HIGH SOLAR FRACTION WITH PIT HEAT STORAGES

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1. Introduction

In the latest years solar district heating has been common as a supplement to the heat production from Danish CHP plants using natural gas. In 2010 has been implemented 45,000 m^2 new solar collectors in connection to natural gas fired CHP plants and more than 100,000 m^2 are expected to be implemented in 2011. But the typical yearly solar fraction is 10-20% and the district heating utilities ask for solutions with higher solar fraction and solutions with 100% renewable energy.

In the projects SUNSTORE 3 and SUNSTORE 4 pit heat storages are used as seasonal storage to extend the solar fraction. The first pit heat storage (1,500 m^3) was build in Denmark in 1996 and a 10,000 m^3 pilot storage was built by Marstal District Heating in 2004 as a part of the project SUNSTORE 2 supported by EU and the Danish Energy Agency. The two new storages represent a further development of the pilot storage in SUNSTORE 2. They are situated in Dronninglund, DK, as part of a new project, SUNSTORE 3, with 50% fraction of renewable energy and 50% fraction of heat from a natural gas fired CHD plant and in Marstal, DK, as a part of another new project, SUNSTORE 4, with 100% renewable energy.

2. Concept

The concept for the energy systems in SUNSTORE 3 and SUNSTORE 4 is illustrated in Fig. 1.

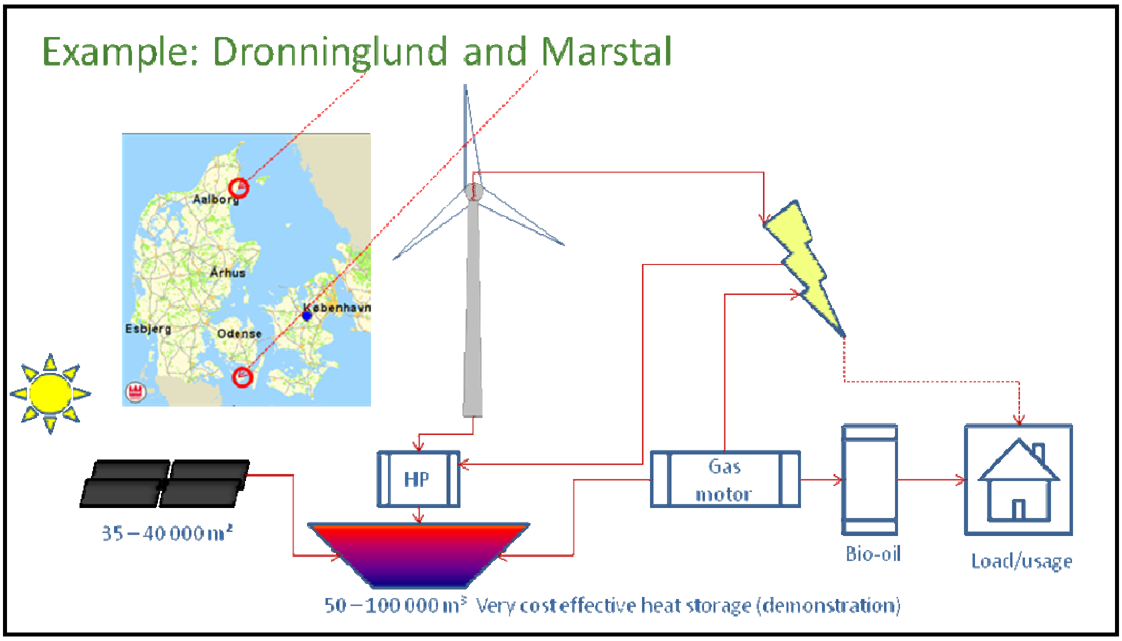

Fig. 1. Illustration of the SUNSTORE concept for energy systems with large solar fractions in DK.

This concept can provide a district heating utility with up to 100% renewable energy. In the summer period the heat demand is produced by the solar thermal plant. Surplus heat is stored in the pit heat storage. In the winter period the heat pump produces heat in periods with low electricity prices and uses the storage as heat source and the CHP–plant produces heat in periods with high electricity prices.

