CONFIGURATIONS AND ENERGY SYSTEM INTEGRATION

IEA DHC ANNEX TS3 – HYBRID ENERGY NETWORKS

Technical Report of the IEA DHC TS3 "Hybrid Energy Networks", subtask A "Technologies and synergy potential", WP2 "Experiences with hybrid energy networks based on large-scale heat pumps": *Configurations and energy system integration*.

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Content

1 Energy system perspective

Heat pumps are expected to play a key role in the future heating supply and thereby the decarbonisation of the overall energy system where heating represents as much as half of the energy demand[1]. The share of heat demand, which could feasibly be covered by district heating (DH) is identified for a range of countries[2], thus also indicating a vast untapped potential for large-scale heat pumps.

Heat pumps enable the integration of (renewable) electricity in the heating sector, and through the DH network they form a "hybrid energy system". An illustration of the synergies between DH networks, heat pumps and energy savings is seen in Figure 1.

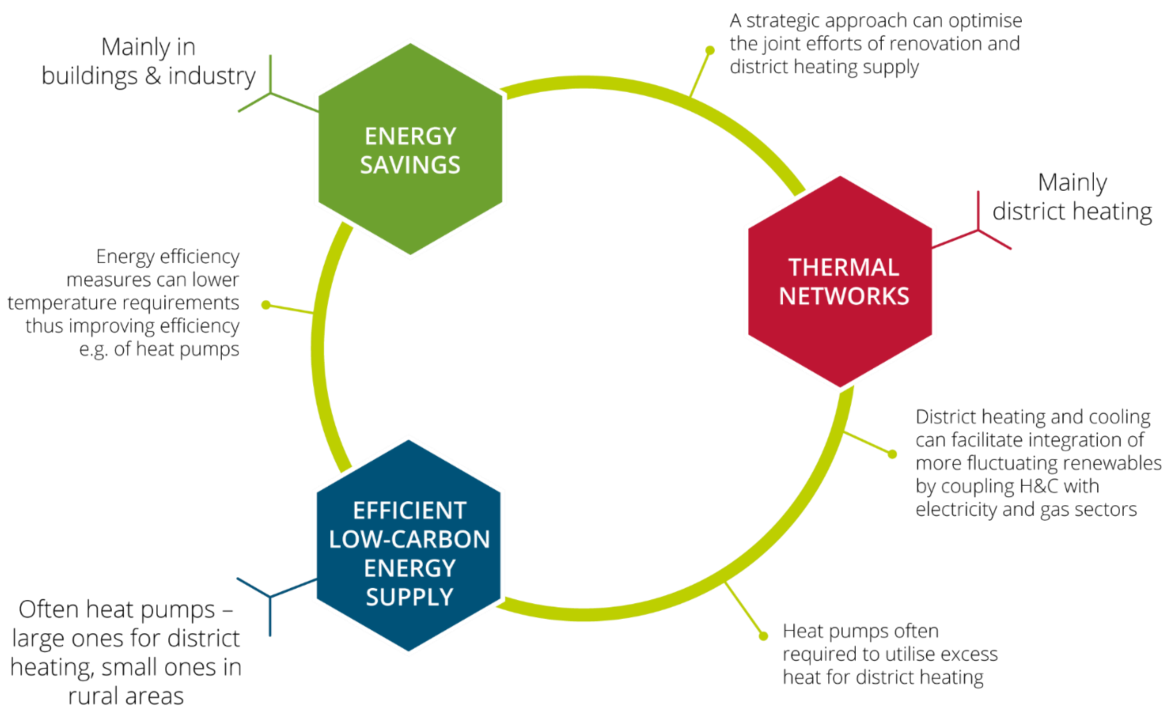

Figure 1. Synergies between selected decarbonisation options (from The Legacy of Heat Roadmap Europe brochure, heatroadmap.eu/legacy-brochure).

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[1] As described in "Profile of heating and cooling demand in 2015", heatroadmap.eu/wp-content/uploads/2018/11/HRE4_D3.1.pdf.

[2] See reports from the Heat Roadmap Europe project on country level at heatroadmap.eu/roadmaps or summarized in the joint report "Towards a decarbonised heating and cooling sector in Europe – Unlocking the potential of energy efficiency and district energy" available at heatroadmap.eu/decarbonised-hc-report.

When considering the feasibility of renovations and energy savings, the value is often considered to be represented by a decreased heat demand – potentially with the addition of extra comfort for the inhabitants. In DH networks, renovations and upgrading the pipes are similarly considered a means to reduce heat losses. However, for both buildings and DH network, renovations often result in lower required temperature levels. While the savings in the energy demand and reduction of losses are significant, the additional benefit for the heat pump should also be considered. A lower forward temperature in the DH network leads to an improvement of the efficiency of heat pumps. This effect should be taken into account when evaluating the feasibility of renovation measures. Such mutual benefits for both DH companies, building owners, and authorities (often representing general emission reduction targets), could be evaluated as part of a strategic partnership between all relevant local stakeholders in a common decarbonisation strategy[3].

