Smart strategies for the transition in coal intensive regions

Project No: 836819

Fact Sheet: Heat Storages

September 2019

Description

Heat storage technologies can help to detach the production from the demand and to balance (buffer) fluctuations of energy production. Storages increase the flexibility to utilize sources of energy that are not available at the same time as the demand. They can also store cheap energy, e.g. low prized electricity that can be converted to heat. Furthermore, storages help to increase the efficiency of production units. They enable e.g. biomass boilers and CHP plants to operate continuous at higher capacity. (Dominik Rutz, 2019)

Depending on the time when the heat is needed from the storage, a typical classification is made between short term storages and seasonal storages. Short-term storages balance the heat supply and demand of a few hours to some days. They are also called buffer tanks. Seasonal storages are much larger, as they balance the heat supply and demand from one season to another. This is mainly applied for storing solar thermal heat from summer to wintertime.

The following types of storage technologies exist:

- Sensible storage: use the heat capacity of the storage material. The storage material is mainly water due to its high specific heat content per volume, low cost and non-toxic media.
- Latent storages: make use of the storage material's latent heat during a solid/liquid phase change at a constant temperature. They use Phase Change Materials (PCM).
- Thermochemical storages: utilize the heat stored in a reversible chemical reaction.
- Sorption storages: use the heat of ad- or absorption of a pair of materials such as zeolite-water (adsorption) or water-lithium bromide (absorption). (Dominik Rutz, 2019)

In **sensible heat storages**, the temperature of a material is increased by addition of heat. In this way, heat is stored in the material and the storage properties depend on the material´s heat capacity as well as thermal insulation of the system. Mainly water is used as storage material. The technology is well known from e.g. hot water tanks in residences.

The most frequently used technologies of sensible heat storages are (Figure 1):

- Tank thermal energy storage, TTES (mainly daily storage)
- Pit thermal energy storage, PTES (daily to seasonal)
- Borehole thermal energy storage, BTES (daily to seasonal)
- Aquifer thermal energy storage, ATES (daily to seasonal) (Dominik Rutz, 2019)