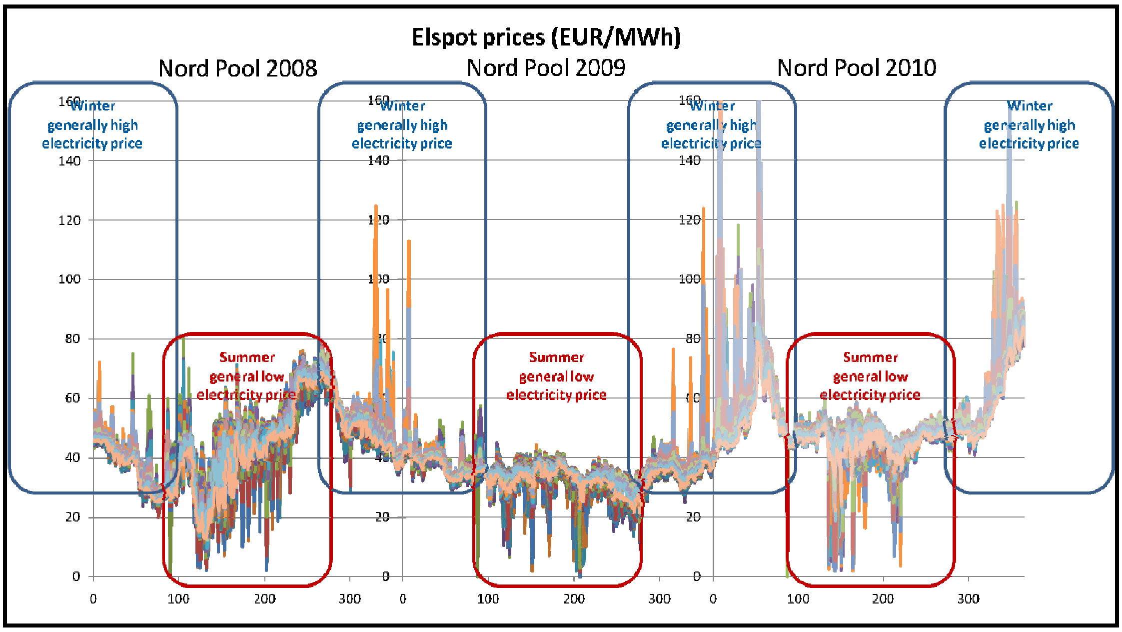

Fig. 2. Electricity prices in DK (Nordpool).

In Fig 2 Danish electricity prices from the last 3 years are illustrated. One of the reasons why the prices are fluctuating is the amount of wind power produced. In periods the wind power production in West Denmark reach more than 100% of the consumption and flexible consumption is therefore needed to reduce the power transmission. The SUNSTORE concept offers flexible electricity consumption and can harvest economical benefits from that. Also the heat production prices will be low because the solar systems are large and with prices at app. 200 €/m^2 and the storages are large and cheap. The advantages by combining the technologies in the SUNSTORE concept is illustrated in Fig. 3.

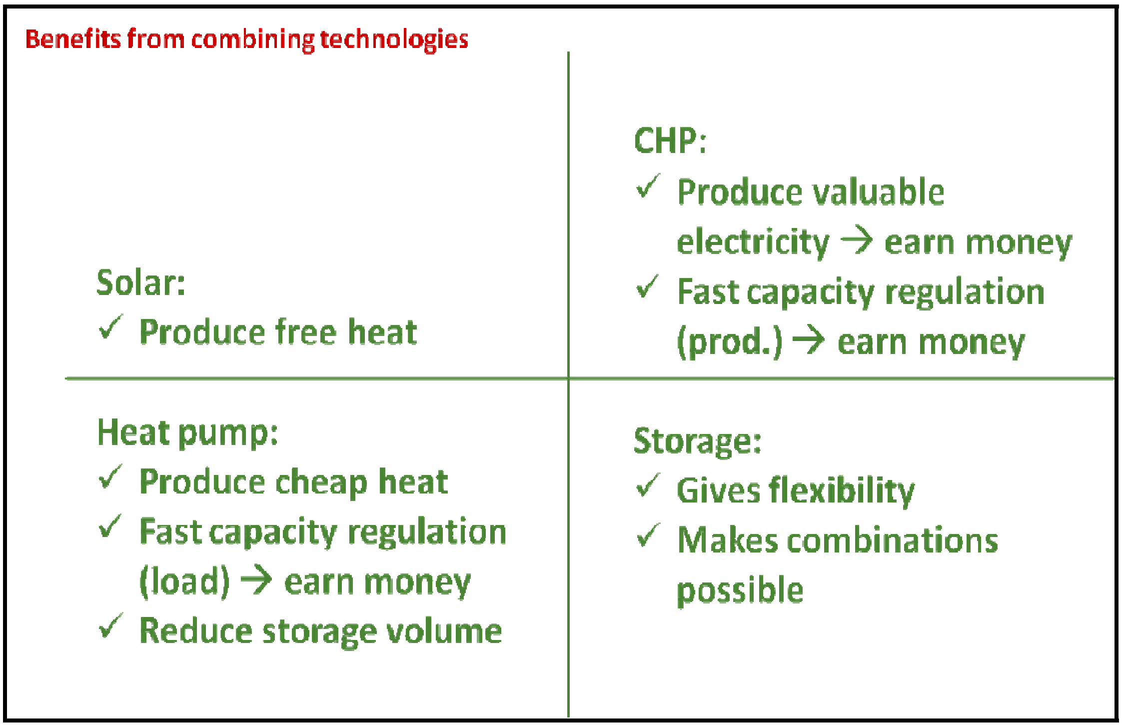

Fig. 3. Advantages by combining the technologies in the SUNSTORE concept.

3. Design in Dronninglund and Marstal

3.1. Dronninglund (SUNSTORE 3)

The district heating utility in Dronninglund has a yearly heat production of app. 40,000 MWh. App. 20,000 MWh is produced from natural gas in gas engines and app. 20,000 MWh is produced from bio oil in bio oil boilers. Dronninglund has decided to replace at least 50% of the present heat production by energy from a large solar thermal plant and heat pumps.

