Heat Pump Glossary of Terms

Part 1. Technical Information

Part 2. Equipment

This glossary of terms is a valuable resource tailored for professionals working with residential heat pumps, aiming to clarify the complex terminology often encountered within the industry.

Whether you are a program administrator navigating the intricacies of heat pump systems, or an experienced contractor looking to expand your knowledge, this resource will equip you with the foundational knowledge needed to understand the terminology you may encounter.

Each entry is carefully selected to offer clarity and understanding, ensuring that you are thoroughly prepared to grasp the terminology encountered in your work.

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Performance and Efficiency Metrics

Performance and efficiency metrics are essential indicators utilized to quantify the operational performance and energy efficiency of heat pump systems under different conditions and applications. These metrics encompass a range of key terms that quantify how efficiently a heat pump transfers heat and manages energy consumption under different scenarios, such as heating and cooling modes, varying outdoor temperatures, and part-load conditions. These metrics are typically prominently displayed on labels, such as Energy Guide labels in the United States, to provide consumers with clear information about the system's energy performance and efficiency standards. In this section, we explore terminology related to heat pump performance and efficiency.

Coefficient of Performance (COP)

The coefficient of performance (COP) is a metric that captures how efficiently a heat pump uses electricity to move heat from one place to another. Specifically, the COP is the ratio of the useful energy output of the system (i.e., heating or cooling) to the electrical energy needed for the system to operate. A higher COP means that less energy is required for the same output. For air-source heat pumps, the COP is higher at higher outdoor temperatures during heating mode and at cooler outdoor temperatures during cooling mode, as a smaller temperature difference between the indoor and outdoor environments (delta-T) results in higher efficiency. COP is measured under specific standardized conditions to ensure consistency and comparability between different systems.

Seasonal Coefficient of Performance (SCOP)

The seasonal coefficient of performance (SCOP) is a metric that captures the overall efficiency of a heat pump over an entire heating or cooling season. Unlike the coefficient of performance (COP), which measures efficiency at a specific operating point, the SCOP accounts for variations in temperature and operating conditions throughout the year. Specifically, the SCOP is the ratio of the total useful energy output of the system (i.e., heating or cooling) to the total energy needed for the system to operate over a season. A higher SCOP means that less energy is required for the same output over the course of a year. This metric provides a more comprehensive view of a heat pump's real-world performance and energy efficiency, considering local climate conditions and seasonal variations. For air-source heat pumps, the SCOP reflects how the system performs across a range of temperatures, providing a more accurate measure of its efficiency and potential energy savings in varying seasonal conditions.

Heating Seasonal Performance Factor (HSPF & HSPF2)

The Heating Seasonal Performance Factor (HSPF & HSPF2) is a metric that quantifies heat pump heating operation efficiency. It is the measure of a heat pump's efficiency during the heating season. HSPF & HSPF2 ratings are calculated by dividing the total heating output during the heating season (measured in BTUs) by the total watt-hours of energy consumed during these months (measured in kWh). The higher the unit's HSPF & HSPF2 rating, the more energy efficient it is. The rated/nameplate HSPF & HSPF2 are based on the temperature in IECC climate zone IV.

Seasonal Energy Efficiency Ratio (SEER & SEER2)

The Seasonal Energy Efficiency Ratio (SEER & SEER2) is a metric that quantifies the efficiency of heat pump cooling operation over the course of one year. More specifically, it is the cooling output (measured in (BTUs) during a typical cooling season (in a specific testing environment) divided by the total electric energy consumed (measured in watt-hours) during the same period. The higher a unit's SEER & SEER2 rating, the more energy efficient it is. The rated/nameplate SEER & SEER2 are based on the temperature in IECC climate zone IV.

Energy Efficiency Ratio (EER & EER2)

The Energy Efficiency Ratio (EER) of a heat pump is the ratio of output cooling energy (in BTU) to input electrical energy (measured in watt-hours) at a given operating point. EER is normally calculated with a 95°F outside temperature and an inside (return air) temperature of 80°F and 50% relative humidity. The higher a unit's EER & EER2 rating, the more energy efficient it is at peak cooling conditions.

Note: EER2 became the new efficiency metric standard for product regulation in 2023. The DOE periodically evaluates energy efficiency levels, available technology and the economic impact of changing standards. In the case of EER2, they determined that changes to the test procedure to better represent the average use cycle were warranted. They also determined that higher efficiency levels were technologically feasible and economically justified. The main difference between the EER2 and EER ratings is the testing conditions for each rating system. The new testing conditions produced different data values and warranted a new rating system.

Heat Pump Performance and Sizing

Understanding the key performance metrics and measurement units related to heat pump capacity is crucial for properly sizing and selecting the right system to meet a building's heating and cooling needs. Capacity ratings quantify how much heating or cooling a heat pump can provide, while heating and cooling loads determine the amount of heating or cooling actually required for a given space. Properly calculating these loads and matching them to the heat pump's rated capacities is essential for ensuring optimal comfort, efficiency, and energy savings. This section explores terms related to fundamental concepts and units used to evaluate heat pump performance and sizing.

BTU (British Thermal Unit)

BTU stands for British Thermal Unit, and it is a unit of measurement used to quantify heat energy. Specifically, a BTU is defined as the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit. When it comes to heat pumps, BTUs are important because they measure the heating or cooling capacity of the system. For heating, the BTU rating indicates how much heat the heat pump can transfer into a space during a certain period, usually an hour (BTU/hr). For cooling, it indicates how much heat the heat pump can remove from a space. The BTU rating of a heat pump is a key factor in determining its efficiency and effectiveness in heating or cooling a given area. Higher BTU ratings generally mean the heat pump can manage larger spaces or provide more heating/cooling power, though efficiency and proper sizing for the specific application are also critical considerations.

Ton of Refrigeration

A ton of refrigeration is a unit used to measure the cooling capacity of a heat pump system. It represents the amount of heat energy that the system can remove from a space in one hour. One ton is equal to 12,000 British Thermal Units (BTUs) of cooling capacity per hour. When choosing a heat pump for a space, the tonnage rating is crucial. It indicates how effectively the system can cool a space, with higher tonnage numbers implying greater cooling capacity. Proper sizing ensures that the heat pump can efficiently maintain comfort levels without unnecessary energy consumption or strain on the system.

Heating Capacity

The heating capacity of a heat pump refers to the amount of heat energy that the system can transfer from the outdoor environment into a building's interior to provide heating. Heating capacity is measured in BTU/hr or kW, providing a standardized way to compare different heat pump models and understand their heating capabilities under various conditions. When the “size” of a heat pump is referenced, it is often in reference to the heat pump's heating and/or cooling capacity.

