Final report

SUNSTORE 3
Phase 2
Implementation

1. Project details

Project title	SUNSTORE 3, Phase 2 and SUNSTORE 3, Additional application
Project identification (program abbrev. and file)	64009-0043 and 64010-0447
Name of the programme which has funded the project	EUDP 2009
Project managing company/institution (name and address)	PlanEnergi Jyllandsgade 1 9520 Skørping
CVR (central business register)	74038212
Date for submission	March 2015

Project partners	**PlanEnergi** (Project manager) Jyllandsgade 1 9520 Skørping, CVR 74038212 Contact: Per Alex Sørensen, pas@planenergi.dk **NIRAS** Vestre Havnepromenade 9 9000 Aalborg, CVR 37295728 Contact: Christian Schmidt, csc@niras.dk **Technological Institute** Gregersensvej 2630 Taastrup, CVR 56976116 Contact: Bjarke Lava Paaske, bjpa@teknologisk.dk **Marstal Fjernvarme** Jagtvej 2 5960 Marstal, CVR 31220319 Contact: Lasse Kjærgaard, info@solarmarstal.dk **Dronninglund Fjernvarme** Tidselbak Allé 18 9330 Dronninglund, CVR 12233418 Contact: Carsten Møller Nielsen, carsten@drlund-fjernvarme.dk **SOLITES** (subcontractor to PlanEnergi) Steinbeis Forschungsinstitut für solare und zukunftsfähige thermische Energiesysteme Meitnerstrasse 8 D – 70563 Stuttgart, Germany Contact: Thomas Schmidt, schmidt@solites.de
CVR (central business register)	74038212
Date for submission	March 2015

Table of contents

2. Short description of project objective and results

English:
The objective of the SUNSTORE 3 project has been to optimize, design and implement a full scale demonstration plant with 35,000 m^2 solar thermal collectors, 60,000 m^3 pit heat storage and a heat pump that utilizes the storage as heat source.

The demonstration plant opened in May 2014. The cost is a little lower than budgeted and the production from the plant seems to be as expected.

Dansk:
SUNSTORE 3 projektet har som formål at optimere, detailprojektere og opføre et fuldskala demonstrationsanlæg med 35.000 m^2 solfangere, 60.000 m^3 damvarmelager og en varmepumpe, som anvender damvarmelageret som varmekilde.

Demonstrationsanlægget blev indviet i maj 2014. Anlægsbudgettet er overholdt og anlægget ser ud til at producere som forventet.

3. Executive summary

The SUNSTORE 3 project started in 2008 where EUDP supported a design project for a large pit heat storage with solar collectors and heat pump in Dronninglund. This part is reported in "Slutrapport, Fase 1" [Ref. 1]. The present report covers Phase 2, implementation of the project, supported in 2009 and in 2010 from EUDP.

The design project ended up with a production plant of 35,000 m^2 solar collectors, 60,000 m^3 pit heat storage and an electrical driven heat pump with heat capacity of 3 MW. But also with a problem with bad economy for the electrical driven heat pump due to the Danish electricity taxes.

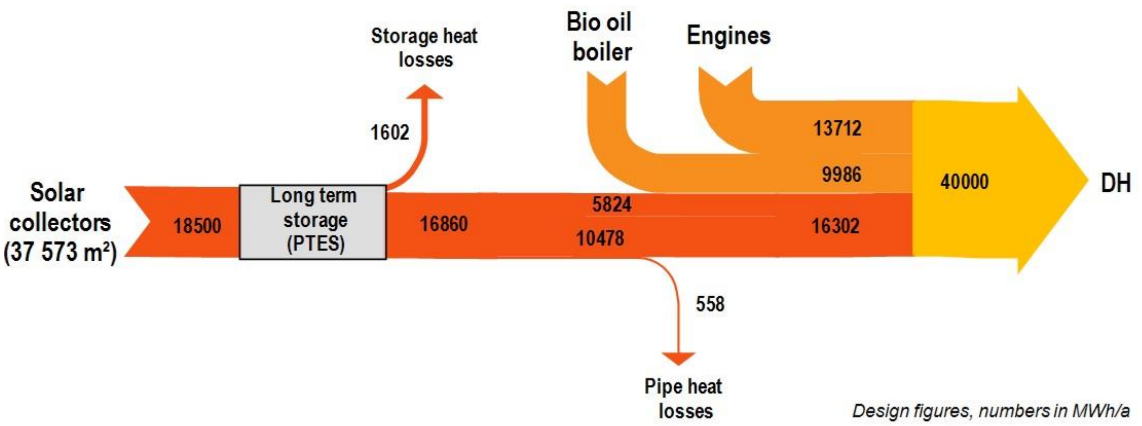
This problem was not solved before the implementation of the plant. The electrical driven heat pump therefore had to be replaced by a heat driven absorption heat pump. TRNSYS calculations showed an optimum of 2.1 MW cooling capacity for the absorption heat pump.

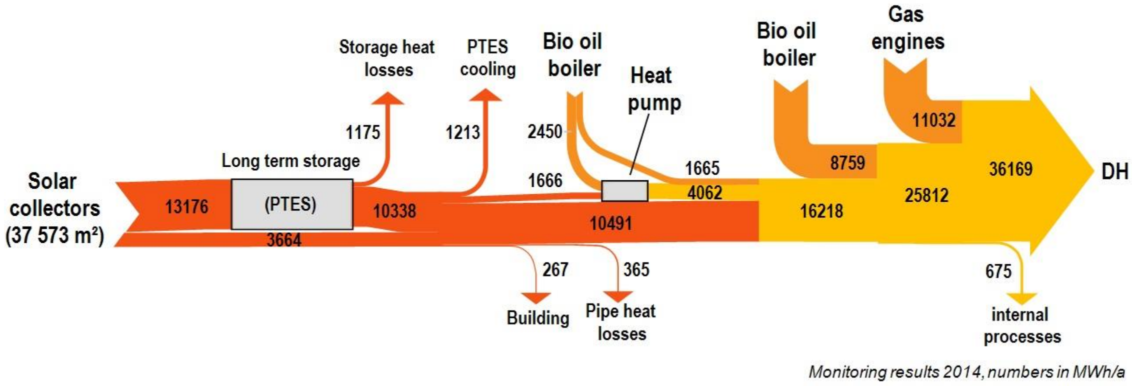
Also the design of the storage lid was changed. The main reason was that Marstal District Heating in 2012 developed and implemented a new type of lid, where the cost was in same level as for the type designed for Dronninglund in Phase 1 of the SUNSTORE 3 project. The design in Dronninglund was improved according to ventilation and anchoring of the insulation material. GSE, supplier of the HDPE-liner for the storage, offered a new type of liner, with a durability guarantee of 20 years if temperatures in the storage don't exceed 90 ^{o}C.

In the solar collector field a new type of Logstor pre-fabricated pipes for solar fields gave room for extra solar collectors. The collector area thus ended at 37,573 m^2 instead of 35,000 m^2 because calculations showed that it would be feasible to extend the solar collector area if the existing natural gas fired CHP plant should join the open electricity market and therefore have only a few running hours in the summer period.

After these changes the budget for the project could be fixed and implementation started in March 2013. During the implementation period there was only miner unexpected problems except for corrosion protection in the storage. Marstal District Heating found corrosion in the first year of operation and therefore a corrosion expert was consulted and it was desided a.o. to treat the water with reverse osmosis to remove all salts and to raise pH to 9.6-9.8 in the storage water.

The plant was opened 2nd May 2014 and a monitoring program has been in function from the beginning. Solites has evaluated the results from project start to 31.12.2014 and the production seem to be as calculated as can be seen from the figures below.





(source: Solites)

Two new projects with large pit heat storages and solar collector fields in Vojens and Gram will be opened in 2015 and a third is planned in Løgumkloster. Besides that several district heating utilities are investigating the feasibility of large scale solar and pit heat storage, and also utilization of pit heat storages to store excess heat from waste incineration, industries and CHP-production is now investigated in- and outside Denmark.

4. Project objectives

4.1 Project objectives

The technical objectives in the project were:

- To demonstrate a full scale pit heat storage in combination with solar thermal and a heat pump.
  The plant is implemented.
- To cover 50 % of the district heat consumption in Dronninglund with solar thermal.
  Calculations show a solar fraction of 41 %. The reason why the 50 % is not reached is that the electrical driven heat pump was part of the 50 % in the original design concept.
- To demonstrate a new cover solution where disadvantages from the 10,000 m^3 pit heat storage in Marstal are solved (air pockets under the cover, water pits near the edge, moisture in insulation and demolition of convection stop.
  The new cover solution seems to have solved these problems.
- Implement a storage that also can be utilized to store excess heat from industries, incineration plants, power plants and biogas plants.
  Since the HDPE-Liner used in Dronninglund has a durability of min. 20 years for temperatures up to 90 ^{o}C the whole year round, the implemented type of storage can be utilized also for the above mentioned purposes.

The commercial objects in the project were:

- To keep storage costs below 250 DKK/m^3.
  Storage costs are 284 DKK/m^3 but since the objective of 250 DKK/m^3 is from 2008, a price increment of 13.6 % is not much more than the cost development in the period.
- To produce heat to 350-400 DKK/MWh (5 % interest, 2 % inflation, 20 years annuity loan).
  The heat production price for the new plant is expected to be as follows:

Investment	*14,300,000 €*	*105,300,000 DKK*
Capital costs (20 year loan, 3 % real interest)	*949,500 €/year*	*7,074,000 DKK/year*
Extra cost, operation	*+21,100 €/year*	*+157,000 DKK/year*
Total extra cost/year	*970,600 €/year*	*7,231,000 DKK/year*
Replaced energy production	*16.302 MWh/year*	
Production price	*59.54 €/MWh*	*444 DKK/MWh*

  This is prices without subsidies for Dronninglund. Future projects show the announced level of 350-400 DKK/MWh even despite inflation since 2008.
- To store excess heat for 200–250 DKK/MWh.
  The cost of the storage is 284 DKK/m^3 or 19.18 DKK/m^3/year. Operation cost is app. 100,000 DKK/year or 1.67 DKK/m^3/year. Total 20.75 DKK/m^3/year.
  The capacity of the storage is 0.085 MWh/m^3 and heat loss 0.027 MWh/m^3. Therefore the storage cost will be 20.75 DKK/m^3 / (0.085-0.027) MWh/m^3 or 358 DKK/MWh with one storage cycle and 145 DKK/MWh with two storage cycles as in Dronninglund (sec. 5.1.3).
- To implement 5 new storage projects without support the next 3-5 years.
  Two new storage projects are implemented in 2015. One project is planned and several are under consideration.

4.2 Implementation of the project

4.2.1 *Final design of the plant*

From compressor to absorption heat pump

During Phase 1 of the project, described in "Slutrapport, fase 1" [Ref. 1] Dronninglund Fjernvarme tried twice through meetings with the Committee for Energy Policy in the Danish Parliament and meetings with the Danish Minister for Taxation to change the rules for taxation of electricity used for heat pumps.

The Minister promised to change the rules, but changes were not decided before the implementation phase in the SUNSTORE 3 project had to start. That meant, that the yearly surplus would be reduced with 546,154 DKK if an electrical driven heat pump is added [Ref. 1, page 22].

Therefore Dronninglund Fjernvarme decided to investigate the feasibility of a heat driven heat pump. The technical calculations were carried out in TRNSYS.

Fig. 1: *Map showing Lunderbjerg, connection pipe and Søndervang.*
1. Solar panels in solar thermal plant
2. Pit heat water storage
3. Technique building with pipes, pumps and heat exchangers
4. District heating pipes
5. Søndervang with absorption heat pump

The calculation showed that if the heat exchanger and the heat pump are moved from Lunderbjerg to Søndervang heat delivery from Lunderbjerg will be 577 MWh extra pr. year. If the substituted heat production price is 350 DKK/MWh, the extra income will be 208,950

DKK/year. Therefore it was decided to move the heat exchanger and the absorption heat pump to Søndervang.

The purpose with the simulation was to gain as much heat as possible from solar plant and the storage in Lunderbjerg and to optimize the economy. In Fig. 2 the amount of heat from Lunderbjerg to Søndervang can be seen, depending on the size of the heat pump generator. The amount of heat can be increased from 11,503 MWh/year without heat pump to 14,322 MWh/year (+24.5%) as maximum with a heat pump.

If the substitution heat price is 350 DKK/MWh, an absorption heat pump costs 2 mio. DKK/MW$_{cooling}$ and the capital costs is calculated as an 5%, 15 year annuity loan, the extra value of different cooling capacity can be calculated. This is illustrated in Fig. 3.

