ELECTRIC POWER RESEARCH INSTITUTE

Air-Source Heat Pumps for Residential and Light Commercial Space Conditioning Applications

Air-source heat pumps provide important options for residential and light commercial space heating and cooling applications. (Residential heat pumps consist of single phase equipment under 65,000 Btu/hr and light commercial equipment is defined as three phase equipment between 65,000 and 135,000 Btu/hr.) This technology brief is designed to provide the user of air-source heat pumps with information about how heat pumps operate, types of air source heat pumps that are available in the U.S. market and their attributes, (including refrigerant selection, and low temperature performance). Information is provided on applicable efficiency standards, how rated efficiencies are determined and the range of cooling and heating efficiencies that can be expected to be seen in the market. A discussion of important customer attributes includes ownership costs, comfort, noise and reliability. Utility benefits such as load factor impacts, and heat pump incentives are also addressed. Suggestions for work needed to improve air-source heat pump technology and market penetration are included.

Table of Contents

How Do Heat Pumps Work?

An air-source heat pump is a device for absorbing heat from the air and raising the air to a higher temperature. For this document we are concerned solely with air-source heat pumps for space heating and cooling. When operating in the heating mode, the air-source heat pump absorbs heat from the ambient air and raises it to a higher, more usable temperature; delivering it to the space. In the cooling mode, heat is removed from the space, elevated to a higher temperature and rejected to the ambient air. (In this mode the ambient air is the heat sink for the heat pump.) The vast majority of air-source heat pumps used for space conditioning in the United States deliver the heating or cooling to the space with air distribution, either through duct work or with air flowing over the refrigerant coil.

All commercially available heat pumps in the United States use the vapor compression cycle, sometimes called the (reverse) Rankine cycle. Vapor compression cycle heat pumps use a volatile working fluid, a refrigerant, and the processes of vapor compression, condensation, pressure reduction, and evaporation. Figures 1a and 1b[1] show the working cycle of a typical air-source heat pump in the heating and cooling modes. In the heating mode (Figure 1a), gaseous refrigerant enters the compressor, is compressed and is delivered as a high-pressure, superheated gas to the condenser (indoor coil), where it transfers heat to the air in the space being heated. Since the refrigerant gas

1 *Heat Pump Manual, Second Edition.* EPRI, Palo Alto, CA: 2007. 109222

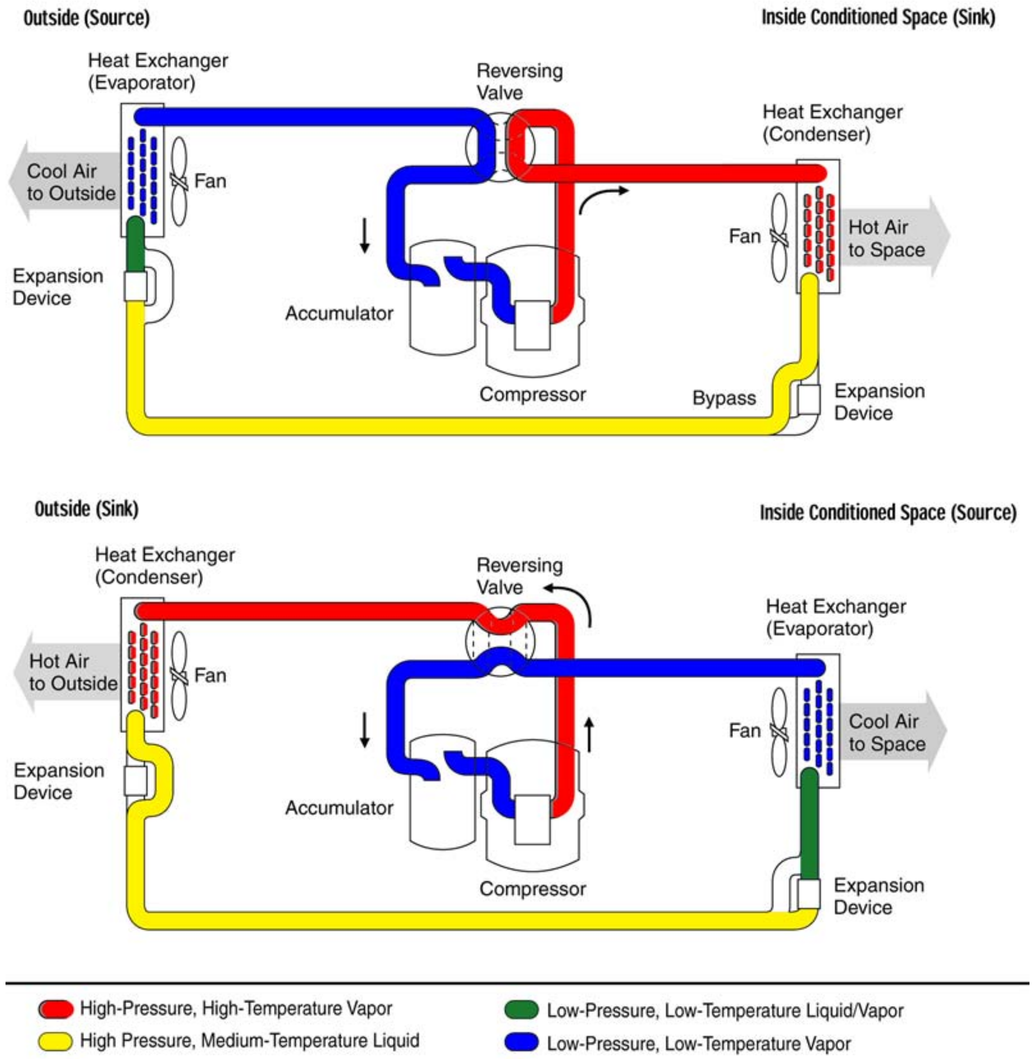


Figure 1. Basic Heat Pump Operation, Air-to-Air Heat Pump, a) Heating, b) Cooling (Heat Pump Manual, Second Edition. EPRI, Palo Alto, CA: 1997. 109222)

is hotter than the return air, the refrigerant gas cools and condenses, correspondingly raising the temperature of the air delivered to the conditioned space. The condensed refrigerant, in the form of a warm, high-pressure liquid, then enters a pressure-reducing device such as an orifice or expansion valve. This pressure reduction causes partial vaporization of the refrigerant. The partially vaporized refrigerant flows into the evaporator (outdoor heat exchanger), and, because the refrigerant's temperature is now below that of the ambient surrounding air, the refrigerant absorbs heat from the outdoor air, causing the remaining liquid to evaporate. The resulting low-pressure, low-temperature vapor then enters the suction port of the compressor, and the cycle continues.

In the cooling mode (Figure 1b) the reversing valve reverses the roles of the indoor and outdoor heat exchanger. The hot discharge gas from the compressor first enters the outdoor heat exchanger (now the condenser) where its heat is released to the outdoor ambient air. The hot high-pressure liquid then passes through the pressure reduction device and enters the indoor heat exchanger (now the evaporator) where it evaporates at low temperature and pressure, absorbing heat from air in the conditioned space and thereby cooling this space.

The heat pump evaporator removes moisture from the surrounding air. When the indoor coil is the evaporator as in the cooling mode, the temperature of the evaporating refrigerant gas is low enough (typically 45°F or lower) that the surface of the evaporator is below the dew point of the return air, moisture condenses on the evaporator surfaces and the humidity of the air declines. In the winter, this process can cause frost to form on the evaporator (now the outdoor heat exchanger) when its surface is below the dew point of the outdoor winter air. This commonly occurs when the outside air temperature is 20–45°F; below 20°F there is usually too little moisture in the air to cause condensation. Frost must be removed to prevent its accumulation on the outdoor coil from blocks airflow and impairing the capability to absorb heat. Most heat pumps are equipped with an automatic defrost cycle for this purpose. Some heat pumps activate the defrost cycle based on temperature and time since the last defrost. Some heat pumps use pressure drop or other measure of performance to trigger defrost (known as demand defrost). Some use both demand defrost with time-temperature as a backup.

The capacity (and the efficiency) of the vapor compression cycle to transfer heat from a lower temperature to a higher temperature decreases as the temperature difference between the source and sink increases. This is illustrated in Figure 2 where the cooling load, heating load and heat pump capacity are plotted versus outdoor temperature. The thermal balance point is where the load and capacity are equal. As the temperature difference increases the load increases. Conversely, as the temperature difference increases the heat pump capacity decreases. This creates a situation where an undersized cooling device cannot meet the cooling load and the space temperature would then rise. If the heat pump cannot meet the load in the heating mode, auxiliary heat may be activated, usually in the form of electric resistance elements (strip heat), to meet the load. For this reason the heat pump is usually sized to meet the cooling load.

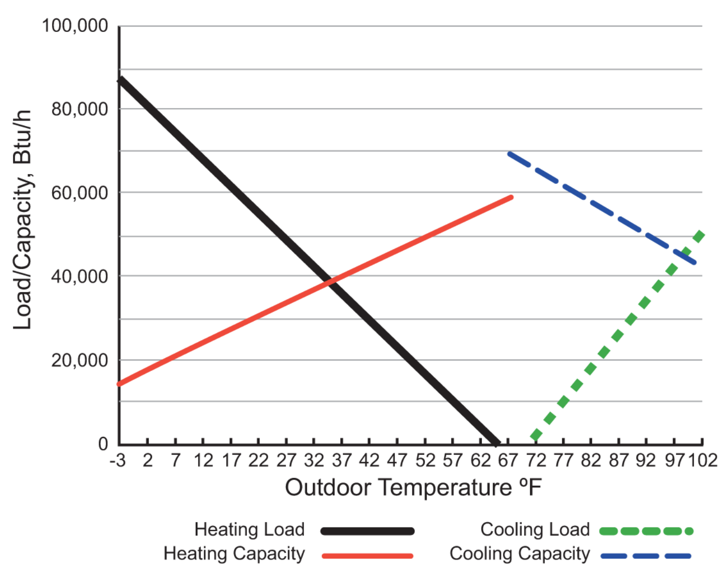


Figure 2. Load and Capacity Lines for a Typical Air Source Heat Pump (Heat Pump Manual, Second Edition. EPRI, Palo Alto, CA: 1997. 109222)

In areas with many hours at low outdoor temperatures the shortfall between the heating capacity and the heating load at low outdoor temperature can require the use of a substantial amount of electric resistance heat with a corresponding increase in the energy use of the heat pump. Because of this, heat pumps have received the widest market penetration in areas of the U.S. with relatively mild winter temperatures. The sidebar on low temperature performance illustrates this point and suggests ways to overcome the problem.

