# HIGH TEMPERATURE SEWAGE HEAT PUMP AS A WAY TO INCREASE SHARE OF RENEWABLES IN DISTRICT HEATING – CASE STUDY

Piotr Krawczyk[1]*, Aleksandra Dzido[1]

[1]Warsaw University of Technology, Institute of Heat Engineering, Warsaw, Poland

*Corresponding Author: piotr.krawczyk@pw.edu.pl

## ABSTRACT

Green energy transformation contributes to increase in renewables not only in electricity production but also in district heating applications. One of the green energy heat source can be a high temperature heat pump, using sewage waste heat as a lower heat source. As the device works as connected to the heating network, its operation depends on several external factors. The crucial one is outside temperature, determining sewage temperature and desired heating water temperature. Among other working conditions cooperation with the others existing sources in the district/city should be enumerated.
The paper covers case study of potential sewage heat pump installation in the 75 000 citizens city in Central Eastern Europe. Current energy policy forces green energy transformation in district heating sector and sludge can be treated as interesting waste heat source, which can be used with the help of heat pumps. Research covers analysis of the heat pump cooperation potential with the existing district heating system, aimed at renewable heat sources share growth. The heat pump calculations were carried out with the help of the mathematical model implemented in Aspen Hysys numerical software. Work contributes to the green district heating development by assessment of waste heat pump cooperation with the existing heat sources.

**Keywords:** district heating, heat pump, renewable heat sources, green energy transformation

## 1 INTRODUCTION

The European Union's (EU) climate and energy package focuses on reducing greenhouse gas emissions, increasing the use of renewable energy sources, and improving energy efficiency. The basic goals in this area were first defined in the 2020 climate and energy package, and then extended to 2030. Ultimately, they are intended to transform the EU economy into a climate-neutral one by 2050.
To achieve these goals, a legislative package called "Fit for 55" has been prepared, in which the European Commission reviews EU instruments and establishes new initiatives to align EU policy with climate targets set by the Council and the European Parliament.
In the field of systemic heating, legislative changes mainly concern the Emission Trading System (ETS), and Energy Efficiency Directive (EED). Particularly important in this regard is the change in the definition of an efficient heating system presented in the EED directive. According to the new regulations, from 2028 onwards, no heating system will be considered efficient if part of the heat supplied to customers is not generated from renewable sources and/or waste heat. The share of such heat is to gradually increase, reaching 100% by 2050 (Lund et al., 2021).
These changes pose challenges for heat suppliers and their producers, who must take action to meet the criteria for an efficient heating system. When considering available heat sources in centralized heating systems, it is necessary to take into account the new legal regulations. Among the potential heat sources, we can mention (Sorknæs et al., 2020):

- Centralized photovoltaic (PV) installations,
- Solar collectors, including those cooperating with heat storage systems,
- Biogas plant systems,
- Blocks powered by solid biomass,
- Use of waste heat, including low-temperature waste heat using heat pumps,
- Use of "green" gases.


https://doi.org/10.52202/077185-0205

Currently, only some technologies have the technical potential to become significant heat sources for centralized heating systems in medium and large cities.
Among them, we can enumerate solid biomass boilers, including cogeneration blocks, and large-scale heat pumps (Levihn, 2017). Additionally, the use of treated wastewater as a low heat source for heat pumps can bring many benefits, such as predictability and stability of the flow, high temperature of the medium, and high energy density .
In many countries, i.e. in Scandinavia high temperature sewage heat pumps are commonly used for district heating heat supply. The example studies of heat pumps potential in Denmark can be found at (Johansen & Werner, 2022), (Østergaard et al., 2022). Researches covering case-study of Stockholm (Sweden) are presented in (Levihn, 2017).The aim of this study is to analyse the potential of such a source implementation in polish conditions, as such a solution on this scale is not popular in the country, following the road map for district heating development in Europe (Neves & Mathiesen, 2018).
Analysis cover selected aspects of sewage heat pump implementation and operation in conditions of a medium-sized city (approximately 75,000 inhabitants) located in central Poland. The peak power demand for the local district heating system is 110 MW, while the summer demand for hot water preparation purposes is 10 MW. The total annual heat production for the system is approximately 1000 TJ. So far the company operates four coal boilers with a capacity of approximately 30 MW each and one gas boiler with a capacity of 10 MW.

