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Large Heat Pumps in German District Heating Systems

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Abstract

As part of living lab “Reallabor_GWP – Large Heat Pumps in District Heating Networks – Installation, Operation, Monitoring and System Integration” initiated and coordinated by the German district heat association, the implementation of large scale heat pumps coupled with district heating technology has been scientifically supported at five locations in Germany since 2021. The first system was commissioned in 2023. Four of the systems are now in the R&D commissioning phase, which is accompanied by an in-situ measurement campaign. The article presents the five locations with regard to the current generation portfolio and identifies the challenges for integrating the heat pumps into the hydraulic and electrical system aside. Based on the requirements at the respective locations, the specifics of the heat pump solution selected are explained. In addition, the installed refrigeration circuit processes are compared. Challenges in the commissioning phase are highlighted. Using the scientifically prepared measurement data, key characteristics such as COP and temperature lift as well as the number of start-stop cycles are analysed to underline the dynamics related to cost of electricity.

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Keywords: large heat pumps; LSHP; district heating; DH; measurement data analysis

1. Introduction

As part of the living lab “RL_GWP - Large Heat Pumps in District Heating Networks” initiated by the German district heat association and funded by the BMWi (Fkz PtJ/BMWi 03EWR008A-L), the implementation of district heating (DH) coupled large scale heat pumps (LSHP) at five locations in Germany and their scientific monitoring has been underway since 2021 and will go on until June 2028.

The aim of the project is to gather experience in the operation of these systems as well as addressing the economic and regulatory framework conditions during planning and construction. As part of this research, five locations are being considered, some of which have been in operation since 2023, while another location (Berlin Köpenick) is still under construction. The systems under investigation have nominal thermal outputs ranging from 1.2 MW_{th} to 21 MW_{th}. High-resolution real-time data is collected in research and development operations and evaluated. This project is intended not only to contribute to the optimization of heat pump operation itself, but also to expand knowledge about the efficiency and challenges associated with integrating such systems into existing power and heating plant infrastructures.

2. System overview

There are five sites located all over Germany which participate in the project. In Berlin the district heating operator Berliner Energie und Wärme (BEW) combines a large heat pump with several sources, namely heat from a solar collector field, waste heat from a gas turbine and a combined heat and power plant (CHP) and heat provided by an air-to-water heat pump. The same heat pump type is also used in Berlin Neukölln by the plant Fernheizwerk Neukölln (FHWNK). There are five existing natural gas CHP units, which provide waste

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heat from the mixture cooling to the LSHP. The other three locations have river water as their heat source. In Stuttgart the operator EnBW has installed the largest heat pump in this project with 21 MW_{th} output at the power station site Münster. It is situated in a waste-to-energy plant next to the river Neckar. MVV Energie AG (MVV) in Mannheim has installed a 20 MW_{th} LSHP in the Mannheim large power plant (GKM) next to the river Rhine. Both these river LSHP apply the river water directly to the evaporator. The heat exchanger is cleaned continuously during operation with the help of cleaning balls directly in the water circuit. The Stadtwerke Rosenheim (SWRO) have installed three LSHPs with 1.5 MW_{th} each. They do not apply the river water directly to the evaporator but have an intermediate glycol circuit. Table 1 provides an overview of the facilities highlighting their capacities and technologies.

Table 1. LSHP sites and key figures

Utility/ location	Capacity LSHP / plant site [MW_{th}]	Producer / type	Com-pressor principle	Refri-gerant	Source		Temperature	
						Capacity [kW_{th}]	Source	Supply
BEW	1.4 / 50	GEA / RedGenium 550 (W)	Piston	R717	Solar heat, AAHP, waste heat	1 100	34.. 45°C	80.. 85°C
EnBW	21 / 447	Johnson Controls / OM455	Turbo	R1234ze (E)	River Neckar	13 800	5.. 30 °C	82.. 90 °C
FHWNK	1.16 / 202	GEA / RedGenium 550 (W)	Piston	R717	CHP waste heat	965	38.. 48 °C	80 °C
MVV	20 / 1500	Siemens Energy / SHP 600	Turbo	R1234ze (E)	River Rhine	12 500	3.. 25 °C	83.. 99 °C
SWRO	3 x 1.5 / 130	Johnson Controls / Sabroe/NS-DualPAC (112 W)	Screw and piston	R717	River Mühlbach	3 315	3.. 21 °C	80.. 88 °C

