Building Science Education Solution Center – Introduction to Heat Pumps

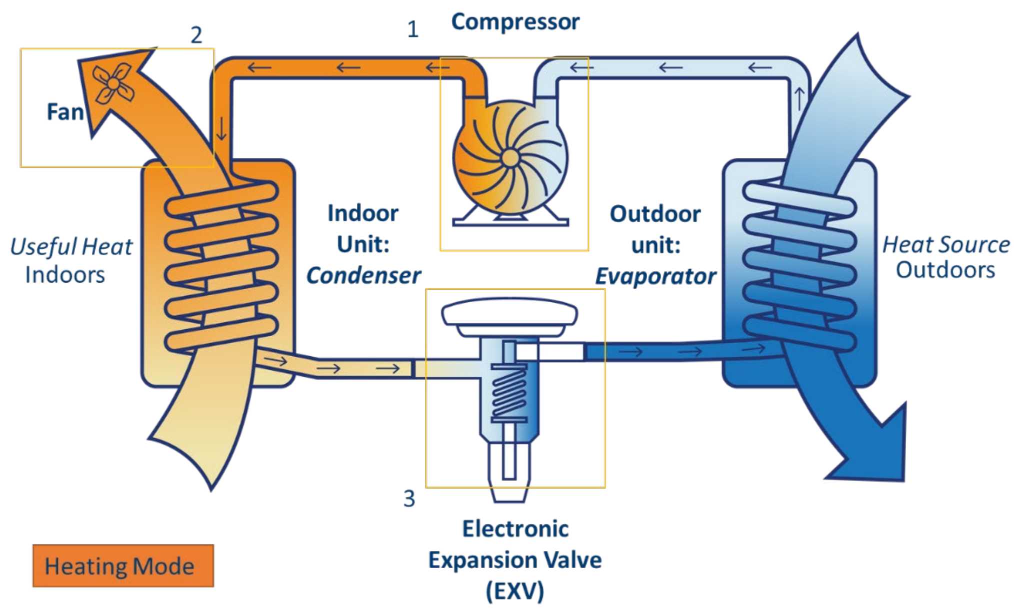
Proficiency Level 2: Understand

Learning Objective 2.1:

- How does a heat pump work?

Lecture Notes 2.1:

Air source heat pumps work by utilizing the vapor compression cycle of a refrigerant, the same cycle that a refrigerator uses. The basic components of a heat pump are the compressor, the indoor coil, the outdoor coil, the expansion valve, and the reversing valve. Refrigerant flows through each of these components in a continuous cycle, powered by the compressor.



The compressor compresses and pressurizes the refrigerant, making it hotter. When the unit is in heating mode, the hot refrigerant flows to the indoor coil where it heats the supply air to the house. The refrigerant then flows to the expansion valve, which expands and depressurizes the refrigerant, making it cold. The cold refrigerant flows to the outdoor coil where it can pick up heat from the outdoor air. Finally, the refrigerant flows back to the compressor to continue the cycle. In cooling mode, the refrigerant flows in the opposite direction such that the indoor coil gets cold while the outdoor coil gets hot. The reversing valve is what directs the refrigerant to flow in a heating cycle or a cooling cycle. This component is the primary difference between a heat pump and a normal air conditioner.

The final major components of the heat pump system are the indoor fan and the outdoor fan. The outdoor fan blows air across the outdoor coil, and the indoor fan blows air across the indoor coil. This heats or cools the air. The air which is heated or cooled by the indoor coil is blown directly into the space being conditioned, most often distributed by a network of ducts.

Because air source heat pumps rely on outdoor air as the source of heat, their capacity to heat is highly dependent on the outdoor air temperature. The colder the outdoor air is, the less is the amount of heat available for the heat pump to extract, and the lower is its heating capacity.

In most locations in the U.S., the outdoor air temperature can get low enough that the heat pump cannot provide the full amount of heat needed by the home. To address this issue, heat pumps can be installed with an auxiliary heat source (sometimes called emergency heat). This could be an electric resistance heating coil (also called strip heat) located in the indoor unit downstream of the heat pump's indoor coil. Auxiliary heat could also be provided by a fossil fuel, as is done in a type of heat pump called a dual fuel heat pump. Dual fuel heat pumps are electric heat pumps which typically use natural gas or propane for auxiliary heat rather than electricity. Another approach is to have a completely separate backup system such as a furnace or boiler to provide auxiliary heat when needed.

