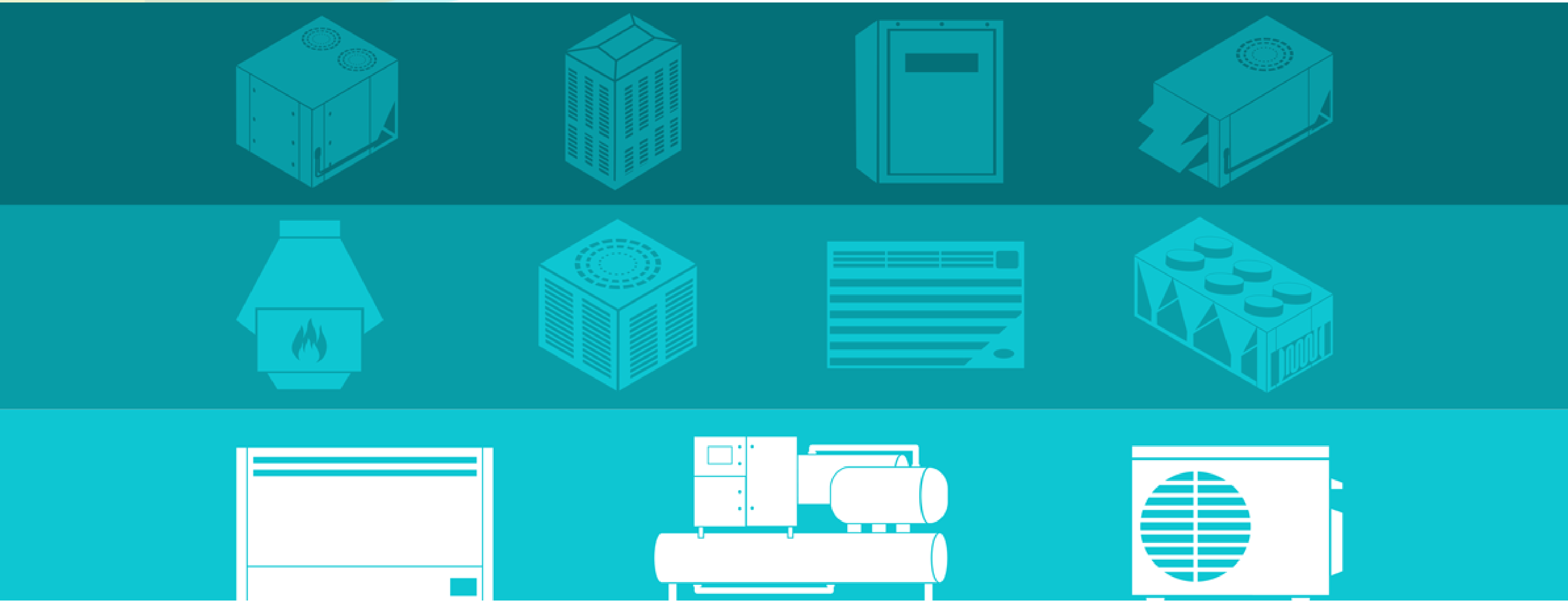
HVAC Technology Guide

Introduction

Bonneville Power Administration (BPA) has begun developing market models to characterize heating, ventilation, and air conditioning (HVAC) consumption in the Pacific Northwest. This guide exists to inform these ongoing market modeling efforts and facilitate a shared understanding of technological and market details among the modeling team. The guide describes HVAC technologies that account for the majority of HVAC consumption in the Pacific Northwest, and discusses their place in the Northwest market landscape.



How to Use This Document

This guide serves as an information resource for the team working on HVAC market modeling, and is designed to be a central repository of the foundational characteristics of HVAC technologies in the Northwest. The guide is organized in three sections.

1

HVAC Basics

Terminology and fundamental concepts

Technology saturations in Northwest stock

Technology features and efficiency

2

HVAC Technologies

Technology specific details
Lifetime, manufacturers, major components, and efficiency features

Applications and competing technologies

Relevant northwest program information

Detailed stock saturation and available product flow data

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State building code information

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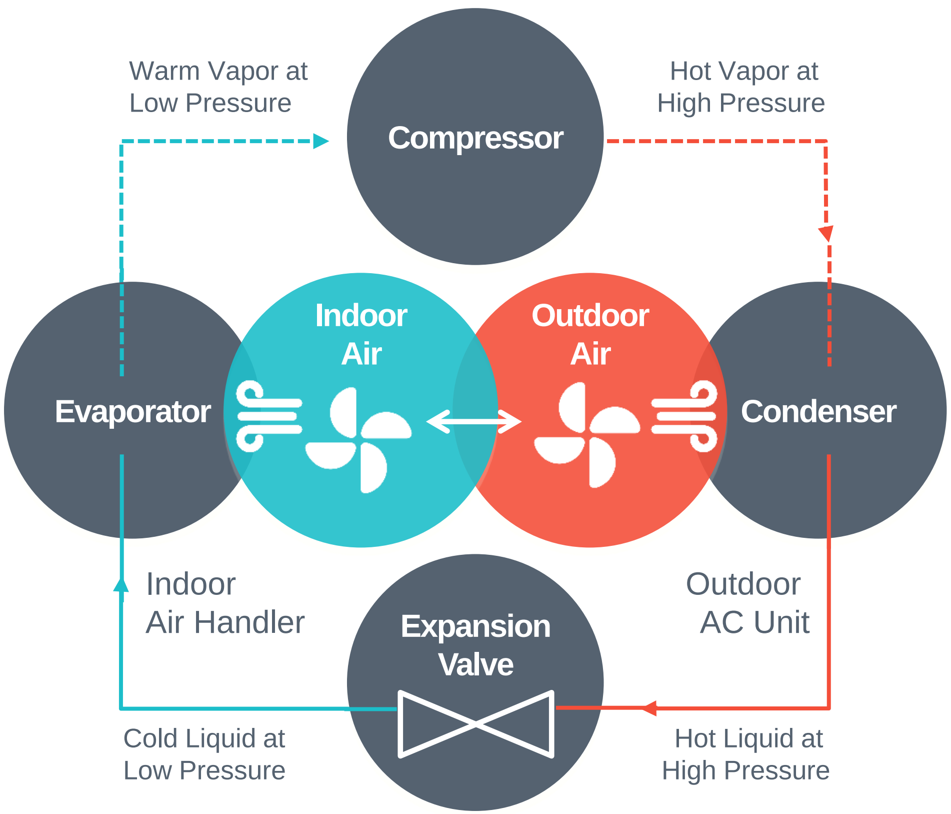
HVAC Basics

This section orients the reader to HVAC technology and the Northwest HVAC market with the following fundamentals:

1. A description of the vapor-compression refrigeration cycle, the process through which most HVAC equipment heats and cools spaces
2. A glossary of HVAC terminology
3. Crosscutting data summary tables describing Northwest equipment saturations
4. A summary comparison of HVAC equipment characteristics

The Vapor-Compression Refrigeration Cycle

Air-Conditioning Cooling Cycle



Many technologies described in this guide use this fundamental process for heating and cooling. Understanding the refrigeration cycle will enable readers to note nuanced differences between technologies that can affect energy consumption. An air-conditioning cooling cycle works as follows, and as illustrated:

1. The compressor pumps refrigerant through the cycle and raises the pressure of the refrigerant.
2. Hot vapor at high pressure enters the condenser.
3. As the refrigerant flows through the condenser, it gives off heat and condenses into a liquid form. Fans increase air flow over the condenser, thus increasing the condenser's capability to give off heat.
4. The hot, high pressure liquid enters the expansion valve where it experiences a pressure and temperature drop.
5. Cold liquid refrigerant enters the evaporator coil where a fan blows hot indoor air over the coil. This heats up the refrigerant and evaporates the liquid into a vapor.
6. The process starts over with the warm vapor once again entering the compressor.

Glossary of Terms

Annual Fuel Utilization Efficiency (AFUE)	The ratio of annual heat output of the furnace or boiler compared to the total annual energy consumed by a furnace or boiler Technologies: Res. FAF, Res. Boilers
Air-Conditioning, Heating, & Refrigeration Institute (AHRI)	A manufacturers' trade association for HVAC products
American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)	A research and standards organization
Coefficient of Performance (COP)	The ratio of the rate of space heating or cooling delivered to the rate of electrical energy consumed. COP measures steady state performance typically at full load Technologies: ASHPs, DHPs, CACs, RACs, Elec. FAFs, PTAC/PTHPs, Chillers, Com. ACs & HPs, VRF
Energy Efficiency Ratio (EER)	The ratio of the rate of space cooling delivered to the rate of electrical energy consumed by the air conditioner or heat pump (usually 95°F) Technologies: ASHPs, DHPs, CACs, RACs, PTAC/PTHPs, Com. ACs & HPs
Heating Seasonal Performance Factor (HSPF)	The total space heating required during the heating season, expressed in Btu, divided by the total electrical energy consumed by the heat pump system during the same season, expressed in watt-hours Technologies: ASHPs, DHPs, Small Com. HPs

Integrated Energy Efficiency Ratio (IEER)	Integrated energy efficiency ratio is a weighted average calculation of mechanical cooling EERs, determined for four load levels and corresponding rating conditions, expressed in Btu/watt-hour Technologies: Com. ACs & HPs, VRF
Seasonal Energy Efficiency Ratio (SEER)	The total heat removed from the conditioned space during the annual cooling season, expressed in Btu's, divided by the total electrical energy consumed by the central air conditioner or heat pump during the same season, expressed in watt-hours Technologies: ASHPs, DHPs, CACs, small Com. ACs & HPs
British Thermal Unit (Btu)	A common unit of measure for energy use in heating and cooling equipment; the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit
Ton	A measure of cooling capacity; one ton of cooling capacity can remove 12,000 Btu/h of heat from a space

Technology Stock Saturation – Single-Family and Manufactured Home Primary Heating

The most common primary heating technology in Pacific Northwest single-family homes is gas forced air furnaces (FAF) (45%), while manufactured homes are most commonly heated by electric forced air furnaces (52%).

	Heating Saturation (% of Homes)	
	Single-Family	**Manufactured Homes**
Gas FAF	**45%**	**12%**
Baseboard Heating & Other Electric Resistance Heat	**14%**	**3%**
Heating Stove	**14%**	**16%**
Air Source Heat Pumps (ASHP) (Ducted)	**12%**	**14%**
Electric FAF	**6%**	**52%**
Boiler	**5%**	**0%**
Ductless Mini-split Heat Pumps	**2%**	**1%**
GSHP	**1%**	**0%**
Other – Not Included in Tech Guide	**1%**	**2%**
None	**0%**	**0%**
Total	**100%**	**100%**

Technology Stock Saturation – Single-Family and Manufactured Home Primary Cooling

In the Pacific Northwest 58% of single-family homes and 46% of manufactured homes do not have cooling. In single-family homes central air conditioners are the primary source of cooling while air source ducted heat pumps are most prevalent in manufactured homes.

	Cooling Saturation (% of Homes)	
	Single-Family	Manufactured Homes
Central Air Conditioners	18%	13%
ASHPs (Ducted)	12%	18%
Ductless Mini-split Heat Pumps	1.5%	1%
PTAC	2%	1%
Room Air Conditioners	7%	18%
GSHP	0.5%	0%
Other – Not Included in Tech Guide	0.5%	3%
None	58%	46%
Total	**100%**	**100%**

Technology Stock Saturation – Multifamily Home Primary Heating

Baseboard heating is the dominant source of in-unit heating for multifamily housing.

Distribution of In-Unit Heating Systems

Baseboard Heater	**82%**
Plug-In Heater	**4.5%**
Gas FAF	**4%**
Ductless Heat Pump (DHP)	**2%**
Electric FAF	**2%**
Heating Stove	**1.5%**
PTAC/PTHP	**2%**
Air Source HP	**1%**
Boiler	**1%**
Total	**100%**

Technology Stock Saturation – Multifamily Home Primary Cooling

In the Pacific Northwest only 25% of multifamily housing has in-unit cooling and packaged terminal air conditioners (PTACs) and packaged terminal heat pumps (PTHPs) make up the majority of these systems.

Distribution of In-Unit Cooling Systems

PTAC/PTHP	**11.5%**
Window AC	**8.5%**
Unit Central AC	**2.5%**
DHP	**1.5%**
ASHP	**1%**
No Cooling	**75%**
Total	**100%**

Technology Stock Saturation – Commercial Buildings Primary Heating and Cooling

In the Pacific Northwest 91% of commercial building square footage is heated and 74% is cooled.

	Cooling Saturation (% of Total sf)	Heating Saturation (% of Total sf)
Gas Furnace Roof-top Units (RTUs)	-	35%
Commercial Boilers	-	16%
Unit Heaters	-	10%
Air Source Commercial Package Air Conditioners and Heat Pumps	32%	5%
ASHP	6%	6%
Water Source Heat Pumps (WSHP)	2%	2%
Packaged Terminal Air Conditioners and Heat Pumps	4%	1%
Chillers – Air-Cooled	4%	-
Chillers – Water-Cooled	2%	-
Chillers – Unknown	1%	-
Ductless Mini-split Heat Pumps	1%	1%
Room Air Conditioners	1%	-
Baseboard Heating	-	1%
Ground Source Heat Pumps (GSHP)	0.5%	0.5%
Variable Refrigerant Flow	0.5%	0.5%
Other – Not Included in Tech Guide	20%	13%
None	26%	9%
Total	**100%**	**100%**

Technology Stock Saturation – Commercial Buildings Primary Heating

In the Pacific Northwest 91% of commercial building square footage is heated and 74% is cooled.

	<5,000 sf	5001-20,000	20,001-50,000	50,001-100,000	100,001+
Gas Furnace RTUs	41%	48%	37%	19%	26%
Commercial Boilers	2%	6%	14%	26%	27%
Unit Heaters	10%	8%	16%	8%	5%
Air Source Commercial Package Air Conditioners & Heat Pumps	10%	8%	3%	1%	4%
ASHPs	18%	9%	4%	3%	2%
WSHPs	0%	0%	3%	1%	5%
Packaged Terminal Air Conditioners & Heat Pumps	0%	0%	2%	3%	1%
Ductless Mini-split Heat Pumps	1%	1%	1%	0%	0%
Baseboard Heating	3%	1%	1%	1%	1%
GSHPs	0%	1%	0%	0%	0%
Variable Refrigerant Flow	0%	0%	1%	1%	0%
Electric Coil Other	1%	1%	4%	10%	15%

Note: These saturations are for technologies included in the technology guide and may not sum up to 100. The CBSA final report did not break out heating and cooling saturations by building size.

Technology Stock Saturation – Commercial Buildings Primary Cooling

In the Pacific Northwest 91% of commercial building square footage is heated and 74% is cooled.

	<5,000 sf	5001-20,000	20,001-50,000	50,001-100,000	100,001+
Air Source Commercial Package Air Conditioners & Heat Pumps	33%	46%	36%	22%	22%
ASHPs	22%	8%	5%	2%	2%
WSHPs	0%	0%	3%	1%	5%
Packaged Terminal Air Conditioners & Heat Pumps	2%	1%	4%	10%	2%
Chillers – Air-Cooled	0%	0%	2%	8%	9%
Chillers – Water-Cooled	0%	0%	0%	2%	7%
Chillers - Unknown	0%	1%	2%	0%	2%
Direct Expansion (DX) - Air VAV	0%	1%	3%	5%	7%
DX - Air Zonal	0%	1%	0%	1%	0%
DX - Air Other	1%	1%	1%	1%	5%
Ductless Mini-split Heat Pumps	1%	0%	1%	0%	0%
Room Air Conditioners	4%	2%	1%	1%	0%
GSHPs	0%	1%	0%	0%	0%
Variable Refrigerant Flow	0%	0%	0%	1%	0%

Note: These saturations are for technologies included in the technology guide and may not sum up to 100. The CBSA final report did not break out heating and cooling saturations by building size.

Technology Comparison – Residential

	ASHPs (Ducted)	Ductless Mini-split Heat Pumps	Central Air Conditioners	Gas Forced Air Furnace	Electric Forced Air Furnace	Baseboard & Other Electric Resistance Heat	Room Air Conditioners
Relative Cost	$$$$$	$$$$	$$$	$$	$$	$	$
Lifetime (Years)	15	15	15	12-17	20-30	20-30	15
Federal Efficiency Standards?	Y	Y	Y	Y	Y	N	Y
RTF Measures	Y	Y	N	N	N	N	N

Technology Comparison – Commercial

	Commercial Boilers	Chillers (Water-Cooled)	Variable Refrigerant Flow	Gas Furnace RTUs (gas packs)	Air Source Commercial Package Air Conditioners & Heat Pumps	Chillers (Air-Cooled)	PTACs & PTHPs
Relative Cost	$$$$	$$$$	$$$$	$$$	$$$	$$$	$
Lifetime	24-35	20-23	15	18	15	20-23	15
Federal Efficiency Standards?	Y	N	Y	Y	Y	N	Y
RTF Measures	N	N	N	Under Development	Under Development	N	N

Efficiency Comparison by Building Type

Comparison Scale

★ Low-end of efficiency range of available technologies
★★
★★★
★★★★
★★★★★ High-end of efficiency range of available technologies

Comparison of Electric Heating Technologies for Residential Applications

	Ductless Mini-split Heat Pumps	ASHPs (Ducted)	PTHP	Electric Forced Air Furnace	Baseboard Heating & Other Electric Resistance Heat
Residential Applications	★★★★	★★★	★★	★	★

Comparison of Cooling Technologies for Residential Applications

	Ductless Mini-split Heat Pumps	ASHPs (Ducted)	Central Air Conditioners	PTHP/PTAC	Room Air Conditioners
Residential Applications	★★★★	★★★	★★	★★	★

The tables here and on the following two slides provide a qualitative comparison of the relative efficiency of available technologies for heating and cooling various building types. These comparisons are highly generalized, and do not reflect all the real-world factors that affect efficiency. For example, a high efficiency technology could be installed or commissioned improperly and result in lower-efficiency operation.

Efficiency Comparison by Building Type

The building types used throughout this slide document align with the building types evaluated as part of the 2014 Northwest Commercial Building Stock Assessment (CBSA).

Comparison of Electric Heating Technologies for Commercial Applications

	Variable Refrigerant Flow Systems (VRFs)	Commercial AC and HP	PTAC/HP
Assembly	-	★★	-
Grocery	-	★★	-
Lodging	★★★	★★	★
Office	★★★	★★	-
Other	★★★	★★	-
Residential Care	-	★★	★
Restaurant	-	★★	-
Retail/Service	-	★★	-
School K-12	★★★	★★	-
Warehouse	-	-	-

Comparison of Gas Heating Technologies for Commercial Applications

	Commercial Boiler	Gas Furnace RTUs
Assembly	★★★	★★
Grocery	-	★★
Lodging	★★★	★★
Office	★★★	★★
Other	★★★	★★
Residential Care	★★★	★★
Restaurant	-	★★
Retail/Service	★★★	★★
School K-12	★★★	★★
Warehouse	★★★	★★

Efficiency Comparison by Building Type

Comparison of Cooling Technologies for Commercial Applications

	Water-Cooled Chillers	Air-Cooled Chillers	Commercial AC and HP	VRF	PTAC/HP
Assembly	★★★★★	★★★★	★★	-	★
Grocery	-	-	★★	-	★
Lodging	★★★★★	★★★★	★★	★★★	★
Office	★★★★★	★★★★	★★	★★★	★
Other	★★★★★	★★★★	★★	★★★	★
Residential Care	★★★★★	-	★★	-	★
Restaurant	-	-	★★	-	-
Retail/Service	-	-	★★	-	★
School K-12	-	★★★★	★★	-	★
Warehouse	-	-	★★	-	-

HVAC Technologies

This section contains a set of slides for each HVAC technology. Each set includes:

1. A description of the technology including lifetime, manufacturers, major components, and efficiency features
2. Application information such as applicable building types and competing technologies
3. Market trends including Federal and state requirements, incremental costs, and RTF and program measures
4. Stock Saturation and Product Flow, if available

Air Source Heat Pumps
Ducted

How It Works

In the Pacific Northwest 12% of single-family homes and 14% of manufactured homes use ASHPs as their primary heat source. In addition, 12% of single-family homes and 18% of manufactured homes use ASHPs as their primary cooling technology.

A heat pump uses the vapor compression refrigeration cycle to transfer heat energy from a source to a destination. An ASHP in heating mode transfers heat from outside air into the conditioned space. In cooling mode, an ASHP is an air conditioner and transfers heat from the conditioned space to the outside air.

An ASHP is a central heating and cooling system that conditions an entire home. It distributes conditioned air with a fan and a system of duct work. By contrast, a ductless heat pump (DHP) is an ASHP that has a fan, but does not use ducting, and it conditions a single room, rather than the entire home.

The RTF assumes ASHPs have a **15-year** lifespan.

The seven largest manufacturers are **Carrier, Goodman, Lennox™, Nordyne, Rheem, Trane®**, and **York®.**

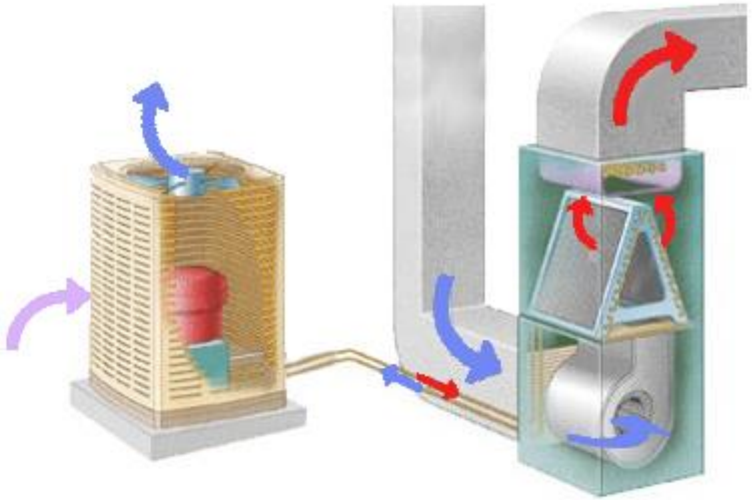


Image Source: Bonneville Power Administration, 2017

How It Works

An installation contractor may size an ASHP using rules of thumb or the industry standard 'Manual J' calculations. Manual J is a specific method for calculating the heating/cooling load for a home.

The RTF CCS measure specifies Manual J calculations for heating sizing. An undersized single stage unit will result in excess use of (inefficient) backup heat, and an oversized single unit will not be as efficient due to cycling losses.

A 2005 Northwest Energy Efficiency Alliance (NEEA) study found that common sizing practices often resulted in undersized equipment. Contractors may undersize equipment because:

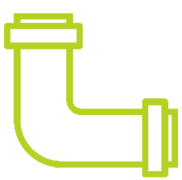
- The unit size is based on the cooling, rather than the heating load
- Smaller units have a lower first cost
- Duct losses were not accounted for
- Sizing was based on the nominal capacity instead of actual capacity

This study also found the average duct efficiency was 73%, meaning the actual efficiency of the system in practice was just 73% of the expected (rated) efficiency. Duct efficiency can be improved by sealing and insulating the duct work. In new construction duct work should be properly designed to minimize energy losses. Duct work should provide desired heating or cooling, be properly sized, maintain a neutral pressure in the house, and minimize losses.

Routine maintenance includes cleanings coils and filters and checking refrigerant charge, motors, and thermostat operation.

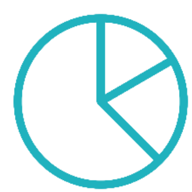
Strengths

Provides high efficiency electric heating



Works with the most common type of heat delivery (forced air ducting)

Weaknesses



May not provide 100% of heating needs

Higher first cost than other electric heating systems or gas heating

Major Components

All heat pumps include a compressor, indoor coil, indoor blower, outdoor coil, outdoor fan, expansion device, and a reversing valve.

The indoor heat exchanger for heat pumps serves as the evaporator during cooling mode and the condenser during heating mode—and vice versa for the outdoor heat exchanger. Hence, the industry refers to heat pump heat exchangers and their fans as indoor or outdoor components (e.g. indoor coil and indoor fan).

https://www.bpa.gov/news/newsroom/Pages/BPA-receives-EPRI-award-for-new-heat-pump-technology.aspx

A heat pump transfers heat, rather than just transforming one form of energy into another and thus uses a relatively small amount of external power to provide useful heat. The term coefficient of performance (COP) is a measure of the heat output of the heat pump compared with the energy input. An electric baseboard heater has a COP of 1.0, since it effectively transforms one unit of electric energy into one unit of heat energy. An ASHP generally operates with a COP in the range of 2-4. The COP varies according to outside temperature - in cold weather the heat pump has to work harder to extract the same amount of heat from the outside air, and the COP of most ASHP's drops below 2 in especially cold weather. Newer "cold climate" heat pumps, however, have improved efficiency in cold weather than standard units.

Some technology advances for ASHPs that improve efficiency include:

- Improved expansion valves for more precise control of the refrigerant flow to the indoor coil
- Variable speed blowers, which are more efficient and can compensate for some of the adverse effects of restricted ducts, dirty filters, and dirty coils
- Improved coil design
- Higher efficiency electric motors
- Compressor modulation

Additional Features

Heat pump controls are a crucial part of the energy savings potential of heat pumps, due to the lower temperature of the heated air provided by the heat pump (compared with combustion or electric resistance). If nighttime setback, which sets heat to come on at a certain time (e.g., 6:00 am), controlled an ASHP the same way it does a forced air furnace (FAF), it would not provide enough time to comfortably heat a home, resulting in a cold home or overuse of the backup heat, which is inefficient. "Smart" controls, such as the Nest or ecobee, can match outside air temperature, heat pump performance, and occupant behavior to minimize reliance on backup heat. However, they can cost up to $250, while a standard programmable thermostat might cost $25.

A well-controlled heat pump will have a minimum setback temperature that does not allow the house to get too cold, allowing for timely recovery, and it will provide a sufficient ramp-up time to meet the setpoints.

In addition, a heat pump-optimizing thermostat will lock out backup heat unless the outside air temperature is below a certain point (e.g., 30°F or 40°F) to avoid the backup heat being used to meet a setpoint that the heat pump could meet. Standard heat pump controls might turn on backup heat if the home temperature is not within 3°F of the setpoint.

Sizing. Equipment sizing significantly impacts heating and cooling efficiency. Not only will an oversized ASHP use more energy than a properly sized unit, but it will also deteriorate faster and may not provide comfortable space conditioning. An oversize unit will cycle more often and in cooling mode this limits the units ability to reduce the space humidity. In addition, oversized units can strain the duct system by causing higher air pressure. Under sizing equipment causes the ASHP to run for longer periods of time to meet the cooling or heating load. In cold climates an undersized unit may use the backup resistance heat more frequently to meet the heating load.

Application

Heat pumps have both residential and commercial applications. Residential heat pumps are generally a maximum of five tons; however, commercial units less than five tons are available. BPA's 2016 study of the ASHP market reported that 93% of ASHP shipments are residential.

ASHP retrofits in existing buildings are best suited to buildings with ductwork and existing forced air HVAC. In new construction, an ASHP is an efficient electric source of heat when gas is not available.

In residential applications ASHP's primarily compete with other electric, ducted central heating systems. These include electric FAFs, GSHPs with forced air, and boilers with forced air. ASHPs are also increasingly competing with DHPs.

In CBSA and RBSA, air source ducted heat pumps are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ☑ Office
- ☑ Retail
- ☑ K-12 Schools
- ☑ Warehouse
- ☑ Grocery
- ☑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ☑ Other

Regulations & Cost

Manufacturers have historically promoted ASHPs as ideal for moderate climates (like the Northwest) because in cold weather the heat pump may not be able to provide sufficient heat on its own. ASHPs typically have electric resistance to act as backup heat. However, manufacturers are marketing newer models as "cold climate" heat pumps, and with higher efficiencies these models may provide needed heat –even in colder parts of the Northwest.