Caused by high taxes on electricity a heat driven absorption heat pump has been chosen instead of a compressor driven heat pump. The system diagram can be seen in Fig. 4.

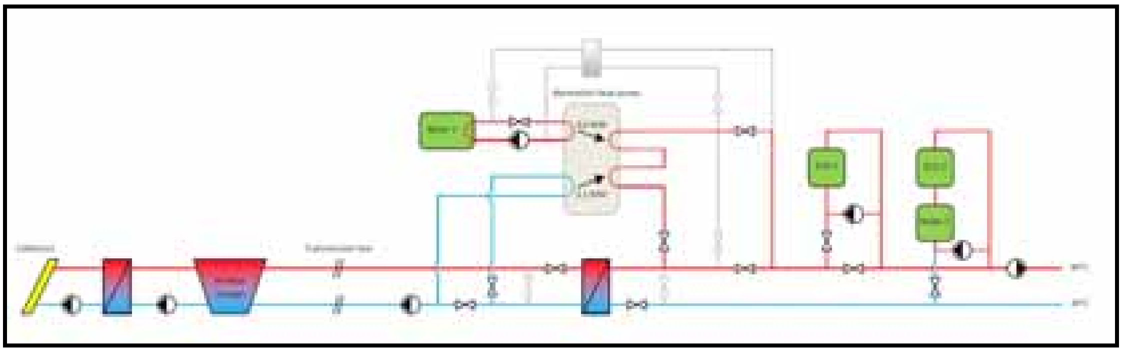

Fig. 4. System diagram for SUNSTORE 3 (Dronninglund). (CHP plant not illustrated).

The total system has been simulated in TRNSYS 16.1. For the pit heat storage the XST-model (type 342) has been used. The shadow in the collector field, the CHP, the DH heat exchanger, boiler 1 and the absorption heat pump has been modeled by equations in the equation component. The absorption heat pump has been modeled by two separate single stage heat pumps. For the remaining components standard TRNSYS types has been used.

The DH mass flow is determined by the heat load. In the control strategy it has been chosen to have the same mass flow on the primary side of the DH heat exchanger. As shown at Fig. 4 the DH water is first heated by directly heat exchange with the water in the pit heat storage and afterwards by the absorption heat pump. Seen from the other side of the DH heat exchanger, the pit heat storage is cooled by first the DH return temperature and then the heat pump.

Some key figures from the simulation are: Heat load = 40,000 MWh/y; overall heat transfer coefficient of the solar HX = 5 MW/K and LMTD of the DH HX = 3 K.

Calculated temperatures in the pit heat storage and monthly heat production can be seen below.

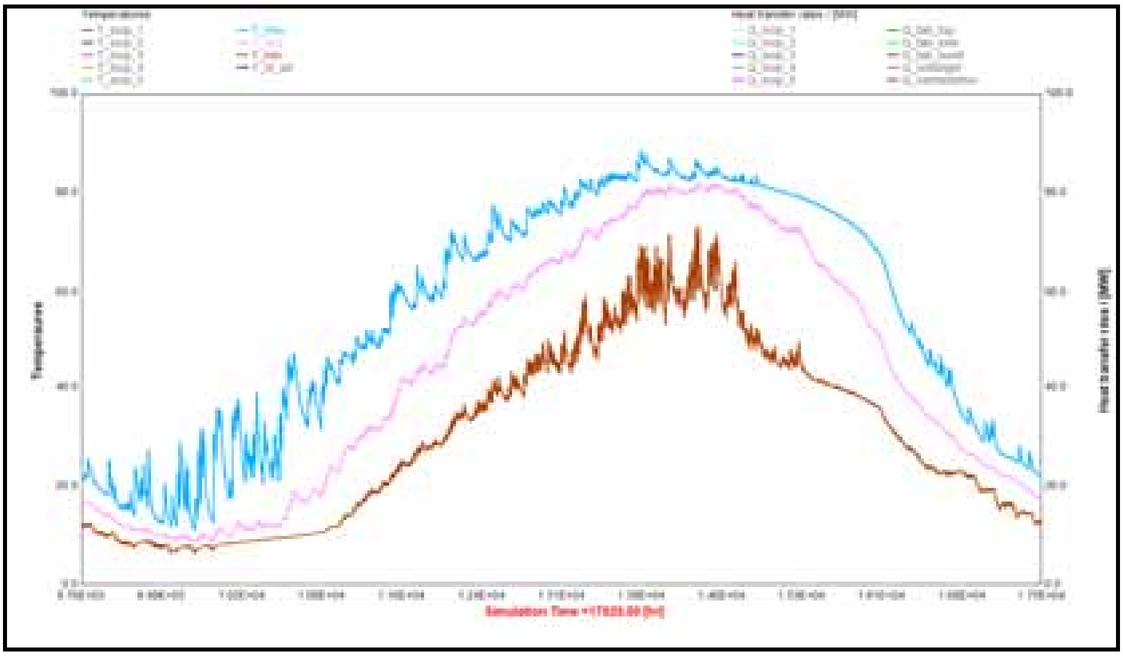

Fig. 5. Calculated max., average and min. temperatures in the pit heat storage, SUNSTORE 3 during simulation year 2.

