HOW HEAT AND COOLING STORAGES BENEFITS FROM ECONOMY OF SCALE

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1 SUMMARY

Almost all energy sources, which can replace fossil fuels, are of low quality or not always available when needed. We have excess heat in summer and too much free cooling during the winter. Likewise, we have surplus of electricity in some hours, days and weeks and deficits in others. In the future there will be increasing demand for energy storage on a system basis - in particular thermal storages for storing heat and cooling directly, stimulating district heating (DH) and district cooling (DC) while shaving uncontrolled peaks in the power systems. Thus, smart integration of storage in the thermal systems can replace and eliminate the need for expensive electric batteries.

The bigger, the better is often used as a guiding term describing different topics, where size or scale matters. In the case with thermal storage technology, this is absolutely true.

The two main drivers for investing in thermal storages are:

1. The marginal capacity investment goes down, when size goes up.
2. The energy losses in pct. of the volume from a thermal storage decreases, as size is increased. All energy losses from the thermal storage can be attributed to the construction surfaces. When lengths increase, surface increase by second order, whereas the storage volume increase by third order.

Investments in large cost-effective thermal storages will stimulate development of DH and secure that all available surplus heat is collected. That will in turn stimulate development of DC showing the way for an efficient and cost-effective transformation to a low carbon society.

2 INTRODUCTION

The integrated energy system, including the 4 energy carriers: electricity, DH, DC and gas, is vital for cost-effective and efficient integration of renewable energy sources. The thermal storage technology is one of the key-technologies in this transformation, ensuring maximal utilization of fluctuating renewables such as solar, wind and surplus heat, e.g. from cooling and CHP plants.

Almost half of all end-use energy demand in our modern society is used to deliver thermal comfort, heating in winter and cooling in summer. Moreover, many industrial processes need cooling, or they deliver surplus heat constantly during the year. A good and recent example is the development of projects where excess low temperature heat from some of the world largest data centers is being harnessed, upgraded and utilized in large DH systems.

3 WHERE TO APPLY LARGE THERMAL STORAGES

In most parts of the world there is surplus of cheap heat but expensive cooling in summer and the opposite in winter. Therefore, it is an old idea to establish seasonal storage for balancing production and demand of heat and cooling. Fortunately, this idea materialized thanks to economy of scale. Whereas it would not be feasible for one individual building alone to store heat or cold on a seasonal basis due to energy losses, it is possible and cost-effective in large scale, if many buildings are interconnected, e.g. at campus or city level. In mild climates, e.g.

Denmark, DH (including thermal storages) is the most cost effective low carbon solution in almost all towns, but DC is only cost effective in clusters of commercial buildings. In warmer climate both DH and DC are the most competitive solution in most cities and at all campuses. In warm climate, DH will only be competitive in very densely residential areas, whereas DC will be competitive in most places. Thus, where will be a market for large thermal storages for DH and/or DC in most urban areas and all campuses.

We will compare costs and temperature losses for small and large storage tanks and not least for our newly developed heat storage pit.

4 THE HEAT STORAGE BENEFITS FROM ECONOMY OF SCALE

In the following we look at the concrete benefits of increasing capacity and geometric scales of a large thermal storage. The figure below shows the economy of scale comparatively for a small one family house (steel tank) going up to larger storages for DH.

Cost of heat storages, Euro per. MWh storage capacity

• One family house, 0.16 m^3	300,000
• Large building, 4 m^3	40,000
• DH tank, 160° C	7,000
• DH tank, < 95° C	4,000
• Storage pit total, 150,000 m^3	800
• The pit alone, 100,000-200,000 m^3	500
• Marginal extension of the pit	200

• Sources: Henrik Lund and Ramboll

Fig. 1: Economy of scale for heat storages

In the figure below, we compare costs of storages for the DH, taking into account temperature and size.

