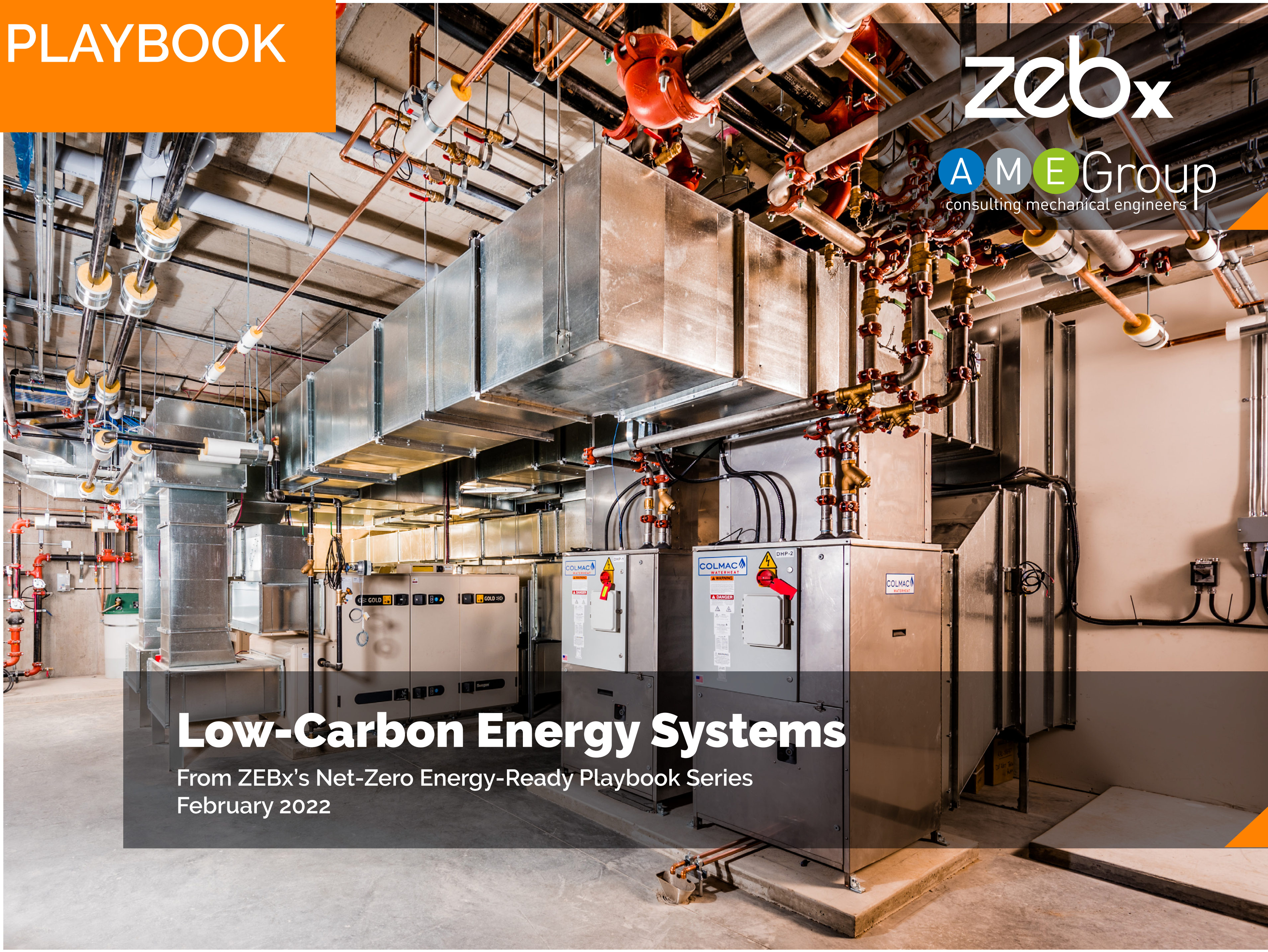
PLAYBOOK



ZEBx

AME Group
consulting mechanical engineers

# Low-Carbon Energy Systems

From ZEBx's Net-Zero Energy-Ready Playbook Series
February 2022

# GHG Targets for Buildings

In 2018, 12% of BC's greenhouse gas (GHG) emissions came from buildings[1]. The British Columbia government has enacted recent changes to climate action legislation. The CleanBC Roadmap to 2030 was released in October, 2021. The plan outlines several reduction targets related to buildings, including:

- Requirements to make all new buildings net-zero emissions by 2030
- Increased energy efficiency requirements, including a requirement that after 2030 (or earlier where feasible) all new space and water heating equipment sold and installed in B.C. will be at least 100% efficient.

A 2030 sectoral target had previously been established by the Province for buildings and communities - a 59 - 64% reduction in GHG emissions relative to 2007 levels. Current BC legislated GHG targets are 40% below 2007 levels by 2030, 60% by 2040, and 80% by 2050[2]. The City of Vancouver is targeting even more ambitious goals - almost all new buildings must be near-zero emissions by 2025.

Many municipalities have recognized these targets and have set their own building bylaws or permitting requirements to align with the Province. A growing number of municipalities are introducing Low Carbon Energy System (LCES) pathways for building permits. This alternate pathway allows buildings to meet a lower level of the BC Energy Step Code. Even higher goals have been adopted by many agencies, developers, and institutions to push reduction targets further.

How will the market change as it tries to adjust to meet the new targets? Educating designers and developers is key to establishing the framework for effective GHG reduction. This playbook focuses on low-GHG heating and hot water solutions for buildings. The different mechanical systems explained in this playbook can be applied to a multitude of building types, both new and existing. Low-GHG energy systems are central to the ongoing reduction of GHG emissions of buildings especially considering the electrical source throughout BC.

## Example

### City of Vancouver

- Any rezoning project must meet a GHG performance limit or be certified to a near zero emission buildings standard such as: CaGBC Zero Carbon Building Standard, Passive House, ILFI Living Building Challenge, ILFI Core Green Building, ILFI Zero Energy, and ILFI Zero Carbon Certification. Large residential, commercial, and hotel & motel construction projects must meet the GHG performance limits listed in Part 10 of the Vancouver Building By-law.

### Cities or Districts of Port Moody, West Vancouver, North Vancouver and Surrey

- All have alternate LCES pathways to encourage the construction of buildings with low operational emissions.