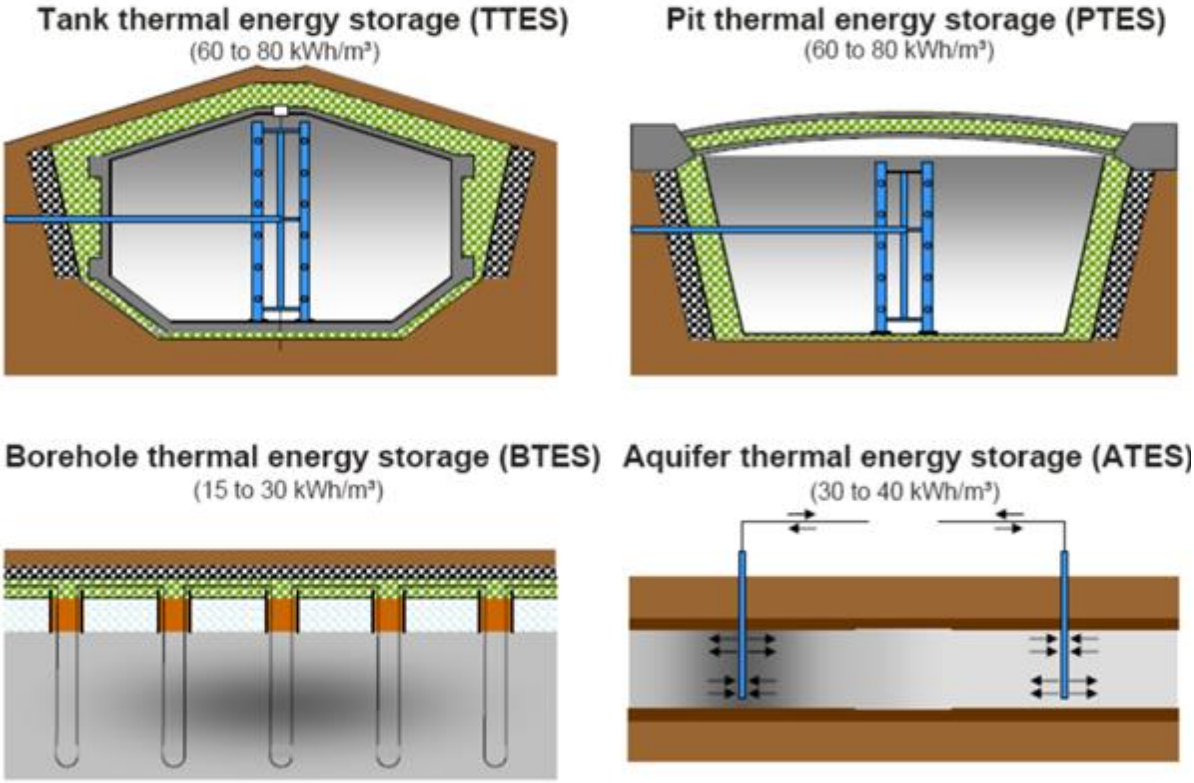

Figure 1: Concepts of thermal energy storages (Source: Steinbeis Forschungsinstitut Solites)

Cool Storage

District cooling systems can be configured with thermal storage to reduce chillers' equipment requirements and lower operating costs by shifting peak load to off-peak times. The cool storage is most commonly sized to shift part of the cooling load, which allows the chillers to be sized closer to the average load than the peak load. Many electric utilities offer lower rates during off peak periods, and thus operating costs for electric-driven chillers can be substantially reduced by shifting some loads to off-peak periods. (Bard Skagestad)

Thermal component activation

Thermal component activation are systems for heating and cooling of rooms or whole buildings. The special feature is that the heating or cooling register be cast in the course of the construction of the building in components. Due to the usually very large register areas such heating and cooling system classified in the category "surface heating".

An important feature of the thermal component activation is that it can not only be used for heating, but also for cooling. The ability to cool already proves to be a valuable, often necessary, contribution to ensuring high thermal comfort throughout the year - even in residential buildings. Against the background of current climate change, the importance of this topic will increase sharply in the near future. The year-round temperature control of residential buildings by means of thermal component activation can thus be classified as an important component of planning approaches with regard to future-proof construction.

The relatively low surface temperatures can be ensured in the case of heating already by unusually low heating medium temperatures. The flow temperatures are also in the harshest outdoor climatic conditions in areas of just over 30 °C. This makes an effective use of renewable energy possible. In addition to the combination of the thermal component activation with thermal solar collectors, the provision of heat via heat pumps, which are predominantly operated by electricity from wind turbines or photovoltaics, is mentioned here. (Friembichler, 2016)

Achievements

Heat storages are getting more and more importance within the energy transition to renewable energy. Some large scale systems and also possibilities for former coal mines are shown in the examples below.

Seasonal storage

Seasonal storages balance the heat supply and demand from one season to another. This is mainly applied for storing solar thermal heat from summer to wintertime. A seasonal storage enables a high solar fraction, but also implies a higher investment. The seasonal storage should be designed for the expected capacity, as it is not suitable for modular expansion like the solar thermal plant.

Besides the use of a seasonal storage in combination with solar thermal heat, it can be combined with a heat pump or facilitate the integration of excess heat, e.g. from industry.

Pit thermal energy storages (PTES) are a relatively cheap storage technology, which has been developed in combination with solar thermal plants. The number of PTES is yet limited and the technology has some development potential. One limitation today is the temperature level, which implies that high temperatures (90°C) shorten the lifetime of the liner. The development of high temperature PTES (90°C) as well as low temperature storage implies that PTES can be used not only in combination with solar thermal, but at the same time in combination with e.g. surplus industrial heat.

Borehole thermal energy storage (BTES) is a relatively new technology which has been applied at a plant in Denmark (Brædstrup). BTES can supplement PTES as seasonal heat storage in areas, where location of a PTES is not possible.