3. Operating Scheme

The LSHP are integrated in the power plant operational structure in different ways as shown in Table 2. All LSHP are driven regarding the hydraulic requirements at each production site to deliver the heat requested by the DH system and take the electricity market into account for operational optimization. At EnBW and MVV sites the power plant specifies the supply temperature and the volume- respectively mass-flow to propagate to the LSHP. In FHWNK no parameter is propagated from the power plant to the LSHP as it is used in the intercooling cycle of the CHP plant. The LSHPs in Rosenheim are operated under the "iKWK" subsidy regime [1]. This means e.g. they have to run a certain minimum amount of hours per year. Once this is fulfilled the LSHPs are driven in orientation to the electricity market. As the LSHP at the BEW site is not yet running it is excluded from this table. All LSHP are integrated into the return flow of the DH system and lifting its temperature. Further requested temperature lift is possible at each site by other generating units.

Table 2. control variables and operating concepts of installed heat pumps

Location	Control variables	Supply temperature range	Supply massflow / heat output range	Operational limits
EnBW	Volume flow; supply temperature	82.. 90 °C	500.. 950 m^3/s	-
FHWNK	Heat output of CHPs	80 °C		Min. 2 CHPs in operation
MVV	Mass flow; supply temperature	83.. 99° C	1 650.. 2 600 t/h	River temperature < 4°C
SWRO	Heat output; supply temperature	80.. 88 °C	500.. 1 500 kW	River temperature < 3.3°C

4. Refrigerant cycle

In the following, the primary circuits of the LSHP are described and compared. The LSHPs at EnBW and MVV both have turbo compressors. The primary circuits resemble one another in a way. The scheme for EnBW can be seen in Figure 1a). Accordingly, the LSHP at MVV does include two stages including the flash-tank principle and interstage injecting technology instead of the four stages shown for the EnBW one. At SWRO a flash-tank is directly integrated into the two-stage system as medium pressure level. It is driven by piston principle in the first and the screw compression principle in the second stage. Heat from cooling motor, gearbox and compressor is integrated to the secondary site at the source in a serial way as shown by the green lines.

