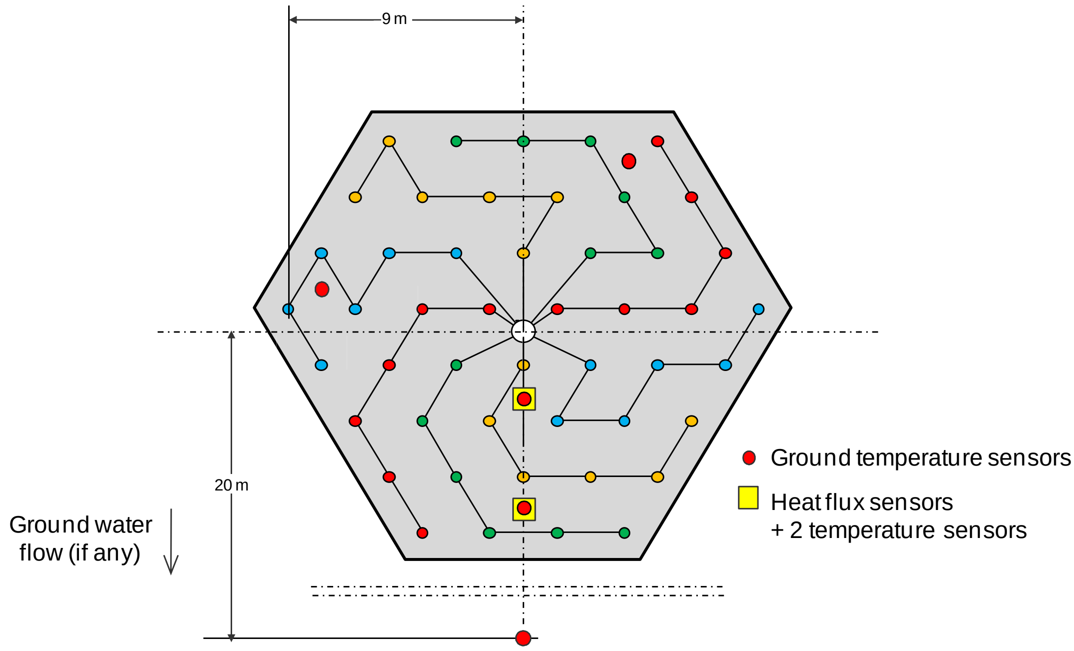
# Best Practice
# for implementation and operation
# of large scale
# Borehole and Pit Heat Thermal Storages

## Based on Danish experiences




Energiteknologisk udvikling og demonstration

## English introduction

In the projects ”Follow up on large scale heat storages in Denmark” and ”Follow up on large heat storages in Denmark, Gram” performance of the large scale storages in Brædstrup, Marstal, Dronninglund and Gram has been monitored to gain operation experiences and to verify design calculations.
Results from the projects are reported in the final reports and in more detailed monitoring reports for each of the plants.
During the projects the project partners (managers from the utilities, technology providers, consultants and researchers) had a yearly meeting where experiences from implementation and operation of the storages were exchanged.
Experiences from implementation and operation of the storages and experiences from designing the storages have resulted in a sum of "Best Practices" for design, implementation and operation of the large-scale Borehole and Pit Heat Thermal Storages (BTES and PTES).
The two monitoring projects have been supported by the Danish EUPD program (support program for development and demonstration of energy technologies).

## Danish introduction

I projekterne "Opfølgningsprogram for store varmelagre I Danmark" og Opfølgningsprogram for store varmelagre I Danmark, Gram" er ydelsen fra de store varmelagre i Brædstrup, Marstal, Dronninglund og Gram blevet målt dels for at samle erfaringer med drift af anlæggene dels for at sammenligne med projekteringsberegningerne.
Resultaterne fra projekterne er dokumenteret i slutrapporterne for projekterne og i mere detaljerede målerapporter for hvert af anlæggene.
I løbet af projektperioden har projektdeltagerne (Varmemestre fra de deltagende fjernvarmeværker, leverandører, konsulenter og forskere) haft årlige møder, hvor erfaringer fra anlæg og drift af varmelagrene er blevet udvekslet.
Erfaringer fra etablering og drift af varmelagrene har resulteret i en sum af ”Best Practices” for projektering, etablering og drift af store borehuls- og damvarmelagre (BTES og PTES på engelsk).
De to måleprojekter har været støttet af det danske EUDP program (Energiteknologisk Udviklings- og Demonstrationsprogram).

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# Content


1. WHY LONG-TERM HEAT STORAGES? 5

**1.1 Long-term or seasonal storage for solar thermal systems 5**

**1.2 Storing of excess heat from industries, waste incineration, power plants and geothermal plants 5**

**1.3 Optimization of CHP systems 6**

**1.4 Storage for power to heat (heat pump) systems 6**

**1.5 As both hot and cold storage if connected to heat pumps 6**

**1.6 In power to heat to power systems (Carnot batteries) 6**

**1.7 As the heart in integrated district heating systems 7**

2. TYPES OF STORAGES 8

3. WHY BTES AND PTES 8

4. BEST PRACTICE FROM BTES IN BRÆDSTRUP 9

**4.1 Design 9**

4.1.1 Temperature levels 9
4.1.2 Ground water and geological conditions 10
4.1.3 Thermal Response Test 10
4.1.4 Distance between boreholes, drilling patterns and depth of drillings 10
4.1.5 Grouting 11
4.1.6 Lid construction 11
4.1.7 Design tools 12
4.1.8 Monitoring equipment 12

**4.2 Implementation 14**

4.2.1 Mud and water from drilling 14
4.2.2 Possible drilling problems 14
4.2.3 Pipe connections 14

**4.3 Operation 15**

4.3.1 Charge and discharge capacity 15
4.3.2 When to operate the heat pump 15

5. BEST PRACTICE FROM PTES IN MARSTAL, DRONNINGLUND AND GRAM 15

**5.1 Design 15**

5.1.1 Temperature levels 16
5.1.2 Water quality 16

5.1.3 Ground water and environmental issues 16
5.1.4 Liner quality 16
5.1.5 Air under lid 17
5.1.6 Rain water 17
5.1.7 Lid insulation and ventilation 18
5.1.8 Design tools 18
5.1.9 Monitoring equipment 19

**5.2 Implementation 19**
5.2.1 Secondary ground water levels 19
5.2.2 Excavation 19
5.2.3 Compression of excavated soil 19
5.2.4 Stones on the banks 19
5.2.5 Rain water under excavation 19
5.2.6 Test of liner welds 20
5.2.7 Water in the lid 20
5.2.8 Protection of water 21

**5.3 Operation 21**
5.3.1 Protection of heat exchangers 21
5.3.2 Water quality and corrosion 21
5.3.3 Water added and level of water 21
5.3.4 Spoiled stratification 21
5.3.5 Daily control 21

# 1. Why long-term heat storages?

Long-term storages are in Denmark developed to extend the solar fraction in district heating systems but long-term thermal storages can have several functions in heating systems

- as long-term or seasonal storage for solar thermal systems
- for storing excess heat from industries, waste incineration, power plants and geo-thermal plants
- for optimization of CHP system as buffer storage
- as storage in power-to-heat (heat pump) systems
- as both hot and cold storage if connected to heat pumps
- in power-to-heat-to-power systems (Carnot batteries)
- as the heat storage in integrated district heating systems with several heat sources

## 1.1 Long-term or seasonal storage for solar thermal systems

Solar thermal systems have traditionally been designed to cover the base load in district heating systems (hot water consumption and losses in the distribution grid). Such systems can reach a solar fraction of up to 25 % in a district heating system under Danish conditions - and with a buffer storage. If a long-term or seasonal storage is added or replaces the buff-er storage the solar fraction can be extended to 80% or even more.. Heat prices for different sizes of solar thermal plants combined with a pit heat storage has been calculated for the Danish district heating utility Nexø. The result can be seen in Fig. 1. In this case the heat production price goes up when the solar fraction exceeds 50%.

