A review of heat pumps and applicable standards in Vermont.

Heat Pump Report

As called for in Act 56 of 2015

Sec. 21a. 30 V.S.A. § 8001(b)

Public Service Department

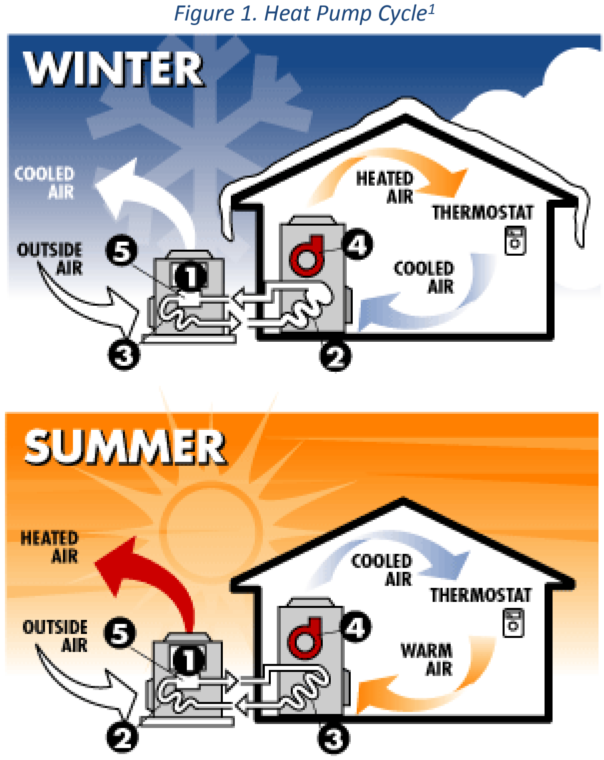
December 15, 2015

Pursuant to Sec. 21a. 30 V.S.A. § 8001(b) the Department of Public Service has prepared this report on heat pumps. The report provides background information on heat pumps, and describes research undertaken to provide a basis for future recommendations on their use in Vermont.

How Heat Pumps Work

Heat pumps utilize the second law of thermodynamics to move thermal energy (heat) from one place to another. By using a relatively small amount of electrical energy, a heat pump is able to move thermal energy from one location to another. Heat pumps have a compressor (See Figure 1: #1) that moves refrigerant fluid around a closed loop (usually copper) between two heat exchange coils; one outside (See Figure 1: #3) and one inside of a building (See Figure 1: #2). "Outside" could mean either in the air or in the ground. In the winter, the liquid refrigerant gets very cold when it evaporates (e.g. "sprays") inside the loop in the outdoor unit so the very cold loop is able to absorb heat from the "warmer" outdoor air – even when it's very cold out. The compressor "compresses" the very cold evaporated refrigerant to heat it back up and sends the heat into the indoor coil. In the summer, the heat pump uses a valve (See Figure 1: #5) to reverse the cycle and acts like an air conditioner. Fans in the outdoor unit and indoor unit (See Figure 1: #4) force air across the coil to speed up the heat absorption and rejection.

Figure 1. Heat Pump Cycle[1]



[1] http://www.savewithsrp.com/advice/graphics/heatpumpdiagram06.gif

Heating efficiency is generally defined as the ratio of heat output to heat input. Electric resistance heat has an efficiency of 100%, all the electric energy is converted to heat. A heat pump operates at efficiencies of 200% to as much as 500% (seasonally calculated) because it does not take any energy to cool off or warm up refrigerant – it only takes energy to speed up the cooling and warming process (fans) and to keep the refrigerant cycle going (compressor). Heat pumps can achieve seasonal average efficiency well in excess of 200%. Other heating fuels (wood, oil, propane) have heating efficiency of less than 100% because heat is lost in the combustion process and because it takes additional energy to move the heat in a building (e.g. furnace fan, boiler pump). Even though non-electric heating fuels are less than 100% efficient, some fuel types might cost less on a btu basis to purchase and burn than the cost of electricity to efficiently heat. For instance, those who heat and/or cool using natural gas may not find the use of heat pumps to be cost-effective given current fuel prices (see heating fuel cost comparison table below).