Note: Manufacturers specify heating capacity ratings based on standardized conditions to provide a benchmark for comparison. Heating capacity is not constant and typically varies *with outdoor temperatures. In general, the heating capacity of a heat pump decreases as the outdoor temperature drops. This is because the efficiency of heat transfer decreases at lower temperatures, requiring the system to work harder to extract heat from the outdoor air. Heat pumps are designed to operate effectively across a range of temperatures, but their ability to provide sufficient heating capacity may diminish in extremely cold climates or during temperature extremes.*

Cooling Capacity

The cooling capacity of a heat pump refers to the rate at which the system can remove heat from a space and transfer it outdoors, effectively providing cooling. It is typically measured in British Thermal Units per hour (BTU/hr) or tons of refrigeration (12,000 BTU = 1 ton). The cooling capacity of a heat pump depends on factors such as outdoor temperature, indoor temperature set points, airflow rate, and the efficiency of the refrigerant cycle. When the "size" of a heat pump is referenced, it is often in reference to the heat pump's cooling and/or heating capacity.

Note: Manufacturers specify cooling capacity ratings based on standardized conditions to provide a benchmark for comparison. Understanding the cooling capacity of a heat pump is essential for selecting the right system size to match the cooling load of a building. Proper sizing ensures efficient operation, optimal comfort levels, and energy savings during the cooling season.

Capacity Maintenance

Capacity maintenance is a ratio that often refers to what percentage of heating capacity an air source heat pump provides at colder temperatures compared to its rated capacity at 47°F. This ratio is often communicated for outdoor air conditions at 17°F, 5°F, and lower.

Load Calculation

A load calculation is a method of determining the heat gain and loss of a home or building so that heat pump equipment is properly sized. A building's heating or cooling design load is based on how well-insulated the building is and in what climate it is located. It represents the amount of heating or cooling capacity that is needed during the coldest or hottest day of an average year to keep the interior of the space comfortable. Properly calculating heating and cooling loads is necessary to choose the right heat pump. Calculating heating and cooling loads typically involves using methods like Manual J calculations, which account for different factors to estimate the heat loss and gain from the building. This calculation is crucial for sizing a heat pump system appropriately—undersized systems may struggle to keep up with heating and cooling demands, while oversized systems can be inefficient and costly to operate.

Note: Oversizing can lead to excessive cycling, low efficiency, shortened equipment life, and ineffective summer dehumidification. Under sizing can result in overreliance on backup heat, or inadequate summer cooling and increase energy costs.

Design Condition (also referred to as “Design temperature”)

The design condition or design temperature for a heat pump is used during the design and sizing stage to ensure the system can maintain indoor comfort under typical extreme weather conditions specific to a location. It involves calculating the heating and cooling loads based on the lowest and highest outdoor temperatures the heat pump will encounter. This information guides the selection of the appropriate heat pump size and capacity, preventing it from being oversized or undersized. Additionally, it influences the overall system design, including ductwork, insulation, and controls, ensuring that the system performs efficiently and reliably while meeting the building’s heating and cooling demands effectively.

Heating Load

In contrast to heating capacity, which refers to the amount of heat energy that a heat pump system can transfer from the outdoor environment into a building's interior to provide heating, heating load is the amount of heat energy that needs to be added to maintain a building's desired temperature setpoint in cold weather. It is determined by factors such as outdoor temperature, building size, insulation levels, and internal heat gains. By accurately assessing heating load, homeowners and HVAC professionals can ensure that the heat pump installed is capable of efficiently meeting the heating needs of the building.

Cooling Load

In contrast to cooling capacity, which measures the amount of heat energy that a heat pump system can transfer from a building's interior to provide cooling, cooling load refers to the total amount of heat energy that must be extracted to maintain a desired indoor temperature setpoint in warm weather. It is determined by factors such as outdoor temperature, building size, insulation levels, solar heat gain, and internal heat sources. By accurately assessing the cooling load, homeowners and HVAC professionals can select a heat pump system that efficiently meets the cooling requirements of the building, ensuring optimal comfort and energy efficiency.

Thermal Balance Point

The outdoor temperature at which the heating load of a building matches the heat pump’s output heating capacity is called the thermal balance point. Above the thermal balance point, the heat pump is capable of meeting the building's heating requirements. Below the thermal balance point, the heat pump may not be capable of meeting the building's heating requirements and supplementary heating will be required (such as a fossil-fuel fired furnace). Many modern heat pump controls can automate a safeguard to ensure occupant comfort is always met in heat pump configurations that utilize supplementary heat.

Note: Setting the switchover point for propane applications at the thermal balance point can result in missed savings. This is because the heating load is often overestimated by Manual J calculations or rules of thumb.

Economic Balance Point

The balance point of a heat pump system can also be determined based on economic considerations. The economic balance point is the outdoor temperature at which it is economically desirable to switch from the heat pump system to a back-up heating source (such as a fossil-fuel fired furnace). It is determined based on the estimated costs of heat delivery by the heat pump versus the backup system. Calculation of the economic balance point requires the cost of electricity, cost of backup system fuel, heat pump COP, backup system efficiency, and outdoor temperature.

Heating and Cooling Degree Days (HDD & CDD)

Degree days are measures of how cold or warm a location is. A degree day compares the mean (the average of the high and low) outdoor temperatures recorded for a location to a standard temperature, usually 65° Fahrenheit (F) in the United States. The more extreme the outside temperature, the higher the number of degree days. A high number of degree days generally results in higher energy use for space heating or cooling. HDD and CDD help HVAC professionals and homeowners determine the annual energy use of heat pumps for specific climates. This ensures the heat pump can manage the peak heating and cooling loads efficiently.

Note: Heating degree days (HDDs) are a measure of how cold the temperature was on a given day or during a period of days. For example, a day with a mean temperature of 40°F has 25 HDDs. Two such cold days in a row have 50 HDDs for the two-day period.

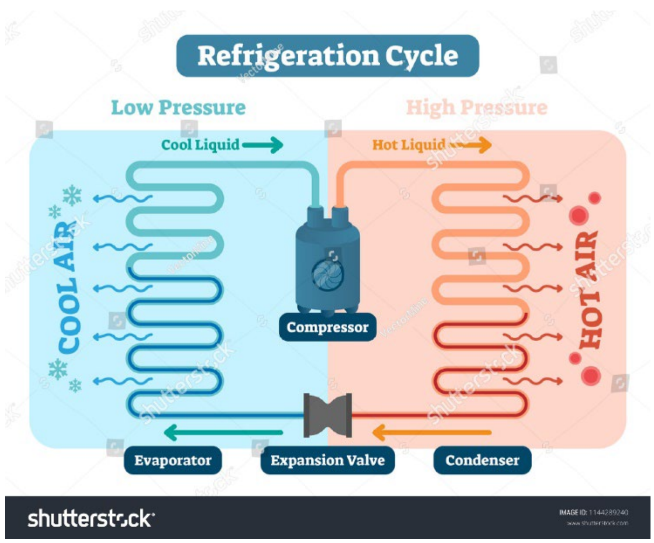
Cooling degree days (CDDs) are a measure of how hot the temperature was on a given day or during a period of days. A day with a mean temperature of 80°F has 15 CDDs. If the next day has a mean temperature of 83°F, it has 18 CDDs. The total CDDs for the two days is 33 CDDs.

