The Agony of the Choice in District Heating: The Impact of Heat Source for Heat Pumps

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Decarbonizing the heating sector requires the increased use of large-scale heat pumps in district heating. In Germany, these are still very rare due to high investments and operating costs. To reduce the operating costs, a high plant efficiency is required. Science efficiency strongly depends on the temperature lift between the heat source and sink; selecting the right source depending on the application is essential for the penetration of large-scale heat pumps in district heating networks. In this article, the most important factors influencing the selection of a heat source are discussed based on potential studies with typical types of heat sources for large-scale heat pumps.

Introduction

About 75 % of the heat supply in Germany is based on fossil fuels [1]. In particular, 8.2% of the heat supply is covered by district heating, and gas or oil boilers provide most of the remaining heat [2]. While heat pumps and hybrid heat pump systems can replace gas and oil boilers in buildings in relatively small power classes (< 50 kWth), large-scale solutions are necessary for district heating. Today, large-scale heat pumps (up to multiple MWth) are already used for district heating, with up to 14 % of generation shares in countries like Norway, Sweden, and Finland. In Germany, however, heat pumps are rarely used to supply district heating [3]. In 2023, there were just 30 plants with a total capacity of 60 MWth and a planned capacity extension of 600 MWth. For comparison, more than 11,500 plants with an overall capacity of about 70 GWth are installed in German networks [3]. In further detail, Agora Energiewende [3] provides an overview of the potential of large-scale heat pumps in Germany, their technical assessment, and political framework.

The available heat source has an impact on the heat pump efficiency. The higher the efficiency, the lower the operating costs. Therefore, the heat source is an essential factor influencing the costs for heat and, thus, market penetration of large heat pumps in Germany.

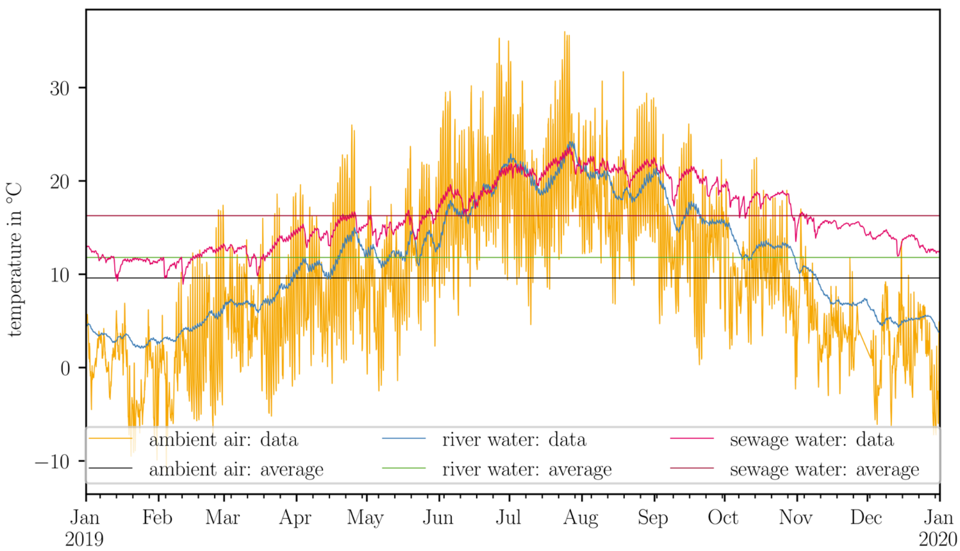

Figure 1: Typical tempature profils for ambient air [5], river water [6] and sewage water.

Agora Energiewende investigates possible heat sources and their potential for application in large heat pumps. Based on the typical temperature ranges of each source type, possible COP ranges for each source type are given. Since the COP ranges differ considerably, the distribution of the operating points within these ranges over a year also impacts the potential of each heat source. Still, this is an open issue. [3]

Closing this gap would allow for a detailed evaluation of the source potentials. For this, the temperature distribution over a typical year must be analyzed, and the integrated efficiency (Seasonal Coefficient of Performance) calculated. This article presents a more detailed consideration of source potentials for typical heat sources in Germany.