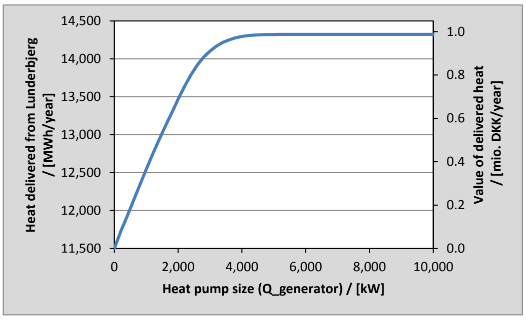


***Fig. 2:** Heat from Lunderbjerg depending on the size of the heat pump.*

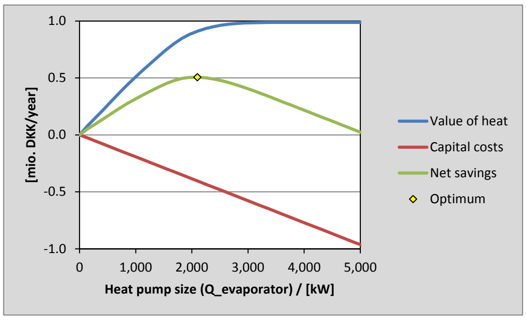


***Fig. 3:** Value of extra heat from Lunderbjerg depending on the size of the heat pump.*

As can be seen from Fig. 3 optimal size of the heat pump is app. 2.1 MW cooling capacity.

Sensitivity analysis of heat price and depreciation period showed optimal heat pump capacities between 1.9 and 2.3 MW$_{cooling}$.

Therefore it was decided to implement a 2.1 MW$_{cooling}$ absorption heat pump in Søndervang. The principle diagram can be seen in Fig. 4.

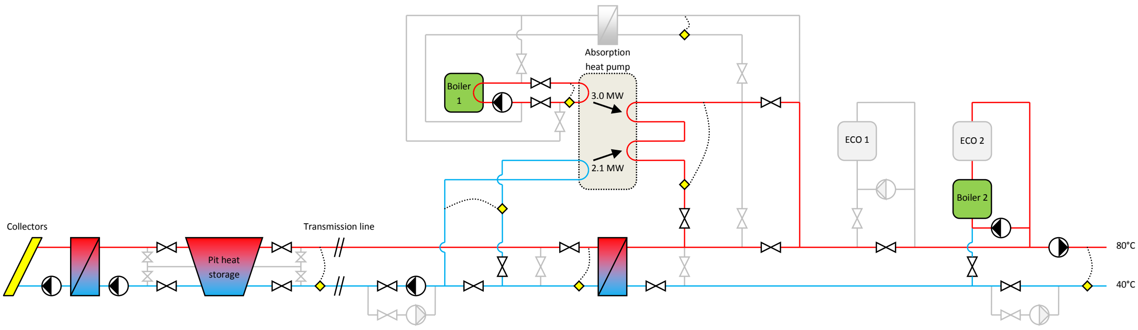


***Fig. 4:** Principle diagram, SUNSTORE 3. Yellow squares are flow/energy meters. The diagram is simplified and not all equipment is shown.*

Design of the storage

The pit heat storage was designed in Phase 1 of the project [Ref. 1, p. 10-17], but during the implementation process in Dronninglund there was a delay from Summer 2011 to Spring 2013 because of complaints from neighbours concerning the local plan procedure. In that period Marstal Fjernvarme implemented a 75,000 m^3 pit heat storage, where the design concept in the tender documents was similar to the design in [Ref. 1]. Marstal got offers using the SUNSTORE 3 design, but decided to develop an alternative concept and ended up using a concept proposed by the liner supplier GSE. The reason why the SUNSTORE 3 design was not used in Marstal was the price and a risk for condensation in the LECA-layer in the lid mentioned from SOLITES in Germany.

Dronninglund Fjernvarme therefore discussed the original SUNSTORE 3 solution compared to the solution used in Marstal and decided to use the Marstal solution for same reasons as in Marstal.

The solution in Marstal differs from the original SUNSTORE 3 solution in design of the lid:

- The lid in the Marstal design is following the water surface when it moves up and down during the year.
- The insulation in the lid is a closed cell PE (Nomalén from company Termonova).
- Rain water on the lid is led to a pump well in the middle of the lid. The middle is lower than the edges because of weight pipes (HDPE-pipes with concrete inside) on the lower geomembrane and the upper geomembrane in the lid.

The construction is described in detail in "IEA-SHC TECH SHEET 45.B.3.2" [Ref. 2]. Fig. 5 shows a cross section of the edge solution.

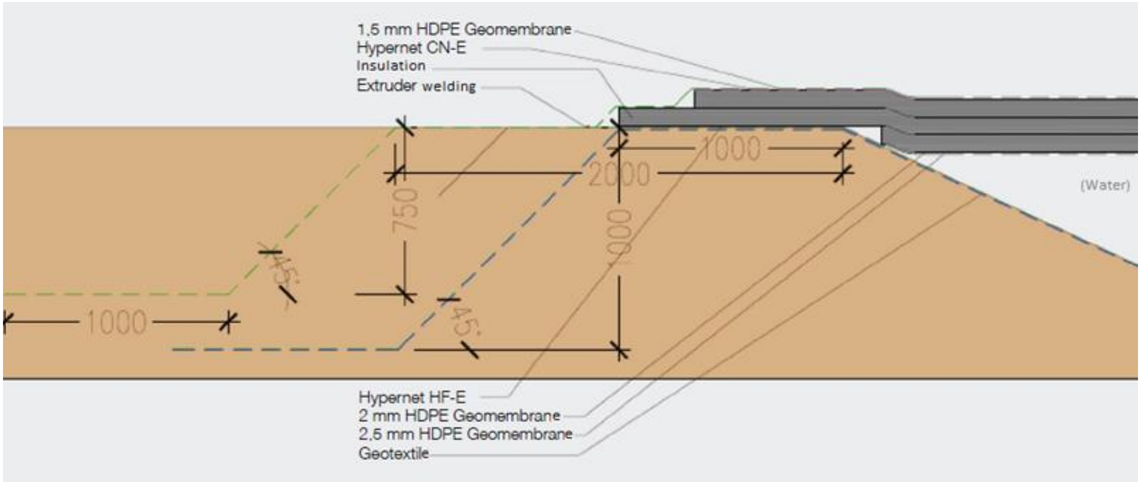


Fig. 5: *Cross section of the edge of a floating cover based on flexible insulation mats.*

In Fig. 6 the weight pipes are illustrated in a cross section of the floating lid, and in Fig. 7 another cross section shows the ventilation solution.

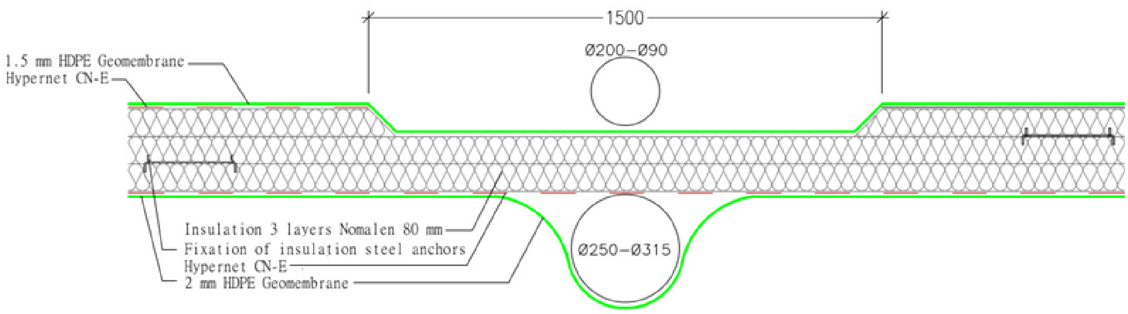


Fig. 6: *Cross section of the weight pipes on the floating liner.*

Between the insulation and the top liner is a ventilation gap to be able to ventilate away water vapour in the cover. Along the edges of the storage the top liner is welded to the floating liner as seen in Fig. 5. Ventilation of the cover is done by roof vacuum vents placed along the edges of the storage. The vacuum vents are mounted as seen in Fig. 7. The vacuum vents only allow air flow out of the cover. Therefore some of the vacuum vents are modified as needed to allow air flow into the cover. Cold air will be drawn into the cover through the modified vents, heated by the warmer atmosphere in the cover while absorbing moisture, and exhausted by the other vacuum vents. In case of severe moisture, e.g. moisture from implementation phase the process can be accelerated by mechanical ventilation (a suction blower connected to one of the vents).

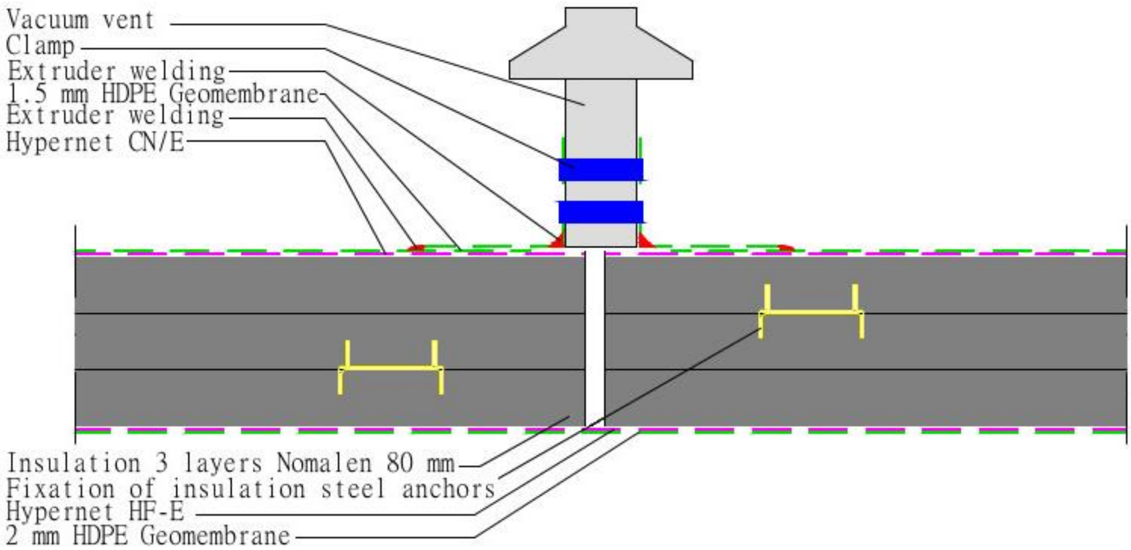


Fig. 7: *Cross section of the cover with vacuum vent and steel anchors.*

Weight pipe layout on top of the cover is shown in Fig. 8.

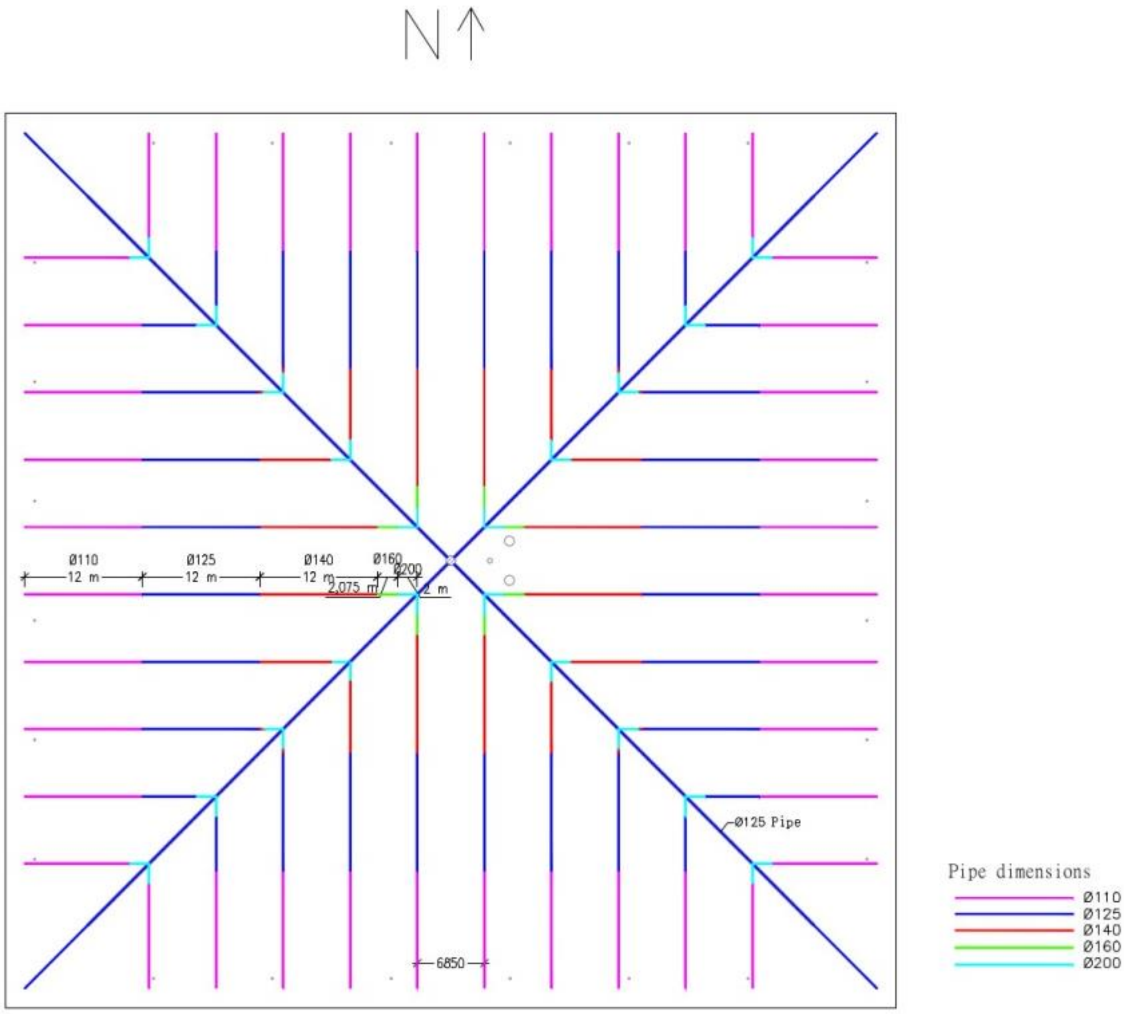


Fig. 8: *Weight pipe layout on the top of the cover.*

The temperatures in the pit heat storage were calculated in TRNSYS. The result for year 2 can be seen in Fig. 9.