Refrigerants

Heat pumps utilize refrigerants as a crucial component in their operation, playing a key role in transferring heat efficiently. Refrigerants enable the heat pump to move heat from one place to another, making them essential for the system's performance. Understanding refrigerants and their function within the heat pump system is vital for grasping how these systems achieve effective heating and cooling. There are different classes of refrigerants used in heat pumps, categorized based on their safety, environmental impact, and efficiency. Regulation of refrigerants is overseen globally by agreements such as the Montreal Protocol and regional regulations that aim to phase out ozone-depleting substances and reduce high Global Warming Potential refrigerants. These regulations drive the adoption of safer, more environmentally friendly alternatives in heat pump technology, ensuring compliance with stringent safety and sustainability standards. In this section, we will explore important terms related to refrigerants.

Refrigeration Cycle

The heat pump refrigeration cycle is the core process by which heat pumps transfer heat between indoor and outdoor environments. This cycle comprises four key components: the evaporator coil, compressor, condenser coil, and expansion valve. These components work together to facilitate the transfer of heat using a refrigerant.



Note: In cooling mode, the heat pump functions by absorbing heat from indoors. The indoor coil acts as the evaporator where the refrigerant, initially a low-pressure, low-temperature gas, absorbs warmth from the indoor air or surroundings, causing it to evaporate. This vapor then moves through the compressor, where it undergoes compression into a high-pressure, high-temperature state. As the refrigerant enters the condenser, it releases heat to the outdoor environment or a heat sink, transforming into a liquid. The expansion valve then regulates the refrigerant's pressure drop, allowing it to return to the evaporator as a low-pressure, low-temperature gas, thereby completing the cycle of cooling. Conversely, in *heating mode, the heat pump reverses the cycle to warm the indoor space. The outdoor coil now acts as the evaporator, where the refrigerant extracts heat from the outdoor air, causing it to evaporate as a low-pressure, low-temperature gas. The compressor then increases the pressure and temperature of the gas, transforming it into a high-pressure, high-temperature state. Upon entering the indoor coil, which now serves as the condenser, the refrigerant releases heat into the indoor environment, turning it into a liquid. Finally, the expansion valve lowers the refrigerant's pressure, returning it to the outdoor coil as a low-pressure, low-temperature gas, ready to repeat the heating cycle.*

Refrigerant Charge

The heat pump refrigerant charge refers to the amount of refrigerant fluid that is present in a heat pump system. This charge is crucial for the system's efficiency and performance. If the refrigerant charge is too low or too high, it can lead to issues such as reduced heating or cooling capacity, increased energy consumption, and potential damage to or failure of the system. Properly maintaining the correct refrigerant charge ensures optimal operation and longevity of the heat pump.

Global Warming Potential (GWP)

Global Warming Potential, or GWP, is a measure of the impact of a substance on global warming relative to carbon dioxide. Refrigerants today are often thousands of times more polluting than carbon dioxide (CO_2). The GWP of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, CO_2, which is assigned a value of 1. GWPs can also be used to define the impact greenhouse gases will have on global warming over different time periods or time horizons. These are usually 20 years, 100 years, and 500 years. High-global warming potential (high-GWP) refrigerants include all ozone-depleting substances and any refrigerant with a GWP of 150 or higher.

Class A1 Refrigerants

A1 refrigerants, classified by ASHRAE as having lower toxicity and no flame propagation, are commonly used in modern heat pump systems. These refrigerants, such as R-410A, are favored for their safety and efficiency in residential heating and cooling applications. Their low toxicity ensures minimal health risks to users and service personnel, while their non-flammable nature enhances overall safety. A1 refrigerants, such as R-410A, are currently under scrutiny due to their relatively high Global Warming Potential (GWP). Manufacturers and policymakers are increasingly focusing on alternative refrigerants, such as A2L (lower flammability) and natural refrigerants (like CO2 and hydrocarbons), which offer comparable or improved performance with significantly lower environmental impact.

Class A2L Refrigerants

A2L refrigerants are classified by ASHRAE as having lower toxicity and lower flammability compared to other classes. These refrigerants, such as R-32 and R-454B, offer a balance between safety and environmental impact. They are increasingly favored for their significantly lower Global Warming Potential (GWP) compared to traditional A1 refrigerants like R-410A. Regulation of A2L refrigerants is stringent, with standards ensuring their safe use and handling in various applications. Their adoption is driven by global agreements and regulations aiming to reduce greenhouse gas emissions, making them a pivotal choice for sustainable heat pump technology.

Class A3 Refrigerants

A3 refrigerants are classified by ASHRAE lower toxicity and higher flammability compared to other classes. These refrigerants, such as R-290 (propane), offer a balance between safety and environmental impact, despite their higher flammability. Despite their higher flammability, these refrigerants are chosen for their excellent thermodynamic properties and exceptionally low Global Warming Potential (GWP). The use of A3 refrigerants in residential heat pumps is more common in regions where regulations and safety standards support their safe handling and application. Manufacturers design these systems to minimize the risks associated with flammability through careful engineering and safety features. Their adoption is driven by global agreements and regulations aiming to reduce greenhouse gas emissions, making them a pivotal choice for sustainable heat pump technology.

Program Administration

The successful implementation and management of heat pump programs requires strong administration practices. Program administrators, typically utilities or state/regional energy efficiency organizations, oversee a range of critical functions to ensure these initiatives achieve their energy-saving goals in a cost-effective manner. Effective program administration encompasses several key elements that are vital for maximizing the impact of heat pump adoption efforts while providing appropriate oversight and quality assurance. These core administrative aspects include program design and planning, customer outreach and marketing, contractor engagement, application processing, quality control inspections, data tracking, regulatory compliance, cost-effectiveness evaluations, and performance measurement and verification. Properly executing these administrative responsibilities is essential for delivering well-run heat pump programs that overcome market barriers, transform markets, and deliver sustained energy and greenhouse gas emissions reductions over time. In this section, we will explore terminology related to program administration.

TRM – Technical Reference Manual

A Technical Reference Manual (TRM) is a comprehensive document that provides standardized methods for calculating energy savings and cost-effectiveness of energy efficiency measures. In heat pump programs, the TRM standardizes assumptions and calculations to ensure consistent and reliable energy savings estimates. It includes detailed algorithms and baseline conditions to assess the impact of heat pump installations. The TRM also aids in evaluating the cost-effectiveness of these programs, ensuring compliance with regulatory standards. Additionally, it supports the design and assessment of incentives and rebates, promoting the adoption of efficient and sustainable heating and cooling solutions.

