

EU DECARBONIZATION OF HEATING CALLS FOR LARGE SCALE HEAT PUMP INNOVATION

**Torben Funder-Kristensen, Ph.D. Head of Public & Industry Affairs,
Danfoss Cooling**

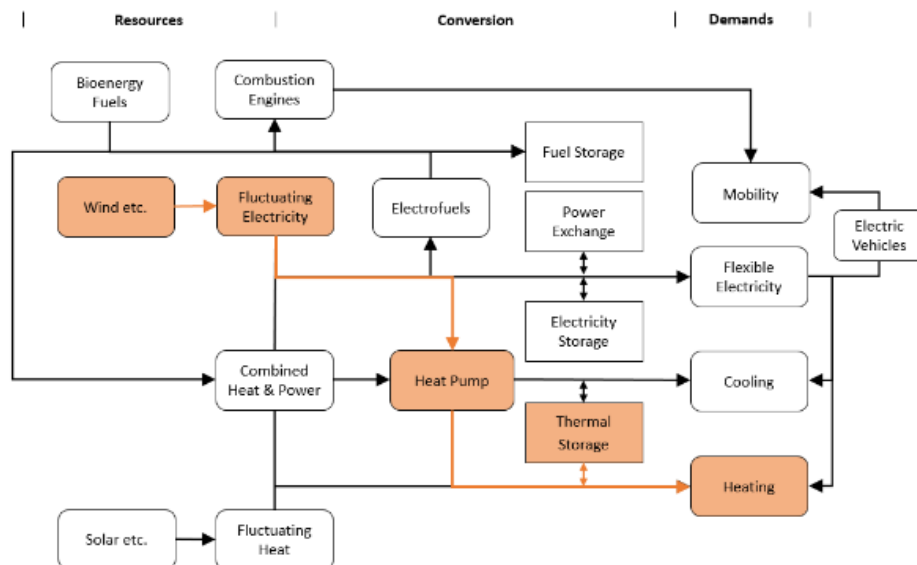
Jan Eric Thorsen, M.Sc. Director of Heating Application Centre, Danfoss Heating

Drew Turner, M.Sc. Global Marketing Manager, Danfoss Cooling

Leping Zhang, M.Sc. System Architect, Danfoss Cooling

Introduction:

The EU energy targets for 2030 and the long term 2050 decarbonization aspirations call for the most efficient and innovative cross sectorial solutions. 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

Figure 1: Operation of a Smart Energy System when there is integration of wind power [1].

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

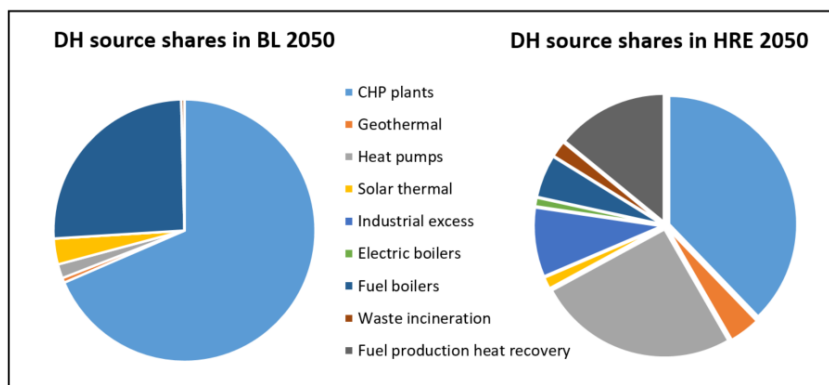


Figure 2: 2050 DH source share. HRE is the decarbonised scenario [1]

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 2. 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. 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.

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.

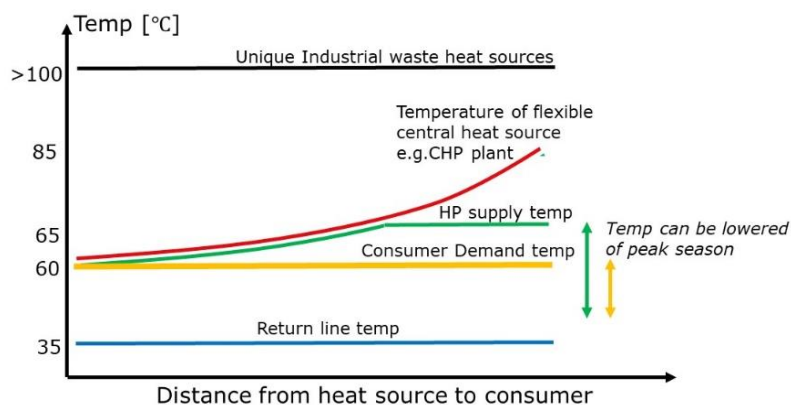


Figure 4; DH flow line temp compared to demand needs

Another parameter determining the DH flow temperature is the architecture of the DH system 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.