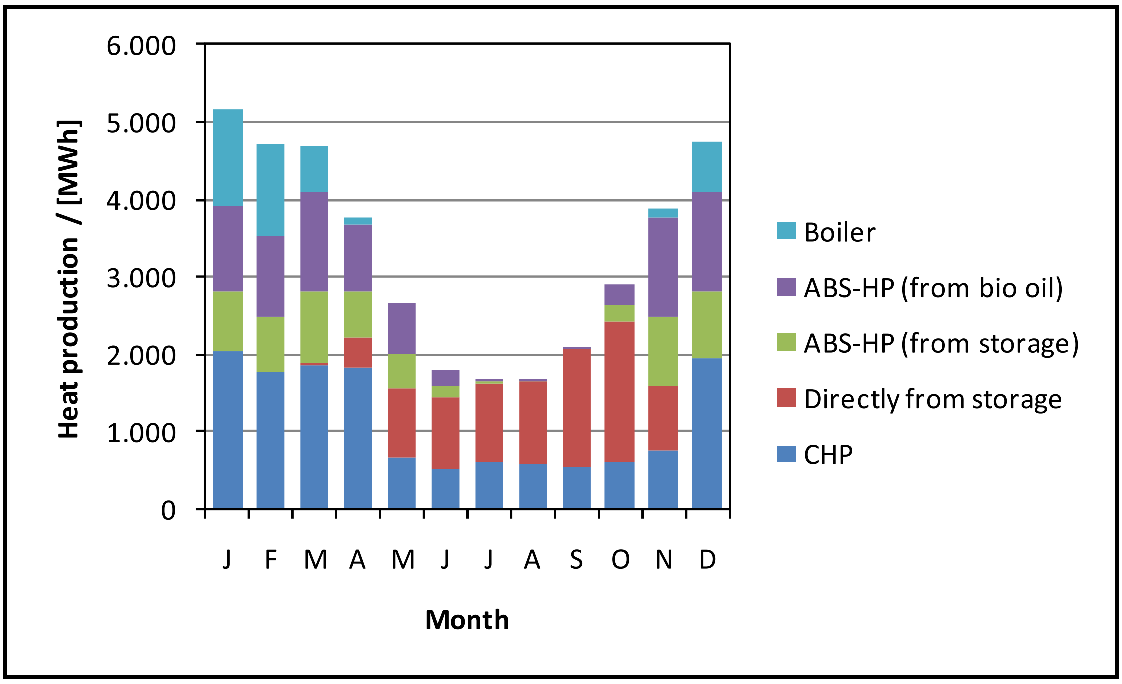

Fig. 6. Monthly heat production.

The resulting size of the production system was 35,000 m^2 solar collectors (ARCON-HT), 60,000 m^3 pit heat storage and 2.1 $MW_{cooling}$ absorption heat pump.

Totally over the year the fuel consumption will be reduced with 30% from 51,815 MWh to 36,486 MWh without any changes in amounts of electricity and heat production.

3.2. Marstal (SUNSTORE 4)

The district heating utility in Marstal had an yearly heat production of app. 28,000 MWh in 2008. Solar covered app. 7,500 MWh (27%) and the rest was covered with bio oil boilers.

Marstal has decided to replace the bio oil with more solar collectors, a pit heat storage, a heat pump and heat from a wood chip boiler with an Organic Rankine Cycle (ORC).

TRNSYS calculations in connection to an application for support from EU (FP7) had as result, that an additional energy system with 15,000 m^2 solar collectors, a 1.5 MW_{heat} heat pump, a wood chip boiler producing 3.25 MW_{heat} and 0.75 MW_{el} combined with a 75,000 m^3 pit heat storage could cover nearly 100% of the heat consumption and more than 50% would be covered by solar and heat pump. The application was accepted and during Autumn and Winter 2010-11 the system has been optimized and designed in detail. The system diagram can be seen in Fig. 7.

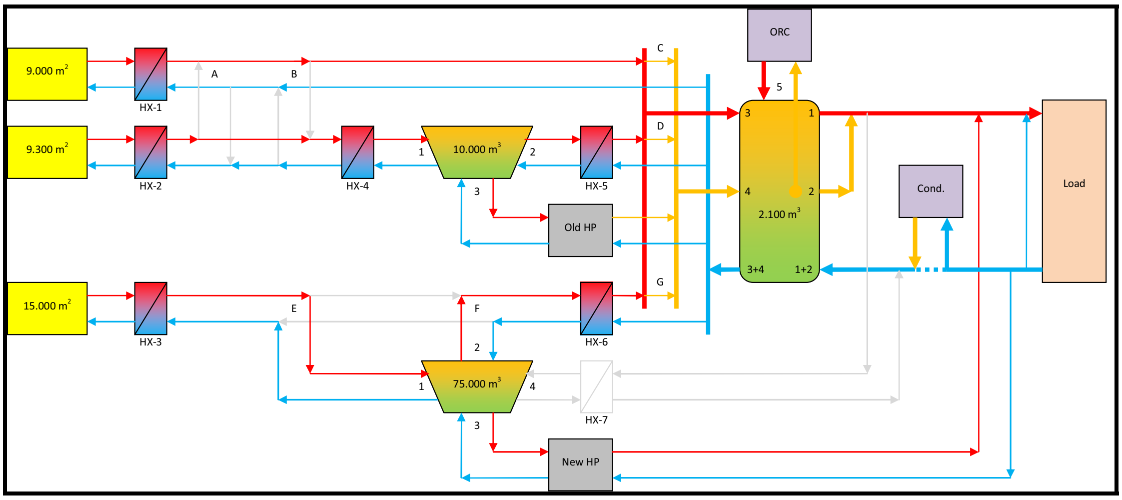

Fig. 7. Preliminary system diagram for SUNSTORE 4 (Marstal).