High Efficiency Heating Fuel Cost Comparison[2]				
Type of Energy	BTU/unit	High Efficiency Case	$/unit	$/MMBtu
Fuel Oil, gallon	138,200	95%	$2.27	$17.31
Propane, gallon	91,600	93%	$2.41	$28.26
Natural Gas, ccf	100,000	95%	$1.39	$14.67
Electricity, kWh (resistive heat)	3,412	100%	$0.15	$43.46
Electricity, kWh (cold climate heat pump)	3,412	240%	$0.15	$18.32
Wood, cord (green)	22,000,000	60%	$227.14	$17.31
Pellets, ton	16,400,000	80%	$294.00	$22.41

Heat pumps operate less efficiently as the temperature of their outside heat source falls. Air-source heat pumps therefore generally require a supplemental heat source in order to meet heat needs on the coldest winter days. Ground-source heat pumps do not require this because the ground doesn't get cold enough to limit performance.

Heat Pump Applications

In Vermont there are four types of heat pumps used to condition space and provide hot water, which are described below.

Ductless mini-split (Air Source, Single Inverter, Single Head):

Air Source Ductless heat pumps (DHPs) are not a new technology but through innovative design they have developed to the point where they have practical applications in Vermont. These units are inverter driven and have the potential to reduce the amount of fossil fuel used for heating during the winter and are referred to as cold climate Heat Pumps (ccHP) as well displacing any air-conditioning load in the area

[2] http://publicservice.vermont.gov/sites/psd/files/Pubs_Plans_Reports/Fuel_Price_Report/2015/November%202015%20Fuel%20Price%20Report.pdf

where they are installed over the summer period. A single unit is likely to displace between 25% and 60% of a home's fossil fuel use. These numbers are highly dependent on the correct sizing of the heat pump for the space it is intended to heat, how the building owner operates the heat pump in conjunction with the secondary heat source, the quality of the thermal envelope, the number of air changes an hour experienced in a building and the 'openness' of the buildings floorplan.

As the name suggests a ductless mini-split has no air ducts, so they avoid the energy losses associated with the ductwork of central forced air systems. Duct losses can account for more than 30% of energy consumption for space conditioning, especially if the ducts are in an unconditioned space such as an attic.

Mini splits have two main components -- an outdoor compressor/condenser and an indoor air-handling unit. A conduit, which houses the power cable, refrigerant tubing, suction tubing, and a condensate drain, links the outdoor and indoor units.

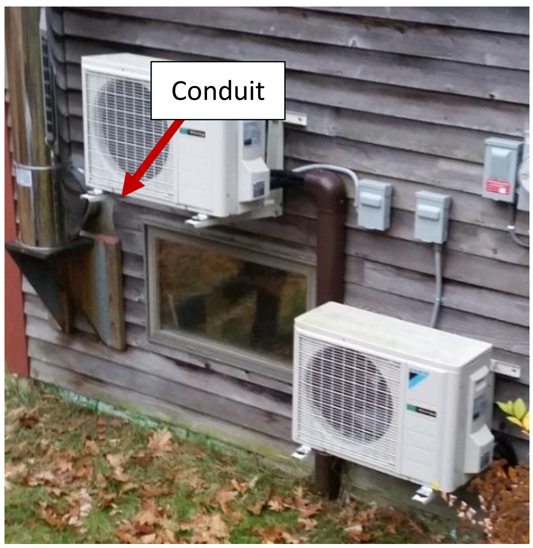


Image taken as part of the VT Heat Pump Evaluation

There are a few different options as to the internal 'head' component that supplies the hot/cold air, below is an example of a typical internal unit installed.

Image taken as part of the VT Heat Pump Evaluation

Ductless mini-split systems are generally easier to install than most other types of space conditioning systems as they generally require only a three-inch hole through a wall for the conduit. However, the cost of purchasing and installing a large capacity or multi-head mini splits can be higher than some other traditional systems, although lower operating costs and rebates or other financial incentives can help offset the initial expense.

The installer must correctly size each indoor unit and determine the best location for its installation. The installer must perform building and room load calculations to correctly size each indoor unit and determine the best location for its installation. An “over-sized” ductless system has the potential to run at really low load and could actually be more efficient than a “correctly” sized system. However, the larger a system the more expensive it is to buy and operate. The ‘over-sized’ unit would have greater capacity to exchange heat and have a higher efficiency at the same load as a properly sized unit however the cost per delivered btu would be higher for the larger system. This is an example of why it is important to correctly size a unit.

The efficiency of a ccHP varies with outdoor temperature, compressor speed, airflow rate of the indoor unit, frost buildup on the outdoor coil, and indoor conditions. At mild outdoor temperature the efficiency of many new ccHP systems may be higher than 500%. At very cold temperatures the efficiency may drop below 100% and the ccHP may stop working below -15°F. In Vermont the heating seasonal performance efficiency of a cold climate air-source heat pump is considered to be 240% for the purposes of analysis. This rating is consistent with most other northeastern states.

