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Large Heat Pumps for Decarbonized District Heating

Torben Funder-Kristensen[a1], Drew Turner[b], Leping Zhang[c]

[a] Ph.D. Head of Public and Industry Affairs , Danfoss, Nordborgvej 81, 6430 Nordborg, Denmark
[b]M.Sc. lobal Marketing Manager, Danfoss, Crossroads Cicle 11665, 21220 Baltimore, USA
[c]M.Sc.System Architect, Danfoss, Gong Ti Bei Lu Pacific Centre Place 2A, 100027 Beijing, China

Abstract

Large scale heat pumps constitute one of the most important technologies to pursue a future decarbonized heating supply. In this paper a quantitative overview is given for the EU based on Heat Roadmap Europe (HRE4) also referred in the IEA report Annex 47. Based on this future heating challenge it is important that the suppliers and technology developers of the large scale heat pumps take up the challenge and replies to the opportunities and challenges to obtain the best scenarios. The conditions for district heating grids and heat sources for addressing the appropriate heat pump technologies are described. Applications using low GWP refrigerants like CO2, Ammonia and HFO are compared. The paper also considers the opportunities for addressing decentralized heating providers like supermarkets and chillers traditionally intended for cooling only.

Keywords: Large Heatpump; Oil Free systems; Low noise level; Efficiency

1. Introduction

The EU energy targets for 2030 and the long term 2050 decarbonization aspirations call for the most efficient and innovative cross sectorial solutions. Some countries are already moving beyond previous targets e.g. Denmark has now a domestic target of 70% emission reduction by 2030 and more countries will likely follow with strengthened targets to decrease emissions. Heating of buildings is the largest energy consumer and CO2 emission source focus is on planning for a resilient and efficient system which can provide affordable heat for all. To minimize investments the energy demand must be reduced by energy efficiency measures on buildings and performance optimization of technical building systems – the second factor is to establish efficient heating supply system and to make it decarbonized, with focus on renewable electricity The nature of renewable primary energy supply will force the demand and supply sector to become much more integrated and this will ultimately call for new applications and technologies like demand side flexibility and thermal or electrical energy storage. In the Heat Roadmap Europe (HRE) studies [1],[2] it has been shown that increasing the district heating to cover 50% of the total heat demand together with a 40 GW heat pump capacity in average can address up to 15 % of total heat demand. In periods with a surplus of renewable electricity heat pumps are supposed to supply most heat and utilize thermal storage. The large-scale heat pumps are estimated to produce 520 TWh/year with a coefficient of performance (COP) of 3, see figure 1 and 3. Such an increase enables a much larger utilization of alternative sources of heat like ground source thermal heat and waste heat from data centers and at the same time can utilize of renewable intermittent electricity.

[1] Torben Funder-Kristensen. Tel.: +45 74 88 41 27
E-mail address: tfk@danfoss.com.

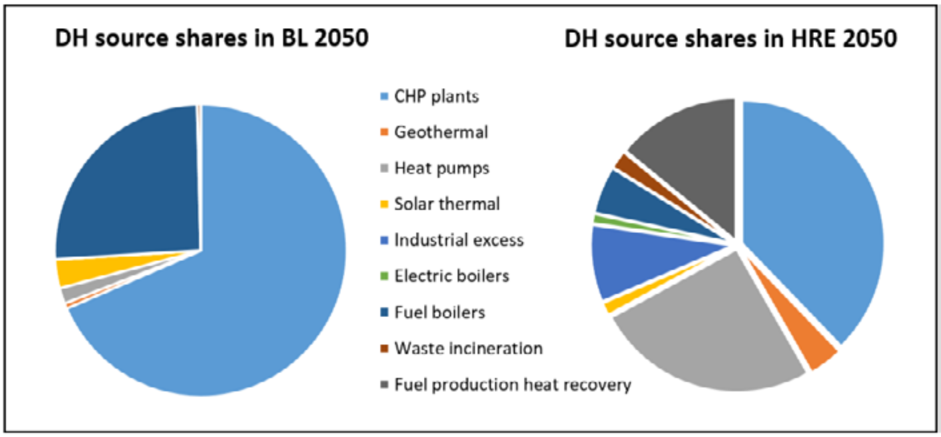

Fig. 1. 2050 DH source share. HRE is the decarbonised scenario [1], likely to increase the HP share with new emission targets

While realized COP in *cooling systems* is important though not a primary business factor (due to existing business models) – it becomes obvious that in heating the 'realized COP' of the heat pumps is a primary business factor for DH operators. The realized COP depends on some basic factors like *temperature lift* and also the *technology* behind the Heat Pump systems. Reported COP values for large heat pumps can be seen in figure 4 [1]. It is obvious that the realized COP values depend on the temperature lift.