Aquifer thermal energy storages (ATES) can be applied for storage of up to 20°C. This low temperature level limits its applications. In Denmark there are a few applications in combination with district heating. Most applications are stand-alone plants for large buildings. There could be a potential for the storage of heat in deep reservoirs (below 250 m), but this depends on the local sub-surface conditions. (Dominik Rutz, 2019)

Examples

Gram district heating – pit thermal energy storage, Gram (Denmark): Gram District Heating Company was until 2009 based on natural gas with a CHP unit and two boilers. The annual heat demand is around 30,000 MWh. The solar collector field was expanded in 2015 to have an area of 44,800 m^2 in total. After that expansion, the system is expected to be able to cover about 60% of the annual heat production. The high penetration rate is only possible through the establishment of a seasonal pit storage, an absorption heat pump and an electric heat pump which allows the collectors to operate at a lower temperature, whereby the efficiency increases significantly. The purpose of the electrically-powered heat pump is to cool the bottom of the seasonal heat storage (Figure 2). By cooling the bottom of the heat storage, the operating hours of the solar plant is increased and thus the utilization of the solar system is increased. (Jensen, 2019)

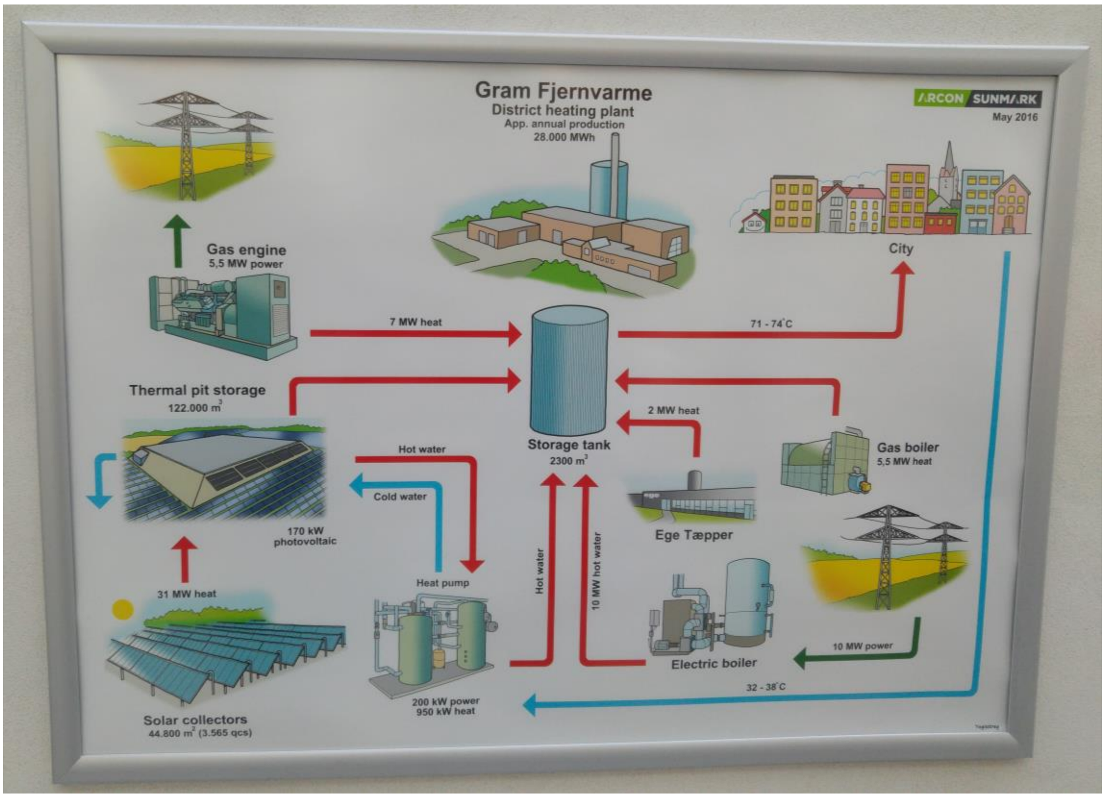

Figure 2: Thermal pit storage as an important balancing part of the whole DH system in Gram (source: Doczekal C.)

Sunstore 3 – Dronninglund (Denmark): The best practice example in Dronninglund uses a 60,000 m³ pit thermal energy storage in combination with 37,500 m² solar thermal panels. A 2.1 MW (cooling) absorption heat pump, supplied with a bio oil boiler, brings the temperature level from the PTES to the needed level from the district heating grid.

