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Smart district heating using the SUNSTORE concept

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The SUNSTORE concept has as its core content a large solar thermal plant and a long term heat storage covering a large part of the energy consumption in a district heating system. Other renewable energy production plants can be added to the solar collectors and the storage (heat pumps, biomass or natural gas fuelled combined heat and power plants etc,) making it possible to cover both district heating and cooling systems with up to 100% renewable energy. In Marstal, DK, the SUNSTORE 4 project, supported by EU 7th Framework Program has been implemented during 2011 and 2012. This document presents the SUNSTORE concept, design of the project in Marstal, experiences with the implementation of the storage in Marstal and variations and future development of the concept.

Inteligentno daljinsko grijanje koristeći SUNSTORE koncept

Izvorni znanstveni rad

SUNSTORE concept se u suštini sastoji od velike solarne toplane i dugoročnog toplinskog spremnika koji okriva veliki dio potrošnje toplinske energije u sustavu daljinskog (centraliziranog) grijanja gradskih oblasti. Drugi obnovljivi izvori energije i toplinski spremnici mogu biti korišteni uz solarne kolektore (toplinske pumpe, biomasa, prirodni plin,…) što bi omogućilo opskrbu energije za daljinsko grijanje i hlađenje iz 100% obnovljivih izvora energije. U gradu Mastal u Danskoj, project SUNSTORE 4 podržan od "7th Framework Program" Europske Unije, je implementiran tokom 2011. i 2012. godine. Ovaj rad predstavlja SUNSTORE koncept, izvedbu projekta, iskustva sa implementacijom skladištenja energije u Marstal-u, i varijacije te budući razvoj projekta.

1. Introduction

In recent years, solar district heating has been common as a supplement to heat production from Danish CHP plants using natural gas. Until medio 2012 has been implemented, 250,000 m2 new solar collectors in connection to natural gas fired CHP plants and more than 300,000 m2 are expected to be implemented in 2012 and 2013. 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 m3) was built in Denmark in 1996 and a 10,000 m3 pilot storage was built by Marstal District Heating in 2004 as a part of the project SUNSTORE 2 supported by the EU and the Danish Energy Agency [1]. The two new storages represent further development of the pilot storage in SUNSTORE 2. They are situated in Dronninglund, DK (to be built in 2013), as part of a new project, SUNSTORE 3, with a 50% fraction of renewable energy and a 50% fraction of heat from a natural gas fired CHP plant, and in Marstal, DK, as a part of the project, SUNSTORE 4, with 100% renewable energy.

2. The SUNSTORE concept

The concept for the energy system in SUNSTORE 4 is illustrated in Fig. 1.

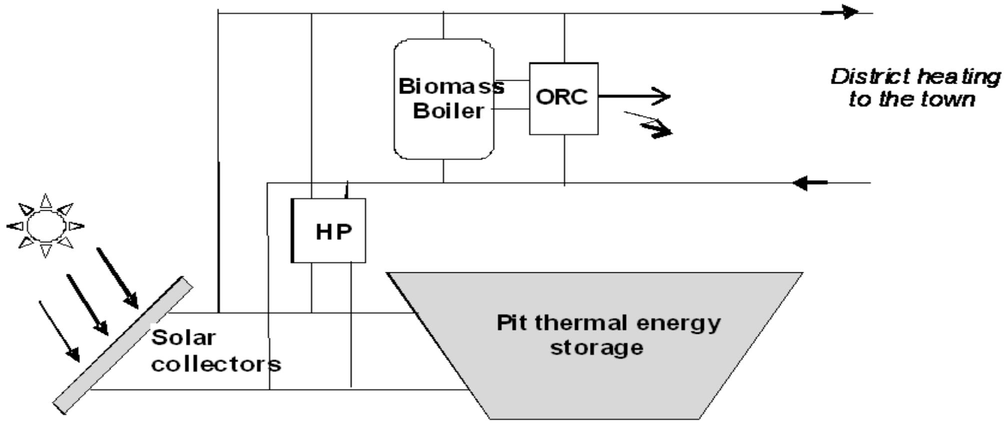

Figure 1. Illustration of the SUNSTORE concept for energy systems with large solar fractions in Marstal, DK.
Slika 1. Ilustracija SUNSTORE koncepta za energetske sustave sa velikim udjelom solarne energije u gradu Marstal, Danska.

