Validation of a simulation model of a plant equipped with ground source heat pumps

This case study is made with the purpose to create a plant model that can serve as a test bench for model predictive control systems. The plant consists of ground source heat exchangers and heat pumps that deliver heat and cooling to a small district. These major components are calibrated using measured data from the actual plant. This article is focused on the validation of the total plant model. Measurements of delivered heating and cooling from the plant in operation are used as input to the simulation model that shows good agreement with the measurements.

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Model predictive control systems uses models as a part of control algorithm. These models are used with some sort of optimization algorithm to present the best momentarily control action that, for example, gives the lowest expected energy use over the next year. This case study is made in the framework of the research project DEBORAH with the purpose to create a plant model that can serve as a test bench for such control systems. The plant as seen in **Figure 1** is owned by Husvärden AB in Mölndal Sweden and delivers heating and cooling to a mix of newly built apartment buildings, commercial buildings and old refurbished industrial buildings converted to commercial buildings.

The plant is built up around three 500 kW heat pumps (1) that use two set of ground source heat exchangers (3) of 80 holes and 35 holes respectively as main source for collecting heat. However, during the summer the cooling system of the buildings is used as source for the heat pumps. As the use for heat is limited in the summer a 665 kW dry cooler (4) is installed to reject the surplus heat. To even out the heat load on the hot side, there are five tanks (2) of 10 m³ each.

Method

The study was carried out using the following workflow with five steps:

Step 1. Based on drawings and control description from the plant designer, a first model of the plant was created using standard models of IDA ICE.

Step 2. The initial simulations of the plant model were analyzed to see if the standard models of IDA ICE were suitable for this study or if additional models had to be created. During this step three models were identified that had to be created:

- The first model was a heat pump. The heat pump manufacturer didn't provide the type of data needed to use the standard heat pump model included in IDA ICE.
- The second model was a model of tanks coupled in series. This model was needed due to loading/unloading through the same pipes creating reversible flows which isn't allowed in the standard models of IDA ICE.

- The third model needed was a simplified borehole model that could be calibrated with reasonable effort. The advanced model in IDA ICE was too detailed to be calibrated when the number of holes is as large as in this study.

Step 3. To extract measurements from the plant a SQL database was created. Measurements from the control system was logged to the data base with 10 minutes sampling time. From the control system about 200 points from temperature sensors, valve positions and fluid flows were logged. The heat pumps are equipped with a tool for analyzing their performance, ClimaCheck. From this system about 156 data points of more detailed information about the heat pumps were logged, COP for each compressor, energy used by each compressor, evaporator and condenser temperatures etc.

Step 4. The system of ground source heat exchangers and the heat pumps needed to be calibrated before the model of the plant could be expected to cope with the measurements. The data set for calibration was from the period Jan 1st 2018 to June 30th 2018.

Step 5. To verify if the simulation model of the plant is valid to use as a test bench two cases were simulated using the calibrated subsystems from step 4. During this step a data set of measurements ranging from July 1st 2018 to April 30th 2019 was used. In the first set-up, Case 1, the simulation model was controlled by measured signals of control signal to the heat pumps, valve positions and fluid flows. In the second set-up, Case 2, the plant was simulated using simulated control based on the control description from the plant designer.

