LOW-CARBON MECHANICAL SYSTEMS FOR HOUSES IN LOWER MAINLAND, B.C.

TECHNICAL PRIMER

This technical primer provides an overview of the opportunities, challenges, and considerations for the use of heat pumps as a low-carbon solution for heating, cooling, and domestic hot water production for high-performance houses in the Lower Mainland, B.C.

July 2020

PREPARED BY

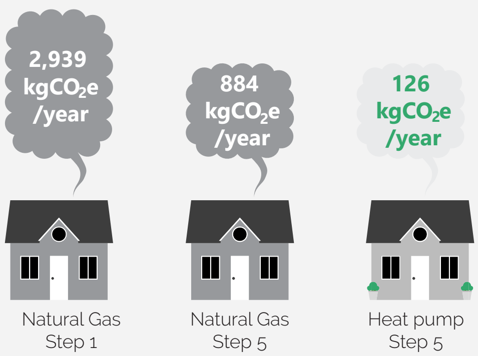
zebx

THE UNIVERSITY OF BRITISH COLUMBIA

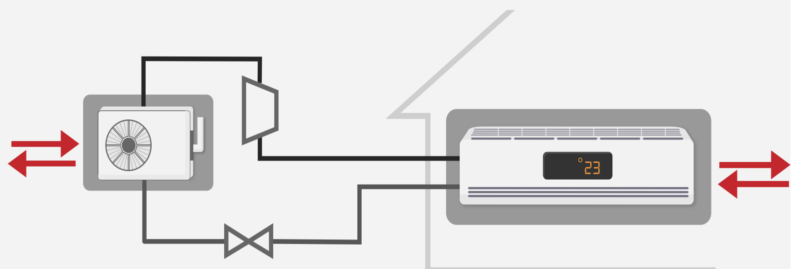
QUICK SUMMARY

WHY HEAT PUMPS?

