Appendix 2:

Research contributions

The scientific research related to the EUDP project SVAF has been based on a combination of theoretical research and modelling verified by measurements and experience from the operation of the heat pump installations. In other words, the research aimed at supporting and qualifying the experimental development of the heat pump, while at the same time generalizing the results for communication to the international, scientific community as well as substantiating the results for the project partners and Danish industry for future implementations. The overall hypothesis of the research was that it is possible to develop economically and technically feasible heat pump solutions for implementation in large district heating networks.

With this focus, the work aimed at documenting the potential of heat pump installation by development of numerical tools with four targets:

1. Decision support for potential heat pump installations
2. Optimal configurations of the heat pump system for wastewater/seawater sources
3. Optimal operation of a given heat pump in varying conditions regarding heat source and heat demand
4. Optimal integration of heat pumps in the energy system including the district heating system and the power system

The work has led to publication of the software tool HPConfig which supports decision support in ammonia heat pump projects. A number of papers in international scientific journals and conferences, in national media and internally in the project have been published. A PhD thesis based on the project results is under preparation and a significant numbers of student thesis have been developed in relation to the project. The student theses have been used in the research work for investigating details not covered in the actual research.

The software tool HPConfig

HPConfig is a software developed for better decision support for heat pump customers and designers when deciding between various configurations of ammonia heat pump systems using air, brine or water as low temperature source. The model includes 13 different configurations including three systems with one heat pump, and five systems with two heat pump each for parallel or serial evaporators. All configurations cover different integrations of single-stage and two-stage heat pumps. The SVAF system is included as C6 with two two-stage heat pumps with serial evaporators and low-stage desuperheating.

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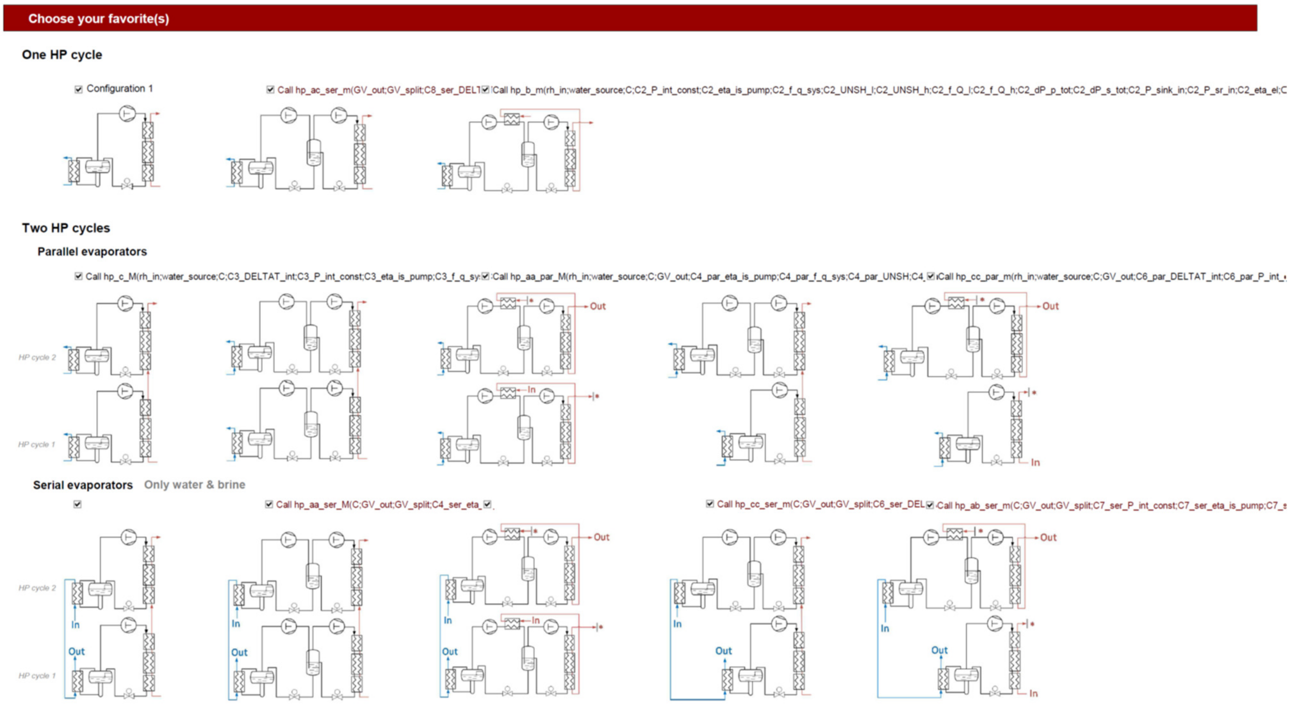

Figure 1: HPConfig system configurations

The inputs required to compare the performance of the cycles is district heating temperatures, source data, and heat pumps capacities. In addition, detailed data for heat pump component performance and economy may be added – even though default values have been carefully selected based on a comprehensive investigation of the state-of-the-art. The economic calculation includes investment, operation and maintanance as well as the energy costs.

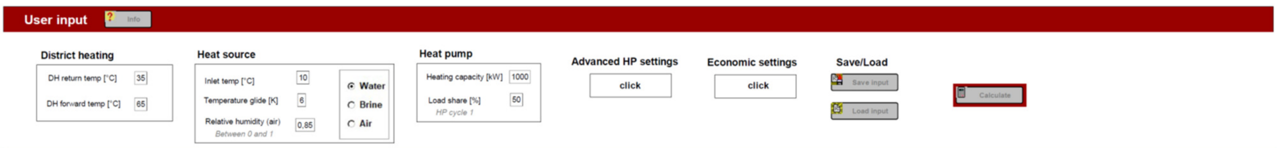

Figure 2: User inputs to HPConfig

The model is implemented EES Engineering Equations Solver. It is rather complex and the compilation becomes rather long – up to approximately 5 minutes – if all configurations are to be included in the results. If few are chosen, it is much faster.

The main results of a calculations are the COP of the system, yearly heat production, investment, annualized investment, annual electricity cost and annual O&M costs. These result in the total annual cost of operating the heat pump and the resulting heat price including and excluding investment.

In addition full details behind the results are available in subwindows.