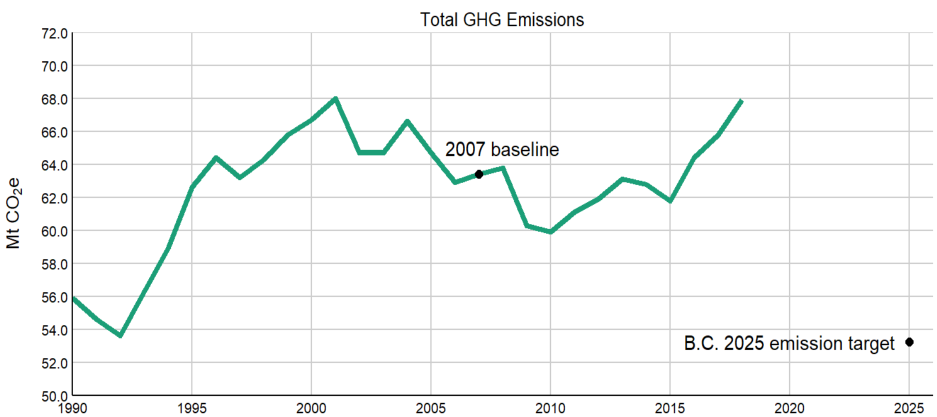
# Clean, Renewable Electricity

## British Columbia's Clean Energy Act

British Columbia has some of the cleanest electricity in the world. While there are two regulated electricity providers in BC (BC Hydro and FortisBC), with BC Hydro providing electricity to the most BC communities. Approximately 97% of BC Hydro's energy is generated from clean, renewable resources, meeting BC's Clean Energy Act[3]. The majority of BC Hydro's electricity is generated from hydroelectric dams which are also supplemented by smaller plants made up of wind, solar, and biomass facilities. BC Hydro is the largest electricity producer in the province and mandated to provide affordable, reliable and clean electricity. Electrification is viewed as a leading solution for climate change mitigation across the globe and technology solutions such as energy storage are improving every year to support this transition. Wind and solar technologies are also becoming more accessible and affordable. With BC's abundant supply of clean electricity, fuel-switching is the most reliable strategy for reducing GHG emissions from buildings. Most building emissions are the result of burning fossil fuels for space heating and domestic hot water.

### Greenhouse Gas Emissions in British Columbia

In 2018, gross greenhouse gas emissions in BC were 7.1% higher than the 2007 baseline year.




Total GHG Emissions
Picture from Environmental Reporting BC

The primary reason for not already using electricity for space heating and hot water systems is that natural gas is often more affordable than electricity.

**In Vancouver for example,** the cost comparison of natural gas and electricity is as follows:

= $0.03 to $0.035 per kWh

= $0.11 per kWh

(Note that this an example only does not include Carbon Tax and is also dependent on rate structure).

Using a heat pump for space heating and domestic hot water can greatly compensate for the difference in cost between natural gas and electricity.

# Low-GHG Building Incentives

Many financial incentive programs are used to encourage the construction of low-GHG energy buildings. Rebates are widely available in BC for both new construction and building retrofits that demonstrate low-carbon solutions. These incentive programs have changed their performance requirements from kWh of energy to CO2e of GHG.

Picture: Daily Hive

Picture: BC Housing

## New Construction

- BC Hydro in partnership with CleanBC offers a CleanBC Commercial New Construction Program incentive of up to $500,000 in capital and $15,000 for energy studies, based on the GHG reductions over the life of the building.
- FortisBC also in partnership with CleanBC offers a Custom Efficiency Program targeting GHG reductions, providing financial compensation for large projects that show gas savings. The capital incentive has a maximum of $500,000 plus an additional $37,500 for an energy study.

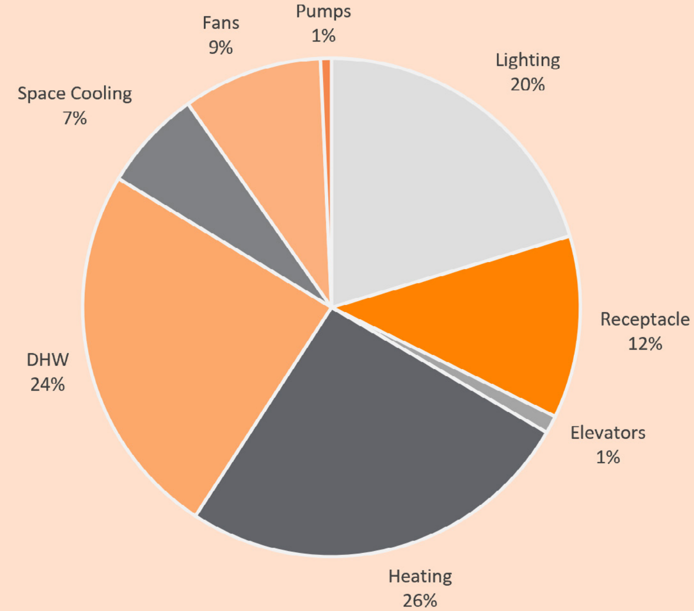
## Retrofits

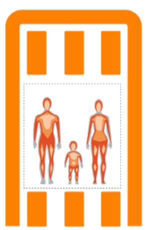
- BC Hydro in partnership with CleanBC offers a CleanBC Custom Program incentive for retrofit projects, ranging from major retrofit projects to equipment electrification projects. Capital incentives range from $48,000 to $200,000 depending on the size of the project.
- The FortisBC Custom Efficiency Program is also available for retrofit projects. The capital incentive has a maximum of $500,000 plus an additional $37,500 for an energy study.

# Building Energy Consumption

## Energy Use Breakdown

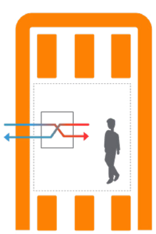
The first step to reducing building energy consumption in all projects should be to first analyze the building energy balance and understand which systems in the building use the most energy. The following pie chart is the energy consumption for a typical mixed-use residential buildings (MURBs) in the Vancouver area. The amount of heat required is largely attributed to space heating, ventilation and domestic water heating.



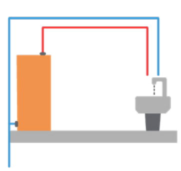
### Space Heating

Insulation and airtightness are the key factors in reducing space heating demand. Improving envelope performance will reduce the amount of energy required to heat the space and allow for optimized sizing of equipment. This in turn will help maximize reduction of overall GHG emissions from building operations.



### Ventilation

By using heat recovery ventilators (HRVs) or energy recovery ventilators (ERVs) the outside air being delivered into the building can be pre-heated by the building exhaust air. These units can be anywhere from 60% to 85% efficient. High occupant zones of buildings such as offices, meeting rooms, or amenity spaces require higher ventilation rates. These areas can be a significant portion of the heating load, providing increased opportunities for energy and GHG savings. For further reading on ventilation options, please refer to Zebx's Net-Zero Energy-Ready Playbook: Ventilation Strategies for High-Performance Multi-Unit Residential Buildings[4].



### Domestic Water Heating

For domestic water heating systems, the amount of energy required to heat water is mostly based on how much water is being consumed in the building, which is related to the flow required at the fixtures. By using low flow fixtures we reduce the amount of energy required as we have less water to heat.