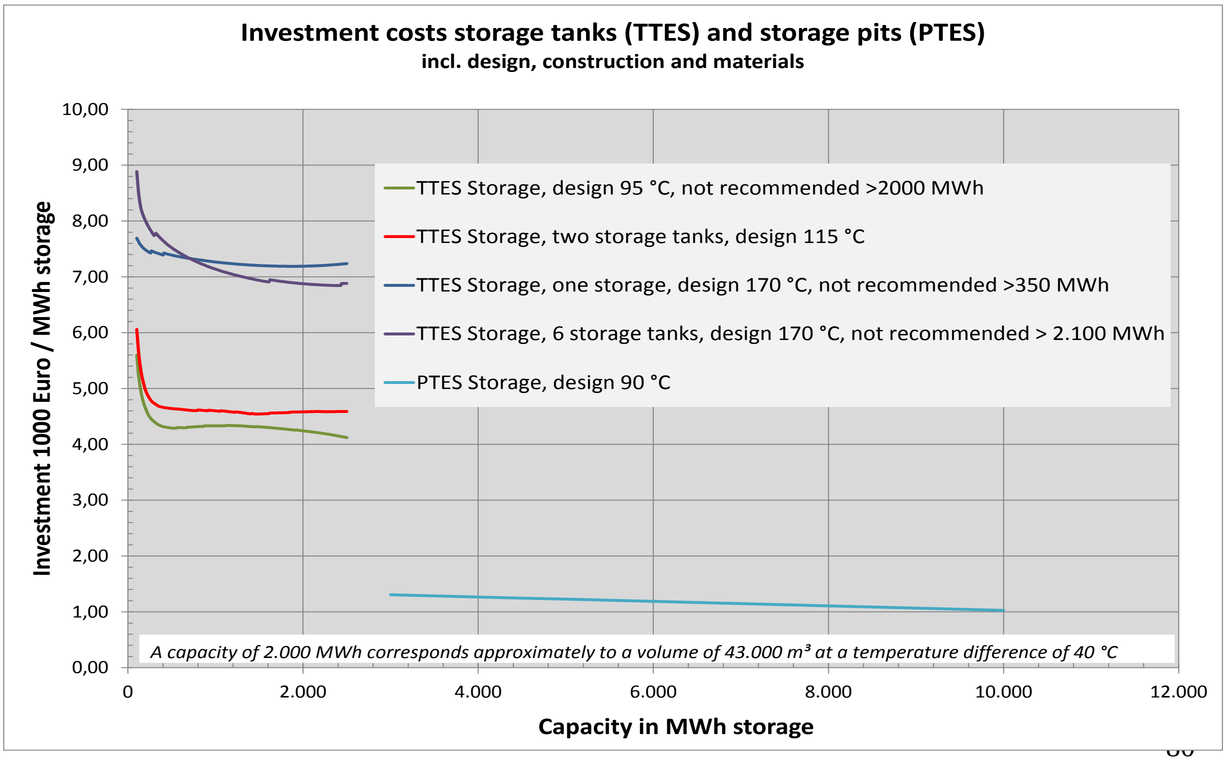

Fig. 2: Unit costs for large thermal storages

The cost break-down is also very much depending on the total size of the storage. In the charts below example is given on a size basis when establishing pit storage of various sizes.

