Chapter 3

Air Source Heat Pumps for Building Heating and Cooling

Kamil Kaygusuz[1]

Abstract

Air Source Heat Pumps (ASHPs) are part of the solution to decarbonize the residential heating sector. The coefficient of performance (COP) is a measure of the instantaneous efficiency of a heat pump. The heat energy produced by an ASHP is deemed renewable if it meets a specified sustained COP over a period of time, e.g., a seasonal performance factor (SPF). Heat pump performance in situ often differs from laboratory test conditions. This paper explores the performance of ASHPs in a field trial of deeply retrofitted Irish houses. Analysis shows that all houses in the trial qualify as producing renewable heat but vary from the manufacturer's laboratory test performance. Air source heat pumps typically include a fan, compressor, refrigeration circuits, and a heat exchanger. To provide heat, outside air is blown over tubes filled with refrigerant. The air warms the refrigerant, converting it from a liquid to a gas. The refrigerant then passes through a compressor, increasing the pressure and creating additional heat. This gas passes into a heat exchanger, enabling the heating of either air or water that is then circulated throughout the building. This transfer of energy, in turn, converts the refrigerant back to a liquid and allows the cycle to be repeated. Heat pumps may also be reverse cycle and provide cooling. To cool a building, a reversing valve changes the direction of the flow of refrigerant, which changes the direction of heat transfer.

1. Introduction

The Paris Agreement sets a goal of limiting the global average temperature increase to "well below" 2°C compared to preindustrial levels. It also calls on countries to "pursue efforts" to limit the increase to 1.5°C and achieve net zero emissions globally by the second half of this century [1]. To accomplish these goals, the global energy system will need to be reshaped to run on

1 Department of Chemistry, Karadeniz Technical University, 61080 Trabzon, Turkey
E-mail: Kamilk@ktu.edu.tr

https://doi.org/10.58830/ozgur.pub250.c1202

mostly carbon-free sources. That transition will involve cutting energy waste, shifting electricity production to carbon-free sources, and using electricity to satisfy a greater share of energy demand, among other strategies [2].

In Turkey, the use of fossil fuels in commercial and residential buildings is currently responsible for roughly 20% of greenhouse gas emissions. Despite this significant contribution, the sector has received less attention with respect to decarbonization strategies than either the power sector (28%) or the transportation sector (30%). Strategies for decarbonizing both the power sector and transportation sector are in general better developed than those for building heating [1-6].

In prominent studies of pathways to a low-carbon Turkish energy system, shifting from furnaces and boilers powered by fossil fuels to air source heat pumps (ASHPs) powered by zero-carbon electricity is the primary strategy for decarbonizing space heating. However, these studies show a wide range of outcomes on the potential for ASHPs to contribute to zero emissions space heating in Turkey by midcentury. The more optimistic studies show the near-universal electrification of space heating over the next few decades, with ASHPs playing an important role, while the more pessimistic studies show electricity failing to even displace natural gas as the leading space heating fuel [2, 7, 8].

Air-Source Heat Pumps are heating and cooling systems that move heat into a home in the winter and draw heat out of the home in the summer. Instead of burning fossil fuels, they operate on the same principle as your refrigerator: using a refrigerant cycle, powered by electricity, to move heat and to keep your home at a comfortable temperature year round. They are much more efficient than electric resistance heating and also provide highly efficient air conditioning [2]. Air-source heat pump systems feature an outdoor unit (containing a compressor, reversing valve, heat exchanger and expansion device) connected to one or more indoor units by small refrigerant piping. The refrigerant is a substance with properties that enable it to easily absorb and release heat [9-12].

This chapter is intended for policy makers who wish to make sense of the disparate evidence on the potential for the adoption of air source heat pumps in Turkey. It explains that ASHPs are already competitive with fossil fuels in certain regions of the country and that innovation and policy support are likely to make ASHPs more competitive in the years ahead. It also explains the barriers that stand in the way of zero emissions space heating, including costs, performance in cold climates, existing infrastructure, and consumer behavioral tendencies.

2. Heat pumps for low-carbon energy transition

Heat always travels from high temperature to lower temperature. A heat pump is a device that pumps heat from a lower temperature to a higher temperature. This is opposite to the natural flow of heat, but this applies for all refrigeration machines. However, the label 'heat pump' has evolved to define those refrigeration machines which can be configured to provide both cooling and heating, commonly referred to as "Reverse cycle" [2].

2.1. Heat pump versus air conditioner

Simply put, both devices are the same except a heat pump can provide cooling in summer, as well as heating in winter using reversing cycle; whereas an air conditioner can only cool. The air conditioners actually remove heat and moisture from the indoor space and transfer it to the air outdoors [2]. This air enters the unit at 80°F and 50% relative humidity and after passing through the indoor coil, it leaves the unit at a temperature of 55°F and a relative humidity of 100%. The heat that has been transferred from this air is carried by a refrigerant (for example R134a) to the outdoor, or condenser coil. The moisture is condensed on the air conditioner evaporator's coil and is drained outside [13-20].