Multi-Head Split Systems:

There is a multi-head variant of the ccHP with one outdoor unit with the potential to supply up to seven internal ‘head’ units. These units cost more and require more internal disruption to a building as all the cabling, tubes and drains would have to be installed inside the buildings thermal envelope. These units are less efficient than the single head units based upon the operation of all the ‘head’ units at the same time, however if only one or two of the ‘heads’ are used at any given time the unit’s efficiency may match or exceed that of the single-head, single inverter unit due to the larger capacity of the outdoor inverter unit, although it would use more electrical power when doing so.

The ccHP, both the single and multi-head units, have great potential to be retrofitted into existing buildings, with high efficiencies, no duct loss and the ability to ‘zone’ the units, they provide a cost-effective option to efficiently heat and cool a home.

Central systems:

A split-system central system typically consists of the indoor portions of a heat pump coupled with a fossil fuel furnace or the outdoor portion of the air conditioner is housed in an outdoor metal cabinet which contains the condenser and compressor and an indoor cabinet contains the evaporator. The air conditioner's evaporator coil is installed in the cabinet or main supply duct of this furnace or heat pump.

In states where the heating load is minimal, heat may also be provided through the use of electrical strip heaters.

Photo courtesy of ©iStockphoto/DonNichols.

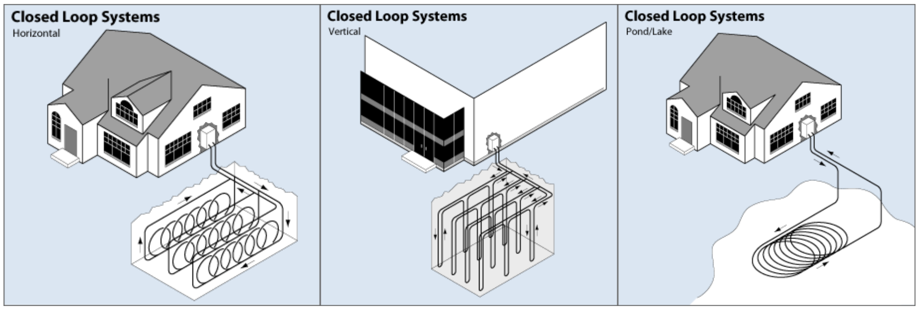
There is an emerging technology[3] that uses the central split concept coupled with a VRF (variable refrigerant flow) heat pumps to provide both heat and cooling from a central ducted plant. These systems are classified as cold climate but have still to be reviewed for effective use in Vermont.

Ground-source:

Ground-source heat pumps have been in use since the late 1940s. They use the constant temperature of the earth as the exchange medium instead of the outside air temperature. This allows the system to reach fairly high efficiencies (300% to 600%) on the coldest winter nights, they are able to do this as a few feet below the earth's surface the ground remains at a relatively constant temperature.

There are four basic types of ground loop systems. Three of these, horizontal, vertical, and pond/lake, are closed-loop systems. The fourth type of system is the open-loop option.

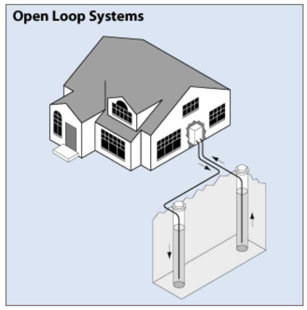
Most closed-loop geothermal heat pumps circulate an antifreeze solution through a closed loop' usually made of plastic tubing, that is buried in the ground or submerged in water. A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze solution in the closed loop. The loop can be in a horizontal, vertical, or pond/lake configuration.



http://energy.gov/energysaver/geothermal-heat-pumps

[3] http://www.mitsubishicomfort.com/press/press-releases/mvz-multi-position-air-handler-rounds-out-diamond-comfort-systemtm-for-efficient-whole-home-cooling-heating

The open loop system uses well or surface water as the heat exchange fluid that circulates directly through the GHP system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge.

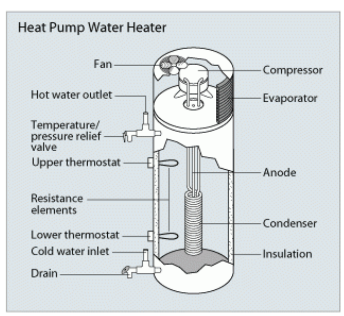


http://energy.gov/energysaver/geothermal-heat-pumps

Heat Pump Water Heater:

Heat pump water heaters use electricity to move heat from the air inside the building to the water inside the water heater instead of generating heat directly through the use of the electricity. They can be two to three times more energy efficient than conventional electric resistance water heaters, but can have performance issues during periods of high hot water demand as they may not be able to 'recover' quickly enough to maintain the temperature of the water in the unit. Most of the units on the market are considered 'hybrid' units as they can use electrical resistance to supplement the heat pump at times of high hot water demand, rather than rely solely on the heat pump to generate the heat.

