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High-Temperature Heat Pump at Berlin City Center: Detailed Results and Experiences from Real-World Operation

Görkem Balyaligil[a,d,**], Kevin Moritz[b], Jochen Schaefer[b], Thorsten Friedrich[b], Thorsten Fippel[b], Steffen Richter[c], Ranjan Saha[a], Samer Sawalha[d]

[a] Siemens Energy, Finspång, 612 31, Sweden
[b] Siemens Energy, Schuckertstrasse 3, Erlangen, 910 58, Germany
[c] Berliner Energie und Wärme (BEW), Berlin, 108 29, Germany
[d] KTH Royal Institute of Technology, Stockholm, 100 44, Sweden

Abstract

High-temperature heat pumps (HTHPs) have the potential to play a key role in decarbonizing district heating systems. This work describes the capabilities of a HTHP installed at Potsdamer Platz, Berlin, which delivers a thermal capacity of up to 9 MW and offers operational flexibility to supply flow temperatures between 85°C and 120°C according to the district heating system's needs. Waste heat from the process cooling of the district cooling system chillers serves as the heat source, with the heat source outlet temperature maintained at a constant level of 27°C throughout the year, despite varying inlet temperatures. Recent performance measurements across a range of temperature lifts (50 K to 85 K) under both part-load and full-load conditions are presented and discussed. Key findings include the efficiency and operational limits of the HTHP, with a COP of up to 3.8 depending on operating conditions, highlighting its energy-efficiency potential. The dynamic operation during start-up, and shutdowns is analysed, providing insights into the flexibility and real-world applicability of the system.

Keywords: High temperature heat pump; Industrial heat pump; District heating; District Cooling;

1. Introduction

District heating systems are essential to urban energy networks, providing heat to millions of homes and businesses globally. However, many of these systems depend on fossil fuels, complicating efforts to meet climate targets and reduce greenhouse gas emissions. Decarbonizing district heating is therefore a critical priority in the global energy transition. High-temperature and large-scale heat pumps (HTHPs) have emerged as a promising solution, capable of recovering waste heat or utilizing renewable energy sources while delivering high-temperature heat compatible with existing infrastructure. These systems allow cities to transition to more sustainable energy networks without extensive retrofitting, making them key technologies in the pursuit of net-zero carbon emissions [1].

HTHPs are specifically designed to meet the high-temperature requirements of district heating systems. Unlike standard heat pumps that typically supply lower flow temperatures, HTHPs deliver higher temperatures that align with the needs of legacy systems. Their operational flexibility enables them to adapt to varying heating demands, making them suitable for urban environments with fluctuating requirements. Additionally, heat pumps can integrate waste heat recovery from sources like district cooling systems, enhancing the sustainability of district heating networks. However, operating under these conditions presents challenges,

[*] Corresponding author: Görkem Balyaligil
E-mail address: goerkem.balyaligil@siemens-energy.com/gorkemb@kth.se

including maintaining efficiency across large temperature lifts and optimizing performance under variable loads. Addressing these challenges is crucial for ensuring the reliability and energy-saving potential of HTHPs and accelerating their real-world adoption.

Recent research initiatives, such as the IEA HPT Annex 47, have highlighted the potential of large-scale heat pumps as foundational components in future district heating and cooling systems [2]. The IEA HPT Annex 58 provides an overview of HTHP technologies and applications, formulating strategic pathways for transitioning to HTHP-based process heat supply. While these initiatives have improved understanding and dissemination of information regarding industrial applications, detailed analytical insights are often lacking [3]. The SPIRIT project focuses on industrial applications of HTHPs, featuring demonstration sites, one achieving a heating capacity of 4 MW [4]. However, published results from these initiatives are currently unavailable, with substantial data primarily from a large-scale heat pump in Esbjerg, Denmark, which lacks performance evaluations and detailed analyses [5].

This situation highlights a critical challenge: despite growing interest and investment in HTHPs, there is a significant deficiency in comprehensive performance data from real-world applications, particularly for large-scale systems operating under diverse conditions. The absence of detailed performance metrics limits understanding of their efficiency, reliability, and operational flexibility, hindering informed decision-making.

Key questions remain regarding the efficiency of HTHPs at elevated temperature lifts, their operational flexibility in dynamic conditions, and their reliability under varying loads. This work aims to address these gaps by investigating the real-world performance of a large-scale HTHP installed at Potsdamer Platz, Berlin. Given the limited availability of detailed performance data, this analysis is unique and contributes valuable insights to the field of high-temperature heat pump technology.