Low Temperature Performance

Figure 2 shows the load and capacity for a typical air-source heat pump. The heating load and the heating capacity match at the thermal balance point of around 37°F and 36,000 Btu/hr. Below that temperature back-up heat is required to satisfy the load. As the outdoor temperature is reduced, the load increases and the amount of back up heat increases to the point where at 0°F the load has more than doubled, the heat pump capacity has dropped by more than half, and back-up heat is providing almost 80% of the heating load. The coefficient of performance (COP) of a heat pump is the amount of energy delivered to the space divided by the amount of energy input into the heat pump. For a typical split system heat pump the COP will be about 3.5 at 47 °F and 2.3 at 17 °F and 1.6 at 0 °F. If the capacity/load curve is as shown in Figure 2 then the effective COP for this heat pump at 0 °F (including the resistance heat needed to meet 80% of the load at a COP of 1) will only be a little more than 1.1. Increasing the compressor size and the heat exchanger sizes will improve low temperature performance. There are several other ways of improving heat pump low temperature performance. These include:

- Using a fossil furnace backup. Since the dual fuel concept uses no resistance heat, all the electric heating will be at a COP of 1.6 at 0°F.
- Using two compressors in series and an economizer to boost performance as with the Acadia system. The Acadia heat pump is claimed[2] to provide more than 100% of its 47°F capacity at 0°F a COP of 2.24. The load at 0°F will be about twice that of the heat pump capacity at 47°F so the effective COP to meet twice the load will be about 1.62. A Daikin variable refrigerant flow system under development that is designed for cold climates using two compressors in series with an intercooler (to subcool liquid entering the expansion device) was reported[3] to have 87% of the nominal capacity at 0°F at a COP of about 2.75. This provides an effective COP of about 1.77.
- Variable speed drive compressors to increase heat pump capacity. Variable speed compressors would require substantial over speed capability of about 5 to 1 in order to increase capacity sufficiently to avoid the use of all or most of the electric resistance backup and thus provide all or most of the heating at a COP of 1.6.
- Enhanced vapor injection (EVI) to "supercharge" the cycle. Vapor injection was reported to provide a VRF system with have a COP of 1.66 and 94% of the full load capacity,[4] but the load could be double at 0°F so the effective COP likely will only be about 1.3.

2 James Bryant, "Designing Air Source Heat Pumps for Cold Climates," Hallowell International in Appliance Magazine, July 2008

3 Chris Bellshaw, "Low Ambient Heating Performance of VRF Systems," Daikin AC, Presented at ASHRAE Annual Meeting, Salt Lake City, June, 2008

4 Joe Bush, "VRF Heating in Northern Climates," Mitsubishi Electric, Presented at ASHRAE Annual Meeting, Salt Lake City, June, 2008

Heat Pump Components

The major components of a vapor compression cycle heat pump are the compressor, heat exchangers (a condenser and an evaporator), and expansion device. Other devices include fans and blowers, suction line accumulators, a liquid line filter dryer, a reversing valve, supplementary heaters and controls.

Compressors

Compressors are discussed in detail in the 2008 ASHRAE Handbook.[5] Air source heat pumps use positive displacement compressors with the traditional workhorse being reciprocating compressors, most often in a single-acting, single stage configuration using pistons that are directly driven through a pin and connecting rod from the crankshaft. Other reciprocating compressor configurations of interest are two-stage compressors (for capacity modulation) and booster compressors (in series with another compressor to achieve "higher lift" conditions. Capacity reduction with reciprocating compressors can be achieved by cylinder unloading. A schematic of the piston operation of a reciprocating compressor is shown in Figure 3.

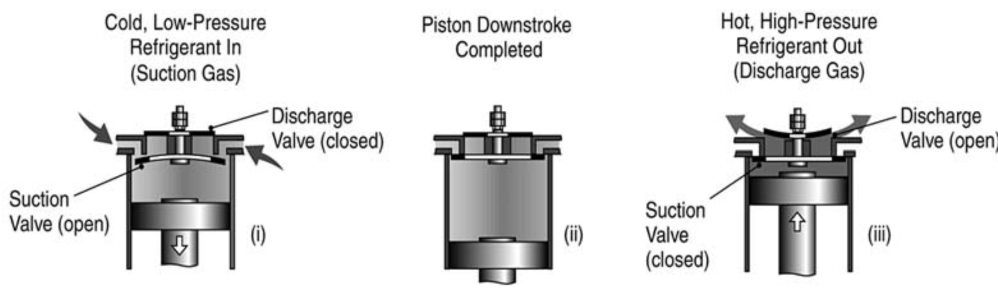


Figure 3. Principle of Operation of Reciprocating Compressor (Heat Pump Manual, Second Edition. EPRI, Palo Alto, CA: 1997. 109222)

Rotary compressors are available in rolling piston/fixed vane and rotary vane configurations. Rolling piston configurations are generally used for smaller capacity units. Rotary compressors are often used in packaged terminal units and in some room heat pumps in the U.S. and are also used in mini-split, multi-split and variable refrigerant flow (VRF) systems now becoming more widely used in the U.S. market. An enhanced version of a rotary compressor is the "swing" compressor shown in Figure 4. This unit should have low vibration, low noise, and high efficiency.

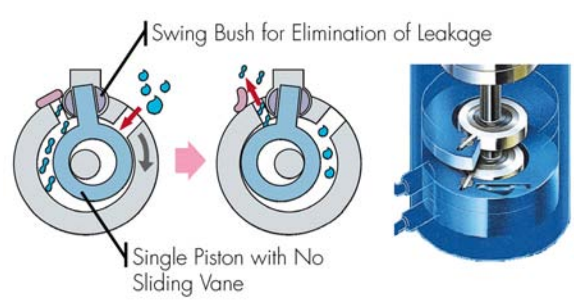


Figure 4. Schematics of Daikin Rotary Swing Compressor Used in Multi-Split Systems (Courtesy of Daikin AC)

5 *HVAC Systems and Equipment*, Chapter 37, Compressors; ASHRAE Handbook, 2008.

Scroll compressors are becoming the compressor of choice for unitary (factory built) heat pumps in the United States. The scroll compressor does not require suction or discharge valves, has a relatively flat volumetric efficiency than reciprocating curve permitting increased high lift capacity. As shown in Figure 5, the lower scroll (the moving scroll) undergoes a circular orbital motion. Compression is accomplished by sealing the suction gas incrementally in pockets of a given volume at the outer periphery of the scrolls.

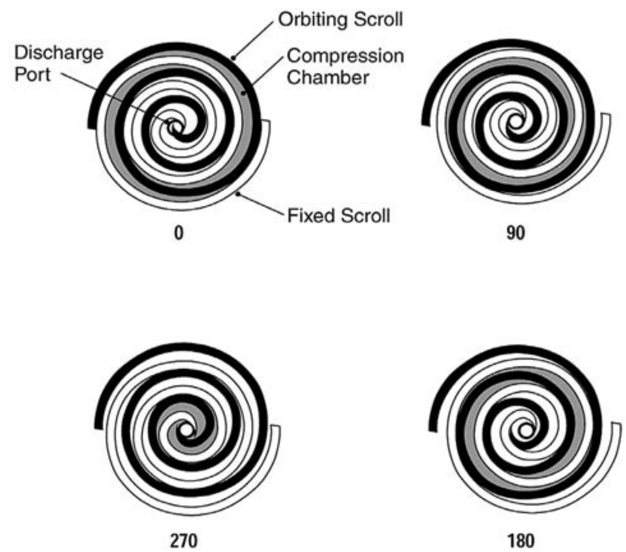


Figure 5. Scroll Compressor, Principle of Operation (Courtesy: Emerson Climate Technologies, Inc.)

As the lower scroll moves toward the discharge port the contained mass is compressed into a smaller and smaller volume, raising its pressure until it exits the central discharge. Two distinct compression paths operate simultaneously with nearly continuous discharge. These units have fewer moving parts and less torque variation compared to the reciprocating compressor resulting in smoother and quieted operation. The lack of a clearance volume (as with the rotary compressor) results in a higher efficiency.

Heat Exchangers

All heat pumps have two heat exchangers (coils), a condenser and an evaporator. The vast majority of air-source heat pumps use air delivery systems; thus both heat exchangers are air to refrigerant units. The refrigerant is contained in tubes, usually copper and often with grooves inside the tubes to enhance heat transfer. The air side of the heat exchanger has enhanced surfaces using fins of various configurations, usually of aluminum. Multiple refrigerant circuits are often used to minimize refrigerant-side pressure drop. The configuration of both the indoor and outdoor coils must be designed to permit condensate drainage since both coils will function as evaporators and will have moisture forming on them. The indoor coil is often arranged in an "A" shape and as such is termed the "A" coil, as shown in Figure 6.

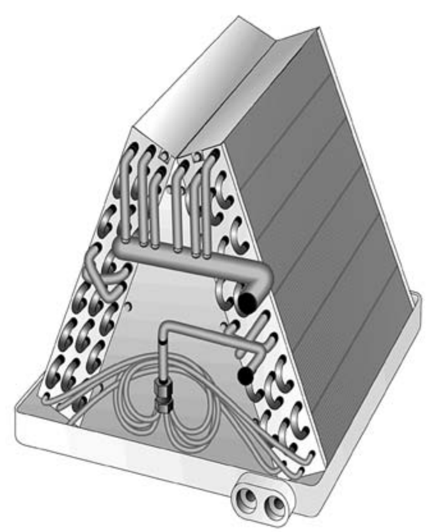


Figure 6. Typical Heat Pump Indoor Coil

Fans and Blowers

Air moving devices assure adequate air-side heat transfer by blowing air over the refrigerant coil. Indoor coils in unitary equipment often use centrifugal blowers with forward curved blades for higher efficiency to force air through the coil. Outdoor fans are often of propeller type, with a direct-driven weatherized motor, pulling the air flow through the coil.

Expansion Devices

Expansion devices are used to lower the temperature and pressure of the condensed liquid refrigerant so that it can be heated from a liquid to a gas in the evaporator section of the heat pump. The simplest heat pump expansion devices are fixed restrictions in the form of orifices or short tubes. Thermostatic expansion valves use a sensing bulb and spring pressure to open or close in response to changes in the pressure (or the superheat) of the fluid/vapor leaving the evaporator. Electronic expansion valves (EXVs) uses solenoid actuated plungers to respond to evaporator requirements. EXVs permit flow in either direction.

Other Components

Suction line accumulators are installed upstream of the compressor to separate liquid from vapor to keep quantities of liquid from entering the compressor. The suction line accumulator also meters refrigerant into the compressor with the oil needed for lubrication. The ***liquid-line filter dryer*** removes water entrapped in the system. The ***reversing valve*** is a solenoid operated valve installed on the suction side of the compressor. The inlet flow to the valve is vapor from the evaporator and the valve switches positions from the heating mode to the cooling mode to bring the vapor from the outdoor coil in the heating mode and from the indoor coil in the cooling mode. Programmable ***thermostats*** are used to preset cooling and heating functions, controlling indoor temperature to ±1°F or less. ***Energy management controls*** are often used in commercial buildings and can control the heat pumps directly or communicate with accessible, addressable thermostats. Smart heat pumps can be controlled via the internet.

Ongoing EPRI studies show how these devices can control heat pumps as part of an overall energy management, demand response strategy. ***Defrost controls*** are either demand or time-temperature. A timed defrost can be set for a given time and to deactivate after a preset time when the outdoor temperature is in the frosting range. Demand defrost units can be activated based on liquid line temperature. They are also often set for a maximum time interval between defrosts and a restriction on the length of the defrost cycle.

The compressor ***motor*** is contained within the hermetic compressor shell and is cooled by refrigerant. Single, two-speed and variable speed compressor motors are used. The most widely used are single speed alternating current induction motors. Some two speed compressor motors automatically switch between two pole and four pole operation to allow the heat pump to operate at two different speeds and capacities. Variable speed compressors are often used in multi-split and variable refrigerant flow systems. Fan and blower motors are air cooled. Fixed and variable speed blowers are used for indoor air movers; using variable speed to provide more precise temperature and humidity control and more gradual stops and starts.

Types of Air-Source Heat Pumps

This section provides information on the characteristics of unitary air source heat pumps (single package, split, dual-fuel, booster, mini-split, multi-split and variable refrigerant flow systems), room heat pumps and packaged terminal heat pumps

Unitary Air Source Heat Pumps

Unitary heat pumps are factory made assemblies that include an evaporator, condenser and compressor. A heat pump with one factory built assembly is called a single-package system and a heat pump with more than one factory built assembly (indoor and outdoor units) is commonly called a split system. Unitary equipment is divided into three classifications; residential, light commercial, and commercial. Residential equipment is single phase with a capacity of 65,000 Btu/hr or less. Light Commercial equipment is three phase with a capacity of between more than 65,000 Btu/hr and less than or equal to 135,000 Btu/hr. Commercial equipment is over 135,000 Btu/hr in capacity. About 2 million single package and split system air source heat pumps of all sizes have been shipped annually in recent years (including mini- and multi-splits). Less than 15% of these shipments were single package; the rest were split systems. Well over 90% of the units were under 65,000 Btu/hr and just over 1% of these 2 million shipments were in the light commercial category.