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 a heat source and the CHP–plant produces heat in periods with high electricity prices.

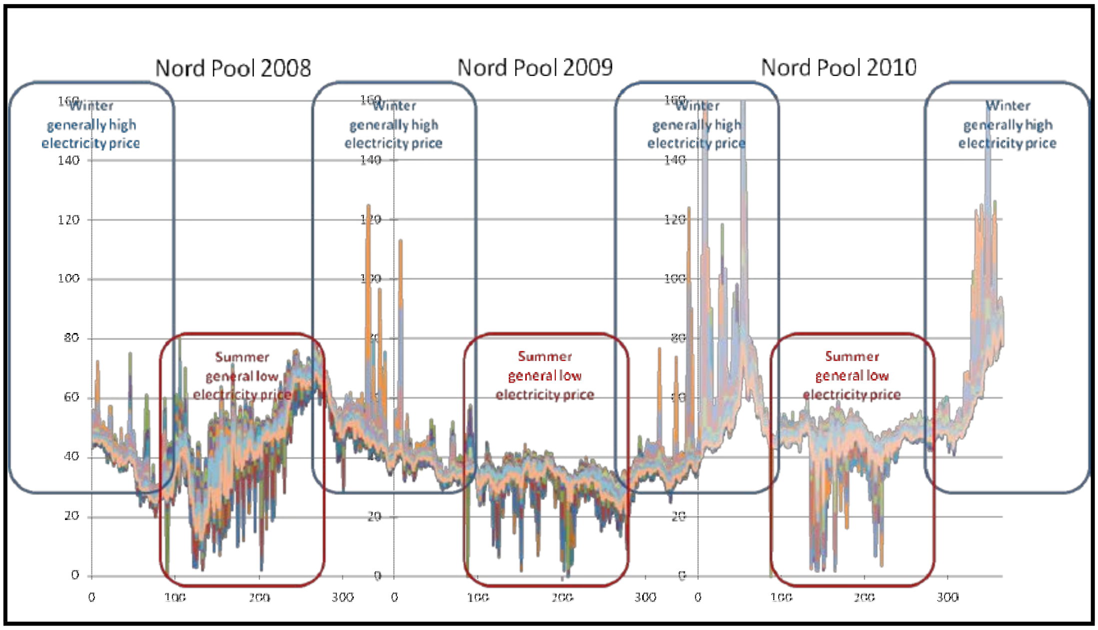

Figure 2: Example of thermal demand in house of a Mediterranean area.
Slika 2. Cijene električne energije u Danskoj (Nordpool), tokom 2008. do 2010. godine. Vrhovi u dijagramu su cijene tokom zimskih mjeseci (winter), a dolovi u dijagramu su cijene tokom ljetnih mjeseci (summer).

In Figure 2, Danish electricity prices from 2008 to 2010 are illustrated. One of the reasons why the prices are fluctuating is due to the amount of wind power produced. In periods when the wind power production in West Denmark reaches more than 100% of the consumption, 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 inexpensive. The advantages of combining the technologies in the SUNSTORE concept are illustrated in Figure 3.

