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Heat Pump Retrofit Technical Considerations, Costs, and Business Case for Multi-Family Building Archetypes

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1 Introduction

1.1 Background

By 2050, the City of Vancouver plans to achieve zero emissions from all buildings in the City. By that time, about 30% of the building stock will be of pre-2010 vintage, having been constructed before stringent energy codes were implemented in the Vancouver Building Bylaw (City of Vancouver, 2015). In order to achieve deep decarbonization of the building stock, retrofit strategies are necessary to convert existing fossil-fuel fired heating systems to all-renewable heating systems, primarily through electrification.

This paper looks at technical barriers and opportunities for various archetypes of multi-unit residential buildings (MURBs) and looks at the economic and environmental performance of specific heat pump technologies suitable for MURB retrofits.

To generalize what upgrades are suitable for certain buildings, various archetypes were defined with the intent that specific upgrades could be applied on a large number of similar buildings.

1.2 Methods

See below for a summary of methods used in the creation of this paper. The sections proceed in chronological order.

1.2.1 Technology Review

The first step of this project was to understand what technologies are available and become familiar with various renewable heating technologies. Looking specifically at heat pumps, there are various technologies that have been around for a several decades (such as split systems); while some have gained popularity in the past ten years (such as large centralized air to water heat pumps with heat recovery). A technology review was undertaken to understand the strengths and limitations of available technologies. Not only were the technologies reviewed for technical performance, but were also studied in terms of costs (capital, energy, and maintenance costs) in order to ascertain financial feasibility.

The technology review was carried out by conducing online research of various types of heat pumps, followed up by meetings with suppliers to learn more detailed information about the equipment as well as maintenance considerations and costs. In the meantime, meetings were held with various mechanical consultants to understand considerations when using the technologies in a building retrofit situation.

1.2.1.1 Literature Review

Several consultants have prepared reports for the City of Vancouver relating to low carbon retrofits for buildings. These were reviewed and provided valuable information on the relative benefits of various technologies available for retrofits.

Additionally, a literature review of mechanical equipment was conducted. This was conducted mainly online by looking at the offerings from various equipment manufacturers and was used as a starting point for the analysis.

1.2.1.2 Meeting with Suppliers

Meetings with equipment suppliers were held to obtain more detailed information not available from the online literature review. Manufacturers were able to provide cutsheets with specific performance data for the equipment they represent, adding detail to the numerical analysis. These meetings were a good opportunity to learn of the technological limitations and maintenance considerations of the equipment. Suppliers are also familiar with other manufacturers in the same industry and were able to provide information on similar competing heat pump technologies available.

1.2.2 Building Site Visits

To come up with recommendations for upgrades to MURBs, it is necessary to understand building architecture and mechanical systems in potential candidate buildings, as certain types of heat pumps would be suitable for certain buildings types and not others. The goal of these site visits was to visit three buildings of each archetype to find common themes, opportunities, and barriers to specific heat pump technologies.

During visits, the following areas were inspected in each building:

- **Mechanical room** (to determine the amount of space available for additional/replacement equipment)
- **Typical suite** (to determine how the temperature is controlled and how the space is heated)

- **Roof** (to determine what space is available for future equipment)
- **Parkade** (to determine the feasibility of a sewage heat recovery system)

The installation requirements, learned from the technology review, along with the site visits made it quite clear what upgrades would be possible in what types of buildings. That being said, every building within a single archetype is different, so care should be taken when considering upgrades to specific buildings.

1.2.3 Archetype determination

At the start of project, basic archetypes were determined for MURBs based on some literature review as well as experience. During the site visits, some archetypes were added and others were eliminated because of certain unexpected differences. See Section 3 for definitions of the building archetypes.

1.2.4 Energy modeling

To determine projected carbon emission reductions and cost savings, the performance of various heat pump systems were modeled in Excel. This modeling was quite simplified compared to what could be modeled on professional energy modeling software like IES<VE>.

The following simulations were conducted in Excel:

- Air-to-Water Heat Pumps (AWHPs)
  - Modeled AWHP capacity based on variation of COP with outdoor air temperature (OAT).
  - OAT determined using climatic data file.
  - Temperature of water in buffer tank modeled hourly using first principles of physics ($Q=mC\Delta T$), knowing the heat input from the heat pump, the mass of the water, and the heat capacity of the water.
- Hourly Domestic Hot Water (DHW) usage
  - When calculating the energy usage for a domestic water preheat system, the domestic hot water usage was determined by referencing the CoV Energy Modeling Guidelines which gave information on domestic hot water consumption at all hours of the day.

- A heat pump with a defined capacity was modeled preheating the domestic water to 120°F, with natural gas heating used to top up the temperature to 140°F.
- The capacity of heat pump was assumed as a reasonable fraction of existing gas equipment capacity by balancing against the electrical capacity in the building.

- Packaged Terminal Air Conditioner (PTAC)
  - Assumed that 75% of heating demand could be met by the PTAC
  - The remaining 25% would be satisfied by the base building hydronic heating system.
  - Heating demand was estimated based on gas bills from various buildings. It was assumed that in the warmest month of the year, there would be no gas space heating demand, and that all the gas consumption would be used for domestic water heating. It was also assumed that the domestic water consumption remained constant for every month of the year. The difference between the total gas consumption and the domestic water demand was determined to be the space heating demand for the building.

After determining the energy usage of the heat pump systems modeled, the results were compared to a standard gas fired system with standard efficiency (which was observed in many buildings) in order to calculate a reduction in energy usage. The comparison of the gas and heat pump systems was conducted in terms of energy, cost, and CO_2 reduction. Results of modeling are in Section 5.

2 Technology Review

The specific technologies studied in the technology review were determined by attending a seminar hosted by APEGBC on centralized heat pump design considerations. Detailed information about specific technologies was obtained through online research and meetings with suppliers who represent heat pump equipment manufacturers. Some high level information based on the literature review is listed below.

2.1 Air to Water Heat Pump (AWHP)

Figure 1 Aermec Air to Water Heat Pumps (AWHPs)

Air-to-Water Heat Pumps (AWHPs) have been around for some time, and have become more wide spread in recent years. Through the use of a refrigerant cycle (typically using R410a or R134a refrigerant), the unit absorbs heat from the ambient outdoor air and injects it into a water stream. The system can be used for cooling by reversing the refrigerant cycle to reject heat to the ambient air.

AWHPs typically operate with a Coefficient of Performance (COP) of between 2 and 4, with low COPs occurring at low ambient temperatures.

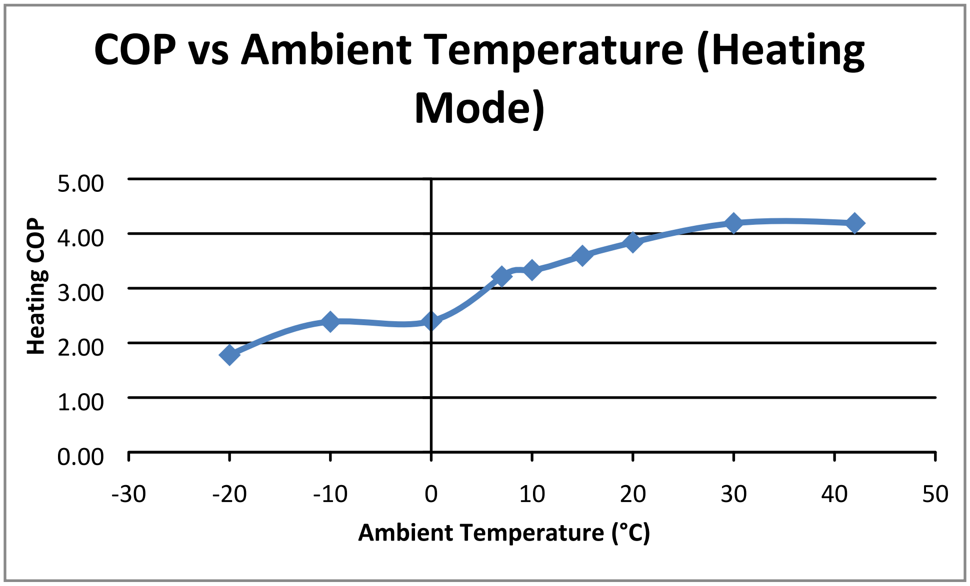


Figure 2 COP vs Ambient Temperature for Aermec NRK 0300

Typically, AWHPs are used for heating and cooling in buildings. Many units have four pipe connections so that heating and cooling can be accomplished with the same unit.

2.1.1 Considerations for retrofit:

A centralized AWHP requires large amounts of power for operation, so it's important to determine if there is sufficient electrical capacity in the building and what electrical components will need to be upgraded.

There is also a fair amount of other mechanical equipment required, such as buffer tanks, pumps, and heat exchangers. Ideally these components would be located in the mechanical room; but if there is no space, another room would need to be built.

2.1.2 Limitations of Technology

Although they can be used for space heating, AWHPs typically can't be used to replace a boiler because they can't lift the temperature of the water high enough. Older hydronic heated buildings typically use 180°F water in the piping system, while a traditional heat pump using R410a refrigerant can only lift the water temperature to around 135°F, but would operate more efficiently at 120°F.

This being the case, an AWHP could be used for central heating if all terminal heating equipment (i.e. hydronic baseboards) were replaced with low temperature equipment that can deliver the same heat output, but can use lower temperature water. This would be a major renovation which would likely only be considered if the entire building were undergoing a major retrofit.

2.2 Packaged Terminal Air Conditioner (PTAC)

Figure 3 Innova Packaged Terminal Air Conditioner (PTAC)

A packaged terminal air conditioner (PTAC) is a unit that is mounted to an exterior wall and can provide heating and cooling as well as outdoor air to a space. The PTAC has an integral refrigerant cycle and fan and distributes air to the space without ductwork or air terminals. PTACs are very common in hotels, where they can be used for both heating and cooling.

Traditional PTAC units are loud and cycle frequently, making them disruptive to room occupants – especially when trying to sleep – but certain units (such as the Innova product) are very quiet.

2.2.1 Considerations for retrofit:

Being a terminal piece of equipment, PTACs are installed in each suite, and potentially each room. If PTACs are to be installed in each suite in a MURB, this could present a logistical challenge for scheduling installation. If it is an upgrade by an individual unit owner then the process would be much simpler.

Since the equipment is distributed in each suite, PTACs don't face the same challenge that other central heat pump systems have with finding enough electrical capacity in the building. The PTAC can either plug in to an existing receptacle in the suite, or be hard wired and take up a spare circuit on the panel (if one is available). Since the building electrical system would be sized to handle the load on a panel, major electrical upgrades are unlikely to be required.

If the PTAC is installed to be used in conjunction with an existing heating system in the building, care must be taken when installing controls to ensure the two heating systems don't "fight" each other.

2.3 Hybrid Gas/Heat Pump Make Up Air Unit

Figure 4 Trane Horizon hybrid gas/heat pump make up air unit

A hybrid heat pump make up air unit (MUA) is an air handling unit that uses both an air-to-air heat pump (AAHP) and a gas burner to supply heated air to a building. The AAHP is used to provide the base heating load, while the gas burner is used when the ambient temperature drops below freezing. Vancouver is an ideal climate for these units because of the mild winter temperatures. In the winter, there are few hours below freezing, so the hybrid MUA can potentially have significantly lower greenhouse gas (GHG) emissions than a strictly gas-fired unit.

2.3.1 Considerations for retrofit:

Hybrid MUAs draw a significant amount of current, and add a significant load to the building electrical infrastructure, so it is necessary to ensure the building electrical system can handle the added load. Even with sufficient building electrical capacity, it will likely be necessary to add additional wiring and electrical panels, adding substantial cost to a retrofit application.

