. No permits may be required for installation.
- **Lower Cost:** The simple installation for the unit provides opportunities for lower cost installations. Given the potential limited heating and cooling capacity of some brands and models, multiple units may be required for MURB suites with multiple zones.
- **Moderate Efficiency:** As window-mounted heat pumps are new to the market the maximum efficiency of the systems is to be determined. Early versions of the Gradient system have a stated

Combined Energy Efficiency Ratio (CEER) of 10.8. The typical range of CEER for an air conditioning unit is between 8 and 15.

- **Zonal Heating and Cooling Controls:** The placement of individual compact size window mounted units in different rooms would allow for occupants to heat/cool individual zones to their preference, improving home comfort and reducing energy bills by not needing to heat/cool via a central system.
- **Aesthetics and Functionality:** A key feature of this unit is its modern looking design, ability to replace older window shaker style air conditioners, ability for installation within a window and still allowing for the window to be used for natural light and (building code permitting) opening and closing for fresh air.

Technical Considerations:

- **Placement of the Unit/Window Compatibility:** Currently available models can only be installed in windows that can slide up and down (single or double hung windows). This limits the suitability of the system for many MURB buildings. Future models of window mounted heat pumps may emerge for other styles of windows. Buildings that are also requiring energy efficient window upgrades could consider a retrofit to a high efficiency double or triple pane window along with the installation of a window mounted heat pump system.
- **Heating and Cooling Capacity:** The maximum and minimum heating and cooling capacity of window mounted heat pump technology is to be determined. The currently available model of the Gradient has a rating of 9,000 BTU/hr for cooling and 8,000 BTU/hr for heating. It is recommended for rooms up to 450 sq ft. Like other models of distributed heat pumps, the system may still be too large for use in smaller rooms (like bedrooms) but would likely be a viable option to be installed in a living room in smaller sized MURB suite to provide cooling and meet a portion of the annual heating load.
- **Auxiliary Heating Requirement:** The need for auxiliary heating with window mounted heat pump technologies is pending confirmation. Gradient states that their current system can handle the cooling load in any climate and 30% to 100% of the heating load, depending on the climate where the installation occurs. As a result, auxiliary heating will likely be required in some regions of BC.
- **Operating Noise:** Given the design of window mounted heat pump, with the outdoor unit immediately outside a window, the operating noise will be a key factor for consumer acceptance. The decibel ratings for the first-generation Gradient system have been identified as: High/Medium/Low: 58/54/48dB. For reference, a typical refrigerator ranges between 32-47dB and an average dryer approximately 70dB.
- **Refrigerant:** The Gradient currently uses R32, but the supplier's goal is to move to more climate-friendly refrigerants, like R290 in the near future.
- **Uncertainty:** Two of the early leading manufacturers of window mounted heat pumps are still in development and finalizing field testing. As a result, the efficiency ratings and other information is pending public release.
- **Electrical Installed Capacity:** While the intent is for these units to be able to be plugged into a typical 120V outlet, its best to ensure that the outlet is not sharing the load with other outlets, as is often the case in MURB suites, which could potentially overload a standard 15A breaker.

Availability in BC/Average Costs (2022):

- The Gradient is offering pre-sales in the U.S, with plans to expand to other regions and countries. The Midea product is not yet commercially available.
- Gradient identifies a $2,000 (U.S. dollars) wholesale cost of the unit. No pricing is available on the Midea product. No data is currently available on installed cost by a contractor in BC.

Space Heating and Cooling: Central Hydronic Systems

Photo source: Aermec US

Description: Central hydronic heat pumps systems are comprised of a central heating source that distributes heat energy by running heated water through a piping loop around the building and delivered to heat-emitting zone terminal equipment which may consist of baseboards, wall/floor radiators, in-floor pipes, or fan-coil units. In most cases in BC, the heat-emitting equipment in central hydronic systems will be floor mounted baseboards or radiators. Traditionally central hydronic systems, or boilers, were fueled by gas or oil. Theoretically, electrifying a gas or oil boiler could be done simply by replacing the heating source with a central heat pump. However, other considerations need to be taken into account. Different applications are described below.

Application: Since central hydronic heating systems are found in most BC MURBS built prior the 1990s, retrofitting to a central hydronic heat pump is a potential solution. However, many hydronic systems are 1) very old, past end of life, prone to leaks (behind drywall), internal blockages and have damaged emitters, 2) high temperature which is extremely difficult, almost impossible to provide with central heat pump systems.

Replacement of Central Boiler Only: With the current central hydronic heat pumps in the market, this type of heating source swap is only feasible for systems with radiant floors and hydronic piping that are in good condition, which represents a very small number of buildings in BC. Since in-floor heating requires lower hydronic temperatures to operate, central air-source heat pumps can meet the heating demand. They may also provide cooling, but "chilled floors" are less comfortable than other forms of cooling delivery, and if the hydronic distribution is not designed for cooling (well insulated and sealed) there will be condensation on pipes and connections which could cause mould growth, corrosion, and leaks.

Replacement of Central Boiler and Emitters: For typical systems that were designed to run at a high-temperature water and have hydronic piping that is in good condition, replacing the emitters (baseboards, wall radiators, or fan-coil units) is necessary since central heat pumps cannot efficiently meet high temperatures. The existing zone terminal emitters can be replaced with water-source heat pumps that can actively heat or cool each individual space in the suite. Water-source heat pumps are equipped with a small compressor, integrated controls, and a fan to deliver supply air to the room. They also require large outdoor mounted central air-source heat pumps to heat the hydronic loop. Although this type of system is common in new commercial construction, for retrofits it is estimated to be at least double the cost of in-suite options. There are no known examples of this type of retrofit in a MURB in BC.

Replacement of Central Hydronic Pipes: For buildings needing to replace their hydronic piping due to age or leaks, replacing the whole central hydronic system (central boiler, emitters, and piping) has been proposed by some designers as a solution, but not implemented yet in BC to our knowledge. The currently proposed central hydronic product replacement consists of a HVRF" system, anticipated to be launched in BC in early 2023-2024, where all refrigerant in the system is contained in a single outdoor unit to reduce concerns about leakage, GWP and toxicity. The new hydronic pipe can be plastic "PEX" pipe, and some designers have postulated they could be retrofitted to hallway ceilings with just a short drop ceiling (only to accommodate the width of the pipe insulation). Emitters will be fan coil wall heads, which have been sized appropriately small (4MBH) in response to requests. The system is capable of exchanging heat hydronically between suites which require heating and those which require cooling (hence the "VRF" in the name even though there is no "Variable Flow Refrigerant" involved).

System Benefits:

- **Avoided or Limited Work in the Suites:** If the original hydronic heat emitting equipment within suites will not be replaced there will be limited, or no, installation work needed in suites. This can avoid tenant disruption and may result in lower overall systems costs.
- **Radiant Heat Rather than Forced Air:** Hydronic heating systems use radiant heat rather than forced air. Some people prefer the feel and comfort of radiant heat. Radiant heat does not blow dust or other allergens around a room and doesn't blow warm or cold air onto the occupants (which for some people may be less comfortable or can dry out eyes).
- **Reduced Amount of Enclosure Penetrations:** Keeping a central system will require a very limited number of enclosure penetrations just for the main outdoor heat pump compared to the option of installing in-suite heat pumps that requires penetrations at each suite.
- **Central Electrical Connection:** Since the new equipment is wired to the 'common/house' (Landlord's) electrical distribution, it avoids costs of upgrading electric service to the suites.

Technical Considerations:

- **High Water Temperature:** Is required for most existing hydronic emitters in typical apartment buildings to adequately heat the buildings. Most (though not all) central hydronic heat pumps are incapable reaching this temperature, which has presented a major challenge to central hydronic retrofits. High temperatures are only required on colder days, but due to practical concerns in existing buildings it is common practice to maintain high temperatures year-round. Central hydronic heat pumps require a 'tandem' configuration with multiple stages to reach these high temperatures increasing system cost, reducing efficiency, and increasing power demand. Additionally, the water returning to the boilers is typically only slightly lower temperature than the supply water. This low "delta-T" is difficult for central heat pumps to work with and reduces capacity and efficiency.
- **Challenges to Adding Cooling:** Retrofitting a central hydronic system and providing cooling introduces additional complexity and cost and limited system solutions.
- **Challenges to Transferring the Heating Costs to Tenants:** Since the system will remain central potentially higher electric heating and cooling bills will be on the central meter, to transfer the heating and cooling costs to the individual tenant "energy meters" would need to be added, which would require additional cost and complexity for the installation. Managing the ongoing metering and billing to the tenants is another ongoing task with a cost.
- **Outdoor Space Requirements for Heat Pump:** Central hydronic air-source heat pumps require considerable space for the outdoor unit(s). The outdoor unit must be installed on a level open space that has excellent air circulation, typically either on rooftops or in a dedicated yard. Outdoor units can be subjected to the weather and, if not on the roof, vandalism.
- **Issues with Existing Piping:** All hydronic distribution piping and emitters (regardless of the heating source) are prone to problems such as leaks, obstruction from built up debris and occasional air locks that prevent heat reaching certain areas. The piping layouts can also limit the temperature control since zones can cover building sections rather than individual suites. As a result, when electrifying a MURB, the costs of upgrading to a heat pump should be evaluated with the potential costs of upgrading the piping since factors such as age, condition and capacity might require it to be upgraded. In many cases, it may be more cost-effective and practical to upgrade to an in-suite heat pump solution.

- **Operating Costs:** Maintaining a central hydronic system requires ongoing maintenance to ensure that all elements of the system are working properly. This can come at a high cost. It is important to keep all elements in good working order since if there is an issue with a central system potentially the whole building could lose heating at once.
- **Electrical Installed Capacity:** The electrical capacity of the central heat pumps will depend on the heating requirements of the building, generally they will require 3 phase power and relatively high load (for example one 50-unit building required additional 42kW). This high electrical load will possibly require a main electrical service upgrade. Some emitters such as fan coils also require a 120V connection which would be wired to the suite panel, but the electrical consumption would be negligible compared to a heat pump, because they are simply low powered fans.
- **Service:** Since these systems are not installed in suites, the heat pump itself requires only one access point to service. However, since the pipe and emitters are located throughout the building, access to fix leaks, airlocks or retrofitted fan coils would require suite access.

Application in BC:

Only one central hydronic heat pump retrofit in a MURB in BC with the capacity to meet full heating loads was identified in this study. It was a central in-floor heating system. Central hydronic heat pumps systems will not be applicable in most BC buildings with existing hydronic heating due to all the above noted technical considerations and limitations.

Cost Range:

A 2021 installation of one central hydronic heat pump systems in BC cost $21,500 per suite. The system including domestic hot water and make up air, as it was a central hydronic plant. Given all the technical considerations of central hydronic heat pump systems and the very few buildings where they would be recommended this cost is not reflective of an average cost.

Space Heating and Cooling: Variable Refrigerant Flow (VRF)

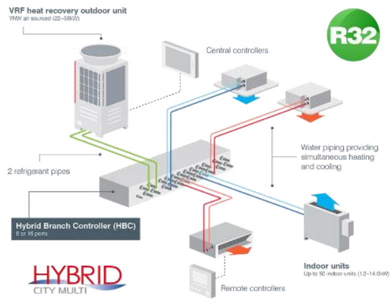


Photo source: Mitsubishi Electric

Description: Variable Refrigerant Flow (VRF) heat pumps consist of an outdoor compressor unit, connected to multiple indoor fan coil units that varies the refrigerant flow using variable speed compressor(s) in the outdoor unit and the electronic expansion valves in each indoor unit. The ability to control the refrigerant mass flow rate according to the heating and/or cooling load allows for the use of individual temperature control in 60 or more indoor units of different capacities with one single outdoor unit. There are two common types of VRF systems:

- Heat Pump (HP) Type: Can be used for either cooling or heating, but not simultaneously.
- Heat Recovery (HR) Type: Can deliver simultaneous heating and cooling to different zones by transferring heat between the cooling and heating indoor units. This generally occurs in the winter season in medium-sized to large-sized commercial buildings with a substantial core such as computer rooms.

Application: VRF systems come in small and medium sizes for residential and small commercial buildings, and in large configurations of up to several hundred tons for high-rise buildings. This technology is more commonly applied in new construction; hospitality (hotels), commercial buildings (offices), and institutional (schools); where existing conditions make the technology more constructable and/or where internal heat loads or solar heat gain offer significant waste heat recovery opportunities. VRF have been less commonly considered for MURB retrofits due to the costs and complexity of installation in older residential buildings.

Benefits:

- **Zonal Heating/Cooling in Centralized System:** VRF systems allow individual control of temperature in different rooms or zones of a building. VRF HR systems can provide heating to some areas and cooling to others simultaneously. This is helpful because the sun can over-heat the South and West facing in afternoon while other the North side still requires heating. Also, some occupants prefer warmer temperatures, some cooler. However, many of the lower cost HP type which lack this feature have been retrofitted to MURBs in BC.
- **Heat Recovery Among Zones:** Some VRF Heat Recovery type systems offer a theoretical efficiency benefit of being able to *transfer waste heat* from warmer zones being cooled to colder zones being heated. However, this potential only exists when both heating and cooling demands occur *simultaneously*, typically only on sunny days in late spring and early fall and/or when there are other building uses that are generating excess heat (computer or server rooms which do not typically exist in MURBs.) Additionally, many of the lower cost VRF systems, likely to be installed, lack this feature.
- **Configuration:** VRF systems can be configured to meet most commercial or larger residential applications. VRF systems also offer the capacity to be adapted to building changes. However, the indoor head size is typically limited to 9MBH, or 6MBH at the minimum, which is too large for most bedrooms.
- **Central Electrical Connection:** Since the new equipment is wired to the 'common/house' (Landlord's) electrical distribution, it could avoid costs of upgrading electric service to the suites. However, this means that billing heating or cooling energy to the tenants must be done through the VRF system, with individual accounts to tenants. This billing system may or may not conform to regulations in BC and would add a management overhead to the building owner.
- **Sophisticated Controls:** For demand response, operations, and maintenance alerts.

Technical Considerations for Retrofit

- **Refrigerant Issues:** VRF technology requires refrigerant piping to be routed from a central location to each zone within a building and each zone within a suite. Because VRF systems are large and distributed systems:
  - They require a large amount of refrigerant to be used in the system.
  - The long refrigerant lines and many branch connections increases the risk of refrigerant leakage.
  - The potential for interior refrigerant leakage carries health risks for building occupants.
  - Utilizing systems with long refrigerant lines within the building envelope may introduce challenges for the introduction of low global warming potential refrigerants, some of which may be flammable and unsafe for applications like VRF systems.
  - The longer the refrigerant lines between the outdoor and indoor units the less efficient the system will operate.
- **Retrofit Cost Considerations:** The retrofit of VRF systems requires penetrations through walls and ceilings and the cost of running and concealing refrigerant, electrical and condensation lines. While VRF systems may be easier to retrofit in commercial spaces, many residential MURB applications would be more challenging and costly.
- **Interior Aesthetics:** The use of bulkheads or drop ceilings may be introduced to cover indoor units or refrigerant lines. This may introduce space and aesthetics concerns or limitations.
- **Auxiliary Heating May Be Required:** Depending on the VRF system, the use of supplemental heating may be required for coldest temperatures. Cold climate VRF systems have demonstrated capacity to meet heat load through winter.
- **Condensate Drainage:** Condensate drainage is required for each VRF indoor unit.
- **Outdoor Units are Large and Heavy:** Utilizing VRF for a retrofit is complicated by the need to make space available for multiple large outdoor units. Large buildings often dedicate entire floors to VRF units, which reduces space available for rent, lease, or sale.
- **Noise:** Because outdoor fans are small and have high air flow, they are much louder than other types of heat pumps. Lower cost VRF equipment may be prone to higher levels of noise. Due to a history of noise complaints in BC for VRF systems, all available sound mitigation strategies are recommended to be integrated into system design to avoid costly post-installation remediation.
- **Repair and Troubleshooting:** Repair can be more complex and costly, especially if the issue is related to identifying refrigerant leakage within the system.
- **No Individual Unit Billing Capacity:** As a central system there is no capacity for utility billing for individual units.
- **Service:** VRF installations typically have many outdoor units in different locations around the building or roof. Since the refrigerant lines, indoor heads and connections are located throughout the building, access to fix leaks and service indoor heads would require suite access as well as access to common area distribution in hallway ceilings, wall cavities, etc.

Application in BC: No data is available on how regularly VRF systems have been used for MURB electrification retrofits in BC.

