Renewable Energy Systems for Building Designers

Fundamentals of Net Zero and High Performance Design

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CHAPTER 11

Heat Pumps

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CHAPTER 11

Heat Pumps

Key Terms

Heat pump: a device that uses mechanical energy to transfer heat from one location to another.

Heat sink: a mass that absorbs or dissipates heat without much change of its own temperature – for heat pumps used in building HVAC systems this is air, water, or earth.

Heat source: a mass that provides heat for a system – for heat pumps used in building HVAC systems this is air, water, or earth.

Heating degree day: the number of degrees that a day's average temperature is below a particular temperature.

Infiltration: uncontrolled air movement through unsealed cracks and holes in the building.

Mini split: ductless air source heat pump that has one outdoor and one indoor unit which are connected with a condenser piping loop.

Multi split: ductless air source heat pump where one outdoor unit is connected with condenser piping loops to multiple indoor units.

Concepts for Success

Many traditional HVAC (heating, ventilation, and air conditioning) systems have relied on fossil fuels such as gas, oil, propane, or coal – all of which contribute to climate change. **Heat pumps** are a great environmental alternative because they are very efficient and are fully electric, so they can be powered with renewable energy.

Heat pumps move heat between the interior and exterior of the building. They are very efficient at moving heat because they use the refrigeration cycle to transfer the heat. Heat pumps that provide only cooling are air conditioners while those that provide both heating and cooling are bi-directional and called heat pumps.

The exterior portion of a heat pump, which can either provide heat or receive heat depending on whether the building needs heating or cooling, uses either air, ground, or water as the **heat sink** and **heat source**. Air source heat pumps (ASHP) transfer heat to the air using an exterior coil and a fan that circulates air across the coil. Ground source heat pumps have exterior closed loops installed in earth or water. Water can alternatively use open loops. There are various configurations for how the loops can be installed. Heat pumps can condition the whole building by using ducts and a central air handler to distribute conditioned air or they can provide heating and cooling to a specific zone within a building by using small ductless indoor units.

Heat pumps can replace the heating and cooling systems in existing buildings. As with any HVAC replacement, it is wise to consider improving the energy

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efficiency of the building by increasing insulation values and sealing air leaks. This will allow you to reduce the size of the equipment needed. Retrofit projects could involve replacing the whole HVAC system, just updating one area, or perhaps displacing a portion of the heating and cooling needs with a heat pump. In colder climates, there are options for backup heating if an air source heat pump is used and temperatures plummet.

Adding a heat pump may require alterations to the existing building's electrical service. If the existing service panel needs more busbars, options (besides upgrading the service, which is costly) include adding a subpanel, a smart circuit and power sharing device, or a smart breaker.

Heat pumps and their the supporting HVAC components must be installed correctly in order to work as designed. All equipment must be maintained according to the manufacturer's specifications in order to keep the equipment under warrantee.

Heat pumps can also be used for heating domestic hot water (DHW) and for clothes dryers. Heat pump water heaters use the heat from the room where they are located to heat the water. Heat pump clothes dryers do not need to be vented because the hot air is recycled through an integral closed system. However, water removed from the process of the clothes drying is condensed from the circulating air by the heat pump coil and needs to be drained.

How a Heat Pump Works

Heat pumps use the physics of compression and state change of refrigerants (referred to as the refrigeration cycle) to move heat from one place to another. Heat pumps are highly efficient, needing only a small unit of electrical power to move a comparatively larger unit of heat energy. For example, a heat pump that uses 1kW of electricity to move 4kW worth of heat operates with a net gain of 3kW. The exact efficiency is measured by the unit's coefficient of performance (see section on performance labeling of heat pumps).

Heat pumps need a compressor, two coils, and an expansion valve. One coil is indoors and the other is outdoors. The outdoor coil is located in or next to a heat sink and heat source – a mass of either air, ground, or water – that is able to accept or provide heat.

Heat can be moved either in or out of the building. We tend to talk about heating and cooling spaces, but actually, the process is just moving heat around. When we move heat out, it feels cooler! The amount of heat moved is regulated by the thermostat.

Air Source Heat Pumps

Figure 11.1 shows a heat pump with the refrigerant flow in heating mode. The heat sink is the air outside the building. The refrigerant is a state change material that shifts from a liquid to a gas and back again. Heat energy is absorbed and released as it changes its state. The basic parts are outdoor and indoor coils, a compressor, and an expansion valve. In an air conditioner (moving heat out), the outdoor coil is always a condenser and the indoor coil is an evaporator. In a heat pump, because it provides both heating and cooling, the coils can be in either mode (condenser or evaporator). When a heat pump is in heating mode, heat is collected from the exterior air by the exterior coil, which acts as the evaporator because the liquid is changing into gas as the refrigerant heats. The compressor compresses the refrigerant, which causes the refrigerant to become

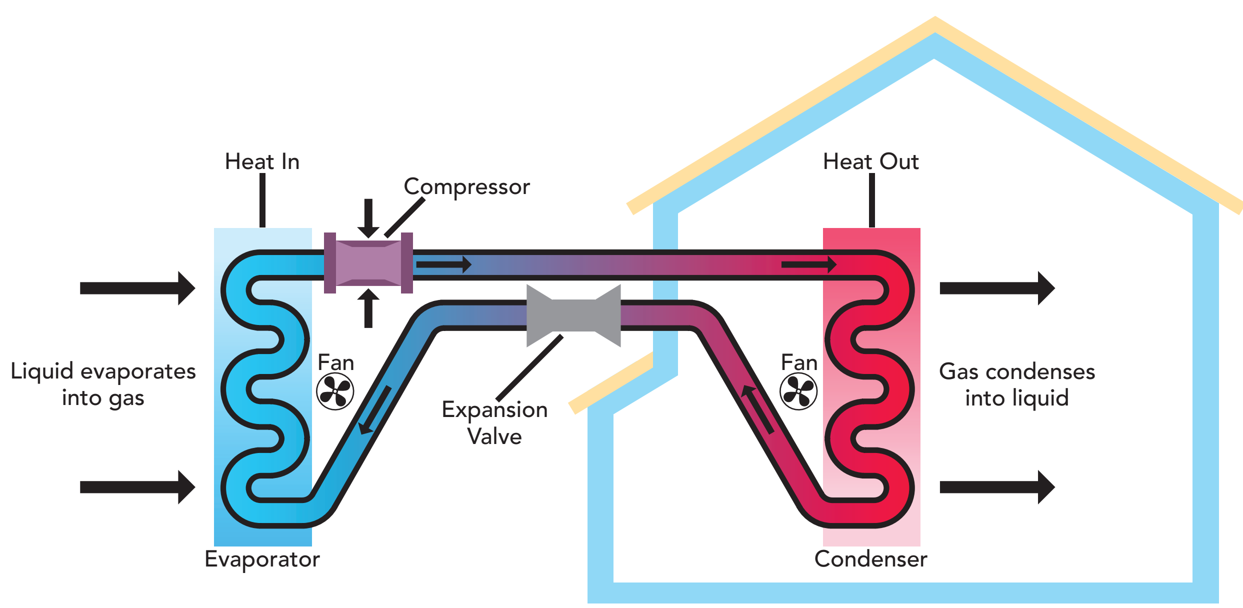

Figure 11.1 Heating mode operation of heat pump.

hotter. The hot, gaseous refrigerant circulates through the interior coil. A fan blows air over the coil, moving the heat into the air of the room or ducts of a mechanical system. In heating mode, the interior coil acts as the condenser because as the refrigerant cools off, it condenses into a liquid. The expansion valve allows the refrigerant to expand, causing the refrigerant to become very cold before it moves through the exterior coil. The cold refrigerant is then warmed up by the outdoor air before it repeats the cycle again.