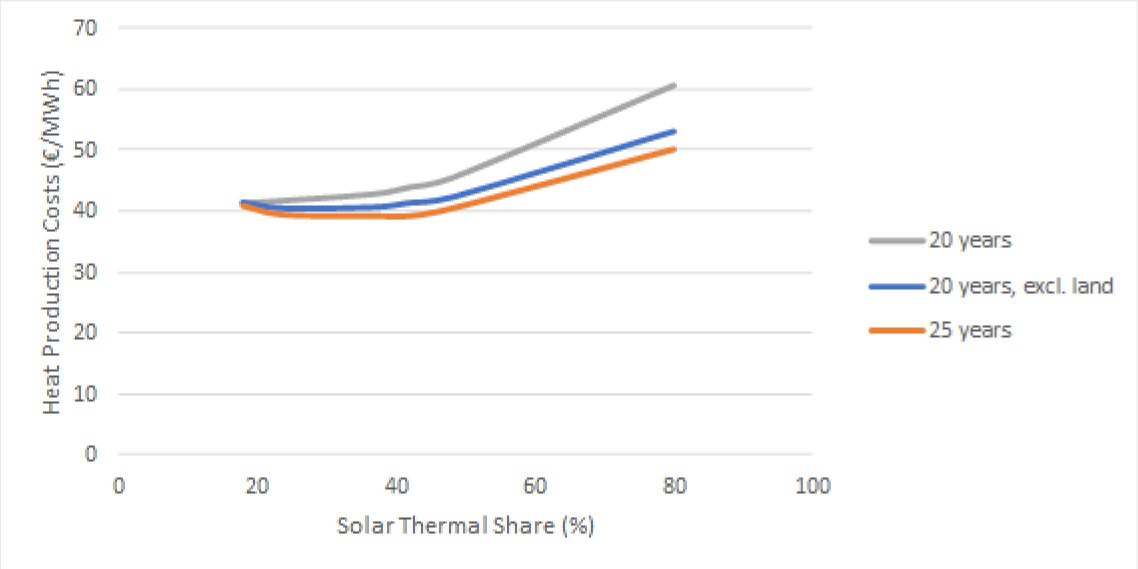


***Fig. 1.*** *Heat production prices for different solar fractions, Nexø. Source: PlanEnergi*

## 1.2 Storing of excess heat from industries, waste incineration, power plants and geothermal plants

In the Heat Roadmap Europe project (www.heatroadmap.eu) excess heat in 14 EU-countries covering 88% of the inhabitants, 92% of the heat demand and 89% of the excess heat in EU 28 has been localized. Altogether the 14 countries have 3.104 district heating systems. 845 out of 2.188 large-scale excess heat facilities with thermal power generation activities >50 MW (39%) were found within coherent district heating areas, another 562 (26%) were found within 20 km of these areas.

So, 64% of all large-scale excess heat facilities in the 14 EU-countries can be found within or nearby existing district heating.

Altogether 895 district heating utilities with 130 mio. inhabitants have large scale excess heat facilities inside their supply area and 378 utilities with 20 mio. inhabitants have large scale excess heat nearby (20 km). [Heat Roadmap Europe D2.3]

The total excess heat from electricity production in EU exceeded in 2009 the demand for heating the total building stock as shown in Fig. 2

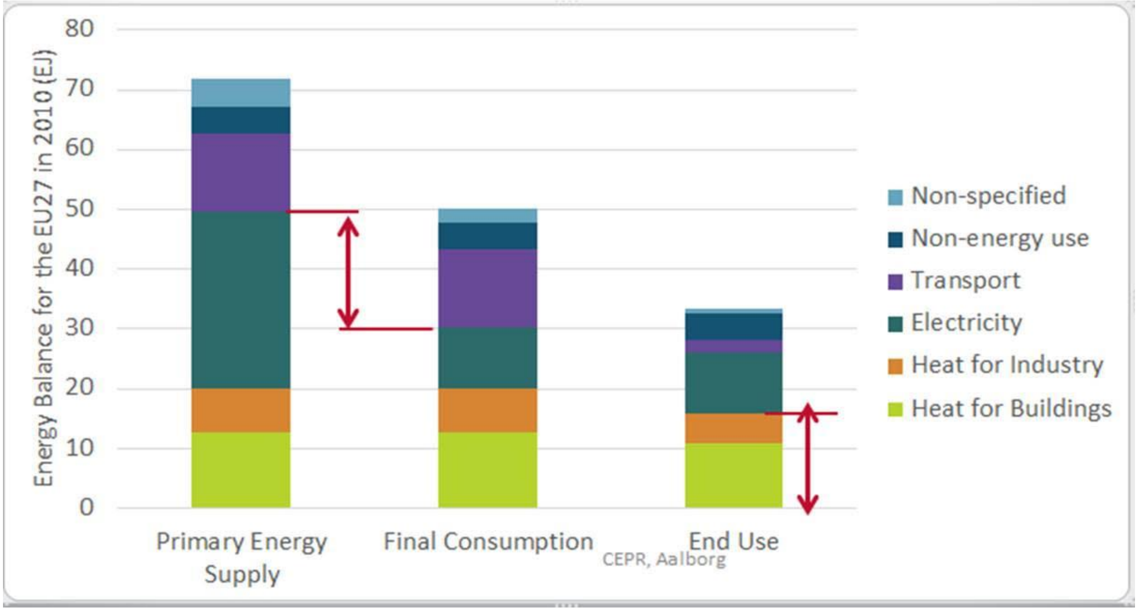

***Fig. 2.*** *Estimated excess heat compared to heating demand in industry and buildings in EU 27. Source: Aalborg University.*

If these huge amounts of excess heat shall be utilized, long-term thermal storages are needed.
Geothermal drillings have limited capacity and if the capacity exceeds the base load in the connected heating system long-term storages might be feasible.

### 1.3 Optimization of CHP systems

A seasonal storage will make it possible to make electricity production from CHP systems independent from heat demand and thus gain new income possibilities on the electricity market.

### 1.4 Storage for power to heat (heat pump) systems

Electricity from wind and solar power will play a large role in future energy systems. Since production regulation of wind and solar power is difficult, regulation will shift from the production side to the consumer side.
The cheapest regulation on the consumer side is to store electricity as heat in a thermal storage using heat pumps or electric boilers to the conversion. Heat sources can be excess heat at low temperatures from for instance data centres or it can be ambient air, rivers etc.

### 1.5 As both hot and cold storage if connected to heat pumps

If the long-term storage include stratification or a warm and a cold side as for instance in pit heat storages (PTES) and aquifer storages (ATES), the storage can have a double function serving both a heating and a cooling demand. This can be utilized in combined district heating and cooling systems and for instance in systems where industrial cooling is needed (data centres, cold stores…).