Cost Range: Given the small sample size of retrofit VRF systems a comprehensive average cost range is not available. Costs per suite from available examples include:

- Fuel switch retrofit: $12,000
- New construction (average cost for three buildings): $13,000
- Toronto Atmospheric Fund Pilot Project: $18,900

MURB ELECTRIFICATION TECHNOLOGY FACT SHEETS

Water Heating Systems

Large Central Modular Array CO_2 Air Source Heat Pump Water Heater

Large Central CO_2 Air Source Heat Pump Water Heater

Small Decentralized Integrated Air Source Heat Pump and Water Tank

Water Heating:
Large Central Modular CO_2 Air Source Heat Pump Water Heater

Photo source: Rod Nadeau, Viddora Developments

Description: Large modular arrays of CO_2 air source heat pumps are the dominant technology currently used for electrification of hot water. They have many outdoor units mounted together, each of which looks superficially like a mini-split outdoor "fan box". All refrigerant is contained inside each outdoor unit. These systems look like mini-split systems, except instead of refrigerant lines, potable water lines run between the outdoor unit and a storage tank which may be located indoors or outdoors. The arrays can be purchased already plumbed and skid mounted, or individual modules can be purchased, and racks made on site.

To heat water, the heat pump extracts warmth from the ambient air by compressing the refrigerant to increase its temperature. A condenser coil inside the hot water system transfers heat from the refrigerant to the water.

Application: These types of systems are used for the majority of large MURB electrification retrofits in BC and elsewhere. They have been proven successful in BC, New York City, California, Washington, and other locations. Pre-plumbed skid mounted systems are more expensive but avoid typical problems from unfamiliar mechanical designers and plumbers. If the units are *not* purchased in a pre-plumbed array, *extreme caution* needs to be taken to get proper design and connections; typical engineer and plumber experience with gas systems leads to problematic installations. Due to the unique characteristics of CO_2 as a refrigerant they are effective at heating up cold water without auxiliary heating down to -25C.

Key limiting factors are the availability of space for mounting arrays of the outdoor unit(s), and location for the storage tanks, Since the storage for heat pump DHW systems is much larger than typical gas DHW systems, space in existing mechanical rooms and roof structural capacity can be a limitation.

System Benefits:

- **High Efficiency and Low Carbon:** CO_2 HPWH are the most energy-efficient way to heat water with electricity, using 50% less energy compared to a standard electric hot water tank, resulting in lower operation costs and, when switching from a natural gas hot water heater, a reduction in greenhouse gases of over 95%.
- **Low Global Warming Potential Refrigerants:** CO_2 refrigerant has 2,000 times less GWP than more commonly used refrigerants, such as R410A.
- **Cold Climate:** For systems using CO_2 refrigerant the systems have capacity to operate in temperatures as low as -25C. R410A is only effective down to –10C when heating cold incoming water.
- **Flexible Placement of Outdoor Units:** Since these systems consist of many small modules, they are more flexible to locate outdoors compared to a single central unit with large footprint and weight. They can be mounted on one or more exterior or walls, distributed on roof tops, parking lots or yard space, arranged in single or multiple rows vertically or horizontally.
- **Scalability:** Since the modules are small, systems can be designed conservatively, and extra rack space can be left for future additions in case of future increases in demand.
- **Light Weight:** Since these units are small and light-weight, they can be brough up elevators or stairs instead of requiring a crane lift which is very expensive and requires extensive co-ordination overhead.

- **Low Noise:** These units are much quieter than single large units with high velocity vertical shaft fans. Noise from multiple small units spread out over space is not additive.
- **Simple Field Service:** Since these units are modular, in case of failure, the rest of the system can continue to work, and a single unit can be removed and replaced with a functional unit. The single unit can be returned for factory repair, unlike very large equipment which requires technicians to work on site outdoors even in poor weather.

Technical Considerations:

- **Placement of Outdoor Unit:** Outdoor units are often placed on building outside walls, on rooftops or in parkades on pre-made or custom-built racks. They can also be placed on the ground. Rack mounting allows the outdoor units to be level. Units need ample airflow to operate properly and should not be placed too close to shrubbery or other obstructions to air flow.
- **Water Line Freeze Protection:** Since these units use potable water, there is risk of freezing during power outages. The lines should be insulated, and in some cases, drain-back connections (like those used in solar DHW arrays) are used.
- **Location for Storage Tanks for Central Applications:** A suitable location for the storage tanks will also need to be found. If using only the built-in pumps, there is a maximum distance of 25-50ft horizontally and 10-16ft vertically, depending on the model. ASHP systems typically require more storage tanks than traditional fossil-fuel fired systems as heat pumps are typically sized with smaller capacity and longer run times per day. Larger tanks can also minimize peak demand charges when hot water consumption in the building matches peak demand periods. While the storage tanks can remain in the existing mechanical room, the additional number of tanks may require structural assessment or reinforcement, particularly when the mechanical room is not located in the basement. Storage tank plumbing is different from that for gas-fired systems and this needs to be taken into consideration when fitting tanks into small spaces.
- **DHW Recirculation Re-Heating:** The DHW recirculation line requires separate re-heating by electrical resistance heat (CO_2 heat pumps cannot heat high-temperature return water because of the characteristics of CO_2 as a refrigerant). Earlier designs included an additional storage tank with electric resistance heat (referred to as a “swing tank”) to re-heat the DHW recirculation line. Sometimes this includes full backup power in case of heat pump failure, in which case it requires higher electrical capacity. Some more recent projects have used smaller capacity “instantaneous” electric resistance heaters sized only to the loss expected in the recirculation line. This reduces cost and electrical demand.
- **Design and Implementation Risk:** Since heat pumps for central hot water is new, most engineers and contractors are unfamiliar with the specific design requirements, which are completely different from fossil-fuel systems. Improper design can cause unnecessary high capital cost, very high energy consumption, peak demand charges, and insufficient hot water. Sizing of heat pump capacity, storage capacity, and re-heating of recirculation are critical details which are completely different from gas systems. It is recommended that engineers and contractors installing their first applications use design guidance from the equipment manufacturers.
- **Condensate and Defrost Drainage:** Heat pump systems produce water that must be appropriately drained. The end point of the drainage must be properly located so that released water does not freeze on walkways creating a slipping hazard.
- **Coring Through Wall:** Running water lines, condensate and electrical lines may require the coring or sleeving a penetration through the exterior wall. The complexity and cost of this task can be variable depending on the type of exterior wall in a building.

- **Operating Noise:** Although these units are extremely quiet (approximately 38dB), the perception of potential noise problems with neighbours and inspectors will need to be managed.

Application in BC:

For central systems, arrays of CO_2 modular HPWH units are the most efficient option for providing hot water for multiple suites. The systems work down to very cold temperatures without auxiliary heat. The available product size range allows selection of the right capacity and flexible physical configuration to meet location constraints.

Single modules of CO_2 HPWH are less likely to be used for a single suite because they are too large; each module typically supplies DHW to 10 people making them more expensive, larger, and require a more complex installation compared to integrated tank type heat pumps or even electric resistance tank type DHW heaters. They could be used for townhomes or penthouse suites but are much larger and more expensive than integrated tank type HPWH.

The Northwest Energy Efficiency Alliance (NEEA) Commercial Heat Pump Water Heater Qualified Products List provides information on available products: neea.org/resources/commercial-hpwh-qualified-products-list

Cost Range per Suite:

- Central modular system average: $2,500 per suite.
- For in-suite use (not typically done due to cost and technical challenges) per system: $5,000 to $6,000 per suite.
- One interviewee who had reviewed many business cases said *"The business case for heat pump domestic hot water is really good…. A few cases where it is actually cheaper to do HPDHW [than gas systems]".*

Water Heating:
Large Central CO_2 Air Source Heat Pump Water Heater

Photo source: Mitsubishi Electric NZ

Description: Central domestic hot water (DHW) systems are electrified by replacing a central natural gas boiler central natural gas domestic hot water heater (typically a direct fired storage water heater or water heater and separate storage tank) with a large central heat pump and separate storage tanks. Two large size CO_2 DHW heat pump options are available now in the BC market. Although these are typically louder, heavier, more difficult to place and more expensive than CO_2 modular systems, many designers prefer them due to their larger size.

A heat pump water heater uses the same technology as a heat pump space heating system. To heat water, the heat pump extracts warmth from the ambient air by compressing the refrigerant to increase its temperature, the heated refrigerant runs inside a heating coil that is placed inside the hot water storage tanks. The heat pumps need to be located outdoors while the storage tanks can be installed in the existing mechanical room.

Application: Electrifying central domestic hot water with CO_2 is a retrofit that has been proven successful in BC and other locations like New York City and California. With proper design and installation, its relatively straight forward to retrofit if there is an adequate location for the required storage tanks and enough electrical capacity. Central DHW heat pump retrofits are more viable in buildings that already have a central hot water system, as adding a new central piping loop would be a disruptive and expensive retrofit.

System Benefits:

- **Large Size/Capacity:** Many designers prefer larger capacity units over arrays of multiple smaller modules. Although larger on a per unit basis compared to modular heat pumps, it is possible that larger size systems take up less space than an entire array of modular units.
- **Glycol for Cold Weather:** One of the newly available systems uses glycol which does not freeze in cold weather. The modular systems, by way of comparison, heat water directly, which poses a risk of freezing in cold weather.
- **High Efficiency and Low Carbon:** CO_2 HPWH are the most energy-efficient way to heat water with electricity, using 50% less energy compared to a standard electric hot water tank, resulting in lower operation costs and, when switching from a natural gas hot water heater, a reduction in greenhouse gases of over 95%.
- **Cold Climate Performance:** For systems using CO_2 refrigerant the systems have capacity to operate in temperatures as low as -25C. R410A is only effective down to –10C when heating cold incoming water. For locations with temperatures below -25C auxiliary heating would be required.

Technical Considerations:

- **Placement of Outdoor Units:** Outdoor units could be placed on rooftops or unused yard space. These units are much larger and louder than small modular type, particularly when heard from above, and care must be taken to avoid or mitigate noise. They are also much heavier and larger. A crane would typically be required to lift them onto roofs or placement in yards. Structural upgrades are likely to be required for roof mounting. The outdoor unit must be level, needs ample airflow to operate properly, and should not be placed too close to shrubbery or other obstructions to air flow.

- **Water Line Freeze Protection:** For units which use potable water, there is risk of freezing during power outages. The lines should be insulated, and in some cases, drain-back connections (like those used in solar DHW arrays) are used. One large central CO_2 system uses glycol lines, thus is inherently freeze protected.
- **Location for Storage Tanks for Central Applications:** A suitable location for the storage tanks will also need to be found; ASHP systems typically require more, or larger, storage tanks than traditional fossil-fuel fired systems because hot water recovery is longer with heat pump systems. Larger tanks can also minimize peak demand charges when hot water consumption in the building matches peak demand periods. While the storage tanks can remain in the existing mechanical room, the additional number of tanks may require structural assessment or reinforcement, particularly when the mechanical room is not located in the basement. These units use single large external pumps (which sometimes are provided with the unit on a skid). The distance and height difference from heat pump to tanks is therefore not limited.
- **DHW Recirculation Re-Heating:** The DHW recirculation line requires separate re-heating by electrical resistance heat (CO_2 heat pumps cannot heat high-temperature return water because of the characteristics of CO_2 as a refrigerant). Earlier designs included an additional storage tank with electric resistance heat (referred to as a “swing tank”) to re-heat the DHW recirculation line. Sometimes this includes full backup power in case of heat pump failure, in which case it requires higher electrical capacity. Some more recent projects have used smaller capacity “instantaneous” electric resistance heaters sized only to the loss expected in the recirculation line. This reduces cost and electrical demand.
- **Design and Implementation Risk:** Since heat pumps for central hot water is new, most engineers and contractors are unfamiliar with the specific design requirements, which are completely different from fossil-fuel systems. Improper design can cause unnecessary high capital cost, very high energy consumption, peak demand charges, and insufficient hot water. Sizing of heat pump capacity, storage capacity, and re-heating of recirculation are critical details which are completely different from gas systems. Storage tank plumbing is different from that for gas-fired systems and this needs to be taken into consideration when fitting tanks into small spaces. It is recommended that engineers and contractors installing their first applications use design guidance from the equipment manufacturers.
- **Condensate and Defrost Drainage:** These systems produce water in winter that must be appropriately drained. The end point of the drainage must be properly located so that released water does not freeze on walkways creating a slipping hazard.
- **Coring Through Wall:** Running water lines, condensate and electrical lines may require the coring or sleeving a penetration through the exterior wall. The complexity and cost of this task can be variable depending on the type of exterior wall in a building. The enclosure penetration is no different in size than CO_2 heat pump arrays. Both types only require one pipe in and out of the enclosure.
- **Higher Noise:** These units are much louder than large arrays of modular units. These units have high velocity vertical fans. The noise is mostly directed upwards, but significant noise is heard nearby. Thus, they are more difficult to locate. Well isolated roof tops are ideal, or non-residential back alleys.

Application in BC:

Large central CO_2 based air source heat pumps can meet the full hot water demand in most MURBs in BC, as they function to -25C. Large units are preferred by some designers over smaller modules. Auxiliary heating will be required in some locations for the coldest days of the year. The NEEA Qualified Product List provides information on available products: neea.org/resources/commercial-hpwh-qualified-products-list

Cost Range Per Suite:

No costs were available for large central CO_2 based systems, as no known systems have been installed in BC.

Water Heating:
Integrated Air Source Heat Pump and Water Tank

Description: Integrated heat pump water heaters (HPWH) have a very small heat pump mounted on top of the storage tank together in one unit. They look similar to a conventional electric hot water storage tank but are approximately 18 inches taller. Air source heat pump water heaters (HPWH) use the same technology as an air source heat pump space heating system. To heat water, the heat pump extracts warmth from the ambient air by compressing the refrigerant to increase its temperature. A condenser coil inside the hot water system transfers heat from the refrigerant to the water.

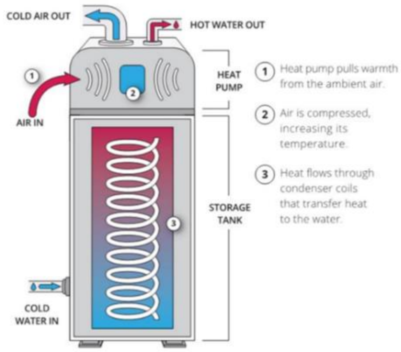


Photo source: City Green Solutions

Application: Integrated HPWH are applicable to townhomes or condos with existing small in-suite electric or gas tank type heaters. The footprint and comparable size of a HPWH allows it to fit in most locations that had an in-suite tank type system. Ideally, for maximum performance, they would be vented to outdoors, but most applications do not, and performance is acceptable.

System Benefits:

- **No Outdoor Unit:** Integrated HPWH are designed as a single unit and may be applicable for locations where there is not sufficient or appropriate space for an outdoor heat pump unit.
- **Low Cost:** Units are about half the cost of larger CO_2 systems with separate tank and outdoor units.
- **Low Electrical Capacity Units:** 120 V models are being introduced into the market, which can provide a more cost-effective option for some applications.