# 2 METHODS

## 2.1 Treated wastewater parameters analysis

From the perspective of utilizing low-temperature heat contained in treated wastewater, important operational parameters of each wastewater treatment plant are (Hepbasli et al., 2014):

- Flow rate of treated wastewater;
- Temperature of treated wastewater;
- Variability of these parameters over time.

Based on measurement results, it is possible to analyse the above-mentioned parameters.

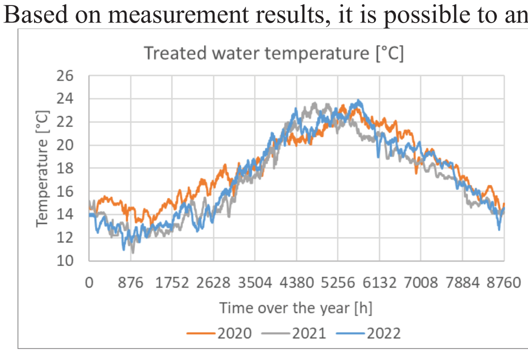


**Fig. 1. Treated water temperature over the year.**

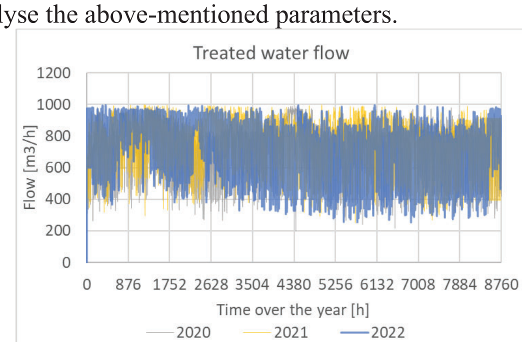


**Fig. 2. Treated water flow over the year.**

The presented data (Fig. 1-2) indicate that:

- The average hourly flow rate of wastewater passing through the pumping station is approximately 750 $m^3/h$;
- There is significant daily variability in wastewater flow, ranging from about 300 to even 1000 $m^3/h$;
- The temperature of wastewater varies from 12-14°C in the winter to approximately 21-23°C in the summer.

Based on the above operational data, the potential of waste heat flow available for utilization in the heat pump system at the given location was determined. For the purpose of analysis, the minimum wastewater temperature at the outlet of the heat pump was assumed to be 8°C. The potential heat recovery flow rate over the course of the year is shown on a chronological chart (Fig. 3) and structured chart (Fig. 4)


https://doi.org/10.52202/077185-0205

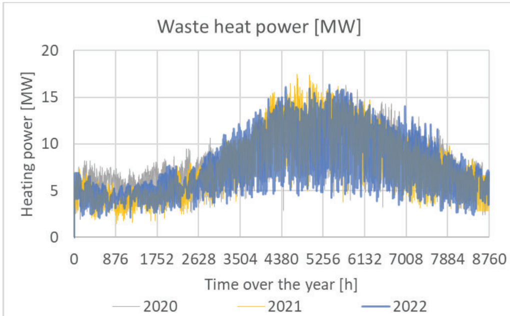


**Fig. 3. The flow of waste heat contained in wastewater on the chronological order.**

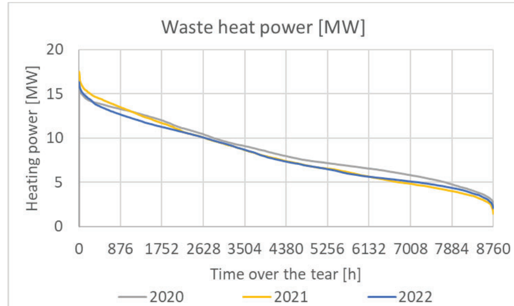


**Fig. 4. The flow of waste heat contained in wastewater on the ordered chart.**

## 2.2 Balance Analysis of the HP System

In real-world conditions, heat pumps integrated into the district heating system operate under constantly changing conditions, such as flow and temperature of wastewater, as well as flow and temperature of network water. To assess the operational parameters of the heat pump installation under these considered conditions, balance calculations were carried out for off-design conditions of the heat pump system. Aspen Hysys software was used for this process. The modelled system was a two-stage heat pump (S. Jiang et al., 2015) (Fig. 5), based on centrifugal compressors (J. Jiang et al., 2022) with R1234ze(E) (Drofenik et al., 2022) as the working fluid.