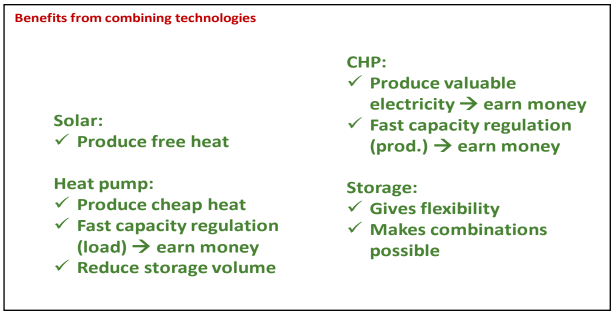

Figure 3: Advantages by combining the technologies in the SUNSTORE concept.

Slika 3. Prednosti kombiniranja različitih tehnologija u SUNSTORE konceptu.

3. Design of the SUNSTORE 4 project in Marstal

The district heating utility in Marstal had a 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 District Heating 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 the EU (FP7) and as a result, an additional energy system with 15,000 m2 solar collectors, a 1.5 MWheat heat pump, a wood chip boiler producing 3.25 MWheat and 0.75 MWel combined with a 75,000 m3 pit heat storage could cover nearly 100% of the heat consumption and more than 50% would be covered by solar energy and heat pump. The application was accepted and during the autumn and winter of 2010-11 the system was optimized and designed in detail. The system diagram can be seen in Fig. 4.

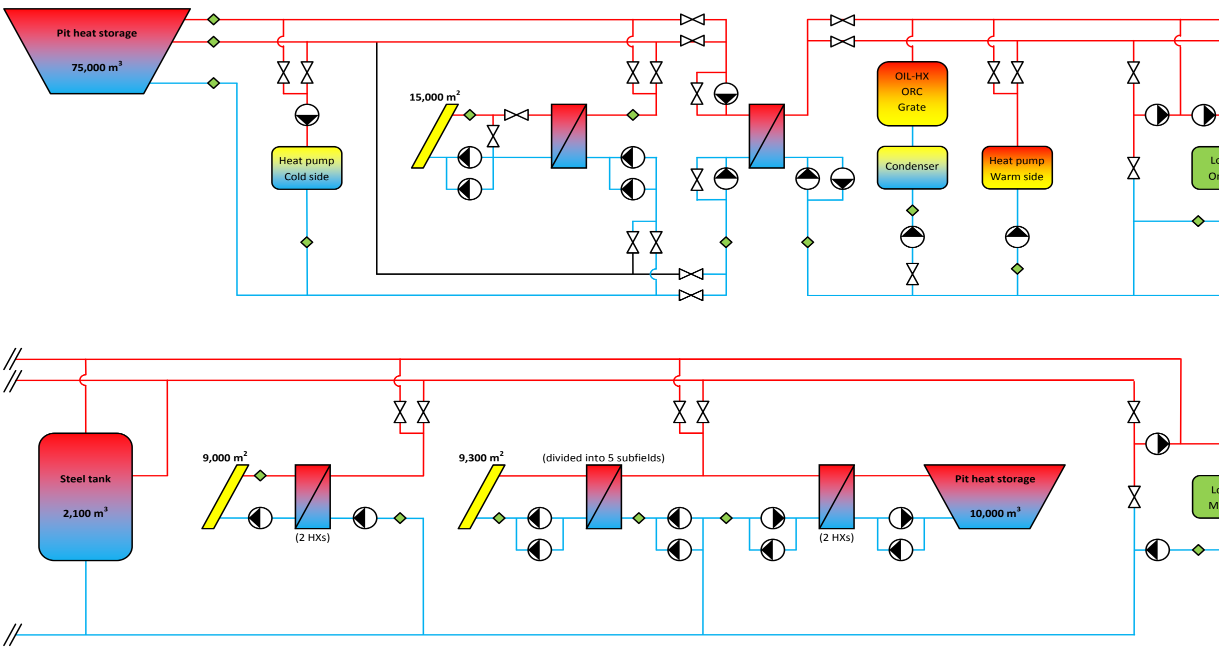

Figure. 4. System diagram for SUNSTORE 4 (Marstal). The upper half represents the new plant, and the lower half represents the "old" plant including SUNSTORE 2.