These MUAs are best used where 575V power is available. Many older MURBs built prior to the 1990s have 208V power distribution in the building, resulting in much higher amperage required by the unit, increasing size of panels and wiring, and further increasing the cost of an upgrade.

Consideration should also be made to the noise level from these hybrid MUAs. These units have a condenser section used for absorbing and rejecting heat to the ambient air, a process which is completed using fans. These fans can produce variable, high pitched noise that could potentially impact neighboring properties.

2.3.2 Limitations of Technology

Some units have limited on-coil temperatures, so that they can't properly operate below 7C ambient temperature. Higher end units, like the Trane Horizon, can be used down to 0C. Below that temperature, the unit could still operate, but the leaving air temperature wouldn't be sufficiently high to provide sufficient heating in the building.

2.4 Sewage Heat Recovery Heat Pump

Figure 5 International Wastewater Systems Piranha sewage heat recovery heat pump

There is a substantial amount of energy that goes down the drain in every building. Warm water from showers, dishwashers and clothes washers is sent down the drain and contains a substantial amount of energy available for re-use. Sewage heat recovery can be used to offset a substantial amount of domestic water heating load in a building, and International Wastewater

Systems – a local engineering company – offer two sizes that have been used in several installations in Vancouver and around the world:

- Sharc (large scale; 200+ units) – custom for each project
- Piranha (building scale; 50-200 units) – "out of the box" almost, with some additional work for storage tanks, etc.

These systems typically operate with a COP of over 4.0 and can be used on a building scale or a neighborhood scale in a district heating system.

2.4.1 Considerations for retrofit:

Sewage heat recovery won't work in every building, and there are relatively few buildings where they could effectively be used as a retrofit option. There are three main criteria that must be met for a building to be a suitable candidate for a sewage heat recovery retrofit:

- The main sewer line must be easily accessible
- The main electrical room must be near the heat pump
- Domestic water heating equipment must be near to heat pump

The heat pump requires some auxiliary equipment such as storage tanks and pumps, and takes up a parking space or two, so the building owner must be willing to give up some parking.

2.4.2 Limitations of Technology

The heat in the warm water in the sewer comes from the domestic water heating equipment, so the maximum theoretical amount of energy that can be recovered from sewage is the amount of energy injected by the domestic water heating system. In reality, about 75-80% of the domestic heating load can be offset by the sewage heat recovery system.

Additionally, the considerations listed above limit how many buildings can actually use this system economically without major piping and electrical costs.

2.5 CO2 Heat Pump for Domestic Water Heating

Figure 6 Sanden CO2 heat pump for domestic water heating

CO2 heat pumps are a relatively new technology that's just recently entered the North American market. More common in Asia, these systems use CO2 as a refrigerant instead of more traditional R410a and R134. CO2 has much lower global warming potential (GWP) and can also achieve much higher water temperatures compared to other refrigerants. While the AWHP is limited to about 135°F, CO2 heat pumps can achieve 190°F, making them applicable for both domestic water heating and space heating.

CO2 heat pumps operate with high COPs in the range of 3 to 5 (depending on ambient temperature).

2.5.1 Considerations for Retrofit

Current systems available in Canada aren't large enough to serve a MURB, so several systems would be required in a parallel installation. When considering using CO2 heat pumps in a retrofit, it is necessary to ensure there is sufficient space for all the additional tanks and condensing units. Also, since these units offset the gas load of domestic water heating equipment, there needs to be sufficient electrical capacity in the building.

2.5.2 Limitations of Technology

At the time of writing, the largest CO2 heat pump system available is from Sanden with a 4.5kW system with an 83 gallon storage tank (but they currently have a 16kW system being tested by certifying agencies for use in Canada). With this relatively small capacity, a large number of parallel systems would be needed to offset the domestic water heating in an existing building, making it more challenging to use in high rise MURBs.

2.6 Heat Recovery Ventilators

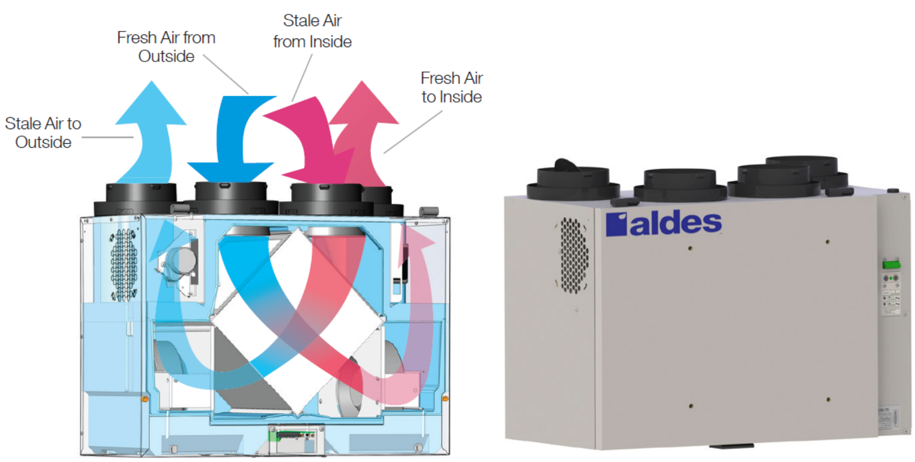


Figure 7 Aldes heat recovery ventilator

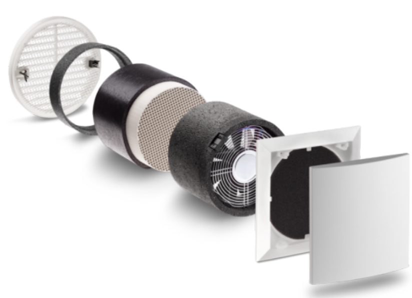


Figure 8 Lunos push-pull heat recovery ventilator

Heat recovery ventilators (HRVs) extract heat from an exhaust stream leaving the building and inject that heat into the incoming air stream from the outdoors. They are very effective in cold climates, where significant amounts of energy are required to heat incoming outdoor air for ventilation of a building. HRVs can either be centralized – serving an entire building – or decentralized – serving one room or suite. For the purposes of this report, only decentralized

HRVs will be discussed, as centralized HRVs are impractical in most MURBs where exhaust air is discharged from each suite.

Decentralized HRVs are becoming common in new MURBs in Vancouver because of new Code requirements stating that all occupied spaces in a building need to have ventilation air, where traditional designs relied on operable windows, corridor pressurization, or leaky envelopes to ventilate the suites.

There are three types of HRVs commonly used:

1. Heat recovery core (typically plastic)
2. Push-pull (used in exhaust mode for one minute, heating a heat recovery core; then switches to ventilation mode for another minute, using the heated core to preheat incoming air)
3. Heat wheel (commonly used on central make up air units in commercial buildings)

2.6.1 Considerations for retrofit:

Installing HRVs in each suite is a very invasive process, especially if the air streams are ducted. Space would need to be found in the ceiling void for the HRV and for duct runs. In high rise buildings, the ceiling is typically the underside of slab and ducts are often run inside the concrete slab, meaning that any new duct runs would have to be below the ceiling in bulkheads. For this reason, a push-pull HRV would be most feasible in a MURB.

2.6.2 Limitations of Technology

While HRVs can offer substantial energy savings in ventilated buildings, an unventilated building would see an increase in energy use by adding and HRV because of the added fan energy and added heating requirement (because the HRV cannot recover 100% of the heat from the exhaust stream). However, there would be other benefits such as improving indoor air quality (IAQ) and reducing moisture and mold issues.

3 Building archetypes

To find common opportunities for retrofits in buildings, it is necessary to define archetypes that accurately define the layout of a large number of buildings. Archetypes are defined here primarily by two factors: building height and mechanical heating system fuel source (electric or gas). The archetypes defined are shown in the table below:

Building Height	**Mechanical System**		
	Electric Baseboard	**Hydronic Baseboard**	**Low Temperature Hydronic**
Low Rise	Low Rise – Electric	Low Rise – Hydronic	Low Rise – Low Temp
Mid Rise	Mid Rise – Electric	Mid Rise – Hydronic	Mid Rise – Low Temp
High Rise	High Rise – Electric	High Rise – Hydronic	High Rise – Low Temp

Table 1 Nomenclature used for building archetypes

3.1 Summary Table

See table below for common features of the specified building archetypes:

		Archetype					
		Mid/High Rise			Low Rise		
		Electric	**Hydronic**	**Low Temp Hydronic**	**Electric**	**Hydronic**	**Low Temp Hydronic**
Architecture	**# floors**	Mid Rise: 5-10 High Rise: >10			<5		
	Underground Parkade	Yes			Yes		
	Glazing	High window-to-wall ratio (WWR); double pane	Low WWR; single pane	WWR varies; double pane	High WWR; double pane	Low WWR; single pane	WWR varies; double pane
	Structure	Concrete			Wood frame		
	Date of construction	1980-2010	Pre-1980	Post-2010	1980-2010	Pre-1980	Post-2010
Make Up Air	**Location**	Roof	Parkade (often not functioning)	Roof	Roof	Roof (often none at all)	Roof
	Fuel type	Natural gas		Natural Gas / hydronic coil	Natural Gas	Natural Gas or unheated	Natural Gas / hydronic coil
Domestic Water Heating	**Location**	High Rise: Penthouse mechanical room; Mid Rise: Parkade mechanical room			Parkade mechanical room		
	Fuel Type	Natural Gas			Natural Gas		
	Description	Boilers heat water stored in tanks	Main boilers used for space heating and DHW heating; or dedicated gas-fired HWTs.	Boilers heat water stored in tanks	Boilers heat water stored in tanks	Main boilers used for space heating and DHW heating; or dedicated gas-fired HWTs.	Boilers heat water stored in tanks
Exhaust	**Service**	Bathrooms and kitchen range			Bathrooms and kitchen range		
	Discharge Location	Side-wall via in-slab ducts	Collected at roof	Side-wall via in-slab ducts	Side-wall or soffit grille	Collected at roof	Side-wall or soffit grille
Sewer Main	**Location**	Exposed in parkade	Collected below parkade slab	Exposed in parkade	Exposed in parkade	Collected below parkade slab	Exposed in parkade
Electrical Service	**Capacity Limitation**	Building service, panel	Building service	Building service, panel	Building service, panel	Building service	Building service, panel
	Elec Room Location	Parkade level P1			Parkade level P1		

Table 2 Common features of archetypes. Note: these are generalizations and therefore don't apply to all buildings within an archetype

Graphical Representation of MURB Archetypes:

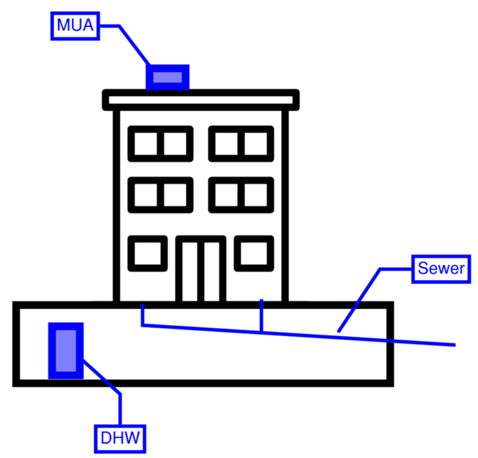
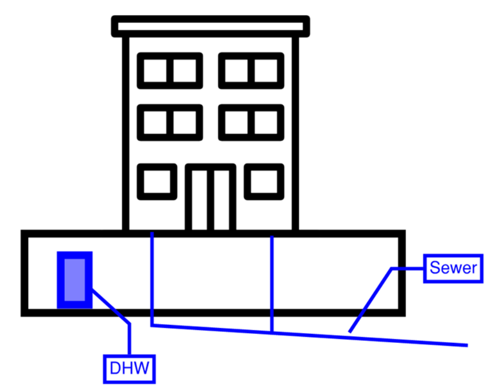
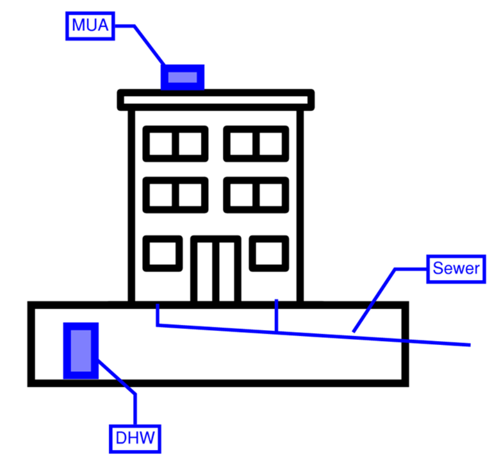
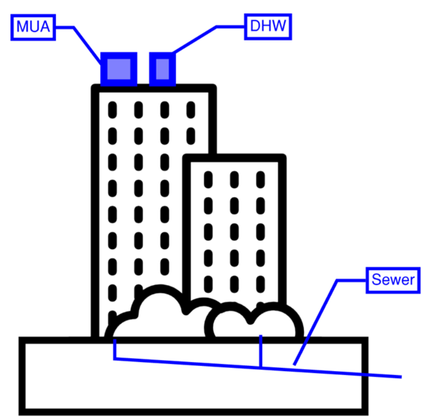
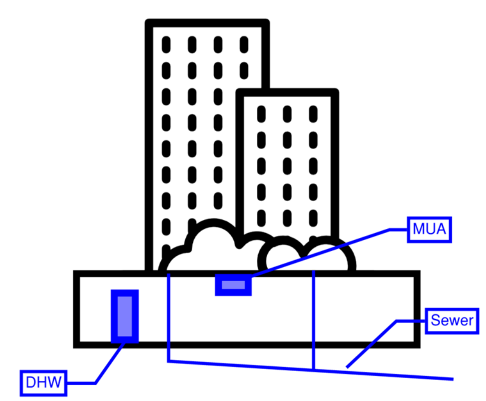
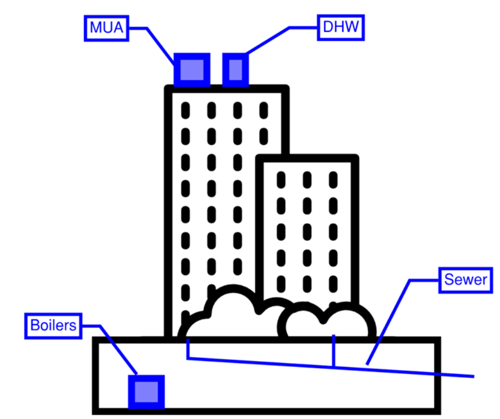
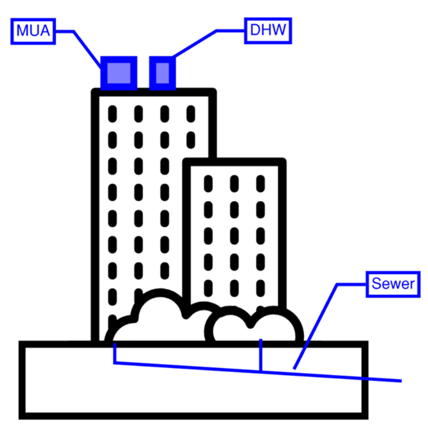
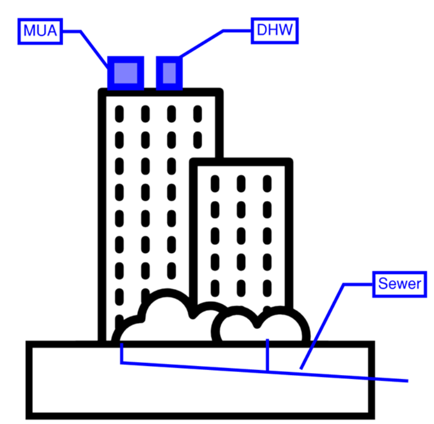
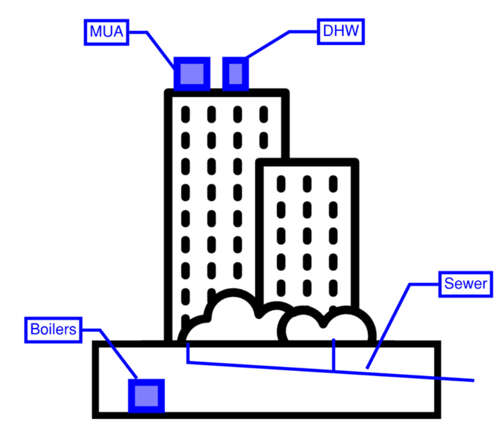
	Mechanical System		
Building Height	**Electric Baseboard**	**Hydronic Baseboard**	**Low Temperature Hydronic**
Low Rise			
Mid Rise			
High Rise			

Table 3 Graphical representation of MURB archetypes

4 Opportunities and Barriers for Specific Building Archetypes

The specific technologies that are applicable for the various building archetypes are highly dependent on the overall building layout. For example, sewage heat recovery won't be an economical retrofit option for a building where domestic water is heated in the mechanical penthouse on the roof of the building due to the large amounts of additional piping required to get hot water from the parkade to the roof. The table below summarizes which upgrades are applicable in specific building archetypes. For a more detailed discussion of this table, refer to the Appendix.

Feasibility of Various Low Carbon Technologies in Building Archetypes		Low Carbon Technology						
		Air to Water Heat Pump (DHW preheat)	Air to Water Heat Pump (space heating)	Air to Air Heat Pump (PTAC)	Hybrid Gas/Heat Pump Make Up Air Unit***	Sewage Heat Recovery Heat Pump	CO2 Heat Pump for Domestic Water Heating	Heat Recovery Ventilators
Building Archetype	High Rise – Electric	✓	✗	✗	✓	✓*	✗	✗
	High Rise – Hydronic	✓	✗	✓	✗	✗	✗	✗
	High Rise – Low Temp Hydronic	✓	✓	✓**	✓	✓*	✗	✗
	Mid Rise – Electric	✓	✗	✗	✓	✓*	✗	✗
	Mid Rise – Hydronic	✓	✗	✓	✗	✗	✗	✗
	Mid Rise – Low Temp Hydronic	✓	✓	✓**	✓	✓*	✗	✗
	Low Rise – Electric	✓	✗	✗	✓	✓*	✓	✓
	Low Rise – Hydronic	✓	✗	✓	✗	✗	✓	✓
	Low Rise – Low Temp Hydronic	✓	✓	✓**	✓	✓*	✓	✓

Table 4 Low carbon technologies applicable to MURB archetypes

*depending on proximity of DHW equipment, sewer main, and electrical room

**depending on wall construction (won't work with glass or structural concrete walls)

***recommended only if original MUA is gas-fired (i.e. doesn't use a hydronic coil)

4.1.1 Summary Table

See below for a checklist of items to consider when looking into a low carbon retrofit for a building. These apply to all building archetypes:

Considerations for Low Carbon Retrofits	Low Carbon Technology					
	Air to Water Heat Pump (DHW preheat)	**Air to Air Heat Pump (PTAC)**	**Hybrid Gas/Heat Pump Make Up Air Unit**	**Sewage Heat Recovery Heat Pump**	**CO2 Heat Pump for Domestic Water Heating**	**In-Suite Heat Recovery Ventilators**
Architecture	If DHW is heated on roof: ☐ Roof can support new equipment without structural upgrades (need to contract structural engineer). ☐ Mechanical Room has enough space for added equipment (buffer tank, heat exchanger, two pumps, piping, etc.). ☐ Roof has enough space for added ASHPs. If DHW is heated in lower level: ☐ There is sufficient space outside to pad mount. ☐ There will be minimal noise impacts on tenants and neighbours.	☐ Exterior wall is able to accommodate PTAC (high WWR or concrete wall will make this challenging). ☐ Base building space heating is from natural gas. ☐ Building overheats regularly. ☐ Ensure PTAC controls don't fight base building controls	☐ Roof can support new equipment without structural upgrades (need to contract structural engineer). ☐ There is gas supply at MUA location. ☐ Roof has enough space for added MUA. ☐ MUA configuration will work with existing duct layout.	☐ Owner finds it acceptable to forfeit one or two parking stalls for equipment.	☐ Check for sufficient space for the required number of parallel systems	☐ There is space to locate HRV above ceiling in washroom or kitchen. ☐ There is space to run ductwork (building with in-slab ductwork likely won't have space). ☐ Exterior wall structure is able to accommodate through-wall HRV (high WWR or concrete wall will make this challenging).
DHW	☐ DHW heating eqpt is close to AWHP.	☐	☐	☐ Heat recovery equipment is located near the main DHW heating equipment to reduce additional piping costs (not feasible with water heaters at roof level).	☐ Main DHW equipment is near to proposed CO2 heat pump location.	☐
Sewer main	☐	☐	☐	☐ Sewer main is exposed so that heat recovery equipment can connect to it.	☐	☐

Electrical service	- Ideally 575V is available at house panel. - Existing wires / buses / panels feeding proposed equipment has sufficient amperage. - Building has sufficient electrical capacity.	- Receptacle is nearby for plug-in models. - There is a spare circuit on suite electrical panel if hard-wiring. - PTAC won't add to overall building load because load is contained within suites.	- Ideally 575V is available at house panel. - Existing wires / buses / panels feeding proposed equipment has sufficient amperage. - Building has sufficient electrical capacity.	- Heat recovery equipment is located near the main electrical room to reduce additional electrical costs.	- Existing wires / buses / panels feeding proposed equipment has sufficient amperage.	- There is a spare circuit on suite electrical panel.
Additional Notes	- Main source of noise is condenser fans. Locate unit where noise won't be an issue and ensure unit has a night time mode, quiet fan blades, or soft-start compressors.	- Upgrade would be fairly invasive for tenant. - Tenant energy bill likely to increase if cooling feature is used.	- Upgrading main building electrical service is prohibitively expensive.	- Not feasible for retrofits in many buildings because of requirement to have sewer main, electrical room, and DHW equipment all in close proximity.	- Current equipment is too small for use in large MURBs.	- Upgrade would be fairly invasive for tenant. - Retrofit likely only necessary to improve IAQ and reduce moisture and mold issues. - Through-wall HRVs cycle every 70 seconds, which may be bothersome to tenants.

Table 5 Considerations for low carbon retrofits

5 Financial Analysis

To determine the financial performance of the low carbon technologies introduced in this report, two buildings were studied, with various low carbon retrofits modeled on each. Costs were normalized per suite to enable the various upgrades to be compared. A more detailed energy analysis could be achieved by conducting energy models, modeling different building archetypes with all major parameters kept constant (window-to-wall ratio, envelope, infiltration, etc.), but changing building height and mechanical system. Refer to Section 0 for results of the energy analysis.

5.1 Incentives

Often, the capital cost of low carbon retrofits present a challenge for many building owners and the savings associated with retrofits take a long time to recover. Currently in BC there are no incentive programs that can be used for heat pump retrofits studied in this paper. A lack of incentives in BC, combined with the low cost of natural gas make for very long paybacks for heat pump equipment, making retrofits unattractive to building owners.