Results Info

		Parallel evaporators								Serial evaporators				
		C1	C2	C3	C4	C5	C6	C7	C8	C4	C5	C6	C7	C8
	Feasible compressor conditions	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
	Feasible compressor number	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
COP_{sys}	[-]	3,48	3,85	3,93	3,70	4,02	4,08	4,02	4,05	3,81	4,09	4,15	4,09	4,12
Yearly heat production	[GWh]	4	4	4	4	4	4	4	4	4	4	4	4	4
Total Capital Investment	[tDKK]	17125	14574	14639	16151	17105	17301	15733	15833	15965	17094	17292	15722	15824
TCI_{MW}	[mio DKK/MW]	17,12	14,57	14,64	16,15	17,1	17,3	15,73	15,83	15,97	17,09	17,29	15,722	15,82
TCI_A	[tDKK/y]	940	800	803	886	938	949	863	869	876	938	949	863	868
$C_{electricity}$	[tDKK/y]	575	519	509	540	497	490	498	494	525	489	481	489	485
$C_{O\&M}$	[tDKK/y]	113,3	79,14	78,33	91,23	122,2	121,5	92,86	92,52	87,19	120,8	120,1	91,45	91,13
Yearly heat expenses	[tDKK/y]	1628	1398	1390	1518	1558	1561	1454	1455	1488	1547	1550	1443	1445
Cost of heat														
Incl. TCI_A	[DKK/MWh]	406,9	349,5	347,5	379,5	389,5	390,1	363,5	363,7	372	386,8	387,6	360,8	361,2
Excl. TCI_A	[DKK/MWh]	172	149,6	146,7	157,9	154,9	152,8	147,7	146,6	153	152,4	150,4	145,2	144,1
Click for detailed results of each configuration →		C1	C2	C3	C4	C5	C6	C7	C8	C4	C5	C6	C7	C8

Click for comparison → | Component sizes & economy | COP & efficiency

Figure 3: Output from HPconfig

In the present example, the configurations shows COPs between 3,48 and 4,15 with the SVAF type C& having the highest value. However, because of the difference in investment other configurations are competitive regarding economic performance and heat cost showing that several configurations (C2, C3, C6, C7, C8) may be relevant candidates in this case taking the tolerance of the estimates into consideration. A complete result output from HPconfig is provided as appendix.

Published works

The complete list of publications is included below. The main outcome of the most relevant of the publication is presented here:

Hartmund Jørgensen, P., Ommen, T., & Elmegaard, B. (2021). Quantification and comparison of COP improvement approaches for large-scale ammonia heat pump systems. International Journal of Refrigeration, 129, 301-316.

This study aims at quantifying and compare five approaches for improving the COP of a heat pump, with a one-stage ammonia cycle used as the reference case with sink temperatures of 50 °C/80 °C (in/out) and source temperatures of 10 °C/3 °C. The approaches include increased complexity of cycle layout, optimization of intermediate pressure in two-stage cycles, a connection of HP cycles in series, optimization of load share between heating capacity for HPs in series, and optimal design of heat exchanger networks (HEN). The latter is based on an implementation of pinch analysis to HP HENs. The results revealed an improvement in COP by +15.8% obtained with increased complexity of cycle layout (two-stage cycle with a low-stage desuperheater) compared to a COP of 2.98 for the reference case. Connecting up to three one-stage HPs and two-stage cycles in series improved COP by 4.42% and 24.5%, respectively. The benefit of optimal load share and intermediate pressure was less than 0.5 % points for all configurations compared to reference values based on theoretical approaches. Exploiting the potential for optimal HEN increased the potential to 10.4% for one-stage cycles in series and nearly 29% for two-stage cycles increasing the COP to a maximum of 3.84.

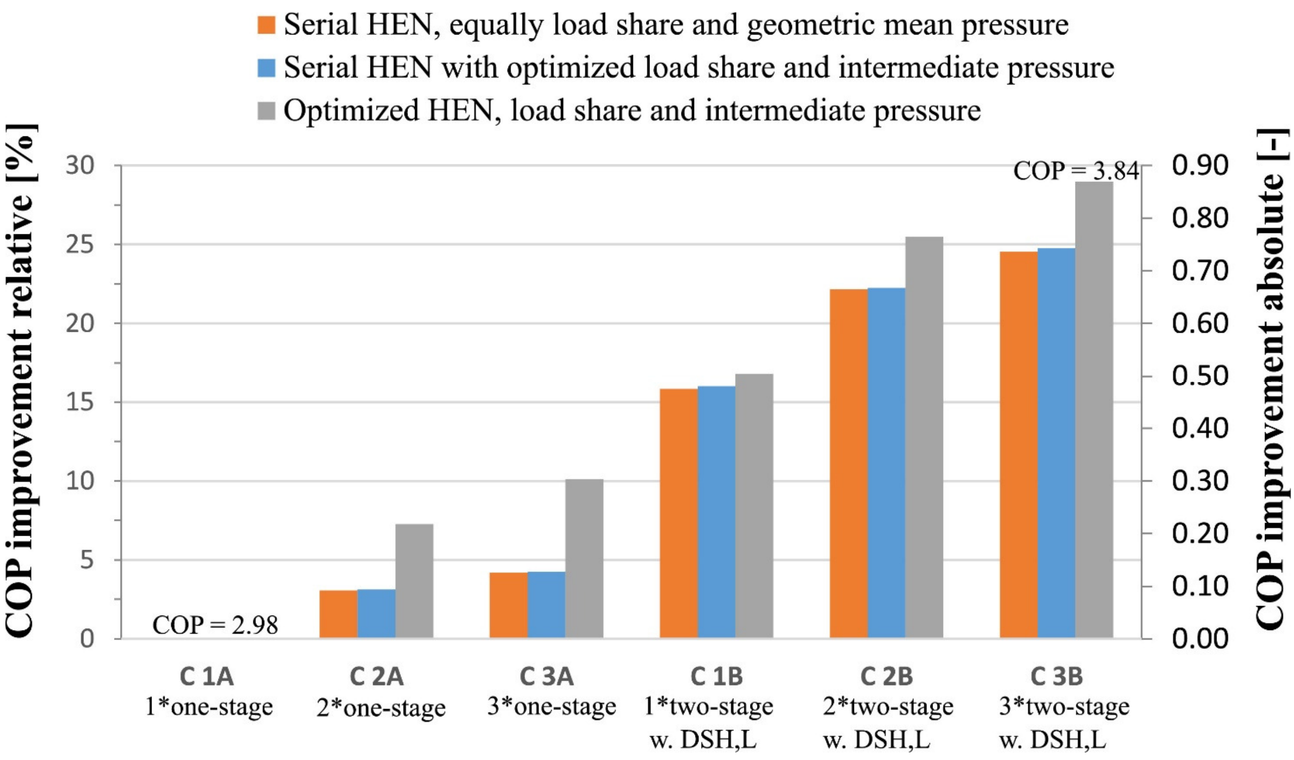

Figure 4: Comparison of configurations and COP optimization potential.

Jørgensen, P. H., Ommen, T., Markussen, W. B., Rothuizen, E. D., Hoffmann, K., & Elmegaard, B. (2018). Design and optimization of the heat exchanger network for district heating ammonia heat pumps connected in series. In Proceedings of the13th IIR-Gustav Lorentzen Conference on Natural Refrigerants (pp. 1225-1235). International Institute of Refrigeration.

To reach the high temperatures needed in current DH systems, the suggested HP installations become complex systems, where heat transfer between the HP cycle and the heat sink takes place at several temperature levels. In this study the heat exchanger network (HEN) between a HP installation consisting of two serially connected two-stage ammonia HP units and a heat sink being heated from 50 °C to 80 °C was investigated. The study applied pinch analysis to estimate the highest attainable Coefficient of Performance (COP) with the given HP configuration. Based on the result of the pinch analysis, a HEN reaching the highest COP was suggested and compared with COPs obtained with three other solutions for a HEN. The result revealed an estimated highest COP of 3.46. The three other design suggestions yielded reductions in the COP of -2.3%, -2.0%, and -1.8% compared to the highest. From this it was concluded that the HEN has an influence on the COP, and that the pinch analysis can be used to estimate the highest COP for a given HP installation. Furthermore, the COP obtained by practical installations was accordingly shown to come close to the target.