Note: A statewide TRM contains approved savings values for all energy efficiency measures that could be included in programs in the state. The value of a TRM comes from having all parties working with the same playbook, with values from the TRM being considered non-controversial in most regulatory situations. TRMs should be created with a process for regular and ongoing updates to account for new technologies and changes to federal appliance standards that may change baseline assumptions. In the absence of a statewide TRM, utility-specific measure lists serve the same purpose but may vary between utilities, making the regulatory role more complicated. Utility measure lists often draw on out-of-state TRMs or vendor-supplied values and may lack the specificity of a regularly updated statewide TRM.

Demand Response

Demand response provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives. Integrating heat pumps into demand response programs can be highly beneficial. These programs strategically automate electric usage to reduce consumption during peak demand periods. This not only helps manage grid constraints but also keeps peaking power plants offline, reducing carbon output.

Note: A demand response-enabled heat pump can automatically adjust its operation to reduce energy consumption without compromising occupant comfort. For instance, homes can be pre-heated slightly before the peak period begins, allowing the heat pump to maintain a constant temperature without drawing excessive power during peak hours. The key to effective demand response lies in smart thermostats and connectivity. Modern thermostats can be programmed to communicate with utility systems, receiving signals to adjust temperature settings during peak demand periods. This seamless integration ensures that the demand response process is automated and minimally intrusive for occupants. Not only can thermostats receive signals from grid operators or utility companies to adjust their operation during DR events, but grid connected heat pump equipment also has this capability.

Measurement and Verification (M&V)

Energy and demand savings cannot be directly measured as they represent energy that was not consumed and demand that did not occur. Therefore, energy and demand savings must be calculated. Measurement and Verification (M&V) is the process for determining energy and demand savings using a combination of measured data and calculations. M&V involves planning, measuring, collecting and analyzing data to verify and report energy savings within a facility by implementing energy efficiency measures (such as heat pump installations). In the context of a heat pump retrofit, M&V involves comparing the measured energy usage of the baseline (e.g., existing) heating system with the heat pump's energy usage while adjusting for weather and any other key differences between the baseline and reporting periods.

Cost-Effectiveness Analysis (CEA)

Cost-effectiveness analysis is a fundamental step in the design and evaluation of energy efficiency programs. In its simplest form, energy efficiency cost-effectiveness is measured by comparing the benefits of an investment with the costs. Five key cost-effectiveness tests have, with minor updates, been used for over 20 years as the principal approaches for energy efficiency program evaluation. These five cost-effectiveness tests are the participant cost test (PCT), the utility/program administrator cost test (PACT), the ratepayer impact measure test (RIM), the total resource cost test (TRC), and the societal cost test (SCT). Regulated utilities must demonstrate cost-effectiveness to obtain program approval from the state public utility commission.

Baseline Energy Consumption

Energy savings are the difference between energy consumption with an energy efficiency activity in place and the consumption that otherwise would have occurred during the same period. The consumption that otherwise would have occurred is called the baseline. Establishing baselines for savings is a key challenge of Measurement & Verification because determining the baseline requires identifying the counterfactual, or what would have happened absent the energy efficient activity.

Return on Investment (ROI)

The return on investment (ROI) of heat pump systems is influenced by various factors, including initial investment, energy savings, maintenance costs, and potential government incentives or rebates. By calculating the projected ROI based on estimated energy savings and operational efficiency, users can determine the payback period for their heat pump investment and evaluate the overall financial feasibility of integrating heat pump technology into their heating and cooling systems. A positive ROI signifies the economic advantages and cost savings associated with heat pump installations, making them a practical and lucrative investment for both residential and commercial properties.

Heat Pump Glossary of Terms

Equipment

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Heat Pump Types

A heat pump is a heating and cooling system that moves heat from one place to another (similar to an air conditioner or refrigerator) instead of generating heat directly. During cold weather, it pulls heat from the outdoor air, ground, or nearby water sources such as lakes or ponds, and pumps it inside to warm a building. During hot weather, it reverses the process - it takes heat from inside a building and pumps it outside to provide cooling.

There are several different kinds of heat pump systems used in residential settings. The main differences are where they source their heat from, and how they distribute the heated or cooled air throughout a building. In this section, we will explore the terms used to describe the most frequently encountered types of residential heat pump systems.

Heat Exchange Medium

Air-source Heat Pump (ASHP)

An air-source heat pump is the most common type of heat pump. The heat pump absorbs heat from the outside air and transfers the heat to the space to be heated in the heating mode. In the cooling mode, the heat pump absorbs heat from the space to be cooled and rejects the heat to the outside air. The term "air-source heat pump" is a broad term used to describe a variety of heat pump system configurations that utilize air as the primary medium for heat transfer. These systems include both air-to-air and air-to-water heat pumps (see definitions below). Additionally, distinct distribution methods are employed, such as hydronic systems for air-to-water heat pumps, ductwork for ducted air source heat pumps, and individual blower heads (wall, ceiling, or floor mounted) for ductless air-source heat pumps.

- **Air-to-air Heat Pump**

An air-to-air heat pump is a type of air source heat pump system that uses forced air distribution. It operates by transferring heat between the indoor air and outdoor air directly using refrigerant.

- **Air-to-water Heat Pump**

Air-to-water heat pumps exchange heat with the outdoor air but distribute the heat indoors through a hydronic system. All air-to-water heat pumps provide heating, and some can also provide cooling. To provide heating, air-to-water heat pumps extract heat from the outdoor air, transfer the heat to water, and circulate the water through radiators or in-floor loops. Air-to-water heat pumps have the potential of also heating domestic hot water, unlike typical air-source heat pumps. They can provide cooling if they are connected to a cooling system that can use chilled water, like a hydronic fan coil.

- **Cold-climate Air-source Heat Pump (ccASHPs)**

Cold climate air source heat pumps are an iteration of traditional heat pump technology, engineered to efficiently heat homes in extremely cold conditions, typically at or below 5°F, while also providing cooling during warmer seasons. These heat pumps utilize advanced technology and enhanced components, such as variable-speed, inverter-driven compressors to maintain comfort and energy efficiency in challenging climates. They offer a sustainable alternative to traditional heating systems by leveraging electric power and renewable energy sources, reducing reliance on fossil fuels and lowering greenhouse gas emissions.

Note: To promote the adoption of cold climate heat pump technologies and address the challenges of heating in colder climates, the U.S. Department of Energy launched the Cold Climate Heat Pump Technology Challenge. This initiative aims to accelerate the development and deployment of high-performance cold climate heat pump systems. Additionally, NEEP maintains a list of cold climate air source heat pumps that meet specific performance criteria. The list includes heat pump models that are well-suited for efficient heating in IECC climate zone 4 and higher, which encompasses regions with extended periods of cold temperatures.

