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The Unique Plant Concept of the Linz District Heating and Cooling System

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Abstract

The utilization of district heating heat pumps (DHHP) has become increasingly prevalent due to their energy-efficient and sustainable operation. However, the use of DHHPs is mainly focused on the supply of heat energy for district heating (DH), with the usage of the provided cooling energy by the heat source often not being considered.
In this paper, we show the unique plant concept of the district heating and cooling (DHC) system of Linz, which is set for a partial start of operation in 2028. The DHC-network (DHCN) stands out from others due to its special heating and cooling operation: In heating operation, the DHHP uses the condensing flue gases from the cogeneration plant "Energiepark Linz-Mitte" as heat source; while during the usual summer DHHP-downtimes, a special hydraulic switching enables the use of the heat source to provide additional cooling energy for the district cooling (DC). In the latter, river water as well as cooling towers are used for re-cooling. Additional DC and DH storage tanks help to avoid operation during unfavorable boundary conditions.
We have found that by the serial arrangement of the DHHP in heating operation, exceptionally high system-COPs of 4.4 at full load (instead of 2.8 in parallel arrangement) can be achieved. Facing very different temperature spreads on the heat source in cooling and heating operation, during cooling operation the source-side serial interconnection is hydraulically switched to parallel. Thereby, excessive variations of the water mass flows in the evaporators are avoided. Furthermore, the necessary maximum installed cooling capacity of the DC supply can be reduced by utilizing the DHHP to provide cooling, resulting in investment savings.
These results are of high significance for both existing DHHP systems and those newly installed, showing the advantages of using the DHHP cooling energy through the implementation of appropriate system designs.

Keywords: District Heating; District Cooling; Heat Pump; Refrigeration; Energy Efficiency

1. Introduction

In the battle against global warming the aim to reduce CO2 emissions and increase energy efficiency takes place in various fields, as can be seen by the fact that over 60 countries are backing the United Nations Framework Convention on Climate Change (UNFCCC) [1]. In order to achieve climate targets, not only primary energy generation must be converted to renewable energy sources, it is also necessary to improve the energy efficiency of the entire energy transport chain [2],[3].

Heat pumps can contribute greatly to this cause. The IEA expects that by 2030, the need for fossil fuels in the areas of heating water and space can be reduced by over 50% with the use of heat pumps [4]. Furthermore, DHCN provide more efficient heating and cooling than individual heat pumps for every consumer, especially in urban areas [5]. This makes DHCN a great way to achieve better results for economy and ecology.

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While common approaches for cost- and energy-efficient solutions for DHCN include using industrial waste heat and solar energy, the local situation influences the possibility and feasibility of certain designs. Regarding seasonal differences, a case study shows the proposed use of wastewater treatment plant sludge to recover energy with which the varying thermal needs due to the change of seasons could be met [6]. Also a system where solar energy was used to compensate the lack of ground heat during the months November to March was tested[7].

However, there can only be found a small number of studies dealing with the double use of the same heat pump in DHC systems (with a hydraulic switching of heat source and heat sink) for heating and cooling at different times of the year (especially with the usage of a flue gas condensation), except for the ones dealing with the same project, such as [8].

As described in [9], DHHPs can be used for the optimization and decarbonization of the Linz DHCN in different ways. One of these is a concept in which the existing excess heat from two different flue gas sources at the "Energiepark Linz-Mitte" combined heat and power plant is used via flue gas condensation or by a scrubber to generate heat from fall to spring. In the summer months it uses river-water of the nearby Danube for re-cooling and supplies the DC-network (DCN) with chilled water. To the best of our knowledge, the plant concept of the DHC system in Linz is unique. In this paper we show how a complex hydraulic system makes this double-usage of the heat pump possible and increases the efficiency during heating operation.

2. Concept

Currently, the DH-network (DHN) of Linz is supplied with heat by several gas-fired combined-cycle power plant units (CCGTs), a biomass combined-heat-and-power plant (BIOM), and a waste-to-energy plant (RHKW), as well as by boilers on very rare occasions. In addition, a thermal energy storage based on DH-water maintains pressure in the DHN and enables the DH to be operated optimally and efficiently.