Single-package heat pumps are configured as self-contained, factory-assembled modules that contain all the components of the refrigeration system: compressor, indoor and outdoor coils, fans and controls, and supplemental heating (See Figure 7).

The majority of these units are designed for installation outdoors, either at grade level or on the roof. This requires bringing the supply and return air ducts through the building envelope to connect to the indoor side of the heat pump. Single phase single package units range from about 18,000 to 62,000 Btu/hr in nominal cooling capacity and from 18,000 to 60,000 Btu/hr in 47°F heating capacity. Practically all three phase single package heat pump units available for sale are larger than 68,000 Btu/hr in nominal cooling capacity. In residential applications, single-package heat pumps are appropriate for smaller homes that are built on a slab or over a crawl-space and have insufficient floor space for an air handler unit. The heat pump is typically located at one end of the house and the main supply and return air ducts are brought to it through the end wall. In some areas (for example the Southwest), single-package heat pumps are installed on rooftops with ducts connected to the side or bot-

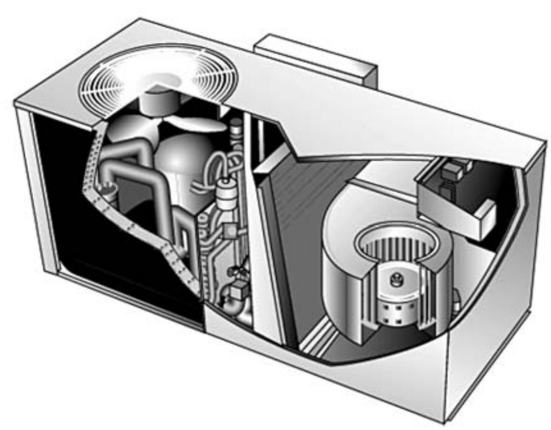


Figure 7. Single Package Heat Pump

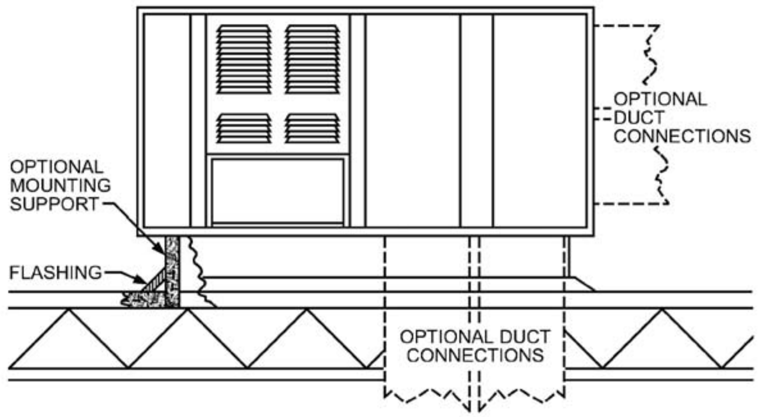


Figure 8. Rooftop Installation of Single-Package Unit (Courtesy of ASHRAE, Systems and Equipment Handbook, Chapter 48 page 48.4. 2008)

tom of the heat pump. Single-package heat pumps installed in commercial buildings are also either ground- or roof-mounted.

The designation rooftop usually implies a commercial-size single-package air conditioning or heat pump unit designed for rooftop installation; with provisions for down flow or side flow duct connections (see Figure 8). Typical applications of rooftops are supermarkets, shopping mall "strip-stores," office complexes, and other buildings with flat roofs. Unitary packaged rooftop units range from around 2 to 30 tons; with most installed rooftop units having a 5 or 7.5 ton cooling capacity. Large multi-zone packaged heat pumps are available in sizes up to 25 tons. Multi-zones are a type of rooftop heat pump in which multiple self-contained heat pump units are assembled on one chassis and have duct connections to serve multiple zones.

The split-system air-source heat pump is the most common type of heat pump sold in the United States, consisting of two or more factory-built modules to be assembled in the field: an outdoor unit containing the outdoor heat exchanger (coil), fan, fan motor, compressor, and reversing valve, and an indoor unit or air handler with a blower, blower motor, indoor heat exchanger (coil), and electric resistance heating elements (see Figure 9). In some models, including those that provide low temperature space heating, the compressor is located in a separate cabinet indoors. The indoor and outdoor units are connected by insulated refrigerant tubing that is put in place when the heat pump is installed.

Split-system heat pumps are popular because of their installation versatility and flexibility. The outdoor unit can be located where it is as unobtrusive as possible; in residential settings, by the side or in back of a house, away from bedrooms. The indoor unit can be installed in a basement, utility closet, garage, or attic, but typically in a central location in order to minimize the length of any one duct run. In commercial buildings, the outdoor unit or units can be placed in back of a building or on the roof, with the indoor units in the ceiling space or in utility closets. Single phase split-system heat pump equipment is available in nominal cooling capacities ranging from about 10,000 to about 60,000 Btu/hr and about the same range in 47°F heating capacity. All three phase split-system heat pump units available for sale are larger than 65,000 Btu/hr in nominal cooling capacity.

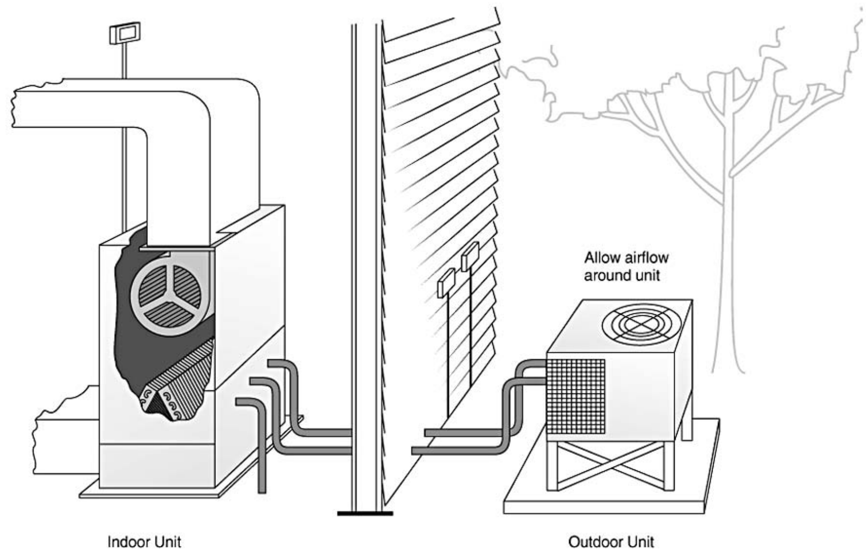


Figure 9. Split-System Heat Pump (Heat Pump Manual, Second Edition. EPRI, Palo Alto, CA: 1997. 109222)

Ductless Mini-Split, Multi-Split and Variable Refrigerant Flow Heat Pump Systems

Ductless heat pumps (DHPs), also known as mini- and multi-split heat pumps are non-ducted, split system heat pumps that were developed in Japan in the 1950s as quieter, more efficient alternatives to window units. They were introduced to the U.S. market by Asian manufacturers primarily for residential applications. A DHP split-system provides space conditioning by distributing cooled and heated refrigerant through a network of insulated refrigerant lines to one or more (typically up to four) fan-coil units located in conditioned spaces. A DHP system with a single outdoor unit and a single indoor unit also is known as a mini-split. Low-profile ceiling- or wall-mounted fan-coil units transfer heat between the refrigerant and the room air. Available in capacity ranges from approximately 1 to 4 tons (3.5 kW to 14 kW), DHPs often include features such as variable-speed fans, variable-capacity compressors, and wireless controls. Such inverter driven variable speed compressor and fan systems have demonstrated substantial energy efficiency and customer comfort benefits. In addition, units with multiple evaporators have individual thermostats to control the operation (e.g., temperature setpoint) of each indoor coil.

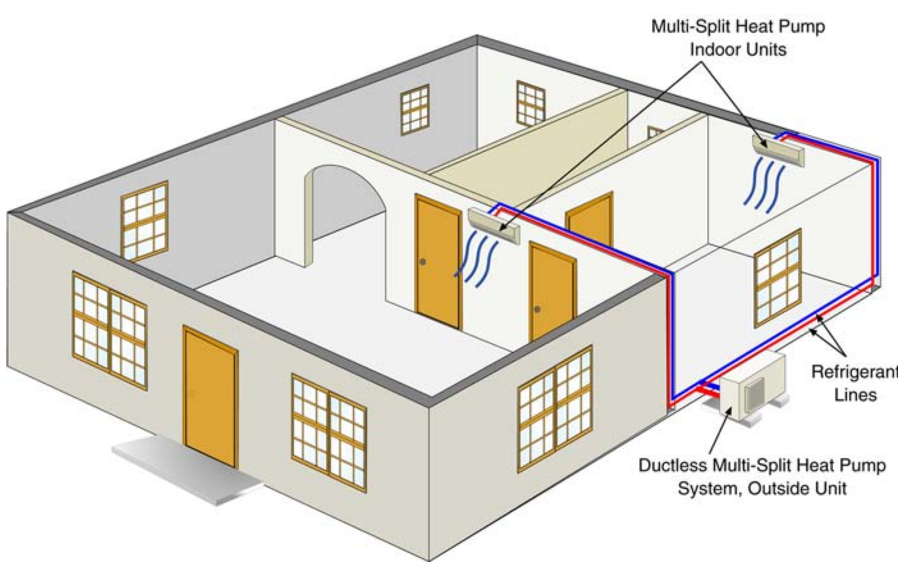
Products have evolved from a single indoor unit operating off each outdoor unit to 4 to units in the late 1980s to current variable refrigerant flow (VRF) configurations (primarily for commercial buildings) that permit as many as 60 units to operate off one outdoor unit. Units are connected with refrigerant lines. A DHP mini-split product for residential application is shown in Figure 10, and a multi-split product is shown in Figure 11 consisting of one outdoor unit and one or more indoor fan-coil units. Like a central (ducted) split-system heat pump, the outdoor unit can be installed on grade or on the roof, placed on the balcony of a high-rise apartment building, or hung from the underside of a balcony, for example.