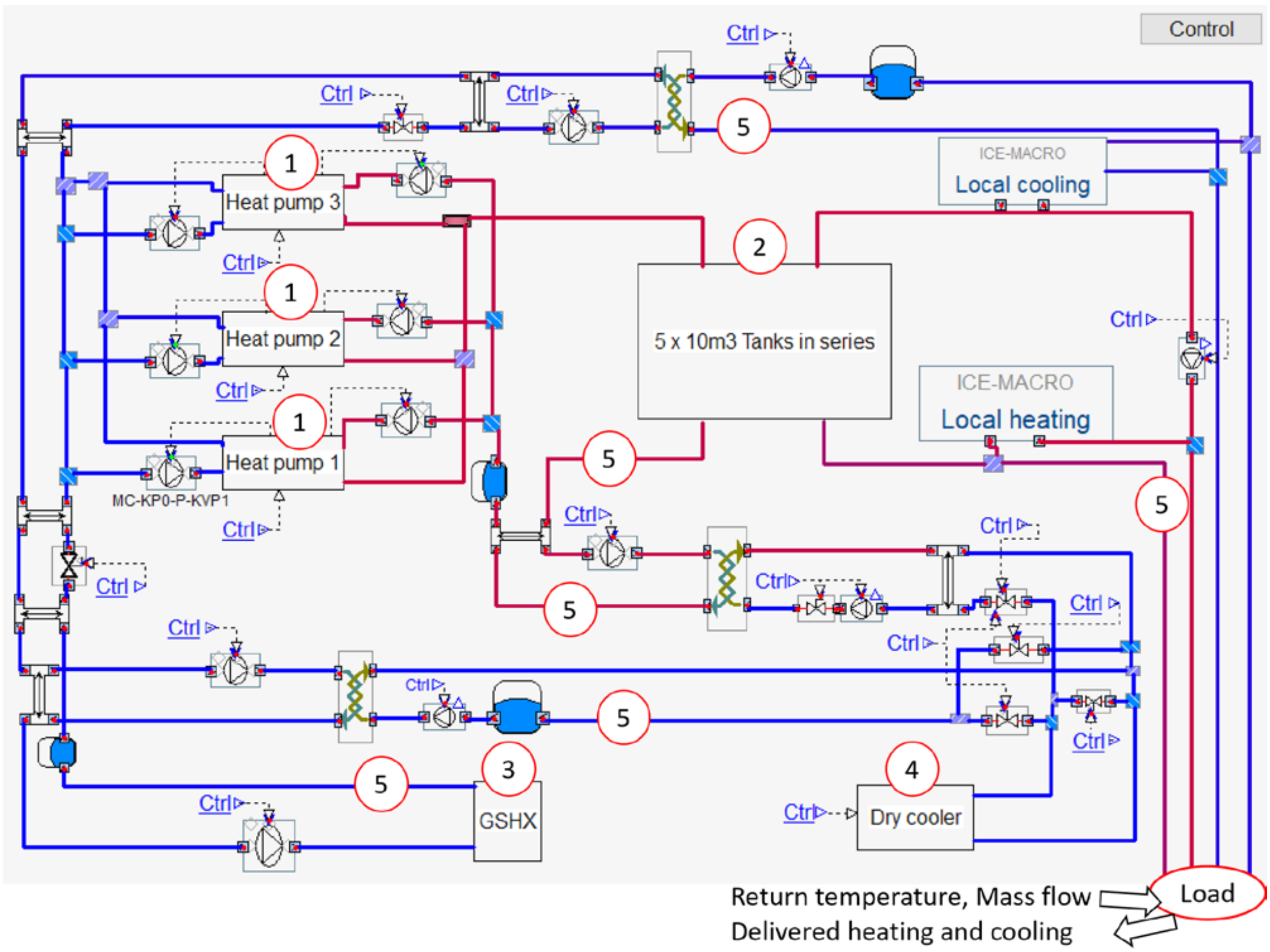

Figure 1. Simulation model of plant. A few components are removed to increase its readability. The model is based on a schematic drawing (Bengt Dahlgren AB) of the plant. The main features pointed out. ① Three 500 kW Heat pumps. ② Five 10 m tanks. ③ Two separate groups of GSHX, 80 holes (in use since 2015) and 35 holes (in use since 2018). ④ Dry cooler, 665 kW. ⑤ Energy meter.

Step 4. Calibration of subsystems

The first of the two sub systems to be calibrated was the ground source heat exchanger. In **Figure 2**, the IDA ICE model used for GSHX calibration is shown.

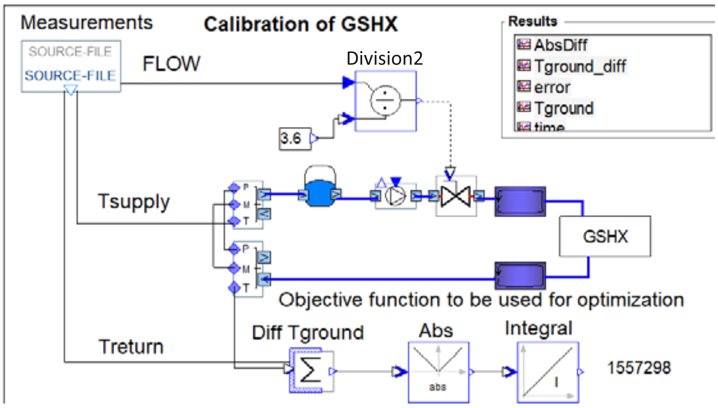

Figure 2. The set-up of the calibration model of the GSHX using IDA ICE.

