

Final report

New heat pump and solar heating



1. Project details

Project title	New heat pump and solar heating
Project identification (program abbrev. and file)	64011-0072
Name of the programme which has funded the project	EUDP-11-I
Project managing company/institution (name and address)	PlanEnergi Jyllandsgade 1 9520 Skørping
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2. Short description of project objective and results

English:

The objective of the project is a full-scale demonstration of a combination of solar heat and heat pump together with an existing decentralised natural gas fired CHP-plant.

The demonstration plant opened the 2nd of March 2015. During the project, the heat pump plant design was optimized to reach the best possible economical and technical solution for district heating production. The system performance was measured during the first year after initial operation and it shows good agreement with the design figures. Now the experience from the demonstration project is being used in the planning and implementation of ground water based heat pump plants at other natural gas fired CHP-plants.

Dansk:

Formålet med projektet er en fuldskala demonstration af en kombination af solvarme og varmepumpe i forbindelse med et eksisterende decentralt naturgasfyret kraftvarmeværk.

Demonstrationsanlægget blev indviet d. 2. marts 2015. I løbet af projektet blev varmepumpens anlægsdesign optimeret med henblik på at opnå den bedst mulige økonomiske og tekniske løsning til produktion af fjernvarme. Anlæggets ydelse blev målt i løbet af det første år efter idriftsættelsen, og målingerne viser god overensstemmelse med designdataene. Erfaringerne fra demonstrationsanlægget bruges allerede nu i forbindelse med planlægningen og implementeringen af grundvandsbaserede varmepumpeanlæg hos andre naturgasfyrede kraftvarmeanlæg.

3. Executive summary

The project "New heat pump and solar heating" was supported by EUDP and started in 2011. The idea of the project is based on findings in the project "Naturgassens afløser" carried out for Region Midtjylland in 2010. In "Naturgassens afløser" it was found that the best solution for Rye Kraftvarmeværk to get robust against changes in the natural gas price and thereby stabilize the heat production price was to implement a combination of a solar heat plant and a ground water based heat pump plant. The combination of solar heat (fuel free), heat pump (electricity consuming) and gas engines (electricity producing) in one plant is a combination that is expected to suit an energy system with fluctuating renewable electricity production very well and stabilize the heat production price. To be able to use a heat pump primarily when the electricity prices are low because of a high share of wind power the heat pump has to be bigger than a heat pump running continuously. An investment in a bigger heat pump is not economical feasible for the district heating company because the fluctuating electricity prices represent a small part of the total electricity price including tax and transportation fees. This together with the fact that heat pumps has to be designed with a focus on district heating to be economical and technical optimized was the main reason for the need of support from EUDP to realize the project.

The work in the demonstration project was carried out in three phases:

- 1) Design
- 2) Implementation
- 3) Measuring

Phase 1) Design

In the design phase the overall system layout for the plant and the heat pump was investigated to aim for an optimised design. The design ended up as shown in the principal diagram in Figure 1.

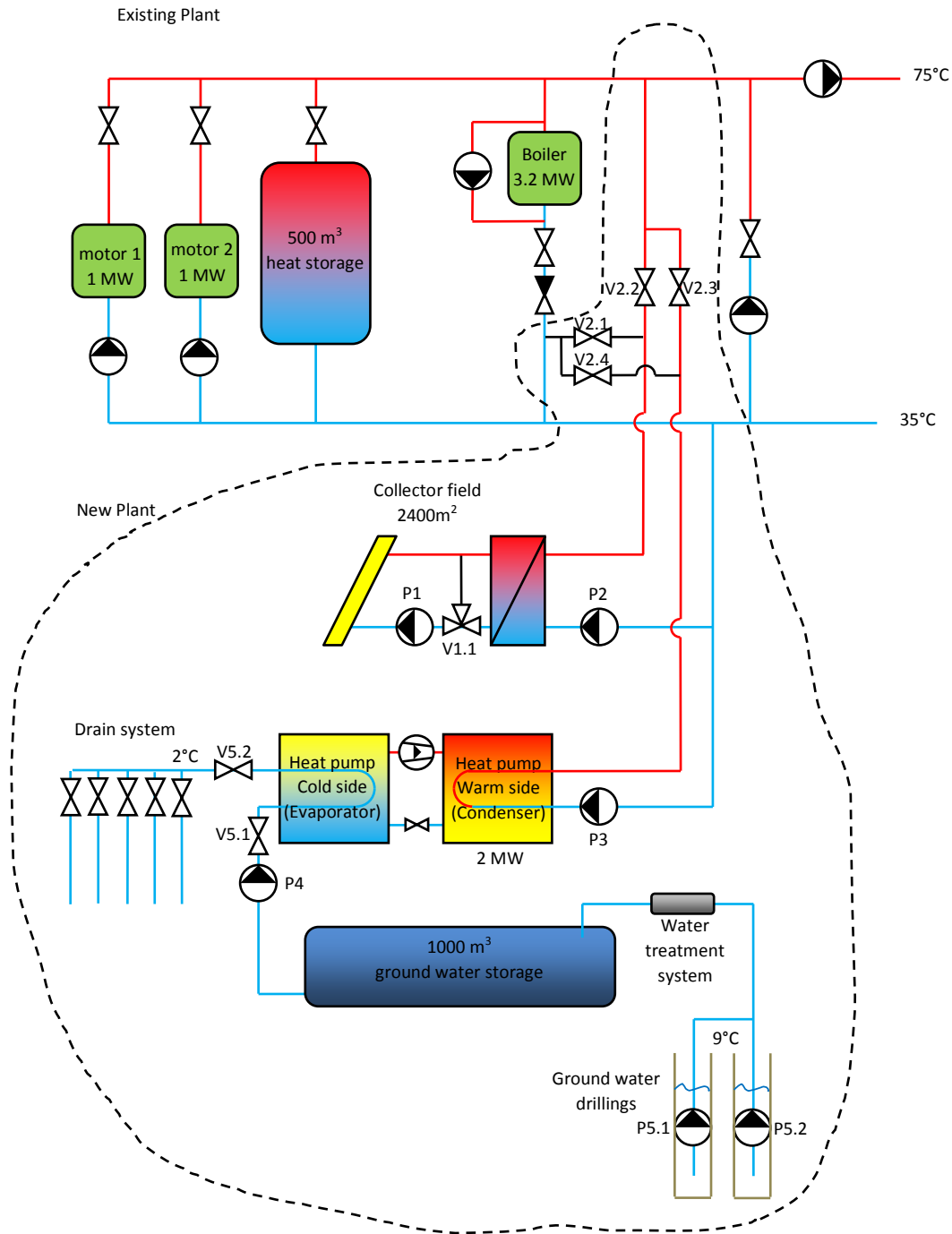


Figure 1: Principal diagram of the final plant.

Phase 2) Implementation

The implementation of the plant started in February 2014 after major delays. The implementation phase was first delayed because the ground water test drilling showed less capacity than expected which demanded a reconsidering of the plant design. Later the implementation was postponed with more than a year because of delays in the authorities' permits and even later, the operation of the heat pump was delayed because the ground water quality was insufficient and demanded a water treatment plant. The solar plant went into operation in July 2014 and the heat pump went into operation in February 2015. The plant officially opened the 2nd of March 2015.

Phase 3) Measuring

The overall plant is operated against the electricity market to reach as low heat production price as possible. In addition to this, the individual parts of the plant are operated in a strategic way to maximize the performance of each part. The performance of the heat pump plant and the solar plant has been measured since start of operation.

4. Project objectives

The aim of the project is a full scale demonstration of a combination of solar heat and heat pump together with an existing decentralised natural gas fired plant.

The demonstration plant at Rye Kraftvarmeværk is implemented and demonstrates that a combination of solar heat and heat pump together with an existing decentralised natural gas fired plant is technical feasible regarding design, implementation and operation.

4.1 Project objectives

The results of the project are:

- Design of an economical and technical optimised heat pump for district heating production replacing boiler produced heat in a "traditional CHP-system". The heat pump uses ammonium as refrigerant and ground water as heat source.
An ammonium based heat pump with ground water as heat source is designed with the aim to produce district heating at as low price as possible.
- Demonstration of the concept solar, heat pump(s) using ground water, accumulation tank and natural gas fired CHP in full scale where the heat pump(s) run in the 2000 hours with lowest electricity prices and most wind electricity.
The concept is demonstrated using not only hot water accumulation tank but also ground water accumulation tank to optimise the investment and operation of the plant against the electricity market.
- Measured results from the heat pump performance and the system performance.
Measured results are reported for the first year of operation (see section 5.1).
- Experiences with economical optimisation of the concept in the electricity market.
The experiences from the operation have continuously been used to improve the production planning system from NEAS who is balance responsible for the electricity production/consumption for Rye Kraftvarmeværk. The heat pump production is planned on a daily basis according to the spot electricity market meaning that the heat pump operates in the hours with lowest electricity prices.
- Experiences with velocity and capacity of electricity regulation.
The experiences so far is that the heat pump is able to participate in the spot market and in down regulation (it can stop within a few minutes). The heat pump is not fast enough to participate in frequency regulation. The time consumption for typical start up and shut down processes are reported in section 5.1.7. The electrical capacity of the heat pump is relatively small (app. 500 kW) and has to be pooled with other heat pumps or electric boilers by the balance responsible company.
- Development of a future concept that can be replicated on natural gas fired (also the smallest) CHP-plants.
The concept is easily replicable. A number of other CHP-plants are now in the planning process of ground water based heat pumps alone or in combination with solar plants.
- Future production of the heat pump in Denmark.
Johnson Controls will be able to use the design and experience from the heat pump in the demonstration project directly for other plants.

4.2 Implementation of the project

In the following the implementation of the project will be briefly described. A layout of the overall plant is seen in Figure 2.

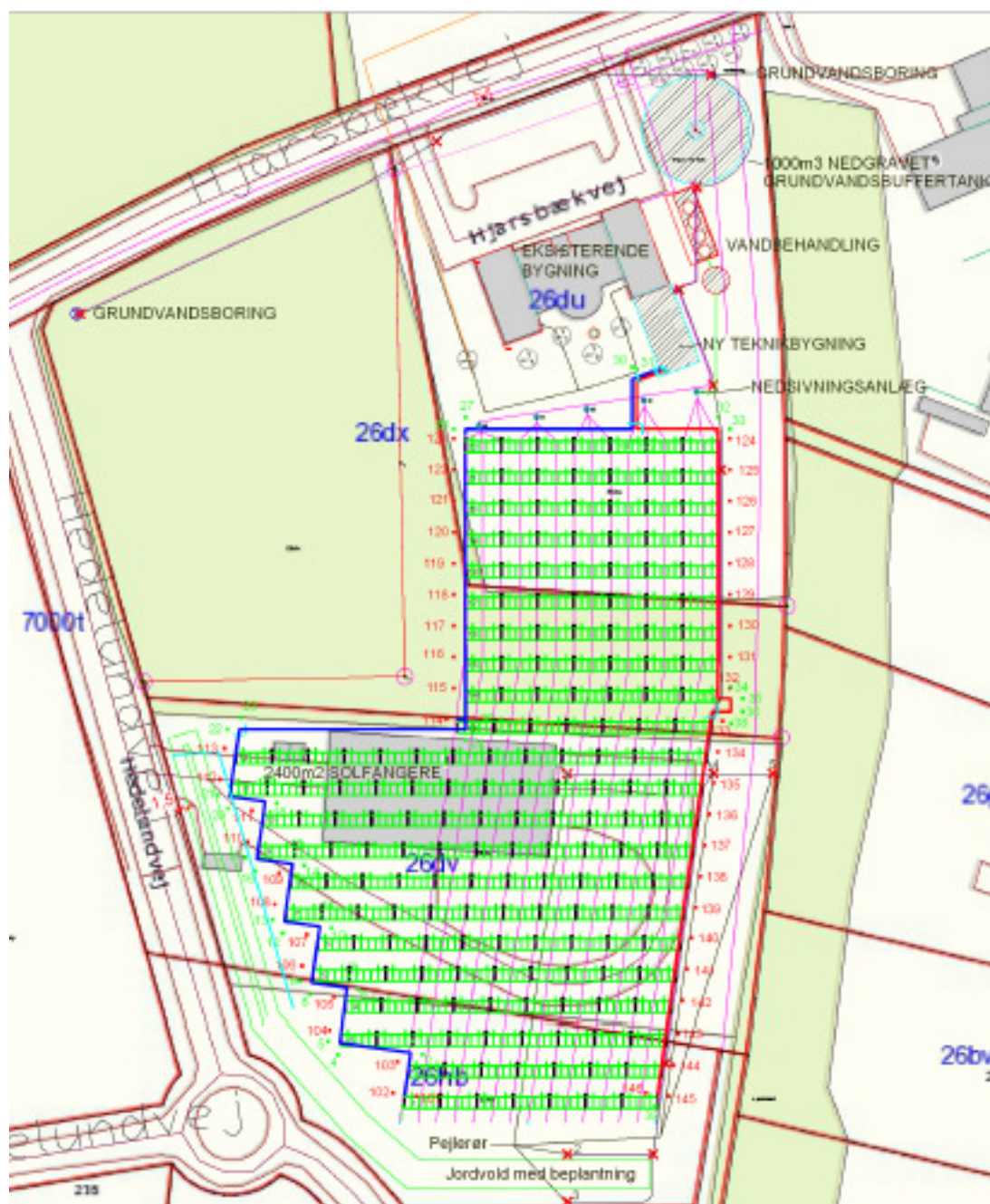


Figure 2: Layout of the plant.

4.2.1 Design and implementation of the plant

Heat pump

The design and optimisation of the heat pump was an ongoing process until end of 2013. A principal diagram of the final design can be seen in Figure 3. The plant is built as two separate ammonium cooling systems: A 2-stage system consisting of a low pressure piston compressor and two high pressure piston compressors cooling ground water from 9-5°C and a 1-stage system consisting of a low pressure piston compressor cooling the ground water from 5-2°C. On the hot side the heat pump is heating district heating water from 35°C to 75°C (nominal values) through a series of heat exchangers.

The heat pump can deliver a heat output of 2048 kW and a COP of 4,02 at nominal values. By reducing the forward temperature to 65°C the COP can be increased to 4,33.

The heat pump is placed in a new building of 82 m² together with the heat exchanger station for the solar plant.

The possibility to use the heat pump to produce cold water for the gas engines and the solar panels to improve efficiency was investigated but found economical unfeasible. When using the heat pump to cool the return water to the solar panels and heat up the supply water from the solar panels the mean temperature in the panels will decrease. This lead to an increased efficiency of the solar panels. As an example at a solar radiation of 800 W/m² a temperature set of 75/35°C can be decreased to 48/15°C by the heat pump which gives an efficiency increase of the solar panels of 10% corresponding to 150 kW from the entire solar plant. The heat pump will require app. 330 kW electricity to cool the return water from 35°C to 15°C and heat up the supply water from 48°C to 75°C which means that the added heat to the system will be 150+330 = 480 kW. Thus the system COP in this example will be 480/330 = 1,45. Therefore it is more economical feasible to use the capacity of the heat pump to cool groundwater where the COP is around 4. For the gas engines, the results are quite similar. Cooling return water for the gas engines is not feasible compared to cooling ground water.

The implementation phase was delayed as mentioned earlier but after the project was ready to order the heat pump the installation of the heat pump took place as scheduled. The initial operation of the heatpump was delayed because of issues with the ground water quality described in the following section.

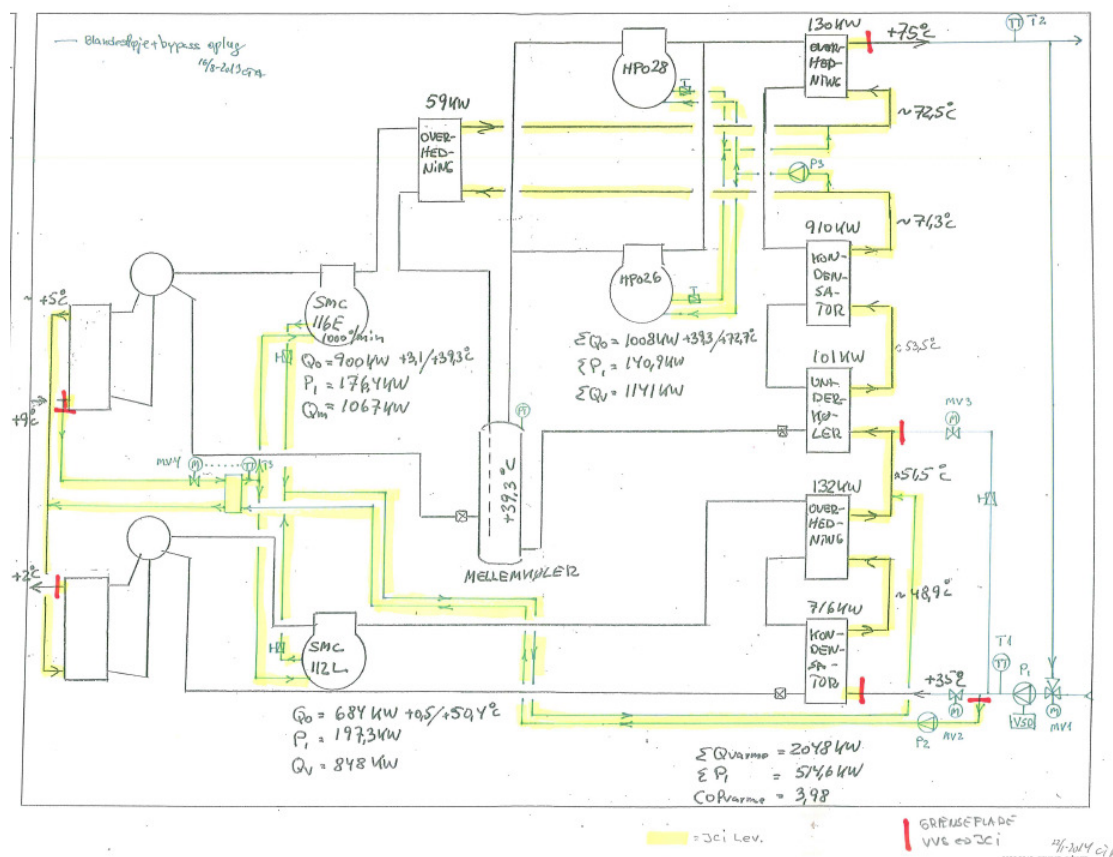


Figure 3: Principal diagram of the heat pump plant. The figures for the electricity consumption on the diagram are based on IE2 motors. In the final design IE3 motors are chosen which increases the COP from 3,98 to 4,02 at nominal values.