Auxiliary heat is not just activated when the outdoor temperature is low. It can also be activated if the thermostat setpoint is increased and the heat pump takes a long time to reach the new set point. The auxiliary heat will then come on to speed the increase in space temperature. Because auxiliary heat is usually much less efficient than heat pump heat, it is generally more energy efficient to limit its usage. This can make efficiency strategies such as night time temperature setback problematic, because in the morning when the thermostat is turned back up, the auxiliary heat will activate and negate the efficiency gains of the night time setback. For this reason, it is often recommended to simply set the thermostat at one temperature and leave it alone. A separate strategy which is often employed (and required by many codes) is to control the auxiliary heat such that it cannot activate until the outdoor air temperature is below a particular threshold (commonly around 35°F). Further discussion of thermostat control of heat pumps is located in the Smart Thermostats module.

Problem Set 2.1:

1) Which of the following components are in both heat pumps and air conditioners?

    a. Compressor
    b. Indoor coil
    c. Expansion valve
    d. All of the above

2) Why do some heat pumps have auxiliary heat?

    a. Auxiliary heat is more efficient
    b. Heat pumps sometimes need assistance in very cold outdoor conditions or with a very large temperature difference between the current indoor temperature and the set point
    c. Heat pumps are never installed with auxiliary heat
    d. Electric, gas or oil-based auxiliary heat still works if there is a power outage

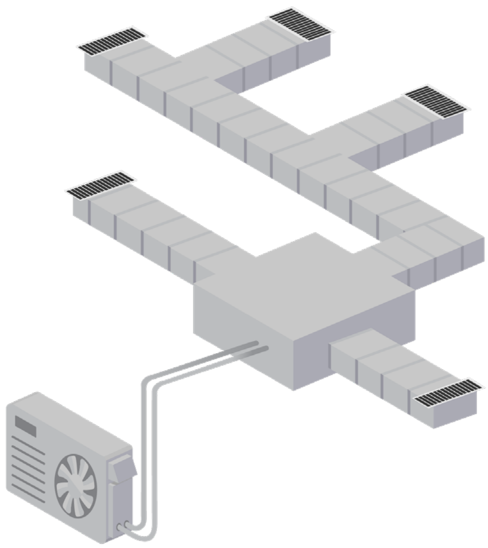
Learning Objective 2.2:

Understand the different types of heat pumps.

Lecture Notes 2.2:

Whole Home Heat Pumps

Several types of heat pumps are available to use. The first category is a whole-home heat pump. This system typically consists of an outdoor unit, often called a “condenser unit”, connected by refrigerant lines to an indoor air handler. The air handler pulls air from return ductwork or pathways and blows air through supply ductwork into each area of the home. These systems must be installed by a licensed HVAC technician as the refrigerant used in these systems must be carefully installed.



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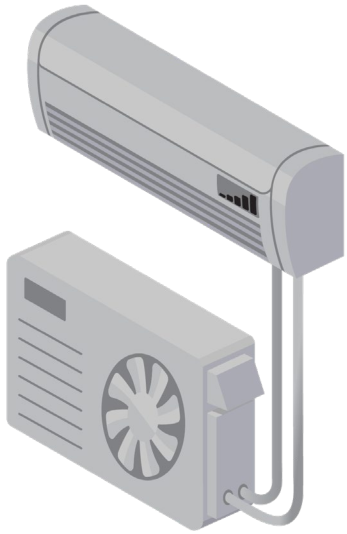
Ductless Mini-Splits/Heat Pumps

Ductless Mini-Splits are typically smaller heat pump systems meant for single zones. A mini-split consists of an outdoor condenser unit connected by refrigerant lines to an indoor unit, typically installed on a wall or in a dropped ceiling. The indoor unit draws air directly from the space and blows it directly into the space with no ductwork. These systems are usually higher efficiency than whole-house systems.