The design point of the heat pump was selected based on the maximum assumed temperature difference between the heated network water at the condenser outlet of the heat pump and the cooled wastewater at the evaporator outlet of the heat pump. Such conditions occur during the winter period when the wastewater temperature is lowest and the expected network water temperature, according to the regulatory table, is highest (Dongellini et al., 2021). The calculations conducted aimed to determine the basic operating parameters of the heat pumps under selected conditions defined by the outdoor air temperature.

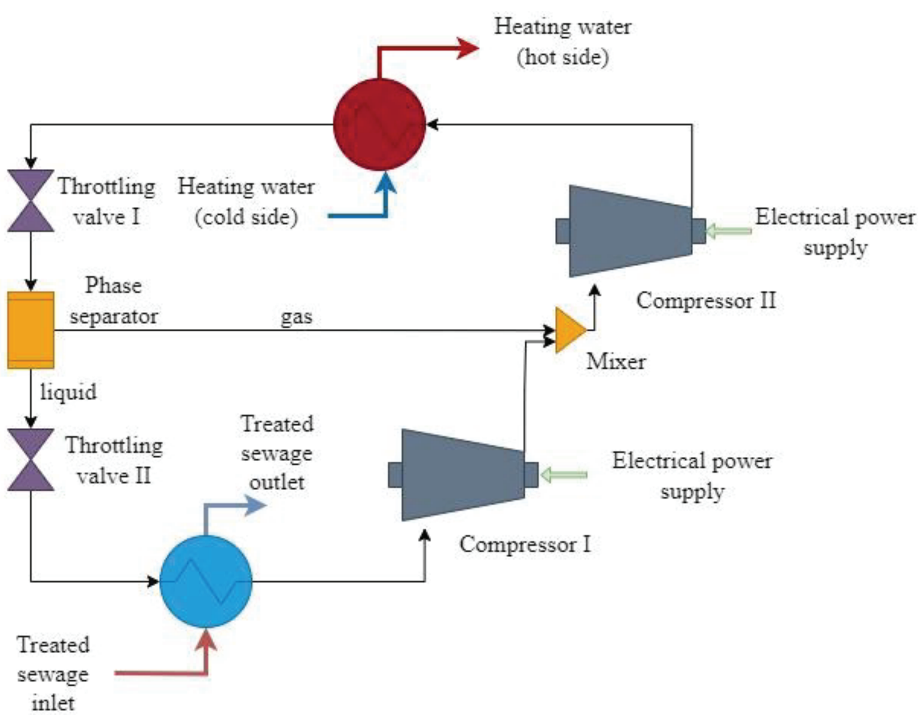


**Fig. 5. Heat pump unit scheme**.


https://doi.org/10.52202/077185-0205

### 2.3 Balance Analysis of the District Heating System

The district heating system load by hours is shown in the Fig. 6. This demand should be covered by the existing sources and heat pump.

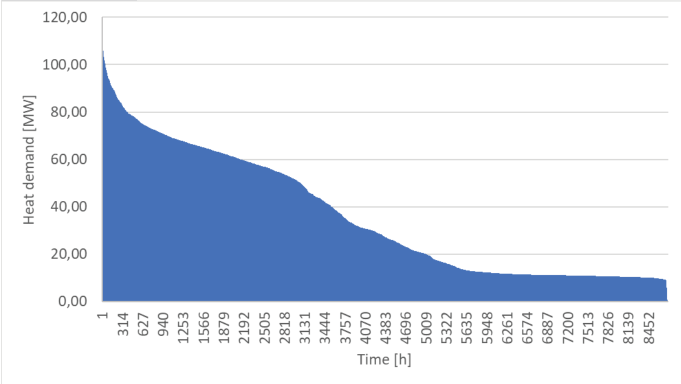


**Fig. 6. Ordered chart of thermal power for the analysed city.**

The developed algorithms for dividing the load among individual generating sources were based on the following assumptions:

- For each variant, the sequence of operation of individual generating sources was determined (from basic to peak sources).
- When developing the load distribution algorithm for each generating source, its minimum power was taken into account.