VRF systems connect the units in a manner that minimizes refrigerant piping and permits heat recovery between units. More information is provided in the EPRI Technology Brief, *Variable Refrig-*

Figure 10. Ductless Mini-Split Heat Pump System

erant Flow Air Conditioners and Heat Pumps for Commercial Buildings,[6] including market adoption, customer issues, how VRF works, and best applications for VRF. Figure 12 taken from this tech brief illustrates the major components of a VRF system including the range of possible indoor unit configurations. Multi-split and VRF units function as a central zoned heating and cooling system, with refrigerant lines instead of air ducts delivering heating and cooling to the various rooms being conditioned. A multi-capacity (two-speed) or variable speed compressor is used to modulate the refrigerant flow to account for lower occupancy or lower loads than required under design conditions. Compressor modulation can be used to increase low temperature capacity, reducing the need for backup heat, improving low temperature performance. Manufacturers are also working on cycle en-

Figure 11. Ductless Multi-Split Heat Pump Installation



6 "Variable Refrigerant Flow Air Conditioners and Heat Pumps for Commercial Buildings," 1016258, Technology Brief-Energy Efficiency Initiative, EPRI, January 2008

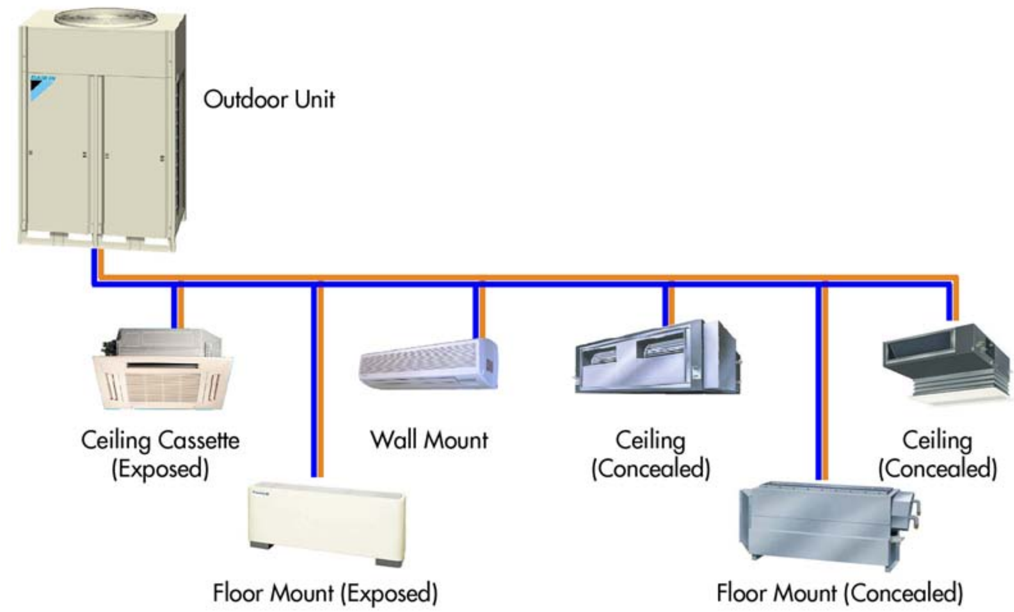


Figure 12. Major Components of a VRF System including the possible range of indoor unit configurations and a typical outdoor unit (Courtesy of Daikin AC)

hancements including using a booster compressor, liquid subcooler, or vapor injection as discussed in the sidebar on low temperature performance. In addition to capacity control these systems offer zoning, ease of retrofit, minimal ducting and energy efficient operation. They are attractive for add-ons to residences and commercial buildings, situations where cooling is desired as an upgrade in a building without ducting, and situations where minimum alterations to the building are desired (as in historic buildings or nursing facilities).

Single phase outdoor units are available up to around 60,000 Btu/hr and three phase outdoor units up to about 300,000 Btu/hr. Indoor wall mounted units for single phase operation are available up to about 24,000 Btu/hr, duct-built-in units up to about 48,000 Btu/hr. Ceiling cassette mounted three phase units for VRF systems are available up to 36,000 Btu/hr.

More than 72,000 ductless mini-split and 16,000 ductless multi-split heat pumps units were sold in North America in 2007. Over 40% of the mini-split market was heat pumps (98,000 were cooling only) and over 80% of the multi-split market was heat pumps (less than 4,000 were cooling only). Both the absolute value of mini-and multi-split shipments and the percentages that are heat pumps have been rising steadily over the past four years.[7]

Dual Fuel Heat Pumps

Dual fuel heat pumps are available in both single package and split system configurations consisting of a heat pump and a forced air furnace (most commonly a natural gas-fired furnace) and as add-on equipment versions where a heat pump is added to a furnace to provide both electric heating and

7 Bellshaw, Chris, "RA Single and Multi-Split Product and Applications Presentation," Daikin, 2008

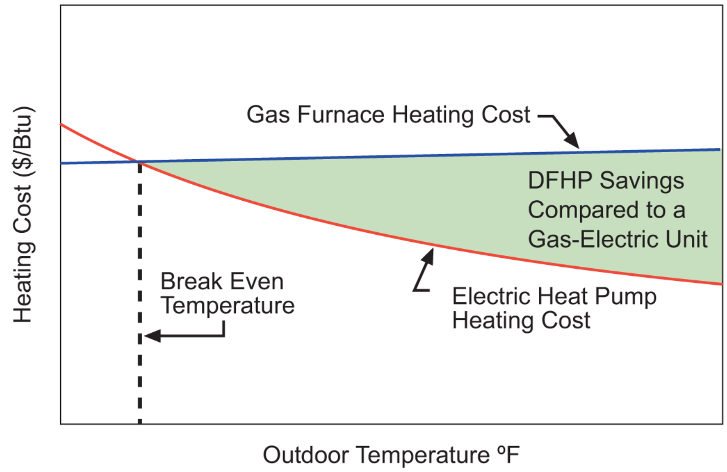


Figure 13. Dual Fuel Heat Pump Breakeven Temperature and Operating Cost Advantages

cooling replacing the air conditioning unit previously used just for cooling. Units are provided by (at least seven) manufacturers as cited in the dual fuel heat pump review guide.[8]

Instructions for installing a heat pump upstream of a natural gas, propane or oil furnace are given in Amana's instruction manual[9] that also includes the following equation for calculating the break-even efficiency of the heat pump and furnace. The breakeven efficiency/COP defines the efficiency and temperature at which both the furnace and heat pump cost the same to operate. Above that breakeven temperature it is most efficient to run the heat pump and below that temperature it is most efficient to run the furnace. This operation is illustrated by the graph in Figure 13 for a case where the balance point is below the breakeven temperature and the heat pump can supply the entire heating load above the breakeven temperature.

The BECOP (break-even coefficient of performance) for dual fuel heat pump using a natural gas furnace is:

> BECOP = 29.3 * AFUE * retail electricity price in ¢/kWh/ natural gas price in ¢/therm
> (AFUE is Annual Fuel Utilization Efficiency)

For a furnace efficiency of 80% (AFUE = .80), national average residential retail electricity price of 10.61¢/kWh[10] and national average residential natural gas price of 182¢ per hundred cubic feet[11] (therm), the BECOP will be 29.3*.80*10.61/182 = 1.37. For the typical heat pump used in the low temperature performance examples, a COP of 1.37 will be equivalent to an outdoor temperature of about -7°F. Since this is likely to be below the balance point temperature, the sequence of operation for this heat pump would be: run the heat pump exclusively above the balance point temperature; run the heat pump below the balance point and above the breakeven temperature to satisfy the first

8 "Heat Pump Review, Dual Fuel heat Pump Review Guide," 2007, http://heat-pump-review.net/dual-fuel-heat-pumps/guide

9 "Amana, FFK03A, Fossil Fuel Kit Installation Instructions," 10664127, April 2000, http://johnstonesupply9.com/TechDocs/Amana/Amana%20Accessorie%20Specs-Manuals/FFK03A%20IO%20MANUAL.pdf

10 "Electric Power Monthly, August 2008 Edition," September 16, 2008, http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html

11 "Natural Gas Monthly, August 2008," August 28, 2008, http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_monthly/current/pdf/figure_03_04.pdf

stage of the thermostat and use the furnace for supplementary heat to satisfy the second stage of the thermostat; run the furnace exclusively below the breakeven temperature.

For local rates the situation could be much different. For example using residential electric[12] and gas prices[13] for Rhode Island of 22¢/kWh and 165¢ per hundred cubic feet (therm), and Idaho of 6.83¢/kWh and 112¢ per hundred cubic feet (therm), provides a BECOP of 3.12 for Rhode Island and a BECOP for Idaho of 1.43. This is equivalent to a breakeven temperature for Rhode Island of about 42°F and a breakeven temperature for Idaho of about 2°F for the typical heat pump used above.

EPRI has studied dual fuel heat pump economics[14] and was a driving force in introducing the first single package units into the market place in 1991[15] and has continued to stay abreast of this technology.[16] EPRI assessments and field tests illustrated the advantages of the concept when gas prices and electricity prices are attractively aligned. For many years gas prices tended to be on the low end or too low for the breakeven temperature to be high enough to provide enough economical heating hours to make the concept viable. The situation can change dramatically with a rapid change in gas prices and relatively modest changes in electric prices. The examples shown indicate that economic breakeven temperature can be enough to encourage a closer look at the concept. Economics depend on the thermal balance point, economic breakeven temperature, climate and application.

Booster Systems

In recent years products have entered the market using two compressors in series with an economizer type liquid subcooler designed to provide increased mass flow, capacity and efficiency at low outdoor temperature. The first units to enter the market were cold climate heat pumps (CCHPs) produced by Nyle Products and were tested in several locations by NRECA and others with mixed results.[17] There were reported manufacturing and installation problems but when the units worked they worked well. The license provided by David Shaw the inventor was terminated with Nyle Products and a new product development arrangement was made with Hallowell Products of Bangor, Maine. Hallowell started producing low temperature heat pumps (LTHPs), also with a booster compressor and an economizer, in 2006. These are predominately 3 and 4 ton split system units, although 2 ton units are also available. They claim sales of about 2,000 units in the past 2 years. Testing of 8 units has been conducted in locations in around the U.S.[18] The units, sold under the brand name Acadia have two compressors paired in series, with the multispeed primary compressor providing two stages of heating (either one cylinder or two cylinder operation) in moderate conditions and two stages of cooling for all cooling operation. When outdoor temperatures drop and supplemental heat is required, a second, larger, booster compressor is used in series with the

12 "Electric Power Monthly, August 2008 Edition," September 16, 2008, http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum.html

13 "Natural Gas Monthly, August 2008," August 28, 2008, http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_monthly/current/pdf/figure_03_04.pdf

14 Joseph Pietsch, "Commercial Unitary Heat Pumps: An Assessment Study," EPRI CU-6371, May 1989

15 Robert E. Hough, "Field Testing of a Dual Fuel Rooftop Heat Pump," EPRI CU-7084, December 1990

16 "Dual-Fuel Heating and Cooling, A Win-Win for Users and Utilities," EPRI 1010986, 2004

17 Linn, Charles, "Can a New Kind of Heat Pump Change the World," Architectural Record, March 2006 http://archrecord.construction.com/resources/conteduc/archives/0603edit-1.asp

18 "Evaluate Low Temperature Heat Pumps" Project 06-16, December 12, 2001 https://crn.cooperative.com/Results/items/2006/CRNResult_06-16.htm

primary compressor (as well as a liquid economizer to subcool the liquid entering the expansion valve) to satisfy the heating load. The primary and booster compressor can generally satisfy the load down to about 15°F and then auxiliary resistance heat is used in combination with the resistance heat. Below minus 35°F the resistance heat operates exclusively. A simple diagram of the system is shown in Figure 14.

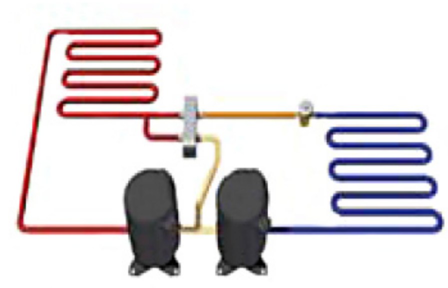


Figure 14. Boosted Compressor System with Economizer. (Courtesy of Hallowell Products)

The resulting performance of this arrangement is a system that maintains more than 100% of its nominal heating capacity at 0°F at a 2.24 COP, and more than 80% at –15°F at a 2.06 COP.[19] The SEER of the Acadia units are around 14 and HSPF of 9.6.[20] (These units are designed primarily for heating with cooling being ancillary in importance.)