Slika 4. Dijagramski prikaz sustava SUNSTORE 4 (Marstal). Gornji dijagram predstavlja novi sustav, a donji dijagram predstavlja „stari“ sustav uključući SUNSTORE 2.

Since 2008, additional customers have been connected to the district heating network, resulting in a calculated yearly heat production of 32,000 MWh from 2012.

Calculated temperatures in the 75,000 m^3 pit heat storage and results from optimization of the total system can be seen below.

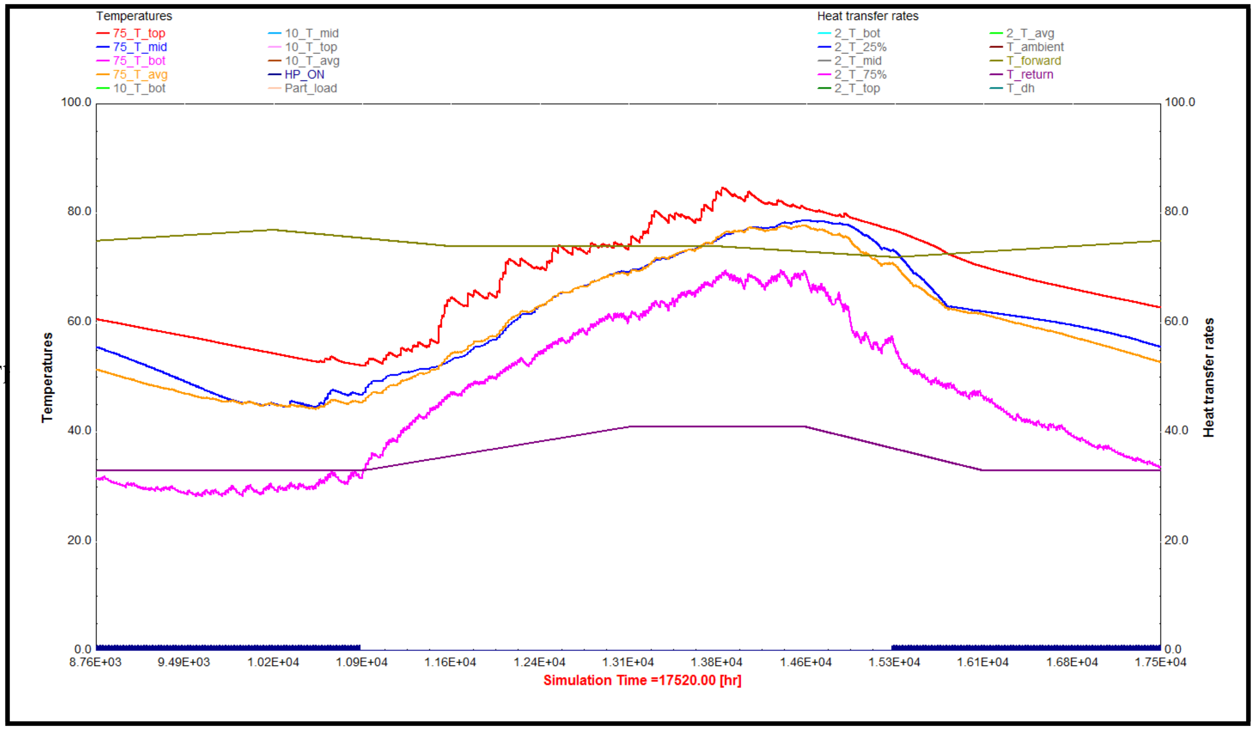

Figure. 5. Calculated max., average and min. temperatures in the pit heat storage SUNSTORE 4 during simulation year 2 as well as DH forward and return temperatures and HP (heat pump) operation [2].

