Heat pumps

In municipal buildings and households

NorTech Oulu

Lauri Mikkonen

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Centre of Northern Environmental Technology P.O. Box 7300 Thule Institute FI-90014 University of Oulu, Finland nortech@oulu.fi

1. Technology review

Heat pumps are refrigeration devices, which transfer heat from one place to another. Heat pumps can exploit heat from low temperature in order to release it to higher temperature. As a mechanical refrigerator device, heat pumps can provide energy for space heating or cooling. Besides central heating and cooling opportunities, one of the main advantages of heat pumps is that substantial amount of heat can be produced by using a small amount of electricity. (Collie, 1979) (Kreider, 2001)

Heat pumps generally consist of condenser, compressor, evaporator and expansion valve. Condenser, literally, condenses vapor to liquid and releases condensation heat to a high temperature system. Compressor raises the pressure of a working fluid (refrigerant), increasing the temperature of the fluid at the same time. Evaporator utilizes the heat from the compressor and transfers heat from the refrigerant to building space. Pressure of the refrigerant is released and temperature decreased by using an expansion valve. (Collie, 1979)

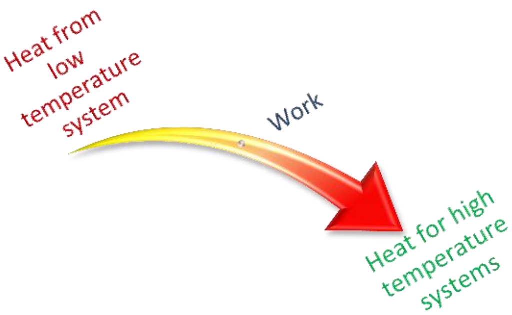
Generally, heat pumps can use air, ground or water as a heat source. The operation of heat pumps in every case is based on different thermodynamic cycles, where temperature, pressure and phase changes in a certain part of the heat pump system. Heat transfer is also an essential phenomenon in heat pump applications, releasing and exploiting heat. In addition, fans for heat energy transfer (conduction) are necessary in heat pump applications. (Kreider, 2001)

Heat pumps are broadly used and well-known technology. Pumps operate reliably and safely, providing efficient heating or cooling to buildings. Furthermore, this technology can bring notable energy and cost savings, adding the comfort of living at the same time. Heat pumps can be integrated in households and municipal buildings. Retrofit is also possible. (Kreider, 2001)

2. Operation of heat pumps

2.1. Briefly about heat pump thermodynamics and efficiencies

The laws of thermodynamics form the base of the operation of a heat pump. Heat pumps are able to exploit heat from a colder place and bring and utilize it in warmer places. Basically, the heat pump requires energy (in this case work, W) in order to transfer heat energy from a low temperature system to a high temperature system as illustrated in figure below.



So without doing work, any heat cannot be extracted from low temperature to high temperature. This is because entropy is always zero or more than zero, meaning that disorder in a system increases spontaneously or stays the same (reversible process). For example, if you pour milk in to your coffee, it starts to spread automatically. Without doing any work, it is impossible that the milk assembles into separate white area, containing only milk. (Wassim M. Haddad, 2005)

In this text, extensive approach to thermodynamics is left out. Still, it is important to know some basic characters of thermodynamics because those are used in order to determine efficiencies for heat pumps. The basic thermodynamic energy balance for a heat pump can be written as:

$$W = Q_H - Q_L \quad (1)$$

where

W = work

Q_H = heat energy in a high temperature system

Q_L = heat energy in a low temperature system

The efficiency of the heat pump is one of the most important factors affecting to economical and energetic operation of the heat pump. It is common to express the efficiency of the heat pump as coefficient of performance (COP), which tells actually the ratio between obtained thermal energy and used work (electrical energy in the compressor). COP can be evaluated for heating purposes by using following equation:

$$COP = \frac{T_H}{T_H - T_L} = \frac{Q_H}{Q_H - Q_L} = \frac{Q_H}{W} \qquad (2)$$

where
W = work
T_H = temperature of a high temperature system
T_L = temperature of a low temperature system
Q_H = heat energy in a high temperature system
Q_L = heat energy in a low temperature system