Ground water system

The ground water system consist of two ground water drillings, a water treatment system, a ground water storage and a drain system as seen in the principal diagram Figure 1. The intention was to design the system with ground water production drillings and injection drillings with full capacity for the heat pump (app. 200 m³/h). Information from the first test drilling indicated that this would be economically unfeasible because the capacity was less than expected and a high number of drillings (at least 8) would be necessary. To be able to make the project feasible it was necessary to reconsider the design of the ground water system. The possibility to return the water by a drain system instead of injection drillings was investigated. It was a cheaper alternative to injection but it was unclear whether the authorities could permit it. Skanderborg Kommune investigated the permission issues, and concluded that they could give the necessary authority permits. The drain system was established as 15 strings of in total 1830 m drain pipe under the solar collectors and is illustrated in Figure 4.

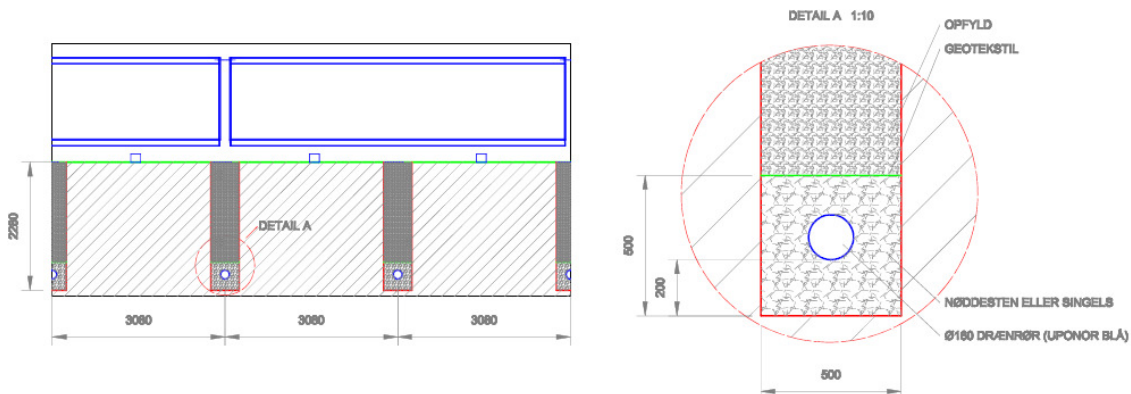


Figure 4: Section view through drain system for returning of cooled groundwater.

The ground water accumulation tank made it possible to reduce the number of production drillings to two with a capacity of 50 m³/h each. The size of the ground water accumulation tank was found to 1000 m³ from a simulation and optimisation of the plant. The tank can be filled with water from the drillings in app. 10 hours and when full it allows continuous operation of the heat pump for 10 hours.

The ground water accumulation tank was also intended to be used as a simple water cleaning tank where iron particles could settle on the bottom after aeration of the water. This water cleaning was measured to be insufficient, and therefore a water treatment system was necessary. The water treatment system was designed as a pressurized sandfilter known from cleaning ground water for drinking water.

Solar plant

The solar plant was designed from the size of the existing accumulation tank. With a size of 2444 m² the solar plant will not need any cooling during an average summer and it covers approximately 12% of the yearly heat demand. After ordering, the installation of the solar plant took place as scheduled.

Control system

The heat pump and solar plant is integrated in the overall control system of the district heating plant. The heat pump has its own control system for internal processes, but it communicates with the overall control system. The control system operates the plant fully automatic under normal conditions and it calculates through formulas the most efficient operation. This means that the heat pump and the solar plant operates at as low temperatures as possible taking into account if there are other units producing heat or stored heat in the accumulation tank that can be mixed with lower temperature from the heat pump or solar collector. The functional description of the control system is attached (in Danish) as appendix 8.2.

4.2.2 Budget and actual cost

Table 1 shows the budget and actual cost for the demonstration plant. The actual cost is app. € 200,000 higher than the budget mainly because of the unforeseen investment in a water treatment plant.

Topic	Budget	Actual cost
Heat pump and solar plant	€ 1,688,266.67	€ 1,676,724.04
Ground water plant	€ 401,066.67	€ 441,389.71
Miscellaneous	€ 230,666.67	€ 169,560.43
Water treatment plant	€ -	€ 255,707.43
Total	€ 2,320,000.00	€ 2,543,381.61
EUDP support, hardware	€ -368,000.00	€ -368,000.00
EUDP support, salary, Gl. Rye	€ -27,333.33	€ -27,333.33
Region Midtjylland support water treatment	€ -	€ -6,666.67
Energy savings certificates	€ -31,333.33	€ -65,700.00
Total including support and energy savings	€ 1,893,333.33	€ 2,075,681.61

Table 1: Budget and actual cost for the demonstration project for Rye Kraftvarmeværk.

5. Project results and dissemination of results

The CHP-plant has a data acquisition system collecting data from the plant's numerous gauges and machines. Data from this system is analysed and presented in the following section for the period the heat pump has been installed. This is in order to evaluate the performance of the plant with both the heat pump and solar plant added as new heat producing units.

5.1 Monitoring results

The main purpose of this section is to document the heat production of the individual heat producing units of the CHP-plant, and evaluating this according to preceding theoretical calculations on the expected distribution of the heat production among the units.

The heat producing units differs greatly in terms of the price and accessibility of their energy input (fuel) and the value of their product (heat and electricity). Therefore it is also of interest to look at which units produce heat at which point in the season. However, there exists too much data in the data sets to graphically depict the heat output of the various units throughout the period of interest. Instead, this investigation is split up and the performance of each unit is studied during the given period of time.

Results in this section solely relies on the data logged in CHP-plant's data acquisition system. However, gaps of missing or incorrect data have been identified in the data sets extracted from the system. This can be the source of uncertainty with respect to the magnitudes of the production from the individual units in relation to the total delivered heat from the CHP-plant. In an attempt to correct this and provide a more realistic picture of the heat production, data have been restored by calculating the heat production from other parameters in the missing periods in time.

The time period chosen for the evaluation of the heat producing units is: **February 23rd 2015 to December 31st 2015**. The reason for this is that the heat pump is first put into service around this time, and the relevant data does not exist before this point.

5.1.1 Total heat production of CHP-plant

The heat productions of the individual units are presented in table 2 and graphically in figure 5.

The values presented in table 2 have been calculated from measured data from the CHP-plant where the gaps of missing data have been filled with data calculated from other system parameters such as flow and temperatures in and out of a unit.

The heat produced is converted into MWh by calculating an average value for the output heat of a heat producing unit in the given period of time, which is then related to the total number of hours included in the period. Missing data are replaced by the number "0" so the average is not artificially increased.

This approach is chosen because exact data regarding the number of operation hours for all the individual units is not present. If this had been the case, this number could instead be related to the output power of the heat producing unit to yield the actual amount of energy produced during the hours of operation. This would otherwise have been a more precise approach.

Table 2 is constructed by converting the following measurement data into energy:

- Heat pump: Value from energy gauge placed on the plant side of the heat pump (NDB640CQ001). Missing data are replaced by multiplying the power consumption of the heat pump by the average COPH-value.
- Solar heat plant: Value from energy gauge placed on the plant side of the heat exchanger connected to the solar heat plant (WTA650CQ001). Missing data are replaced by using the water flow gauge and temperatures difference across the heat exchanger (WTA650CF001, WTA650CT002, WTB650CT001). Properties of water are evaluated at 60 °C for converting the volume flow into a mass flow.
- Combustion engines: Total heat production from both engines is used (Aktuel_varme_prod). The split in individual production is the ratio of the electrical power production from their generators (Aktuel_El_effekt_motor_1, Aktuel_El_effekt_motor_2).
- Boiler: A calculated parameter for the given output power is used (Beregnet_kedeleff). Missing data are replaced by using the district heating return water flow gauge and temperature differences across the boiler. The flow gauge (Flow_kedel_1) is placed before a branching of the flow to the boiler and to the heat pump and solar plant. Therefore calculations are cross referenced according to the opening position of the valve placed prior to the boiler (Ventil_kedel_POS). The inlet temperature is the water temperature as it returns to the CHP-plant from the grid (Returtemperatur_fra_by). Outlet temperature is given as the outlet temperature from the boiler (Temp_fra_kedel).
- Heat delivery from plant: A calculated parameter for this is used (Aktuel_varme_til_by).

It is evident from table 2 that the heat pump by far delivers the largest part of the total heat production. Together with the solar heat plant they represent 82.3% of the heat produced during the period in question.

Adding up the individual heat production from the units, the sum comes very close to the total amount of heat delivered to the grid from the CHP-plant. The remaining 266 MWh could be due to both uncertainties in the calculation approach based on average values and on different amounts of heat stored in the plant's heat storage at beginning and at the end of the period.

Unit	Measured and restored data	
	MWh	%
Heat pump	4,168	59.4%
Solar heat plant	1,063	15.2%
Combustion engine 1	90	1.3%
Combustion engine 2	88	1.2%
Boiler	1,602	22.9%
Sum	7,012	100%
Heat delivery from plant	7,278	

Table 2: Individual and total heat production of the CHP-plant based on logged data with restored data replacing gaps of missing data. Period of interest: February 23rd 2015 to December 31st 2015.

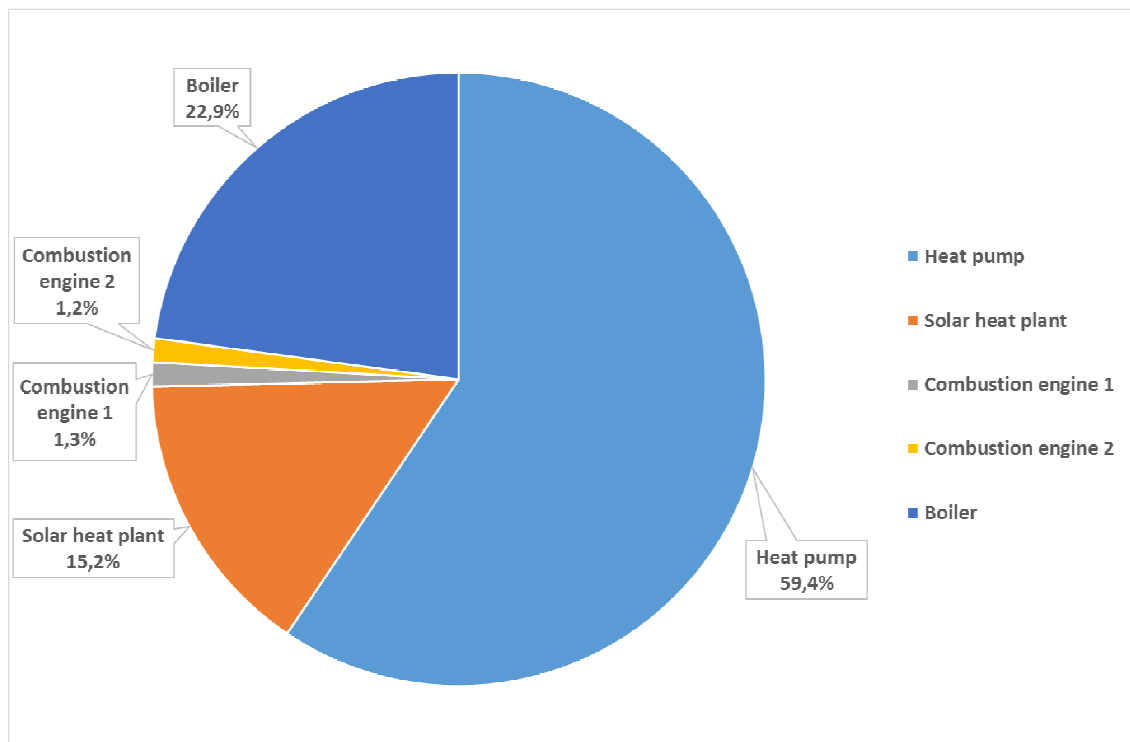


Figure 5: Graphical representation of the data presented in table 2.

5.1.2 Total heat production compared to theoretical calculations

Values from table 2 are compared to the calculated values for the presumed heat production in table 3. The results are calculated the plant simulation software "EnergyPRO" from given conditions regarding the CHP-plant. Furthermore, a COP_h of 4.1, market price of electricity of 2013 and energy tariffs and taxes of 2014 are used as conditions.

Calculated values are also presented graphically in figure 6.

The calculations for the theoretical heat production is carried out as an annual production. As the period under consideration here is less than a year the calculated data are adjusted to this time period of 312 days or 0.855 year. The individual heat productions per unit are multiplied by the factor 0.855 in order to get the values corresponding to the given time period. The two different basis will then stretch over the same amount of time. However, the reduced amount of days in the theoretical basis is distributed evenly across the entire year, but the measured basis are missing days only in the winter months of January and February. This may be a source of error with regard to the results.

If we first of all consider the amounts of energy produced, the total delivery to the grid is 693 MWh less than the expected 7,971 MWh. While larger gaps of missing data have been

identified and restored, there are most likely still minor gaps during the time period, which could explain some of the lack in meeting the expected value.

Naturally, the individual contribution from the units are smaller as well except for the boiler, which have produced 102 MWh more than expected. The solar heat plant and the combustion engines are fairly close to their expected values, but the heat pump is as much as 1144 MWh below the expected. Even if the extra production of 102 MWh from the boiler is subtracted it is still fairly off target.

However, when expressing the distribution of heat production between the units in terms of percentages most of the values are not far off. The heat pump for instance is only about 7% off and the solar plant ~3%. The combustion engines still only make a marginal contribution, while the boiler is around 4% off. This is partly due to the total heat production being less than expected.

In terms of the results of table 3, please bear in mind that while they rely on measured data, the values are still calculated into amounts of energy by average values over time period, which undoubtedly will introduce an error of some magnitude. However, it is the best information available about the performance of the system over a longer period of time, and therefore a comparison to theoretically calculated is still relevant.

Unit	Measured and restored data		Theoretically calculated data	
	MWh	%	MWh	%
Heat pump	4,168	59.4%	5,312	66.6%
Solar heat plant	1,063	15.2%	937	11.8%
Combustion engine 1	90	1.3%	121	1.5%
Combustion engine 2	88	1.2%	100	1.3%
Boiler	1,602	22.9%	1,500	18.8%
Sum	7,012	100%	7,971	100%
Heat delivery from plant	7,278		7,971	

Table 3: Individual and total heat production of the CHP-plant based on logged data with restored data replacing gaps of missing data, and data from preceding theoretical calculations.

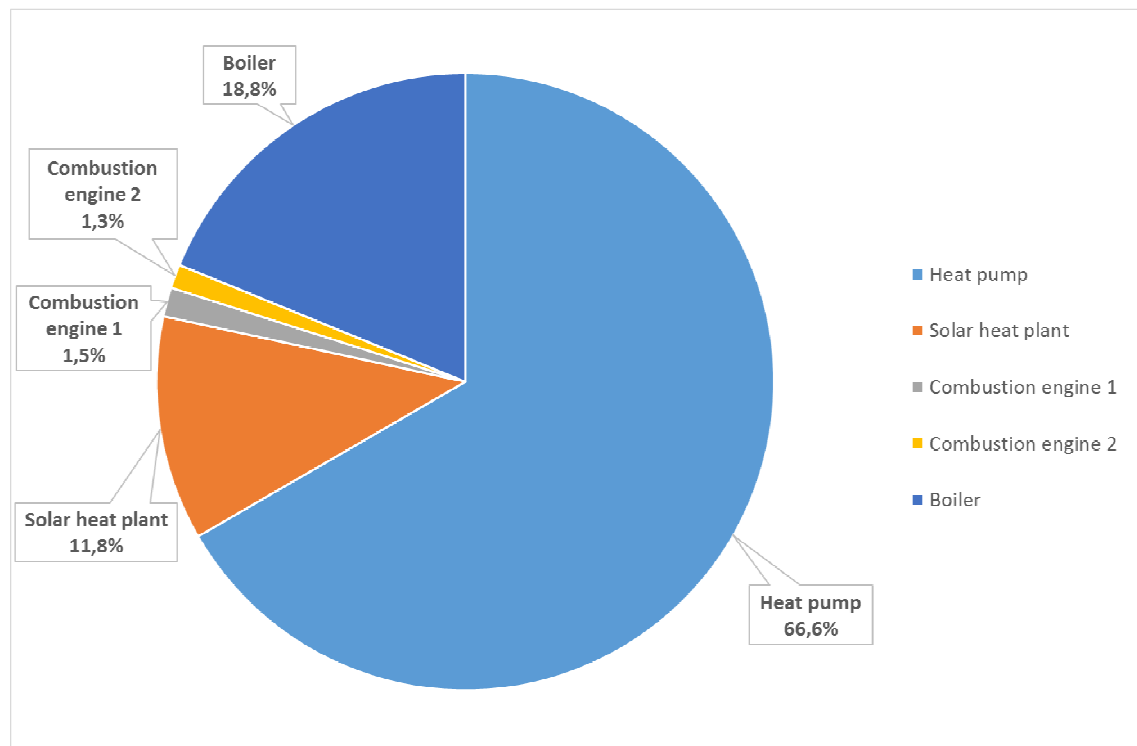


Figure 6: Graphical representation of the theoretically calculated heat production of the CHP-plant.