DECARBONIZING BUILDING OPERATION

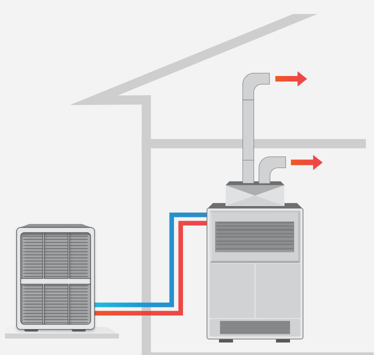


HEATING & COOLING IN ONE EFFICIENT SYSTEM

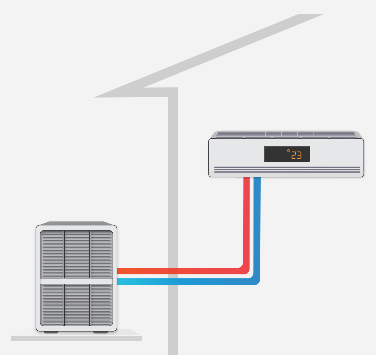


HEAT PUMPS FOR SPACE HEATING & COOLING

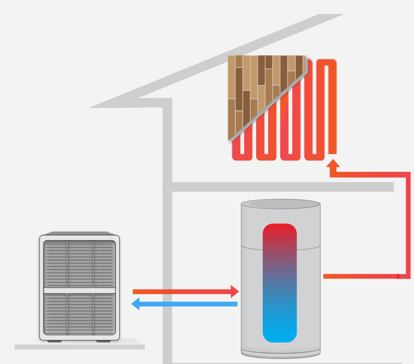
CENTRAL AIR-AIR HEAT PUMPS



MINI-SPLIT HEAT PUMPS

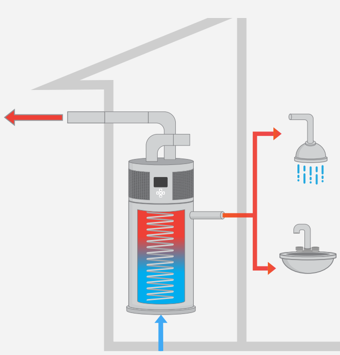


AIR-TO-WATER HEAT PUMPS

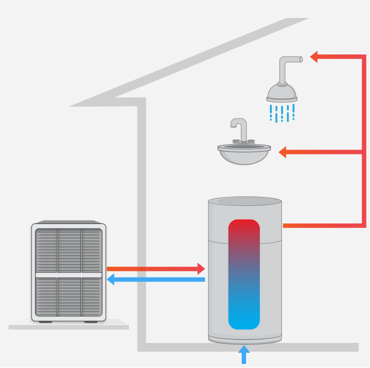


HEAT PUMPS FOR DOMESTIC HOT WATER

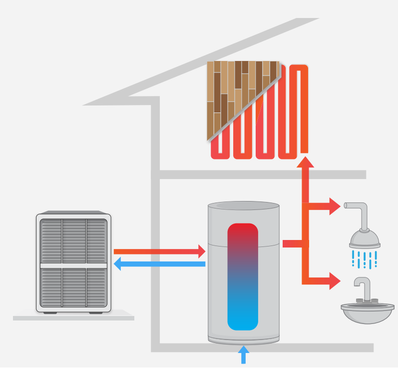
INTEGRATED SYSTEMS



SPLIT SYSTEMS



COMBINED SYSTEMS



WHY HEAT PUMPS?

Heat pumps are a proven and effective way to decarbonize building heating and hot water while also adding air conditioning in a warming climate. They can provide comparable operating costs as natural gas systems and are increasingly becoming important technology solutions towards meeting new building code requirements.

Context

Building heating and hot water systems are one of Canada's largest sources of carbon emissions, resulting in about 12% of national GHG emissions.

In response to the climate change crisis, various levels of government are developing policies and plans like the City of Vancouver's Zero Emissions Building Plan and the B.C. Energy Step Code, to improve energy efficiency and reduce carbon emissions from buildings. In Vancouver, the energy used for space heating and domestic hot water makes up the majority of the 59% of greenhouse gas emissions that buildings contribute to the overall city emissions. Therefore, energy efficient and low carbon mechanical systems can significantly reduce overall GHG emissions.

Why Heat Pumps?

Since close to 95% of the electricity in B.C. is generated from renewable resources, electric heat pumps are a low-carbon alternative to furnaces, boilers, and other heating systems that use natural gas or other fossil fuels and are 2 to 4 times more efficient. Heat pumps can have comparable operating costs to natural gas equipment under the right design, installation and operating conditions. See Additional Resources on page 8 for detailed information on heat pump design, installation and operation.

Heat pumps also provide heating and cooling in one piece of equipment, whereas furnaces, boilers and electric resistance heating provide heating only solutions. While air conditioning has not historically been commonplace in the Lower Mainland, B.C, the warming temperatures resulting from climate change and increasing risks of air quality from wildfire smoke have increased the need.

How Heat Pumps Work

Heat pumps move heat from outside to inside, or vice versa, using a fluid called refrigerant, which can evaporate and condense at the desired indoor and outdoor temperatures. Even when it is cold outside, a heat pump can extract heat from the ambient air or the ground and provide heating inside the house. This is called the heating cycle. In reverse it works just like a conventional air conditioner, extracting heat from the house and rejecting it outside, making the home cool.

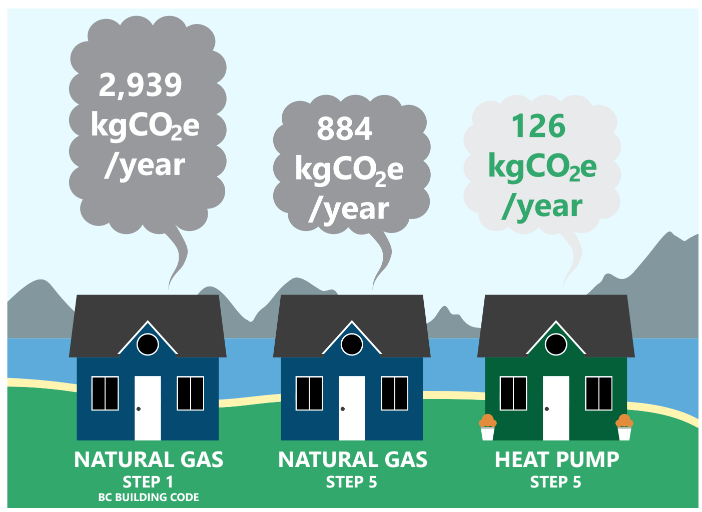
The key performance indicators of heat pumps are further described in BC Housing's Illustrated Guide for Energy Efficiency Requirements for Houses in British Columbia.