Slika 5. Izračunate maksimalne, prosječne i minimalne temperature u toplinskom spremniku SUNSTORE 4 tokom simulirane druge godine, kao i polazne i povratne temperature daljinskog grijanja i rad toplinske pumpe [2].

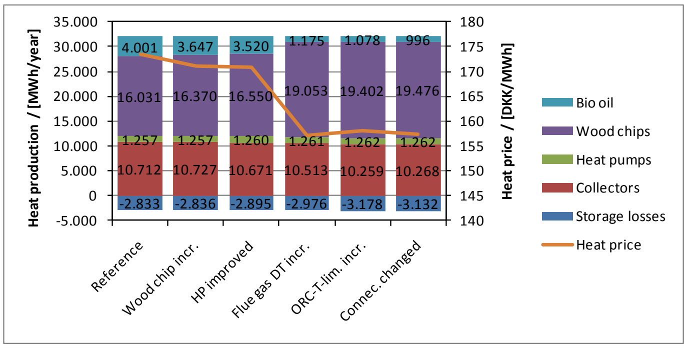

Figure 6. Yearly heat production and heat production prices for TRNSYS simulations with different preconditions [2].

Slika 6. Godišnja proizvodnja toplinske energije [MWh/year] i cijene toplinske energije [DKK/MWh] za TRNSYS simulacije sa različitim preduvjetima [2].

4. Design of the pit heat storage

The 75.000 m^3 pit heat storage in Marstal is in principal a pyramidal frustum upside down excavated in the ground as shown in Fig. 7. Soil excavated from the hole

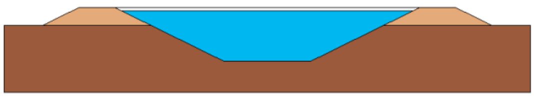

Figure 7. Principal section view of the pit heat storage.

Slika 7. Principijelni prikaz presjeka solarnog toplinskog spremnika u jami.

is placed around the storage as an embankment contributing to the effective volume.

The water depth of the storage is app. 16 m and the water surface is app. 113 x 88 m. To ensure the stability of the sides during excavation the slope is made as 1:2 (~27°). Fig 8a shows a picture from the excavation process.

The sides and the bottom of the storage is covered by a fully welded HDPE liner to make the storage water tight. The liner is tested against temperature in an accellerated life test and is able to withstand the temperatures in storage for more than 20 years. The design and installation process of the side and bottom liner is well known. One limitation of the liner is that it does not allow continously high temperatures. If the temperature exceeds 90°C continously, the liner will degrade within a few years.

Figure 8. a) Picture of excavation of pit heat storage. The in- and outlet tower is in place and can be seen in the left part of the picture. b) Picture of lid construction of the pit heat storage. The different layers can be seen. In the right part the geo net on top of the liner, in the middle part the three layers of insulation and in the left part another layer of geo net folded back on the white top liner.

Slika 8. a) Fotografija iskapanja jame za toplinski spremnik. Toranj sa ulaznim i izlaznim priključcima je vidljiv na slici lijevo. b) Fotografija konstrukcije pokrova jame za toplinski spremnik. Pokrov jame je sastavljen od nosive mreže, tri sloja toplinske izolacije i zaštitnog pokrova.

The most critical part of the storage is the insulated lid. In contrast to the bottom and the sides, the lid has to be insulated to avoid too much heat loss. The lid has to be able to withstand the temperature and humidity exposure from the storage itself and the exposure from the surrounding environment (rain, UV-radiation etc.).