5.1.3 Heat pump

The heat pump is evaluated in terms of the hot side or heat pump COP (COPh) and in- and output power. COPh is calculated from the electric power consumption of the compressors (VP_effektforbrug) and the output power in terms of heat (NDB640CQ001).

COPh varies along the time period and is naturally "0" when the heat pump is not running. However, it is of interest to examine the COPh when the system is running, and in this respect only the data points reflecting this should be taken into consideration. The calculated average COPh for all data points included in the time period is 1.43 based on average values as mentioned above.

As the data is logged for every 5th minute and the possibility of a time lag between the power consumed by the compressors and the output power in form of heated water is present, the COPh can have rather large jumps. This is shown in figure 7 where the unfiltered data for the COPh is presented up to COPh = 30. The data showed values as large as 1450 for COPh which of course is an unrealistic data point. If all data points with COPh < 0.2 are ignored the average COPh is 4.54.

However, start-up and shutdown is a part of the realistic heat performance so all values related to this cannot be ignored altogether. If the data for COPh is filtered so that values lower than 0.2 and higher than 10 are discarded, the most extreme values are avoided and the realistic operation of the heat pump is reflected. When doing so the COPh is 3.74, which is meant as being a realistic average across the time period. This filtering of data with both a lower and an upper bound is showed in figure 8 along with the average COPh of 3.74. Here it is also evident that the variation in COPh during operation is of minor magnitude as there is a clear locus of data points.

The consumption of electric power for the compressors and the output power are presented in figure 9. The largest gap appearing in the time period is the gap mentioned earlier in this section for which data have been restored. The largest variations in output power are placed in the first months of operation, but otherwise the heat pump has a fairly constant output for a large part of the year.

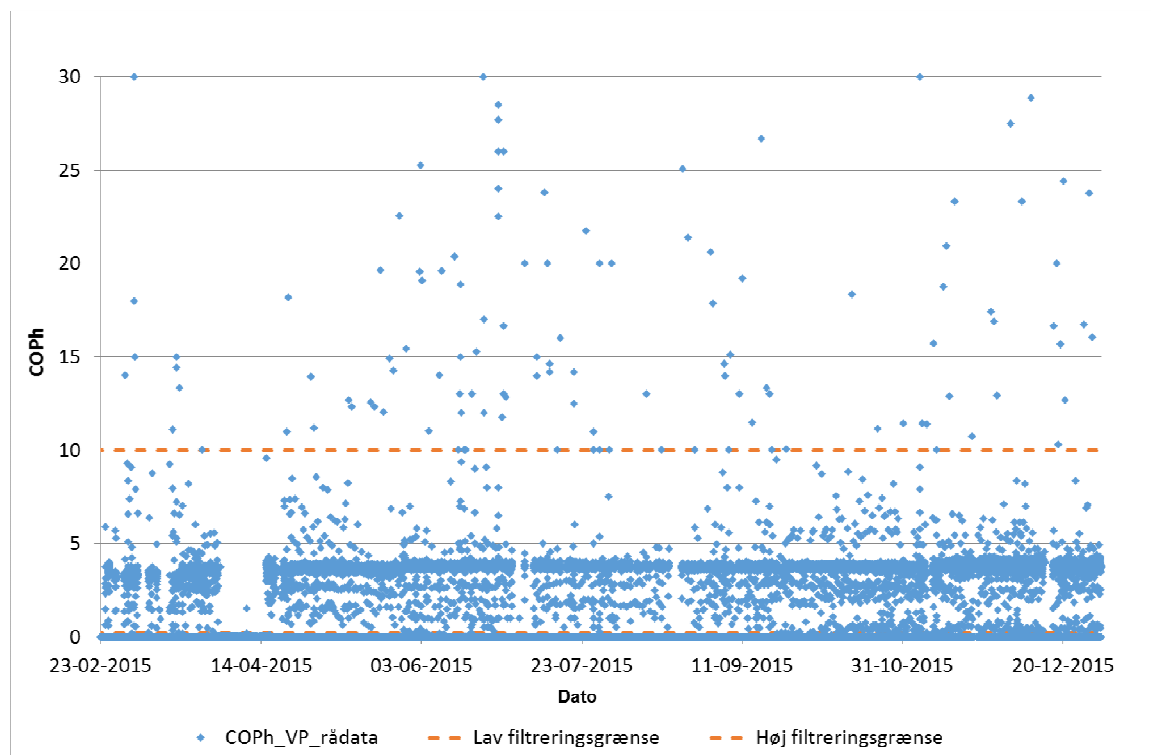


Figure 7: COPh for the heat pump calculated with unfiltered data.

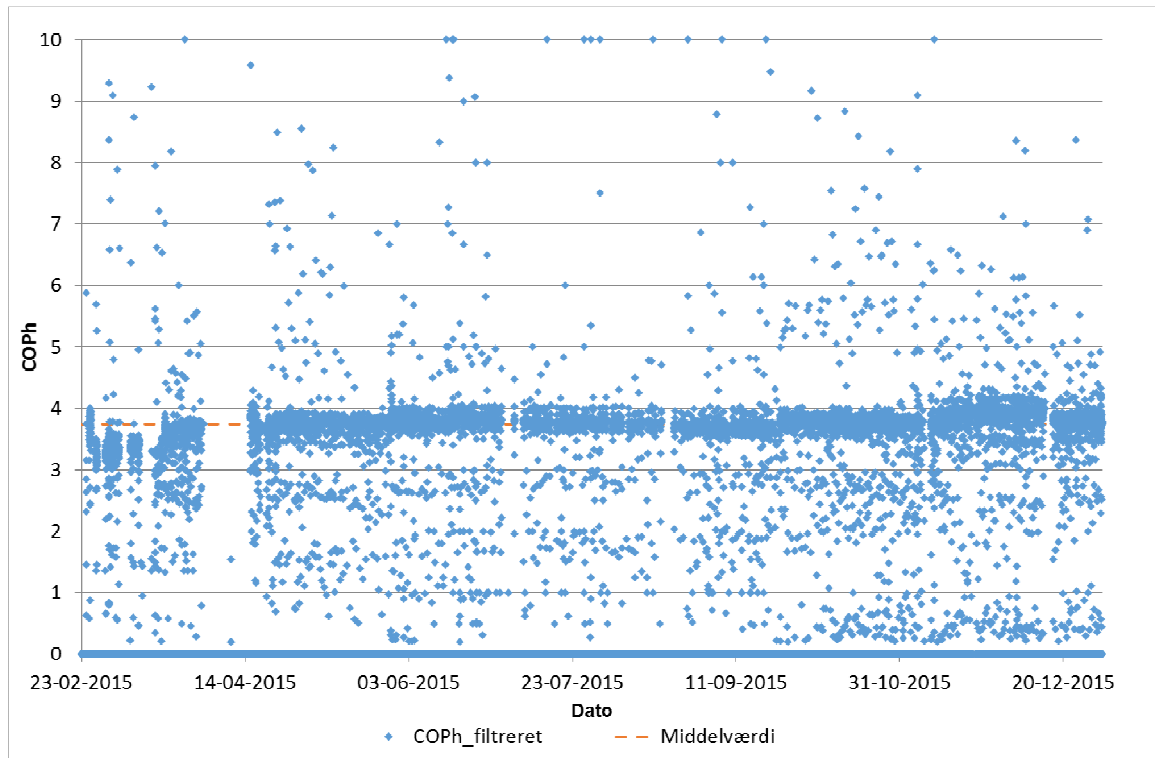


Figure 8: COPh for the heat pump calculated with filtered data: $0.2 < COPh < 10$. Average value showed through the locus of data points.

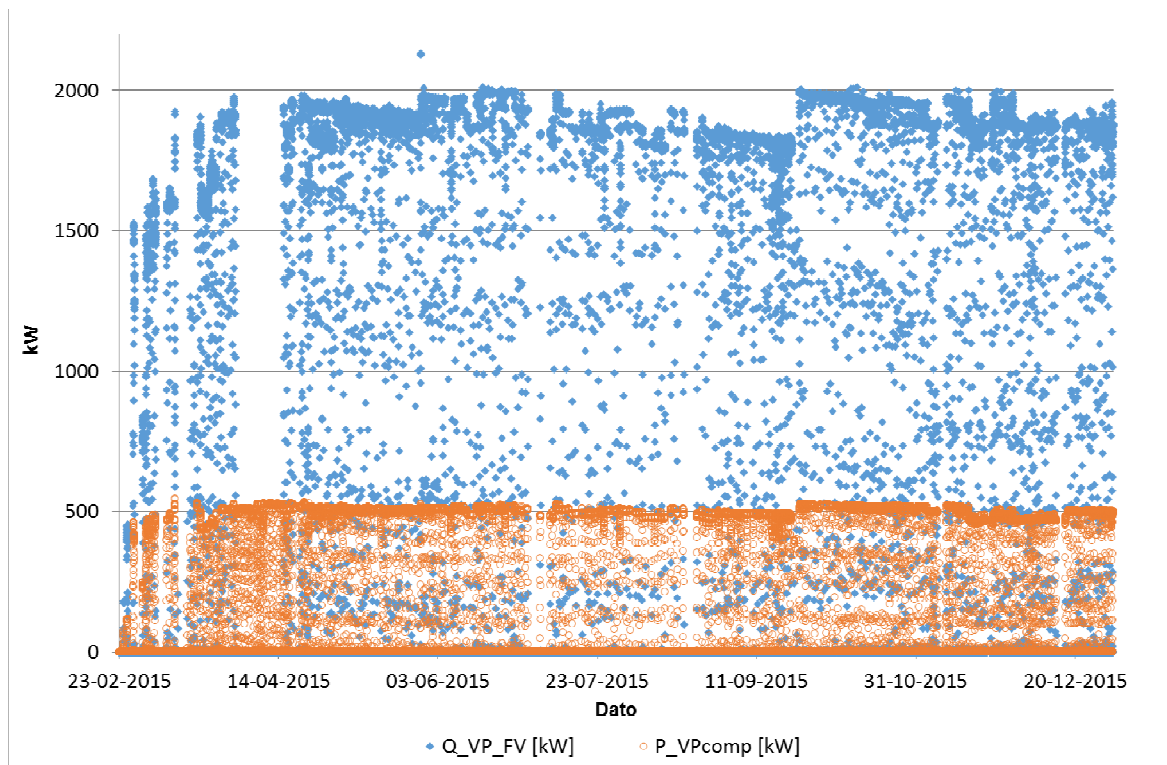


Figure 9: Power consumption by the compressors of the heat pump depicted along with the output power on the water side.

5.1.4 Solar heat plant

In the following, the output power in terms of heat, in- and output temperatures, and flow are presented for the water side of the solar heat plant. Output power data is acquired from an energy gauge (WTA650CQ001), water temperatures in and out of the heat exchanger connected to the solar plant (WTB650CT001, WTA650CT002), and the water side flow meter (WTA650CF001).

Considering figure 10 the missing data as discussed earlier in this section is clear when comparing with the gradual declination of output power and temperature as seen in the fall of 2015. This is more obvious from figure 11 which show the flow meter, output temperature and valve position of valve WTA650AA006. Figure 11 is actually missing the input temperature, but this is shown in figure 12 instead. If there is a flow and a temperature difference across the heat exchanger then heat must be transferred.

The output power with restored data and valve position are depicted in figure 13.

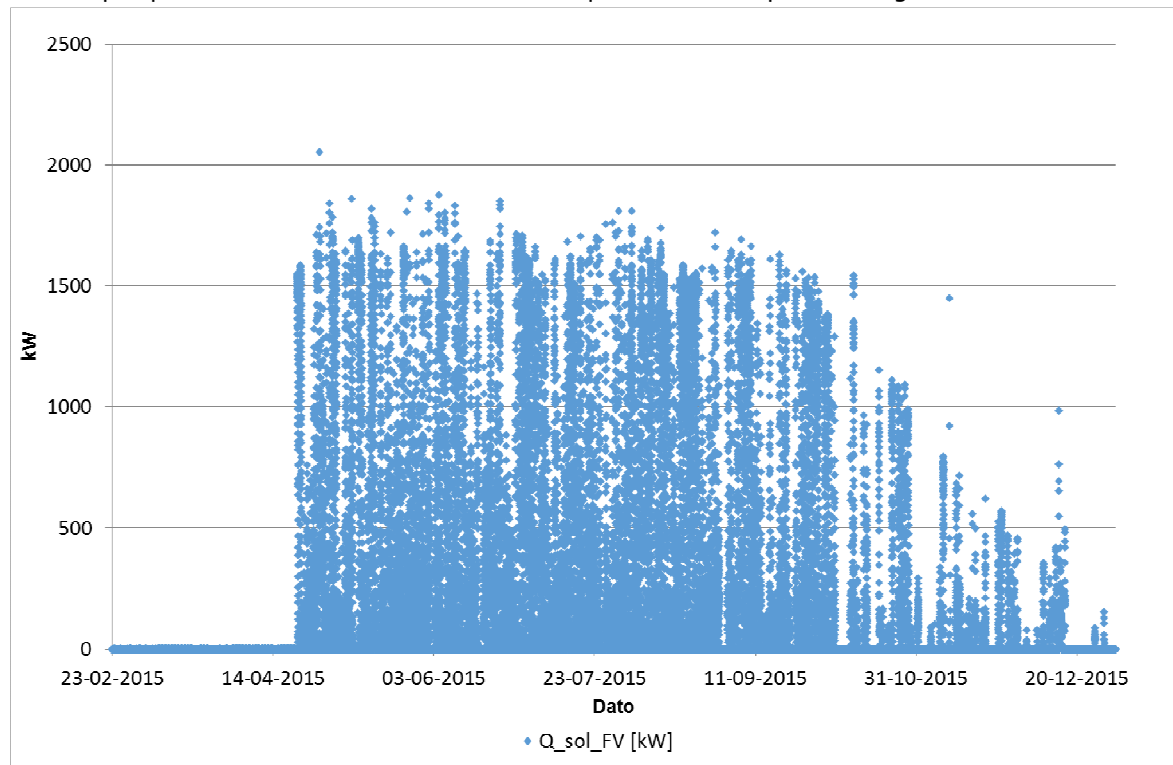


Figure 10: Output power of the solar heat plant during the time period. Data missing in the first part of the period.

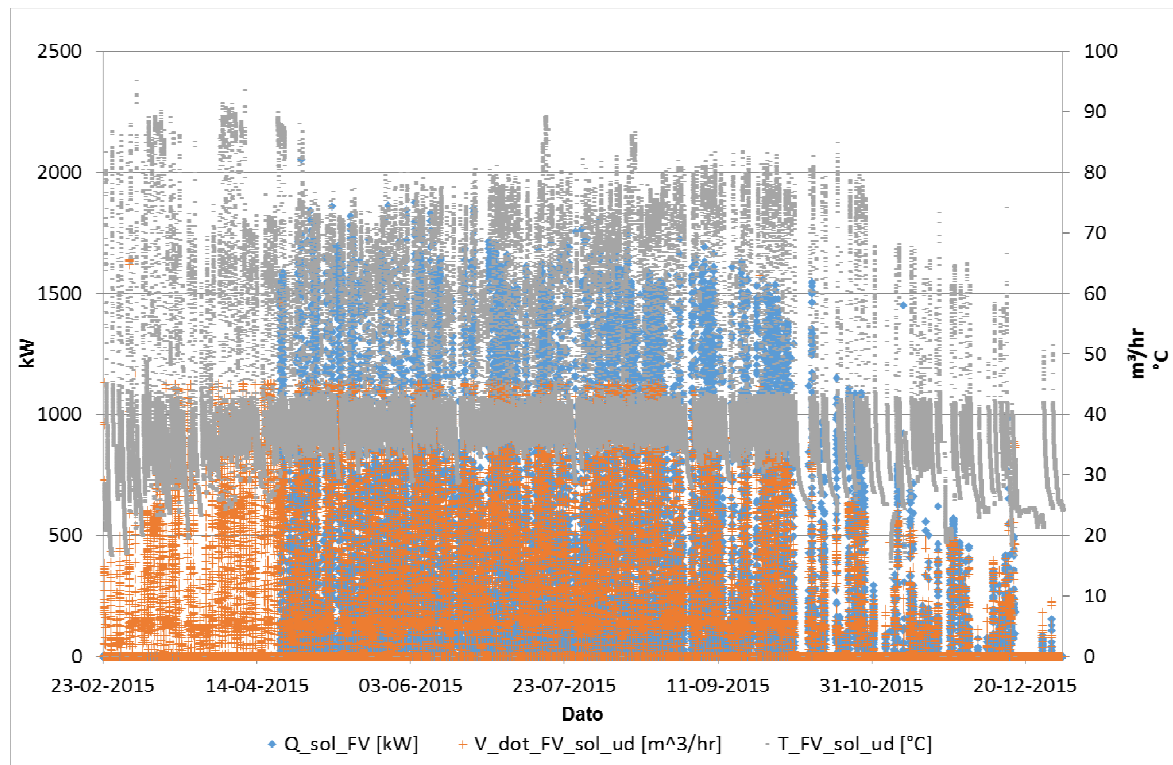


Figure 11: Output power, output temperature and flow for the water side of the heat exchanger connected to the solar plant. Missing data in the first part of the period.