2. Application of HTHPs at Potsdamer Platz

In March 2022, Siemens Energy and Berliner Energie und Wärme GmbH (BEW) (formerly: Vattenfall Wärme Berlin AG) commenced the construction of a large-scale heat pump installation in Berlin, Germany. The installation is located within the existing district cooling center close to Potsdamer Platz ("Kältezentrale"). The cooling center consists of a grid substation, two absorption chillers and 11 compression chillers, which supply chilled water at 6°C to a district cooling network in central Berlin. Construction was completed in November 2023, and the system was subsequently commissioned. The project is supported by funding from the German Federal Ministry for Economic Affairs and Energy (BMWE) under the “EnEff:Wärme program: Quartiers-Wärme-Kraft-Kälte-Kopplung” [6].

Figure 1 illustrates the integration of HTHPs at utility. The site currently houses multiple compression chillers that generate waste heat, which is typically re-cooled using wet cooling towers installed on the building's roof. The heat pump system has been integrated to utilize this waste heat for district heating purposes. Specifically, the evaporator in the heat pump lowers the temperature of the waste heat produced by the chillers from around 32°C to 27°C, enabling heat recovery [6].

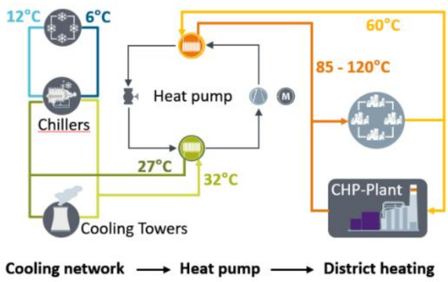

Figure 1. Integration of High Temperature Heat Pump at utility BEW in Berlin, Germany [7]

During this process, the refrigerant R1233zd(E) absorbs heat from the waste stream in the evaporator, causing it to evaporate and superheat. A single-shaft centrifugal compressor then compresses the refrigerant and discharges it at a higher pressure to the condenser. In the condenser, heat is transferred from the refrigerant to the district heating water, which enters the system at approximately 60°C and is heated to temperatures ranging from 85°C to 120°C, depending on the requirements of the district heating network.

The heat pump has a nominal thermal output of 8 MW and is designed to deliver approximately 55 GWh of district heating annually, with an expected average coefficient of performance (COP) of 3 for the overall system, considering various losses. By utilizing this recovered waste heat, the project is projected to reduce annual CO2 emissions by approximately 6,500 metric tons. Additionally, it is estimated to save around 120,000 m³ of cooling water annually, further enhancing the environmental benefits of the installation [7].

Further the heat pump is connected in parallel to existing cooling towers and provides up to 6 MW cooling power to the closed or open operated cooling water system. Compliance with limits for cooling water inlet temperature to the Chillers is a key priority for this application.

3. Result and Analysis

As part of the project, a series of operational tests were conducted to evaluate the performance of the heat pump under varying district heating forward temperatures, both in full-load and part-load conditions. The operational data collected during these tests are presented and analysed in this section.

3.1. Full Load Operation Tests

Full-load operation is defined as scenarios in which the district heating output reaches 92.5% or more of the nominal thermal output. During the entire test run, the heat pump was able to re-cool the chillers and reduce the cooling water temperature from about 32°C to 27°C.

The Figure 2 shows the heat pump's average COP under full-load conditions, with bars. It describes the relationship between the district heating forward temperature, the corresponding temperature lifts and the COP over the temperature range given by the application case.

