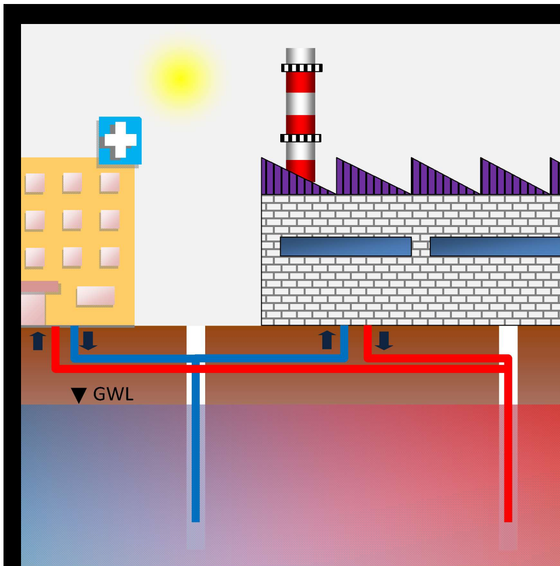
AQUIFER THERMAL ENERGY STORAGE



In aquifer thermal energy storage (ATES) systems, excess heat produced/rejected during summer (from solar collectors, building heat rejection, industrial processes, deep geothermal, etc.) is exchanged with groundwater, causing a localised temperature to raise in the water body. This allows a more efficient use of heat during winter (eventually "free heating") compared to groundwater heat exchangers (GWHEs).

1 PROVEN CONCEPTS

IF THERE IS WATER, USE IT!

Water is characterised by an outstanding energy storage capacity (per unit volume) compared to soils (Figure 1). This represents **an inherent advantage of ATES** over borehole thermal energy storage (BTES) **whenever an aquifer is present, and its exploitation is feasible.**

ATES		BTES
4.18 MJ/m³K	↔	1.3-2.7 MJ/m³K

Figure 1. Heat storage capacity of water (ATES) vs. soil (BTES).

First ATES systems were conceived in the 1960's in Shangai (China), although The Netherlands is currently a world leader in the deployment of ATES (> 2500 systems). They can follow different configurations, typically bi-directional systems, with a mono-well or a well doublet, allowing heat injection during summer for its use during winter and inject cold water during the wintertime for efficient cooling during summer.

SIZE MATTERS

ATES is oriented mostly to large **systems (> 100 kW$_{th}$ of installed power)**. The **minimum stored volume** to consider an economically viable ATES system is **around 0.1 hm³**. Depending on its thermal losses, which are greatly determined by the **temperature** of the injected water and **ground flow characteristics**, this volume can oscillate. Besides, three exploitation schemes related to the storage water temperature (T_{in}) are commonly accepted:

- Low temperature **(LT)-ATES: < 30 ºC** (Example: **Klina Hospital, Brasschaat, Belgium)**. Heat source: Building excess heat.
- Medium temperature **(MT)-ATES: 30 – 60 ºC** (Example: **Dolfinarium Harderwijk, The Netherlands)**. Heat source: Residual heat from the combined heat and power (CHP) plant in the same building.
- High temperature **(HT)-ATES: > 60 ºC** (Example: **Reichstag building in Berlin, Germany)**. Heat source: Residual heat from a CHP plant nearby.

2 FUTURE CONCEPTS

GREATER POTENTIAL, GREATER CHALLENGE

Although nowadays there are few active HT-ATES systems worldwide**, the potential is clear**: given a certain amount of thermal energy required, the higher the temperature, the smaller the HP requirements. Furthermore, high temperature water implies **high quality heat**, which means that **"free heating" without heat pumps** is possible and the **range of applications is wider**. However, the list of challenges and potential risks also grow with T_{in}:

- Thermally induced chemical changes in groundwater composition favour the **precipitation of minerals and scaling**. This poses a greater restriction on groundwater chemistry (low carbonate content) or implies the **use of acids (HCl) for water treatment** to minimise scaling.
- Higher **distance between extraction and injection wells** is needed in order to minimise thermal losses. Alternatively, the

combination of a shallow (< 50 - 100 m; cold well) and a deep aquifer (> 100 - 150 m; warm well), reduces drastically the problem of land use, although the water mixing **between different aquifers** adds additional risks and has to be avoided.

- HT-ATES can affect the **microbiological activity** in groundwater severely.

3 GOOD EXISTING PRACTICES

DESIGN CONSIDERATIONS

Confined aquifers show advantages concerning **thermal isolation** and **temperature stability** along the year over unconfined ones. On the contrary, a **higher depth implies higher drilling costs** and generally higher pumping power, which depends on the piezometric level. In any case, the main technical requirements for an aquifer to admit feasible ATES projects are:

- Low groundwater flow velocity ($\mathbf{v_{gw}} \lesssim 25$ m/y).
- High hydraulic conductivity ($\boldsymbol{k} \gtrsim 10^{-5}$m/s) (sands, gravels, limestone). Note that high values of *k* also favour buoyancy flow and thermal losses. Hence, a trade-off is required.
- Favourable water chemistry at high temperatures.
- Minimum aquifer thickness of 20 m.