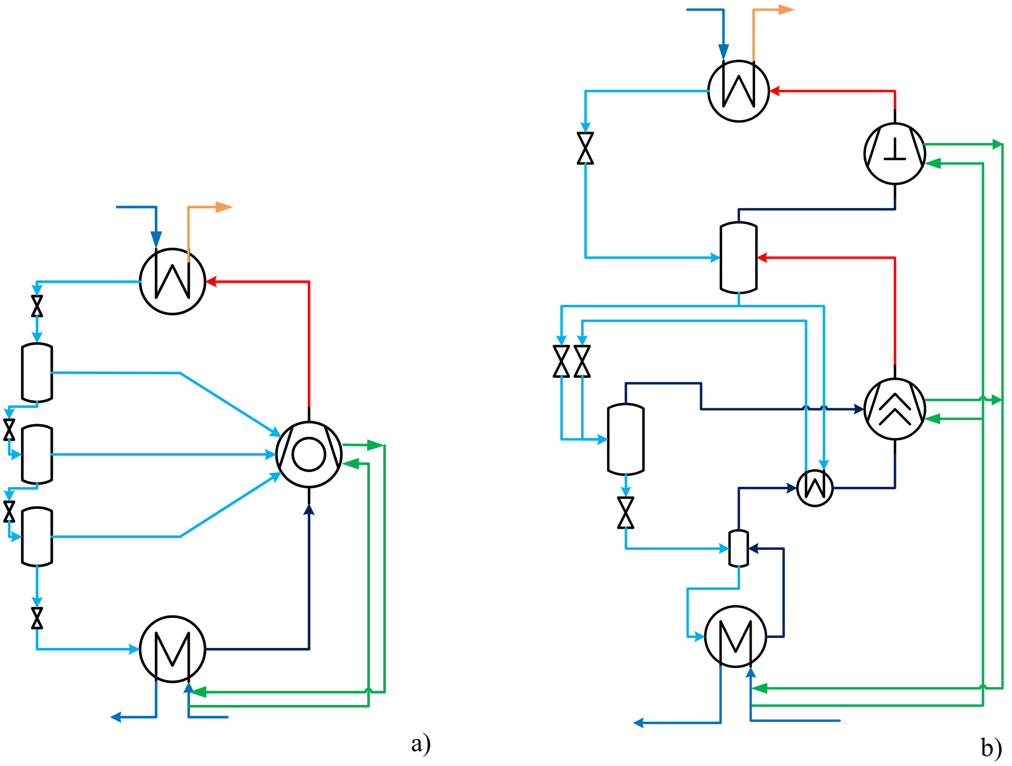

Figure 1. Refrigeration circuit schematic for turbo compressor at EnBW a) and screw and piston compressor at SWRO b)

At the FHWNK and BEW sites in Berlin, the installed LSHPs are of the same type, featuring a piston compressor with direct cooling via a refrigerant injection system.

5. Measurement Data Analyses

The scientific measurement concept has been published in [2]. It does include temperature and flow meters on the source and sink side of the LSHP systems, the outdoor temperature and certain sensors in the primary circuit. In Figure 2 the availability of data and the operating times of the heat pumps are shown. For all evaluation, the period of 24 months from November 1st in 2023, to October 31st in 2025, is considered. After the data transmission from FHWNK was established, an overhaul has been carried out, so there is no data available during the specified period.

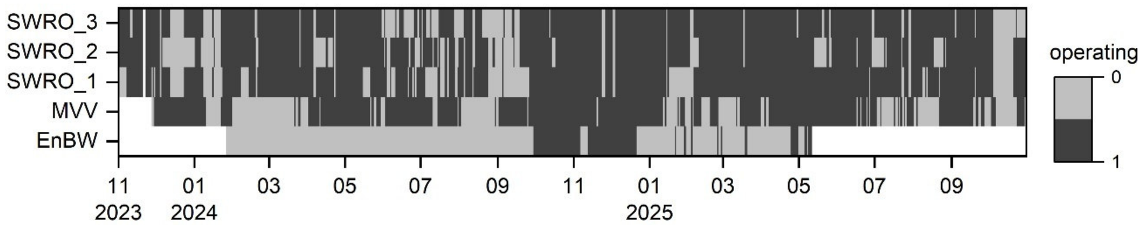

Figure 2. Operation and data availability of heat pumps over the period of two years ("0" = LSHP is not operating, "1" = LSHP is operating, white = no data transmission)

5.1. Operation periods

In Table 3 the operation hours and number of start-stop cycles of the LSHPs are shown. It is important to mention that the period does include the R&D commissioning phase and is not to be considered as normal operation. During this period operation has been intermitted for instance due to optimization of control parameters.

Table 3. Operating of the LSHPs over a period of two years (2023-11-01 00:00:00 to 2025-10-31 23:45:00) including R&D commissioning phase divided into a first period of 12 month a) and another subsequent 12 month b)

Location	Operation h		Number of start-stop cycles -		Mean operation time h	
	a)	b)	a)	b)	a)	b)
EnBW	621	1 012	16	41	39	25
MVV	4 671	4 504	137	177	34	25
SWRO_1	4 219	5 638	122	243	35	23
SWRO_2	4 211	5 541	131	219	32	25
SWRO_3	4 552	5 475	126	257	36	21

5.2. Signature of data and KPI

The following analyses takes data into account, that are marked as “quasi-stationary” as stated in [2]. This means that a moving average over a certain period of time does vary just in a certain maximum range.