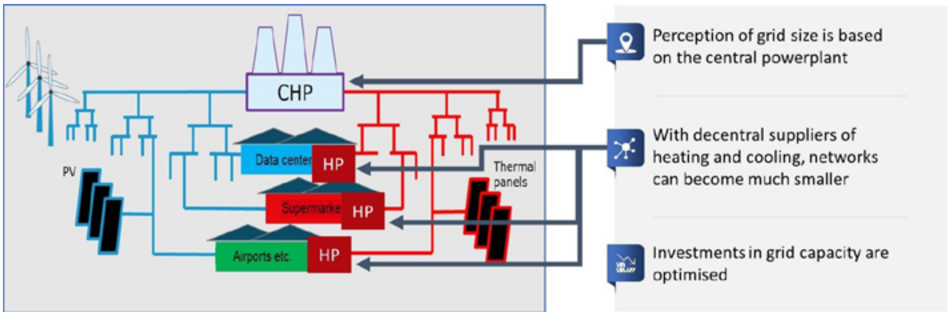

Fig. 2. Decentral large heat pumps can source energy from various utilities. Advantages are listed on the right part of figure

2. Temperature lift

The temperature lift is the difference of the temperature of the heat source inlet and the temperature supplied to the DH system (outlet). DH grids have developed through more than 130 years and can be divided into 4 generations. For simplicity, systems are called by generation names like 3G or 4G. The main parameter characterizing the G-level of the system is the flow line temperature. 3G systems have a flow temperature below 100°C while new 4G systems will go as low as 40°C [4]. The overall system efficiency increases with the lowering of temperature and the opportunities for adding decentral heat sources like heat pumps - or waste heat from supermarkets - can be applied. The first parameter determining how low the flow temp can go is the size of the heating surfaces in buildings. Large surfaces e.g. using floor heating can utilize 40°C water while old radiators in poorly insulated buildings will demand 80°C – at least in cold periods.

Low temp heating is still a rare case for the majority of the building stock in the EU but is expected to grow as renovation of the old building stock takes place. For new city areas low temperature DH is an obvious choice. Specific high temperature needs will then be handled by dedicated heat pumps.

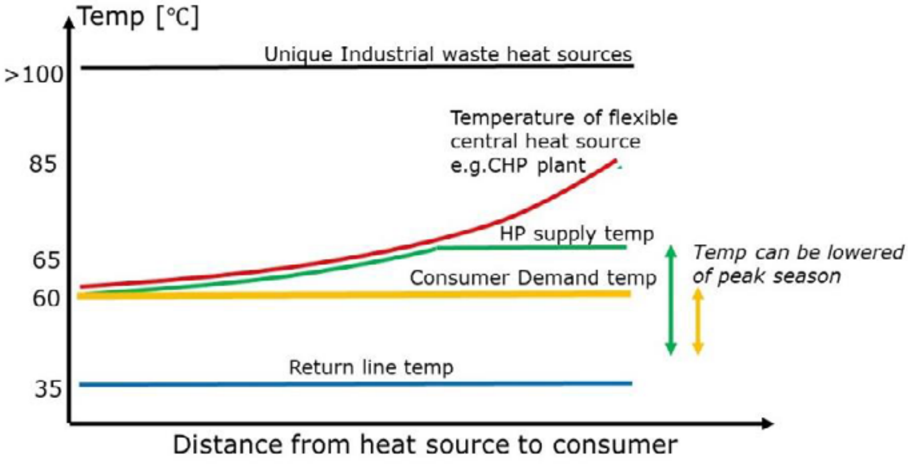

Fig. 3. DH flow line temp compared to demand needs

Another parameter determining the DH flow temperature is the architecture of the DH system layout i.e. pipe diameter, distance between heat supply sources and the density of end consumers. Seasonal variations in heat demand will set the constraints for the flow line temperatures – but the trend is to lower temperatures even during winter. Good practice is to lower the temperature until the most demanding heat consumer will call. Then specific action can be taken towards raising the performance of that specific consumer like better insulation etc. Each City has special opportunities for unique large heat sources i.e. CHP plants, industrial plants, data centers, sea water etc. This will of course reflect the outline of the DH system and likely the flow temperature as some heat sources may have higher temperatures than others. Figure 3 shows a qualitative connection between flow and return line temperatures dependent on distance from heat source and also the heat source type (unique centralized or decentralized heat pumps).

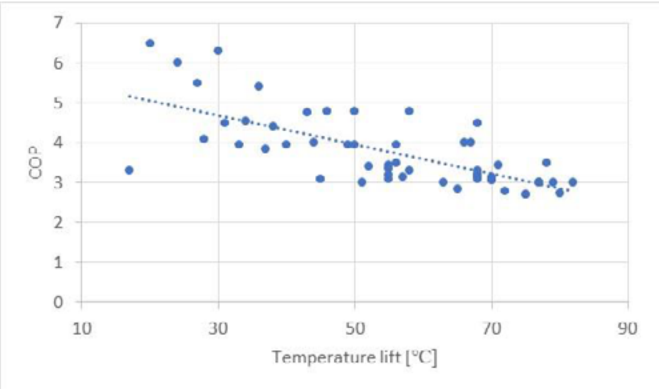

Fig. 4. HP COP versus temperature lift; data from [1]

The flow line temperature is not necessarily reflecting the demand from end consumers but may often be based on the grid piping constraints or specific heat sources. A lower temperature – ensuring sufficient capacity throughout the grid - can be obtained by having multiple and decentralized distributed energy sources like heat pumps. Smaller heat pumps can boost 4G flow temperatures for apartments or multi apartments buildings or large heat pumps can supply heat to the grid via ground source. Also, the tertiary sector as supermarkets have shown to be able to deliver extra heat to the DH. This issue has already shown to be an important factor to discuss when planning the introduction of heat pumps to the district heating grid and the learning is that the necessary temperature lift may often be smaller than the official flow temperature. This is an important parameter to consider when discussing heat pump heat delivery.