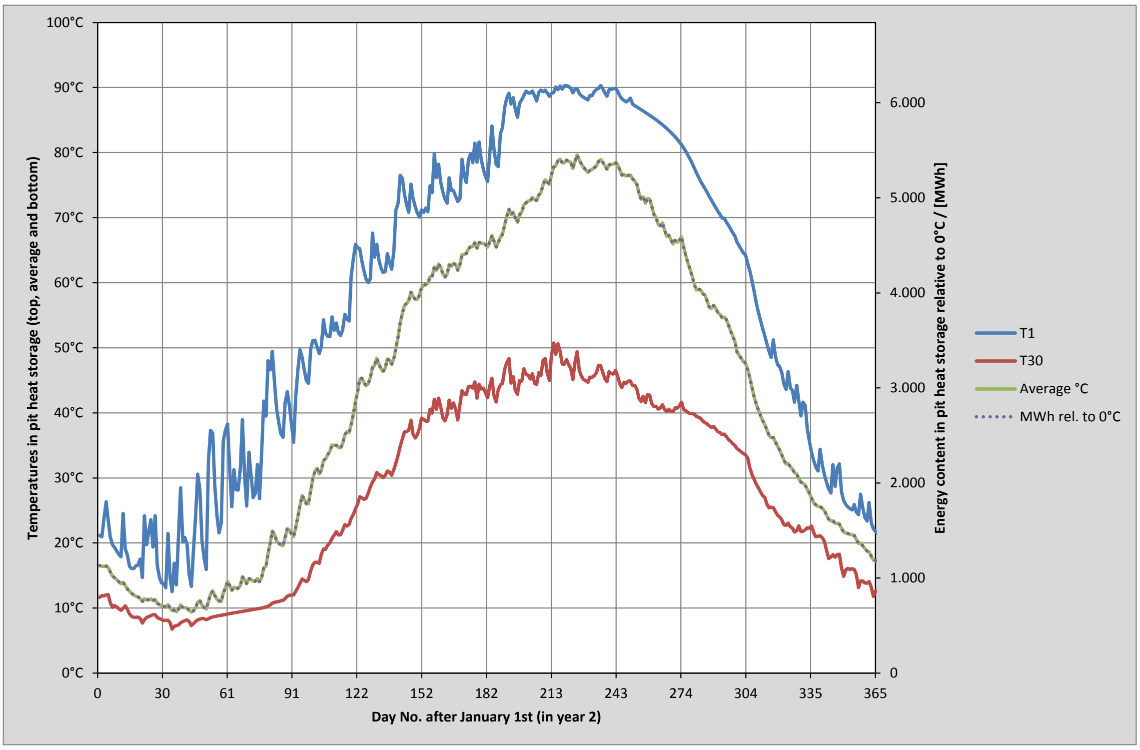


Fig. 9: *Calculated temperatures in the pit heat storage year 2.*

The geomembrane (liner) used in Marstal has a limited lifetime at high temperatures (3.2 years at 90 °C and 7.2 years at 80 °C). That would make it difficult to make the Marstal-liner last in 20 years under the conditions in Dronninglund. Fortunately the liner supplier, GSE, had developed a new generation of high temperature liners where they guaranteed a 20 year lifetime if the liner temperature would not exceed 90 °C. This liner is used in Dronninglund. Product Data Sheet is annexed as Annex 1.

4.2.2 *Implementation*

Implementation took place from 15th March 2013 to April 2014. Heat production from the solar collectors started in March 2014 and the official opening was 2nd May 2014. The plant was opened by the Danish Minister for Climate, Energy and Buildings Rasmus Helweg Petersen.

The implementation phase was without major problems. For the different parts of the project experiences in the implementation phase are highlighted at the following pages.

The pit heat water storage

The storage was established in an old gravel pit. Ground water level is app. 3 meters below the bottom of the storage and the soil consists of gravel and sand. That made the implementation easy mainly because rain and ground water did not cause problems. Also the weather conditions were brilliant since there was nearly no rain in the Spring and beginning of the Summer 2013, where excavating and liner welding took place. Excavation was ready after two months, and implementation of side and bottom liner took one month. In the middle of June the water filling could begin.

The in- and outlet pipes in Dronninglund comes into the storage through the bottom. Therefore the in- and outlet pipes had to be stabilized to resist wind influence during the period from implementation until water was filled in. Stabilisation was done with wires. See Fig. 10.

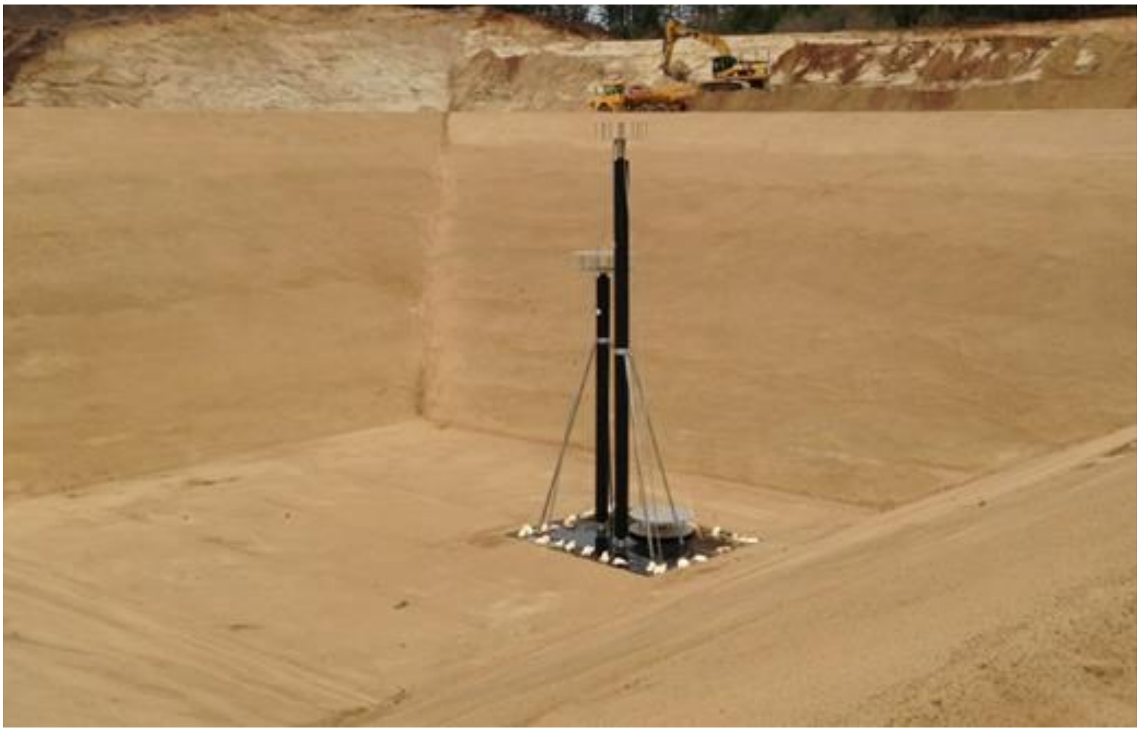


Fig. 10: *In- and outlet with stabilization wires.*

In the storage in Marstal some of the lessons learned from the first year of operation was reduced capacity of the heat exchanger between solar plant and storage because of dirt in the water and corrosion (probably galvanic and bacterial) in in- and outlet pipes. In Dronninglund in- and outlet pipes are in stainless steel, but even then corrosion can occur. Therefore a corrosion expert was consulted and the following precautions were taken against corrosion and to protect the heat exchangers:

- Pipes between solar central, storage and Søndervang were cleaned before water was filled in.
- Filters were implemented to protect the heat exchangers.
- As much oxygen as possible without heating up the water was mechanically removed when filling in water in the storage.
- Water was treated with reverse osmosis to remove all salts (especially chlorides) when filling in water in the storage.
- pH was raised to 9.6-9.8.

During operation the water in the storage will be analyzed for content of oxygen, salts, bacteria and pH-value at least annually.

After implementation of the HDPE-liner, the liner was tested for leakages. A wet geotextile was rolled over the weldings, electrical potential put on and if electric conduction could be traced outside the storage wall, a leakage was found. During the test no leakages were found.

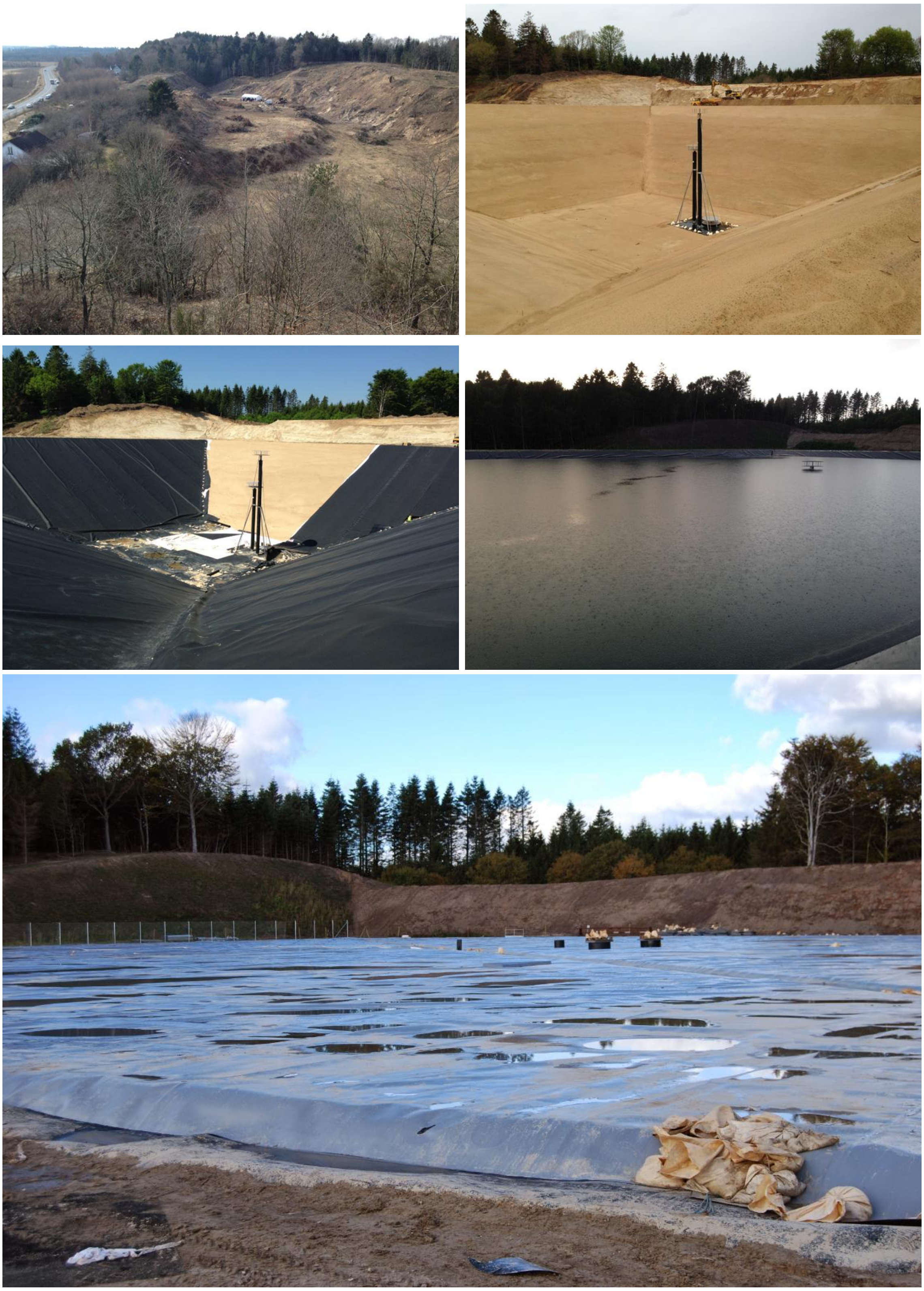


Fig. 11: *Pictures from implementation of pit heat water storage.*

The solar collectors

During contract negotiation with ARCON Solar it was discussed if it was feasible to avoid the insulating foil in the first solar collectors in the rows. Therefore the solar system was calculated in TRNSYS with two solar fields serially connected. The first solar field was without foil (η_o = 0.845,a_1 = 2.94, a_2 = 0.013) and the second with foil (η_o = 0.817, a_1 = 2.205, a_2 = 0.0135). The total area was 36.897 m^2. The result can be seen in Fig. 12.