Signature is drawn for the LSHP SWRO_1 in the following Figure 3 of various parameters regarding the temperature of the river.

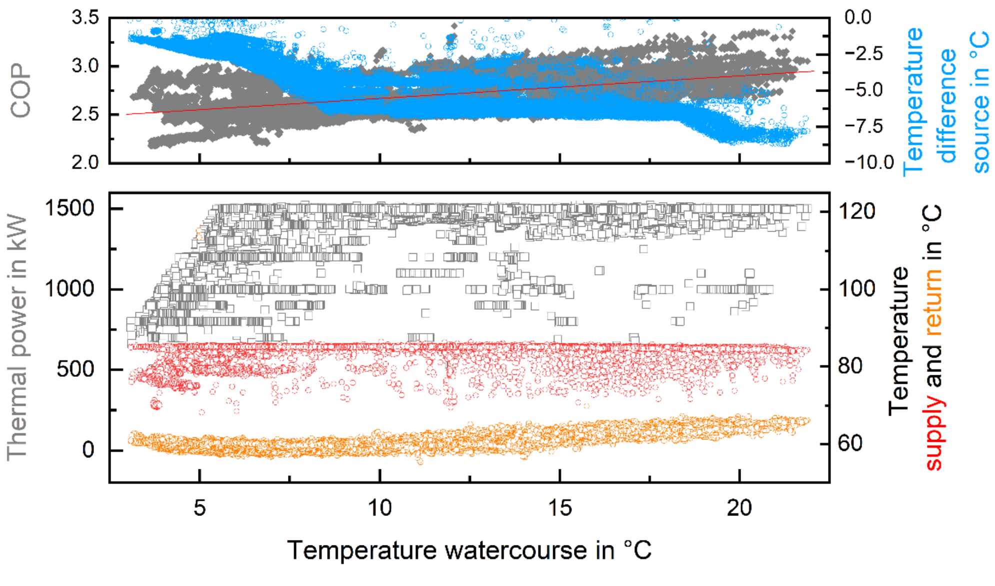

Figure 3. SWRO_1: Thermal output and COP (gray), flow (red) and return temperature (orange), and temperature difference of the source (blue) plotted against the temperature of the flowing water

Thermal output is constant at approx. 1.5 MW_{th}. The produced flow temperature is quasi constant at a level of 88 °C. It becomes clear that the LSHP is put to be driven in reduced load at temperatures of the watercourse lower than 6 °C to make sure its DH forward flow temperature is at the same level to be delivered. It is taken out of operation at a minimum temperature of the watercourse of 3 °C. Certain optimization of parameters has been conducted during the R&D operation phase to ensure that level of forward flow temperature at these low temperatures of the watercourse as well. That becomes visible in a much wider spread of measurement points in this area. The temperature difference of the corresponding heat exchanger HX1 that does extract heat of the watercourse to the intermediate glycol cycle does especially at high river temperatures implicate the need for hydraulic balancing as temperature difference drops at values larger than about 18 °C. The HX1 is part of a hydraulic rail that all three LSHP are integrated in.

5.3. Key performance indicators

In the following Table 4 values are stated as mean over the entire operation time of each system following the date filtering applied in [2]. The coefficient of performance COP is calculated based on electricity consumption and the thermal output in accordance with the balancing introduced in [1]. Whereas COP1 accounts for the electricity consumption of the entire heat pump system including oil circuits and any auxiliary devices. COP2 corresponds to the additional amount of electricity utilized to integrate the source of each heat pump. The COP_{Carnot} corresponds to the carnot-efficiency and is calculated based on the temperatures for source inlet and sink outlet temperatures.