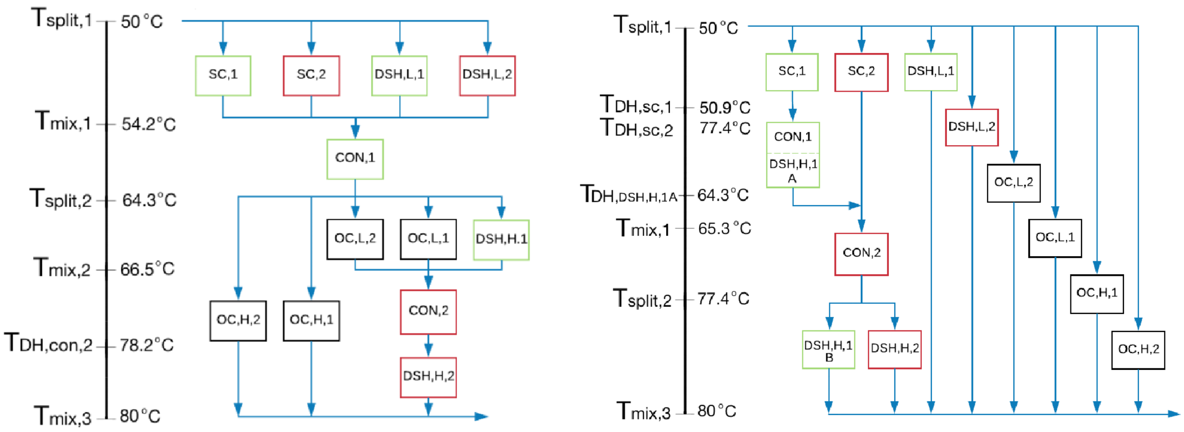

Figure 5: Two possible heat exchanger configurations reaching high COP.

Jensen, J. K., Ommen, T., Reinholdt, L., Markussen, W. B., & Elmegaard, B. (2018). Heat pump COP, part 2: Generalized COP estimation of heat pump processes. In Proceedings of the13th IIR-Gustav Lorentzen Conference on Natural Refrigerants (Vol. 2, pp. 1136-1145).

Today estimation of expected COP is often done by IHP suppliers and involves choices such as working fluid and compressor technology. By extending the method (of part 1) to include a generic and generalized estimation of COP, the feasibility of integration is elaborated to include real process parameters such as working fluid, compressor and heat exchanger characteristics. The method allows analysis of the credibility of assumptions for heat pump performance and estimated COP improvement from changes of the individual characteristics. For systems with predetermined economic constraints (part 1), the extended model may be used to eliminate combinations of working fluids, compressors and heat exchangers that will not lead to a viable IHP integration.

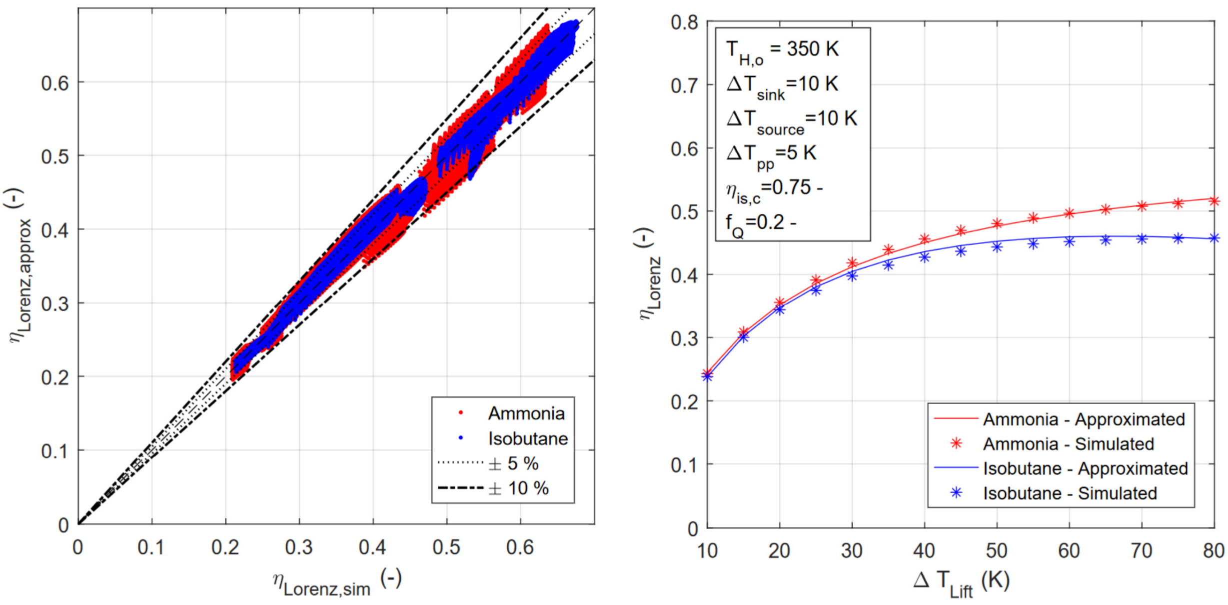

Figure 6: Comparison of estimation and detailed simulation value of heat pump COP

Jørgensen, P. H., Ommen, T., Markussen, W. B., & Elmegaard, B. (2019). Performance Optimization of a Large-Scale Ammonia Heat Pump in Off-Design Conditions. In Proceedings of the 8th Conference on Ammonia and CO2 Refrigeration Technologies (pp. 107-114).

A thermodynamic model of a 5 MW test and demonstration heat pump, implemented in the district heating network of Copenhagen, is presented. A genetic algorithm was applied to the model for 27 different operating conditions, optimizing the system Coefficient of Performance (COP) by adjusting the available set points (SP) in the heat pump system. Analyzing the optimization result, new SP values depending on the operating conditions were proposed. The potential improvement in COP was between 0.4 % and 2.9 %. A performance map for all operating conditions was presented and discussed. In general, the COP increased with decreasing forward temperatures, increasing source temperatures and further an optimum at 80 % heating load was observed within the investigated span of operating conditions.