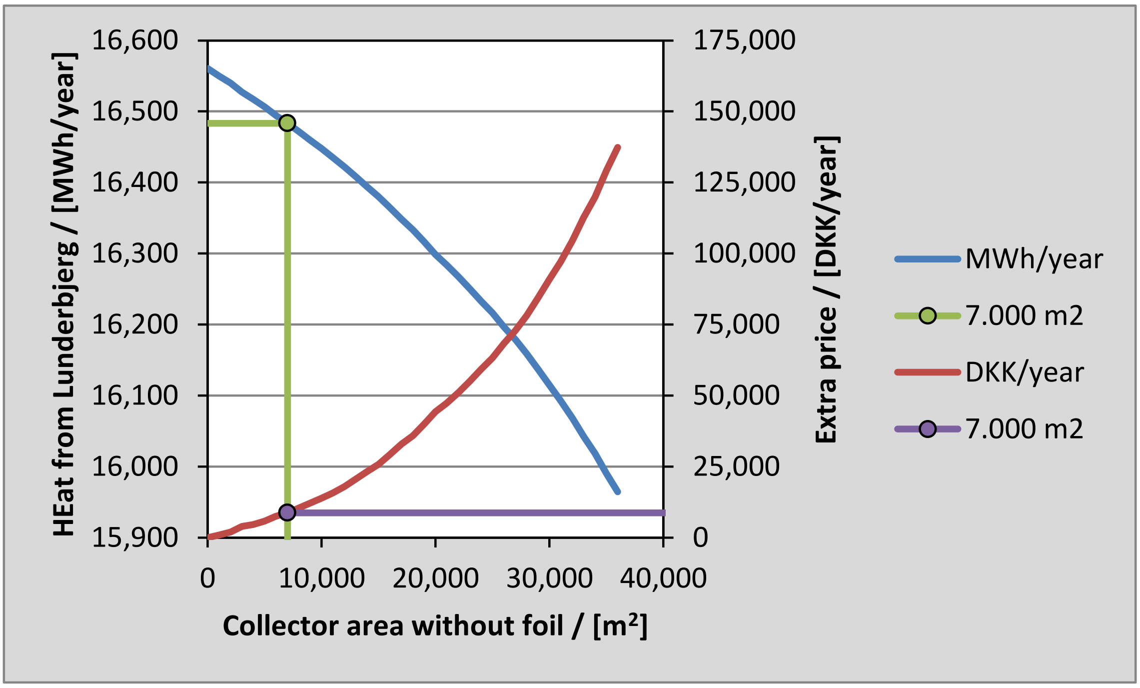


Fig. 12: *Feasibility with and without foil.*

The blue curve shows the yearly heat delivered from Lunderbjerg to Søndervang as a function of the solar area without foil. The steepness of the curve show that the amount of produced heat is reduced with 11 kWh/m^2/year if there is no foil in the first solar collectors in a row and with 26 kWh/m^2/year if there is no foil in the last solar collectors in a row.

The foil price is 10.6 €/m^2. Yearly cost is calculated with a 25 years annuity loan with a 1.5 % real interest. The price of substituted heat is expected to be 62 €/MWh (bio oil).

The red curve show the extra price for produced heat if foil is removed and the green line show the result if 7,000 m^2 solar collectors are without foil:

- Reduction in investment — 7,000 m^2 x 10.6 €/m^2 = 74,200 €
- Capital cost reduction — (4.8 % of investment) 3,562 €/year
- Reduction in heat production — 77 MWh/year
- Extra cost bio oil — 77 MWh/year x 62 €/MWh = 4,774 €/year

With the conditions in Dronninglund it is not feasible to remove foil since the red curve shows lowest price if all solar collectors have foil, so it was decided to have foil in all solar collectors in Dronninglund. If the price for substituted heat is more than 50 €/MWh foil is still feasible for the total plant. And if the price for substituted heat is below 20 €/MWh foil is not feasible for the total plant.

Dronninglund Fjernvarmes contract with ARCON Solar included punctual foundation of the solar collectors because the level of the area where the solar collectors are placed is not allowed to be changed more than 0.5 m compared to the original level. Punctual foundation was in earlier projects done with concrete foundations, but during the project in Dronninglund ARCON Solar changed to galvanized steel profiles.

This technology is used for PV-systems, but for flat plate solar thermal collectors the profiles were modified, and pulling tests for each 2,000 m^2 were carried out to calculate the depth of the foundation in the soil. The depth in Dronninglund was calculated to 1.5-2.0 m depending on the soil. The solution is described in Annex 2 and illustrated in Fig. 13.

The steel solution was 1 mio. DKK cheaper than the concrete punctual foundations and precision is +/- 0.5 cm.

Fig. 13: *Pictures from implementation of the solar collectors.*

Logstor has a fixed length of pipes for connecting the collector rows. In Dronninglund the distance between the collector rows was modified to 16 m / 3 = 5.33 m to fit the fixed lengths. That gave room for more collector rows in the same area. Therefore Dronninglund Fjernvarme applied Brønderslev Municipality for an extension of the collector field to 2,882 solar panels, or 37,573 m^2. The permission was given before implementation of the solar collectors.

Søndervang

The central at Søndervangsvej includes two new bio oil boilers of 5 and 10 MW. The 5 MW boiler produces 160 ^{o}C hot water for the absorption heat pump.

Fig. 14: *Pictures from implementation in Søndervang (Boiler for absorption heat pump and absorption heat pump).*

Lunderbjerg

The central at Lunderbjerg includes heat exchangers, pumps, pipes, valves and control system for the SUNSTORE 3 project.

Fig. 15: *Pictures from implementation in Lunderbjerg (Building, heat exchangers and pumps).*

4.2.3 *Budget and actual costs*

The budget and the actual costs were as follows:

Table 1: *Budget and actual cost for the project.*

Topic	Contract €	Final cost €	
Solar collectors	5,570,000	5,856,000	1)
District heating pipes	951,000	985,000	
Transmission pipe, excavation and mounting	309,000	344,000	
Solar field, mouting of pipes	136,000	144,000	
Solar field, excavation for pipes	189,000	177,000	
Technique building with pipes, pumps, heat exchangers, absorption heat pump and boilers in Lunderbjerg and Søndervang	3,263,000	3,551,000	
Storage excavation and landscaping	585,000	673,000	
Storage, membrane	1,263,000	1,263,000	
Other costs	1,419,000	1,137,000	
Unforeseen	671,000	0	
Total	**14,356,000**	**14,130,000**	

1) Including 2,573 extra m^2 solar collectors.

Included in the cost for the Technique Building is also heat exchanger, pumps, valves, piping and in- and outlet for the storage. These costs are estimated to 350,000 € making the total price of the storage at 2,286,000 € or 38.10 €/m^3.

5. Project results and dissemination of results

5.1 Monitoring results

5.1.1 System energy balance

This chapter presents monitoring results from 2014, the first year of operation. The evaluations prove a solar fraction of 34 % and a contribution of renewable energies of 70 %. In general the comparison with design data regarding energy contributions from the different components shows a good agreement, taken into account that the solar thermal system and the pit thermal energy storage (PTES) first went into operation in March 2014.

During the design phase the energy contributions of the different components where calculated compared to a non-solar reference configuration. Table 2 shows the calculated energy production in the reference and the actual project case for a normal year.

Table 2: *Calculated contributions from the design phase (source: PlanEnergi).*

	Reference	Project
Preconditions		
Natural gas, calorific value, kWh/Nm^3	11	11
Bio oil, calorific value, MWh/ton	10.0756	10.0756
Engines, electricity efficiency, %	35	35
Engines, heat efficiency, %	59	59
Engines, heat capacity, MW	5.9	5.9
Bio oil boiler, efficiency, %	92	94
Energy		
Heat produced, MWh	40,000	40,000
Degree day dependent heat, %	65	65
Max. heat demand, MW	11.3	11.3
Min. heat demand, MW	1.4	1.4
Heat production, engines, peak load, MWh	7,086	7,086
Heat production, engines, high load, MWh	6,626	6,626
Heat production, bio oil boilers, MWh	26,288	9,986
Heat from solar collectors, MWh	0	18,500
Heat loss from storage, MWh	0	–1,602
Energy change in storage, MWh	0	+38
Heat ab Lunderbjerg, MWh	0	16,860
Heat loss from transmission line, MWh	0	–558
Heat an Søndervang, MWh	0	16,302
Heat via heat exchanger, MWh	0	10,478
Absorption heat pump, cooling, MWh	0	5,824
Electricity production, peak load, MWh	4,204	4,204
Electricity production, high load, MWh	3,931	3,931
Natural gas consumption, MWh	23,240	23,240
Bio oil consumption, MWh	28,574	10,623

In Fig. 16 the design energy flow diagram of the system can be seen. According to these figures a design solar fraction of 41 % can be calculated with the following formula:

Solar fraction: $F_{Sol} = \frac{Q_{Load} - Q_{Aux}}{Q_{Load}} = \left(1 - \frac{Q_{Aux}}{Q_{Load}}\right)$

Q_{Load}: heat supply to the DH network

Q_{Aux}: auxiliary heat delivered to the system (by boilers, gas engines etc.)

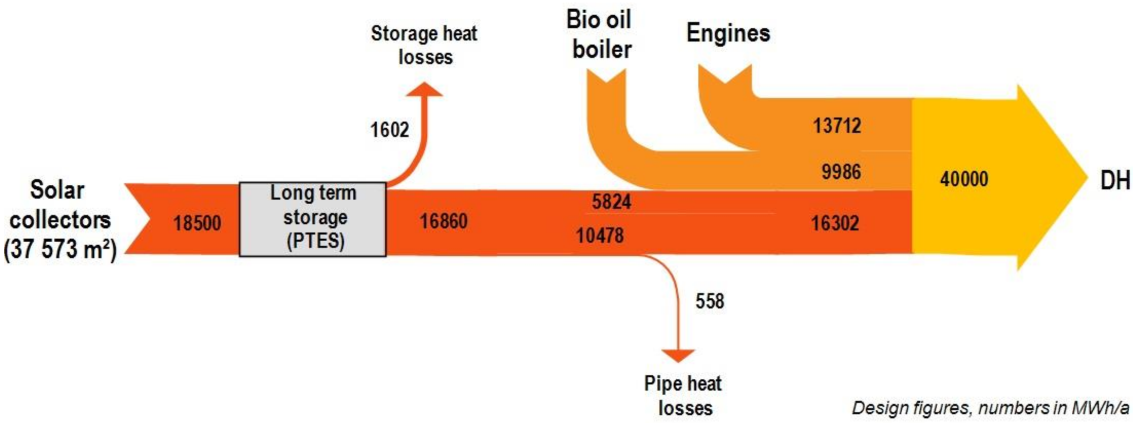


Fig. 16: *Yearly energy flow diagram according to design figures, see Table 2.*

In Fig. 17 the energy flow diagram for the entire plant is illustrated according to monitoring data of the year 2014. Based on the given numbers a solar fraction of 34 % and a RES[1] fraction of 70 % can be calculated. A comparison of the monitored yearly energy values with the corresponding design values, see Fig. 16, shows in general a good agreement.

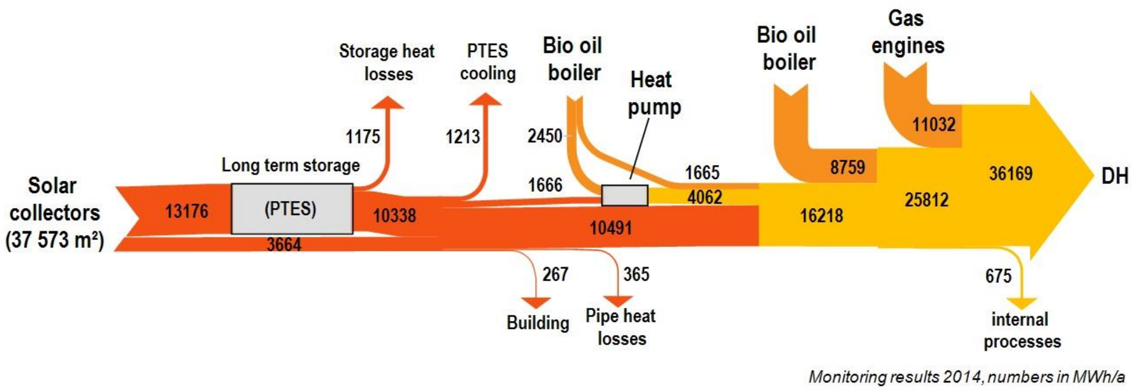
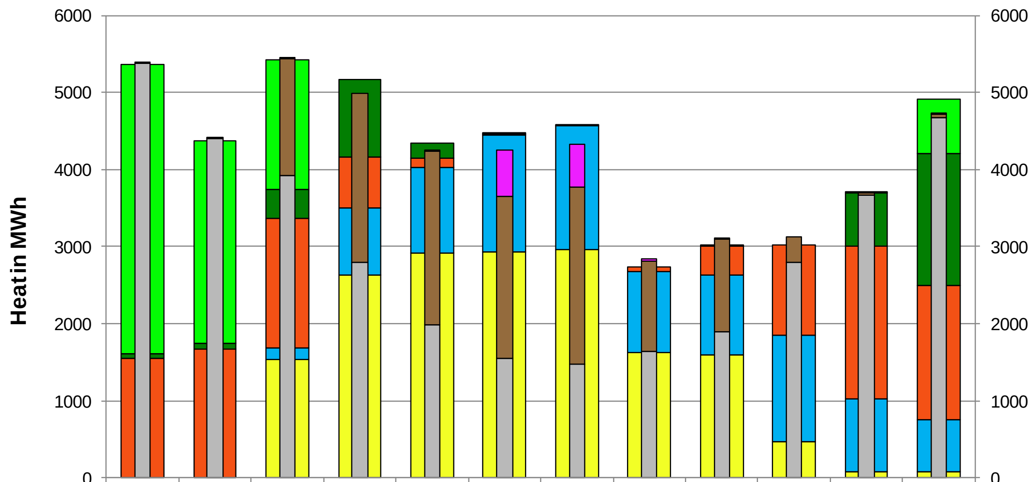


Fig. 17: *Energy flow diagram according to 2014 monitoring data.*

The monthly contributions of the main components can be seen in Fig. 18. According to this the summer heat load can be covered completely by the solar system. In spring, autumn and winter the bio oil boilers in combination with the four gas engines cover the major part of the heat load assisted by solar heat either delivered directly from the solar collectors or discharged from the seasonal pit thermal energy storage (PTES).

