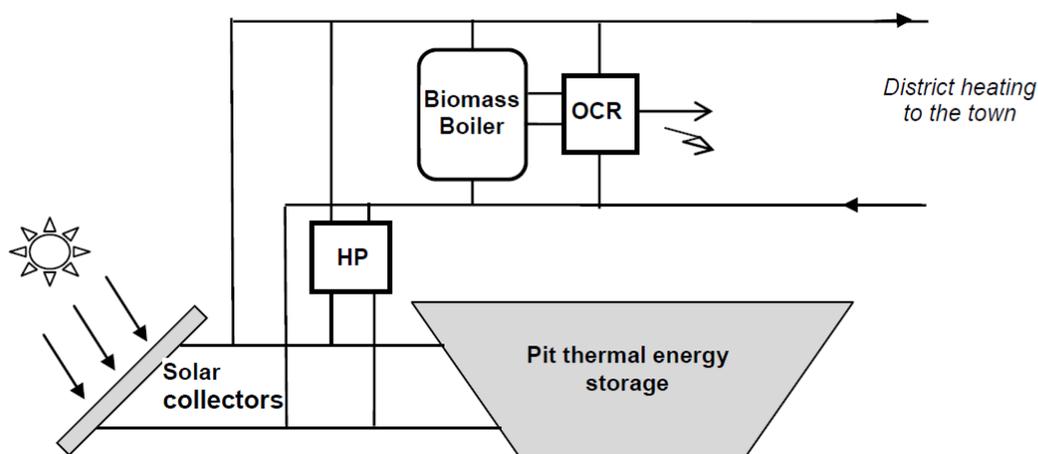


Summary technical description of the SUNSTORE 4 plant in Marstal

The purpose of the SUNSTORE™ concept implemented in Marstal is to show that district heating can be produced with 100 % RES of which solar thermal can cover 50 % or more. This is done by implementing a large heat storage in the production system. The heat storage is combined with a heat pump making it possible to

- reduce the size of the storage
- utilize low storage temperatures
- reduce the heat loss of the storage
- consume electricity in periods with high wind power production and store it as heat

The SUNSTORE™ configuration in Marstal is



In the **Summer** period the solar system loads the storage and provides Marstal with district heating.

From end of September the stored heat has to be supplied with heat from the wood chip boiler or the heat pump. The boiler runs with app. 3.25 MW heat output and the integrated ORC will produce 750 kW electricity. The heat pump runs when the electricity prices are low to cool the storage and heat up the return temperature to 75° C.

In the **Winter** period the back-up boilers will have to supply a few hours and/or the heat pump has to run also when the electricity price is higher.

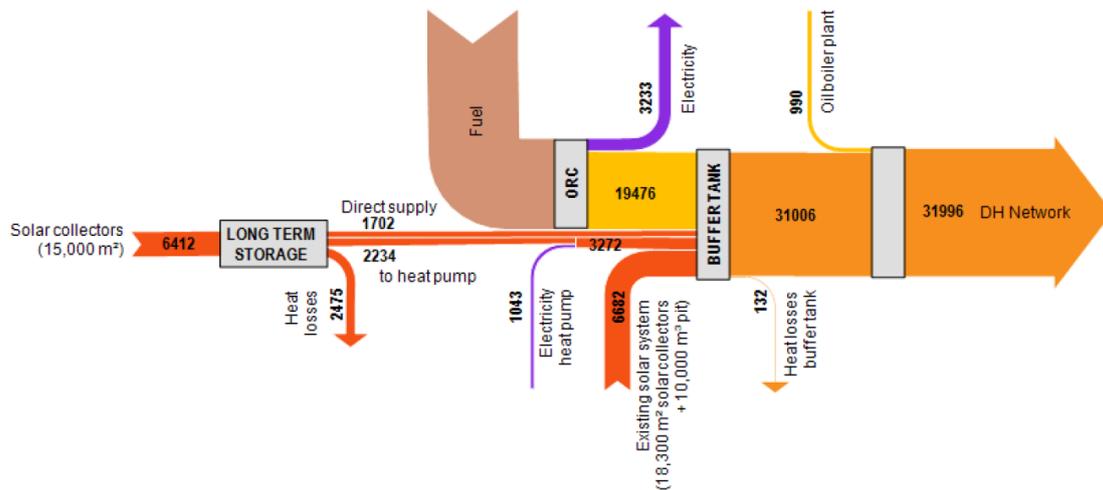
In February the solar system will begin to heat up the storage again. The wood chip boiler will run app. full time until April.