Technical Considerations:

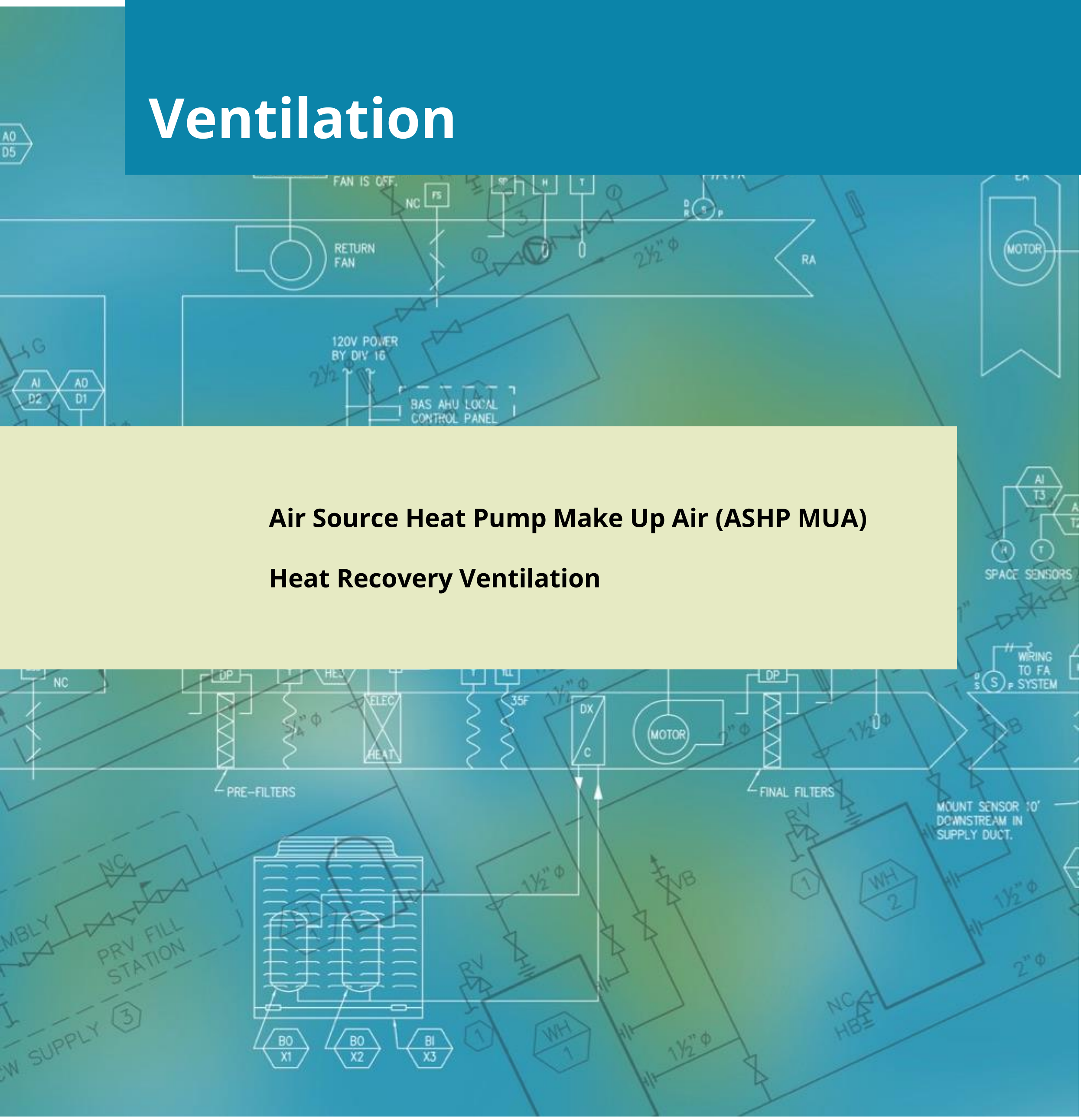
- **Ducting Air Intake and Exhaust:** Since integrated HPWH are installed indoors, the system could be vented with an air intake and exhaust to outdoors. Due to cost this is seldom done, and they are instead mounted in closets which need to be well ventilated. When they are not ventilated to the outdoors, they discharge cool and dry air, which may be welcome in summer, but increases the demand for space heat in winter.
- **Check for Sufficient Height:** Since the heat pump components are mounted on top of the tank the unit can be more than 18" taller than natural gas or electric resistance tank heaters.
- **Condensate Drain:** Produce condensate that needs to drain to a floor drain or pumped elsewhere.
- **Noise:** Because Integrated HPWH are installed indoors and make a noise similar to a dehumidifier when running, they must be in a location that would be moderately sound proofed to block the noise. Noise levels range around 60dB (about as loud as a conversation) to 80 decibels (about as loud as a hairdryer or vacuum cleaner)
- **Operating Temperature:** The current heat pump tank heaters available can only operate above 3C, if the unit's air intake is ducted to the outdoors, for temperatures below 3C they will need to rely on auxiliary resistance heat.

Application in BC: Only one example of integrated HPWH was found in the data; for townhomes which previously had individual gas fired tank heaters in each unit. Integrated HPWH are designed to replace the compact in-suite electric resistance tank heaters which are common in BC homes.

Cost Range Per Suite: $4,000-$5,500.

MURB ELECTRIFICATION TECHNOLOGY FACT SHEETS

Ventilation



Air Source Heat Pump Make Up Air (ASHP MUA)

Heat Recovery Ventilation

Ventilation:
Air Source Heat Pump Make Up Air (ASHP MUA)

Photo source: Daikin Industries

Description: A makeup air (MUA) unit delivers tempered (heated) outdoor air to the hallways and other common areas of the building to "make up" for local exhaust in the suites. When MUA units are used, hallways are pressurized for indoor air quality and to prevent odors, or smoke in the event of a fire, from a suite to enter common areas. Standard gas make up air units (MUA's) are rated 80% efficiency and are often very oversized. Heat pump MUA's are two to three times more efficient than standard gas MUA's (or electric resistance systems) and may provide cooling as well as heating. When a heat pump MUA unit is designed it can be right sized to reduce capital costs, operational costs, and excess heated air.

Application: Since MUA systems are common in MURBs from the late 80's onwards, heat pump central MUA's can be installed in a wide variety of multi-unit residential building types built after the late 80's. Key technical considerations that can be used to determine if ASHP MUA system is the best option for building electrification retrofit include a) Is there sufficient electrical capacity for the electrification of the MUA system, and; b) Is the building structure strong enough for the heavier ASHP MUA to be installed on the roof.

System Benefits:

- **Strong Economics:** In many circumstances, since the capital cost is relatively low and there are high rebates from CleanBC there is a strong business case.
- **Maximum Efficiency:** Electricity may cost more than gas, but since heat pumps are several times more efficient than boilers, the energy costs can be similar or lower than heating with gas. Investing in a less efficient unit could cost more over the life of the system.
- **GHG Reduction:** GHG reductions can be significant, when switching from a natural gas system to a 'hybrid' HP MUA with electric resistance for auxiliary heating.
- **No Tenant Disruption:** Since MUA systems are mounted outside the building it requires no work in the suites.
- **Limited Amount of Added Central Cooling:** A small amount of central cooling can be added with this approach. Air conditioning applied this way is very limited and has no individual control; it will likely not satisfy demand for cooling, though could reduce some of the issues presented by building overheating.
- **Symbiotic Efforts:** Gas heated MUA's in older apartment buildings are almost always grossly oversized by a factor of 2 to 4. Improvements to existing ventilation can enable loads to be reduced. This may include relatively simple measures such as reducing air loss first by adding weather stripping, recommissioning or improvements that enable demand-controlled ventilation.

Technical Considerations:

- **Added Equipment Weight:** ASHPs MUA units are typically heavier than existing MUA units so the installation may require a structural evaluation and structural upgrades.
- **Added Electrical Load:** Existing gas heated MUAs only require a small electrical connection to operate. An ASHP MUA will require a larger electrical connection that will vary in cost depending on the available spare capacity of the building and how easy it is to route the new electrical connection to the new MUA.

- **Need for Auxiliary Heating:** Auxiliary heating may be needed for peak heating loads. One BC supplier indicated that many common heat pump MUA units are not capable of providing heating below -3C, and that no heat pump MUA units for sale in BC were capable of heating below -18C. Auxiliary heat can be provided by an electric resistance heater or a gas heater. While using an electric resistance heater will completely electrify the MUA, it will add a considerable amount of electrical load which might not be available from the existing electrical service and may increase operational costs.
- **Potential for Excessive Use of Auxiliary Heating:** Since the operation of heat pump and the auxiliary heat relies exclusively on controls and building operators, there is a high risk that MUA systems run using the auxiliary heat even when the heat pump has not maxed out its capacity. This risk is present for the entire life of the equipment. Excessive use of the auxiliary energy will increase operating costs and reduce energy and GHG savings, which is particularly concerning with gas auxiliary heat since it could negate the desired emissions savings.
- **Equipment Noise:** Heat pump MUA's are generally considerably louder than existing gas MUA's. Many systems in operation in BC were reported to have noise complaints from residents and neighbours. BC Housing reported that one system had to be shut down due to complaints from a neighbour to the city. Sound baffles were added, and a quieter fan was sourced, which took a year to arrive. Many other systems were reported to have similar situations, most with the same very common lower cost brand.
    - *FRESCo recommends policies or design guidelines to ensure that engineers design and specify Heat Pump MUA's properly to minimize or eliminate noise problems. Quieter systems can be achieved by including acoustic studies within system design, specifying higher efficiency equipment with quieter sound ratings from efficient (quieter) fans and higher quality balanced compressors, planning for better vibration isolation, and using sound baffles.*
- **Service:** Since these systems are located typically on rooftops, they require only one point of access to replace filters, belts, and service the heat pump. This is often touted as a benefit when compared to in-suite ventilation. However, rooftop access is often very difficult, sometimes dangerous on older MURBs due to ladder access, slippery decks and roofing materials and fall hazards. It also requires working outdoors. FRESCo experience on many site visits has found about half of MUA's have filters missing, bypassing, or completely clogged.

Application in BC: Heat Pump MUA systems are increasingly being installed in BC. This is generally the most cost-effective way to reduce GHG per dollar spent, albeit only a limited portion of the total GHG at the site. Not all MURBs have MUA's. For example, the most critical building stock, those built before the mid 1980's did not have heated MUA's.

- **Sample Project**: An ASHP MUA with electric back up was installed and commissioned in December 2021, at The Remington (Concert Properties) in the Collingwood Village neighborhood of Vancouver. The Remington is a 21-story, 256-unit building, built in 1999. The building received an MUA options assessment and linear regression analysis on the gas utility bills which identified that MUA heating likely accounted for roughly half of the gas consumption. The installation of a heat pump MUA with electric back up presented a significant opportunity to reduce emissions while also potentially reducing operating costs by replacing the original inefficient gas system with a better performing unit.

Cost Range Per Suite: Average $1,900.

Ventilation:
Heat Recovery Ventilation

Photo source: Small Planet Supply

Description: Heat recovery ventilation (HRVs) is a system that uses the temperature of the stale exhaust air to preheat or precool incoming fresh air. A typical HRVs consists of a core unit, channels for exhaust and fresh air, and blower fans. Exhaust air is used as either a heat source or a heat sink depending on the climate, time of year and requirements of the occupants. HRVs can recover between 60 to 95% of the heat in exhaust air and can significantly improve the energy efficiency, comfort, and indoor air quality in a building.

Application: While HRVs are not an electrification measure, they can make a significant reduction in heating loads in MURBs while improving air quality for residents. The new Building Code requirements in BC that requires ventilation for all occupied areas of MURBs has resulted in an increasing number of HRVs integrated into new construction designs. For MURB retrofit applications there are two HRV options:

- **Centralized** HRV's are challenging and costly to retrofit to existing buildings, due to the ducting required. Centralized HRVs are generally only feasible in buildings with existing centrally ducted exhaust systems.
- **In-suite** HRV's can efficiently provide good ventilation in the suite. Decentralized equipment provides flexibility to either install HRVs in all units at once, or gradually on tenant turnover. These units come in two main types: ducted and alternating flow. Ducted units require ducts to be added in the suites, which can be costly and challenging, especially in slab buildings. Alternating flow units are simpler to retrofit since they are mounted entirely within the wall cavity but require at least two enclosure penetrations in each suite and maintenance requires suite access (for filter changing).
- Both centralized and in-suite HRV's can be applied to centralized or in-suite suite heating electrification approaches.
- Both approaches can also work in conjunction with central make-up air (MUA) heat pumps since HRVs help reduce the heating or ventilation capacity required by the central MUA resulting in possibly downsizing the MUA.
  - Central HRV's can allow for the use of a heat pump MUA without auxiliary heating because they preheat the incoming fresh air to the central MUA which allows for the MUA heat pump to operate within its typical minimum range of 5C.
  - In-suite HRV's help reduce the ventilation and heating requirements of the central MUA by providing ventilation directly to each suite resulting in a central MUA that only requires enough ventilation to service the common areas of the building. To effectively reduce the ventilation requirements of the central MUA, the suite door undercuts would need to be sealed with an inexpensive door sweeper.

System Benefits:

- **Improved Air Quality with Increased Efficiency:** Traditional MURB designs relied on ineffective and inefficient suite ventilation strategies, including operable windows, corridor pressurization or leaky envelopes. Each of the traditional ventilation strategies can result in increased energy consumption in a building and less than optimal ventilation. HRVs can dramatically improve suite indoor air quality while using energy more efficiently, potentially reducing heating loads which can reduce the capacity required for space heating or make up air units.

- **Occupant Benefits:** The primary benefit of HRV's in suites is to improve indoor air quality and provide filtration of outdoor air, especially during smoke events from wildfires. HRVs also provide higher indoor oxygen levels, reduce mildew risk through dehumidification, and improve comfort by providing more even temperatures in the suite.

Technical Considerations:

- **Difficulty Retrofitting:** Central HRV's require a major change to retrofit insulated duct work into and out of each suite. In-suite HRV's require either enclosure penetrations, or window spandrel panels. Ducted in-suite HRV's require expensive ductwork throughout the suite.
- **Difficult Savings Calculations:** In buildings without an HRV, the business case looks poor because practitioners are unable to calculate savings in these "unventilated" buildings. The buildings of course are actually ventilated; by convection from windows opened by occupants. Unfortunately, there is no well accepted methodology for estimating the energy lost through convection from these windows. Since HRV's require some additional fan energy, if there is no savings calculated, the business case is negative.
- **Lack of Value for Quality of Life:** There is no value assigned to the life safety and quality of life improvements from filtration and ventilation in business cases.
- **Condensate Drain:** Some models of HRVs require a condensate drain which, for those models, can limit the location of installation.
- **Servicing:** Like other mechanical equipment HRVs require regular servicing. When the changing of filters is left to owner/occupants it is a maintenance item that can be forgotten, impacting the effectiveness and efficiency of the operation of the system.
- **Bypass:** In summer when it is still cooler outside than inside, it is advantageous to be able to bypass the heat exchange function and bring air inside to provide "free cooling". Ducted models achieve this with automated dampers. Alternating flow models accomplish this by going into single direction mode, never alternating. Lower cost models do not have a summer bypass.

Application in BC: HRVs offer valuable improvements to indoor air quality and significant energy savings which can reduce heat pump size and consumption. Unfortunately, health and life safety are not typically accounted for in business cases, and a lack of consensus on energy calculations (due to a lack measured case studies). This is likely to change due to climate change concerns, owner interest and future regulations. The only known examples in BC are in social housing, which put a high value on improving indoor air quality for enhancing occupant health and comfort. These examples are MURBs with existing central exhaust systems that have been retrofitted with central HRV systems. However, anecdotal reports from building managers, and extensive experience of FRESCo staff during on-site energy assessments highlight widespread issues in central HRV's with lack of scheduled maintenance leading to poor performance, challenges with air balancing and difficulty cleaning HRV cores. More research and investigation is needed to confirm these claims and to highlight solutions to the issues.

Cost Per Suite: Not available.

MURB ELECTRIFICATION TECHNOLOGY FACT SHEETS

Hybrid Systems

Hybrid Heat Pump Systems (For All Applications)

Hybrid Heat Pump Systems (For All Applications)

Description: The term "Hybrid" is typically used in BC to describe systems with gas auxiliary (as opposed to electric). Practically any heat pump system could be applied as a hybrid system. Note that electricity is also used as an auxiliary or backup heating source for many heat pumps, but these are *not* normally described as "hybrid". An exception is the Rheem Pro-Terra integrated heat pump/tank with internal resistance heating which is confusingly marketed as "hybrid". It is important to differentiate integrated and non-integrated systems. MLI is using "hybrid" or "hybrid dual fuel" to refer to integrated systems (i.e. one controller for both). Mini-splits with a gas boiler hydronic backup are not referred to as a "hybrid system" under this terminology convention.

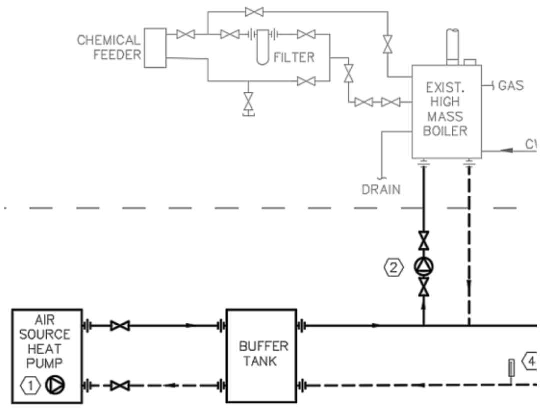


Photo source: FRESCo

Application: Any type of system can be hybrid (space heating, domestic hot water, or ventilation). While full electrification is often desired, technology, space, electrical capacity can make that expensive. For those situations, hybrid systems at least allow for partial electrification.

System Benefits:

- **Peak Heating:** Hybrid systems can help 'top up' the heat provided by the heat pump under very low outdoor temperatures when the heat pump has either reduced its efficiency or in some cases surpassed its operating temperature range.
- **Reduced Need to Upgrade Electrical Service Size:** Hybrid systems can also be used to avoid the cost of electrical upgrades by limiting heat pump capacity to only the spare electric capacity which currently exists in the building.
- **Reduce the Size of the Required Heat Pump:** Using a hybrid system can reduce the size of the heat pump since other heat sources will help supply the load. This is an option that is considered where either space, cost, electrical capacity, or structural concerns prohibit supplying 100% of the load with a heat pump. This is particularly common for make-up air (MUA) or central hydronic systems.
- **Can Retain Existing Equipment:** Existing gas equipment with remaining life is often retained as an emergency backup, or to facilitate gradual phase-out, in the case of in-suite heating.