In the heating and cooling mode diagrams, the exterior coil has a fan that blows the air across the coil, acting either as a heat source (figure 11.1) or as a heat sink (figure 11.2). The coils are made of copper tubing which is typically surrounded by aluminum fins to aid the transfer of heat. Notice in figure 11.2 that the cooling mode of the heat pump circulates the refrigerant in the opposite direction from the heating mode. This causes the interior coil to act as the evaporator, absorbing heat from the interior air, and the exterior coil acts as the condenser, releasing heat to the exterior air.

Heat pumps can condition a whole building or one space. Whole-building air-to-air (with fan coils both inside and outside) heat pumps are larger, heavier, and noisier than small ones. Whole-building heat pumps are typically mounted on either a plastic or a concrete pad and connect to an air handler that's on the interior (figure 11.3). The heating or cooling is then distributed through supply air ducts to the building's rooms. Building HVAC systems may have additional components for recovering heat and controlling how much air is being distributed into zoned spaces and at what temperature. Remember that all ducts should be insulated and sealed and should be located inside the building's thermal envelope. The actual size of the heat pump depends on the heating and cooling demand for the building.

Mini split heat pumps are ductless. They are great for retrofits in older homes where it would be difficult to run ducts. In less efficient buildings, a mini split can condition one or two rooms, depending on the size of the unit and spaces. The single outdoor unit can be connected to multiple indoor units and is referred to as a **multi split** system. In energy efficient buildings, a mini split may be able to provide all of the heating and cooling needs for the building or tenant space. As shown in figure 11.4, mini splits have a smaller air-to-air heat pump located outside, a condenser piping that is generally covered with a casing, and an interior air handler (fan coil unit or head). The air handler is fairly small and is mounted near the ceiling of the room. A drain line to the exterior is installed to remove the condensation from the interior air handler. The mini split is controlled with a wireless remote.

Single mini split outdoor units are installed near the location of the interior unit. The exterior unit can be mounted on the ground, on a heat pump pad, or raised up on a stand as seen in figure 11.5 B and C. Alternatively, an outdoor unit can be supported by brackets on a wall, as shown in figure 11.5 A. Both of these methods are effective at keeping the outdoor unit above snowfall levels, snowdrifts, and other snow buildup as well as raising it above likely flooding heights. In colder climates, keeping snow and ice (or water that will freeze) from shedding or gathering on the outdoor unit is important: in figure 11.5 A, note the metal cover on the unit is sloped and has an extended drip edge while the shed roof (figure 11.5 B and C) over the unit protects it from getting buried. Remember that the unit has to be exposed to the air, so it cannot be enclosed.

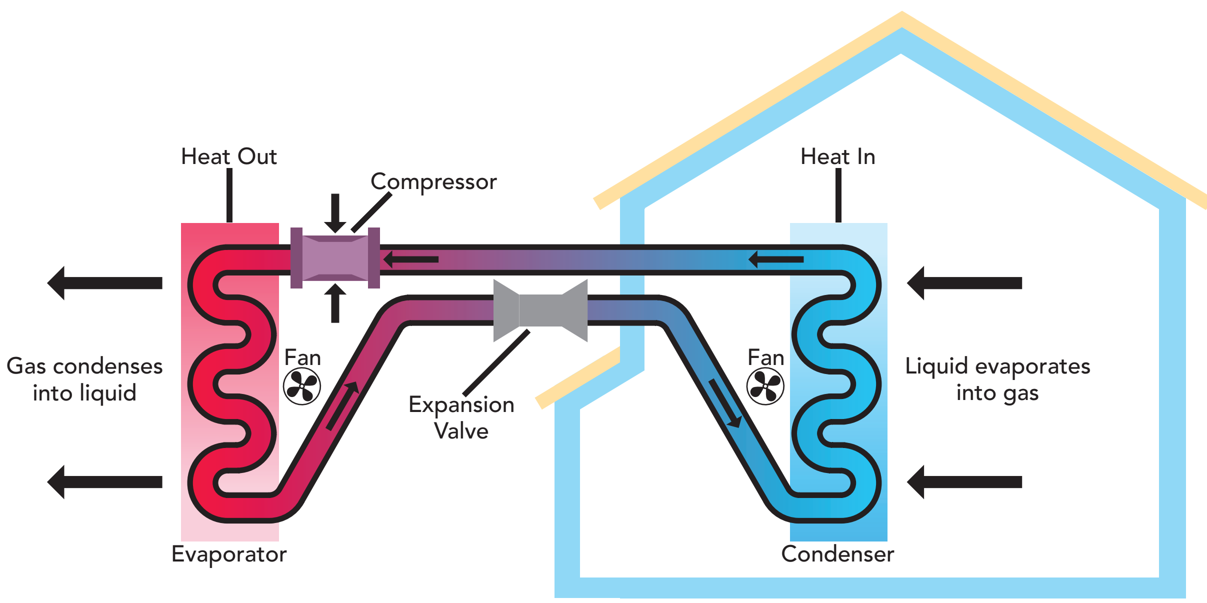

Figure 11.2 Cooling mode operation of heat pump.

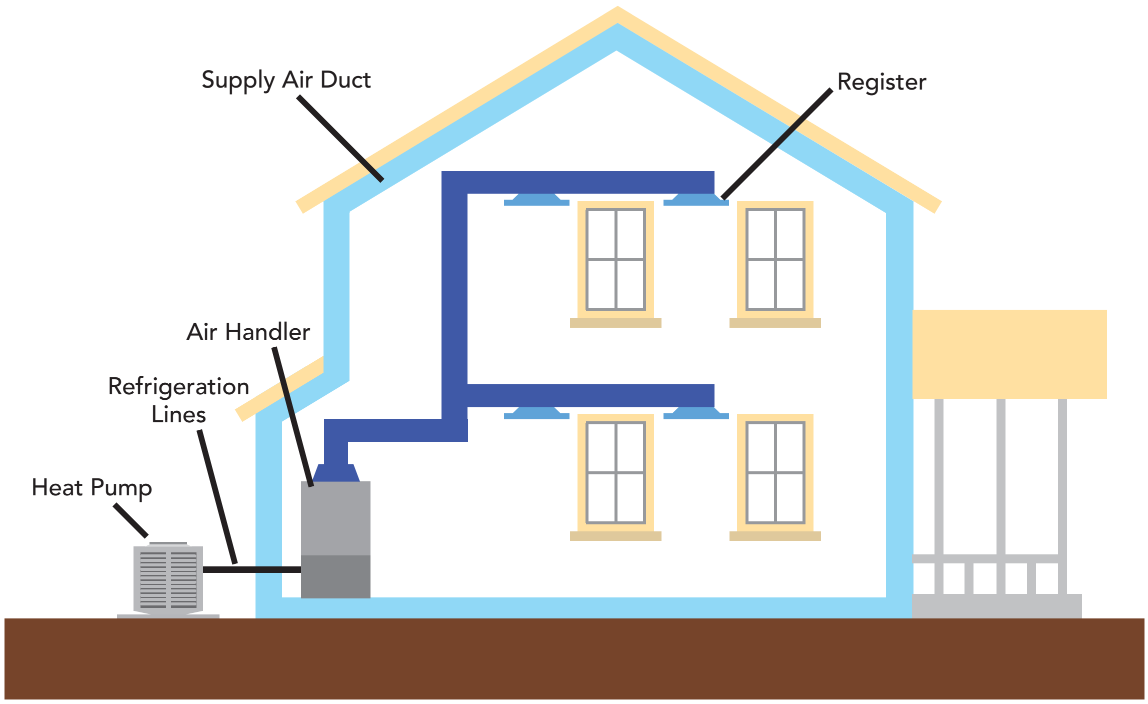

Figure 11.3 Whole building heat pump connects to an air handler and ductwork.