### 1.6 In power to heat to power systems (Carnot batteries)

Carnot batteries are under development in e.g. the Chester project ([www.chester-project.eu](http://www.chester-project.eu)). The idea is to use electricity in a heat pump, and to store the heat produced in a high temperature storage in periods with high electricity production from wind and solar and produce electricity from the stored heat in periods with low/fluctuating electricity production. The concept is illustrated in Fig. 3

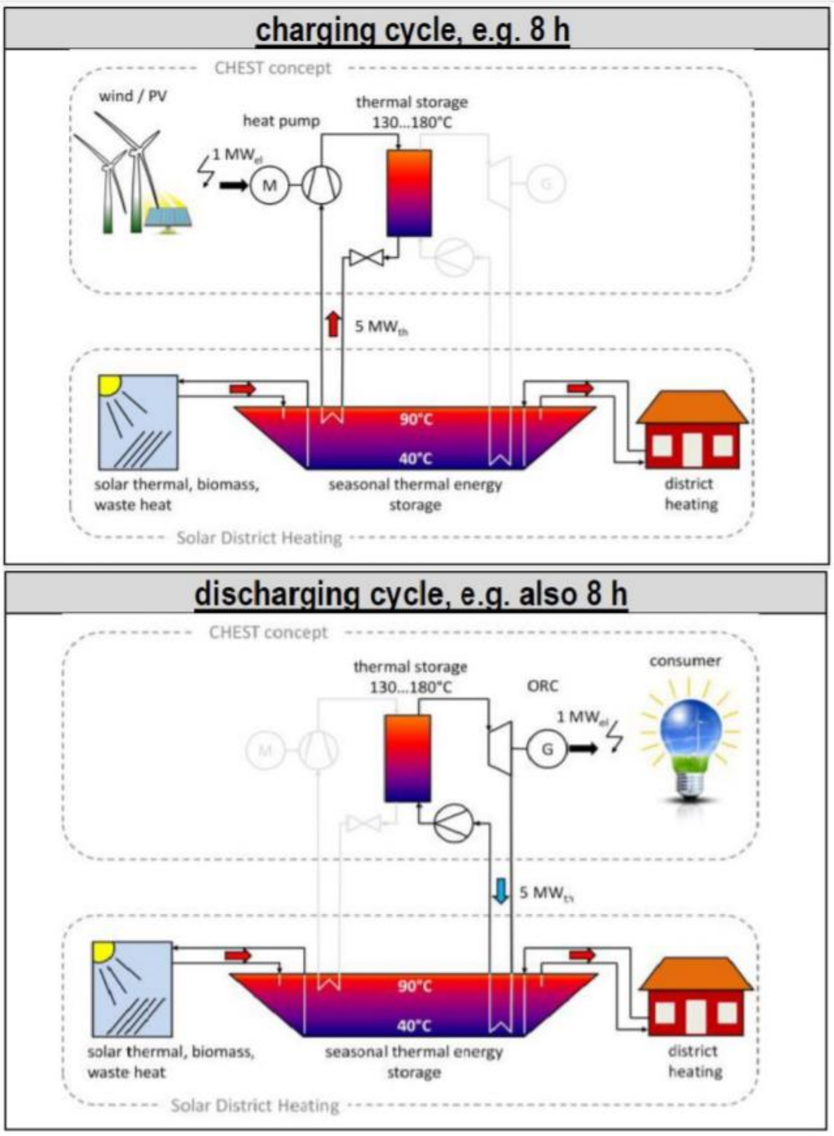


***Fig. 3.*** *The concept for a Carnot battery. Source: DLR.*

## 1.7 As the heart in integrated district heating systems

Future decarbonized heating systems will be based on many sources (renewable heat from solar, power to heat, excess heat…) and has to be flexible to provide services to the electricity system as well as heating and cooling services. Long-term storages can integrate all these services and resources and thus **long-term thermal storage is a key technology in future flexible, decarbonized heating and cooling systems.**

## 2. Types of storages

There are four main types of long-term thermal storages for temperatures below 95° C. The types are illustrated in Fig. 4.

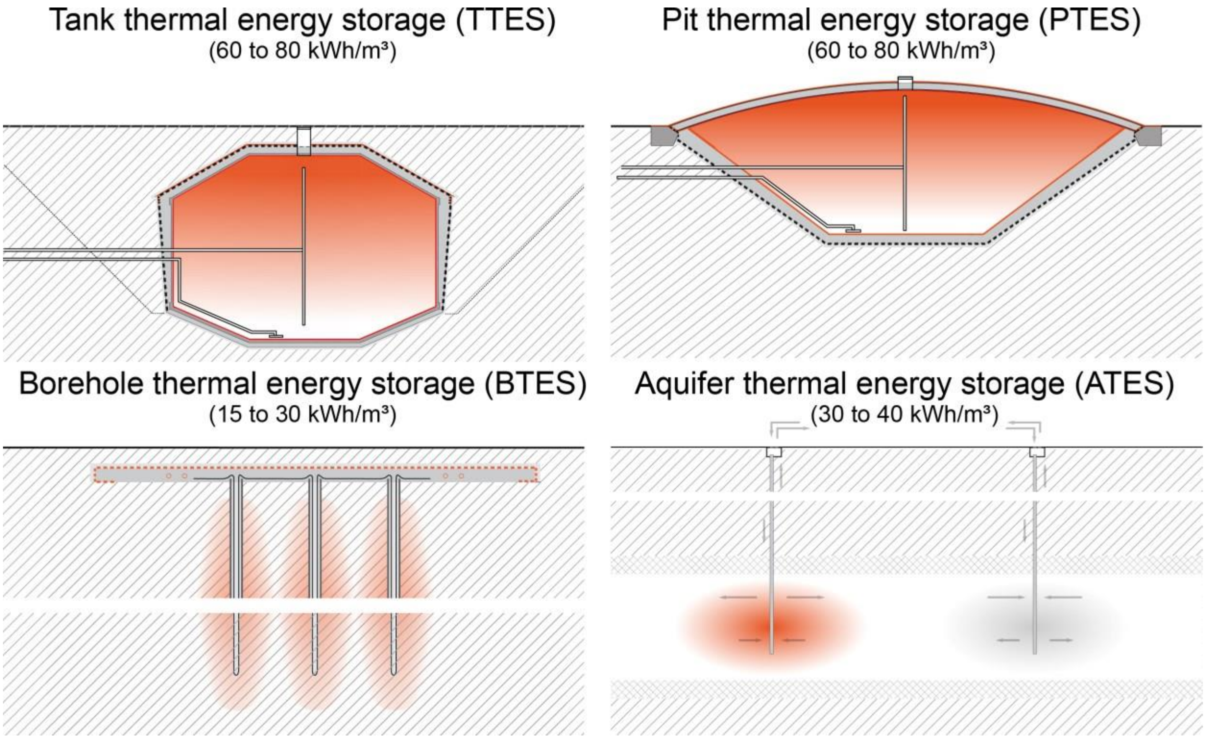


***Fig. 4.*** *Types of long-term storages. Source: Solites.*

The four types of storages are more detailed explained in [PlanEnergi 2013] and in [Solites 2018].
This "Best Practice" report include experiences with BTES and PTES in Denmark.

## 3. Why BTES and PTES

The most suitable long-term thermal storage concept has always to be found by a technical and economical assessment of the boundary conditions and the integration in the energy system. Danish research and development have been focused on cost reduction and storing at temperatures near the district heating flow temperature of 75-80 °C and up to 95° C.
In general tank storages (TTES) are too expensive for large scale thermal storages (>50.000 $m^3$ water equivalent) and the average temperature of aquifer storages (ATES) are by law reduced to 20° C. Thus, BTES and PTES are preferable for district heating. Fig. 5 shows the investment cost per $m^3$ water equivalent for different storages types implemented in Denmark, Germany and Canada. The aquifer in Rostock is deep (in a water reservoir below drinking water) and can therefore be heated up to >60° C, but beside that example, the Danish BTES and PTES storages are among the cheapest solutions.