In 2015, BPA collected sales data for ASHPs. These sales data represent about 45%-60% of the market and generally show that the majority of ASHPs do not exceed the Federal minimum efficiency.

In the Seventh Power Plan (Seventh Plan), the baseline efficiency for ASHP in a single-family or manufactured home is 8.5 Heating Seasonal Performance Factor (HSPF). This is slightly higher than the Federal minimum efficiency which is 8.2 HSPF.

Cost. The RTF measure for ASHP's assumes that a three-ton ASHP costs $6,118 (2012 dollars, cost to homeowner, including installation). The Energy Information Administration (EIA) estimates that the cost for ASHPs will increase 20% by 2040. The incremental cost for more efficient ASHPs is:

- Baseline to ENERGY STAR® (8.2 HSPF) = 10% increase in total cost
- Baseline to high efficiency (9.0 HSPF) = 40% increase in total cost

Codes. Washington, Oregon, Idaho, and Montana residential building codes require heat pumps to have controls that minimize the use of electric resistance supplemental heat. In addition, Washington's and Oregon's respective codes include pathways where high efficiency heat pumps may be selected to comply with these building codes.

Standards. The U.S. Department of Energy (DOE) has minimum efficiency standards for ASHP that have single phase power and rated capacity below 65,000 Btu/h. The current Federal efficiency standards measure heating efficiency in terms of HSPF and cooling efficiency in terms of Seasonal Energy Efficiency Ratio (SEER). DOE established the current standard in a 2011 rulemaking, which went into effect on January 1, 2015.

On January 6, 2017, DOE adopted new efficiency levels for ASHPs that go into effect on January 1, 2023. These new efficiency levels are based on an updated test method, which will cause an adjustment to heat pumps ratings, making the 2023 standard not directly comparable to the current standards. These new efficiency levels are in terms of HSPF2 and SEER2.

Measures

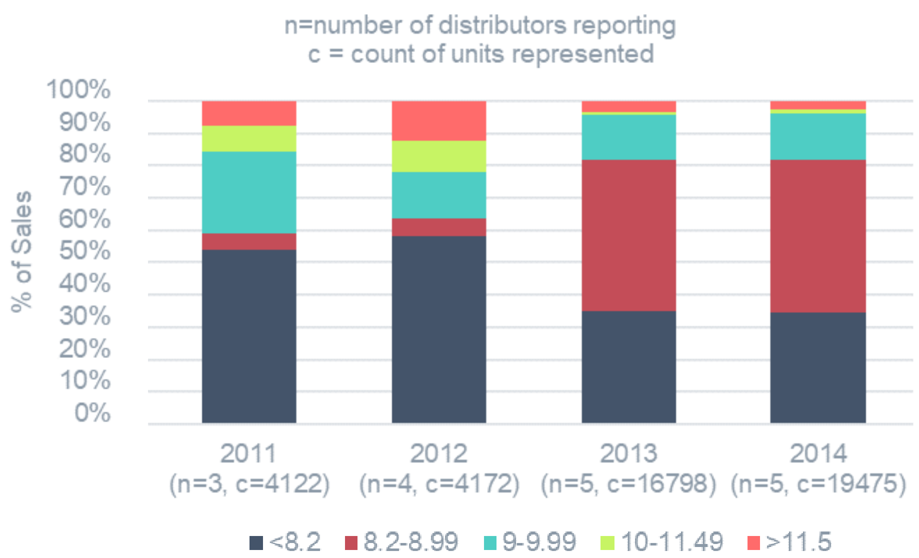
Measure Title	RTF Category	BPA Qualified	Description
Air Source Heat Pump Conversions	Planning	Yes	Single-family (site-built) conversion of forced air furnace to air source heat pump
Air Source Heat Pump Upgrades	Planning	Yes	Single-family upgrade of ASHP to higher efficiency ASHP
Air Source Heat Pump Conversions	Planning	Yes	Manufactured home conversion of FAF to ASHP
Air Source Heat Pump Upgrades	Planning	Yes	Manufactured home upgrade of ASHP to higher efficiency ASHP
Commissioning, Controls, & Sizing	Planning	Yes	Proper sizing, charging, and controls so the system is installed to operate efficiently in a single family or manufactured home.
Duct Sealing	Planning – SF Suspended - MH	Yes (SF & MH)	Duct sealing measures for existing single-family homes or existing manufactured homes.
Commercial Heat Pump Conversion	N/A	Yes	A BPA Qualified measure only - Replace existing electric resistance heating system with a heat pump in commercial, industrial and agricultural sectors
Commercial Heat Pump Upgrade	N/A	Yes	A BPA Qualified measure only - Replace existing code minimum ASHP with a CEE Tier 2 heat pump or install an efficient ASHP in new construction in commercial, industrial and agricultural sectors

Stock Saturation and Product Flow

Stock Saturation in the Pacific Northwest - Residential

Cooling Saturation (% of buildings)		Heating Saturation	
Single-Family	Manufactured Homes	Single-Family	Manufactured Homes
12%	18%	12%	14%

Distribution of HSPF for split system ASHPs based on sales data for 45% -60% of the Northwest market



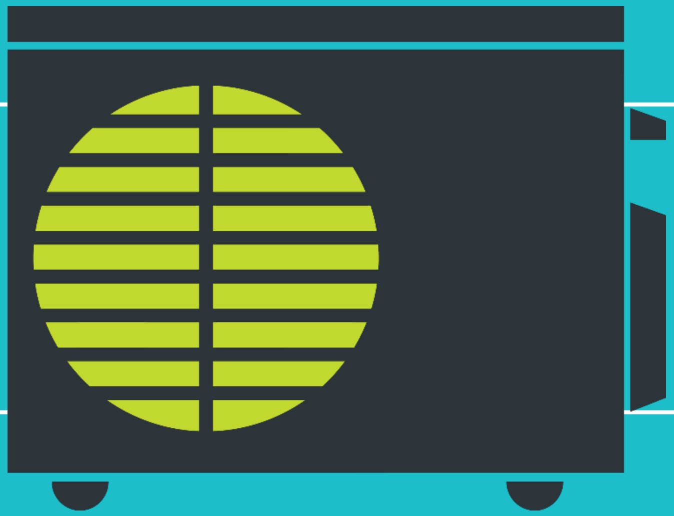
Stock Saturation

ASHPs heat about 5% and cool about 6% of total Pacific Northwest commercial square footage.

Stock Saturation in the Pacific Northwest - Commercial

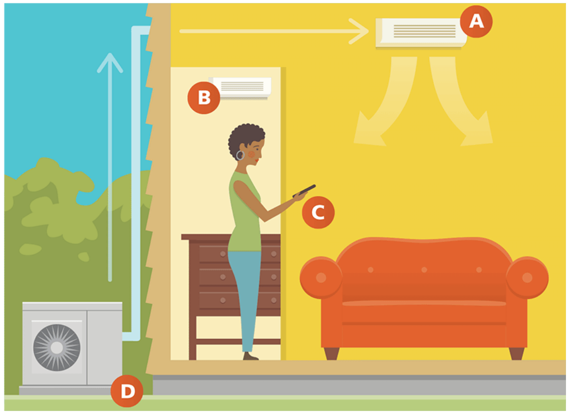
Building Type	Heating Saturation	Cooling Saturation
Assembly	7%	7%
Grocery	6%	7%
Lodging	5%	5%
Office	12%	13%
Other	3%	2%
Residential Care	7%	7%
Restaurant	7%	8%
Retail/Service	3%	3%
School K-12	4%	5%
Warehouse	1%	1%

Ductless Mini-split Heat Pumps



How It Works

In the Pacific Northwest 2% of single-family homes and 1% of manufactured homes use DHPs as their primary heat source. In addition, 1.5% of single-family homes and 1% of manufactured homes use DHPs as their primary cooling technology.



DHP's generally provide heat for the central area of the home, with other heat sources supplying other rooms in the home. A DHP uses the vapor compression refrigeration cycle to transfer heat energy from a source to a destination. A DHP is a form of ASHP that does not have duct work. Since a heat pump is transferring heat, rather transforming one form of energy into another, a heat pump uses a relatively small amount of external power to accomplish the work of providing useful heat.

The RTF DHP measure requires that the DHP be installed in the main living area of the house. However, multi-headed systems with capacities of up to five tons are available for whole-house conditioning.

DHP systems are a good match for retrofits of homes without ducting. The RTF retrofit DHP measure is for homes with existing electric baseboard heating. The baseboard heating provides backup heat.

The RTF assumes a DHP has a **15-year** lifespan.

The primary manufacturers for DHPs in the U.S. market include **Mitsubishi Electric, Fujitsu, Daikin, Sanyo, LG, Samsung, EMI/Retroaire, Goodman, Heil,** and **Unionaire. Trane, Carrier,** and **Lennox** private label DHPs that are manufactured by a third party.

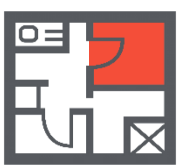
Image Source: https://www.portlandgeneral.com/residential/energy-savings/heating-cooling/high-efficiency-heat-pumps/ductless-heat-pumps>

How It Works

Contractor experience and rules of thumb typically determine DHP sizing. Manual J calculations, which are based on whole-house heating or cooling load, are unlikely to apply to DHP installations that serve selected areas of the home—though contractors might use them for whole-house conditioning. Oversized or incorrectly located indoor units often result in short-cycling, which wastes energy and does not provide proper temperature or humidity control. Too large a system is also more expensive to buy and operate.

Routine maintenance includes cleanings the condenser coil and filters and checking for refrigerant leaks and the electrical connections.

Strengths

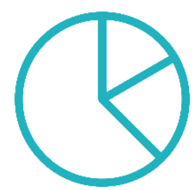


Provides zonal heat and cooling

Does not have duct losses

Provides efficient all-electric heat

Weaknesses



May not provide 100% of heating needs

Expensive

Some people may not like appearance of the indoor unit

Major Components

All DHPs include a compressor, indoor coil, indoor fans, outdoor coil, outdoor fan, expansion device, and a reversing valve.

For heat pumps, the indoor heat exchanger serves as the evaporator during cooling mode and the condenser during heating mode—vice versa for the outdoor heat exchanger. Hence, the industry refers to heat pump heat exchangers and their fans as indoor or outdoor components (e.g. indoor coil and indoor fan).

A DHP conditions the room in which it is installed rather than the entire home. Some DHP systems have indoor units (heads) installed in multiple rooms of the home or use short duct runs to distribute cooling to multiple rooms.

DHPs are an efficient type of heating system because they transfer heat instead of generate heat. More sophisticated ductless heat pumps can provide customized heating and cooling for each room. In addition, DHPs avoid duct losses associated with ducted ASHPs and air conditioners. Duct losses can account for more than 30% of energy consumption for space conditioning, especially if the ducts are in an unconditioned space like an attic.

Additional Features

One type of high efficiency DHP uses **inverter technology.** An inverter driven compressor can modulate capacity to match the heating load. Beginning in 2006, a number of Asian manufacturers introduced inverter-driven, mini-split heat pumps into the U.S. market. These models offered a number of advantages over traditional ducted units, including quiet operation, higher delivered air temperature (and thus comfort), high efficiency, and acceptable performance even at temperatures below 0°F. The RTF measure, and some programs in the region, require inverter-driven DHP systems.

A **programmable thermostat or a smart thermostat may be less important** for DHP installations. This is because the programmable thermostat would only control one zone, and therefore does not result in as much energy savings for DHPs as for other heating system types. In addition, the RTF smart thermostat measure does not apply to DHPs.

DHPs do not include **integrated backup resistance heat**. As such, the DHP is controlled separately from the backup heating system. The Ecotope analysis for NEEA found that DHP savings were not as great as originally expected. This may be a result of users heating the DHP zone to a greater degree or because of the lack of coordination between the DHP and the electric resistance back up heat. DHP controls that lock out the backup heat in the DHP zone, would be optimal to achieve DHP savings; however, these controls do not yet exist on the market.

Application

DHP's have both residential and commercial applications. A DHP as a retrofit is most suited to buildings without existing forced air duct work. A DHP retrofit in a home with existing central forced air heat is a means of zoning the home heating by enabling a lower thermostat setting in the non-central part of the home. As a means to condition a whole building with existing central air, DHP solutions can be cost prohibitive.

In new construction, a DHP may well serve applications desiring zonal space conditioning, especially where it is advantageous to avoid forced-air ductwork to deliver heat and cooling. In new construction, a DHP has a higher first cost than electric baseboard heat. A new DHP installation is comparable in cost to an electric FAF with ducts plus central air-conditioning (CAC), and it costs less than an ASHP with ducts.

In residential applications ductless mini-split heat pumps primarily compete with other zonal systems. These include baseboard heating, boilers with radiators or radiant systems, heating stoves, GSHPs with radiant systems, and room air conditioners. DHPs are increasingly competing with ducted systems like electric FAFs and ASHPs.

In small commercial applications DHPs may compete with ASHPs, small commercial packaged air conditioners and heat pumps, VAV systems, PTAC/PTHPs, and WSHPs.

In CBSA and RBSA, ductless mini-split heat pumps are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ☑ Office
- ❑ Retail
- ❑ K-12 Schools
- ☑ Warehouse
- ❑ Grocery
- ☑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ❑ Assembly
- ☑ Other

Regulations & Cost

A 2016 NEEA study found that customers in the Pacific Northwest are increasingly interested in DHPs and are installing them. However, the cost of purchasing and installing a DHP is a primary market barrier, and NEEA found that rebates are an important driver of DHP sales.

In 2015, NEEA and BPA collected sales data for DHPs. These sales data represent about 45%-60% of the market. Based on the sales data, the majority of DHPs sold exceed the Federal minimum (8.2 HSPF) efficiency and have an HSPF of 10 or more.

The Seventh Power Plan assumes a DHP has an efficiency greater than 9.5 HSPF, when converting from a FAF to DHP.

Cost. The RTF estimates a DHP under two tons costs around $4,000 to install.

Codes. Washington residential building codes require an inverter-driven DHP in the largest zone of new single-family and small multifamily zoned electrically heated homes. Additionally, Oregon’s prescriptive requirements incent high efficiency DHPs.

Standards. The DOE has minimum efficiency standards for DHPs that have single phase power and rated capacity below 65,000 Btu/h. The current Federal efficiency standards measure heating efficiency in terms of HSPF and cooling efficiency in terms of SEER. DOE established the current standards in a rulemaking in 2011, and they went into effect on January 1, 2015.

On January 6, 2017, DOE adopted new efficiency levels for DHPs that go into effect on January 1, 2023. These new efficiency levels are based on an updated test method, which will cause an adjustment to air conditioners and heat pumps ratings, making the 2023 standard not directly comparable to the current standards. These new efficiency levels are in terms of HSPF2 and SEER2.

Measures

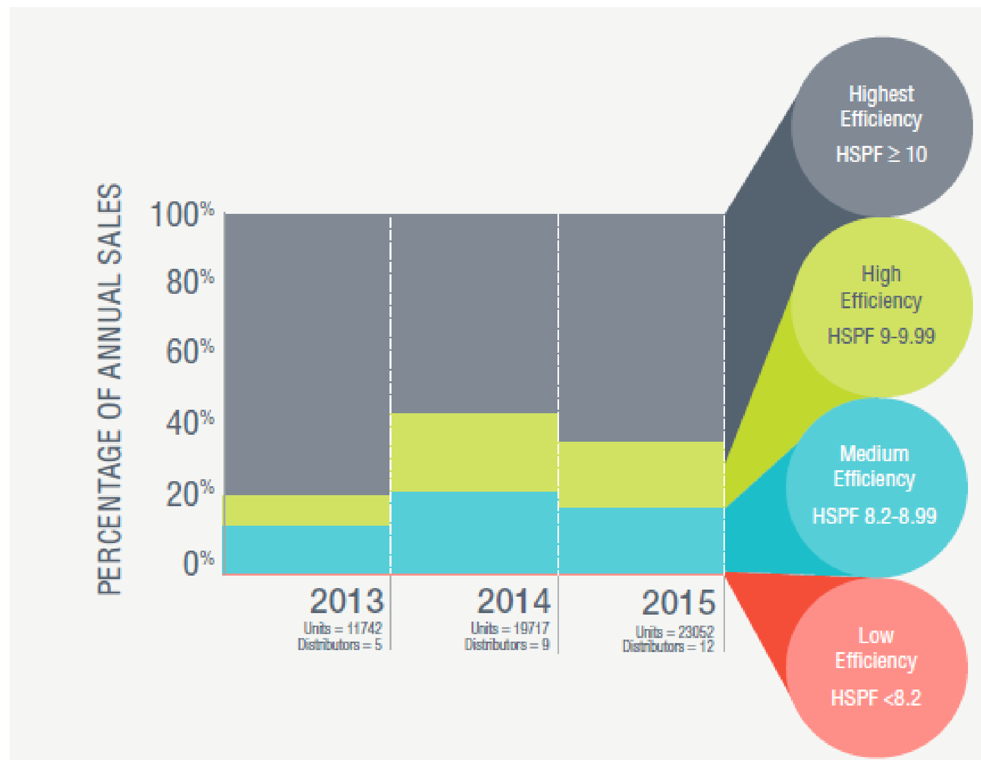
Measure Title	Category	BPA Qualified	Description
DHP for Zonal Heat – SF	Proven	Yes	Addition of inverter-driven DHP in central part of existing single family home with baseboard heat
DHP for Zonal Heat – MH	Small saver	Yes	Addition of inverter-driven DHP in central part of existing manufactured home with baseboard heat
DHP New Construction	Planning	Yes	Installation of DHP, plus zonal resistance heat in single family new construction (not eligible in WA)
DHPs for FAF SF and MH	Planning	Yes	Addition of inverter-driven DHP to existing manufactured or site-built home with FAF
DHPs for Multifamily	To be determined	No	Installation of DHPs in multifamily units with zonal heat
Short Duct Minisplit	To be determined	No	This measure is currently under development
Commercial DHPs	N/A	Yes	BPA qualified measure only – Install high efficiency DHPs with inverter driven compressor in existing commercial buildings
Multiple Indoor Heads Ductless, Multiple Indoor Ducted HPs	N/A	Yes	Install multiple indoor heads ductless, multiple indoor ducted mini-split heat pumps or a combo in existing single family homes with zonal heat or electric FAF
DHP Upgrade	N/A	Yes	BPA qualified measure only - upgrade an existing DHP in a single family home to a high efficiency DHPs with inverter driven compressor

Stock Saturation and Product Flow

Market Saturation in the Pacific Northwest

Cooling Saturation (% of buildings)		Heating Saturation	
Single-Family	Manufactured Homes	Single-Family	Manufactured Homes
2%	1%	2%	1%

Distribution of HSPF of Ductless Mini-Split Heat Pumps based on distributor sales data for 45% -60% of the Pacific Northwest market and NEEA program data



Stock Saturation

Ductless mini-split heat pumps heat about 1% and cool about 1% of total Pacific Northwest commercial square footage.

Stock Saturation in the Pacific Northwest - Commercial

Building Type	Heating Saturation	Cooling Saturation
Assembly	0%	0%
Grocery	0%	0%
Lodging	0%	1%
Office	1%	0%
Other	1%	2%
Residential Care	2%	1%
Restaurant	2%	2%
Retail/Service	0%	0%
School K-12	0%	0%
Warehouse	1%	0%

Stock Saturation and Product Flow

Total sales of DHPs in the Pacific Northwest

	2011	2012	2013	2014	2015	Total
Incented Heating and Cooling	4,893	5,289	7,688	8,701	10,176	36,747
Non-Incented Heating and Cooling	6,280	8,835	8,175	14,091	16,830	54,211
Non-Incented Cooling Only	1,367	1,909	2,089	2,098	2,364	9,827
Total Outdoor Unit Sales	12,540	16,033	17,952	24,890	29,370	100,785

Central Air Conditioners

How It Works

In the Pacific Northwest 18% of single-family homes and 13% of manufactured homes use CACs as their primary cooling technology.

Central air-conditioning (CAC) refers to a system that provides cooled air to an entire building or home. CAC uses the vapor compression refrigeration cycle to transfer heat energy from an indoor space to an outdoor space.

CAC capacity in the U.S. is measured in tons, which is a measure of cooling capacity; one ton of cooling capacity can remove 12,000 Btu/h of heat from a space. Residential CAC would typically be in the range 1 to 5 tons.

The RTF assumes CACs have a **15-year** measure life.

The seven largest manufacturers are **Carrier, Goodman, Lennox, Nordyne, Rheem, Trane, and York.**

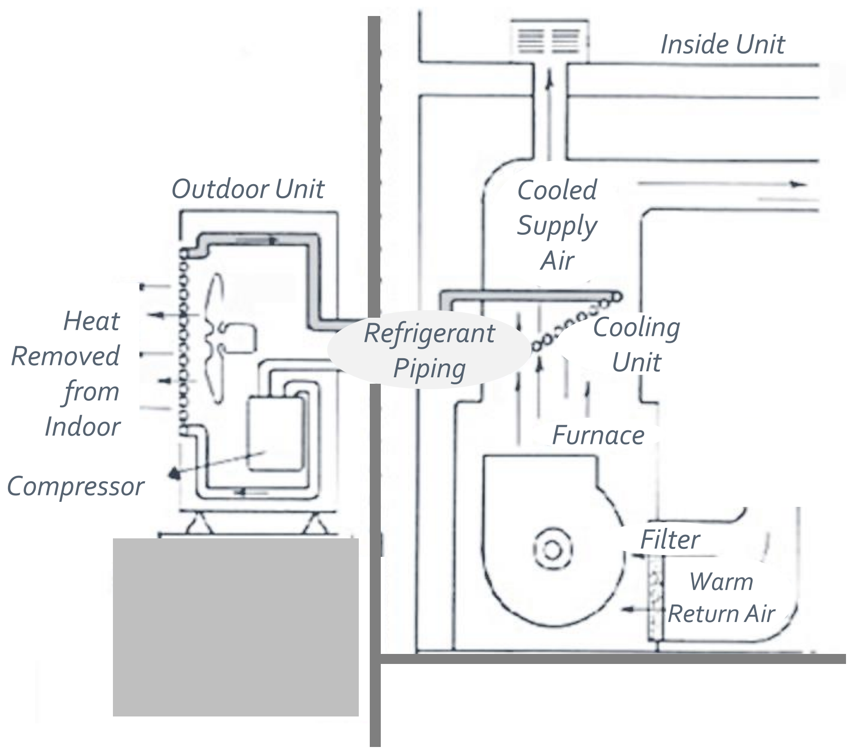


Image Source: Bonneville Power Administration, 2017

How It Works

Contractors may size CACs using rules of thumb or standard charts, or using the industry standard Manual J calculations. The RTF CCS measure specifies Manual J calculations for heating sizing, but does not specify cooling systems sizing. (RTF measures encourage the use of ASHPs and DHPs rather than CACs.) Equipment sizing significantly impacts cooling efficiency, but cooling loads in the Northwest are low. An oversized air conditioner will use more energy than a properly sized component at less than full load. Equipment will run at a fraction of full load most of the time. In contrast, an undersized unit will not provide sufficient cooling at higher outside air temperatures.

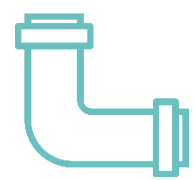
Routine maintenance on CAC units includes coil cleaning, cleaning the condensate drain line, and refrigerator charge updates.

Strengths

Provides cooling to the entire home/building

Has a lower first cost than a ducted heat pump when paired with addition of a FAF

Weaknesses



Duct losses lead to loss of efficiency

Major Components

All central air conditioners include a compressor, evaporator, evaporator fan, condenser, condenser fan, and an expansion device.

The evaporator is indoors, extracting heat from the interior, and the condenser is outdoors, rejecting heat into the surrounding area. The unit transfers heat between the outdoor condenser component and the indoor component via refrigerant lines.

A CAC requires a means of delivering the heat from the evaporator coils to the conditioned space. It accomplishes this by blowing air across the coils and through the ducting to rooms in the home.

CAC systems lose energy through ducts in two ways: leakage and heat transfer through the ducts from unconditioned space. Properly joining and sealing duct segments can alleviate leakage, and duct insulation can reduce heat transfer losses.

Image Source:https://www.flickr.com/photos/cmtdrt/2497751040

Additional Features

Controls can reduce CAC energy use. The DOE recommends a setpoint of 78°F during the day, with a nighttime temperature that is as high as tolerable, as well as turning off the system when the residence is not occupied. Smart thermostats that turn off the system when nobody is home would save energy. The team did not find data on actual set points and behavior for CACs in the Northwest.

Types of controls include programmable and smart thermostats. **Programmable thermostats** can store and repeat multiple daily settings (six or more temperature settings a day) that operators can manually override without affecting the rest of the daily or weekly program. **Smart thermostats** also store temperature settings on a schedule. Smart thermostats also have learning algorithms and often allow users to control the settings through Internet-connected devices. In addition smart thermostats may have occupancy or proximity sensing features to reduce energy use.

Application

CACs have both residential and commercial applications. While most applications are residential, CACs may be found in some small commercial applications.

In existing construction, a CAC is most suited to buildings with an existing FAF.

In new construction with electric heat and ducts, a ducted heat pump is a better alternative, because it provides efficient heating in addition to cooling.

In residential applications central air conditioners compete with other electric, ducted central cooling systems. These include ASHPs and GSHPs with forced air. In addition, central air conditioners increasing compete with DHPs.

In RBSA, CACs are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:*

- ❑ Office
- ❑ Retail
- ❑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ❑ Lodging
- ❑ Residential Care
- ❑ Assembly
- ❑ Other

**Although residential style CACs are used in some commercial buildings, CBSA did not provide enough detail to distinguish residential style CACs from other types of direct expansion air conditioning.*

Regulations & Cost

The Seattle Times reports that central air in the Pacific Northwest is increasing in popularity. Since 2010, 25% of newly constructed homes have central air. In the Northwest, landlords advertise central air as an amenity which may lead to increasing demand.

In 2015, BPA collected sales data for CACs. These sales data represent about 15%-25% of the market and generally show that the majority of CACs do not exceed the Federal minimum efficiency.

The team's review could not identify a baseline efficiency for CACs in the Seventh Power Plan.

Cost. The RTF estimates residential CACs cost $2,200 in the Northwest. An electric FAF would add an additional $1,000 to make a complete space conditioning system.

EIA estimates the following incremental cost for more efficient CACs:

- Baseline to ENERGY STAR = 10% increase in total cost
- Baseline to high efficiency = 130% increase in total cost

Standards. The DOE has minimum efficiency standards for CACs that have single phase power and rated capacity below 65,000 Btu/h. The current Federal efficiency standards measure cooling efficiency in terms of SEER. DOE established the current standards in a 2011 rulemaking and they went into effect on January 1, 2015.

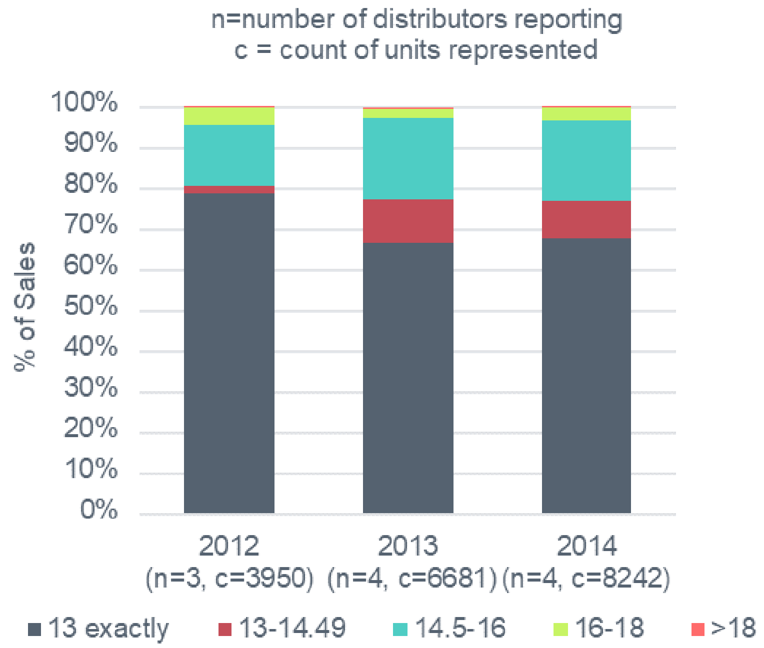
On January 6, 2017, DOE adopted new efficiency levels for CACs that go into effect on January 1, 2023. These new efficiency levels are based on an updated test method that will cause an adjustment to air conditioner ratings, making the 2023 standards not directly comparable to the current standards. These new efficiency levels are expressed in terms of SEER2.