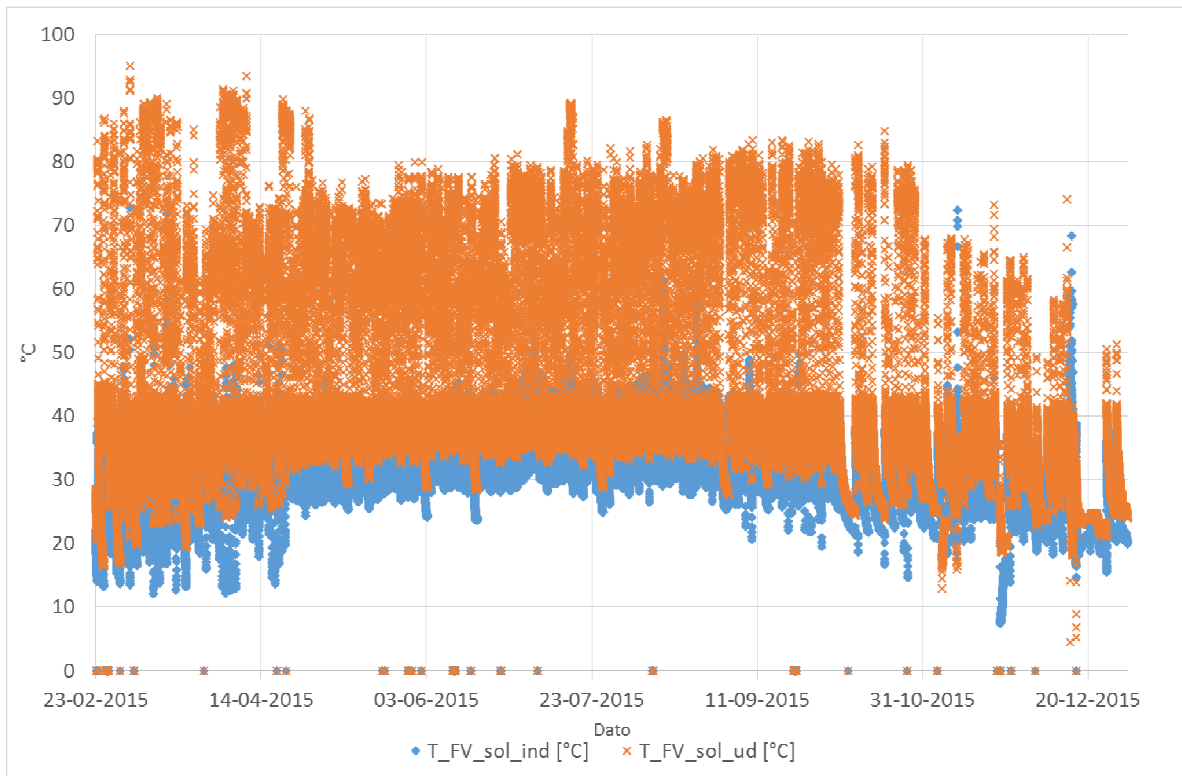


Figure 12: Input and output temperatures of the water side of the heat exchanger connected to the solar heat plant.

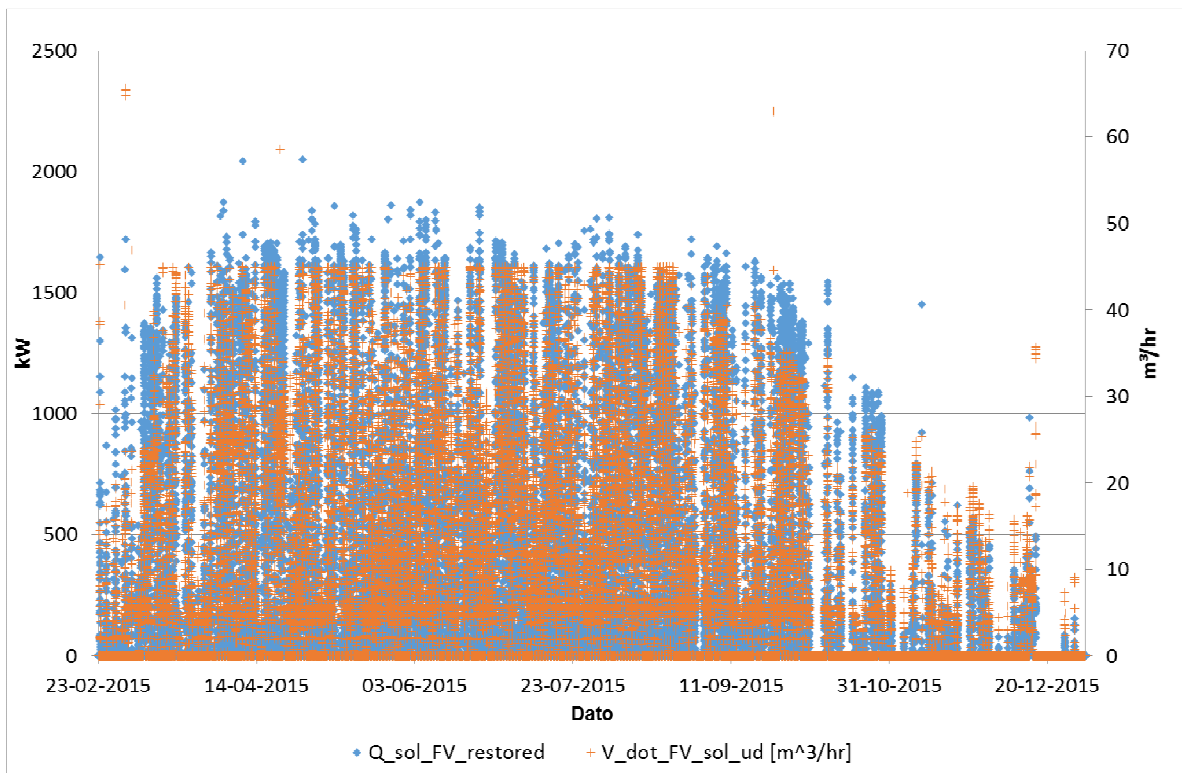


Figure 13: Output power with restored data and the flow rate of the water side of the solar heat plant.

5.1.5 Heat delivery from plant

A graphical representation of the heat delivery and flow from the CHP-plant to the grid during the time period is given in figure 14 in Appendix 8.1. The shape of the curve is as expected with a large demand for heat during the winter months and a low demand during summer.

5.1.6 Combustion engines

The total output power in terms of heat and in terms of electrical power produced each engine are presented in figure 15 in Appendix 8.1. Furthermore, the market price of electricity in western Denmark during the time period is included in the plot. As expected, the engines are only running when the market price is at a high level, and they primarily run during the winter season.

5.1.7 Boiler

Finally, the output power in terms of heat produced by the boiler during the time period is shown in figure 16 in Appendix 8.1. The gap of missing data is clear when compared to the plot with restored data in figure 17. The boiler is primarily used during the winter season where the demand for heat is greater. The operation time during the remaining part of the year is minor.

5.1.8 Start-up and shutdown time of the heat pump

The ability of fast load adjustment is studied in the following.

In order to evaluate the agility of the heat pump in terms on fast start-up and shutdown, a few samples have been selected along the duration of the period, which are presented in table 4. Due to time interval of 5 mins in the data sets the time resolution is a bit coarse for this purpose so please bear in mind that the values presented in the table have an uncertainty of +/- 5 mins.

There is a large reduction from the first to the second sample. The reason for this is most likely the alteration of timers in the software controlling the heat pump, which was tested during a visit to the CHP-plant on 21-04-2015. How large the reduction can be made remains uncertain, but a heat pump installation like the one in question will have a natural lower limit.

The heat pump consists of multiple compressors, heat exchangers and separator tanks just to mention some of the large components of the system. The heat pump is designed to first build up pressure in one part of the system before more compressors can start up and then increase the load. The variation in pressures across the system must be within a certain range to avoid setting off low- or high pressure alarms. Increasing the load must therefore be done gradually, which sets some lower limit for the start-up time.

Because of this, it is not fair to compare start-up and shutdown times for a heat pump system like this to the equivalent of e.g. an electrically heated boiler, which is able to increase the load quite fast.

Date	Start-up	Shutdown
	mins.	mins.
19-03-2015	~70	~30
25-04-2015	~25	~15
23-06-2015	~25	~15
18-12-2015	~30	~15

Table 4: Samples of approximate start-up and shutdown time of the heat pump. Time intervals of 5 mins.

5.2 Dissemination of results

Rye Kraftvarmeværk has information of the plant and photos from the implementation phase on their webpage: www.ryekv.dk.

Several decentralized CHP-plants from Denmark has visited Rye Kraftvarmeværk and had a presentation of the demonstration plant.

There has been an article of the project in the journal "Fjernvarmen"

The project is included as a case in the report: "Udredning vedrørende varmelagrings-teknologier og store varmepumper til brug i fjernvarmesystemet" carried out for the Danish Energy Agency.

The project has been mentioned in Danish media, for instance TV2/Østjylland.

PlanEnergi has for instance presented the project at:

Dansk Fjernvarmes ERFA-groups:

- Dansk Fjernvarme meeting in ERFA-group for straw, Kolding, 14. November 2014
- Dansk Fjernvarme meeting in ERFA-group for small natural gas fired CHP-plants, Middelfart, 20. May 2014

IDA Energiteknisk gruppe

- Aalborg, 18. March 2014

6. Utilization of project results

The concept heat pump and solar heat combined with decentralized CHP-plants contributes to realization of Danish energy policy objectives, because it utilizes solar energy for heat production and it contributes to the energy system by using electricity in periods with cheap electricity prices (high wind production). In periods with high electricity prices (lack of wind production), the concept is able to produce electricity instead of using electricity.

PlanEnergi utilize the results obtained in the project in marketing to costumers who are interested in projects with heat pump and/or solar heating. PlanEnergi can use the experience from the project in planning and designing future projects. The project will be used for presentations at meetings and workshops arranged by Dansk Fjernvarme.

Johnson Controls utilize the results in direct marketing to district heating companies interested in heat pumps.

The Danish Technological Institute utilize the results to keep their position in the field of heat pumps and continuously be able to support producers in the field.

None of the partners are expecting to take out patents or has taken out patents.

The demonstration project is replicated by other decentralized district heating plants, which are now planning for similar plants. Examples of plants are:

- Farstrup-Kølby Kraftvarmeværk – planning for a heat pump with ground water as heat source.
- Dronninglund Fjernvarme – planning for a heat pump with ground water as heat source in combination with an existing solar plant.
- Præstø Fjernvarme – planning for a heat pump with ground water as heat source.
- Broager Fjernvarmeselskab – planning for a heat pump with ground water as heat source in combination with an existing solar plant.

PlanEnergi is involved in the planning and implementation of these plants.

7. Project conclusion and perspective

The demonstration project has shown that the concept heat pump and solar heating in combination with decentralised CHP-plants is technical feasible. It also shows that it is possible to obtain a good COP from a heat pump even though the heat source is at a relatively low temperature and the heat supply is at a relatively high temperature, which is very important for the economic feasibility of heat pump projects for district heating.

The project is expected to influence future development in the following ways:

- Help the energy system by using electricity when prices are low (power to heat) and produce electricity when prices are high.
- Stabilize and minimize the heat production cost for natural gas fired CHP-plants.
- Facilitate further development in heat pump plants for district heating making the feasibility better.

8. Appendix

8.1 Monitoring results

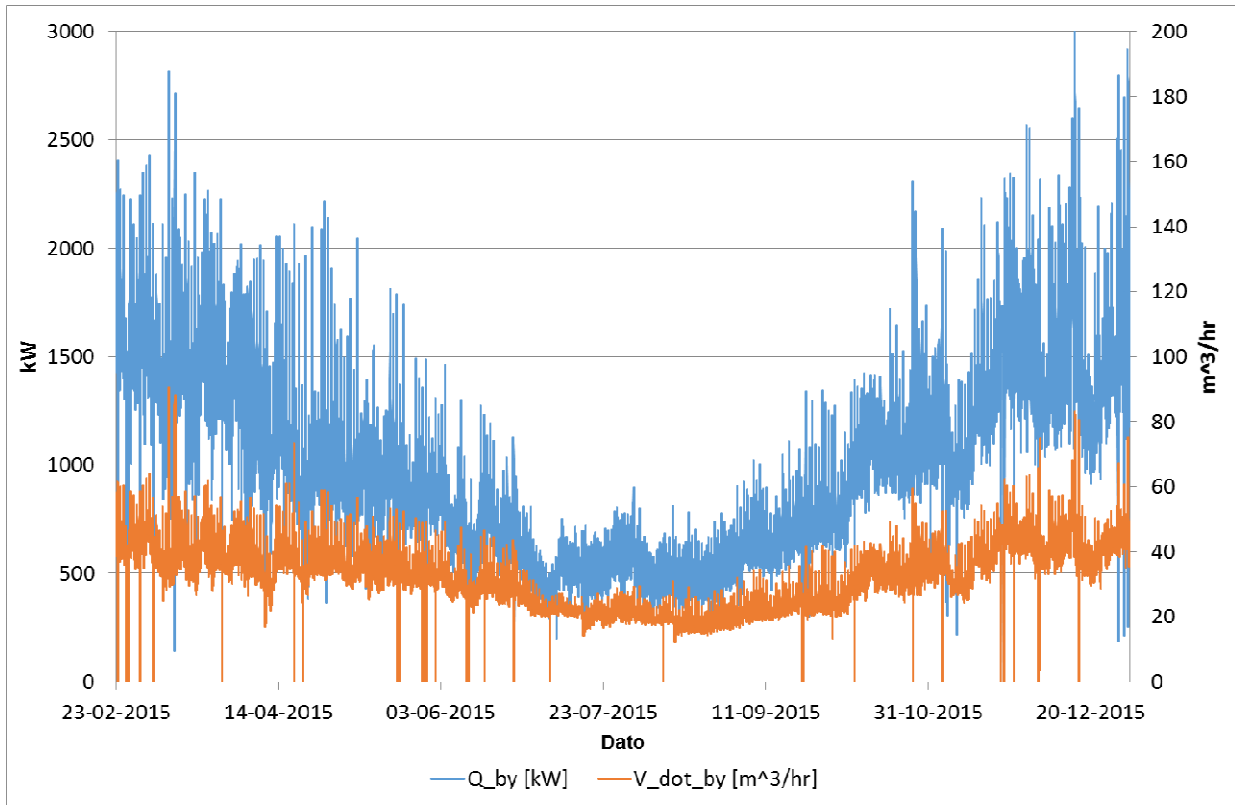


Figure 14: Heat delivery and flow from the CHP-plant to the grid.

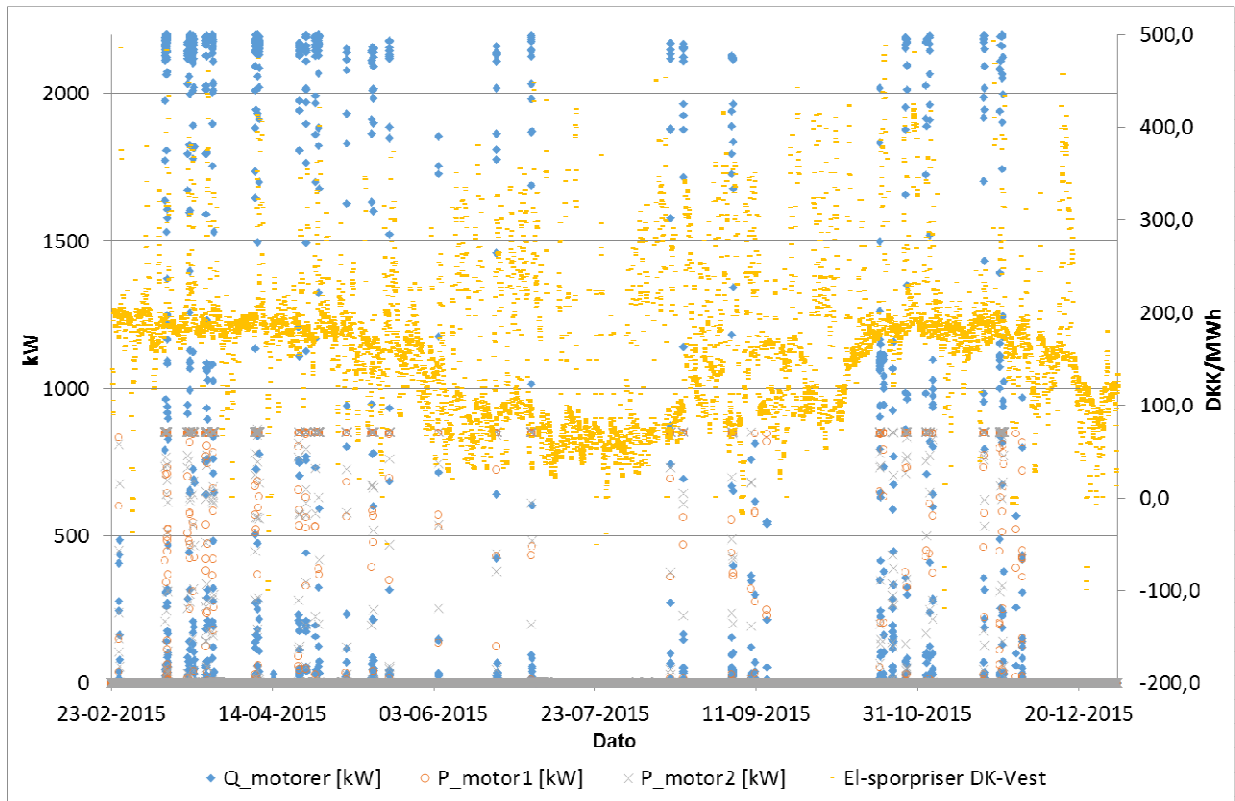


Figure 15: Total output power in terms of heat and in terms of electrical power produced each engine. On the right axis: the market price of electricity in western Denmark during the time period.

