Appendix D - Heat Pumps

The 2021 State Energy Strategy proposes a carbon reduction approach requiring existing and new buildings to transition to high-efficiency electric space and water heating. This Appendix has been included to provide additional information on the use of heat pumps in residential, commercial and industrial applications. Additional reading recommendations are listed at the end of this section.

In Washington, the majority of space and water heating is provided by natural gas and less efficient electric resistance heating. Currently, heat pumps represent only a small portion of installed heating systems (Table 1).

To achieve the objectives of the deep decarbonization modeling's electrification scenario requires building space and water heating applications to transition to high-efficiency heat pumps. Opportunities to use heat pumps in industrial processes heating or district heating systems should also be considered.

Table 1. Washington Primary Space Heating Equipment [1, 2]

Primary Space Heating	Commercial	Single Family Residential	Multifamily Residential
Natural Gas	80%	52%	11%
Electric Resistance	10%	30%	83%
Electric Heat Pump	9%	12%	5%

How Electric Heat Pumps Work:

Heat pumps and air conditioning systems both utilize a refrigeration principle, collecting heat from one place and delivering the heat someplace else. These systems provide space cooling in the majority of the buildings in Washington, but they have been underutilized as a heating system.

Heat pumps and air conditioning equipment use a working fluid to absorb heat from one space and transfer and reject it in another. (Figure 1. Refrigeration Cycle). The working fluid is relatively cold when it is a low-pressure gas and absorbs heat. When compressed, the working fluid concentrates the heat, allowing it to be extracted. In an electric heat pump, the electric energy used to compress the working fluid uses much less energy than creating heat using an electric resistance coil. This results in heating efficiency of 200-400%.

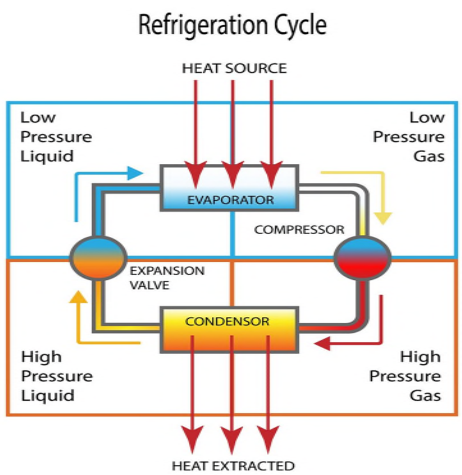
There are a wide variety of heat sources or sinks used in heat pumps, including air, water and the ground. Ground source systems circulate a fluid underground to transfer heat to the heat pump system. Water sources include ground water or water from lakes or the sea (Figure 2. Air source, Ground Source, Water Source).

[1] *Commercial Building Stock Assessment, 2019*, Northwest Energy Efficiency Alliance. Figures are for Commercial Buildings in the Pacific Northwest. https://neea.org/data/commercial-building-stock-assessments#

[2] *Residential Building Stock Assessment, 2016-2017*, Northwest Energy Efficiency Alliance, Figures are specific to Washington State. https://neea.org/img/documents/Residential-Building-Stock-Assessment-II-Multifamily-Homes-Report-2016-2017.pdf

Heat pumps also use waste heat sources. Heating efficiency can be significantly enhanced by placing the evaporator in the path of warm commercial or industrial exhaust systems or in industrial or municipal wastewater streams.

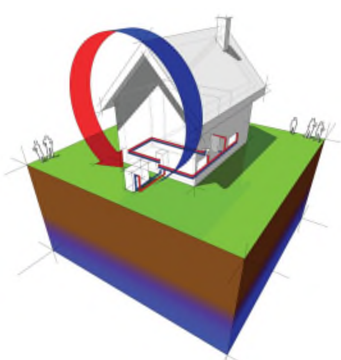
Figure 1. Refrigeration Cycle



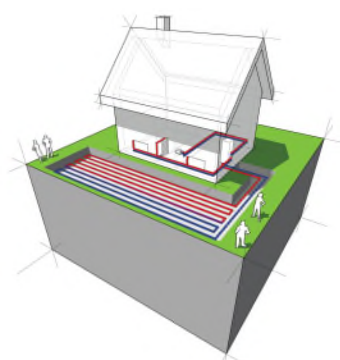
Cold Climate Heat Pumps

In the discussion of heat pump applications, a misperception is that heat pumps do not work well in colder climates. This is no longer true because of updates to the equipment used. As described below, there are now solutions that can employ high-efficiency electric heating designed for cold climates.