Stock Saturation and Product Flow

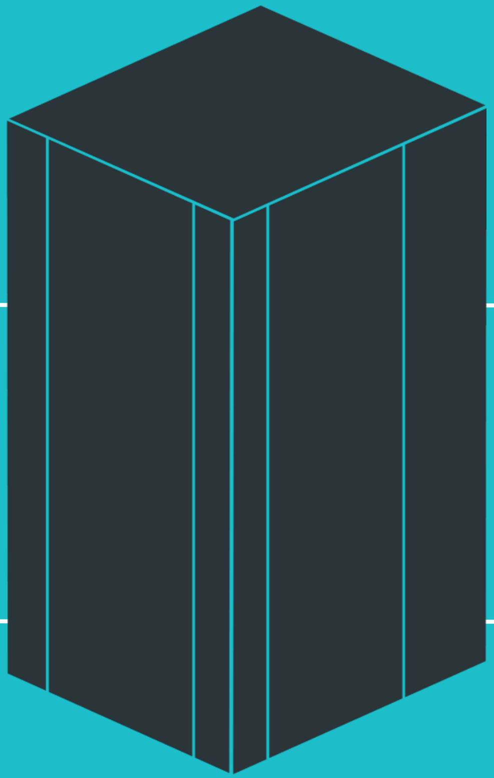
Market Saturation in the Pacific Northwest

CAC Saturation (% of buildings)	
Single-Family	**Manufactured Homes**
18%	**13%**

Distribution of SEER for residential split system air conditioners based on sales data for 15% -25% of the Pacific Northwest market



Gas Forced Air Furnaces



How It Works

In the Pacific Northwest 45% of single-family homes and 12% of manufactured homes use gas forced air furnace s as their primary heating technology.

A gas forced air furnace will burn gas with blown-in intake air. The combustion will heat a heat exchanger, which in turn will warm air being circulated throughout the central ducting system. The system releases fumes from the combustion process to the exterior of the structure.

A gas forced air furnace must be installed in a home designed to accommodate a central air system with ducting to each conditioned space. The installed furnace must fit inside a space designed for a furnace to meet building and fire codes.

Some spaces limit the size and furnace configuration. For that reason furnaces come in a variety of air flow configurations like upflow, downflow, and horizontal. Compact furnaces, called “lowboys,” are shorter furnaces designed to go in small spaces like low ceiling basements.

A gas forced air furnace has an expected life of **12** to **17 years**, depending on the configuration and maintenance quality.

Seven U.S. manufacturers make up almost the entire U.S. domestic gas furnace market: **Carrier, Goodman, Lennox, Trane, Rheem, York,** and **Nordyne.**

Image Source: https://commons.wikimedia.org/wiki/File:Condensing_Forced_Air_Gas_Furnace.jpg

How It Works

An improperly installed furnace may lead to less effective transfer of heated air to the conditioned spaces, resulting in more heating hours and lower overall efficiency.

Contractors determine furnace size in one of two ways:

1) Using tables developed by HVAC vendors that consider total conditioned square footage and climate zone.
2) Using a precise heating load estimate that accounts for building construction. Although this method is more costly, it can yield higher savings from more careful design and cost analysis.

Regular maintenance can improve furnace life and the effectiveness of the heating system. EIA estimates maintenance costs about $45 per year. Maintenance includes:

- Changing the air filters
- Checking for leaks and resealing connections between the furnace and main ducts
- Remove dirt soot and corrosion
- Maintaining blower motors

Strengths

Low fuel price

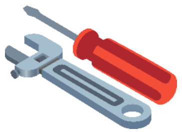
Effective at maintaining comfortable temperatures

Low operating cost compared to room air heaters

Low first cost compared to heat pump

Weaknesses

Requires gas lines and ducting



Requires periodic maintenance for efficiency and safety

Major Components

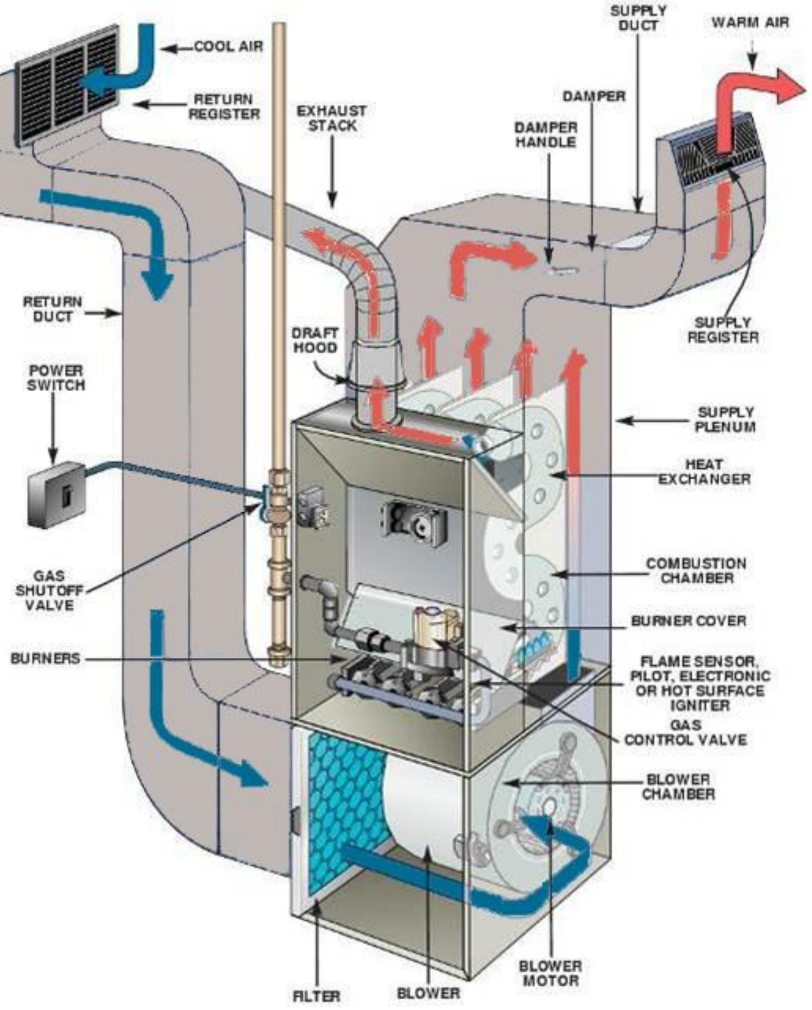


Image Source: Bonneville Power Administration, 2017

All gas forced air furnaces include a heat exchanger, combustion system, venting components, circulating air blower and motor, and controls.

The combustion system includes a gas fired heating element (burner) to heat supply air and an ignition system (pilot light).

The heat exchanger is made up of a compact array of tubes and fans and separates the combustion air from supply air. The use of a heat exchanger ensures minimum contamination of supply air with combustion products.

Controls and sensors help to control combustion rate and to supply air at the correct temperature.

Additional Features

Gas forced air furnaces may also include humidifiers and electronic air cleaners to improve air quality. In addition, in the air handler with the heating components there may also be a cooling coil from the air-conditioning system. Alternatively, the cooling coil may be installed in a separate housing on the supply side.

Higher efficiency features include:

- **Variable speed and electrically commutated motors** can increase central air blower efficiency. This allows for operation at lower speeds, which requires less fan power.
- Advanced ignition sources like **intermittent pilots, direct spark, and hot surfaces** are replacing standing pilot lights. Standing pilot lights are an old technology that have phased out with Federal standards
- **Programmable thermostats or smart controls** can save as much as 10% a year on heating by simply turning thermostats back 7°F-10°F from normal settings for eight hours a day.

Application

Gas forced air furnaces primarily serve single-family homes although they could be installed in any residence that has gas lines and meets ducting requirements.

Existing construction can accommodate a gas furnace if there are gas lines running to the residence, and if the residence has the space to run (or has preexisting) central air ducting. Due to the low cost of natural gas, some utilities provide incentives to replace electric furnaces with gas furnaces.

Although small commercial buildings can use gas furnaces, larger buildings tend to favor hot water and central boiler coils for ducted heating instead.

In residential applications gas forced air furnaces primarily compete with other gas, ducted central heating systems such as boilers with forced air.

In CBSA and RBSA, gas forced air furnaces are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ❑ Office
- ❑ Retail
- ❑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ❑ Lodging
- ❑ Residential Care
- ❑ Assembly
- ❑ Other

Regulations & Cost

Gas forced air furnaces provide an inexpensive source of heating, particularly when natural gas prices in the U.S. are low. On a $/Btu heating basis, gas is less than half the cost of electricity. As long as prices remain stable or continue to drop, costs to operate natural gas heating will remain competitive.

Gas FAFs are either condensing or non-condensing. Condensing furnaces have higher efficiencies than a non-condensing furnace of equivalent size. Switching from a non-condensing to condensing gas furnace often requires modifying the furnace ventilation at additional expense.

The efficiency levels of a gas forced air furnace typically range from 80%-98%.

Cost. For homes converting to gas heat, the cost to install a new gas line can be $600-$900. The furnace itself will range from $750-$1,100.

EIA estimates the following incremental cost for more efficient gas furnaces:

- Baseline to ENERGY STAR = 60% increase in total cost
- Baseline to high efficiency = 80% increase in total cost

Standards. The DOE has minimum efficiency standards for gas forced air furnaces. The current efficiency standards are in terms of AFUE. DOE currently has an open rulemaking that may amend the efficiency standards.

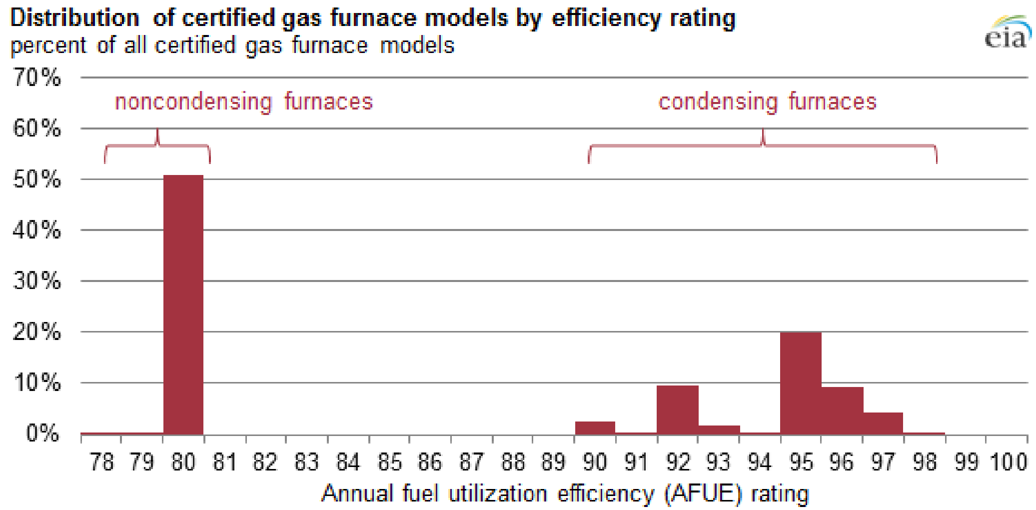
Codes. Washington, Oregon, Idaho, and Montana residential building codes require gas forced air furnaces to have a programmable thermostat. Washington and Oregon also include high efficiency gas forced air furnaces as an option to comply with their prescriptive compliance pathways.

Stock Saturation and Product Flow

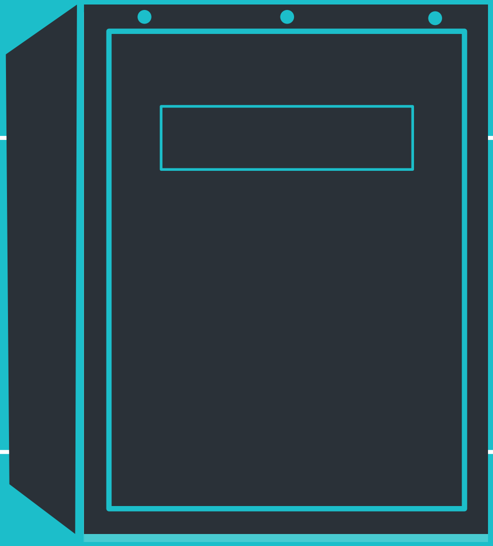
Market Saturation in the Pacific Northwest

Heating Saturation (% of buildings)	
Single-Family	Manufactured Homes
45%	0%

National Distribution of Efficiency Rating



Electric Forced Air Furnaces



How It Works

In the Pacific Northwest 6% of single-family homes and 52% of manufactured homes use electric forced air furnace s as their primary heating technology.

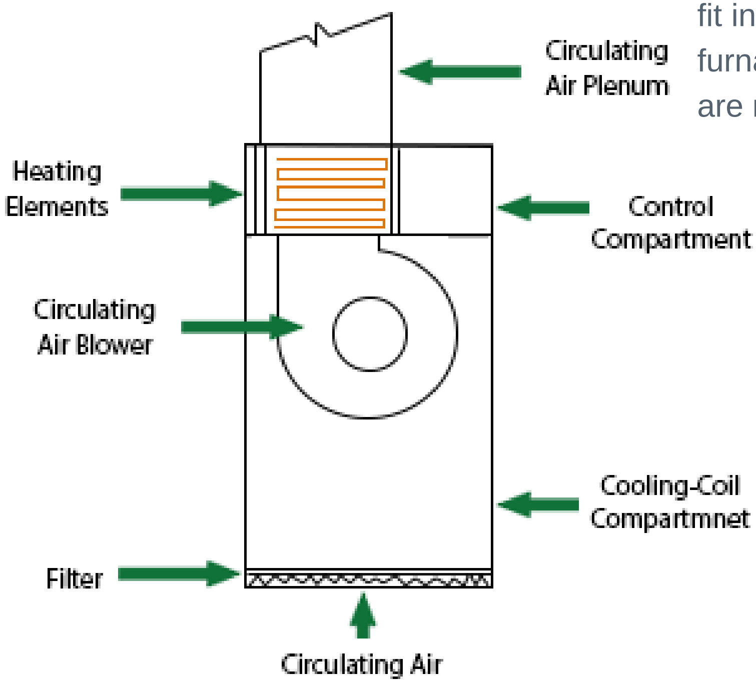


Image Source: Bonneville Power Administration, 2017

An electric forced air furnace uses electric resistance coils to heat warm air being circulated throughout the central ducting system.

A electric forced air furnace must be installed in a home that can accommodate a central air system with ducting to each conditioned space. The installed furnace must fit inside a space designed for a furnace to ensure building codes are met.

Some spaces limit the size and furnace configuration, which is why furnaces come in a variety of air flow configurations like upflow, downflow, and horizontal. Compact furnaces, called “lowboys,” are shorter furnaces designed to go in small spaces like low ceiling basements.

A central forced air furnace has an expected life of **20-30 years**, depending on the configuration and quality of maintenance.

The primary electric furnace manufacturers are **Trane, Carrier, American Standard, Goodman, Rheem, Nordyne,** and **Hamilton (mobile home furnaces).**

How It Works

An improperly installed furnace may lead to less effective transfer of heated air to the conditioned spaces, resulting in more heating hours and lower overall efficiency.

A contractor may determine the size of furnace in one of two ways:

- Using tables developed by HVAC vendors that consider total conditioned square footage and climate zone.
- Using a precise heating load estimate that accounts for building construction. Although this method is more costly, it can yield higher savings from more careful design and cost analysis.

Regular maintenance can improve furnace life and the effectiveness of the heating system. EIA estimates maintenance costs about $40/year. Maintenance includes:

- Changing the air filters
- Checking for leaks and resealing connections between the furnace and main ducts
- Replacing aging heating elements
- Maintaining blower motors

Strengths

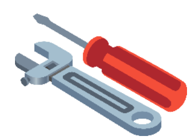
Effective at maintaining comfortable temperatures

Lower operating cost than room air heaters

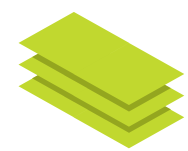
Low first cost compared to heat pumps

Weaknesses

Requires ducting



Requires periodic maintenance for efficiency and safety



More expensive to operate than a gas forced air furnace or heat pump

Major Components

All electric forced air furnaces include a heat exchanger, electric resistance heating element, circulating air blower and motor, and controls.

The electric resistance element works by heating up as electricity passes through it. The amount of heat can be adjusted by changing the amount of current passing through the element. The heat exchanger is used to transfer heat from the heating element to the supply air.

Electric forced air furnaces are practical for heating a building with more than one room. The on-site energy efficiency tends to be high because air passes directly over the heating element and circulates effectively throughout the rooms compared to in-room resistance heaters. Electric furnaces are less efficient than heat pumps because they don't take advantage of "free" heat sources and sinks.

Controls and sensors can make this equipment more efficient. Controls and sensors help keep the heating rate and supply air at the correct temperature. Controls also prevent electrical overload, which can cause coil or motor burnout.

Image Source: http://www.jbcharleston.jb.mil/News/Features/Display/Article/238916/cut-back-household-electricity-during-energy-awareness-month/

Additional Features

Electric forced air furnaces may also include humidifiers and electronic air cleaners to improve air quality. In addition, in the air handler with the heating components there may also be a cooling coil from the air-conditioning system. Alternatively, the cooling coil may be installed in a separate housing on the supply side.

Higher efficiency features include:

- **Variable speed and electrically commutated motors** increase central air blower efficiency and allow for lower operation speeds, which requires less fan power.
- **Programmable thermostats or smart controls** can save as much as 10% a year on heating by simply turning your thermostat back 7°F-10°F from its normal setting for 8 hours a day.

Application

Electric forced air furnaces are most common in single-family and manufactured housing, although they can also be found in duplexes and multifamily homes with central air ducting.

Existing construction may accommodate an electric furnace if the residence has the space to run (or has preexisting) central air ducting.

Although small commercial buildings can and do use electric furnaces, larger buildings tend to favor hot water and central boiler coils for ducted heating.

In residential applications electric forced air furnaces primarily compete with other electric, ducted central heating systems. These include ASHP, GSHPs with forced air, and boilers with forced air. Electric FAFs are increasingly competing with ductless mini-split heat pumps.

In CBSA and RBSA, electric forced air furnaces are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ❑ Office
- ❑ Retail
- ❑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ❑ Lodging
- ❑ Residential Care
- ❑ Assembly
- ❑ Other

Regulations & Cost

Standards. The DOE has minimum efficiency standards for electric forced air furnaces. The current efficiency standards are in terms of AFUE and went into effect in 1992.

Codes. Washington, Oregon, Idaho, and Montana residential building codes require FAFs to have a programmable thermostat.

The typical AFUE for an electric furnace is 99%. This describes the efficiency of transferring electric energy to heat. Furnace fans or blowers have no impact on AFUE measurements but should be accounted for in home energy use.

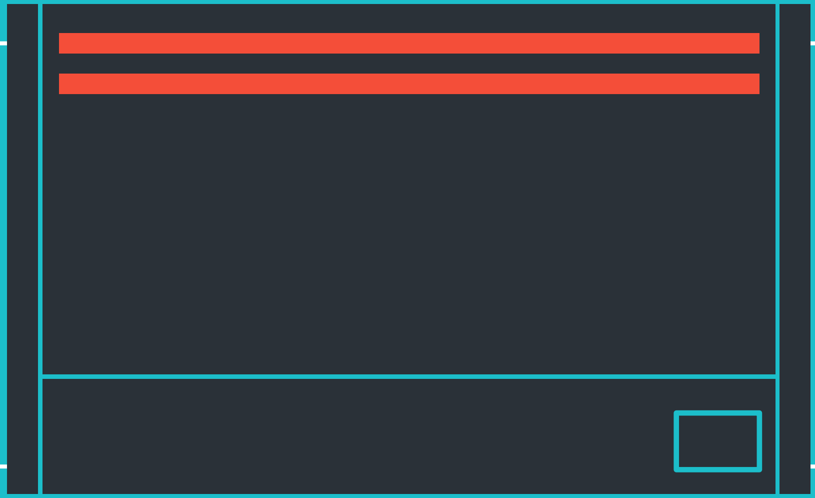
Stock Saturation and Product Flow

Market Saturation in the Pacific Northwest

Heating Saturation (% of buildings)	
Single-Family	Manufactured Homes
6%	52%

No sales data identified for electric forced air furnaces .

Baseboard Heating & Other Electric Resistance Heat



How It Works

In the Pacific Northwest 14% of single-family homes and 3% of manufactured homes use baseboard and other electric resistance heat as their primary heating technology.

Image Source: https://www.bchydro.com/news/conservation/2015/baseboard-heaters.html

A zonal electric resistance heater will be either recessed, surface mounted, or a cord-connected portable unit. This type of heater provides heat in two ways: By heating the air, which moves through the space by convection, and by infrared radiation, which directly heats occupants and other objects in the path of the radiation. Baseboard heaters accomplish space heating mostly through convection, while wall or ceiling mounted units rely more on radiation. Typically they will last **18 years** and have an equipment cost of $75-$200 per strip.

Baseboard heaters and recessed heaters work by heating an electric element and blowing room air over it (convection), before circulating that air back into the room.

Personal corded heaters may also be convection type heaters with mobile enclosures. Other corded heaters include radiant (which may also be portable), that only direct heat towards specific areas in the space.

Typically electric resistance heaters are 120 Volts and rated for less than 20 Amps**. King Electric, Cadet Heat, Lasko Products, Marley Engineered Products, DeLonghi®, Honeywell, Dimplex, Optimus Enterprise,** and **TPI Corporation** manufacture baseboard heaters. These can be sold through distribution or retail channels.

How It Works

A contractor decides the number of unit heaters needed using a series of tables and sizing rules of thumb. Efficiency is not typically the goal with these types of units, although correct placement can prevent drafts, dew, and mold formation.

Zonal electric heaters are inefficient compared to other heating technologies. They fill space heating needs where ducting is not available.

Strengths

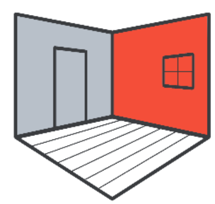
Low installation cost

Versatile

Negligible maintenance cost

Weaknesses

Not effective at circulating heat through an entire residence



Creates hotspots within a room while trying to meet heating demand

Can be costly to maintain whole living space at desired temperature

Major Components

All electric heaters will include an electric resistance heating element that produces heat as current flows through it. A metal enclosure encases the heating element and other components to prevent direct contact with the heating element. Some convection-type space heaters will also have an air circulation fan to move heat into the space.

In addition, zonal electric resistance heaters may have **control circuitry** that can be connected to a room thermostat. Some models may also have **variable heating elements**.

Baseboard board heaters can be used with a **programmable thermostat** to setback the temperature when the zone is not in use.

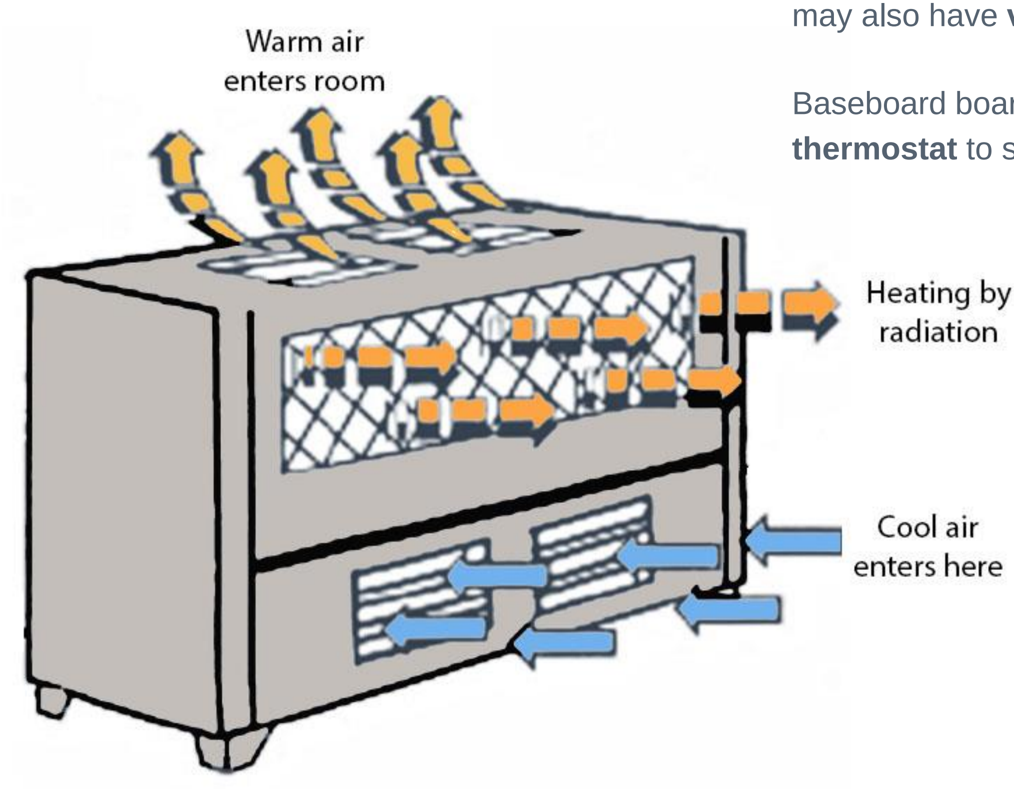


Image Source: Bonneville Power Administration, 2017

Application

Electric resistance heat is a popular choice in older homes without ducting and in multifamily apartment buildings without ducting. It is also a popular choice for multifamily units due to negligible maintenance cost and very low installation cost.

Retrofits can easily accommodate these types of units; all they require is electric service and they can be placed nearly anywhere.

Room resistance and radiant heat are ineffective for heating large open spaces. However, they are sometimes used in large spaces, where it would not be feasible to heat the entire space, for heating a small area around the unit. (e.g., loading docks). The operating costs can be quite high to maintain comfort levels in a single room, or a whole building.

In residential applications baseboard heating and other electric resistance heaters primarily compete with other zonal heating systems. These include DHPs, boilers with radiators or radiant systems, heating stoves, and GSHPs with radiant systems.

In CBSA and RBSA, baseboard heating & other electric resistance heaters are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ❑ Office
- ☑ Retail
- ☑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ☑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ❑ Other

Regulations & Cost

The primary reason baseboard or electric resistance heating is used is if heat must be localized, or other types of heating are cost prohibitive. Baseboard and electric resistance heat can also supplement primary heat sources in areas that already have zone heat. These types of heaters are good for areas that need localized heat like mudrooms, garages, and warehouses.

Cost. Overall, the individual units are inexpensive ($75-$200 per unit) and prices may drop as more models produced abroad meet code standards. In general, baseboard and other electric resistance heaters are not an efficient source of heat.

Standards. The DOE does not have energy efficiency standards for baseboard heaters.

Stock Saturation and Product Flow

Market Saturation in the Pacific Northwest

Heating Saturation (% of buildings)	
Single-Family	Manufactured Homes
14%	3%

No sales data identified for baseboard heat.