[1] RES: Renewable energy sources



	Jan 2014	Feb 2014	Mar 2014	Apr 2014	May 2014	Jun 2014	Jul 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	Dec 2014
bio oil boiler	3740	2638	1675	0	0	0	0	0	0	0	2	704
HT bio oil boiler	68	66	377	1002	196	0	0	0	0	0	692	1713
heat from gas engines	1546	1664	1677	666	131	15	2	64	379	1175	1976	1737
discharging PTES	4	11	147	872	1102	1529	1605	1048	1031	1375	945	668
solar collectors	0	0	1540	2630	2919	2926	2960	1626	1599	472	81	88
PTES cooling*)	0	0	0	0	5	605	560	27	16	0	0	0
charging PTES	1	1	1520	2198	2250	2106	2304	1181	1197	334	36	49
DH Heat delivery	5376	4402	3922	2794	1990	1548	1470	1636	1895	2800	3665	4673

Fig. 18: *Monthly system heat balance according to 2014 monitoring data.*
**) Night cooling of PTES by way of solar collectors because of high temperatures.*

5.1.2 *Solar collector field*

From March to December 2014 the solar collectors delivered 16,841 MWh or 448 kWh/m² of heat to the system. The mean efficiency of the solar collector circuit was 43 %.

Fig. 19 shows the monthly heat production of the solar collector fields for the entire period under review together with the solar irradiation into the collector pane and the solar collector circuit efficiency.

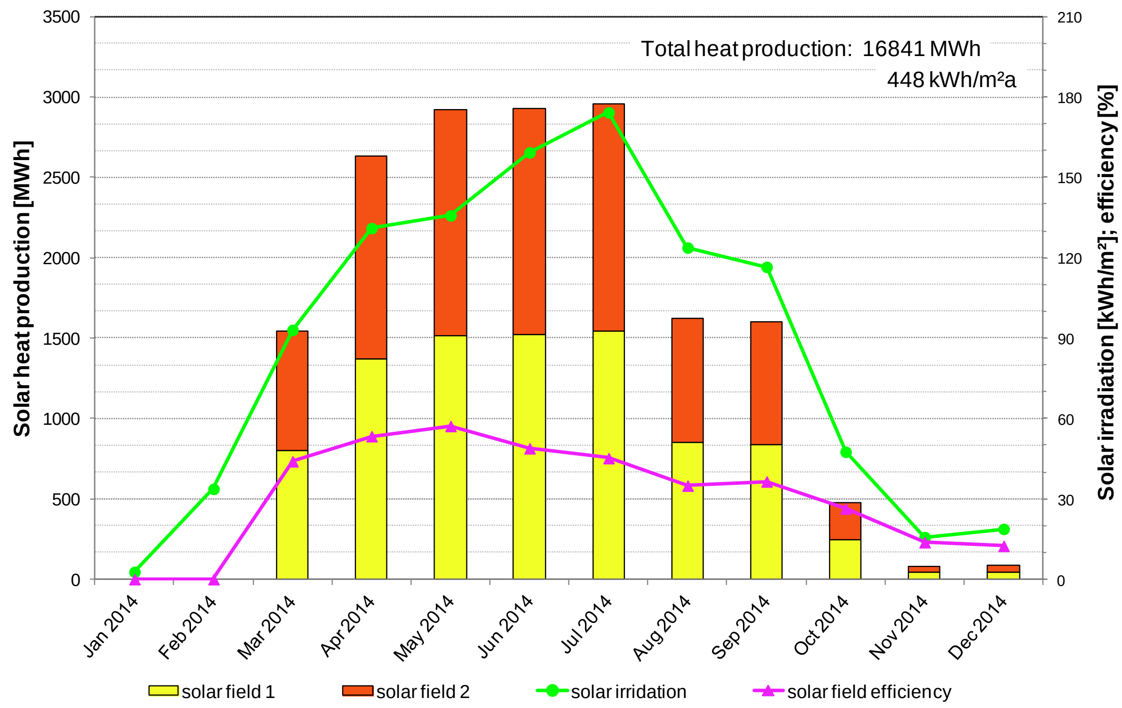


Fig. 19: *Solar collector heat production according to 2014 monitoring data.*

5.1.3 *Pit thermal energy storage*

Fig. 20 shows the heat balance of the PTES. The given internal energy change is calculated based on the values of 32 temperature sensors distributed in different heights inside the storage volume for the period between 31.01.2014 and 30.12.2014.

With the numbers of the heat balance and the measured maximum and minimum temperatures inside the storage in 2014 (86 °C and 12 °C respectively) the following characteristic figures can be identified:

- Storage efficiency: 78 %
- No. of storage cycles: 2.0
- Heat capacity: 5,100 MWh

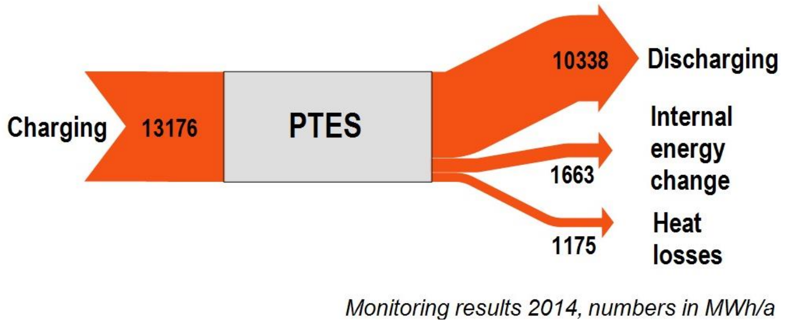


Fig. 20: *PTES heat balance according to 2014 monitoring data.*

The storage efficiency is defined as discharging % of charging, and the No. of storage cycles is defined as discharging divided by the heat capacity in the storage.

Fig. 21 illustrates the monthly heat balance of the PTES. The main charging of the storage takes place during the summer months, discharging in the summer as well as in the winter period. From end of July until end of September the PTES is filled with maximum energy content.

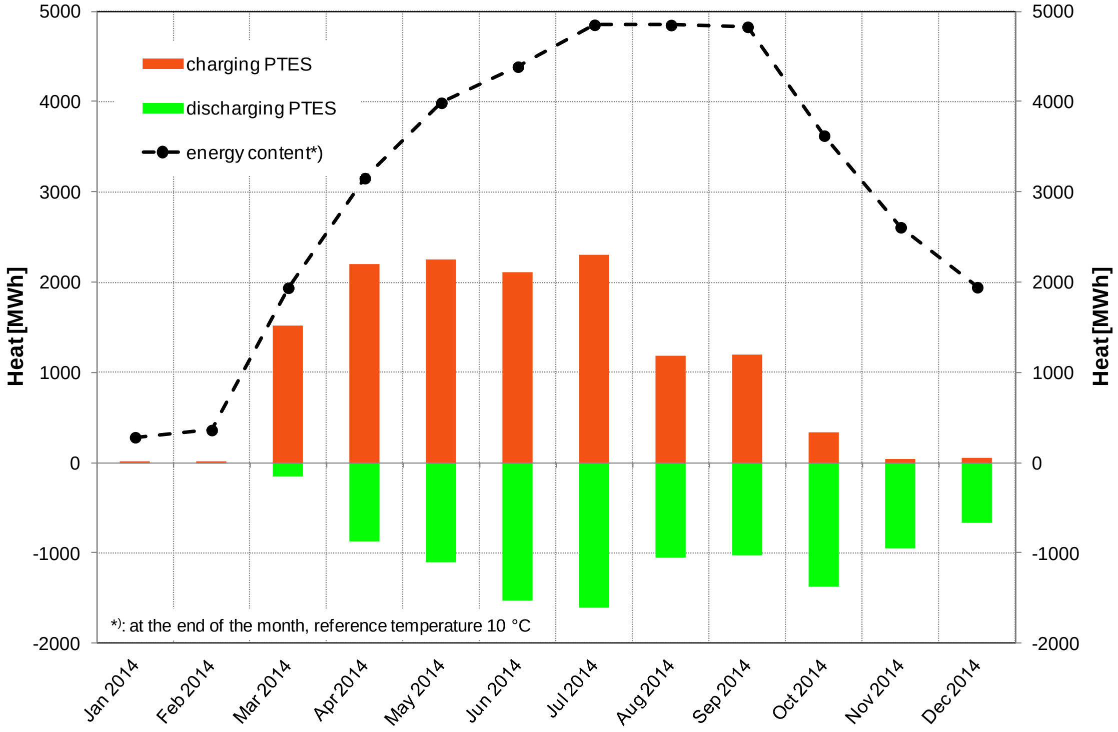


Fig. 21: *PTES monthly heat balance according to 2014 monitoring data.*

In Fig. 22 the temperature development inside the storage is presented. The minimum temperature of 12 °C at the bottom of the storage was reached end of December (without consideration of January and February). These low temperatures were possible because of the discharging of the storage by way of the heat pump.
From March until September the main charging of solar heat took place leading to maximum temperatures of 86 °C at the top of the storage end of July. The energy content of the storage shown in Fig. 22 is calculated with a reference temperature of 10 °C.

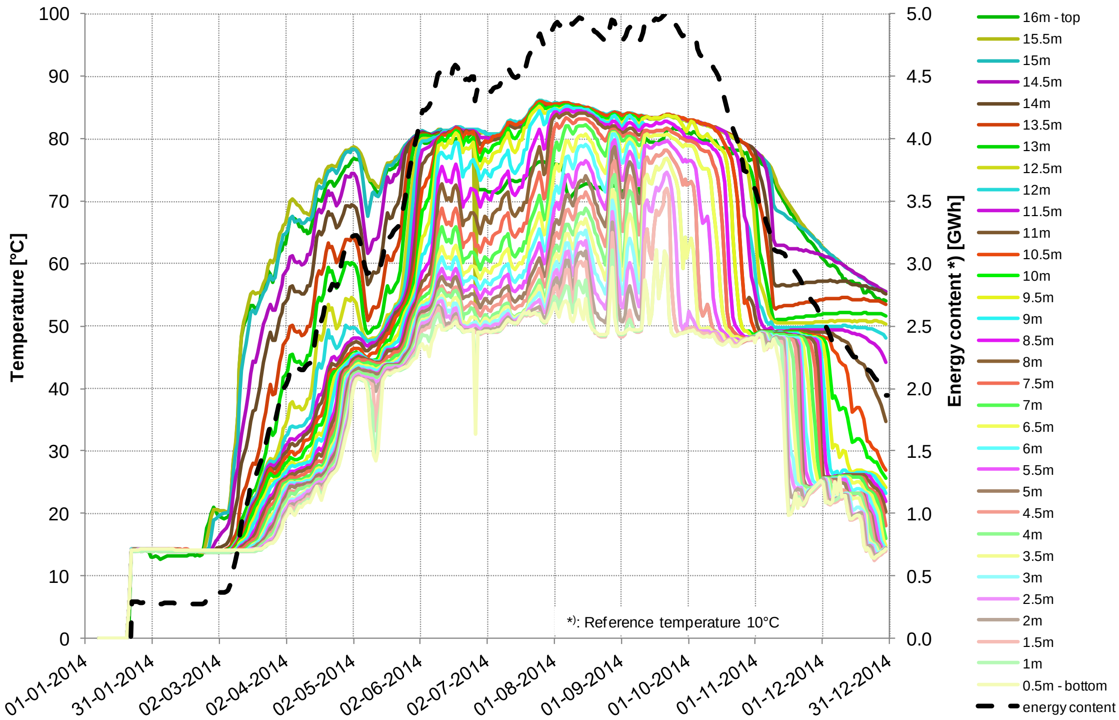


Fig. 22: *PTES internal temperature development in 2014.*

Fig. 23 shows a monthly development of the water temperatures inside the storage (left hand side) and the soil temperatures outside the storage (right hand side). The temperatures outside the PTES are given by four ground temperature sensors that were installed to enable for a long term observation of the ground temperature development around the PTES.