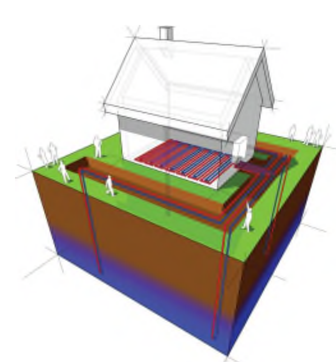
Figure 2. Air source



Ground Source



Water Source



Air source heat pumps for cold climates

Cold climate heat pumps (CCHPs) provide heating when outdoor temperatures are as low as -13F. This allows heat pumps to be the primary source of heat even in the coldest parts of our state. The same technology provides increased efficiency year-round.

CCHPs are the latest evolution in efficient air-source heat pump design. An inverter driven variable speed compressor allows these heat pumps to achieve high levels of efficiency even during the winter season. CCHPs operate with nearly 400% efficiency at 47°F or above. When temperatures drop to zero, a CCHP will sustain efficiencies of about 200%. The outcome is that CCHPs deliver two to four units of heating energy for every one unit of energy consumed.

Heat pump systems include both heat pump heating and electric resistance heating. The heat pump operates until the outdoor air is too cold to provide all the required heating. Then the electric resistance heating helps meet the remaining loads. Older heat pump systems did not operate at lower temperatures, requiring a good deal of resistance heating at low temperatures. This erodes overall system efficiency. Using updated technology, CCHPs can provide most of the heating needed at the lowest temperatures experienced in Washington State.

Markets are well developed for CCHPs. A good listing for residential and light commercial heat pumps meeting cold climate criteria is provided by the Northeast Energy Efficiency Partnership.[3] The Northwest Energy Efficiency Alliance has adopted this list to support programs in our region.

Select commercial rooftop package units and most variable refrigerant flow (VRF) systems designed for commercial buildings use the inverter-driven heat pump technology, achieving similar low-temperature performance. Variable refrigerant flow systems have the additional advantage of providing zone control with heat recovery. Systems that combine VRF with a dedicated outdoor air ventilation system can provide the most efficient heating, cooling and ventilation results.

Variable Refrigerant Flow Heat Pumps

Ground and Water Source Heat Pumps

Ground and water source heat pumps also provide good performance regardless of outdoor air temperatures. Shallow ground temperatures remain relatively stable (about 45-50° F) throughout the year. This is a good source for efficient heating or cooling using a heat pump. Water source heat pumps use closed loop and open loop systems to access the stable temperatures of ground or surface water.[4]

New Homes Built to the 2018 Washington State Energy Code: Gas Heat and Heat Pumps Compared

The following summarizes the findings of a recent report developed under the guidance of the Washington State Building Code Council (SBCC). The results demonstrate that heat pumps are efficient when compared to other systems. It also shows that heat pumps are important to meeting the statutory code improvement requirements.

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[3] NEEP Cold Climate Heat Pump List: https://neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

[4] Use of ground a surface water is regulated in Washington State. The Governor's Office of Regulatory Innovation and Assistance has developed specific guidance on the use of this resource. https://www.oria.wa.gov/site/alias__oria/463/Geothermal-Heat-Pumps.aspx