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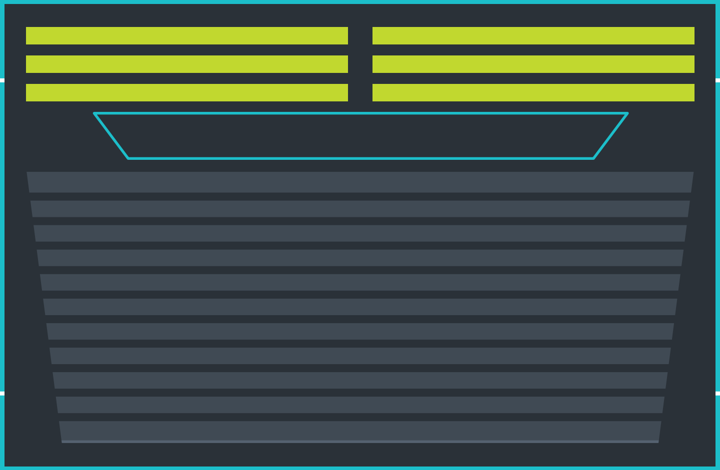
Stock Saturation

Baseboard heaters heat about 1% of total Pacific Northwest commercial square footage.

Stock Saturation in the Pacific Northwest - Commercial

Building Type	Heating Saturation
Assembly	1%
Grocery	0%
Lodging	4%
Office	0%
Other	0%
Residential Care	13%
Restaurant	1%
Retail/Service	1%
School K-12	1%
Warehouse	0%

Room Air Conditioners



How It Works

In the Pacific Northwest 7% of single-family homes and 18% of manufactured homes use RACs as their primary cooling technology.

Room air-conditioning (RAC) refers to a self contained system that provides cooled air to a single room or area, rather than the entire building. These units are mounted in a window or through an exterior wall. (RACs do not include portable air conditioners, which are regulated separately.) RACs use the vapor compression refrigeration cycle to transfer heat energy from an indoor space to a warmer outdoor space.

The DOE assumes a lifespan of **12.5 years** for a RAC. The RTF assumes a lifespan for all residential HVAC equipment of **15 years.**

DOE estimates there are less than 10 key manufacturers supplying the U.S. market. In 2008, four manufacturers controlled nearly three quarters (70%) of the domestic market**: LG, Fedders Corporation (Fedders), Frigidaire,** and **Whirlpool.**

Image Source: https://commons.wikimedia.org/wiki/File:Air_Condition_Unit_Interior_View_USA.jpg

How It Works

Residential RACs typically range from 6,000-20,000 Btu/h.

A homeowner or contractor would probably size a RAC using rules of thumb or standard charts for square footage covered by a given capacity unit. Oversized room air conditioners may be less effective and, as a result, may not remove humidity.

Routine maintenance on RAC units includes coil cleaning, condensate drain line cleaning, and refrigerant charge checks.

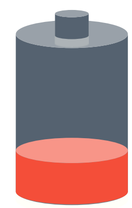
Strengths

Provides low-cost zonal cooling

Has a lower first cost than other cooling equipment

Weaknesses

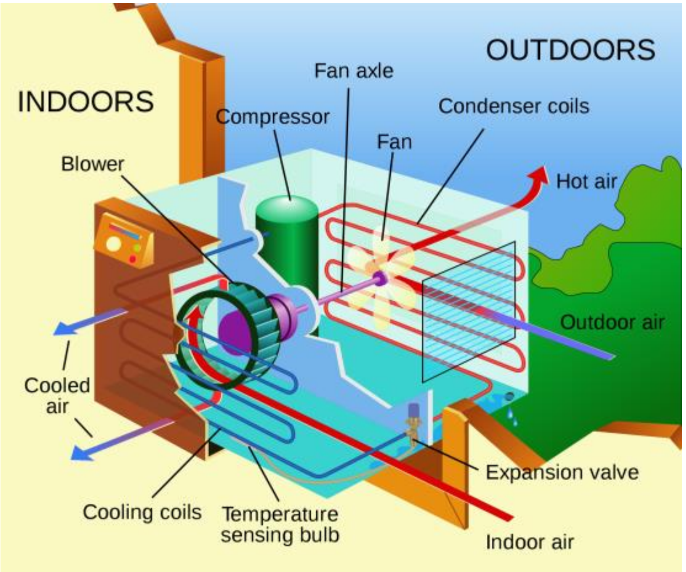
Blocks windows



Is less efficient than a DHP, CAC, ASHP

Some people may not like the appearance

Major Components



A RAC includes the typical components of a refrigeration cycle device, including a compressor, evaporator, evaporator fan, condenser, condenser fan, and expansion valve. The evaporator is indoors, extracting heat from the interior, and the condenser is outdoors, where it rejects heat to the surroundings. A RAC is typically installed in a window, or through a wall.

This equipment can be made more efficient by implementing:

- Higher efficiency compressor and fan motors
- Programmable and Wi-Fi enabled controls

Additional Features

An integrated thermostat typically controls a RAC. Remote (in-room) control units may also be available.

Room air conditioners generally also feature louvers to distribute the air and prevent recirculation.

Other add-on features might include dehumidification mode, resistance heating, and fan modes.

Image Source: https://commons.wikimedia.org/wiki/File:Air_conditioning_unit-en.svg

Application

RACs provide zonal cooling. This technology is most likely to appear in existing construction without the ductwork necessary to install a central cooling system.

Commercial buildings may feature residential-style RACs in individual rooms, but most applications are not suitable because RACs breach the building envelope and make central air applications less efficient.

In residential applications room air conditioners primarily compete with other zonal cooling systems. These include DHPs, PTACs and PTHPs, and portable air conditioners.

In CBSA and RBSA, room air conditioners are found in the following building types:

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ☑ Office
- ☑ Retail
- ❑ K-12 Schools
- ❑ Warehouse
- ☑ Grocery
- ❑ Restaurant
- ❑ Lodging
- ☑ Residential Care
- ❑ Assembly
- ☑ Other

Regulations & Cost

The DOE reported that from 1997 to 2006 sales of ENERGY STAR qualified room air conditioners grew more than 40% which is an indicator of market demand for high efficiency equipment.

New ENERGY STAR room air conditioners have connected functionality which can lead to additional energy savings.

Cost. EIA estimates the following incremental cost for more efficient room air conditioners:

- Baseline to high efficiency 35% increase in total cost

Standards. The DOE has energy efficiency standards for room air conditioners. The minimum efficiency standards are in terms of CEER and went into effect in 2014. On June 18, 2015 DOE published a request for information to consider increasing the current standards for room ACs.

Stock Saturation and Product Flow

Market Saturation in the Pacific Northwest

Cooling Saturation (% of buildings)	
Single-Family	Manufactured Homes
7%	18%

National Industry Shipments of Room Air Conditioners

Year	Room Air Conditioners (Thousands)
2008	9,086
2007	9,550
2006	10,055
2005	8,032
2004	8,082
2003	8,216
2002	6,153
2001	5,575
2000	6,496

National Room Air Conditioner Energy Efficiency and Consumption Trends (Shipment Weighted Averages)

	Percentage of Domestic Shipments (%)		
Year	Less than 8.5 EER	8.5 - 9.4 EER	9.5 EER and Higher
2004	0.04	11.2	88.8
2003	0.03	9	91
2002	0.02	12	88
2001	0.1	14	86
2000	14.2	34	52

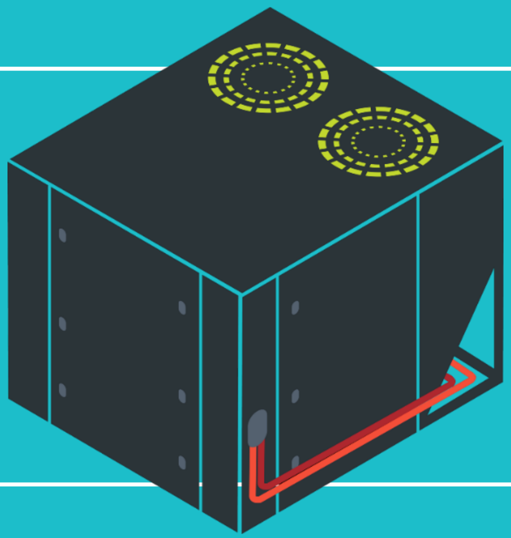
Stock Saturation

Room air conditioners cool about 1% of total Pacific Northwest commercial square footage.

Stock Saturation in the Pacific Northwest - Commercial

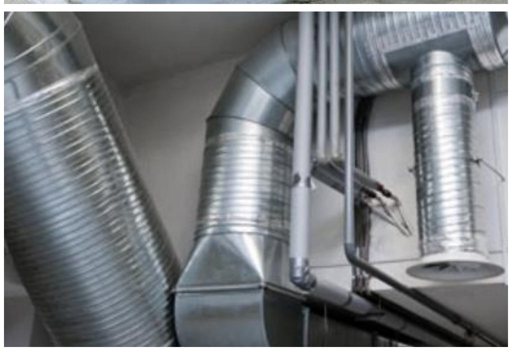
Building Type	Cooling Saturation
Assembly	0%
Grocery	1%
Lodging	0%
Office	1%
Other	1%
Residential Care	10%
Restaurant	0%
Retail/Service	1%
School K-12	0%
Warehouse	0%

Air Source Commercial Package Air Conditioners and Heat Pumps



How It Works

HVAC Unit



HVAC Ductwork

Package air conditioners and heat pumps are HVAC units in which a single, self-contained enclosure (or "package") has all the components necessary for heating and cooling. These units use a refrigeration cycle for cooling (and, in the case of heat pumps, heating). They are typically installed on roof-tops and are therefore commonly referred to as roof-top units (RTUs). RTUs can combine various technologies, including ASHPs, air conditioners, electric resistance heat, or gas heat, which is described in more detail in the next section.

Package air conditioners and heat pumps differ from other technologies in that they are self-contained units, with all components except the ductwork and room thermostat delivered to the site inside a single enclosure.

The average lifespan of these products is typically **15 years**.

The major manufacturers of this technology are**: Carrier, Trane, Lennox, York, Goodman,** and **AAON.** These six companies hold the majority of the market.

Image Sources:
https://commons.wikimedia.org/wiki/File:Rooftop_Packaged_Units.JPG
https://c1.staticflickr.com/6/5542/10136155754_37359080bc.jpg

How It Works

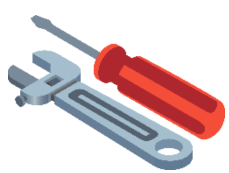
Contractors typically install air source commercial package air conditioners and heat pumps on roof-tops. Unit installation is usually straightforward, but must be coordinated with structural design due to the weight placed on the roof.

Commissioning can help ensure optimum efficiency and involves functional testing of all features under various conditions and tuning of setpoints and control sequences.

RTUs are typically installed on a roof curb. Roof curbs are designed to support the weight of the unit and provide access to supply and return ducts. Because equipment size increases at higher efficiency levels, replacing an old RTU requires a conversion curb to accommodate a new unit with a footprint larger than the unit it is replacing.

Strengths

Low cost

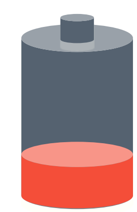


Ease of installation

Accessibility, self-contained

Weaknesses

High maintenance cost



Short lifespan

Major Components

All air source commercial package air conditioners include a direct expansion (DX) evaporator coil(s), evaporator fan(s), DX condenser coil(s), condenser fan(s), compressor(s), expansion device, and a controls package. Air source commercial package heat pumps also have reversing valves that allow the system to switch from cooling mode to heating mode. A commercial package unit may also have an electric resistance coil or gas furnace to provide heating.

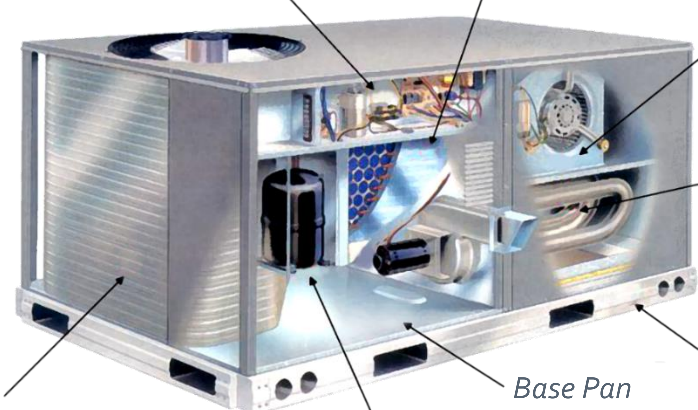


Image Source: https://library.cee1.org/sites/default/files/library/9181/CEE_CommHVAC_CarrierPres_29May2012_32.pdf

This equipment can be made more efficient with:

Variable-capacity allows the refrigeration system to modulate in order to match the cooling load. The unit is more efficient at part load operation, which increases the effectiveness of the heat exchangers. Variable capacity can be achieved by using variable speed compressors or staging the multiple compressors.

Variable speed fan motors can improve air conditioner and heat pump efficiency by varying fan speed to reduce air flow rate at part load.

Advanced controls. Modulating the supply fan in conjunction with demand controlled ventilation (DCV) can reduce heating/cooling and fan energy. A 2013 study by Pacific Northwest National Laboratory found that implementing multi-speed fan control, integrated economizer controls, and DCV reduced the annual energy consumption by 57%.

Additional Features

In the Pacific Northwest market, package units typically include add-ons such as an **outside air economizer**, which provides free cooling using outside air during periods of moderate weather. **Heat recovery**, which heats incoming outside air using outgoing return air, is also common.

The following add-on features may be present for this technology:

- Fan-powered exhaust
- Outside air economizer
- Heat recovery
- Demand controlled ventilation (controlling outside air via space CO2 levels)
- Supplemental electric resistance heat (for low temperature heat pump applications)
- Condensing furnaces
- Variable speed compressors
- Intelligent controls

AHRI Data: 2014 National Economizer Shipment Volumes

Equipment Category	% Units with Economizers
SMALL Commercial Package AC and HP (Air-Cooled) ≥ 65,000 Btu/h and <135,000 Btu/h Cooling Capacity	**60%**
LARGE Commercial Package AC and HP (Air-Cooled) ≥ 135,000 Btu/h and <240,000 Btu/h Cooling Capacity	**67%**
VERY LARGE Commercial Package AC and HP (Air-Cooled) ≥ 240,000 Btu/h and <760,000 Btu/h Cooling Capacity	**77%**

Application by Building Type

Package units typically operate independently to condition the space, without the need for additional technologies. In some cases, however, other technologies are present. A few examples include:

- Package units are used in buildings with central systems to independently treat spaces with specialized requirements (e.g., kitchen areas requiring much more outside air than surrounding spaces).
- In cases where multiple zones are served by a single package unit, supplemental heat like baseboard heating may be present to provide better individual zone control.

These units typically serve commercial buildings with simple HVAC requirements. Each unit usually serves a single zone or area (i.e., a single thermostat).

Package units are suitable for both existing buildings and new construction. Unit costs for new construction is low compared to alternative systems, although maintenance costs can be higher, due especially to the units location on roof-tops, where they are exposed to the elements. For existing buildings, package air conditioners and heat pumps are most suited to buildings with duct work.

Competing technologies in commercial applications include VAV systems, water-source heat pumps, GSHPs, variable refrigerant flow systems, water-cooled chillers, air-cooled chillers, and boilers. There is increasing competition from variable refrigerant flow systems, which is a fast-growing technology.

In CBSA and RBSA, package units are found in the following building types. Package units are common in all commercial building types. For RTUs with heat pumps or electric resistance heat, retail, office, and grocery are the most common building types.

Residential Building Types:

- ❑ Single-family detached homes
- ❑ Manufactured homes
- ❑ Low-rise multifamily (1-3 stories)
- ❑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ☑ Office
- ☑ Retail
- ☑ K-12 Schools
- ☑ Warehouse
- ☑ Grocery
- ☑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ☑ Other

Regulations & Cost

Overall, the market for package units in the Pacific Northwest is large and relatively stable. However, demand for high efficiency units, especially in retrofits, is growing as new products enter the market and efficiency standards become more stringent.

Specifically, there is increased demand for these units at schools, universities, and hospitals/healthcare facilities, as well as in the more traditional sectors of office and retail.

Increases in efficiency requirements have also led to growing demand for higher cooling efficiency in these units. Heating efficiencies are also increasing due partly to the availability of new technologies. Specifically, variable speed compressors, intelligent controls, and heat recovery are seeing increased market adoption.

In 2015, however, BPA collected sales data for commercial package air conditioners. This sales data represents about 35% of the market and shows the majority of units did not exceed the Federal minimum efficiency.

Cost. EIA estimates the following incremental cost for more efficient air source commercial package air conditioners and heat pumps:

- Baseline to ENERGY STAR = 10% increase in total cost
- Baseline to high efficiency = 180% increase in total cost

Codes. Washington, Oregon, Idaho, and Montana commercial building codes generally require package electric heating and cooling equipment to be heat pumps. In addition these codes specify minimum efficiency requirements for equipment that is not Federally regulated.

Standards. DOE has minimum efficiency standards for air source commercial package air conditioners and heat pumps with capacities up to 760,000 Btu/h. The Energy Policy Act of 2005 established the current Federal efficiency standards, which are in terms of EER. The standards went into effect on January 1, 2010.

On January 15, 2016, DOE adopted new efficiency levels for commercial package air conditioners and heat pumps. These new efficiency levels are in terms of Integrated Energy Efficiency Ratio (IEER) and go into effect in two stages. The first stage is effective January 1, 2018 and is about 10% more efficient than the current standards. The second stage is effective January 1, 2023 and is about 25%-30% more efficient than the current standards.

Measures

Measure Title	Status	BPA Qualified	Description
Advanced Roof-top Controls	Under development (A corresponding BPA measure is already active).	Yes	From corresponding BPA measure: "ARC Retrofits to roof-top heating, ventilating, and air-conditioning (HVAC) units can cut electricity use in half through changes in control of supply fan, ventilation, and economizers, as well as other potential control features."

Stock Saturation

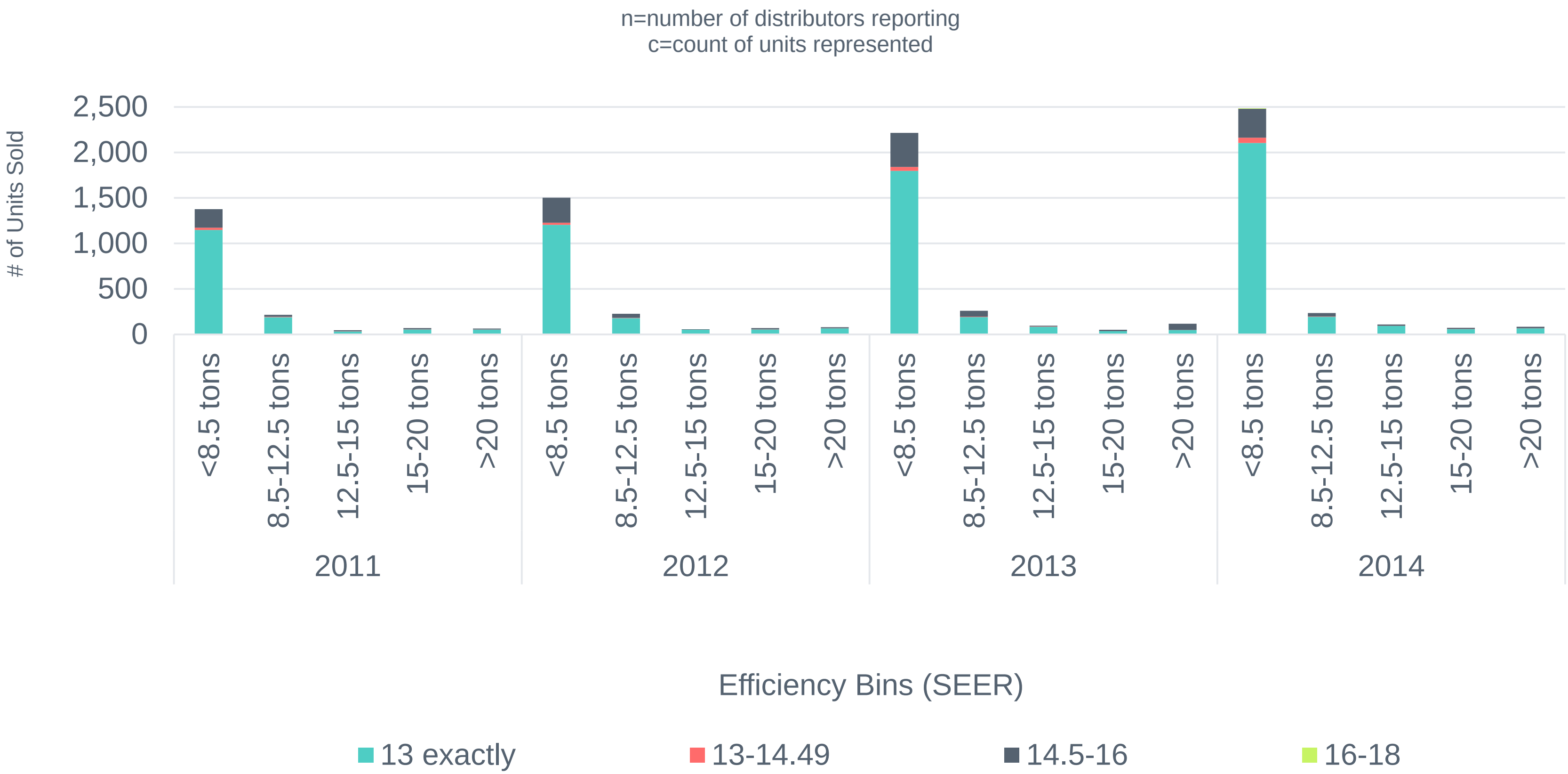
Air source commercial package air conditioners and heat pumps heat about 5% and cool about 32% of total Pacific Northwest commercial square footage.

Stock Saturation in the Pacific Northwest - Commercial

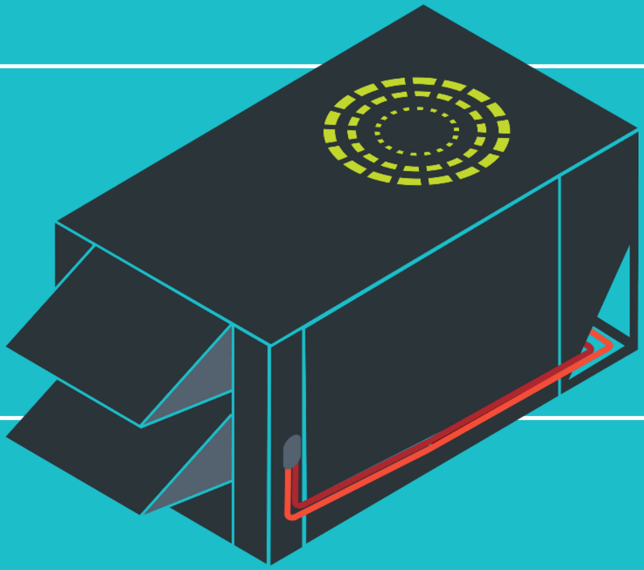
Building Type	Heating Saturation	Cooling Saturation
Assembly	3%	43%
Grocery	6%	66%
Lodging	3%	15%
Office	6%	26%
Other	4%	33%
Residential Care	4%	27%
Restaurant	3%	73%
Retail/Service	9%	54%
School K-12	5%	20%
Warehouse	0%	10%

Product Flow

Size and efficiency distribution of commercial package air conditioners based on sales data for 35% of the Pacific Northwest market



Commercial Gas Furnace Roof-top Units



How It Works

Commercial gas furnace roof-top units generate heat through gas combustion, which heats supply air via heat exchangers. In practice, commercial gas furnaces (also called gas packs) are the heating components of package RTUs used for small- to mid-sized commercial buildings. Commercial gas furnaces are typically shipped already assembled with a package RTU. For more information about RTUs see the section on Air Source Commercial Package Air Conditioners or and Heat Pumps.

This technology differs from other heating technologies in that it uses gas combustion to heat the air. The furnace operates by cycling on/off to meet the supply air temperature setpoint of the RTUs.

The average lifespan for a furnace is **18 years**. Note that this is longer than the average lifespan of the RTU itself (**15 years**).

Manufacturers of commercial gas furnaces include **AAON, Carrier, Daikin, Johnson Controls, Lennox, Nordyne, Nortek, Rheem, Thermo Products,** and **Trane.**

Image Source: https://www.regulations.gov/document?D=EERE-2013-BT-STD-0021-0015

How It Works

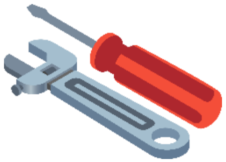
Commercial gas furnace are typically included in a package RTU system. Installation is usually straightforward, but must be coordinated with structural design due to the weight placed on the roof.

Although it is less common, furnaces may appear separately in supply air ducts (i.e., "in-duct furnaces") or in heating/ventilating units, which consist of outside air return or supply ducting, fans, and a furnace.

In high efficiency condensing gas furnaces, condensate management is a key issue. Because gas-fired commercial warm air furnaces (CWAFs) are typically installed on a roof, the condensate cannot be easily neutralized and then directed to an existing floor drain. Instead, the manufacturer must make accommodations to ensure the unit can safely and consistently capture and drain the acidic condensate to prevent damage to the unit or the building.

Strengths

Low cost



Ease of installation

Accessibility, self-contained

Weaknesses

High maintenance

Major Components

Commercial gas furnace RTUs include a modulating gas valve, burner, and flue assembly.

The following features can improve its efficiency:

- **Condensing secondary heat exchanger**: Furnace efficiency increases because of the additional heat loss from the combustion gases, as well as the energy captured from the phase change of the combustion products from a gas to a liquid upon cooling (i.e., the latent heat of vaporization).
- **Two-stage or modulating combustion:** Staging or modulation allow the unit to operate at lower capacity to meet the building load.
- **Advanced control systems**: Demand control ventilation and energy management systems (EMS) reduce the call for ventilation and heating to met the building load.

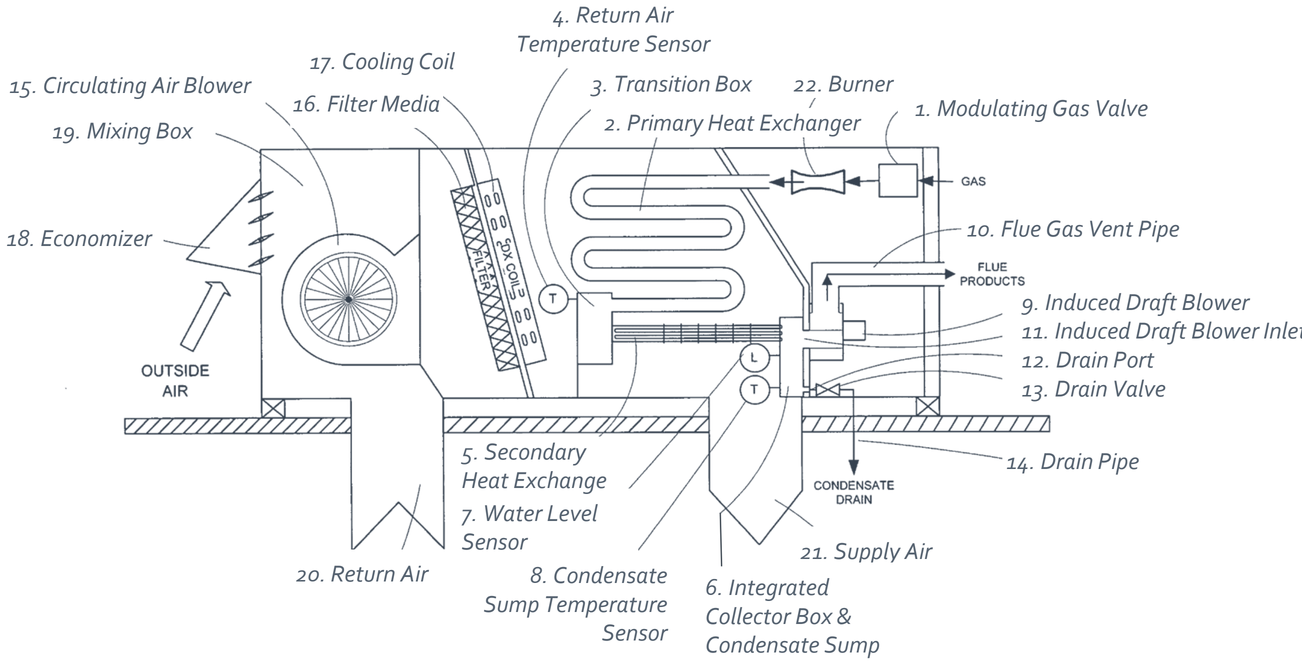


Image Source: https://www.google.com/patents/US20130108971

Additional Features

Furnaces in the Pacific Northwest market do not differ appreciably from other markets, but associated RTU configurations do differ and can include heat recovery and advanced roof-top controls, both of which influence furnace operation. See slides on commercial package air conditioners and heat pumps in this technology guide for further details.