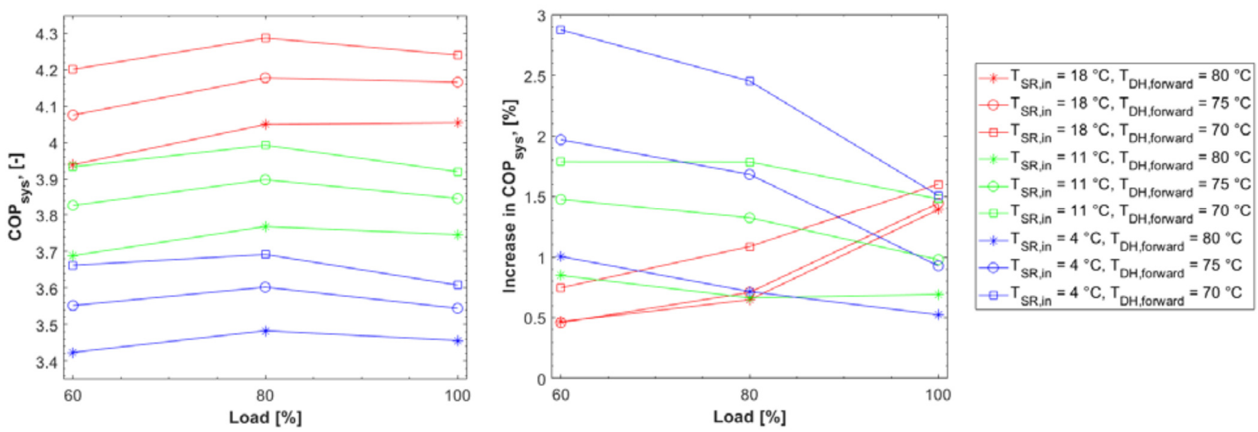

Figure 7: Left: System COP based on optimized set points. Right: Improvement compared to initial settings

Jørgensen, P. H., Ommen, T., Markussen, W. B., & Elmegaard, B. (2019). Mapping of Coefficient of Performance for large-scale ammonia heat pumps for district heating systems. In Proceedings of the 25th IIR International Congress of Refrigeration International Institute of Refrigeration.

Thermodynamic models of eight different HP configurations are used to compare the Coefficient of Performance (COP) and Lorenz efficiency, for a range of sink and source outlet temperatures. Furthermore, for a specific case the total volume flow rate for each configuration was compared. The results revealed that a configuration with two two-stage cycles with low stage desuperheat heat exchangers in most operating conditions was superior in terms of COP. However, for all considered operating conditions at least three configurations obtained a COP which was less than 3 % lower than the best one. Comparing the volume flow rates among the configurations a combination of a one- stage cycle and a two-stage cycle with low stage desuperheat heat exchanger holds the lowest needed volume flow rate.

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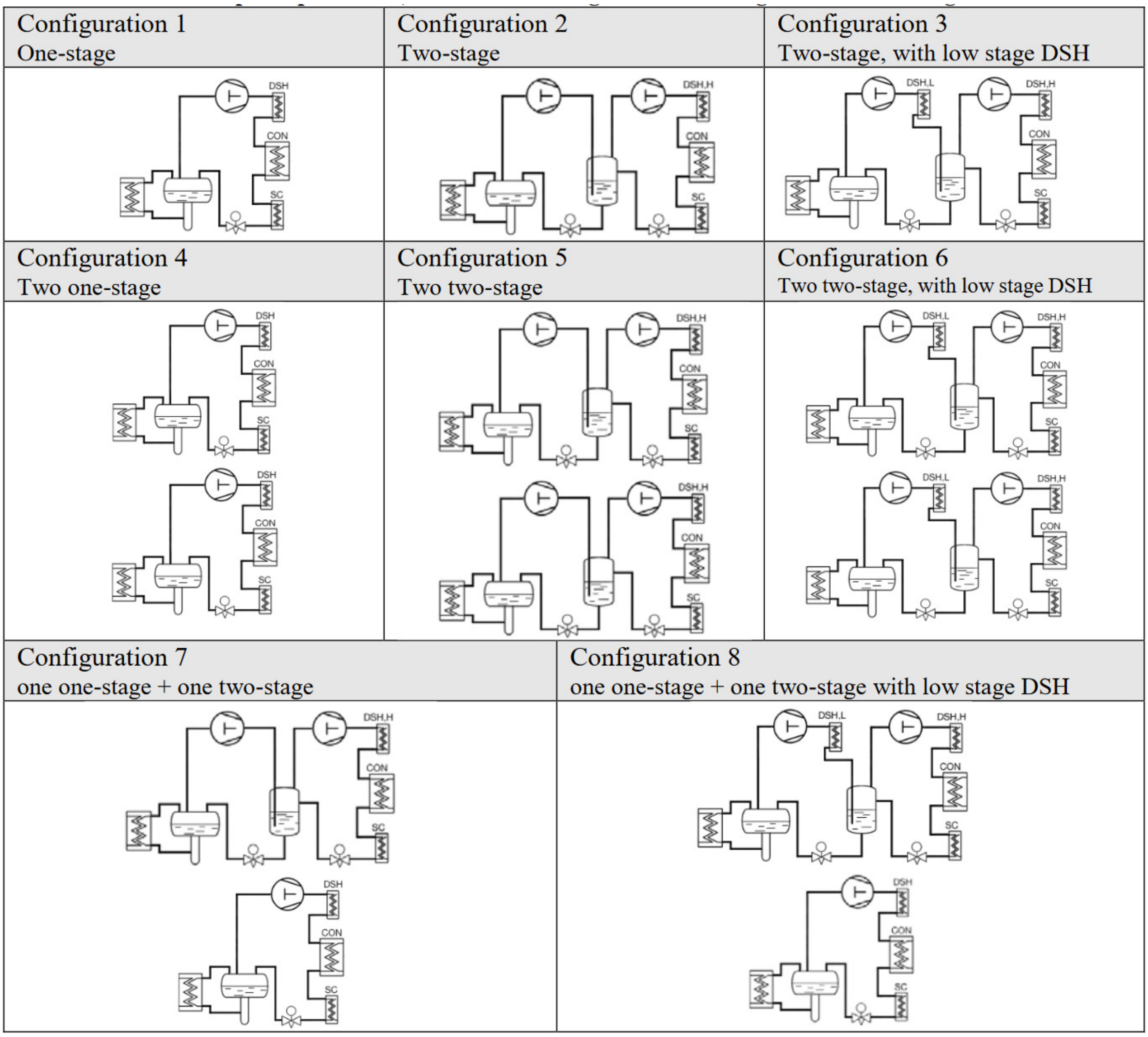

Figure 8: Compared configurations

Jørgensen, P. H., Ommen, T. S., Markussen, W. B. & Elmegaard, B., Technical note on HFOs as refrigerant in large scale heat pump applications, 2017

The note serves as an introduction to the subgroup of HFCs refrigerants, named HFOs. The note covers both general information about the HFOs as well as some chosen aspects of the available technology. The background for this work was a change in the Danish regulation of HFCs as refrigerant. The current statutory order no. 525 of 21 May 2017 states that all HFCs with a Global Warming Potential (GWP) less than 5 are allowed for import, sale and use from the 1st of July 2017. The former statutory order only allowed HFCs as refrigerants in systems with a charge between 0.15 kg and 10 kg [13]. The change made it possible to use HFOs as refrigerant in all heat pump applications, regardless the amount of charge used. Due to the strict Danish environmental legislation, natural refrigerants have been, and still are, of special interest on the Danish market for installations with charge above 10 kg. This has resulted in a rather large and developed industry for technology utilizing ammonia, CO2 and to some extent hydrocarbons, as refrigerant. Especially ammonia seems to be the preferred choice in relation to large scale plants. HFOs are compared to R717 and R134a for reference, both on a general level and as a design parameter in large scale heat pump systems.