2 Configurations

Heat pump configuration

Figure 2 illustrates an example of a heat source cooled from 40 °C to 15 °C while the DH supply is heated from 60 °C to 90 °C. The numbers are simply examples while the DH temperature levels are typically lower in Danish DH systems (often around 70-75 °C forward temperature).

In comparison, the process could be split in several sub-processes, each representing part of the total needed temperature increase and heat transfer. The final temperature increase to reach the DH forward temperature is then the *last* step seen from the DH water perspective whereas it is the *first* step for the cooling circuit (where the heat source temperature is highest). This energy transfer link in this process is illustrated with a dark green arrow in Figure 3. Correspondingly, the final step at the end of the cooling circuit cycle is raising the DH temperature from its return water level as is indicated in Figure 3 with the brightest arrow.

Such a stepwise configuration connecting processes operating in series enables significantly higher COP levels. The chosen configuration of a heat pump is therefore a key point to obtain an efficient system.

[3] Further information on this topic can be found in "Guidelines for the Energy System Transition – Recommendations for Local and Regional Policymakers" available at heatroadmap.eu/project-reports.

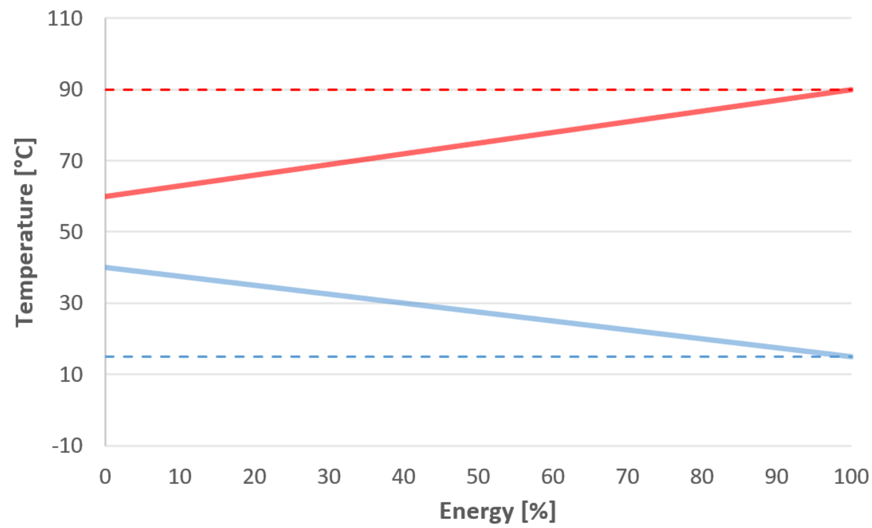

Figure 2. Example of temperature development for a heat pump associated with the energy transfer. The heat pump supplies DH at a temperature indicated with dashed red. The DH water temperature is indicated in full red. The heat source is cooled down to the dashed blue level in the process shown with a blue line.

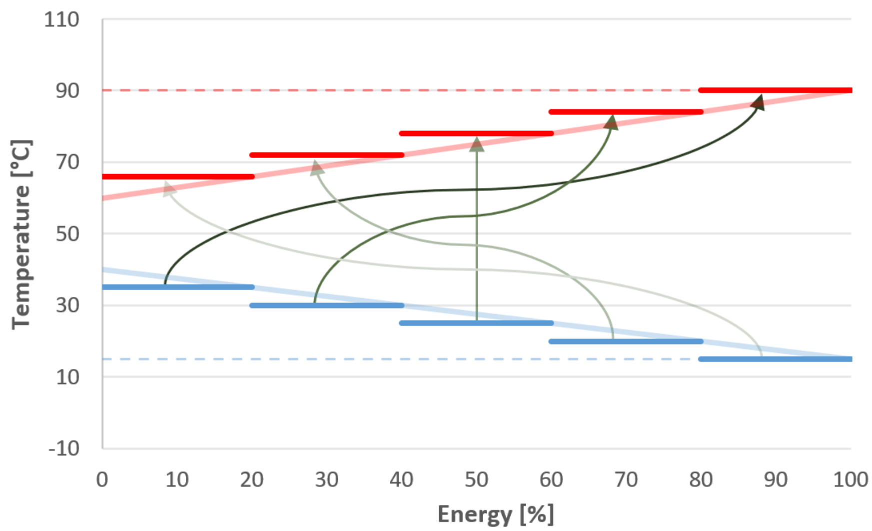

Figure 3. Example of temperature development for a heat pump associated with the energy transfer when split in five sub-processes each representing part of the heat exchange and temperature increase/reduction. Heat source temperatures are seen in blue, DH temperatures in red and connections between each of the five processes are illustrated with green arrows.

