E3S Web of Conferences **17**, 00032 (2017) DOI: 10.1051/e3sconf/20171700032
EKO-DOK 2017

Heat pumps as a way to Low or Zero Emission district heating systems

Piotr Jadwiszczak[1,*]

[1]Wroclaw University of Science and Technology, Faculty of Environmental Engineering, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

Abstract. In traditional district heating (DH) system heat is generated from fossil fuel (FF) combustion in heating only boilers (HOB) or in combined heat and power (CHP) plants. It results in greenhouse gases and other pollutants emission. The reduction of emission is one of the main target in EU climate policy. Among the alternative technologies in DH heat pumps (HP) play a crucial role and enable to decrease or even eliminate emission to create a low or zero emission (LZE) DH system. The emission reduction effect of integration the large scale HP units into DH systems can by defined by four groups of factors: the share of HP in the heat demand, the heat source for HP, the driving energy for HP and heat sink for HP. This paper illustrates the main options for large scale HP units application for LZE DH based on HP technology.

1 Introduction

District heating (DH) is an important option to supply the heat to the numerous consumers, especially in urban areas with high heat demand density. The DH system supplies heat generated in central source to the large number of consumers using double pipe distribution network. In traditional DH heat generation is based on the fossil fuels (FF) combustion, which results in greenhouse gases and other pollutants emission. The development in heat generation technologies open a wide opportunity to improve the DH systems in order to reduce or eliminate emission, including renewable energy sources (RES) and heat pumps (HP) technology. The significant reduction of emission in DH system creates the low or zero emission (LZE) DH system. The LZE DH meets the EU energy and climate targets in 2020, 2030 and 2050 and the challenges of sustainable energy future [1, 2].

The DH systems offer energy flexibility, which allows to create the fuel and energy mix system in large scale. The DH can integrate the different kinds of heat and energy generation technologies like conventional heat sources or power plants (coil, gas, oil etc.), combined heat and power (CHP) plants, thermal RES plants (thermal solar, geothermal, biomass etc.), HP units, thermal energy storage (TES), RES power plants (hydro power, wind power, PV ect.) [3]. The total emission in DH system is the sum of emissions from each used heat or power generation technology, including the technology share in energy

* Corresponding author: piotr.jadwiszczak@pwr.edu.pl

demand and the distribution networks losses. The integration of HP technology into a DH system is one of most effective ways to decarbonise the district energy sector, due to decreasing of FF, increasing of energy efficiency and increasing the share of RES through balancing. HP expands the range of renewable energy sources that can be used to supply DH including biomass, solar and geothermal heat, see water, river or lake, sewage, geothermal, industrial and waste heat.

Among the different kinds of developed HP technologies the electrically driven HP are the most widely used. Fig. 1 shows the principle of electrically driven heat pumps: the HP upgrades the low-grade heat (from heat source) to the useful heat (e.g. with the DH supply line as a sink) using electricity as a driving energy. The efficiency of HP describes the coefficient of performance (COP) and the seasonal performance factor (SPF). The COP is determined in the steady state and is defined as the ratio of the generated heat to the electricity needed to drive the HP. The SPF described the ratio of annual heat generation and annual electricity consumption of the HP.

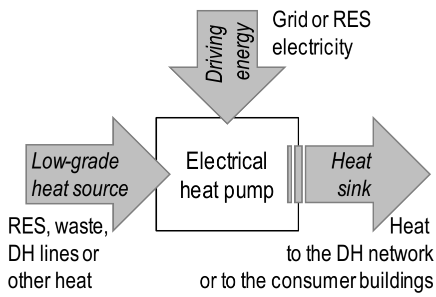

Fig. 1. The principle of electrically driven heat pumps.

