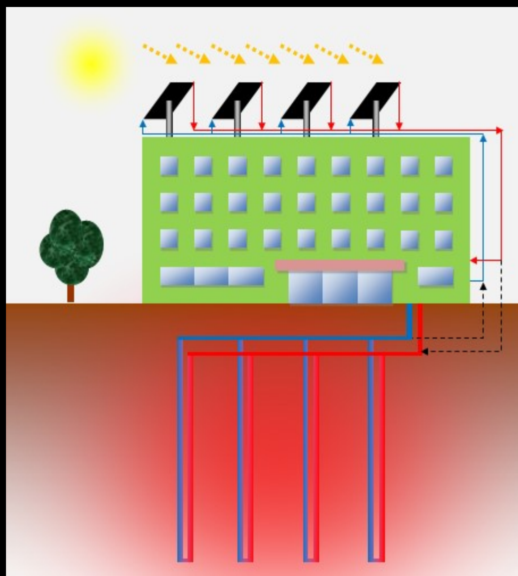
BOREHOLE THERMAL ENERGY STORAGE



In borehole thermal energy storage (BTES) systems, excess heat (e.g. from solar collectors, heat rejection from cooling in buildings, industrial processes, deep geothermal, etc.) is exchanged with the ground by means of a borehole heat exchanger (BHE) array. This causes a localised and sustained-over-time temperature raise in the surroundings. Thus, the stored heat can be used later during the cold season. The same principle is applicable to cooling, although it is less common.

1 PROVEN CONCEPTS

HEAT STORAGE WORKS!

The main advantage of BTES compared to aquifer thermal energy storage (ATES) is the much **larger availability of locations**. Investment costs are higher, mostly due to borehole drilling, but **flexibility does pay the difference**. BTES is also versatile in size, being a feasible and profitable solution from large buildings to very large installations and district-heating networks (E_{stored} = 0.5 to 10 GWh/year and more).

The first commercial BTES system worldwide was implemented at the campus of the University of Luleå (Sweden, 1983 - 1989). Heat source was the residual heat from a steel plant (maximum T_{in} = 82 °C). Since then, **BTES systems have gained popularity mostly in Northern Europe**, but also in the US and Canada. Most of the large systems **store residual heat from industrial processes and solar thermal collectors (STCs)** (T_{in} = 60-90 °C). However, there are also BTES systems with low temperature heat sources (T_{in} = 15-30 °C), like the heat rejected by buildings during the warm season (cooling). In this case, heat pumps are used.

SUN AND SOIL: NATURAL PARTNERS

In most climates the thermal loads are not balanced over the year and consequently the continued use of a ground source heat pumps for heating can decreased ground temperature in the long term and therefore lose efficiency. An option to tackle with this problem might be to increase the borehole depth, but this leads to an increase in the cost. The easiest alternative is storing heat in the ground with solar heat energy. In some cases, it is even possible to avoid the use of heat pumps (**"free heating")**. Maybe the most outstanding example is the **Drake Landing Solar Community in Okotoks (Canada, 2007)**. This installation meets more than 90% (100% in 2015-2016) of space heating with solar energy in a cold climate location, with no heat pumps involved ($T_{gr} \sim$ 55 °C after the first 5 years of operation).

2 FUTURE CONCEPTS

DEEP STORAGE AGAINST SHALLOW LOSSES

The presence of shallow aquifers can be an important limiting factor for BTES projects. **Advection thermal losses and conflicts of use (like drinking water use) are inherent risks**. The solution usually adopted is to drill a larger number of boreholes at a greater depth in order to avoid interaction with the shallow aquifer (Figure 1). However, this implies a larger land use, which poses a new challenge in densely populated urban areas.

A new concept is yet to be developed, called **medium-deep borehole thermal energy storage (MD-BTES)**. This will translate soon into a **pilot plant at the campus of the Technische Universität Darmstadt (Germany)**. The project will drill just 4 boreholes (~750 m) through the aquifer in order to reach the rock formation underneath. This way, the actual storage volume will be located beneath the **aquifer, which is expected to act as a top insulator layer**.