This is a theoretical definition for COP, but in real life heat pumps, COP values are smaller due to the efficiency of the compressor, energy consumption of auxiliary equipment, heat losses, pressure drop, defrost cycle etc. However, COP in building applications varies from 2 to 8. Higher temperature of heat source increases also the value of COP. In addition, the value of COP rises, when the difference between outside and inside temperature is as small as possible. However, the value of COP is always more than 1. (IEA, 2012) (Collie, 1979)

Cooling efficiency of heat pumps is evaluated by using a term called energy efficiency ratio. The higher value of EER indicates the higher value of the cooling efficiency. It is common that the value of EER is at the same level or even much more higher than the value of COP.EER can be defined by the following equation:

$$EER = 3{,}412 \times COP \qquad (3)$$

As EER is used for some point of operation time, it only tells about the cooling efficiency at given moment. Thus, EER can be extended to seasonal energy efficiency ratio, SEER, which is an average of EER value during one year. For evaluating annual heating performance, in proportion, a seasonal performance factor (SPF) can be used. (Brumbaugh, 2004) (Banks, 2009)

2.2. Heat pump cycles

Heat pumps are considered as refrigerator devices. Thus, the operation of heat pumps is based on thermodynamic cycles. The basic operation, as mentioned before, is based on the fact that heat pumps can exploit heat from a low temperature system and bring it to a high temperature system. For example, outdoor air acts as a low temperature system and indoor air as a high temperature system during winter. The other way around situation happens during summer. In order to bring energy from low temperature system to high energy system, work must be done in the system. Cycles can be open or closed. (Brumbaugh, 2004)

Heat pumps use a thermodynamic cycle called as refrigeration cycle. Cycles can be reversed, leading to heating cycle or cooling cycle. Heating cycle begins from a compressor, which raises the pressure of a working fluid, called as refrigerant (isentropic compression). With increased pressure, the temperature of the fluid is also increased. At this stage, fluid is in a vapor phase. (Kreider, 2001)

From the compressor, pressurized high temperature vapor is led to a condenser (inside coil). In the condenser, the vapor from the compressor starts to cool down and condensate to a liquid phase, releasing heat and condensation heat (constant pressure heat rejection). A fan leads this heat to the inside air, warming up the interiors of a building. (WayneWhiteCoop, 2012)

Condensed liquid from the condenser is then led to an expansion valve, which decreases the pressure and temperature of the fluid (isenthalpic throttling). The fluid is now partly in liquid and partly in vapor phase. Very low temperature fluid is led from the expansion valve to an evaporator (outside coil), where heat from a low temperature system is transferred to even colder working fluid. The temperature raise of the fluid at this stage makes the fluid to reach the boiling point, and the fluid vaporizes again. From the evaporator, fluid is led to the compressor, closing the loop. Figure 1 shows the operation of heating cycle in heat pumps. (Brumbaugh, 2004)

