SYSTEM-LEVEL IMPACTS OF MEDIUM-TEMPERATURE HEAT PUMP INTEGRATION IN DISTRICT HEATING: A DYNAMIC SIMULATION STUDY

Summary

This extended abstract presents a simulation study on the system-level impacts of connecting a medium-temperature heat pump (HP) to a district heating (DH) network. The HP supplies part of the network at medium temperature, while the rest of the network is supplied in combination with two additional plants installed in series, who provide the required additional temperature lift. Using a detailed 15-minute dynamic network model of the planned backbone network topology and consumer clusters, a benchmark return-to-supply (RtS) configuration (all plants connected in parallel to the supply line) is compared with a medium-temperature connection of the HP. KPIs include HP seasonal performance factor (SPF), total heat production, total network heat losses, pumping energy, and operating costs. Preliminary annual results using measured 15-min HP source temperatures and assumed consumer return-temperature scenarios show that medium-temperature HP connection can improve the SPF and reduce operating costs. The authors assume that benefits depend strongly on return temperature, HP source temperature and control/dispatch assumptions. To evaluate influences on KPIs, sensitivity analyses on several simulation inputs are outlined.

Keywords: district heating networks, heat pumps, ammonia heat pumps for district heating

Field of application for the findings: district heating operation

Addressed audience: researchers

1. Introduction

Heat pumps are increasingly deployed in district heating (DH) systems as a decarbonization measure. Recent literature describes multiple integration approaches: medium–high-temperature HPs in fourth-generation DH (4GDH) topologies (Sayegh et al. (2018)), booster HPs for domestic hot water in fifth-generation DH (5GDH) (Zhu et al. (2023)), and hybrid configurations combining decentralized HPs with other heat sources in the DH network (Soleimani et al. (2025)). Studies indicate potential operational cost savings and CO_2 reductions from DH–HP integration which differ depending on HP source and sink connection (Ommen et al. 2014; Barco-Burgos et al. (2022)).

1.1 Research gap, novelty, and scope

Potential benefit of low-temperature HPs is particularly notable when the HP can use relatively cool sinks, like in return-to-return (RtR) connection, consisting in lifting the return temperature up to an intermediate temperature, which tends to increase COP/SPF relative to lifting at a higher sink temperature. Prior numerical examples (Ommen et al. 2014; Barco-Burgos et al. (2022)) report high system performance for RtR layouts, yet they commonly place boundary conditions at the HP and not at the network scale. The magnitude and even the sign of RtR or medium-temperature preheating benefits cannot be reliably inferred from component-level SPF alone, as they emerge from network-level interactions. In fact, the RtR connection of a HP unit affects the operation of downstream heat plants whose efficiencies depend on supply and return temperatures. This study explicitly models the hydraulic connection of a medium-temperature HP and two co-located downstream plants (a biomass CHP and an electric power to heat (P2H) unit) within a district-heating network. Preliminary results are presented in this abstract; sensitivity analyses on key operating temperatures (supply/return) will be reported in the full paper.

2. Methods

2.1 Network model

The case study uses the planned backbone topology from an ongoing feasibility study with four consumer clusters, backbone pipe diameters and lengths per planning documents, and a yearly energy density ≈ 1.5 MWh/m. Pipe insulation and friction factors follow manufacturer datasheets; feeder pipes' diameters to consumers clusters are sized to meet peak velocity constraints. Annual simulation runs are performed with the district heating simulation tool Leanheat Network (Danfoss, Leanheat Network) at 15-minute timesteps.

2.2 Heat demand and consumers grouping

Annual space-heating (SH) and domestic-hot-water (DHW) demands per cluster are taken from the feasibility study. SH consumption profiles are derived based on room to outdoor temperature difference, and considering in a simplified way the effect of building thermal inertia and solar gains. DHW consumption is modeled following standard profiles with randomized household start times for simultaneity. Clusters aggregate consumers and are grouped into classes (single-family, multi-family, commercial buildings) to represent heterogeneous heating demand and return-temperature behavior in sensitivity runs.