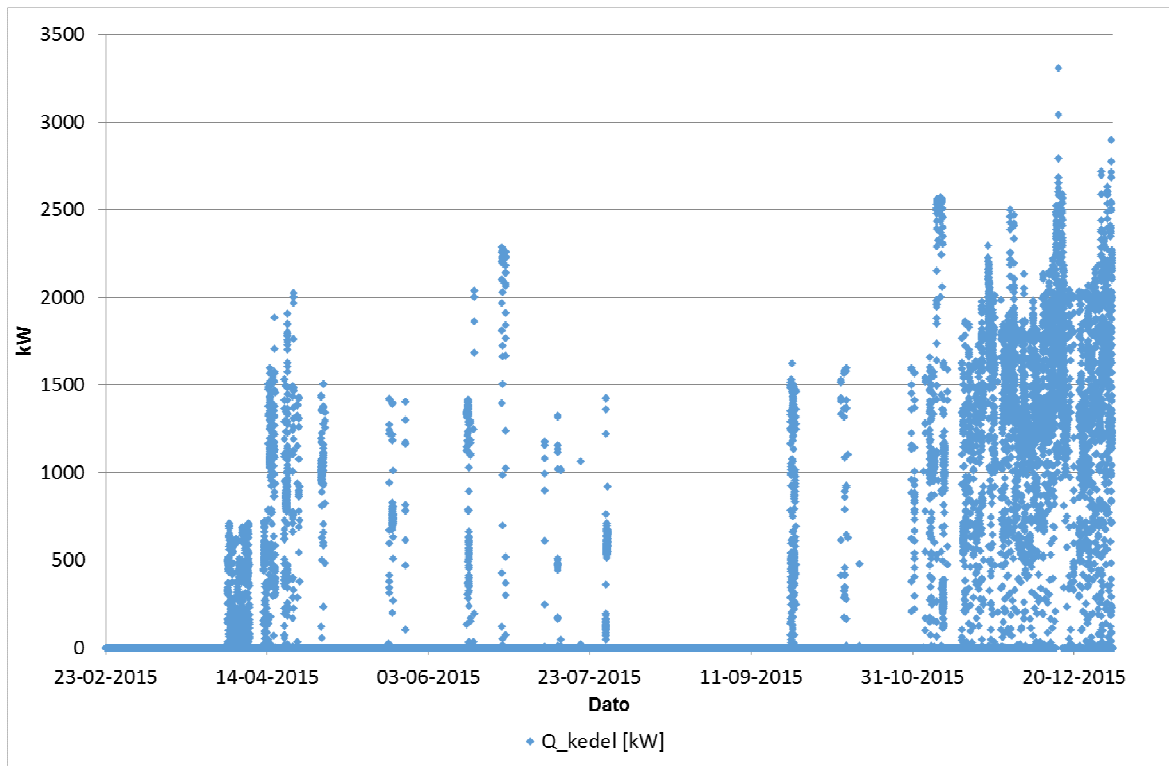


Figure 16: Output power in terms of heat produced by the boiler. Data is missing at the beginning of the time period.

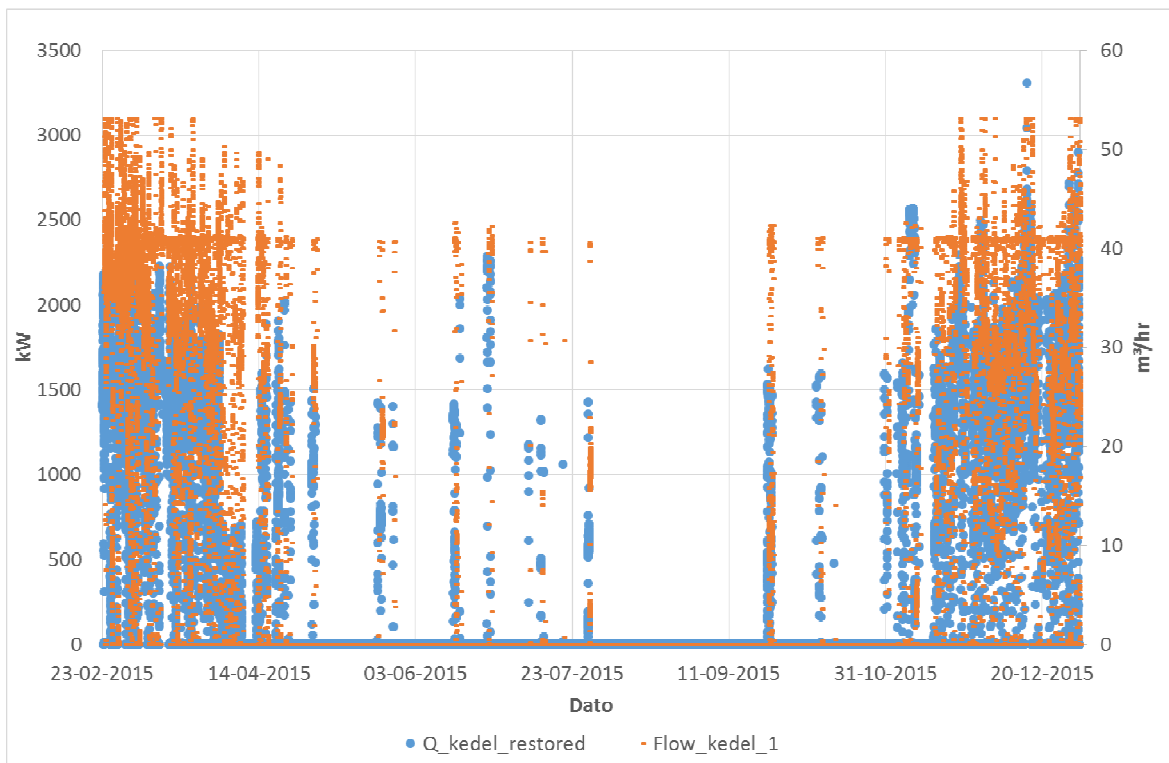
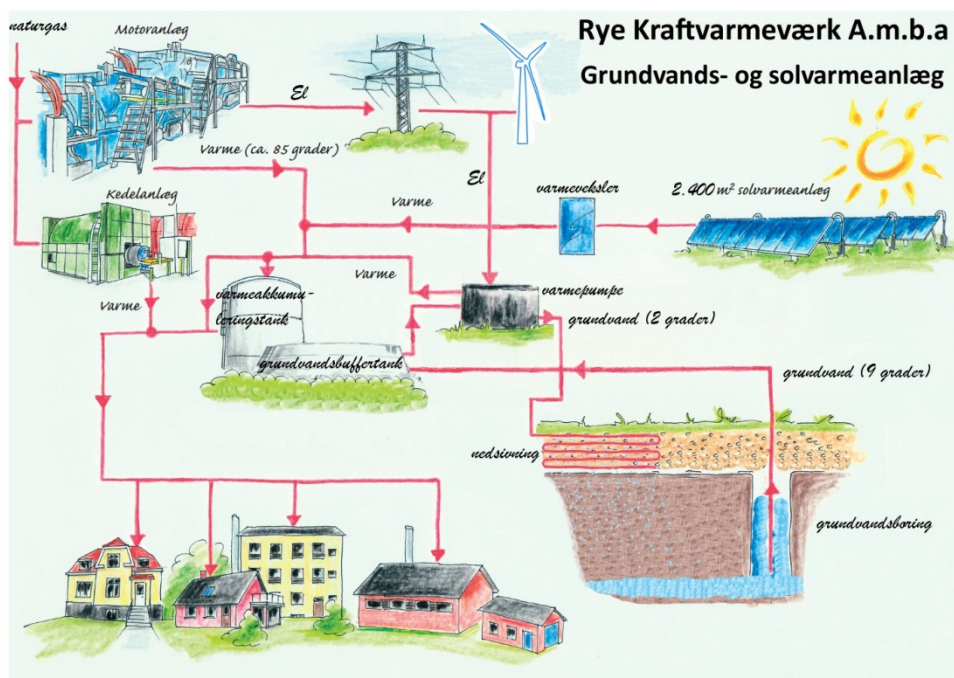


Figure 17: Output power and flow for the boiler. Data is restored in the first part of the time period.

8.2 Functional description of control system

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 11. juni 2015

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Bilag A I/O-liste for varmepumpe

Bilag B I/O-liste for PBAS

Bilag C I/O-liste for Galten Elværk

Bilag D Lastmatrix for varmepumpe

1 Indledning

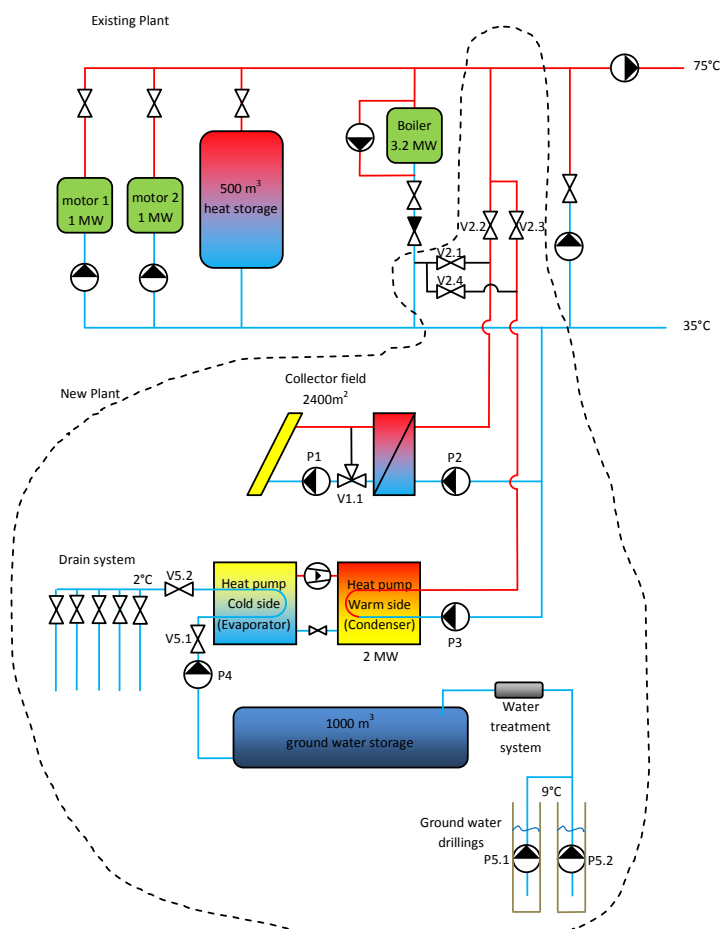
I projektet *Rye Kraftvarmeværk – Grundvands- og solvarmeanlæg* er følgende energianlæg etableret:

- Et solvarmeanlæg på 2.444 m² effektivt areal.
- En el-drevet varmepumpe på nominelt 2,05 MW_{varme} som udnytter energien i grundvandet ved hjælp af:
 - To grundvandsboringer med en samlet nominel ydelse på 100 m³/h
 - En grundvandsbuffertank på 1000 m³
 - Et nedsivningsanlæg bestående af 1.800 m dræn fordelt på et areal på 5.000 m²

Det nye anlæg er idriftsat i 2014.

Det nye anlæg er integreret i og kører i samdrift med det eksisterende anlæg bestående af to naturgasmotorer på hver 1 MW og en naturgaskedel på 3,2 MW.

Figur 1 viser et principdiagram over energisystemet. Principdiagrammet er for overblikkets skyld og viser ikke det fuldstændige anlæg. Det fuldstændige anlæg fremgår af P&I-diagrammet, som danner udgangspunkt for styringsbeskrivelsen.



Figur 1: Principdiagram med det eksisterende anlæg øverst og det nye nederst

2 De overordnede principper

Styringen skal først og fremmest tilstræbe at minimere produktionsomkostningerne, således at den leverede varme bliver så billig som muligt. Det betyder, at solvarmeanlægget og varmepumpen skal levere varme ved så lave temperaturer som muligt for at sikre størst mulig virkningsgrad og størst mulig varmeeffekt. Dette opnås ved:

- 1) En behovsstyring af værkets fremløbstemperatur, som tilstræber at fremløbs- og returtemperaturen til enhver tid ikke er højere end nødvendigt
- 2) At der shuntes med motorvarme fra akkumuleringstanken eller efteropvarmes med kedlen når varmepumpens (og solvarmens) effekt er for lav til at dække varmebehovet alene.
- 3) At varmeproduktionen fra motorer og varmepumpe planlægges i forhold til el-markedet og akkumuleringstankene.

Dernæst skal det tilstræbes, at styringen bliver så simpel som muligt, således styringen bliver nem at bruge i dagligdagen, samt at eventuel fejlfinding og optimering bliver så simpel som muligt.

2.1 Driftsscenerier

Der er i alt 6 relevante driftsscenerier for kombinationen, varmepumpe, motorer og kedel:

- 0) Stilstand
- 1) Ren varmepumpedrift
- 2) Ren motordrift
- 3) Ren kedeldrift (nøddrift)
- 4) Varmepumpe + kedeldrift
- 5) Varmepumpe + motordrift
- 6) Motor + kedeldrift

For hvert scenarie er der 3 muligheder for solvarmeproduktion:

- a) der er ingen solvarmeproduktion ($P_{sol}=0$)
- b) solvarmeproduktionen er større end nul, men mindre end varmebehovet ($0 < P_{sol} < Q$)
- c) solvarmeproduktion er større end varmebehovet ($P_{sol} > Q$)

Når solvarmeproduktionen er mindre end varmebehovet og i samdrift med motor- og/eller kedelanlæg skal solvarmeanlægget producere med lavest mulig temperatur under hensyntagen til at fremløbstemperaturen til byen kan holdes ved blanding eller efteropvarmning med de andre produktionsenheder.

Når solvarmeproduktionen er mindre end varmebehovet og i samdrift med varmepumpen skal solvarmeanlægget og varmepumpen producere varme med den beregnede fremløbstemperatur til byen.

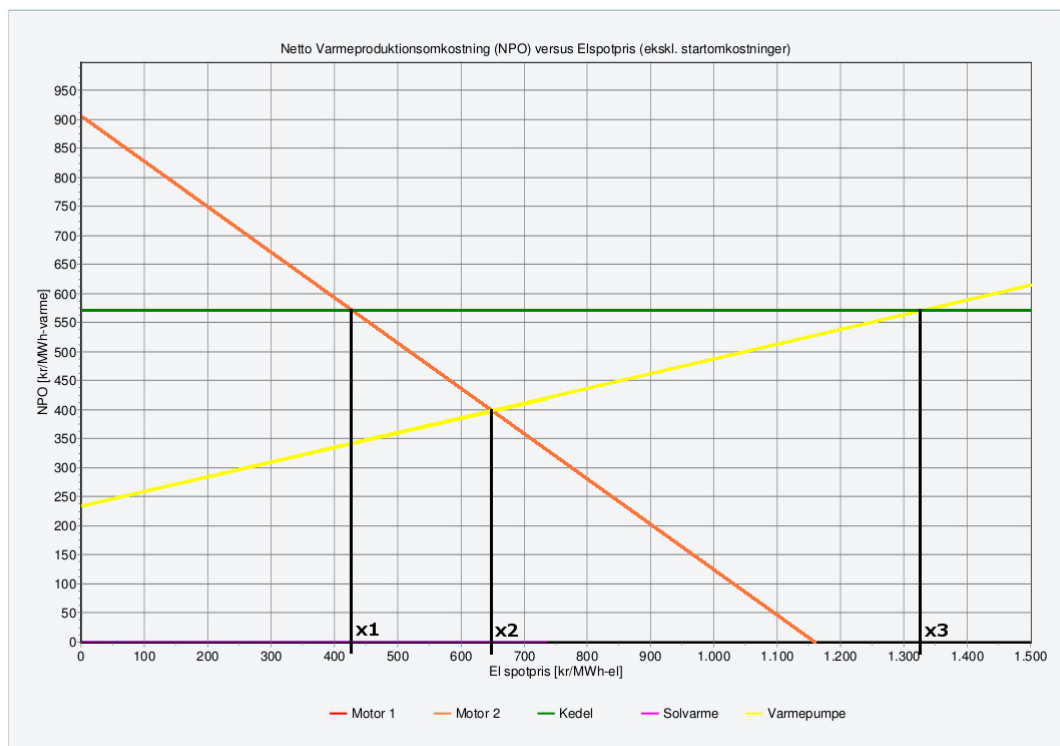
Når solvarmeproduktionen er større end varmebehovet skal solvarmeanlægget producere delvist til lager, og derfor producere ved den fastsatte lagringstemperatur (sætpunkt). Når der lades med højere temperatur end den nødvendige fremløbstemperatur sørger returshunten for at reducere temperaturen til fremløbet.