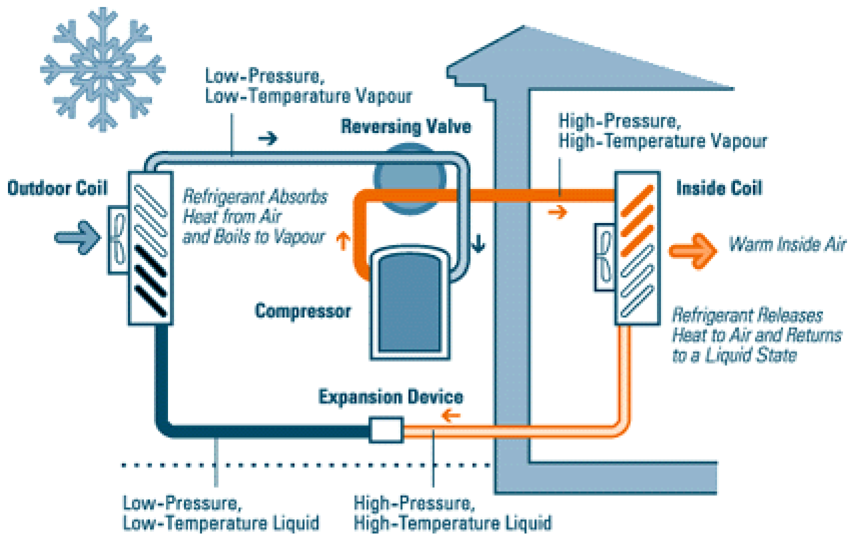


Figure 1. The components and operation of heating cycle (WayneWhiteCoop, 2012)

As mentioned before, heat pumps can be used also to provide cooling energy for buildings. In this case, the heating cycle is reversed, which means that the condenser becomes an evaporator and an evaporator becomes a condenser. When cooling cycle is on, heat pumps remove heat from the building and transfer it outside (in this case, a building operates as a low temperature system). Reversing valve enables the movement of the fluid in both directions. Figure 2 illustrates the situation, when cooling cycle is on. (WayneWhiteCoop, 2012)

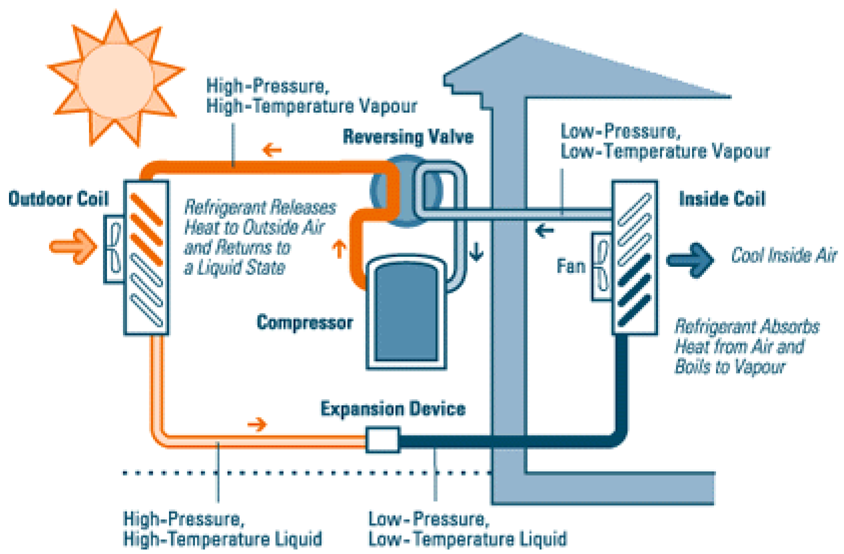


Figure 2. The components and operation of cooling cycle (WayneWhiteCoop, 2012)

So, heating and cooling cycles are the basic cycles in heat pump applications. Sometimes, the temperature of a low temperature heat source can be less than 0 ° C, especially if heat is extracted from the air. In this case, some frost can be formed, decreasing the efficiency and distracting the operation of a heat pump. Thus, a defrost cycle is needed in order to remove frost and ice. As mentioned before, heat pumps use heating cycle during winter, moving heat inside a building. In the defrost cycle, heating cycle is reversed at times in order to heat up outdoor coil and remove frost. In most applications, the defrost cycle is automatized by using a defrost thermostat and defrost timer. (Brumbaugh, 2004)

Closed cycle requires a working fluid. There are several different working fluids available commercially, which have different properties and thus each of those is suitable in certain climatic conditions and applications. Generally, CFCs, HFCs, HCFCs and blends of these are commonly used. Nowadays, CFCs are forbidden because its high contribution to ozone layer depletion. These compounds can have notable environmental impact if leakage happens. Hence, there are more environmentally friendly working fluids available, such as water, ammonia, CO_2 and hydrocarbons. (IEA, 2012)

3. Adaptation of different heat pump types to buildings

As mentioned before, heat pumps suit well in different buildings from bigger municipal office buildings to smaller households. How these systems are adapted to building structures depends on the used application and source of energy. Next chapter will discuss about the most common heat pump applications in buildings.