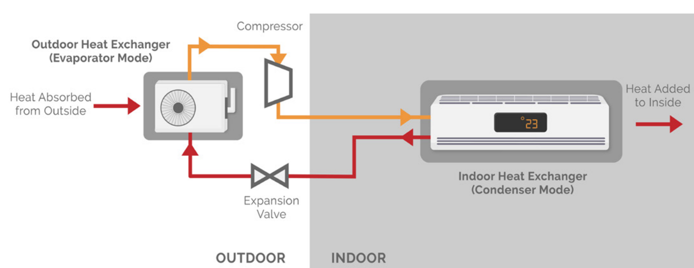
B.C. Energy Step Code

The B.C. Energy Step Code provides a path to achieving net-zero energy ready buildings by 2032. The current version of the Step Code does not mandate that any specific type of fuel source be used in a building. Rather it specifies the total heating requirements or Thermal Energy Demand Intensity (TEDI) and Mechanical Energy Use Intensity (MEUI) for Part 9 homes.

However, the higher steps of the Step Code (Step 4 and 5) are most cost-effectively achieved using higher efficiency mechanical systems like heat pumps, especially for domestic hot water (DHW) supply.

In addition, a number of growing municipalities are enacting policies that will require higher levels of the Step Code well ahead of the minimum requirements set by the B.C. Building Code with allowances for lower Step Code levels provided that homes use low carbon heating and hot water equipment .





Top: A study by Integral Group showed that a medium-sized, single-family house using natural gas heating emits more than seven times the carbon emissions of one using electric heat pumps, even when built to the highest levels of the B.C. Energy Step Code.
Bottom: Heating cycle of air-source heat pumps

HEAT PUMP APPLICATIONS
Heating & Cooling

There are many types of heat pumps that can be used in place of conventional gas-fired heating systems.

Three main types of air-source heat pumps that can be used in place of conventional systems in the Lower Mainland

Conventional heating system in the Lower Mainland	Recommended air-source heat pump alternative
Forced air central heating	Central air-to-air heat pumps
Baseboard or wall furnace	Mini-split ductless or ducted heat pumps
Central hydronic system or radiant floor	Air-to-water heat pumps

Types Of Heat Pumps

Air source heat pumps transfer the heat between the outdoor and indoor air. This type of heat pump is typically more cost-effective than ground source heat pumps, which require drilling on-site to create an underground heat exchange area for transferring heat.

While there are air source heat pumps that can operate at very low outdoor air temperatures (below -20˚ C), capacity and efficiency of heat pumps decrease at lower temperatures, making them especially ideal for temperate climates like the Lower Mainland.

Air temperature fluctuates more than ground temperatures, thus air source heat pumps perform better and are more common in moderate climate zones, like the Lower Mainland. Ground source heat pumps can maintain higher efficiencies in colder climates as the ground is more stable throughout the year compared to air.

The outdoor units of a heat pump in a high-performance townhouse in Vancouver, B.C. (Credit: Futrhaus, b Squared Architecture Inc.)

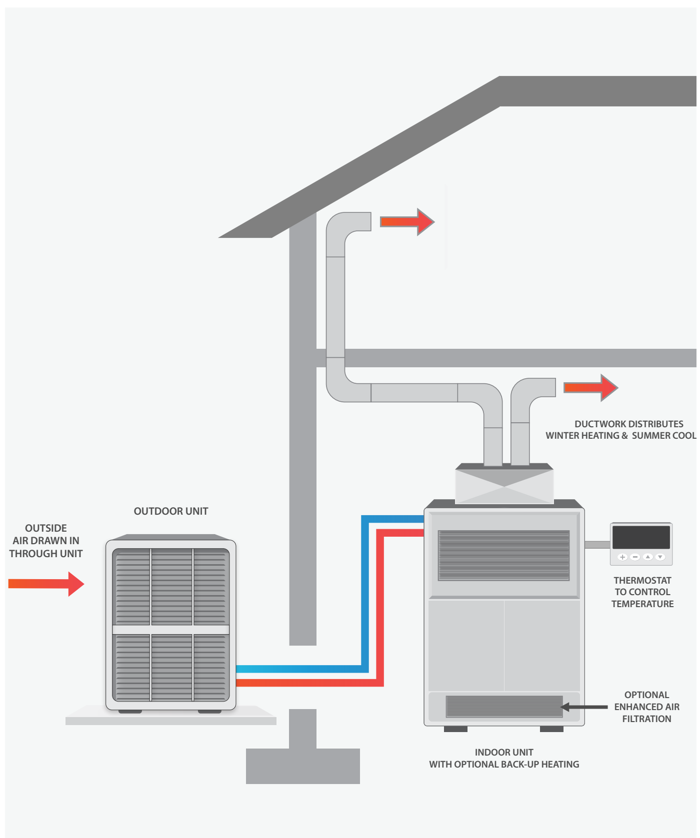
The following applications focus on air-source heat pump solutions as these are most common in Lower Mainland, B.C.