Throughout the lifetime of the storage the lid has to maintain the insulation value that it is designed for. Both in theory and in practice this has proven to be very difficult. The relatively high water temperature below the lid causes a considerable amount of moisture to diffuse through any polymer material used for liners. To avoid vapour penetration and condensation in the insulation it is necessary either to have a completely vapour tight barrier between the water and the insulation or to ensure sufficient ventilation of the insulating layer. During the project, different designs were developed and investigated. The resulting design is based on the concept of ventilating the insulating layer and the use of insulation that has a relatively closed structure. The construction of the lid can be seen in Fig. 8b. It consists of a HDPE liner on top of the water surface. This liner is welded onshore section by section (app. 7 m wide) while it is pulled out to the water surface. On top of the liner a geo net (HDPE) is placed to allow air flow between the liner and the insulation. Three layers of insulation are installed. Each layer consists of 80 mm cross bonded PE foam insulation in a closed cell structure. Another layer of geo net is placed on top of the insulation to allow airflow between the insulation and the top liner, which is installed on the top. The ventilation of the insulation is done by vacuum (roof) valves placed along the side of the lid.

Another major challenge in the lid design is to make sure that the construction is able to absorb movements of the lid in relation to temperature expansion of both the water volume and the individual materials. In the Marstal storage, this is done by strategically placed weight pipes both on the lower and upper liner of the lid. These weight pipes will weigh down the liner into the water and take up excess liner material. The weight pipe section is shown in Fig. 9b. Besides handling the thermal expansion, the weight pipes have two functions. They help to direct rain water to the center of the lid where it will be pumped out and help to lead airtraps between the water and the lid towards the edges of the lid.

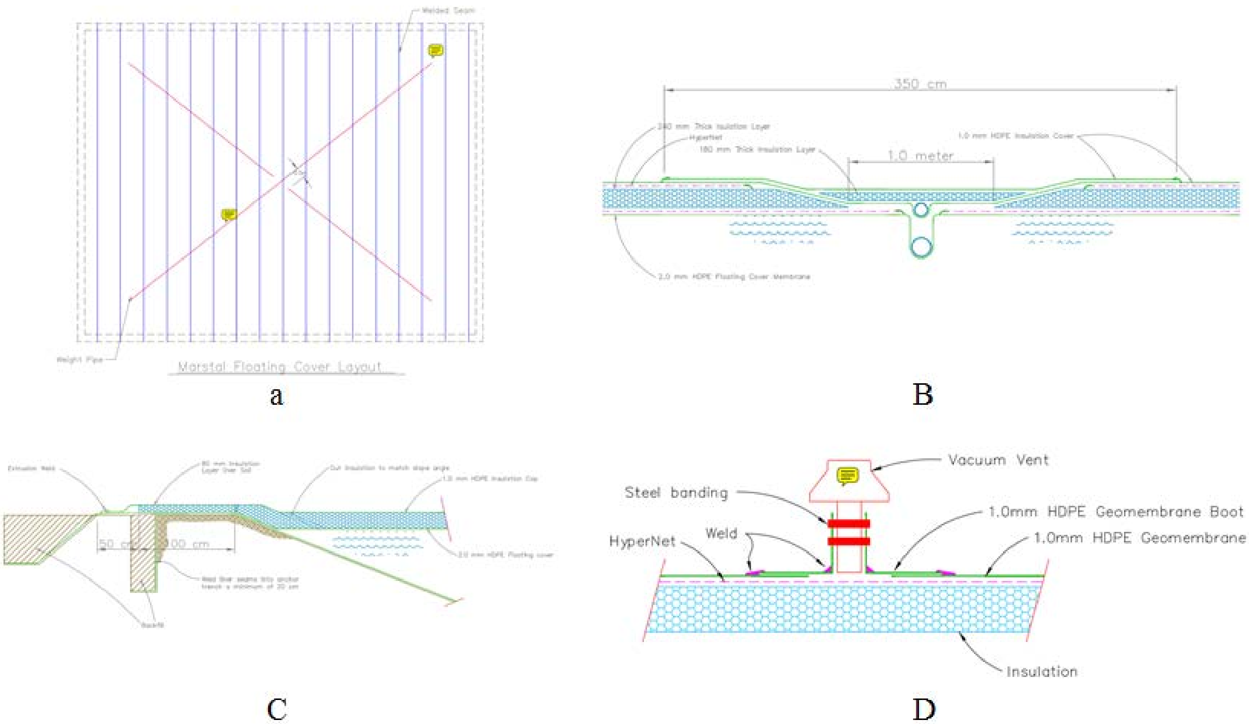

Figure 9. a) Top view of storage showing placement of weight pipes. b) Weight pipe section. c) Anchor trench section. d) Vacuum vent.