3.1 Use of different types of heat pumps

3.1.1 Air-source heat pumps

There is a huge amount of heat in the ambient air available. This highly distributed low grade energy can be extracted by using air-source heat pumps. Air source heat pumps literally take heat from air. During winter, heat is taken from the outside air and during summer, heat is removed from the inside air. Air source heat pumps are commonly used in both new buildings and retrofits. Compared to other heat pump types, installation costs are relatively low. Still, air heat pumps can cause some noise problems and the devices can be harder to conceal. (Brumbaugh, 2004)

Air source heat pumps suit best to warmer climates. In colder climates, air-source heat pumps can operate well, but the value of COP decreases when the outside temperature decreases leading to less economic operation. This happens during the winter time, when the heating load is at biggest. Thus, an auxiliary heating system is required in colder climates. In addition, air-source heat pumps in colder climates can have some energy penalty because of the defrost cycle. (Dincer, 2010)

Most of air source heat pumps are so called split-system heat pumps, meaning that one part of the system is physically located inside and other outside of a building. Both sides are interconnected with refrigerant tubes. Generally, a compressor is located in the outside part of the heat pump system. However, single package units (all the heat pump equipment are in the same unit) are also available. (Brumbaugh, 2004)

Generally, in split-system heat pumps, the outside part of the heat pump can be located practically everywhere, such as next to the wall, on the roof, on the ground etc. Typically, the inside part of the heat pump is located on the wall, as shown in the figure 3.

Figure 3. The inside part of the air-source heat pump (Hanakat, 2012)

Air-source heat pumps are often used for heating or cooling the building air. However, air-to-water heat pumps can be used for heating or pre-heating water. Air-to-water heat pumps utilize the heat from the inside or outside air and transfer it to water. Thus, these devices can provide warm water for showers, for instance. Moreover, warm water can be still used in space heating, for example by constructing heating pipes in the floor or by leading warm liquid to a radiator. This kind of procedure requires bigger heat pump unit and usually require a backup heating system, especially in cold climates. (Dincer, 2010)

The width of the inside unit can vary from 50 cm to 150 cm, depending of the type. The width of the outdoor unit is at the same level with the indoor unit and the height of the outside coil can vary around 30 – 150 cm. The price of the system, including outdoor and indoor units varies from 700 – 3000 euros (in Finland) depending on the properties of the system. In addition of the system, electric and refrigerant installation must be done, increasing the price by 50 – 1000 euros. These are the typical prices for household applications. In bigger municipal buildings, more units are needed, and thus the price also increases. (Kuluttajavirasto, 2012)

3.1.2 Ground-source heat pumps

A ground-source heat pump utilizes ground as a heat source or heat sink. During winter, heat is extracted from the ground (evaporator locates in the ground) and during winter, heat is pumped in to the ground (condenser locates in the ground). So the operation in principle is similar to other heat pump applications. As a result, ground-source heat pumps can be installed and retrofitted in all scale municipal buildings and households. (Brumbaugh, 2004)

Ground as a heat source is rather stable compared to air. Thus, during winter, ground-source heat pumps can be more efficient compared to air-source heat pumps due to relatively high temperature of the ground. So in cold climates, COP of ground-source heat pumps is usually bigger than in air-source heat pumps. With a specific depth of pipes, the source for heat can stay above freezing annually, besides rather stable seasonal temperature. The depth of pipes depends on design method and climatic conditions. (Banks, 2009)

Ground-source heat pumps are often closed loop systems. Pipes can be installed vertically or horizontally in the ground. The horizontal installation (Figure 4) requires more land area, which can be a restricting factor. In the vertical installation, larger