There are many scenarios of HP integration into DH system. The HP technology in scale of DH systems includes both the large scale and the individual HP units. This article focuses on large scale electrically driven HP units, as a widely used technology in both the new and the existing DH systems across EU. This kind of HP units can be fitted into DH network as a part of central source or plant, or as a locally placed HP unit cooperating with central heat source. Centrally or locally placed the large scale HP unit can supply DH as a single heat source, in parallel with FF heat sources or in parallel with RES, with different share in covering the heat demand in DH. The large scale HP units can use the RES (e.g. ambient air, water or ground), waste (e.g. industrial), DH lines or other low-grade heat as a heat source; and the local or FF, CHP or RES grid electricity as a driving energy. The electrical large scale HP units enable higher share of RES in DH through balancing and utilizing the excess renewable electricity from wind and solar plants [5].

Each above mentioned factor influences on total emission value in DH. It is clear that the large share of HP, high COP and SPF, and low-carbon heat and electricity sources for large scale HP are preferred to create the LZE DH.

2 HP in LZE DH

Many lessons have been learnt since the first DH systems were installed. The HP technology has the large emission reduction potential, which can be realised in large scale in DH systems. The aim is a DH system that supplies the largest number of consumers with low or without any emissions. It can be achieved by integrating the large scale HP units into DH, with maximum share in heat demand covering, using a renewable heat sources and electricity from renewable energy sources.

DOI: 10.1051/e3sconf/20171700032

Achieving a LZE DH system based on HP technology can be realised in many different option, and is defined by four groups of technical factors, as shown in Fig. 2. The groups are: 1) the HP share in heat demand covering, 2) the kind of RES heat source for HP, 3) the kind of HP driving energy, and 4) the kind of HP heat sink. The share of heat supplied from large scale HP can vary from 0 to 100% of yearly heat demand. The 0% share means a fully FF heat supply, and the 100% means heat supply only by HP as a single heat source. The middle shares can be realised by cooperation of large scale HP as a base heat source and a FF as a supporting (backup) heat source, or by cooperation of the large scale HP and other RES, and long term TES tank. The LZE DH requires to use only zero carbon renewables heat sources for HP, like a low-grade heat of water, ground, ambient air etc. It should be noted, that temperature and thermal capacity of heat source define the COP and SPF of large scale HP unit. The electrically driven HP units in DH can by powered by locally generated or grid electricity, both form FF (e.g. power plants or CHP) and RES power plants (e.g. hydro, wind or solar power plants). Only the RES electricity results in zero emissions, in each other case the emission is related with FF combustion and distribution grid losses. The needed temperature of HP heat sink (water to the DH supply line) determines the kind of HP technology and the value of achieved COP and SPF. The combination of all above mentioned factors affects on total emission in DH system. The local thermal conditions, economics, climate policy and legislation will form the structure of DH and its total emission.

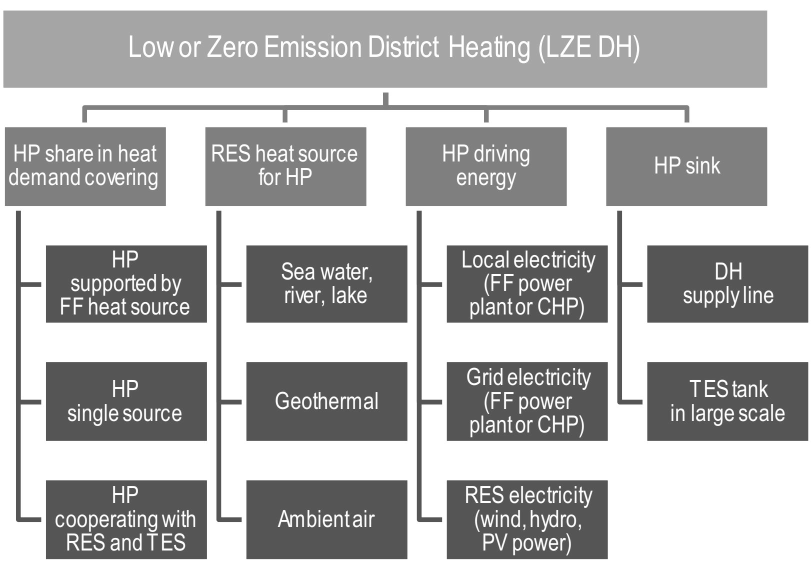

Fig. 2. The main factors in the pursuit of low or zero emission, heat pumps based district heating system.