The production system has been implemented in 2011-12 and the following has been achieved for the single elements:

- 10 % better efficiency of solar collectors (15,000 m²)
- 11.7 % lower price for the solar collectors
- COP 3.1 from heat pump with CO₂ as refrigerant delivering 78° C. cooling capacity 0.962 MW

- Price for heat storage of 39 €/m³ water equivalent (including in-and outlet, transmission pipes, pumps, geo-technical support etc). 28 €/m³ for the storage alone (75,000 m³)
- A wood chip boiler with total efficiency of 109% (4 MW total)
- An ORC with efficiency of 19,5 % (0.75 MW)

The production showed in a Sankey diagram can be seen below



System history of Marstal

The beginning

The yearly solar radiation in Denmark represents app. 200 times the amount of energy which we use yearly for heat, electricity, transport etc. With an energy source like that, we wonder why it is not utilized by many more.

Up to 1994 there were only 2 District Heating plants utilizing solar energy for large scale heat production in Denmark.

The idea of solar heating was born when Marstal Fjernvarme A.m.b.a. (Marstal District Heating Ltd.) was researching the possibilities in using bio fuels instead of waste oil for heating purpose.

Provided that the solar fraction should be 100 % in the summer months, the demand to the supply temperature was 72 –70° C.

To comply with this demand, it was considered to build the system with adjustable flow to reach a higher supply temperature, even when the solar radiation was low. This method of controlling a solar collector plant was however not very known, most plants runs with constantly high flow and a variable supply temperature.

Early in 1994 Marstal District Heating Ltd. achieved a grant of 10,000 DKK for design of a 75 m² solar collector plant at the municipal swimming pool, and 20,000 DKK for design of a large scale solar heating plant connected to the exciting District Heating plant. In July 1994 the solar plant on the swimming pool was implemented. This plant was build after same principles as a future large scale plant would be, and after half a year

of operation the results was so promising that a 8,000 m² plant was decided build.

The design showed that an 8,000 m² plant with an accumulating tank on between 1,500-2,000 m³ should be able to cover 13-15 % of the heat demand, in a way covering 100 % in 3-4 summer months.

The solar collector plant has in 1999 been enlarged with 1,000 m², now counting 9,043 m².

Marstal Fjernvarme A.m.b.a. was the building owner in the project, and Engineer Per Alex Soerensen from PlanEnergi in Skoerping was chosen as adviser and Flemming Ulbjerg from Ramboll's Svendborg department was chosen as projecting engineer. The plant consisted of 640 solar panels (in 1999 of 720) with a size of 12.5 m² each, produced of the firm ARCON, which was lined up in 32 (in 1999 36) rows at a 20,000 m² land area.

Next to the plant a 150 m² building was erected. It contains heat exchanger, controls, emergency power generator and a show room.

Next to the building a 2,100 m³ accumulating tank was erected. Fully uploaded it should be able to manage the heat supply to Marstal in 3-5 days. The tank has a capacity of app. 100 MWh.

The temperature in the accumulating tank is normally about 70 to 75° C and in especially sunny periods up to 95° C.

If periods with low heat contribution from the sun should arise, the boilers will automatically start up and increase the supply pipe temperature. In the winter period the solar collector plant will increase temperature of the water returning from the city, before it is led to the boilers.

One of the huge problems when we are talking about solar heat and renewable energy sources in general, is storage technologies. Provided that our energy systems in the future should consist of windmills, solar collectors, solar cells or wave energy operated with high long term efficiency, the seasonal storing will become a necessity.

Therefore Marstal District Heating established in 1998, together with The Danish Energy Agency, the earth pipe storage. The project was financed by The Danish Energy Agency 7,400,000 DKK and Marstal District Heating contributed with labour and 600,000 DKK for a heat pump, but the economical feasibility of this type of storage was not convincing.

SUNSTORE 2

In august 2001 the first meeting was held concerning the project SUNSTORE 2. The project SUNSTORE 2 is an enlargement of the solar collectors with approximately 10,000 m² and a pit heat storage of 10,000 m³. Then the solar collector plant should be able to cover 30% of the yearly energy consumption.

SUNSTORE 2 consists of 5 different solar plants:

- 8,019 m² flat plated solar collectors from ARCON. The new collectors was improved by 18% compared to the old solar collectors from 1996.