Obviously, outdoor ambient temperatures can be quite high during the periods when space requires air conditioning. The refrigerant must transfer the heat it removed from the air in the indoor space to the outdoor air, but the outdoor air can be at a temperature of 35° C or more. Because we need to transfer this heat to air that is 35°C, the temperature of the refrigerant we are removing the heat from, must be substantially higher than the outdoor ambient temperature. The system is designed to blow outdoor air over tubes containing refrigerant at a temperature that is approximately 35°C warmer than the ambient air, so that the heat within the refrigerant can be transferred to the outdoor air [2].

Technically, any air conditioner can be considered a heat pump, but the HVAC industry considers heat pumps, to be air conditioners that have the ability to operate with a "Reverse cycle". It you have walked behind a window air conditioner on a summer day, you might have felt the hot air being discharged by these machines [1, 2, 4]. As described above, the temperature of the air leaving these units has increased because the refrigerant in the system picked up heat from the air inside the building, and that heat is being transferred to the air passing over the outdoor coil, thereby raising the temperature of the air [21-28].

2.2. What is the heat pump benefit?

The most important characteristic of a heat pump is that the amount of heat that can be transferred is greater than the energy needed to drive the cycle [2].

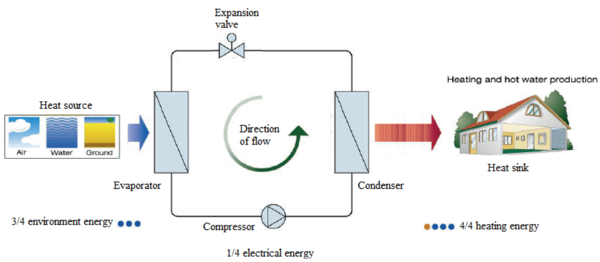

Figure 1. Heat pumps for building heating and cooling [2].

The key to the efficiency of a heat pump is the Coefficient of Performance: the "COP". In spite of the first law of thermodynamics, which tells us that energy can neither be created nor destroyed, the heat pump can yield up to four units of heat for each unit of electricity consumed. The heat pump is not creating this energy, but simply moves heat from cooler outdoor air into the warmer inside. Even in air that's seems too cold, heat energy is present [2]. When it's cold outside, a heat pump extracts this outside heat and transfers it inside. When it's warm outside, it reverses directions and acts like an air conditioner, removing heat from your indoor space. It pushes heat in a direction counter to its normal flow (cold to hot, rather than hot to cold).

On the other hand, COP is determined by dividing the energy output of the heat pump by the electrical energy needed to run the heat pump, at a specific temperature. Electrically driven heat pumps used for space heating applications in moderate climates usually have a COP of a least 3·5 at design conditions. This means that 3·5 kWh of heat is output for 1 kWh electricity used to drive the process. In simple terms, such a heat pump will be cheaper to operate provided that the electricity price is no more than 3·5 times the price of an alternative fuel. Irrespective, even when the operating costs for heat pumps and fuel fired boilers are rather similar, the case for heat pumps as a low carbon technology is more conclusive [2].

2.3. Refrigeration cycle

The refrigeration cycle is the basis of operation of all vapor-compression air conditioners and heat pumps. Although a detailed knowledge of thermodynamics is not required for the practical application of heat pumps, a basic understanding of the refrigeration concepts is important for all heating, ventilation and air conditioning (HVAC) system designers. Let's revisit the basic vapor compression refrigeration cycle first [2].

A simple vapor compression refrigeration cycle includes four major components: 1) compressor, 2) evaporator, 3) condenser and 4) expansion valve – all connected through a tube in closed circuit. It contains a refrigerant fluid that vaporizes and condenses inside the tubing as part of the operation process. These four components can be explain as [25-28]:

- The compressor is a pump that causes the refrigerant to circulate through the system. The compressor is rated to pump a set volume of vapor, so it will have a set capacity as a unit of BTU depending on the refrigerant being used, and the operating temperature in the evaporator. One ton of refrigeration is equivalent to 12000 BTU's/hour.
- The evaporator is a heat exchanger where the refrigerant vaporizes; i.e. it absorbs heat and the surroundings get cold.
- The condenser is a heat exchanger where the refrigerant condenses; i.e. it releases heat and the surroundings get hot.
- Expansion valve is a device used to reduce the pressure and temperature of the refrigerant at the end of the process cycle. Lowering the pressure of the refrigerant allows it to vaporize once heat is added.

The basic arrangement of a refrigeration circuit (cooling mode) is shown below [2]:

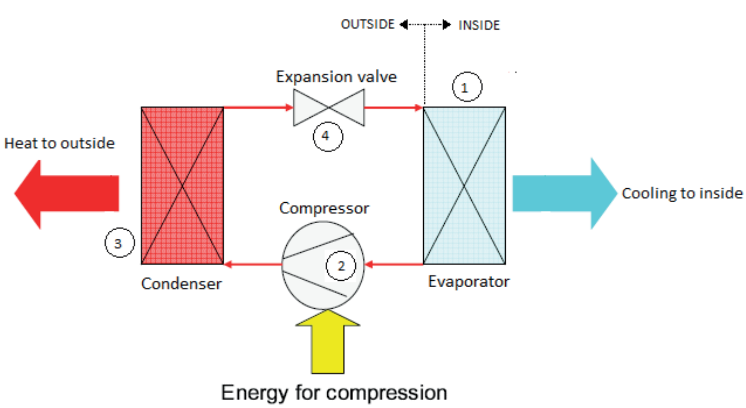

Figure 2. Basic arrangement of a refrigeration circuit (cooling mode) [2].