3 Exemplary cases

The choice of proper technical solution for LZE DH based on large scale DH units is a complex engineering task and, as mentioned above, there are no one way to create the LZE DH using HP technology. According to the diagram in Fig. 2 the exemplary scenarios of LZE DH based on HP will be presented. All fuels and energy carriers, all energy sources and all energy losses are taken into account, in both generation and demand side.

DOI: 10.1051/e3sconf/20171700032

3.1 Traditional FF based DH system

Figure 3 presents the fuel and energy flux, and emission placement and value in traditional FF based DH system. The FF heat source covers 100% of heat demand in DH. The FF combustion in central HOB or CHP plant affects with a high value of emission. The emission value is related to the heat demand in DH, the kind of FF, the heat source performance and the heat losses in distribution network.

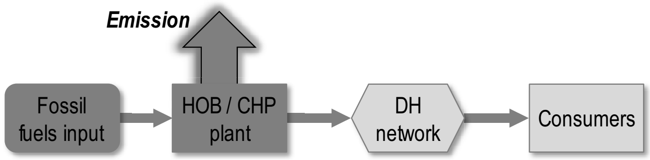

Fig. 3. The fuel and energy flux and emission value in traditional FF based DH.

3.2 Conventional FF based DH system boosted by HP in central plant

The conventional FF based DH can be boosted by large scale HP unit integration in central CHP plant, as is shown in Fig. 4. The emission is still placed in central FF CHP plant, but it is reduced. The large scale HP unit covers a part of heat demand using the heat from zero carbon RES and consuming the electricity generated in CHP. The integration of CHP and HP technology in central plant allows to decrease the total emission in DH, according to the CHP and HP ratio in heat supply. The adjusting of CHP heat and power generation, and HP heat supply ratio, taking into account the COP and SPF, will result in high efficiency of district system and significant reduction of total emission.

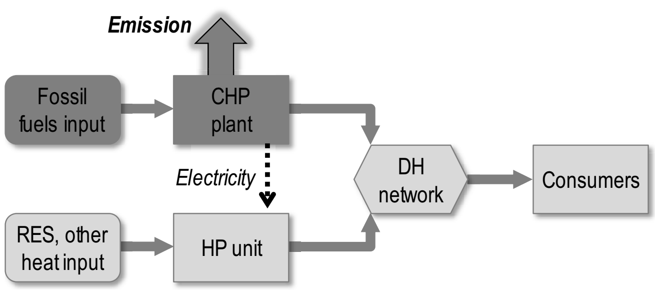

Fig. 4. The fuel and energy flux and emission value in FF CHP based DH boosted by HP.

The reduction of total emission in FF based DH boosted by large scale HP unit depends on the HP share in heat demand and achieved SPF. Fig. 5 shows the percentage reduction of total emission in DH system presented in Fig. 4, according to the share in heat demand and the SPF value of HP unit. Calculations was made for current Polish energy sector structure and emissions factors. It is evident, the higher share of the HP powered by CHP and the higher SPF, the greater reduction of total emission. Even by 99% share of HP the emission occurs, are reduced to 57 and 44% according to the SPF (e.g. SPF = 3.5 and SPF = 4.5), because HP is powered by electricity from FF CHP.