2.3 Simulation scenarios and hydraulics

"Benchmark": all three plants are connected in parallel supplying a uniform 85 °C supply temperature.

"Study case" (Figure 1): the HP is installed upstream at a different node and primarily supplies Cluster 1 ($T_{sup,HP} = 75\,°C$) while optionally feeding a controlled flow to clusters 2 to 4 via an intermediate pipe.

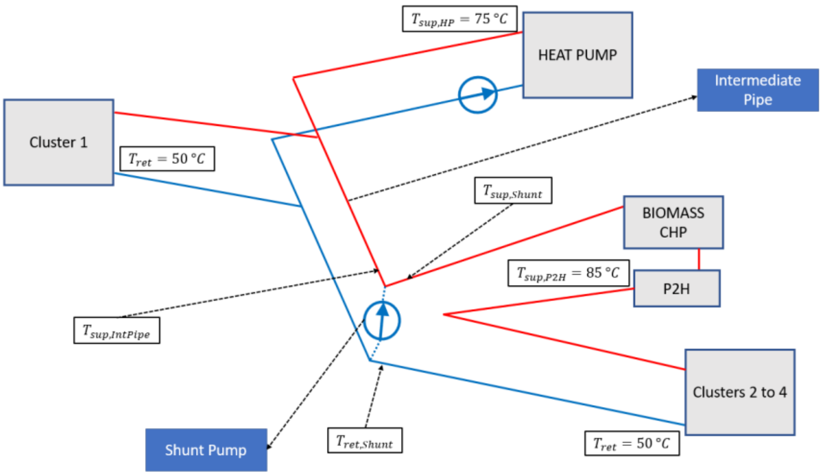

Fig. 1: Conceptual hydraulic scheme used for the "Study-case"

Biomass CHP and P2H are co-located at a fixed downstream node; when the HP's flow to the intermediate pipe is insufficient a shunt pump provides the required mass flow and biomass CHP and P2H perform series temperature-lifting up to the 85 °C setpoint for the rest of the network. If total network demand falls below biomass CHP nominal capacity, the HP is switched off and biomass CHP unit supplies the network alone in return-to-supply (RtS) configuration.

2.4 Temperatures, heating plants and control

Heating plants supply setpoints are: HP unit: 75 °C; Biomass CHP and P2H unit: 85 °C. The baseline return temperature for all clusters is equal to 50 °C; sensitivity analyses on cluster/time-varying return temperatures are planned.

Plants and merit order: (1) Biomass CHP — 1,000 kW constant output; (2) Sewage-source HP — nominal power: 5,000 kW (measured 15-min source inlet temps 8–22 °C); (3) P2H electric boiler — nominal power: 5,000 kW. Thermal power control method: constant-outlet temperature combined with variable-flow (CT-VF). The HP flow (and thermal power) is controlled so that the biomass CHP, is reaching the setpoint 85 °C while supplying constantly 1000 kW to the network.

3. Preliminary Results

Figure 2 shows three time-dependent plots (16-21 Jan) illustrating the “study-case” hydraulics and control. Top: thermal output of each plant (biomass CHP, HP, P2H). Middle (Mass flow rates): mass flow through the intermediate pipe (black) and the shunt pump (blue), and the mass flow to clusters 2-4 (pink), i.e. the sum of intermediate pipe and shunt pump flows. Bottom (Temperature Levels): return temperature at the shunt pump (blue), supply temperature in the intermediate pipe (cyan), supply temperature downstream the shunt (resulting from the mixing), and the supply temperature downstream the P2H (= 85 °C) (red).