Since 2008 further customers has been connected to the district heating network, resulting in a calculated yearly heat production of 32,000 MWh from 2012. Therefore the wood chip boiler ended up at 4 MW_{heat}.

Calculated temperatures in the 75.000 m^3 pit heat storage and results from optimization of the total system can be seen below.

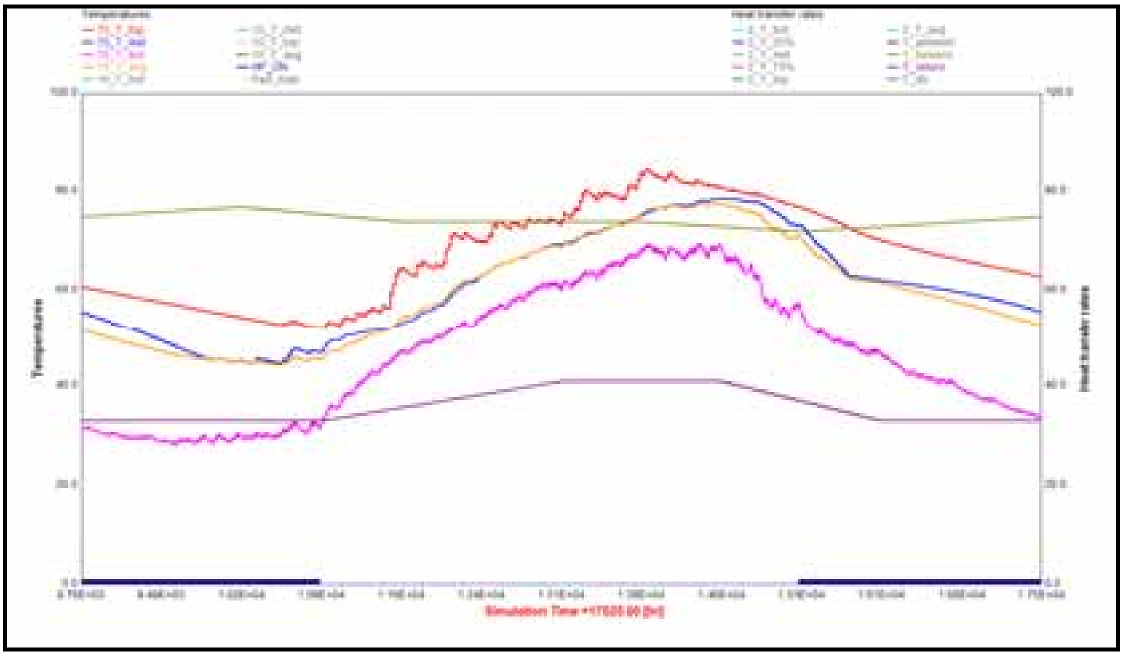

Fig. 8. Calculated max., average and min. temperatures in the pit heat storage SUNSTORE 4 during simulation year 2 as well as DH forward and return temperatures and HP (heat pump) operation.