In the computational process for each generating source, a parameter defining the capacity factor was used. The capacity factor is the ratio of the actual power output to the nominal power of the unit. Capacity factors for each source are calculated hourly throughout the analysed period, i.e., one year. Subsequent energy sources from base to peak are activated to meet the current heat demand of the system. For each hour, the load of individual sources,the thermal and electrical efficiency as well as fuel consumption characteristic of this load are determined. Regarding the modelled heat pump system, the change in system power at different times of the year was taken into account.

## 3 RESULTS

In this chapter, an energy balance of the heat pump system dedicated to the considered location was conducted. For analysis selected, discretised cooperating conditions of district heating system were selected. For the calculations, the following assumptions were made:

- Average flow rate of wastewater according to measurement data: 755 m3/h;
- Wastewater temperature after cooling under design conditions: 7°C;
- Heat pump power under design conditions: 7 MW.

As a result of the performed calculations for each operating point, the following parameters were determined:

- Thermal power of the heat pump installation;
- Electrical power required to supply the heat pump system;
- Flow rate of network water passing through the pump;
- Thermal power extracted from the lower heat source (treated wastewater);
- Wastewater temperature after cooling;
- Coefficient of Performance (COP) determining the system's efficiency.

The results of the calculations at each balancing point are summarized in the Tab. 1 below.



https://doi.org/10.52202/077185-0205

**Table. 1. Operational parameters of the possible heat pump installation built at the outflow from the wastewater treatment plant for the analysed city - calculation results.**

| No. | Outside temperature [°C] | District heating feed water temperature [°C] | District heating return water temperature [°C] | Treated water inlet temperature[°C] | Treated water outlet temperature [°C] | HP thermal power [MW] | Low source heating power [MW] | District heating water flow [m³/h] | HP electrical power [MW] | Peak source heating power [MW] | COP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -20 | 119 | 55 | 12 | 7.00 | 7.00 | 4.39 | 150.43 | 2.61 | 4.20 | 2.68 |
| 2 | -8.5 | 95 | 43.5 | 13.28 | 8.08 | 7.24 | 4.56 | 120.74 | 2.67 | 0 | 2.71 |
| 3 | -3 | 84 | 39 | 14.40 | 8.78 | 7.39 | 4.94 | 141.10 | 2.45 | 0 | 3.01 |
| 4 | 3 | 73 | 36 | 15.93 | 9.86 | 7.63 | 5.33 | 177.10 | 2.29 | 0 | 3.32 |
| 5 | 8 | 68 | 35 | 17.45 | 11.05 | 7.89 | 5.62 | 205.32 | 2.26 | 0 | 3.48 |
| 6 | 15 | 67 | 35 | 19.95 | 13.12 | 8.34 | 6.00 | 223.81 | 2.34 | 0 | 3.56 |

The selected results of the computational analyses of the subject system are presented graphically in the following charts.

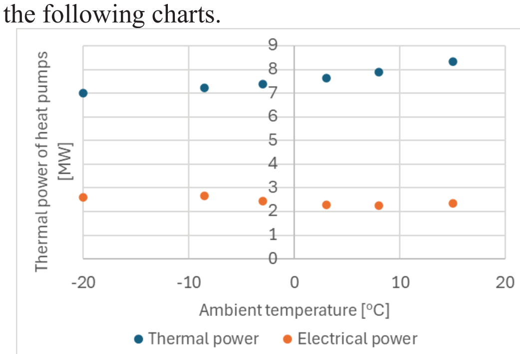


**Fig. 7. The thermal and electrical power of the heat pump system as a function of ambient temperature - calculation results.**