Nasrin Arjomand Kermani, Fouling in heat exchanger evaporator, 2023

Brian Elmegaard, Large-scale heat pump development in district heating, 2023

Torben Ommen, Flexible operation for regulating power

Árting, J. B. (2017). Seasonal operation of an ammonia heat pump system for district heating in Copenhagen, Denmark, speciale

The aim of this thesis is to investigate how an 5,5MW two-stage ammonia heat pump for district heating, using low temperature sources, is affected by the seasonal changes. In order to simulate the heat pump performance response to a range of changes in external (environmental) and internal parameters a numerical model has been implemented. Based on a specified design point the response of coeffcient of performance (COP), heating cost, and exergy destruction rate and effciency were estimated by parametric analysis. The COP range for the heating season (October-April) is found to be 2,95-3,65 with a mean of 3,21 for seawater and 3,18-3,71 with a mean of 3,40 for sewage water. The forward temperature is found to have the largest effect on COP, with higher temperature yielding lower effciency. The COP was found to be at its highest in October with values of 3,54 for seawater and 3,60 sewage water, corresponding heat costs of 494 and 491 DKK/MWh.

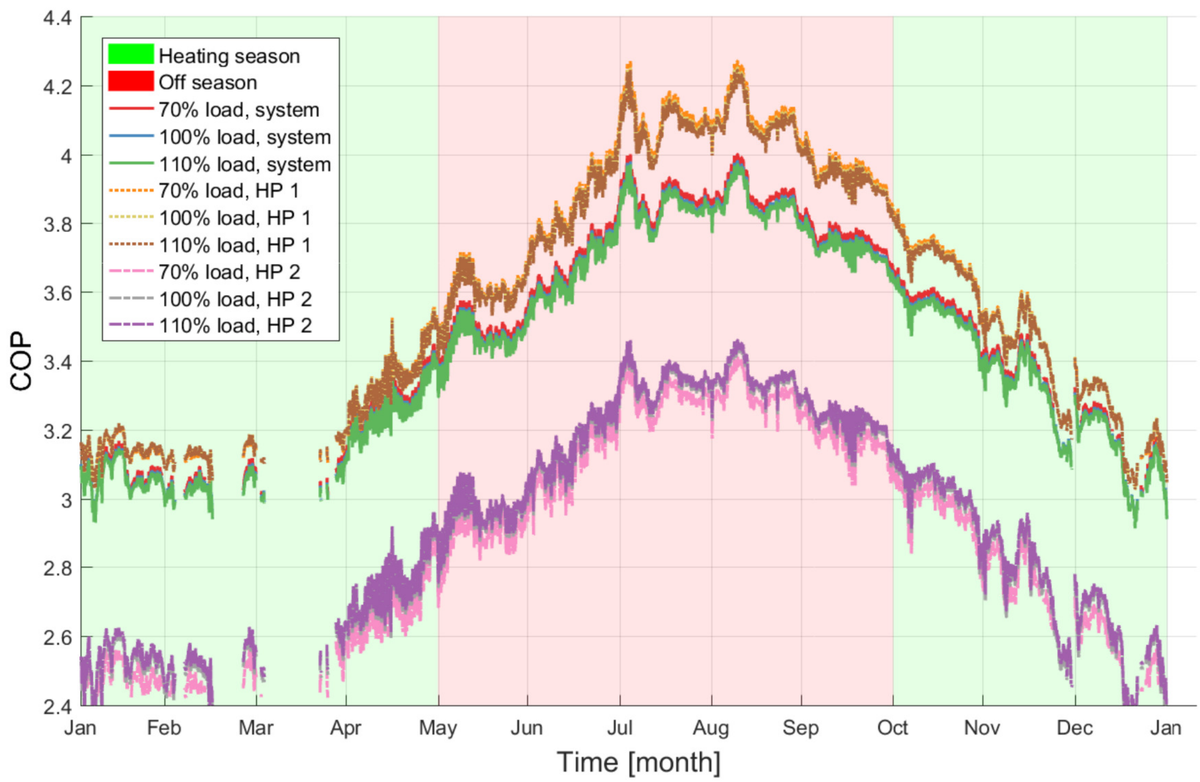

Figure 9: Seasonal performance variation

Martinez Santaclara, S. (2018). Design of Large-Scale Heat Pump for Copenhagen's District Heating System. Speciale

The aim of the project is to supply two modelled heat demands in Nordhavn with a peak consumption of 18-27 MW respectively. Two configurations are studied: "Island", where all the demand is supplied by the new system and ”Back-up”, where if the demand cannot be fulfilled it is assumed to be an auxiliary connection not defined. A serial connection between two 2-stages HPs using HFO R1233zd(E) with EB technol- ogy as capacity booster and Back-up DH network configuration has the lower average annualized heat price. The optimal installed ratio of heat pump capacity has been found to be 54 % to61 % of the peak demand. The annualized average heat price under operation constraints on the sea water temperature is found to be 306-602 DKK/MWh (covering electricity spot price 2.5 % to 97.5 % percentiles). The operation constraints increased the heat price by an average of 80 DKK/MWh. The influence of not replacing the installed capacity of EB during the project lifetime is found to be 17 DKK/MWh.

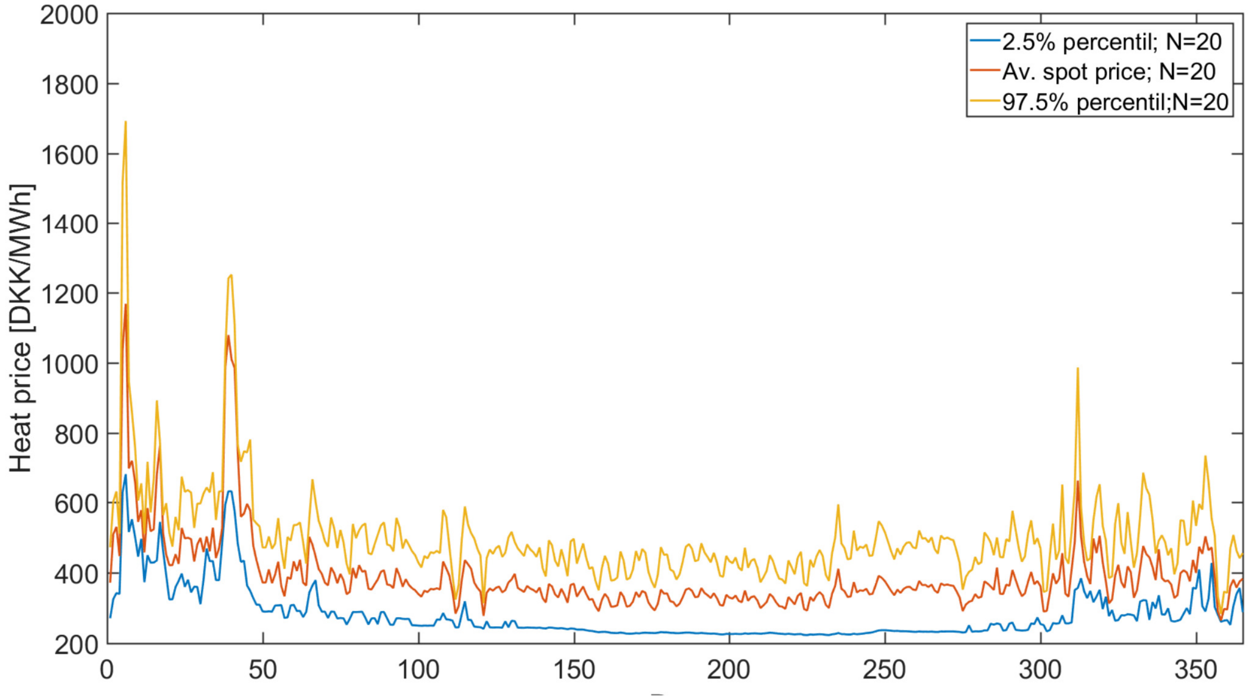

Figure 10: Island configuration heat price

Lucchetta, F. (2019). Optimization of heat pump for utilization of geothermal energy in district heating, Speciale