Central Air-to-Air Heat Pumps

Central air-to-air heat pumps can replace the conventional forced-air heating and cooling systems. These heat pumps can also be used in retrofitting houses that have existing ductwork in place.

An advantage of these types of heat pumps is their ability to combine heating and cooling in one equipment, as opposed to conventional systems that use separate furnaces for heating and air conditioners for cooling.

There is a wide range of performance and quality with the type of outdoor unit which can impact the cost, efficiency, and noise.



Central air-to-air heat pumps consist of an outdoor unit connected to an indoor unit that distributes the hot or cool air through ducting.

HEAT PUMP APPLICATIONS
Heating & Cooling

There are many types of heat pumps that can be used in place of conventional gas-fired heating systems.

Mini-Split Heat Pumps

Mini-split heat pumps are efficient alternatives for houses that do not have a central ducting system and would use a conventional baseboard or wall furnace for heating.

These heat pumps are increasingly popular in smaller houses with insufficient space for ducting. In addition to energy use reduction and cooling production, mini-split heat pumps can improve the indoor air quality compared to baseboards as they can filter recirculating air.

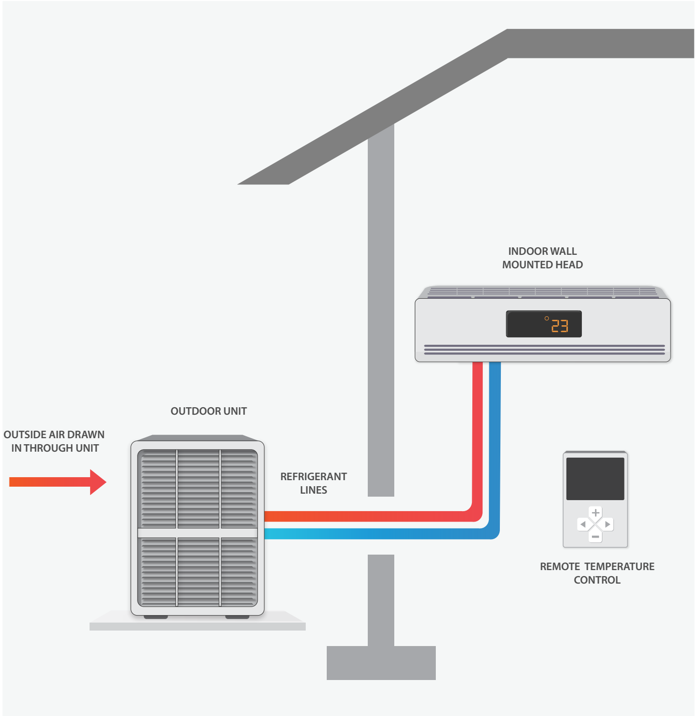
Mini-split heat pumps have two main components, the outdoor compressor/condenser unit, and an indoor air-handling evaporator unit. They are easy to install usually requiring only a three-inch hole through a wall for the conduit; which houses refrigerant tubing, and a condensation drain line, linking the outdoor and indoor unit. Mini split heat pumps can be used for both single-zone systems and multi-zones, with some products allowing up to eight indoor units connected to one outdoor unit.

Air-to-Water Heat Pumps

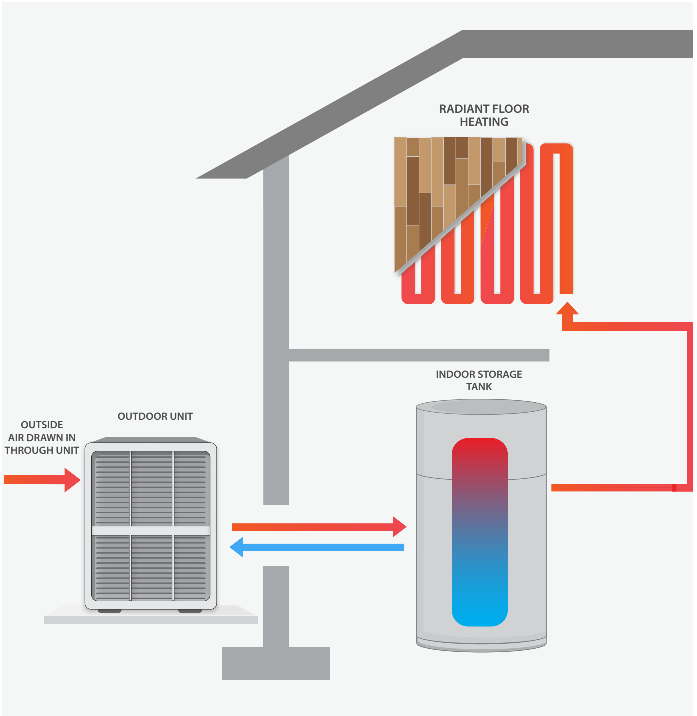
Air-to-water heat pumps are suited for hydronic heating systems, such as in-floor radiant heating. The low-temperature needed for in-floor radiant heating systems is compatible with heat pump technology, where greater efficiencies are achieved at lower temperatures.