5.2 Utility Cost

5.2.1 Natural Gas

The commodity price of natural gas has been in steady decline in recent years and is currently at a record low:

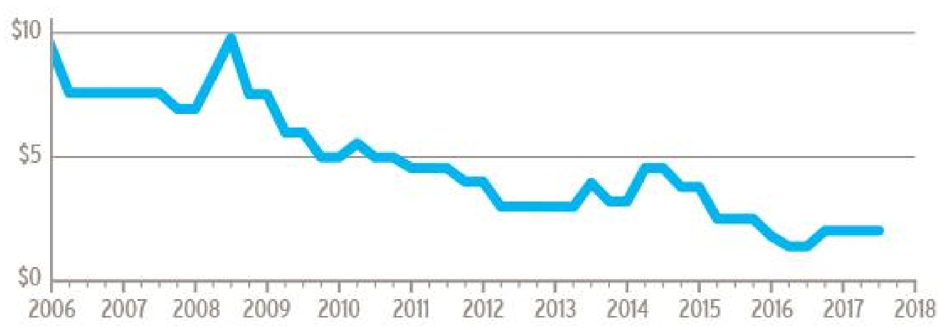


Figure 9 Commodity price of natural gas since 2006 (Fortis BC, 2017)

The financial analysis presented in this paper was conducted using the Fortis BC Lower Mainland residential rate:

- Delivery charge per GJ $4.299
- Storage and transport charge per GJ $0.811
- Cost of gas per GJ $2.05
- **TOTAL** **$7.16/GJ**

To model the financial performance of the studied measures over the life span of the equipment (~20 years), a factor was applied to the cost of gas, representing a percentage increase of the cost of utility each year. The Fortis BC Long Term Resource Plan (LTRP) contains projections of the future cost of natural gas:

- ~6% increase/yr in commodity price
- Assumed all other costs increase with inflation (2.5%)
- Overall 3.5% increase/yr average

5.2.2 Electricity

Electricity in BC is sourced primarily from hydroelectric sources. The composition of electricity in the grid is from large scale hydro dams as well as many run-of-river hydro installations and other low carbon Independent Power Producers (IPPs). This high mix of hydro means Vancouver enjoys the 3rd cheapest residential electricity rates in Canada (BC Hydro).

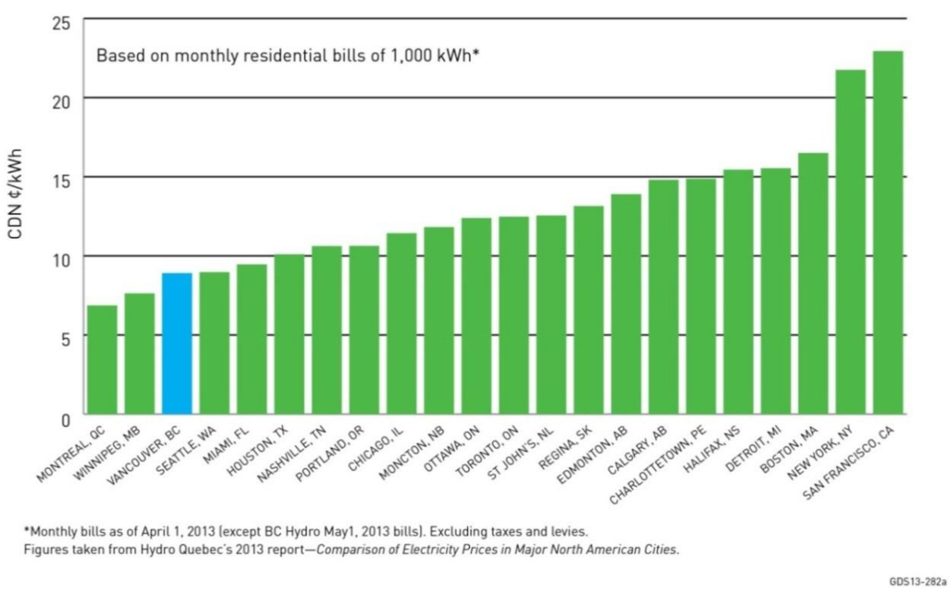


Figure 10 Cost of electricity in North American cities

Residential electricity rate used in this financial analysis:

- 7.641 cents/kWh blended rate (RDH Building Science, SES consulting, Integral Group, 2017)
- No demand charge

Similar to natural gas, electricity rates were modeled to increase, as per BC Hydro's 10-year rates plan. According to Hydro, the rates in the next 10 years are going to increase to cover upgrades to existing facilities using the following increases:

- year 1 (F15): 9%
- year 2 (F16): 6%
- year 3 (F17): 4%
- year 4 (F18): 3.5%
- year 5 (F19): 3%
- years 6 – 10 (F20-24): rates set by BC Utilities Commission

Assuming a 2.5% increase in rates over subsequent years to keep up with inflation, this represents an average of 3.0% increase in rates over the next 20 years.

5.3 Carbon Cost

BC was the first jurisdiction in North America to implement a revenue neutral carbon tax in 2008. Today, the carbon tax rate sits at $30/tonne of CO2 and is projected to increase by $5/tonne in the coming years according to the 2017 Confidence and Supply Agreement between the BC Green Caucus and the BC New Democrat Caucus. No date is specified to end the increases of the tax, nor is there a mention of a cap for the carbon tax. For the purposes of this study, it was assumed that the tax would cap out at $100/tonne in 2031.

5.4 Results

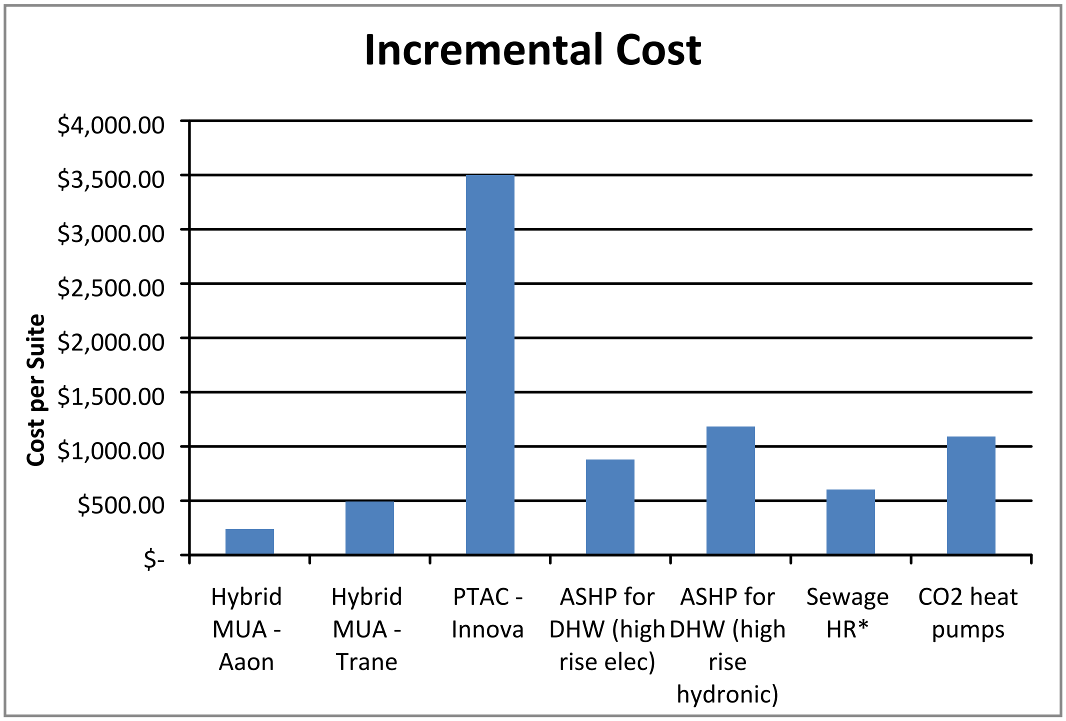
See table below for the results of the financial analysis conducted in this study. Refer to the Appendix for details of each upgrade, as well as detailed pricing breakdown. All values in the table below are normalized per suite:

Measure	Capital Cost	Utility Savings	CO2 reduction (kg/yr)	NPV	Simple Payback	CO2 cost of abatement
Hybrid MUA - Aaon	$237.12	$5.15	83	$(128.30)	46	$143.01
Hybrid MUA - Trane	$492.34	$18.36	213	$(370.30)	27	$115.66
PTAC - Innova	$3,500.00	$42.75	1036	$(2,457.68)	82	$168.96
ASHP for DHW (high rise elec)	$879.05	$3.64	111	$(781.14)	242	$395.29
ASHP for DHW (high rise hydronic)	$1,183.25	$5.60	185	$(1,027.06)	211	$319.90
Sewage HR*	$600.00	$27.78	313	$(67.96)	22	$96.00
CO2 heat pumps	$1,088.61	$49.23	597	$21.75	22	$182.28

* (Ions Engineering, 2015)

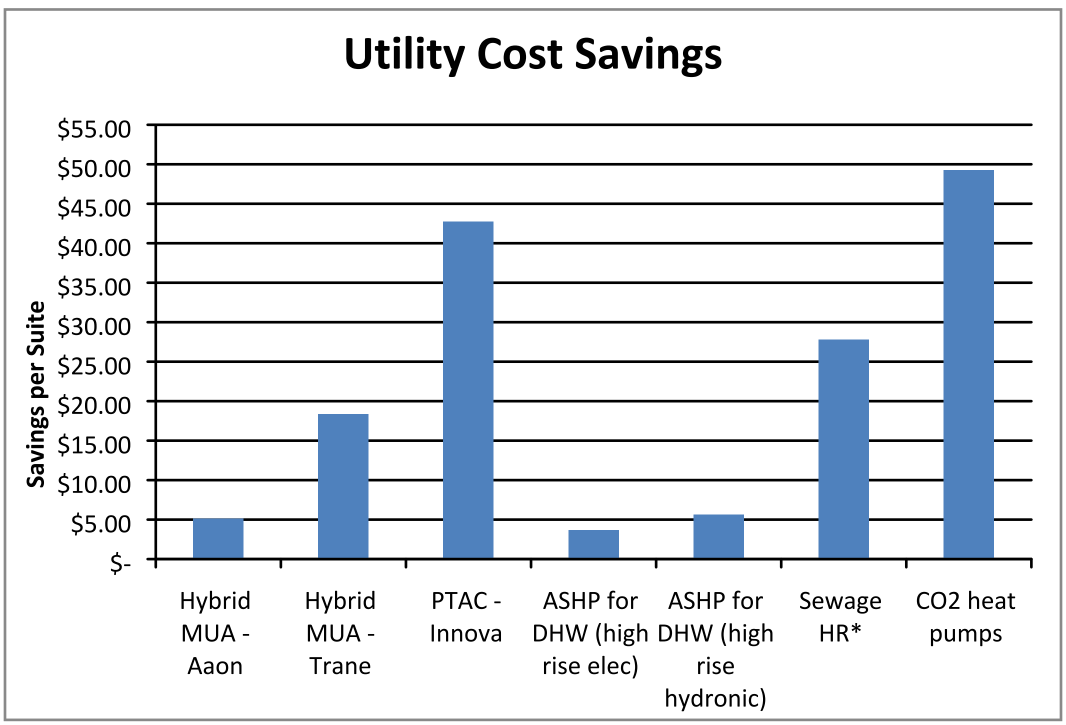
Table 6 Results from financial analysis

Refer to charts below for comparison of technology based on several different criteria. Again, the values are normalized per suite:



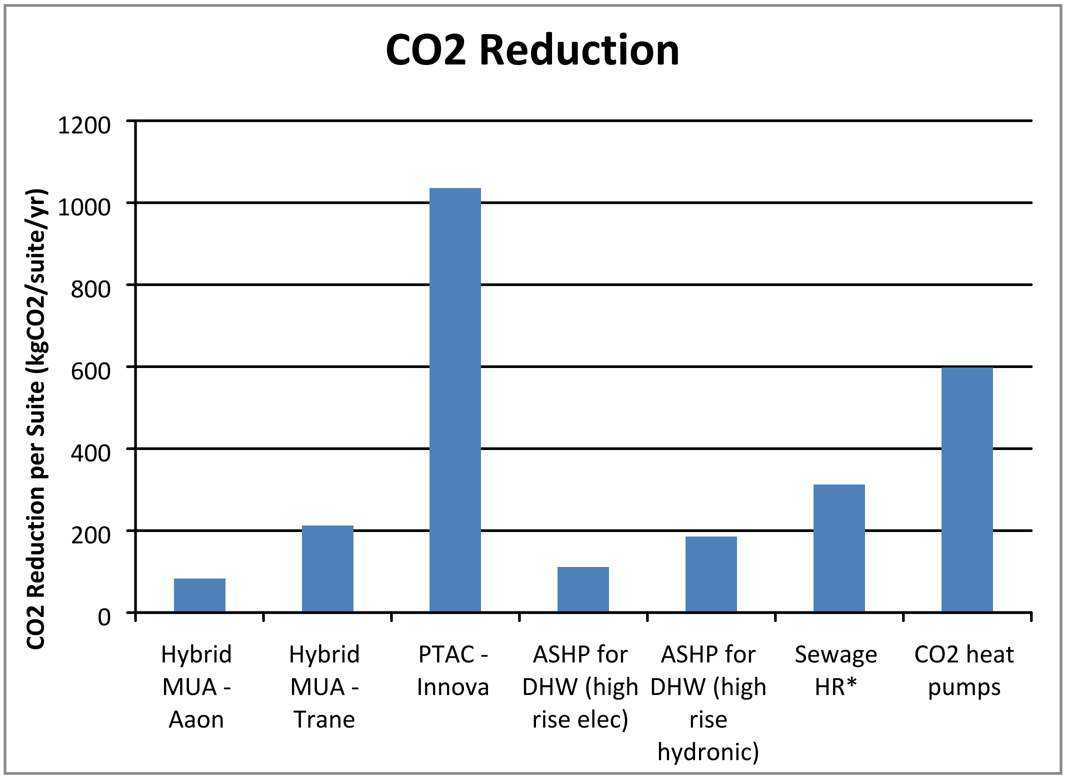
* (Ions Engineering, 2015)

Figure 11 Incremental cost per suite of various low carbon technologies



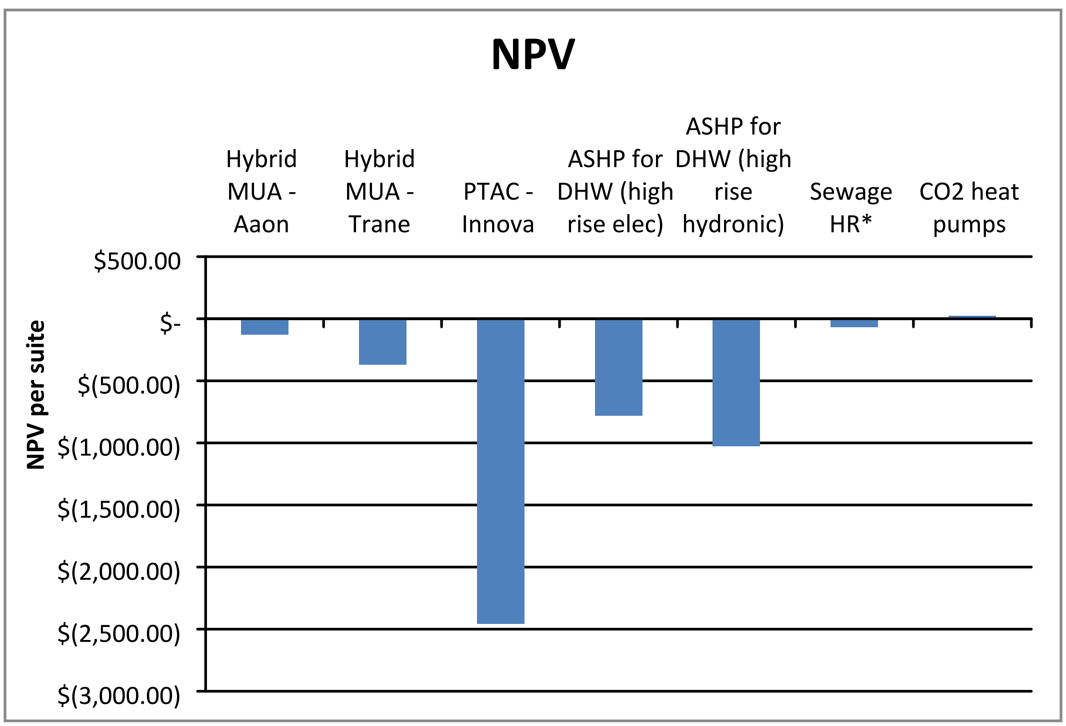
* (Ions Engineering, 2015)

Figure 12 Utility cost savings per suite of various low carbon technologies



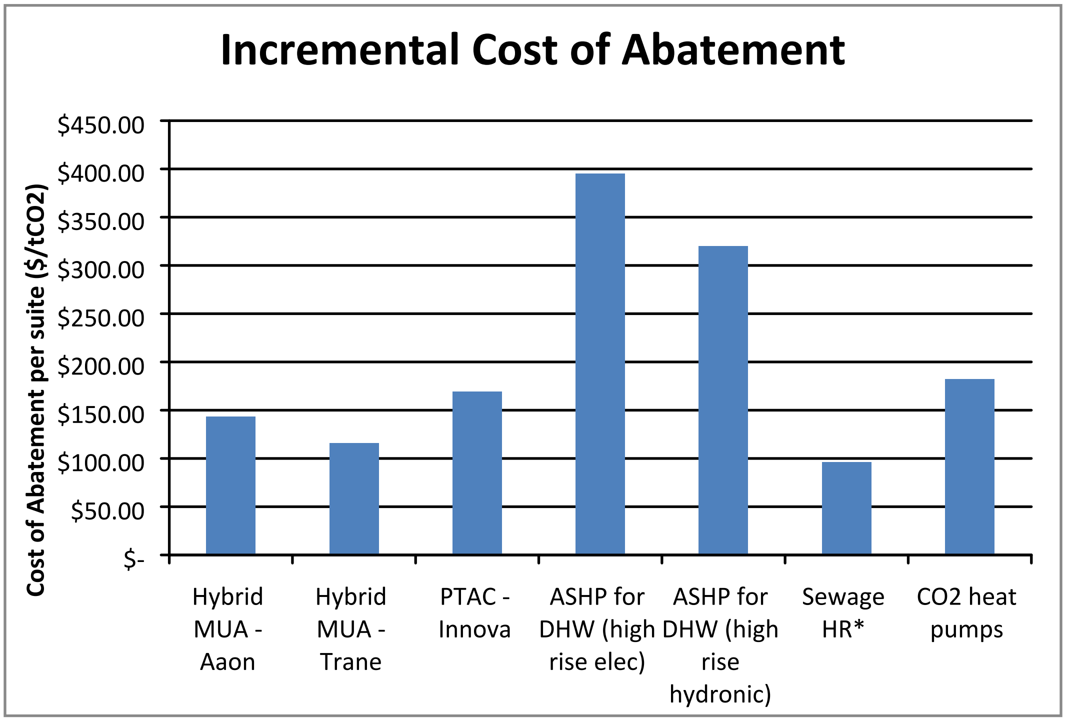
* (Ions Engineering, 2015)

Figure 13 CO2 reduction per suite of various low carbon technologies



* (Ions Engineering, 2015)

Figure 14 Net Present Value per suite of various low carbon technologies



* (Ions Engineering, 2015)

Figure 15 Incremental Cost of Abatement per suite of various low carbon technologies

5.5 Assumptions

Several assumptions were made for this analysis which would need to be verified on a case-by-case basis when planning low carbon retrofits in buildings:

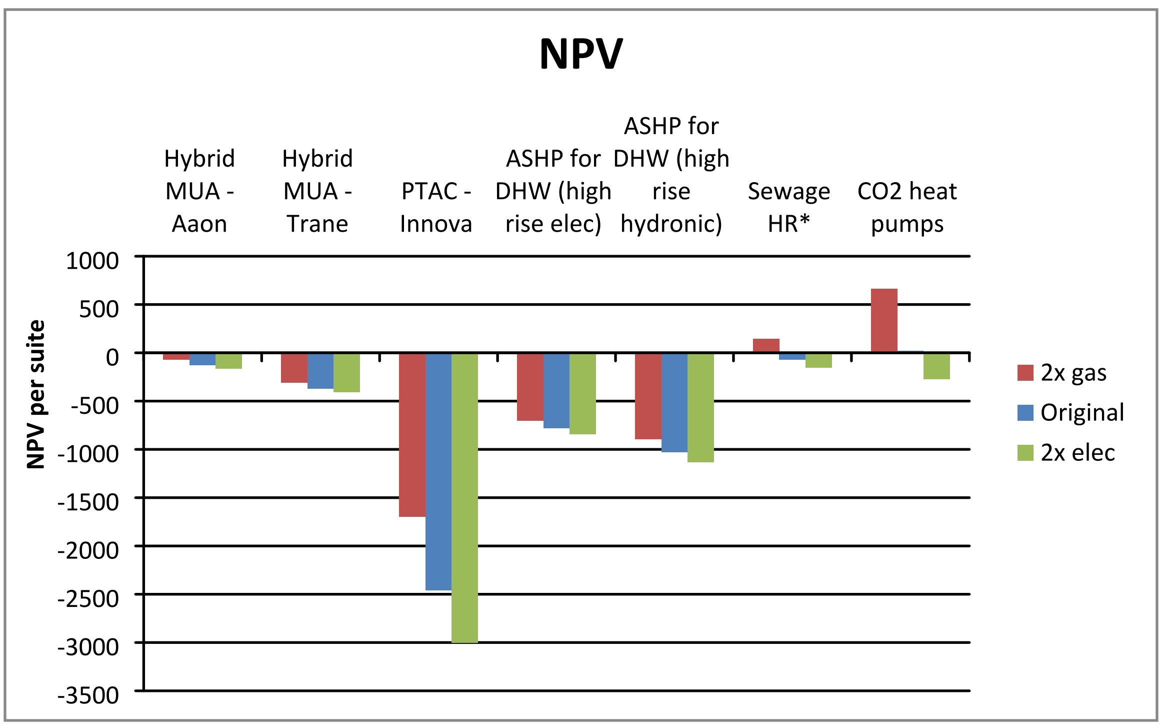
- Assume main building transformer doesn't need to be upgraded. If it does, this adds ~$250k, which would kill any business case.
- Assumptions were made for exactly what electrical components would be needed as part of a retrofit. Different buildings will require varying degrees of electrical upgrades and an electrical engineer should be engaged on a case-by-case basis to determine actual costs for specific buildings. The numbers presented in this report are a rough order of magnitude.
- Electrical upgrades are a highly variable cost. Upgrades could be as simple as connecting to the nearest panel, but could involve upgrading the service to the entire building.

- PTAC assumed to provide 75% of heating; remaining 25% derived from existing fossil fuel sources within building
- DHW heating energy assumed to be gas load at lowest month in a year, assuming all gas energy used that month is for domestic water heating and none is used for space heating.