Reports and conversations with principals indicate that Nyle Products plans to re-enter the market with an enhanced version of their cold climate heat pump soon and that Electro Industries of Monticello, Minnesota is developing a two compressor split system with the compressor in the indoor unit. Electro Industries plans to look at a variable speed product in their development work with Herrick Laboratory at Purdue. Since their main products are in the radiant floor heating line their advanced heat pump product might have some application there as well. Hallowell is also developing new units for 2009 that would be compatible with radiant floor heating.

Room Heat Pumps

Room heat pumps (also called reverse-cycle room air conditioners) are designed to heat and cool single zones and are best suited to applications where ducts are not available for providing space conditioning or where single zones need to be conditioned separately. Room heat pumps are available in nominal cooling capacities of about 7000 to 17,000 Btu/h. The U.S. market for room air conditioners has been around 10 million units per year (10,055,300 in 2006 and 9,543,400 in 2007).[21] The room heat pump market was estimated to be about 1% of the room air conditioner market in an Energy Star® market assessment.[22]

In a typical room heat pump, both indoor and outdoor sections are encased in a single cabinet that is installed in a window or through the wall, as shown in Figure 15. The outdoor section usually has side and back louvers that serve as the air intake and exhaust. Therefore, a part of the unit extends out from the side of the building to allow outside air to be drawn in and exhausted out after passage over the outdoor coil. The indoor section serves as both a return air intake and a conditioned air supply.

19 James Bryant, "Designing Air-Source Heat Pumps for Cold Climates," Hallowell, Appliance Magazine, July 2008 http://www.appliancemagazine.com/ae/editorial.php?article=1996&zone=215&first=1

20 "Acadia™ Heat Pump, Product and Technology Review," EnergyIdeas Clearing House, http://www.energyideas.org/documents/Factsheets/PTR/AcadiaHeatPump.pdf

21 Shipments, HVAC Equipment," Appliance Design, March 2008, http://www.appliancedesign.com/AM/Home/Files/PDFs/MarchShipments.pdf

22 "Proposed Expansion of Energy Star® Room Air Conditioner Criteria to Include Reverse Cycle (Heat Pump) Room Air Conditioners," May 5, 2005, http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/RAC_Expansion_Analysis.pdf

Figure 15. Room Heat Pump

Although a few smaller 115-volt models are available, most room heat pumps are designed for 208/230 volts to accommodate electric resistance supplemental heaters. Room heat pumps (and air conditioners) are typically plug-and-cord connected, rather than hard-wired. Because room heat pumps are installed in conditioned spaces, including bedrooms, quiet operation is important. Most room heat pumps use cycle reversal as a means of defrosting, or shut off the compressor altogether and rely upon resistance heat when the coil is subject to freezing. Some utilize so-called "natural" defrost when the air temperature is above freezing: the compressor stops and the outdoor fan draws air over the evaporator coil until the frost melts; electric resistance elements supply heat until the compressor is able to start up again.

The majority of room air conditioners especially of the 115-volt type, are sold by consumer retail outlets—department stores, appliance stores, and large discount chains—rather than by heating and cooling contractors. They are installed by the purchaser or by the vendor's installers. Room heat pumps, however, are typically installed by appliance installers or licensed electricians. In general, room heat pumps and room air conditioners are both considered appliances.

Packaged Terminal Heat Pumps

Packaged terminal heat pumps are designed to heat and cool single rooms in applications such as hotels, offices, hospitals, nursing homes, and apartment buildings. They were originally designed in the mid 1950's as a simple means of adding air conditioning to central hydronic heating systems. Later, electric heat and heat pump versions were developed, eliminating the need for the central heating system. Packaged terminal heat pumps have a relatively low first cost, allow individual control of room temperature, and represent an economical means of heating and cooling in situations where installation of ductwork is impractical. Packaged terminal heat pump equipment is available in nominal 47°F heating capacities of about 5,800 to 13,900 Btu/hr for 208/230 volt service. These heat pumps are typically sold and installed by heating and cooling contractors, not retail stores. The typical packaged terminal heat pump (see Figure 16) is contained in a refrigeration chassis that fits into a standard-size wall sleeve in the conditioned space. Most of the cabinet often extends into the room to provide a smooth, unobtrusive outdoor envelope that does not degrade the building architecture. Most packaged terminal heat pumps (and air conditioners) are installed as free delivery systems without ductwork.

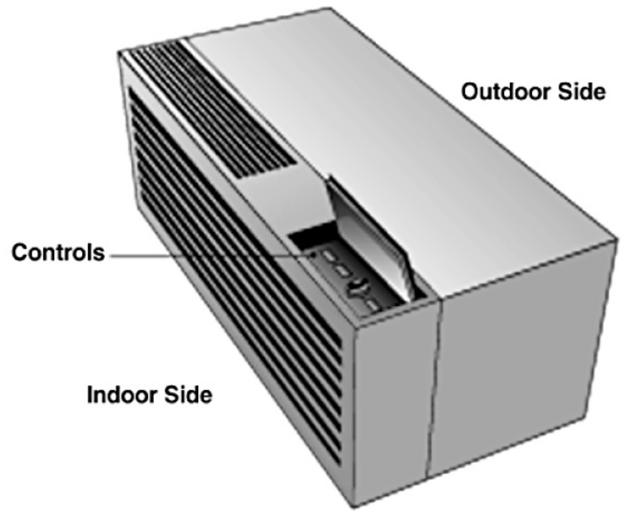


Figure 16. Packaged Terminal Heat Pump

In the heating mode, some packaged terminal heat pumps shut the compressor off and revert to use of electric resistance heat at a pre-set low temperature. For defrost, some use reverse cycle operation and others employ a “natural defrost” scheme: the compressor is shut off, the electric resistance elements are energized, and the outdoor fan draws air through the evaporator coil to melt the ice. This natural defrost method works as long as the ambient air is above freezing; below freezing, most units revert to resistance heat. Noise levels tend to be higher with packaged terminal systems than with central systems, because all the equipment is located in or near the conditioned space.

Other Configurations

Air-to-water heat pumps for space heating have been introduced into Europe in recent years. Early developers of this technology, working closely with Copeland, included Kensa Heat Pump[23] and TEV (formerly IMI Air Conditioning Ltd) producers of HeatKing Air Source Heat Pumps.[24] Work by EdF,[25] Viessmann/Satag and Copeland resulted in units providing 35°C (125°F) to 65°C (149°F) water for radiant floor delivery for space heating down to -12°C (10°F) outdoor temperature. The units are single stage with an economizer and intermediate injection of vapor. A Viessmann Vitocal catalogue[26] claims to have air to water heat pumps that can provide outlet temperatures of up to 55°C (131°F) as well as 35°C (125°F) delivery temperature with a COP up to 3.31 at 2°C (36°F) outdoor temperature and can also operate in combination with a second heat source. The Copeland scroll compressors use vapor injection and R-407C to provide higher lift than a conventional heat pump.[27] Units of this type might be attractive in the U.S. market particularly in the Northeast where hydronic heating has been widely used but also in other parts

23 “Kensa Heat Pumps,” http://www.kensaengineering.com/architects/about-us.htm

24 “HeatKing Renewal Energy, Air Source Heat Pumps,” http://www.heatking.co.uk/aboutustev.html

25 Jean- Benoit Ritz, “High Temperature Heat Pump in France,” EdF R&D, August 29, 2005 http://www.annex28.net/pdf/Annex28_N134.pdf

26 “Vitocal heat pumps,” Viessmann, March 26, 2007 http://www.econrgltd.com/images/ppr-vitocal.pdf

27 “Scroll compressors with vapour injection for Dedicated Heat Pumps,” Application Guidelines, Emerson Climate Technologies, July, 19, 2005 http://www.ecopeland.com/literature/eCopeland/EN_C060218_AGL_ZHEVI_0.pdf

of the country wherever radiant floor heating is employed. Aqua products appears ready to offer a heating –only product (the Reverse Cycle Chiller) in collaboration with York, Coleman and Luxaire.[28]

Codes and Standards and Heat Pump Efficiencies

Test procedures for measuring efficiency levels and corresponding minimum efficiency levels have been developed for most of the heat pump products described in this document. This section outlines both heating and cooling test procedures based on Air-conditioning, Heating and Refrigeration Institute (AHRI) test protocols and minimum efficiency levels for single package, split system, mini-split and multi-split, and packaged terminal heat pumps. Room heat pumps are certified (only on their cooling performance) based upon Association of Home Appliance Manufacturers (AHAM) test procedures. Test procedure information and rating points are followed by DOE minimum efficiency levels. These minimum efficiency levels are the lowest efficiency products that can be sold in the U.S. Threshold levels needed to satisfy selected incentive programs are also provided. The section on Highest Efficiency Products (see sidebar) provides information and data on the best available efficiency units in each category.

Single Package and Split System Residential Heat Pump Equipment

Tests required for single speed units with single speed fans, cooling mode: 95°F dry bulb/75°F wet bulb outdoor temperature and 82°F dry bulb/65°F wet bulb outdoor temperature; with 80°F dry bulb/67°F indoor wet bulb indoor temperature. Also optional cyclical tests can be run at 82°F dry bulb outdoor temperature.

Tests required for single speed units with single speed fans, heating mode; 47°F dry bulb/43°F wet bulb outdoor temperature, 35°F dry bulb/33°F wet bulb outdoor temperature (frost accumulation test) and 17°F dry bulb/15°F wet bulb outdoor temperature; with 70°F dry bulb /60°F indoor wet bulb indoor temperature. Also optional cyclical tests can be run at 47°F dry bulb/ 43°F wet bulb outdoor temperature. See the Final Rule of October 11, 2005[29] regarding test procedures for residential air conditioners and heat pumps for more details. The tests and calculations outlined in this reference may be used to calculate Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factor (HSPF) for each of the DOE regions using binned temperature data representing each of the six DOE climatic regions. Region IV values are what is reported and used for certification. Region IV has 800 cooling load hours and 2250 heating load hours and is representative of areas stretching across the middle of the country bordered in the east by southern New York and northern Virginia, in the middle of the country by South Dakota and Kansas and in the west by parts of Washington and the coast of Southern California as described in the October

28 "Aqua Products Company, Reverse Cycle Chiller," https://www.aquaproducts.us/home/index.php?option=com_content&view=article&id=27&Itemid=32

29 "Energy Conservation Program for Consumer Products: Test Procedure for Residential Central Air Conditioners and Heat Pumps; Final Rule," Federal Register, October 11, 2005, http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/cac_tp_101105.pdf

15, 2005 Federal Register.[30] Rules documented in the August 17, 2004 Federal Register[31] require all split system and single package heat pumps manufactured after January 23, 2006 and prior to 2010 to have an SEER of no less than 13 and an HSPF of no less than 7.7. Dual-fuel heat pumps are rated as if they had electric resistance backup and as such their low temperature performance is understated with current procedures. (Dual fuel heat pumps cited in the Dual Fuel Heat Pump Review Guide[32] have SEERs as high as 18 and HSPF up to 9.65.)

Energy Star® and the Consortium for Energy Efficiency (CEE) encourage customers to exceed the federally mandated levels by recognizing those who adhere to the Energy Star® and CEE specifications. In addition, CEE has been active in assisting electric utilities in shaping rebate and other incentive programs and as such, adherence to CEE levels could assist customers who install more efficient equipment in obtaining monetary benefits.