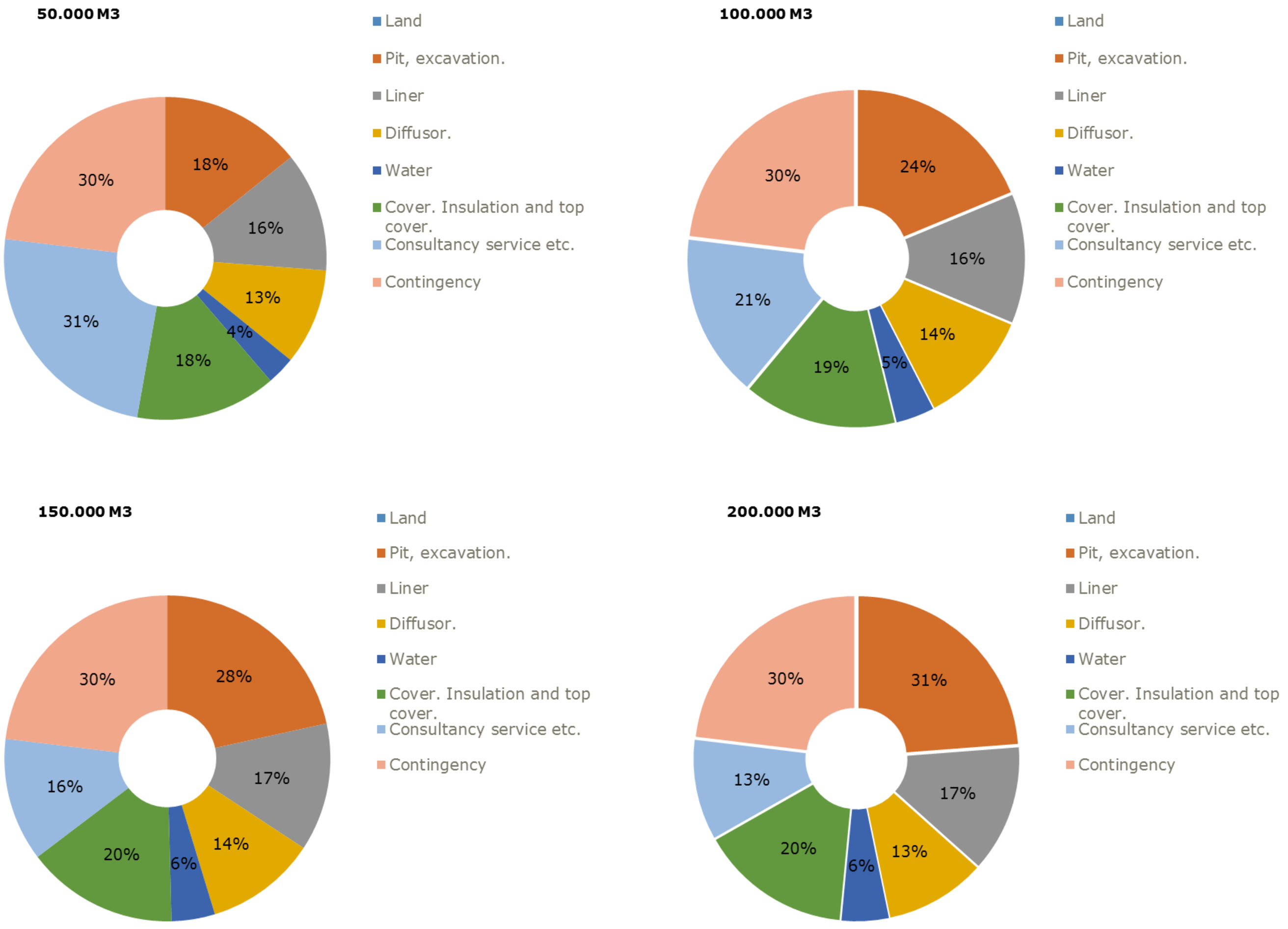

Fig. 3: Cost break down of the pit storage on a size basis

In order to compare the costs of operation, the heat losses and the number of annual load cycles have to be taken into account. The annual heat loss in pct. of the stored volume is several hundred pct. for small tanks, whereas the annual load cycles typically can be 365. For the large heat storage pits, the annual heat loss, e.g. at the newest plant in Toftlund, Denmark, is estimated at approximately 15% of the storage volume in stable operation. In case the storage only stores solar heat from summer to winter to cover up to 60% of the heat production, the storage will almost have two load cycles per year, and thus a relatively stand-by heat loss of less than 10%. In case the storage can be used to store other fluctuating energy sources, e.g. from CHP plants and electric boilers in the winter period, the relatively heat loss will be even lower due to the higher degree of utilization. In the first years after construction the losses from a pit storage has shown larger as the soil around the storage has to be heated to be part of the storage capacity. Also, unexpected water in the insulation material, e.g. from leaks during the construction phase reduces the insulation capability compared to the theoretic design loss calculations until the insulation material is completely dry.

5 THE HEAT STORAGE PIT

The heat storage pit is a simple innovative combination of the storage tank technology and the technology of modern protected landfills sealed by a water tight plastic liner. The only new element is the floating insulating cover. We have taken part in development of this technology since the first test projects at Marstal District Heating in Denmark and can present the lessons learned and the newest design concepts which are tested in full scale.