Technical Considerations:

- **Risk of Excessive Auxiliary Energy Use:** Since the operation of the heat pump and the auxiliary heat relies exclusively on controls and occupants, there is a high risk that hybrid systems run using the auxiliary heat even when the heat pump has not maxed out its capacity. This risk is present for the entire life of the equipment. Excessive use of the auxiliary energy will increase operating costs and reduce energy and GHG savings, which is particularly concerning with gas auxiliary heat since it could negate the desired emissions savings. A few real-life examples of hybrid systems highlight some of the potential scenarios of excessive auxiliary energy use:
  - **Contractor Set-Up:** Two hybrid MUA units were installed in BC to run primarily on the auxiliary heat (one electric and one gas). In both cases the contractor was simply concerned that the equipment provided the desired heat without regard for GHG savings or utility costs. This was noticed by the owner and had the control set up properly to use the heat pump as the primary

heat source as intended. (Several other cases of this phenomenon with MUA's with gas auxiliary were also reported by owners interviewed for this project).

- **Control Systems Issues:** The controls to switch on auxiliary heating can be simple built-in controls in the heat pump, or more complex external code in a building computer system (DDC) or computerized thermostats. Typically, simple direct control by the heat pump is more reliable and effective. Built-in controls have the advantage of being programmed by the manufacturer to know the limitations of the heat pump and control appropriately. DDC systems are vulnerable to many problems including connectivity, communication, sensor calibration and connections, software upgrades, programmer errors and operator interventions, which are often cause problems when they are used to directly control boilers instead of the built-in boiler controls. In one instance identified in this project, a CO_2 domestic hot water system ran exclusively on gas after start up due to a temporary line in the DDC code at installation which forced the system to only run on auxiliary heat.

Application in BC: Hybrid systems, in their various forms, are common in BC. Heat pump MUA retrofits are almost certain to require auxiliary heating of some sort and almost all known installs in BC have gas auxiliary. Domestic Hot Water (DHW) systems with R410a require gas auxiliary, but this is a poor application that should be avoided as CO_2 DHW systems do not require gas auxiliary heating. Some CO_2 DHW systems do have gas auxiliary heating either mistakenly deemed necessary by unfamiliar engineers (several cases) or to avoid the cost of an electrical upgrade (at least 2 cases). Central hydronic systems with low temperature emitters or in-suite water to air heat pumps are typically proposed with gas auxiliary, but it is not necessary in most cases in lower mainland. Central hydronic with high temperature emitters (such as baseboards) would almost certainly require gas auxiliary in any BC climate, but there are more effective retrofit alternatives available that do not require gas auxiliary.

More Training and Commissioning: Due to the potential issues of over reliance on auxiliary heating, considerably more work should be invested in developing training for the design and installation of hybrid systems and there should be a commissioning and verification process that ensures the system is functioning as intended immediately after installation and on an ongoing basis.

Cost Range: The cost range for hybrid heat pump systems can be highly variable based on the type of system. In some cases, the existing gas system is retained as the "hybrid" portion. Even in this case however, the additional cost of controls, significant extra commissioning time and ongoing verification of GHG savings needs to be accounted for in hybrid projects, otherwise there may be no GHG savings and there may be premature failure of the heat pumps and poor occupant comfort.

07

7: Strategies – Scaling Up Building Electrification

There are a wide range of program and policy considerations and strategies that can be used to enable a scaling up and acceleration of multi-unit residential building electrification. A high-level summary of key strategic issues and recommendations is provided on the following:

Table 10: Summary of Program and Policy Considerations

Program Considerations	Policy Considerations
▪ Expand and improve rebates and incentives for MURB electrification ▪ Make it easier to access MURB retrofit incentive programs ▪ Provide more electrification retrofit planning and implementation support ▪ Integrate or align EVSE and building electrification rebates and programs ▪ Streamline electrical capacity calculations to reduce time, cost and complexities ▪ Staging (and bundling) building enclosure and electrification retrofits ▪ Validate MURB electrification post-retrofit performance and savings ▪ Introduce comprehensive program requirements to ensure hybrid systems deliver anticipated GHG emission reductions. ▪ Introduce industry MURB electrification training	▪ Provide owners and industry access to energy (electric/gas) data to enable MURB electrification ▪ Valuation of life safety and non-energy benefits ▪ Mechanical and other end-of-life replacements as a regulated "electrification trigger" ▪ Streamlining and standardizing permits/bylaws MURB for electrification ▪ Addressing heat pump refrigerant leakage and high global warming potential refrigerants

It is important to note that the MURB sector is not monolithic as it includes private rental, market condos, and a range of different forms of social housing. Each of these sectors within the MURB sector have different needs, perspectives, and goals on building electrification. MURBs in different regions in the province also have different building electrification considerations, including priorities for accessing air conditioning, need for cold climate heating systems or auxiliary heating solutions.

7.1 PROGRAMMATIC CONSIDERATIONS (GOVERNMENT AND UTILITY) TO SCALE UP MURB ELECTRIFICATION

Expand and Improve Rebates and Incentives for MURB Electrification

Financial rebates and incentives are a common tool used by utilities and governments to motivate building owners to undertake home and building energy retrofits and by contractors to sell their preferred retrofit services. Financial incentives reduce the capital cost of upgrades, reduce the financial payback timeline, create a more favorable return on investment and provide financial motivation for participants to retrofit.

Comparing the rebates available for gas mechanical system upgrades and fuel switching from gas to electric mechanical systems highlights several important differences.

1. **There are different levels of accessibility and complexity between building natural gas upgrade rebates and electrification rebates.** For example, gas upgrade rebates are prescriptive and electrification rebates are performance. Prescriptive rebates are when the provider prescribes a certain dollar amount to each upgrade as a flat rebate or as a dollar amount by an easy to determine factor (size and thermal efficiency of a system). Performance rebates are more complicated and require more complex calculations to be able to determine the rebate amount. Prescriptive rebates are easier to communicate, easier for participants to understand and importantly easier for contractors to sell. There are good reasons why the electrification rebates are performance rebates – but more work needs to be done to make the prescriptive rebates easier to understand and for contractors to sell.

2. **The electrification rebates offer different rates and maximum dollar values based on different electrification solutions:**

    - For heat pump rooftop units, the rebate rate is \$60/t C02e of lifetime GHG savings up to \$72,000 per project.

    - For other solutions, the rebate rate is \$40/t C02e of lifetime GHG savings, the program will support up to \$48,000 per project.

    This difference in rebate rates and maximum rebates may encourage building owners to select an electrification retrofit solution that might not be the best solution. From input provided through this project research make up air rooftop heat pump units might be less likely to deliver expected energy and greenhouse gas savings (due to overreliance on auxiliary heating systems and other factors). In these cases, a higher rebate might be provided to a technology option that is less likely to deliver the intended results.

3. **Gaps in Rebates/Incentives:** There may be some key gaps in rebates between what is available for natural gas and electrification and what could be needed to accelerate electrification retrofits.

a. The gas upgrade rebate structure includes a 'Right Sizing Bonus,' while no rebate for right sizing is available for electrification projects. The adequate sizing of heating systems, of all types is critical to the effective functioning and efficient performance of the system.

b. There is no rebate or incentive for electrical service upgrades for MURBs. For example, in the CleanBC and Home Renovation Rebate Offer there is an electrical service rebate for single family detached and attached homes. Electrical service upgrades are a cost barrier for MURB electrification. See Section 5.6 (Table. 6) for a summary of electrical service upgrade costs.

c. In 2022 there was no prescriptive rebate option for in-suite MURB air source heat pump retrofits. Rebates may be introduced in 2023-2024.

d. Higher rebates, or top-up rebates, should be introduced for heat pump technologies using low global warming potential refrigerants.

Table 11 provides a summarized breakdown of the rebates available (as of fall 2022) for MURB retrofits.

Table 11: Summary of Rebate Offers – FortisBC Natural Gas Upgrades and CleanBC Electrification

	Incentives	Description	Units of Rebate	Amount
Natural Gas Upgrades	FortisBC Natural Gas Boiler Rebate	Upgrade to eligible high-efficiency hot water natural gas boiler.	Incentive amounts determined by size (in 1,000 Btu/hour or MBH) and thermal efficiency (TE) of the natural gas boiler.	90% Thermal Efficiency (TE) or higher= $9/MBH, max of $45,000/boiler. 85%-89.99% TE=$4/MBH, max of $20,000/boiler.
			Right Sizing Bonus: Qualified boilers can get this bonus if sized in accordance with FortisBC guidelines	Right sizing bonus is lesser of the invoiced amount: -or $500 for systems with input rating of 1,500 MBH. -or $1000 for systems with input rating of 1,500 MBH or higher
	FortisBC Commercial Natural Gas Water Heater Rebate	Upgrade to eligible high-efficiency natural gas commercial water heater.	Incentive amounts determined by the size (MBH) and thermal efficiency (TE) of the water heater.	Storage tank water heater (90% TE and higher) -Up to 199.90 MBH= $1,000/unit -200-399.99MBH= $2,000/unit -400MBH & higher= $3,000/unit Hot water supply boiler (90% TE and higher) =$9/MBH High-efficiency tankless water heater=$1,000/unit
	FortisBC HVAC Controls Rebate	Install controls on your HVAC systems to help you run your building more efficiently and reduce maintenance costs	Available rebates: -Connected thermostats -Domestic hot water recirculation controls -Hydronic additives	-$40/connected thermostat/unit -$1,500/domestic hot water recirculation controls/unit -$200/hydronic additives/gallon
Electrification	CleanBC Custom-Lite Program	Help building owners and operators reduce greenhouse gas (GHG) emissions in their existing commercial buildings. facilitate smaller electrification opportunities across the commercial and institutional building sector.	Rebate based on a rate of $/tonne C02e of lifetime GHG savings. Different levels of rebates based on technology	Based on a rate of $40/t C02e of lifetime GHG savings, the program will support up to $48,000 per project. For heat pump rooftop units, the rate will be $60/t C02e up to $72,000 per project.

	CleanBC Custom Program	Offers energy study funding and capital incentives for fuel switching and other electrification measures.	Rebate based on a rate of \$/tonne C02e of lifetime GHG savings. Different levels of rebates based on technology	Based on a rate of \$40/tCO2e of lifetime greenhouse gas savings, CleanBC will support up to \$200,000 per customer. For heat pump rooftop units, the Program offers a rate of \$60/tCO2e of lifetime greenhouse gas savings.

Recommendation: Review financial incentives and incentive program terms and conditions to:

A. Ensure streamlined access to MURB electrification rebates.
B. Provide higher incentives for technologies most likely to deliver GHG emission reductions.
C. Fill gaps for non-incentivized heat pump technologies.
D. Ensure adequate financial incentives are available for electrification, to facilitate cost effective projects.

Make it Easier to Access MURB Retrofit Incentive Programs

There are a variety of different programs that offer rebates and incentives that may be applicable for building electrification for MURBs. Programs include, but are not limited to:

- CleanBC Custom Light
- CleanBC Custom
- Green Municipal Fund/Community Housing Fund
- Green Municipal Fund/Sustainable Housing
- Social Housing Retrofit Support Program (SHRSP)
- Social Housing Incentive Program
- CMHC Preservation Funding for Community Housing
- CMHC Repair and Renovation Fund (CRF)
- Natural Resources Canada – Greener Homes (MURB)

Building owners, industry and other stakeholders consulted for this report explain that the programs are difficult to understand and work with. While some of the programs are 'stackable' (meaning participants can access incentives or rebates from both programs), for many there are different terms and conditions, timelines, goals, and non-stackable requirements and limits. For some of the programs the processes and implementation timelines are either too long or too short limiting options for many buildings to utilize. As of fall 2022, there is no developed documentation available for stakeholders to clearly understand all the program offers that may be available. Consultants and organizations engaged in supporting building electrification invest moderately high amounts of time and costs in understanding rebate program offers, which makes programs and services more expensive. As a result, stakeholders in BC are likely not maximizing access to all the rebate programs supports that could support acceleration of MURB electrification.

Recommendation:

A. Support the development of communications materials and training that helps stakeholders understand how they can maximize access and rebates from the available programs that support MURB electrification. These materials should include: comparison of eligibility criteria (building types, retrofits supported), stackability with other programs, timelines for applying, requirements for applying, etc.
B. Introduce programs that offer MURB energy coaching or concierge support to understand and access the variety of rebate and incentive offers.

These recommendations align with the Building Energy Road Map Action 2.10: Support a Retrofit Coordinator Program.

Provide More Electrification Retrofit Planning and Implementation Support

The process of conducting a building electrification retrofit has many steps and can be technically complex. At the current early stage of market adoption in BC there is very limited stakeholder (building owners, consultants, and contractors) knowledge about the process and steps involved in supporting the implementation of a successful MURB electrification project. For example, the steps can include, but are not limited to: identification of retrofit options, electrical capacity analysis, technology selection, identification of rebates, development of design specification for appropriate, and right-sized, electrification options, tendering upgrade with qualified contactors, quote review, support with permits, oversee installation, verification of system commissioning, support with rebate applications, etc.

As of fall 2022, as summarized in Tables 12 and 13, despite electrification projects being more complex, there is significantly more implementation support available for buildings planning on upgrading low/mid-efficiency gas mechanical equipment with high efficiency equipment than what is available for a building to upgrade to electric mechanical equipment. While there is a higher dollar amount available from CleanBC (up to $20,000), CleanBC only provides up to 50% of support costs while FortisBC provides up to 100%.

Table 12: Summary of Differences Between Electrification and Gas Retrofit Implementation Support

<table>
<tr><th colspan="2">Summary of Differences Between Rebate Programs Offers</th></tr>
<tr><td>FortisBC Programs
▪ Rental Apartment & Accommodations Program (RAP)
▪ Commercial Energy Assessment Program (CEAP)</td><td>The CleanBC Programs
▪ Custom
▪ Custom Light</td></tr>
<tr><td>• Support for a more straight forward, like-for-like, upgrade of a less efficient natural gas system to a more efficient natural gas system.
• Action orientated supports are easy and quick to access and <u>are provided at no cost</u> to building owners:
o 100% of the cost of an energy assessment to identify building upgrade opportunities (valued over $3,000).
o 100% of the cost for free mechanical engineering implementation support (valued over $6,000).
• Offer prescriptive rebates. The dollar value of the prescriptive rebates can easily be determined and communicated to the participating buildings by consultants or contactors. No analysis and engineering work is required to determine incentive amount.</td><td>• Support for a more complicated fuel switch retrofit that may require electrical capacity assessments, electrical upgrades and more detailed mechanical engineering design.
• <u>Provide only partial financial support</u> for energy studies that may have a longer timeline:
o Custom Light: 50% of the cost of an energy study, up to $2,000
o Custom: 50% of the cost of an energy study, up to $20,000
• No funding specific for mechanical engineering design is available for MURB electrification (although it could be included in the study funding).*
• Offer performance rebates. The dollar value of the performance rebate is more complicated for consultants and contractors to communicate to potential participants.

*Note: Some implementation support is available for social housing through the BC Non-Profit Housing Association.</td></tr>
</table>

Table 13: Details of Program Support – CleanBC Electrification

	Program Name	Energy Study	Implementation Support	Rebates	Other Notes
Electrification	CleanBC Custom-Lite	Up to 50% funding for an energy study up to a maximum of $2,000. In contrast, natural gas programs provide fully funded studies	Implementation support (e.g., engineering, tendering, business case development) not provided. In contrast, natural gas programs provide fully funded implementation support.	Custom Capital Funding Incentives: Based on a rate of $40/t C02e of lifetime GHG savings, the program will support up to $48,000 per project. For heat pump rooftop units, the rate will be 60/t C02e up to $72,000 per project	
	CleanBC Custom	Up to 50% funding for an energy study up to a maximum of $20,000. In contrast, natural gas programs provide fully funded studies	Implementation support (e.g., engineering, tendering, business case development) not provided. In contrast, natural gas programs provide fully funded implementation support.	Custom Capital Funding Incentives: Based on a rate of $40/tCO2e of lifetime greenhouse gas savings, CleanBC will support up to $200,000 per customer. For heat pump rooftop units, the Program offers a rate of $60/tCO2e.	One of the eligibility requirements is that you must have a BC Hydro Key Account Manager. Use of Energy Star Portfolio manager is required for benchmarking purposes. For some projects that meet Measurement and Verification criteria, an M&V plan will be included in the Incentive agreement before implementation.

Recommendation: Develop programs to provide various levels of energy assessment and implementation support needed to enable MURB electrification. The program supports should be sufficiently robust to make the process relatively easy for owners/managers. Supports could include: building electrification advisors, various levels of energy assessments, electrical service capacity assessments, technical assistance with implementation of fuel switch retrofits, applying for rebate applications, and post-installation follow up.

Integrate or Align EVSE and Building Electrification Rebates and Programs

The Province of BC has progressive emissions reduction targets. Electrification of both the building and transportation sector has been identified as a key strategy to achieving these targets.