# Space Heating

There are numerous approaches and system types that can be implemented to heat buildings. The best solution for the project will depend on a variety of factors and related priorities such as the building type, size, energy targets, ownership and cost (capital and ongoing).

## Electric Based Heating Options

### Electric Resistance:

- **Traditional Electric Baseboard Heater**

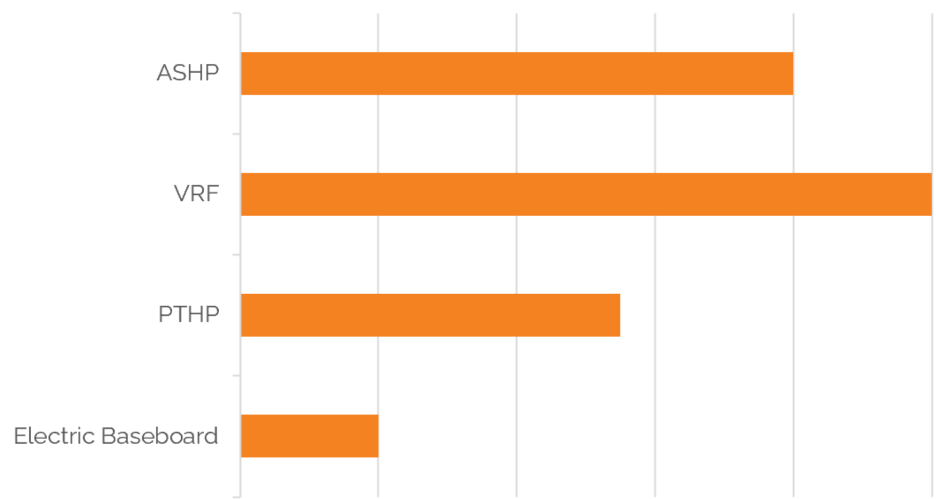
### Heat Pump:

- **Packaged Terminal Heat Pump (PTHP) Units**
- **Variable Refrigerant Flow (VRF) System**
- **Air Source Heat Pump (ASHP)**

### How to Measure Efficiency

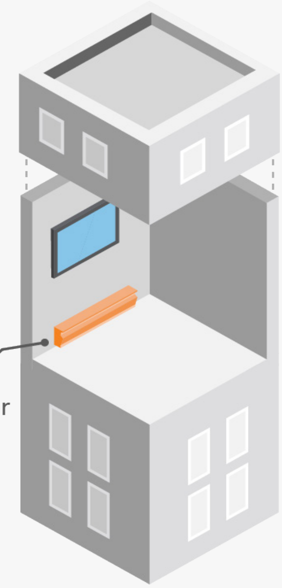
The measure of a system's heating efficiency is based on its Coefficient of Performance (COP). This is the amount of electric energy that is required to produce heating energy. Electric resistance heating systems will always have a COP of 1, meaning 1 kW of electric energy input provides 1 kW of heating energy. Although this sounds efficient, the other technologies described in this playbook have much higher COPs. As technology develops continually, more options are available for heating sources with even higher efficiencies and often lower environmental impacts from the materials used to manufacture them.

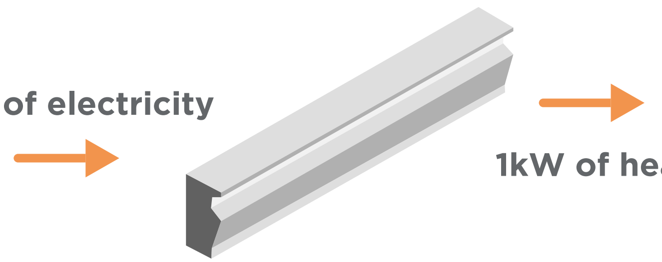
### Typical Heating System Efficiency (COP)



# Traditional Electric Baseboard Heater

Electric baseboard heaters simply use a resistance heating element that turns on or off as needed to maintain the space temperature. In residential units of multi-family buildings, one baseboard heater is typically installed in each room. This ensures that only the rooms that require heating are heated. Developments pursuing low capital cost solutions will often incorporate electric baseboard heating in the design. As electric baseboard heaters are much less efficient than other electric heating solutions, they should be used in supplemental or backup systems rather than for primary heating. Other electric resistance heating components can also be used in mechanical systems such as inline electric duct heaters, HRVs with post-heating, and rooftop heat pumps with electric preheat. Typically, these components with electric heating are used to control supply air temperature or to prevent freezing of system components in colder climates. For an electric baseboard heater, the COP is always 1, meaning 1kW of electric energy input provides 1kW of heating energy. Although this sounds efficient, the other technologies described in tis playbook have higher COPs.