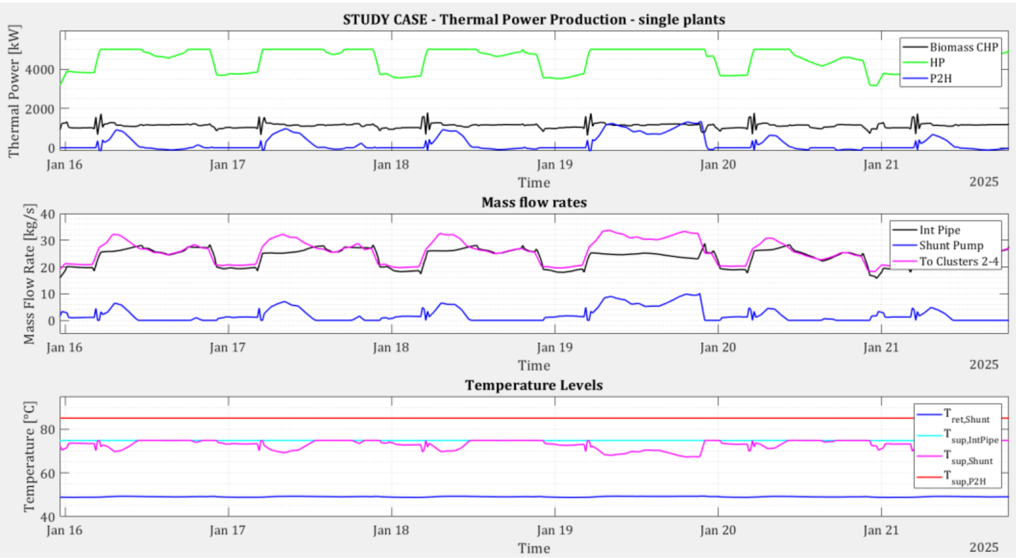

Fig. 2: Study-case time series (16–21 Jan): plant outputs (top), mass flow rates (middle), and temperatures (bottom), showing HP feeding and shunt/series lifting dynamics.

The oscillations in the thermal power produced by biomass CHP are due to numerical fluctuations in the tool. A null flow rate in the shunt pump indicates that the HP is providing enough flow to the network, which reaches the rest of the network through the intermediate pipe. During peak demand, when P2H is active, the shunt pump is providing the additional flow required by clusters 2-4 by mixing the flow from the return line with the flow in the supply line of the intermediate pipe.

The results show an increase in HP seasonal performance between the “benchmark” and the “study-case”: January SPF rises from 2.83 to 3.17 (+12%) and annual SPF from 2.89 to 3.26 (+13%). The “study case” compared to the “benchmark” yields slightly lower total annual heat production due to reduced network heat losses (3,742 vs. 3,799 MWh), while annual pump energy increases (73.3 vs. 85.2 MWh). Lower losses are due to a lower supply temperature (75 °C vs. 85 °C) for the part of the network supplied by the HP; higher pump energy is caused by the reduced temperature difference on the HP-supplied branch to Cluster 1 and the shunt pump node (75/50 °C → 25 K vs. 85/50 °C→ 35 K), which raises mass flow for the same heat delivery.

4. Discussion

Preliminary results indicate that the proposed HP connection raises HP SPF by operating parts of the network at lower sink/supply temperatures, but system-level gains are moderated by higher pumping energy and the need for series temperature-lifting upstream for the rest of the network. Series lifting by the biomass CHP is acceptable since its efficiency is largely insensitive (or only weakly sensitive) to the upstream temperature it receives, but heavy reliance on the electric P2H would erode system efficiency and may indicate that expanding HP capacity is preferable.

Limitations of this preliminary analysis include the use of a baseline constant return temperature for all clusters, the CT-VF control assumption, and COP estimation from a Carnot-based, manufacturer-calibrated map. Planned work will add cluster-level/time-varying return temperature models, compare CT-VF with variable temperature – variable flow (VT-VF) control, explicitly assess biomass CHP sensitivity to upstream temperature, and run sensitivity analyses on supply/return temperatures.

5. References

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