Let's see how this cycle works (Figure 2). **Stage1:** Refrigerant enters the evaporator in the form of a cool, low-pressure mixture of liquid and vapor. Heat is transferred from warm indoor air to the refrigerant; causing the liquid refrigerant to boil. **Stage 2:** The refrigerant vapor from the evaporator now enters the compressor, where its pressure and temperature is increased. **Stage 3:** The resulting hot, high-pressure refrigerant vapor enters the condenser where heat is transferred to ambient air or water. Inside the condenser, the refrigerant condenses into a liquid. **Stage 4:** This high pressure liquid refrigerant then flows from the condenser to the expansion device, which reduces its pressure. At this low pressure, a small portion of the refrigerant boils,cooling the remaining liquid refrigerant to the desired evaporator temperature [2].

2.4. Heat pump cycle

Heat pump uses the same principle of vapor compression refrigerant cycle and has the same basic components like a traditional air conditioner, except that it can reverse the refrigeration cycle or in other words, swap the functions of the condenser and evaporator. Refer to the schematic below and note the application is reversed for heating mode.

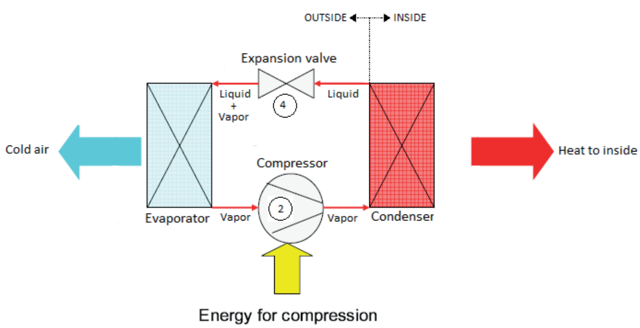

Figure 3. Basic arrangement of a refrigeration circuit (heating mode) [2].

Let's see how this cycle works (Figure 3). **Stage 1:** Outside heat exchanger picks up heat from the earth, groundwater or air and transfers it to the refrigerant. The refrigerant gets evaporated and now enters the compressor. **Stage 2:** The refrigerant, having now absorbed the environmental heat now enters the compressor and is compressed. The compressor increases the pressure of the refrigerant and also its heat content. This is the only part of the cycle where additional energy is required. **Stage 3:** The refrigerant gas now passes through the "indoor side" heat exchanger where it gives up its heat and turns back into a liquid. **Stage 4:** In order to be able to start the cycle again, the refrigerant must be de-pressurized, and so it is passed through an expansion valve, where it returns to a low-pressure liquid/gas mix and can begin to absorb heat from the air/earth/water again as it moves towards point 1 [2].

2.5. Operation of a heat pump in cooling mode

The heat pump in cooling mode operates as a conventional air-conditioner with the indoor coil as an evaporator and the outdoor coil as a condenser. The refrigerant first flows through the reversing valve where it is directed to the outdoor coil. Since the refrigerant always flows to the condenser first after leaving the compressor, the outdoor coil is acting as the condenser. In this mode of operation, the heat from the refrigerant is rejected to the outside air. From the outdoor coil, the refrigerant flows through the expansion device and then to the indoor coil, where the refrigerant absorbs heat from the air in the area being cooled. The refrigerant then flows back to the compressor via the reversing valve and the cycle repeats itself [25-28].

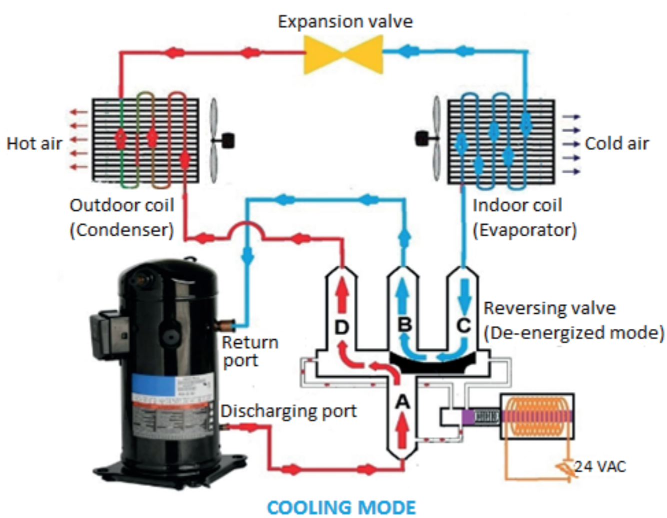

Figure 4. Operation of a heat pump in cooling mode [2].

2.6. Operation of a heat pump in heating mode

In heating mode, the refrigerant first flows through the reversing valve where it is directed to the indoor coil. Since the refrigerant always flows to the condenser first after leaving the compressor, the indoor coil is acting as the condenser. In this mode of operation, the heat from the refrigerant is rejected to the air in the occupied space. From the indoor coil, the refrigerant flows through the expansion device and then to the outdoor coil, where the refrigerant picks up or absorbs heat from the outside air. The refrigerant then flows back to the compressor via the reversing valve and the cycle repeats itself [2].