2.1 Design optimization – investment choices

Complex systems provide an opportunity to maximize the COP, but in turn include a larger number of potential component failure points. The stability of the chosen solution is increasingly important when the heat pump plays a main role in the DH company's energy mix. Electricity costs – even with less-than-ideal COP levels – may be manageable, while longer periods of downtime can be extremely costly due to the use of expensive backup production capacity. However, a less practical risk involved in aiming for a cheaper, simpler solution is the uncertainty of future electricity prices and the impact of unforeseen events causing periods of extreme electricity prices. A more efficient system will be more resilient based on the lower electricity demand while the down payments on the loan for the investment can remain fixed.

The trade-off between efficiency and investment costs is a critical point when choosing the most suitable heat pump solution for a given case. The range of investment costs for a given thermal capacity can be significant, representing additional cost to achieve higher efficiency. Hence, the expected future electricity price becomes an important parameter in this respect – and not only when comparing heat pumps to other production capacity options.

Presuming the decision is made to invest in a heat pump with a selected heat source to cover a certain share of the heating demand, a comparison to consider involves two different approaches for a given project – even if the total investment costs are similar:

A. A certain heat pump capacity operating at high COP levels to minimize operation costs.
B. Extra heat pump capacity in a simpler setup compared to option A – which in turn entails a lower COP – combined with (extra) thermal storage capacity. The extra capacity enables the operator to produce extra heat (and store it) in periods with the lowest electricity prices/carbon footprint.

The extra production and storage capacity of option B – together with a potentially more agile system accepting quick ramping up/down – may represent additional flexibility, which could compensate for the lower efficiency. However, the majority of flexibility may be obtained by a thermal storage thus representing an ideal mix between efficient operation *and* flexibility. There is not one "right" answer and the best solution in a given case is also affected by the options for integrating the heat pump with the remaining production units. More information on evaluation can be found in the document "Tendering process".

2.2 Storages

In many cases, new or additional short-term storage capacity to cover several hours (or up to a few days) represents valuable flexibility and stability for the system. A storage enables the optimization of the heat production by utilizing the hours with the lowest electricity prices and making it possible to avoid operation during electricity peak load hours.

A variety of sensors check that the conditions for normal operation of the heat pump is met. In case the temperature fed to the heat pump at the condenser side (i.e., at the DH return water temperature) fluctuates too much – in case of swift variations in the DH demand – a heat pump outage may occur. A storage acting as a buffer between the heat pump operation and DH demand can help ensure stable operation conditions.

The points mentioned above are especially important in DH plants where one heat pump covers most of the heat demand. It is generally recommendable to consider the option of adding a thermal storage feature in a large-scale heat pump investment.

2.3 Connection to other production units

The integration of heat pumps in the DH plant is not simply a matter of space and practicalities but can result in significant additional value associated with the operation strategy. The chosen connection points define what options are later available in terms of combining different production units. Since the COP is affected by the required supply temperature, it should be analysed to which extent the heat pump is expected to operate in connection with other units and how the desired operation strategies can be realised in practice (based on piping, valves, and connection point). The combined operation when the heat pump cannot cover the demand by itself can be done in parallel or in series:

I. Standard parallel operation where each unit received the DH return temperature and delivers the DH forward temperature (non-optimised.)
II. Series connection where the heat pump is used to increase from the DH return level to an intermediate temperature (optimized).
III. Series connection where other units deliver the first temperature increase feeding this to the heat pump, which then supplies the remaining temperature lift (often not ideal).

Option I above indicates the most simple operation since the different production units can operate independently. Option II requires a more complex control where the temperature settings must be aligned with the flow rates, which also may be limited in some units. In this case a storage can act as a buffer applying stability to the operation.
Option III is typically not relevant since the heat pump will benefit from lower temperatures while for example boiler operation is less affected. However, with the combination of solar thermal systems, there are periods where the system efficiency will benefit from this setup though these periods are in general limited.
One option is also to apply a parallel connection where the temperature levels are adjusted to minimise the outlet temperature from the heat pump by shunting the output flow with a

higher temperature e.g., from a boiler. In any case the overall efficiency of the system should be evaluated rather than considering each unit separately.

2.4 Self-supply of electricity

There is an increasing interest from DH companies regarding the installation of solar PV and wind turbines close to large-scale heat pumps in order to apply a direct connection between the units. The reduced cost of renewable electricity represents a relevant business case for many DH companies. At the same time, the solution represents a reduced dependency of fluctuating electricity prices thus making the DH company and associated heat prices more resilient. The latter has shown to be of increased importance during 2022. It also ensures a 100% renewable electricity supply for the share covered by the PV system or wind turbine. Local and/or national legislation may, however, limit the potential number or size of such production. The ability to produce electricity as a DH company mainly to use in a heat pump but also to sell to the grid underlines the generational change in Danish decentralised DH plants, formerly relying heavily on CHP based on natural gas, while in the future primarily acting as electricity consumer though with the ability still to supply electricity to the grid by means of CHP units and possibly PV/wind when the prices are high. The direct connection and the ability to optimise the use/sale of produced electricity increases the feasibility of thermal storage as described in section 2.2.