Geothermal Heat Pump (also referred to as “Ground source, Water-source, Water-to-water, Water-to-air, GeoExchange, and Earth-coupled heat pumps”)

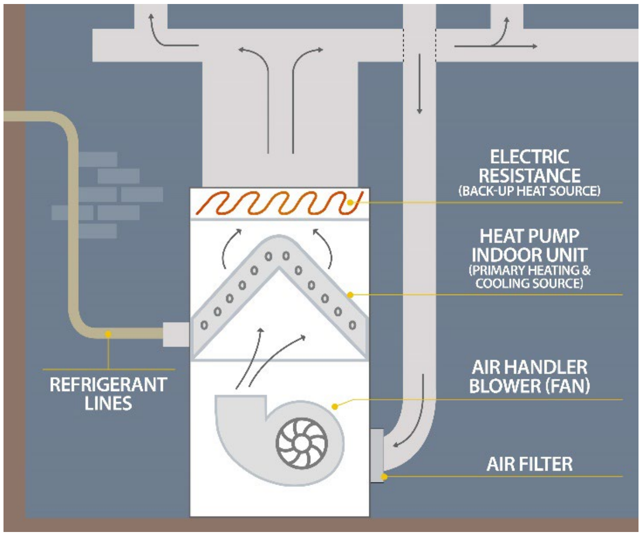
Geothermal heat pumps are similar to air-source heat pumps, but instead of using heat found in outside air, they rely on the relatively constant heat of the earth (thermal energy) to provide space heating, air conditioning and, in many cases, domestic hot water. In winter, geothermal heat pump systems collect the Earth’s natural heat through a series of pipes made of copper or plastic, called a loop, installed below the surface of the ground or submersed in a body of water. Fluid circulating in the loop carries this heat to the home. There, an electric compressor and a heat exchanger concentrate the Earth's energy and release it inside the home at a higher temperature. In summer, the process is reversed in order to cool the home. Excess heat is drawn from the home, expelled to the loop, and absorbed by the Earth.

Note: There are four basic types of [geothermal heat pump] ground loop systems. Three of these—horizontal, vertical, and pond/lake—are closed-loop systems. The fourth type of system is the open-loop option. Several factors such as climate, soil conditions, available land, and local installation costs determine which is best for the site.

System Fuel Type

All-electric Centrally Ducted Heat Pump System

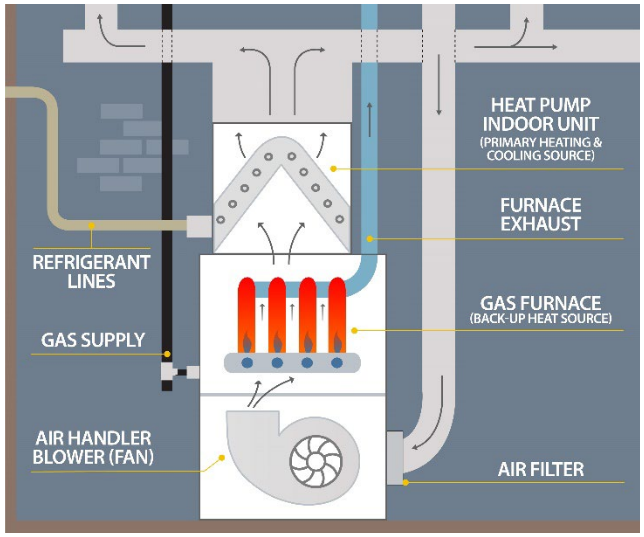
An all-electric centrally ducted heat pump system can either rely solely on the heat pump for heating or can merge the capabilities of an electric air-source heat pump with auxiliary electric heat. No gas-powered heating system is involved in either scenario. If the heat pump has auxiliary electric heat, when outdoor temperatures reach a certain low point, the auxiliary electric heat turns on to supplement the heating from the heat pump. All-electric heat pumps offer the most potential for lowering greenhouse gas emissions over time, depending on how quickly the local electric grid is decarbonizing.



Note: Ductless heat pumps may be integrated with a variety of other heating systems. All-electric ductless heat pump systems may be integrated with electric baseboard heating or boilers as a "multi-system" application.

Hybrid Heat Pump System (also referred to as "Dual-fuel heat pump system")

A hybrid heat pump system merges the capabilities of a centrally ducted electric air-source heat pump with a secondary fossil-fuel-fired furnace. As outdoor temperatures change, the system alternates between the two fuel sources, maximizing comfort, economics, and efficiency – offering the homeowner the key benefits of both fuel sources. In moderate winter weather, the heat pump efficiently draws warmth from the outdoor air to heat the home, while in summer, it reverses its operation to provide cooling. There are different methods used to control when the hybrid system switches from the electric air-source heat pump to the fossil-fuel-fired secondary heating source. The most common method is based on outdoor air temperature. When outdoor temperatures dip below a pre-set switchover point defined by the homeowner, the system seamlessly shifts to the secondary heating source, like a gas furnace, ensuring consistent comfort levels. This adaptability empowers homeowners to tailor energy usage and operational expenses to their preferences.



Note: In addition to the commonly used outdoor air temperature control method, other control methods for hybrid heat pump switchover include indoor air temperature "droop" and more sophisticated algorithm-based controls. In the indoor air "droop" control method, the system continuously monitors the indoor air temperature for variations. If the indoor temperature begins to "droop" or fall below the desired setpoint, the system recognizes that the heat pump alone is not sufficient to maintain the desired comfort level. As the temperature continues to drop, the system engages the fossil-fuel-fired secondary heating source to provide the necessary warmth. There are also more advanced algorithm-based control methods, which use a combination of data inputs and predictive models to optimize hybrid heat pump system performance, such as minimizing operational costs.

Absorption Heat Pump System (also referred to as "Gas-fired heat pump system")

Absorption heat pumps are essentially air-source heat pumps driven not by electricity, but by a heat source such as natural gas, propane, solar-heated water, or geothermal-heated water. Because natural gas is the most common heat source for absorption heat pumps, they are also referred to as gas-fired heat pumps. There are also absorption (or gas-fired) coolers available that work on the same principle. Residential absorption heat pumps use an ammonia-water absorption cycle to provide heating and cooling. As in a standard heat pump, the refrigerant (in this case, ammonia) is condensed in one coil to release its heat; its pressure is then reduced, and the refrigerant is evaporated to absorb heat. If the system absorbs heat from the interior of your home, it provides cooling; if it releases heat to the interior of your home, it provides heating.

Heat Pump System Configurations

Residential heat pumps are available in a wide array of configurations that offer versatility to accommodate individual preferences, building designs, and spatial constraints. There are multiple indoor/outdoor unit types, sizes, mounting styles, and design options available. In this section, we will explore the definitions of terms used to describe the various configurations of residential heat pump systems.

Location of Heat Pump Components: Split system vs. Packaged system

Split-system Heat Pump

Most heat pumps are split-systems—that is, they have one refrigerant coil inside and one outside. Supply and return ducts connect to the indoor blower fan in ducted, central systems. In ductless heat pumps, air is distributed via one or more indoor units mounted to the wall, ceiling, or floor.