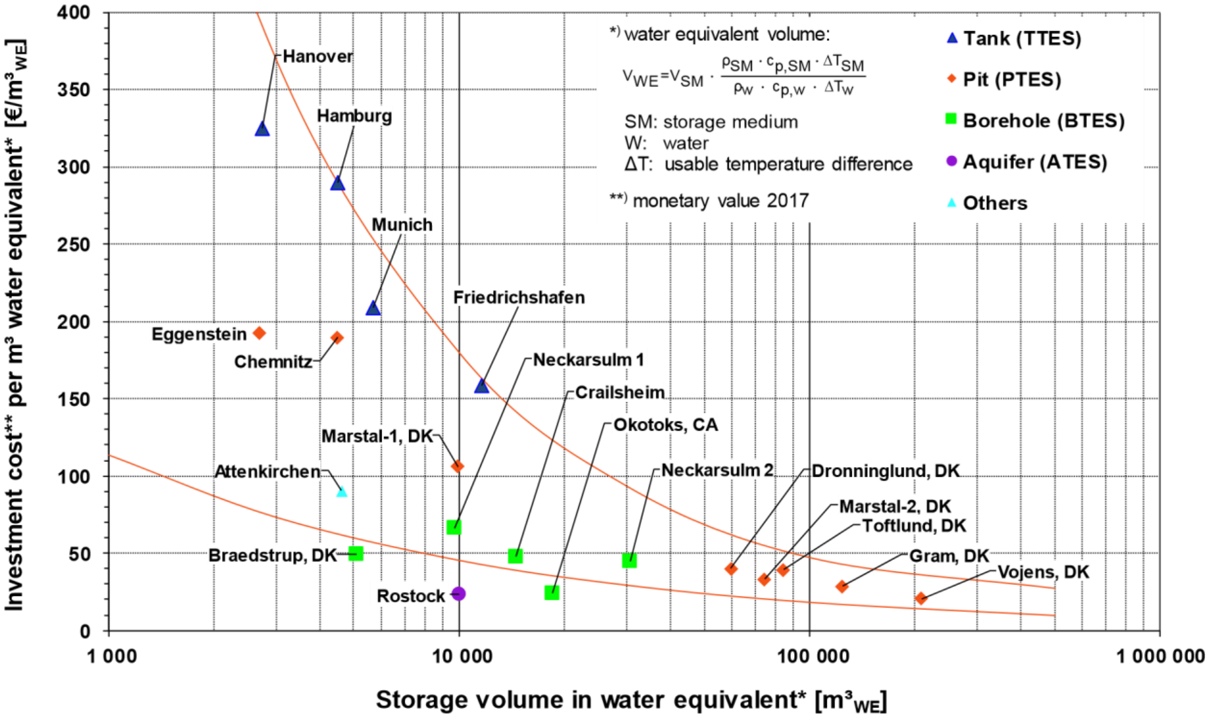


***Fig. 5.*** *Specific investment cost for large-scale thermal energy storages (including all necessary cost for building the storage device, without design, without connecting pipes and equipment in the heating plant, without VAT). Source: Solites.*

# 4. Best Practice from BTES in Brædstrup

The BTES in Brædstrup was implemented in 2011-2012. The design was inspired by the borehole storage in Crailsheim, Germany, but with changed patterns for boreholes, changed connections between the boreholes and changed insulation in the lid.

In the following, best practice from Brædstrup is given for design, implementation and operation.

## 4.1 Design

When designing a BTES you have to be aware of

- temperature levels and charging and discharging capacity
- ground water and geological conditions
- thermal response test
- distance between boreholes, drilling patterns and depth of drillings
- grouting
- lid construction
- design tools
- monitoring equipment

### *4.1.1 Temperature levels*

It is possible to heat up a borehole storage to 90° C, but because there is no insulation on side and bottom and the storage has to be deep (30-50 m) there is a risk of heating up ground water to >20° C. And so high temperatures will only be possible with long charging periods or shorter distance between the boreholes than possible when drilling in the Danish underground.

The result is, that temperatures maybe goes up to 60 °C when the boreholes are charged during the summer period and a heat pump or very low flow and return temperatures are needed to secure usable flow temperatures for district heating and storage capacity.

### *4.1.2 Ground water and geological conditions*

Preferable conditions are drillable ground, high heat capacity, high thermal conductivity, low hydraulic conductivity ($<10^{-10}$ m/s) and natural ground water flow <1 m/a.
GEUS has mapped the Danish underground and areas fitted for BTES (areas with low ground water level, areas with tight clay in the first 100 m, areas with tight limestone and areas with tight rock).
The maps can be found under www.data.geus.dk/?mapname=varmelagring and are connected with the Jupiter database of drillings and classification of drinking water areas.
Site investigations where drillings are carried out to further decide the geological conditions and ground water flow and velocity has to be added to the screening results from GEUS database because the Danish underground conditions can be changed within short distances.

### *4.1.3 Thermal Response Test*

To define thermal conductivity and thermal resistance of the boreholes a Thermal Response Test has to be carried out. This is done by drilling a borehole, fill in water, measure the temperature and then heat up the water with a steady power load and monitor the heat transfer into the ground surrounding the borehole.
The results from the Thermal Response Test are necessary for the design calculations.

### *4.1.4 Distance between boreholes, drilling patterns and depth of drillings*

A drilling can be deflected from the vertical line by for example stones. Therefore, the drilling company in Brædstrup wanted a minimum borehole distance of 3 m. The optimal cross section area for a borehole was in Brædstrup calculated to 7.76 m² and to reach that, a honeycomb pattern was the most efficient (Sørensen et. al. 2013).

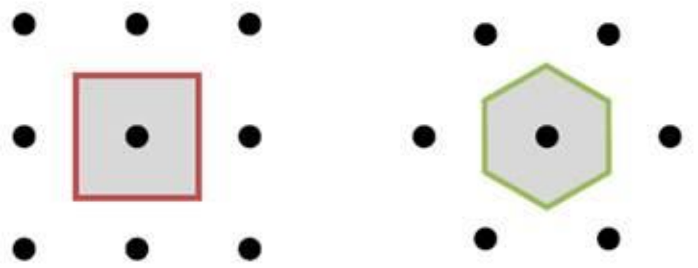

***Fig. 6.*** *Top view of the borehole section areas of 7.76 m² for a square pattern and a "honeycomb" pattern. Source: PlanEnergi*

The boreholes depth is depending on an economical optimization, but under Danish conditions they shall normally be as deep as possible. This can as in Brædstrup be a level 5 m above the ground water level or in other cases determined by drilling costs or geological conditions. Each borehole is equipped with a double U-pipe, the number of boreholes in series is limited by the pressure drop in the pipes. In Brædstrup we accepted a pressure drop of 2.0 bar and could thus connect 6 boreholes.

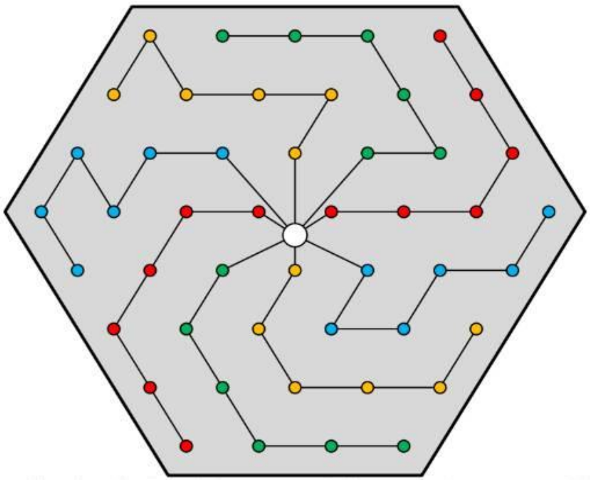

*Fig. 7. Pipe layout for the boreholes in Brædstrup. Only connection to one of the U-pipes in each borehole are shown. Source: PlanEnergi*

Pipes are PEX-pipes with build in oxygen barrier.

#### 4.1.5 Grouting

When mounting the pipes in the borehole the pipes are surrounded with grouting. See Fig. 8.