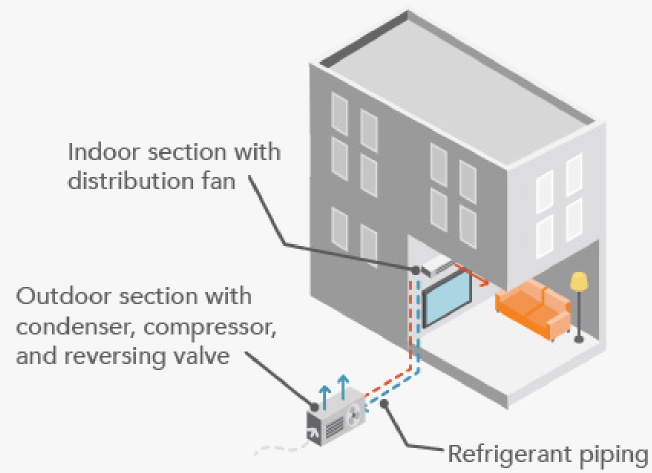

## How it works

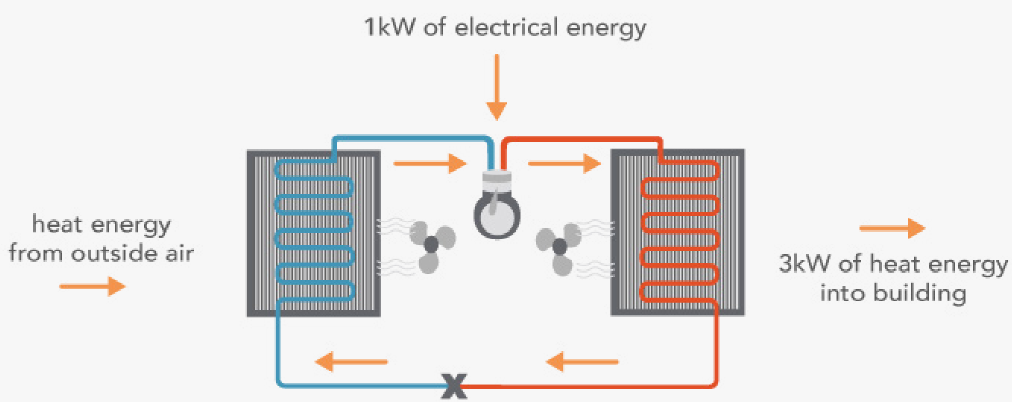
An electric baseboard heater consists of a simple electric heating element made of a metal tube with fins. Electric baseboard heaters operate similar to a kitchen toaster with an electric resistance heating element within an enclosure to prevent users from touching the extremely hot element. When the thermostat in the room sends the signal to the unit to turn on, an electric current runs through the heating element, which in turn heats the air surrounding the element. As the air warms up, the air will rise in the room which will draw cooler air across the element. The heat is also radiated out from the heater in the room. These units are typically located on the walls below windows to prevent cool air along the surface of the window from falling to the floor in the room. The infrastructure for this system is minimal as it only requires an electric connection and a thermostat. This is an option for buildings that are only providing heating. A building with this type of space heating will require a separate system for the ventilation, including heating the ventilation air.

While the COP for an electric baseboard heater is 1, resistance heating is by far the most inefficient way of producing heat from electricity. This results in much higher ongoing operating costs (and environmental impact) for the life of the building, whereas the benefits are only ease of replacement and low installation cost.

# Heat Pump

The key to efficient electric heating systems is the use of heat pumps. One of the benefits of using heat pumps is that the same system can be used for both heating and cooling. Heat pumps vary in scale from small, one-room units to larger central systems. Heat pumps can also transfer heat to and from a variety of different sources such as water, air, and the ground. The efficiency of heat pump cooling is defined differently than that of heat pump heating. Heat pump cooling operation efficiency is defined by the Energy Efficiency Ratio (EER). Detailed adjusted cooling efficiencies for heat pumps include Seasonal (SEER) and Integrated (IEER) Energy Efficiency Ratios that take into account overall seasonal operation or part-load performance. Efficiency of heat pump heating operation is the COP or Heating Season Performance Factor (HPSF) number. The seasonal numbers take into account overall seasonal value, whereas numbers that are not season specific are instantaneous efficiency values that vary as source and space temperatures change.



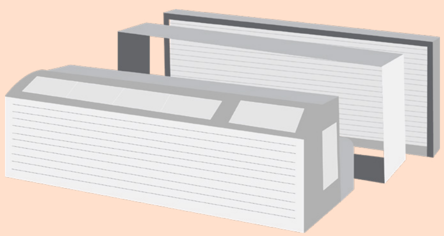

## How it works

All air conditioners and refrigerators use a refrigerant cycle, which includes a compressor and other components to move heat energy away from the area to be cooled. This is accomplished by manipulating the pressure of the working refrigerant (air, water, synthetic refrigerants, etc.) through a cycle of compression and expansion driven by a compressor with an electric motor. A heat pump uses this same technology but has the ability to provide both heating and cooling by way of an internal reversing valve The reversing valve is important as it is used to alternate the compression cycle and overall direction of heat flow, providing heating mode in cold weather and cooling mode in warm weather with the same set of components. Because electricity use is often more expensive than gas, choosing a heat pump with a high COP will make operational costs of a heat pump comparable to using a gas-fired boiler when the carbon tax is taken into consideration.

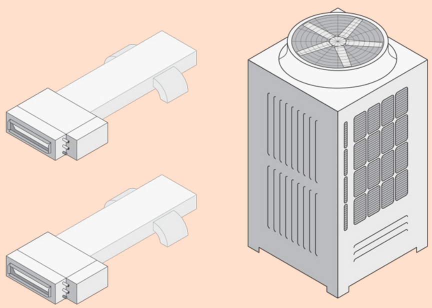
The source of heat that is transferred into a building can be described as either air source or water source.

- Air Source: Where the heat energy is transferred directly between the atmosphere and the heat pump.
- Water Source: A building based water system is directly connected to each heat pump. The building based water system is then used to transfer heat energy between the heat pumps and a subsurface ground loop (also referred to as groundsource), a loop in the ocean or lake, or central equipment such as a cooling tower or heat exchanger to a neighborhood based energy system. Regardless of how cold the source may appear, there is still energy to be moved.
- Advanced controls systems allow certain types of heat pumps to be interconnected with each other, thereby providing additional energy efficiency. This can allow parts of buildings with simultaneous heating and cooling demands to efficiently move heat from one zone to another while reducing the net source heat demand.
- The combination of source type and also how heat pumps are interconnected results in many building heat pump system options. The most common heat pump based systems are packaged terminal heat pumps, variable refrigerant flow units, and air source heat pumps.

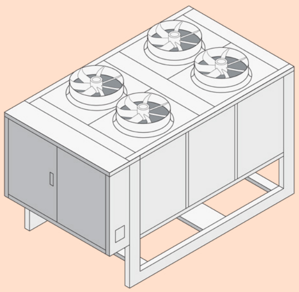
## Common Types of Heat Pumps



**Packaged Terminal Heat Pump (PTHP)** units are often the lowest cost heat pump solution. PTHPs are air source and cannot interconnected to each other. PTHPs are physically located within the zone that it serves and can generate significant noise disruption primarily because of its close proximity to occupants.



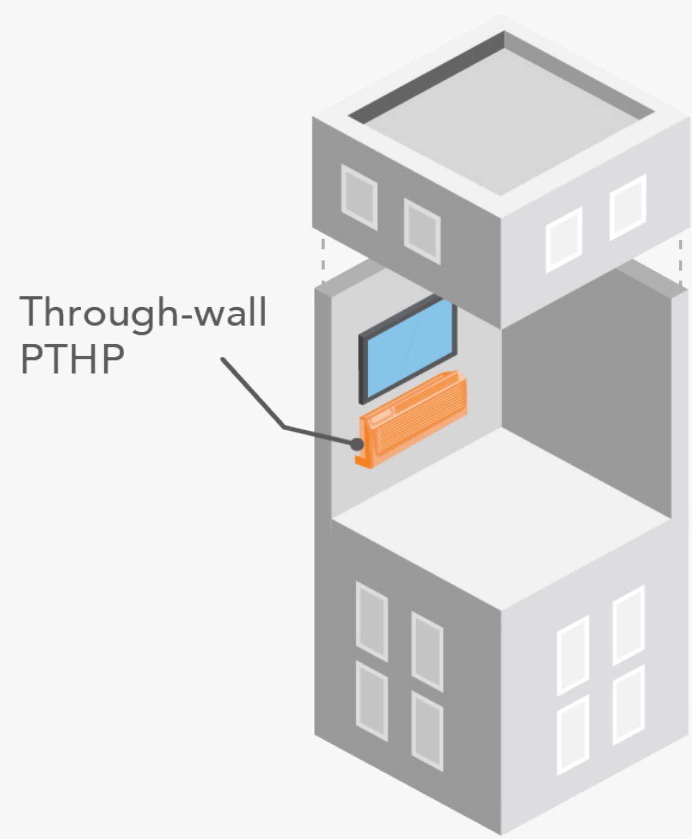
**Variable Refrigerant Flow (VRF)** heat pumps are typically interconnected to each other by refrigerant piping and can result in highly efficient operation. VRF systems can either be water source or air source. Advanced controls systems are needed to operate the system.