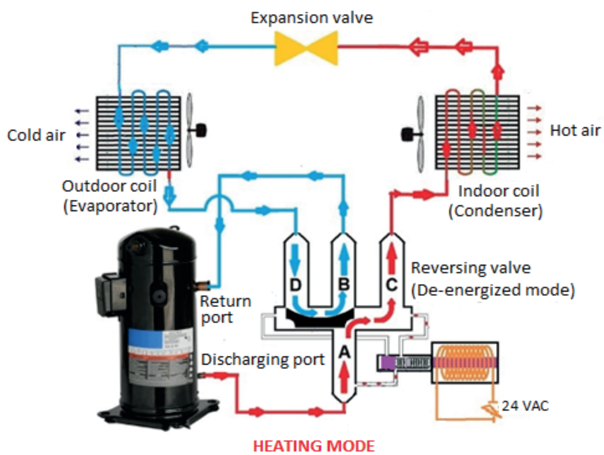

Figure 5. Operation of a Heat Pump in Heating Mode.

2.7. Thermal performance terms

A Btu/h, or British thermal unit per hour, is a unit used to measure the heat output of a heating system. One kWh of heat = 3414 Btu/h. A ton is a measure of heat pump capacity. It is equivalent to 3.5 kW or 12 000 Btu/h. On the other hand, heating degree-days is a measure of the severity of the weather. One degree-day is counted for every degree that the average daily temperature is below the base temperature of 18°C. For example, if the average temperature on a particular day was 12°C, six-degree-days would be credited to that day. The annual total is calculated by simply adding the daily totals [2].

The performance of heat pumps is indicated by the coefficient of performance (COP). It measures the amount of heat energy moved (in watts), divided by the electric energy used to move it (also in watts), at a given outdoor temperature. Higher COP values indicate a more efficient system. An electric resistance heater generating heat at 100% efficiency will have COP = 1, while a heat pump in heating mode ranges from a COP of 3 to 4. The COP of a heat pump is solely determined by the condensation temperature and the temperature lift (the difference between condensation and evaporation temperature) and is given by [2]:

$$COP = \frac{T_{con}}{T_{con} - T_{evap}} \quad (1)$$

Where temperatures are given in Kelvin. A basic rule for the design of an efficient heat pump systems is to minimize the temperature difference between the heat sink and the heat source to achieve maximum efficiency; for example, for a heating application use the warmest available heat source and lowest possible distribution temperature.

The heating seasonal performance factor (HSPF) is a measure of the total heat output in Btu of a heat pump over the entire heating season divided by the total energy in watt hours it uses during that time. This number is similar to the seasonal efficiency of a fuel-fired heating system and includes energy for supplementary heating.

EER (energy efficiency ratio) is similar to COP, but only for cooling. It measures how efficiently a cooling system operates. It means that, the higher the EER, the more efficient the unit. The EER is most commonly applied to window units and smaller standalone air conditioners and heat pumps. The EER is the ratio of Btu/hr of cooling divided by the watts of electricity used at an outside temperature of 95°F (35°C). Room air conditioners should have an EER of at least 9.0 for mild climates and over 10.0 for hot climates [2].

The seasonal energy efficiency ratio (SEER) measures how efficiently a smaller residential air conditioner or heat pump operates over an entire cooling season, as opposed to a single outdoor temperature. As with EER, a higher SEER reflects a more efficient cooling system. SEER is the ratio of the total amount of cooling Btu's the system provides over the entire season divided by the total number of watt-hours it consumes. The SEER is based on a climate with an average summer temperature of 28°C.

The heating seasonal performance factor (HSPF) measures how efficiently heat pumps operate in heating mode over an entire heating season. It is like SEER but for heating and the higher the HSPF, the more efficient the system. HSPF is calculated by dividing the total number of Btu's of heat delivered over the heating season by the total number of watt-hours of electricity required to deliver that heat. The thermal balance point is the temperature at which the amount of heating provided by the heat pump equals the amount of heat lost from the building. At this point, the heat pump capacity matches the full heating needs of the building. Below this temperature, supplementary heat is required from another source.

2.8. Hot and cold source

The external medium from which heat is recovered is called a cold source. In the heat pump the refrigerant absorbs heat from the cold source by means of the evaporator. The cold source can be ambient air, earth, ground or surface water. The medium to which the heat is transferred is called a hot source. In the heat pump, the refrigerant transfers both the heat drawn from the cold source and the heat energy supplied by the compressor to the hot source by means of the condenser. The hot source can be air or water.

3. Air source heat pumps (ASHP)

An Air-source heat pump (ASHP) uses AIR as the heat source when the system is operating in the heating mode. We can use the heat in the air to heat air or water. Accordingly, there are two types of air-source heat pumps:

- Air to Air heat pump
- Air to Water heat pump

The first word in the category name is the source of heat. The word following "to" is the media that is being treated. This means that when we use the heat in the air to heat air, we call that heat pump an air-to-air heat pump. When we use the heat in the air to heat water, we call that heat pump an air-to-water heat pump.

