Heat Pump

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Contributor: Rokas Valancius

The Heat Pump (HP) is an environmentally friendly and renewable energy technology that exploits renewable heat energy from the ground, air or water for building or industrial applications by reversing the natural heat flow from a lower to a higher useful temperature. HP technology is commonly classified according to its source, function, type of energy and application.
The HPs in cold climate countries are accepted as one of the most outstanding technologies of heating in both residential and commercial buildings, because they provide high seasonal performance factor (SPF), 1.8–3.4 for air source heat pump (ASHP) and 2.5–5.6 for ground source heat pump (GSHP) and water source heat pump (WSHP). However, the spread is large, because of different equipment, design and installation quality as well as maintenance.

air source heat pump (ASHP) | ground source heat pump (GSHP) | water source heat pump (WSHP) | coefficient of performance (COP) | seasonal performance factor (SPF)

1. Definition

The Heat Pump (HP) is an environmentally friendly and renewable energy technology that exploits renewable heat energy from the ground, air or water for building or industrial applications by reversing the natural heat flow from a lower to a higher useful temperature.

2. Introduction

Heat Pump (HP) technology is commonly classified according to its source, function, type of energy and application as described below:

- heat source: air, ground, water, solar heat, waste water etc.
- function: cooling, heating, cooling and heating, DHW heating etc.
- type of energy supplied to a HP: electric, mechanical, thermally driven (natural gas, propane, solar heated water, geothermal heated water etc.).
- application: residential, commercial, industrial, district heating etc.

The operation principle of the HP is shown in Figure 1. Energy transfer in the HP is based on the phase change of refrigerant under the constant thermodynamic cycle**.** The heat is extracted from the source and transferred to the building energy systems. Reverse cycle HPs have a cooling ability as well, by changing the flow direction of the refrigerant, resulting in heat extraction from the building and rejection to the outside source [1][2].

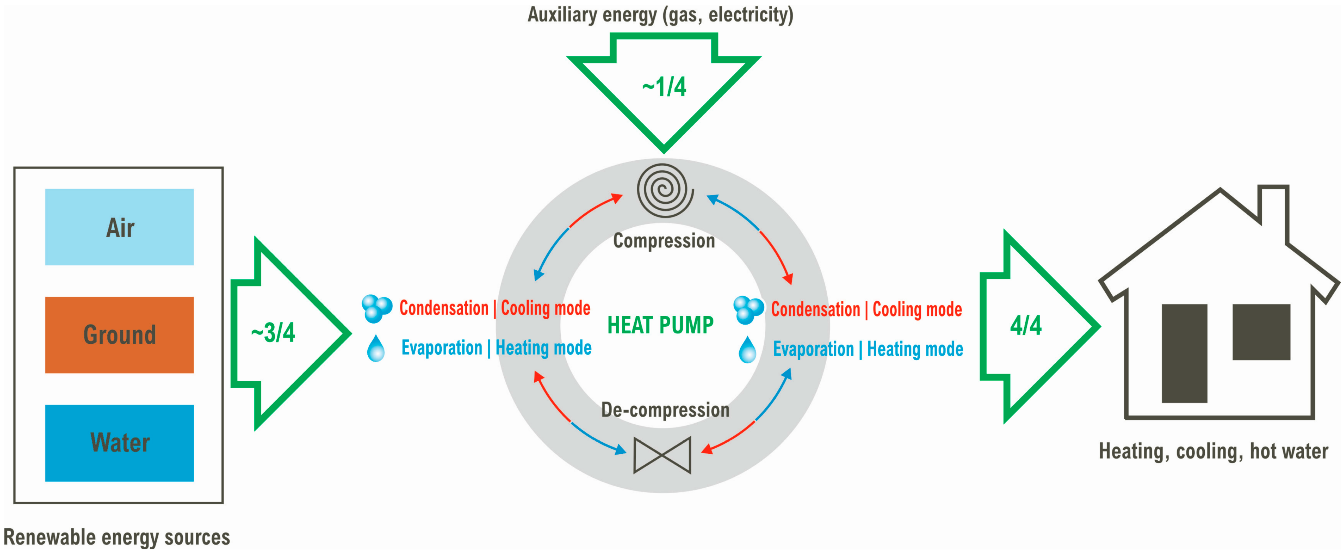

Figure 1. Operation principle of the HP in heating (clockwise/red) or cooling (counter clockwise/blue) mode.

Four main components incorporated within the HP are: the compressor, an expansion valve and two heat exchangers for evaporation and condensation (Figure 1). The main auxiliary components are fans, piping, controls and housing. HP for heating purposes operates as per the following steps:

1. In the evaporator, the liquid refrigerant extracts heat from a heat source and evaporates. After the evaporator refrigerant is in the state of low-pressure vapor, then the temperature increases slightly.
2. The refrigerant in vapor state flows into the electrical compressor; here the pressure is increased, resulting in the increase of the temperature.
3. High temperature vapor flows to the condenser. The heat transfer to the building's heating system causes the refrigerant to cool down and condensate to high pressure and temperature liquid.
4. Hot liquid runs through an expansion valve, where its pressure is reduced, in turn lowering the temperature. The refrigerant returns to the evaporator and the cycle is repeated.

Desuperheaters are included in some HPs performing as an auxiliary heat exchanger supplying heat to a DHW tank (up to 65–70 °C). The desuperheater is placed at the compressor's exit; it transfers thermal energy of compressed vapor to water that circulates through a hot water tank, therefore reducing or eliminating the energy required for DHW heating [2].