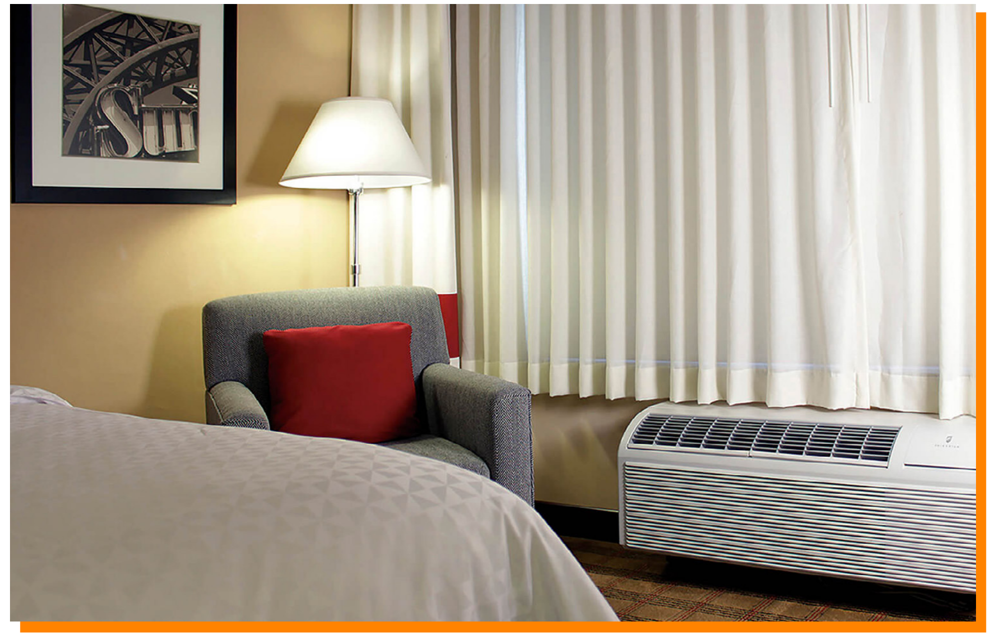


**Air Source Heat Pump (ASHP)** units are typically centralized within a building are air to water systems, meaning that two sets of water piping are distributed throughout many zones performing both heating and cooling functions. Each zone would use a fan coil unit to transfer cooling or heating (depending on the temperature setpoint for the zone) from the water piping tied to the central plant. A central ASHP can often be the most efficient solution for larger buildings.

# Packaged Terminal Heat Pump

Packaged terminal heat pump (PTHP) units are wall-mounted, and installed on an exterior wall, typically below a window. These are small units which contain all the components required to operate.



Picture: hotelmanagement.net

**How it works**

An air transfer grille on the exterior wall allows the heat pump to transfer heat between the interior and exterior. The advantage of these units is that they are self-contained systems that do not require additional piping or connection to a central heating and cooling plant. Their COP typically ranges from 2.5 to 3.5 with a typical SEER range of 15 to 18. Although they are efficient on their own, there is no ability for PTHP units to be interconnected to one another, thereby reducing overall building efficiency capabilities. The primary advantage of PTHPs is the simplicity of straightforward replacement, making this a desirable option for apartment or hotel buildings. As there is no interconnection between multiple PTHPs, a single room can be independently shut down for equipment replacement without affecting any other portion of the building.

# Variable Refrigerant Flow

A variable refrigerant flow (VRF) system allows for whole-building heat recovery.The use of interconnected fan coil units (typically one per zone) allows simultaneous heating and cooling, resulting in increased efficiencies and heat recovery.

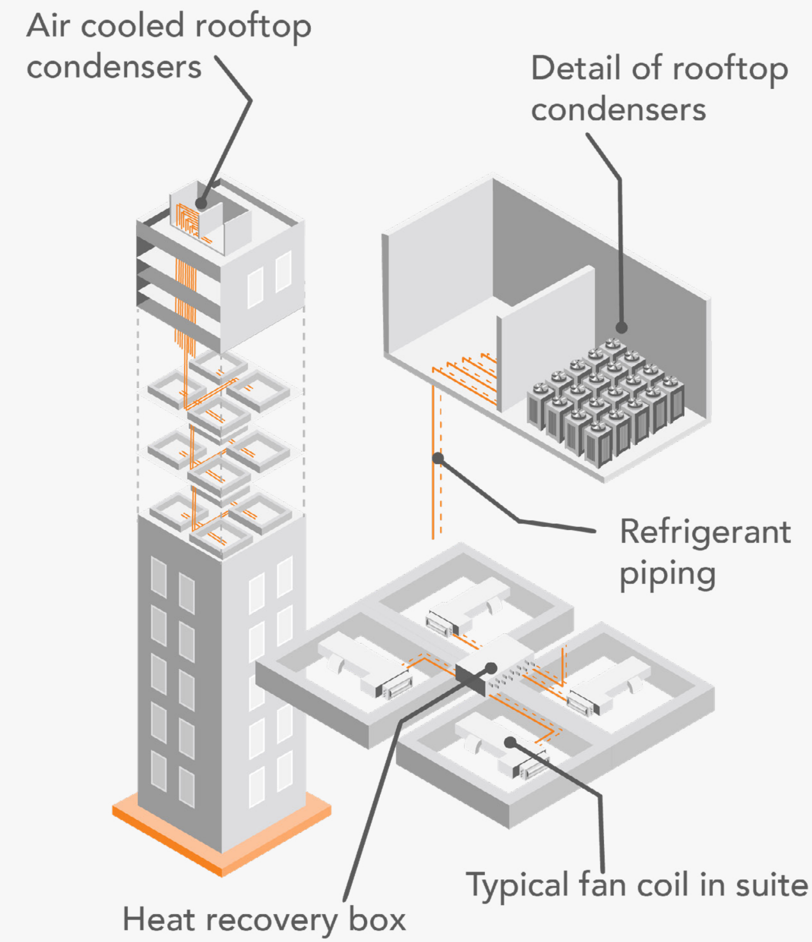
Air-cooled VRF systems contain fewer components and each component is provided by a single manufacturer. The system includes an air-cooled condenser located outside, with refrigerant piping that runs into the building to all the fan coil units in the suites. There is one small additional component that is installed between the two called a heat recovery box. When a building requires both heating and cooling, moving heat within a building is more efficient than moving heat between the inside and outside. Heat rejection or recovery is needed when a portion of the building requires cooling. The VRF system heat recovery box is typically located centrally on each floor. It includes control valves and sensors and acts as the brain of the heat recovery portion of the system.