A challenge of meeting emissions reductions targets in both sectors is that most existing MURBs have limited electric power capacity available for electrification. There is a fundamental conflict for this available electrical resource between electrification of space heating, cooling and domestic hot water and providing electrical vehicle charging for personal vehicles. Since the electrical capacity of any existing building is limited, any electrification upgrade will compete for the same available capacity. However, current rebate and support programs for building space and water heating electrification and electric vehicle supply equipment (EVSE) are not integrated in a way that allows stakeholders to plan for, budget for, or adequately prioritize their long-term building electrification needs:

For example:

- Building energy efficiency and electrification programs such as Clean BC's Custom or Custom Light program are aimed at building retrofits but have no integration with EVSE programs.
- Current EVSE programs under the Clean BC- Go Electric EV Charger Rebate Program (funded by the Province of BC) provide incentives to support the electrical design to accommodate charging stations and install EVSEs but exclude any analysis of electrical capacity needed for upgrades not related to EVSEs.[13]
- Up to $3,000 (or 75% of the costs) plus local government top-ups is available for MURBs to create an **EV Ready Plan** to guide decision making on EVSE. The EV Ready plans do not take into account the electrical capacity that could be needed for other building electrification.
- The Plug In BC - EV Advisor Service provides free advice on EVSE installation and programs but does not provide information on the electrical capacity needs for building electrification.[14]
- Licensed electricians contacted to provide an electrical capacity assessment for EVSEs, are not being hired to do an electrical capacity assessment for electrification of space and water heating.
- Companies installing ESVE equipment have a business objective to sell ESVE equipment and are not taking other building electrification needs into consideration.

As of 2022, the creation of *EV Ready Plans* has taken priority over the creation of *Building Electrification Ready Plans.* Best practices call for electrical capacity assessments and electrical infrastructure upgrades to a building should be planned together or there are risks that whichever installation occurs first will be the upgrade that uses the available electrical capacity.

If not analyzed together, there will often be additional personal, building owner, organizational, strata or government costs of having to modify recent electrical upgrades when additional electrification upgrades are needed. For example, if a building upgrades the electrical infrastructure to install EVSE one year and then a few years later initiates a plan to install electric space heating/cooling and/or electric hot water heating they will likely need to upgrade their electrical infrastructure again. The combined electrical upgrade

[13] "CleanBC - Go Electric EV Charger Rebate Program." CleanBC, https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/electric-vehicles/EV-incentive-program-guide.pdf

[14] "EV Advisor Service for Strata and Workplaces." Plug In BC, https://pluginbc.ca/ev-advisor-service/

costs of two upgrades may be higher than if the electrical upgrade was planned and implemented at one time.

Good planning should allow for both heat pumps and EVSEs. When deciding where to focus resources, consideration should be given to the fact that the provision of cooling in a MURB (by way of a heat pump) can be a life safety issue, particularly for vulnerable populations. Thankfully, where capacity is limited, load management technologies can be used. When using such systems, decisions will need to be made regarding which systems to prioritize. Generally speaking, EV charging can be made secondary so that the heating system takes precedence when required.

In the June 2022, Engineers and Geoscientists of BC (EGBC) "Electrical Considerations for Decarbonizing Existing Part 3 Buildings" a new Practice Advisory was introduced for engineers to consider the holistic, long-term planning for current and future electrical needs and implications for load planning, utility and peak demand-side management, and resiliency.[15] Although this Practice Advisory provides a solid foundation to guide the work of engineers to consider full electrification of building systems and making buildings EV ready, engineering firms providing fee-for-services only undertake the analysis for what they are hired to do. In the case of the EV Ready programs, engineers only provide electrical capacity analysis on a specific electrification measure – EV charging, rather than both EV charging and building mechanical system electrification.

Recommendation:

A. Explore options to integrate, or align, rebate programs for building system electrification and electric vehicle supply equipment in a way that allows stakeholders to plan for, budget for, and adequately prioritize their long-term building electrification needs.
B. Support the development of a Building Electrification Ready Plan program with an emphasis on long term planning for full building electrification and load management. Programs could include funding for electrical capacity assessments, provide building electrification ready advisors, incentivize electrical upgrades, and align EV charging station and building electrification incentives.

Streamline Electrical Capacity Calculations to Reduce Time, Cost and Complexities

MURB electrification projects always require an electrical capacity assessment to determine if the building's electrical infrastructure can support the new equipment.

[15] "Practice Advisory Electrical Considerations for Decarbonizing Existing Part 3 Buildings." EGBC, June 16, 2022, https://www.egbc.ca/app/Practice-Resources/Individual-Practice/Guidelines-Advisories/Document/01525AMW5K7OKYS6AQCZFYXR4QVJBNKNMH/Electrical%20Considerations%20for%20Decarbonizing%20Existing%20Part%203%20Buildings

Currently there are no clear, straightforward methods on to how to calculate the available electrical capacity of an existing MURB in BC, particularly challenging when the utility cannot provide historical peak kW demand.

The challenges and complexities of performing electrical capacity calculations lead to professionals doing calculations in different ways, with different levels of effort and cost (and possibly accuracy). The estimated cost range is between $3,000-$7,000 per electrical load study without sub-metering. The uncertainty of how to apply certain Canadian Electrical Code rules tends to result in more conservative calculations and the risk that any deviation/interpretation can result in BC Hydro reviewers and/or the inspector overseeing the electrical permit for the upgrade rejecting the calculations, which can put the whole retrofit at risk. Ultimately all these challenges extend the length and cost of electrification retrofits.

See *Appendix C: Calculating Electrical Capacity* for further discussion on this topic.

Recommendation: Authorities Having Jurisdiction (i.e., municipalities, or Technical Safety BC) in collaboration with the electrical utilities should work to issue a bulletin explaining *the acceptable approach to calculate electrical capacity for existing MURBs*, especially when utility-metered peak kW is not available. This will not only save building owners time and money it will also streamline the Authority Having Jurisdiction and the utility's own review process as they would get consistent submission of electrical calculations.

Validate MURB Electrification Post-Retrofit Performance and Savings

MURB electrification projects are very new in BC. To ensure GHG savings and expedite industry knowledge growth, post-install billing analysis should be mandated for every project after 6 months, 12 months, and every year following. Based on a major finding of this report identifying the prevalence of over-use of auxiliary gas in hybrid systems this should be a high priority.

Evaluations should be conducted to gather feedback that can inform MURB electrification program design, mechanical design strategies, and validate the persistence of energy savings and greenhouse gas emission reductions over time. Evaluations, assessing the real-word performance of retrofits through billing analysis, can be used to highlight the most cost-effective and appropriate electrification technologies as well as better system designs and improved installation procedures. Major building owners interviewed for this project identified that whenever building electrification is undertaken there should be ongoing, and regular, evaluations to assess the performance and operation of the retrofit and ensure the heat pump is operating efficiently.

One major building owner representative said "*whenever we do electrification, we should do 6-month, 1-year, and ongoing verifications – a continuous optimization program. No-one has done a critical performance review of* *electrification systems – with noise, heating & cooling performance, integration with existing building management systems*."

Recommendation: Introduce regular evaluation on MURB electrification retrofits to validate the persistence of energy savings and greenhouse gas emissions, inform retrofit program design, identify contractor and mechanical engineer training opportunities, and continually improve MURB electrification retrofit programs.

Staging (and Bundling) Building Enclosure and Electrification Retrofits

While building electrification has been identified as a strategic priority for the Province of BC, with a focus on switching off fossil fuels and onto electricity for space and water heating, some stakeholders are calling for wholistic-whole building (various depths) approach to MURB retrofits rather than a 'just add heat pumps' approach. Advancing whole building electrification solutions was a key recommendation of the BC Building Energy Road Map (Action 2.1) "The existing CleanBC fuel switch incentives offer a good start in this regard, but to make these incentives more effective in terms of their uptake, incentive amounts should be increased and expanded to include **whole building electrification** solutions. This is especially important for older existing buildings, as their overall heating loads will likely require significant reductions before high-efficiency electric solutions become a realistic option for them to consider."[16]

Staging retrofits, or splitting a retrofit into stages, can get a building started on an energy retrofit path, prior to space and water heating systems reaching end-of -life. Bundling retrofits, or combining multiple retrofits at one time, can better deliver energy savings and greenhouse gas emission reductions and allow for retrofit synergies. This activity aligns with BC's Building Electrification Roadmap (Action 2.1), "help home and building owners" to prepare for a fuel switch well in advance."[17] Opportunities and benefits of staging and bundling MURB retrofits to enable building electrification include, but are not limited to:

- Start with smaller capital projects first – such as sealing suite doors and eliminating air leakage between suites and common areas and suites and the exterior. Air sealing provides the multiple benefits of reducing entry of heat, cold, pests, noise, dirt, odor transmission, and wildfire smoke.
- Electrifying on suite turn-over. When the suite turns over from one tenant to another, landlords often invest in drywall and paint renewal, new flooring, kitchen and bathroom cabinets and plumbing, upgraded electrical outlets and switches and suite panels. Additionally, they may consider adding in-suite laundry, kitchen appliances and air conditioning. This is an ideal time to add heat pumps and decommission existing hydronic baseboards. FRESCo is currently working on methodology for doing this in projects, as it is not well established.

[16] British Columbia's Building Electrification Roadmap, March 2021. https://www.zebx.org/wp-content/uploads/2021/04/BC-Building-Electrification-Road-Map-Final-Apr2021.pdf

[17] Ibid.

- Bundling in-suite electrification retrofits including: Installing a heat recovery ventilation system and an in-suite air source heat pump.
- Upgrading appliances (fridge and stove) to more efficient models.
- Staged time of replacement mechanical system retrofits (space and water heating).
- Planning for building envelope upgrades or remediation, such as window, insulation, and air sealing upgrades, prior to heating system electrification. For example, many older MURBs are undergoing window upgrades. New building code improvements call for fiberglass frames resulting in a significant energy efficiency improvement over the original windows. By creating staged MURB retrofit plans that take into consideration both building envelope upgrades and heating system upgrades, stakeholders can reduce building heating and cooling demand prior to installing new right sized mechanical equipment. Upgrading the mechanical systems prior to building retrofits may result in oversized equipment with poor performance and higher operating costs.

Recommendation:

A. Develop best practices for in-suite MURB electrification on tenant turn-over.
B. Develop a process for gradual retirement plan for existing systems as well as long-term analysis of electrical upgrade options.
C. Investigate options for making it easier to collect building level data to enable whole building retrofit planning.
D. Develop best practices MURB electrification retrofit guides highlighting the options, process, and benefits of and bundled retrofits, with specific guidelines on how to air seal and ensure appropriate ventilation systems in MURB suites and buildings.
E. Engage stakeholders to design comprehensive MURB whole-building retrofit/electrification incentive and implementation programs that promote and support both staging and bundling of MURB building retrofits of various depths.

Introduce Comprehensive Program Requirements to Ensure Hybrid Systems Deliver Anticipated GHG Emission Reductions

Over-use of auxiliary heating in hybrid heat pump/gas systems was reported in multiple projects researched for this project, identifying that hybrid systems may not be meeting the decarbonization intent and GHG savings expected of the retrofit. Hybrid make up air units, central domestic hot water and central space heating systems are all susceptible to this issue.

Recommendation:

A. Measurement and verification should be completed on past projects that have received rebates for hybrid system installations to identify the extent and causes of the issue and to inform program and training design.
B. Best practices training in the design and installation of hybrid systems should be introduced. Engineers and contractors supporting clients to access rebates for hybrid systems should be required to take this training.
C. Startup commissioning and a sign-off on expected GHG savings should be introduced as a requirement of accessing CleanBC funding.
D. Consider energy benchmarking reporting through ENERGY STAR Portfolio Manager for all projects.
E. Provide more technical implementation support and higher rebates for full electrification retrofits (as compared to hybrid retrofits) to acknowledge the additional time and costs that may be associated with full electrification (i.e., electrical capacity assessments, mechanical design, etc.).

Introduce Industry MURB Electrification Training

See 7.3 Build Industry Capacity for MURB Electrification Retrofits (Contractors and Engineers) for summary of issue and recommendation.

7.2 POLICY CONSIDERATIONS (GOVERNMENT & UTILITY)

Provide Owners and Industry with Access to Energy (Eletric/Gas) Data to Enable MURB Electrification

Lack of access to whole-building electrical demand data is a <u>critical barrier</u> to building electrification.

Typical MURBs do not have a main electrical meter, the electricity is metered by both a *'common or house' meter account* owned by the building owner or strata and by an *individual suite meter accounts* owned by each resident.

Accessing the required data is quite difficult and time consuming:

- Utilities only provide access to electrical consumption records online for individual account holders. There is no ability for a building owner, strata, or other stakeholder to access the overall consumption of their building online.
- BC Hydro will only provide aggregated data from suite meters due to privacy policies.
    - Buildings with greater than 10 suites can be aggregated through Energy Star Portfolio Manager. This process takes up to 2 weeks, only provides monthly kWh consumption and

    does not always provide reliable data. Any discrepancies in data leads to lengthy back and forth email communication between the utility and the stakeholder.

  - For other buildings with fewer suites, or when requesting demand data, requests can be made via email. This process takes at least 1 month. The data provided is not always clear leading to back-and-forth email communication to resolve.

- Fortis Electric does not have a suite aggregation procedure, instead it requires every suite account owner to sign a release form in order to provide suite data, then submit it over email and wait several weeks before receiving an answer. This is impractical as it requires a time intensive and costly process to survey all suite owners and access permission. It often results in suite data with different billing periods which is extra work to aggregate.
- Demand in kW is not measured or provided at all by many utilities (smaller BC Hydro & FortisBC accounts, New Westminster Electrical Utility and Fortis Electric), forcing those analyzing electrical consumption to rely on more conservative calculations rather than real measured data.

Anecdotally, owners and residents seem to consistently have no concern with energy bill privacy and readily provide consent for access to energy data. Conversely, there appears to be a high level of concern for energy consumption privacy at the level of government and utilities and even with owner consent the processes to access the data are complex and time consuming.

Energy data is needed to:

- Determine if building has sufficient electrical capacity for Low Carbon Electrification (LCE) retrofits.
- Analyze energy baseline to calculate energy and GHG emissions reductions anticipated from a MURB electrification retrofit.

The time and cost associated with accessing data can double the costs of consultant analysis work. Without standardized ways to get tenant consent and quick access to energy data, MURB electrification projects can be stalled or potentially overlooked as a viable alternative, especially in a situation where equipment is failing and needs to be replaced on a short timeline.

Recommendation: To support the work needed to accelerate MURB electrification, streamlined processes, and/or regulations should be introduced, to enable easy access to energy utility data for all meters in a building. Additionally, Kilowatt demand metering should be enabled for all rates.

Valuation of Life Safety and Non-Energy Benefits

Traditionally in an *energy conservation measure business* case and in *utility cost effectiveness tests,* life safety and other participant non-energy benefit considerations are not appropriately valued. Improvements such as air conditioning, smoke filtration, improved ventilation, and occupant comfort, health and safety are not given a monetary value and do not contribute to the cost effectiveness of a retrofit. For example, FRESCo has been asked to include the anticipated increase in electrical consumption (kWh) from air conditioning in energy conservation measure reporting, but not to add a "benefit" to the "total savings" column. This leads to distorted decision making where energy conservation is measured without taking into consideration important health and safety considerations. The full value of efficiency and MURB electrification becomes significantly understated and financial analysis shows a reduction of payback and return on investment – negatively affecting decisions to electrify a building and improve life safety.

Recommendation: To support the work needed to accelerate MURB electrification, regulators, utilities, and other funders should explore options for methodologies for rebates to better reflect life safety and other non-energy benefits of electrification (e.g., the value of cooling in a heat pump retrofit).

Mechanical and Other End-of-Life Replacements as a Regulated "Electrification Trigger"

Mechanical end-of-life is currently the main trigger for electrification as identified in the projects in this study and as experienced by FRESCo in the field. Building off the potential of this opportunity, mechanical end-of-life replacement as an "electrification trigger" has been put forward by Provincial legislation and the City of Vancouver.

- According to the CleanBC Roadmap to 2030, "*after 2030, all new space and water heating equipment sold and installed in B.C. will be at least 100% efficient, significantly reducing emissions compared to current combustion technology. Electric resistance technologies like baseboard and electric water heaters are 100% efficient: they convert all the energy they use into heat. But heat pump technologies exceed 100% efficiency by capturing and moving ambient heat, without having to produce it. The new requirements will encourage more people to install electric heat pumps while continuing to allow the use of electric resistance technologies. They will also allow hybrid electric heat pump gas systems and high-efficiency gas heat pumps*." [18]
- According to the City of Vancouver, "the Climate Emergency Response big moves commits that by 2025, all new and replacement heating and hot water systems will be zero emissions."[19]

However, it is important to note the at the point of emergency replacement of heating systems in the winter it can be extremely challenging to electrify a building. There are a variety of steps that need to occur before a MURB can switch from gas to electric heating. Processes need to be put in place to allow for building owners and managers to plan ahead for building electrification.