- Test plants with subsidy
  - 10,000 m³ Test plant in 2010 in Marstal
  - 70,000 m³ Full-scale test plant 2012 in Marstal
  - 62,000 m³ Full-scale test plant 2014 in Dronninglund

- Commercially, without subsidy, new floating cover
  - 125,000 m³ Gram district heating 2015
  - 200,000 m³ in Vojens district heating 2015
  - **70,000 m³ in Toftlund district heating 2017**
  - 150,000 m³ in Løgumkloster district heating 2017/18

Several more in the pipeline, may be 100 in 2025

Fig. 3: Development of heat storage pits in Denmark

In the picture below, we see a heat storage pit under construction. In case an old sand pit is available, this can be used as a basis for the pit. In case the top layer of sand is filtered there is no need for other materials. In case there is no pit available, the pit can be constructed with an embankment around the pit, thereby achieving soil balance. Only a thin layer of fine sand is necessary to protect the liner.

The diffuser tower is the same construction, as the ones used inside the smaller steel storage tanks and are as such considered fully tested, except that corrosion protection is necessary. One might think that a wide heat storage pit would require several diffuser towers, but surprisingly one tower is enough to ensure stratification of the water.

Fig. 4: Heat storage pit under construction

The floating cover, which replaces a traditional construction with pillars and decks, as we see in the old ancient cisterns, is vital in order to reduce costs. In the first plants, two main principles have been tested. Both rely on a top liner which shall prevent the water in the pit from penetrating into the insulation and a top liner on top of the insulation which shall drain off rain water and water from melting snow.

It has been a challenge to drain water from the almost horizontal surface efficiently and it has also been a challenge to avoid holes in the top liner, implying that special attention must be applied during the liner assembly phase. Execution of laying and welding of liners should be carried out using proven and standardized methods with extensive testing and under strong supervision during the entire phase.

As with regards to the insulation material used in the lid construction, there has so far been used two different types of material: plastic foam and ceramic clay (LECA).

As it is impossible to prevent oxygen in the water it is necessary to separate the water in the pit from the district heating water as well as from the antifreeze in the solar heating system, in case solar is one of the energy sources.

6 THE COLD STORAGE PIT

Storing cooling from winter to summer is not that difficult. For centuries, it was e.g. big business to use ice from our lakes in large cold storage cellars for cooling, but the electrical refrigerator took over. In the old days, buildings were designed to store cooling directly from the cold underground, but modern buildings need active cooling and air conditioning, which in most summer scenarios is supplied by electrical chillers. They are expensive and in some cases, we can observe that the uncontrolled use of electricity leads to brown-outs or worst case a black-out in the electrical grid.
Today we combine the good old traditions with new technologies to save cost and energy. Ground source cooling is an efficient way of storing cooling from winter to summer. This can of course only be applied in regions where hydrological conditions allow it and the temperature is cold enough. Ice storages and chilled water tanks can level the daily fluctuations and save expensive electricity, but not for days and weeks. The storage technologies mentioned in this paper is not temperature specific as such, and can therefore be applied in cooling applications as well as the perhaps more acknowledged purpose in various heating systems. The concept does not change, switching from hot to cold water, only the design parameters change. Large-scale thermal storages are cost effective regardless of temperature levels. The storage pit technology can therefore be used for storing cold water. So far, this idea is only in the conceptual design phase. The biggest problem seems to be that land is expensive in districts with large cooling demands.

An alternative solution is to utilize underground caverns where the underground is solid rock or limestone at the given geographical location. which could be cost effective in case the value of the gravel or rock could compensate for the construction cost. There is e.g. established a chilled water storage in an underground cavern in Finland.

7 CONCLUSION

The concept for the large-scale thermal storage tanks and pits, have proved to be a cost effective and energy efficient way to integrate fluctuating and cheap sources of hot water into our energy supply.

However, the presence of a distribution network is essential in order to benefit from economy scale.

Traditional tanks for district heating, storing daily or weekly fluctuations can have between 50 and 365 load cycles a year and has proven to be the most cost-effective storage technology for volumes between 1,000 and 100,000 m3.

For integrating monthly and seasonal variations, the number of load cycles per year goes down, and the cost per stored energy goes up. Therefore, the heat storage pit can be an interesting solution. If cheap land is available and the main purpose is seasonal storage, e.g. to store solar heat to cover up to 50% of the annual heat demand, heat storage tanks are too expensive and pits the only cost-effective solution at the moment. In case the storage can benefit from daily and weekly fluctuations from e.g. wind, one or two more load cycles can be added and the costs per unit will be reduced further.

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