 DOI: 10.1051/e3sconf/20171700032

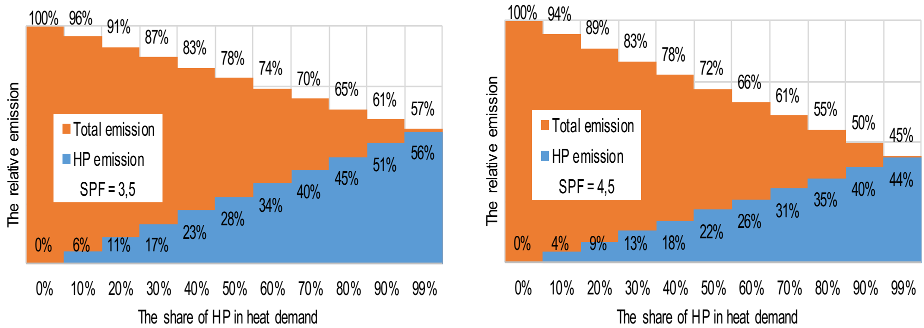

Fig. 5. The total emission and HP emission in FF CHP based DH boosted by HP, according to the HP share in heat demand and the SPF value.

3.3 Conventional FF based DH system boosted by locally placed HP

Figure 6 presents FF and HP based DH system, where the large scale HP unit is placed locally, near the favorable heat source (e.g. sea, river, lake water). In this case HP is located far from the central plant, but is still connected to the DH network. The HP unit consumes the grid electricity generated in FF CHP plant as a driving gear, so the distribution losses are included in total emission. Fig. 7 presents smaller reduction in emission compare to the previous case, 63 and 49% according to the SPF (e.g. SPF = 3.5 and SPF = 4.5).

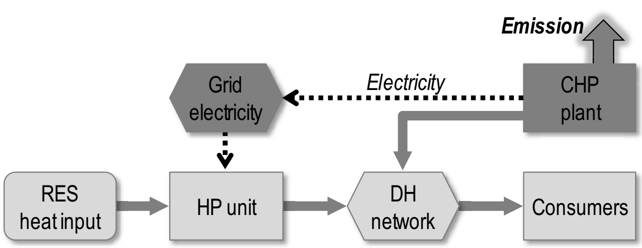

Fig. 6. The energy flux and emission value in FF CHP based DH with locally connected HP powered from grid electricity.

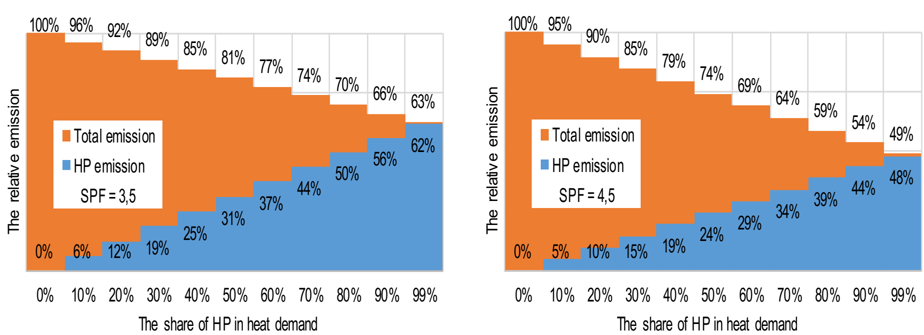

Fig. 7. The total emission and HP emission in FF CHP based DH boosted by HP, according to the HP share in heat demand and the SPF value.

 DOI: 10.1051/e3sconf/20171700032

3.4 DH system based on HP unit

The next options for LZE DH based on large scale HP is the HP single operation mode, where the large scale HP alone covers all heat demand in DH system. The HP unit can be powered by grid electricity from FF CHP or FF power plant (Fig. 8), by RES electricity from hydro, wind or solar power plant (Fig. 10), or simultaneously both by FF and RES electricity (Fig. 11).

The total emission in HP based DH shown in Fig. 8 includes the heat demand, the DH network and electrical grid losses and the SPF of HP. It should be mentioned, that the 100% share of large scale HP unit in heat demand requires the heat source for HP with stable and large thermal capacity, like geothermal, sea water, large lake or river, etc. The emission depends strongly on SPF of HP unit and on technology of electricity generation and distribution. It should be noted, that such a scheme strongly reduces, but does not eliminate the emission. By a high SPF and high power generation performance, the presented DH system may become the LZE DH. The lower SPF of large scale HP unit leads to the emission higher than in equivalent FF DH system, as shown in Fig. 9.

