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ASSOCIATION OF ENERGY SERVICES PROFESSIONALS

MAGAZINE

2020

An Official Publication of the Association of Energy Services Professionals

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Two examples of exterior units for an electric heat pump system[2,3]

(ALMOST) ALL ABOUT HEAT

By Jeff Ihnen and Kevin DeMaster with contribution from Ryan Kerr

ORIGINS

Generating heat with fire dates back to, well, the stone age, but moving heat from a colder space or substance to a warmer one (refrigeration), didn't begin until the mid-nineteenth century. Heat pump technologies were born with the advent of refrigeration. They move heat from cold air or water, to warm air or water for space conditioning. Moving heat "uphill" from cold to warm, as with refrigeration, requires energy.

Everyone knows space cooling, and therefore heat pumps, require electrical energy, but few beyond the engineering community and the manufacturers who make them, know of the absorption refrigeration cycle. The absorption cycle uses heat from steam or directly by burning natural gas to provide cooling! To my surprise, the absorption cycle was developed just two years after the vapor compression (electric) cycle was developed in 1849.[1]

This article features a broad overview of electric and natural-gas-fired heat pumps, their applications, and some advantages and disadvantages of each technology.

Figure 1 – Common Heat Pump Refrigerant Pressures

Input Energy

	Boiling Pressure @ 35 Degrees F (psia)	Condensing Pressure @ 105 Degrees F (psia)	Used For
Ammonia	66	229	Vapor compression or absorption
R410a	122	356	Vapor compression
CO2	528	Off the chart	Vapor or thermal compression
R134a	45	150	Vapor compression
Water	0.1	1.1	Absorption

Concepts

Nearly all heat pumps and refrigeration cycles use a refrigerant that boils at low temperature and pressure, and condenses at high pressure and temperature. The production of high pressures and temperatures requires energy input. Figure 1 shows boiling and condensing pressures at typical cooling (indoor) and outdoor temperatures.

The primary energy requirement for a vapor-compression cycle is the compression stage, which is driven by natural gas or electricity, as we shall see. The primary input for the absorption cycle is heat.

For reference, ammonia is the most common industrial refrigerant, particularly in food processing and freezing. It is also used in the absorption cycle with water. Refrigerants 410a and 134a are common for residential and commercial space cooling. Carbon dioxide is gaining ground as a "low side" (low temperature) refrigerant, and as a working fluid in emerging heat pump technologies. As a refrigerant, water is strictly for absorption when paired with lithium bromide.

PUMPS

ELECTRIC HEAT PUMPS

Electric heat pumps are significantly more common than absorption heat pumps, primarily because of two factors: they are less expensive to manufacture, and they are reversible. This reversibility means they can provide heat in winter and cooling in the summer with the same system. We will explore four classes of electric heat pumps.

- Single zone central residential
- Zoned
- Variable refrigerant flow
- Water-source

Figure 2 – Simple Refrigeration Circuit

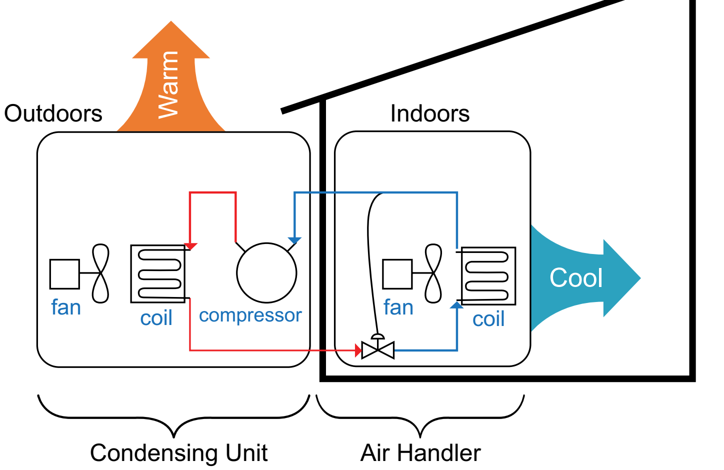
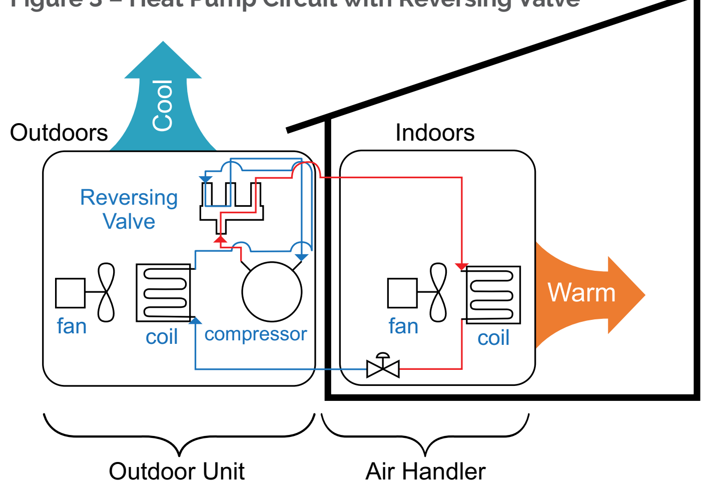