CEE Unitary Heat Pump Specification:

Under 65,000 Btu/hr Tier I, SEER = 14, HSPF = 8.5 and Tier II, SEER = 15, HSPF = 9.0

Energy Star® criteria are currently SEER = 14 and HSPF = 8.2 for split systems and SEER = 14 and HSPF = 8 for single package systems.[33] Levels are planned to increase to SEER = 14.5 and HSPF = 8.2 for split systems and to SEER = 14 and HSPF =8 for single package systems for Tier II requirements on January 1, 2009.[34]

LEED® for residences[35] has a prerequisite of achieving at least as SEER = 13 and an HSPF of 8.2 with air source heat pumps for International Energy Conservation Code (IECC)[36] climate zones 4 to 8 and SEER = 14 and HSPF = 8.2 for IECC climate zones 1 to 3. Two points can be captured by achieving SEER = 14 and HSPF = 8.6 in zones 4 to 8 and SEER = 15 and HSPF = 8.6 in zones 1 to 3. Four points can be captured by achieving SEER = 15 and HSPF = 9.0 in zones 4 to 8, and SEER = 16 and HSPF = 9.0 in zones 1 to 3.

Room Heat Pumps

Cooling mode tests are performed at 95°F outdoor temperature and 80°F indoor dry bulb temperature/67°F indoor wet bulb temperature.[37] The heating capacity and electrical input ratings for room heat pumps are measured at standard test conditions, which are: room air tem-

30 "Energy Conservation Program for Consumer Products: Test Procedure for Residential Central Air Conditioners and Heat Pumps; Final Rule," Federal Register, Table 19 and Figure 2, Page 59179, October 11, 2005, http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/cac_tp_101105.pdf

31 "Energy Conservation Program for Consumer Products: Central Air Conditioners and Heat Pumps Energy Conservation Standards; Final Rule," Federal Register, August 17, 2004 http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/ac_fr_081704.pdf

32 "Heat Pump Review, Dual Fuel Heat Pump Review Guide," 2007, http://heat-pump-review.net/dual-fuel-heat-pumps/guide

33 "Air-Source Heat Pumps and Central Air Conditioners Key Product Criteria," http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_crit_as_heat_pumps

34 "New ENERGY STAR® Specification to Take Effect January 1, 2009," http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_as_heat_pumps

35 "LEED® for Homes Rating System," U.S. Green Buildings Council, January 2008, http://www.usgbc.org/ShowFile.aspx?DocumentID=3638

36 Z. Todd Taylor, "New Climate Zones in the IECC 2004 Supplement," Chart 5, 2005 National Workshop, Building Energy Codes Program, June 28, 2005 http://www.energycodes.gov/news/2005_workshop/presentations/plenary-day/hot-topics/residential/t_taylor-new_climate_zones.pdf

37 "Technical Support Document For Energy Conservation Standards For Room Air Conditioners," September 1997, http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/tsdracv2.pdf

perature, 70°F dry bulb; outside air temperature, 47°F dry bulb temperature, 43°F wet bulb temperature.[38]

According to the Federal Register for September 24, 1997[39] minimum Energy Efficiency Ratio (EER) levels were established for 16 classes of room air conditioners, disaggregated by size, whether they have louvered sides, whether they have reverse cycles, and other configuration options. There are four classes of room heat pumps with the following DOE/Federal minimum EER levels:

EER ≥ 9.0 for capacity less than 20,000 Btu/hr and louvered sides

EER ≥ 8.5 for capacity greater than 20,000 Btu/hr and louvered sides

EER ≥ 8.5 for capacity less than 14,000 Btu/hr without louvered sides

EER ≥ 8.0 for capacity greater than 14,000 Btu/hr without louvered sides

Units without louvered sides are typically through the wall units. There are no minimum heating efficiencies for room heat pumps.

Energy Star® levels exceed the DOE efficiency levels as follows:[40]

EER ≥ 9.9 for capacity less than 20,000 Btu/hr and louvered sides

EER ≥ 9.4 for capacity greater than 20,000 Btu/hr and louvered sides

EER ≥ 9.4 for capacity less than 14,000 Btu/hr without louvered sides

EER ≥ 8.8 for capacity greater than 14,000 Btu/hr without louvered sides

CEE Tier 1 and Tier 2 Levels are provided for room air conditioners but not for room heat pumps.

Mini- and Multi-split (and VRF) Heat Pumps

For multispeed or variable speed fans and compressors additional tests required beyond those described above for packaged and split system units are provided in the Final Rule of October 11, 2005 as well as the Final Rule of October 22, 2007.[41] Required efficiency levels are the same as for split system heat pumps; SEER ≥13.0 and HSPF no less than 7.7.

Single Package and Split System Commercial Unitary Heat Pump Equipment

For single package and split system commercial unitary heat pump equipment with, capacities less than 65,000 Btu/hr, cooling and heating efficiency tests referenced in the October 21, 2004 Federal Register[42] citing ARI (Air-conditioning and Refrigeration Institute) Standard 210/240-

38 "The AHAM Certification Program for Room Air Conditioners," http://207.140.180.12/dirsvc/aham.nsf/frmAboutRac?OpenPage

39 "Energy Conservation Program for Consumer Products; Conservation Standards for Room Air Conditioners; Final Rule," Federal Register, September 24, 1997, http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/racrlbod.pdf

40 "Room Air Conditioners Key Product Criteria," http://www.energystar.gov/index.cfm?c=roomac.pr_crit_room_ac

41 "Energy Conservation Program for Consumer Products: Test Procedure for Residential Central Air Conditioners and Heat Pumps: Final Rule", Federal Register, October 22, 2007, http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/cac_tp_102207.pdf

42 "Energy Efficiency Program for Commercial and Industrial Products; Test Procedures and Efficiency Standards for Commercial Air Conditioners and Heat Pumps; Direct Final Rule," Federal Register, October 21, 2004, http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/ac_hp_tp_102104.pdf

2003[43] apply. For equipment with capacity ≥65,000 Btu/hr and <135,000 Btu/hr the provisions of ARI (Air-conditioning and Refrigeration Institute) Standard 340/360-2000[44] apply. For this equipment, the cooling efficiency EER is measured at 95°F outdoor temperature and 80°F indoor dry bulb temperature/67°F indoor wet bulb temperature. Heating efficiency tests measure the COP at 47°F dry bulb/43°F wet bulb outdoor temperature and 70°F indoor temperature and at 47°F dry bulb/43°F wet bulb outdoor temperature and 70°F indoor temperature. Dual-fuel heat pumps are rated as if they had electric resistance backup and as such their low temperature performance is understated with current procedures.

Minimum efficiency levels for air source Small Commercial Packaged Heat Pumps (three-phase) established in the Federal Register on January 12, 2001[45] are as follows:

<65,000 Btu/hr, Split System, SEER = 10.0; HSPF = 6.8

<65,000 Btu/hr, Single Package, SEER = 9.7; HSPF= 6.6

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package,
EER = 8.9; COP = 3.0

ASHRAE 90.1[46] has efficiency levels effective January 23, 2006 that are somewhat higher than the federally mandated minimums for three phase equipment:

Before January 1, 2010:

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package,
EER = 9.9; COP = 3.2

After January 1, 2010:

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package,
EER = 10.3; COP = 3.3

Energy Star® qualified equipment[47] must meet the following efficiency levels which are identical to the levels recommended for purchase by the Federal Energy Management Program:[48]

<65,000 Btu/hr, Split System or Single Package, SEER = 12.0; HSPF = 7.7

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package,
EER = 10.1; COP = 3.2

---

43 "Unitary Air Conditioning and Air-Source Heat Pump Equipment," ARI (Air-conditioning and Refrigeration Institute) Standard 210/240-2003

44 "Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment," ARI (Air-conditioning and Refrigeration Institute) Standard 340/360-200

45 "Energy Efficiency Program for Commercial and Industrial Products; Efficiency Standards for Commercial Heating, Air Conditioning and Water Heating; Final Rule," Federal Register, January 12, 2001, http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/coml_equp_rule.pdf

46 "Energy Standards for Buildings Except Low-rise Residential Buildings," ANSI/ASHRAE/IESNA Standard 90.1-2007, http://openpub.realread.com/rrserver/browser?title=/ASHRAE_1/ashrae_90_1_2007_IP_1280

47 "ENERGY STAR® Program Requirements for Light Commercial HVAC," http://www.energystar.gov/ia/partners/prod_development/archives/downloads/lchvac/Draft_LC_HVAC.pdf

48 "How to Buy an Energy-Efficient Commercial Unitary Air Conditioner, Federal Energy Management Program," February 5, 2007 http://www1.eere.energy.gov/femp/procurement/eep_unitary_ac.html

The Consortium for Energy Efficiency (CEE) Tier 1, Tier 2 and Tier 3 levels[49] are as follows:

CEE Tier 1

<65,000 Btu/hr, Split System, SEER = 14.0; HSPF = 8.5

<65,000 Btu/hr, Single Package, SEER = 14.0; HSPF = 8.0

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package, EER = 11.0; COP = 3.4

CEE Tier 2

<65,000 Btu/hr, Split System, SEER = 15.0; HSPF = 9.0

<65,000 Btu/hr, Single Package, SEER = 15.0; HSPF = 8.5

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package, EER = 11.5

CEE Tier 3

≥65,000 Btu/hr and <135,000 Btu/hr, Split System and Single Package, EER = 12.0

Packaged Terminal Heat Pumps

Packaged terminal heat pump testing and rating procedures were established in the October 21, 2004 Federal Register[50] according to ARI (Air-conditioning and Refrigeration Institute) Standard 310/380-2004. All EER values must be rated at 95°F outdoor temperature and 80°F indoor dry bulb temperature/67°F indoor wet bulb temperature in the cooling mode and at 47°F dry bulb/43°F wet bulb outdoor temperature and 70°F indoor temperature in the heating mode. Federally mandated minimum efficiency levels depend upon equipment size with the minimum:

EER = 10.0-(0.16*[capacity in Btu/hr]/1000) and the minimum

COP = 1.3 + (0.16*EER), where the EER is as obtained above

Example:

For a 7,000 Btu/hr PTHP the minimum EER is 8.88 and the minimum COP is 2.72

Packaged terminal heat pumps are not covered by Energy Star® or CEE.

49 "CEE UNITARY HEAT PUMP SPECIFICATION," Revised June 16, 2008 http://www.cee1.org/com/hecac/hecac-tiers.pdf

50 "Energy Efficiency Program for Commercial and Industrial Products; Test Procedures and Efficiency Standards for Commercial Air Conditioners and Heat Pumps; Direct Final Rule," Federal Register, October 21, 2004, http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/ac_hp_tp_102104.pdf

Highest Efficiency Products

The AHRI Directory[51] (as of 9-05-2008) listed a Samsung model as the residential split system heat pumps (AHRI designation HORCU-A-CB) unit with the highest cooling efficiency with an SEER = 20, a cooling capacity of 9000 Btu/hr and an HSPF = 9.999. There were five models of split system heat pumps (AHRI designation HRCU-A-CB) from Lennox and Aspen with SEER =19 and three manufacturers (Coleman, Luxaire, and York) of nine models with HSPF = 10.75. This searchable directory also yielded six models of Trane and American Standard as the residential single package heat pumps (AHRI designation HSP-A) with the highest cooling efficiency with SEER = 16.4 and HSPF = 9. The highest HSPF was also 9.0 with ten Trane models and ten American Standard models attaining that level.

The AHRI Directory[52] (as of 8-28-2008) listed eleven manufacturers of variable speed mini-split and multi-split heat pumps with a Fujitsu model (9,000 Btu/hr) having the highest heating efficiency with an HSPF = 11; and an Mitsubishi model (9,000 Btu/hr) having the highest cooling efficiency with SEER = 23.