Air-to-water heat pumps normally consist of two parts: an indoor tank and an outdoor unit. The outdoor unit draws air into the heat pump, where the refrigerant is subject to the pressure by the compressor. The refrigerant, whose temperature is increased considerably under pressure, travels to the heat pump's condenser, where the hot gaseous refrigerant transfers its heat to water. This hot water is stored in the indoor tank and is distributed to be used in radiators and/or in-floor pipes to heat the house.

In some cases, air-to-water heat pumps can also provide radiant in-floor cooling. However, it is important to avoid condensation on the floor by keeping the surface temperatures above the dew point. Alternatively, central or localized chilled-water fan coils can be used to distribute cooling.



Mini-splits have an outdoor unit and an indoor unit, which is mostly wall-mounted. The two units are connected with refrigerant piping.



The indoor and outdoor units of air-to-water heat pumps are separated, similar to the mini-split heat pumps. The refrigerant transfers the heat to the hydronic coils via a heat exchanger.

HEAT PUMP APPLICATIONS
Domestic Hot Water

The main types of DHW heat pumps available on the market are split and integrated systems.

Split System

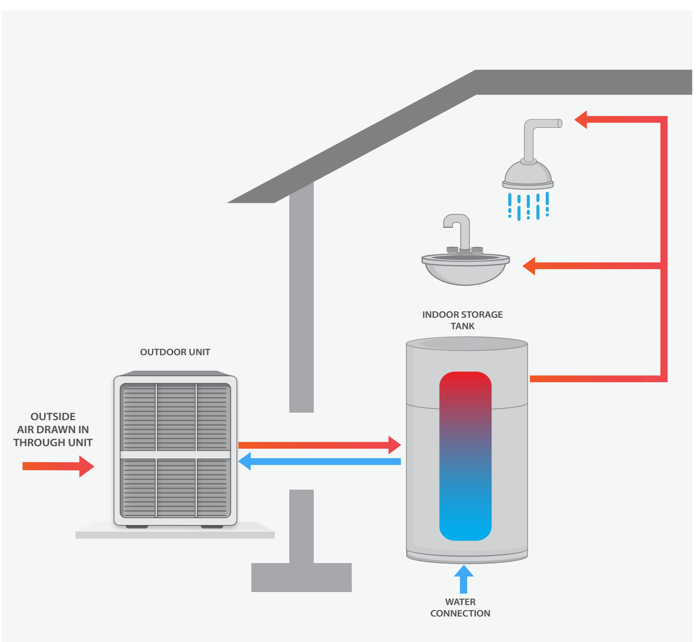
Similar to the mini-split heat pumps, split-system heat pumps for DHW have separate outdoor and indoor units. These systems are typically more expensive but can provide a higher heating capacity and performance characteristics.

The external unit of the split systems can be connected directly to the internal hot water tank via water pipes. The popularity of these systems is growing due to their relatively easy installation. This is because all of its systems are integral to the unit and therefore there is no need for the refrigeration work to be done separately.

In very low temperatures, however, the risk of freezing increases when water runs within the piping from inside to outside. Therefore, the connections between outdoors to indoors may be connected through refrigerant piping.