The aim of this thesis is to find the thermodynamically optimal configuration for a 5 MW heat pump using geothermal water available at 73℃ as a heat source. This heat pump is hence a relevant application in the context of utilization of geothermal energy for the district heating of Copenhagen. The geothermal resource is located in Amager, south of Copenhagen, and that is the place in which this system is supposed to be built. To study this energy system, different mathematical models of the system were developed using EES (Engineering Equation Solver). The results show that the best solution consists in using a direct heat exchanger followed by the series of two 2-stages HPs using ammonia as refrigerant. The COP that is achieved with this solution is 6.39. Encouraging results are also obtained with the same configuration using HFO’s, as the highest COP with R-1243zf is 6.29.

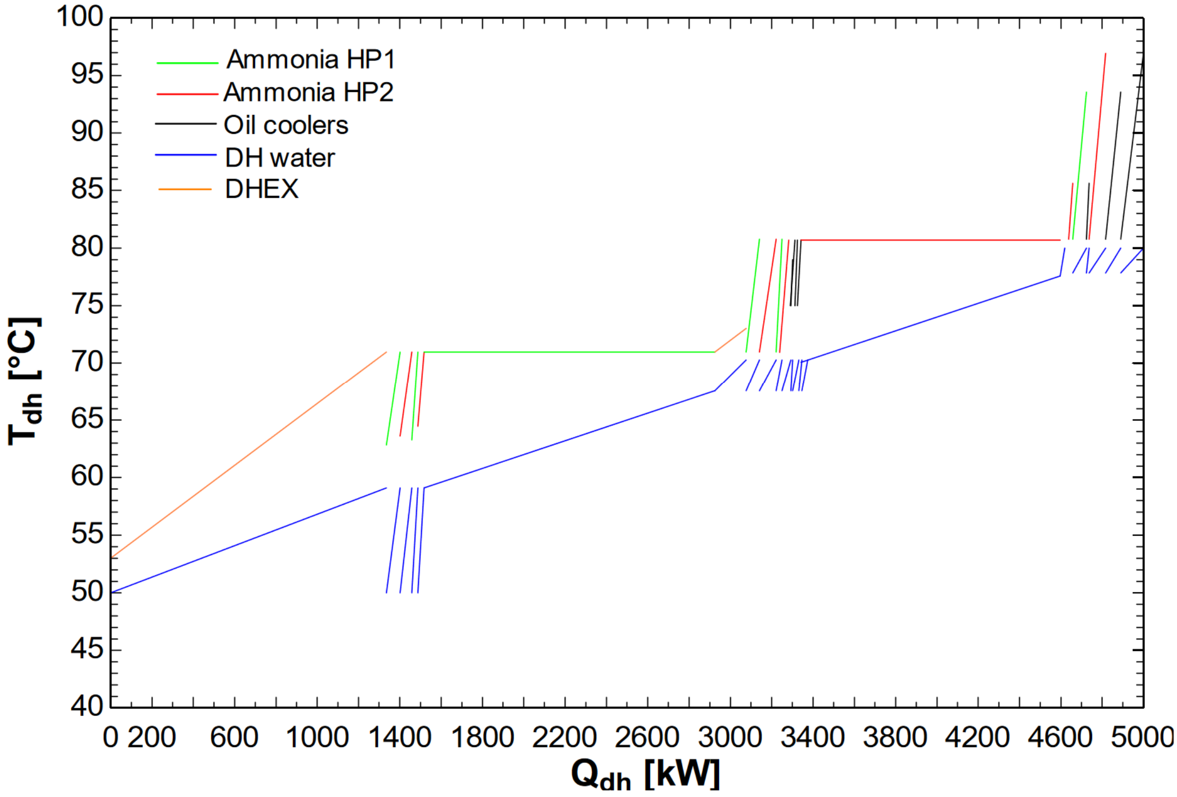

Figure 11: Optimized two-stage configuration for geothermal source ammonia heat pump

Philip Michael Højgaard Wood (2020). Design and analysis of heat exchanger networks for heat pumps in series. Speciale

This thesis deals with the design and analysis of heat exchanger networks in heat pump systems. Using data provided by Johnson Controls, a thermodynamic model based on a district heating plant in Kalundborg, Denmark is established. The model consists of two 2-stage heat pumps in series. Subsequently, based on qualitative assessments, three alternative heat exchanger networks, referred to as HEN 2, HEN 3 and HEN 4, are designed and modelled. A pressure drop analysis for the various configurations is completed, based on supplier data. Prices of components are then used for a cost analysis of the possible system solutions Overall the work suggests improvements of up to at least 2 % of COP are attainable through the applied methods. The pressure drops are found to vary highly on the specific network. Furthermore, the alternative heat exchanger networks are able to provide economically feasible solutions.

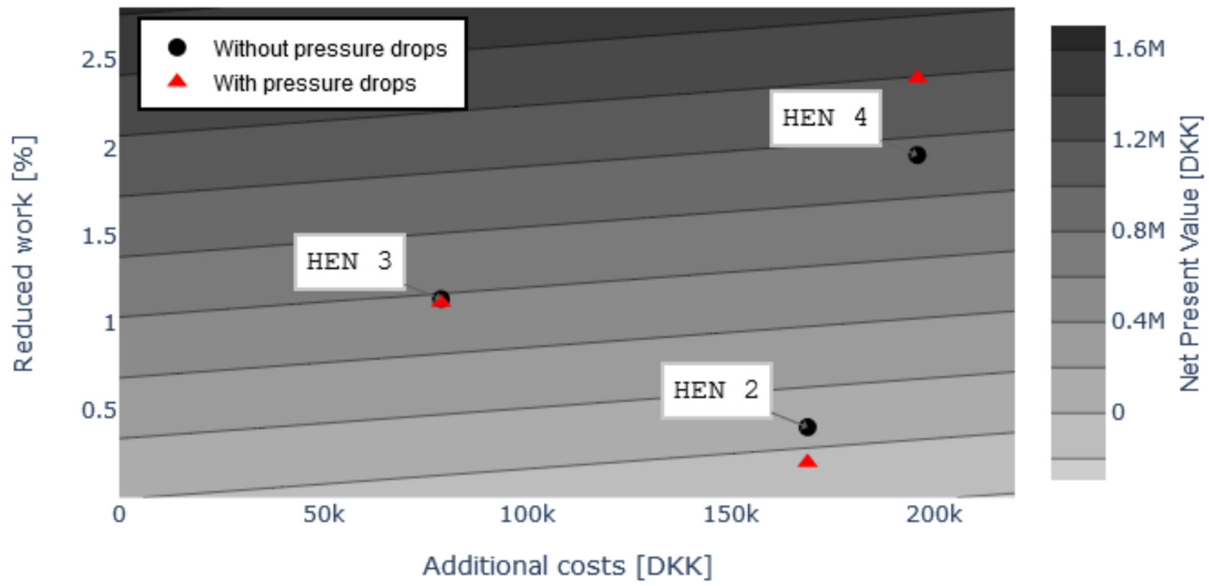

Figure 12: Net present value of advanced configuration including additional investment and impact of power consumption.