51 "AHRI (Air-conditioning, Heating and Refrigeration Institute) Directory for Heat Pumps and Heat Pump Coils", http://www.ahridirectory.org/ahriDirectory/pages/hp/defaultSearch.aspx

52 Certified Variable-speed Mini-and Multi-split HP Certification: 210/240," August 28, 2008 http://www.ahridirectory.org/ahriDirectory/pages/vrfhp/VR-FHP8-28-08.pdf

For room heat pumps, the AHAM (Association of Home Appliance Manufacturers) Directory of Room Air Conditioners[53] lists 14 manufacturers and 151 models of room heat pumps the Friedrich Model YS09L10, capacity 9200 Btu/hr was the highest efficiency room heat pump model with a cooling efficiency, EER of 12.

The AHRI Directory[54] (as of 9-05-2008) listed four models of GE Zoneline units as the highest efficiency packaged terminal heat pump units with EER = 13. Their COPs are 3.7 at 47°F.

The AHRI Directory[55] (as of 9-05-2008) listed one model of Trane with a cooling capacity of 68,000 Btu/hr as the highest efficiency split system light commercial heat pump (AHRI designation HRCU-A) unit available with EER = 12 and COP of 3.6 at 47°F and 2.7 at 17°F. For single package light commercial heat pumps (AHRI designation HSP-A), this searchable data base yielded four units with EER = 11.5; three Goodman units (in sizes ranging from cooling capacity of 90,000 to 1118,000 Btu/hr with COPs at 17°F = 2.4 and COPs at 47°F = 3.4) and one Lennox unit (90,000 Btu/hr cooling capacity) with COP at 17°F = 2.2 and COP at 47°F = 3.3.

53 "AHAM (Association of Home Appliance Manufacturers) Directory of Certified Products, Room Air Conditioners," Edition No. 3, July 2008

54 "AHRI (Air-conditioning, Heating and Refrigeration Institute) Directory for Packaged Terminal Heat Pumps," http://www.ahridirectory.org/ahriDirectory/pages/pthp/defaultSearch.aspx

55 "AHRI (Air-conditioning, Heating and Refrigeration Institute) Directory for Unitary Large Equipment," http://www.ahridirectory.org/ahriDirectory/pages/ule/defaultSearch.aspx

Customer Attributes

Customers desire space heating and cooling products that provide comfort and productivity at a with reasonable ownership costs. Good temperature control, low noise, and high reliability are important attributes that affect system selection and customer satisfaction.

Comfort control should be best with systems that have sensors and capacity modulation capability (especially with inverter driven variable speed drives) that permit the temperature and humidity in the space to be controlled by the occupant within narrow limits. This should be available with systems such as multi-split and VRF that permit occupant control of each zone and capacity modulation to follow the load and limit cycling and associated temperature excursions and air flow interruptions.

Ownership costs include installation, operation and maintenance and are highly dependent on the application, local dealer markups, energy prices, and other site-specific variables. For installation costs, potential purchasers of air-source heat pumps or other space heat and cooling equipment should seek bids from qualified contractors for the types of systems they are considering. Means Mechanical Cost Data[56] provides equipment costs, labor cost indices and other information that can be useful in developing consistent cost comparisons independent of contractor estimates. It is difficult to compare one heat pump system against another and heat pumps against other types of systems without using consistent baseline installation conditions and unbiased information on all systems. Relative cost information taken from the trade journals or from conversations with advocates of their particular system should not be accepted unequivocally. For an existing building installation it would be logical to first look at systems that are best suited to the existing delivery system, if it is in good operating condition. For example, if a ducted split system was the original system then a similar, newer ducted split system will likely have the lowest first costs.

Energy Star® has developed life cycle cost estimating tools that calculate energy costs and can be used to illustrate the economics of upgrading from conventional equipment to high efficiency equipment. The examples used with those tools provide some illustration of the economics of the use of high efficiency equipment. For air source heat pumps an example is given[57] showing replacement of a 3-ton standard efficiency heat pump with SEER = 13 and HSPF = 7.7, with a 3 ton high efficiency unit having SEER = 14 and HSPF = 8.2. The standard efficiency unit has an initial estimated retail price of $5700 and the high efficiency unit has an initial estimated retail price of $6700. For the Region IV Washington, DC climate and rates (9.7¢/kWh) the high efficiency unit saves 25% of the retail price per year in energy savings for a simple payback of 3.5 years. Over the life of the unit (assumed to be only 12 years) the life cycle energy savings were projected to be about 35,000 kWh, or $1655, and the life cycle CO2 reduction was 53,678 pounds. (Work performed by EPRI on residential heat pumps in Alabama[58] showed that median heat pump service life was around 20 years.)

The Federal Energy Management Program provides an energy cost calculator for commercial heat pumps[59] that has a default service life value of 15 years.

Energy use comparisons should be obtained from detailed analysis using information based on corresponding rigorous laboratory and field test data of systems of interest.

56 RS Means Mechanical Cost Data 2008 Book, 30th Edition, http://www.rsmeans.com/bookstore/detail.asp?sku=60028

57 "Life Cycle Cost Estimate for Energy Star® Qualified Air Source Heat Pumps," See "Savings Calculator," in the following link: http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_as_heat_pumps

58 Carl Hiller, "Measuring Heat Pump Service Life," EPRI , March 1, 1986 http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5462796

59 "Energy Cost Calculator for Commercial Heat Pumps (5.4 >=< 20 Tons)," http://www1.eere.energy.gov/femp/procurement/eep_comm_heatpumps_calc.html

Proper heat pump maintenance can reduce energy consumption by 10 to 25% compared to a severely neglected heat pump.[60] The homeowner or occupant should perform the following maintenance functions:

- Clean or change filters once a month or as needed
- Remove debris from around the outdoor unit
- Clean outdoor coil with a garden hose
- Turn off fan power and clean fan
- Clean supply and return registers within the space
- Assure that vents and registers are not blocked by furniture, carpets or other items

As with any heating and cooling system a professional technician should service the heat pump at least every year.[61] The best time to service a unit is usually at the end of the cooling season, prior to the start of the next heating season.[62] The technician should do the following:

- Inspect ducts, filters, blower, and indoor coil for dirt and other obstructions
- Diagnose and repair duct leakage
- Verify adequate airflow by measurement
- Verify and correct refrigerant charge by measurement
- Check for refrigerant leaks
- Inspect electric terminals, clean and tighten connections, apply nonconductive coating
- Verify correct electric control and thermostat operation.

Selecting an experienced dealer and service organization, and conducting regular recommended maintenance will enhance the performance of air-heat pump systems.

Noise levels are generally lowest when the fans and compressor are furthest away from the occupied space. Extra care can be taken to reduce the sound level of any heat pump system including that of packaged terminal and room heat pump units but since all the components of these systems are essentially in the occupied space they will tend to be the noisiest. Split systems and single package ducted systems will have fans and compressors furthest from the occupied space therefore these should be the quietest of the systems addressed in this tech brief. If noise is important to the customer they should look at manufacturers' literature or should ask the dealer/specifier to provide sound level estimates for each of the systems being considered.

60 "Operating and Maintaining Your Heat Pump," DOE EERE, September 12, 2005 http://apps1.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12690

61 "Energy Star® Home, Energy Star® Yardstick," http://www.energystar.gov/index.cfm?fuseaction=home_energy_yardstick.showStep2

62 "Air Source Heat Pumps," Natural Resources Canada, April 18, 2005, http://www.oee.nrcan.gc.ca/publications/infosource/pub/home/heating-heat-pump/asheatpumps.cfm

Reliability of equipment alternatives depends on the soundness of the system design and operating strategy, the quality of the components used, the care taken is assembling the equipment in the factory and installing it in the field, and the careful maintenance provided in keeping the equipment in good working order. The customer would be wise to purchase equipment (and its installation) from dealers with strong local presence and established track records and from manufacturers that can provide substantial assurance of proper equipment operation and longevity (through warranties and maintenance contracts).

Utility Benefits

High efficiency heat pumps provide opportunities for utilities to promote newer energy savings and efficient technologies. It has been shown that heat pumps with high COP reduce the carbon footprint across the spectrum. In fact, high efficiency inverter driven heat pumps used for heating have the potential to reduce greenhouse gases when compared to gas furnaces. It is to be noted that Japanese utilities promotes the use of efficient heat pumps as an important measure to reduce greenhouse gases.

Summer peaking utilities can benefit from installations of all-electric heat pumps, since the systems' additional heating loads in the winter will improve utility load factor, thereby providing utilities the opportunities to pass the savings to their customers. Summer peaking and winter peaking utilities alike benefit when an inefficient, outdated air-conditioner or heat pump model is replaced with a new more efficient heat pump; providing both summer and winter savings to the customer, and lower peak demand for the utility.

Winter peaking utilities can encourage their customers to use heat pumps with superior low temperature performance such as dual fuel heat pumps, multi-split and VRF systems with variable speed compressors, or booster systems with compressors in series. This will minimize the addition of electric load during peaks (especially electric resistance loads) driven by low outdoor temperatures.

Heat pumps systems with zoning capability can be of benefit in providing demand response flexibility. To use multi-split or VRF heat pumps, or room heat pumps, or packaged terminal heat pump systems as a demand response tool, it is possible to turn off the indoor units in one or more spaces, and letting the space temperature and humidity drift (with some spillover of conditioned air from the adjacent conditioned spaces). Alternately, units could be operated at a fraction of normal capacity to maintain minimally effective environmental conditions in the occupied space. Units with capacity modulation capability (especially with inverter driven variable speed compressors) could be operated at a fraction of normal capacity to maintain minimally effective environmental conditions in the occupied space.

The on-off sequencing between zones could be alternated to minimize temperature changes to minimize occupant discomfort. Sequentially starting of the outdoor units serving a building is possible to spread out demand spikes caused by starting power transients. With regard to interoperability, VRF system air conditioners and heat pumps have sophisticated controls and components that will enable the units to adjust their performance in response to internal or external signals. Other unitary heat pumps with advanced features may also have controls and components that enable response through remote access and to permit integration into "smart" buildings.

Heat Pump Incentives

Because of the substantial advantages of efficient air-source heat pumps in saving energy and improving the economics of utility operations, utilities and government/energy efficiency agencies provide incentives for installation of efficient air-source heat pumps. To find the incentives that may be applicable to an electric air source heat pump installation of interest, the Energy Star® rebate finder[63] keyed to zip code may be useful.

Another searchable data base for incentives is provided by the DOE Industrial Technology Program for commercial and industrial facilities.[64] This States Incentives and Resources Database, contains energy incentives, tools, and resources for commercial facility managers at the national, state, county, and local levels. Utilities, private companies, and non-profits also offer incentives for energy efficiency measures including rebates, waived fees, tax credits, and loans. Resources include analysis tools, education and training programs, and energy audits.

The **Database for Energy Efficient Resources** (DEER) is a California Energy Commission and California Public Utilities Commission (CPUC) sponsored database, developed in 2005, designed to provide well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life (EUL) all with one data source.[65] Information on energy efficiency measures, included in the data base are regularly used by California utilities and others to shape incentive programs. Additional information developed in 2008 is available on a password protected web site.[66]

Heat pump incentive information is also available in DSIRE (Data Base of State Incentives for Renewables and Efficiency)[67] maintained by the North Carolina Solar Center. DSIRE is searchable by Eligible Sector (including; Commercial/Industrial, Residential), Implementer (including Utility), Incentive Type (including rebates, loans, standards), State, and Technology (including heat pumps).

The Consortium for Energy Efficiency (CEE) conducted a member survey regarding the extent of their residential HVAC incentive programs.[68] Fifteen utilities and regional/state agencies provided information on assistance given for the installation of energy efficient heating and cooling equipment and measures. This assistance included equipment rebates, and assistance for installation, training, and certification. The rebates, keyed in many cases to CEE Tier levels, were as much $750 per unit in Sacramento and Tacoma and up to $900 in Wisconsin. CEE is currently conducting a survey of HVAC incentive programs for member utilities keyed to CEE Tiers; with a questionnaire to be completed in late 2008.