In an electrically-powered HP, the amount of transferred heat can be three or four times larger than the electrical power consumed, resulting in a coefficient of performance (COP) value of 3 to 4. The seasonal coefficient of performance (SCOP) describes the average COP during a heating season. Alongside the COP and SCOP, another important parameter should also be considered when describing the energy performance of HPs, namely their seasonal performance factor (SPF). This SPF is the 'net seasonal coefficient of performance in active mode' defined as the ratio between annual usable energy provided by the HP and the annual energy supplied to the whole heating and/or DHW system under real operating conditions.

The most common type of HP classification is according to the heat source. In general, there are three principal types of HPs based on heat source: an air source heat pump (ASHP), ground source heat pump (GSHP) and the water source heat pump (WSHP), and they are described in the following sections.

The other heat sources are worth mentioning too: waste water, industrial waste heat, geothermal water flue gas, district cooling or solar heat. These HP technologies are very promising, but still have limited use.

3. Classification, Operating Principles and Performance Efficiency

3.1. Air Source Heat Pump (ASHP)

Air Source Heat Pump (ASHPs) use the ambient air as a heat source. ASHPs (air to air or air to water) utilizing ambient heat are less efficient compared to other types of HPs, when the outside air temperature is lower than −10 °C. They can also be noisy according to the study [3] performed in Sweden, reporting the average sound level of tested ASHP outdoor units of 61 dB. However, the performance of the ASHP has improved significantly in recent years. Due to better performance of compressors, heat exchangers and refrigerants, modern ASHPs can operate at outside air temperatures as low as −15 °C to −30 °C, subject to the manufacturer and region of distribution. These features, alongside the lower investments and easier installation, made ASHPs more cost-effective in recent years. These units are widely used in residential houses in Scandinavian countries [4][5][5][6]. In recent years this is also reflected in the sales of HPs in Lithuania [7][8].

However, as reported in [9], in the Finnish cold climate, typical SPF values of ASHP were: 1.8–2.2 for air to air HPs. The study in Canada [2] showed that equivalent COPs of ASHPs for various heating systems are 2.3–3.5. The analysis of ASHP system in the single family building in Latvia showed that the system can reach an SPF of 3.43, with a lowest COP of 2.6 during the coldest month of January [10]. The other case studies in Latvia [11] showed that the SPF of an ASHP varies from 2.45 to 2.62 for average outside air temperatures, respectively, within +2.4 °C and +6.0 °C. These studies suggest that during the cold months ASHPs can operate with an average SPF from 2.93 to 3.2 in a cold climate.

The current level of technical development of ASHP units still suggests these HPs are to be used as a supportive heating source in cold climates. In most cases, ASHP-based systems must be equipped with an additional electric heater or other source of energy to be utilized during the coldest periods of winter.

3.2. Ground Source Heat Pump (GSHP)

The Ground Source Heat Pump (GSHP) uses the ground as a heat source; therefore it consists of heat exchanging loops installed in a horizontal, vertical or oblique fashion. A much lower variation of the source temperature on a daily basis throughout the year is common for GSHP installations compared to the ambient air installations [12]. The threshold depth of relatively stable ground temperature is considered 0.8 m [13], yet it depends on such factors as solar radiation patterns, air temperature variations, average snow cover, precipitation and the thermal properties of the soil [2]. It has been also reported that ground temperature variations are more pronounced on a seasonal basis rather than on a daily basis [14]. When the range between inside and outside temperatures is large, as is the case for the ASHP, more energy is required to provide the same amount of heat, which reduces the COP [15]. Operation of GSHPs are usually less affected by excessive temperature differences.

The studies in Finland and Canada showed that typical SPF values for GSHP are 2.6–3.6, while the equivalent COP of GSHP for various heating systems can vary between 3 and 5 in cold climates [2][3][4][6][16] .

Higher installation cost of GSHP due to drilling compared to ASHP in most cases is compensated by higher performance. However, the cost also depends upon soil properties, and because Lithuania has mainly soft soils, this results in affordable drilling [7].

3.3. Water Source Heat Pump (WSHP)

A typical WSHP uses water as a heat source brought directly to the HP unit. If there is no barrier between the water heat source (ground water or surface water body) and the evaporator of the HP, the term “open-loop” is applied for this type of HP.

Several factors need to be considered in open-loop installations, and water quality is one of the most important ones. It affects the operation of the heat exchanger between the refrigerant and groundwater, and may lead to its fouling, corrosion and blockage. The second important factor is the adequacy of available water volume and flow rate. The required flow rate through the primary heat exchanger between the refrigerant and groundwater is usually within 5.5 and 11 l/min per system cooling ton (0.027 and 0.054 L/s-kW) [17]. The demand of water amount can be significant, and it can be regulated by local water resource regulations. The third important factor is handling of the discharged water. There are two options: The groundwater can be re-injected into the ground through separate wells, or it can be discharged into the surface water basins, i.e., rivers, lakes, etc. The feasibility of open-loop systems depends on the local codes and regulations [18].

The main advantage of WSHP in comparison to GSHP is lower installation costs. Also, it has better thermodynamic performance than closed-loop systems because of wells that supply groundwater at ground temperature and the heat exchanger delivers heat-transfer liquid at temperatures other than ground temperature. Also, the system can be combined with a potable water supply well, in turn decreasing operating costs if water was already pumped for other purposes, such as irrigation [18].

The study in Romania [19] showed that the average COP of WSHPs is similar to that of the GSHPs, reaching up to 4.

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