- 881 m² flat plated solar collectors from GJ-teknik. GJ-teknik is a local company who also has produced the collectors for the plant in Rise. FJ-teknik has later started production in Vietnam under the name SUNMARK.
 - 211 m² focusing collectors from IST, US.
 - 108 m² vacuum tube solar collectors from Thermomax, UK.
 - 103 m² roof integrated solar collectors from Wagner, DE.
- An expansion on 9322 m², the total area was now 18.365 m².

The ARCON and GJ fields were put in to operation in February 2003, the rest of the solar collector fields were put in to operation during the spring of 2003. But the pit heat storage wasn't established yet, because they were waiting for test of the plastic liner to be used in the storage.

They really needed the storage in 2003. They had to paint the old solar collector field with shadow paste, which is normally used for greenhouses. That way the old collector field only produced 25 % of its normal capacity. And in august they had to start up the pumps to cool in the night time.

They started establishing the storage in July and finished in October. The control system wasn't finished before June this 2004.

IN 2004 they mounted 60 solar photovoltaire panels on the old building, which contribute some to our electricity demand.

SUNSTORE 4

The overall objectives of the project are to demonstrate a "SUNSTORE 4" energy concept of a large scale innovative, cost efficient, and technical reliable 100 % renewable energy supply system for a (Marstal, DK) large scale (district) heating system with yearly heating production of 28,000 MWh - based on solar energy and biomass energy (willow wood chips from energy crops) including a CO₂ heat pump and electricity production from biomass energy through an Organic Rankine Cycle (ORC) unit.

The plant comprise: 15,000 m² solar system, CHP system with a low emission 4.0 MW wood chip thermal oil boiler and a 750 kW_{el} ORC, 75,000 m³ pit heat storage, 1.5 MW (thermal) heat pump with CO₂ as refrigerant - supplementing the existing demonstration plant (SUNSTORE 2) including 18,365 m² solar thermal and 10,340 m³ pilot pit heat storage.

The targets on cost efficiency are for solar thermal to meet the vision of ESTTP with a cost of 3-6 €-cent per kWh, and (low) investment costs of 33 €/m³ of the pit heat long term storage. Other types of SUNSTORE 4-energy concepts will be developed adapted to the regional conditions of energy loads, energy costs, renewable energy sources etc. in regions of Eastern, Southern, Central and Northern-Western EU. Dissemination activities will be carried out in 10 EU-countries with short term impact with an indicative target of 20 systems in AT-CZ-DK-FR-DE-IT-PL-ES-SE-UK.

SUNSTORE 4 was implemented in 2011-12.

Overall objectives of SUNSTORE 4

A European perspective of the system concept and thereby of the demonstration project is that it is potentially applicable and adaptable to different regions of Europe with different types of conditions. This includes:

- Energy output in terms of heat, cooling, electricity and according to the demand in the region;
- Flexibility in the mix of solar, biomass energy and electricity (heat pump) e.g. related to the costs of the 3 energy sources;
- Flexibility in the types of biomass energy sources, e.g. using relatively wet biomass sources or sources being not very homogeneous.

Specific objectives of SUNSTORE 4

Demonstration of

- An innovative integrated 100% renewable energy system focusing on energy and cost efficiency with a good replication potential in a European context with an estimated heat cost price in Northern Europe of 50-55 €/MWh excl. salaries for the staff;
- A technical reliable energy system based on proved individual technologies, where innovation is related to integration of these individual technologies;
- An innovative flexible energy system, which can deal with the challenges related to summer overheating, including ORC and a compressor heat pump using CO₂ as refrigerant;
- A long term full scale pit heat storage including a heat pump to cool the storage and thus reduce heat losses.