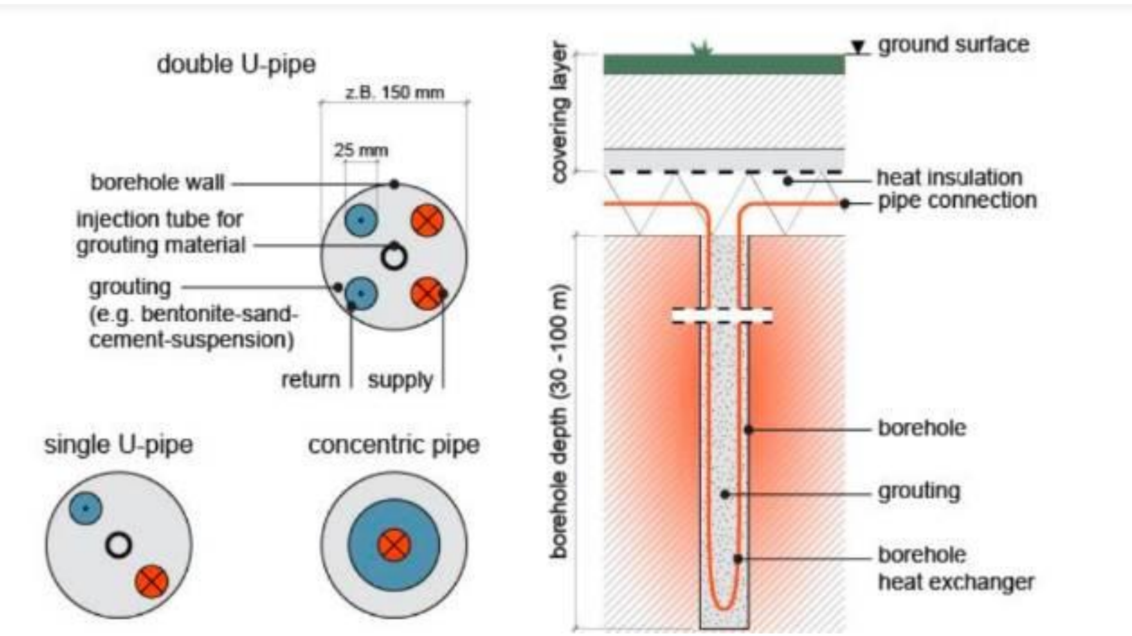


***Fig. 8.** Common types and vertical section of borehole heat exchangers. Source: Solites*

Commercial grouting materials are available. Test of materials in Brædstrup showed that HGD Thermo HS had the best thermal conductivity.

#### 4.1.6 Lid construction

The lid has three functions 1) insulation, 2) carrying capacity and 3) draining of rain water. According insulation we only found two materials, that could meet the demands:
Foam glass gravel. Price 80 €/m³ and lambda value 0.08 W/mK and mussels shells. Price 10 €/m³ and lambda value 0.112 W/(m·K) (crushed to 60% volume).
Tests showed that the mussels shells layer should be app. 50 cm and a semi permeable membrane should divide the layer in two to avoid convection. The lid design can be seen in Fig. 9.

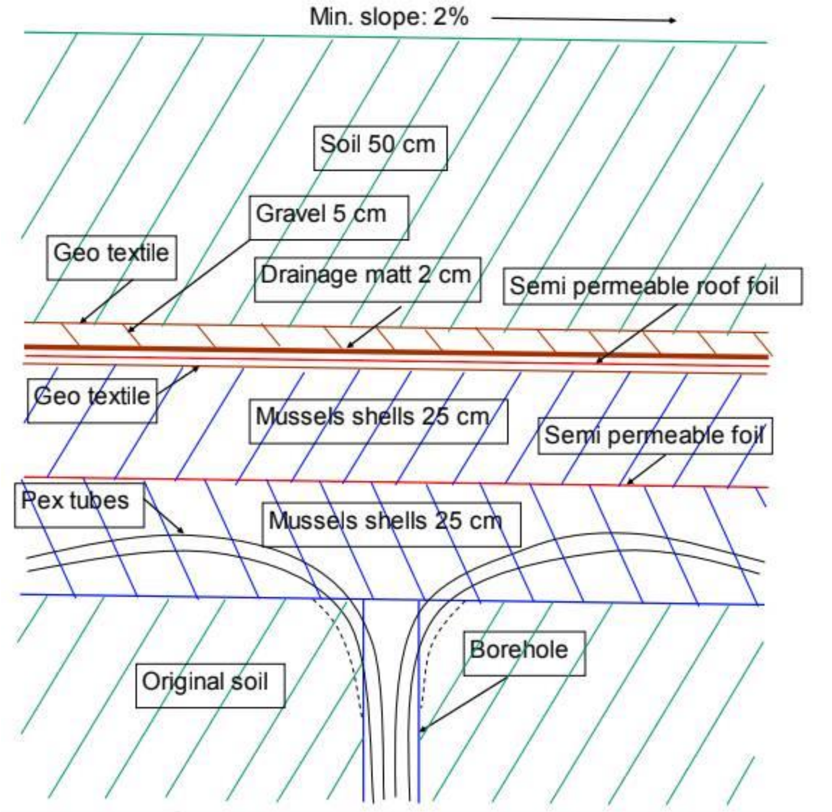


***Fig 9.*** *Design of lid. Source: PlanEnergi*

In the lower part of the figure the top of a borehole is shown. The top of the hole is modified to allow the PEX tubes to leave the hole without sharp curves. After the tubes have been connected and tested for leaks the first part of the insulation is installed. The shells are installed by a loader. The loader places the shells in front of the wheels in order to protect the tubes. When the first part of the insulation is sufficiently compressed the separating layer is installed. It consists of an ordinary foil used in the building industry under tiled roofs to stop the wind without stopping humidity to leave the house.

On top of this a new layer of shells is placed and compressed. This in turn is covered by a non-woven geotextile which has the function of protecting the semi permeable roof foil type DOW Roofmate MK. This foil is suited to stop rainwater from entering the insulation but to allow humidity to pass from the relatively warm insulation into the soil above. The roof foil is protected from above by a drainage matt consisting of two layers of geotextile with a woven grid of polycarbonate in between.

To further facilitate the drainage of rainwater a 5 cm layer of gravel is placed on top of the matt. To maintain the drainage capacity of the gravel a further geotextile is placed on top of the gravel. 50 cm of soil finalize the cover.

#### *4.1.7 Design tools*

PlanEnergi used TRNSYS with the DST-model, type 557a for design calculations.

The monitoring program showed nice correlation between monitored and calculated results (Sørensen and Schmidt 2018) for the pilot storage.

#### *4.1.8 Monitoring equipment*

Monitoring in Brædstrup was done very detailed to control that the storage was equally heated up, to be able to estimate the storage content and to be able to prove, that the ground water temperature did not exceed 20 °C.