Heat pump water heaters require installation in locations that remain above 40°F year-round and provide at least 1,000 cubic feet (28.3 cubic meters) of air space around the water heater.



http://energy.gov/energysaver/heat-pump-water-heaters

Heat Pump Water Heaters should be installed in a space with excess heat, such as a furnace room. Heat pump water heaters will not operate efficiently in a cold space. They also tend to cool and dehumidify the spaces they are in.

Cold-climate Air-source Heat Pump Performance

A heat pump must meet a specific standard to be considered a cold climate heat pump by the Energy Efficiency Utility (EEU) programs in Vermont and to receive an incentive. It must be a new variable speed mini-split or multi-split heat pump that meets or exceeds the following efficiency criteria.

Equipment	HSPF[4]	SEER[5]
Air-Source Heat Pump	10.3	20.0

To put these numbers into context a current Energy Star rated[6] air-source heat pump must meet the following standards;

Equipment	HSPF	SEER
Air-Source Heat Pump	8.2	14.0

Additionally, the following criteria are required for eligibility:

- COP[7] at 5°F ≥ 1.75 (at maximum capacity operation)
- Rated operation at -5°F

All of these requirements together mean that to be considered a ccHP suitable for use in Vermont units have to maintain the ability to operate efficiently at temperatures as low as -5°F. Many qualifying units have a manufacturers' rated operating temperature as low as -15°F.

Most buildings would require multiple indoor units or a central system to meet a majority of their heating demand throughout an average winter. Due to the limited performance of air-source units at temperatures below -15°F, buildings would also need to maintain a secondary heating system to provide heat when the outside air temperature dropped below the unit's ability to provide enough heat for the building.

As of December 2015, 1,296 cold climate qualified heat pumps were installed as part of Vermont's EEU's upstream distributor based program. The EEU's are anticipating that by the end of the year a total of 1,800 qualifying heat pumps installations will have been incentivized through their program. Sales data relating to heat pumps sold in Vermont is not available, so a market share comparison between cold climate qualifying and non-cold climate units is not currently possible.

[4] HSPF (Heating Seasonal Performance Factor) is a term used in the heating and cooling industry. HSPF is specifically used to measure the efficiency of air source heat pumps. The higher the HSPF rating of a unit, the more energy efficient it is. HSPF is a ratio of the heat output over the heating season to the electricity used.

[5] SEER (Seasonal Energy Efficiency Ratio) is the cooling output during a typical cooling-season divided by the total electric energy input during the same period. The higher the unit's SEER rating the more energy efficient it is

[6] https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/75

[7] COP (coefficient of performance) of a heat pump is a ratio of heating or cooling provided to work required. Higher COPs equate to lower operating costs.

Performance Standards

The Federal government establishes minimum energy conservation standards for appliances. Effective January 1, 2015, these standards are 14.0 SEER & 8.2 HSPF for split system heat pumps[8]. The Energy Star program requires 15.0 SEER & 8.5 HSPF for certification.[9]

Due to Federal preemption, Vermont is not permitted to mandate that all air source heat pumps sold in Vermont meet the cold climate standard developed for use in the state's Energy Efficiency Utility programs. All States are required, when federal minimums have been established, to use these as the minimum energy conservation requirements for equipment.

While States may apply for a waiver, or an exemption from, the federal standard, as detailed in 10 CFR part 430, subpart D[10], this process can be both lengthy and expensive for individual states to pursue. Two waivers have been sought by individual states- California for clothes washers and Massachusetts for gas furnaces; neither of these waivers were granted. Because the waiver process is an expensive administrative burden and it not likely to be approved, it may not be worth pursuing at this time.

It is also worth considering whether a standard based on system capacity at low temperature, rather than an energy conservation standard, would be subject to Federal preemption. Such a standard would require development or adoption of an appropriate test procedure.