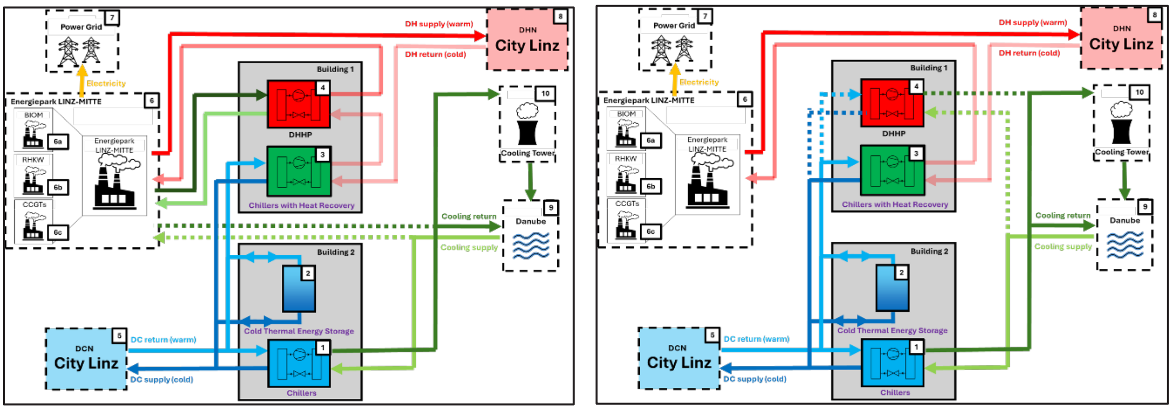

Figure 1. Schematic plant concept for district heating and cooling supply in the city of Linz (see also [8]);
Left: heating operation of DHHP-system; Right: cooling operation of DHHP-system

As shown in Fig.1, left image, a DHHP system (4) will be used to utilize the waste heat of the flue gas from the BIOM (6a) and RHKW (6b) in order to ensure reliability of supply of the DHN (8) in the future and further to reduce the fossil fuel share of LINZ AG's DH supply. Together with the CCGTs (6c), this provides the power grid with electricity (7).

As part of the construction of a new DCN (5) for the city of Linz, LINZ AG is planning to build a DC station (1) including a thermal energy storage (2) and refrigeration units (chillers) featuring a heat recovery (3) which supply waste heat directly to the DHN. The necessary remaining re-cooling is carried out using cooling towers (10) and river water from the Danube (9). In addition, during the summer months (or during periods of low DH demand), the DHHP system is to be operated as chillers via a hydraulic switchover, see Fig. 1, right-hand illustration, which makes it possible to also supply the DCN.

2.1. DHHP-system in heating operation

The basic concept of the DHHP-system is to use up to four heat pumps to raise the temperature of the DHN-return flow during heating operation. The waste heat from the flue gas of the BIOM and the RHKW is to be used as a heat source for this purpose through flue gas condensation.

Fig. 2 shows that the condensers and evaporators of the DHHP are connected in series. This results in stepwise cooling at the heat source by the individual evaporators and stepwise heating at the heat sink by the condensers. Furthermore, the flow directions of the source and sink were chosen according to the counterflow principle, so that the DHHP with the highest heat source temperature results in the highest heat sink temperature. Thus, the DHHP with the lowest heat source temperature also has the lowest heat sink temperature. For the individual DHHPs, this results in a significantly lower temperature lift compared to the total temperature difference between the source and sink outlets. This results in high system efficiency even at full load. At full load, very low source temperatures (up to 5 °C) are achieved at the outlet, while in partial load operation, values of up to 30 °C are possible, resulting in even higher efficiency. High sink temperatures (up to 75 °C) can be reached at the outlet of the DHHP.