Det optimale driftsscenarie til et givent tidspunkt afhænger af el-spotprisen og varmebehovet, og driftsstrategien kan visualiseres ved at afbilde nettoproduktionsomkostningerne i forhold til el-

spotprisen for de enkelte produktionsenheder. Figur 2 viser et eksempel på dette. Figuren kan deles op i 4 intervaller for el-spot-prisen:

El-spot-pris [kr/MWh]	Størrelse af varmebehov	Driftsscenario med lavest netto varmeproduktionsomkostning
<x1 (<430)	$Q < P_{VP} + P_{sol}$	1
	$Q > P_{VP} + P_{sol}$	4
x1-x2 (430-650)	$Q < P_{VP} + P_{sol}$	1
	$Q > P_{VP} + P_{sol}$	5
x2-x3 (650-1380)	$Q < P_m + P_{sol}$	2
	$Q > P_m + P_{sol}$	5
>x3 (>1380)	$Q < P_m + P_{sol}$	2
	$Q > P_m + P_{sol}$	6

Tabel 1: Eksempel på valg af driftsscenario ud fra el-spotprisen. Q = varmebehovet, P_{VP} = varmepumpens makseffekt, P_m = motoranlæggets makseffekt, P_{sol} = beregnet solvarmeproduktion ud fra solindstråling og temperaturer.



Figur 2: Eksempel på nettoproduktionsomkostninger (kr/MWh varme) som funktion af el-spotprisen (kr/MWh el) for hhv. motoranlæg, kedel og varmepumpe. Eksemplet tager udgangspunkt i afgiftsforudsætninger for 2014, el-spotpriser for 2013 og en naturgaspris på 3 kr./Nm³. [udskrift fra energyPRO-beregning].

2.2 Beregning af netto varmeproduktionsomkostning

Beregningen af netto varmeproduktionsomkostningen (NPO) for de enkelte driftsscenerier beregnes i produktionsplanlægningssystemet (aktuelt PBAS fra Neas Energy). NPO er udover de traditionelle parametre som gaspris, el-spotpris, afgifter mv. afhængig af varmepumpens COP, som primært er afhængig af varmepumpens fremløbstemperatur. Den nødvendige fremløbstemperatur fra varmepumpen afhænger igen af fremløbstemperaturen fra værket, samt fordelingen mellem varmepumpens varmeproduktion og varmeproduktionen fra evt. andre enheder den kører i samdrift med. For at kunne planlægge den optimale produktion er det derfor nødvendigt at beregne eller estimere disse parametre på forhånd i PBAS.

For at simplificere produktionsplanlægningen bruges der for varmepumpen en konstant COP på 4,0 i beregningen af NPO samt en konstant varmeeffekt på 2,05 MW. COP-værdien og effekten indtastes i PBAS af driftspersonalet, og kan således ændres efter behov og årstid så den stemmer nogenlunde overens med den faktiske COP. På sigt kan der indføres en mere automatiseret forudsigelse af COP-værdien i PBAS, men dette er fravalgt i første omgang for at mindske kompleksiteten. Den målte COP for varmepumpeanlægget overføres fra den overordnede styring til PBAS så de historiske varmepriser vises korrekt og kan sammenlignes med forudsigelsen.

I praksis vil varmepumpen stort set altid være den billigste produktionsenhed, da balanceprisen mellem varmepumpen og motoren (jf. figur 2) ligger relativt højt og balanceprisen mellem varmepumpe og kedel ligger endnu højere. Med afgiftsforudsætninger for 2014, el-spotpriser for 2013 og en naturgaspris på 3 kr/Nm³ vil varmepumpen beregningsmæssigt altid være billigst bortset fra 19 timer i året, hvor el-spotprisen var højere end 650 kr./MWh. Det betyder at produktionsplanlægningen i praksis går ud på at estimere hvor meget varme der mangler i planlægningsperioden når varmepumpen og solvarmen har dækket så stor en del af varmebehovet som muligt. Varmepumpens driftstimer skal lægges i de billigste el-spot-timer og eventuel suppleringsvarme fra motorerne i de dyreste el-spot-timer. Eventuel suppleringsvarme fra kedlen lægges så kedlen så vidt muligt kører i samdrift med varmepumpen. Derved udnyttes det faktum at varmepumpens COP reelt er højere når den kører i samdrift med kedlen fordi varmepumpens fremløbstemperatur kan reduceres. I PBAS sættes kedlens effekt beregningsmæssigt til 675 kW når den kører i samdrift med varmepumpen, hvilket betyder at afgangstemperaturen fra varmepumpen kan hæves fra 65°C til 75°C. Den nødvendige kedeleffekt bestemmes mere præcist i den overordnede styring under hensyntagen til den aktuelle nødvendige fremløbstemperatur.

3 Integrationer

Den overordnede styring integrerer de enkelte produktionsenheders selvstændige styring (motorer, kedel, og varmepumpe). Solvarmeanlægget har ikke nogen selvstændig styring, og styres direkte af den overordnede styring. Ud over produktionsenhederne har den overordnede styring snitflade med produktionsplanlægningssystemet (PBAS fra NEAS) samt et kontrolsystem fra AURA Energi. I det følgende gives en oversigt over integrationen af de enkelte enheder.

3.1 Integration af motorstyring

Der ændres ikke i integrationen af den eksisterende motorstyring. Den eksisterende integration med den oprindelige styring overføres til den nye overordnede styring.

3.2 Integration af kedelstyring

Kedelstyringen overføres fra den eksisterende styring og eksisterende signaler for driftmelding, fejlmelding mv. bibeholdes. Derudover skal kedelstyringen integreres således lasttrinet (0-100%) samt afgangstemperaturen fra kedlen kan styres via den overordnede styring.

3.3 Integration af varmepumpestyring

Varmepumpens styring integreres i den overordnede styring ved at sende signal for ønsket driftsmode (høj/lavtemperaturdrift), ønsket last (0-100%) samt ønsket afgangstemperatur. Afgangstemperaturen ved hhv. høj- og lavtemperaturdrift kan sættes mellem 65-75°C og 43-51,5°C. De præcise grænser for afgangstemperaturen skal dog eftervises eksperimentelt. Ud over de tre primære sætpunkter for varmepumpens drift udveksles der en række informationer i form af måledata mv. over kommunikationsprotokollen. Den komplette I/O-liste for kommunikationsprotokollen fremgår af Bilag A.

Ud over kommunikationsprotokollen er der 3 hårdtfortrådede signaler til varmepumpestyringen: hhv. nødstop til varmepumpen, normalt start/stop til varmepumpen og driftskvittering fra varmepumpen.

3.4 Integration af PBAS

Den overordnede styring modtager start/stop kommandoer mv. til motorer, varmepumpe og kedel fra PBAS og sender de nødvendige informationer til PBAS for at PBAS kan optimere produktionsplanen. I/O-liste for kommunikationen mellem PBAS og den overordnede styring i relation til kedel og varmepumpedrift fremgår af bilag B. Kommunikationen i relation til motordrift er uændret i forhold til den eksisterende styring.

3.5 Integration af kontrolsystem fra AURA Energi

Da varmepumpen er tilsluttet med begrænset netadgang har AURA Energi mulighed for at overvåge og begrænse varmepumpens drift. Dette foregår ved at den overordnede styring sender signaler for varmepumpens drift til styringen fra AURA Energi, samt modtager signaler for evt. stop eller reduceret tilladelig drift. I/O-liste for kommunikationen med AURA Energis styreboks fremgår af Bilag C.

3.6 Integration af Solvarmedata.dk

Data til Solvarmedata lægges op som en tekstfil til en FTP-server hos Solvarmedata. Der lægges en tekstfil op med aktuelle værdier hvert 5. minut.

FTP-login:

Host: solvarmedata.dk

Brugernavn: ftptry

Kodeord: wrhg23f

Filen navngives data.txt. og indeholder:

- aktuel solvarmeproduktion i MW
- aktuel solindstråling i W/m²

med 2 decimaler og ',' som decimalseparator. De to værdier er semikolonsepareret.

Filen indeholder således en linie med ovenstående data. F.eks.

2,05;650,00

hvis den aktuelle solvarmeproduktion er 2,05 MW og den aktuelle solindstråling er 650,00 W/m²

3.7 Integration af ARCON-kommunikation

ARCON har leveret solvarmepaneller og solvarmeunit til anlægget. For at ARCON har mulighed for at følge solvarmeanlæggets drift og evt. bidrage med optimeringsmuligheder etableres der en VPN-adgang for ARCON. Der opsættes en OPC-server i SCADA-systemet (IGSS), som ARCON kan bruge til at hente live data fra. Dermed har ARCON adgang til alle TAG-numre for anlægget og kan løbende hente udvalgte data ned til deres egen server.

4 Fjernvarmekredsen

Som en del af projektet er der installeret en behovsstyring af fremløbstemperaturen. Den beregnede varmeeffekt og fremløbstemperatur anvendes som kriterier og beregningsinput for styringen af solvarmeanlægget, varmepumpen og retur-shunten. Flowet i fjernvarmekredsen styres af differensterkningen i byen. Trykholdeventiler styres som på det eksisterende anlæg efter at holde det nødvendige tryk i fjernvarmekredsen.

4.1 Retur-shunten

Retur-shunten skal sikre, at fremløbstemperaturen ikke overstiger den ønskede fremløbstemperatur. Retur-shunten styres efter den beregnede fremløbstemperatur.

4.2 Akkumuleringstank

Akkumuleringstanken bruges som varmelager, for solvarme, motoranlæg og varmepumpe samt til dels kedelvarme. Tanken indgår i produktionsplanlægningen så produktionsenhederne kan udnyttes så optimalt som muligt i forhold til spotpriser og solindstråling. Akkumuleringstanken fyldes automatisk når varmeproduktionen er større end byens forbrug og tømmes når varmeproduktionen er mindre end byens forbrug. Akkumuleringstanken kan afspærres med en motorventil. Denne skal være åben når der er behov for op- eller afladning af akkumuleringstanken. Der skal gives en alarm når temperaturen i bunden af tanken > 45°C. (sætpunkt)

5 Valg af driftsscenario

Det aktuelle driftsscenario vælges primært af PBAS, som sender start/stop-signaler for de enkelte produktionsenheder ud fra den planlagte produktion. Derudover skal det være muligt at vælge driftsscenario manuelt. På skærmbilledet skal det fremgå hvilket driftsscenario der er aktivt.

Der er 4 ventiler (jf. PI-diagrammet), som bestemmer hvilket driftsscenario der er aktivt:

NDA651AA001 (V2.1 på figur 1) – solvarmefremløb til kedelretur.

NDA650AA001 (V2.2 på figur 1) – solvarmefremløb til fjernvarme frem.

NDA640AA005 (V2.3 på figur 1) – varmepumpe fremløb til fjernvarme frem.

NDA643AA001 (V2.4 på figur 1) – varmepumpe fremløb til kedelretur.

Nedenstående tabel viser ventilstillingerne for de enkelte scenarier:

Ventil		NDA651AA001	NDA650AA001	NDA640AA005	NDA643AA001
Scenarie					
0	a ($P_{sol}=0$)	x	x	x	x
	b ($0 < P_{sol} < Q$)	x	o	x	x
	c ($P_{sol} > Q$)	x	o	x	x
1 (VP)	a ($P_{sol}=0$)	x	x	o	x
	b ($0 < P_{sol} < Q$)	x	o	o	x
	c ($P_{sol} > Q$)	x	o	o	x
2 (M)	a ($P_{sol}=0$)	x	x	x	x
	b ($0 < P_{sol} < Q$)	x	o	x	x
	c ($P_{sol} > Q$)	x	o	x	x
3 (K)	a ($P_{sol}=0$)	x	x	x	x
	b ($0 < P_{sol} < Q$)	o	x	x	x
	c ($P_{sol} > Q$)	x	o	x	x
4 (VP+K)	a ($P_{sol}=0$)	x	x	x	o
	b ($0 < P_{sol} < Q$)	o	x	x	o
	c ($P_{sol} > Q$)	x	o	x	o
5 (VP+M)	a ($P_{sol}=0$)	x	x	o	x
	b ($0 < P_{sol} < Q$)	x	o	o	x
	c ($P_{sol} > Q$)	x	o	o	x
6 (M+K)	a ($P_{sol}=0$)	x	x	x	x
	b ($0 < P_{sol} < Q$)	x	o	x	x
	c ($P_{sol} > Q$)	x	o	x	x

Tabel 2: Ventilstillinger for de enkelte scenarier (x = lukket, o = åben).

6 Styring af produktionsenhederne

6.1 Motoranlæg

Styringen af selve naturgasmotorerne bibeholdes i forhold til før etablering af varmepumpe- og solvarmeanlægget. Det eneste der ændres er prioriteringen af motorerne i forhold til de nye produktionsenheder, så det følger retningslinjerne i tabel 1 i forhold til el-spotmarkedet. Derudover kan der som hidtil meldes ind på andre markeder (primær regulering, nedregulering mv.), hvor lasten styres af et eksternt signal. Alarmer for motoranlægget er ligeledes uændret.

6.2 Kedel

Kedlen er aktiv i driftsscenario 3, 4 og 6.

Scenarie 3a:

I dette scenarie er akkumuleringstanken tom og kedlen er den eneste produktionsenhed der skal producere varme. Ventilene til det nye anlæg, NDA651AA001, NDA650AA001, NDA640AA005 og NDA643AA001 skal derfor lukkes og kedlen styres som hidtil for det gamle anlæg. Motorventil for akkumuleringstank lukkes.

Scenarie 3b:

I dette scenarie efteropvarmer kedlen fremløbet fra solvarmeanlægget (akkumuleringstanken er tom). Dette gøres ved at NDA651AA001 åbnes efter kedlen er startet op og NDA650AA001, NDA640AA005 og NDA643AA001 lukkes. Motorventil for akkumuleringstank lukkes.

Fremløbstemperaturen for solvarmeanlægget beregnes som:

$$T_{sol} = T_F - \frac{(Q - p_{sol})(T_F - T_R)}{Q} \text{ [}^\circ\text{C]}$$

hvor: P_{sol} = Aktuell solvarmeeffekt [kW]
 Q = Fjernvarmeeffekt til byen [kW]
 T_F = Fjernvarme fremløbstemperatur [°C]
 T_R = Fjernvarme returtemperatur [°C]

Fremløbstemperaturen fra kedlen styres efter den nødvendige fremløbstemperatur til byen. Returshunten skal ideelt set ikke bruges.

Scenarie 3c:

Dette scenarie er ikke et relevant driftsscenario, da kedlen ikke skal producere når solvarmeanlægget dækker mere end byens forbrug. Der skal derfor ske en nedlukning af kedlen (skift til scenarie 0c).

Scenarie 4a:

I dette scenarie skal kedlen supplere varmepumpen ved at efteropvarme fremløbet fra varmepumpen. Når kedlen er startet op åbnes NDA643AA001 hvorefter NDA651AA001, NDA650AA001 og NDA640AA005 lukkes.

Varmepumpen sættes til 100% last og minimums afgangstemperatur (65°C)

Kedlen styres efter at levere den nødvendige fremløbstemperatur til byen.

Hvis varmepumpen leverer større effekt end byens forbrug stoppes kedlen (skiftes til scenarie 1).

Scenarie 4b:

Som 4a, men både NDA643AA001 og NDA651AA001 åbnes.

Varmepumpen sættes til 100% last og minimums afgangstemperatur (65°C).

Solvarmeanlægget styres efter at producere samme fremløbstemperatur som varmepumpen (65°C)

Kedlen styres efter at levere den nødvendige fremløbstemperatur til byen.

Hvis varmepumpe + solvarme leverer større effekt end byens forbrug stoppes kedlen (skiftes til scenarie 1).

Scenarie 4c

Dette scenarie er ikke et relevant driftsscenario, da kedlen ikke skal producere når solvarmeanlægget dækker mere end byens forbrug. Der skal derfor ske en nedlukning af kedlen (skift til scenarie 1c).

Scenarie 6a

NDA651AA001, NDA650AA001, NDA640AA005 og NDA643AA001 lukkes. Kedlen supplerer motorerne ved at shunte i fremløbet som ved det gamle anlæg.

Scenarie 6b

NDA650AA001 åbnes. NDA640AA005, NDA651AA001 og NDA643AA001 lukkes. Kedlen og solvarmeanlægget leverer ind på fremløbet. Solvarmeanlæggets fremløbstemperatur skal styres efter ønsket sætpunkt for lagringstemperatur eller den beregnede fremløbstemperatur til byen + offset (sætpunkt).

Scenarie 6c

Dette scenarie er ikke et relevant driftsscenario, da kedlen ikke skal producere når solvarmeanlægget dækker mere end byens forbrug. Der skal derfor ske en nedlukning af kedlen (skift til scenarie 2c).

6.3 Varmepumpe

Varmepumpen er aktiv i scenarie 1, 4 og 5. Af Bilag D fremgår estimerede fuldlast og dellast-data for varmpumpen.

I produktionsplanen tages der højde for begrænsningerne i forsyning af grundvand samt buffer-tank for grundvand. Opstår det alligevel at grundvandstanken er ved at løbe tør (alarm for lavt-lavt niveau) skal varmpumpen standses.

Pumpen på varmpumpens kolde side, GAC010AP001, startes når der sendes startkommando til varmpumpen. Pumpen styres efter et flow på 195 m³/h (sætpunkt). Pumpen stoppes efter varmpumpen er stoppet.

Scenarie 1a:

Varmepumpen leverer alene varme til byen og/eller akkumuleringstanken

Ventilen NDA640AA005 åbnes. NDA651AA001, NDA650AA001 og NDA643AA001 lukkes.

Varmepumpen producerer efter sætpunkt for last (0-100%) og fremløbstemperatur (65-75°C) – normalt fuldlast og den beregnede fremløbstemperatur til byen. Det skal kunne vælges om varmpumpen kører efter sætpunkt for afgangstemperatur eller den beregnede fremløbstemperatur til byen + et offset (sætpunkt).

Scenarie 1b:

NDA650AA001 og NDA640AA005 åbnes. NDA643AA001 og NDA651AA001 lukkes.