3.1. Air to air heat pumps

An air-to-air is used for comfort cooling and heating.

- In the winter, a heat pump extracts heat contained in the outdoor air anddelivers it inside the occupied space.
- On hot summer days, it works in reverse, extracting heat from the occupiedspace and pumping it outdoors to cool the house.

Most of Air to Air heat pumps are so called split-system, meaning that the heat is absorbed at one place and released at another location. Split system consists of two heat transfer surfaces. One coil or heat transfer surface is located inside the structure, while the other is located outside the structure. These surfaces are referred to as the condenser and the evaporator. The evaporator absorbs heat, while the condenser is responsible for rejecting heat. The function of the heat transfer surfaces can be changed to produce the desired mode of system operation. So, the indoor and outdoor coils can function as either the condenser or the evaporator, depending on the mode it's operating in. The schematic below shows the main components and the arrangement [1-6].

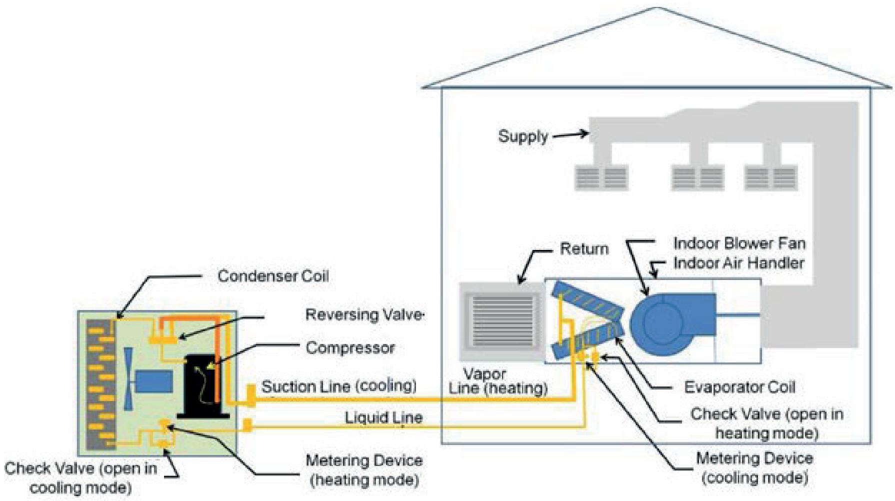

Figure. 6. Building heating and cooling by air-source heat pump [2].

The indoor and outdoor units are inter-connected with tubing and a heat transfer medium, known as a refrigerant, which is circulated through the loop to facilitate the desired heat transfer. With a special 4-way reversing valve, the refrigerating cycle can be switched to the heating or cooling mode. During heating, the outdoor unit serves as an evaporator to extract heat from air; the indoor unit performs condensation, and blows hot air into the room. The reverse happens during summer cooling, i.e. the heat pump takes heat out of the indoor air and rejects it outside [2].

3.2. Heating mode operation

In the heating mode, the indoor coil functions as the condenser and the outdoor coil functions as the evaporator. Refer to the schematic of Air to Air Heat Pump in the heating mode below:

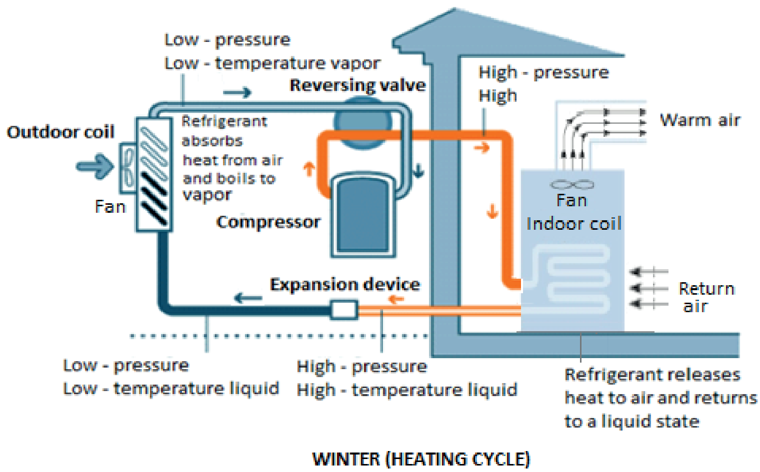

Figure 7. Operation mode of the air-source heat pump in winter season [2].

The outdoor unit fan draws air from open environment, which flows over the outdoor coil containing a refrigerant liquid. The liquid refrigerant absorbs the heat from the air and boils (evaporates) to vapor. The outside coil is thus referred to as Evaporator. The refrigerant vapor is than compressed to higher temperature and pressure and is moved to the indoor coil. The refrigerant gives up its heat to the indoor air and condenses to liquid. Therefore, in the heating mode, the indoor coil is referred to as the Condenser Coil [2]. The refrigerant circulates in the equipment repeating the processes of compression, condensation, expansion and evaporation and back to compression in order to remove the warm air inside the room to the outdoor. This process is automatically controlled by a thermostat until the required room temperature is reached. When extra heat is needed on particularly cold days, supplemental electric-resistance heater kicks on to add warmth to the air that is passing through [1-10].