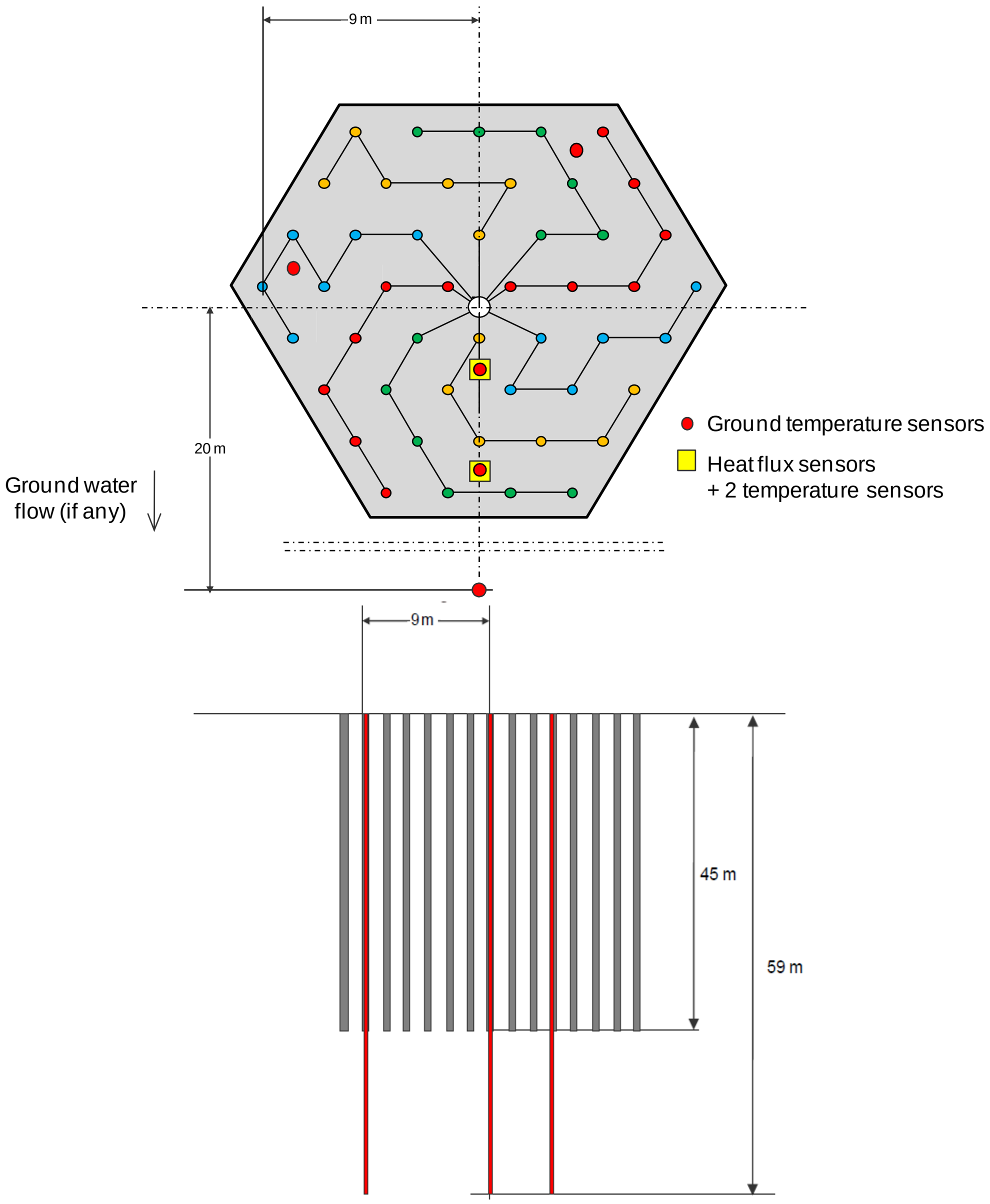


***Fig. 10.*** *Monitoring sensors in and around the BTES volume. Source: PlanEnergi*

Fig. 10 shows the sensor positions in- and outside the storage volume. Four temperature sensor strings inside the storage volume were established first and were also be used to estimate the direction of the ground water flow too. One temperature sensor string outside the storage volume wasthen be placed in the direction of the identified ground water flow, if any.
The vertical distribution of the temperature sensors in and around the storage volume (Fig. 10) should take into account areas where increased temperature gradients are expected. These areas are (numbers in meters below ground surface):

- The surface 0 m (= bottom of insulation layer)
- The bottom area of the storage volume 45 m (= borehole depth)
- The natural ground water level. 52 m

The vertical distribution of the temperature sensors according to this is:
+0.5, 0, -1, -2, -3, -4, -5, -10, -15, -20, -25, -30, -35, -40, -45, -49, -50, -51, -52, -53, -54, -59 m

With: +: meters above insulation layer bottom
-: meters below insulation layer bottom
"0": level of insulation layer bottom

(Sørensen et. al 2013)

## 4.2 Implementation

In the implementation phase you have to be aware of

- mud and water from drilling
- possible drilling problems
- pipe connections

### *4.2.1 Mud and water from drilling*

The drilling was carried out as a wash drilling down to 47 m since the length of the probes was 45 m and the weight in the end approx. 1 m. Drilling diameter was 15 cm. Since it was a wash drilling water and mud is all the time coming from the borehole. This was pumped into a container.

***Fig. 11.*** *Drilling of boreholes. Source: PlanEnergi*

### *4.2.2 Possible drilling problems*

In the south-east area there was a stone layer where the drilling material broke. It took long time to replace the drilling material, so when implementing a full scale storage, extra drilling material must be available.

### *4.2.3 Pipe connections*

The PEX-pipes were connected with press fittings. The pipes were connected by each bore-hole. It is very important to have a precise numbering system of the pipes to connect them correct.

***Fig. 12.*** *Connection pipes and well. Source: PlanEnergi*

### 4.3 Operation

Since the BTES in Brædstrup was a pilot scale project, the operation experiences cannot fully be translated to full scale projects. Although no remarkable technical problems or stops because of malfunction were observed, two problems were recognized during the operation:

- charge and discharge capacity
- when to operate the heat pump

#### *4.3.1 Charge and discharge capacity*

During operation, the limited charge and discharge capacity of the Brædstrup storage was observed. 10.600 m² buffer of solar collectors is connected to the boreholes and a 5.500 m³ buffer tank. The maximum power of the solar collectors is more than 7 MW, but the borehole storage can be charged with 600 kW in the beginning of the season and down to 300 kW in the end of the season.
Discharging has similar values. So even if you can charge and discharge 24 hours per day the borehole storage is very slow compared to water storages.

#### *4.3.2 When to operate the heat pump*

The idea was to operate the heat pump during periods with low electricity prices. But to optimize the heat pumps operation is difficult since:

- you don't in beforehand know the hourly electricity prices during a whole winter
- the longer you wait the more heat will be lost in the storage

So, the rule of thumb is to empty the storage if you can do that with a heat price lower than the production price from the CHP engine.

## 5. Best practice from PTES in Marstal, Dronninglund and Gram

The PTES in Marstal was implemented 2011-2012, Dronninglund 2013 and Gram 2015. The design in Marstal and Dronninglund is similar. In Gram the lid has a different design and the topliner was implemented in a different way. In the following, best practice is given for design, implementation and operation.

### 5.1 Design

When designing a PTES, you have to be aware of

- temperature levels
- water quality
- ground water and environmental issues
- liner quality
- air under lid
- rain water
- lid insulation and ventilation
- design tools
- monitoring equipment

### *5.1.1 Temperature levels*

The higher the temperature level in the PTES the higher the storage capacity. Therefore, it is preferable to go up to 90 °C as maximum temperature. It has been demonstrated in Denmark that a PTES - charged in the summer period (from e.g. a solar thermal plant or waste incineration) and discharged in the winter period - can be designed to withstand the temperatures in the storage. If a heat pump is connected to the storage, it is possible to cool down the storage to app. 10 °C during winter and thus extend the storage capacity and lifetime of the polymer liner used for tightening.
If a PTES is used for optimization of CHP systems or for other purposes, where the temperature level is 90 °C most of the year it is at present difficult to find a suitable liner solution (see chapter 5.1.4).