Multi-zone ductless heat pumps are similar to mini-splits, except that several indoor units share the same outdoor unit. These systems can be useful for homes without central ductwork or where the existing ductwork is too small.

[1] NYSERDA

[2]

Packaged terminal heat pumps

Packaged terminal heat pumps are a single unit that passes through the wall of a home. The operation is similar to a mini-split, where the indoor side recirculates air from the immediate area. These systems are a single unit and do not require an initial refrigerant charge, which makes them easier to install, however they require creating a large hole in the building wall.

"DIY" Heat Pumps with Pre-Charged Refrigerant

Heat pumps require specialized installation by a HVAC technician because of the refrigerant in the system. The refrigerant must be properly charged in a system in order for it to operate reliably and efficiently. Additionally, most refrigerants are very potent greenhouse gasses, meaning that they contribute to global warming and must be reclaimed by an HVAC technician.

Some mini-split systems and, to a lesser extent, whole-home heat pump systems are available as "DIY" systems that have pre-charged refrigerant lines with exactly the right amount of refrigerant for the system. The refrigerant lines have special connections to allow the installer to connect the refrigerant lines without the need for additional charging the refrigerant or for testing for leaks.

Learning Objective 2.2:

- What are the different heat pump options when looking for alternatives for homes that are currently heated by a gas furnace or boiler?

Lecture Notes 2.2:

[2] NYSERDA

When considering upgrading to an air-source heat pump (ASHP) from an existing fossil fuel-based heating system, it is essential to consider the primary goal of the upgrade and best ASHP solution for the application. Generally, there are two primary approaches when fuel switching in residential space heating systems: replacing the whole HVAC system ("replacement method") or installing an ASHP to displace some or most of the heating loads while still retaining the existing fossil-based system as the backup ("displacement method").

Replacement Heating

Replacing the whole HVAC system with a ASHP that can carry all of the load is quite common in warmer climates, especially if the furnace and an existing air conditioner need replacement around the same time. In this case, the size of the equipment should be determined based on typical Manual J load calculations that are otherwise taught in HVAC training courses. With the increasing availability of cold climate heat pumps, colder areas in the United States may also be feasible for heat pump replacement. See the **Cold Climate Heat Pump Sizing Module** for more information.

Displacement Heating

Depending on the scope of the HVAC upgrade and the climate zone the house is in, an existing fossil-based heating system may be retained as a backup heating system. In this case, the heat pump is the primary heating system that has operational priority. In other words, the heat pump is called on first to address the heating demand. If the heat pump is unable to provide adequate heating, such as during especially colder outdoor air temperatures, the backup system is called on to provide supplemental heating. Integrated automated controls ensure that the heating load is optimized between the heat pump and the fossil-based backup system. The **Smart Thermostats and Dual Fuel Controls Module** covers this is more detail.

Another type of displacement method is installing a mini-split or other system to serve one portion of the home. This unit could be installed to help improve comfort in unbalanced or sensitive areas of the home. When two separate systems are in use, make sure to coordinate the control of the system so they do not work against each other. Often this means setting both systems to either "heat-only" or "cool-only" at the same time. When possible, the more efficient heat pump should be prioritized.

Problem Set 2.2:

1) A homeowner would like to add cooling to two offices in their 3,000 SF home with natural gas boiler. What is the best option for a heat pump in this scenario?
    a. Replace an existing ducted furnace system with a ducted heat pump
    b. Install a heat pump as the primary heating system but keep the existing furnace or boiler as backup
    c. Install a ductless heat pump system in the offices.
2) A homeowner is looking to replace their air conditioner in the mixed humid or hot-humid climate. They currently have a gas furnace as well. Which type of heat pump makes the most sense for this homeowner?
    a. Replace an existing ducted furnace system with a ducted heat pump

b. Install a heat pump as the primary heating system but keep the existing furnace or boiler as backup
c. Install a multi-zone ductless heat pump system

Learning Objective 2.3:

- Understand the market trends for heat pumps and the benefits of switching to heat pumps in existing homes

Lecture Notes 2.3:

Electrification

An important driver behind the installation of heat pumps in new homes is the nationwide trend toward electrification of buildings and fuel switching from fossil fuels to electricity. In general, fuel switching is the process of replacing fossil-fuel fired end uses in buildings (e.g. heating, water heating, cooking and laundry drying to electric end uses) For this lesson, fuel switching (or electrification) more specifically refers to the installation of an electric heat pump to replace or supplement an existing gas, oil, propane, or coal furnace or boiler.