Commercial gas furnace RTUs may also include demand controlled ventilation, EMSs, and heat recovery.

Demand controlled ventilation

- CO_2 controlled ventilation can reduce volume of outside air heating

Energy management systems (EMS or "building automation systems")

- Schedule room temperature setpoints to reduce heating during unoccupied hours

Heat recovery

- The transfer of heat from outgoing return air to incoming outside air

Image Source: https://www.regulations.gov/document?D=EERE-2013-BT-STD-0021-0015

Application

This technology typically serves commercial buildings with simplistic HVAC requirements. Each unit usually serves a single zone or area (i.e., a single thermostat). Some applications serve multiple zones with supplemental heating.

Gas furnaces are suitable for both retrofit and new construction. Unit cost for retrofit and new construction of RTUs, of which this technology is a part, is low compared to alternative systems, although maintenance costs can be higher because they are exposed to the elements. For existing buildings, gas furnaces are most suited to buildings with duct work.

Competing technologies in commercial applications include variable air volume (VAV) systems, water-source heat pumps, GSHPs, variable refrigerant flow systems, and boilers. There is increasing competition from variable refrigerant flow systems, which is a fast-growing technology.

In CBSA and RBSA, commercial gas furnace RTUs are found in the following building types, with the most common commercial building types being assembly, grocery, restaurant, and retail:

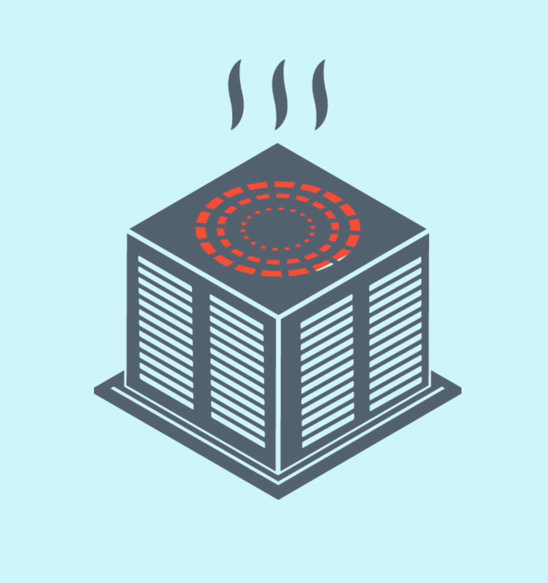
Residential Building Types:

- ❑ Single-family detached homes
- ❑ Manufactured homes
- ❑ Low-rise multifamily (1-3 stories)
- ❑ Medium/high-rise multifamily (4 stories and above)

Commercial Building Types:

- ☑ Office
- ☑ Retail
- ☑ K-12 Schools
- ☑ Warehouse
- ☑ Grocery
- ☑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ☑ Other

Regulations & Cost



The market for commercial gas furnaces is relatively stable, but demand is growing for high efficiency condensing gas furnaces.

Standards. The DOE has minimum efficiency standards for commercial gas furnaces with capacities of 225,000 Btu/h or more. The current Federal efficiency standards are in terms of thermal efficiency (TE), and DOE adopted them in 2001. On January 15, 2016 DOE established new TE levels for commercial gas furnaces that go into effect January 1, 2023.

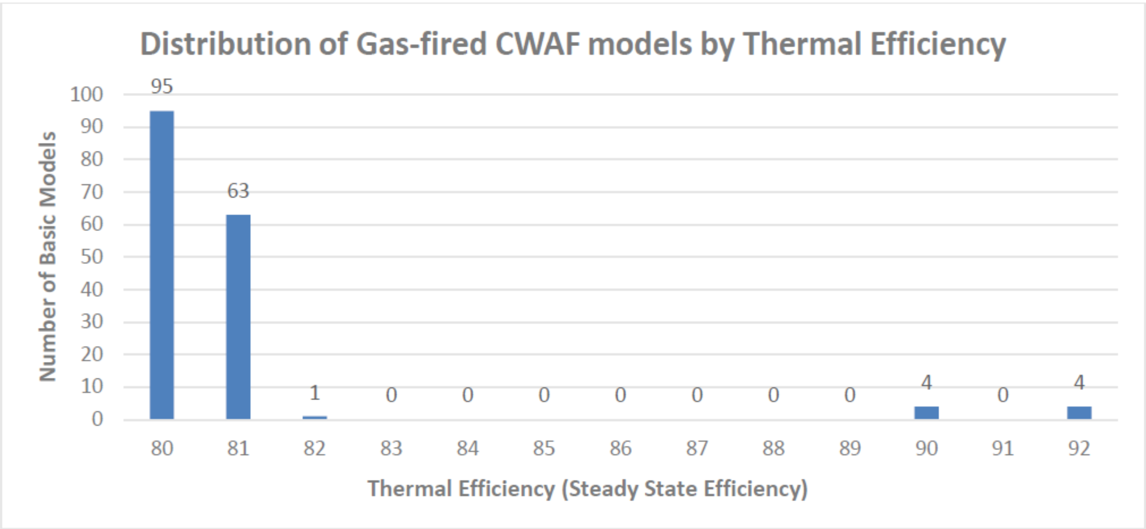
Codes. Washington, Oregon, Idaho, and Montana commercial building codes require gas forced air furances to have an intermittent ignition or interrupted device or a flue damper/vent damper. Additionally, gas furnaces located outdoors must have reduced jacket losses. All gas furnaces >500 kBtu/h must be multi-stage or modulating.

Cost. EIA estimates the following incremental cost for more efficient commercial gas furnaces:

- Baseline to high efficiency = 20% increase in total cost

Stock Saturation and Product Flow

Distribution of gas furnaces based on available models.



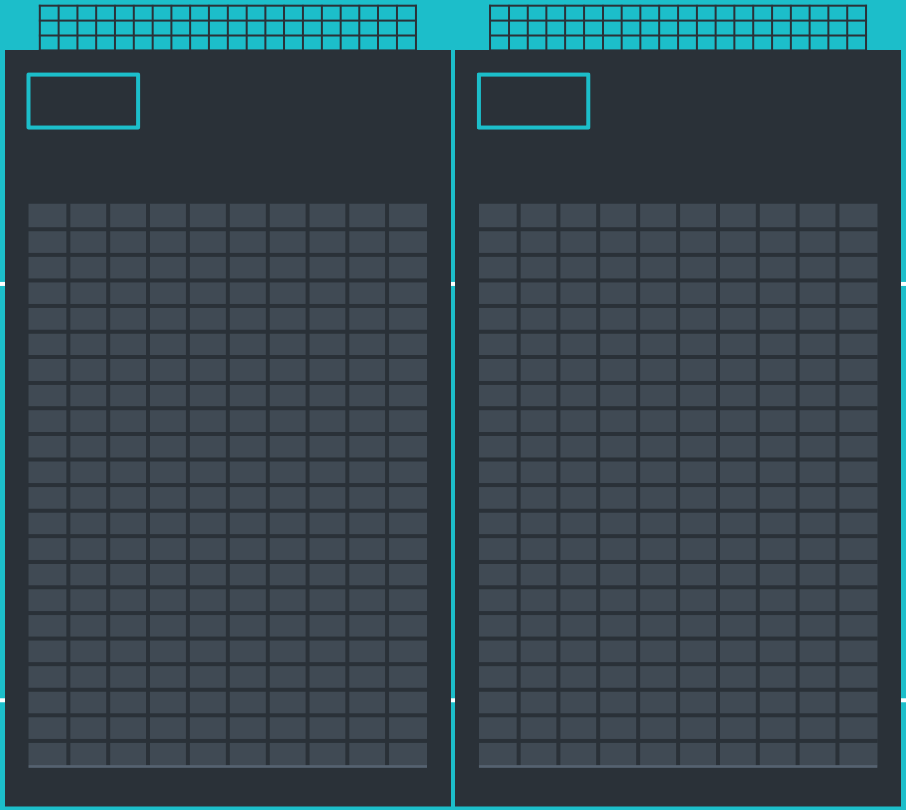
Stock Saturation

Commercial gas furnace RTUs heat about 35% of total Pacific Northwest commercial square footage.

Stock Saturation in the Pacific Northwest - Commercial

Building Type	Heating Saturation
Assembly	54%
Grocery	60%
Lodging	13%
Office	23%
Other	34%
Residential Care	26%
Restaurant	69%
Retail/Service	54%
School K-12	24%
Warehouse	20%

Variable Refrigerant Flow Systems



How It Works

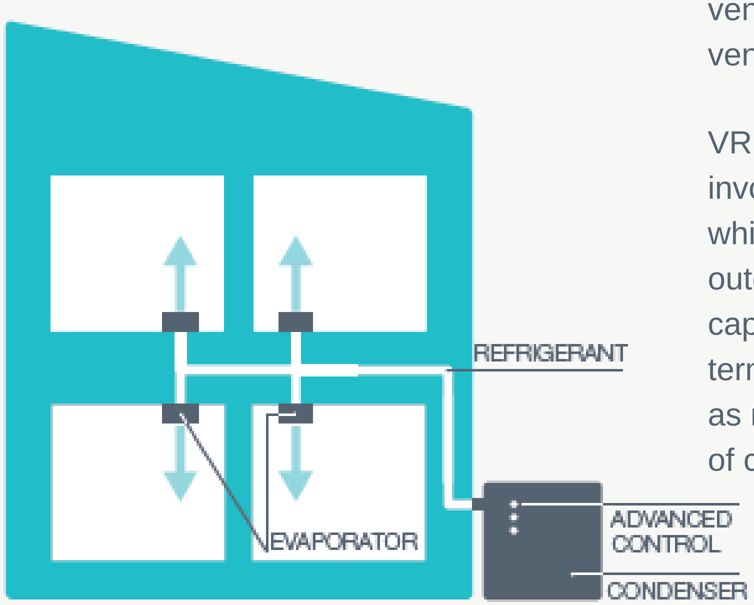


Image Source: https://www.bpa.gov/EE/Utility/research-archive/Documents/Momentum-Savings-Resources/2016_HVAC_Market_Intelligence_Booklet.pdf

Variant Refrigerant Flow (VRF) systems are larger capacity, more complex versions of ductless mini-split systems. VRF systems can control the amount of refrigerant flowing to each of the indoor units, which makes it possible to control temperate zones individually. Many VRF systems can transfer heat between spaces requiring cooling and spaces requiring heating. VRFs do not provide ventilation, so a separate ventilation system is necessary.

VRF system design typically involves a modular approach in which contractors install more outdoor units to increase cooling capacity and connect more terminal units to each outdoor unit as needed to increase the number of conditioned zones.

Contractors commonly place outdoor units on the roof and/or around the perimeter of the building. System operation is complex and usually involves proprietary control algorithms that adjust refrigerant flowrate to each zone based on outdoor conditions and conditions of each zone.

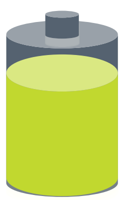
VRF is a relatively new technology, so average lifespan data is scarce. Lifespan for other systems that use refrigerant-based cooling is around **15 years.**

Manufacturers include **Daikin, Fujitsu, Midea, Gree, Johnson Controls, Lennox, LG, Mitsubishi, Panasonic, Samsung,** and **Toshiba.**

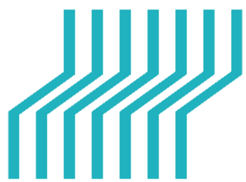
How It Works

VRFs are generally easier to install than other technologies because they are lightweight and modular. Proper installation (including proper unit sizing and piping) ensures optimum efficiency, and commissioning is usually necessary to ensure that component installation is correct and control sequences are optimal. VRF maintenance can be intensive and involves regularly checking for refrigerant leaks, and cleaning or repairing both outdoor air units and individual zone units.

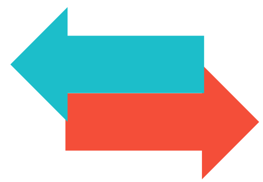
Strengths



Higher efficiency

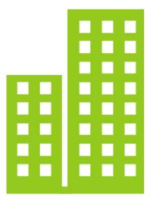


Flexible



Ability to transfer heat between zones

Enhanced ability to control temperatures

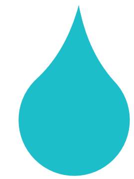


Scalable

Maintenance savings comparable or smaller than for competing systems

Weaknesses

More expensive than competing systems



Possible issues with refrigerant leaks

Proprietary systems (i.e., Customers are bound to a particular manufacturer for the life of the system)

Major Components

Major components include the following:

Outdoor units: These include a compressor and a condenser (typically air-cooled) and are responsible for heating/cooling refrigerant.

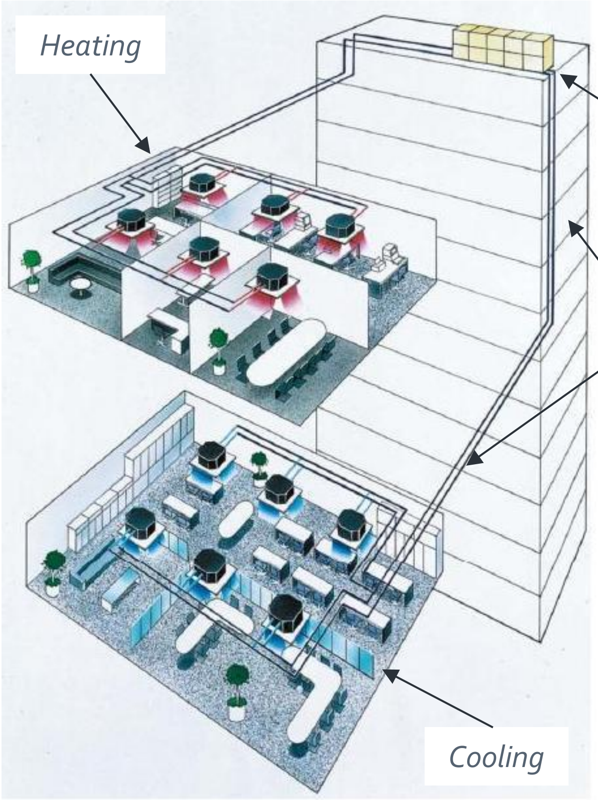
Indoor units: These terminal units use refrigerant to condition the space. The most common indoor units include wall-mounted, floor-mounted, four-way ceiling cassettes, and ducted products. Ducted indoor units are popular in retrofit applications where existing ductwork is present.

Dedicated outdoor air systems (DOAS): VRFs do not supply outside air, so they work in conjunction with ventilation systems. A DOAS is necessary to provide ventilation air to each space.

Efficiency improvements include:

- **Variable speed and capacity-modulated compressors**
- **Variable frequency drive (VFD), inverter-driven fans**
- **Variable capacity indoor units**
- **Improved controls**

Additional Features



EMS, or building automation systems: EMS can schedule room temperature setpoints to reduce heating during unoccupied hours.

Refrigerant heat recovery: Although some VRFs do not feature it, most systems use refrigerant heat recovery to transfer heat between spaces requiring cooling and spaces requiring heating, instead of rejecting heat. This often appears in buildings with simultaneous heating and cooling loads. One example is high-rise office buildings, in which the solar load on one side of the building may result in a cooling load, while shade on the opposite side results in a heating load. Heat recovery does, however, increase system costs significantly.

Image Source: https://commons.wikimedia.org/wiki/File:VRF_System_Concept_(Multi_Split_System_air_conditioner).jpg

Application

VRF systems can be found in many different building types, with office buildings being the most common.

They can be a good option for new construction and retrofit because they require less mechanical space.

In commercial applications VRF systems compete with other central heating and cooling technologies such as commercial package air conditioners and heat pumps including those with gas furnaces, VAV systems, water-source heat pumps, GSHPs, water-cooled chillers, air-cooled chillers, and boilers.

Variable refrigerant flow systems may also compete with zonal heating and cooling technologies such as PTACs and PTHPs and baseboard heating.

In CBSA and RBSA, variable refrigerant flow systems are found in the following building types:

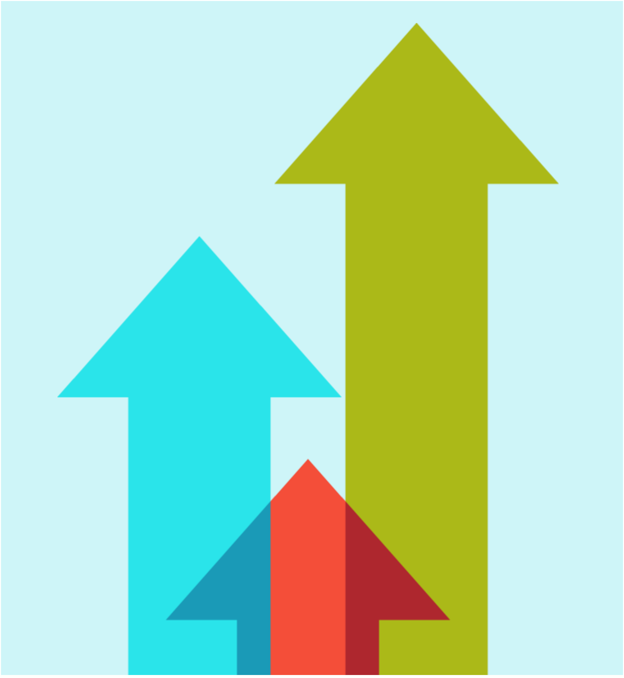
Residential Building Types:

- ❑ Single-family detached homes
- ❑ Manufactured homes
- ❑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (4 stories and above)

Commercial Building Types:

- ☑ Office
- ❑ Retail
- ☑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ☑ Lodging
- ❑ Residential Care
- ❑ Assembly
- ☑ Other

Regulations & Cost



VRFs are currently the fastest growing commercial air-conditioning technology. Since 2011, VRFs sales have increase by at least 10% each year, and manufacturers expect this trend to continue for the next several years. Manufacturers have also reported that heat recovery has become more prevalent in recent years.

Standards. The DOE has minimum efficiency standards for air-cooled and water source VRF equipment with capacities less than 760,000 Btu/h. The current Federal efficiency standards are generally in terms of EER and COP. The most recent standards for air-cooled VRFs became effective in January 2010, and the recent standards for water-source VRF became effective in October 2013. In July 2017, DOE published a test procedure RFI initiating a rulemaking to consider amending the test procedure for VRFs.

The Seventh Power Plan includes VRFs; however, researchers could not identify a baseline efficiency.

Cost. Washington State University Extension Energy Program found that baseline, code-minimum systems typically cost $12 to $15 per square foot (sf), while VRFs cost about $18/sf.

Measures

Measure Title	RTF Category	BPA Qualified	Description
Variable Refrigerant Flow System	N/A	Yes	A BPA Qualified measure only - Replace zonal or forced-air, electric-resistance heating systems with a new VRF in existing commercial buildings

Stock Saturation

VRF systems heat about 0.3% and cool about 0.3% of total Pacific Northwest commercial square footage.

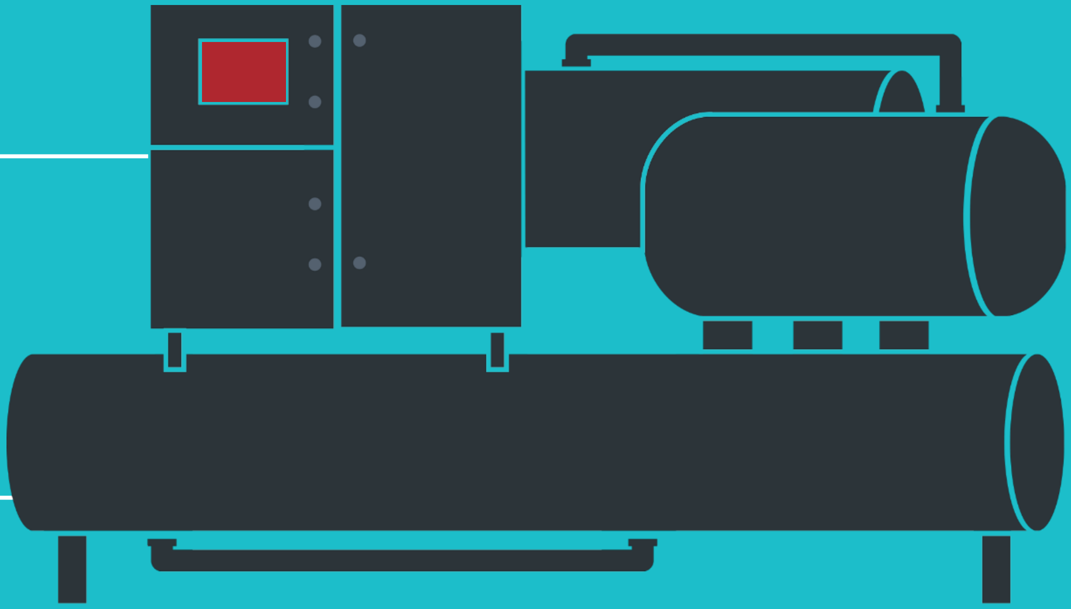
Stock Saturation in the Pacific Northwest - Commercial

Building Type	Heating Saturation	Cooling Saturation
Assembly	0%	0%
Grocery	0%	0%
Lodging	1%	1%
Office	1%	1%
Other	1%	1%
Residential Care	0%	0%
Restaurant	0%	0%
Retail/Service	0%	0%
School K-12	1%	0%
Warehouse	0%	0%

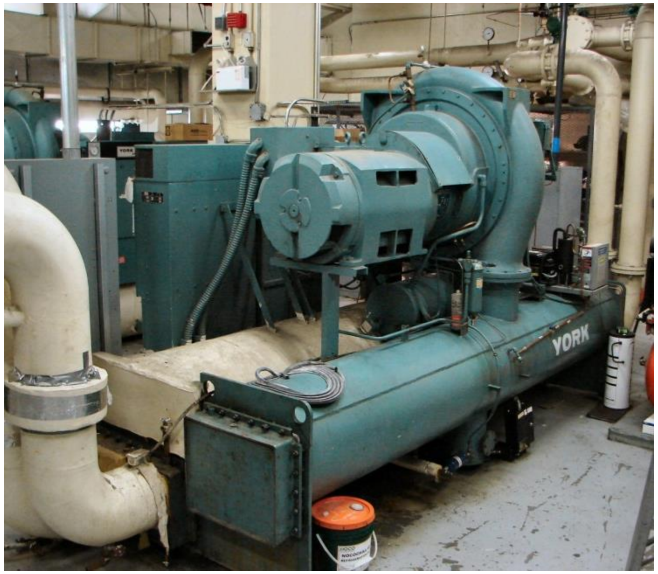
Product Flow

National Efficiency Distribution for VRF Sales	Efficiency Levels (EER)											
	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	14 - 15	15 - 16	16 - 17	17 - 18	18 - 19	19 - 20	20 - 21
Air-Cooled, >=65,000 Btu/h and <135,000 Btu/h, All Other Types of Heating	0%	0%	32%	26%	20%	16%	5%	0%	0%	0%	0%	0%
Air-Cooled >=135,000 Btu/h and <240,000 Btu/h, All Other Types of Heating	0%	32%	34%	25%	8%	1%	0%	0%	0%	0%	0%	0%
Air-Cooled >=240,000 Btu/h and <760,000 Btu/h, All Other Types of Heating	40%	38%	13%	7%	2%	0%	0%	0%	0%	0%	0%	0%

Water-Cooled Chillers



How It Works



A water-cooled chiller provides space cooling by circulating cooled water to air handlers or fan-coil units. These air handlers or fan-coils use the cooled water to condition the supply air to the space.

To provide this cooled water the chiller removes heat from the water through a vapor-compression or absorption refrigeration cycle.

Unlike an air-cooled chiller, in a water-cooled chiller the condenser rejects heat to water. The condenser water then carries heat from the chiller to a cooling tower which acts as a heat sink.

Chillers are typically located in a penthouse, central mechanical plant or the basement. The cooling tower is located outdoors, typically on the roof.

The average lifespan for a chiller is **20-23 years**. The lifespan for cooling towers averages around **20 years**.

Major manufacturers of chillers include **Carrier, Daikin, Johnson Controls,** and **Trane.**

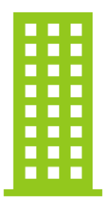
Image Source: https://commons.wikimedia.org/wiki/File:Chiller.jpg

How It Works

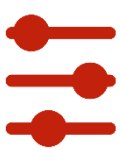
Contractors typically install water-cooled chillers in buildings with large cooling loads. In the Pacific Northwest, they operate mainly during summer months, although they may operate year-round in facilities with high constant cooling loads, such as data centers. Maintenance can be intensive due to the high number of individual mechanical components, and it usually occurs when the system is shut down for heating season.

Installation includes the physical installation of the chiller and associated components, as well as chiller commissioning. Commissioning maximizes the efficiency of the chiller plant. This involves testing all components for functionality during all conditions and adjusting operation to optimize plant efficiency. Lack of or improper commissioning can result in significant impacts to plant efficiency.

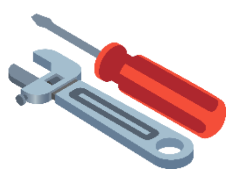
Strengths



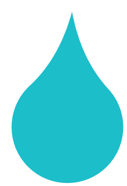
Higher capacity



Greater ability to vary capacity



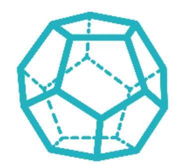
Greater design and operational customizability



Less reliance on refrigerants

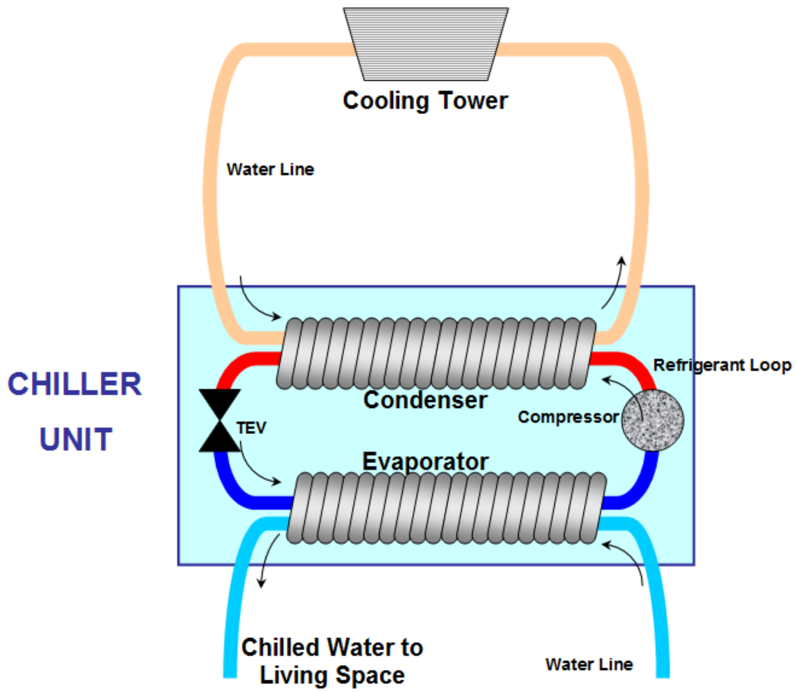
Weaknesses

Higher installation and maintenance costs



Higher operational complexity

Major Components



Water-cooled chillers include the following components:

- **Condenser:** Water chillers typically use shell and tube heat exchangers.
- **Compressor:** This may be centrifugal compressors, screw compressors, or scroll compressors.
- Condenser water and chilled water pumps to circulate water.