## How it works

When one fan coil unit is in cooling mode, the heat being removed from the space is first analyzed by the heat recovery box. If that component determines that another fan coil unit on that same system needs the heat, it will move that heat to that unit. If there is no need for heat, it will move it up to the condensing unit where it is rejected to the outdoor air.

It is important for the design team to understand that a VRF system is limited by building height, climate, routing of refrigerant piping, among other considerations.

VRF system components must be all from the same manufacturer when installed. This allows each component to meet very specific requirements and operate effectively as a whole via integrated controls that are often proprietary. Highly efficient and variable speed compressor and condenser motors result in excellent efficiency values that often reach or exceed other technologies.




## There are two types of VRF systems: water-cooled and air-cooled.

Both are similar in how they operate, however the air-cooled option is the simplest to provide as a fully electric system.

# Air Source Heat Pump

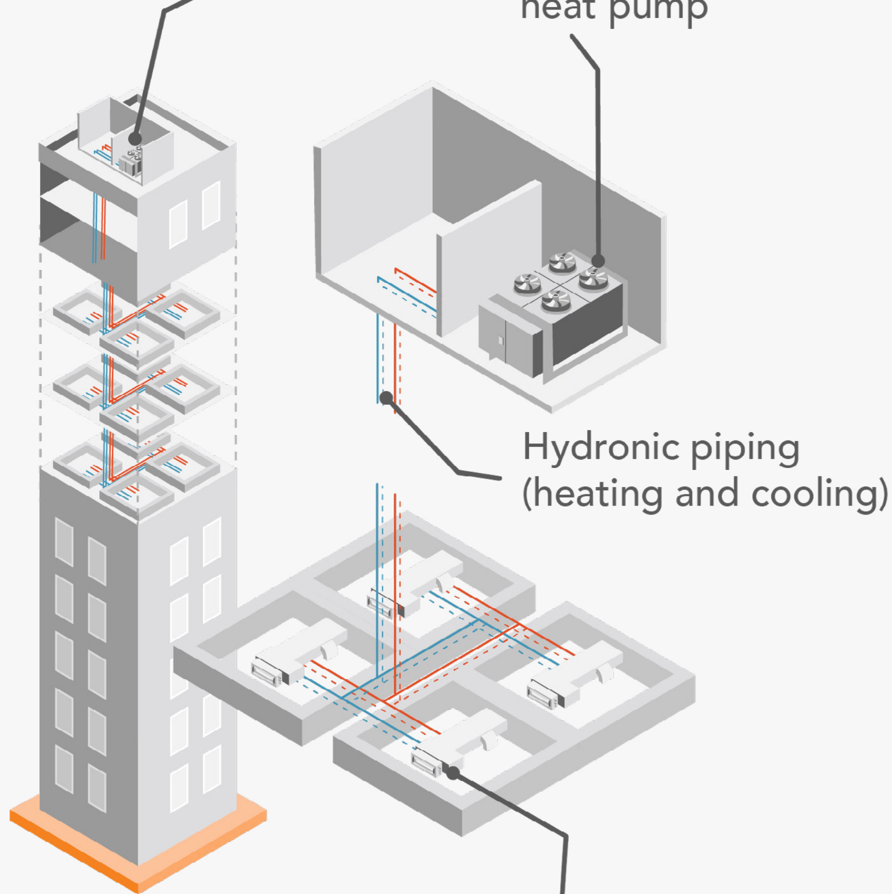
An air source heat pump (ASHP) can provide for whole-building heat recovery. The ASHP can be located on a roof or at grade as part of a central plant for heating and cooling. The unit is piped to all fan coil units within the building using water piping.

The level of interconnection between fan coil units and the central ASHP can optimize the opportunity for energy conservation and resulting GHG and energy cost reduction.

### How it works

An ASHP will move heating or cooling energy from the outdoors to the water systems in the building where it is distributed to fan coil units. Some ASHPs can operate in a heat recovery mode. When in this mode, the control system will monitor the amount of cooling in the building and then see if any spaces within the building require heat. If heat is required, the system will reject heat to the space before it rejects it to the outdoors. If the entire building is in need of heat however, it will operate in full heating mode and move the heat energy from the outdoors into the building.

This system has a high COP and is slightly more complex in that all the components can be from different manufacturers, requiring an independent control system design. This system does allow flexibility with different types of terminal units like fan coil units, hydronic baseboard heaters or radiant panels.



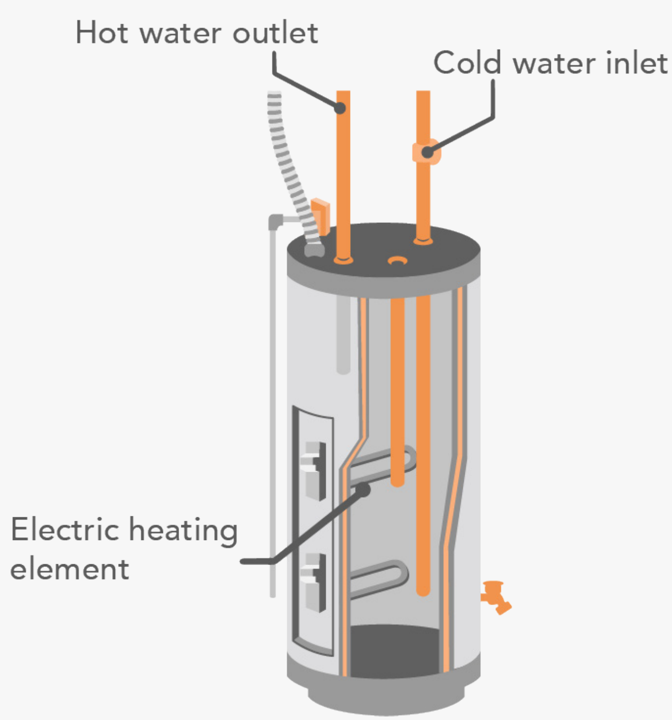
# Domestic Hot Water

Domestic hot water (DHW) systems can be installed centralized and piped throughout the building or decentralized with smaller individual tanks inside each suite. The heating of DHW often uses natural gas as a heating source. Similar to a space heating system, different all-electric technologies can be used to heat water. All-electric DHW systems can be categorized into systems which use electric resistance heating and systems which use heat pumps.