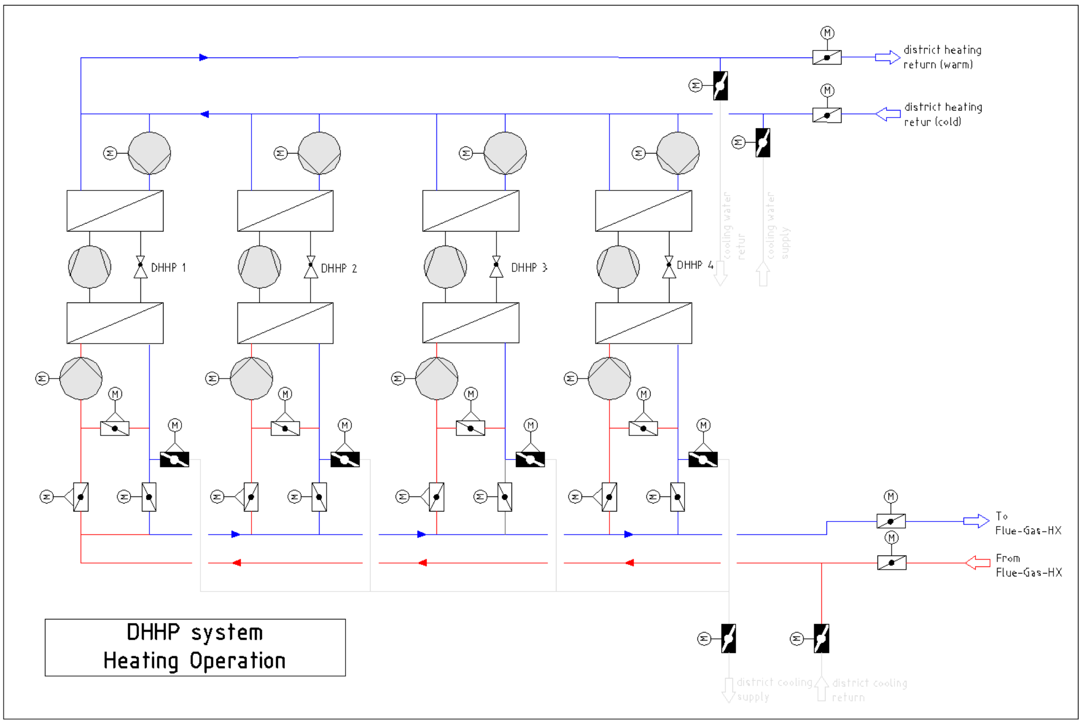

Figure 2. Simplified process flow diagram – DHHP system at heating operation

In the RHKW, heat is extracted from the flue gas in the form of a flue gas scrubber. The scrubber is connected and cooled via a heat exchanger to the heat source of the DHHP-system. Depending on the amount of removed heat, the flue gases are cooled until condensation occurs because of the flue gas temperature falling below the water dew point. The DHHP system was designed so that the source outlet temperature at full load and thus the scrubber inlet temperature, considering the temperature difference of the heat exchangers, is approximately 8 °C. This ensures maximum utilization of the flue gas waste heat.

Heat transfer from the BIOM flue gas is achieved by means of a flue gas condensation heat exchanger that is integrated directly into the flue gas flow. Here, thanks to the very low source outlet temperatures of up to 5 °C selected for the DHHP system, the waste heat from the flue gas can also be utilized optimally.

2.2. DHHP-system in cooling operation

The DHHP can be used as chillers via a hydraulic switchover. The DHHP heat source is now used to provide cooling for the future DCN. The waste heat extracted in this process is transferred to the environment at the heat sink using cooling water supplied via the Danube or cooling towers. It is important to note that the DHHP already reach a source outlet temperature of approx. 5 °C at full load in heating mode and are therefore suitable for cooling mode, which requires a source outlet temperature of approx. 5.5 °C.

Fig. 3 shows that the condensers of the DHHPs are connected in series in both cooling and heating mode (also see Fig. 2). This has major advantages in terms of investment costs, as only four additional shut-off valves are required on the heat sink to switch from heating to cooling operation, as further the same pipes and installations can be used in both modes. Due to the significantly reduced overall temperature spread on the source side from approx. 50 K in heating operation to 9 K in cooling operation, it is necessary to connect the evaporators (heat source) in parallel. This is achieved by means of an additional control valve and a shut-off valve (including associated piping) per DHHP. The DC return is distributed to the DHHPs via the same pipes as in heating mode, then cooled and supplied to the DCN via the planned control valves and piping.