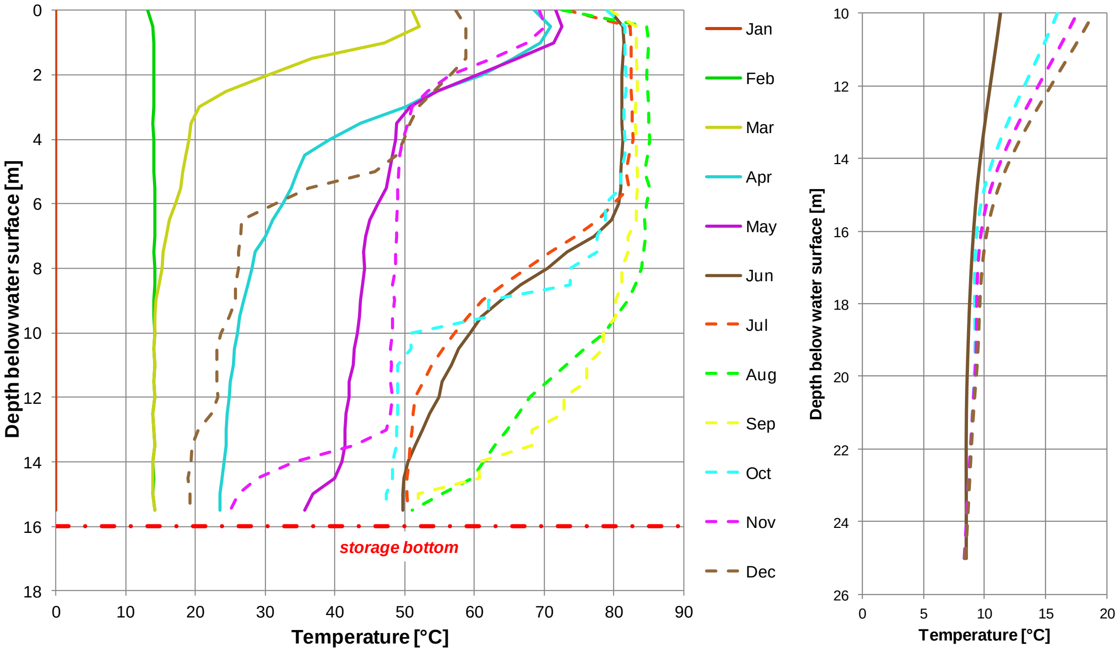


Fig. 23: *PTES monthly temperature development in 2014, left: inside the storage, right: outside the storage (0,5 m horizontal distance from PTES surface edge).*

5.1.4 *Absorption heat pump*

With the energy balance around the absorption heat pump (see Fig. 17) a COP value of 1.66 and an efficiency of 98.7 % can be calculated for the monitoring period. Fig. 24 shows the monthly energy balance.

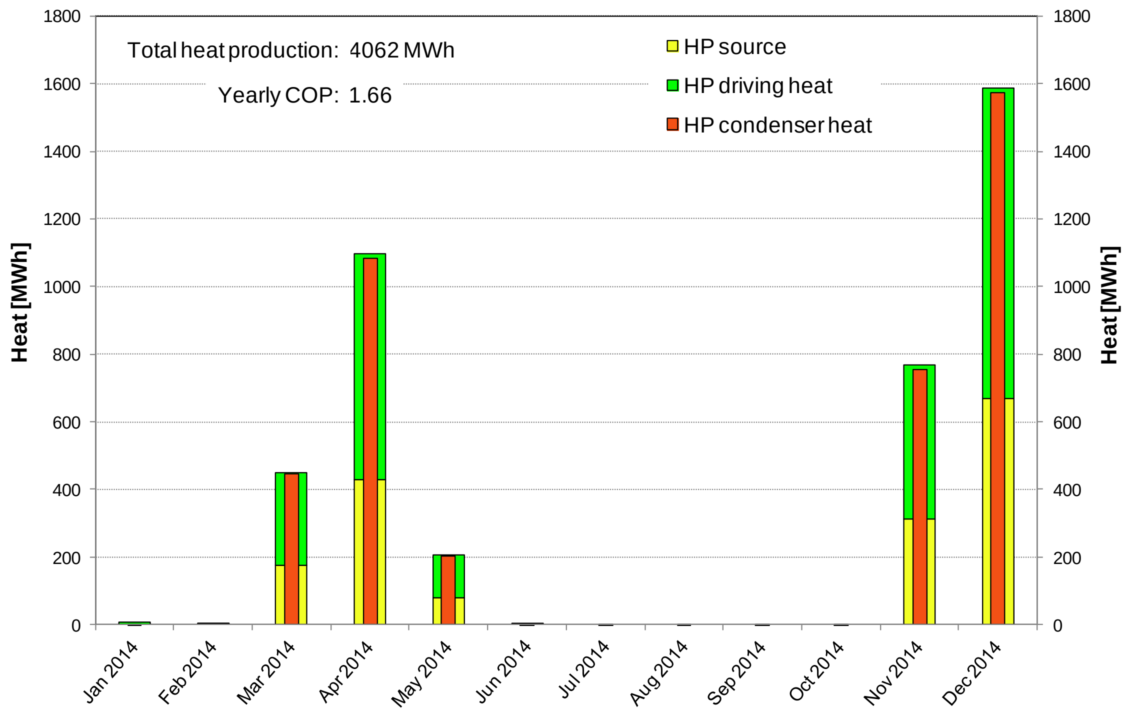


Fig. 24: *Monthly energy balance of the heat pump in 2014.*

Fig. 25 shows the operation conditions of the heat pump during the year. A variety of inlet temperatures between 30 and 50 °C to the evaporator can be seen. In the heating season this is mainly the temperature delivered by the seasonal storage. The delivered condenser outlet temperatures are between 60 and 75 °C with daily COP values between 1.5 and 1.8. Fig. 26 shows performance data of the heat pump for the main operation conditions.

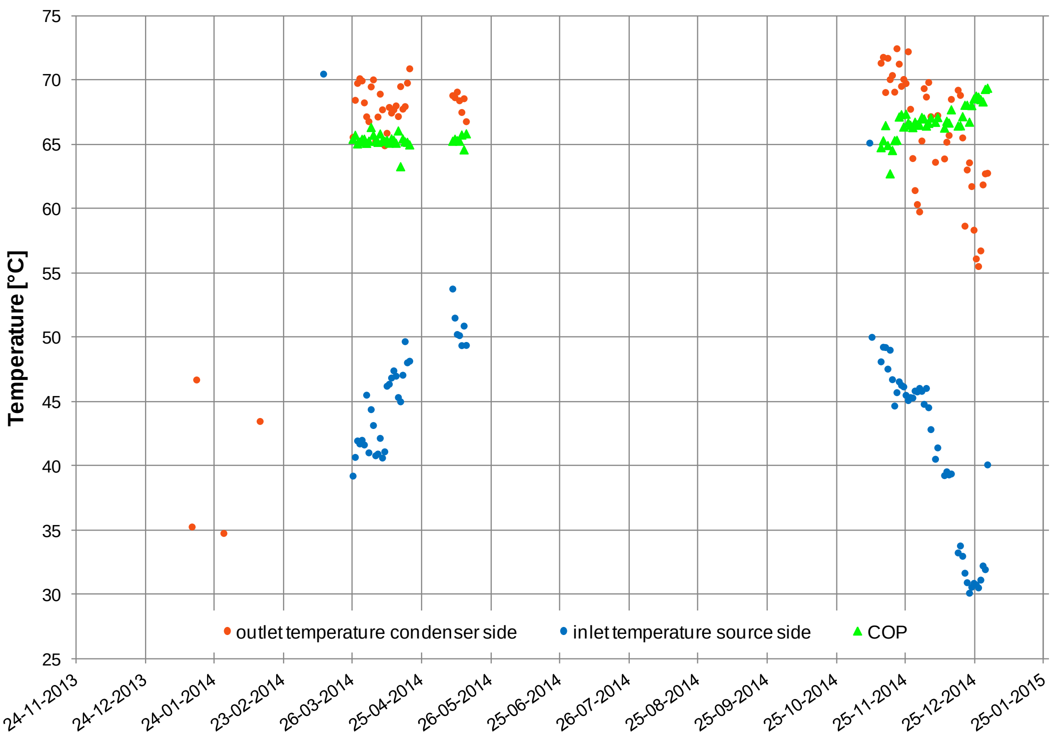


Fig. 25: *Heat pump operation conditions in 2014 (daily mean values).*

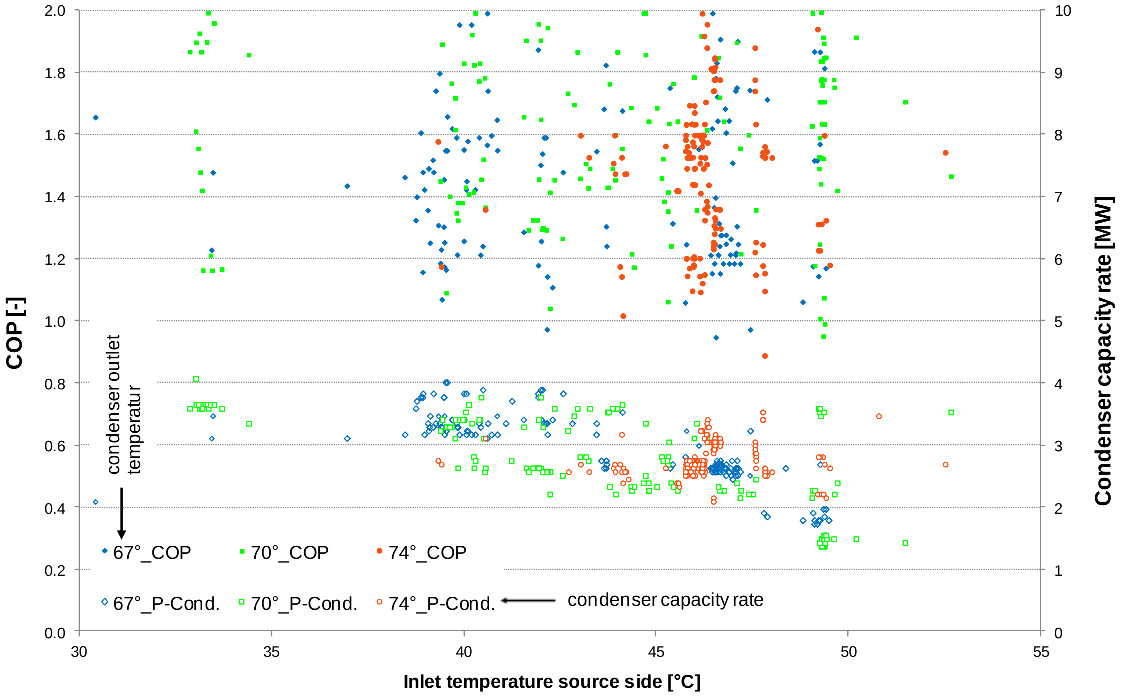


Fig. 26: *Heat pump performance map based on 10-minute values from 2014.*

5.2 Dissemination of results

Dronninglund Fjernvarme has built an exhibition pavilion with information boards about the energy production plant in the SUNSTORE 3 project. The annexed brochure shows text and pictures from the information boards and can be downloaded from www.dronninglundfjernvarme.dk.

Dronninglund has frequently visitors and has also presented the SUNSTORE 3 project at conferences in- and outside Denmark.
See the list below:

- 2013-08-30 Region hovedstaden
- 2013-09-01 IDA lokalforening
- 2013-10-24, PlanEnergi fremviser ifb. landsmødet
- 2013-11-04 Simon Rix, Martec
- 2013-11-05 Teddy Skræm
- 2013-11-18, EUDP
- 2013-11-20, Rambøll, Uldbjerg
- 2013-11-22 GSE, Per Ken Åberg
- 2013-11-27 Dansk Fjernvarme, seminar og damvarmelagre og store varmepumper
- 2014-01-31, Fleksenergi
- 2014-02-21 Martec
- 2014-02-21 Smørum kraftvarme
- 2014-03-11 Fleksenergi, Thy-mors
- 2014-03-20, Temadag om fremtidens fjernvarme. NIELS FROM TOG HELE PUNKTET
- 2014-03-25, Martec Kaj Jørgen Nielsen
- 2014-03-27 PlanEnergi, Kinesisk besøg
- 2014-04-07 ARCON, Søren Elisiussen
- 2014-05-08 Nordjyske kommuner, Aalborg
- 2014-05-12 Dronninglund Gymnasium
- 2014-05-20 DTU studerende via Arcon
- 2014-05-21, Berliner Energitage
- 2014-05-23 Hans Erik Tjelum
- 2014-05-23 LINDGAARD Rådgivende Ingeniører
- 2014-05-28 Vrå Fjernvarme og Knud Erik
- 2014-06-01 IDA lokalforening
- 2014-06-12 Rotary, Hjallerup
- 2014-06-14 Niras Thomas Poulsen
- 2014-06-25_27, Konference i Østrig
- 2014-08-13 Roman Dinslage
- 2014-09-01,02 Energiministeriet
- 2014-09-04 AMU
- 2014-09-04 FleksEnergi
- 2014-09-10 Spansk delegation
- 2014-10-06, Dronninglund Efterskole, 90 elever
- 2014-10-24, Bulgarien, Institute Zero Energy Buildings
- 2014-10-24, State of Green
- 2014-10-29, Sønderborg Fjernvarme
- 2014-11-02 Mark Lange og Kongerslev Fjernvarme
- 2014-11-24, Stuttgart, Solites
- 2015-01-22, Graz og PlanEnergi

PlanEnergi has presented the SUNSTORE 3 project and the Sunstore® concept at:

- Intersolar München, June 2011
- ISES Solar World Congress, Kassel, 28. August – 2. September 2011
- Eurosun 2012. Rijeka 18.-20. September
- IRES 2013. Berlin 18.-20. November

Beside that PlanEnergi has used Dronninglund as example in the EU-supported project SDH Plus and in IEA SHC Task 45.