The monitoring results for 2015 showed a storage efficiency of 90%, a minimum temperature of 10 °C, a maximum temperature of 89 °C and a storage capacity of 5,500 MWh of the PTES. With this PTES concept they reached a solar fraction of 41% and a renewable energy fraction of 77%. (Worm, 2017) Further information: https://energiteknologi.dk/sites/energiteknologi.dk/files/slutrapporter/sunstore_3_-_final_report_1_23102015_1501.pdf

Minewater 2.0 – using former coal mines as energy storage, Heerlen (Netherlands): In 2012 a totally new concept (Minewater 2.0) was developed by using former coal mines as an energy storage to generate heat and cooling. The energy is stored in coal mines reservoirs. The system is fully automatic demand-driven with the capacity to deliver heating and cooling at any time.

A fully-fledged thermal 'smart grid' for delivery of heating and cooling water with a sustainable hybrid energy infrastructure has been developed. This includes an independent pipe network to deliver both heating and cooling water to the connected clients. Transfers of residual heating and cooling capacity from incoming return water to other outgoing pipes takes place in underground exchange stations equipped with heat exchangers and pumps.

In this Minewater 2.0 system the water in the mines, whether warm or cold, just serves as a storage reservoir – a kind of battery. The most important element of the system is the exchange of heating and cooling capacity between businesses and lessors of residential and commercial buildings. (Mijnwater, 2019) Further information: https://www.mijnwater.com/wp-content/uploads/2014/04/Energy-procedia_IRES-2013_Verhoeven-V20012013-Final-1.pdf

Renewable industrial process heat with large scale high temperature heat storages, Berlin (Germany): The German company Lumenion developed high temperature heat storages using steel as material to generate industrial process heat. The storage technology aims at the sore point of the renewables, the volatility of the generation (Figure 3). Those generation tips, e.g. wind turbines are used to heat steel elements to approx. 650 °C using conventional heating elements. The system is thermally insulated and the losses are about 0.5% per day. This heat can be carried out on the secondary side via heat exchangers either as process heat (for industries with high steam demand) or as district heating. All this with a high efficiency of approx. 95%. If necessary, a steam turbine can be operated to generate electrical energy again via a generator. The main fields of using this technology are:

- Industries with a high demand for process heat (CO_2-free steam at prices competitive with steam from gas - CHPs, fuel-flexibility)
- Energy producers (wind and solar operators, optimization of existing and new CHPs - peak shaving, retrofitting of coal power plants to be closed, sector coupling immediately after production)
- District heating networks (especially in cities, low space requirement due to high energy density, very low CAPEX and life cycle costs, no dangerous substances)
- industrial parks (Piereder, 2019)

A pilot project is installed at Bottroper Weg in Berlin, Germany, with a connection to a district heating system. The storage capacity is 2.4 MWh, the charging power 360 kW, the thermal discharging power 100 kW. The required space is 5 x 5 meters and the generated heat level is 90 °C. (LUMENION, 2019)