## Electric Resistance Heating

The simplest system that can be used to generate DHW within a tank uses electric resistance heating elements. The simplicity of the electric hot water tank allows for a very large range of sizes that can be used from an individual residence washroom all the way up to an entire mixed use residential building.

Electric hot water tanks have typically been favoured due to their low capital installation cost.




**How it works**

The system includes at least one heating element inside a tank that will automatically turn on to maintain the tank's internal water temperature, similar to a simple electric oven. One or multiple tanks can be grouped together as a central system serving several suites or floors in a building. Alternatively, a decentralized approach can be used where each suite contains a much smaller dedicated tank. This is a simple, traditional, low capital cost option.

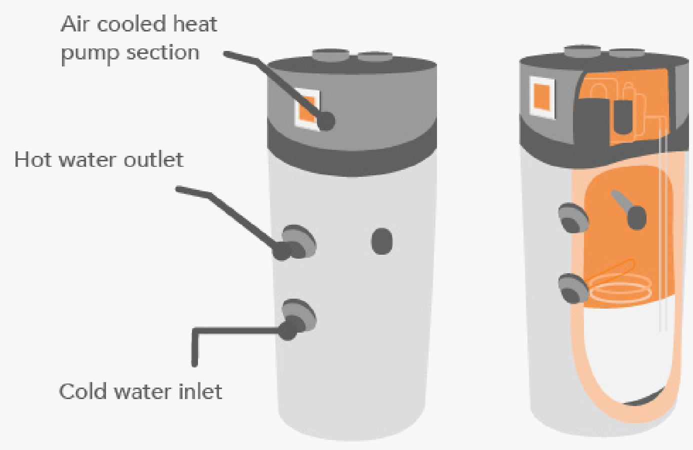
Similar to electric resistant space heating, electric DHW tanks have a COP of 1. The efficiency of the DHW system can be improved by increasing insulation of the tank and piping systems. For more efficient systems, heat pumps can be used. The use of heat pumps for DHW in BC is increasing as a result of many factors including the mild climate and regulations aiming to reduce the GHGI of buildings.

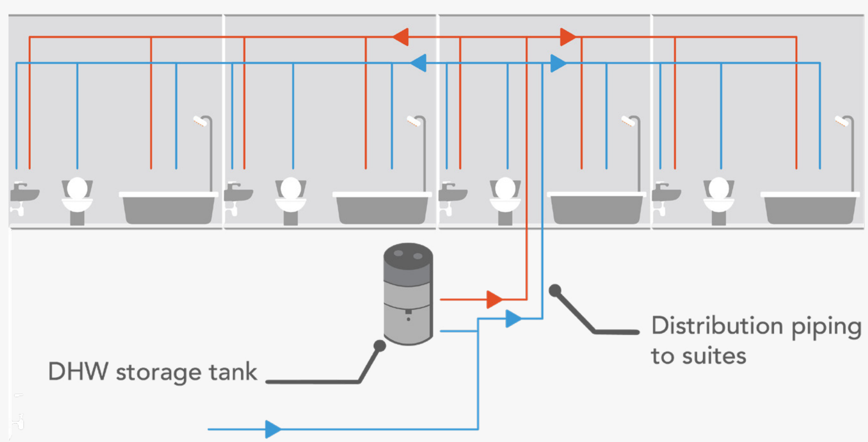
# Heat Pump

There are a few different configurations for DHW heat pump systems. These all have COPs of approximately 3 and in in some cases, more, making these much more energy efficient than a resistance heated electric DHW tank. As with all heat pumps, the COP will vary depending on the operating temperature for each part of the refrigerant cycle. Understanding the anticipated operating conditions such as ambient air temperature variation throughout the year and desired water temperature are considerations that need to be evaluated during the design phase.

## Hybrid Heat Pump

A hybrid DHW storage tank can be used – one that combines an air source heat pump with a traditional electric heating element. The term hybrid often refers to the combination of heating source where the heat pump acts the primary source with a small electric resistance heater as a backup source. It should be noted that the ASHP only operates in heating mode as the purpose is only to generate DHW.




### How it works

The heat pump is installed on top of the tank and will move the energy from the air around the tank to the water in the tank. To operate more efficiently, this unit should be installed in a space that will remain warm like a furnace room or utility closet. Considerations must be taken to prevent overcooling of the room where the hybrid heat pump is installed. Should overcooling be a concern, the heat pump can be ducted to the exterior of the building to allow cold air to be expelled to the outdoors. Hybrid DHW tanks include their own packaged controls and require no additional components, similar to a traditional electric hot water tank. Hybrid DHW tanks can operate in many different modes and will sometimes use electric heating elements to supplement the heat pump should the demand on the tank be higher than the capacity of the heat pump.

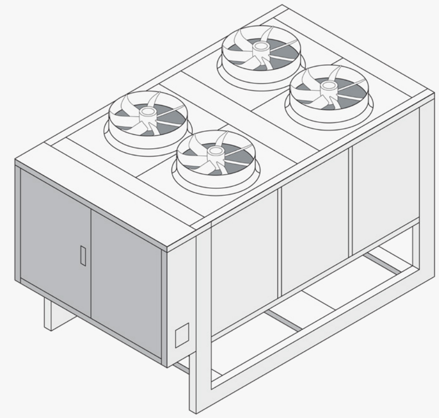
In all cases, DHW systems using heat pumps require a double-walled heat exchanger to ensure the refrigerant or hydronic fluid does not contaminate the potable water.

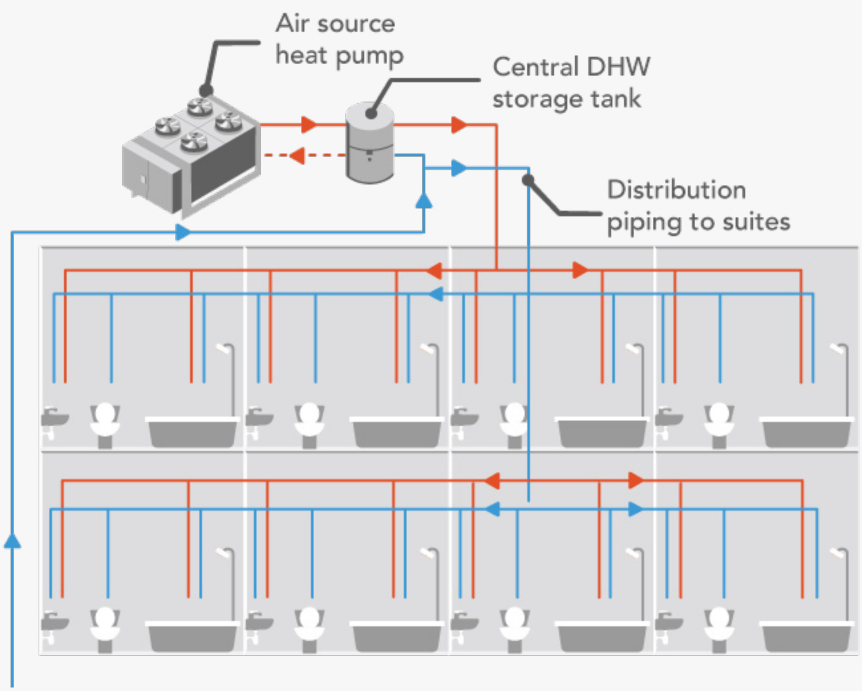
## Air Source Heat Pump

An ASHP system can be used where the physical location of the indoor DHW tank does not need to meet the same specific requirements of the traditional hybrid DHW heat pump.