Slika 9. a) Tlocrt jame sa prikazanim utežnim cijevima, b) presjek utežne cijevi, c) sidrište sekcije rova, d) odušnik.

5. Experiences with the implementation of the storage

Construction of the storage in Marstal started 26. April 2011 and the in- and outlet arrangement was placed on 12. July 2011. The excavation was very complicated because of heavy rain during June, July, August and September 2011.

In the middle of August, heavy rain totally stopped work until the end of September. Therefore the side- and bottom liner work had to take place in November and water was filled in during the winter. Implementation of the lid started in April 2012 and was finalised July 2012, 8 months later than expected.

6. Costs of energy from the SUNSTORE concept

The costs of pit storages in Denmark built according to the chosen design are shown beside.

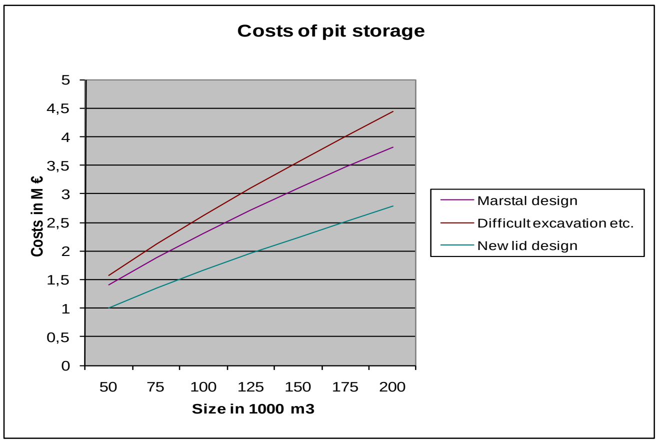

Figure. 10. Costs of the pit heat storage.
Slika 10. Troškovi jame za toplinski spremnik u milionima EUR, u odnosu na veličinu jame u 1000 m^3. Legenda (od gore prema dolje): Marstal izvedba, problematično iskopavanje, novi dizajn pokrova jame.

The central line is based on the results of the tender for the 75,000 m^3 storage in Marstal.
The extrapolation to other sizes is based on the assumption that excavation costs variy with the size of the storage in cubic metres. 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 top line represents an upper limit for situations where costs are as 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 1. Investment and savings in the SUNSTORE projects.
Tablica 1. Ulaganja i uštede u SUNSTORE projektima (milioni EUR).

	SUNSTORE 3 [5]	**SUNSTORE 4**
Investment, mio. € 1)	13.9	15.5
Yearly surplus excl. capital costs, mio. € 2)	0.83	0.71
Support, mio. €	2.20 3)	4.10 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 SUN- STORE 4 is 5-6 €cents/kWh. Financial costs are calculated as the average cost for a 20 years annuity loan with 5% interest rate and 2% inflation. The solar heat production corresponds to conditions in Northern Europe.

7. Variations and future development of the concept.

The SUNSTORE concept can be varied in different ways.

The storage can be pit heat storage or borehole storage
The solar collectors can be flat plate, evacuated tubes or CSP collectors. If CSP collectors are used, an absorption heat pump for production of hot and cold water might be added.
The heat pump could be electrical (compressor) driven or heat driven
The additional heat could come from biomass CHP or biomass.

The combination depends on the local resources and the local need for heating and cooling.

In the SUNSTORE 4 project, as part of the dissemination, 20 new SUNSTORE projects situated in Southern, Eastern, Central and North Europe will be calculated and the implementation process will begin.

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