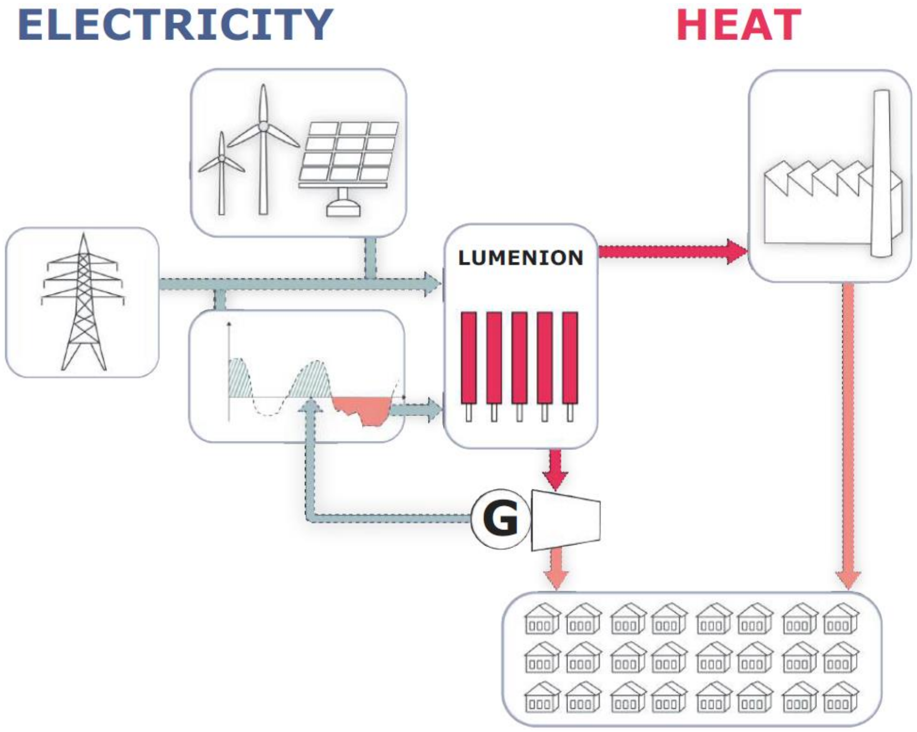

Figure 3: Principal functionality of LUMENION high temperature heat storage (LUMENION, 2019)

Challenges

Using storing technologies always needs benefits for the user, e.g. balancing fluctuations in production or consumption, shifting (hours, days or month') energy to other periods or providing different temperature levels. That's why heat storages are always facing the investment and operation cost problem. Figure 4 shows specific investment costs for different kind of thermal energy storages. It can be seen that for small scale heat storages "large tank thermal storages, TTES" could be used and PTES for large scale heat storages.

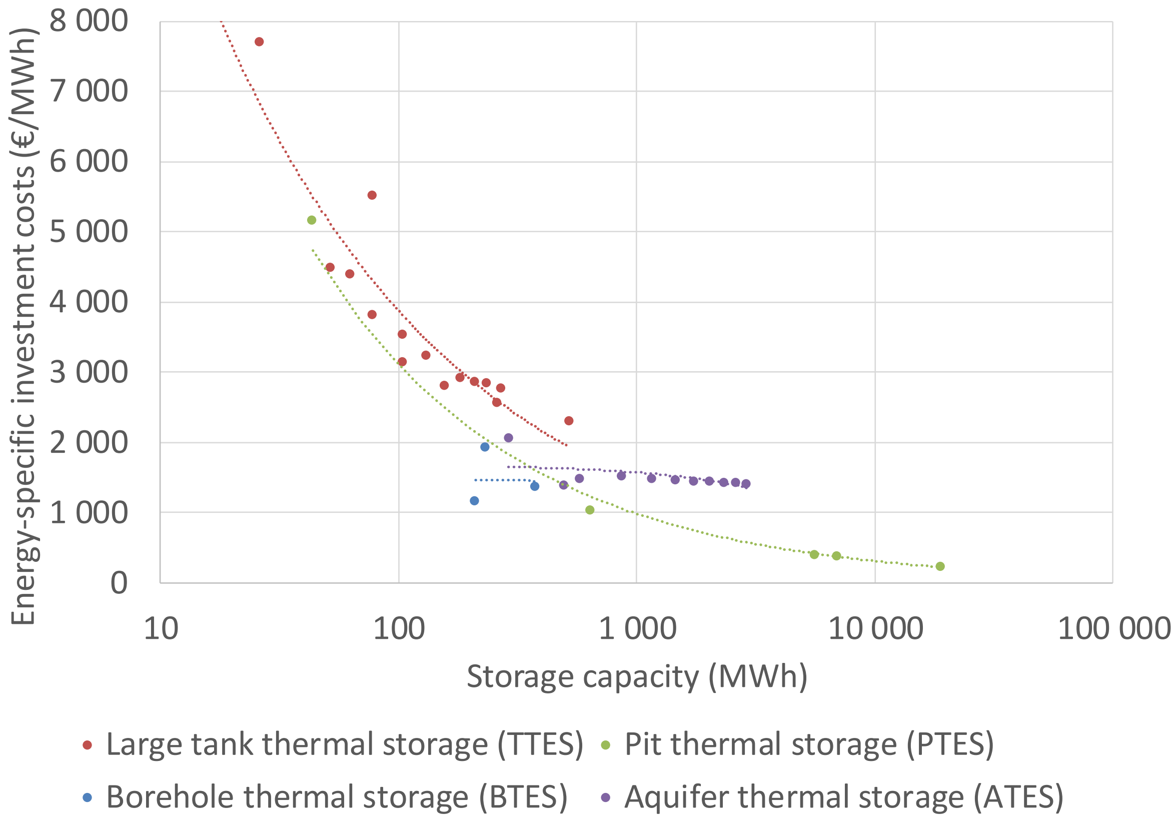

Figure 4: Thermal energy storage investment costs (source: Worm, 2017)