5.6 Sensitivity Analysis

The cost of natural gas and electricity can display some volatility. For that reason, a sensitivity analysis is presented here to compare the studied case with hypothetical situations where either the cost of gas or electricity increases at double the rate used in the analysis. The change in rate increase will only affect NPV, so the NPV graph shown above is replicated here with three cases:

1. "Original" case with rate increases as described above (blue)
2. The price of gas increases at a rate double in the "original" case (red)
3. The price of electricity increases at a rate double in the "original" case (green)



* (Ions Engineering, 2015)

Figure 16 Net Present Value per suite of various low carbon technologies with rapidly increasing gas utility cost (red), anticipated utility cost increase (blue), and rapidly increasing electrical utility cost (green)

6 Recommendations

Unfortunately, with the above financial analysis, there is no clear technology that significantly reduces CO2 emissions while being financially beneficial in BC. With the low cost of natural gas, most technologies show a negative NPV.

6.1 Detailed Energy Modeling

The analysis presented here was based on first principles, best practices, and assumptions based on experience. To get a more realistic picture of the relative performance of certain measures (especially PTAC), it would be necessary to conduct a detailed energy model for the measures that are most promising.

Additionally, when conducting the energy model, the various measures should be applied to buildings with identical geometry to get a better sense of how each would perform on a level playing field.

6.2 Analyze Each Building

Within each archetype, there are many differences between buildings, so there's no solution that will work for every building in one archetype. Therefore, any retrofits that are undertaken should be considered on a case-by-case basis, with mechanical and electrical engineers conducing detailed analysis.

6.3 Incentives

As mentioned in this report, it's difficult to make a financial case for low carbon retrofits in BC without incentives. BC Hydro has had some valuable energy conservation programs in the past (such as the Power Smart New Construction Program), and it could be worthwhile for the City of Vancouver to collaborate with BC Hydro to develop low carbon incentive programs to achieve the common goals of both entities.

6.4 Demand Side Measures

While outside the scope of this project, a study of demand side measures that could be used to manage peak energy demand in buildings could provide insight into how to avoid the high cost of electrical retrofits. By employing an energy management system to schedule the use of heavy energy demands (washers, dryers, dishwashers) off of peak hours, more spare capacity can be made available for heat pumps that require high current draw. If it can be shown that the peak power will not exceed building capacity, no electrical service upgrade would be necessary, avoiding a ~$250,000 expense.

7 Conclusion

The only technology with a positive NPV is CO2 heat pumps, which is a technology not sufficiently mature in Canada and would require several systems in parallel, making it only feasible for low rise building retrofits. It is expected that in the future, CO2 heat pump technology will mature further, with MURB-scale systems becoming available. In that situation, central CO2 heat pumps for DHW heating for MURBs will become an attractive option for GHG reductions and utility cost savings.

Ironically, the technology that shows the poorest financial performance may in fact be the most likely to be a success in Vancouver. Using PTACs in MURBs has the benefit of improved thermal comfort through providing cooling in the summer, and also has the potential for substantial GHG reductions when used in heating mode.

The technology exists today to achieve deep carbon reductions through significant building retrofits. The challenge lies in making these retrofits in a manner that does not disrupt tenants (through invasive construction work or excessive noise) and does not incur substantial costs (capital and operational costs) for building owners.

8 References

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10 Appendix A – Sample Buildings

10.1 Sample Calculation (Building 1)

Building Description	
Archetype	High Rise Electric
Units	431
Area	257,000 sf
Feasible Upgrades	Hybrid MUA AWHP for DHW preheat

10.1.1 Hybrid MUA

- There are two buildings in the facility analyzed, both of which have large gas-fired MUAs
- Sufficient space for new MUA, but ducting will likely need to be reworked.
- Recommended unit is Trane Horizon b/c of high performance relative to cost.
- Other less expensive options are available, but don't have the performance to make it financially worthwhile.

10.1.1.1 Costs of upgrades

- Refer to Appendix for detailed breakdown of costs associated with this upgrade.
- Equipment cost is ~$108,000, but avoided cost of replacing MUA is ~$44,000.
- The largest auxiliary cost is electrical because there is not a panel sized sufficiently on the roof to provide power to new MUA. Fortunately there's a 575V cct on the roof, so the upgrade could be limited to a new panel on the roof with new wiring running from the panel to the MUA.
- If new panel is required in elec vault in P1, add'l $40k of wiring would be necessary.

10.1.1.2 Energy Savings and Additional Costs

Gas and electricity savings:	
Natural Gas Energy Savings	20.8%
Electrical Energy Savings	-7.2%

10.1.1.3 Payback Analysis

Payback Analysis – Inputs		
Total Incremental Cost	$212,200	
Annual Utility Savings	$(7,914.11)	/yr
Annual CO2 Reduction	91.7	tonnes CO2/yr
Equipment Service Life	20	years

Payback Analysis – Results		
Simple Payback	26.8	years
NPV	$(163,656.70)	(using 7% discount rate)
Cost of Abatement	$(115.66)	/tonne CO2

10.1.2 ASHP for DHW preheat

- Hot water tanks located on roof
- Roof space available for ASHPs for HW preheat.
- Recommend 2x Aermec 0300 units (40 ton capacity each). Represents 37% of existing gas boiler capacity.
- Require 300 gallon buffer tank to prevent short cycling of compressor (ensures minimum 5 minute run time). Increasing buffer capacity could ensure more reliable performance, but had no impact on energy in this analysis.

10.1.2.1 Costs of upgrades

- Lots of additional equipment and piping required (see table in Appendix)
- Need new panels and switches and need to pull new wires to serve new equipment.

- Assume there's no need to pull wires from electrical vault, but a detailed electrical engineering analysis would be required to determine if this is the case or not.

10.1.2.2 Energy Savings and Additional Costs

Gas and electricity savings:	
Natural Gas Energy Savings	10.9%
Electrical Energy Savings	-6.6%

10.1.2.3 Payback Analysis

Payback Analysis – Inputs		
Total Incremental Cost	$378,869.47	
Annual Utility Savings	$(1,568.40)	/yr
Annual CO2 Reduction	-47.9	tonnes CO2/yr
Equipment Service Life	20	years

Payback Analysis – Results		
Simple Payback	241.6	years
NPV	$(342,111.93)	(using 7% discount rate)
Cost of Abatement	$(395.29)	/tonne CO2

10.1.3 Conclusion

- Not a good business case for either upgrade
- Very high capital cost of equipment
- Combined, both technologies don't provide deep decarbonization because of limits on operating temperatures.
- Improved CO2 reductions would require much larger equipment, adding substantial capital costs, adding more weight to roof, and roof structure may be a limiting factor.
  - Could potentially reduce GHGs by 26% for ASHP for DHW preheat, with very high capacity, but can't get much more than that because HP will only heat up water to ~120F, and gas is needed to bump up to 140F.

10.2 Sample Calculation (Building 2)

Building Description	
Archetype	High Rise Hydronic
Units	86 studio suites
Area	39,615 sf
Feasible Upgrades	PTAC AWHP for DHW preheat

10.2.1 PTAC

- Use PTAC for primary heating; use existing hydronic baseboards for top-up
- For analysis, assumed 75% of load would be covered by PTAC
- Wall construction found to be able to accommodate PTAC
- Poor insulation and single pane glazing makes for overheating suits in the summer

10.2.1.1 Costs of upgrades

- $3500/suite
- Since PTAC can be wired into suite panel, only upgrades would be within suite, and no major electrical upgrades would be required for the building

10.2.1.2 Energy Savings and Additional Costs

Gas and electricity savings:	
Natural Gas Energy Savings	40%
Electrical Energy Savings	-157% (!)

- Assuming PTAC can handle 75% of heating load; remainder covered by existing hydronic baseboards
- Assumed no controls upgrades
- 157% increase in elec usage because a substantial amount of building energy is being replaced with electricity

10.2.1.3 Payback Analysis

Payback Analysis – Inputs		
Total Incremental Cost	$301,000.00	
Annual Utility Savings	$(3,676.31)	/yr
Annual CO2 Reduction	-89.1	tonnes CO2/yr
Equipment Service Life	20	years

Payback Analysis – Results		
Simple Payback	81.9	years
NPV	$(221,475.06)	(using 7% discount rate)
Cost of Abatement	$(168.96)	/tonne CO2

10.2.2 ASHP for DHW Preheat

- DHW heating done on P1
- Only location available for AWHP would be pad mounted outside building on ground floor; location should be picked carefully to minimize impact of noise on residents and neighbors
- Should ensure night time mode and soft start on compressor to reduce night time noise
- Need electrical engineer to assess if elec upgrade is required, because of limited capacity in building (600A @ 208V)
- No 575V service in the building, so 208V equipment would be required, meaning very high amperage, and large wire gauge which is very expensive.
- Assuming only minor electrical upgrades are required (assume sufficient capacity in building)

10.2.2.1 Costs of upgrades

- High cost of equipment
- Similar to cost for eqpt at high rise elec, except less elec cost b/c less distance to run wiring from incoming elec room

- Since heavy eqpt located on ground floor, no costly structural upgrades, so large buffer tanks can be used without risk of impacting structure.

10.2.2.2 Energy Savings and Additional Costs

Gas and electricity savings:	
Natural Gas Energy Savings	7.1%
Electrical Energy Savings	-35.2% (!)

10.2.2.3 Payback Analysis

Payback Analysis – Inputs		
Total Incremental Cost	$101,759.33	
Annual Utility Savings	$(481.61)	/yr
Annual CO2 Reduction	-15.9	tonnes CO2/yr
Equipment Service Life	20	years

Payback Analysis – Results		
Simple Payback	211.3	years
NPV	$(90,132.86)	(using 7% discount rate)
Cost of Abatement	$(319.90)	/tonne CO2

10.2.3 Conclusion

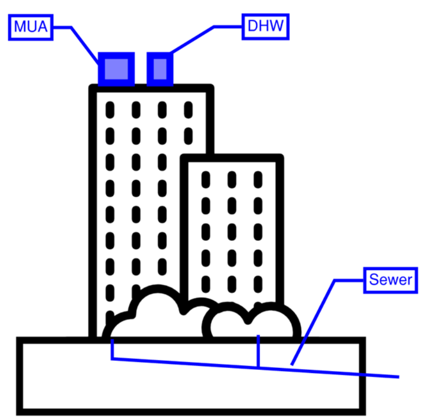
- From financial perspective, it makes no sense to use PTAC
- But from occupant comfort perspective, it makes sense
- Significant offset of GHGs possible
- Depending on capacity available in panel, could include electric heating coil in PTAC to completely offset hydronic heating
- Poor financial performance and CO2 reduction make this an undesirable option
- CO2 heat pumps are almost feasible, but would require ~12 systems in parallel to serve this building, which would take up a lot of space in the parkade.
- Once CO2 heat pumps increase in capacity, they will be more feasible for this building.

11 Appendix B – Detailed Archetype Definitions

11.1 High Rise Residential

- 14% of bldg. stock by floor area (for mid/high rise)
- Becoming a popular housing model (with so much rezoning along corridors like Kingsway, around Lougheed, Brentwood, etc.
- Recent high rises have high WWR, resulting in them overheating in the summer.
- Many old units have poor temperature control, poor exterior insulation, and single pane windows. Temperatures strongly affected by neighboring units
- New building codes and rezoning bylaws impose strict energy requirements on new buildings

11.1.1 High Rise – Electric heating



11.1.1.1 Common Features

MUA – The high rise electric archetype typically has a MUA on the roof of the building feeding air downward, and distributing into the corridors on each floor of the building. The purpose is to maintain a positive pressure in the corridor to prevent the migration of smells from one suite to another. The pressure in the corridor often suffers from leaky elevator doors and stairwell doors (RDH Building Science Inc., 2012)

DHW – Typically two boilers in the rooftop mechanical room heat domestic hot water in large storage tanks connected in parallel, and distribute water down to suites. The boilers observed in this study were all standard efficiency (80%) and were original, being installed at the time of construction. Mid-rise (~10 storeys) buildings were observed to have boilers on the ground floor, distributing water up.