Integrated System

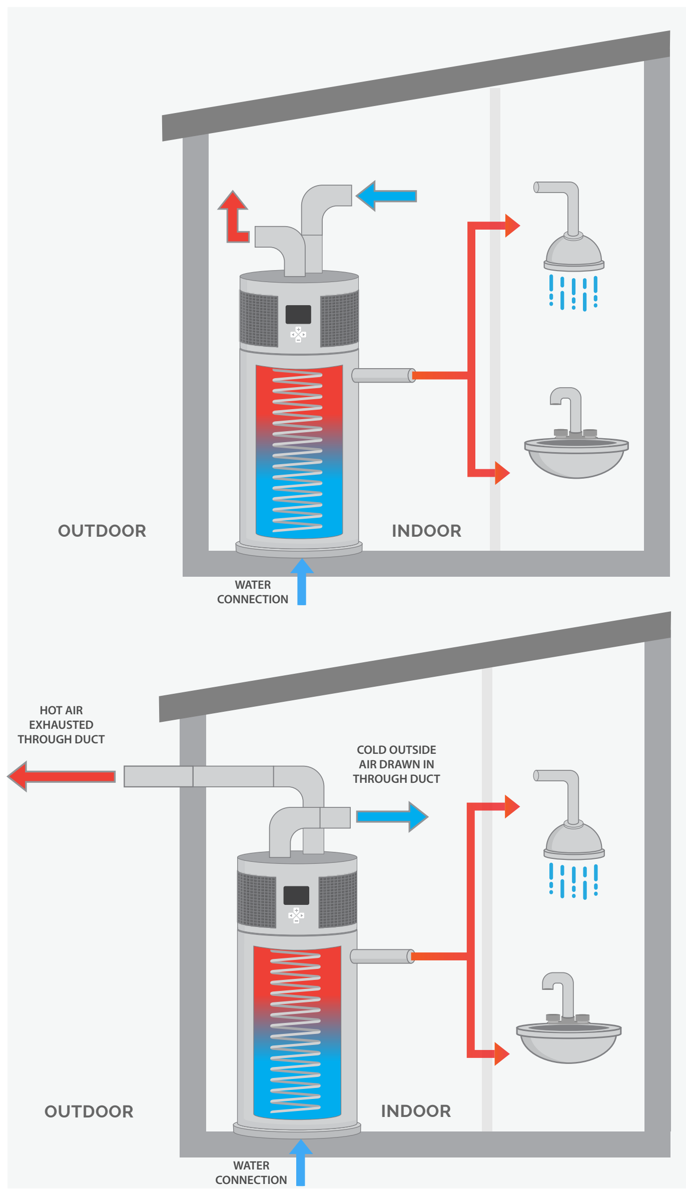
Integrated system heat pumps are best suited for small sites, where there may not be enough space outside to place the outdoor unit. In this type of heat pump, a single unit is mounted directly on top of the water tank.



Similar to mini-splits, the refrigerant inside the split system DHW heat pump is compressed by a compressor and used for generating DHW via a heat exchanger.

The heat is extracted from the space where the tank is located and the cold air is exhausted in the same space. They meet the heating demand during the summer months.

Since the heat is extracted from inside the house, during winter it may cause localized cold spaces and increase the heating load of the heating system of the house. However, in such cases, there is a possibility to simply duct the cold air to the outside.



The ambient air from the indoor is used to heat the refrigerant inside the Integrated heat pump that heats the water that is stored in the tank to be used for DHW needs.