The project has several times been mentioned in Danish media and especially in media from Northern Jutland: DR P4 Nordjylland, TV2 Nordjylland, Nordjyske.

Beside that the project has been presented in:

- HotCool 3/2013 "Dronninglund-major breakthrough for solar heating"
- Solarthermalworld (www.solarthermalworld.com June 1, 2014, April 10, 2013)
- "Udredning vedrørende varmelagringsteknologier og store varmepumper til brug i fjernvarmesystemet". Energistyrelsen, November 2013.

6. Utilization of project results

The SUNSTORE 3 concept contributes to realization of Danish energy policy objectives, because it makes it possible to extend the solar fraction in district heating production. If an electrical driven heat pump is part of the energy system it contributes by offering electricity consumption in periods with cheap export prices (power to heat).

The commercial partners (PlanEnergi, NIRAS and Solites) utilize the results obtained in the project, in their direct marketing to customers, that could utilize solar district heating with pit heat storage as a future solution.

PlanEnergi regularly presents results from the project in Dronninglund at meetings and workshops arranged by Danish District Heating Association (Dansk Fjernvarme).

Solites regularly presents results from the project in Dronninglund at meetings and workshops arranged by AGFW (parallel to Danish District Heating Association, but covering Germany and Austria).

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

The project has inspired other district heating utilities in Denmark to replicate the solution in Dronninglund.

Vojens District Heating is implementing a 200,000 m^3 pit heat storage combined with 70,000 m^2 solar collectors. Production start spring 2015.

Gram District Heating is implementing a 122,000 m^3 pit heat storage combined with 44,000 m^2 solar collectors. Production start Autumn 2015.

Løgumkloster District Heating has planned to implement a 150,000 m^3 pit heat storage combined with 50,000 m^2 solar collectors.

PlanEnergi has carried out design calculations for these 3 plants.

Several other district heating utilities are investigating pit heat storage and solar solutions in future master plans.

Besides that, the marked for pit heat storages has been extended since the HDPE liner can stand 90 ^oC in 20 years.

Storage solutions are therefore now calculated in systems with waste incineration plants and CHP plants with surplus heat production in the summer period.

7. Project conclusion and perspective

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

- Extend solar fraction in Danish district heating systems by adding pit heat storages.
- Extend utilization of excess heat from waste incineration, industrial processes and CHP plants in DK.
- Pave the road for large scale solar and storages outside DK. Primarily Germany and Austria.
- Pave the road for extended utilization of excess heat from incineration, industrial processes and CHP plants outside DK. Primarily Northern and Eastern Europe.

References

1. SUNSTORE 3. Fase 1. Projektering og udbud. Slutrapport. Marts 2011.
2. Seasonal storages – Guidelines for materials and construction. IEA-SHC Task 45.

Annexes

1. Product Data Sheet, geomembrane, GSE.
2. Referenceblad, Galvaniserede stålfundamenter. ARCON Solar.
3. Dronninglund solar thermal plant. Information brochure.

Annex 1 - Product Data Sheet, geomembrane, GSE.

PRODUCT DATA SHEET

High Performance GSE HD Smooth Geomembrane

Technical Specification for Dronninglund Heat Storage Reservoir

High Performance GSE HD Smooth is a co-extruded high density polyethylene (HDPE) geomembrane specifically designed to be used in the most stringent applications. This product contains only the finest raw materials to enable a unique combination of elasticity, environmental stress crack resistance, and excellent ageing resistance. Included in this product is a custom additive package that has been engineered to enable extended geomembrane lifetime and improved resilience in elevated temperatures, hazardous waste containment, or a harsh chemical environment. In addition to a superior UV stabilization package, a well-dispersed premium grade of carbon black is utilized to deliver superb UV resistance in exposed applications.

[*]

AT THE CORE:
An HDPE geomembrane used in applications that require excellent chemical and heat resistance as well as enhanced endurance properties.

Product Specifications

Tested Property	Unit	Test Method	Values (*)	
			2.00 mm	2.50 mm
Thickness (a) Lowest individual reading	mm	DIN EN ISO 9863-1	2.00 1.80	2.50 2.25
Density	g/cm³	DIN EN ISO 1183-1/A	> 0.94	> 0.94
Tensile Properties (each direction) Strength at Break Strength at Yield Elongation at Break Elongation at Yield	 MPa MPa % %	DIN EN ISO 527-3 (Type 5; 100 mm/min; lo = 50 mm)	 28 (25) 20 (18) 600 (525) 11 (10)	 28 (25) 20 (18) 600 (525) 11 (10)
Tear Resistance	N	DIN ISO 34-1/B (a)	300 (280)	375 (350)
Puncture Resistance	N	DIN EN ISO 12236	5,900 (5,500)	5,900 (5,500)
Multi-axial Break Resistance	%	ASTM D 5617	pending	pending
Carbon Black Content	%	ASTM D 1603	2.0 - 3.0	2.0 - 3.0
Carbon Black Dispersion	Category	ASTM D 5596	1/2 (b)	1/2 (b)
Dimensional Stability (each Direction)	%	DIN 53377 (120°C/1 h)	± 2	± 2
Melt Flow Index (c)	g/10 min	DIN EN ISO 1133 (190°C / 5.0 kg) (190°C / 2.16 kg)	 ≤ 3.0 ≤ 1.0	 ≤ 3.0 ≤ 1.0
Oxidative Induction Time	min	ASTM D 3895, 200°C; O_2, 1 atm	160	160
High Pressure Oxidative Induction Time	min	ASTM D 5885, 150°C; O_2, 3.4 MPa	800	800
		Reference Property		
Stress Crack Resistance (d) @ 80°C (SP-NCTL)	h	ASTM D 5397 (modified)	≥ 500	≥ 500
Oven aging at 85°C High Pressure OIT - retained after 6 months	%	ASTM D 5721 ASTM D 5885	≥ 80	≥ 80
UV Resistance (e) High Pressure OIT - retained after 1,600 hours (f)	%	GM 11 ASTM D 5885	≥ 80	≥ 80
		Typical Roll Dimensions		
Roll Length (g)	m		105	80
Roll Width (g)	m		7.5	7.5
Roll Area	m²		787.5	600

NOTES:
(*): All values - unless otherwise noted - are nominal values. Values in brackets are minimum values within the 95% confidence interval.
(a): Tolerance ± 10% - Special thickness available upon request.
(b): Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be category 1 or 2. No more than 1 view from category 3.
(c): Standard test conditions: 190°C / 5.0 kg.
(d): NCTL is tested according to ASTM D 5397, but modified to 80°C and 3.4 Mpa (500 psi) stress.
(e): Test-Conditions: 20 hours UV cycle at 75°C followed by 4 hours condensation at 60°C; total: 1,600 hours.
(f): UV Resistance is based on percent retained value regardless of the original High Pressure - OIT value.
(g): Roll widths and lengths have a tolerance of ± 1%.

Annex 2 - Referenceblad, Galvaniserede stålfundamenter. ARCON Solar.

Referenceblad
Galvaniserede stålfundamenter

Elegante stålprofiler til montering af solfangere

ARCON Solar A/S tilbyder nu en elegant ny-udviklet funderingsløsning til solfangere af galvaniserede stålprofiler. Profilerne er udviklet i samarbejde med førende leverandører og rådgivere inden for området
og resultatet er en elegant og økonomisk bæredygtig løsning, der baserer sig på gennemtestede og veldokumenterede metoder fra montering af autoværn, forskellige typer af skilte, hegn m.v.

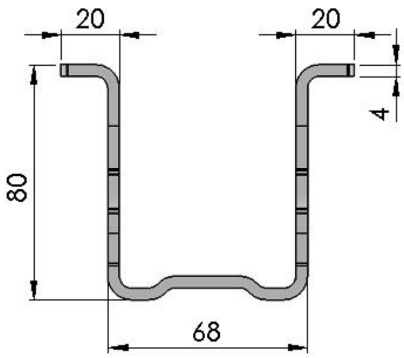
For beregning af stål anvendes:
EN 1993 for stålkonstruktioner
EN 1997 for geoteknik.

Med tilhørende danske annekser

For beregning af vindlaster anvendes :
EN 1990, Projekteringsgrundlag for bærende konstruktioner" for fastsættelse af sikkerheder
EN 1991, Last på bærende konstruktioner for fastsættelse af laster.

Til fastsættelse af lagtykkelse for galvanisering af 4 mm stålprofiler anvendes EN1461 typisk med lagtykkelser ml 70-100 mhy.

ARCONs galvaniserede stålprofiler er bukket i stålplade og efterfølgende varmt-galvaniseret (100 µm). De færdige u-formede profiler presses/bankes ned i jorden, i 130 – 150 cm dybde, afhængig af jordbundsforholdene.



Stålprofilerne har både trækstyrken kendt fra de traditionelle betonfundamenter og fordelene ved det klassiske punktfundament i beton:

- Stålprofilerne kan placeres med **stor nøjagtigt**,
- Profilerne forbliver i den **samme position**, så solfangerne kræver ingen opretning.
- Profilerne gør det let at **holde beplantningen nede**
- Og endelig fremstår **løsningen elegant** i landskabet.
- Stålprofiler kan optage ujævnheder i arealet på op til +/- 150 mm. Dette miniminerer driftsomkostningerne idet profilerne bl.a. ikke skal rettes op efter frost.

For yderligere information om stålprofiler til solfangere
kontakt ARCON Solar A/S

Annex 3 - Dronninglund solar thermal plant. Information brochure.

Dronninglund
Solar thermal plant

Solar thermal plant at Lunderbjerg, west for Dronninglund

Dronninglund Fjernvarme (Dronninglund District Heating)
PlanEnergi and Niras

The story

Dronninglund Fjernvarme is a consumer-owned cooperative. In 1989, it became the first Danish district heating company to install natural gas-driven engines for combined heat and power production.

Around 2005, the board and the general assembly of Dronninglund Fjernvarme realized that they should replace natural gas with renewable energy over time.

At that time, several Danish district heating companies had installed solar thermal plants that covered approximately 20 % of the yearly heat production. However, Dronninglund Fjernvarme wanted to take it a step further and aspired to cover up to 50 % of the yearly production with solar heat. In 2007, Nordjyllands Vækstforum subsidized a pre-feasibility study. The study showed that a solar thermal plant with seasonal storage could cover up to 50 % of the heat consumption. Furthermore, the heat production price would not be increased for the consumer with a subsidized investment. Therefore, Dronninglund Fjernvarme decided to continue the project and applied for subsidy from EUDP (Energy Technology Development and Demonstration Programme), a program financed by the Danish state. The application was approved and subsidy was granted for detailed design and for investments in long-term storage, piping, heat exchangers and a control system to connect the production units.

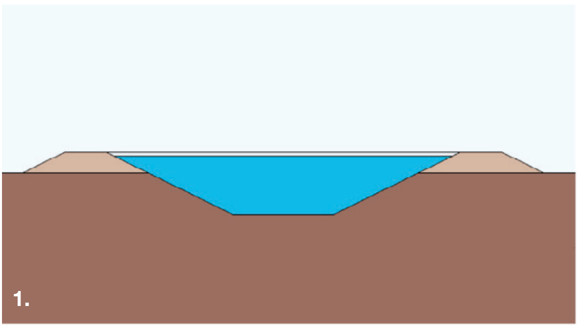
1. Cross-section of pit heat water storage
2. The water storage integrated in the surroundings
3. Situation of the water storage and the solar thermal plant.
4. Cross-section of the water storage and technique building with pipes, pumps and heat exchangers

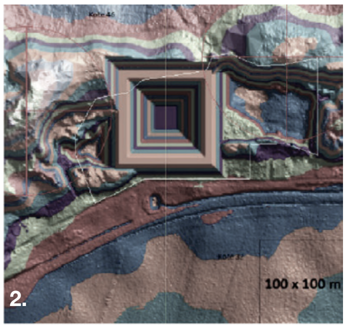
Why is the plant placed in a gravel pit?

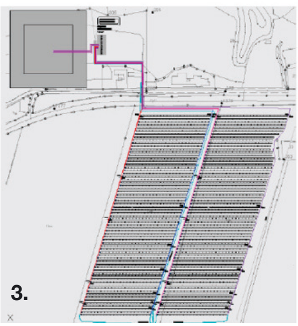
Pit heat water storage is made by digging a hole formed as an upside-down pyramid cone and use the soil as banks. It is ideal if the ground water level is below the storage.