Configuration of production units

The configuration of the SUNSTORE 4 production units in Marstal can be seen in the system diagram in fig. 1:

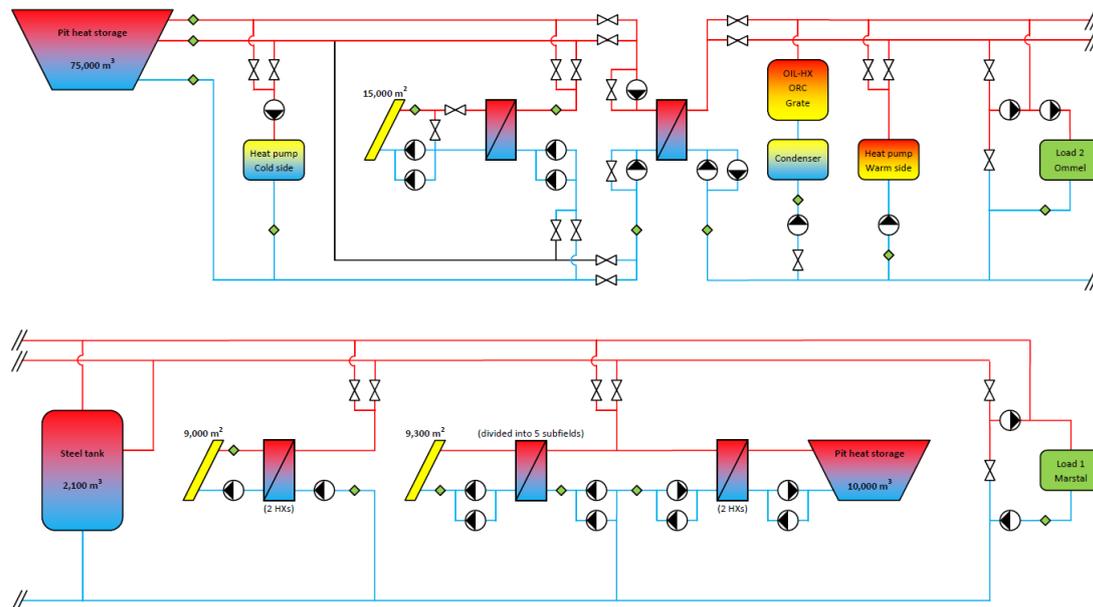


Fig. 1: System diagram of SUNSTORE 4 in Marstal

In the **Summer** period the solar system loads the storage and provides Marstal with district heating.

From end of September the stored heat has to be supplied with heat from the wood chip boiler or the heat pump. The boiler runs with app. 3.25 MW heat output and the integrated ORC will produce 750 kW electricity. The heat pump runs when the electricity prices are low to cool the storage and heat up the return temperature to 75° C.

In the **Winter** period the back-up boilers will have to supply a few hours and/or the heat pump has to run also when the electricity price is higher.

In February the solar system will begin to heat up the storage again. The wood chip boiler will run app. full time until April.

Distribution network and substations

It is essential for the production from a solar district heating plant, that the return temperature from the distribution network is low. Therefore Marstal District Heating always use storages (typical 110 or 160 liters) in the consumer substation installations. That allows low flow to load up the storages, low return temperatures and minimization of the pipes to the houses (and thus also reduced heat losses). Marstal District Heating has visited all their consumers and controlled substations and distribution system in the houses. The result is return temperatures of 33° C in Winter going up to 40° C in summer. Forward temperatures are between 72° C (Summer) and 76° C (Winter).

1,550 consumers are connected to Marstal District Heating. Sale in 2012 was 26,500 MWh. Production was 32,000 MWh (heat loss from pipes 5,500 MWh or app. 17 %). The pipe system is up to 30 years old but is continuously renewed.

The unique about the SUNSTORE concept is its flexibility

The concept makes it possible

- to use all types of renewable heat and waste heat, because of the storage and the heat pump (solar thermal, geothermal, biomass, waste heat from incineration, excess heat from industries).
- to provide consumers with district heat from 100 % RES, also without use of biomass.
- to consume and to produce electricity when needed in the electricity system and thus to integrate fluctuating electricity production from wind and solar.
- the concept can be built up gradually.

Impact on community

Nearly all inhabitants in Marstal are district heating consumers. Marstal District Heating is a consumer owned co-operative. Daily decisions are taken by the board elected at the yearly general assemblance.

All major investments (the 8,000 m² plant, SUNSTORE 2 and SUNSTORE 4) have been discussed and decided by the general assemblance, where all consumers are invited. As an example the first project was decided with 144 votes for and 0 against. During the project preparation the community is informed from articles in the local newspaper (and by meeting members of the board or employees from the district heating company in the daily life)

Every year 2,000 – 4,000 persons from inside and outside Denmark visit Marstal District Heating.

The SUNSTORE 4 project will produce heat to 50-60 €/MWh. This has to be compared to a heat production price of more than 70 €/MWh from bio oil. Thus the consumer price for heat is lowered because of the project.