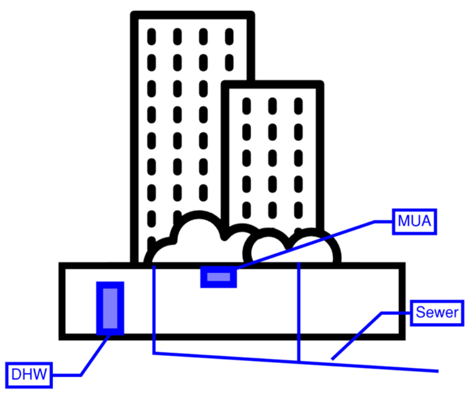
Space Heating – electric baseboards provide heating for these buildings. While this is a low-carbon option in BC, it is also more expensive than gas heating. Often in buildings with fireplaces and electric baseboards, residents use the fireplaces for heating rather than the baseboards as a way to save money.

Sewage – a common sanitary main is exposed in the first or second level of parking.

Typical Neighborhood – Yaletown, Coal Harbour

Date of Construction – 1980-2010

11.1.2 High rise – hydronic heating



11.1.2.1 Common Features

MUA – The high rise hydronic archetype is very common for 60's-70's era buildings. Make up air is often from a fan coil located I the lower level of the building. Due to the small size of the units, effectiveness is likely low. In two of the buildings visited, the MUA was not working at all.

DHW – Most of the buildings of this archetype visited were around 10 storeys tall. At this height, it is common to have domestic water heated in the lower level of the building with water being fed up to suites. The heating can either be achieved by a heat exchanger connected to the main boilers used for space heating, or directly by gas-fired hot water tanks.

Space Heating – hydronic baseboards provide heating for these buildings. The heating for these comes from a boiler typically located in the lower level of the building. During this study, some buildings were observed to have original boilers that have been rigorously maintained by property managers; while other buildings were observed to have new high-efficiency condensing boilers with DDC controls.

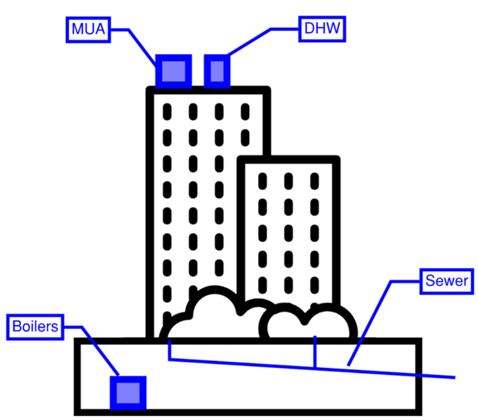
Zone temperature is typically controlled by a low-voltage thermostat in each suite that controls a 2-way zone control valve in each suite. Some of these thermostats were observed not to be functioning or were turned down while temperatures rose above setpoint even at moderate outdoor temperature (~18C)

Sewage – sanitary mains were observed in these buildings to drop below the parkade slab before connecting to one main. There was no common sanitary main exposed in the parkade.

Typical neighborhood – West End

Date of Construction – 1960-1980

11.1.3 High rise – low temperature hydronic



- New condo towers (post-2010 vintage)
- Subject to more stringent energy codes (ASHRAE 90.1-2007 and later; VBBL 2007 and later)
- Often use heat pump for space heating (Marine Gateway)

- Some buildings (esp. those that are supposed to tie into future DES) use boilers for space heating.
- typical distribution temp ~120F with ~100F return temperature. (Older mid-efficiency boilers need to stay above 140F to avoid condensing flue gas, which is corrosive and can damage the boiler.)
- Central pumps have a variable frequency drive (VFD) and temperature would likely be controlled by outdoor air temperature reset.
- Envelope already fairly high performance.

11.1.3.1 Common Features

MUA – Refer to High Rise Electric heating

DHW – Refer to High Rise Electric heating

Space Heating – low temperature hydronic baseboards provide heating for these buildings. The heating for these comes from a boiler typically located in the lower level of the building. Often these buildings are designed to be connected into a future low-carbon district energy system (LC DES). Condensing boilers are used to heat water to 120F supply temperature.

Sewage – Refer to High Rise Electric heating

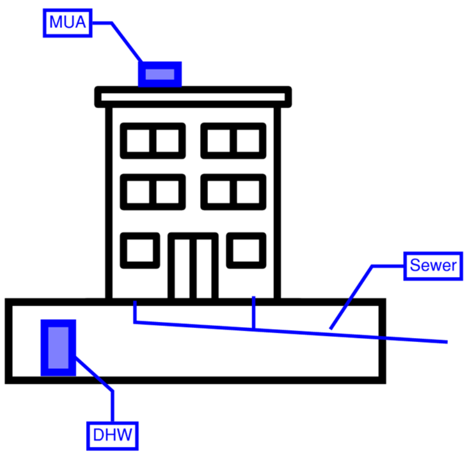
Typical neighborhood – Marine Gateway

Date of Construction – post-2010

11.2 Low rise residential

- 18% of bldg. stock by floor area

11.2.1 Low Rise – Electric heating



11.2.1.1 Common Features

MUA – The low rise electric archetype typically has a MUA on the roof of the building feeding air downward, and distributing into the corridors on each floor of the building.

DHW – Typically two boilers in the lower level of the building heat domestic hot water in large storage tanks connected in parallel, and distribute water up to suites. Some property managers opted to replace old boilers with new high efficiency condensing boilers for DHW.

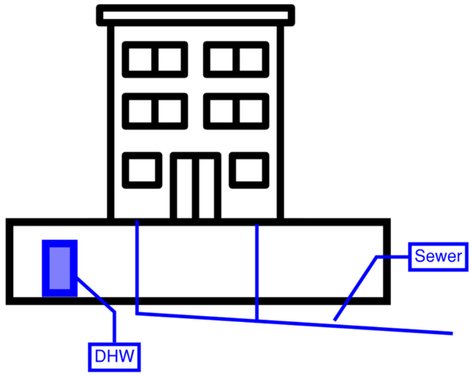
Space Heating – electric baseboards provide heating for these buildings. While this is a low-carbon option in BC, it is also more expensive than gas heating.

Sewage – a common sanitary main is exposed in the parkade.

Typical Neighborhood – UBC South Campus

Date of Construction – 1980-2010

11.2.2 Low rise – hydronic heating



11.2.2.1 Common Features

MUA – This archetype of building often has no corridor make up air or has unheated make up air.

DHW – Refer to Low Rise Electric Heating

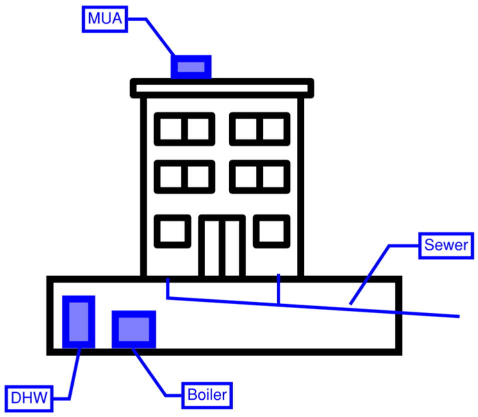
Space Heating – Refer to High Rise Hydronic heating

Sewage – Refer to High Rise Hydronic heating

Typical neighborhood – West End

Date of Construction – 1960-1980

11.2.3 Low Rise – Low Temp Hydronic



11.2.3.1 Common Features

MUA – Refer to Low Rise Electric Heating

DHW – Refer to Low Rise Electric Heating

Space Heating – Refer to High Rise Hydronic heating

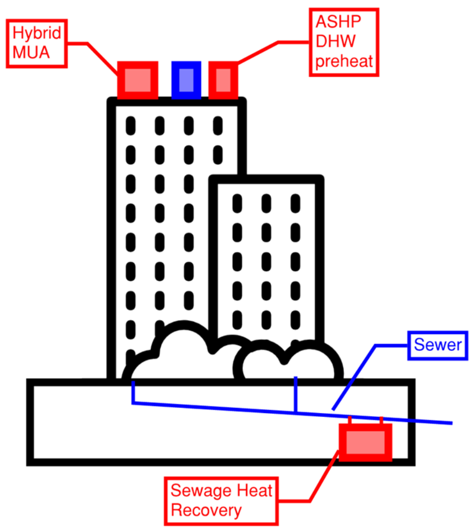
Sewage – Refer to High Rise Hydronic heating

Date of Construction – post-2010

12 Appendix C – Detailed Retrofit Considerations by Archetype

12.1 High Rise Residential

12.1.1 High Rise – Electric heating



Air to Water Heat Pump (DHW pre-heat):

- can be used to preheat domestic water
- limited invasiveness with DHW eqpt on roof
- can be connected into DCW line just before connection to DHW storage tanks
- with eqpt being added to roof, may need structural engineer to review structure and recommend equipment placement. Structural upgrades are expensive.
- Equipment list:
    - ASHP
    - 2x circulators
    - Double wall HX
    - Buffer tank
    - Piping, fittings, valves, pipe accessories
    - Heat tracing or use glycol loop

Air to Air Heat Pump (PTAC):

- Not ideal for this archetype

- Many of this archetype are 100% glass, making it impossible to mount PTAC in exterior wall.
- Not necessary to use PTAC for GHG reductions because of low carbon heating system
- Can use PTAC to add cooling, improving thermal comfort for occupants

Hybrid Gas/Heat Pump Make Up Air Unit

- Lots of room on roof
- MUA would use existing gas infrastructure
- May need new elec service to supply high amperage req'd by HP
- Being at the roof level, MUA is farthest point from elec service
- If insufficient service is supplied at roof level, may need to run conduit and wires all the way from P1, which would add significant cost.

Sewage Heat Recovery Heat Pump

- With sewer main exposed in parkade, there's opportunity for using heat pump to recover heat from sewage.
- 1-2 parking spaces required for equipment (storage tanks, heat pump, piping, circulators…)
- Feasibility of sewage HR totally depends on layout of building:
    - Nearby electrical room and panel
    - Sewer main needs to be exposed and easily accessible in parkade (which is often the case)
    - Water heating equipment needs to be nearby
- (only feasible on mid-rise because of water being heated in lower level – not feasible for high rise with DHW on roof).

CO2 Heat Pump for Domestic Water Heating

- Not feasible for this archetype
- Currently, only 4.5kW units are on the market, which is a good size for single family detached homes, but would require many installed in parallel for a MURB.
- Would require all to be located in one place if connecting into central DHW heating equipment.

- Would require 40+ systems for large high rise developments. Obviously this is not feasible at the DHW equipment location (penthouse mech room).
- Even on mid-rise, there would be a large number of systems in parallel required.

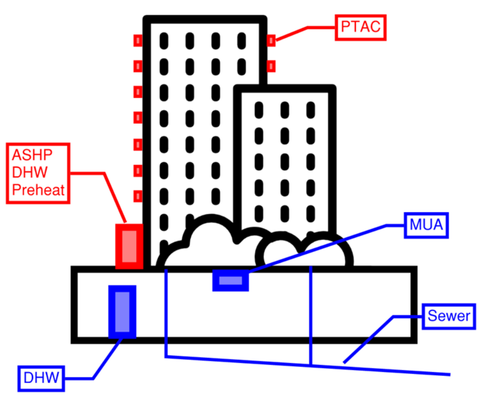
Heat Recovery Ventilators

- Not easily implemented for 2 reasons:
  - Side wall may be 100% glass
  - No room to run ducts from central HRV (all ducts are in-slab)
- MUA supplied from roof; exhaust ducted to side wall. No way to recover exhaust heat for central HRV.
- Many new buildings use small in-suite HRVs for improved indoor air quality (IAQ)
- Central HRV with all exhaust ducted back tor of a possibility for new construction, but not for retrofit. This is rare because of the amount of space required for duct shafts, and developers don't want to give up any space with ever square foot being valuable.