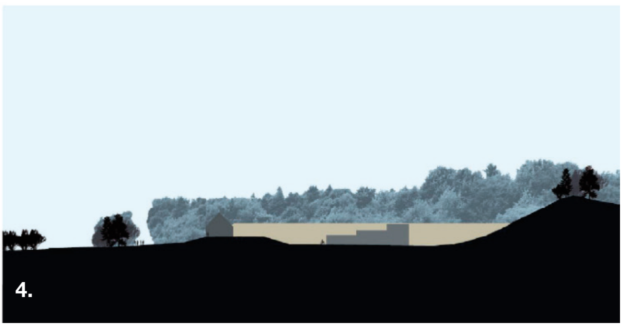
Geotechnical investigations showed that it was impossible to find locations close to Dronninglund that fulfilled the above conditions. The ground water level was high and the soil was not usable for banks. The only place where the conditions could be met was in an abandoned gravel pit.

The solar thermal plant must be located near the water storage, but the area near the gravel pit was classified as “valuable cultural environment” in the regional plan. Besides that, distance to old viking tombs, distance to forest, protection of drinking water, etc. had to be taken into account. The last approvals for the project were given in October 2012, and call for tender and implementation could begin.



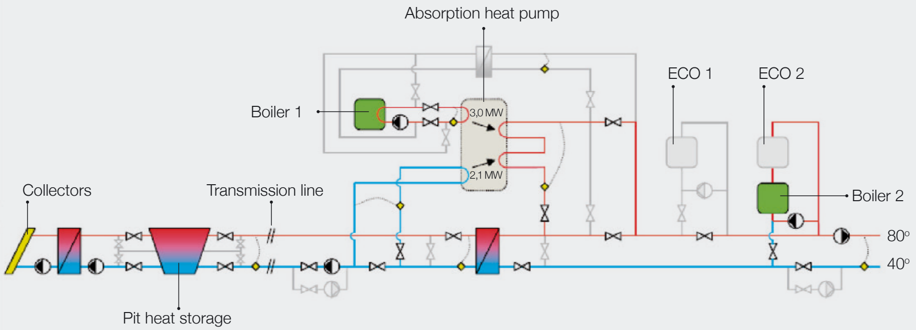






The new production plant

The main components in the new production plant are a large solar thermal plant and a pit heat water storage. In the summer, the solar thermal plant produces much more heat than Dronninglund consumes. The surplus is used to heat up the water storage. In the autumn, the storage is cooled down by adding water with district heating return temperature to the bottom of the storage and send hot water from the top of the storage to the city. The district heating return temperature is approximately 40º C. To utilize the storage further, it is cooled down from 40º C to 10º C as heat source for a heat pump. This will increase the storage capacity before the next summer, reduce the heat loss and increase the production from the solar collectors.



// Principle diagram. Yellow squares are flow/energy meters.

Placement of the components

The placement of the components can be seen below:

1. Solar panels in solar thermal plant
2. Pit heat water storage
3. Technique building with pipes, pumps and heat exchangers
4. District heating pipes
5. Søndervang with absorption heat pump

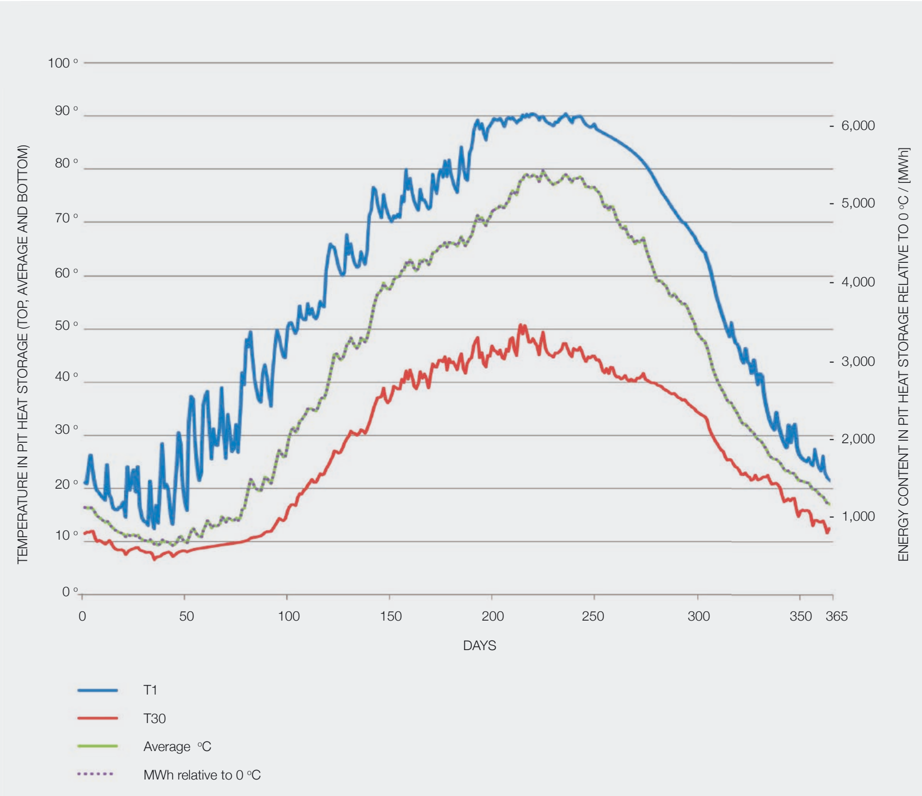
The solar thermal plant

The solar thermal plant consists of 2,982 solar panels or 37,573 m^2 from Arcon Solar. The panels are divided into fields, each connected to a heat exchanger in the technique building. Maximum power from the collector fields is 26 MW – this can be compared to the maximum consumption, which is 12 MW in the coldest winter periods. Each row in the collector fields has 21 solar collectors connected in sequence. The cold water is heated gradually through the 21 solar collectors. This ensures that the temperature in the last solar collector of the sequence is as decided in the control system. The solar collectors are mounted on galvanized steel profiles processed into the ground. At the opening in May 2014, the solar collector field was the largest in the world.

// Photos from construction showing foundation and mounting solar panels

The technique building

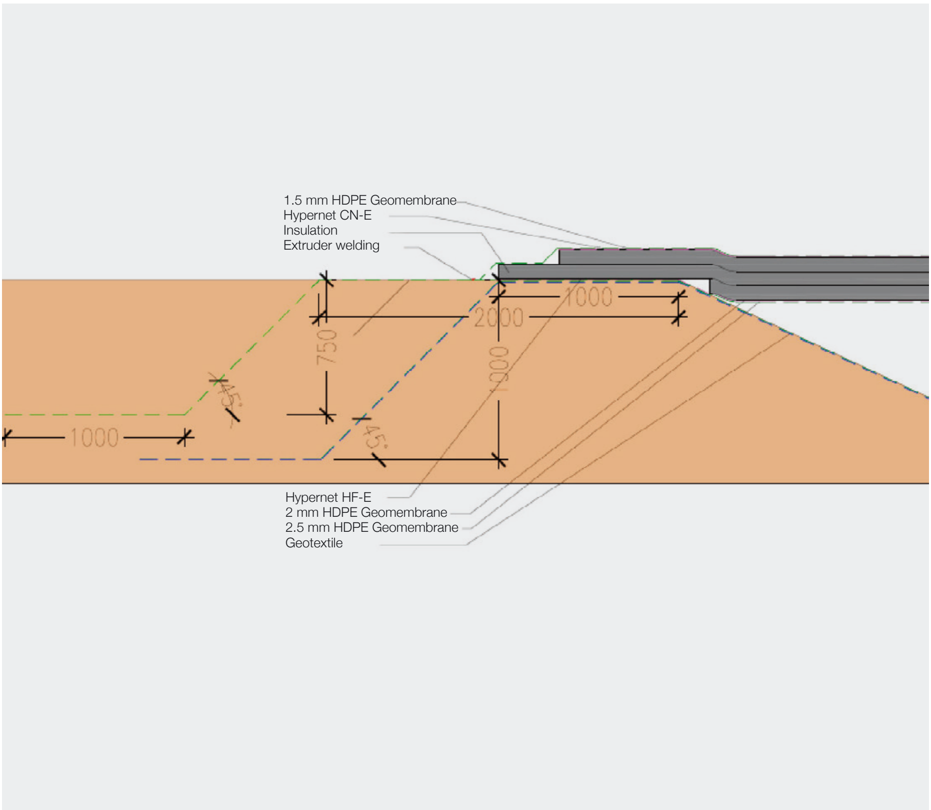
The technique building contains heat exchangers and pumps. If, during the winter, the solar collectors can produce water with temperatures beyond the bottom temperature in the storage, the solar collector pumps start and the storage is heated up. During the summer, the flow from the solar pumps is regulated to ensure that the production temperature exceeds the district heating flow temperature (approximately 75º C). When the production is higher than the consumption in the city, the storage is heated by adding hot water to the top of the storage and send cold water out of the bottom. The calculated storage temperatures during the year can be seen below (top, average and bottom temperatures).



The water storage

The water storage contains 60,000m3 water. Construction of the storage began in March 2003 and ended in November 2013. Inlet and outlet pipes run through the bottom, as the bottom of the storage lies at the same level as the technique building. The storage is tightened using a 2.5 mm welded polyethylene liner. Tightness of all of the welding is tested after welding is completed. The supplier of the liner has guaranteed a 20-year lifetime if the liner temperature does not exceed 90º C.

When the liner was implemented by the end of June, water filling could begin. Drinking



water from Dronninglund water company was used, but oxygen salts and calcium were removed from the water. The lid is constructed by welding a 2 mm polyethylene liner onshore and pulling it gradually over the water. Thereafter, the insulation is constructed on top of the liner, floating on the water.

On the inside and on the surface of the lid, weight pipes (plastic pipes with concrete) are mounted in order to create a slope towards the middle of the lid, where rainwater is collected and pumped away.

The top of the lid is a roof foil with vacuum vents removing moisture coming from the storage through the polyethylene liner.

// Photos from construction of the pit heat water storage

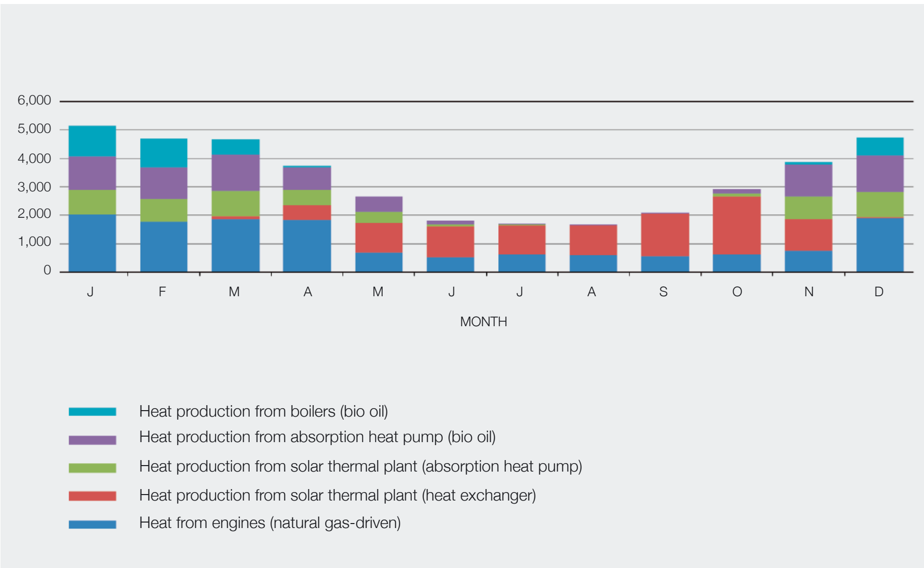
The heat pump

The heat pump is an absorption heat pump driven by heat from a bio oil boiler placed at Søndervang in Dronninglund. The bio oil boiler heats up the water to 160º C. The hot water runs the absorption heat pump. The heat pump uses the storage water as heat source and produces district heating at flow temperature.

Heat production

The future heat production from solar collectors to the water storage is calculated to 17,453 MWh/year.

The monthly production from the different plant components is expected to be as illustrated below:



List of suppliers

Consultant:	PlanEnergi	CVR 74038212
Consultant:	NIRAS	CVR 37295728
Solar collectors supplier:	ARCON SOLAR	CVR 10778530
Main entrepreneur:	AEA Averhoff Energi Anlæg A/S	CVR 28098197
Excavation, storage:	JAKOBSEN & BLINDKILDE A/S ENTREPRENØRFIRMA	CVR 18458144
Liner work, storage:	PBJ Miljø	CVR 35051473
Pipes supplier:	LOGSTOR	CVR 21330248
Entrepreneur, transmission pipes:	L&H-Rørbyg Vi gør det nemt for dig	CVR 86503417
Electrical installations:	DRONNINGLUND EL-SERVICE A/S	CVR 32272843
Control system:	DME® Dansk Miljø- & Energistyring A/S	CVR 12047495
Building:	JE BYG APS MURER & ENTREPRENØR	CVR 30533704
Boiler and heat pump:	Danstoker	CVR 16147249

The project is subsidised from EUDP
(Energy Technological Development and Demonstration Program) administrated by the Danish Energy Agency.


Dronninglund Fjernvarme
PlanEnergi and Niras