Figure 11.4 Mini split heat pump has a small exterior heat pump unit and a fan coil on the interior.

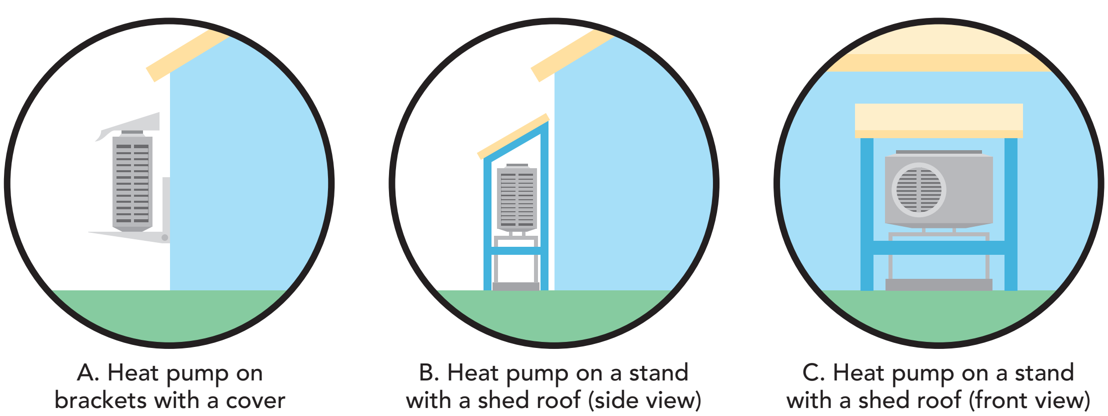

Figure 11.5 Mini-split air source heat pumps. On the left A: a wall mounted outdoor unit with a metal cover with positive drainage a drip edge. On the right B and C: an outdoor unit on a stand under a shed roof, note that the unit cannot be enclosed—all the sides must be open to the air.

Heat pumps have some vibration. Wall mounted units can transmit vibrations through the wall – this is more of a problem in older buildings with smaller framing members and not much insulation to dampen movement. Transmitted vibrations can be irritating to occupants.

Larger air source heat pump outdoor units are relatively square, as shown in figure 11.6, often 3–4′ wide (91–122cm), 3′ deep (91cm), and 3–4′ tall (91–122cm). As units increase in capacity, they stay about the same width and depth but get taller. For large buildings, multiple outdoor units may be needed to meet the whole building's heating and cooling needs. These units need a minimum clearance of 1–3′ (30cm–91cm) on all sides for airflow and share the same concerns for keeping out of reach of ice, snow, and flood waters as mini split units. Since these units are larger and heavier, they are not hung on a wall with brackets. The units can be noisy, vibrate, and chill or heat the air in the vicinity. Therefore, it's best if these units are not located near bedrooms, patios, or other functional areas where occupants prefer a quiet environment.

When multiple heat pumps are used for large commercial and multi-tenant residential buildings, the outside units need to be spaced apart from each other on the roof or wall to ensure they each have adequate air exposure and allow maintenance access. Heat pumps that are located too closely together may not be able to defrost (a regular cycle in cold conditions that removes frost from the outdoor coil) or can even be susceptible to icing on the coils of heat pumps nearby because the air has been super cooled. Furthermore, condensate from one unit should be prevented from dripping onto another unit as this can also cause icing in cold conditions. Heat pumps must have enough air with which to exchange heat or they cannot operate effectively. Poor operating conditions can result in excessive energy use and equipment failure.

Figure 11.6 Large whole building heat pump.

Ducted vs. Mini or Multi Split: Choosing a System and Retrofits

HVAC systems are designed to meet the heating and cooling needs of a building (see section on building loads), and older buildings typically are not very energy efficient. (See chapter 7, Building Performance and Energy Efficiency, for an in-depth discussion of this topic.) It is important to consider how to improve the energy efficiency of an existing building when considering updating the HVAC system. Although there are extra upfront costs involved, retrofitting buildings makes it possible to install new HVAC equipment that is smaller, resulting in lower first costs of the system and lower operational costs over time. The advantage is that lower monthly energy costs add up to big savings over time, not to mention that the occupants will be very happy about how much more comfortable they are!

Smaller buildings can use either ducted systems with heat pumps (like figure 11.3), one or more mini split (like figure 11.4) or multi split systems. Multi split systems use one exterior heat pump and multiple indoor units in different areas, called zones, of the building (see figure 11.7). The number of interior units that can be connected depends on the capacity of the heat pump. The indoor units can be any combination of wall, floor or ceiling mount, ceiling cassette, or low profile ducted as shown in figure 11.8. Each of these types has different air distribution patterns and mounting requirements. Ducted units must be hooked up to a duct system and an air handling unit.

If you have an existing building that already has ducts, you may be able to use the existing ductwork for the new system, although the registers may need to be changed to achieve better air distribution in the spaces. Heat pumps often operate at higher supply flowrates, so the existing ductwork could be too small for the new system – especially if you didn't apply energy retrofits to reduce building loads. Often, new heat pump systems replace an older heating system and could be providing the whole building with cooling for the first time. Ducts need to be checked to ensure that they are properly insulated with a vapor barrier jacket on the outside to reduce the risk of condensation during cooling mode. Figure 11.9 shows properly sealed and insulated ducts, which are much more efficient at distributing heating

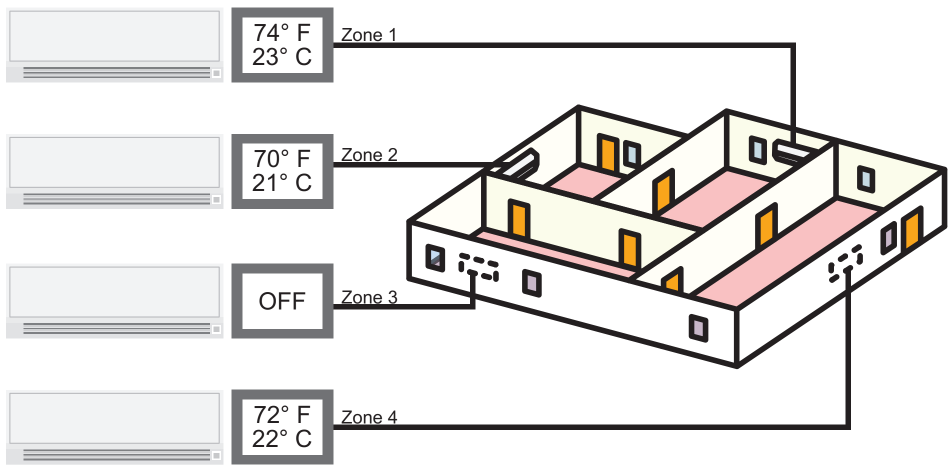

Figure 11.7 Interior units installed in throughout various rooms in a building to create individualized temperature control in each zone.