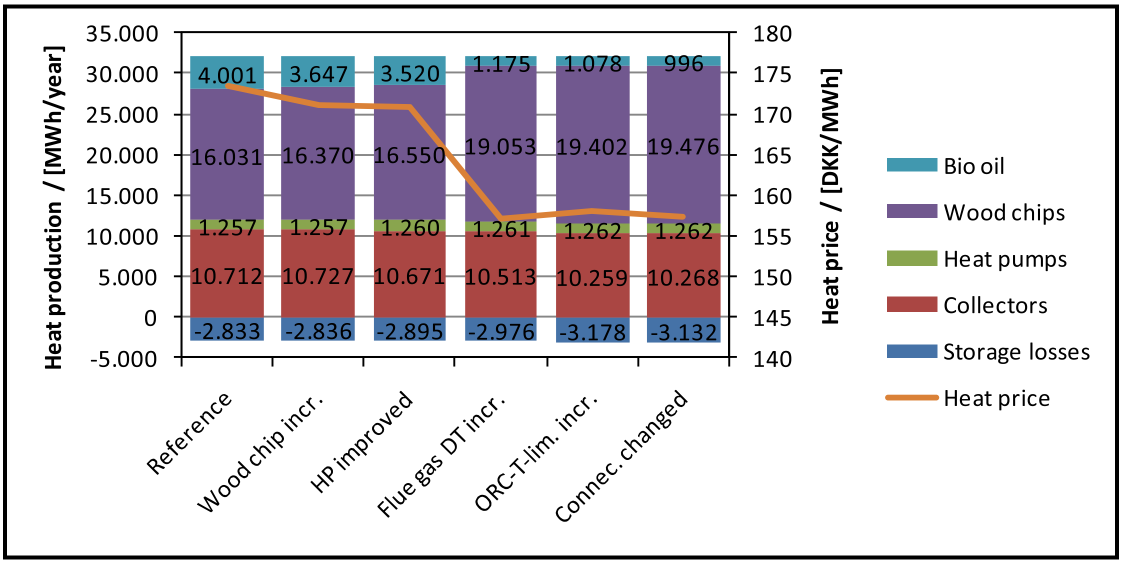

Fig. 9. Yearly heat production and heat production prices for TRNSYS simulations with different preconditions.

4. Tests of liners for pit heat storages

The pit heat storage is a quite simple construction. A 10,000 m^3 pilot storage was implemented in Marstal in 2004.

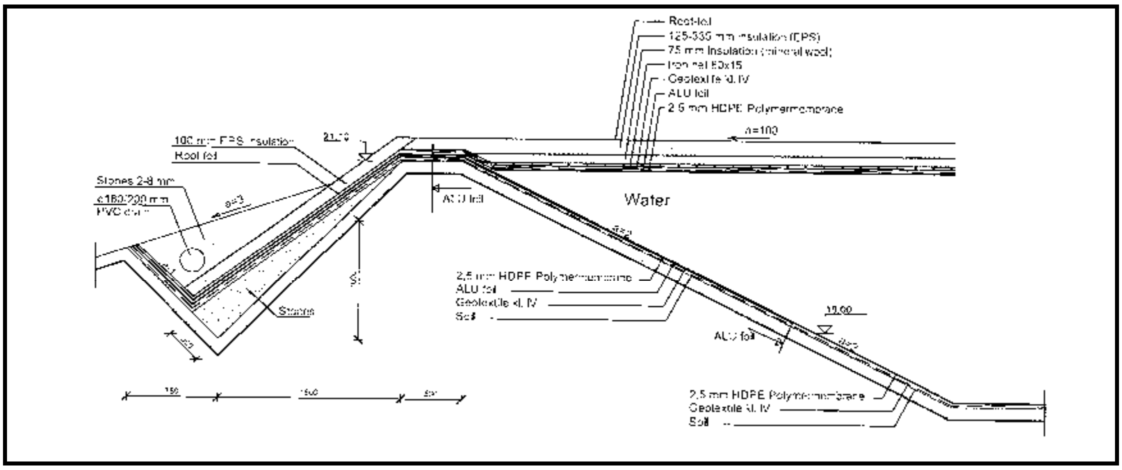

Fig. 10. Cross section of the edge of the pit storage in SUNSTORE 2.

The storage is filled with water and covered with an insulated floating lid. Plastic liners secure water tightness, but these liners have limited lifetime primarily depending on the water temperatures in the storage. Therefore Danish Technological Institute has carried out tests of lifetime of different liners. In year 2000 a 1.7 mm PolyPropylen-liner (PP) was tested, in 2003 two 2.5 mm HDPE-liners were tested and in 2010-11 a third 2.5 mm HDPE-liner was tested. The tests has been a carried out as accelerated tests. Typical test temperatures has been 100-117°C. The tests has taken place in “eldering cells” (see Fig. 11) with constant temperature.

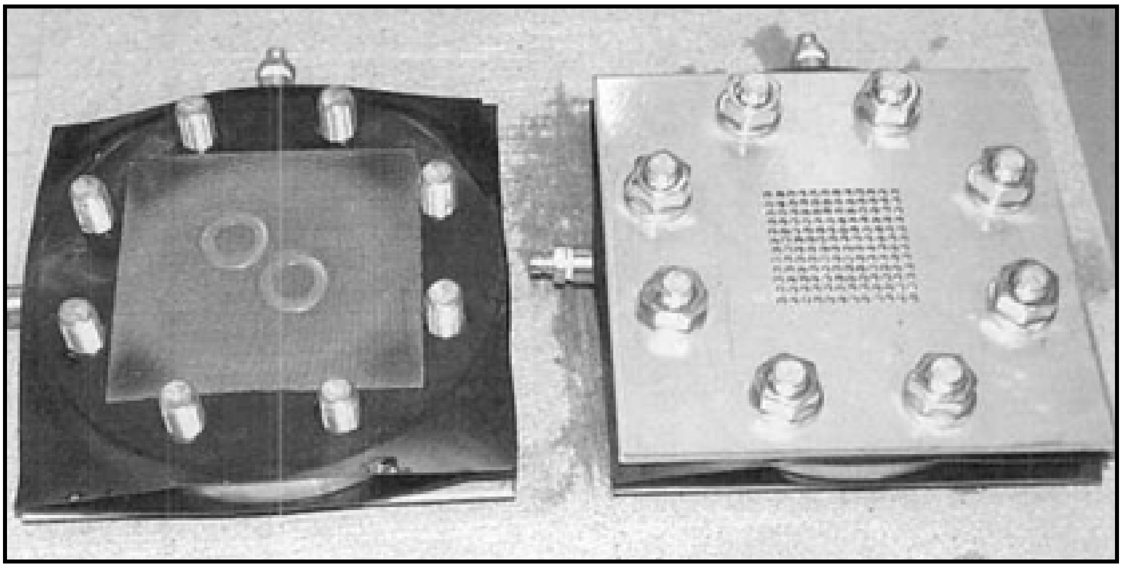

Fig. 11. "Eldering cells".

