

Project: Experimental development of electric heat pumps in the Greater Copenhagen DH system (SVAF phase 2)



Figure 1: 5 MW_{thermal} heat pump system for district heating in Copenhagen [Source: HOFOR].

Summary of project

The overall purpose of the project is to accelerate the use of large electric heat pumps (HPs) for district heating (DH) through industrial co-operation, research and experimental development. The project is the second phase of the total project, which includes large-scale HP investments carried out to demonstrate optimal design, smart system integration, cost efficiency and climate benefits.

Large electric HPs are expected to play an important role towards CO₂ neutral DH systems. The HPs can make up a significant supplement to heat production on biomass, and furthermore, electric HPs, when operated in a smart way, can support wind power integration in the overall energy system.

This project addresses the main barriers in order to accelerate the use of HPs using natural refrigerants in the DH sector through the development of optimized HPs for system integration with improved cost efficiency and with potential for scaling up concepts to 50-100 MW. The demonstration heat pump built can use both seawater and waste water as heat sources, and can be seen in Figure 1. The system consists of two parallel 2-stage heat pumps with NH₃ as working fluid.

A key focus in the project is monitoring and set-point tuning of large-scale HP systems, where two different approaches will be evaluated:

- HP AutoTune - for continuous optimization of operating conditions (see Figure 2).
- HP Doctor - for monitoring purposes and fault detection (see Figure 3).

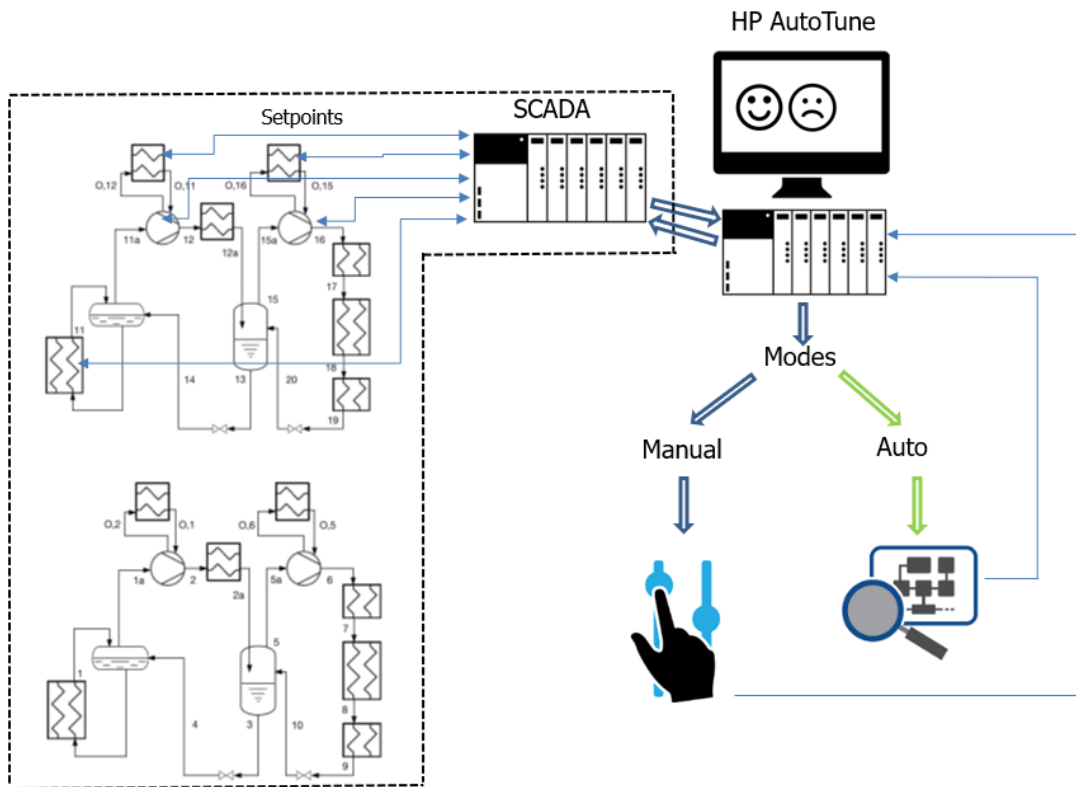


Figure 2 - Concept for HP AutoTune.