COP can be reached and the space requirement is much smaller compared to the horizontal installation (vertical installation could be suitable for urban areas, for instance). Still, the vertical installation requires adequate knowledge of geological structure of the ground. Also spiral loop systems can be available, combining the properties of vertical and horizontal installations. (Dincer, 2010)

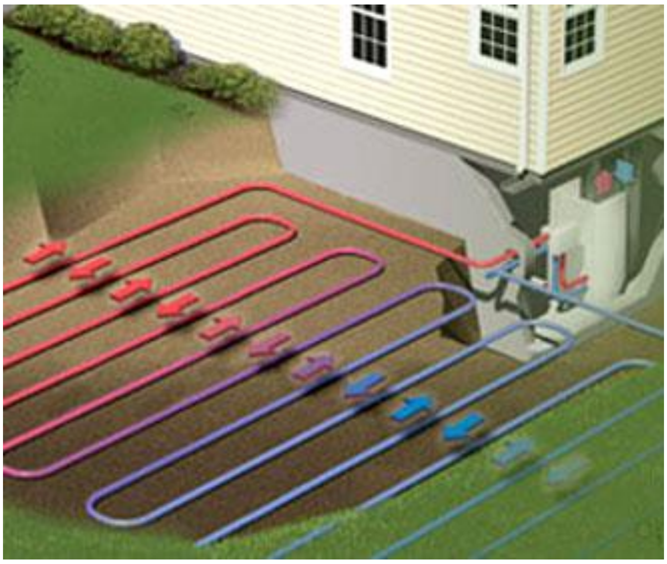


Figure 4. Illustration of a ground-source heat pump (Glynns, 2012)

Pipes can be installed in soil or in solid bedrock. In soil applications, the properties of soil (heat conductivity, porosity etc.) have to be known in order to achieve as efficient system as possible. Solid bedrock installations require drilling, which can be rather expensive. After drilling, a vertical U-shape pipe is embedded to the borehole and rest of the space between U-pipe and borehole is filled with grout, for instance. (Banks, 2009)

It is common to heat up water with so called ground-to-water heat pump system. This kind of system has a heat exchanger, which transfers heat from condenser to water. Heated water can be utilized in different purposes, such as in showers or radiators. However, space cooling or heating is also possible with the ground-to-air system. (Brumbaugh, 2004)

As a contrast to air-source heat pumps, ground-source heat pump units can be located inside a building (excluding piping system, obviously). Typically, the main unit, including the compressor and the expansion valve, can be located in a separate room. Heating and cooling system can be located on the wall or ceiling, depending on the design. Distribution air can be ventilated to building interiors, or, in the case of ground-to-water system, rooms can be heated with radiator or heating pipes installed in the floor. (Glynns, 2012)

Ground-source heat pumps are highly energy efficient systems with a high COP value. COP stays stable throughout the year because the temperature does not differ much. Thus, ground as a heat source is not that highly depended on weather conditions. By the same reason, maintenance costs can be lower, especially because pipes and equipment are not exposed to weather stress. In addition, defrost cycle is not needed, leading to even higher heat utilization. Generally, the main disadvantages of ground-source heat pump systems are high capital costs and big space requirement for the pipe system. (Brumbaugh, 2004)

The size of ground-source heat pump indoor unit is at the same size than a refrigerator. The price of the unit varies between 5000 and 10 000 euros (in Finland). The installation work includes electrical work, pipes installations in the ground etc., which can form a big part of the total costs. In the end, the cost of total investment typically varies between 10 000 – 25 000 euros. (Geodrill, 2012)

3.1.3. Water-source heat pumps

Water-source heat pumps use water as a heat source or sink. The main advantage of water as a heat source is that the temperature of groundwater or surface water (in certain depth) stays rather stable. Thus, water-source heat pumps can operate efficiently throughout the year. (Brumbaugh, 2004)

Water-source heat pumps can be open or closed loop systems. Open loop systems use typically ground water or sea water as a heat source. Water is pumped from the source in to a heat exchanger, where heat is taken or released to the water. After the heat exchanger (condenser or evaporator), water is rejected back to the initial source or other place. This kind of procedure can have some disadvantages, such as fouling of the heat exchanger unit, high cost, environmental impact of the reject water and possible lack of regulations for the system. (Dincer, 2010) (Brumbaugh, 2004)