System type	T_{WS} [°C]	T_{DH}°C	WW-HP COP	System/Refrigerant
1	26/19 19/12 12/5	55-65 45-55 35-45	4,7	Centr. Oil free 1234ze(E)
1	26/19 19/12 12/5	55-65 45-55 35-45	4,0	Screw/NH_3
2	26/19 19/12 12/5	35/65	3,9	Recip/CO_2
3	*26;19*	55-65 45-55 35-45	*5.4*	Centr. Oil free 1234ze(E)
3	*15;8*	55-65 45-55 35-45	*3,9*	Centr. Oil free 1234ze(E)
4	26/19	35/65	4.6	Recip/CO_2
4	*15;8*	*35/65*	*3,5*	Recip/CO_2

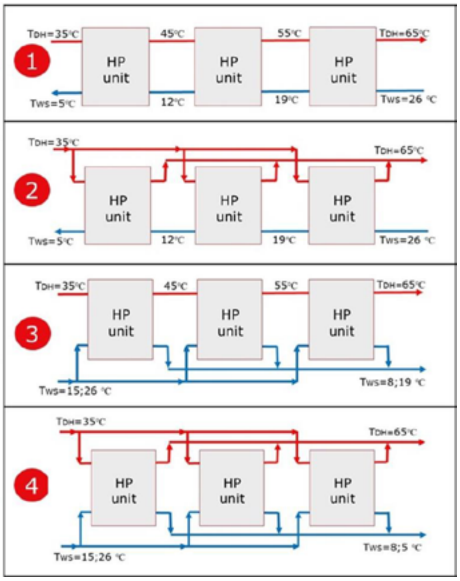

Fig. 5. System type versus refrigerant comparison

3. Technology behind the low GWP heat pump systems

Heat pumps larger than 1 MW are often based on well-known ammonia technology and described in various papers. Also, CO_2 heat pumps can be a good source for high temperature DH but is rarely seen yet. The HFO refrigerant; R1234ze(E), has been introduced to the market during the last years and has a very good HP performance due to its high critical point (165℃). Furthermore, it can be utilized for centrifugal compressors due to its high molecular weight. Assuming a temperature lift of 30-50 ℃ normally two-three stages of compression are suitable; however, CO2 can due to its transcritical properties, utilize counterflow heat exchanger technology and be effective also for one stage compression. A survey [1] shows COP values from 149 large HP installed in the EU with capacities ranging up to 230 MW and average capacities >10 MW. Looking at figure 6, even with a clear trend line, a high deviation variance of reported COP is evident and can be explained by numerous factors dependent on system architecture, On/off duty cycle or VSD, level of maintenance, etc. As a rule of thumb, the higher the capacity of the system the higher the efficiency due to higher level of complexity and optimization procedures. It should be noticed that potential future rollout of large ground source heat pumps would have capacity limits around 5-10 MW and call for more modular system designs.

4. System comparison

The oil free Air Conditioning chillers using centrifugal compressors have a superior energy efficiency, small size and low noise levels due to high compressor RPM and contact free operation. Even though oil free systems have not yet been used for large scale heat pumps they are notoriously interesting due to high efficiency and the low noise levels which make them suitable to be placed in dense populated areas. To evaluate the efficiency compared to other low GWP refrigerants we did some basic simulations comparing, CO_2 reciprocating

technology and NH_3 screw compressor technology, with the state of art oil free systems for heat pumps around 2 MW capacity. Increased efficiency can likely be obtained in the future due to the ongoing research on utilizing tailor made low GWP refrigerant blends suitable for counterflow heat exchangers [5].
All systems use economizer. The CO_2 and NH_3 system are more complex due to oil management. CO_2 systems evaluated do not use ejectors nor parallel compression. The results in figure 5 show system COP values ranging from 3.5-5.4 depending on the water supply temperatures of 15 °C (high temp level ground source) and 26 °C (Data Center source). The oil free system shows significant good results and the complexity is low which makes it suitable for large scale system production.

5. Conclusion

The energy outlooks for Europe calls for an ambitious increase and investment in district heating networks. District heating will facilitate large scale heat pumps necessary to adopt to the increasing amount of renewable electricity.

The temperature demands of the District Heating grid have continuously decreased during history and it is anticipated that future DH grids will go as low 40°C allowing for decentral heat suppliers like super markets.

Heat pumps can effectively be introduced on a mass scale as decentral zero carbon heat suppliers.

The simplicity of systems and the noise levels and refrigerant safety are qualifying factors to establish MW sized pumps within the cities.

Efficiency of the heat pumps are the business parameter to deliver affordable heat. Efficient, safe and low noise heat pumps can be ensured with oil free heat pump systems.

6. References

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