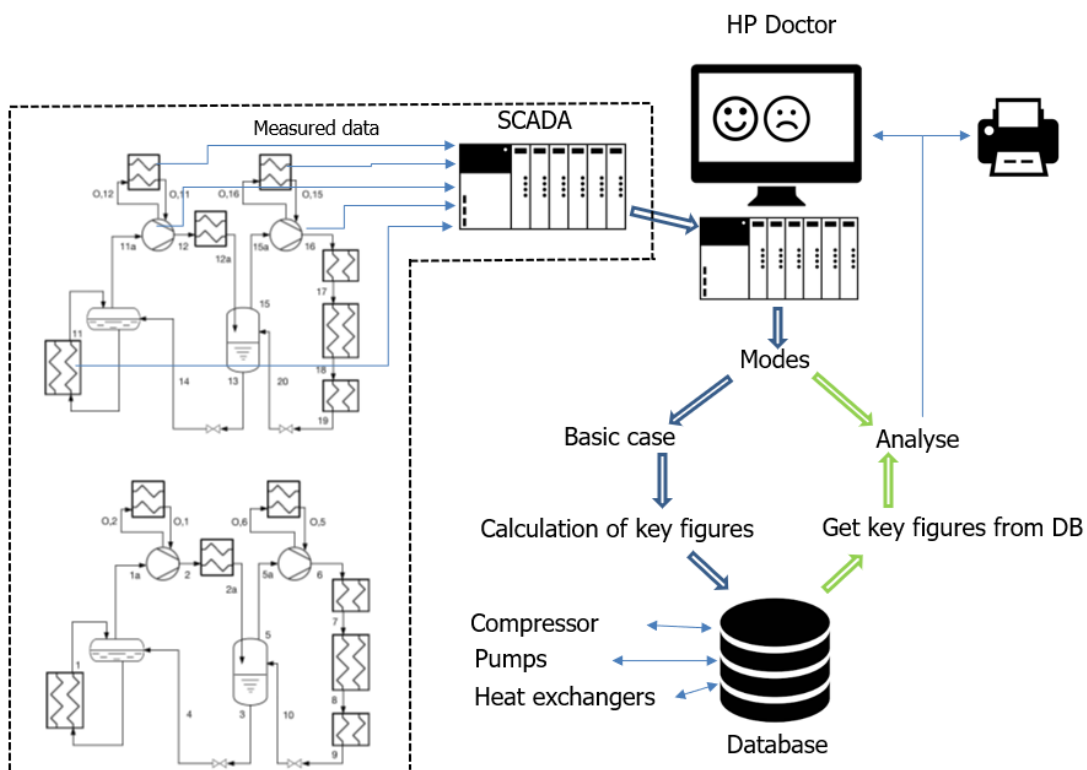


Figure 3 - Concept for HP Doctor.

The HP AutoTune concept to be developed in the project is to guide the heat pump installation to always have the highest available COP, and through all operating conditions. The HP AutoTune will be investigated in the project through different approaches. The first is based on IWO (Invasive Weed Optimization) approach and the second on use of analytical equations:

HP AutoTune - IWO

In this approach, a number of system control loops have been chosen. Each of these control loops have a set point which is accessible from the IWO. The main goal is to optimize the COP at all times, and this is done by the IWO by changing one set point at a time and register the change in COP. If the result is improved COP, the change is kept and otherwise the set point is returned to the original value. The IWO then cycle through the selected set points and thereby gradually optimize the total COP of the system aiming at finding the top of the COP curve in the allowed operating domain (see Figure 4).

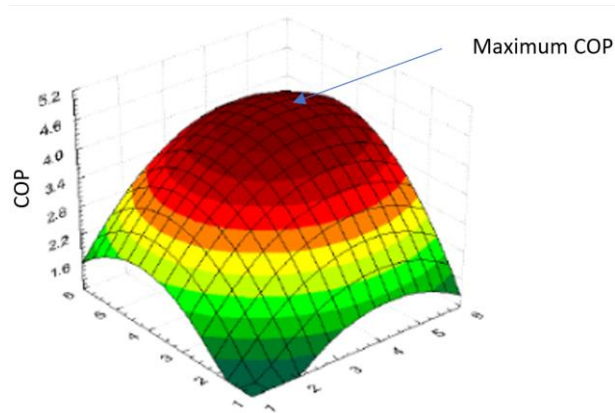


Figure 4 - Concept for optimum COP based on IWO.