The lifetime is defined as the time it takes to reduce the extension of the liner to 50% when it is broken according to the conditions in ISO 527-3, 1997. The results were, that the PP liner has a significant shorter lifetime than the HDPE-liners and for the HDPE-liners the results can be seen below.

Table 1. Lifetime for HDPE-liners.

Temperature °C	Lifetime (years)		
	Liner 1	Liner 2	Liner 3
90	2.5	3.2	2.9
80	6.1	7.2	6.8
70	15.9	17.0	15.6
60	43.7	42.4	35.9

Liner 2 is slightly better than liner 1 and 3 and is therefore used.

It is our target to have a lifetime for the pit heat storages of at least 20 years. To ensure an acceptable lifetime of the liner the maximum water temperatures in the storage has to be limited.

According to experts in plastic liners it should be possible to develop HDPE or PEX liners with better thermal resistance than the liners already tested. We look forward to that!

5. Design of lid for pit heat storages

The storage lid is the most expensive part of the pit heat storages and the part causing the main part of the heat loss. In the 10,000 m^3 pilot storage in Marstal a floating lid (see Fig. 10) was designed. This was a cheap solution, but it had some weak points.

- When the water is heated up air occurs under the lid, and since the construction is not steady it can make “bumps” in the lid.
- Rain water pits on top of the lid can deform the lid.
- The insulation (mineral wool and EPS) cannot stand wet conditions.
- It has not been possible to find a cheap material for moisture protection.

A new design of the lid has therefore been carried out for SUNSTORE 3 and SUNSTORE 4.

- Ventilation pipes will be introduced to get rid of air under the lid.
- The slope of the top will be changed to min. 5 ‰ near the edge of the lid.
- The insulation will be changed to ventilated expanded clay (LECA) so that condensed water can be avoided.

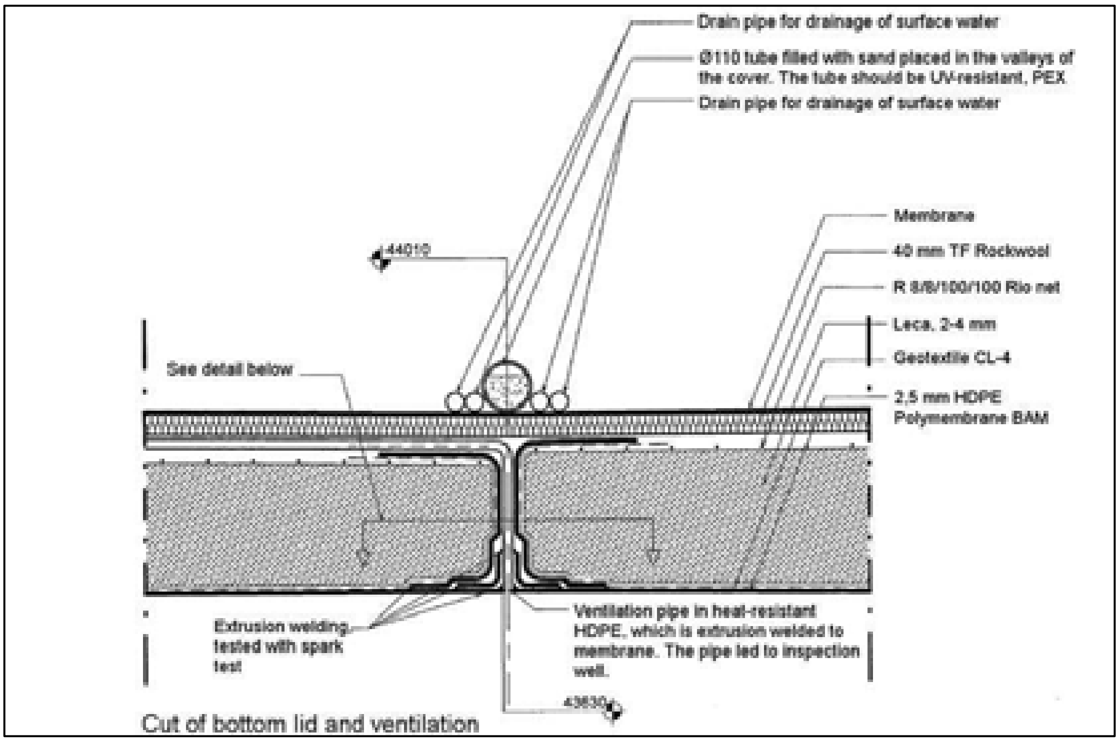

Fig. 12. Detail of new lid construction

In the tender process for the storage in the SUNSTORE 4 project an alternative lid solution was proposed. In this alternative solution coated elements of PUR are used as lid. The elements can be glued together. This construction is remarkably cheaper than the expanded clay solution and tests are therefore going on to investigate if the alternative solution can be used.