3.3. Cooling mode operation

The air to air heat pump will reverse to cooling mode in summer months when the outdoor air temperature is higher than the room temperature. In the cooling mode, the indoor coil functions as the evaporator and the outdoor coil functions as the condenser. Air from the occupied space passes over the evaporator, or cooling coil, and heat energy is transferred from the air to the coil. This heat is ultimately transferred to the outdoor coil, which is acting as the condenser. At the condenser, the heat is then rejected to the outside. Refer to the schematic below for the cooling cycle [11-20].

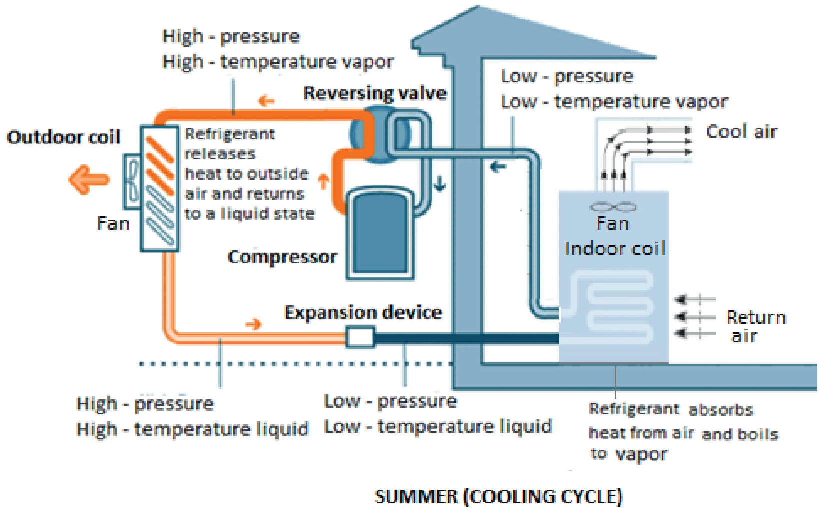

Figure 8. Operation mode of the air-source heat pump in summer season [2].

3.4. Heating capacity

Normally, a heat pump is capable of delivering a maximum of about 1.25 times its cooling capacity as heating capacity. If it provides 100,000 BTUH of cooling, it will provide nearly 125,000 BTUH of heating at maximum capacity. However, maximum heating capacity occurs at 70°F outdoor temperatures, when we need it least. The ability of the heat pump to transfer heat from the outside air to the inside depends on the outdoor temperature. As the outside air temperature drops, the ability of the heat pump to absorb heat also drops. The minimum outdoor temperature at which a heat pump can satisfy the heating requirements of a space without the use of auxiliary electric heat is defined as the "Balance point." This balance point is determined by plotting the heating requirement of the space at different outdoor temperatures, the heating capacity of the heat pump, and the lowest outdoor ambient design temperature. The place where the space heating requirement and heat pump output lines cross is the balance point. For any temperature below the balance point, supplemental heat will be required [25-28].

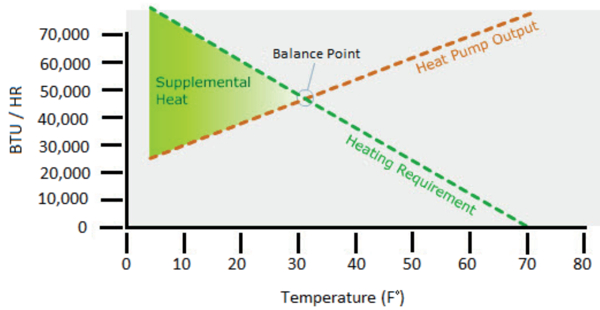

Figure 9. Heat pump temperature balance point [2].

3.5. Air to water heat pumps

Air to Water heat pumps take heat from air outside the property and transfer this to water that can be used for space heating or as hot water for taps, showers, washing or laundry services within the house. The criteria by which heat is transferred can be simplified by way of the schematic shown for space conditioning system [2, 26-29]:

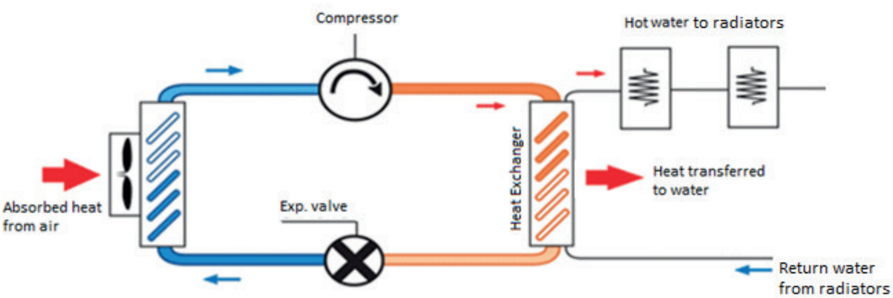

Figure 10. A schematic overview of air to water heat pump.

The air source heat pump does not produce the sort of hot water temperature you would associate with a gas, LPG or oil powered boiler. With a boiler, you would expect the hot water to be heated to about 85°C, while a heat pump produces water to about 55°C. This means, greater volume of water will be needed to satisfy the heating requirements.