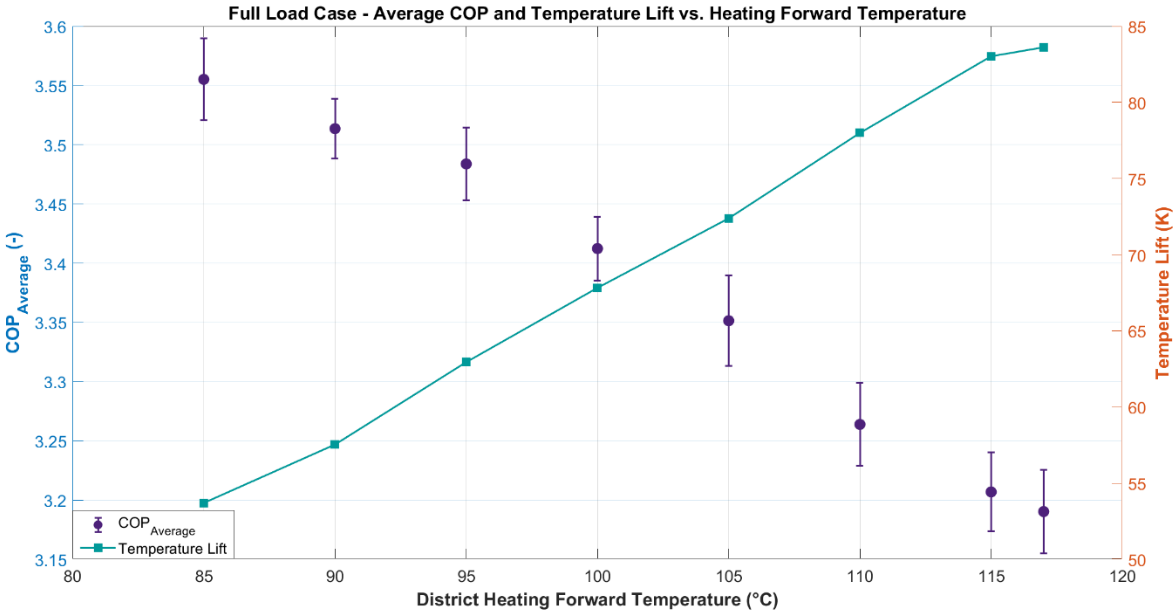

Figure 2. Full Load Case - COP as a Function of District Heating Forward Temperature

As can be observed in Figure 2, the data show a decreasing COP trend as forward temperatures increase, demonstrating higher efficiency at lower forward temperatures. Specifically, COP values range from 3.5 to 3.7 at forward temperatures of 85°C, dropping to 3.1–3.2 when temperatures exceed 110°C. The bars reveal the variation in COP at the same forward temperatures/temperature lift, attributable to fluctuations in heat source mass flow, and inlet temperature as well as measurement errors.

3.2. Part Load Operation Tests

In the Part Load Test section, scenarios are analyzed where the district heating power drops below 92.5% of the full load, indicating part load conditions in which the heat pump is not operating at full capacity.

An example of a part-load and full-load operating condition is presented in Figure 3, which illustrates the system's performance when the district heating forward temperature is maintained at 95°C. The figure highlights the results obtained under reduced heating demand, providing valuable insights into the heat pump's behavior and efficiency during part load scenarios.