Table 4: Mean values and standard deviation during operation time of LSHP systems

Location	COP1	COP2	COP_{Carnot}	Temperatures		
	-	-	-	Source	Sink	Lift
				°C	°C	K
EnBW	2.78 ± 0.19	2.64 ± 0.19	52.3 ± 5.2	17.1 ± 3.7	85.2 ± 6.6	68.9 ± 4
MVV	2.87 ± 0.2	2.77 ± 0.2	59.6 ± 4	14.4 ± 5.5	89.2 ± 5.9	75.2 ± 9.8
SWRO_1	2.64 ± 0.18	2.59* ± 0.18	57.9 ± 3.38	10.9 ± 4.3	86.4 ± 2.7	75.8 ± 4.6
SWRO_2	2.67 ± 0.33	2.62* ± 0.32	58.6 ± 6.4	11 ± 4.4	86.1 ± 2.6	75.4 ± 4.6
SWRO_3	2.35± 0.25	2.32* ± 0.23	57.8 ± 5.8	11.2 ± 4.5	86.2 ± 7.7	75.2 ± 9.7

*an additional principal pump is not part of the measurement that is lifting the river water for purpose of the entire utility

All systems are operated according to the schemes in Table 2 and show expected efficiencies as in their design process. The minimum operational temperature at the river side that has been measured is in a range of about 10 °C for EnBW, 5 °C für MVV and 4 °C at SWRO. The COP_{Carnot} is calculated for the turbo, as well as for the combined piston and screw LSHP systems as shown in Figure 4. It is in an expected range corresponding to [3].

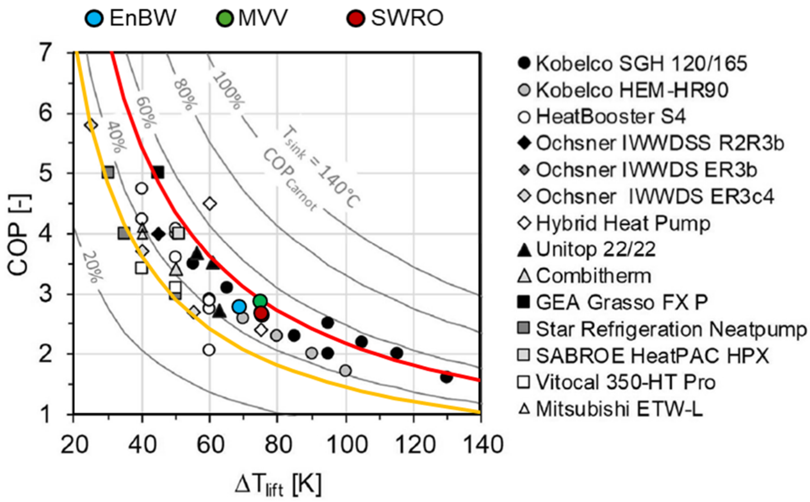

Figure 4. Mean of COP1 in respect to the temperature lift for the analysed systems corresponding to a modified figure of [3], the COP_{Carnot} has been adapted to T_{sink} = 90°C by the yellow line (40%) and red line (60%)

5.4. Operation in energy market

As shown in Figure 2 two of the LSHP systems have been set into operation during the analysed period of measurement (EnBW and MVV). So for those data is missing in respect of the entire course of two years. The other three LSHP systems at site of SWRO have been operated in a regular way and are running under the subsidy regime of iKWK [1] as stated in chapter 3. All LSHP systems are operated to ensure heat production of the plant site. Operation regarding the electricity market is secondary and a matter of optimizing hydraulics and cost for heat production at the plant site. In the following Figure 5 operation of the LSHP systems is shown over the period of three days in December 2024 whilst an extreme event of cost in the Day-Ahead market. It becomes clear that all LSHP have been taken out of operation during this event of time. The operating regime that can be examined at the other days is much more usual as operation is performed during night – and in some cases following low prices during midday as well.