Solvarmanlægget styres efter at levere den beregnede fremløbstemperatur til byen + et offset (sætpunkt) eller et sætpunkt for fremløbstemperaturen.

Varmepumpen producerer efter sætpunkt for last (0-100%) og fremløbstemperatur (65-75°C) – normalt fuldlast og den beregnede fremløbstemperatur til byen. Det skal kunne vælges om varmpumpen kører efter sætpunkt for afgangstemperatur eller den beregnede fremløbstemperatur til byen + et offset (sætpunkt).

Scenarie 1c:

Som 1b.

Scenarie 4:

Beskrevet under kedlen.

Scenarie 5a:

NDA640AA005 åbnes. NDA651AA001, NDA650AA001 og NDA643AA001 lukkes.

Varmepumpen producerer efter sætpunkt for last (0-100%) og fremløbstemperatur (65-75°C) – normalt fuldlast og den beregnede fremløbstemperatur til byen. Varmepumpens fremløb blandes med motorvarmen.

Scenarie 5b:

solvarmen blandes med i fremløbet sammen med motorerne og varmpumpen ved at NDA650AA001 og NDA640AA005 åbnes. NDA651AA001 og NDA643AA001 lukkes. Fremløbstemperatur for varmpumpe og solvarme sættes til den beregnede fremløbstemperatur til byen + offset (sætpunkter).

Scenarie 5c:

Som scenarie 5b. Der produceres til lager med den beregnede fremløbstemperatur for byen + offset (sætpunkt) eller den valgte lagringstemperatur.

Grundvandspumper og grundvandstank

Grundvandspumperne, GAF010AP001 og GAF020AP001 kører konstant indtil niveauet i grundvandstanken målt med niveautransmitter GAD010CL001 når sætpunktet "grundvandstank fuld". Når niveauet falder til sætpunktet "start grundvandspumper" skal pumperne starte igen. For hver pumpe defineres et sætpunkt for ønsket flow, som pumperne reguleres efter. Flow måles med GAF010CF001 og GAF020CF001. Der defineres alarmgrænser for lavt niveau i grundvandsboringerne samt lavt lavt niveau som automatisk stopper grundvandspumpen. Der defineres alarmgrænse for lavt niveau, lavt-lavt niveau og højt niveau i grundvandstanken. Målt flow for grundvandspumperne samt aktuelt niveau i grundvandstanken kommunikerer til PBAS-systemet.

Pejleboringer

Pejleboringernes funktion er at overvåge om der sker en terrænnær op stuvning af grundvand fra nedslivningsanlægget. Vandstanden i pejleboringerne måles, og der defineres følgende alarm og stop-grænser. Ved vandstand for automatisk stop af varmpumpen skal der ske en almindelig kontrolleret nedlukning af varmpumpen.

Pejlerør nr.:	1	2	3	4	5
Vandstand for alarm	2 m U.T.	5 m U.T.	7 m U.T.	2 m U.T.	7 m U.T.
Vandstand for automatisk stop af varmpumpe	1 m U.T.	3 m U.T.	5 m U.T.	1 m U.T.	5 m U.T.

Kølemiddeludslip

Varmepumpen anvender ammoniak som kølemiddel. Kølemidlet er desuden tilsat en mindre mængde kompressorolie for at smøre kompressorerne. For at minimere risiko for forurening af grundvandet må ventilerne GAC010AA003 og GAC030AA005 kun være åbne når varmpumpen er i drift. Ved alarm fra varmpumpen som følge af trykfald i kølekredsen skal de desuden lukkes af omgående. Som yderligere sikkerhed er der installeret en ammoniakdetektor i grundvandsrøret efter varmpumpen. Ved detektering af ammoniak lukkes ventilerne omgående og der gives alarm. Ammoniakudslip i bygningen overvåges og håndteres af varmpumpens egen styring og er beskrevet i dokumentationen for varmpumpen.

6.4 Solvarmeanlæg

Solvarmeanlægget kan som det fremgår ovenstående være aktivt i samtlige driftsscenerier med de andre produktionsenheder. Derudover kan det være aktivt i scenarie 0, hvor det kun er solvarmeanlægget der kan producere varme.

Scenarie 0b:

Fremløbet fra solvarmeanlægget blandes med fremløbet fra akkumuleringstanken. NDA650AA001 åbnes. NDA640AA005, NDA651AA001 og NDA643AA001 lukkes. Det beregnes hvor stor fremløbstemperaturen skal være fra solfangeranlægget for at levere den nødvendige fremløbstemperatur til byen. Dette beregnes som:

$$T_{sol} = \frac{p_{sol}(T_F - T_R)(T_R - T_{akku})}{(Q - p_{sol})(T_F - T_{akku}) + p_{sol}(T_R - T_{akku})} + T_R \text{ [}^\circ\text{C]}$$

hvor:

- P_{sol} = Aktuel solvarmeeffekt [kW]
- T_{akku} = Temperaturen i toppen af akkumuleringstanken [°C]
- Q = Fjernvarmeeffekt til byen [kW]
- T_F = Fjernvarme fremløbstemperatur [°C]
- T_R = Fjernvarme returtemperatur [°C]

Fremløbstemperaturen skal være mellem fjernvarme returtemperaturen og den maksimalt tilladte fremløbstemperatur T_{max} (sætpunkt). Ellers sættes fremløbstemperaturen til den maksimalt tilladte fremløbstemperatur:

$T_{sol} = T_{max}$ hvis $T_{sol}(\text{beregnet}) > T_{max}$ eller $T_{sol}(\text{beregnet}) < T_R$

Scenarie 0c:

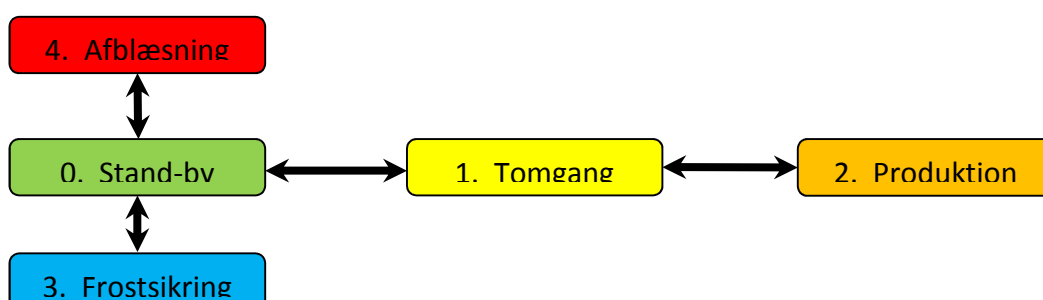
Solvarmeanlæggets fremløbstemperatur skal styres efter den ønskede lagringstemperatur for solvarme i akkumuleringstanken (den beregnede fremløbstemperatur til byen eller et valgfrit sætpunkt). NDA650AA001 åbnes. NDA640AA005, NDA651AA001 og NDA643AA001 lukkes.

Solvarmelasttrin

Solvarmeanlægget har 5 lasttrin:

0. Stand-by
1. Tomgang
2. Produktion
3. Frostsikring
4. Afbæsning

Mulighederne for skift mellem de enkelte lasttrin fremgår af figur 3.



Figur 3: Oversigt over lasttrin for solvarmeanlægget inkl. tilladte skift mellem disse.

G = solindstråling målt med solarimeter.

Q_{sol} = solvarmeproduktion beregnet v.h.a. solfangerligningen.

Lasttrin 0: Stand-by

Beskri- velse	Stilstand.																	
Hvor- dan	Ventiler: WTB650AA002 holdes åben for at undgå trykopbygning i rørsystemet på sekundærsiden <table border="1" style="width: 100%; text-align: center;"> <tr> <td>WTA650AA006</td> <td>WTB650AA002</td> <td>WTB652AA001</td> <td>WTB651AA001</td> <td>WTA600AA007</td> <td>WTA601AA001</td> </tr> <tr> <td>X</td> <td>O</td> <td>X</td> <td>X</td> <td>X</td> <td>X</td> </tr> </table> Primærpumpe: OFF Sekundærpumpe: OFF						WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001	X	O	X	X	X	X
WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001													
X	O	X	X	X	X													
Stopkri- terier	Skift til lasttrin 1 hvis ($Q_{sol} > 50 \text{ kW}$) eller ($G > 100 \text{ W/m}^2$) (sætpunkter) Skift til lasttrin 3 hvis omgivelsestemperaturen eller en af afgangsfølerne på solfangerne $< -8^\circ\text{C}$ (sætpunkt). Skift til lasttrin 4 hvis afblæsningsfunktionen er tilladt og en valgfri føler i akkumuleringsstanken overstiger 55°C (sætpunkt) og ($Q < 0,5 \text{ MW}$) og tidspunktet er mellem kl. 22:00 og 05:00 (sætpunkter).																	

Lasttrin 1: Tomgang

Beskri- velse	Bruges til at forvarme primærsiden når solindstrålingen er for lav til egentlig produktion.																	
Hvor- dan	Ventiler: <table border="1" style="width: 100%; text-align: center;"> <tr> <td>WTA650AA006</td> <td>WTB650AA002</td> <td>WTB652AA001</td> <td>WTB651AA001</td> <td>WTA600AA007</td> <td>WTA601AA001</td> </tr> <tr> <td>X</td> <td>O</td> <td>X</td> <td>X</td> <td>O</td> <td>X</td> </tr> </table> Primærpumpe: Min. flow Sekundærpumpe: OFF						WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001	X	O	X	X	O	X
WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001													
X	O	X	X	O	X													
Stopkri- terier	Skift til lasttrin 0 hvis [$(Q_{sol} < 10 \text{ kW})$ eller ($G < 50 \text{ W/m}^2$)] og en af afgangsfølerne på solfangerne er under 45°C . (sætpunkter) Skift til lasttrin 2 hvis ($Q_{sol} > 100 \text{ kW}$) og (fremløbstemperaturen før solvarmeveksleren er over 45°C i 5 min.). Minimum driftstid: 30 min. (sætpunkter)																	

Lasttrin 2: Produktion

Beskri- velse	Solvarmeproduktion.																	
Hvor- dan	Ventiler: <table border="1" style="width: 100%; text-align: center;"> <tr> <td>WTA650AA006</td> <td>WTB650AA002</td> <td>WTB652AA001</td> <td>WTB651AA001</td> <td>WTA600AA007</td> <td>WTA601AA001</td> </tr> <tr> <td>O</td> <td>O</td> <td>X</td> <td>X</td> <td>O</td> <td>X</td> </tr> </table> Pumper: se beregning af flow i solvarmeanlægget						WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001	O	O	X	X	O	X
WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001													
O	O	X	X	O	X													
Stopkri-	Skift til lasttrin 1 når alle afgangsfølerne på solfangerne er under 45°C og temperaturen																	

terie	før veksleren er under 45°C i 5 minutter (sætpunkter).
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Lasttrin 3: Frostsikring

Beskrivelse	<p>Primærsiden er frostsikret med 30% glykol ned til ca. -15°C.</p> <p>Ved lavere omgivelsestemperaturer tilføres varme fra sekundærsiden ved at lede returvand fra fjernvarmenettet gennem solvarmeveksleren til retursiden af kedlen.</p> <p>For at undgå isdannelse i solvarmeveksleren må vandtemperaturen på sekundærsiden ikke komme under frysepunktet.</p>												
Hvordan	<p>Sekvens:</p> <p>Frostsikring startes når udetemperaturen eller en af temperaturfølerne i solvarmefeltet kommer under -8°C (sætpunkter).</p> <p>Ventil NDA651AA001 åbnes og ventilerne for solvarmeuniten stilles som:</p> <table border="1"> <tr> <td>WTA650AA006</td> <td>WTB650AA002</td> <td>WTB652AA001</td> <td>WTB651AA001</td> <td>WTA600AA007</td> <td>WTA601AA001</td> </tr> <tr> <td>o</td> <td>o</td> <td>x</td> <td>x</td> <td>x</td> <td>o</td> </tr> </table> <p>Sekundærpumpen styres efter en afgangstemperatur fra varmevekslerens sekundærside (WTA650CT002) på 20°C (sætpunkt), men ikke under min. flow.</p> <p>Primærpumpen startes med 80% last (sætpunkt).</p> <p>Hvis temperaturen fra solfangerfeltet (WTA600CT001) kommer under -10°C tilføres varme fra veksleren ved at WTA600AA007 åbnes og WTA601AA001 lukkes. Ventilerne åbnes/lukkes så langsomt at det sikres at reguleringen af sekundærpumpen kan følge med.</p> <p>Hvis afgangstemperaturen fra solfangerfeltet (WTA600CT001) kommer over 0°C (sætpunkt) stoppes tilførsel af varme (WTA600AA007 lukkes og WTA601AA001 åbnes).</p> <p>Hvis temperaturen fra solfangerfeltet (WTA600CT001) kommer under -12°C sættes primærpumpen til 100% last indtil temperaturen kommer over -10°C</p>	WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001	o	o	x	x	x	o
WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001								
o	o	x	x	x	o								
Stopkriterie	Skift til lasttrin 0 når omgivelsestemperaturen og temperaturfølerne i solvarmefeltet > -6°C (sætpunkter) og luk NDA651AA001.												

Lasttrin 4: Afbæsning

Beskri- velse	Hvis der ikke er plads til næste dags solproduktion i akkumuleringstankene, anvendes solfeltet til afblæsning af varme natten før (ca. 3 W/m ² K). Det kan vælges om funktionen er tilladt / ej tilladt på skærmbilledet																	
Hvor- dan	<p>Afbæsning startes når en valgfri føler i tanken overstiger 60°C (sætpunkt) og tidspunktet er efter kl. 22.00 (sætpunkt)</p> <p>Ventiler: NDA650AA001 åbnes</p> <table border="1"> <tr> <td>WTA650AA006</td> <td>WTB650AA002</td> <td>WTB652AA001</td> <td>WTB651AA001</td> <td>WTA600AA007</td> <td>WTA601AA001</td> </tr> <tr> <td>X</td> <td>X</td> <td>O</td> <td>O</td> <td>O</td> <td>X</td> </tr> </table> <p>Primærpumpe: Styres efter en afgangstemperatur på solvarmevekslerens sekundærside på 45°C (sætpunkt)</p> <p>Sekundærpumpe: balanceret flow i forhold til primærpumpen.</p>						WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001	X	X	O	O	O	X
WTA650AA006	WTB650AA002	WTB652AA001	WTB651AA001	WTA600AA007	WTA601AA001													
X	X	O	O	O	X													
Stopkri- terier	Skift til lasttrin 0 når temperaturen på en valgfri føler i akkumuleringstanken kommer under 50°C (sætpunkt) eller tidspunktet bliver efter kl. 8.00 og luk for NDA650AA001.																	

Beregning af flow i solvarmeanlægget

Der skal normalt være balanceret flow på solvarmeveksleren.

Der beregnes/fastsættes enten et ønsket flow eller en ønsket afgangstemperatur fra solvarmevekslerens sekundærside (T_{set}) ud fra hvilket driftsscenario der er valgt.

Styres der efter en ønsket afgangstemperatur beregnes et grundflow på primærsiden ud fra T_{set} og solfangerligningen (jf. Tabel 1).

Grundflowet korrigeres med en PI-regulator, som styrer efter T_{set} .

$$\text{Primærflow} = \text{Grundflow}(T_{set}) * [1 + \text{PI}(T_{set})]$$

Styres der efter et ønsket flow på sekundærsiden beregnes flowet på primærsiden som:

$$\text{Primærflow} = \text{sekundærflow}/k_{bal}$$

hvor $k_{bal} = 0,95$ (forhold mellem varmekapacitet for glykolblanding og fjernvarmevand) (sætpunkt)
Ved behov for lavere flow end pumperne leverer ved minimumslast reguleres flowet ned på sekundærsiden ved hjælp af WTA650AA006, og der tillades asymmetrisk last af varmeveksleren.

Beskrivelse	Symbol	Eksempelværdi / formel	Enhed
Ønsket min. afgangstemp. fra solvekslerens sekundærside	T_{min}	= 60	°C
Ønsket max. afgangstemp. fra solvekslerens sekundærside	T_{max}	= 90	°C
Min. flow på solvekslerens primærside	V_{min}	= 5	m ³ /h
Max. flow på solvekslerens primærside	V_{max}	= 60	m ³ /h
Temperaturen i bunden af tanken	T_{bund}	–	°C
Solfangernes starteffektivitet	η_0	= 0,817	–
Solfangernes 1. ordens koefficient	a_1	= 2,205	W/m ² ·K
Solfangernes 2. ordens koefficient	a_2	= 0,0135	W/m ² ·K ²
Solfangerareal	A	= 2.444	m ²
Densitet på primærside (30% glykol)	ρ_{prim}	= 1.002	kg/m ³
Varmekapacitet på primærside (30% glykol)	$c_{p,prim}$	= 3,973	kJ/kg·K
Densitet på sekundærside (vand @ 66°C)	ρ_{sek}	= 980	kg/m ³
Varmekapacitet på sekundærside (vand)	$c_{p,sek}$	= 4,19	kJ/kg·K
Ca. delta-T over solvarmeveksleren	ΔT_{vv}	= 3	K
Solindstråling	G	–	W/m ²
Omgivelsestemperatur	T_a	–	°C
Tilgangstemperatur på solvekslerens sekundærside	T_{kold}	Hvis $V_{sek} = 0$ bruges T_{bund}	°C
Ønsket afgangstemp. fra solvekslerens sekundærside	T_{set}	–	°C
Middeltemperatur på solvekslerens sekundærside	T_m	= $(T_{kold} + T_{set}) / 2$	°C
Temperaturdifferens til solfangerligning	ΔT_{sol}	= $T_m + \Delta T_{vv} - T_a$	K
Solfangerydelse	Q	= $A * (\eta_0 * G - a_1 * \Delta T_{sol} - a_2 * \Delta T_{sol}^2) / (1.000 \text{ W/kW})$	kW
Temperaturforskel på solvekslerens sekundærside	ΔT_{sek}	= $T_{set} - T_{kold}$	K
Temperaturforskel på solvekslerens primærside	ΔT_{prim}	= ΔT_{sek}	K
Grundflow på solvekslerens primærside	V_{sol}	= $Q / (\rho_{prim} * c_{p,prim} * \Delta T_{prim}) * (3.600 \text{ s/h})$	m ³ /h
Flowkorrektion beregnet af PI-regulator i.f.t. T_{set}	F	–	–
Flow på solvekslerens primærside (primærpumpe)	V_{prim}	= $\text{MAX}(V_{min}; \text{MIN}[V_{max}; V_{sol} * (1 + F)])$	m ³ /h
Min. flow på solvekslerens sekundærside	$V_{sek,min}$	= 0	m ³ /h
Max. flow på solvekslerens sekundærside	$V_{sek,max}$	= 75	m ³ /h
Flow på solvekslerens sekundærside (sekundærpumpe)	V_{sek}	= $\text{MAX}(V_{sek,min}; \text{MIN}[V_{sek,max}; [V_{sol} * (1 + F)] * (\rho_{prim} * c_{p,prim}) / (\rho_{sek} * c_{p,sek})])$	m ³ /h

Tabel 1: Parametre og beregninger for solvarmeanlægget

Blow-off-tank

Blow-off-tanken er udstyret med en niveau-føler (GDL010CP001). Der defineres en alarm-grænse for lavt niveau i tanken.