A closed loop system extracts or rejects heat from/to the ground, while the same refrigerant is circulating in all the time. The operation principle is the same than in air or ground-source heat pumps. Closed loop water-source systems can utilize practically all water sources, including ground water, sea water and surface water (lakes, ponds, rivers etc.). Heat can be utilized also from waste water. (Dincer, 2010)

Water source heat pumps can be integrated to buildings similarly than ground-source heat pumps. The biggest advantage is the constant temperature of the water as a heat source. However, these kinds of systems can be rather expensive and have some environmental effect on aquatic system. (Dincer, 2010)

The price of the water-source heat pump unit is around the same level with the ground-source heat pump. The cost of the total installation depends on the application (surface water, ground water etc.). The rough estimation for the total costs for water-source system is 10 000 – 20 000 euros. (Geodrill, 2012)

3.1.4. Other heat pump types

Solar-source heat pumps are also an option, especially in very warm areas, where the amount of irradiation is big enough to satisfy the heat production. However, solar-source heat pumps have many disadvantages such as very high capital costs, space requirements for storages and so on. However, heat pumps can be integrated with solar thermal collectors in order to produce separately heat for a building. In addition, solar thermal collectors can increase the temperature of the heat source, leading to higher COP. (Dincer, 2010)

3.2. Control and auxiliary equipment

Appropriate operation of the heat pump requires a control system. There are several devices to be controlled in heat pump systems, such as the compressor, fans and reversing valve. One of the main control devices of the heat pump system is a thermostat. Usually, there is a two-stage thermostat, which allows the heat pump to operate under normal conditions as far as the compressor cannot produce enough heat for a building. In this case, the two-stage thermostat will turn on an auxiliary backup heating system. (Herman & Sparkman, 2010)

A room thermostat enables the operation of the heat pump at the desired level, consisting mainly of temperature dial and indicator, fan switch and system switch. Temperature dial enables the user to decide the set point for temperature manually. The temperature indicator shows the current temperature of the room. The operation of fan can be controlled by fan switch and it can have ON-mode, CLOSE-mode or AUTO-mode, for instance. The system switch allows the user to use the heat pump as a cooling or heating system. There is also an AUTO setting to ensure that the heat pump can automatically decide the cooling or heating mode. (Brumbaugh, 2004)

A reversing valve is also an important part of heat pumps, allowing the system to operate either on heating or cooling cycle. When heating cycle is on, the reversing valve allows the refrigerant to flow from compressor to the condenser (inside coil). When cooling mode is on, the direction of the refrigerant flow is reversed. (Herman & Sparkman, 2010)

Defrost cycle in heat pumps requires a defrost thermostat and defrost control device. The defrost thermostat is located outside, sensing the temperature. When the outside temperature is cold enough, the defrost thermostat closes and allows the operation of defrost control device (or board). A defrost timer in the control board is activated in order to start defrost cycle for certain period of time or as long as there is frost on the system. Indeed, the activation of the defrost timer energizes and activates also the reversing valve to provide heat for the outside coil. Defrosting cycle can take from one minute to 10 minutes, depending on the present conditions. Defrosting cycle can be set to operate in every 30, 60 or 90 minutes, in many applications. (Brumbaugh, 2004) (Herman & Sparkman, 2010)

The main control box contains all necessary relays, starting and running capacitors, transformers, compressor contactors etc. that are required in order to achieve adequate and safe operation of the heat pump. The main control box contains also the defrost control board. (Brumbaugh, 2004)

In cases, when the compressor can handle only gas (liquid causes problems with the compressor), an accumulator is needed. The purpose of the accumulator is to separate the liquid refrigerant from the vapor refrigerant, before this mixture enters to the compressor. (Brumbaugh, 2004)

3.3. Installation and practical information

This chapter will provide general guidelines for installation of the heat pump. More detailed information related to installation can be found from instructions provided by a manufacturer, so in the end, the most accurate and trustful information can be found from there. Emphasize is mainly on air-source heat pumps, which require usually more maintenance than other heat pump systems.