Potential heat sources for district heating

Potential heat sources can be divided into two categories. On the one hand, natural heat sources include air, geothermal energy, or water, independent of industrial processes. On the other hand, there are non-natural heat sources (waste heat) behind which there are industrial processes. These include, for example, waste heat from industrial processes, the ventilation of subways, or sewage water. [4]

Air as a heat source for a heat pump process is generally freely available and unlimited. Figure 1 shows the profile of the ambient air temperature of a German weather station [5]. On average, the air temperature is 9.6 °C. The annual variation is 47.7 K, with a minimum temperature of -11.2 °C (February) and a maximum temperature of 36.5 °C (July). Furthermore, the monthly mean values are shown. From this, it can be seen that in the winter months (October to February), the temperatures average between -1°C and + 10 °C. In the summer months (March to September), the average temperature varies between 8 °C and 19 °C.

The daily fluctuations also vary over the months (cf. Figure 2). While the difference between the daily maximum and minimum in the summer months is up to 15 K, it is only 6 to 10 K in winter. Compared to the air, the temperatures of river water [6] and sewage water fluctuate less. The difference between the annual maximum and minimum is 22.1 K for river water and 15.8 K for sewage water. The difference between river water and sewage water in the summer months is only marginal, and the temperatures average about 15 °C. On the other hand, the temperature is higher in the winter months. In winter, however, river water is colder than sewage water (5 °C vs. 11 °C). The daily variations are more minor than for air and range between 0.5 K and 3 K.

Overall, the temperature profiles differ in their characteristics. Air shows the highest fluctuations, whereby the most elevated temperatures are reached in the summer and the lowest in winter. River water and sewage water show only slight daily changes. The average temperature of sewage water is highest at 16 °C. River water has an average temperature of 11.8 °C and air 9.6 °C. Since the heat source temperature directly impacts the thermodynamically maximum possible efficiency (Carnot-COP) of a heat pump, the different characteristics of the heat sources following the choice of the heat source have to be considered in planning a new heat pump.

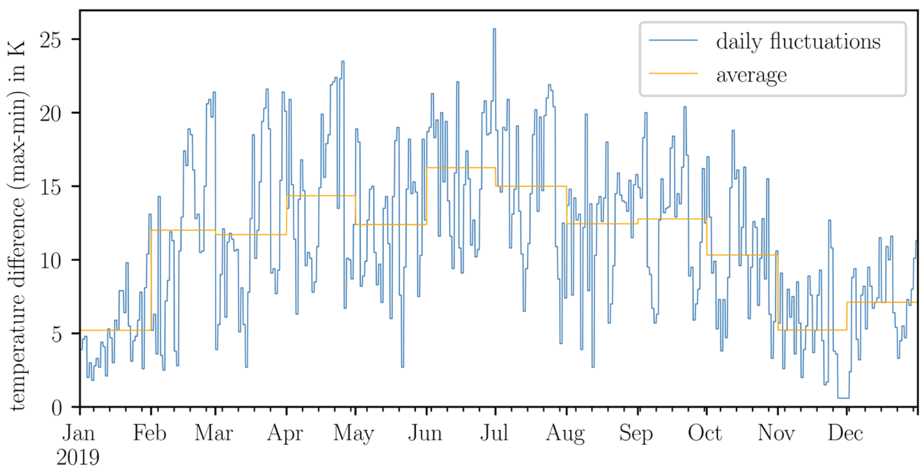

Figure 2: Daily air temperature fluctuations.

Effect of source characteristics on theoretic efficiency

Figure 3 shows the Carnot-COP of the three considered sources and a constant sink temperature of 75 °C. Due to the high daily variation in air temperature, the Carnot-COP for air varies between 5 and 9 a day in the summer months. In winter, when the daily variations in temperature are more minor, the Carnot COP varies between 4 and 5. The variations in river water and sewage water sources are minor. In the winter months, the Carnot-COP is 5 and 5.5, respectively, with sewage water having the larger Carnot-COP due to the higher temperature. In the summer, there are hardly any temperature differences between river and sewage water. The Carnot-COP is up to 6.5, and the daily fluctuations are negligible in each case.