### *5.1.2 Water quality*

The quality of water is important to prevent corrosion of metallic components and degradation of the plastic liner, but the water at the same time has to be harmless to nature.
In the first Danish storages was used softened drinking water, but this has caused corrosion in pipes of black steel. The storage in Dronninglund is filled with water with pH 9.8 and no salts, but even then, there is risk for corrosion in pipes of black steel because the water is saturated with oxygen. If the oxygen level can be reduced or if pipes are made of stainless steel the solution from Dronninglund is acceptable, but if a non-corrosive in- and outlet system can be developed it will be preferable according corrosion and harm to nature since softened drinking water can be used.
Degradation of the plastic liner is caused by temperature and oxygen in the water, so the oxygen level must be minimized if temperatures in the PTES are high (see also chapter 5.1.4)

### *5.1.3 Ground water and environmental issues*

PTES can be placed at locations with stable ground conditions and preferable no ground water until 5-15 m. The Danish company GEUS has mapped the subsurface underground. The maps show e.g. ground water levels, ground conditions and drinking water protection and can be used for screening of possible sites for PTES. The maps can be found under www.data.geus.dk/geusmap/?mapname=varmelagring.
When potential sites are located, a more detailed investigation of environmental issues for a specific site must be carried out.

### *5.1.4 Liner quality*

In the Danish PTES a polymer liner of High Density Polyethylen (HDPE) has been used because it is cheap and can be welded. The liner has been tested under high temperatures. The tests show that the degradation starts from the water side and is depending on temperature level and oxygen content of the water. Test results show liner lifetime of 5-25 years at 90 °C depending on oxygen content.
The lifetime can be extended by using a double liner construction if liner no. 2 is not in contact with water.
Another possibility is to use a PolyPropylen (PP) liner because it’s degradation in contact with water is less than for the HDPE-liner. The price is similar, but the diffusion rate for hot humid air is higher for PP.

### 5.1.5 Air under lid

When water is heated up air can be released. This can cause air pockets under the lid. To get rid of the air pockets, the lid must have a slope leading the air to the edge or to a ventilation hole. This is in Marstal, Dronninglund and Gram done by mounting weight pipes on the liner. In Fig. 13 is shown the solution in Marstal and Dronnninglund.

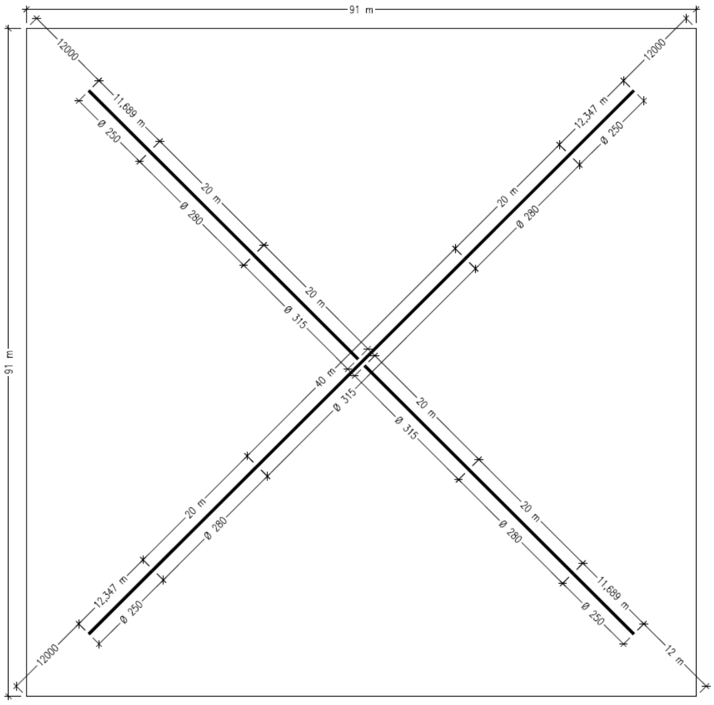


***Fig. 13.*** *Weight pipes on the floating liner leading air to the edge. Source: PlanEnergi*

### 5.1.6 Rain water

Rain water can be led to the edge of the lid or to pumping wells. In Marstal and Dronninglund weight pipes secure a slope of the lid leading rain water to a pumping area in the middle of the lid. This is illustrated in Fig. 14.

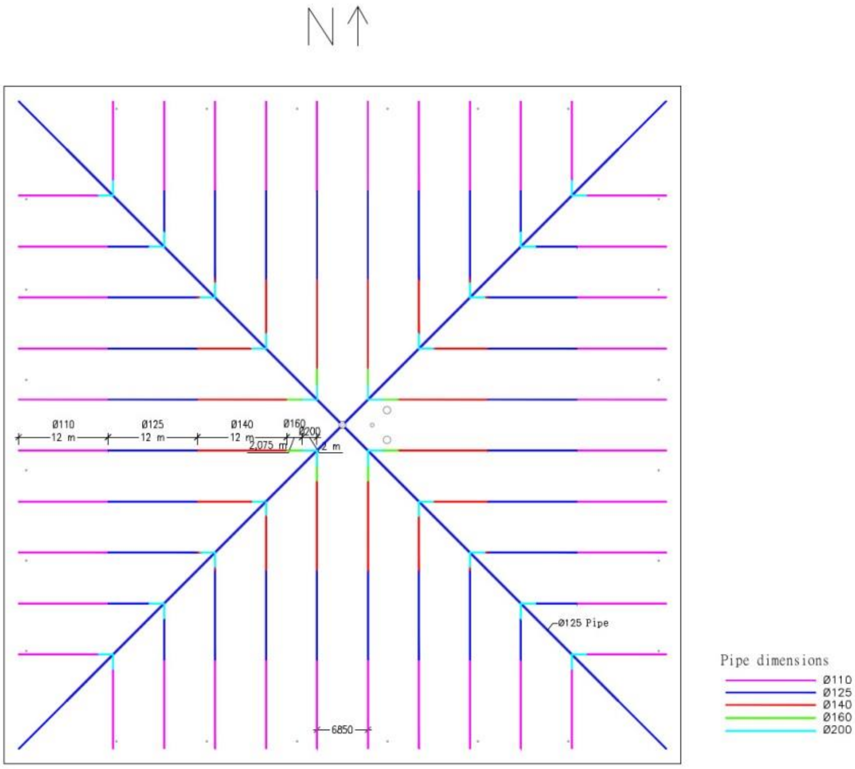


***Fig. 14.*** *Weigh pipes on top of the lid leading rain water to a pumping area in the middle of the lid. Source: PlanEnergi*

### 5.1.7 Lid insulation and ventilation

Since plastic liners are not tight at high temperatures hot humid air will pass from the water through the plastic liner into the insulation. To avoid condensation, the insulation therefore has to be ventilated. This is in Dronninglund done by installing hypernets directly connected with a pipe to the vacuum vent as can be seen in Fig. 15.
Diffusion rate at 90 °C is 5-6 g/m²/day or 50-60 l/day for 10.000 m² liner.