At first, when installing the unit, it is important to ensure the tightness of all wirings and the refrigerant line besides following the regulations and standards. In addition, the sealing of ducts and fittings is necessary to do correctly. After installation it is important to check wirings and refrigerant installations again and ensure that the possible drain line is having adequate angle and appropriate place for condensation water. One must ensure the adequate working of compressor as well as check the operation of inside coil. Unusual noise or odor tells about problems in the system. Table 1 below provides some basic guidelines for installation of outdoor coil.

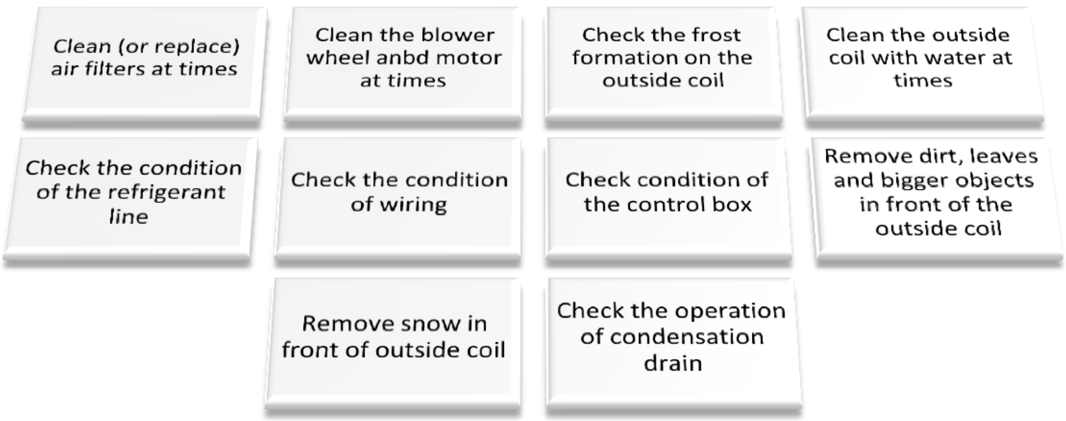
Table 1. Guidelines for installation of outdoor unit

Location the unit is decided so that it does not disturb neigbours	Do not install the unit under a bedroom window	Shelter the unit from wind and snow, if possible
Provide free air flow from and to the unit (no bushes etc.)	Do not put the unit under roof eaves (falling snow etc.)	The distance between outdoor and indoor unit should be minimized

After installation it is also important to check that the system is producing heat and cooling energy appropriately. At the same time, one can ensure that the thermostat and fans are under control and working well. Temperature must be raised or decreased slowly enough, so that the system has time to respond the change. (Brumbaugh, 2004)

As always, also the heat pump system requires some maintenance at some level. Table 2 presents some of the most important maintenance activities for the heat pump system, which can be done without any external help or technician. Please notice that in some cases, a technician is needed. Such cases can include e.g. problems with the refrigerant. Removing and adding a new refrigerant requires always a technician, who knows how to handle with these compounds. This is also true if there are problems with the compressor, operation of defrosting cycle etc. (Brumbaugh, 2004)

Table 2. Checklist for maintenance



Heat pump system can have some problems once operating. Thus, in some cases one has to troubleshoot the system. Generally, the information from the table 2 is sufficient in order to solve many problems, such as obstructed outdoor coil, plugged filters and fan air flow paths. Still, there can be several different electric and machinery malfunctions in the system, which require a technician. For instance, too small voltage in the system may require a new electric circuit system or the inadequate operation of the compressor may require replacing of the capacitor or even installing a new compressor. So, these kinds of malfunctions require a technician in order to troubleshoot the system.