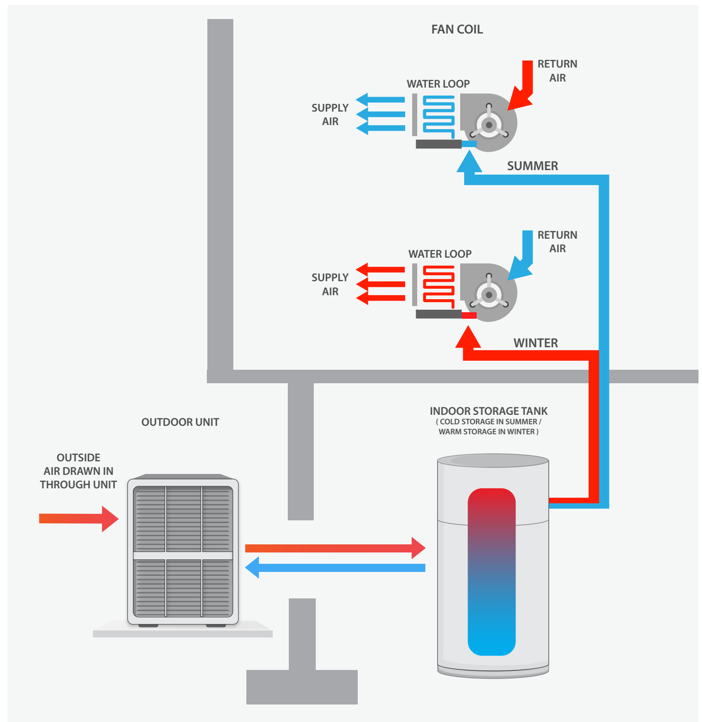
COMBINED HEAT PUMPS

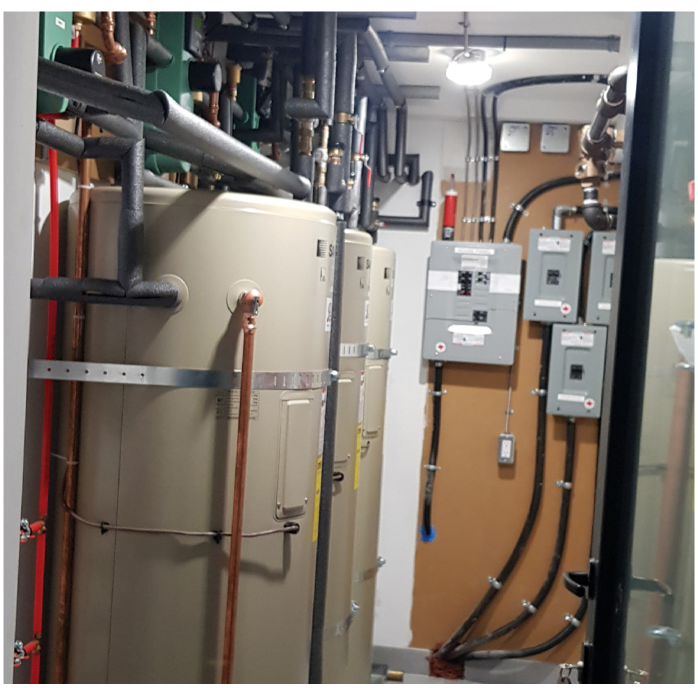
The heating needs of super high performing houses can be met by incorporating combined air-to-water heat pumps for providing heating, cooling and domestic hot water needs.

As shown in this primer, heat pumps can provide heating, cooling and DHW for different applications and through the use of different technologies. In some instances, air to water or water to water heat pumps can provide heating, cooling and DHW with one heat pump through an integrated design. These designs require careful attention to hydraulic distribution and system controls. The image on the right is an example of an air to water heat pump for heating and cooling, but could also potentially include DHW.

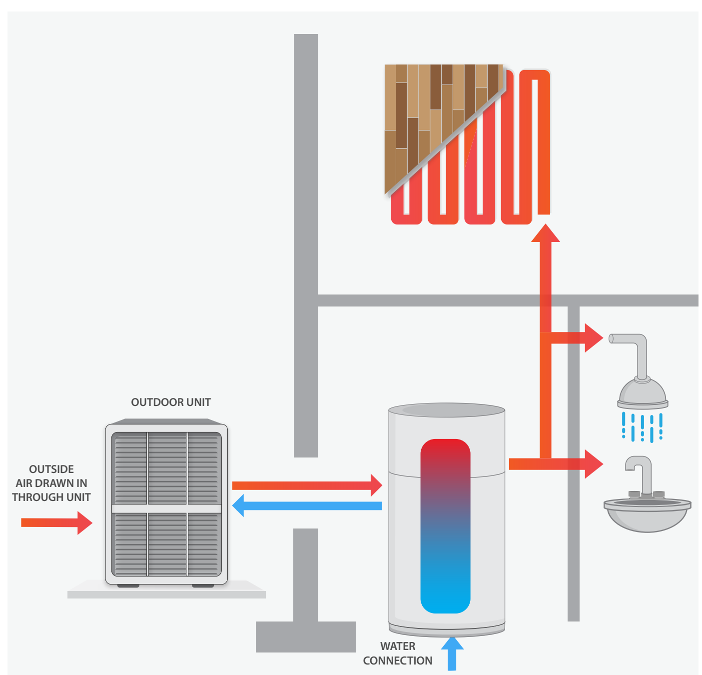
In smaller and very high-performance houses, such as those that are certified to Passive House, their minimal heating demand can be supplied through a DHW heat pump only. Because the heating load of these houses is very low, efficient DHW air-to-water heat pumps can meet both needs.

Heat pumps that use CO_2 as their refrigerant are among the most efficient air-to-water heat pumps. Additionally, CO_2 refrigerants are preferable over HFCs because of their lower negative environmental impacts in case of a refrigerant leakage or when the heat pumps are retired. However, the drawback of the current CO_2 heat pumps in the market is that they cannot provide cooling, because the phase change occurs at higher pressure and temperatures.





Hot water tanks of Sanden CO_2 heat pumps in a high-performance townhouse in Vancouver (credit: Futrhaus by b Squared Architecture Inc.)



Top: Combined air-to-water heat pumps can provide both space heating and cooling needs.
Bottom: CO_2 heat pumps are typically Air-to-Water and supply domestic hot water, but in very high-performance houses, the same hot water can be used for minimal space heating loads.