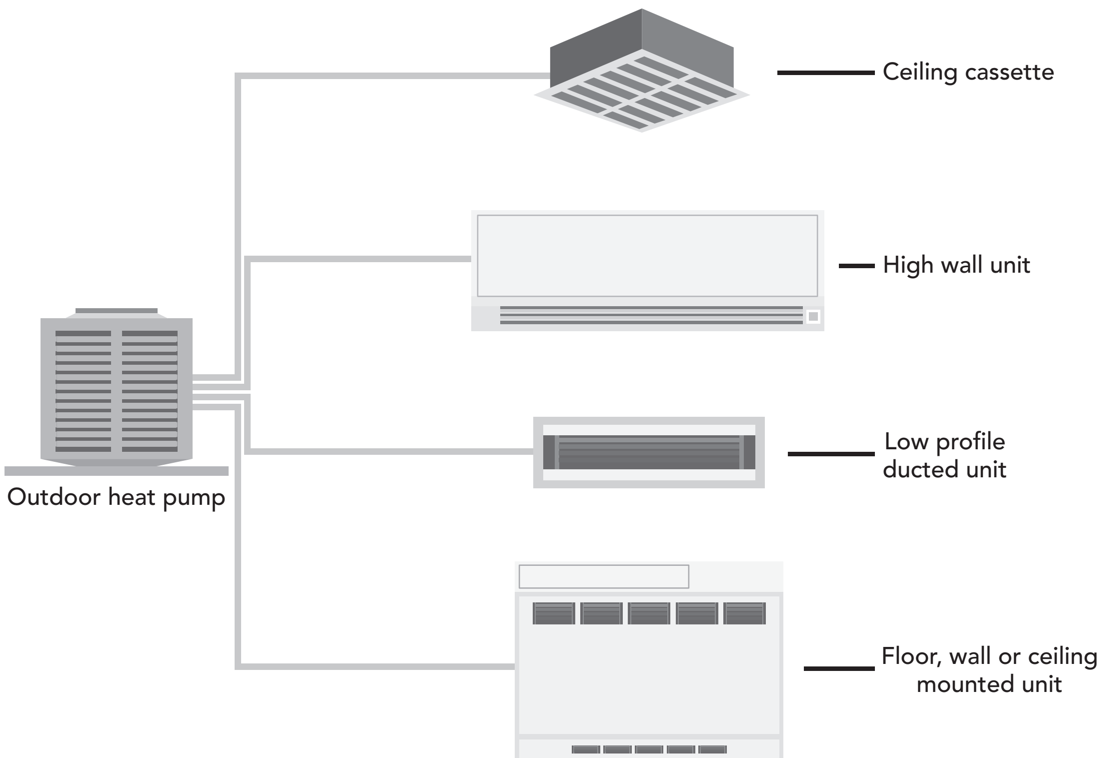

Figure 11.8 Various types of indoor units can be attached to a multi split system. Shown here from top to bottom are: ceiling cassette, high wall unit, low profile ducted unit, and a unit that can be mounted on either the floor, wall or ceiling.

and cooling to all areas of the building. If ductwork has to be replaced, compacting the ductwork design and keeping all ductwork inside the building's thermal envelope will reduce costs and increase efficiency.

Many types of traditional HVAC systems do not have ducts. In these cases, due to the lack of chase spaces to install ductwork, it may be more economical to use ductless mini splits or a multi split system. Note that these systems do not provide fresh air for the occupants, but are just providing heating and cooling. See the discussion under the building loads section and chapter 9 for more information about indoor air quality.

Building owners need to be aware that changing out a traditional fossil fuel burning system with a heat pump changes the distribution temperature of the heated supply air. Building occupants that are used to snuggling up to the registers for warmth will notice that the heat pump air feels cooler, even though the same temperature in the room is achieved. As has been stated multiple times, improving the performance of the building envelope makes the interior of the building more comfortable – occupants can use the whole room and be happy!

Another consideration for building retrofits is whether you are replacing the whole HVAC system or only

Figure 11.9 Well insulated and sealed ductwork performs better, ensuring comfortable air distribution throughout the whole building.

Figure 11.10 Main service panel on the left with subpanel to the right.

providing displacement heating and/or cooling. Displacement means that instead of replacing the total building demand with heat pumps, only a portion of the demand is supplied with heat pumps. For instance, a homeowner may want living areas of their home to be more comfortable than they currently are. Remember that air sealing and insulation improvements can make a big difference for occupant comfort – even newer construction can be missing insulation and have poorly sealed openings. One mini split could be added to the area to provide supplementary heating and cooling throughout the year. In a colder climate, a whole building heat pump could be added that is sized only to provide the heating to a particular temperature, at which point the existing building heating system would take over. See the section on cold climate air source heat pumps and backup heating options for further discussion on this type of displacement (dual fuel) system.

Larger buildings use heat pumps in many configurations depending on the building's size and loads. Heat pumps supply the heating and cooling to the HVAC system. Ducted systems include split systems similar to the ducted residential heat pumps described above and packaged rooftop units with the outdoor unit and air handling unit in a single rooftop unit. Ductless systems can use variable refrigerant flow (VRF) in which a large central system distributes hot and/or cold fluid to indoor coils throughout the building. HVAC systems can include heat recovery from excess heat generated from processes and activities, which can be used to heat the building. In addition, high-efficiency HVAC systems often utilize heat recovery in the ventilation system with either a heat recovery ventilator (HRV) or energy recovery ventilator (ERV); read more on this in the building loads section.

Electrical Panel Capacity in Retrofits

The capacity of the main electrical service panel, also sometimes called a breaker box, needs to be evaluated when retrofitting a building for a heat pump. Generally, buildings in the USA built after the late 1960s will have 100A service. Today, buildings in the USA typically have services of 150A or 200A, and even 400A to handle charging electric vehicles. The service panel has multiple breakers from which wiring is distributed to all electrical loads in the building. In the USA, each breaker is 30 amps. For a typical residential project, a heat pump needs to have two breakers feeding it power.

If the service panel doesn't have enough capacity, rather than having to upgrade the panel, it is possible to install a subpanel as shown in figure 11.10. In the photo, the main service panel is to the left with the cover door open so you can see the black switches in each breaker slot. The subpanel is to the right and is directly wired from the main service panel and then wired to the new equipment.

Figure 11.11 Ground source closed loops: horizontal, coiled, and vertical.

Another option is to install a smart circuit and power sharing device or a smart breaker on the main service panel. These devices allow for real time energy monitoring of electrical use and balancing of demand between circuits. This works because an occupant is not always using all the power on a particular circuit. Smart circuits are often used for optimizing electric vehicle charging, while smart breakers create easy integration of renewable energy into the main service panel. Both types of devices have apps that allow you to control your energy use, which can reduce costs, and tend to be easily integrated with other smart home systems.

Ground Source Heat Pumps

Ground source heat pumps use the earth, or a large body of water or aquifer, as a heat sink and source. The exterior coil exchanges heat with the fluid circulating through the ground source loop. The field can be configured as either closed or open loop, but closed loop is more common. The loops are usually made of high-density polyethylene plastic tubing and piping. Closed loops circulate a nontoxic antifreeze mix, while open loops circulate water. Closed loops are buried deep enough to avoid freezing and fluctuating ground temperatures. Deep earth temperatures vary by location and climate: generally, the earth is warmer at the equator and colder as you move toward the poles. Geothermal systems typically have very little maintenance.

If cooling loads are significantly larger than heating loads, geothermal may be combined with a cooling tower.