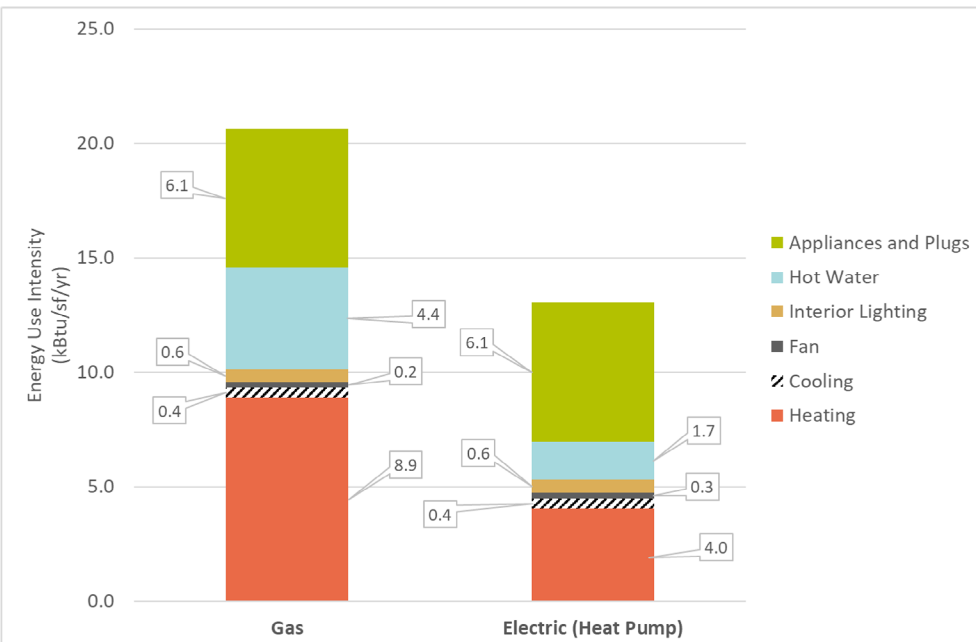
The Washington State Legislature has directed the SBCC to reduce building energy use by 70% compared to the 2006 edition of the code, and to "construct increasingly energy efficient homes and buildings that help achieve the broader goal of building zero fossil-fuel greenhouse gas emission homes and buildings by the year 2031." The recent SBCC report documents progress toward these requirements.[5]

The report provides a comparison between two 2200 sf homes built to the 2018 Washington State Energy Code. One home is provided with gas space and water heating, while the other uses heat pumps for space and water heating.

In this example, both homes are equipped with high-efficiency space and water heating equipment. The gas home uses condensing space and water heating equipment. The heat pump home uses equipment that exceeds the minimum heat pump standards. To meet the new edition of the code, the gas-heated home also meets a more rigorous building envelope standard that includes triple pane windows and extra insulation. These measures reduce heat loss by 30% compared to the heat pump home.[6]

As noted in Figure 3, the heat pump home uses about half the space and water heating energy as the gas home. Because the gas home requires additional building envelope improvements, the gas home has a higher upfront cost. In this example, the heat pump and gas homes will have comparable annual energy costs.

Figure 3. Average Modeled EUI of a Single-Family Dwelling (by EUI) in 2018 - Gas and Electric (Source: Ecotope 2020)



It is also important to note, the SBCC report shows the gas-heated home has reduced energy use by 44%, compared to the 2006 state energy code. The heat pump home achieves a 64% reduction compared to the 2006 baseline. The heat pump home provides most of the savings prescribed by the energy code statute. This will result in a "zero fossil-fuel greenhouse gas emission" home when the Clean Energy Transformation Act

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[5] Odem, H. et al. *Modeling the Washington State Energy Code - 2006 & 2018 Baseline Energy Consumption.* Appendix to *2018 Washington State Energy Code Progress toward 2030*, State Building Code Council Report to the legislature, November 2020. https://sbcc.wa.gov/sites/default/files/2020-12/Final%202018%20Report.pdf

[6] Refer to the report for a complete description of the building code criteria considered in this comparison.

provides net-zero carbon emissions electricity in 2030. Advancing the code to meet the standards required by the statute will be most cost-effectively met through the use of heat pumps.

Commercial Energy Code Requirements

The Washington State Energy Code has adopted high-efficiency heat pumps with a dedicated outdoor air ventilation system as the reference standard system for many commercial building types. Other systems must demonstrate that they also meet or exceed this standard. Much of the commercial building energy use savings achieved in commercial buildings can be attributed to this energy code provision.[7]

Moving forward, a study by the Northwest Energy Efficiency Alliance demonstrates that heat pumps can achieve the statutory requirements of the energy code most effectively. The choice of other system types must include additional energy efficiency features to achieve similar results.[8]

Global Warming Potential of Refrigerants

Refrigerants that escape into the atmosphere can contribute to global warming. Refrigerant emissions are significantly more potent than carbon emissions. As a result, relatively small amounts will have negative impacts in meeting the state greenhouse gas limits.