3.6. Efficiency of a heat pump

Efficiency of a heat pump is measured using a term "Coefficient of Performance" (COP), and it is the ratio of the useful heat that is pumped to a higher temperature to a unit amount of work that is put in. It will look at COP in terms of air-source heat pumps. A general expression for the efficiency of a heat engine can be written as [2]:

$$COP = \frac{(\text{Heat Energy})_{hot}}{\text{Work}} \tag{2}$$

Using the same logic that was used for heat engines, this expression becomes:

$$COP = \frac{Q_{hot}}{Q_{hot} - Q_{cold}} \tag{3}$$

Where,

Q_{hot} = Heat input at high temperature and

Q_{cold} = Heat rejected at low temperature.

The expression can be rewritten as:

$$COP = \frac{T_{hot}}{T_{hot} - T_{cold}} \tag{4}$$

Note: T_{hot} and T_{cold} must be expressed in the Kelvin scale.

Example 1: Calculate the ideal coefficient of performance (COP) for an air-to-air heat pump used to maintain the temperature of a house at 70°F when the outside temperature is 30°F.

Solution: First, convert the Fahrenheit temperatures to Celsius temperatures using this formula:

$T_{hot} = (70-32) \times 5/9 = 21°C$

$T_{cold} = (30-32) \times 5/9 = -1°C$

Next, convert the Celsius temperatures to Kelvin temperatures by adding 273.

$T_{hot} = 21°C + 273 = 294K$

$T_{cold} = -1°C+273=272K$

Finally, use the formula from the previous screen to solve for the COP.

$$COP = \frac{T_{hot}}{T_{hot} - T_{cold}} \rightarrow COP = 294K / (294K-272K) = 294 / 22 = 13.3$$

The example above shows that for every watt of power we use to drive this ideal heat pump, 13.3 W is delivered to the interior of the house and 12.3 from the outside. This seems to be a deal that one cannot refuse. However, the theoretical maximum is never achieved in the real world. In practice, a COP in the range of 3 to 4 is typical. Even with this range, it is an excellent choice, because for every watt of power that we use, we transfer 2 to 3 additional watts from outside. What this means is that they will always cost less to operate than electric resistance heat. If it cost $30 per week to heat a space with electric resistance heat, it would cost $10 per week to heat the space with a heat pump. Unfortunately, this coefficient of performance varies with the outdoor temperature.

Example 2: Compare the ideal coefficients of performance of the same heat pump installed in two different locations with average outdoor temperatures of 40°F and 15°F respectively. Assume the inside temperatures in both the cases are maintained at 70°F.

For Location 1;

$T_{hot} = (70-32) \times 5 / 9 = 21°C$

$T_{cold} = (40-32) \times 5 / 9 = 4°C$

Next, convert the Celsius temperatures to Kelvin temperatures by adding 273.

$T_{hot} = 21°C + 273 = 294K$

$T_{cold} = 4°C+273 = 277K$

Finally, use the formula to solve for the COP.

COP= 294K / (294K−277K) = (294 / 17 =17.3

For Location 2;

$T_{hot} = (70-32) \times (5/9) = 21°C$

$T_{cold} = (15-32) \times (5/9) = -9.4°C$

Next, convert the Celsius temperatures to Kelvin temperatures by adding 273.

$T_{hot} = 21°C + 273 = 294K$

$T_{cold} = -9.4°C+273=263.6K$

Finally, use the formula to solve for the COP.

COP= 294K / (294K−264K) = 294 / 30.4 =9.7

The example shows the COP decreases on the cold days because it is much more difficult to extract heat from cooler air.

4. Conclusions

If you are exploring the heating and cooling options for a new house or looking for ways to reduce your energy bills, you may be considering a heat pump. A heat pump can provide year-round climate control for your home by supplying heat to it in the winter and cooling it in the summer. Some types can also heat water. In general, using a heat pump alone to meet all your heating needs may not be economical. However, used in conjunction with a supplementary form of heating, such as an oil, gas or electric furnace, a heat pump can provide reliable and economic heating in winter and cooling in summer. If you already have an oil or electric heating system, installing a heat pump may be an effective way to reduce your energy costs.

Nevertheless, it is important to consider all the benefits and costs before purchasing a heat pump. While heat pumps may have lower fuel costs than conventional heating and cooling systems, they are more expensive to buy. It is important to carefully weigh your anticipated fuel savings against the initial cost. It is also important to realize that heat pumps will be most economical when used year-round. Investing in a heat pump will make more sense if you are interested in both summer cooling and winter heating. Air-source heat pumps draw heat from the outside air during the heating season and reject heat outside during the summer cooling season.

There are two types of air-source heat pumps. The most common is the air-to-air heat pump. It extracts heat from the air and then transfers heat to either the inside or outside of your home depending on the season. The other type is the air-to-water heat pump, which is used in homes with hydronic heat distribution systems. During the heating season, the heat pump takes heat from the outside air and then transfers it to the water in the hydronic distribution system. If cooling is provided during the summer, the process is reversed: the heat pump extracts heat from the water in the home's distribution system and "pumps" it outside to cool the house. These systems are rare, and many don't provide cooling; therefore, most of the following discussion focuses on air-to-air systems.