  Cooling tower to reject heat from the condenser water loop to the outside air.

  Chilled water coils located inside an air handler.

The following components can improve chiller efficiency:

- **Waterside economizers** use the cooling tower to provide "free cooling" during cooler outdoor temperatures when the chiller is not operating.
- **Variable volume chilled water and/or condenser water loops** vary flowrate based on demand.
- **Variable speed cooling tower fans** vary fan speed based on cooling demand and outside air conditions.
- **Condenser water and/or chiller temperature reset** strategies automatically adjust the chilled and/or condenser water supply temperature setpoint based on outside air conditions.

Image Source: https://commons.wikimedia.org/wiki/File:Water_Cooled_Chiller_Diagram.png

Additional Features

Additional features on a water-cooled chiller include:

- **Safety controls:** Safety controls prevent the unit from operating in an unsafe manner. Controls include features like pressure and temperature monitoring, pressure relief valves, and time delays.

- **Purge units:** Purge units consist of compressors, motors, separators, and condensers, and function to remove contaminants like air and moisture in order to maintain efficient operation.

- **Pump out units**: A pump out unit can simplify chiller maintenance. A pump out is used to store refrigerant for maintenance and consists of a storage tank, a small compressor, a condenser, and interconnecting piping.

- **Heat recovery:** Desuperheaters or parallel condensers provide low temperature heating for space conditioning or domestic hot water.

Application

This technology primarily serves larger commercial buildings with centralized HVAC systems in which there are multiple zones with differing cooling loads. System types may include fan coil units, VAV air handling systems, multizone systems, etc.

Water-cooled chillers typically have a long life and are more likely to be repaired during their lifespan due to the high cost of replacing this equipment.

Other technologies typically used with these systems include VAV air handling systems, fan coil systems, and chilled beam systems.

This technology competes primarily with air-cooled chiller, packaged air conditioners and heat pumps, and variable refrigerant systems.

In CBSA and RBSA, water-cooled chillers are found in the following building types:

Residential Building Types:

- ❑ Single-family detached homes
- ❑ Manufactured homes
- ❑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (four stories and above)

Commercial Building Types:

- ☑ Office
- ❑ Retail
- ❑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ☑ Other

Regulations & Cost

Water-cooled chillers historically had the largest share of the chiller market. However, AHRI sales data show that water-cooled chiller sales declined sharply between 2000 and 2005.

Cost. The cost of a chiller alone ranges from $200 to $600 per ton of cooling on average, with costs of the entire chiller plant being $1,500 to $1,800 per ton. Costs vary widely because chiller plants are highly customizable.

Codes. Washington, Oregon, Idaho, and Montana commercial building codes specify minimum efficiency requirements for water-cooled chillers. In addition, cooling towers with large horsepower fans must have controls that vary flow.

Standards. DOE does not regulate water-cooled chillers, so this technology does not have national efficiency requirements.

Stock Saturation and Product Flow

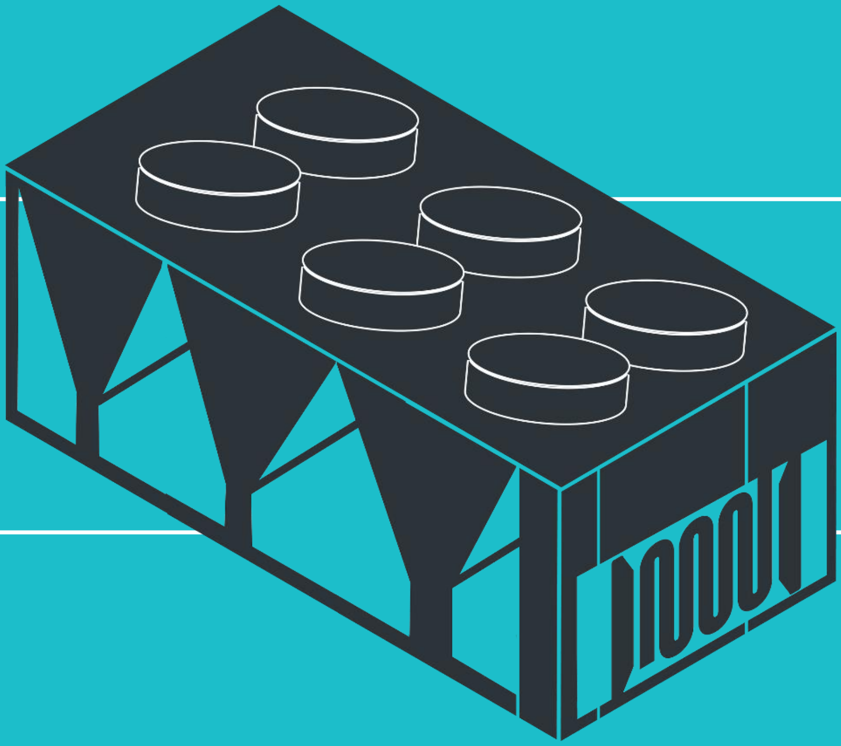
Water-cooled chillers cool about 2% of total Pacific Northwest commercial square footage.

The research team could not locate sales data for water-cooled chillers.

Stock Saturation in the Pacific Northwest - Commercial

Building Type	Cooling Saturation
Assembly	2%
Grocery	0%
Lodging	2%
Office	6%
Other	2%
Residential Care	1%
Restaurant	0%
Retail/Service	0%
School K-12	0%
Warehouse	0%

Air-Cooled Chillers



How It Works

Air-cooled chillers have condenser coils cooled by fan-driven air. A chiller removes heat from the water through a vapor-compression or absorption refrigeration cycle. The cooled water flows through pipes in a building and passes through coils in air handlers, fan-coil units, or other systems, thus cooling and usually dehumidifying the air in the building.

Contractors typically install air-cooled chillers outside (usually on a roof). Chilled water is distributed from the chiller's evaporator via pumps to air handlers or fan coil units, then returned to the evaporator. Unlike a water-cooled chiller, an air-cooled chiller's compressor will cycle on or off based on demand. These units may also be used together in modular fashion to increase available cooling capacity. Required maintenance is less complex than it is for water-cooled chiller systems.

Average lifespan is approximately **20 years.**

Major manufacturers of chillers include **Carrier, Daikin, Johnson Controls,** and **Trane.**

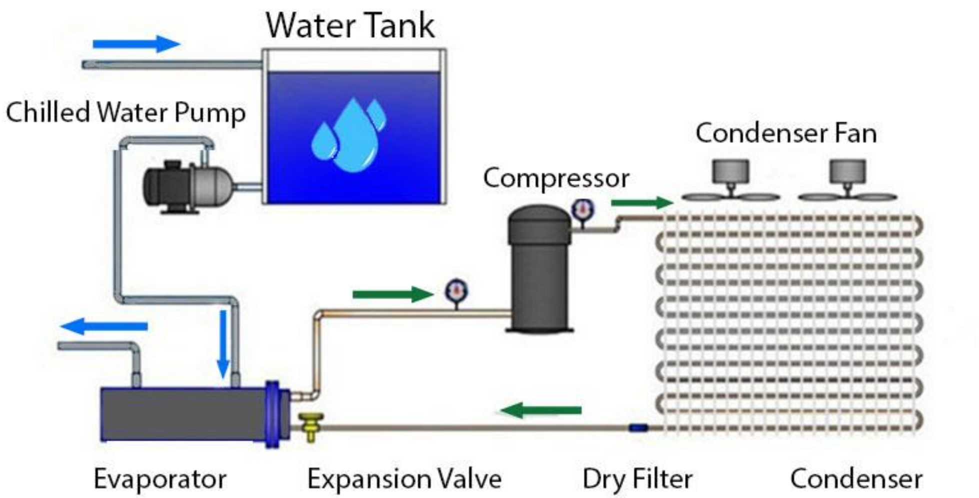


Image Source: Bonneville Power Administration, 2017

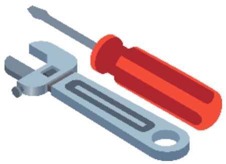
How It Works

This technology differs from other cooling technologies in that it provides a packaged approach to central cooling. It can be described in many ways as a mid-point between packaged RTUs and water-cooled central chiller plants because it uses air to condense the refrigerant and provides central cooling.

Installation includes the physical installation of the chiller and associated components, as well as chiller commissioning. If contractors install the unit on the roof, they must consider the building's structural design.

Commissioning usually occurs after installation to ensure proper operation and to maximize the efficiency of the chiller plant. Lack of or improper commissioning may result in significant impacts to plant efficiency.

Strengths



Lower maintenance complexity

Lower cost

Easier installation due to packaged nature

Weaknesses

Not as customizable

High operating cost

Major Components

Air-cooled chillers typically come with all components packaged in a single enclosure. The components include:

- A condenser, which rejects heat from the refrigerant to the air
- A compressor (common types are scroll, screw, and centrifugal)
- An evaporator that removes heat from the chilled water loop
- An expansion device

They also contain pumps to distribute chilled water to coils inside air handlers or fan coil units.

The following technologies may improve chiller efficiency:

Variable speed condenser fans improve cooling efficiency at partial loads.

Chilled water temperature reset automatically adjusts the chilled water supply temperature setpoint based on outside air or other conditions.

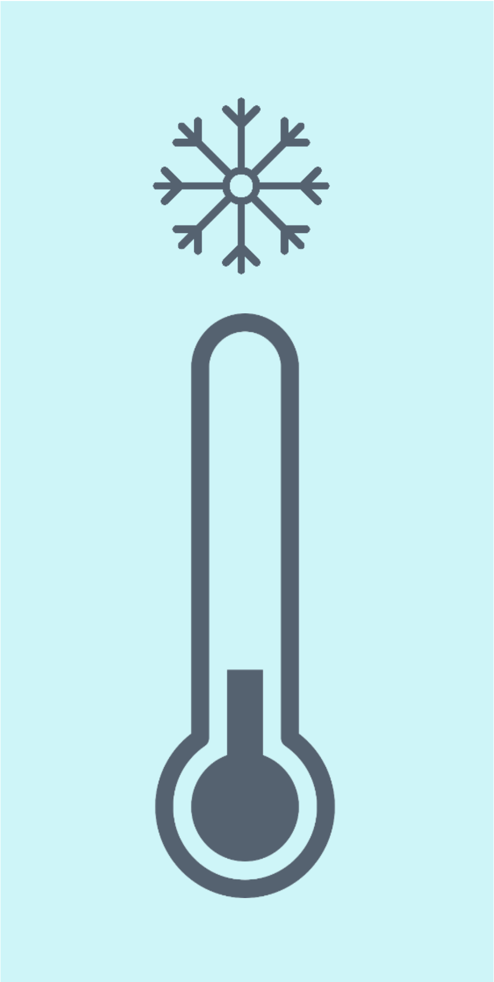
Variable volume chilled water loops vary flowrate based on demand.

EMS use strategies like chilled water reset and demand limits to reduce energy consumption.

Additional Features

Additional features may include:

- **Hot gas bypass**, which allows unit operation below the designed conditions
- **Recirculating and bypass lines** to redirect excess water
- **Freeze protection** (may include electric heaters installed on exposed pipes)
- **Air separators** to remove excess air and improve system efficiency



Application

Contractors primarily install air-cooled chillers in buildings with lower, less complex cooling loads. These systems are suitable for both replacement of water-cooled chillers and retrofit applications.

This technology competes with VAV systems, water-cooled chillers, variable refrigerant flow systems, and packaged air conditioners and heat pumps. Variable refrigerant systems may pose the greatest competition due to lower costs and less complexity.

In CBSA and RBSA, air-cooled chillers are found in the following building types:

Residential Building Types:

- ❑ Single-family detached homes
- ❑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (4 stories and above)

Commercial Building Types:

- ☑ Office
- ❑ Retail
- ☑ K-12 Schools
- ❑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ☑ Lodging
- ❑ Residential Care
- ☑ Assembly
- ☑ Other

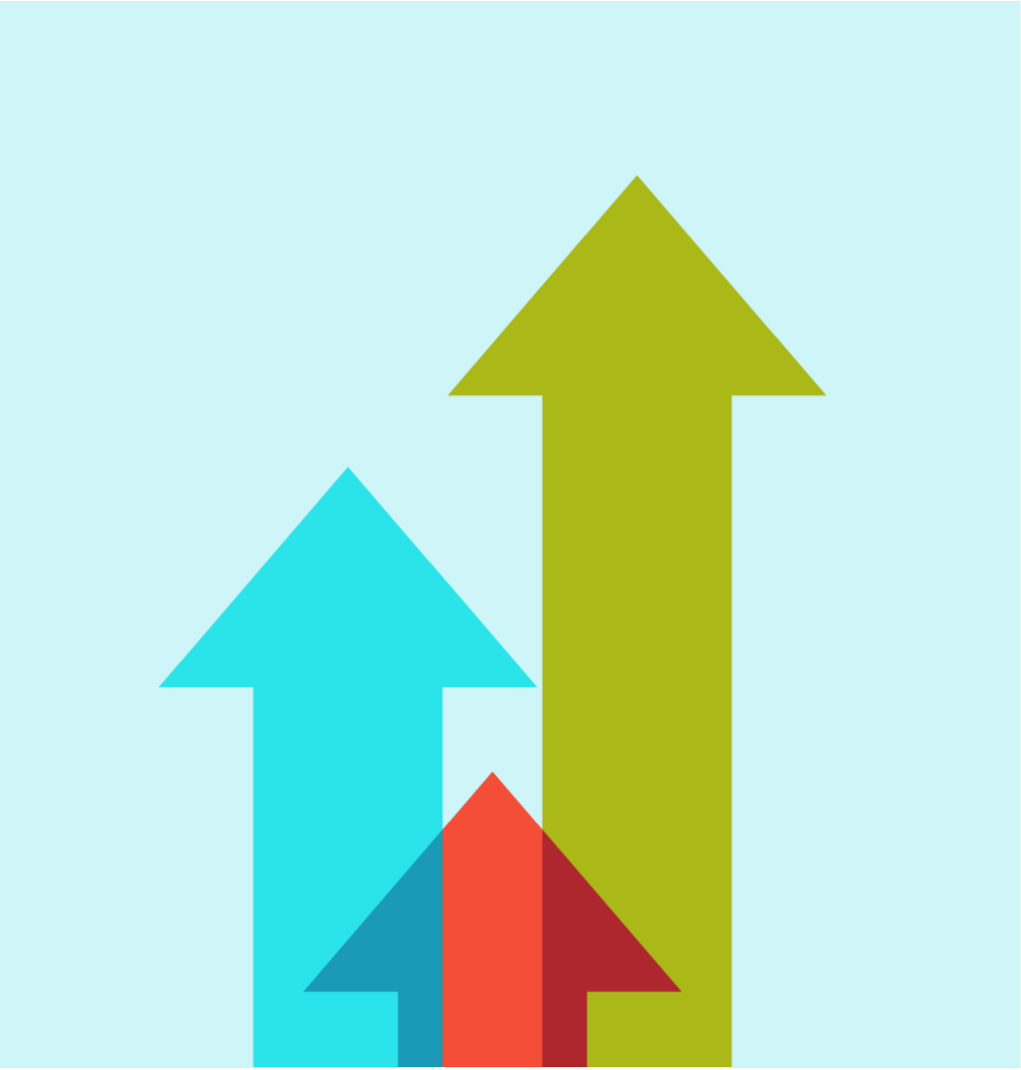
Regulations & Cost

The U.S. air-cooled chiller market has grown an average of 27% since 2012. AHRI sales data show air-cooled chillers have surpassed water-cooled chillers, which previously dominated the market. Manufacturers attribute the growth to the lower cost of air-cooled chillers and improved efficiencies. Comparatively, however, air-cooled chillers are typically less efficient than water-cooled chillers.

Cost. On average, the total installation cost of an minimum efficiency air-cooled chiller ranges from $625 to $800 per ton. The type of compressor used in the system impacts the cost. EIA estimates that high efficiency air-cooled chillers are 60% more expensive.

Codes. Washington, Oregon, Idaho, and Montana commercial building codes specify minimum efficiency requirements air-cooled chillers.

Standards. DOE does not regulate water-cooled chillers, so this technology does not have national efficiency requirements.



Stock Saturation and Product Flow

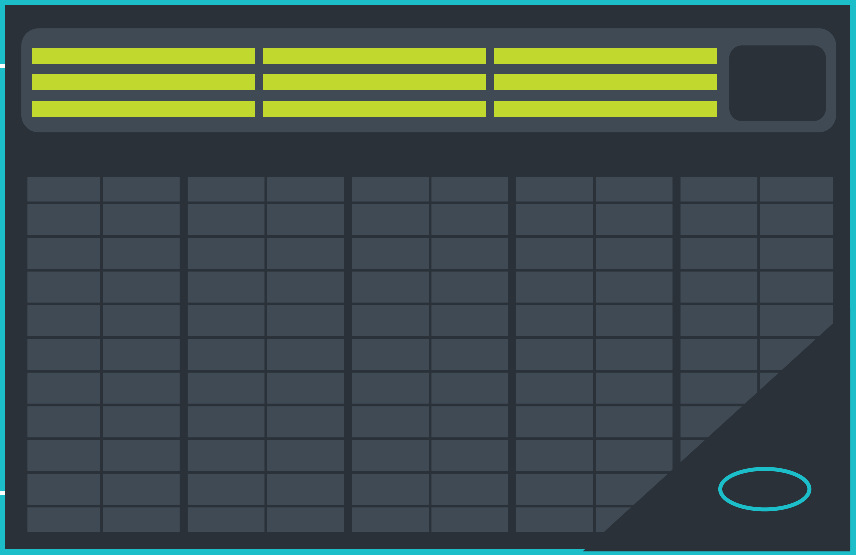
Air-cooled chillers cool about 4% of total Pacific Northwest commercial square footage.

The researchers team could not locate sales data for air-cooled chillers.

Stock Saturation in the Pacific Northwest - Commercial

Building Type	Cooling Saturation
Assembly	8%
Grocery	0%
Lodging	1%
Office	10%
Other	5%
Residential Care	0%
Restaurant	0%
Retail/Service	0%
School K-12	4%
Warehouse	0%

Packaged Terminal Air Conditioners & Heat Pumps



How It Works

Packaged terminal air conditioners and heat pumps (PTACs and PTHPs) are packaged units that provide heating, cooling, and ventilation air. Installers mount them through an exterior wall. Both types of units provide cooling via a refrigeration cycle (direct expansion, or "DX," cooling). PTACs may provide heat using hot water, steam, or electric resistance heat. PTHPs provide heat using a heat pump cycle. This technology differs from competing technologies in that it is a packaged unit located inside the space it is conditioning.

These products have a median life of **15 years.**

Major manufacturers include **GE, Carrier, Amana, Trane,** and **McQuay International**. These manufacturers made up 90% of the market in 2012.

Image Source: https://www.flickr.com/photos/rapidtravelchai/12520712685

How It Works

Unit installation differs from other systems in that the unit itself penetrates the exterior building wall. Structural and other building code requirements are therefore different than they are for other systems. Installation practices do not typically affect equipment efficiency because the unit comes pre-manufactured. Poor installation can increase infiltration, however, if penetrations are not adequately sealed.

Installers size these systems to meet the load for a single smaller space like a hotel room.

Maintenance is straightforward, requiring regular cleaning of the unit parts, filter replacement, and periodic charge of the refrigerant loop.

Strengths

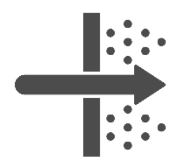
Small

Generally inexpensive

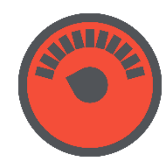
Self-contained

Weaknesses

Small capacity



Must penetrate exterior wall to install



May not control space temperature as well as competing systems

Major Components

Image Source: Bonneville Power Administration, 2017

Major components include a supply fan, compressor, evaporator, condenser, and controls.

This following components can improve the efficiency of PTACs and PTHPs:

Variable speed compressors. Variable capacity allows the refrigeration system to modulate in order to match the cooling load. These are only available from a couple small manufacturers.

Advanced controls. Digital energy management control interfaces enable digital remote control from another location or central EMS. An operations manager or EMS can turn off or digitally set the temperature of the PTAC or PTHP units not in use to conserve energy. Heat pump controllers minimize the use of electric resistance to improve efficiency and meet the space comfort.

Additional Features

Features common to these include occupancy controls and Wi-Fi enabled control.

A contractor may install an **occupancy sensor** in a space to shut the system down or set temperature back when space is unoccupied.

Many manufacturers offer **Wi-Fi enabled controls**. This reduces the expense of controls wiring in cases where thermostats need to be located away from the units themselves.

Application

This technology primarily serves small spaces that need individual control, such as hotel rooms and multifamily units.

Technologies that accompany these systems may include separate HVAC units like RTUs or air handlers to condition corridors in the building. A central heating system like a hot water boiler will also be present if PTACs require hot water for heating.

PTACs and PTHPs primarily compete with baseboard heating, room air conditioners, ductless mini-split heat pumps, and variable refrigerant flow systems.

In CBSA and RBSA, air-cooled chillers are found in the following building types (although they are rare in single-family and manufactured homes):

Residential Building Types:

- ☑ Single-family detached homes
- ☑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (4 stories and above)

Commercial Building Types:

- ☑ Office
- ☑ Retail
- ☑ K-12 Schools
- ❑ Warehouse
- ☑ Grocery
- ❑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ☑ Other

Regulations & Cost

PTACs and PTHPs are well-established in the market and seem to be relatively stable. There is likely growth in PTHPs and high efficiency PTACs due to incentives offered by programs in the region.

Cost. DOE estimates that high efficiency PTAC and PTHPs are 10% more expensive that minimum efficiency units.

Standards. DOE has minimum efficiency standards for PTACs and PTHPs. The current Federal efficiency standards are in terms of EER and COP. DOE most recently updated its efficiency standards for this technology by a rulemaking that published in July 2015. These updated efficiency levels took effect on January 1, 2017.

Stock Saturation

Stock Saturation in the Pacific Northwest - Residential

Cooling Saturation (% of Buildings)	
Single-Family	Manufactured Homes
2%	1%

Stock Saturation

PTACs and PTHPs heat about 1% and cool about 4% of total Pacific Northwest commercial square footage.

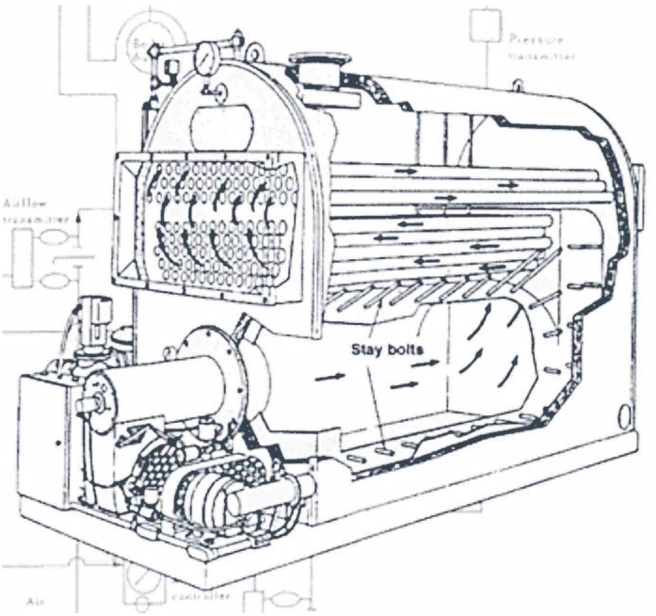
The researchers team could not locate sales data for PTACs and PTHPs .

Stock Saturation in the Pacific Northwest - Commercial

Building Type	Heating Saturation	Cooling Saturation
Assembly	0%	1%
Grocery	0%	1%
Lodging	13%	42%
Office	0%	1%
Other	0%	1%
Residential Care	9%	18%
Restaurant	0%	0%
Retail/Service	0%	1%
School K-12	0%	1%
Warehouse	0%	0%

Commercial Boilers

How It Works



A boiler is a pressure vessel in which the combustion of fuels such as natural gas or oil generates hot water or steam to heat building spaces.

Gas boilers produce either hot water or steam, and contractors install them inside a mechanical space along with associated piping, hot water/condensate pumps, and steam risers. Boilers take air from the surrounding space for combustion. Exhaust gases exit through a flue to the outside.

This technology differs from competing technologies in that it uses gas or oil instead of electricity, and it transfers heat to a water or steam loop instead of an airstream.

The average lifespan of these products ranges from **24** to **35 years.**

Manufacturers including **Raypak, Lochinvar, Thermal Solutions and Camus Hydronics** offer the highest number of models of small boilers (≥300 kBtu/h and ≤2,500 kBtu/h). **Bosch Thermotechnology Corp., Cleaver-Brooks,** and **Weil-McLain** offer the highest number of large boilers (>2,500 kBtu/h and ≤10,000 kBtu/h). Major manufacturers of very large boilers (> 10,000 kBtu/h) include **Group Simoneau Inc., Cleaver-Brooks Inc.,** and **Power Master.**

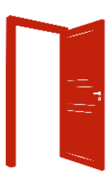
Image Source: http://www.mississippipower.com/my-business/save-energy/equipment-know-how/space-heating-systems/hot-water.cshtml

How It Works

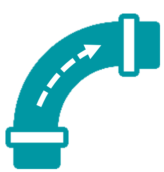
Boiler installation includes locating the boiler, installing piping/pumps, and boiler startup/tune-up. An improperly tuned boiler (which creates inefficiency combustion) can greatly affect the system's efficiency. Tune-up ideally occurs seasonally to limit reduced efficiency over time.

Boiler maintenance is extensive and includes chemical water treatment, inspection, blowdown (draining boiler to remove dissolved solids), tune-up, etc. Maintenance occurs regularly on a daily, weekly, monthly, and annual basis. Boilers typically shut down during summer months for more extensive maintenance.

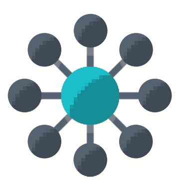
Strengths



Centralizes heating equipment to one location



Steam boilers reduce the need for pumps

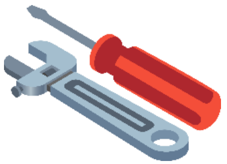


Highly customizable

Greater opportunity for increased efficiency

Weaknesses

Can be expensive to replace



More intensive maintenance than some competing systems

Major Components

Major components include the burner, combustion chamber, heat exchanger, exhaust stack (flue), and boiler controls.

Implementing the following measures improve commercial boiler efficiency:

Condensing technology: Most of the non-condensing boilers have a thermal efficiency of 85% and most condensing boilers have a thermal efficiency of 94% to 95%.

Advanced controls: Temperature reset controls, VFD fan controls, and thermal post-purge controls can help improve boiler efficiency by adjusting boiler performance to the actual heating demand. Temperature reset controls adjust the required heating load based on outdoor air temperature. VFD fan controls adjust fan speed in response to boiler load. Thermal post-purge controls use residual heat from the boiler to continue heating the building after the burner is shut off.

Image Source:

Additional Features

Features common (but not exclusive to) the Pacific Northwest market include condensing boilers, flue gas economizers, and advanced burner controls.