4. Advantages and technological challenges

Heat pumps are safe energy production systems, which rarely cause serious danger to ambient environment. Technology is well known and heat pumps are used all over the world in different climatic conditions and applications. Heat pumps can be integrated in to bigger municipal buildings, but also retrofitted in small households. There is also a big market for available heat pump technologies with different scales and functions.

Heat pumps are really energy efficient devices. By using e.g. 1 kW of electricity, even 2-8 kW of heat can be obtained, depending on the present COP value. With electric resistance heating, for example, 1 kW of electricity produces approximately 1 kW of heat. Thus, lot of electricity can be saved by using heat pumps. Heat pumps have also an advantage that besides heating energy, also efficient cooling energy can be provided. (Dincer, 2010)

Savings in energy with heat pumps compared to conventional heating systems lead to savings in money. Even though investment costs can be high, especially with ground-source heat pumps, the heat pump system payback time can be 2 – 5 years. Operation costs of heat pumps are also rather low and maintenance of the system is not time consuming and expensive. (Dincer, 2010)

Heat pumps have several environmental benefits. At first, in order to produce large amount of heat, heat pumps require smaller amount of primary energy in comparison with conventional heat production systems. Thus, heat pumps have lower CO_2 emission, besides other harmful compounds. Heat pump itself utilizes renewable energy, before the electricity powered compressor steps in. After that it is always question that how electricity is produced for the compressor.

If electricity for the heat pump system is produced by conventional fossil fuels, heat pumps can effectively reduce the amount of NOx, SOx, CO and hydrocarbon emissions due to smaller electricity consumption in comparison with traditional heating systems. Furthermore, the operation of the heat pump does not normally produce any greenhouse gases and other harmful emissions that could contaminate the indoor and outdoor air.

In some cases, the refrigerant can consist of hazardous compounds, and if leakage happens, those compounds can harm the ambient environment and contribute to the global change. However, there are more environmental friendly refrigerant available. In addition, air-source heat pumps can have some noise effects. It is also true with air-source heat pumps that auxiliary heating system is usually necessary in colder climates. (Collie, 1979)

Installation of ground-source heat pumps can be difficult, if the geological structure of the ground in the installation area is unknown. When installing a vertical piping system, an adequate drilling technology must be used. Same kind of problems can be faced with water-source heat pumps. The level and quality of water source can also vary in time. The environmental effect of the water-source heat pump to aquatic ecosystem can be also unknown. (Dincer, 2010)

5. Where can I get one?

There are many manufacturers and installers for heat pumps in Finland and Russia. There are also a large number of international suppliers for heat pump systems. Table 3 presents some of Finnish or Russian heat pump suppliers. For instance, in Finland there are vast amount of different suppliers, so the list contains only fraction of those.

Table 4. Different suppliers for heat pump systems in Finland and Russia

Greentex Oy	•http://www.greentex.fi
Scanoffice	•http://www.scanoffice.fi/fi/english/
LämpöYkkönen	•http://www.lampoykkonen.fi/tuotteet/ilmalampopumput?gclid=COzHwcaYqrACFQE4cgodTAJETg
Kaukomarkkinat	•http://www.kaukomarkkinat.com/portal/fi/tuotteet/lampopumput/ilmalampopumput/?gclid=CNHotOmaqrACFUM4cgodiGE8TQ
JämpiJuttu Ky	•http://www.jamptijuttu.fi/?Yhteystiedot&utm_source=google&utm_medium=cpc&utm_campaign=kampanja
FG Finland	•http://www.fgfinland.fi/
Profilane	•http://www.profilane.fi/ilmalampopumput
Suomen Ilmalämpöpumppu Oy	•http://suomenilmalampopumppu.fi/
Oulun Ekolämpö Oy	•http://www.oulunekolampo.fi/
Hitachi	•http://www.hitachicool.fi/jalleenmyyjat.php
EST	•http://www.est-kaliningrad.ru/
Thermotech Russia	•http://www.thermia.com/Russia%5Cthermotech-russia.asp
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