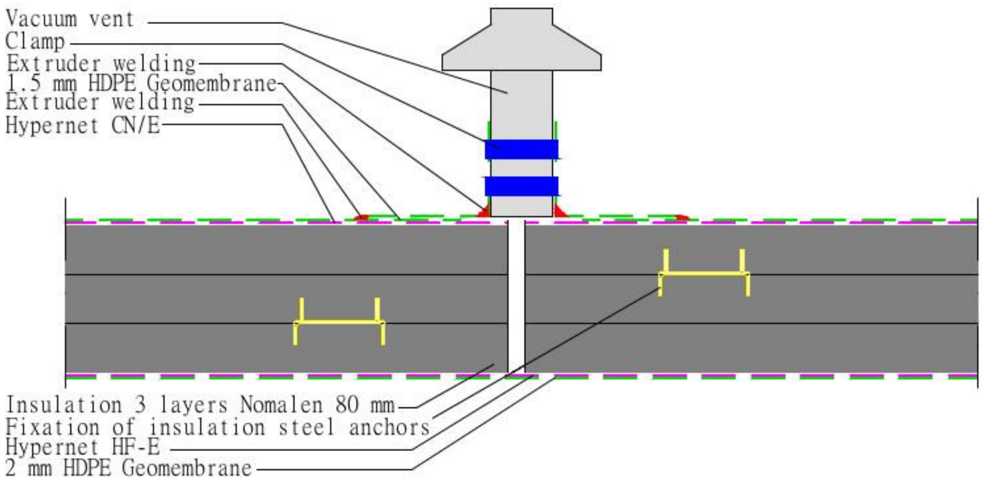


***Fig. 15.*** *Lid and ventilation solution in Dronninglund. Source: PlanEnergi*

Since humid air is passing through the liner into the insulation, the insulation material has to be resistant to these conditions.
Materials could be foam glass gravel, Perlite or expanded clay. But these materials can be difficult to control during implementation and operation because for instance air pockets under the lid might move the materials. Mussel shells could be another opportunity but since they also can be difficult to control, and they are heavier than water it can be risky to use them. The choice in Marstal and Dronninglund has therefore been PE/PEX mats called Nomalen as shown in Fig. 15.

### 5.1.8 Design tools

Design calculations for the Danish PTES has been carried out in TRNSYS in a cylinder model and results compared to monitoring results can be seen in Fig. 16.

Monitoring and Simulation results, cylinder model
energy flow year 2015

| | monitoring | simulation |
|---|---|---|
| Storage efficiency: | 90 % | 89 % |
| No. of storage cycles: | 2.18 | 2.01 |

T-max= 90 °C; T-min= 12 °C; Heat capacity: 5 500 MWh

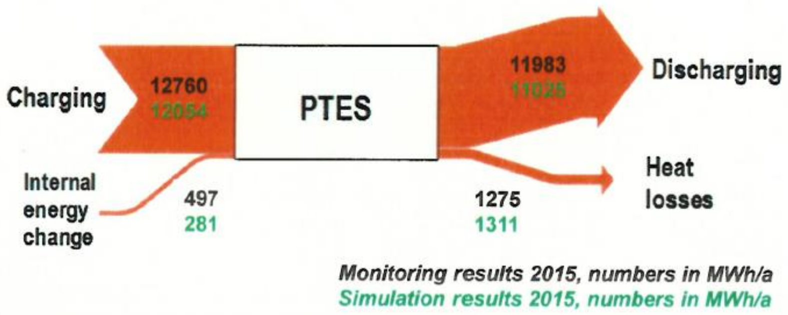


***Fig. 16.*** *Comparison between calculated and monitored results from Dronninglund. Source: Solites*

In 2018 a 3-dimensional truncated pyramid model was developed for PlanEnergi and Solites. The same calculation as in Fig. 16. results in 90% in storage efficiency and 2.16 storage cycles.

### *5.1.9 Monitoring equipment*
To control the energy system the temperatures and energy content of the storage has to be known. Because of stratification temperatures must be monitored for every 0.5 m. Temperature influence on the ground water has to be monitored to avoid heating up ground water beyond 20° C. Finally, the water surface level must be known since it indicates leakages in the storage.

## 5.2 Implementation
In the implementation phase you have to be aware of
- secondary ground water levels
- compression of excavated soil
- stones on the banks
- rain water under excavation
- test of liner welds
- level of banks
- water in the lid
- protection of water

### *5.2.1 Secondary ground water levels*
Be careful with geotechnical investigations, soil and ground water conditions before tendering and define how many days you want dewatering of the excavation.
If secondary ground water levels are localized it is important to get a precise price from the excavating entrepreneur for drainage measures. Ask for total costs/day for dewatering and price for extra days. Remember that authority's permission is needed to discharge water from dewatering.

### *5.2.2 Excavation*
Be careful when starting excavation. A land surveyor must give precise positions and instructions to the entrepreneur. Control during excavation by an independent land surveyor is needed. Especially control with the upper edge of the storage is important since the water level is 100% equal. A maximum deviation of 2 cm is tolerated so as not to lose storage capacity.

### *5.2.3 Compression of excavated soil*
When soil is rebuilt in the banks, it has to be compressed to a certain standard defined in the tender documents. This standard has to be proved by taking out samples for laboratory testing.

### *5.2.4 Stones on the banks*
Before the liner contractor begins the liner installation, stones have to be removed from the banks and a geotextile with high penetration resistance must be placed to protect the polymer liner.
The liner entrepreneur must accept the surface of the excavation before starting the liner work. During excavation ready slopes can be covered with plastic to prevent damage from rain.

### *5.2.5 Rain water under excavation*
Rain will drain from the banks and collect at the bottom areas. This can cause problems, especially if there is clay. A drain in the bottom with drainage pumps is necessary during construction until the liner work is finalized.

***Fig. 17.*** *Marstal a few days after a cloud burst. Source: PlanEnergi*

### *5.2.6 Test of liner welds*

The liner welds must be properly pressure tested. But not all weldings are double. Electrical tracer detection of the total area of liner and welds is recommended after the liner work has been completed.

### *5.2.7 Water in the lid*

When the liner for the lid construction is floated on the water, waves can easily cause water on the liner. The edge of the liner must be raised to prevent incoming water. Incoming water shall be returned to the storage. Not discharged.
Rain during construction of the lid cannot be avoided but must be removed before the roof foil is implemented and dried away after the construction period.

***Fig. 18.*** *Implementation of the lid, Marstal. The HDPE-liner is welded onshore and drawn on the water. Then hypernet, 3 layers of insulation and topliner is implemented. Source: PlanEnergi*

### 5.2.8 Protection of water

When filling in water, the water quality has to be controlled continuously. It can be necessary to remove oxygen to reduce corrosion risk and air production when the water is heated up. The water can preferably be protected by a thin plastic liner floating on the water when water is filled in to prevent organic material and dirt from coming into the water.
If water has to be filled in during winter ice can break the liner unless water is filled in continuously. Ice must be removed when to prevent damage of in- and outlet.

## 5.3 Operation

During operation of the PTES you have to be aware of

- protection of heat exchangers
- water quality
- corrosion
- water added and level of water
- spoiled stratification
- daily control

### 5.3.1 Protection of heat exchangers

When starting operation there will always be some dirt in the storage water. Therefore heat exchangers must be protected by installing a filter for the total flow of water coming to the heat exchanger. In Dronninglund was used a 10 µ filter and the filter had to be cleaned after few hours in the beginning. In operation the filter is changed to 50 µ and cleaned once a year. Marstal had no filter and had to separate and clean the heat exchanger after one year.

### 5.3.2 Water quality and corrosion

Check the water quality at least yearly for pH, oxygen content and salts.
Check the PTES for corrosion by a yearly diver inspection. The diver can also be able to localize leakages and to repair them, but if the water temperature is more than 40 °C the diver is not able to work.

### 5.3.3 Water added and level of water

Water is evaporating through the floating liner and the lid. The amount is 50-60 l/day at 90 °C. This has to be replaced by water of same quality as the storage water. The lid is moving up and down according to the water temperatures. It is important to calculate where the water surface level is expected to be and control continuously the water level to be sure that no leakages has occurred.

### 5.3.4 Spoiled stratification

It is important to have temperature stratification in the storage water because the larger temperature difference the larger capacity in the storage. If the storage is heated up by solar collectors and the bottom temperature is too high there is risk of boiling (>100° C) when heated water comes from the solar collectors. Therefore, it can be necessary to run the solar system at night to cool the bottom of the storage water.

### 5.3.5 Daily control

Daily control of the PTES is recommended: Is the insulation still in place, are water ponds on the lid, what is the water level, is the topliner intact.

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