ADDITIONAL RESOURCES

Additional resources, guidelines, and manuals that complement the information provided in this technical primer

Incentives & Rebates

CleanBC Better Homes & Home Renovation Programs
administered by BC Hydro, FortisBC and the Province of BC, provides rebates for improving the energy efficiency of houses through energy-efficient solutions

Betterhomes B.C.
provides various municipal top-ups and rebates for different B.C. jurisdictions.

Near Zero Program
provides incentives for Passive House and Step 4 and 5 low-rise residential buildings that use heat pumps.

Choosing a Heat Pump

BC Hydro
provides an online database of eligible heat pump models for various provincial rebate programs

Energystar certified split-system air-source heat pumps,
is a dataset on the U.S. ENERGY STAR website for certified split-systems.

Energystar certified Air-Conditioning, Heating and Refrigeration Institute (AHRI) directory
is a data set of all other certified air source heat pumps,

Selecting a Contractor

CleanBC Contractors
provides an online database of trained contractors

Heat Pump Design & Installation Guide

Heat Pump Best Practices Installation Guide for Existing Homes
Home Performance Stakeholder Council

References Used

Implications of the BC Energy Step Code on GHG Emission
Integral Group

Energy Step Code - 2018 Metrics Research – Full Report
BC Housing, Morrison Hershfield, Integral Group

Guide to Sizing and Selecting Air-source Heat Pumps in Cold Climates
National Energy Efficiency Partnerships (NEEP)

Heating and Cooling with a Heat Pump
Natural Resources Canada

Towards Net Zero Energy Ready Residential Buildings
Light House Sustainable Building Society

Energy Consumption in Low-Rise Multi-Family Residential Buildings in British Columbia
RDH Building Science

An Examination of the Opportunity for Residential Heat Pumps in Ontario
IESO

Air Source Heat Pump (ASHP) Installation Practices
Fisher Resource Efficiency Solutions Company Ltd. (FRESCo)

GLOSSARY

Key terms, definitions, and abbreviations used in this case study arranged alphabetically

Air-to-Air Heat Pump
A type of air source heat pump that draws heat from the outside air and then transfers it directly into space via a fan system. These are least expensive heat pumps and help to heat the space quickly.

Air Conditioning System
These are used to stabilize and control the condition of the air in a given space. They control the temperature, humidity, and purity of the air by transferring heat and moisture from the interior space to the outside.

Air-to-Water Heat Pump
A type of air source heat pump that draws heat from the outside air and uses water to transport the extracted heat. These heat pumps are more efficient as they can provide domestic hot water and central heating/cooling at the same time.

B.C. Energy Step Code
A voluntary provincial standard that provides an incremental and consistent approach to achieving more energy-efficient buildings that go beyond the requirements of the base BC Building Code.

Decarbonization
The process of reducing the amount of carbon emissions in primary energy use of the building. This is achieved through the increased use of renewable energy and fuels.

Domestic Hot Water
The water used for everyday human needs like drinking, food preparation, sanitation, and personal hygiene. As they are mostly the water that is exposed to direct contact, it must not be hotter than 105 F.

Forced Air Central System
Method of heating or cooling which uses air as its medium of heat transfer and uses ductwork, vents, and plenums as the means of air distribution.

GHG Emissions
A measure of greenhouse gas contributions from a building and its systems.

Hydronic System:
A heating and/or cooling distribution system that uses water, that is usually recirculated through pipes in a building

Hydrofluorocarbons (HFCs)
Organic compounds that are used in heat pumps as refrigerants. They contribute to carbon emissions and hence are harmful to the environment. They include R-410A, R-407C, and R-134a refrigerants.

Mechanical Energy Use Intensity (MEUI)
An energy use metric that includes the energy consumption from heating, ventilation, and air conditioning systems but omits base loads such as plug loads and lighting. This a Step Code metric for Part 9 buildings.

Split Unit
A type of air-to-water heat pump that uses refrigerant lines to connect between the outdoor unit and the indoor unit. The outdoor unit contains the compressor, air to a refrigerant heat exchanger, and outdoor air fan. The indoor unit contains the refrigerant to a water heat exchanger, circulator, expansion tank, controls, and in some systems an electric resistance element for auxiliary heating.

Thermal Energy Demand Intensity (TEDI)
A metric of the building's modeled heating needs that is primarily influenced by the building enclosure insulation, airtightness, and ventilation system. A more highly insulated, airtight enclosure with recovery ventilation will achieve a better TEDI value.

Zero Emissions Building Plan
A phased approach by the City of Vancouver to combat and reduce carbon emissions in the city by establishing specific targets and actions to achieve zero emissions in all new buildings by 2030

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https://zebx.org/resources/#case-studies

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