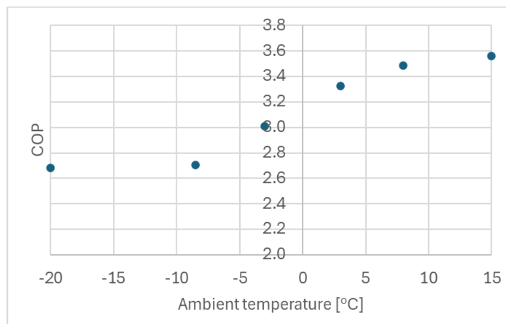


**Fig. 8. The coefficient of performance (COP) of the heat pump system as a function of ambient temperature - calculation results.**

The obtained calculation results allow the following conclusions to be drawn:

- The analysed heat pump system exhibits variable thermal power potential throughout the year, ranging from 7 MW in winter conditions to approximately 8.4 MW in summer conditions.
- The coefficient of performance (COP) of the heat pump varies for each balancing point, ranging from about 2.7 for winter conditions to around 3.5 for summer conditions, which remains in agreement with literature data for such a class of devices (Friedel, 2019).
- The electrical power requirement to drive the heat pump system varies depending on current conditions, ranging from 2.25 MW to approximately 2.67 MW.
- In case of the desire to ensure the operation of the heat pump system in accordance with the regulatory table for ambient temperatures below -8.5°C, external heating of network water should be applied. In extreme cases, such as at an ambient temperature of -20°C and the heat pumps operating at full capacity, the power of such an additional heat source would need to be approximately 4 MW.

Based on the determined operational characteristics of the heat pump system under the considered conditions, an energy balance calculation of the district heating system was conducted to determine the possibility of integrating the new heat source in the form of heat pumps with existing sources utilizing fossil fuels. In the deliberations, it was assumed that the heat pump source would operate at the base load of the system. Additionally, it was assumed that due to limitations regarding the maximum


https://doi.org/10.52202/077185-0205

temperature of heat produced in the heat pump system, which is 95°C, the source would not operate during the lowest external temperatures, i.e., below -8.5°C (Schlosser et al., 2020). The obtained results of the district heating system operation after the introduction of the heat pump source are presented in the charts below (Fig. 9-10).

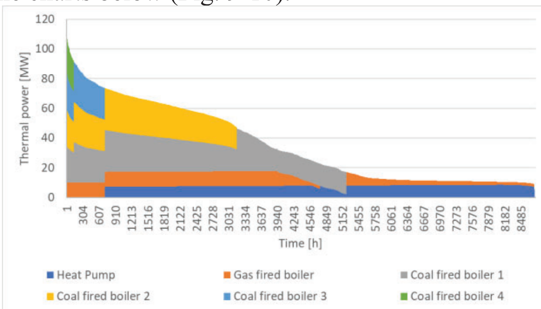


**Fig. 9. Ordered chart of heat production in the considered district heating system after the introduction of the heat pump source.**

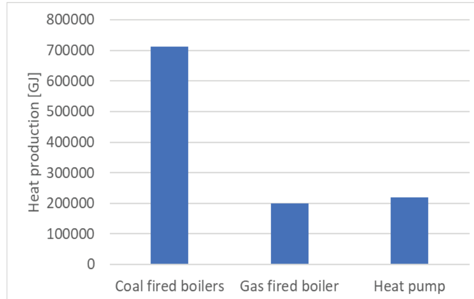


**Fig. 10. Distribution of heat production among sources.**

## 4 OUTCOMES

The obtained results lead to the following conclusions:

- There is a significant potential for waste heat contained in treated wastewater flowing from sewage treatment plants, which should be utilized in modern district heating systems. This potential varies throughout the year. For the analysed city with a population of approximately 75,000 inhabitants, this potential ranges from about 4 MW in winter to up to 12 MW in summer.
- Consequently, there is also a significant potential for the production of useful heat using heat pumps. This potential also varies throughout the year. For the analysed city, these changes range from about 3 MW in winter to about 15 MW in summer (Fig. 3).
- Under the considered conditions, from a technical standpoint, it seems rational to install a heat pump system with a thermal power ranging from about 7 MW to about 8.4 MW, and electrical power from 2.25 MW to about 2.67 MW, depending on the season.
- Utilizing waste heat from wastewater for the preparation of useful heat for the district heating system can contribute significantly to the reduction of fossil fuel consumption and the associated $CO_2$ emissions. In the analysed case, the heat pump system will be responsible for generating almost 20% of the useful heat delivered to consumers Assuming that the electricity to drive the heat pumps will come from renewable energy sources, this will result in an adequate, i.e. 20%, reduction in greenhouse gas emissions from the analyzed source.

