
In the current Danish energy system, the majority of electricity and heat is produced in combined heat and power (CHP) plants. With increasing shares of intermittent renewable power production, it becomes a challenging task to match power and heat production to its demand curves, as production capacity constraints limit the efficient operation of the CHP plants. Heat pumps (HPs) can be used to decouple such constraints, but current state of the art are not competitive all things considered. Methods to improve the high energy efficiency are required to match the politically agreed carbon emission goals. The presented study investigates the possible introduction of HPs from both a thermodynamic and a system/operation management perspective, in order to find optimal integration schemes in both current and future energy scenarios. Five generic configurations of HPs in district heating (DH) systems were identified and compared based on a thermodynamic analysis. The operational performance of the configurations were investigated at both local and system level considering different DH network temperatures, different fuels and different production technologies in the DH network. The analysis show that three configurations are particular advantageous, whereas the two remaining configurations result in system performance close to or below what may be expected from an electric heater. One of the three advantageous configurations is required to be positioned at the location of the heat demand, whereas the two remaining can be located at positions with availability of high temperature sources by utilising the DH network to distribute the heat. A large amount of operational and economic constraints limit the applicability of HPs operated with natural working fluids, which may be the only feasible choice in Danish conditions. The limitations are highly dependent on the integration of heat source and sink streams. An evaluation of feasible operating conditions was carried out considering the constraints of available refrigeration equipment and a requirement of a positive net present value of the investment. Six vapour compression heat pump (VCHP) systems were considered along with the ammonia-water hybrid absorption compression heat pump (HACHP), corresponding to an upper limit of the sink temperature of up to 150 °C. The best available technology was determined for each set of heat sink and source temperatures. The results showed that five different HP systems propose the best available technology at different parts of the complete domain. Ammonia-water HACHP and ammonia VCHP systems utilising either low or high pressure components are preferable very broad range of sink temperature and temperature lifts. With the considered economic constraints in place, the requirements in terms of sink temperatures and temperature lift are not met for many DH networks considering the configurations which heat to forward temperatures. The specific performance for two DH HP configurations were studied in detail, using the finite temperature levels of a range of common DH networks. Eight systems were examined in terms of applicability, and the systems were optimised for each operating condition using exergoeconomic theory. The HPs were compared based on cost of heat. The results show that including the practical applicability of components causes a significantly increased cost at high temperature lifts, compared to the most competitive thermodynamic cycle. At high and medium temperature lifts cycle efficiencies of 45 - 50 % of the theoretical maximum (Lorenz cycle limit) can be achieved, whereas for low temperature lifts, efficiencies as low as 36 % may be expected. Three frequently used operation optimisation methods were examined, in order to investigate their impact on operation management of energy system technologies. By focussing on the physical representation of a CHP-plant, it is clear that a simple representation allows infeasible production. Using MIP or NLP optimisation, the number of operation hours and the total production of heat from HPs are significantly increased, as the HPs may be used to shave the load patterns of CHP units in significantly constrained energy systems. A MIP energy system model was developed with focus on the detail level of features for representation of CHP and HP units. Two energy scenarios were considered, one current, which is a validated model for 2011, and a future scenario, as proposed by energy planners for 2025, where reductions in carbon emissions for heat is of major interest. The changed distribution of electricity generation technologies may suggest a reconsideration of optimum for DH network temperatures, in order to achieve low cost and minimum carbon emissions. The developed energy system model was used to investigate the changed operation. Production curves from typical CHP-plant technologies were used to represent the changed power and heat production for changed DH temperatures. The results show that both primary fuel consumption and cost can be reduced approximately 5-7 % at DH forward temperatures of 60 - 70 °C in 2025 scenario. Further reduction results in contrary tendencies as hot tap water requires increasing amounts of electricity to reach required temperatures. The results are network specific, as they represent the specific DH utility technologies and network constraints, but similar trends can be expected for other large DH networks.

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