Other solutions:

- One property manager is looking into using special glass with tint controlled by electric current
- Found that tinted glass improves thermal comfort better than portable AC unit in buildings with high WWR.

12.1.2 High rise – hydronic heating



Air to Water Heat Pump (DHW preheat)

- All water heating is done in P1

- To use ASHP for preheat, would need to locate eqpt on a pad outside
- This may cause lots of noise for occupants on the wall facing the heat pump
- Noise should be a primary consideration if this is the case: soft start, night time mode, low noise fan blades
- New elec connection required, but ensure elec room is nearby to reduce cost of running new conduits and wires
- However, these buildings typically built in 60s-70s, when plug loads were much lower than today. With modern plug loads, existing incoming service may be maxed out (often 400A service)
- Concern that building infrastructure may not be sufficiently sized to allow for demand from large heat pump.

Air to Air Heat Pump (PTAC)

- Some models use 120V receptacle, so won't require any elec upgrades
- Can also hard wire, but can take off from existing circuit, not requiring a panel upgrade

Hybrid Gas/Heat Pump Make Up Air Unit

- not feasible because MUA is just a small fan coil that often isn't even working.
- Effectiveness of existing MUA questionable due to low flow rate.
- Probably not ventilating suites effectively
- Need another solution to improve IAQ
- Suites ventilated by leaky envelopes. But if the envelope is improved and better sealed, there's no ventilation and mold and moisture can become an issue.
- If tenants don't leave bathroom exhaust fan on after showering, moisture forms on windows.

Sewage Heat Recovery Heat Pump

- Not feasible
- Sanitary mains drop separately through parkade slab
- No central sewer main to connect into
- To access sewer would require digging up the slab, which adds significant cost to the measure

- If sewer main were exposed, might be good archetype because water is heated in lower levels.

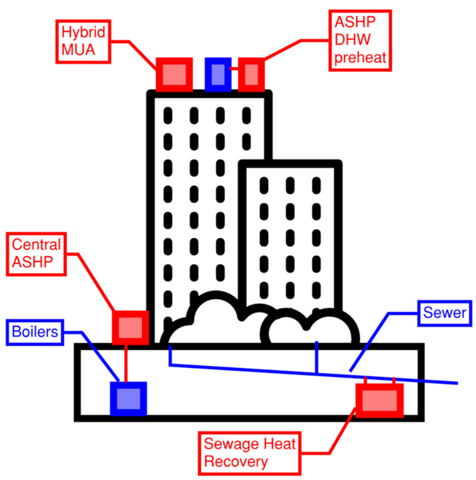
CO2 Heat Pump for Domestic Water Heating

- Refer to High Rise – Electric heating

Heat Recovery Ventilators

- Refer to High Rise – Electric heating
- Except an in-wall solution may work (Lunos).
- Buildings typically have low WWR

12.1.3 High rise – low temperature hydronic



Air to Water Heat Pump (DHW preheat)

- Refer to High Rise – Electric heating

Air to Air Heat Pump (PTAC)

- Not recommended
- Buildings are configured to connect to low-carbon DES
- Often high WWR
- Could be used for thermal comfort if envelop would allow
- Prefer looking to other solutions to mitigate heat gain like tinted windows

Hybrid Gas/Heat Pump Make Up Air Unit

- Refer to High Rise – Electric heating

Sewage Heat Recovery Heat Pump

- Refer to High Rise – Electric heating
- But maybe not if it's connected to NEU b/c NEU recovers heat from sewage already to use for heating.

CO2 Heat Pump for Domestic Water Heating

- Refer to High Rise – Electric heating

Heat Recovery Ventilators

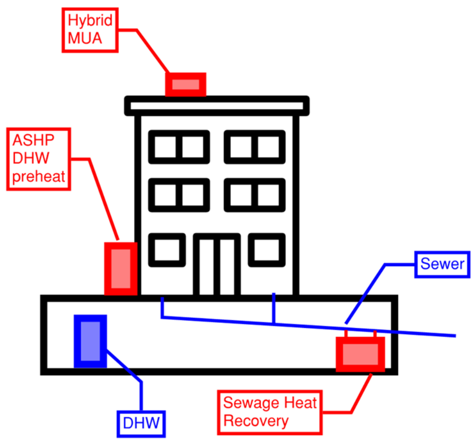
- Refer to High Rise – Electric heating

Other Solutions

- Central ASHP if hot water supply temperature is ~ 120°F
    - Can reach temperatures required by distribution system
    - May require elec upgrades b/c of high demand
    - Recommend hybrid system with HP providing base load, then gas boilers used as top-up (i.e. size HPs for 25% of peak load)

12.2 Low rise residential

12.2.1 Low Rise – Electric heating



Air to Water Heat Pump (DHW preheat)

- DHW heating in lower levels, so ASHP could be located on the roof without very far to run piping (cut through a few floors), or pad mounted on level 1.
- If noise is an issue with ASHP on lower floor, could mount to the roof, and pipe preheated water down to boilers. Only ~4 floors to run pipe.
- If cost prohibitive or invasive to core through floors in building, could run piping down outside wall (use glycol loop for this piping) with tanks and pumps inside mech room (prefer not to have tanks outside b/c of heat loss).
- Similar concerns with elec capacity as high rise hydronic buildings.

Air to Air Heat Pump (PTAC)

- Not necessary because of low-carbon electric resistance heating

Hybrid Gas/Heat Pump Make Up Air Unit

- Lots of room on roof
- MUA would use existing gas infrastructure
- May need new elec service to supply high amperage req'd by HP
- MUA isn't too far from elec rm if it's just 4 floors up
- If insufficient service is supplied at roof level, may need to pull new wires through existing conduits from P1.

Sewage Heat Recovery Heat Pump

- Feasibility depends on whether or not the sewer main is exposed in the parkade or not. If SAN collects below slab, lots of digging would be required, which would add substantial cost
- Refer to High Rise – Electric heating

CO2 Heat Pump for Domestic Water Heating

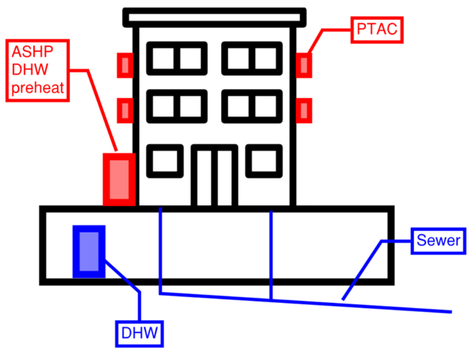
- Limited size makes using this technology difficult in a retrofit application.
- Because of hot water distribution, using CO2 heat pumps would likely require being tied into main boilers at central location.
- In new construction, it would be simple enough to have one system distribute vertically to serve 4 levels of suites.
- Locate in parkade (feed up) or on roof (feed down)

Heat Recovery Ventilators

- Possible to install in ceiling void above bathroom or kitchen and run ducts between joists to outside wall or to soffit grille
- MUA supplied from roof; exhaust ducted to side wall. No easy way to recover exhaust heat for MUA.
- Many new buildings use HRVs in suites for IAQ
- Central HRV with all exhaust ducted back to roof a possibility for new construction, but not for retrofit. This is rare because of the amount of space required for duct shafts, and developers don't want to give up any space with ever square foot being so valuable.
- Could add HRV to suite above washroom or kitchen dropped ceiling and duct between joists to outside.
- Distributing air within suite would have to be between joists or in new dropped bulkhead.
- Fairly invasive to do this upgrade.
- Only way to really justify HRV retrofit is if there's moisture problems or poor IAQ in suites. Buildings of this vintage should have sufficient ventilation from existing MUA, but older ones with leaky stairwell doors and elevator doors could be candidates (b/c windows would be better sealed in more modern buildings)

- Through-wall HRV might be most attractive solution (but noise can be an issue as it cycles on and off during the night).

12.2.2 Low rise – hydronic heating



Air to Water Heat Pump (DHW preheat)

- Most buildings of this archetypes are quite old, and have very limited elec service (350-600A @ 208/3)
- DHW heating in lower levels, so ASHP could be located on the roof without very far to run piping (cut through a few floors), or pad mounted on level 1.
- If noise is an issue with ASHP on lower floor, could mount to the roof, and pipe preheated water down to boilers. Only ~4 floors to run pipe.
- If cost prohibitive or invasive to core through floors in building, could run piping down outside wall (use glycol loop for this piping) with tanks and pumps inside mech room (prefer not to have tanks outside b/c of heat loss).
- Similar concerns with elec capacity as high rise hydronic buildings.

Air to Air Heat Pump (PTAC)

- As promising as for high rise hydronic
- Have to check that there is enough capacity on suite panel (should be OK… could just steal a cct from a receptacle)
- Installation easier than for high rise b/c of all wood construction

Hybrid Gas/Heat Pump Make Up Air Unit

- Likely no benefit for low rise MURB b/c some don't have MUA, and those that due are often not heated anyway.

Sewage Heat Recovery Heat Pump

- Not feasible without digging up the sewer main

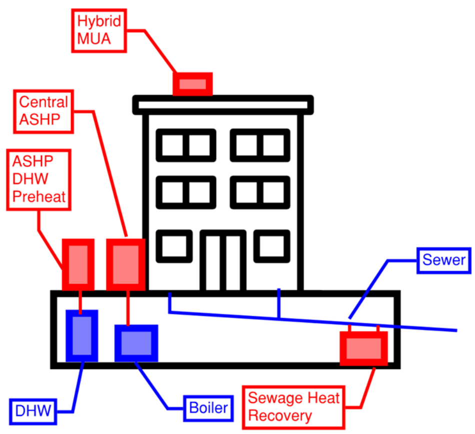
CO2 Heat Pump for Domestic Water Heating

- Refer to Low Rise – Electric heating

Heat Recovery Ventilators

- Refer to Low Rise – Electric heating

12.2.3 Low rise – low temp hydronic



Air to Water Heat Pump (DHW preheat)

- Water heating done in P1
- To use ASHP for preheat, would need to locate eqpt on a pad outside
- This may cause lots of noise for occupants on the wall facing the heat pump
- Noise should be a primary consideration if this is the case: soft start, night time mode, low noise fan blades
- New elec connection required, but elec room shouldn't be too far
- Low temp buildings post-2010, so should be designed for high plug loads.
- Likely enough capacity in the building, so elec upgrades would be limited to downstream of elec vault.

Air to Air Heat Pump (PTAC)

- this is most promising!!! (as long as there is a 208V circuit in the suite).
- Some models use 120V plug, so won't require any elec upgrades
- Can also hard wire, but can take off from existing circuit, not requiring a panel upgrade

Hybrid Gas/Heat Pump Make Up Air Unit

- Lots of room on roof
- Low temp system may use hydronic heating coil for MUA. If so, a central heat pump would be best
- If original MUA uses gas, hybrid MUA would use existing gas infrastructure
- May need new elec service to supply high amperage req'd by HP
- MUA isn't too far from elec rm if it's just 4 floors up.
- If insufficient service is supplied at roof level, may need to pull new wires through existing conduits all the way from P1.

Sewage Heat Recovery Heat Pump

- Only feasible if sanitary collects in parkade level and is accessible for equipment to connect into
- To access sewer would require digging up the slab, which adds significant cost to the measure
- If sewer main were exposed, might be good archetype b/c water is heated in lower levels.

CO2 Heat Pump for Domestic Water Heating

- Refer to Low Rise – Electric heating

Heat Recovery Ventilators

- Refer to Low Rise – Electric heating
- Except an in-wall solution may work (Lunos).
- Buildings typically have low WWR