6. Experiences with implementation of the pit storage

Construction of the storage in Marstal started 26. April 2011. The in- and outlet arrangement was placed 12. July 2011 and implementation of the liner started 15. August 2011. The excavation has been very complicated because of heavy rain during June and July and therefore the project is app. 8 weeks delayed.

Fig. 13. The storage in Marstal 2. August 2011.

7. Costs of energy from the SUNSTORE concept

The costs of pit storages in Denmark build according to the chosen design are shown below.

The graph shows the costs for a relevant range of sizes.

The central line is based on the results of the tender for the 75.000 m^3 storage in Marstal (primo 2011). In rounded figures the costs were as shown in the table below:

	M €
Excavation etc.	0.34
Liners	0.27
Insulation in lid	0.75
Roof foil	0.34
In- and outlet etc.	0.13
Consultants	0.07
Total	**1.90**

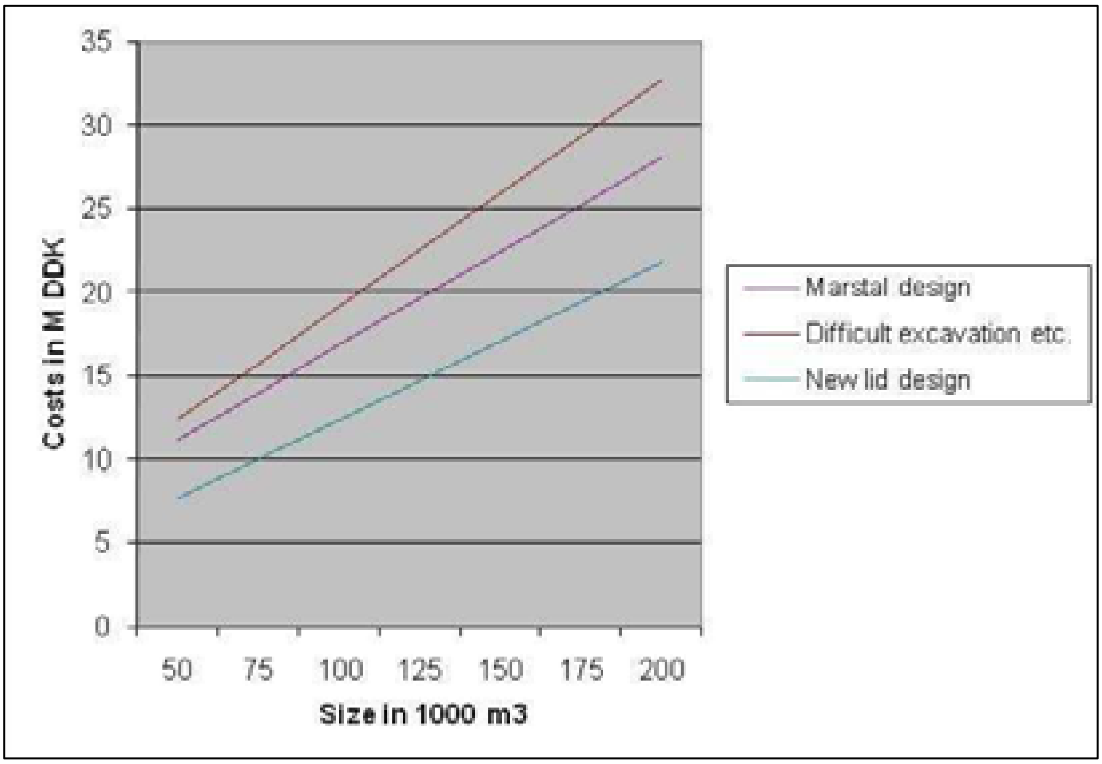

Fig. 14. Costs of pit heat storage.

The extrapolation to other sizes is based on the assumption that excavation costs varies with the size of the storage in m^3. Liners, insulation and roof foil varies with the size to the power of 2/3 (area) and finally 'others' varies with the power of 0.5.

The lower line in the graph represents the possibility of savings by further developments in the design of the lid. The estimate is based on ongoing experiments with a solution based on floating elements with cores of PUR foam.

The top line represents an upper limit for situations where costs are higher than in the actual project in Marstal e.g. because of more difficult conditions for excavation.

Total costs and yearly savings are as follows in the two projects.

Table 2. Investment and savings in the SUNSTORE projects.

	SUNSTORE 3	**SUNSTORE 4**
Investment, mio. €[1)]	13.92	13.65
Yearly surplus excl. capital costs, mio. €[2)]	0.83	0.71
Support, mio. €	2.24 [3)]	4.08 [4)]

[1)] Excl. support

[2)] Compared to the present situation

[3)] From the Danish EUDP program

[4)] From EU, FP7

Without support and including financial costs the heat production price from SUNSTORE 3 and SUNSTORE 4 is 5-6 €cents/kWh. Financial costs are calculated as average cost for a 20 years annuity loan with 5% interest rate and 2%/year inflation.

8. Literature

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