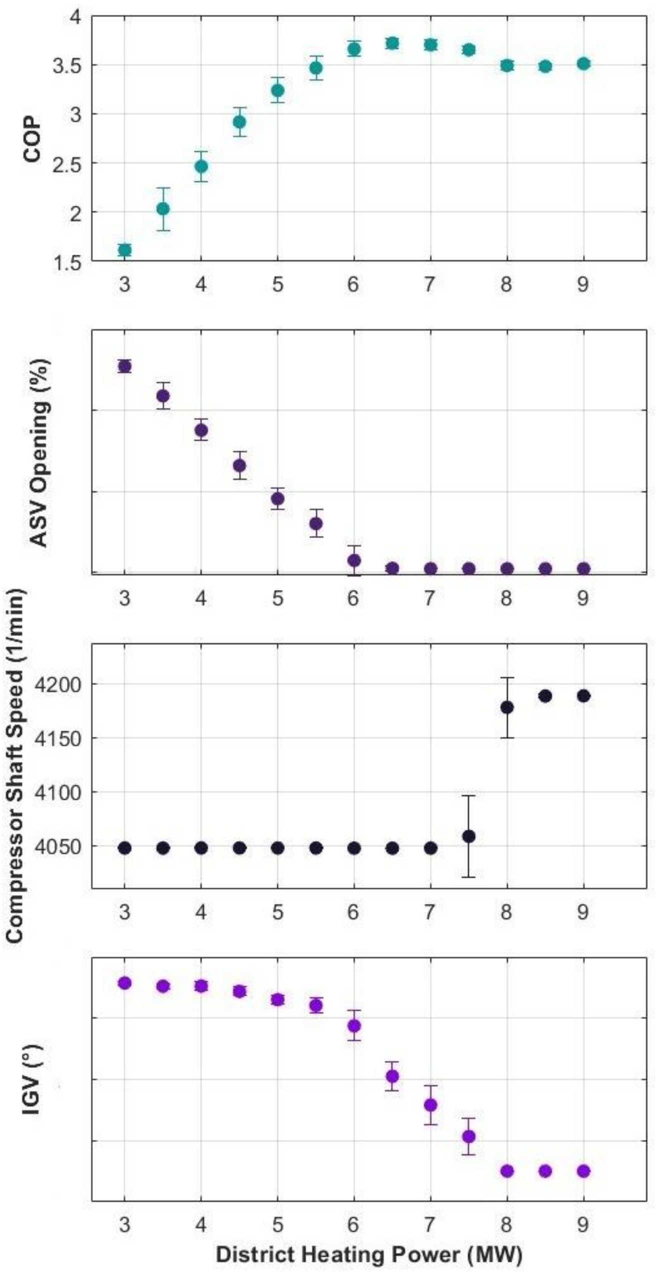

Figure 3. Heat Pump's COP from Part to Full Load Operation and the Influencing Parameters of Anti-Surge Valve Opening, Inlet Guided Vanes Angle Degree, and Compressor Speed.

The heat pump has been designed for a nominal thermal output of 8 MW. During full load operation, a slight decrease in the COP is observed after reaching approximately 7.5 MW. At this stage, there is no opening of the Anti-Surge Valve (ASV), suggesting stable operating conditions without the risk of surge. The compressor speed increases to approximately 4185 RPM, reflecting the higher demand for heating power. Additionally, the Inlet Guide Vane (IGV) is fully open, optimizing flow to enhance system efficiency. When ideal conditions in the heat source a maximum thermal output of 9 MW is monitored.

As the district heating power reaches around 6 MW to 7.5 MW, a region characterized by a constant COP emerges. This area is notable for exhibiting the highest COP values. During this phase, the ASV remains closed, and the compressor shaft speed stabilizes at around 4050 RPM, consistent with other part load cases. However, changes in the IGV angle begin to occur, with an increase observed that further optimizes the flow of refrigerant and enhances heat transfer.

When the district heating power decreases to below 6 MW, the COP starts to decrease. In this region, the ASV opening begins to increase, indicating a need for better flow management as the system adjusts to lower loads. The compressor shaft speed remains consistent at around 4050 RPM, similar to the previous part load cases. The IGV angle, which had already increased, continues to rise, albeit at a slower rate compared to earlier part load conditions. This gradual adjustment reflects the system's efforts to maintain efficiency while adapting to changing heating demands.

The average COP of the heat pump is 3.3, while the overall performance of the system is 3.03. These results demonstrate both the operational flexibility of high-temperature heat pumps (HTHPs) and their energy efficiency potential. Several factors contribute to the sustained performance of the heat pump system. The optimization of superheating ensures that the refrigerant is adequately heated before entering the compressor, thereby enhancing its thermodynamic properties. Furthermore, an optimized correlation between the ASV opening and the expansion valve opening facilitates better control of refrigerant flow, minimizing energy losses and promoting system stability. The implementation of a feed-forward control strategy plays a crucial role in enhancing performance by anticipating changes in load and proactively adjusting system parameters to maintain efficiency. Additionally, the system continuously monitors the heat balance in the evaporator, ensuring that heat transfer is maximized and that the refrigerant operates within optimal conditions.

3.3. Start-up and Shut-down Sequences

3.3.1. Start-up Sequences

This section evaluates the start-up sequence of the heat pump as illustrated in Figure 4, highlighting the key parameters and their interactions during the initial operational phase.