Condensing Boilers: Conventional boilers exhaust moisture from the combustion process out the flue. Condensing boilers use a lower return water temperature and condenses the moisture in the combustion gas. The process captures energy from this phase change from water vapor to liquid, resulting in increased heating efficiency.

Flue Gas Economizer: A heat exchanger transfers heat from hot flue gas to cold makeup water (feedwater) or cold air (combustion air) entering the boiler. This can result in an efficiency increase of 3%-4%.

Advanced Burner Controls: Controls that reduce the amount of excess air introduced into the combustion process.

Application

Gas boilers serve larger commercial buildings with central heating systems such as air handling units, fan coil units, and fin tube radiators.

In new construction this technology competes with other forms of heating such as electric boilers, heat pumps, VRF systems, and RTUs with gas furnaces. Gas boilers usually do not replace these systems (with the exception of electric boilers) due to the cost of running hot water or steam piping throughout the building and the space requirements of a new boiler system.

Other technologies used with gas boilers to meet heating loads include hot water coils in HVAC units such as air handlers, fan coil units, and fin tube radiators; hot water pumps to circulate hot water; condensate pumps to feed condensate back to the boiler; shell and tube heat exchangers for transferring heat from a steam loop to a hot water loop; and supplemental electric heat, etc.

In CBSA and RBSA, commercial boilers are found in the following building types:

Residential Building Types:

- ❑ Single-family detached homes
- ❑ Manufactured homes
- ☑ Low-rise multifamily (1-3 stories)
- ☑ Medium/high-rise multifamily (4 stories and above)

Commercial Building Types:

- ☑ Office
- ☑ Retail
- ☑ K-12 Schools
- ☑ Warehouse
- ❑ Grocery
- ❑ Restaurant
- ☑ Lodging
- ☑ Residential Care
- ☑ Assembly
- ☑ Other

Market Trends

The condensing boiler market has expanded significantly in the U.S., from 30% of the total boiler market in 2012 to 60% in 2016. Experts expect the share to increase to 80% by the end of 2017. Increased interest in high efficiency products and incentive offerings is driving the increase. It is likely that increases in code-minimum efficiency are also having an impact.

The incremental costs for a more efficient commercial gas-fired boiler include:

- Baseline to mid-tier efficiency = 15% increase in total cost
- Baseline to high efficiency = 25% increase in total cost

Codes. Washington, Oregon, Idaho, and Montana commercial building codes require commercial boilers >500 kBtu/h to be multi-stage or modulating.

Standards. The DOE has minimum efficiency standards for hot water and steam commercial packaged boilers (both gas and oil fired). These efficiency standards are in terms of thermal efficiency or combustion efficiency, depending on the equipment category. The current standards went into effect on March 2, 2012. A second, higher tier of efficiency standards for gas-fired natural draft steam boilers go into effect on March 2, 2022.

On December 28, 2016, DOE published a pre-publication final rule. In this final rule, DOE adopted more stringent standards for commercial packaged boilers and created a new product category for very large boilers—input greater than 10 million Btu/h. If this rule becomes effective, these new standards will go into effect three years after the publication date in the Federal Register.

Stock Saturation

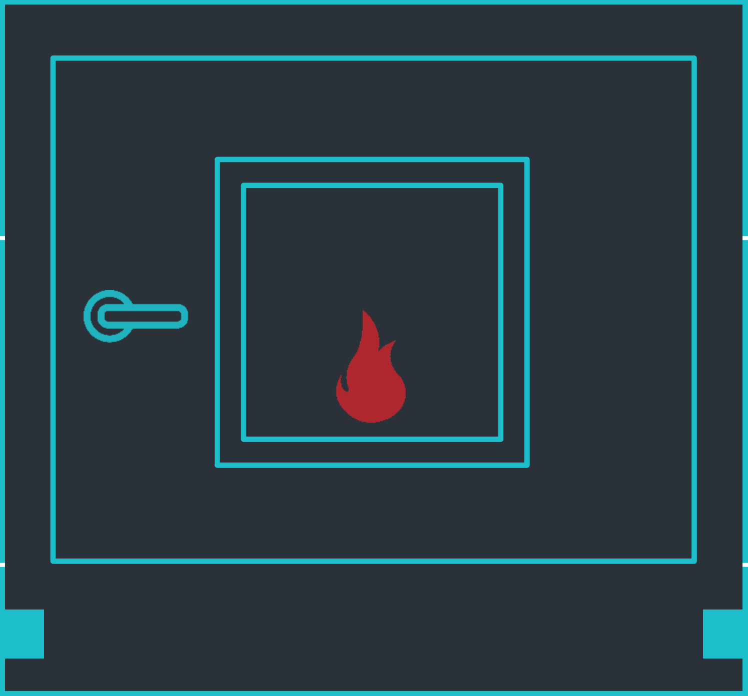
Commercial boilers heat about 16% of total Pacific Northwest commercial square footage.

The researchers team could not locate sales data for commercial boilers.

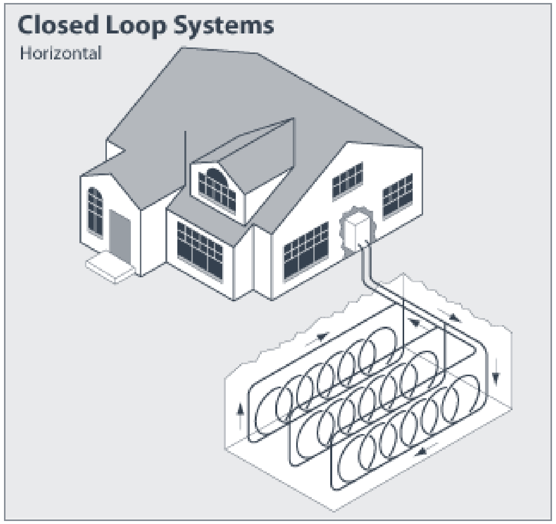
Stock Saturation in the Pacific Northwest - Commercial

Building Type	Heating Saturation
Assembly	21%
Grocery	0%
Lodging	9%
Office	20%
Other	25%
Residential Care	11%
Restaurant	0%
Retail/Service	3%
School K-12	55%
Warehouse	2%

Other Technologies



Ground Source Heat Pumps



Ground source heat pumps (GSHP) are an efficient type of heating system because they use the constant temperature of the earth as the exchange medium. There are four basic types of ground loop systems: horizontal closed-loop, vertical closed-loop, pond/lake closed-loop, and open-loop systems. In an open-loop system, the GSHP pumps water from an underground water source though the unit then discharges the water to a drainage site.

The most significant and obvious barrier is the initial system cost. EIA estimated that in 2013 a typical three-ton GSHP had a COP of 3.2 and the total installed cost ranged from $10,000-$15,000. A high efficiency unit with a COP of 4.5 had a total installed cost of $20,000-$27,0000.

DOE estimates that the indoor components of a GSHP last **25 years,** and the ground loop has a lifetime of **50-plus years**. The additional costs of a GSHP are paid back in 5-10 years.

A NEEA study from 2000 estimated that GSHP could be retrofit into 50% of existing single-family and manufactured homes.

Market Saturation in the Pacific Northwest

Cooling Saturation (% of buildings)		Heating Saturation	
Single-Family	Manufactured Homes	Single-Family	Manufactured Homes
1%	0%	1%	0%

Image Source: https://energy.gov/energysaver/geothermal-heat-pumps

Heating Stoves

A heating stove is a room heater that uses combustion as the heat source. The 2011 RBSA found that in single-family homes 60% of heating stoves are wood burning. Wood stoves generally consist of a cast iron- or steel-enclosed fire chamber and an adjustable air control. Some wood stoves include fans to circulate heated air.

Washington, Oregon, and Idaho residents are among the top polluters in the nation when it comes to fine particle emissions from burning wood to heat homes.

Conventional wood stoves manufactured prior to the mid-1980s typically have overall efficiencies ranging from 40%-55%. New stoves may include catalytic combustors for cleaner, more efficient operation. Catalytic wood stoves typically have an efficiency of 72%. Catalytic combustors may be retrofitted to existing heating stoves. Other noncatalytic, low-emission wood-burning appliances typically have an efficiency of 63%.

EIA estimates wood stoves have a lifespan of **12** to **25 years**. The installed cost of a typical catalytic cordwood stove is $7,500 and a non-noncatalytic, low-emission stove is $7,000.

Market Saturation in the Pacific Northwest

Heating Saturation (% of buildings)	
Single-Family	Manufactured Homes
14%	16%

Image Source: https://en.wikipedia.org/wiki/Wood_fuel

Residential Boilers

Residential boilers use combustion gases or electricity to heat water and provide either hot water or steam to heat a home. Space heating may be achieve through radiant heating (in-floor, radiant panels, radiators, baseboard) or forced air using fan coils. The 2011 RBSA found 77% of boilers in single-family homes are gas.

The DOE has minimum efficiency standards for residential boilers, which went into effect in 2012. The current standards for each type of boiler include a requirement for AFUE and/or design requirements.

In 2016, DOE finalized new standards for residential boilers that increase the minimum AFUE requirements for gas-fired boilers by 2%. The new standards will take effect in 2021.

Using condensing technologies in residential boilers can achieve significant savings. Condensing boilers extract additional heat by condensing the water vapor in the flue gases, resulting in efficiency levels of 90% or higher.

The installed cost of a typical minimum efficiency gas boiler is about $4,050 and high efficiency boilers are about 60% more expensive.

Residential gas boilers typically have an average life of **17** to **24 years.**

Market Saturation in the Pacific Northwest

Heating Saturation (% of buildings)	
Single-Family	**Manufactured Homes**
14%	**16%**

Image Source: https://commons.wikimedia.org/wiki/File:Pompe_%C3%A0_chaleur_BBC_Silenz_Amzair.jpg

Unit Heaters

Unit heaters are self-contained space heaters. All unit heaters include a fan, motor, and heating element within an enclosure. They heat open commercial spaces such as factories, warehouses, and garages, and typically hang from ceilings. They may also provide spot heating in entry ways or auxiliary spaces. Unit heaters may be steam, hot water, gas, oil, or electric. Most gas or electric unit heaters have a lifespan of **13 years.**

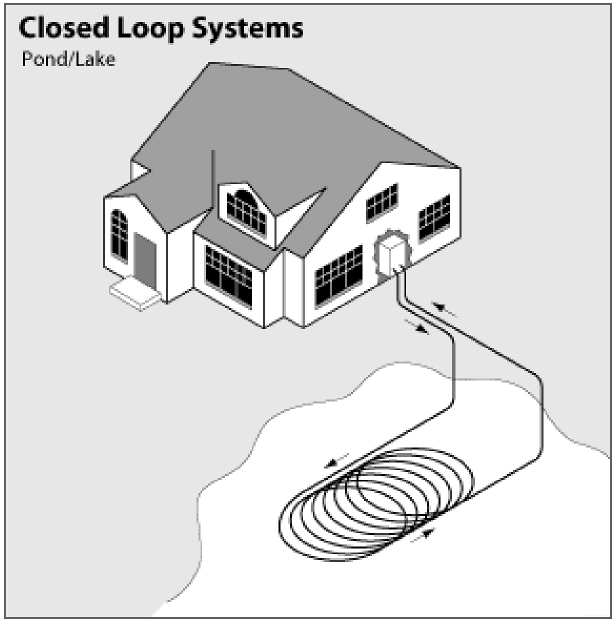
Image Source: https://commons.wikimedia.org/wiki/File:SAHARA01.jpg

The DOE has efficiency standards for gas-type unit heaters, which have been in effect since 2008. The standard requires that unit heaters be equipped with an intermittent ignition device and have either power venting or an automatic flue damper.

Most gas unit heaters have a thermal efficiency of 80%. The incremental cost of a 90% efficient condensing unit heater is about $2,600. Electric unit heaters have a nominal efficiency of 98%, but this does not include fan power.

About 10% of commercial square footage is heated with electric or gas unit heaters.

Water Source Heat Pumps



Water source heat pumps (WSHPs) provide space heat by using water as the heat source or heat sink. These systems include an indoor space conditioning heat exchanger, compressor, and liquid-side heat exchanger. There are two types of WSHPs: water-to-air and water-to-water. Water-to-air heat pumps use air to transfer heat to or from the conditioned space while water-to-water heat pumps use water to transfer heat to the conditioned space. WSHPs may simultaneously cool and heat different zones as needed. Like cooling towers, WSHPs require circulating pumps and a means for adding and rejecting heat to the water loop. Additional features may include capacity modulation, VAV, and outside air economizers and water side economizers.

The average lifespan of a commercial WSHP is **19 years.**

DOE has efficiency standards for commercial package WSHPs less than 135 kBtu/h. These standards are in terms of EER and COP and have been in place since 2003.

Commercial package WSHPs range in efficiency from 4.6 to 5.7 COP.

About 2% of commercial square footage is heated and cooled with WSHPs.

Image Source: https://energy.gov/energysaver/geothermal-heat-pumps

Crosscutting Appendices

This section includes supplemental information for the readers reference. In this section there is:

1. A summary of impacts on BPA's market models
2. Detailed state building code information
3. Detailed Federal efficiency standards

Impacts on BPA's Market Models

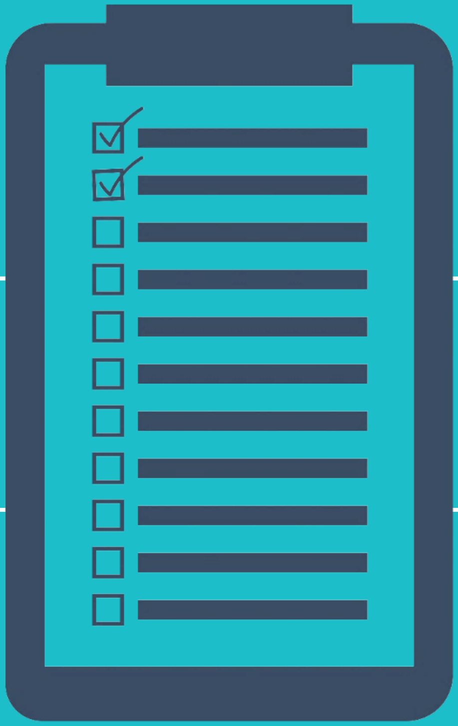
In addition to describing certain HVAC technologies this guide helps inform BPA's ongoing market modeling efforts. This slide highlights key factors that may impact BPA's market models. Specific model methodology decisions will be determined and documented in forthcoming model methodology memos and presentations.

Federal efficiency standards can be accounted for in a stock turnover model by allowing equipment replacements at the minimum efficiency level or above in that year that standard goes into place and afterward. Other modeling approaches, such as econometric or a stock-to-stock model that utilizes building surveys (CBSA, RBSA) to measure the distribution of equipment efficiency levels are unable to address the impacts of standards because there are no mechanisms in those modeling approaches to examine what would have happened absent the standard.

State building codes, such as those in Washington often involve much more than just the box efficiency of equipment. Their impacts at a market level are best modeled in a stock turnover model by using energy consumption estimates that are derived from a building simulation that accounts for the changes to shell characteristics outlined in the building code. The code-impacted consumption estimates are only applicable to new construction from the years in which the codes are applicable. New construction typically accounts for a only small portion of the overall building stock over a medium-term (5 year) horizon; due to the population of buildings that state building codes are applicable to, their impact on overall energy consumption is also small.

In a **momentum savings** context, both Federal standards and state building codes should be accounted for in the baseline, rather than the market scenario. Even if the codes and standards were unknown at the time when the regional power plan was written, the "spirit of the plan" would place them in the baseline consumption scenario, as measure-level savings in a potential study should net out any savings due to codes and standards. With codes and standards in a baseline scenario, they only have second order impacts momentum savings, to the extent that they drive changes in the efficiency mix observed in the market.

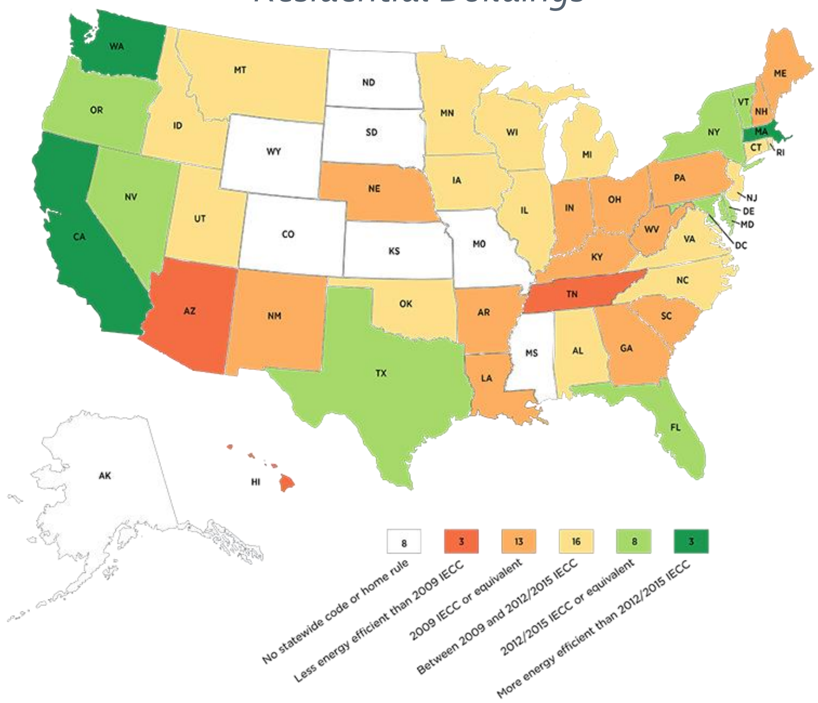
Building Codes



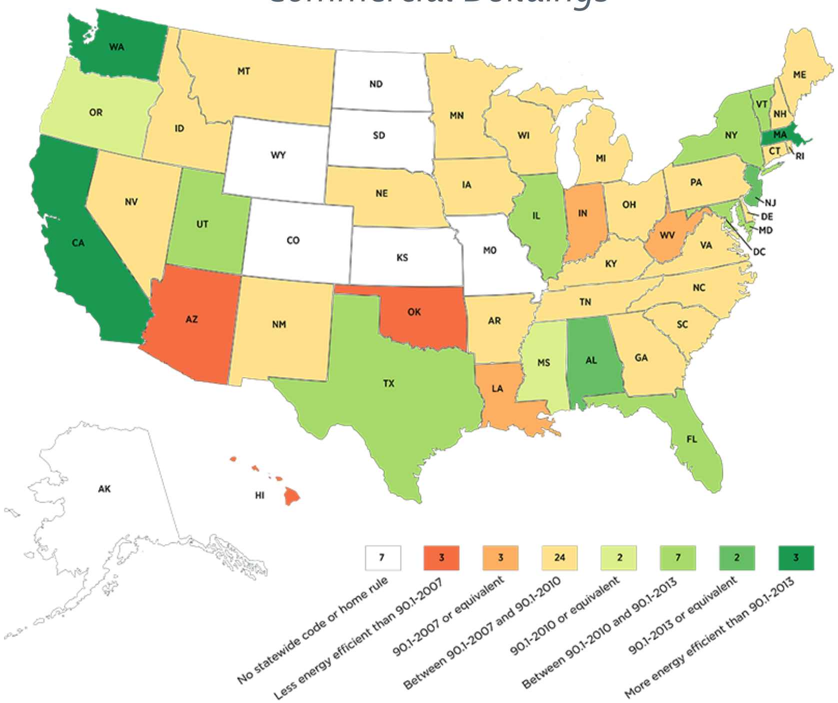
Comparison of State Energy Code Requirements

In the Pacific Northwest, Washington State has the most stringent code requirements, followed by Oregon, then Idaho and Montana.

Residential Buildings



Commercial Buildings



Washington – Residential

Scope

Residential buildings include one- and two-family dwellings and multiple single-family dwellings (townhouses), as well as residential buildings three stories or less in height above grade plane. Applies to new construction and major remodels.

Residential HVAC efficiency provisions do not apply to systems that serve multiple units.

HVAC Efficiency Requirements & Sizing

Requires Federal minimum efficiency units for new or replacement HVAC systems.

- **New in 2015**: Contractors must install ductless HPs in the largest zone of the home for buildings with electric zonal heating as the primary heating source.

Contractors must size heating and cooling equipment in accordance with ACCA Manual S based on building load calculations per ACCA Manual J.

- Must select equipment in next available size to meet load.

Controls

Each heating and cooling system must have at least one thermostat.

For homes with FAF, at least one thermostat must be programmable on a 5-2 schedule and control zone temps between 55ºF and 85ºF, with default setpoints of 70ºF for heating and 78ºF for cooling.

Unitary air-cooled heat pumps must include controls that minimize supplemental heat by using vapor compression as first stage of heating, controls that minimize use of ER heating above 40ºF, and a visual indicator. During final inspection, the compressor lock-out temp is to be 35ºF or less.

Residential boilers must have an outdoor temperature reset that lowers boiler supply water temperature based on outdoor air temperature.

Additional HVAC Load-Related Requirements

Ducts outside the building envelope must be insulated to R-8 and in-ground ducts to R-10. Ducts must be sealed and tested to have less than 4cfm/100 sf of conditioned floor area of air leakage. This includes a requirement that air handlers must have less than 2% leakage at design flow rate when tested with ASHRAE 193.*

Ventilation design must be generally in accordance with ASHRAE 62.2, which may increase HVAC load, although not appreciably.

More aggressive shell requirements that result in reduced heating and cooling loads.

*State code interpretation does not require strictly meeting this threshold, but testing is still required.

Washington – Residential

In addition to prescriptive or performance-based requirements, Washington code requires new buildings to acquire a certain number of additional energy efficiency credits:

Building Type	Credits
SMALL dwelling unit (<1500 sf CFA/300 sf fenestration; additions of >500 and <1500 CFA)	**1.5**
MEDIUM dwelling unit (not small or large)	**3.5**
LARGE dwelling unit (>5000 sf CFA); except those serving R-2 occupancies	**4.5**
LARGE dwelling units serving R-2 occupancies	**2.5**
Additions <500 sf CFA	**0.5**

High efficiency HVAC equipment worth 1 credit

- Gas, propane, or oil-fired furnaces with a minimum AFUE of 94%
- Gas, propane, or oil-fired boilers with a minimum AFUE of 92%
- ASHPs with a minimum efficiency of 9.0 HSPF
- Ductless split-system heat pumps, zonal control
  - In homes where the primary heating system is zonal electric heating contractors must install a DHP that provides heating to the largest zone

High efficiency HVAC equipment worth 1.5 credits

- Closed-loop GSHPs with a minimum COP of 3.3
  -or-
- Open loop WSHPs with a maximum pumping hydraulic head of 150 ft and a minimum COP of 3.6

Other energy-efficiency options affecting HVAC include:

- Efficient building envelope
- Air leakage control and efficient ventilation
- High-efficiency HVAC distribution system (ducts in conditioned space)

Additional non-HVAC energy-efficiency options include:

- Efficient water heating
- Renewable electric energy

Oregon – Residential

Scope

Residential buildings include one- and two-family dwellings and multiple single-family dwellings (townhouses), as well as residential buildings three stories or less in height above grade plane. Applies to new construction and major remodels.

Residential HVAC efficiency provisions do not apply to systems that serve multiple units.

HVAC Efficiency Requirements & Sizing

Requires Federal minimum efficiency units for new or replacement HVAC systems.

Contractors must size heating and cooling equipment in accordance with ACCA Manual S based on building load calculations per ACCA Manual J or other approved heating and cooling calculation methodologies.

Must select equipment in next available size to meet load.

Controls

Each heating and cooling system must have at least one thermostat. Zoning is required by automatic or manual means.

For homes with FAF, at least one thermostat must be programmable on a 5-2 schedule and control zone temps between 55ºF and 85ºF, with default setpoints of 70ºF for heating and 78ºF for cooling.

Unitary air-cooled heat pumps must include controls that minimize supplemental heat by using vapor compression as the first stage of heating, controls that minimize use of ER heating above 40ºF, and a visual indicator. During final inspection, the compressor lock-out temp should be 35ºF or less.

Residential boilers must have an outdoor temperature reset that lowers boiler supply water temperature based on outdoor air temperature.

Additional HVAC Load-Related Requirements

Ducts outside the building envelope insulated to R-8 and ducts in ground insulated to R-10. Ducts must be sealed and tested to have less than 4cfm/100 sf of air leakage.

Air handler must have less than 2% leakage at design flow rate when tested with ASHRAE 193.

Ventilation design must be generally in accordance with ASHRAE 62.2, which may increase HVAC load, although not appreciably.

Oregon – Residential

In addition to prescriptive requirements, new buildings must have one of the following conservation measures. Measures A, B, C, and E incentive HVAC improvements.

A	**High efficiency HVAC system:** Gas-fired furnace or boiler with minimum AFUE of 90%, an ASHP with a minimum HSPF of 8.5, or a closed-loop GSHP with a minimum COP of 3.0.
B	**Ducted HVAC system within conditioned space:** All ducts and air handler are contained within building envelope.
C	**DHP:** Replace electric resistance heating in at least the primary zone of dwelling with at least one ductless mini-split heat pump having a minimum HSPF of 8.5. Unit shall not have integrated resistance heat and the unit shall be sized to have capacity to meet the entire dwelling design heat loss rate at outdoor design temperature condition. Conventional electric resistance may be provided for any secondary zones in the dwelling. A PTHP with comparable efficiency ratings may be used when no supplemental zonal heaters are installed in the building and integrated backup resistance heat is allowed in a PTHP.
D	**High efficiency water heating & lighting:** Natural gas/propane, on-demand water heating with a minimum EF of 0.80, or a heat pump water heater with a minimum EF of 1.8 (northern climate) and a minimum 75% of permanently installed lighting fixtures, such as CFL or linear fluorescent, or a minimum efficacy of 40 lumens/W as specified in Section N1107.2.
E	**Energy management device & duct sealing:** Whole-building energy management device that is capable of monitoring or controlling energy consumption, performance tested duct systems, and a minimum 75% of permanently installed lighting fixtures are high-efficacy lamps.
F	**Solar photovoltaic:** Minimum 1 watt/sf conditioned floor space.
G	**Solar water heating:** Minimum of 40 sf of gross collector area.

Idaho + Montana – Residential

Scope

Residential buildings include one- and two-family dwellings and multiple single-family dwellings (townhouses), as well as residential buildings three stories or less in height above grade plane. Applies to new construction and major remodels.

Residential HVAC efficiency provisions do not apply to systems that serve multiple units.

HVAC Efficiency Requirements & Sizing

Requires Federal minimum efficiency units for new or replacement HVAC systems.

Contractors must size heating and cooling equipment in accordance with ACCA Manual S based on building load calculations per ACCA Manual J.

- Must select equipment in next available size to meet load.

Controls

Each heating and cooling system must have at least one thermostat.

For homes with FAF, at least one thermostat must be programmable on a 5-2 schedule and control zone temps between 55ºF and 85ºF, with default setpoints of 70ºF for heating and 78ºF for cooling.

Unitary air-cooled heat pumps must include controls that minimize supplemental heat by using vapor compression as the first stage of heating, controls that minimize use of ER heating above 40ºF, and a visual indicator. During final inspection, the compressor lock-out temp should be 35ºF or less.

Residential boilers must have an outdoor temperature reset that lowers boiler supply water temperature based on outdoor air temperature.

Additional HVAC Load-Related Requirements

Ducts outside the building envelope must be insulated to R-8 and ducts in ground insulated to R-10. Ducts must be sealed and tested to have less than 4 cfm/100 sf of air leakage.

Air handler must have less than 2% leakage at design flow rate when tested with ASHRAE 193.

Ventilation design must be generally in accordance with ASHRAE 62.2, which may increase HVAC load, although not appreciably.