The fluid flow and supply temperature to the ground was used as input. Then the integral of the difference between calculated and simulated return temperature from the ground was used as an objective function to be minimized.

The ground source heat exchangers needed to be calibrated for two reasons. The first reason is the deviations between the proposed layout of the bore holes and the actual bore holes drilled. Also, although there are thermal response tests (TRT) performed on the site, the site is so large that they can't represent the entire site. The second reason is that there are two different sets of boreholes that were taken into use at different stages. The first set of 80 holes with single U-pipes were taken in to use 2015 and the second set of 35 holes with double U-pipes a few years later, 2017. The usage history of mostly the first set was unknown when the measurements started. Hence, there are two problems in one. Estimating the temperatures in the ground to be used as starting point for the simulation and calibrating the performance of the GSHX. Looking at hourly mean values of the return temperature from the ground, the maximum deviation between the calibrated model and the measurements, is about ±0.4°C.

The three heat pumps have two compressors each which are used according to an internal control system. This internal control makes the calibration of them important as there is no information available describing this control. In **Table 1** some of the results from the calibration are shown. As can be seen the difference between the calibrated and un-calibrated models is substantial.

Table 1. *Results from calibration of heat pumps. The deviation calculated is difference in energy during the simulated period. The deviation before calibration is quite different among the heat pumps. After the calibration the deviation is less than 1% for all cases.*

	Heat pump 1	Heat pump 2	Heat pump 3
Evaporator energy			
Uncalibrated, %	8.2	0.2	18
Calibrated, %	–0.026	0.224	0.178
Compressor energy			
Uncalibrated, %	4.3	8.3	8.6
Calibrated, %	0.499	–0.959	0.187

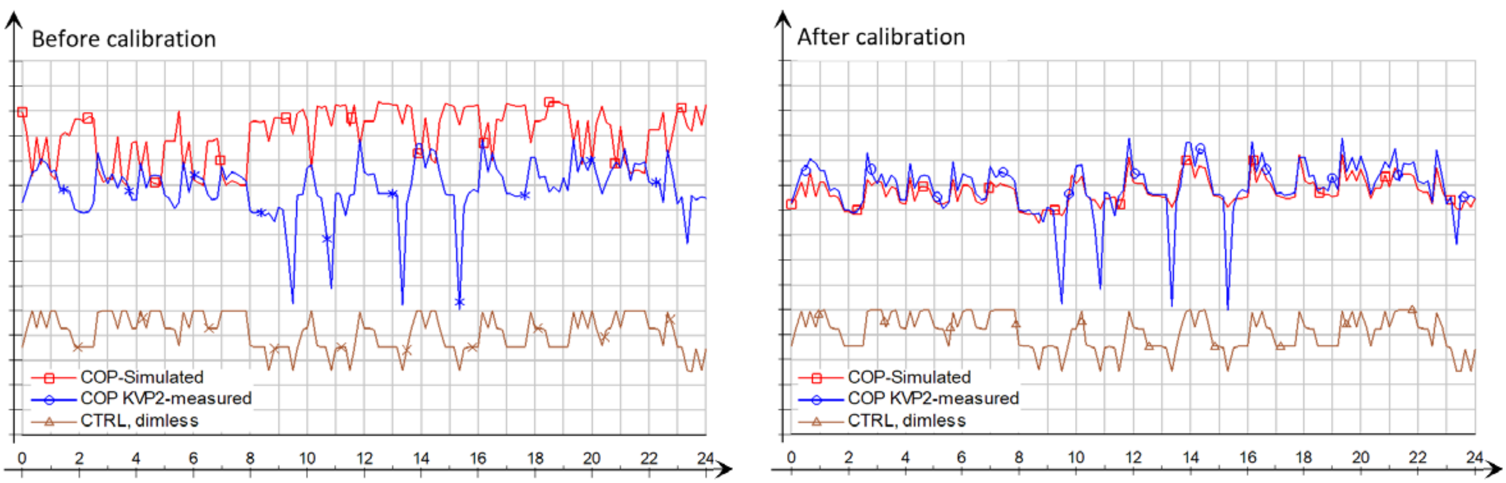

Figure 3. An example of model behavior before and after calibration. The catalog data implied better performance at part load than the actual performance.

Step 5. Plant simulation for verification of performance

The final step in this study was to see if the simulation of the entire plant could match the reality. To do this, two cases was studied. In Case 1, the plant was controlled by measured signals and in Case 2, the plant was controlled using a simulated control based on information from the control description. As driving data for the simulation, the return temperature and mass flow from the heating circuit and the cooling circuit are used. To verify the performance, the measured heating and cooling power are used to compare the simulation result with the measurements. In **Figure 1**, the simulated plant is shown.