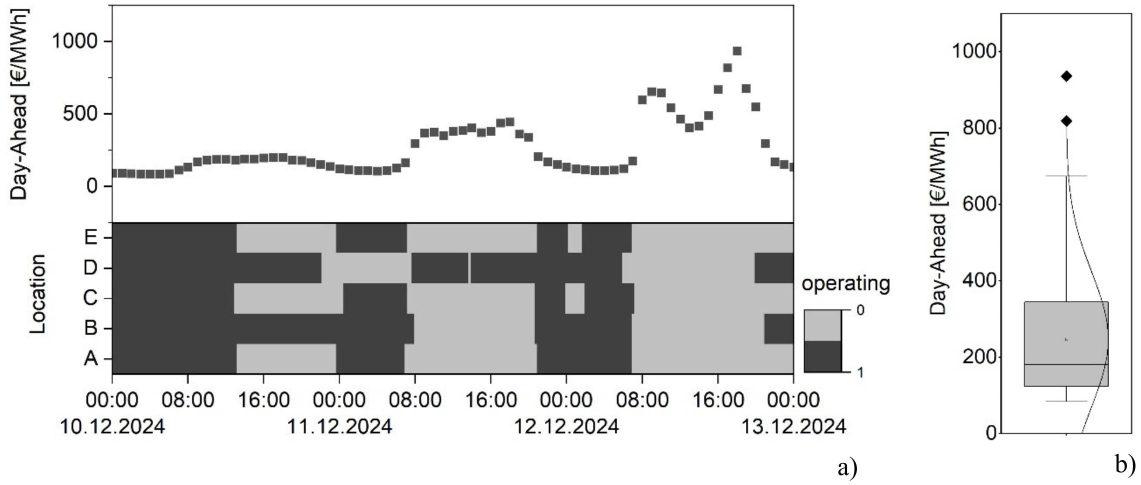

Figure 5: a) Operating of LSHP systems and day-ahead price for three days in December 2024. Distribution of Day-Ahead prices for the investigated period of time [4] with outliers (“0” = LSHP is not operating, “1” = LSHP is operating)

This demands for at least one start-stop cycle for each day that might rise to two during summertime. Resulting effects on service intervals and cost are part of further R&D investigation.

6. Evaluation and outlook

Successful initial operation has been shown for three utilities. All systems are operated well along the previous design and show efficiencies as expected. The mean for COP1 is at about 2.7 at temperature lifts in a range of 69.. 76 °C where COP_{Carnot} is in a range of 50.. 60 %. Operating cycles in means of the number of start-stop procedures requested to the LSHP systems are far away from seasonal characteristics that have been expected. This is due to the fact that the electricity market does implicate meanwhile higher fluctuations that have not been taken into account in the design phase. This might lead to at least one or even two on / off cycles at each day, resulting in LSHP components set under more stress than expected.

Further research will be performed to analyse the dynamic behaviour of the systems focussing on its dynamic operation procedures in regard to the hydraulic requirements of the plant site.

7. References

[1] "Kraft-Wärme-Kopplungsgesetz vom 21. Dezember 2015 (BGBl. I S. 2498), das zuletzt durch Artikel 1 des Gesetzes vom 21. Februar 2025 (BGBl. 2025 I Nr. 54) geändert worden ist"

[2] Seiz J, Oliva A. Vorstellung der Liegenschaften und messtechnische Analysen aus der FuE-Inbetriebnahmephase für fernwärmetechnisch gekoppelte Großwärmepumpen. Symposium Zukunft Wärme, Bad Staffelstein, 2025.

[3] Arpagaus, C., Bless, F., Uhlmann, M., Schiffmann, J. u. Bertsch, S. S.: High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. Energy 152 (2018), S. 985–1010

[4] https://www.energy-charts.info/, Fraunhofer Institute for Solar Energy Systems ISE, 15th November 2025

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