Christian Snekloth Vestergaard (2019), Analysis of different compressor technologies and refrigerants for large-scale heat pump systems. Speciale.

In this thesis, an analysis of large-scale heat pump systems for district heating, using seawater as heat source is conducted. The analysis considers different refrigerants and heat pump configurations, in order to optimise the coefficient of performance (COP). Different compressor technologies are investigated, to identify the most suitable technology for a given refrigerant. An analysis of the yearly performance, considering both base load and part-load conditions, of different configurations is conducted to obtain insights into operational characteristics of both the heat pump and the compressor technologies. The analysis is conducted using variation in source and sink temperatures and variations of the heat demand. The investigations are concluded by an analysis of the levelised cost of heat for the final configurations. The thesis is confidential.

Christian Koch Jensen (2019), Optimization of Heat Exchanger Configuration for Heat Pump for District Heating. Speciale.

Through numerical models in the commercial software package Engineering Equation Solver, the thesis will optimize a 5 MW ammonia two-stage heat pump for district heating by increasing the complexity of the district heating configuration and in the meantime vary the applied heat exchangers type from plate heat exchangers to a shell and plate heat exchangers. In total, four combinations are studied and their coefficient of performance, district heating and pressure drop are compared. The two thermodynamically best per- forming heat exchangers are moreover compared economically. Subsequently, sensitivity's analysis of the coefficient of performance, the district heating area and pump power are created for the economical best performing configuration in order to better understand the influence of the geometry and internal variables of the heat exchanger. Finally, the sensitivity analysis is used to optimize the coefficient of performance and district heating area of the best performing heat exchanger configuration. The optimization shows that when the corrugation angle is 53, 66◦, the velocity is 0, 8 m/s and the pinch point temperature difference is 2,0 K, the best design of the 5 MW large-scale ammonia HP with plate heat exchanger is obtained.

Seeger, A. N. (2018). Design of integrated ammonia heat pump and electric heater system. Bachelorprojekt

This project is based on the SVAF project, which is carried out by DTU, HO- FOR and more. The goal with this project is to design and simulate an ammonia heat pump with an electric heater system. The heat pump should deliver heat to 1,204,000 m2 in new building complexes build in the area Nordhavn, Copenhagen, Denmark in 2030. The energy source is seawater Three different configurations were made and simulated in the software EES. The capacity of the heat pumps was set to 13 MW and 15 MW. All configurations were 2-stage heat pumps with screw compressor using oil cooling. The results showed that the most economical configuration was a 2-stage heat pump in series and had a COP=2.95 throughout a simulation over a oneyear period. The heating price were found to vary between 305.30 [DKK/MWh] to 517.48 [DKK/MWh] depending on different scenarios for the electricity prices in 2030.

Hansen, M. L., & Førby, N. L. (2018). Optimisation of hybrid heat pump system for geothermal application. Bachelorprojekt

In this project is an optimisation of an Ammonia-Water Hybrid Absorption Compression Heat Pump (HACHP) using a geothermal heat source conducted for application in the district heating network. The project consists of primarily four parts; an investigation of an ejector implementation in an HACHP, an optimisation of the geothermal injection temperature, a configuration analysis for a heat pump plant and an economic analysis for a complete geothermal plant. The result of the geothermal injection temperature optimisation was that for a single-stage HACHP an optimum exists at 21◦C, which is caused by a shift in the pinch point in the heat exchanger for the source. This optimum was for a two-stage HACHP found to be around 35◦C. The configuraion analysis applies the case study, a thermodynamic HACHP model and an exergy model to detemine the best technically performing configuration. The configuration analysis found that compared to the investigated system setup, a configuration with a direct heat exchanger and a two-stage HACHP serially connected is the best technical solution with a coefficient of performance of the system of 5.2. The economic analysis found that the best economic solution was the same as the best technical solution regardless the number of full load hours per year of the complete geothermal plant.