A primary motivation behind fuel switching is the mitigation of climate change. Fossil fuels inherently are carbon-intense to create and release carbon dioxide and other harmful byproducts into the atmosphere. Moving forward, the electric grid continues to become s create less and less carbon dioxide and harmful byproducts due to renewable technologies (e.g. solar and wind generation) and nuclear power plants. Therefore, the more end uses that can be converted to electricity, the more likely our buildings will be able to operate in a carbon-neutral environment in the future.

Increased Efficiency[3]

Often the motivation to install an ASHP is to increase efficiency and reliability by replacing an aging, inefficient system. About 30% of households that use heating and about 16% of households that use air conditioning have equipment that is 15 years old, or older – meaning that 16.5 to 33.7 million households use space conditioning equipment that is at or nearing the end of its life expectancy.

Heating and cooling needs account for 50% or more of a household's energy use, on average. Depending on the current equipment, efficiency upgrades can reduce energy use by 20% or more. This reduction will be the largest on homes with outdated, broken, or improperly sized equipment. While there are many types of space conditioning equipment, few will be both cost-effective and efficient for a given home, and installation practices can majorly influence efficiency and cost effectivity.

ASHPs are three to four times more efficient than traditional fossil fuel equipment: typical gas furnaces have a COP of 0.8 while typical heat pumps have a COP of 2-5. In many cases heat pumps can also reduce operating costs of a home's heating system since they are so much more efficient than fossil-fuel or electric resistance systems. However, there are climate, home location, and current system

[3] https://rpsc.energy.gov/energy-data-facts#:~:text=Of%20the%20energy%20used%20in,remaining%2045%25%20of%20total%20consumption.

considerations that will impact the efficiency, effectivity, and feasibility of installing a heat pump, especially in retrofit situations.

Improved Comfort

Sometimes homeowners want to add air-conditioning to a house that doesn't have cooling, and choose to install a heat pump rather than to add an air-conditioner to their existing furnace or boiler system. Heat pumps are a common choice when choosing a system for an addition or retrofit – They are available in small capacities well suited to additions, and the ductless versions are excellent for areas with space constraints as is often the case with retrofits (it can be difficult to find space for duct work if a space wasn't originally designed for it).

New Availability for Cold Climates

One factor in the increase in heat pump installations is the fact that heat pumps appropriate for use in very cold areas are now available. Historically heat pumps had only been able to provide sufficient heating when it was moderately cold outside, so heat pumps were only installed in warm to moderate climates. However, the availability of new cold climate heat pumps makes it possible and attractive for homeowners in colder areas to install a heat pump as well.

Heat pumps can also reduce safety and health concerns associated with fossil-fuel leakage including reducing or eliminating the potentially deadly byproducts of fuel combustion such as carbon monoxide.

Problem Set 2.3:

1) Explain three benefits of air source heat pumps compared to fossil fuel heating systems

Learning Objective 2.4:

- Understand the business case for ASHP installation services

Lecture Notes 2.4:

As national trends toward electrification drive increased demand for ASHPs, business are expanding into offering ASHPs instead of just fossil fuel furnaces. This expanded offering can provide additional business opportunities maintaining and installing both heating and cooling systems.

Additionally, existing customers have several potential reasons to install a heat pump before the typical end of life of their existing equipment. Customers wishing to install additional heating or cooling capacity, or to replace their existing system with lower cost or lower carbon heat pumps, will bring in more sales and maintenance.

Heat pumps can be installed in more locations as well, due to the availability of cold climate heat pumps, which can operate at temperatures below 0 °F. These heat pumps can efficiently operate at lower temperatures and in some climates require zero or only very small amounts of backup heating.

The increased ASHP sales will drive increased demand for HVAC technicians, sales people, designers, and manufacturing positions, with demand only increasing as more systems are put in place and cold climate technologies improve.