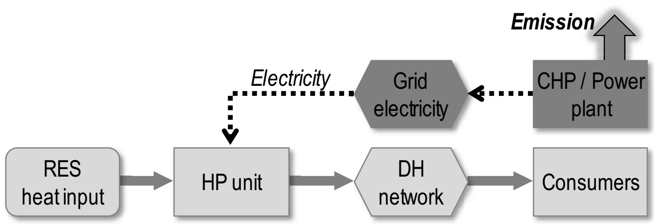

Fig. 8. The energy flux and emission value in LZE DH supplied by HP powered by grid electricity from FF CHP or power plant.

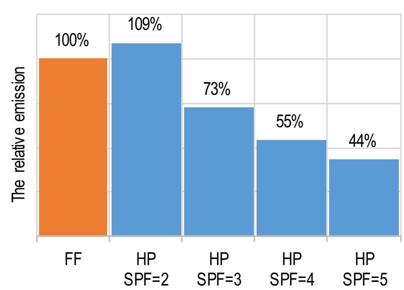

Fig. 9. The total emission depending on SPF of HP unit.

In HP based DH, were the large scale HP is powered only by RES electricity, the TES tank is recommended to balance the electricity and heat generation and demand side, as is shown in Fig. 10. The large scale HP unit powered by zero carbon electricity covers the 100% of heat demand without any emission. The needed electricity can by generated in stable RES like hydro power plant or in variable RES like wind or solar power plant, which influence on the needed TES scale. The thermal capacity of heat source for HP should be large and stable in scale of year, like geothermal, sea water, large lake or river, ect. to cover all heat demand, including the short or long term TES tank [4]. Due to using the zero carbon heat sources and the zero carbon driving energy for large scale HP unit the presented DH system certainly is a LZE DH.

 DOI: 10.1051/e3sconf/20171700032

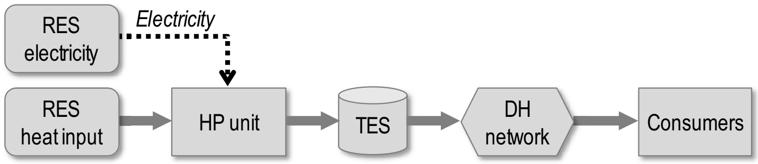

Fig. 10. The energy flux and emission value in LZE DH supplied by HP powered by RES electricity.

Fig. 11 shows the HP based DH in next option, were large scale HP unit is powered partially by RES and FF electricity generated in FF CHP or power plant, and distributed by electricity grid. The FF CHP or power plant can balance the variability of RES electricity generation or just complements RES power plants. It is clear, that large scale HP unit covers the 100% of heat demand, needs the zero carbon heat source with large and stable thermal capacity. The emission dependent on the achieved SPF and the ratio of consumed RES and FF electricity. By high SPF and large share of RES electricity, such DH system may become the LZE DH.

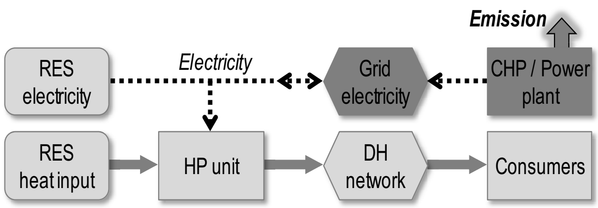

Fig. 11. The energy flux and emission value in LZE DH supplied by HP powered partially by RES and grid electricity.

3.5 PEB in DH system based on HP unit

The plus energy buildings (PEB) technology can be integrated into the DH network. Fig. 12 presents the large scale HP based DH system with TES, suppling both the PEB and traditional buildings. The energy fluxes between PEB and district energy systems are bidirectional, this means that the heat and the electricity is periodically consumed or produced in PEB. The large number of PEB in DH system has a significant influence on energy balance, and has a great potential to create the LZE DH system. The low or zero carbon heat generated in PEB decreases the needed thermal capacity of HP unit, but requires the long term heat accumulation in large scale TES tank. The large scale HP unit will integrate the electricity from RES and PEB, and storage it in form of heat in long term TES tank. It is evident, that the proper sizing of TES is crucial to the energy balance of the whole system. Each component of presented DH has no emission, so it certainly is a LZE DH.