[18] CleanBC Road Map to 2030, https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_roadmap_2030.pdf

[19] City of Vancouver website, November 29, 2022, https://vancouver.ca/green-vancouver/zoning-amendments-to-support-climate-emergency.aspx

Other building upgrade triggers include:

When **building envelopes** are upgraded (cladding, insulation, and air sealing) prior to, or alongside, a heating system upgrade there are opportunities to reduce the heat load of the building, right size the heating system and incorporate building penetrations for heat pump into the larger renovation.

Window upgrades are an ideal time to consider electrification. Window replacements occur often in our older MURB stock, and most are *not* part of a larger enclosure upgrade. Owners replace windows because of safety, condensation damage, comfort, and noise concerns. FRESCo projects in process have proposed use of window penetrations for All-In-One direct heat pump air exchange, HRV's and line-sets. Window size on older MURBs is often much larger than required and there is good potential to reduce enclosure penetration costs by combining heat pump installations with window upgrades.

PCB Transformer cleanup and replacement of leaking transformers is another potential trigger. A calculation of power level for electrification could be required when any transformer needs replacement, and replacement with a larger transformer could be considered. In one site FRESCo is involved, due to lack of foresight and communication in the owner's team, the transformer was *downsized* just prior to commencement of our electrification project. Now, due to requests from residents, they are adding electric car charging and planning for electrification.

Major renovations spurred by building renewal, fire or water damage are also an ideal 'trigger' for building electrification. Whenever there is major work being done on the building there is an opportunity to introduce a fuel switch into the renovation.

Recommendation: Stakeholders and regulators should explore all options for mechanical system end-of-life replacements (and other retrofits) to be 'triggers' for building electrification. To provide the foundation for mechanical system end-of-life replacements to be successful as an 'electrification trigger' processes must be put in place that enable building owners or managers to plan ahead with sufficient time to organize the most appropriate and cost-effective retrofit. This would require information on the age of gas mechanical systems in all buildings to be collected, the replacement year to be estimated and the details on the steps to electrification to be provided to the building owners or managers. This information could be collected by local governments or other stakeholders and the collection mechanisms could include, but are not limited to, depreciation reports, energy benchmarking programs, utility rebate programs, dedicated third party services designed to collect the information, and other options.

Streamlining and Standardizing Permits/Bylaws MURB for Electrification

With electrification projects there is increased complexity for planning, designing, and permitting relative to more conventional fossil-fuel fired equipment retrofits. Currently, the permitting process for electrification retrofits is not straight forward and varies greatly by municipality. The costs for electrification retrofits can be significantly more than the cost for like-for-like gas heating system upgrades. This added complexity and uncertainty of costs, effort and timelines often incentivizes building owners and contractors to replace building systems with moderately more efficient versions of the system they currently have, since like-for-like replacements simply require a trades permit.

Both the CleanBC Roadmap to 2030 (Province of BC 2021b) and the Building Electrification Roadmap (Integral Group 2021) have identified that the streamlining of permitting processes to support low-carbon and electrification projects is a key priority that will proactively require collaboration with regulatory agencies, the province of BC, utilities, and local governments.

Permit related considerations for MURB electrification projects include, but are not limited to:

1. **Costs of Electrical Permits:** MURB fuel switching permits can cost more and have longer timelines than permits required for like-for-like gas system upgrades. See below for an example of a process and cost streamlining from the City of Vancouver.

2. **Local Noise Bylaws:** May provide guidance on heat pumps. These bylaws should be investigated to determine if they are unnecessarily limiting heat pump installations. Guidance, and possibly incentives, could be provided on the heat pump technologies that can meet noise bylaw requirements. Lower noise heat pump systems and installation best practices for reducing the noise impacts of heat pumps are available, but often not utilized.

3. **Building Height and Sightlines:** Development permits of variances can be required for electrification designs that impact building height or sightlines (i.e., variable refrigerant flow heat pump rooftop installations). Processes can be investigated to streamline variance approvals and/or alternative heat pump technology options can be promoted that do not require rooftop installations.

4. **Structural Load:** Rooftop or deck installation of heat pump can lead to a requirement for a building permit.

5. **Building Envelope Penetrations:** Installations of heat pumps will almost always require a penetration through a roof, floor or wall and vapour barrier. Standardized guidance should be provided for sealing all types of building envelope penetrations.

An example of a streamlining of process and cost reduction for an electrification permitting process is provided below. In this example, the permit costs for upgrading a heat pump make up air system was reduced from $5,635 to $1,900, which is a significant reduction in cost (but still not as cost-effective as a $300 gas MUA upgrade permit).

In July of 2022 the City of Vancouver led by example by releasing a new mechanical permit process for the installation and replacement of heating and cooling systems for new construction and existing buildings.

Permitting Example: Replacing a gas MUA with a more efficient gas MUA.
Estimated Cost of work $200,000.

Approximate Costs:

- Electrical permit: $200
- Gas permit: $100
- **Total permit cost: $300**

Effort & Complexity: Low, contractor can pull the permits, no consultants are required to be involved.

Timeline: Approximately 1 month

Past (2019) Permitting Example: If upgrading gas MUA with a heat pump MUA System

Approximate Costs:

- Electrical permit: $1,000 (for work $10k - $50k)
- Gas permit: $100
- Building permit: $1,535 (confusing tiered price depending on project estimated cost)
- Letters of assurance (3 disciplines): $3,000
- **Total permit costs: $5,635**

Effort & Complexity: high, needed letters of assurance from different disciplines (structural, electrical, mechanical)

Timeline: Added about 8-12 months to the project (not including COVID-19 related delays)

Updated City of Vancouver Permit Example: Upgrade gas MUA with a heat pump MUA

Approximate Costs:

- Electrical permit: $1,000 (for work $10k - $50k)
- Gas permit: $100
- Mechanical permit: $800 (simple to estimate)
- **Total permit costs: $1,900**

Effort & Complexity: More requirements than a standard trades permit but the requirements are clearly outlined and easy to complete by a consultant providing the details to the contractor. Adds a requirement that contractors complete the Municipal Heat Pump Certification.

Timeline: Quick to get the mechanical permit online within days and then the same timeline for trades permits as any other project.

Recommendation: Stakeholders should convene to identify all potential permit, bylaw, and regulatory barriers to MURB electrification. Where possible streamlining of permitting should be undertaken with the goal of minimizing costs and shortening timeframes to access permits. Permitting cost, complexity timelines should aim to be lower than the costs for like-for-like upgrades. Where permit costs cannot be reduced sufficiently - incentives, or other supports, should be introduced to close the gap. Where appropriate, standardization of technical solutions should be provided (i.e., approved methodologies for sealing envelope penetrations) to limit additional engineering costs, permitting challenges, and time delays.

Addressing Heat Pump Refrigerant Leakage and High Global Warming Potential Refrigerants

Refrigerant used in heat pumps systems can have a high global warming potential (GWP) and refrigerant leakage could represent one of the larger contributors to climate change in the building sector. The refrigerant currently sold in most residential heat pump systems in BC is R410a, which has a high Global Warming Potential (GWP). R32 or R545 are being heavily promoted as "low GWP" replacements but still have GWP's of 700 or 600, more than 2 orders of magnitude higher than R290. While new refrigerants are rapidly emerging and promise to offer far lower GWP, each refrigerant and technology provides a different performance across the range of outdoor temperatures, and some have limited applicability to space heating or air conditioning.

Refrigeration mechanics with qualifications are required to make refrigeration connections, to initially fill or recharge units with refrigerant and to capture refrigerant from equipment at end of life. They also typically startup, trouble-shoot and repair units (which usually involves removing and/or adding refrigerant). Units which have all the refrigerant inside (such as CO2 DHW and other mono-block systems, AIO in-suite heat pumps) do not require refrigeration mechanics to install since no field refrigeration connections are required. Refrigeration mechanics make significantly higher income working on large systems (industrial processes, arenas, food processing and cold storage, supermarkets). Most building HVAC companies have at least one person with a refrigeration ticket. The market for refrigeration work on building HVAC systems is currently primarily only on roof top chiller units and air conditioning sections of air handlers. Most of the work for mini-splits is in detached homes, and is the province of smaller companies with smaller revenue. The work of retrofitting in-suite mini-splits in an entire apartment would more likely fit the profile of a construction contractor with a refrigeration mechanic on staff than the profile of a small general HVAC company.

Four of the key challenges related to addressing the issue of refrigerant leakage are:

- The amount of refrigerant leaked per system, or in total in the Province of BC, is currently unknown, as it is not measured or tracked and there are no enforcement mechanisms in place.
- The "phase out" of higher GWP refrigerants and the implementation of concrete actions to reduce refrigerant leakage have both been too slow.

- There is minimal industry, consumer, or stakeholder awareness of the low GWP refrigerants available, of the heat pump technologies that use the least refrigerant and are less prone to leakage, or of the installation practices to minimize or eliminate leakage.
- Few program mechanisms are being used to reduce and eliminate refrigerant leakage. For example, there are no incentives and rebates for low GWP refrigerant and lower risk of leakage heat pump options and, there is no specific refrigerant leakage training for contractors and no post heat pump installation refrigerant inspections being implemented.

Recommendation: A comprehensive multi-pronged strategy to limit the negative impacts of the use of refrigerants should be investigated. Easy to adopt strategy options should be implemented immediately while work on longer term solutions is developed. The strategy options include, but are not limited to:

A. Build stakeholder awareness about the refrigerant leak risks by heat pump system type. For example:
   - o Variable Refrigerant Flow (VRF): Higher risk for leakage due to large number of difficult to access connections and the larger amount of refrigerant in the system. In addition to GWP, this also has potential safety risks.
   - o Mini-Split Heat Pumps: Lower risk. Four refrigerant connections per head (plus joints in longer refrigerant lines.)
   - o All-in-One Heat Pumps: Lower leakage risk. No external refrigerant line connections.
   - o Semi-Central Monobloc: Lower leakage risk. All refrigerant located outdoors in a sealed unit.
   - o Central Hydronic Monobloc: Lower leakage risk. All refrigerant located outdoors in a sealed unit.

B. Promote, and incentivize, the available heat pump systems that use the lowest available GWP refrigerant. For example, CO_2 has very low GWP and is effective in heat pumps for domestic hot water. CO_2 can also work in heat pump MUA systems for tempering outdoor air in cold weather (eliminating the current practice of using gas for peak heating in MUA systems). It is important to note that although CO_2 has the very low GWP, its refrigerant cycle properties do not work well for space re-heating or cooling.

C. Where low GWP alternatives exist there should be a rapid phase out of poorer performing refrigerants and/or a market signal should be introduced through higher incentives for low GWP systems. For example,
   a. CO_2 heat pumps for domestic hot water can replace systems using higher GWP R410a and R32.
   b. E.g., R290 could be incentivized for larger refrigerant volume applications. R32 or R545 are being heavily promoted as “low GWP” replacements but still have GWP’s of 700 or 600, dramatically higher than R290, which has a GWP of 3.

D. Introduction of comprehensive contractor training on installation best practices for limiting and eliminating refrigerant leakage. This could include quick to implement training and exams for practical applications (such as how to install refrigerant line flare nut connections) to comprehensive refrigerant leakage reduction trainings for all types of heat pumps systems. Mandatory requirement for training on ongoing education can be based on the types of heat pumps systems installed, the risk of refrigerant leakage of that system type and the GWP of refrigerants used. For example, the training for VRF installations should be much more intensive, due high risk for leakage, than the training for All-in-One heat pump systems.

E. Utility rebate program inspections should consider a requirement for refrigerant leakage testing for installations on heat pumps technologies with higher refrigerant leakage risks.

F. Comprehensive systems should be introduced to prevent refrigerant leakage. Refrigerant use should be adequately regulated (including tracking and enforcement).

G. The responsibility of tackling the issue of refrigerant leakage and advancement of regulations and standards for use of refrigerant needs to be made a priority for the appropriate ministry of government in BC.

7.3 BUILD INDUSTRY CAPACITY FOR MURB ELECTRIFICATION RETROFITS (CONTRACTORS AND ENGINEERS)

Contractors

As of fall 2022, based on the number of MURB electrification retrofits that have been completed in the province and a FRESCo industry capacity scan, there is a moderately low level of contractor experience and capacity with MURB electrification retrofits in BC. However, contractor capacity could be dramatically increased with the introduction of the right supports, including: introducing more incentive offers for MURB electrification measures, introduction of installer training for MURB electrification, and enhancing consumer and industry awareness on the new technologies available for, and benefits of, MURB electrification.

A FRESCo industry capacity scan has identified several factors that highlight why there is relatively low capacity of contractors to accelerate MURB Electrification.

1. Limited specialized training in MURB electrification
2. Few contractors specializing in MURB electrification
3. (Relatively) New technologies on the market

Limited MURB Electrification Training:

The training programs for heating system and mechanical contractors have primarily focused on training for installations of heat pump systems for detached homes or commercial buildings. For example:

- **Heating, Ventilation, Air Conditioning and Refrigeration (HVACR) Technicians Training** is focused on building skills and qualifications for the installation of smaller residential heat pump installations applicable to detached homes. The Thermal Environmental Comfort Association (TECA) and Home Performance Stakeholder Council (HPSC) trainings are examples of this training for residential heat pump installation This workforce is primarily composed of small to medium contractors with pre-existing qualifications in plumbing, gas-fitting, sheet metal and HVACR controls. Much of this training is also applicable to MURB in-suite installations, but less so for MURB central heat pump systems.
- **Refrigeration Mechanic Training** is primarily intended to qualify people to work on large central chiller systems (i.e., supermarkets, ice rinks, industrial and other commercial applications). Individuals with this level of knowledge expect higher wages and expect more complex work than routine installations of mini-split heat pumps. In MURB applications, their knowledge is best applied to Variable Refrigerant Flow (VRF) heat pump system installations. However due to the limited application for VRF systems for retrofits and due to refrigerant leakage risks, VRF systems will likely not be the predominant system for MURB retrofits.

Market Scan of Industry Servicing MURB Mechanical Systems

An informal market scan, completed by FRESCo, to identify which mechanical system contactors have experience with electrification of MURBS, identified that most of the mechanical contractors and engineers providing retrofit services for MURBs have more knowledge, skills, and experience with selling services for upgrading gas hydronic systems. Few contractors have extensive experience with MURB electrification retrofits.

New Technologies

Within recent years there has been an introduction of a wide range of new heat pump technologies and innovations and improvements in the efficiency of other heat pump technologies. The advancements in heat pumps which do not require refrigeration connections (i.e., All-in-One Systems) are simpler to install and as a result could have a strong impact on contractor readiness, as the barrier to entry for a new business is comparatively low which could allow for quick diversification for existing contractors or the entry of new businesses into the market.

Mechanical Design Engineers

There is a relatively low level of capacity amongst engineers for MURB electrification retrofits in BC. Most mechanical engineers' experience has been with natural gas systems, particularly in retrofit scenarios. Examples of challenges include:

- Many engineers are risk adverse to recommending technologies they have limited experience with and advocate for options they are familiar with. End-users that are initially interested in heat pumps are likely to follow the engineer's recommendations and may end up dismissing heat pumps as a feasible option.
- It is common for lower performance, non-cold climate rated heat pumps (e.g., older single or two speed vertical axis type systems, or even discontinued systems) to be recommended even when the total cost difference between less and more efficient is relatively small.
- There is a tendency to include back-up or auxiliary heating in designs, even when unnecessary. This can increase costs and decrease overall savings.
- A focus on complex control systems that are not a good fit for many electrification strategies (e.g., heat pump systems that perform best without setbacks). If there is backup /auxiliary heating being used, controls are indeed required but the less complex they are, the more reliable.
- Lack of familiarity with heat recovery ventilation and tendency to specify older low efficiency HRV models.

Input from the Field: Engineers and MURB Electrification

BC is very fortunate to have many companies and engineers that are knowledgeable and interested in electrification. However, feedback from building owners and engineers interviewed on MURB electrification provides information on the need for education and awareness building for engineers. The more information the industry has on electrification technologies, electrification technical considerations, and best practices for mechanical design the more confidence the industry will have in proposing building electrification. Three examples are provided.