Acknowledgement: The author acknowledged to Turkish Academy of Sciences for financial support of this study.

References

[1] Heating and cooling with a heat pump. Produced by Natural Resources Canada's Office of Energy Efficiency, Energy Efficiency Natural Resources Canada, December 2004.

[2] Bhatia, A. Heat pumps for heating and cooling. Course No: M06-047. Credit: 6 PDH. Available from www.cedengineering.com/(accessed 10 September 2018).

[3] Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment. AHRI, Air-Conditioning, Heating, and Refrigeration Institute, Standard 210/240, 2017.

[4] K.J. Chua, S.K. Chou, W.M. Yang. Advances in heat pump systems: A review. Applied Energy 2010; 87: 3611-3624.

[5] Renato M. Lazzarin, R.M. Dual source heat pump systems: Operation and performance. Energy and Buildings 2012; 52: 77–85.

[6] Hadorn, J.C. Solar and heat pump systems for residential buildings. Berlin: Ernst & Sohn, A Wiley Brand, 2015.

[7] Duffie, J.A., Beckman, W.A. Solar engineering of thermal processes, Fifth Edition, New Jersey: John Wiley & Sons, 2018.

[8] Sauer, HJ. Howell, RH. Heat pump systems, New York: John Wiley and Sons, 1983.

[9] Reay, DA., Macmichael, DBA. Heat pumps. 2th ed. Pergamon Press, UK, 1988.

[10] Howell, JR., Bannerot, RB., Vliet, GC. Solar thermal energy systems. McGraw-Hill, New York, 1982.

[11] Kaygusuz, K. Performance of solar-assisted heat pump systems. Applied Energy 1995; 51: pp. 93-109.

[12] Kaygusuz, K., Ayhan, T. Experimental and theoretical investigation of combined solar heat pump system for residential heating. Energy Convers Mgmt, 1999, 40: 1377-1396.

[13] Kaygusuz, K. Theoretical thermal performance of the air-source heat pumps in Trabzon, Turkey. Journal of Engineering Research and Applied Science 2019; 8 (2): 1291-1298.

[14] Kaygusuz, K., Kaygusuz, O. Theoretical performance of solar heat pump residential heating applications. J. of Engineering Research Applied Science 2019; 8 (1): 1099-1108.

[15] Kaygusuz, K. Performance of solar assisted parallel and series heat pump systems with energy storage for building heating. J. Eng. Res. App. Science 2018; 7 (1): 759-764.

[16] Kaygusuz, K. Karadeniz Bölgesindeki Konutların Güneş Destekli Isı Pompası Yardımıyla Isıtılabilirliğinin Araştırılması. PhD-Thesis, KTU, Trabzon, Turkey, 1992.

[17] R. Dott, T. Afjei, A. Genkinger, A. Dalibard et al., Models of Sub-Components and Validation for the IEA SHC Task 44/HPP Annex 38, Part C: Heat Pump Models, Final Draft, Date: 10 Jun 2013.

[18] Ivar S. Uncertainties in heat-pump coefficient of performance (COP) and exergy efficiency based on standardized testing. Energy and Buildings 2011; 43: 1937-1946.

[19] Johnson, E.P. Air-source heat pump carbon footprints: HFC impacts and comparison to other heat sources. Energy Policy 2011; 39: 1369–1381.

[20] Yokoyama, R., Shimizu, T., Ito, K., Takemura, K. Influence of ambient temperatures on performance of a CO_2 heat pump water heating system. Energy 2007; 32: 388-398.

[21] Ruqun, W. Energy efficiency technologies: air source heat pump vs. ground source heat Pump. Journal of Sustainable developement. 2009; 2: 14-23.

[22] Kim, D.S., Moretti, I., Huber, H., Monsberger, M. Heat exchangers and the performance of heat pumps, Analysis of a heat pump database. Appl. Ther. Eng. 2011; 31:911-920.

[23] Guo-yuan, M., Qin-hu, C. Characteristics of an improved heat-pump cycle for cold regions. Applied Energy 2004; 77: 235–247.

[24] Nishimura, T. Heat pumps-status and trends in Asia and the Pacific. Int. J. of Refrigeration 2002; 25: 405–413.

[25] Chesser, M., Lyons, P., O'Reilly, P., Carroll, P. Air source heat pump in-situ Performance. Energy & Buildings 2021; 251: 111365.

[26] Carroll, P., Chesser, M., Lyons, P. Air Source Heat Pumps field studies: A systematic literature review, Renew. Sustain. Energy Rev. 2020; 134: 110275.

[27] Hundy, G.F., Trott, A.R., Welch, T.C. Refrigeration, air conditioning and heat pumps. Fifth Edition, Elsevier, Oxford, 2016.

[28] Huang, H (Ed.). Heat pumps for cold climate heating. CRC Press is an imprint of Taylor & Francis Group, LLC, 2020.

[29] Gram-Hanssena, K.G., Christensen, T.H., Petersen, P.E. Air-to-air heat pumps in real-life use: Are potential savings achieved or are they. Energy and Buildings 2012; 53: 64-73.