Since the heat demand differs, on the one hand, every month and the other in the day, the momentary Carnot-COP at any point in time is insufficient to decide on a good heat source. For this, the Carnot-COP has to be weighted with the demand. The weighted Carnot-COP can be represented as Carnot-SCOP. The district generator is used to get a typical annual demand profile for district heating in Germany [7]. The district generator generates the heat demand profiles for space heating and domestic hot water based on weather data and typical quarter buildings, shown in Figure 4. Carnot-SCOP can be determined by determining the electrical power via the Carnot-COP (cf. Figure 3) and integrating the electrical and thermal power. The resulting utilization rates, depending on the source type, are illustrated in Figure 5.

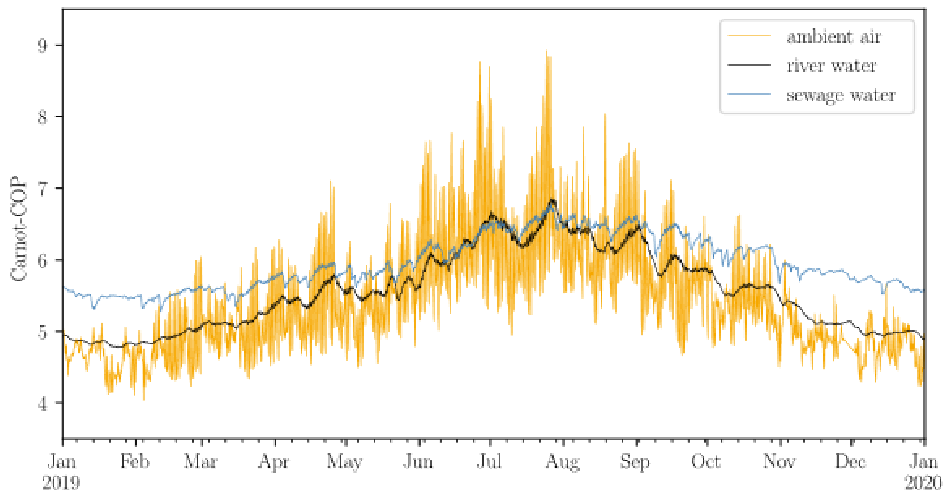

Figure 3: Theoretical achievable efficiency (Carnot-COP) for ambient air, river water, and sewage water as a heat source at a constant district heating temperature of 75 °C.

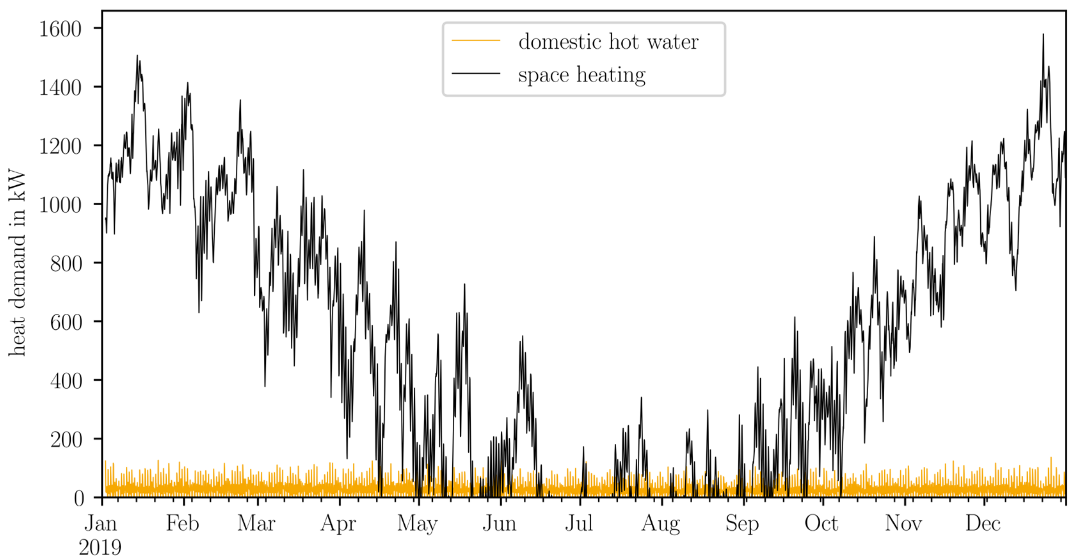

Figure 4: Heat demand of a typical district (calculated using the District Generator).