- One major building owner representative interviewed said, *"Many engineers tell me heat pumps won't work. Many have proposed non-cold climate rated units, and often even discontinued equipment when better, more cost-effective, equipment is available. Engineers often ask me what they should specify. One I asked to include heat recovery ventilation (in a building with a mold problem) and the engineer replied: "there is no such thing as heat recovery ventilation".*

- When a mechanical engineer was asked why he had quoted a client on an electric resistance DHW system instead of a CO_2 heat pump in January 2021 the engineer replied, *"I had the impression they are low volume, sort of custom systems. We're working for developers; we need to have 99% confidence it will work. Nothing's as good as gas, you just turn it on. … Now I've heard they are more plug & play and heard about the good COP of CO_2 heat pumps, I feel they will be more popular."*

- When a mechanical engineer, who has signed off on many installations, was asked what he thought about converting buildings from gas to electric – the engineer replied, *"You know, I'd be worried I'd get a call at Friday 5PM, saying it's not working, and I just don't want that call! Don't think I'd recommend it, I'd say "You know what? Don't do it!".* When speaking of a CO_2 DHW job which they were initially reluctant to accept, and was surprised to find worked well – the engineer stated *"I thought I was sticking my neck out a bit signing off on that… I expected that the gas boilers would have to run."*

Recommendation:

A. Engage stakeholders to develop comprehensive industry capacity building strategy to educate both engineers and contractors on the available technologies and best practices for designing and installing electrification technologies in MURBs. The acceleration of training for these sectors may need requirements and regulations to motive broad uptake.
B. Industry training should be as flexible as possible with resources and support to rapidly deploy training opportunities to address common installation issues associated with heat pump technologies. Examples of targeted training include: in-suite mini split heat pump systems, All-in-One systems, window mounted heat pumps systems, CO2 domestic hot water heat pumps systems, in-suite HRV's, ways to prevent long-term overuse of gas auxiliary in central hydronic systems and MUA's, mechanical design strategies to minimize demand charges, noise mitigation, how sizing, plumbing and control requirements are completely different from gas systems, etc.
C. Implement ongoing awareness building focused on successful MURB electrification retrofits to enhance industry understanding of the options and build confidence in the technologies.
D. Implement various forms of MURB electrification pilot and demonstration programs to build awareness of the options and opportunities and as real-life case studies to inform capacity building.

08

8: Conclusion and Summary of Recommendations

The electrification of MURBS in BC is still in early stages of development. There is much work to be done to fully understand the changing financial and technical considerations of MURB electrification and further explore, and begin implementing, the program, policy and industry capacity building recommendations made within this report.

LandlordBC, the industry leader for the residential rental housing industry in British Columbia that operates with the mission to support landlords and their rental businesses, has supported the development of this report. The information within this report will be used to inform LandlordBC activities, programs, education for members and advocacy for its members.

The broad network of other stakeholders (government, utilities, industry, housing providers) that will be involved in MURB electrification should be further consulted and convened to discuss the most effective options and opportunities for accelerating MURB electrification.

A summary of the key financial, technical, program, policy and industry capacity building findings and recommendations from this report is provided in Table 14.

Table 14: Summary of Recommendations

Financial Considerations	Recommendation
Standardized Building Electrification Database (Costing and Technical)	To accelerate building electrification, additional work must be invested in more deeply understand the costs and finding innovative ways to reduce costs. To streamline future financial (and technical) analysis of building electrification projects, FRESCo recommends that stakeholders collaborate to define a standard set of data points for tracking and reporting on electrification projects. This would facilitate more accurate and cost-effective analysis and improve stakeholder understanding of the costs associated with building electrification and the opportunities to reduce costs. Data points could include: defined building characteristics, fuel types per end use before and after retrofit, auxiliary fuel types, original utility rates, type and capacity of systems, emitter types, mechanical costs, electrical costs, service upgrade costs. This work could also explore how confidentiality can be protected while tracking and reporting on building and/or suite-level energy consumption.
Technical Considerations	**Recommendation**
Understanding the Technical Considerations for Each Building Electrification Option	There are many technical considerations for each building electrification retrofit technology. For stakeholders to be able to identify the most appropriate electrification technology for any given building it is important to have summarized information on each option to determine the: a) appropriateness of the technology for the building type and type of system it is replacing, b) benefits and other considerations of using the technology compared to other options, and c) cost-effectiveness of the technology (product and installation) compared to other options. The FRESCo MURB Electrification Technologies Fact Sheets represents a building block for the type of information that is needed to advance stakeholder understanding of the technical considerations for building electrification. Versions of these types of fact sheets could be develop the various stakeholders, including building owners and managers, mechanical designer and installation contractors.
Program Considerations	**Recommendation**
Expand and Improve Rebates and Incentives for MURB Electrification	Review financial incentives and program terms and conditions to: A. Ensure streamlined access to MURB electrification incentives. B. Provide higher incentives for technologies most likely to deliver GHG emission reductions. C. Fill gaps for non-incentivized heat pump technologies. D. Ensure adequate financial incentives are available for electrification, to facilitate cost-effective projects.
Make it easier to access to MURB Retrofit Incentive Programs	A. Support the development of communications materials and training that helps stakeholders understand how they can maximize access and incentives from the available programs that support MURB electrification. These materials should include: comparison of eligibility criteria (building types, retrofits supported), stackability with other programs, timelines for applying, requirements for applying, etc. B. Introduce programs that offer MURB energy coaching or concierge support to understand and access the variety of rebate and incentive program offers.

Provide More Electrification Retrofit Planning and Implementation Support	Develop programs to provide various levels of energy assessment and implementation support needed to enable MURB electrification. The program support should be sufficiently robust to make the process relatively easy for owners/managers. Supports could include: building electrification advisors, various levels of energy assessments, electrical service capacity assessments, technical assistance with implementation of fuel switch retrofits, applying for incentive applications, and post-installation follow up.
Integrate or Align EVSE and Building Electrification Rebates and Programs	A. Explore options to integrate, or align, incentive programs for building system electrification and electric vehicle supply equipment in a way that allows stakeholders to plan for, budget for, and adequately prioritize their long-term building electrification needs. B. Support the development of a Building Electrification Ready Plan program with an emphasis on long term planning for full building electrification and load management. Programs could include funding for electrical capacity assessments, provide building electrification ready advisors, incentivize electrical upgrades, and align EV charging station and building electrification incentives.
Calculating Electrical Capacity – Cost and Complexities	Authorities Having Jurisdiction (i.e., municipalities, or Technical Safety BC) in collaboration with the electrical utilities should work to provide *an acceptable electrical capacity calculator for existing MURBs*; this will not only save building owners time and money it will also streamline the AHJ and the utility's own review process as they would get consistent submission of electrical calculations.
Validate MURB Electrification Post-Retrofit Performance and Savings	Introduce regular evaluation on MURB electrification retrofits to validate the persistence of energy savings and greenhouse gas emissions, inform retrofit program design, identify contractor and mechanical engineer training opportunities, and continually improve MURB electrification retrofit programs.
Staging (and Bundling) Building Enclosure and Electrification Retrofits	A. Develop best practices for in-suite MURB electrification on tenant turn-over. B. Develop a process for gradual retirement plan for existing systems as well as long-term analysis of electrical upgrade options. C. Develop best practices MURB electrification retrofit guides highlighting the options, process, and benefits of and bundled retrofits, with specific guidelines on how to air seal and ensure appropriate ventilation systems in MURB suites and buildings. D. Engage stakeholders to design comprehensive MURB whole building retrofit/electrification incentive and implementation programs that promote and support both staging and bundling of MURB building retrofits of various depths.
Introduce Comprehensive Program Requirements to Ensure Hybrid Systems Deliver Anticipated GHG Emission Reductions	A. Measurement and verification should be completed on past projects that have received rebates for hybrid system installations to identify the extent and causes of the issue and to inform program and training design. B. Best practices training in the design and installation of hybrid systems should be introduced. Engineers and contractors supporting clients to access rebates for hybrid systems should be required to take this training. C. Startup commissioning and a sign-off on expected GHG savings should be introduced as a requirement of accessing CleanBC funding. D. Consider energy benchmarking reporting through ENERGY STAR Portfolio Manager for all projects. E. Provide more technical implementation support and higher rebates for full electrification retrofits (as compared to hybrid retrofits) to acknowledge the additional time and costs that may be associated with full electrification (i.e., electrical capacity assessments, mechanical design, etc.).

Introduce Contractor Training for MURB Electrification	A. Engage stakeholders to develop comprehensive industry capacity building strategy to educate both engineers and contractors on the available technologies and best practices for designing and installing electrification technologies in MURBs. The acceleration of training for these sectors may need requirements and regulations to motive broad uptake. B. Industry training should be as flexible as possible with resources and support to rapidly deploy training opportunities to address common installation issues associated with heat pump technologies. Examples of targeted training include: in-suite mini split heat pump systems, All-in-One systems, window mounted heat pumps systems, CO2 domestic hot water heat pumps systems, in-suite HRV's, ways to prevent long-term overuse of gas auxiliary in central hydronic systems and MUA's, mechanical design strategies to minimize demand charges, noise mitigation, how sizing, plumbing and control requirements are completely different from gas systems, etc. C. Implement ongoing awareness building focused on successful MURB electrification retrofits to enhance industry understanding of the options and build confidence in the technologies. D. Implement various forms of MURB electrification pilot and demonstration programs to build awareness of the options and opportunities and as real-life case studies to inform capacity building.
Policy Considerations	**Recommendation**
Provide Owners and Industry with Access to Energy (Electric/Gas) Data to Enable MURB Electrification	To support the work needed to accelerate MURB electrification, streamlined processes, and/or regulations should be introduced, to enable easy access to energy utility data for all meters in a building. Additionally, Kilowatt demand metering should be enabled for all rates.
Valuation of Life Safety and Non-Energy Benefits	To support the work needed to accelerate MURB electrification, regulators, utilities, and other funders should explore options for methodologies for rebates to better reflect life safety and other non-energy benefits of electrification (e.g., the value of cooling in a heat pump retrofit).
Mechanical and Other End-of-Life Replacements as a Regulated "Electrification Trigger"	Stakeholders and regulators should explore all options for mechanical system end-of-life replacements, building envelope, window, PCB transformer and major renovations to be 'triggers' for building electrification.
Streamlining and Standardizing Permits/Bylaws for MURB Electrification	Stakeholders should convene to identify all potential permit, bylaw, and regulatory barriers to MURB electrification. Where possible, streamlining of permitting should be undertaken with the goal of minimizing costs and shortening timeframes to access permits. Permitting cost, complexity timelines should aim to be lower than the costs for like-for-like upgrades. Where permit costs cannot be reduced sufficiently - incentives, or other supports, should be introduced to close the gap. Where appropriate, standardization of technical solutions should be provided (i.e., approved methodologies for sealing envelope penetrations) to limit additional engineering costs, permitting challenges, and time delays.
Addressing Heat Pump Refrigerant Leakage and High Global Warming Potential Refrigerants	A comprehensive multi-pronged strategy to limit the negative impacts of the use of refrigerants should be investigated. Easy to adopt strategy options should be implemented immediately while work on longer term solutions is developed. The strategy options include, but are not limited to: A. **Build stakeholder awareness about the refrigerant leak risks by heat pump system type**. For example

	o Variable Refrigerant Flow (VRF): Higher risk for leakage due to large number of difficult to access connections and the larger amount of refrigerant in the system. In addition to GWP, this also has potential safety risks. o Mini-Split Heat Pumps: Lower risk. Four refrigerant connections per head (plus joints in longer refrigerant lines.) o All-in-One Heat Pumps: Lower leakage risk. No external refrigerant line connections. o Semi-Central Monobloc: Lower leakage risk. All refrigerant located outdoors in a sealed unit. o Central Hydronic Monobloc: Lowe leakage risk. All refrigerant located outdoors in a sealed unit. B. **Promote, and incentivize, the available heat pump systems that use the lowest available GWP refrigerant**. For example, CO_2 has very low GWP and is effective in heat pumps for domestic hot water. CO_2 can also work in heat pump MUA systems for tempering outdoor air in cold weather (eliminating the current practice of using gas for peak heating in MUA systems). It is important to note that although CO_2 has the very low GWP, its refrigerant cycle properties do not work well for space re-heating or cooling. C. **Where low GWP alternatives exist there should be a rapid phase out of poorer performing refrigerants and/or a market signal should be introduced through higher incentives for low GWP systems**. For example, a. CO_2 heat pumps for domestic hot water can replace systems using higher GWP R410a and R32. b. E.g., R290 could be incentivized for larger refrigerant volume applications. R32 or R545 are being heavily promoted as "low GWP" replacements but still have GWP's of 700 or 600, dramatically higher than R290, which has a GWP of 3. D. **Introduction of comprehensive contractor training on installation best practices for limiting and eliminating refrigerant leakage.** This could include quick to implement training and exams for practical applications (such as how to install refrigerant line flare nut connections) to comprehensive refrigerant leakage reduction trainings for all types of heat pumps systems. Mandatory requirement for training on ongoing education can be based on the types of heat pumps systems installed, the risk of refrigerant leakage of that system type and the GWP of refrigerants used. For example, the training for VRF installations should be much more intensive, due high risk for leakage, than the training for All-in-One heat pump systems. E. **Utility rebate program inspections should consider a requirement for refrigerant leakage testing for installations on heat pumps technologies with higher refrigerant leakage risks**. F. **Comprehensive systems should be introduced to prevent refrigerant leakage**. Refrigerant use should be adequately regulated (including tracking and enforcement).
Industry Capacity	**Recommendation**
Build Industry Capacity for MURB Electrification Retrofits (Contractors and Engineers)	A. Engage stakeholders to develop comprehensive industry capacity building strategy to educate both engineers and contractors on the available technologies and best practices for designing and installing electrification

	technologies in MURBs. The acceleration of training for these sectors may need requirements and regulations to motive broad uptake. B. Industry training should be as flexible as possible with resources and support to rapidly deploy training opportunities to address common installation issues associated with heat pump technologies. Examples of targeted training include: in-suite mini split heat pump systems, All-in-One systems, window mounted heat pumps systems, CO_2 domestic hot water heat pumps systems, in-suite HRV's, ways to prevent long-term overuse of gas auxiliary in central hydronic systems and MUA's, mechanical design strategies to minimize demand charges, noise mitigation, how sizing, plumbing and control requirements are completely different from gas systems, etc. C. Implement ongoing awareness building focused on successful MURB electrification retrofits to enhance industry understanding of the options and build confidence in the technologies. D. Implement various forms of MURB electrification pilot and demonstration programs to build awareness of the options and opportunities and as real-life case studies to inform capacity building.

Appendix A: Glossary (Terms and Acronyms)

Apt2.0: a replicable way to Electrofit space heating in any apartment consisting of 3 fundamentals; 1) air seal the interior and suite door, 2) HRV and outdoor air filter, 3) in-suite heat pump.

Air Conditioning (AC)

Air Source Heat Pump (ASHP)

BC Building Code (BCBC)

Building Electrification Road Map (BERM): launched in March 2021, the road map's overarching goal is to significantly reduce the greenhouse gas emissions attributable to BC's building sector. The map lays a path with different actions required to achieve BC climate targets.

Carbon Dioxide (CO_2)

CO_2equivalent (CO_2e): A carbon dioxide equivalent or CO_2 equivalent, is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide.

Decarbonization: phasing out technologies and energy sources that have high carbon dioxide (CO_2) emissions and replacing them with low-carbon and zero-carbon alternatives.

Domestic Hot Water (DHW)

Electrofit: Electrification Retrofit. A contraction to describe a building's conversion from the original fossil fuel burning equipment to heat pumps.

Electrification: refers to the replacement of fossil fuel-based building systems, (such as space heating, domestic hot water, and cooking) with low carbon electric powered systems.

Environmental, Social & Governance (ESG)

Gallons Per Minutes (GPM)

Gigajoules (GJ)

Global Warming Potential (GWP): climate change potency of refrigerant gasses released to the atmosphere; how many times more potent the climate change effect of a gas is than CO_2. Figures for GWP have typically been over a 100-year span, but in more recent years alternative figures for the 10-year span have been proposed in recognition of the immediacy of the “tipping point” of the global warming effect.

Greenhouse Gasses (GHG)

Ground Water Heat Pump (GWHP)

Heat Recovery Ventilation (HRV)

Kilowatt (kW)

LandlordBC (LLBC)

Low Carbon Electrification (LCE)

Make-up Air (MUA)

Multi-Unit Residential Building (MURB)

Packaged Terminal Heat Pump (PTHP)

Property Assessed Clean Energy (PACE)

Renewable Natural Gas (RNG)

Residential Tenancy Act (RTA)

Residential Tenancy Branch (RTB)

Return on Investment (ROI)

Variable Refrigerant Flow (VRF)

Water Source Heat Pumps (WSHP)

BC Non-Profit Housing Association (BCNPHA)

Social Housing Retrofit Support Program (SHRSP)

Heat Pump Water Heater (HPWH)

Heat Pump Make Up Air (HPMUA)

Appendix B: BCNPHA Summary of Costs from Energy Studies

The BC Non-Profit Housing Association (BCNPHA) provided data from 101 SHRSP energy studies for social housing sites. The database included 764 "Energy Conservation Measures (ECM)'s" of all kinds, including 98 fuel switching measures. An analysis of the results of the energy studies identified:

- The studies were dated between October 2018 and August 2021, during which time there were very significant changes in cost, product availability and general knowledge in the engineering consultant community.
- The studies were done by many different consultants, and there is a wide range of costs estimated for similar ECMs. Many parameters for these ECM's varied by a factor of 10.
- The data received did not include key comparative information (for example, whether the base case was a very significant cost or zero, if auxiliary gas heat was used to minimize heat pump size, whether the ECM was applied to all suites, solely common areas, or the whole building.)