Closed loop geothermal systems have varying loop configurations (figure 11.11). Which one you use depends on the heating and cooling load, the soil type, and the ground temperature. All loops must be contained within the property line and must meet code and zoning requirements. Jurisdictions usually require that loop locations are kept away from wells, septic systems, and water and sewer lines.

Vertical bores are holes about 4″ (102mm) in diameter that are located at least 20′ apart from each other. The higher the heating and cooling demand, the farther apart the holes need to be so that they don't change the temperature of the heat sink. The vertical height of the hole can vary from 100–400′ (30–122m) deep. As you can see in figure 11.5, there is a horizontal a loop to and from the interior heat exchanger. Each vertical bore creates a loop that attaches to the horizontal piping in the opposite location along the supply/return loop to equalize pressure. Vertical bores can be made in rocky soil or on smaller sites where there isn't enough room for a horizontal-type loop. Larger commercial buildings use vertical bores.

Horizontal loops can be effective if you can dig trenches 4–6′ (1,219–1,828mm) deep and 100–400′ (30–122mm) long. The piping can either be in the form of two pipes that are buried about 2′ (610mm) vertically apart from each other or be coiled in a loop that can be buried flat or vertically. Coiled loops take up less horizontal area than a straight set of pipes.

Closed loops in ponds require a large body of water within 200′ (61m) of the building. The water must have enough mass that it maintains a fairly consistent temperature at the bottom. Depending on exactly how cold your climate is, you probably need about a half-acre of water that is 8–10′ (2,438–3,048mm) deep. Coils of piping 300–500′ (91–152m) long are anchored at the bottom of the pond.

Open loop systems are used with larger bodies of water, a well, or deep aquifer (figure 11.12). Open loops pull the water directly from the source, run it through the heat pump, then return it to the source. In some instances, a recharge well or surface discharge may be used. There are often a lot of permission requirements because of the possibility of water contamination. Open loop systems need a consistent supply of fairly clean water. Particulates, sediments, and microorganisms can clog the system, causing down time for maintenance. It can also be difficult to know the exact temperature of deep aquifers.

Sizing Ground Loops

The main considerations for the amount of bore or horizontal tubing depends on the load demand, deep earth temperature, soil type, and characteristics of the site. A general number for estimating runs for heating-dominated climates is 150–200′ (46–61m) of

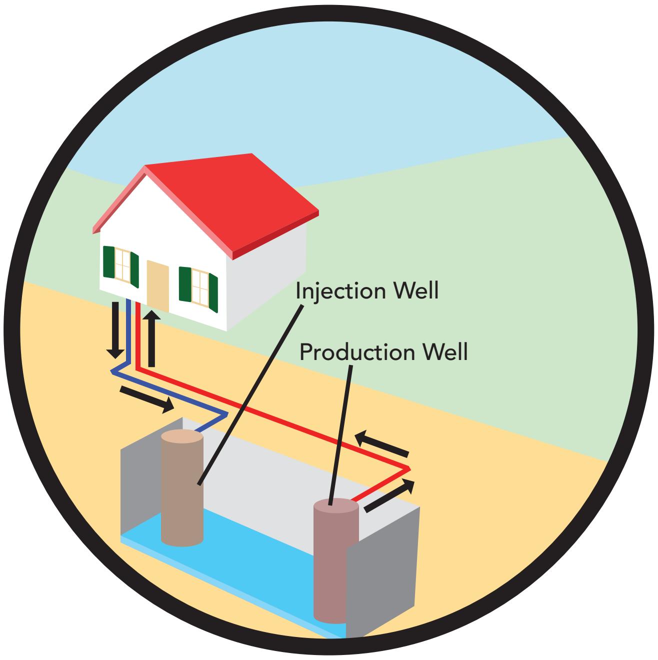

Figure 11.12 Ground source open loop draws and returns water directly from a source.[1]

vertical bore per ton of heating demand. The size of the piping loop depends on the flow rate needed for the heat pump, the size of the circulating pump, and the demand. Each ton of heating capacity needs a flow of three gallons per minute (11 liters per minute).[2]

Building Loads

How do you know how amount of heating and cooling load for your building? You have to calculate the heat losses and gains throughout the year. In the USA, residential loads are calculated using ANSI/ACCA Manual J. This takes into account the insulative values of the building envelope, climate zone, relative humidity, **infiltration**, and shading. Manual D also specifies performance of ducts if using a ducted system. Computer simulations can estimate loads for both residential and commercial buildings. Commercial buildings in the USA use *ASHRAE Handbook – Fundamentals* (the methodology is given in chapter F18) for determining heating and cooling loads.

Improperly sized equipment is inefficient. If undersized, it will run too much, causing stress that can lead to breakdowns, costly repairs, and reduced lifespan. Under-sizing the equipment may also void the warranty. Undersized equipment may not be able to properly heat, cool, or dehumidify the building, leaving occupants far from satisfied. Conversely, oversized equipment uses more energy than needed and has higher initial costs. Traditionally, mechanical engineers have over-sized equipment to ensure that building occupants are comfortable. Unfortunately, in today's high-performance buildings, oversized equipment uses extra energy as it over-produces heating or cooling. Right-sizing creates an energy efficient building, which provides the best occupant comfort and protects equipment from undue stress.

Sometimes, it can be tricky to identify the right size for a heat pump. This happens when the cooling and heating loads are quite different. Traditional single-stage compressors have the same amount of heating capacity as cooling capacity and can only run at full capacity. If a single-stage heat pump is oversized, it will cycle on and off too frequently (short-cycling), which can lead to lower efficiency and shorter lifespan. Variable speed compressors allow heat pumps to modulate their heating and cooling, which can accommodate mismatched heating and cooling loads as well as improve the overall efficiency of the system. In cold climates, specifying an air source heat pump with a variable speed compressor makes it possible to meet a very high heating demand without short-cycling in the summer, and will likely have better dehumidification capability.

Remember that the heating and cooling loads are determined by the climate and by the building envelope. You can create that important energy efficient envelope by adding insulation and air tightness to a design or existing building. These improvements will reduce building loads, allowing for smaller-sized equipment.

Buildings that are designed for high performance and net zero energy need to have envelopes that are much better than minimum code requirements. For example, a PHIUS certified three-bedroom house in a moderately cold climate can be heated with a single mini split because the heating loads are so low. [3] See case study 23A about the Rocky Mountain Institute (RMI) for an example of how to achieve integrated high-performance design. Some low-cost retrofit options for existing homes include attic insulation, low-e storm windows, adding exterior insulation during siding replacements, and duct sealing.

If you've improved the efficiency of an existing building, you need to check the actual loads because you'll be able to use smaller equipment. The energy savings and reduced first costs of the equipment will help to balance out the costs of the envelope improvements. Even better, these improvements also translate to increased property value. Many countries, localities, and power companies recognize the benefits of improved efficiency and offer a variety of grants and tax incentives.

Infiltration is uncontrolled air movement through unsealed cracks and holes in the building. Older buildings, especially residences, rely on infiltration to provide fresh air for occupants. Most current USA codes still allow this for residences, but require mechanical ventilation for commercial buildings. Infiltration is a very unreliable way to get "fresh" air into a building and there are many issues related to air quality and quantity. High performance buildings work to eliminate infiltration and far exceed air tightness required in current codes.