Washington law was recently changed to require the Department of Ecology to adopt rules to manage and phase out the worst refrigerants. Ecology has adopted initial rules and will adopt additional rules as equipment meeting new standards becomes available. This is expected to occur in the next few years.[9]

There is a global consensus that transitioning to refrigerants with low global warming potential is essential. This has resulted in the rapid development of heat pumps and air conditioning equipment that do not use harmful refrigerants and also provide increased efficiency.[10],[11]

Workforce Development

Because the 2021 State Energy Strategy recommends a significant market shift to heat pumps, we can expect that there will be an increased need for a qualified workforce. This requires electrical and refrigeration management skills. Licensing and/or certification is required to install HVAC and refrigeration equipment. These are good family-wage jobs that require specific jobs skills

Electrical licensing administered by the Department of Labor and Industries provides a path for qualification that progresses from electrical trainee to master electrician. U.S. EPA 608 certification is required to service, repair and install refrigeration and air-conditioning equipment.[12] Proper management of the working fluids is required to assure they do not pollute the atmosphere or harm the occupants of the facility. Additional training

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[7] Odem, H. et al. *Modeling the Washington State Energy Code - 2006 & 2018 Baseline Energy Consumption.* Appendix to *2018 Washington State Energy Code Progress toward 2030*, State Building Code Council Report to the legislature, November 2020. https://sbcc.wa.gov/sites/default/files/2020-12/Final%202018%20Report.pdf

[8] Athalye,R. *Washington State Commercial Energy Code Technical Roadmap Report,* Northwest Energy Efficiency Alliance, 2020. https://neea.org/resources/washington-state-commercial-energy-code-technical-roadmap

[9] Hydrofluorocarbon transition, Washington State Department of Ecology, https://ecology.wa.gov/Air-Climate/Climate-change/Greenhouse-gases/Reducing-greenhouse-gases/Hydrofluorocarbons

[10] Cooling Emissions and Policy Synthesis Report: Benefits of cooling efficiency and the Kigali Amendment, International Energy Agency (IEA), 2020. https://www.iea.org/reports/cooling-emissions-and-policy-synthesis-report.

[11] Shah, N. et al, *Opportunities for Simultaneous Efficiency Improvement and Refrigerant Transition in Air Conditioning*, Lawrence Berkeley National Laboratory, 2017.

[12] The Department of Labor and industries provides a listing of available apprentice programs in the state. https://secure.lni.wa.gov/arts-public/#/program-search

related to the mechanics of systems or specific manufacturers' training may also be required to provide quality installation.

Additional Reading
Residential and Commercial Building Applications:

How a Heat Pump Works | This Old House: https://www.youtube.com/watch?v=-vU9x3dFMrU

Cold Climate Air-Source Heat Pumps: An Innovative Technology to Stay Warm in Winter and Cool in Summer, U.S. Department of Energy. Cold Climate Air-Source Heat Pumps: An Innovative Technology to Stay Warm in Winter and Cool in Summer | Department of Energy

Heat Pump Water Heaters, U.S. Department of Energy. https://www.energy.gov/energysaver/water-heating/heat-pump-water-heaters

Heller, J., Oram S., Reverse Cycle Chiller (RCC) Best Practices Design Guidelines, Ecotope, for Bonneville Power Administration 2015. (Heat pump water heaters for multifamily buildings) https://ecotope-publications-database.ecotope.com/2015_007_RCCDesignGuidelines.pdf

Washington State Energy Program, Et3, Variable Refrigerant Flow Heat Pumps:
http://e3tnw.org/ItemDetail.aspx?id=200#:~:text=Variable%20Refrigerant%20Flow%20(VRF)%20systems,spaces%20(ECW%2C%202014).&text=The%20refrigerant%20flows%20through%20pipes,condition%20and%20recirculate%20indoor%20air

Heat Pumps for Industrial and District Heating:

Industrial Heat Pumps for Steam and Fuel Savings U.S. Department of Energy, 2003.
https://www.energy.gov/sites/prod/files/2014/05/f15/heatpump.pdf

Geyer, et al, Heat Pumps in District Heating and Cooling Systems: Executive summary, International Energy Agency, Technology Collaboration Program, 2020.
https://heatpumpingtechnologies.org/publications/heat-pumps-in-district-heating-and-cooling-systems-executive-summary/