The year is divided into quarters to analyze the heat demand's influence better. In all quarters, sewage water shows the highest Carnot-SCOP. While this behavior is understandable in winter, one would expect air to have the best Carnot-SCOP in summer, caused by higher maximal temperatures. To explain why sewage water has a higher SCOP, the daily fluctuations must be looked at more closely. There is still a small demand for space heating in the summer, mainly at night. During these hours, the air temperature is minimal, and the sewage water has a higher temperature. This results in a higher Carnot-COP and Carnot-SCOP. Over the entire year, sewage water has the highest potential based on the Carnot-SCOP of 5.71. The Carnot-SCOP decreases by 9.8 % when using river water and 13.5 % when using air as a heat source.

Conclusions

This work provides a detailed analysis of heat sources' impact on air, river water, and sewage water temperature. The Carnot-COP and Carnot-SCOP for each heat source are calculated based on a simplified thermodynamic assessment, including typical temperature and heat demand profiles. Overall, the results illustrate the agony of choosing a heat source. The choice of heat source only based on the maximal or minimal temperatures can lead to efficiency disadvantages. Temperature deviations and fluctuations must be considered instead of the interactions between head demand. A better understanding of the influencing factors on the efficiency of large-scale heat pumps, such as the choice of the heat source, improved the penetration of large-scale heat pumps in district heating.

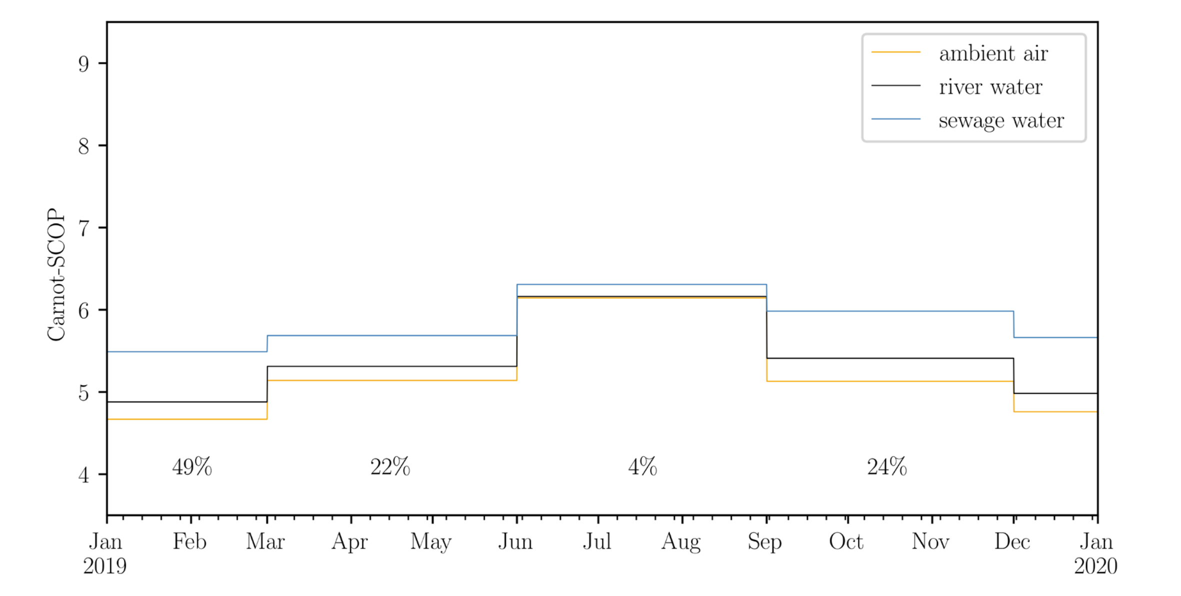

Figure 5: Theoretically achievable seasonal efficiency for ambient air, river water, and sewage water as a heat source at a constant district heating temperature of 75 °C (In addition, the share of the annual heat demand for each quarter is entered).

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For references see p. 30
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