Figure 3 – Heat Pump Circuit with Reversing Valve



All electric heat pumps work on a reversible refrigeration cycle. A simple vapor-compression refrigeration cycle is shown in Figure 2, for air conditioning. The difference between the Figure 2 system and a heat pump is the heat pump has extra plumbing and a reversing valve to reverse the flow of refrigerant. The difference, including the reversing valve, is shown in Figure 2. The valve switches the direction of heat flow from inside-out (summer cooling) to outside-in (winter heating). Figure 3 shows the system in heating mode. The ingenious valve design simply slides the "U-turn" shown to reverse flow direction. With reversibility, the outdoor coil serves as the condenser in the summer and evaporator in the winter and vice versa for the indoor coil.

Single Zone Central Residential

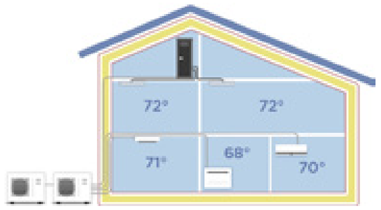
Perhaps the most common heat pump system is the single zone unit. Like the decades-old central air conditioning systems, these outdoor units supply heating and cooling to an air handler that distributes heating and cooling via ductwork to an entire home or group of rooms in a commercial building.

Installations of this type of system are most appropriate to retrofit or replace air handlers where ductwork is already in place. Air source systems, as shown above, or ground source heat pumps, discussed below, are viable options.

Zoned Systems

Zoned heat pump systems, also known as "ductless" or "mini-split" systems are newer and preferred technology compared to the single zone system described above. In general, the industry uses a wide variety of terms, but this section describes zoned systems for residential applications. They can also include an air handler that serves multiple rooms, such as one floor in a home, as shown in Figure 4.[4]

Figure 4 – Zoned Home Solution



Most mini-split heat pumps offer variable speed (inverter) compressor technology. Advantages over single zone central systems include a variety of indoor unit styles from non-ducted (ductless) wall, floor, and ceiling mounted units, to fully ducted zones for flexible new construction and retrofit options. Inverter technology provides very quiet operation indoors and outdoors, and offers optimal efficiency with multiple temperature control zones. Technological advancements deliver 100% heat pump capacity down to 5˚F, and operation to -13˚F. Future products are continuing to push this performance to even lower temperatures.

Ductless options work well for retrofitting zoned systems. Cooling delivered via ductwork retrofitted to an entire home is costly and, in many cases, unsightly, not to mention they will always leak to some extent. Ductless systems provide heating and cooling with only refrigerant tubing and power supplied to the indoor units, whereas, of course, ducted systems deliver conditioning via airflow, which requires a much larger cross-section and space. The smaller, more flexible power and refrigerant tubing is a big advantage, and it can be mostly run on the exterior of the building – a low cost, non-invasive solution.

Zoned systems can serve up to eight temperature-control zones of heating and cooling. A zone includes one fan and coil (indoor unit) to satisfy space temperature setpoints. Ductless zoning offers elegant, reliable, and efficient zone control compared to ducted systems with remote dampers and actuators. It improves comfort and saves energy by heating and cooling where the loads are highest for given conditions – e.g., more cooling upstairs in the summer and more heating downstairs in the winter. By default, temperature sensing occurs at the indoor unit but can be configured at a thermostat or auxiliary sensor.

Variable Refrigerant Flow

Variable refrigerant flow (VRF) systems are larger versions of zoned residential systems, and many are designed for heat recovery, allowing heat to be moved within a building. Many commercial buildings, especially those with large footprints, have internal spaces, such as conference rooms, cubicle areas, or large retail floor areas that need cooling all year because they have no heat loss. They only have heat gain from people, electronics, and lights. In northern climates, the heating season spans more than six months. During this time, heat from internal spaces can be moved with the VRF system to external spaces where heating loads exist. Similarly, solar exposure throughout the day and seasons impact building loads. The VRF option can save a lot of energy as only one vapor compression cycle is needed to simultaneously cool inboard spaces and heat outboard spaces. It also reduces the capacity required for the outdoor compressor unit.

Water Source Heat Pumps

To this point, all types of heat pumps discussed are used to exchange heat between indoor air and outdoor air, or in the case of VRF, from one indoor space to another indoor space. Water source heat pumps are used to condition spaces with a circulating water loop, which acts as a heat source and heat sink.