While the electrification recommendations made by consultants were sound, the data on capital costs is not reliable for determining current (2022-2023) average costs of MURB electrification by suite or for whole building. As a result, the information from the BCNPHA energy studies were not used in *Section 5 Financial Considerations for MURB Electrification Retrofits.*

Data from BCNPHA database of SHRSP audits (averages over all ECM's of each end use category). Average electric and gas rates (including Carbon tax) were used to extrapolate the payback figures below.

ECM Category	Incremental Capital/ Suite	Operational cost/ savings per suite	GHG redux %	Incremental Cost/ LtGHG	Total Project Cost/ GHG	Payback years
Space Heating - LCE	$3,550	$74	53%	$205	$478	48
DHW – LCE	$1,765	$48	24%	$201	$270	37
MUA – LCE	$1,386	$85	28%	$140	$292	16
Furnace - LCE	$1,645	$18	14%	$270	$380	90

Appendix C: Calculating Electrical Capacity - Costs & Complexities

Since electrification aims to switch building systems from fossil fuels to electricity, any electrification retrofit will consume more electricity than the fossil system it is replacing. For most electrification retrofits, the new electrical equipment requires higher electrical capacity than the existing electrical infrastructure was designed to provide meaning that electrical upgrades, to different extents, will be required. Any electrical upgrades will increase the cost of a MURB electrification retrofit.

To explain some of the challenges it is important to understand the typical MURB electrical distribution. The main electrical feed from the utility comes into the building's electrical room and splits into the 'common or house' meter which serves the common areas of the building and the meter stack(s) for the suites that includes an individual meter per each suite. It is important to highlight that there is no single 'main feed' meter measuring all electricity into the building. The total electrical consumption of a building can only be found by adding the 'common/house' meter to all the individual suite meters.

The key challenges related to MURB electrical upgrades include:

Calculating available electrical capacity

- To calculate the available electrical capacity when adding new loads in a MURB, the Canadian Electrical Code (CEC) allows two methods:
    - A) **Calculated:** Calculate the load per Rule 8-202 for apartments which provides a prescriptive method of estimating minimum loads based on square footage and connected loads with respective diversity factors . This method:
        - Yields a very conservative estimate which would suggest an electrical upgrade even when existing use demonstrates sufficient capacity.
        - Is challenging to estimate for common area loads since MURBs do not usually keep good records of their equipment hence requiring a time-consuming survey of all the connected electrical loads and the demand factors to use for each load are not easily found in the CEC.
    - B) **Metered**: Per sub-rule 8-10-8), sum the additional loads, with demand factors permitted by the code, to the maximum demand of the existing installation measured over the most recent 12-month period. This method:
        - Is appealing because it is much more likely to avoid the cost of an upgrade
        - Cannot be used if there or no access to whole building maximum demand; for more details refer to Section 7 *Access to Energy Data to Enable MURB Electrification.*

- The challenges and complexities of performing electrical capacity calculations leads to professionals doing calculations in different ways, with different levels of effort and cost. The estimated cost range is between $3,000-$7,000 per electrical load study without sub-metering. The uncertainty of how to apply certain CEC rules tends to result in more conservative calculations and the risk that any deviation/interpretation can result in BC Hydro reviewers and/or the inspector overseeing the electrical permit for the upgrade to reject the calculations, which can put the whole retrofit at risk. Ultimately all these challenges extend the length and cost of electrification retrofits.

Electrical upgrades are currently analyzed in isolation

- The risks of not considering the electrical capacity for all the future needs of the building are the financial cost, time, and waste (including the life-cycle carbon emissions) of doing an isolated upgrade now that could have to be re-done in the future.
- A clear example is the approach how electrical upgrades are undertaken for the installation of Electric Vehicle Supply Equipment (EVSE) infrastructure without considering the future power required to electrify building mechanical systems or vice-versa.
- For more details, refer to Section 7 *Integrating or Aligning EVSE and Building Electrification Rebates and Programs.*

Building (site-side) upgrades

- When adding an electrical load to any existing electrical system it needs to be ensured that all the elements in the electrical infrastructure feeding that new equipment can handle the additional load, this includes outlets, distribution wires, fuses and breakers, electrical panels, meters, and transformers. (See also “Building Triggers” section of this report.)
- Some common issues are:
  - Old panels or switchgear where new breakers or sections are not available anymore, so even though the equipment is in good condition, to make additions the whole panel or switchgear would have to be replaced.
  - Panels rated higher than the distribution wiring and overcurrent protection serving them. (e.g., a 100 Amp panel may be served by a feeder wire and upstream breaker only rated for 60 amps). Panels rated higher than the loads warranted were sometimes installed due to stock availability and compatibility between suites. This can give the false impression that additional capacity is available if only the panel rating is observed.
  - Appliances have been added in suites which do not exceed the panel rating, but collectively may approach or exceed the main building service.
  - Additions of more than 10kW (TBC), even if capacity is available, need to be approved by the electrical utility.

    - Unsafe wiring may be present, although from an informal survey it is rare. Most buildings since 1960 have adequate wiring, and only a very small percentage were built prior to that. Aluminum wiring is not inherently dangerous and is often left in place. Some aluminum wiring buildings had poor connections which are dangerous. Many have been upgraded (with pig-tailed sockets and panel replacements), but some problems may remain.

  - Converting from central system to in suite

    - Usually when shifting from central systems to in-suite systems the suites are typically too small either physically and/or in capacity to accept new in-suite equipment, upgrading the suite panels including the breakers and wires that feed them is estimated around $5,000 per suite.

- **Main service (utility side) upgrades:** If it is identified that the existing main electrical service for a building does not have enough capacity for the electrification upgrades, a main service upgrade would be required. Upgrading an electrical main service comes at a high cost (typically over $100,000), adds complexity to the retrofit and may take over 6 months to complete. For this reason, it is best to explore other alternatives before deciding to upgrade the main service. Common challenges are:

  - **Estimating time and cost to upgrade:** To determine the work required for an upgrade, the utility needs to be engaged. If it's identified that modifications need to be done from the utility side, the utility's engineering department needs to be engaged by paying a deposit (amount only estimated on a case-by-case basis) and later their design services will be charged to the building owner. The costs are uncertain and the timelines to work with the utility's design engineers has been quoted at a current minimum of 6 months.

    For these reasons it was identified in the BERM the need to improve response time for electrical service upgrades to reduce the transaction cost associated with fuel switching.

  - **BC Hydro Electric Tariff for Transformer Upgrades:** Since each building is part of an electrical utility grid and several buildings in a given area are typically supplied by the same utility transformer, if the transformer is overloaded, it may not be possible for the building to electrify until that transformer is upgraded. Per the current Electric Tariff, those 'Distribution Extension' costs are to be covered mostly the building owner, these costs can be prohibitively expensive. In contrast, Fortis BC will upgrade a natural gas line is typically much less expensive.

  - **Additional Municipal Requirements:** If the upgrade will require new connections that go through public property, costs like trenching an underground electrical line or removing trees are to be paid by the building owner. These costs are unknown until the project is in the design stage and can amount to thousands of dollars.

Electrical Load Demand Management and Utility Demand Response

- Currently electrical load management solutions are not wildly available nor considered for MURBs.
- Electrical load management systems can:
    - Avoid main service upgrades that pose the challenges
        - One example is that the Canadian Electrical Code which relaxes the rules for calculating EVSE demand under certain conditions in the following two subrules:
            - Subrule 8-106(10), which allows the demand load for EVSE controlled by an EVEMS (electric vehicle energy management system) to equal the maximum load allowed by the EVEMS; and
            - Subrule 8-106(11), which removes the requirement to include the demand load for the EVSE in the determination of the calculated load where an EVEMS monitors the service and feeders and controls the EVSE loads.
    - Help future proof a building against potential changes in electrical rates such as the addition of "time-of-use" billing which penalizes electrical consumption at busy times; and higher peak demand charge which penalize electrical consumption spikes. BC Hydro has indicated those changes as a potential solution to meet their customer's future electricity needs by reducing demand on peak periods (BC Hydro 2021 Integrated Resource Plan) BC Hydro Integrated Resource Plan 2021[20].
    - Allow for load management if there is any future addition of on-site renewable energy (e.g., solar PV, solar thermal or geothermal) and/or battery energy storage systems.

[20] "2021 Integrated Resource Plan (IRP)." BC Hydro and Power Authority, December 21, 2021, https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/regulatory-planning-documents/integrated-resource-plans/current-plan/integrated-resource-plan-2021.pdf

Appendix D: Site-by-site Data

This table is an example extract from the data assembled for this project. It was filtered to include only completed projects and only fuel switch projects. None are energy studies. It is primarily data received from BC Housing (SHRSP program for social housing) and from BCHydro (CleanBC for private rental buildings). For some records, data was compared and or/merged with that from other sources, such as public presentations, interviews with Owners and Engineers, and the data provided by BCNPHA (which overlapped entirely with the BC Housing data).

All records here were gas to heat pump retrofits except one oil to heat pump. A limited number of electric-to-electric retrofits are in the database, but primarily have just basic building information, and most are located in Ontario. Costs for electric to electric are mostly just verbal/ ballpark costs and anecdotal or % savings references.

The costing charts in the body of the report were produced from the database by selecting small sub-sets of comparable data. Because there are so many variables in the measures themselves this was done manually.

Most of the savings' figures were from initial estimates, not actual measured values. They include electric and gas costs and may in some cases include some electric savings (from fan or pump speed reduction). "Savings" here are just estimates produced by different Engineers from different organizations at different times. Assumptions including pre and post rate assumptions, Carbon escalation were not available. Therefore, these savings were not used as a basis of calculation.

Site Code	Elecrofit Measure(s)	Lifetime tons GHG Savings	*Initial Estimates of* Fuel Savings/ yr	Region	Type	Storeys	Original Building Year	Retro or NC?	Units (Suites)	Area ft2	Final Total Project Cost incl Engineering	Payback on Fuel (Years)
CRV	Hydronic BBs to mini-splits	699	$1,755	OK	Apt	2	1975	Retrofit	75	39,852	$1,825,216	527
RP	Central ASHP & HRV	279	-$7,118	North	Apt	1	1965	Retrofit	32	30,000	$126,950	-14
CV	Mini-split HPs & electric DHW	358	$4,687	OK	Apt	1	1978	Retrofit	14	9,041	$271,081	37
SG	Central ASHP Plant to radiant floors, DHW & MUA	592	$3,458	LM	Apt	4	1994	Retrofit	29	30,000	$622,740	65
SG	MUA Hybrid NG/HP	395	$5,139	LM	Apt	4	1994	Retrofit	29	30,000	$622,740	9
CT	CO_2 DHW HP	936	$6,799	LM	Apt	3	1974	Retrofit	82	64,000	$390,000	57
SM	DHW HP	196	$3,390	LM	Apt	3	1975	Retrofit	37	29,000	$46,137	14
GM	MUA Hybrid NG/HP	253	$3,045	LM	Apt	4	2004	Retrofit	49	30,000	$88,726	23
CP	MUA Hybrid NG/HP	543	$5,898	LM	Apt	7	2005	Retrofit	64	48,000	$118,500	5
ESL	MUA Hybrid NG/HP	227	$2,048	Kootenays	Apt	4	2000	Retrofit	23	26,300	$44,673	5
LMP	MUA Hybrid NG/HP	738	$9,279	LM	Apt	11	1989	Retrofit	80	46,000	$98,038	7
CM	MUA Hybrid NG/HP	515	$14[21]	OK	Apt	5	1959	Retrofit	90	110,000	$107,527	3,526
SGP	MUA Hybrid NG/HP	261	$3,575	LM	Apt	4	1999	Retrofit	19	20,000	$77,543	16
HBR	MUA HP with back-up electric heating	239	-$803	LM	Apt	4	1981	Retrofit	64	19,245	$64,505	-42

[21] The one outlier, site "CM" with savings of only $14 is illustrative. Possibly the difference is just a more conservative estimation of heat pump performance, or possibly longer heat pump operation vs gas was assumed, or an increase in rates, or different assumption for Carbon escalation. Possibly there was something fundamentally different at this site, but that level of detail was not provided.

BCH-08247	3 MUA's with electric auxiliary heating	4,200	-$25,471	LM	Dormitory, mostly res but incl some office space	18 & low-rises	-	Retrofit	?404?	295,256	$690,000	-18
BCH-05773	Existing Geoexchange/distributed HPs - a fluid cooler rejects low temp excess heat- Proposed bump it up for DHW & Pool	1,065	$10,958	LM		"High rise"	-	Retrofit	71	149,019	$86,974	8
BCH-07544	A2A (ductless or mini-split) with High-efficiency (75%) HRV; Electric Water Heater; Rooftop A2A Make Up Air Unit with Electric Auxiliary heating	3,268	-$33,187	OK		>6	2020+	NC	38	97,541	$373,195	-7
BCH-07672	A2W central plant to radiant heat & cool floors; central HP DHW; 86% eff HRV	3,885	$29,781	LM	Apt + medical / healing centre	11	2020+	NC	490	123,403	$865,000	15
BCH-07798	Air-to-Water CO_2 HP Water Heater (with gas auxiliary heating - only 50% gas saving claim!)	1,440	$9,237	LM		>6	-	Retrofit	211	107,931	$325,000	25
BCH-07814	PTHP	5,778	$27,066	LM		6	2020+	NC	360	274,423	$1,656,400	19
BCH-08134	Central plant (SH, DHW, hydronic MUA) 7yr old gas boiler to A2W HP!	3,480	$14,694	LM	Mixed Use	>6	-	Retrofit	184	94,053	$475,640	22
BCH-07078	VRF, Resistance MUA	1,781	-$12,450	LM	Apt, mixed?	13	2020+	NC	97	167,102	$1,021,770	-74
BCH-06408	VRF, A2W (central plant)	1,789	$7,585	LM		12	2020+	NC	72	49,702	$903,000	28
BCH-06438	VRF, central DHW A2W+gas, MUA 3x reduction with in-suite HRV's,	1,876	$8,541	LM		11	2020+	NC	68	57,277	$993,000	40
BCH-07419	VRF	774	$5,638	LM		<=6	-	Retrofit	20	19,046	$245,000	43
BCH-07438	Gas hydronic fan coils to Innova	1,278	$5,914	LM	Apt	13	1992	Retrofit	192	62,007	$2,020,000	24
BCH-07325	SH Gas boiler supplying in-suite W2A's; DHW Gas to W2W	7,731	$64,908	LM	Mixed wi 2 office bldgs. & 1 retail	28&32, 3, 1	2020+	NC	1,134	549,124	$4,709,914	10
BCH-07913	DHW Sewage Heat Recovery HP	510	$4,999	LM	$0	5	2020+	NC	44	52,419	$204,200	35
BCH-07624	DHW Sewage Heat Recovery HP	525	$3,303	LM	Mixed wi 1 retail building	4 & 1	2020+	NC	70	38,274	$135,000	29
BCH-07917	PTHP, distributed electric resistance DHW tanks	618	-$8,624	LM	Apt	3	2020+	NC	40	21,571	$240,000	-17
OH	DHW	0	$0	LM	SRO	6	1910	Retrofit	54	21,875	$173,450	0
BO	HBB to mini-splits	13	-$4,385	VI	Apt	2	1961	Retrofit	13	9,551	$94,675	-5
RA	Sanden RETROFIT, very new building	0	$0	SL	Apt	4	-	Retrofit	45	0	$100,000	0

Appendix E: Interviews

A breakdown of interviewee categories and who was interviewed includes:

Consultant	8
Social Housing Operator	3
Private Owner	2
Cost Consultant	1
Government	2
Supplier	5
Contractor	4
Total	**25**

The following individuals were interviewed:

Person	Company
Andrew Melville	Avalon Mechanical
Al Crawford	Crawford Electrical
Brad White	SES Consulting Inc
Brandon Clevenger	City of Vancouver
Chris Higgins	City of Vancouver
Christy Love	RDH
Devon Reynolds	RSL non-commercial branch manager, Vancouver
Fabian Navarro	BC Housing
Geoff de Ruiter	Geoff de Ruiter
George Friedrich, Adrian Lynch	Metro Vancouver
George Polychroniou	Clima Design Technologies
Grant McGinn	Delta-T Engineering
Illia Baiman	Airlux Heating and Air conditioning
Jamie Clarke	Avalon Mechanical
Jay Jagpal	Olympic International
Jeffry Besant	Besant and Associates Engineering
Ken King	Hanscombe
Kim Schuss	Dorset Properties
Parm Mohar	RSL Commercial Division VRF
Ruffy Ruan	Impact Engineering
Scott Graham	Renew Energy
Shahab Soltani	BC Housing
Sunny Brar	Hollyburn
Tony Ogbonna	BC Housing
Vic Burconak	Koben Systems - Genius Smart Panels