Currently there is no testing procedure for the efficiency or performance of heat pumps in a cold climate setting. The existing testing protocol, *'AHRI Standard 210-240-2008 for Unitary Air-Conditioning and Air-Source Heat Pump equipment'* is poorly formatted for testing prospective cold climate heat pumps as it only measures performance at three set temperatures, 47°F, 35°F and 17°F under full load and minimum load conditions. Since cold climate heat pumps are inverter driven variable speed units this testing does not adequately capture performance metrics of the equipment at the lower operating temperatures of the units. The DOE is currently in the process of updating this procedure[11] and are proposing to include an optional testing temperature at between 2°F and 5°F but still not allowing the units to modulate the speed of the compressor. This modulation is where the majority of the efficiency for ccHPs come from. As a result, even with a waiver there would be no applicable testing standard that could be used to approve a DHP as cold climate.

Vermont and other northeast regions efficiency programs have adopted standards for cold climate air source heat pumps (NEEP maintains a ccHP specification[12]). The promotion of a regional cold climate 'brand' should be supported to encourage not only the purchase of a 'cold climate' branded heat pump

---

[8] https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/75#standards
[9] https://www.energystar.gov/products/heating_cooling/heat_pumps_air_source/key_product_criteria
[10] http://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol3/pdf/CFR-2011-title10-vol3-part430-subpartD.pdf
[11] http://www.regulations.gov/#!documentDetail;D=EERE-2009-BT-TP-0004-0052
[12] http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump

but also to encourage distributors to increase the stock they maintain to insure at adequate supply to meet the demand for the units. There is currently a Canadian testing procedure being developed to more accurately measure the performance of DHPs at low temperatures as well as allowing the units to modulate themselves to accurately measure the efficiency of the unit rather than artificially forcing them to operate at full load. The EEUs could be directed to require all units go through their program meet this Canadian standard. This would be dependent upon reviewing the final testing procedure and determining if it should be used as a programmatic standard or not.

Installation and Operation

It cannot be stressed enough the importance of a quality installation of a ductless heat pump (DHP) when it comes to its overall performance. Only properly trained HVAC contractors should install DHP units; training on the correct installation of these units are often provided by manufactures.

These units work best in open floorplans as space heaters, because of this correct zoning of the units is critical to ensure the efficient operation of these units along with building owner education to improve the understanding of the proper methodologies for controlling DHP's when displacing heat from the buildings existing heating system.

Variable speed heat pumps work best when allowed to operate at a set temperature for several hours at a time. Continually adjusting the thermostat setting will result in higher operating costs for the heat or cooling delivered by a unit. DHPs also operate most effectively with a remote thermostat, rather than the hand-held unit that is typically packaged with the unit. If a remote thermostat is used, it senses the temperature of the room and controls the unit. Without a remote thermostat, room temperature is sensed at the return air flow into the unit, which is not the best indication of the room temperature.

DHPs may require more customer maintenance than traditional heating systems. These units must be kept clear of snow and ice buildup around the outdoor unit as these conditions have a direct and immediate impact of the unit's ability to operate if they are unable to blow air through its heat exchanger. Additionally, these units have filters on the indoor components which if they become clogged with dust/dirt would reduce the airflow through the unit which would also impact overall operational efficiency of the unit.

In a review of heat pump evaluations, it has been noted that a building owners previous use of biomass or a woodstove had led to higher than anticipated use of the DHP to increase the room 'comfort' for the occupant. With the high amount of residential biomass use in Vermont there may be more instances of this occurring than noted in other studies.

Vermont Specific Cold Climate Air-Source Heat Pump Study

The Department of Public Service has hired a contractor to complete a yearlong residential and small commercial ccHP evaluation, complete results from this evaluation will be available in the fall of 2016.

The evaluation includes extensive metering of the heat pump as well as analyzing the internal environment of the building (temperature set points, use of fossil fuels, and wood use)

This study will look at both the heating season use of the ccHP as well as any use for cooling. Additionally, during the meter installation, in-depth interviews with the building owners will be conducted to ascertain their expectations when choosing to install a heat pump. Fuel use/delivery records will be collected to calculate the amount of deliverable fuels displaced by the ccHP. Additionally, information will be collected on the use of air conditioning in the building and particularly within the space where the ccHP was installed and all subsequent use of the ccHP to provide cooling will be tracked by the meters and other installed sensors. There will be an 'exit' interview in the fall of 2016 when meters are removed to gauge any changes from the responses to the questions asked the previous year.

The intent of this evaluation is to establish how heat pumps are used by building owners as well as the impacts on the electrical grid, especially at peak times of use. From this information the Department intends to develop a comprehensive measure characterization to update the EEU heat pump programs and DU programs under the energy transformation requirements of the Renewable Energy Standard, as well as a series of recommendations relating to the future deployment of the technology.