Theoretically, this solution minimises aquifer interaction, reduces thermal losses and reduces drastically the land surface required.

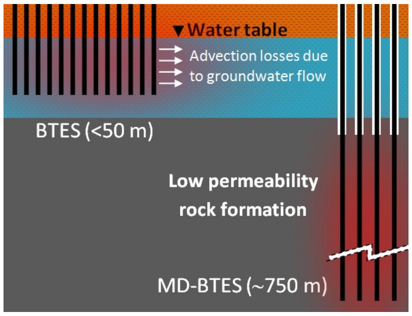


Figure 1. Schematic not to scale representation comparing shallow BTES (left) and MD-BTES (right). Adapted from Schulte D. O. et al., EGC 2019.

3 GOOD EXISTING PRACTICES

NOT STOPPED, BUT SLOWED

Thermal losses are inevitable in UTES systems, since they are **"open systems" from a heat transfer perspective**. Therefore, minimisation of heat losses is a crucial factor in the design, construction and operation of such infrastructures. In BTES, this translates into the **following requirements**:

- **Almost no groundwater flow** to avoid or minimise advection losses.
- **Maximised volume-to-surface ratio** of the storage volume. The ideal shape resembles a cylinder with equal height and diameter.
- **Optimised borehole distribution layout**. Hexagonal patterns perform better than quadratic ones (same borehole-spacing in less surface area), although the latter can be advantageous from the construction and operation perspective (see Figure 2).

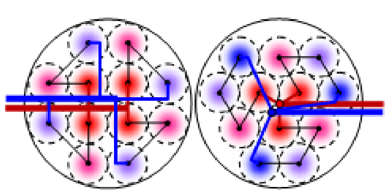


Figure 2. Quadratic and hexagonal layouts and proposed interconnections for a set of 12 boreholes. The position of the boreholes and their series connections are represented by black dots and lines. Red and blue lines represent the parallel connections.

- **Optimised borehole connection**. Radially symmetric grouped boreholes connected in series from the centre to the periphery favours heat concentration at the centre.
- **High volumetric thermal capacity (C_V) and low-moderate ground thermal conductivity (λ_{gr})**. By definition, a ground with high C_V is a "must" (>2 MJ/m^{3}K). Low-to-moderate λ_{gr} (1 - 2.5 W/mK) implies slow heat transfer rates, but also minimum conduction losses. However, high λ_{gr} (>3 W/mK) are preferred when high heat transfer rate is prioritised over low losses.

4 LESSONS LEARNED

NOT JUST A BUNCH OF BOREHOLES

A **warm-up or cool-down period of 3 to 6 years** is necessary for a BTES system in order to reach the new operating temperature in the ground.

It is highly recommended to **drill extra boreholes to implement an environmental monitoring** system (e.g.: ground temperature distribution and evolution).

A **buffer water tank** is the most reliable solution to be used on surface to **compensate for the slow response** in heat charging and de-charging.