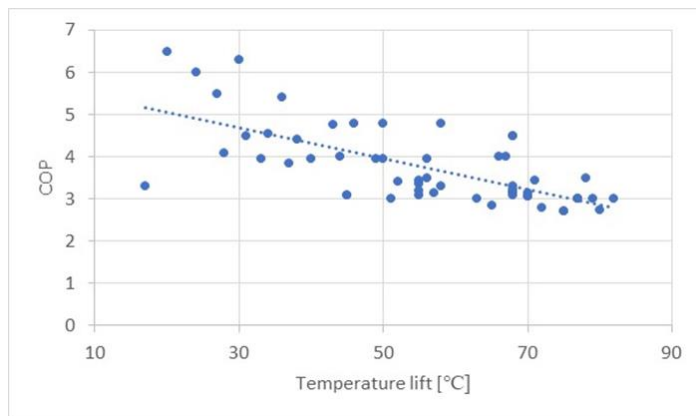


Figure 5 HP COP versus temperature lift; data from [1]

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.

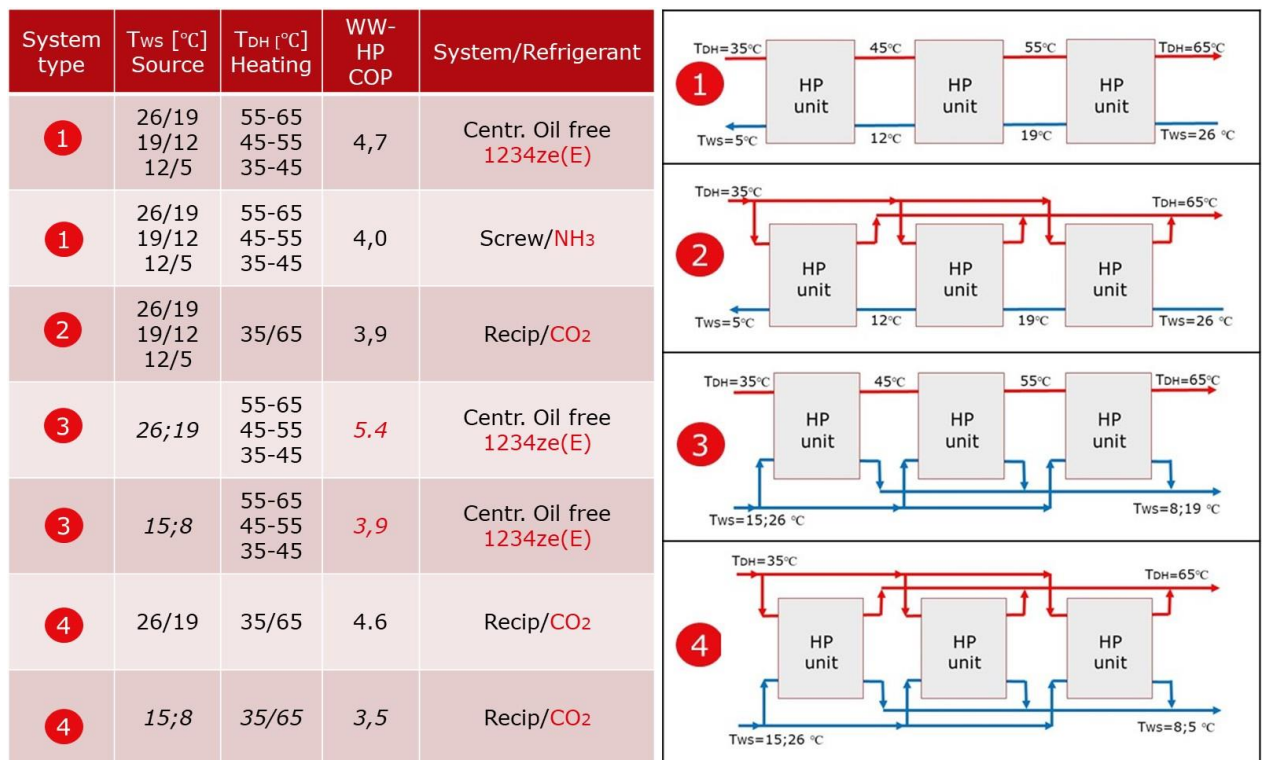


Figure 6; System type versus refrigerant comparison

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, CO₂ 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 (109,4°C). Furthermore, it can be utilized for centrifugal compressors due to its high molecular

weight. Assuming a temperature lift of 30-50 °C 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.

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, CO₂ reciprocating technology and NH₃ 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 CO₂ and NH₃ system are more complex due to oil management. CO₂ systems evaluated do not use ejectors nor parallel compression. The results 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.

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 silent heat pumps can be ensured with oil free heat pump systems.

References:

- 1 :Andrei David et al ; Heat Roadmap Europe: Large-Scale Electric Heat Pumps in District Heating Systems; *Energies* 2017, 10, 578; www.mdpi.com/journal/energies
- 2: Connolly, D. et al ; Heat Roadmap Europe: First Pre-Study for EU27; Aalborg University: Aalborg, Denmark, 2012.7.
- 3: Connolly, D. et al; Heat Roadmap Europe: Second Pre-Study; Aalborg University: Aalborg, Denmark, 2013.
- 4: Lund, H. et. al. (2014) 4th Generation District Heating (4GDH). Integrating Smart Thermal Grids into Future Sustainable Energy Systems. *Energy* 68(2014) 1-11.
- 5: Zühlsdorf B., et al, *Heat pump working fluid selection—economic and thermodynamic comparison of criteria and boundary conditions*, *International Journal of Refrigeration* 98 (2019) 500–513.