63 "Special Offers and Rebates from ENERGY STAR® Partners," http://www.energystar.gov/index.cfm?fuseaction=rebate.rebate_locator

64 "Search States Incentives and Resources Programs," http://www1.eere.energy.gov/industry/about/state_activities/incentive_search.asp

65 DEER - Database for Energy Efficient Resources http://www.energy.ca.gov/deer/

66 Database for Energy Efficient Resources http://www.deeresources.com/

67 "DSIRE, Data Base of State Incentives for Renewables and Efficiency," http://www.dsireusa.org/

68 "Residential HVAC Programs, National Summary," Consortium for Energy Efficiency, November 2006

Refrigerant Issues

An international environmental agreement developed in 1987 in Montreal[69] established requirements that began the worldwide phase out of ozone-depleting CFCs (chlorofluorocarbons). A 1992 amendment to the Montreal Protocol established a schedule for the phase out of HCFCs (hydrochlorofluorocarbons). HCFCs are less damaging to the ozone layer than CFCs, but still contain ozone-destroying chlorine. The Montreal Protocol as amended is carried out in the U.S. through Title VI of the Clean Air Act[70] as implemented by EPA.

HCFC-22 also known as R-22 has been the refrigerant of choice for heat pump -conditioning systems used for space conditioning for many years. The manufacture of R-22 is being phased out over the coming years as part of the agreement to end production of HCFCs, and manufacturers of residential air conditioning systems are now offering equipment that uses ozone-friendly refrigerants. The following paragraphs discuss the phase out schedule for R-22, and the likely availability of R-22 for existing units and those purchased in the future.[71] The availability, applicability and attributes of the new refrigerant, R-410A developed to replace R-22 in new equipment will also be presented.

The use of non-ozone depleting refrigerants is less harmful to the environment. It is prudent therefore to consider the availability of new non-ozone depleting, chlorine-free refrigerants when purchasing new equipment. The primary non-ozone

69 "The Montreal Protocol on Substances that Deplete the Ozone Layer," http://www.epa.gov/ozone/intpol/index.html

70 "Clean Air Act Title VI – Stratospheric Ozone Protection," http://www.epa.gov/oar/caa/title6.html

71 "What you Should Know About Refrigerants When Purchasing or Repairing a Residential A/C or Heat Pump," U.S. EPA http://www.epa.gov/Ozone/title6/phaseout/22phaseout.html

Phase out Schedule for R-22

By January 1, 2004, the Montreal Protocol required the U.S. to reduce its consumption by 35 percent below the baseline cap by January 1, 2004. As of January 1, 2003, EPA issued baseline allowances for production and import of HCFC-22. EPA allocated both consumption and production allowances to individual companies for HCFC-22.

- After January 1, 2010, chemical manufacturers may still produce R-22 to service existing equipment, but not for use in new equipment. As a result, heating, ventilation and air-conditioning (HVAC) system manufacturers will only be able to use pre-existing supplies of R-22 to produce new air conditioners and heat pumps. These existing supplies would include R-22 recovered from existing equipment and recycled.
- Beyond January 1, 2020, use of existing refrigerant, including refrigerant that has been recovered and recycled, will be allowed to service existing systems, but manufacturing and importing of R-22 will not be permitted even for servicing existing heat pumps.

Mandated reclamation and recycling will help ensure that existing supplies of R-22 will be available to service existing equipment well into the future. A draft report documenting an EPA sponsored study of refrigerant needs for R-22 equipment into the future estimated that recovery rates of 50% would be needed to provide R-22 servicing demand in 2020.

depleting, chlorine-free refrigerant for use in heat pumps in the U.S. is R-410A, a 50%/50% blend of hydrofluorocarbons (HFCs), R-32 and R-125, substances that do not contribute to depletion of the ozone layer. R-410A is manufactured and sold under various trade names, including GENETRON AZ-20®, SUVA 410A®, and Puron®. R-407C is commonly found in residential A/C systems and heat pumps in Europe but is not yet available for residential applications in the U.S.

The current wholesale price[72] of R-410A is about $7.5/lb to $9.5/lb and the current wholesale price of R-22 is about $5.25/lb to $6.65/lb; depending upon the quantities purchased. Thus the wholesale price of R-410A is about 40% higher than that of R-22. The quantity of refrigerant in a heat pump varies between units depending upon the configuration, type of equipment and application. A quick review of specification sheets and other product literature showed that refrigerant charge can be as little as about 1.5 lb/ton for room units to 5 lb/ton for larger split system configurations. For a typical 3 ton split or single package system the refrigerant charge might typically be around 10 pounds. Thus there is about a $20 to $30 difference in wholesale refrigerant cost between typical R-22 and R-410A residential units. With a dealer markup of around 1.27[73] the retail price difference should be about $25 to $38.

Refrigerant shipped in new heat pumps currently being sold consists of about 30% R-410A and 70% R-22. This is expected to shift rapidly to 100% for R-410A as January 1, 2010 approaches.

As greater quantities of R-410A are produced and production economies are realized its price may decrease; at the same time R-22 will becomes scarcer and it is logical that its price will increase, eventually exceeding that of R-410A.

Existing units using R-22 should continue to be serviced with R-22. The new substitute refrigerants cannot be used without making some changes to system components.

New units using R-410A have been redesigned to operate at higher pressure and have been shown to provide reduced equipment size, and increased efficiency compared to R-22 equipment of similar capacity.[74] A more recent literature review reported test results showing cooling efficiencies of R-410A equipment were between 1 and 7 % higher than R-22 equipment of similar capacity and heating efficiencies ranging from 3% lower to 7% higher for R-410A equipment. R-410A has superior transport properties to R-22[75] (with higher vapor thermal conductivity and much higher vapor density with similar viscosity); resulting in reduced viscous losses and lower compressor/system pressure drop and improved efficiency. New systems incorporating compressors, components and cycle modifications specifically designed for use with R-410A promise to make R-410A units measurably more efficient than those using R-22.

Since R-410A is a blend of two components (and not an azeotrope), care must be taken to recharge units from the liquid phase. Properly installed home comfort systems rarely develop refrigerant leaks, and with proper servicing, a system using, R-410A or another refrigerant will minimize its impact on the environment. Consumers should deal with contractors who have technicians schooled in installation and service techniques required for use of the refrigerant being used.

72 "Discount Refrigerants, Inc.," http://www.koolit.net/prod_list.php?sci=3

73 "Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps," Chapter 4, Engineering Analysis, DOE, EERE, Office of Building Research and Standards, May 2002 http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/chap4_engineer.pdf

74 "Properties and Performance of Suva® 407C and Suva® 410A in Air Conditioners and Heat Pumps," ART-14, DuPont, February 1, 2002 http://refrigerants.dupont.com/Suva/en_US/pdf/h47125.pdf

75 D.B. Bivens, et al, "R-410A – Applications Experience," DuPont, Euro Cooling and Heating Conference, June 9, 2007, http://www.eurocooling.com/articler410a.htm

What Else is Needed?

Although air source heat pumps are solidly entrenched as a preferred form of space conditioning in buildings in the United States, there are a number is things that could be done to improve their appeal to users and utilities. These improvements include testing, documentation, rating procedures and market development for existing products as well as development of advanced features for future products.

- Energy analysis tools are needed to permit simple calculations with reasonable accuracy to be performed to permit comparison of the various types of air-source heat pump systems with each other and with alternative gas-electric systems and ground-source and water source heat pumps.
- Develop equipment cost and installation cost estimates for each heat pump type and for realistic alternative systems using a panel of experts and accepted cost estimating data for a number of typical residential and light commercial cases of interest. These estimates should serve as default values for any life cycle or payback analyses to be performed.
- Characterize extreme temperature performance (for utilities and customers that are concerned with temperature induced peaks), whether they be in low temperature in winter or high temperature in summer, by developing test procedures and rating methods (perhaps local or regional SEER or HSPF with specific EER or COP ratings at high and/or low temperatures) and publishing ratings for these extreme conditions to permit buyers and specifiers to determine how well comparable candidate units can satisfy their extreme temperature needs.
- Well designed field tests and design and construction evaluations need to be performed by independent third parties in order to derive reliable energy use and ownership cost data to permit understanding of the true installed costs and operating cost of air source heat pump systems and comparable HVAC systems.
- Demonstration of inverter driven DHPs to document energy efficiency opportunities and potential customer comfort in residential applications.
- The EPRI Heat Pump Manual, last issued as the second edition in November 1997, could be updated. This would provide the latest information on all heat pump technologies for residential and small commercial markets including the range of components, systems and installations, sizing methods, heat pump software and energy estimating methods. The manual would also include the latest information on codes and standards, utility programs, and system selection, installation, operation and maintenance. An alternative to this manual could be regular updates of this technology brief that reflect current changes in equipment, standards and incentives.
- Scan the horizon and encourage manufacturers to provide air-source heat pump system developments that could provide better choice for the customer. These could include:
    - booster configurations with intercooling for VRF systems
    - enhanced vapor injection systems for VRF systems

- booster configurations with economizers for hydronic delivery
- enhanced vapor injection systems hydronic delivery
- development of controls that permit mini-, and multi-split and VRF systems to be used with existing fossil fired heat systems as dual fuel heat pump systems

- Scan the horizon and for component and technology developments that could lead to air-source heat pump improvements. These could include:
  - New, low-cost motor and inverter drive technologies
  - advanced heat exchangers using micro-channels[76] and brazed plates[77]
  - alternative heat exchanger materials and passive and active means of enhancing and controlling heat transfer[78]
  - enhanced vapor injected heat pumps used for delivering water at 65°C to hydronic radiant floor systems[79]

76 Thomas Kopp, "Session 6- Advanced Concepts – Components," p30, IEA Heat Pump Newsletter, Volume-No.3/2005 www.heatpumpcentre.org
77 Larry Adams, "Enhanced Exchangers," Appliance Design, pp 22- 28, April 2008 http://www.appliancedesign.com/Articles/Feature_Article/BNP_GUID_9-5-2006_A_10000000000000297197
78 "IEA HPP Annex 33 Deliverables, Compact Heat Exchangers in Heat Pumping Equipment," Zurich, May 2008 http://www.compactheatpumps.org/
79 "Heat Pump for the Retrofit Market," EdF presentation to EPRI, 2008

Acknowledgements

The author would like to acknowledge the framework provided by the *Heat Pump Manual, Second Edition*. EPRI, Palo Alto, CA: 109222, published November 11, 1997, that was invaluable in creating portions of this report.

Principal Author

Morton H. Blatt, Energy Utilization Consultant

Technical Reviewers and Contributors

Ammi Amarnath, EPRI
Mark Menzer, AHRI
Lee Smith, Daikin AC
Chris Bellshaw, Daikin AC
John Taylor, Consortium for Energy Efficiency
James Bryant, Hallowell
Bill Cunningham, Lennox
Dutch Uselton, Lennox
Michael McMurrough, Sanyo Commercial Solutions
Gary Nettinger, Sanyo Commercial Solutions
James Crawford, The Trane Company

Graphics and Layout

Nanette Jones, EPRI

For further information, please contact:

Ammi Amarnath, Technical Lead, Energy Efficiency
email: aamarnath@epri.com
phone: 650.855.1007

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California; Charlotte, North Carolina; and Knoxville, Tennessee, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together…Shaping the Future of Electricity

1016075 December 2008

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

Printed on recycled paper in the United States of America