The ASHP contains all heat pump components within a single unit located outdoors and is similar to the type used for space heating. It should be noted that the ASHP only operates in heating mode as the purpose is only to generate DHW.

ASHP systems are most commonly used as part of a centralized DHW system due to their overall complexity and ability to integrate with other centralized building heating systems.






### How it works

The ASHP unit must be located outdoors with water piping connections that are used to interconnect to an indoor DHW storage tank. The indoor tank then distributes hot water to the plumbing fixtures. When used for DHW production, ASHPs include an internal heat exchanger allowing all piping connections to be potable water based. The ASHP is a more complex system from an equipment control perspective however it allows flexibility in using equipment from different manufacturers. It also requires more distribution piping and is typically most cost effective in larger buildings because of the fewer overall system components when compared to a decentralized system.

# Emerging Technologies

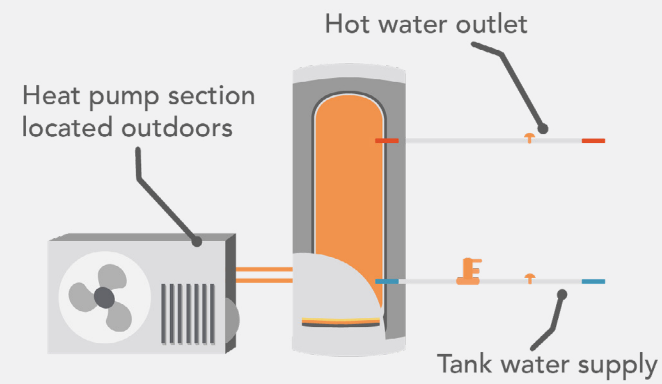
## $CO_2$ Based Heat Pumps

Historically, heat pumps have used hydrochlorofluorocarbon (HCFC) or hydrofluorocarbon (HFC) refrigerants, but a growing number of DHW heat pumps are being designed to use carbon dioxide as a refrigerant. $CO_2$ has a significantly lower global warming potential than the more common HFC refrigerants.

Picture: 475 High Building Performance Supply

### How it works

$CO_2$ heat pumps must operate at very high pressures, but they can be more efficient than HFC-based heat pumps. Heat pumps using $CO_2$ can have COPs of up to 5 and are also able to easily generate sufficiently hot DHW allowing additional application flexibility. Until recently, $CO_2$ heat pumps have been used for buildings with relatively low DHW demand, such as single-family homes.



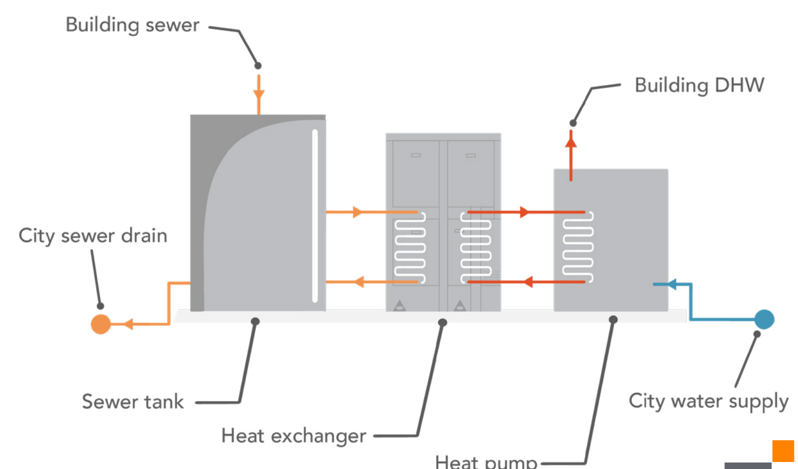

## Wastewater Heat Recovery

Some large-scale projects in BC reclaim heat from wastewater leaving the building. As occupants are taking showers, doing laundry or washing dishes, this heat, instead of going down the drain, can be reclaimed to heat the DHW that is needed for these tasks.


Picture: Sharc Energy

### How it works

This system will pump wastewater through the heat pump via a heat exchanger. The refrigeration loop within the heat pump then transfers the heat to the DHW supply through another heat exchanger. Passive options for small scale applications are also available, even on a fixture-by-fixture basis. An example of this is a simple water supply coil wrapped around a shower drain which will passively transfer heat from the wastewater to the DHW supply.



## Additional Resources

The intent of this playbook is to discuss some common options for electrification of building systems for the purposes of reducing GHGI. Building system designs can include many additional options and technology is evolving at a rapid rate as the industry responds to building regulations and concerns about climate change. To learn more about the topics covered in this playbook and additional approaches, please consult the following publications and website links.

1. Heating and Cooling With a Heat Pump
   https://www.nrcan.gc.ca/energy-efficiency/energy-star-canada/about/energy-star-announcements/publications/heating-and-cooling-heat-pump/6817
2. What's a Heat Pump and How Does it Work?
   https://www.bchydro.com/powersmart/residential/building-and-renovating/considering-heat-pump-info-tips.html
3. Guide to Residential Water Heaters
   https://www.nrcan.gc.ca/energy-efficiency/spotlight-energy-efficiency/2019/04/20/guide-residential-water-heaters/21861
4. Heat Pump Water Heaters
   https://www.energy.gov/energysaver/heat-pump-water-heaters
5. District Energy Systems
   https://www.toolkit.bc.ca/tool/district-energy-systems
6. Canada's Actions to Reduce Emissions
   https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/reduce-emissions.html

## End Notes

1. Source: *Trends in Greenhouse Gas Emissions in B.C.*
   https://www.env.gov.bc.ca/soe/indicators/sustainability/ghg-emissions.html

2. Source: *B.C.'s Climate Change Targets*
   https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action?bcgovtm=May15#targets

3. Source: *Clean Energy Act*
   https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/10022_01

4. Source: *Ventilation Strategies for High-Performance Multi-Unit Residential Buildings*
   https://www.zebx.org/ventilation-strategies-for-high-performance-multi-unit-residential-buildings/

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