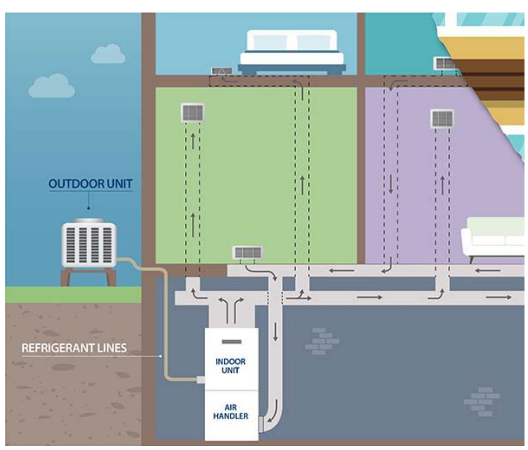
Packaged Heat Pump

Packaged systems usually have both coils and the blower fan located outdoors. Heated or cooled air is delivered to the interior from ductwork that is connected to the packaged heat pump and passes through a wall or roof.

Type of Distribution System: Ducted vs. Ductless vs. Short-run Ducted vs. Hydronic

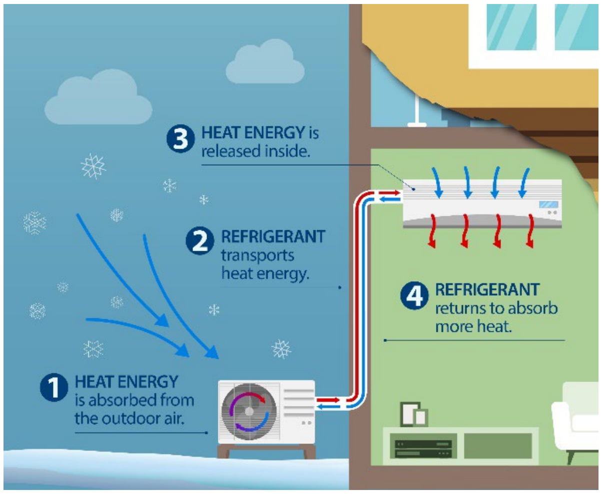
Ducted Systems (also referred to as "Central systems")

Ducted systems, also known as central heat pumps, use a network of ducts to distribute heated or cooled air throughout the home. They can integrate with existing ductwork or be installed with planned ductwork as part of new construction. Several types of heat pumps can have ducted configurations, including air-source heat pumps, geothermal heat pumps, and hybrid heat pumps.



Ductless Systems

Whereas traditional heat pumps and central air conditioning systems force cooled and heated air through ducts, ductless heat pumps deliver air directly into different zones. The term “ductless” refers to a type of distribution system where air is delivered through individual indoor units, or “heads,” that are mounted to the wall, ceiling, or floor of the room that they condition. A head or several heads (see single-zone vs. multi-zone definitions below) can be connected to a single outdoor unit to create zones. Several types of heat pumps can have ductless configurations, including air-source heat pumps and geothermal heat pumps.



Note: Ductless systems are a cost-effective way to replace inefficient window air conditioning units and replace or displace space heaters and electric baseboard heaters. They can be installed in home additions, new construction, condominiums, and apartments, or to improve temperature control in specific rooms. Ductless systems can even be fit for buildings that currently use ducted forced-air systems.

Short-run Ducted Systems (also referred to as Compact-ducted systems”)

Short-run ducted heat pumps have an indoor unit located above the ceiling or below the floor that is connected by short runs of ductwork to one or more registers. One advantage is that the indoor unit is out of sight and the registers are inconspicuous. Because one indoor unit can be ducted to multiple registers, they can also be well suited to heating several small rooms like bathrooms and bedrooms. A common configuration is an indoor unit installed in an insulated attic connected to a grill in a hallway ceiling below. Hallway air is returned to the unit, heated or cooled, then supplied to multiple adjacent rooms via ceiling vents. Alternatively, they can be installed beneath the floor (typically in the basement ceiling below). Super-insulated homes with very small heating demands may be good candidates for a small mini-duct indoor unit with ducts throughout the house.

Hydronic

Hydronic distribution systems for heat pumps use water as a medium to transfer heat to and from a home through a closed-loop system of pipes. For both heating and cooling, the water circulates through various types of indoor emitters, such as radiators, radiant panels, baseboards, or fan coil units. These emitters release heat from the water into the living spaces for warmth or absorb heat from the living spaces into the water for cooling. Radiators and radiant flooring provide radiant space conditioning, while fan coil units use forced air circulation. The hydronic system efficiently moves heat by taking advantage of water's high thermal capacity.

Zoning: Single-zone vs. Multi-zone

Single-zone Heat Pump

A single-zone heat pump is a ductless heat pump that consists of one indoor air-handler unit (or 'head') and one outdoor compressor unit. This type of system is designed to provide air conditioning in one specific area or 'zone' within a space, providing individualized control over temperature settings in that area. Single-zone systems are often used in scenarios where there is only a need for additional heating or cooling in a specific room, or to bring air conditioning to a section of a home that doesn’t receive heating and cooling through its original HVAC system, like a garage, a newly finished basement, or a home addition.

Multi-zone Heat Pump (also referred to as “Multi-split heat pump”)

A multi-zone heat pump is designed to provide air conditioning to multiple rooms or areas in a space. The system features a single outdoor unit (or sometimes more depending on the size of the home) that connects to multiple indoor units. Unlike single-zone systems, multi-zone systems allow for individualized temperature control in different zones. While the entire system must be in heating or cooling mode, each zone in a multi-zone system can be controlled independently for optimal individual comfort. Multi-zone heat pumps often utilize ductless distribution systems, though some models combine both ductless and ducted distribution.

Heat Pump Components

Heat pump systems are composed of various components that work together to provide heating and cooling. Each component plays a crucial role in the system's functionality and efficiency. In this section, we will explore the definitions of key terms used to describe the components of residential heat pump systems.

Air Handling Unit (AHU)

The air handling unit (AHU) plays a vital role in the heat pump system by conditioning and circulating air within the building or space. Tailored for heat pump operations, the AHU incorporates essential components like a blower or fan for air circulation, air filters to eliminate particulates, and a coil serving as a heat exchanger. During operation, the air handler directs air across the coil, where heat is added or removed, depending on the heating or cooling requirements, ensuring optimal indoor comfort.

Note: For ducted central heat pump systems, the AHU houses the coil, blower, and filters within its casing. The coil inside the AHU allows heat transfer between the refrigerant piped from the outdoor unit and the air being circulated by the blower. The conditioned air is then distributed throughout the building via the duct network.

For ductless heat pump systems, the AHU is an indoor unit, or head, often mounted on the wall, ceiling, or floor. Each individual unit houses a coil, fan, and filter to condition the air in that particular zone or room.

For packaged heat pump systems, the AHU is located outdoors and consolidates all the necessary air handling components like the coil, blower, and filters into a single enclosed casing.