HP AutoTune - Analytical

The second approach is to develop equations for the components included in the control loops e.g. heat exchangers, compressors, pumps etc. The equations consist of constants independent of operating condition and variables dependent of

the running conditions. By differentiating the equation and set equal to zero a general equation can be developed for the optimum condition of the control variable. This equation contains constants and variables. At start-up of the heat pump plant with the system tuned in to the design conditions, the coefficients in these equations can be found. When running with the system off design, the equations with the established constants is used to calculate the optimum set points. It is also an option to investigate set-point tuning done in manual model.

The HP Doctor concept is intended to monitor the heat pump running with highest COP adjusted by the HP AutoTune. At start up with new and clean system a start-up procedure is performed where the heat pump runs through the operating range and collects measured values for the different components in the heat pump and saves them to a database. Equations for the efficiency of different components are developed and the efficiency for each component is calculated and stored in the database. Later, when the heat pump is released to normal duty the HP Doctor will continuously calculate the efficiency and compare the stored values. The HP Doctor can then alert the operator of possible loss of efficiency or of a threatening system failure.

A test campaign has been carried out in Q1 2022 to evaluate HP AutoTune. These tests were *short term tests*, in which one parameter was changed at a time and its influence on COP was measured. In total 6 different parameters were studied, from which flows in different heat exchangers and load repartition between stages of the heat pumps. A difficulty encountered was the fluctuation of the COP throughout the day. Indeed, short term tests were carried out during up to 3 days, and the influence of a specific value of a parameter was observed on a few hours. The COP being highly dependent on other conditions, such as

temperatures of the sources and of the district heating (DH) water, a method should be found to isolate the studied parameters influence. A regression of COP during normal operation (outside tests) was made to compare COP during tests with expected COP (as it should be during normal operation). This regression is dependent on temperatures on the source side and on the DH side, as well as the compressors capacity.

With this expected COP, it was much easier to evaluate the impact of one parameter on the COP. For example, as presented on Figure 5, the impact of the water flow through the desuperheater of heat pump 2 was studied. The results show that the higher the flow, the higher the performance.

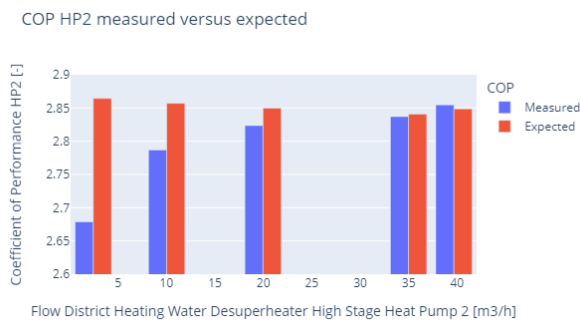


Figure 5 - Use of the regression to evaluate influence of water flow through desuperheater

Other short-term tests will be run in Q4 2022 in order to study the influence of other parameters, such as liquid level in evaporator separator or water flows on the source side.

A test campaign for evaluating HP AutoTune and HP doctor is planned for Q1 2023.

FACTS ABOUT THE PROJECT

IoT Category: Optimize heat pump operation and predictive maintenance.

Goal: The goals for the projects includes development of concepts regarding optimizing the operating conditions of the heat pump and monitoring of the heat pump in order for giving notifications when the heat pump is ill and points out the component causing the illness.

Beneficiary: Operator.

Data required: Operating data for the heat pump.

Analysis method Invasive Weed Optimization and development of analytical equations for COP optimization based on operation in design point.

Modelling requirements: Development of equations for components included in the control loops

Quality-of-Service: Real-time.

Project participants: Danish Technological Institute, HOFOR, CTR, VEKS, Vejlegårdens Fjernvarmecentral, COWI, Innoterm, Dansk Miljø- og Energistyring, Alfa Laval, and DTU.

Time schedule: 2016-2023.

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