A challenge is also that the physical footprint of PTES is significant, therefore applicability of PTES is dependent on the local conditions. (Dominik Rutz, 2019)

Enabling conditions

With the energy transition, there are further arguments today with regard to a purely electrical solution for heat generation. Both wind power and photovoltaic systems generate electricity in a very irregular time sequence. The question of effective storage options for electricity surpluses is already becoming apparent. With the increasing switch to the use of renewable energies, this question will become crucial. The **thermal component activation** represents an interesting approach in this respect insofar as the storage of heat in thermally activated concrete ceilings is possible without the thermal comfort noticeably influence in the rooms. Heat generation by means of heat pumps acquires a very special significance against this background. (Friembichler, 2016)

In Denmark for example, the trend is using large scale solar thermal plants in combination with **PTES** to supply up to 60% of the annual heating needs of the district heating system. The PTES is a key technology for that purpose. Why is there such a development in Denmark? They only have partially subsidies and the climate conditions are not optimal. Solar heat is competitive with natural gas heat due to high taxes on fossil fuels and low production price for solar heat (<30 to 55 €/MWh with 20 years' loan and 3% interest rate). Additional enabling conditions are the low temperature levels within the district heating grid and that small user-owned district heating companies supply even small villages in the countryside. Some boundary conditions are shown in Table 1. (Worm, 2017)

Table 1: Boundary conditions for different types of thermal energy storage (source: Worm, 2017)

Type	**TTES**	**PTES**	**BTES**	**ATES**
Storage medium	Water	Water (Gravel-water)	Soil surrounding the boreholes	Groundwater in aquifers
Specific capacity [kWh/m³]	60 - 80	60 - 80 30 - 50 for gravel-water	15 - 30	30 - 40
Water equivalents	1 m³ storage volume = 1 m³ stored water	1 m³ storage volume = 1 m³ stored water	3 - 5 m³ storage volume = 1 m³ stored water	2 - 5 m³ storage volume = 1 m³ stored water
Geological requirements	• stable ground conditions • preferably no groundwater • 5 - 15 m deep	• stable ground conditions • preferably no groundwater • 5 - 15 m deep	• drillable ground • groundwater favourable • high heat capacity • high thermal conductivity • low hydraulic conductivity (k_f < 10^{-10} m/s) • natural ground-water flow < 1 m/a • 30 - 100 m deep	• high yield aquifer
Application	Short-time/ diurnal storage, buffer storage	• Long-time/ seasonal storage for production higher than 20,000 MWh • Short time storage for large CHP (around 30,000 m³)	Long-time /seasonal for DH plants with production of more than 20,000 MWh/year	Long-time /seasonal heat and cold storage
Storage temp. [°C]	5 – 95	5 - 95	5 - 90	7 - 18
Specific investment costs [EUR/m³]	110 - 200 EUR/m³ (for TTES above 2,000 m³)	20 - 40 EUR/m³ (for PTES above 50,000 m³)	20 - 40 EUR/m³ (for PTES above 50,000 m³ water equivalent incl. buffer tank)	50 - 60 €/m³ (for ATES above 10,000 m³ water equivalent) Investment costs are highly dependent on charge/discharge power capacity
Advantages	High charge/discharge capacity	• High charge/discharge capacity • Low investment costs	Most underground properties are suitable	• Provides heat and cold storage • Many geologically suitable sites
Disadvantages	High investment costs	Large area requirements	Low charge/discharge capacity	• Low temperatures • Low ΔT

There will be a **significant need for heat storages in the future** to support the energy transition to renewables. Smaller heat storages could be used on consumer level (in the buildings as buffer storage tank or thermal component activation), e.g. to balance the fluctuations of their PV collectors and to higher the own consumption. Larger tank storages could be used for district heating utilities to reduce the peak loads of boilers and to get more full load hours of renewable energy heat generators. Large scale PTES will be used in areas with enough space, because of the high physical footprint of the storage. Unused land at motorways was considered in Austria for it.

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