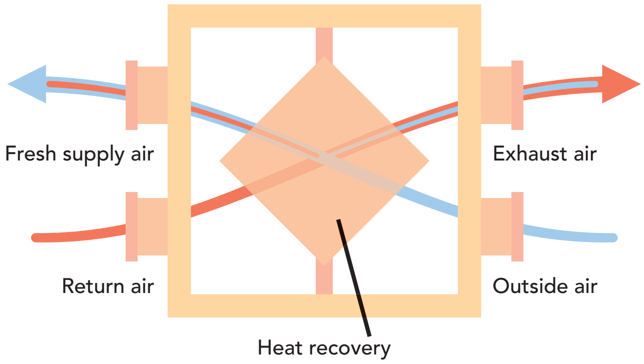

Figure 11.13 Diagram showing the interior of an HRV and how the warmth of the return air is transferred to the cold outside air, preheating the fresh supply air.

This means that mechanical ventilation must be added to an "old" building as it is tightened up, delivering complete control over the quality and quantity of air being introduced.

Another big advantage to providing mechanical ventilation is that you can add a heat recovery ventilator (HRV) or energy recovery ventilator (ERV) which is able to exchange the heating (or cooling) of the interior air being exhausted with the cold (or hot) fresh exterior air (see figure 11.13). This saves a lot of energy because the incoming fresh air is now closer to the actual temperature you want inside of your building. In addition, some of the HRV/ERV manufacturers have small, flexible ductwork that is much easier to install in new or retrofit conditions (see figure 11.14). HRV/ERV systems also provide balanced ventilation, which means that the exhaust and intake of air is always the same. For systems with mechanical ventilation, it is essential that the ventilation equipment, including HRV/ERV, is regularly maintained. Providing building owners with clear information on how their systems work and required maintenance schedules is very important. Durable instructions help current and future owners understand what systems they have and how they should operate.

Performance Labeling of Heat Pumps

Heat pumps are rated based on their efficiency for heating or cooling. The higher the rating number, the more efficient the heat pump. That is because all of the ratings are based on output divided by input energy.

Air source heat pumps use seasonally adjusted ratings for heating and cooling. Air temperature varies over the season, so ratings are based on fluctuating temperatures. The heating is rated by the heating season performance factor (HSPF), while the cooling is rated by the seasonal energy efficiency ratio (SEER). HSPF = output heating energy in Btu over a season/input electrical energy in Wh during the same season. SEER = output cooling energy in Btu over a season/input electrical energy in Wh during the same season.

Figure 11.14 Image of whole house ventilation system with HRV.[4]

HSPF is not tested in temperatures below 17°F (–8.3°C), so care must be taken to properly design backup heating systems when the air temperatures are very cold. The building may require a backup heating source in very cold temperatures. The exact efficiency and operating temperatures will depend on the particular unit. Cold climates should use air source heat pumps with variable speed compressors, which have increased efficiency in cold weather.

Ground source heat pumps used in HVAC systems use the coefficient of performance (COP) to determine heating efficiency. COP = power output/power input. Cooling efficiency is measured by the energy efficiency ratio (EER). EER = output cooling energy in Btu/input electrical energy in Wh. The difference between EER and SEER, as well as COP and HSPF, is that EER and COP are measured at a specific temperature because the ground at a particular location is going to remain a constant temperature. If COP and EER are provided for an air source heat pump, it will be a number range or its performance at a specific temperature.

In the USA, the Department of Energy (DOE) has established minimum performance requirements for heat pumps. These numbers increase over time. Third-party rating systems require much higher efficiencies than the minimum requirements. Currently, the minimum cooling efficiency is 14 SEER for residential air-source heat pumps, although some mini split units are available at 27.2 SEER. The minimum for heating is 8.2 HSPF. For geothermal units, heating is 3.1 COP and cooling is 16.1 EER for closed loop systems.

Cold Climate Air Source Heat Pumps and Backup Heating Options

It is important to match your air source heat pump to the climate it is being installed in. Colder climates need specific systems in order to work at colder air temperatures. The Northeast Energy Efficiency Partnerships (NEEP) has a list for cold climate air source heat pumps (ccASHP).[5] Colder climates are defined in the USA as climate zones 4 and higher per the International Energy Conservation Code (IECC) section R301. NEEP released Version 4.0 of their specifications effective January 1, 2023. Key to these specifications for ccASHP are these requirements: certification is per the applicable standard depending on the type of heat pump; compressor is variable capacity (three or more distinct operating speeds or continuously variable); ccASHP is air source; and ccASHP can be ducted or non-ducted. Heating performance capacity is documented at outdoor temperatures for 47°F (8.33°C), 17°F (–8.33°C), and 5°F (–15°C). Non-ducted systems require 10 HSPF and 15 SEER, while ducted systems require 9 HSPF and 15 SEER. COP at 5°F (–15°C) is greater than or equal to 1.75 at maximum capacity operation.

For the purpose of reaching net zero carbon and/or energy, the best-case design is to create a building with very small loads and then size the heat pump to cover the heating loads. If it is not cost-effective to size the heat pump to meet the most extreme temperatures, then backup heating can be used. If the heating load is very small and very cold temperatures don't happen often, then using small electric resistance heating elements can fill the gap. If heating demand happens more frequently, you may need to add a hot water coil to the HRV/ERV and it may need to be combustion powered. An example of this is shown in case study 23E where the home is located in a climate with over 8,000 annual **heating degree days (HDD)**.

Existing buildings in climates with over 6,000 annual HDD will have higher heating demands – especially if the building envelope is not well insulated and sealed. As mentioned previously, envelope updates will reduce heating demand and increase occupant comfort. However, owners may have cost limitations that impact the amount of renovation and size of ccASHP. In these cases, it is viable to use the existing heating system (or upgrade to a much more efficient combustion furnace) as a backup heat source. The use of both is called dual fuel systems. The heat pump provides the majority of the heating load while a gas furnace will take over or provide supplemental heat at very cold temperatures. Heat pumps in a dual fuel system work best when installed with smart thermostat controls because setbacks and sudden changes in heating loads cause inefficient operation and can trigger unnecessary running of the backup heating system. Dual fuel heat pumps require specific thermostat control to appropriately change between heating sources. Typically, the thermostat is programmed to use the balance point of the system to change the heating source from the heat pump to the furnace (see figure 11.15).

The balance point method programs the smart thermostat controls to switch over from the ccASHP

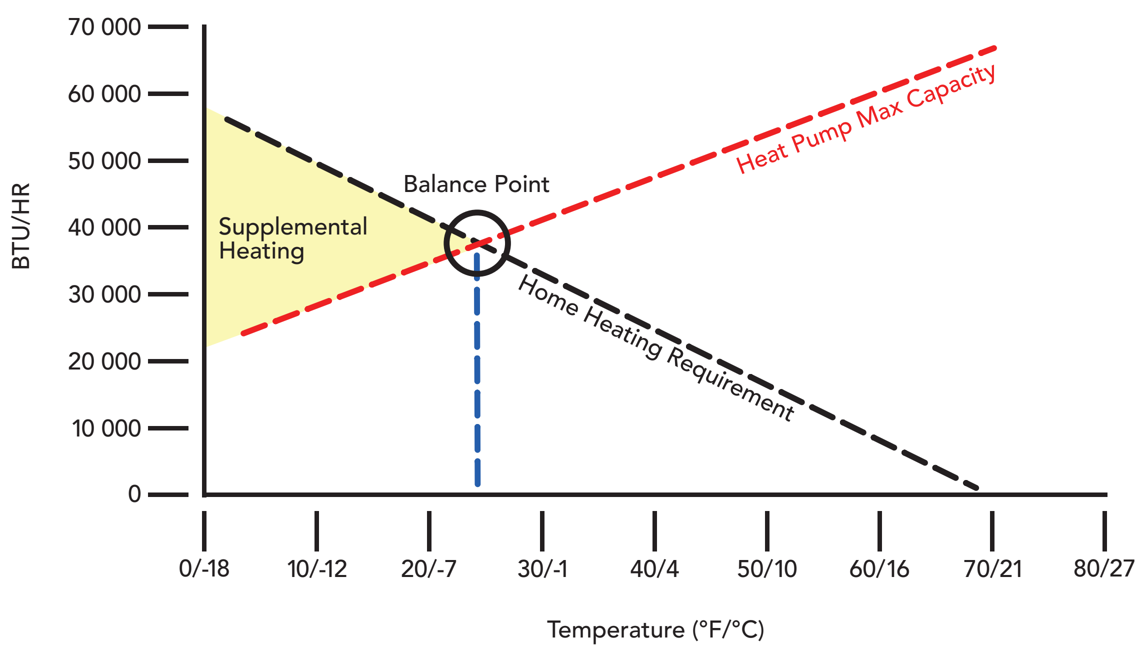

Figure 11.15 Determining the balance point temperature by plotting the heat pump maximum capacity versus the heating demand (load).