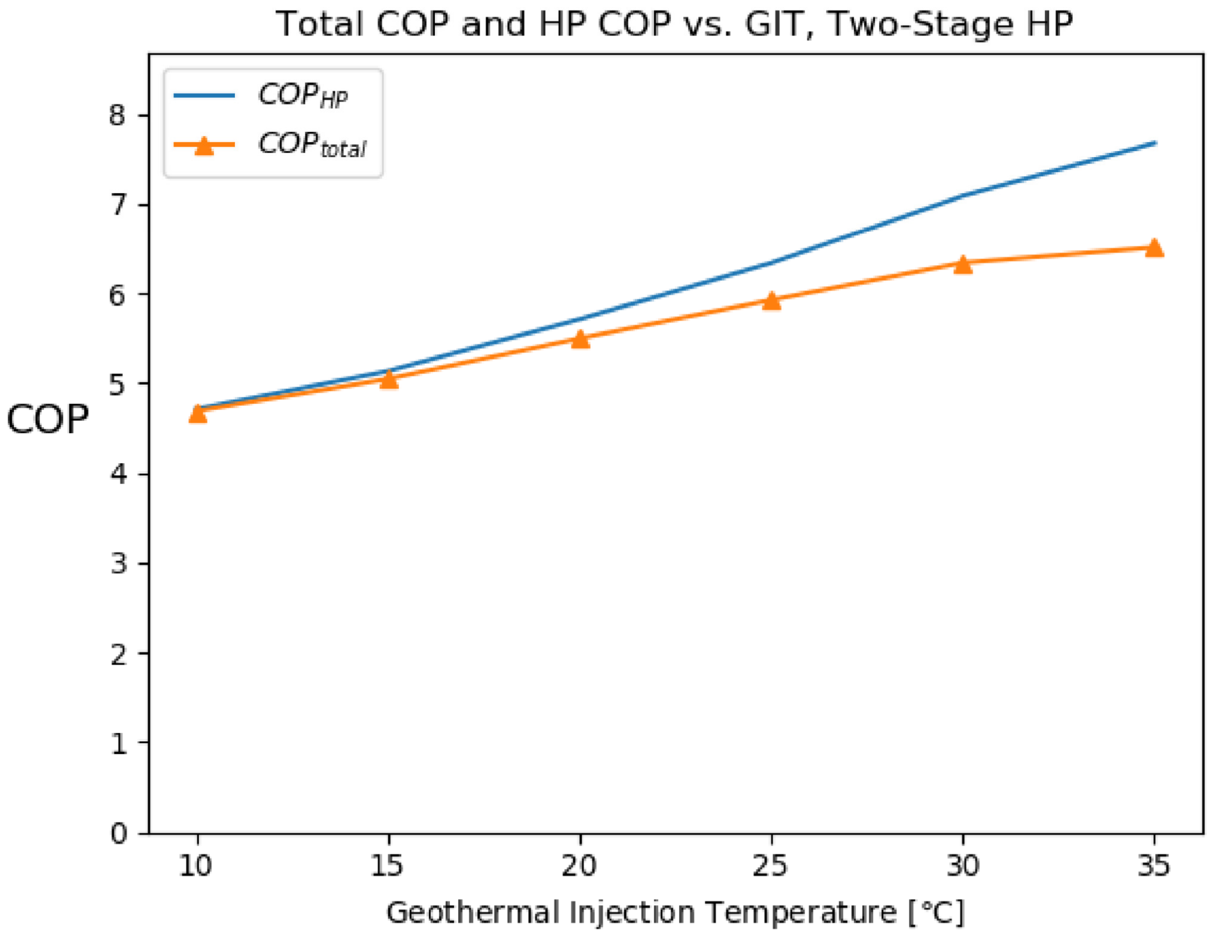

Figure 13: Two-stage heat pump COP

PhD thesis in preparation

Hartmund Jørgensen, P., Heat Pump Integration in the Greater Copenhagen District Heating System, expected 2024

International Scientific Journals

Hartmund Jørgensen, P., Ommen, T., & Elmegaard, B. (2021). Quantification and comparison of COP improvement approaches for large-scale ammonia heat pump systems. International Journal of Refrigeration, 129, 301-316. https://doi.org/10.1016/j.ijrefrig.2021.04.016

International conferences

Jørgensen, P. H., Ommen, T., Markussen, W. B., Rothuizen, E. D., Hoffmann, K., & Elmegaard, B. (2018). Design and optimization of the heat exchanger network for district heating ammonia heat pumps connected in

series. In Proceedings of the13th IIR-Gustav Lorentzen Conference on Natural Refrigerants (pp. 1225-1235). International Institute of Refrigeration. https://doi.org/10.18462/iir.gl.2018.1400

Reinholdt, L., Kristófersson, J., Zühlsdorf, B., Elmegaard, B., Jensen, J., Ommen, T., & Jørgensen, P. H. (2018). Heat pump COP, part 1: Generalized method for screening of system integration potentials. In Proceedings of the13th IIR-Gustav Lorentzen Conference on Natural Refrigerants (Vol. 2, pp. 1097-1104). International Institute of Refrigeration. https://doi.org/10.18462/iir.gl.2018.1380

Jensen, J. K., Ommen, T., Reinholdt, L., Markussen, W. B., & Elmegaard, B. (2018). Heat pump COP, part 2: Generalized COP estimation of heat pump processes. In Proceedings of the13th IIR-Gustav Lorentzen Conference on Natural Refrigerants (Vol. 2, pp. 1136-1145). International Institute of Refri-geration. https://doi.org/10.18462/iir.gl.2018.1386

Salgado Fuentes, V., Fuentes Lejarza, G., Bühler, F., Jørgensen, P. H., Skaarup Brødsgaard, M., & Elmegaard, B. (2019). Energy analysis of a cleaning-in-place system. In Proceedings of ECOS 2019: 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems

Jørgensen, P. H., Ommen, T., Markussen, W. B., & Elmegaard, B. (2019). Performance Optimization of a Large-Scale Ammonia Heat Pump in Off-Design Conditions. In Proceedings of the 8th Conference on Ammonia and CO2 Refrigeration Technologies (pp. 107-114). International Institute of Refrigeration. Institut International du Froid. Bulletin https://doi.org/10.18462/iir.nh3-co2.2019.0014

Jørgensen, P. H., Ommen, T., Markussen, W. B., & Elmegaard, B. (2019). Mapping of Coefficient of Performance for large-scale ammonia heat pumps for district heating systems. In Proceedings of the 25th IIR International Congress of Refrigeration International Institute of Refrigeration.

Ommen, T. S. (Author), Jørgensen, P. H. (Author), Jensen, J. K. (Author), Markussen, W. B. (Author), & Elmegaard, B. (Author). (2017). Design considerations for integration of two 5 MW vapour compression heat pumps in the Greater Copenhagen district heating system. Sound/Visual production (digital), Technical University of Denmark.

Elmegaard, B., Bühler, F., Jensen, J. K., Jørgensen, P. H., Mancini, R., Markussen, W. B., Meesenburg, W., Ommen, T. S., Pieper, H., Rothuizen, E. D., & Zühlsdorf, B. (2017). Heat Pumps for Efficient and Flexible Heat Supply in Copenhagen. In Book of Abstracts, Sustain 2017 [S-5] Technical University of Denmark.

National contributions

Pernille Jørgensen, Presentation of HP Config at IDA Webinar Nye simuleringsværktøjer til køle- og varmepumpeteknologi-branchen November 3 2020.

Elmegaard, B., Jørgensen, P. H., Ommen, T. S., & Markussen, W. B. (2018). Varmepumper og kølemidler. Fjernvarmen, 6, 56-57.

Pernille Hartmund Jørgensen, Wiebke Meesenburg, Henrik Pieper, Torben Ommen, Wiebke Brix Markussen, Brian Elmegaard, The future of district heating – Large-scale heat pumps, Poster ved Tværpolitisk Klimadebat, DTU, Marts 2019

Internal Project Reports

Jørgensen, P. H., Ommen, T. S., Markussen, W. B., Elmegaard, B., Technical note on HFOs as refrigerant in large scale heat pump applications, 2017

Erasmus Rothuizen, Dynamic simulation of start-up of a large scale heat pump, 2018

Nasrin Arjomand Kermani, Fouling in heat exchanger evaporator, 2023

Brian Elmegaard, Large-scale heat pump development in district heating, 2023

Torben Ommen, Flexible operation for regulating power 2023

Student theses related to the project

Árting, J. B. (2017). Seasonal operation of an ammonia heat pump system for district heating in Copenhagen, Denmark, speciale

Santiago Martinez Santaclara (2018). Design of Large-Scale Heat Pump for Copenhagen's District Heating System. Speciale

Lucchetta, F. (2019). Optimization of heat pump for utilization of geothermal energy in district heating. Speciale

Muguruza Fuentes, I. (2019). Analysis and Optimization of Heat Pumps for Integration of Datacenters in District Heating, Speciale

Philip Michael Højgaard Wood (2020). Design and analysis of heat exchanger networks for heat pumps in series. Speciale

Christian Snekloth Vestergaard (2019), Analysis of different compressor technologies and refrigerants for large-scale heat pump systems. Speciale.

Christian Koch Jensen (2019), Optimization of Heat Exchanger Configuration for Heat Pump for District Heating. Speciale.

Anders Boysen (2020). Large-scale heat pump integration in the district heating system at Amagerværket. Fleksibel Master

Mathiesen, J. B., & Andersen, M. P. (2019). Heat pump integration at Amagerværkets biomass fired unit 4, Bachelorprojekt.

Seeger, A. N. (2018). Design of integrated ammonia heat pump and electric heater system, Bachelorprojekt

Hansen, M. L., & Førby, N. L. (2018). Optimisation of hybrid heat pump system for geothermal application, Bachelorprojekt

Jensen, A. S., & Rein, J. L. (2017). Investigation of fouling in sewage water heat pump, Bachelorprojekt.