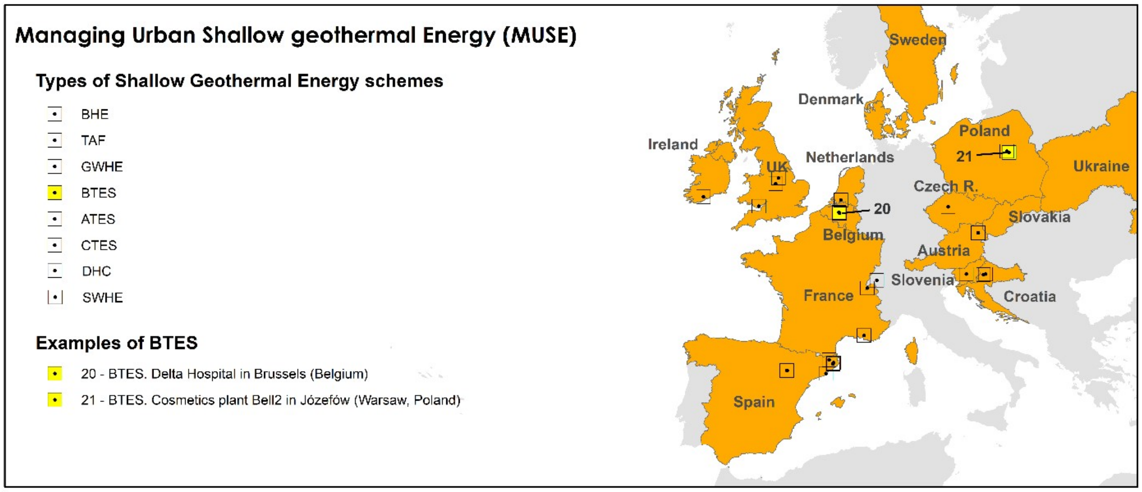
Regardless of λ_{gr} of the ground, **borehole thermal resistance should be minimised**. In locations with hard rock formations (Scandinavia), the water can flow in contact with the borehole walls in a coaxial configuration, but in many other cases, this is not possible and high thermal conductivity grouts are required around the probes. In U-tube probe configurations "shank-spacing" must be maximised.

The top part of the BTES is the most sensitive to ambient temperature variations. Insulation layers like hard extruded polystyrene (XPS), foam glass gravel for instance (as a cost-effective approach) should be implemented.

Cross-linked high density polyethylene (PEX) probes are preferred for BTES for its better performance at high pressure and temperature.

In practice, drift from the targeted drilling trajectory can easily reach more than 1cm/m, so **the risk of overlapping boreholes must be an input in borehole layout design**.

5 EXAMPLES



BTES-1. Delta Hospital in Brussels (Belgium)

BRUSSELS PILOT AREA

Location (WGS84 coordinates): N 50.816377 E 4.399962

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	2411	28

Initial $T_{brine\text{-}cool\ season}$: unknown

Initial $T_{brine\text{-}warm\ season}$: unknown

Undisturbed T_{ground} [ºC]: 12.2

Number of Boreholes: 176

Total length [m]: 15840

	Heating	Cooling
Capacity installed [kW]	600	450
Demand [MWh]	4.5	4.4
Seasonal performance (SPF_{H2})	4.5	4.5

The Chirec-Delta Hospital in Brussels is equipped with an oversized heating and cooling capacity. It has 7 MW_t of condensing boilers (only 4 MW_t are used by the hospital building), 0.6 MW_e + 0.8 MW_t from a cogeneration plant, a set of solar thermal collectors (100 m^2) plus the ground source heat pumps for heating and cooling. The excess heat is stored at the borehole thermal energy storage field or supplied to a district heating network that covers a commercial area.

BTES-2. Cosmetics plant Bell2 in Józefów (Warsaw, Poland)

WARSAW PILOT AREA

Location (WGS84 coordinates): N 52.141219 E 21.196917

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	3254	30

Initial $T_{brine\text{-}cool\ season}$: 16

Initial $T_{brine\text{-}warm\ season}$: 22

Undisturbed T_{ground} [ºC]: No data

Number of Boreholes: 35

Total length [m]: 3500

	Heating	Cooling
Capacity installed [kW]	315	390
Demand [MWh]	No data	No data
Seasonal performance (SPF_{H2})	No data	No data

The main goal of the applied installation is the ability to recover the excess heat from the production machinery, store it in the ground and use seasonally for active heating and cooling of the facility. The heating and cooling system uses a cascade of ground source heat pumps of ~60 kW$_t$ each. The system is also equipped with a "free cooling" solution, which enables operation in the cooling mode without using the GSHPs, so based only on the ambient temperature of underground. The local geological conditions are quite beneficial in the context of the GSHPs efficiency due to presence of a 40 m thick Pleistocene aquifer characterised by high values of thermal conductivity (>2 W/mK) and volumetric heat capacity (2.3 MJ/m^{3}K).