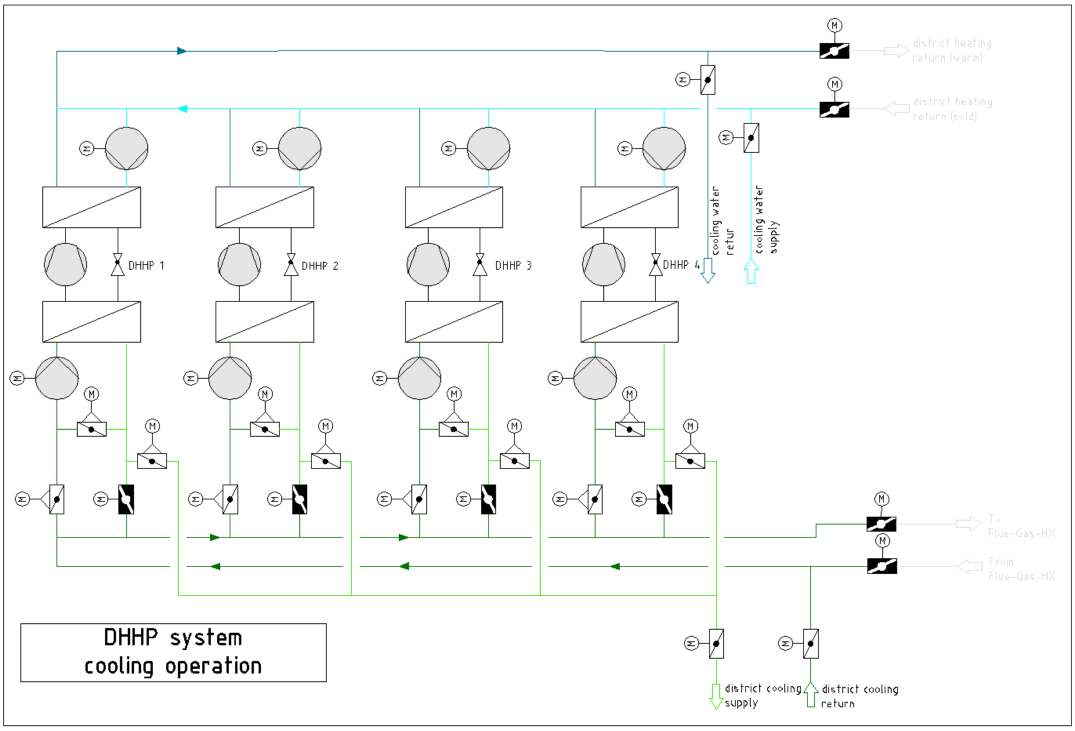

Figure 3. Simplified process flow diagram – DHHP system at cooling operation

2.3. Description DHHP

The DHHP-system is to be installed with four identical DHHPs from Johnson Controls, type "HP CYK K7 U2 68 62 ze". The pressure is increased in two stages using turbo compressors. Some relevant data are listed below:

Refrigerant: R 1234 ze

Condenser
- Min./Max. temperature –outlet: 45/72 °C
- Min./Max. temperature –inlet: 50/80 °C
- Min./Max. mass flow: 970/2.270 t/h

Evaporator
- Min./Max. temperature –outlet: 3/50 °C
- Min./Max. temperature –inlet: 10/66 °C
- Min./Max. mass flow: 320/720 t/h

3. Results

3.1. DHHP-system in heating operation

In the heating capacity-temperature-diagram (Q-T-diagram, Fig. 4) of the heating mode of the DHHP-system, the temperature trend over the heating or cooling capacity is shown. The red line represents the temperature curve of the four condensers connected in series and the blue line represents that of the evaporators connected in series. The yellow dots divide the temperature curves of the individual condensers (C1 to C4) and evaporators (E1 to E4) of every of the four DHHPs. A source outlet temperature of 5 °C with a mass flow of 535 t/h and a sink inlet temperature of approx. 54.7 °C with a mass flow of 3,044 t/h were selected as the basis for the Q-T-diagram. This represents a realistic full-load case for the DHHP system in heating operation. The source capacity was calculated based on measurement data from the flue gas of the BIOM and the RHKW. the assumed source outlet temperature of 5 °C and der mass flow of 535 t/h.

As mentioned above, it was found that, due to the serial arrangement of the DHHPs in counterflow, the temperature lift of the individual machines (from 27.4 K for DHHP1 to 51.8 K for DHHP4) is significantly lower than the total temperature lift (60.2 K) of the system. Based on the DHHP manufacturer's specifications, a total COP of approximately 4.4 can be achieved with the DHHP system at full load. The COPs of the individual DHHPs range from 5.6 (DHHP1) to 3.5 (DHHP4).

In comparison, using the same assumptions with four DHHPs connected in parallel at full load, only a total COP or individual COP of 2.8 can be achieved, as each individual heat pump must overcome a temperature lift of 60.2 K.