Overvågning af max. temperatur på solfangerne

Det skal af levetidsmæssige årsager så vidt muligt undgås at solvarmeanlægget koger (stagnerer). Dette gøres ved at køre pumperne op hvis afgangstemperaturerne i solfeltet bliver for høje. Hvis en af afgangstemperaturerne fra solfangerne overstiger 105°C, gives der en alarm og primær-pumpen sættes til 100% last.

Hvis solvarmeanlægget alligevel kommer i kog, skal dampslag begrænses mest muligt. Dette gøres ved at stoppe pumperne indtil kogningen er ophørt af sig selv.

1 time efter solnedgang startes følgende procedure:

1. Primærpumpen startes på min. flow og kører ½ time (sekundærpumpen startes ikke).
2. Glykol fra blow-off-tanken påfyldes primærkredsen ved manuel drift af fyldepumpen under overvågning af trykket i primærkredsen.
3. Herefter kører primærpumpen en ½ time med max. flow.
4. Trykket i primærkredsen kontrolleres og glykol påfyldes til det korrekte tryk.
5. Solvarmeanlægget lukkes ned.
6. Glykolniveauet i blow off-tanken kontrolleres.

Sikkerhed mod høje tryk og temperaturer i solfeltet

Af sikkerhedsmæssige årsager skal det sikres at tryk og temperatur holdes under henholdsvis 10 bar og 110°C. Dette sikres på følgende måde:

Hvis trykket i primærkredsen stiger til 10 bar åbner sikkerhedsventilen GDL010AA003 og leder glykol til blow-off-tanken. Stiger temperaturen til 110°C lukkes for ventilen WTA600AA002 og sikkerhedstermostaten WTA600DT001 stopper primærpumpen. Ventilen WTA600AA002 lukkes desuden automatisk ved strømsvigt.

Sikkerhed mod udslip af glykol

1. Der er installeret alarmtråde i alle nedgravede rør i primærkredsen. I tilfælde af lækage i disse rør gives der alarm.
2. Trykket i primærkredsen (WTA600CP002, WTB600CP001 og WTB600CP003) overvåges. Hvis et af trykkene i primærkredsen falder til under 1,8 bar (setpunkt), gives der alarm for lavt tryk. Hvis mindst to af trykkene falder til under 1,3 bar (setpunkt), gives der alarm for lavt-lavt tryk. Hvis mindst to af trykkene falder til under 0,2 bar (setpunkt) standses primærpumpen.

7 Beregning af relevante driftsdata for rapportudtræk

Der skal kunne laves rapportudtræk for alle målte værdier på døgn-, uge-, måneds- og årsbasis. Derudover skal der beregnes følgende driftsdata, som ikke måles direkte for at inkludere disse i rapportudtrækkene:

- Byens akkumulerede effekt.
- Kedlens akkumulerede effekt.
- Motorenes akkumulerede effekt.
- Solvarmens akkumulerede effekt.
- Varmepumpens akkumulerede effekt.
- Varmepumpens COP.
- Akkumuleret grundvandsflow fra boring 1
- Akkumuleret grundvandsflow fra boring 2
- Akkumuleret grundvandsflow fra grundvandstank

8 Ændringslog

Ver.	Dato	Ændringer
1	17-06-2014	Første reviderede udgave
2	01-07-2014	Afsnit omkring integrationer tilføjet
3	04-08-2014	Afsnit om styring af pumpe på varmepumpens kolde side tilføjet under afsnit 6.3 Varmepumpe. Afsnit om beregning af flow i solvarmeanlægget ændret så flow ikke begrænses ved hjælp af ventil på primærsiden, men udelukkende sekundærsiden. Bilag A opdateret
4	01-04-2015	Beregninger gennemgået og opdateret. Tabel 1 for beregninger for solvarmeanlægget tilføjet.
5	01-06-2015	Galten Elværk rettet til AURA Energi Afsnit om integration med solvarmedata tilføjet Solvarmelasttrin redigeret og diverse sætpunkter ændret efter dialog med Intego
6	11-06-2015	Scenarie 6b ændret til at solvarmen leverer til fremløb i stedet for til kedelretur.

Bilag A

I/O-liste for varmepumpe

Intego PLC		DP/DP	JCI PLC			
Tagnavn	Slot nummer	Udveksling	Slot nummer	Adress	Tagnavn	Beskrivelse
	Slot 1 ("????") "2 Byte Output consistent"	-BYTE→	Slot 1 ("Bits_in_BYTE") "2 Byte Input consistent"	%I0.0	Bits_in_BYTE %MB60 (%M60.0 "Bits_in_JCI mode")	0 = normal drift (både høj- og lavtrykside kører), 1 = Lavtemperatur drift (kun lavtrykside kører)
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW12	Recieve data_DB.Integers_IN.hotPower_INT	Varm side målt effekt [kW] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW14	Recieve data_DB.Integers_IN.hotTempIn_INT	Varm side temperatur ind [°C] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW16	Recieve data_DB.Integers_IN.hotTempOut_INT	Varm side temperatur ud [°C] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW18	Recieve data_DB.Integers_IN.hotFlow_INT	Varm side flow [m³/h] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW20	Recieve data_DB.Integers_IN.coldPower_INT	Kold side målt effekt [kW] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW22	Recieve data_DB.Integers_IN.coldTempIn_INT	Kold side temperatur ind [°C] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW24	Recieve data_DB.Integers_IN.coldTempOut_INT	Kold side temperatur ud [°C] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW26	Recieve data_DB.Integers_IN.coldFlow_INT	Kold side flow [m³/h] x10
	Slot 2 ("????") "64 Bytes Output consistent"	←INT→	Slot 2 ("Integers_IN") "64 Bytes Input consistent"	%IW30	Recieve data_DB.Integers_IN.tempSP_INT	Temperatursetpunkt på varm side [°C] x10 (65-75°C ved normalmode og ?-51,5°C ved lavtemperaturmode)
	Slot 3 ("????") "2 Byte Input consistent"	←BOOL-	Slot 3 ("Bits_out") "2 Byte Output consistent"	%Q10.0	Bits_out_BYTE %MB61 (%M61.0 "Bits_out_extSafeOn")	Varmepumpeanlæg ekstern sikkerhed OK (AT-boks, nødstop OK, NH3 alarm OK og Intego nødstop OK)
	Slot 3 ("????") "2 Byte Input consistent"	←BOOL-	Slot 3 ("Bits_out") "2 Byte Output consistent"	%Q10.1	Bits_out_BYTE %MB61 (%M61.1 "Bits_out_JCI warnin")	Advarsel fra varmepumpe
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW12	Send data_DB.Integers_OUT.heatpumpPower_INT	Effektforbrug fra varmepumpe alene [kW] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW14	Send data_DB.Integers_OUT.totPower_INT	Totalt effektforbrug fra varmepumpe og eksterne pumper [kW] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW16	Send data_DB.Integers_OUT.+AR10-EC01_LP	Sugetryk for SMC116E [bar] x100
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW18	Send data_DB.Integers_OUT.+AR10-EC01_HP	Afgangstryk for SMC116E [bar] x100
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW20	Send data_DB.Integers_OUT.+AR20-EC01_LP	Sugetryk for SMC112L [bar] x100
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW22	Send data_DB.Integers_OUT.+AR20-EC01_HP	Afgangstryk for SMC112L [bar] x100
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW24	Send data_DB.Integers_OUT.+AR10-EC02_HP	Afgangstryk for HBO28 [bar] x100
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW26	Send data_DB.Integers_OUT.+AR10-EC03_HP	Afgangstryk for HBO26 [bar] x100
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW28	Send data_DB.Integers_OUT.+AR30-BT02	Varm side indløbstemperatur til varmepumpe [°C] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW30	Send data_DB.Integers_OUT.+AR30-BT03	Varm side mellemtemperatur til varmepumpe [°C] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW32	Send data_DB.Integers_OUT.+AR30-BT04	Varm side udløbstemperatur til varmepumpe [°C] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW34	Send data_DB.Integers_OUT.+AR10-BT02	Kold side indløbstemperatur til varmepumpe [°C] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW36	Send data_DB.Integers_OUT.+AR10-BT01	Kold side mellemtemperatur til varmepumpe [°C] x10
	Slot 4 ("????") "64 Bytes Input consistent"	←INT→	Slot 4 ("Integers_OUT") "64 Bytes Output consistent"	%QW38	Send data_DB.Integers_OUT.+AR20-BT01	Kold side udløbstemperatur til varmepumpe [°C] x10

Bilag B

I/O-liste for PBAS

	Beskrivelse
NEAS_VP_COP	Til NEAS. Varmepumpe COP
NEAS_Energi_Tank	Til NEAS. Energiindhold i akkumuleringstank
NEAS_VP_el_effekt	Til NEAS. EL-effektoptag varmepumpe
NEAS_Start_VP	Fra NEAS. Start varmepumpe
NEAS_Stop_VP	Fra NEAS. Stop varmepumpe
NEAS_VP_maa_fjernstyres	Til NEAS. Varmepumpe må fjernstyres
NEAS_VP_Alarm	Til NEAS. Varmepumpe alarm (0=alarm)
NEAS_Flow_til_GV_Tank	Til NEAS. Flow for grundvandspumper
NEAS_Indhold_GV_Tank	Til NEAS. Grundvandstank, vandindhold
NEAS_Start_Kedel	Fra NEAS. Start gaskedel
NEAS_Stop_Kedel	Fra NEAS. Stop gaskedel
NEAS_Kedel_maa_fjernstyres	Til NEAS. Gaskedel må fjernstyres
NEAS_Kedel_Alarm	Til NEAS. Gaskedel alarm (0=alarm)

Bilag C

I/O-liste for AURA Energi

	Beskrivelse
GE_tavle_VP_SP	Setpunkt Varmepumpe fra AURA Energi
GE_tavle_VP_I	Strømforbrug på Varmepumpe (0-10V)
GE_tavle_VP_drift_tilladt	Fra AURA Energi tavle. Stop Varmepumpe ved logisk 0
GE_tavle_VP_stop	Fra AURA Energi tavle. Stop Varmepumpe ved logisk 1
GE_VP_drift	Til AURA Energi. Varmepumpe i drift

Bilag D

Lastmatrix for varmepumpe

Hornslet : 28.05.2014/cth

RYE Kraftvarmeværk : Matrix med estimerede dellast data.																
Last index	Kap. varme	SUM Varme-effekt	FV frem	FV retur	Indg. varm til VP	Flow i VP shunt varm	Trykfald varm	Flow i FV	SUM Køle-effekt	Flow kold	Trykfald kold	Kold ind	Kold mellem temp.	Kold ud	Sum el-optag	COP varm
	[%]	[kW]	[°C]	[°C]	[°C]	[m3/h]	[kPa]	[m3/h]	[kW]	[m3/h]	[kPa]	[°C]	[°C]	[°C]	[kW]	
1	100	2048	75	35	35	44	130	44	1584	194,6	50	9	5,0	2,0	509,4	4,02
2	90	1840	75	35	39	44	130	39,6	1415	194,6	50	9	5,0	2,7	468	3,93
3	80	1635	75	35	43	44	130	35,2	1250	194,6	50	9	5,0	3,5	427	3,83
4	70	1430	75	35	47	44	130	30,8	1080	194,6	50	9	5,0	4,2	380	3,76
5	90	1843	71	35	35	44	130	44	1448	194,6	50	9	5,4	2,6	450	4,10
6	80	1638	67	35	35	44	130	44	1300	194,6	50	9	5,7	3,3	387	4,23
7	70	1434	63	35	35	44	130	44	1141	194,6	50	9	6,1	4,0	330	4,35
8	60	1229	59	35	35	44	130	44	986	194,6	50	9	6,5	4,6	279	4,41
9	50	1024	55	35	35	44	130	44	829	194,6	50	9	6,9	5,3	226	4,53

RYE Kraftvarmeværk : Data med teoretiske estimerede fuldlast data.																
Last index	Kap. kompresorer	SUM Varme-effekt	FV frem	FV retur	Indg. varm til VP	Flow i VP shunt varm	Trykfald varm	Flow i FV	SUM Køle-effekt	Flow kold	Trykfald kold	Kold ind	Kold mellem temp.	Kold ud	Sum el-optag	COP varm
	[%]	[kW]	[°C]	[°C]	[°C]	[m3/h]	[kPa]	[m3/h]	[kW]	[m3/h]	[kPa]	[°C]	[°C]	[°C]	[kW]	
1	100	2048	75	35	35	44	130	44	1584	194,6	50	9	5,0	2,0	509,4	4,02
10	100	2046	70	35	35	50,3	175	50,3	1610	205,3	60	9	5,2	2,3	494	4,14
11	100	2090	65	35	35	59,9	240	59,9	1653	232,2	75	9	5,6	2,9	472	4,43
12	100	2134	60	35	35	73,4	365	73,4	1723	301,0	120	9	6,3	4,1	455	4,69
13	100	2159	55	35	35	92,8	580	92,8	1730	327,8	145	9	6,5	4,5	430	5,02

RYE Kraftvarmeværk : Estimerede dellastdata med fast koldvandside.																
Last index	Kap. kompresorer	SUM Varme-effekt	FV frem	FV retur	Indg. varm til VP	Flow i VP shunt varm	Trykfald varm	Flow i FV	SUM Køle-effekt	Flow kold	Trykfald kold	Kold ind	Kold mellem temp.	Kold ud	Sum el-optag	COP varm
	[%]	[kW]	[°C]	[°C]	[°C]	[m3/h]	[kPa]	[m3/h]	[kW]	[m3/h]	[kPa]	[°C]	[°C]	[°C]	[kW]	
1	100	2048	75	35	35	44	130	44	1584	194,6	50	9	5,0	2,0	509,4	4,02
14	Del.	2025	70	35	35	49,7	170	49,7	1584	194,6	50	9	5,1	2,0	490	4,13
15	Del.	1999	65	35	35	57,3	225	57,3	1584	194,6	50	9	5,1	2,0	461	4,34

RYE Kraftvarmeværk : Data med estimerede fuldlast data.																
Last index	Kap. kompresorer	SUM Varme-effekt	FV frem	FV retur	Indg. varm til VP	Flow i VP shunt varm	Trykfald varm	Flow i FV	SUM Køle-effekt	Flow kold	Trykfald kold	Kold ind	Kold mellem temp.	Kold ud	Sum el-optag	COP varm
	[%]	[kW]	[°C]	[°C]	[°C]	[m3/h]	[kPa]	[m3/h]	[kW]	[m3/h]	[kPa]	[°C]	[°C]	[°C]	[kW]	
1	100	2048	75	35	35	44	130	44	1584	194,6	50	9	5,0	2,0	509,4	4,02
16	100*	2039	70	35	35	50,1	170	50,1	1596	196,1	51	9	5,1	2,0	494	4,13
17	100*	2027	65	35	35	58,1	230	58,1	1607	197,4	52	9	5,1	2,0	468	4,33
18	100**	2062	70	35	35	50,7	170	50,7	1615	220,0	65	9	5,5	2,7	493	4,18
19	100*	2058	65	35	35	59,0	235	59,0	1633	220,0	65	9	5,4	2,6	439	4,69
20	100	966	51,5	35	35	50,3	170	50,3	790	194,6	50	9	9,0	5,5	206	4,69
21	100	983	51,5	35	35	51,2	175	51,2	800	220,0	65	9	9,0	5,9	207	4,75
22	100	948	51,5	35	35	49,4	170	49,4	775	165,0	40	9	9,0	5,0	205	4,62

* = HPO dellast (pga. at mellemtryk er fast +39,3°C på højtemp. del af varmepumpe; 116E kan ikke levere nok til at HPO'ere køre 100%).

** = 116E dellast (pga. at mellem tryk er fast +39,3°C på højtemp. del af varmepumpe; 116E kan lave mere end HPO'ere kan aftage)

Index 1: Design

16 & 17: Vand køles til +2°C

18 & 19: Max. flow kold side

20, 21 & 22: Kun drift med lav temp. kompressor.