With water source heat pumps, the combinations of heat sources, types of heat pumps, and systems expand exponentially. Water heat sources and sinks include:

- Closed-circuit loops heated by boilers and cooled by cooling tower heat exchangers outdoors.
- Closed-circuit ground-source heat exchangers.
- Open-circuit groundwater source heat sinks.[5]

Most water source heat pumps are single-zone water-to-air type. Each heat pump has its own compressor, air-side, and water-side heat exchanger. As described above, the refrigerant boils at low pressure and temperature to cool air or condenses high-pressure refrigerant to heat air. Heat is rejected to or extracted from the water loop, respectively.

Other water source heat pumps exchange heat between two water loops to make chilled water for cooling or hot water for heating. Chilled water and hot water are circulated to heat exchangers in buildings to exchange heat with air to condition occupied spaces.

GAS FIRED HEAT PUMPS

We're almost home! We will describe three types of gas-fired heat pumps: engine driven, absorption, and thermal compression.

Engine Driven Heat Pumps

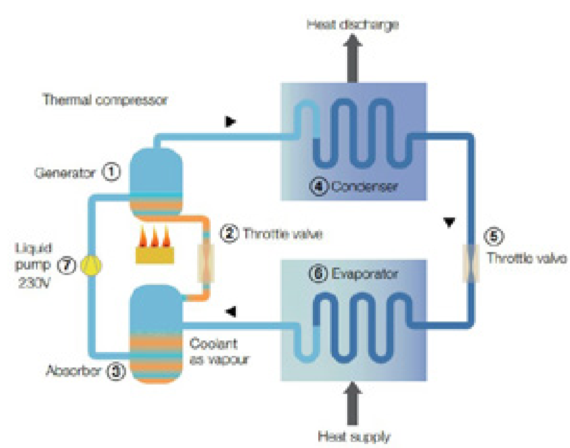
The engine-driven heat pump uses an internal combustion engine with natural gas as a fuel, like many standby generators, rather than an electric motor to drive the refrigeration cycle as described above. Engine-driven heat pumps have potential advantages over electric heat pumps in that they can be fitted with heat recovery off the engine for supplemental heat in very cold weather.

Absorption Heat Pumps

Absorption heat pumps require two sources of energy: heat, in this case, from burning natural gas, and electricity to drive a low-power pump to move the refrigerant. Absorption cycles use solute (water) and a solvent (ammonia) to move heat. Commercial systems use lithium bromide as the solute and water as the solvent to produce chilled water. The absorption cycle is shown in Figure 5.[6] In this diagram, the heat supply at the bottom is from outdoor air. That heat, plus the heat of natural gas combustion is included in the heat discharge for space heating.

The absorption cycle works as follows: Water has a strong affinity to absorb ammonia, creating a low-pressure, low-temperature fluid state that boils at low temperatures to absorb heat. The ammonia refrigerant enables the cycle to absorb heat in the evaporator at cold outdoor air conditions for space heating. Heat

Figure 5 – Absorption Cycle



from outdoors is leveraged with the heat from natural gas to drive the cycle resulting in efficiencies, also known as coefficients of performance, of greater than 100%. A typical seasonal efficiency, or annual fuel utilization efficiency, is 140% for these systems.

However, unlike vapor compression cycles, absorption systems are not reversible, and can only move heat in one direction. The water/ammonia system is used for heating for smaller applications, and the lithium/water system is used for cooling in commercial and industrial applications.

Figure 6 – Heat Pump Application Summary

	Multiple Zones	Heats and Cools Simultaneously	Retrofit	New Construction	Cold Weather Performance	Heating and Cooling
ELECTRIC						
Single Zone	–	–	±	–	±	+
Zoned	+	–	+	+	±	+
Variable Refrigerant	+	+	+	+	±	+
Ground-source	+	±	±	+	±	+
GAS						
Engine Driven	–	–	±	±	+	+
Absorption	±	–	–	±	+	–
Thermal Compression	±	+	–	±	+	±

Thermal Compression Heat Pumps

Thermal compression heat pumps are an emerging technology using external combustion to drive a piston in a cylinder filled with helium or carbon dioxide to exchange heat by compressing the gas to heat, and expanding the gas to cool. The heat from compression is used for space and water heating. The heat absorbed by the cooling expansion of the working fluid is used to produce chilled water for space cooling. Unlike every other heat pump described in this article, there is no phase change from gas to liquid and back with this technology.

Summary and Closing

Options for heat pump and system design are as unlimited as the building designs to which they can be applied. This article covers only common electric and less-common gas-fired heat pumps. A summary of usual applications and best fits are provided in Figure 6. A plus sign indicates a good fit or superiority. A plus/minus sign indicates case-specific applications, and minus signs indicate a typical mismatch of technology to application.

References

For image credits and the list of References, go to aesp.org/page/Magazine2020references

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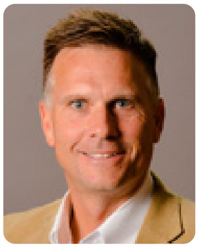
About the authors

Jeff Ihnen is the CEO of Michaels Energy. He has an insatiable appetite for learning how things work, optimally



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