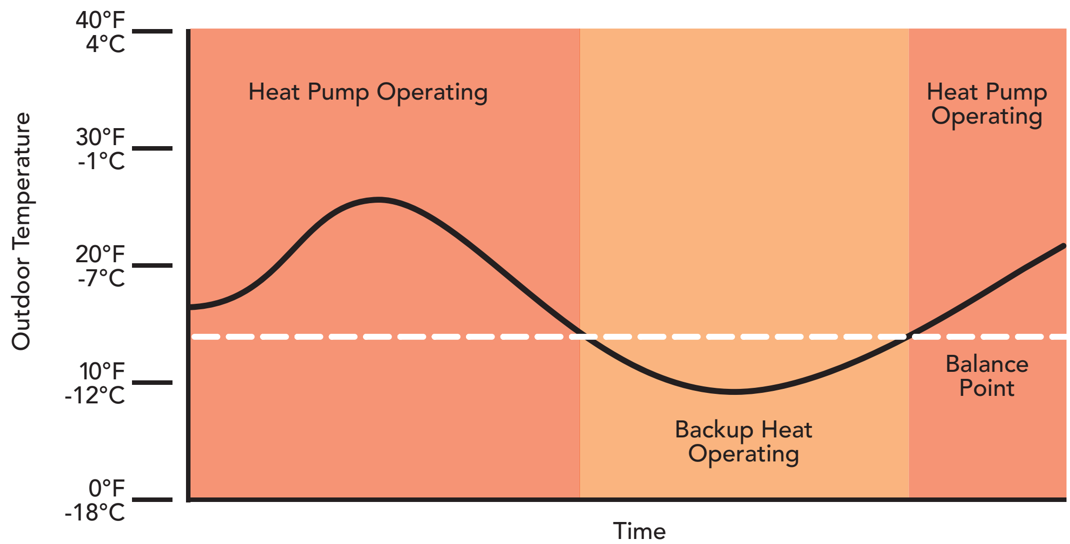

Figure 11.16 Graph showing the balance point method where the smart thermostat automatically switches between the heat pump and the backup heat based on outdoor balance point temperature. In this example, the heat pump provides heating when the outdoor temperature is 14°F (–10°C) and above. Below this temperature the backup heat will provide heat for the building.

at a set outdoor temperature, typically between 5°F (−15°C) and 35°F (1.67°C) depending on the unit's performance values and the load calculation demands. The heat pump capacity is based on the manufacturer's extended performance data or the NEEP database. The point at which the heating demand exceeds the heat pump capacity is the balance point temperature (see figure 11.15). The smart thermostat is programmed to supply heating with the heat pump until the outdoor air temperature drops below the balance point, then it will automatically switch to the backup system. When the outdoor air temperature heats up again, the controls automatically switch back to the heat pump. Only one system is running at a time (see figure 11.16).

A second control strategy for dual fuel systems, called the droop method, can be used when the heat pump and backup heating system are two distinct systems (such as a mini split heat pump and a boiler–radiator system) and usually has separate thermostats for each system. This method allows simultaneous operation of both the heat pump and the backup heating system based on indoor air temperature. The heat pump is always providing heating, while the backup system generates the "extra" heat needed to meet the remainder of heating demand when temperatures are very cold. For example, the heat pump thermostat could be set to 68°F (20°C) and that setting keeps the indoor air temperature at 66–70°F (19–21°C). The thermostat for the backup heating is set so that it will maintain an indoor air temperature of 65°F (18°C). When the room temperature falls below 66°F (19°C) because the heat pump cannot produce enough heat due to a very cold outdoor air temperature, the furnace will start up. Care must be taken to ensure that thermostats are programmed correctly so that the backup heating is only running when the heat pump is not able to provide enough heat.

Importance of Proper Installation and Maintenance

HVAC systems in high performance buildings will not work as designed unless they are correctly installed and the controls have been programmed properly. Technicians need to follow industry standards, systems need to be commissioned after installation to ensure that they are working properly, and owners need to properly maintain equipment over its lifetime. A recent study found that 70–90% of the systems in residences in the USA with central air conditioning and/or air source heat pumps had an energy wasting fault and at least 20% of the systems experienced failure due to improper installation.[6]

Today's technicians have smart diagnostic tools and applications that can assist in checking and troubleshooting heat pump installations. Smart tools have very accurate digital readouts because they are attached to the system or placed within the ductwork. These tools communicate wirelessly with diagnostic applications on your smartphone, tablet, or laptop. The applications are programmed to provide detailed performance information about the system, making it easier to identify and fix issues.

Heat Pump Water Heater (HPWH)

Domestic hot water (DHW) can be heated with a heat pump. The heat pump water heater (HPWH) transfers heat from the interior air into the water in the storage tank (figure 11.17). When hot water is in high demand,

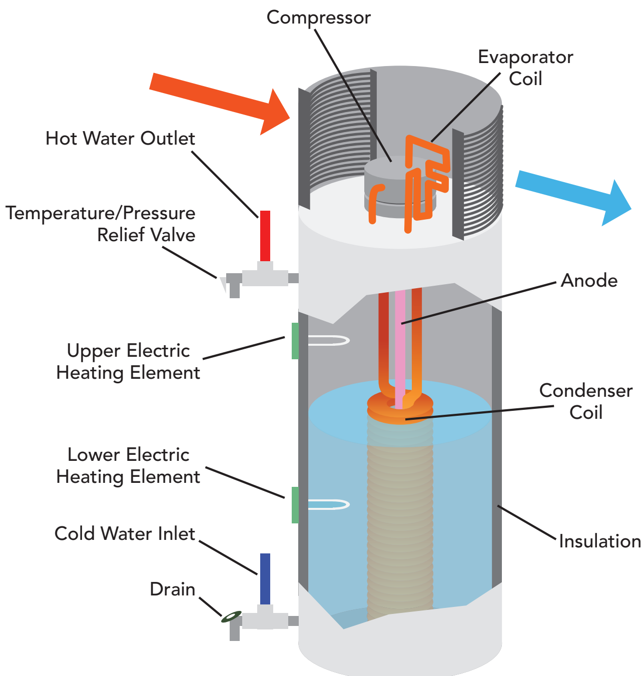

Figure 11.17 Heat pump water heater.[7]

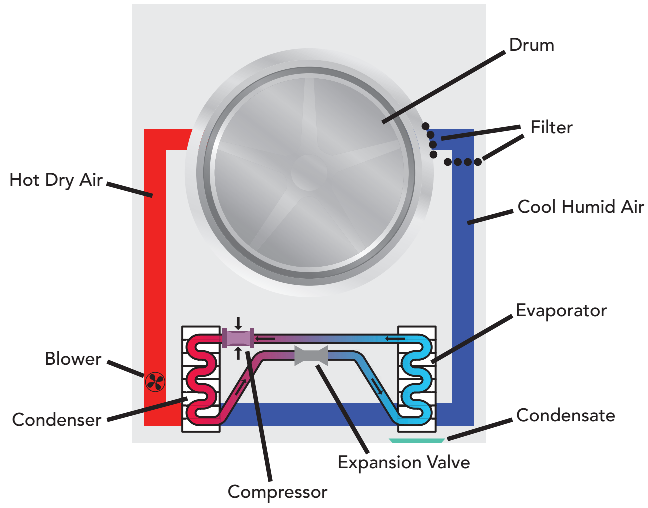

Figure 11.18 Heat pump clothes dryer.