Distance between warm and cold wells ($d_{W\text{-}C}$) should be at least **three times the thermal radius (r_{th})** of the thermally affected volume:

$$r_{th} = \sqrt{c_w V / c_{aq} \pi L}$$

Where $\mathbf{c_w}$ and $\mathbf{c_{aq}}$ are water and aquifer volumetric heat capacity [J/m^{3}K], **V** is the volume of the injected water [m^3] and **L** is the length of the well screen [m]. Besides, **too long $d_{W\text{-}C}$** could cause large differences in hydraulic head, favouring **subsidence / differential settlement. Extra monitoring wells adjacent to injection and extraction wells** are necessary to monitor the temperature of the reservoir without the perturbations caused by the water flow as well as to control groundwater levels.

HEAT STORAGE vs. HEAT EXCHANGE

Some authors refer to GWHEs as “recirculation” systems within the ATES category, although there is a crucial difference: **GWHEs do not rely on underground heat storage.**

In ATES systems, the orientation of warm and cold wells with respect to the groundwater flow should avoid or minimise a thermal **short-circuit** between them. In GWHE systems, it is advised to place the extraction well upstream (Figure 2.).

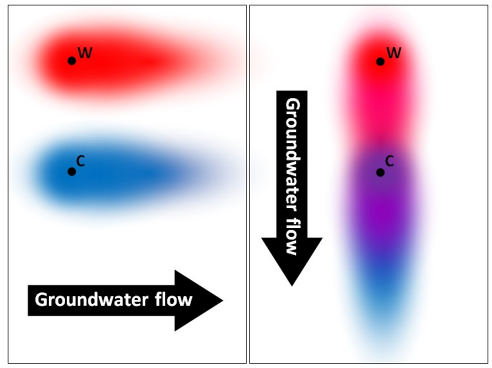


Figure 2. Illustrative representation of thermal plume evolution around the warm (W) and cold (C) wells, depending on the groundwater flow direction with respect to the well position. Left side scheme represents the ideal configuration in ATES systems. Right side scheme represents an ideal configuration for GWHE systems.

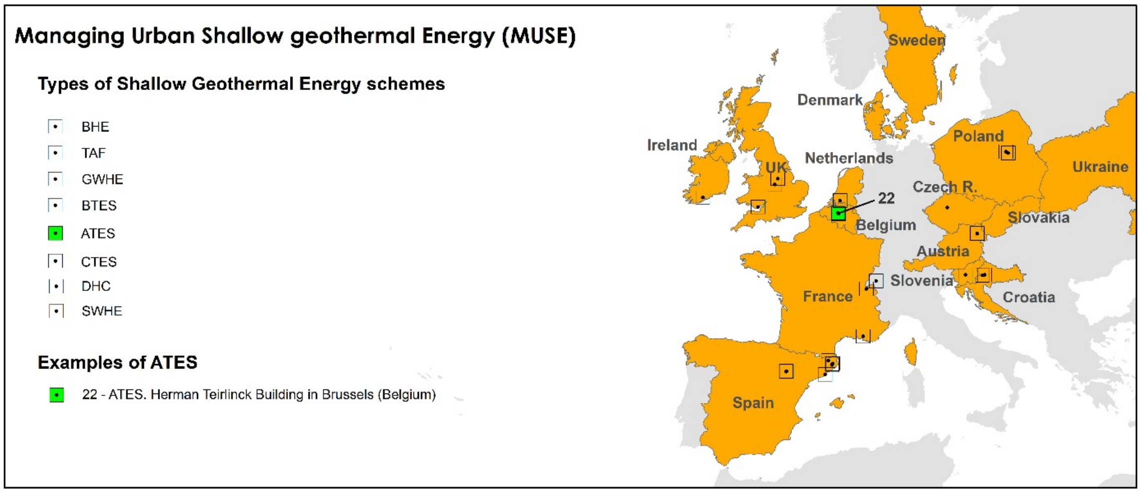
4 LESSONS LEARNED

RECOVERY EFFICIENCY IS THE KEY

Recovery efficiency η_{rec} (ratio of heat extracted to heat injected) and **T_{in}** are the most comprehensive **figures of merit that define ATES systems** and its performance (η_{rec} oscillates mainly between 40 and 60%). The minimum admissible value of η_{rec} to consider a project as viable depends mainly on the **cost of the injected heat** (e.g. heat from solar collectors vs. industrial processes), and the **value of the recovered heat** (low temperature water might require the use of heat pumps, high temperature water may not). The higher the cost, the higher the expected η_{rec} will be.

η_{rec} is not only driven by thermal losses in the aquifer, but a **good match between heat injection and heat demand**. Moreover, the minimum temperature at which groundwater is still usable (**cut-off temperature**) should be as low as possible. **This issue must be tackled in the planning phase**.

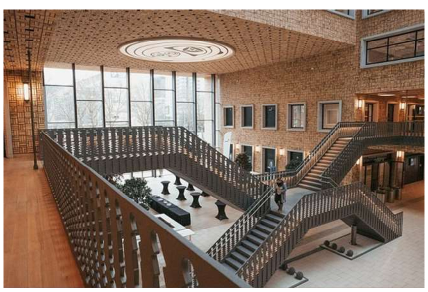
5 EXAMPLES FROM PILOT AREAS



ATES-1. Herman Teirlinck Building in Brussels (Belgium)

BRUSSELS PILOT AREA

Location (WGS84 coordinates): N 50.866171 E 4.350024



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

Maximum flow [m^3/h]:
Minimum T_{gw} [ºC]: No data
Maximum T_{gw} [ºC]: No data
Depth of extraction [m]: No data
Depth of injection [m]: No data

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

The Herman Teirlinck Building was recently built for the Flemish Environment Ministry at Brussels (area called Tour& Taxis). The ATES system comprises 4 injection wells and 4 production wells.