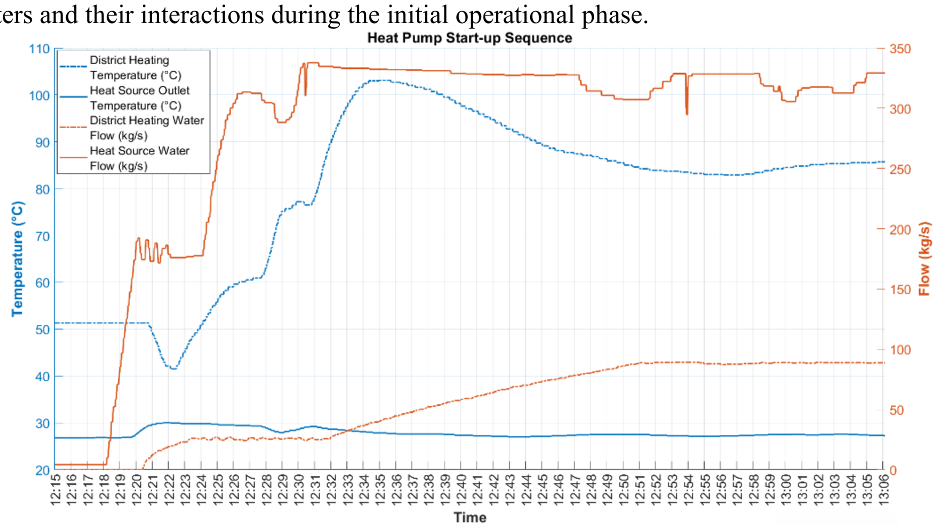

Figure 4. Start-up Sequence of the Heat Pump

The heat pump start-up sequence begins with an increase in the heat source water flow, which is essential for supplying thermal energy to the system. Overall start-up time from starting district heating water pumps until reaching district heating forward temperature varies between 7 min and 15 min depending on start conditions and conditions in secondary systems. Looking into several start-up event it can be concluded that the large-scale heat pump is the fastest part of the three systems, where the district heating typically is the slowest part as controls needs to consider boundaries in the secondary systems. Considering the increase of the heat source mass flow as starting point and a constant district heating water outlet temperature at target temperature and full flow/load as end of the start-up sequence, the start-up sequence in this example shown in Figure 4 took about 35 minutes. As the heat source water flow rises, the heat source outlet temperature initially increases; however, this temperature stabilizes after a short time and subsequently begins to decrease, ultimately settling around 27°C. Following this, the district heating water flow starts to increase, allowing for the distribution of heat generated by the system. Throughout this process, the heat source outlet temperature remains relatively stable, reflecting consistent heat transfer from the source to the heating system.

3.3.2. Shut-down Sequences

This section evaluates the shut-down sequence of the heat pump as illustrated in Figure 5, focusing on the key parameters and their interactions during the final operational phase.

The shut-down sequence is initiated by the operator and starts with a decrease in the heat source water flow. At this point, the district heating temperature also starts to decrease and stabilizes with decreasing the district heating water flow. Finally, the district heating water flow is stopped, indicating the completion of the shut-down sequence.

The shut-down is very fast reducing the electric power consumption of the compressor drive within less than one up to two seconds, showing that grid balancing services are possible with large scale heat pumps, e.g. in the Nordics Frequency Containment Reserve for disturbances FCR-D in case of frequency deviations.

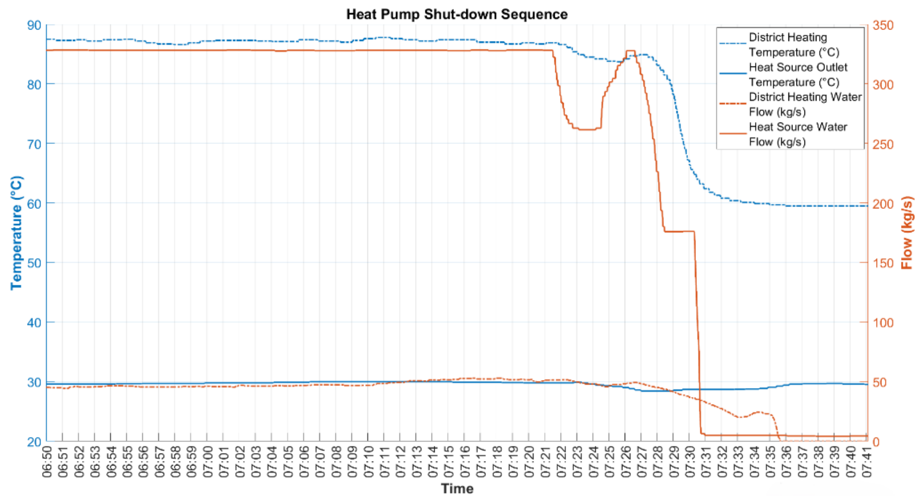

Figure 5. Shut-down Sequence of the Heat Pump

4. Conclusion

This paper describes the implementation of HTHP at Potsdamer Platz in Berlin. The heat pump successfully re-cooled the chiller plant, i.e., it lowered the cooling water temperature to 27 °C as specified. By recovering heat from the cooling water circuit, the heat pump supplied between 3 and 9 MW of thermal power to the district heating system, responding flexibly to fluctuating heat flows from the heat source and district heating flow temperatures requirements, which correspond to temperature lifts between 50 and 85 °C. COPs between 1.5 and 3.8 were measured depending on the operation conditions. The average COP of the heat pump is 3.3, while the overall performance of the system is 3.03. These results demonstrate both the operational flexibility of HTHPs and their energy efficiency potential. The findings obtained during the project and presented here help to close the gap in existing literature, as there is a significant lack of comprehensive performance data from real-world applications of HTHPs.

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