Figure 5. Results comparing the case with uncalibrated heat pumps to the measurements.

In Case 1, the simulation is performed using measured signals to control the plant. In **Figure 1**, at each point where "Ctrl" is written in blue, a signal from the measurements is used. The signals used are control signals to the heat pumps and valves and where available the actual fluid flow. The fluid flow is available at each point where an energy meter is located, see **Figure 1**. The comparison of delivered heat and cooling between measurements and simulation is shown in **Figure 4**. The mean error during the simulated period is 5.1% for delivered heat and 1.4% for delivered cooling. Due to measurement problems the compressor power was only logged from April 3rd. The mean error during this period was 6.6%. A more detailed analysis shows that the larger errors occur at small compressor powers.

In Case 2, the simulation is performed using simulated control. However, the actual setpoint signals for the supply temperature for heating and cooling are used in the control. In the results below shown in **Figure 4**, the error is less than in Case 1. The mean error during the simulated period is –0.7% for delivered heat and 1.3% for delivered cooling This is due to the simulated control that corrects for some of the modelling faults.

Was a calibration of the subsystems really needed? To answer that question a complimentary simulation was performed equal to Case 1 with measured signals as control but leaving the heat pumps uncalibrated. The deviation during the simulation period regarding heat delivered from the plant is 18%, it can be seen quite clear in **Figure 5**. The compressor energy of April had an 8% error which is similar as with the calibrated model. This implies a better COP in the model than the measurements.

Conclusion

The result states that it is possible to create reliable simulation models of small district plants using IDA ICE and the model provides a perfect test bench for alternative controls. In this kind of system where a measured load is used, the driving data for plant simulation must contain the return temperature otherwise the temperature level of the system may drift. As heat pumps have internal control, a simulation model needs calibration to capture their real performance. ■

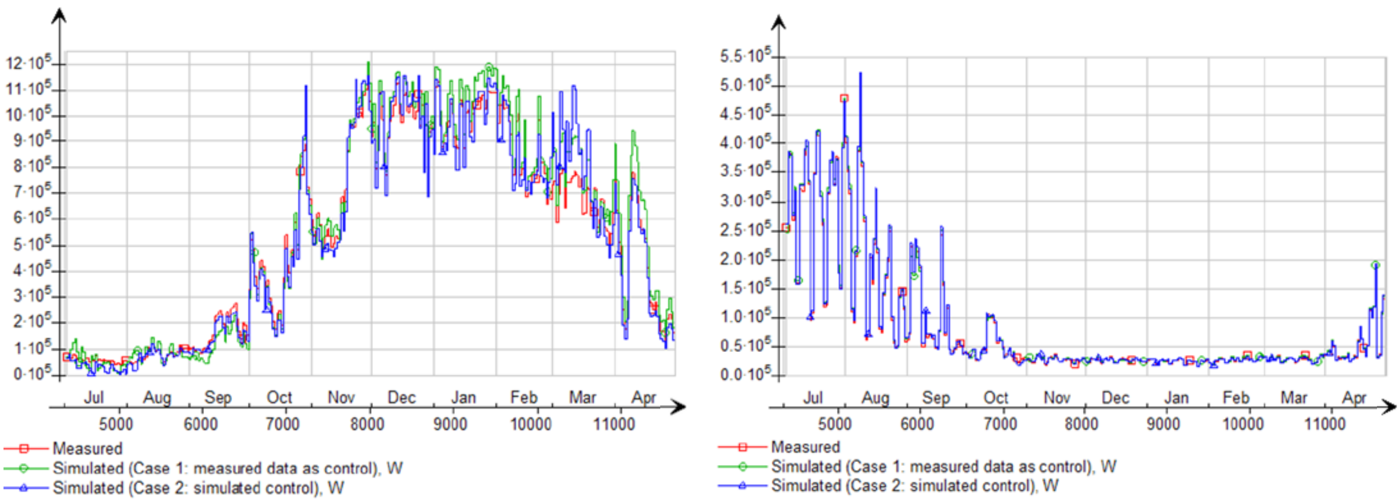

Figure 4. The graphs show the daily mean of the supplied heating and cooling from the plant. Red is measured data. Green represent Case 1 and blue Case 2.