Washington – Commercial

Scope

Commercial code applies to all buildings that are not residential and HVAC systems that serve multiple dwelling units. Applies to new construction and major remodels. HVAC requirements also apply to HVAC systems used to provide heating, cooling, or ventilation to commercial buildings and data centers.

Compliance

The commercial code allows either a prescriptive or a performance-based option. The performance-based option requires increased efficiency compared to standard reference design, which varies based on the efficiency options selected.

Sizing

Contractors must size heating and cooling equipment in accordance with ANSI/ASHRAE/ACCA Standard 183 and the ASHRAE HVAC Systems and Equipment Handbook or another approved method.

- Must size to next available capacity
- For buildings with total cooling load ≥300 tons, no one unit shall carry more than 2/3 of the load

Ventilation

Requires ventilation in accordance with Chapter 4 of the IMC, which requires ventilation generally in accordance with ASHRAE 62.1.

HVAC Requirements

Systems designed using either the performance or prescriptive approaches must meet the requirements. In general, for all new HVAC systems must meet Federal efficiency standards, where applicable. Additionally, WA Code applies additional requirements to already regulated systems and new requirements to systems that fall outside the scope of Federal standards:

Equipment	Capacities	Requirement
All packaged electric heating and cooling equipment	**≥6 kBtu/h**	**Must be heat pump; this has a large impact on HVAC equipment selection!**
Air-, water-, and evaporatively-cooled commercial AC & HP with electric resistance or none & all other heating systems	≥760 kBtu/h	EER/IEER values comparable with other Federally-regulated minimum efficiency requirements
Air-, water-, and evaporatively-cooled condensing units	≥135 kBtu/h	EER/IEER values comparable with other Federally-regulated minimum efficiency requirements
Ground source HPs (Water source, ground source, water-to-water mode, and brine to water)	<135 kBtu/h	EER (for AC) COP (for HP) based on entering water temp
Gas-fired and oil-fired FAFs and all unit heaters	≥225 kBtu/h (FAF only)	Have intermittent ignition or interrupted device (IID) or a flue damper/vent damper
All furnaces (gas, oil, electric) not in conditioned space	≥225 kBtu/h	Jacket losses ≤ 0.75 % of the input rating
All furnace and boiler systems	>500 kBtu/h	Must be multi-stage or modulating
Water-cooled centrifugal chilling packages not designed to operate at AHRI 550/590 specified test conditions	ALL	Adjustment to maximum full-load and part-load kW/ton ratings
Positive displacement (air- and water-cooled) chilling packages with leaving fluid temp >32°F and water-cooled equipment with condenser leaving fluid temp <115°F	ALL	Table C403.2.3(7)
Cooling tower fans	≥7.5 hp	Must have controls that vary flow by controlling the leaving fluid temperature or condenser temperature/pressure
Cooling towers on hydronic (water loop) heat pumps	ALL	Provisions to bypass or shut down cooling tower to minimize heat loss

Washington – Commercial

HVAC Efficiency Additional Options

In addition to prescriptive requirements, new buildings must have at least two "additional energy efficiency credits." Two of the eight options impact HVAC performance:

- **More efficient HVAC equipment and fan performance.** At least 90% of total HVAC capacity must be supplied by equipment listed in tables C403.2.3(1)-(9) and exceed all efficiency requirements by at least 15% and all stand-alone supply, return and exhaust fans >1 hp must have an FEG ≥71.
- **DOAS.** Not less than 90% of the building conditioned floor area shall be served by DOAS.

Controls

At least one thermostat must be provided for each zone and must prevent simultaneous heating and cooling of adjacent zones.

All occupied zones must have controllable thermostats with the following features:

- **Non-residential zones.** Setback controls that can control zone temps between 55ºF and 85ºF on a seven-day schedule, with two-hour override.
- **Hotel/motel guest rooms.** Controls that adjust temperature at least 5ºF when room is unoccupied
- **R-2 and R-3 dwelling units and R-2 sleeping units**. Primary space conditioning systems must have minimum 5-2 programmable schedule with at least two setbacks per day, with specific setpoint and deadband requirements. Additional units must be controlled via occupancy sensor, manual timer with max operation of two hours, or be a ductless heatpump.

Certain applications must include Direct Digital Controls that:

- Monitor zone and system demand for fan pressure, pump pressure, heating and cooling.
- Transfer information to air distribution and heat and cooling plant controllers.

See C403.2.4.12 for specific applications.

Occupancy sensing is required to close fans and/or dampers in classrooms, gyms, auditoriums, and conference rooms > 500 sf.

Equipment-Specific Controls

Equipment with economizers must have multi-stage cooling and activate economizer as first stage of cooling, must continue to provide cooling via economizing when mechanical cooling serves the remainder of the load, and must have controls that maximizes economizer operation.

Heat pumps must have controls that minimize use of supplemental heat above 40ºF.

All AC & HP with economizers must be equipped with FDD that measures outdoor, supply, and return temp and refrigerant pressure; reports and controls system status; and report certain faults.

Combustion heating equipment with capacity >225,000 Btu/h (except boilers and radiant heaters) must have modulating or staged combustion controls.

Hot water boilers that supply heat through one or two pipe heating systems must have an outdoor setback control that lowers boiler supply water temperature based on outdoor air temperature.

Multiple zone HVAC systems must include supply-air reset based on outdoor air temperature or representative building loads.

Humidification

If an economizer is required on a cooling system for which humidification equipment is to be provided, the humidifier must be of the adiabatic type (direct evaporative media or fog atomization type)

- Except health care facilities, systems with water economizers, 100% outdoor air systems with no provision for air recirculation to the central supply fan.

Energy Recovery

- Air Side energy recovery with specific performance requirements is required for systems with outside air requirements >5,000 cfm see Table C403.5.1.
- Condensate and condenser heat recovery is required for onsite condensate systems, certain refrigeration condensers, and certain service hot water systems.

Washington – Commercial

Washington Code Requirements for Dedicated Outdoor Air Systems (DOAS)

Washington code requires DOAS in many applications, which may drive HVAC system choice toward non-ducted HVAC systems.

- DOAS or high-efficiency variable air volume (VAV) is required in office, retail, education, library, and fire station facilities
    - High-efficiency VAV requires significant additional equipment efficiency and controls
    - DOAS is more appropriate for non-ducted applications, while high-efficiency VAV leverages existing ductwork.
- DOAS can be selected as one of the required energy-efficiency options
- Buildings with DOAS are allowed a higher window-to-wall-area ratio

These combined requirements may lead to an increased adoption of DOAS and non-ducted HVAC systems (e.g., VRF).

Piping and Ducts

Ducts conveying air from outside the building envelope must meet insulation and air-leakage requirements of section C402 for metal-framed walls.

Otherwise, ducts must be insulated to R-12 in CZ5 and R-8 in CZ4 for ducts outside conditioned space, R-6 for ducts in unconditioned space, or R-3.3 for ducts in conditioned space conveying air that is <55ºF or >105ºF. (C403.2.8)

All ducts must be sealed and 25% of ducts must be tested to have leakage less than 4.0 CL.

Pipes must be insulated according to table C403.2.9, except for pipes in HVAC equipment, renewable heating systems, valves, buried piping.

Additional Requirements Affect HVAC System Performance

All systems must be commissioned in accordance with section C408.

Mechanical air systems serving multiple zones must be VAV systems, except for when the zones have specific requirements or are controlled independently.

Limitation on use of hot gas bypass.

More aggressive shell requirements that result in reduced heating and cooling loads.

Oregon – Commercial

Generally consistent with Washington State code except:

Duct insulation:

- Unconditioned ducts only required to be insulated to R-5 and no requirement for ducts in conditioned space

Requirements split into simple and complex HVAC systems

Economizing

- Only required for systems >54,000 Btu/h with no additional efficiency requirement (not to exceed 240,000 Btu/h per building)
- Excepts computer and equipment rooms entirely

Energy recovery with 50% efficiency required for all systems with design supply air capacity of ≥5,000 cfm

No DOAS requirements

No options tables

Idaho and Montana – Commercial

Generally consistent with Washington State code except:

Duct insulation:

- No requirement for ducts in conditioned space

Requirements split into simple and complex HVAC systems

Economizing

- Only required for systems ≥33,000 Btu/h
- Exempts computer and equipment rooms entirely
- Exempts more efficient cooling equipment

Energy recovery requirements trigger at slightly different supply air flow capacities. See Table C403.2.6.

No DOAS requirements

Only requires one option from option tables

- One option is more efficient HVAC tables

Code Implementation – Key Dates

The residential and commercial code in each state is amended every 3 years.

In the Pacific Northwest codes are typically consistent with revisions of the International Energy and Conservation Code (IECC). The following tables notes the effective dates of the following code revisions and their general efficiency as compared to the IECC code

State	2009	2012	2015
Washington	IECC 2009 with significant amendments++ (1/1/2011)	IECC 2012 with significant amendments+ (7/1/2013)	IECC 2015 with significant amendments+ (7/1/2016)*
Oregon	IECC 2009 with amendments+ (7/1/2010)	Res: IECC 2012 with amendments+ (12/1/2014) Com: State-specific code roughly equivalent to ASHRAE 90.1–2010 (7/1/2014)	Res: Recently adopted new code based on IECC 2015 with amendments+ (10/1/2017) Com: No updates
Idaho	IECC 2009 (1/1/2011)	Res: IECC 2012 with amendments- (1/1/2015) Com: IECC 2012 (1/1/2015)	No updates
Montana	IECC 2009 (3/26/2010)	Res: IECC 2012 with amendments- (11/7/2014) Com: IECC 2012 (11/7/2014)	No updates

++These amendments serve to make the code **significantly more efficient** than the base IECC code. (More than half the requirements are unique to Washington.)
+These amendments serve to make the code **more efficient** than the base IECC code.
- These amendments serve to make the code **less efficient** than the base IECC code.
* Some provisions are effective 7/1/2017.

Federal Regulations

Federal Regulations

DOE defines a central air conditioner or CAC heat pump as a product that is powered by single-phase electric current, air-cooled, rated below 65,000 Btu/h.

The Federal energy conservation standards for heat pumps also apply to DHPs.

Current *Energy Conservation Standards in Effect*

Product class	Minimum SEER	Minimum HSPF	Compliance Date
Split Systems—Air Conditioners	13		January 1, 2015
Split Systems—Heat Pumps	14	8.2	January 1, 2015
Single Package Units—Air Conditioners	14		January 1, 2015
Single Package Units—Heat Pumps	14	8	January 1, 2015
Small-Duct, High-Velocity Air Conditioners	12		January 1, 2015
Small-Duct, High-Velocity Heat Pump	12	7.2	January 1, 2015
Space-Constrained Products—Air Conditioners	12		January 1, 2015
Space-Constrained Products—Heat Pumps	12	7.4	January 1, 2015

Product Class	Maximum Average Off Mode Power Consumption Allowed (Watts)	Compliance Date
Split-System Air Conditioners	30	January 1, 2015
Split-System Heat Pumps	33	January 1, 2015
Single-Package Air Conditioners	30	January 1, 2015
Single-Package Heat Pumps	33	January 1, 2015
Small-Duct, High-velocity Systems	30	January 1, 2015
Space-Constrained Air Conditioners	30	January 1, 2015
Space-Constrained Heat Pumps	33	January 1, 2015

*Split system air conditioners install in southern states must have a SEER of 14.
** Split system air conditioners and single package air conditioners install in southwestern states must meet specific EER requirements.

Federal Regulations

Future Energy Conservation Standards Going into Effect

Product Class	Minimum SEER2	Minimum HSPF2	Compliance Date
Split Systems—Air conditioners with a certified cooling capacity less than 45,000 Btu/h	13.4		January 1, 2023
Split Systems—Air conditioners with a certified cooling capacity equal to or greater than 45,000 Btu/h	13.4		January 1, 2023
Split Systems—Heat Pumps	14.3	7.5	January 1, 2023
Single-Package Units—Air Conditioners	13.4		January 1, 2023
Single-Package Units—Heat Pumps	13.4	6.7	January 1, 2023
Small-Duct, High-Velocity Systems	12	6.1	January 1, 2023
Space-Constrained Products—Air Conditioners	11.7		January 1, 2023
Space-Constrained Products—Heat Pumps	11.9	6.3	January 1, 2023

*Split system air conditioners install in southern states have increased SEER2 requirements.
** Split system air conditioners and single package air conditioners install in southwestern states must meet increased EER requirements.

Federal Regulations

Current Energy Conservation Standards in Effect

Product Class	Minimum AFUE	Compliance Date
Non-Weatherized Gas Furnaces	80%	November 19, 2015
Weatherized Gas Furnaces	81%	January 1, 2015
Mobile Home Gas Furnaces	80%	November 19, 2015
Non-Weatherized Oil-fired Furnaces	83%	May 1, 2013
Weatherized Oil-Fired Furnaces	78%	January 1, 1992
Mobile Home Oil-Fired Furnaces	75%	September 1, 1990
Electric Furnaces	78%	January 1, 1992

Product Class	Maximum Standby Mode Electrical Power Consumption, $P_{W,SB}$ (Watts)	Maximum Off Mode Electrical Power Consumption, $P_{W,OFF}$ (Watts)	Compliance Date
Non-Weatherized Oil-Fired Furnaces	11	11	May 1, 2013
Mobile Home Oil-Fired Furnaces	11	11	May 1, 2013
Electric Furnaces	10	10	May 1, 2013

Future energy conservation standards going into effect:

Federal Regulations

***Current** energy conservation standards in effect*

Product class	Minimum CEER	Compliance Date
1. Without reverse cycle, with louvered sides, and less than 6,000 Btu/h	11	June 1, 2014
2. Without reverse cycle, with louvered sides, and 6,000 to 7,999 Btu/h	11	June 1, 2014
3. Without reverse cycle, with louvered sides, and 8,000 to 13,999 Btu/h	10.9	June 1, 2014
4. Without reverse cycle, with louvered sides, and 14,000 to 19,999 Btu/h	10.7	June 1, 2014
5a. Without reverse cycle, with louvered sides, and 20,000 to 27,999 Btu/h	9.4	June 1, 2014
5b. Without reverse cycle, with louvered sides, and 28,000 Btu/h or more	9	June 1, 2014
6. Without reverse cycle, without louvered sides, and less than 6,000 Btu/h	10	June 1, 2014
7. Without reverse cycle, without louvered sides, and 6,000 to 7,999 Btu/h	10	June 1, 2014
8a. Without reverse cycle, without louvered sides, and 8,000 to 10,999 Btu/h	9.6	June 1, 2014
8b. Without reverse cycle, without louvered sides, and 11,000 to 13,999 Btu/h	9.5	June 1, 2014
9. Without reverse cycle, without louvered sides, and 14,000 to 19,999 Btu/h	9.3	June 1, 2014
10. Without reverse cycle, without louvered sides, and 20,000 Btu/h or more	9.4	June 1, 2014
11. With reverse cycle, with louvered sides, and less than 20,000 Btu/h	9.8	June 1, 2014
12. With reverse cycle, without louvered sides, and less than 14,000 Btu/h	9.3	June 1, 2014
13. With reverse cycle, with louvered sides, and 20,000 Btu/h or more	9.3	June 1, 2014
14. With reverse cycle, without louvered sides, and 14,000 Btu/h or more	8.7	June 1, 2014
15. Casement-Only	9.5	June 1, 2014
16. Casement-Slider	10.4	June 1, 2014

Future energy conservation standards going into effect:

Federal Regulations

Current *Energy Conservation Standards in Effect*

Product Class	AFUE	Design Requirements	Compliance Date
Gas-Fired Hot Water Boiler	82%	Constant burning pilot not permitted. Automatic means for adjusting water temperature required (except for boilers equipped with tankless domestic water heating coils).	September 1, 2012
Gas-Fired Steam Boiler	80%	Constant burning pilot not permitted.	September 1, 2012
Oil-Fired Hot Water Boiler	84%	Automatic means for adjusting temperature required (except for boilers equipped with tankless domestic water heating coils).	September 1, 2012
Oil-Fired Steam Boiler	82%	None.	September 1, 2012
Electric Hot Water Boiler	None	Automatic means for adjusting temperature required (except for boilers equipped with tankless domestic water heating coils).	September 1, 2012

Future energy conservation standards going into effect:

Federal Regulations

Future *Energy Conservation Standards Going into Effect*

Product Class	Minimum AFUE	Maximum Standby Mode Power Consumption (Watts)	Maximum Off Mode Power Consumption (Watts)	Design Requirements	Compliance Date
Gas-Fired Hot Water Boiler	84%	9	9	Constant-burning pilot not permitted. Automatic means for adjusting water temperature required (except for boilers equipped with tankless domestic water heating coils).	January 15, 2021
Gas-Fired Steam Boiler	82%	8	8	Constant-burning pilot not permitted.	January 15, 2021
Oil-Fired Hot Water Boiler	86%	11	11	Automatic means for adjusting temperature required (except for boilers equipped with tankless domestic water heating coils).	January 15, 2021
Oil-Fired Steam Boiler	85%	11	11	None.	January 15, 2021
Electric Hot Water Boiler	None	8	8	Automatic means for adjusting temperature required (except for boilers equipped with tankless domestic water heating coils).	January 15, 2021
Electric Steam Boiler	None	8	8	None.	January 15, 2021

Future energy conservation standards going into effect:

Federal Regulations

Current energy conservation standards going into effect

Equipment Type	Cooling Capacity	Subcategory	Heating Type	Efficiency Level	Compliance Date
SMALL Commercial Package Air-Conditioning and Heating Equipment (Air-Cooled, 3-Phase, Split-System)	<65,000 Btu/h	AC	All	SEER = 13	June 16, 2008
		HP	All	SEER = 14	January 1, 2017
SMALL Commercial Package Air-Conditioning and Heating Equipment (Air-Cooled, 3-Phase, Single-Package)	<65,000 Btu/h	AC	All	SEER = 14	January 1, 2017
		HP	All	SEER = 14	January 1, 2017
SMALL Commercial Package Air-Conditioning and Heating Equipment (Air-Cooled)	≥65,000 Btu/h and <135,000 Btu/h	AC	No Heating or Electric Resistance Heating	EER = 11.2	January 1, 2010
			All Other Types of Heating	EER = 11.0	January 1, 2010
		HP	No Heating or Electric Resistance Heating	EER = 11.0	January 1, 2010
			All Other Types of Heating	EER = 10.8	January 1, 2010
LARGE Commercial Package Air-Conditioning and Heating Equipment (Air-Cooled)	≥135,000 Btu/h and <240,000 Btu/h	AC	No Heating or Electric Resistance Heating	EER = 11.0	January 1, 2010
			All Other Types of Heating	EER = 10.8	January 1, 2010
		HP	No Heating or Electric Resistance Heating	EER = 10.6	January 1, 2010
			All Other Types of Heating	EER = 10.4	January 1, 2010
VERY LARGE Commercial Package Air-Conditioning and Heating Equipment (Air-Cooled)	≥240,000 Btu/h and <760,000 Btu/h	AC	No Heating or Electric Resistance Heating	EER = 10.0	January 1, 2010
			All Other Types of Heating	EER = 9.8	January 1, 2010
		HP	No Heating or Electric Resistance Heating	EER = 9.5	January 1, 2010
			All Other Types of Heating	EER = 9.3	January 1, 2010

Federal Regulations

On January 15, 2016, DOE adopted new energy conservation levels for commercial package air conditioners and heat pumps. In addition, DOE transitioned the efficiency metric from a full load energy efficiency ratio ("EER") to an IEER metric which accounts for part loading.

Future *energy conservation standards going into effect*

Equipment Type	Cooling Capacity	Subcategory	Heating Type	Efficiency Level	Compliance Date
SMALL Commercial Packaged Air-Conditioning and Heating Equipment (Air-Cooled)	≥65,000 Btu/h and <135,000 Btu/h	AC	Electric Resistance Heating or No Heating	IEER = 12.9	January 1, 2018
			All Other Types of Heating	IEER = 14.8	January 1, 2023
		HP	Electric Resistance Heating or No Heating	IEER = 12.7	January 1, 2018
			All Other Types of Heating	IEER = 14.6	January 1, 2023
LARGE Commercial Packaged Air-Conditioning and Heating Equipment (Air-Cooled)	≥135,000 Btu/h and <240,000 Btu/h	AC	Electric Resistance Heating or No Heating	IEER = 12.2	January 1, 2018
			All Other Types of Heating	IEER = 14.1	January 1, 2023
		HP	Electric Resistance Heating or No Heating	IEER = 12.0	January 1, 2018
			All Other Types of Heating	IEER = 13.9	January 1, 2023
VERY LARGE Commercial Packaged Air-Conditioning and Heating Equipment (Air-Cooled)	≥240,000 Btu/h and <760,000 Btu/h	AC	Electric Resistance Heating or No Heating	IEER = 12.4	January 1, 2018
			All Other Types of Heating	IEER = 14.2	January 1, 2023
		HP	Electric Resistance Heating or No Heating	IEER = 12.2	January 1, 2018
			All Other Types of Heating	IEER = 14.0	January 1, 2023

Future energy conservation standards going into effect:

Federal Regulations

DOE defines a commercial warm air furnace as a warm air furnace that is industrial equipment, and that has a capacity (rated maximum input) of 225,000 Btu/h or more. This equipment type does not include unit heaters and duct furnaces.

Current *energy conservation standards in effect*

Product Class	Minimum Thermal Efficiency	Compliance Date
Gas-fired commercial warm air furnaces	80%	January 1, 1994

Future *energy conservation standards going into effect*

Product Class	Minimum Thermal Efficiency	Compliance Date
Gas-fired commercial warm air furnaces	81%	January 1, 2023

Future energy conservation standards going into effect:

Federal Regulations

DOE defines a commercial warm air furnace as a warm air furnace that is industrial equipment, and that has a capacity (rated maximum input) of 225,000 Btu/h or more. This equipment type does not include not include unit heaters and duct furnaces.

***Current** Energy Conservation Standards in Effect*

Equipment Category	Subcategory	Certified Rated Input	Minimum Thermal Efficiency	Minimum Combustion Efficiency	Effective Date
Hot Water Commercial Packaged Boilers	Gas-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	80%	–	March 2, 2012
Hot Water Commercial Packaged Boilers	Gas-fired	>2,500,000 Btu/h	–	82%	March 2, 2012
Hot Water Commercial Packaged Boilers	Oil-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	82%	–	March 2, 2012
Hot Water Commercial Packaged Boilers	Oil-fired	>2,500,000 Btu/h	–	84%	March 2, 2012
Steam Commercial Packaged Boilers	Gas-fired—all, except natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h	79%	–	March 2, 2012
Steam Commercial Packaged Boilers	Gas-fired—all, except natural draft	>2,500,000 Btu/h	79%	–	March 2, 2012
Steam Commercial Packaged Boilers	Gas-fired—natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h	77%	–	March 2, 2012
Steam Commercial Packaged Boilers	Gas-fired—natural draft	>2,500,000 Btu/h	77%	–	March 2, 2012
Steam Commercial Packaged Boilers	Oil-fired	≥300,000 Btu/h and ≤2,500,000 Btu/h	81%	–	March 2, 2012
Steam Commercial Packaged Boilers	Oil-fired	>2,500,000 Btu/h	81%	–	March 2, 2012

***Future** Energy Conservation Standards in Effect*

Steam Commercial Packaged Boilers	Gas-fired—natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h	–	79%	March 2, 2022
Steam Commercial Packaged Boilers	Gas-fired—natural draft	>2,500,000 Btu/h	–	79%	March 2, 2022

Future energy conservation standards going into effect:

Federal Regulations

DOE recently initiated a test procedure rulemaking to evaluate amending the test procedure for VRFs and adopt part loading metrics.

Current *Energy Conservation Standards in Effect*

Equipment Type	Cooling Capacity	Heating Type*	Minimum Efficiency Level	Compliance Date:
VRF Multi-Split Air Conditioners (Air-Cooled)	<65,000 Btu/h	All	13.0 SEER	June 16, 2008
	≥65,000 Btu/h and <135,000 Btu/h	No Heating or Electric Resistance Heating	11.2 EER	January 1, 2010
		All Other Types of Heating	11.0 EER	January 1, 2010
	≥135,000 Btu/h and <240,000 Btu/h	No Heating or Electric Resistance Heating	11.0 EER	January 1, 2010
		All Other Types of Heating	10.8 EER	January 1, 2010
	≥240,000 Btu/h and <760,000 Btu/h	No Heating or Electric Resistance Heating	10.0 EER	January 1, 2010
		All Other Types of Heating	9.8 EER	January 1, 2010
VRF Multi-Split Heat Pumps (Air-Cooled)	<65,000 Btu/h	All	13.0 SEER	June 16, 2008
			7.7 HSPF	
	≥65,000 Btu/h and <135,000 Btu/h	No Heating or Electric Resistance Heating	11.0 EER	January 1, 2010
			3.3 COP	
		All Other Types of Heating	10.8 EER	January 1, 2010
			3.3 COP	
	≥135,000 Btu/h and <240,000 Btu/h	No Heating or Electric Resistance Heating	10.6 EER	January 1, 2010
			3.2 COP	
		All Other Types of Heating	10.4 EER	January 1, 2010
			3.2 COP	
	≥240,000 Btu/h and <760,000 Btu/h	No Heating or Electric Resistance Heating	9.5 EER	January 1, 2010
			3.2 COP	
		All Other Types of Heating	9.3 EER	January 1, 2010
			3.2 COP	
VRF Multi-Split Heat Pumps (Water-Source)	<17,000 Btu/h	Without Heat Recovery	12.0 EER	October 29, 2012
			4.2 COP	October 29, 2003
		With Heat Recovery	11.8 EER	October 29, 2012
			4.2 COP	October 29, 2003
	≥17,000 Btu/h and <65,000 Btu/h	All	12.0 EER	October 29, 2003
			4.2 COP	
	≥65,000 Btu/h and <135,000 Btu/h	All	12.0 EER	October 29, 2003
			4.2 COP	
	≥135,000 Btu/h and <760,000 Btu/h	Without Heat Recovery	10.0 EER	October 29, 2013
			3.9 COP	
		With Heat Recovery	9.8 EER	October 29, 2013
			3.9 COP	

*VRF Multi-Split Heat Pumps (Air-Cooled) with heat recovery fall under the category of “All Other Types of Heating” unless they also have electric resistance heating, in which case it falls under the category for “No Heating or Electric Resistance Heating.”

Federal Regulations

Current *Energy Conservation Standards in Effect*

Equipment Type	Category	Cooling Capacity	Minimum Efficiency Level	Compliance Date
PTAC	Standard Size	<7,000 Btu/h	EER = 11.9	January 1, 2017
		≥7,000 Btu/h and ≤15,000 Btu/h	EER = 14.0−(0.3 × Capacity)	January 1, 2017
		>15,000 Btu/h	EER = 9.5	January 1, 2017
	Non-Standard Size	<7,000 Btu/h	EER = 9.4	October 7, 2010
		≥7,000 Btu/h and ≤15,000 Btu/h	EER = 10.9−(0.213 × Capacity)	October 7, 2010
		>15,000 Btu/h	EER = 7.7	October 7, 2010
PTHP	Standard Size	<7,000 Btu/h	EER = 11.9 COP = 3.3	October 8, 2012
		≥7,000 Btu/h and ≤15,000 Btu/h	EER = 14.0−(0.3 × Capacity) COP = 3.7−(0.052 × Capacity)	October 8, 2012
		>15,000 Btu/h	EER = 9.5 COP = 2.9	October 8, 2012
	Non-Standard Size	<7,000 Btu/h	EER = 9.3 COP = 2.7	October 7, 2010
		≥7,000 Btu/h and ≤15,000 Btu/h	EER = 10.8−(0.213 × Capacity) COP = 2.9−(0.026 × Capacity)	October 7, 2010
		>15,000 Btu/h	EER = 7.6 COP = 2.5	October 7, 2010

Developed for the Bonneville Power Administration

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