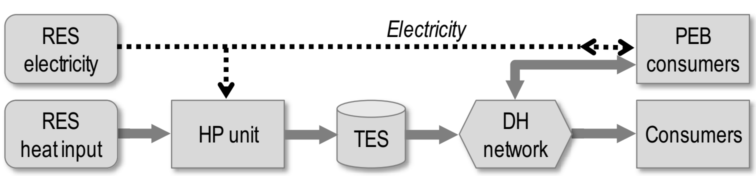

Fig. 12. The energy flux in LZE DH supplied by HP powered from RES and PEB.

The DH system in the next option contains thermal RES plant, e.g. large thermal solar plant. The large scale HP unit and thermal RES supply in parallel the large scale TES tank,

DOI: 10.1051/e3sconf/20171700032

as shown in Fig. 12. The thermal RES has priority in TES charging, and allows decreasing the needed thermal capacity of HP unit. The driving energy for both HP and thermal RES is generated in RES power plant and in PEB. The RES energy variability requires the long term and large scale energy storage. Each component of presented DH has no emission, so it certainly is a LZE DH.

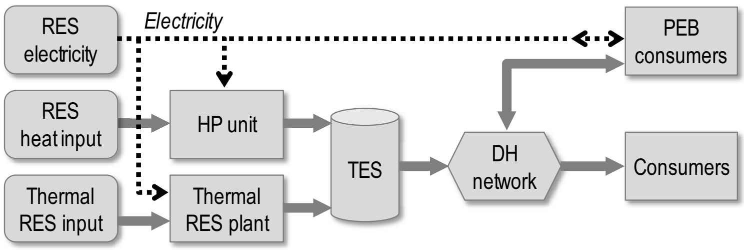

Fig. 13. The fuel and energy flux in DH with TES supplied partially by RES and HP powered from RES and PEB.

4 Conclusions

The emission saving potential of HP based DH is really significant. The HP technology plays an important role in the decarbonisation of the district energy sector. In every case the proper integration of large scale HP unit into DH should bring the environmental benefits. By reducing FF use, the large scale HP DH can lead to reduction in indoor and outdoor air pollution and the associated health impacts [5].

Depending on the kind of driving energy and heat source for HP unit, the DH may become the LZE. Low or zero carbon electricity and heat sources for HP are preferred. The LZE DH system based on large scale HP units allows to supply the low or zero carbon heat to the large number of consumer. The scenario of LZE DH based on HP technology can be replicated and scaled to many cities or residential areas.

The design of LZE DH must take into account the HP share in heat demand covering, the kind of RES heat source for HP, the kind of HP driving energy, and the kind of HP heat sink. The calculations of a total emission made for Polish energy sector structure prove the emission saving potential of HP technology in DH. All the emissions carried out along the whole energy flux were taken into account.

The total emission in HP boosted or HP based DH system strongly depends on the COP and SPF of HP unit, and the source of driving electricity. The possibility of emission savings was approved by LZE DH scenarios and calculations, which are investigated in this article.

References

1. EU Strategy on Heating and Cooling, SWD 24 final report (European Commission Brussel, 2016)
2. European Heat Pump Statistics, The European Heat Pump Association (EHPA), Brussels, 2009
3. DISTRICT ENERGY IN CITIES, Unlocking the Potential of Energy Efficiency and Renewable Energy (UNEP, Paris 2015)
4. V. Dagilis, L. Vaitkus, Combined heat pump and water-power plant at Kaunas Lagoon, The 9th International Conference ENVIRONMENTAL ENGINEERING, Vilnius, Lithuania 2014