## REFERENCES

Dongellini, M., Naldi, C., & Morini, G. L. (2021). Influence of sizing strategy and control rules on the energy saving potential of heat pump hybrid systems in a residential building. *Energy Conversion and Management*, *235*(March), 114022. https://doi.org/10.1016/j.enconman.2021.114022

Drofenik, J., Urbancl, D., & Goričanec, D. (2022). Comparison of the New Refrigerant R1336mzz(E) with R1234ze(E) as an Alternative to R134a for Use in Heat Pumps. *Processes*, *10*(2). https://doi.org/10.3390/pr10020218

Friedel, P. (2019). *Technology Collaboration Programme on Heat Pumping Technologies ( HPT TCP ) Annex 45 Hybrid Heat Pumps* (Issue October). https://heatpumpingtechnologies.org/publications/hybrid-heat-pumps-final-report/

Hepbasli, A., Biyik, E., Ekren, O., Gunerhan, H., & Araz, M. (2014). A key review of wastewater source heat pump (WWSHP) systems. *Energy Conversion and Management*, *88*, 700–722. https://doi.org/10.1016/j.enconman.2014.08.065

Jiang, J., Hu, B., Wang, R. Z., Deng, N., Cao, F., & Wang, C. C. (2022). A review and perspective on



https://doi.org/10.52202/077185-0205

industry high-temperature heat pumps. *Renewable and Sustainable Energy Reviews*, *161*(January), 112106. https://doi.org/10.1016/j.rser.2022.112106
Jiang, S., Wang, S., Jin, X., & Zhang, T. (2015). A general model for two-stage vapor compression heat pump systems. *International Journal of Refrigeration*, *51*, 88–102. https://doi.org/10.1016/j.ijrefrig.2014.12.005
Johansen, K., & Werner, S. (2022). Something is sustainable in the state of Denmark: A review of the Danish district heating sector. *Renewable and Sustainable Energy Reviews*, *158*(April 2021), 112117. https://doi.org/10.1016/j.rser.2022.112117
Levihn, F. (2017). CHP and heat pumps to balance renewable power production: Lessons from the district heating network in Stockholm. *Energy*, *137*, 670–678. https://doi.org/10.1016/j.energy.2017.01.118
Lund, H., Østergaard, P. A., Nielsen, T. B., Werner, S., Thorsen, J. E., Gudmundsson, O., Arabkoohsar, A., & Mathiesen, B. V. (2021). Perspectives on fourth and fifth generation district heating. *Energy*, *227*, 120520. https://doi.org/10.1016/j.energy.2021.120520
Neves, J., & Mathiesen, B. V. (2018). *Heat Roadmap Europe : Potentials for Large-Scale Heat Pumps in District Heating*.
Østergaard, D. S., Smith, K. M., Tunzi, M., & Svendsen, S. (2022). Low-temperature operation of heating systems to enable 4th generation district heating: A review. *Energy*, *248*, 123529. https://doi.org/10.1016/j.energy.2022.123529
Schlosser, F., Jesper, M., Vogelsang, J., Walmsley, T. G., Arpagaus, C., & Hesselbach, J. (2020). Large-scale heat pumps: Applications, performance, economic feasibility and industrial integration. *Renewable and Sustainable Energy Reviews*, *133*(March), 110219. https://doi.org/10.1016/j.rser.2020.110219
Sorknæs, P., Østergaard, P. A., Thellufsen, J. Z., Lund, H., Nielsen, S., Djørup, S., & Sperling, K. (2020). The benefits of 4th generation district heating in a 100% renewable energy system. *Energy*, *213*, 119030. https://doi.org/10.1016/j.energy.2020.119030


https://doi.org/10.52202/077185-0205