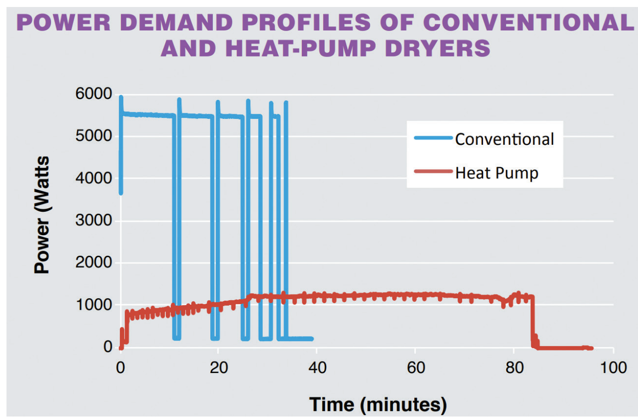

Figure 11.19 Comparison of power demand and drying time between electric resistance (conventional) and heat pump clothes dryers.

the HPWH uses standard electric heating elements to quickly heat water. A HPWH has to be located in an insulated space that remains 40°-90°F (4.4°–32.2°C) all year. Because the heat pump is moving heat out of the space, it needs to have at least 1,000 cubic feet (28.3 cubic meters) of air space around it and must be located in a room that has excess heat. If multiple HPWH are in the same space, they can cool the space too much, resulting in poor performance. Cooled air can be exhausted to the room or outdoors. HPWH can be used with a geothermal system by adding a desuperheater. HPWH can also be integrated with pre-heated water from a solar thermal hot water system.

Heat Pump Clothes Dryer

Electric clothes dryers use a lot of power by using resistance heat to make air hot enough to evaporate the water in the wet clothes. Heat pumps in clothes dryers are located at the bottom of the unit (figure 11.18). The dryer is unvented and uses the air in the room. Air is drawn into the dryer and then across the evaporator and condenser and through the clothes in the drum. It then continues to circulate around the loop. The air is dried out by the evaporator because the cold coils cause the water vapor to condense and drip the water into a drained pan. The dry air then passes over the condenser coil, which is hot, so the air is warm and dry as it is reintroduced into the dryer. The coils are set up so the refrigerant only flows one direction. The compressor and expansion valve work as they normally would in any heat pump. Heat pump clothes dryers can use between 40–50% less energy than electric resistance dryers. According to EnergyStar, 6% of US residential electrical consumption is used for drying clothes.[8]

Heat pump dryers can take longer to dry clothes. However, they have much less energy demand at any given time to complete the drying. This helps to reduce peak load electrical demands (figure 11.19).

Resources

1. Office of Energy Saver. (n.d.). *Geothermal heat pumps*. US Department of Energy. Retrieved from www.energy.gov/energysaver/geother mal-heat-pumps
2. Williams, C. (2011, June 29). 4-step guide to designing geothermal systems. *HeatSpring Magazine*. Retrieved from https://blog.heatspring.com/how-can-i-design-geothermal-systems-a-4-step-guide-to-designing-geothermal/
3. PHIUS certification: www.phius.org/certifications /
4. Office of Energy Saver. (n.d.). *Whole-House Ventilation*. US Department of Energy. Retrieved

from www.energy.gov/energysaver/whole-house-ventilation

5. Northeast Energy Efficiency Partnerships. (n.d.). *Heating electrification*. Retrieved from https://neep.org/smart-efficient-low-carbon-building-energy-solutions/air-source-heat-pumps
6. EERE. (2019*). Residential HVAC Installation Practices: A Review of Research Findings*. US Department of Energy. Retrieved from https://www.energy.gov/sites/prod/files/2018/06/f53/bto-ResidentialHVACLitReview-06-2018.pdf
7. ENERGY STAR. (n.d.). *How it works — Heat pump water heaters (HPWHs)*. US Environmental Protection Agency & US Department of Energy. Retrieved from www.energystar.gov/products/water_heaters/high_efficiency_electric_storage_water_heaters/how_it_works
8. Super Efficient Dryer Initiative. (2012, October). *Potential energy savings from heat pump dryers in North America* [Fact sheet]. Retrieved from www.energystar.gov/ia/partners/pt_awards/SEDI_Fact_Sheet_H.pdf

Study Questions

1. Look at a map (or climate information) that shows deep earth ground temperatures. How does deep earth ground temperature change as you move from 0–90° latitudes? How does deep earth ground temperature compare to air temperature?
2. Find images of a mini split heat pump installation showing the installation of the outside unit in different configurations, such as on a pad, wall-mounted, or protected from snow.
3. Draw sketches of different geothermal system loop layouts: one with four vertical bores, one with four horizontal loops, and one of an open loop using deep well water.
4. Go to the NEEP website and look through the heat pump list. Note that you can search by product type, ducting configuration, brand, or specific model. There are also slider bars to set limits for heating capacity at two different temperatures. Search the list and click through to see the specifications of at least five different ccASHP (ducted, non-ducted, multizone, and so on). Explore and compare the type of information given and the performance specs. Note that you can save a PDF of the posted information.
5. Identify the following terms relating to heat pumps:
   - **a.** Output heating energy in Btu over a season/input electrical energy in Wh during the same season
   - **b.** Output cooling energy in Btu over a season/input electrical energy in Wh during the same season
   - **c.** Power output/power input
   - **d.** Output cooling energy in Btu/input electrical energy in Wh
   - **e.** A heat pump system with one outdoor unit and one indoor unit connected by a condenser piping loop
   - **f.** A heat pump system with one outdoor unit and multiple indoor units connected by condenser piping loops
   - **g.** The type of source heat pump that uses vertical bores for closed loop piping
   - **h.** The type of mass that heat pumps exchange with heat
   - **i.** A retrofit heat pump that is only providing part of the heating and cooling loads
   - **j.** The type of heat pump system that requires an air handler in order to distribute the heating and cooling throughout the building

Study Answers

5a = HSPF

5b = SEER

5c = COP

5d = EER

5e = mini split

5f = multi split

5g = ground

5h = air, ground, water

5i = displacement

5j = ducted

*The author and publisher of this book, as well as the US Department of Energy, have put forth their best effort to ensure that the content contained herein is accurate and up-to-date. The purpose of this content is to assist the reader to understand the scope of work and the issues that need to be addressed when designing a building with a renewable energy system. Professional aid should be obtained when designing the specifics of any renewable energy system. The author and publisher shall not be held liable for incidental or consequential damages connected to, or arising from, the use of this book's content.