Compressor

A heat pump compressor is a crucial component that circulates refrigerant through the system, enabling the transfer of heat for both heating and cooling. It works by compressing the refrigerant, raising its temperature and pressure, which facilitates heat exchange with the surrounding environment. The type of compressor significantly impacts the heat pump's efficiency and performance. The compressor's efficiency directly affects the overall energy consumption and operating costs of the heat pump system, making it a key factor in system selection and performance optimization. Residential heat pump systems use compressors with various designs (scroll, rotary, or reciprocating) and speed configurations.

- ### Single-stage Compressor

  Single-stage, or single-speed, compressors are the most basic compressors for heat pumps. They have two settings: on or off, meaning they operate at full capacity or not at all. These systems work at full speed to reach the desired temperature and then shut off completely once the indoor temperature is reached. Because of the frequent switch from on to off, and because they can only operate at 100% max speed, heat pumps with single-stage compressors are usually the most expensive to operate.

- **Two-stage Compressor**

  Two-stage, or two-speed, compressors take heat pumps with single-stage systems up a notch and control temperature more accurately. While single-stage systems must operate at either 0 percent or 100 percent capacity, two-stage systems add more variety by offering a high and low setting. In most cases, the low stage operates at around 65 percent capacity, while the high stage operates at 100 percent capacity. Compared to single-stage systems, the two-stage system provides improved efficiency and temperature control.

- **Variable-speed Compressor** (also referred to as "Inverter-driven compressor")

  Variable speed compressors use inverter technology to adjust the compressor's speed continuously to match the exact heating or cooling demand, offering the highest efficiency and most precise temperature control. When the temperature is set on the thermostat, a variable speed system takes into account the indoor and outdoor temperatures, the indoor and outdoor humidity levels, and the run time needed to reach your desired temperature, in order to determine the appropriate output. Variable speed systems can operate anywhere from 25 percent capacity to 100 percent capacity to meet temperature needs. Because they can operate at lower speeds, they consume less power, which makes them the least expensive to operate over time. You will often hear efficient heat pumps with variable-speed compressors referred to as variable-speed heat pumps, variable-capacity heat pumps, or inverter-driven heat pumps. Cold climate heat pumps are a subtype of variable-speed heat pumps.

Coils (also referred to as "Heat exchangers")

The evaporator and condenser coils inside a heat pump make it possible for these systems to complete the heat exchange process, which is the basis of refrigerated cooling and heating. The coils form a loop and, even though they are continuous, each has a different function. The ability of the condenser and evaporator coils to reverse their roles is a fundamental feature of heat pumps, enabling efficient heating and cooling by reversing the direction of the refrigerant flow through a reversing valve.

- **Condenser Coil**

  In a heat pump, the condenser coil's role varies depending on whether the system is in heating or cooling mode. It is responsible for rejecting the heat from the refrigerant to the surrounding environment.

  Cooling Mode: In cooling mode, the outdoor unit's coil serves as the condenser coil. The high-pressure, high-temperature refrigerant gas flows into the condenser coil, where it releases heat to the outdoor air, condensing into a high-pressure liquid.

Heating Mode: In heating mode, the indoor unit's coil serves as the condenser coil. The high-pressure refrigerant gas releases heat to the indoor air, warming the space, and condenses into a high-pressure liquid in the process.

- **Evaporator Coil**

The Evaporator Coil is responsible for absorbing heat from the air and transferring it to the refrigerant. The evaporator coil's function changes based on the system's mode of operation.

Cooling Mode: In cooling mode, the indoor unit's coil serves as the evaporator coil. The low-pressure, low-temperature refrigerant vapor/liquid enters the evaporator coil, where it absorbs heat from the indoor air and evaporates into a low-pressure gas, cooling the indoor space.

Heating Mode: In heating mode, the outdoor unit's coil serves as the evaporator coil. The low-pressure refrigerant liquid absorbs heat from the outdoor air and evaporates into a low-pressure gas, even in cold temperatures, to provide heating indoors.

Note: In packaged heat pump systems, both the condenser and evaporator coils are housed in the same outdoor unit.

Reversing Valve

The reversing valve is a crucial component in a heat pump system, allowing it to provide both heating and cooling functions by reversing the flow of refrigerant. The reversing valve has four ports that connect to different parts of the system: the compressor, the indoor coil, the outdoor coil, and the expansion valve. When the heat pump is in heating mode, the reversing valve directs the flow of refrigerant through the outdoor coil, absorbing heat from the surrounding air. Refrigerant then flows to the indoor coil where it releases the absorbed heat to the indoor air, providing warmth. In cooling mode, the reversing valve changes the flow of refrigerant through the indoor coil, absorbing heat from the indoor air. Refrigerant then flows to the outdoor coil where it releases the absorbed heat to the outdoor air, providing a cooling effect inside the home or building.

Expansion Valve

The expansion valve drops the refrigerant pressure and expands the refrigerant as it passes from the condenser coil into the evaporator coil. The expansion valve's control of refrigerant pressure helps the evaporator coil to transfer heat most efficiently over its entire surface area while still guaranteeing the refrigerant fully evaporates before entering the compressor.

Blower Motor

The blower motor is the component of a heat pump that turns the system's fan that circulates the hot or cold air through the air handling unit and into a home. The exact HVAC blower motor location will vary slightly depending on the system type and model. For central heat pumps, it will be located inside the air handler (i.e., the indoor unit). For a ductless system, each indoor unit will have its own blower motor that is typically located behind the air handler casing and between the control panel and the fan blade. The efficiency and performance of a heat pump are heavily influenced by the type of blower motor employed. Single-speed motors operate at a fixed speed, while two-speed motors offer high and low settings for better efficiency and comfort. Variable-speed motors adjust their speed precisely to meet heating or cooling demands, maximizing energy efficiency and comfort. The choice of blower motor impacts energy use, noise levels, and overall comfort in the home.

Refrigerant

Refrigerants are the working fluids used in heat pump systems. They are chemical compounds that change temperature as they transition between liquid and gas form – cooling as they vaporize and heating up as they condense. It is this property that gives heat pumps their ability to heat and cool. Refrigerants are circulated throughout the heat pump system during the refrigeration cycle to effectively transfer heat between the indoor and outdoor environments (see below definition of refrigeration cycle).

Line Set (also referred to as "Refrigerant lines")

A pair of copper tubes that connect a condenser to an evaporator so refrigerant can move between the two. The smaller tube is called a liquid or discharge line and carries the liquid refrigerant to the evaporator. The larger tube is called a suction line, and it moves refrigerant in its gaseous form back to the condenser.