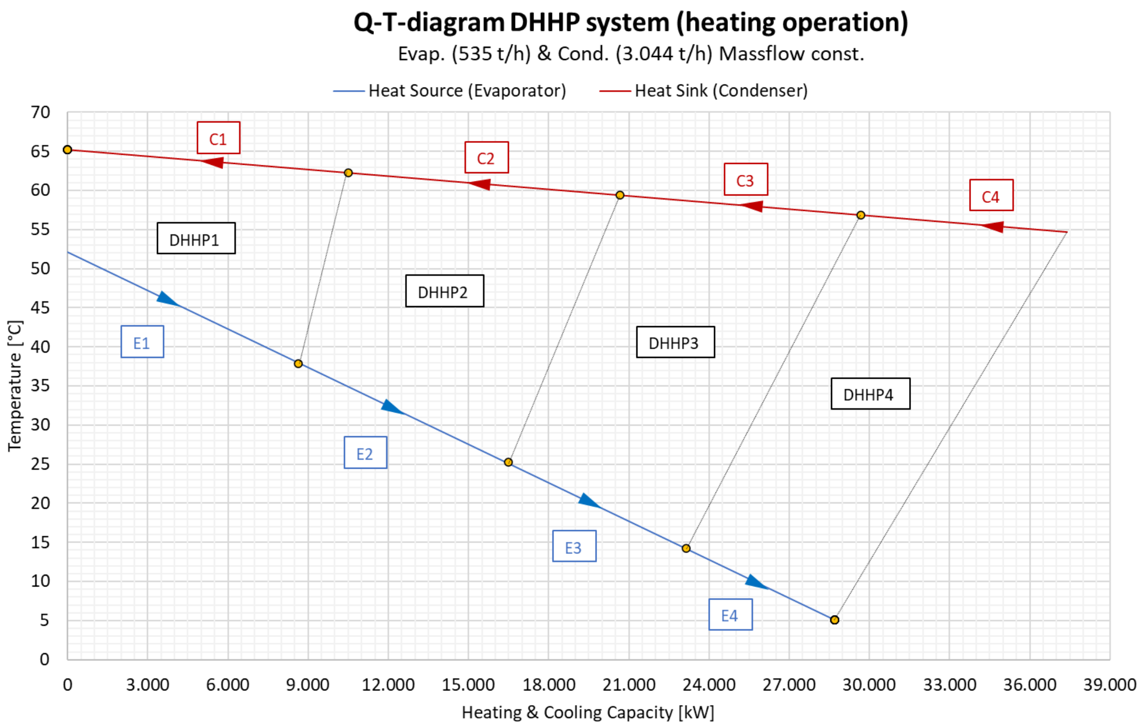

Figure 4. Q-T-diagram of DHHP system in heating operation

It should also be noted that a full-load case was presented and calculated here. In partial load cases, the source outlet temperature would rise significantly, and the sink outlet temperature would drop slightly. Both factors lead to a reduction in the overall temperature lift of the DHHP-system, which further increases the achievable overall COP. Assuming a realistic annual load profile, a SCOP of greater than 6 can be achieved.

3.2. DHHP-system in cooling operation

With the previously described hydraulic switch from heating operation to cooling operation, the DHHPs can be used as chillers for the DCN in summer (or at times of low DH demand) at low investment costs. This double use results in a supporting cooling capacity of at least 20 MW during peak cooling demand in summer to supply the DCN. This has the great advantage of accelerating the amortization of the DHHPs due to the significantly increased operating times and, on the other hand, that less cooling capacity needs to be installed by chillers in the planned district cooling center in the future. This is mainly because the peak demand of the DCN occurs when there is no or only low DH demand. Further information on the DC can be found in [7].

4. Summary and Discussion

- With the help of the flue gas scrubber or the flue gas condensation heat exchanger, the waste heat from the flue gas of the BIOM and the RHKW is made usable via the DHHP system. This results in a very high utilization of the energy sources used and thus a very high level of efficiency.
- The construction of the DHHPs increases the security of supply for the Linz DHN and furthermore enables the integration of new consumers.
- By connecting the DHHPs in series using the counterflow principle, a significant reduction in the temperature lift of the individual DHHPs can be achieved. This has a direct positive effect on the overall COP of the DHHP system. Over an entire year, a theoretical SCOP of greater than 6 can be reached, which leads to a significant reduction in the electrical energy requirement of the DHHPs for providing DH.
- With the hydraulic switching, it is possible to use the DHHPs as chillers in summer (or when the DH demand is low). This increases operating times and thus accelerates amortization. In addition, this means that less cooling capacity needs to be installed to supply the DCN in the DC center.

5. Outlook

The concept of the DHHP-system is intended to increase the overall output of the "Energiepark Linz-Mitte" through the climate-neutral use of available heat sources. The DHHP system, which is scheduled to start operation in 2028, is a milestone in the decarbonization of the DH supply of the city of Linz. The dual use of the DHHP-system as heat pumps and chillers optimizes operating times and amortization and reduces the construction costs of the DC center.

Another project that has already been launched with ENERTEC as general planner focuses on the construction of a DC center. The basic cooling demand is to be covered by chillers that feed waste heat into the DH system. In addition, further chillers and a cold thermal energy storage are to be installed to cover peak loads and optimize the DCN.

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- **„Wärmewandler"** (General planner: „ARGE Wärmewandler" including „ENERTEC Naftz & Partner GmbH & Co KG". Operator: „LINZ AG")
- **„Fernkälteerzeugung Energiepark Linz-Mitte"** (General planner: „ENERTEC Naftz & Partner GmbH & Co KG". Operator: „LINZ AG")
- **„Fernkältenetz Linz"** (LINZ AG)

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