Heat Strips (also referred to as "Electric resistance heating elements or Plenum heaters")

Heat strips, also known as electric resistance heating elements, are commonly integrated into the air handler unit of a heat pump system. Depending on the specific design of the system, they are strategically placed either downstream of the heat pump's refrigerant coil or in parallel with it. In colder climates or during periods of extreme cold, heat pumps may experience reduced efficiency as they struggle to extract heat from the air. To maintain consistent heating performance, heat strips automatically activate to provide additional warmth. This ensures that occupants remain comfortable and the desired temperature is maintained throughout the home or building, regardless of external conditions impacting the heat pump's efficiency.

Note: Heat strip activation can be linked to outdoor air temperature and/or supply air temperature, depending on the controls. Utilizing supply air temperature as the control can help maintain occupant comfort.

Thermostat

A heat pump thermostat is a specialized device that controls the operation of a heat pump system. It regulates indoor temperature by activating the heat pump based on predefined settings, typically triggered by temperature thresholds. Additionally, thermostats may offer programmable scheduling options, allowing users to automate temperature adjustments throughout the day or week. Advanced models, such as smart thermostats, connect to the internet for remote access and may incorporate adaptive learning algorithms to optimize comfort and energy efficiency. Heat pump thermostats can also activate supplementary heating elements when necessary to maintain indoor comfort levels.

Mounting System

The primary goal of a mounting system is to keep the outdoor unit above the snow. There are several options available for mounting outdoor units. Foundation brackets (mounted to the homes foundation) do the best job at minimizing noise and staying out of the way of rakes, shovels, and lawn mowers. Ground stands minimize noise but can be susceptible to frost heaves if installed with inadequate drainage. Wall mounts keep units away from rakes, shovels, and mowers, but can transmit a low hum inside.

System Features and Functions

Heat pumps offer a range of modern features and functions, many of which differ from traditional residential HVAC systems. These capabilities are necessary for efficient heating and cooling, as well as for ensuring comfortable indoor temperatures throughout the year. Familiarity with diverse features and functions is essential for understanding how heat pumps operate in residential settings. In this section, we will explore key terms related to heat pump features and functions.

Auxiliary Heat (also referred to as "Supplemental heat")

Auxiliary heat is a feature on some heat pump systems that is used when the outside temperature is too cold for the heat pump to efficiently heat the home on its own. Auxiliary heat supplements the heat pump by providing extra heat using a secondary source, such as electric heat strips, to ensure that the desired indoor temperature is reached. When the auxiliary heat setting is activated, the heat pump will continue to pull in as much heat as it can from the outside, but it will also use the secondary heat source to maintain the desired indoor temperature. If the outdoor temperature increases and the heat pump is able to efficiently heat the home on its own, the auxiliary heat setting will automatically turn off.

Note: The terms "auxiliary," "supplemental," or "secondary" heat is also often used to refer to a fossil fuel-fired system in hybrid heat pump systems. The distinction lies in how the heat pump system operates: instead of augmenting the heat pump's heat with electric heating elements, it switches off the heat pump entirely and transitions to the fossil fuel system.

Emergency Heat

Emergency heat is a setting on a heat pump system that is used in emergency situations, such as when the heat pump is not functioning properly. This setting is activated manually and bypasses the heat pump, using an alternate heating source, such as a fossil-fuel-fired furnace or electric resistance, to heat the home. The emergency heat setting is meant to be used as a temporary solution when there is not enough time to call a technician for repairs or when the heat pump is not working. It serves as the secondary heat source for the system, allowing the home to continue to be heated while the heat pump is being repaired or replaced.

Defrost Cycle (also referred to as "Defrost mode")

In heating mode, a heat pump pulls heat from the outside air and transfers it inside to warm it. Under certain ambient temperature and humidity conditions (more common when outdoor temperatures are around freezing and outdoor humidity is relatively high), the moisture in the air freezes on the outdoor unit's heat exchanger as the fan blows the air across it, and frost can form on the outdoor coil. This layer of frost will ultimately make the heat pump operate inefficiently, so it needs to be removed. During the defrost cycle, the heat pump is operated in reverse (switches to cooling mode). A defrost control tells the reversing valve when to send hot refrigerant outdoors to thaw the outdoor coil, turn the outdoor fan off, and the internal heater on. When the heat pump switches over, the outdoor fan is prevented from turning on and the temperature increase of the coil is accelerated. The time it takes to thaw the outdoor coil will vary, but heat pumps will typically be in defrost cycle until the coil reaches around 58 degrees. Once the unit is free of frost, the internal heater will stop, the valve will reverse, the outdoor fan will turn on, and the unit will resume the heating cycle.

Note: During the defrost cycle of a heat pump, an occupant might hear a noise similar to a tire losing pressure, which is normal for single-stage systems. Additionally, it may appear as though smoke is coming from the unit, but this is actually steam generated during the defrost process. Both of these phenomena are typical and indicate that the defrost cycle is operating correctly.

Dehumidification

Dehumidification is the process of reducing the moisture or humidity levels in the indoor air, typically by condensing water vapor into liquid form and removing it from the air. Similar to air conditioning, one feature of heat pump systems is their ability to provide dehumidification of indoor air by removing moisture while operating in cooling mode. During the cooling mode, warm, humid air from the home is drawn into the system by the indoor fan. Inside the unit, this air passes over the evaporator coil, which is maintained at a colder temperature. The temperature difference between the warm indoor air and the cold evaporator coil causes moisture (water vapor) in the air to condense. This condensed moisture collects on the surface of the evaporator coil and drips down into a drain pan or drainage system.

Note: Some heat pump models include a specialized "dry mode" setting. In dry mode, the unit operates at a lower fan speed, allowing the evaporator coil to stay colder for longer periods. This extended exposure helps the coil remove more moisture from the air without significantly lowering the room temperature. Additionally, variable-speed heat pumps tend to be more proficient at dehumidification than other types of systems.

Grid-connectivity

A grid-connected heat pump has built-in communication capabilities allowing it to receive signals and commands from the utility company over the electrical grid. This two-way communication link allows the utility to remotely control or curtail the heat pump's operation during periods of peak energy demand as part of demand response programs. In exchange for this control, utilities often provide incentives like rebates or lower electricity rates to customers with connected heat pumps enrolled in demand response programs. However, many variable-speed heat pump units are currently incompatible with utility demand response programs.

Zoning

Zoning is a feature of some heat pump systems that allow them to divide a home into different areas, or zones, to provide separate heating and cooling. Instead of having one thermostat or controller for the entire building’s air conditioning, each zone could have its own thermostat or controller to adjust the temperature according to occupant preferences, making it possible to meet different temperature requirements in different zones.

Note: Zoning can be done using both ducted and ductless heat pump systems. In the case of ducted systems it requires dampers, which are movable vents that channel the air that circulates through the ducts by fully or partially opening and closing them. Modern systems have automatic dampers that move according to the comfort required in each zone and are controlled by the thermostat or controller. Ductless heat pump systems can be zoned using multi-split systems. Depending on the system, each interior unit can have its own remote control to adjust temperature to different zones' requirements. There is also the option of having a centralized controller that gives the operator full visibility of a zoned heat pump system's operation.