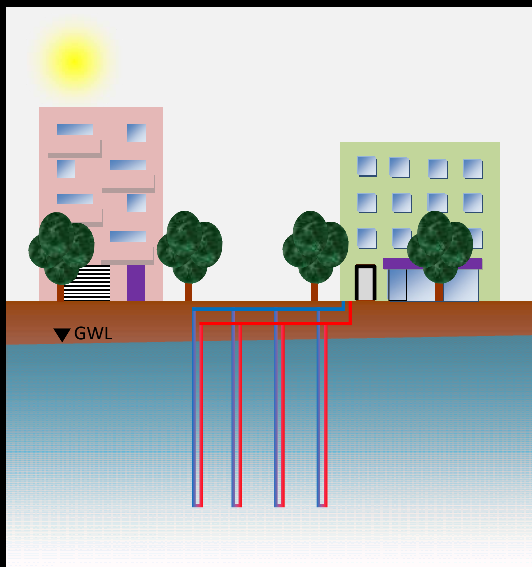
FACTSHEET1 Managing Urban Shallow Geothermal Energy

CLOSE-LOOP VERTICAL BOREHOLE HEAT EXCHANGER SYSTEMS



In closed-loop Borehole Heat Exchangers (BHE), heat is exchanged with the ground by means of a brine flow (mainly water or water mixed with a portion of antifreeze) circulating through a set of probes buried in vertically drilled boreholes ranging between 50 and 200 m typically.

1 PROVEN CONCEPTS

SCALING-UP

Very large BHE fields (> 1 MW_{th}) offer the well-known advantages of the economies of scale. The aggregation of a distributed energy resource such as shallow geothermal energy (SGE) allows a more efficient management of it (including the ground and the system monitoring, and the processing of permits).

Three different typologies of very large installations can be identified:

- **Large buildings** (Hospital de Sant Pau, Barcelona, Spain, 3.6 MW_{th})
- **District heating and cooling networks** (Viertel Zwei and Austria Campus, Wien, Austria, 0.45 MW_{th} and 1.2 MW_{th} for heating and cooling, respectively)
- **Residential areas with individualised BHE systems** (Neighbourhood in Etten Leur, The Netherlands, 5 MW_{th} and 6.7 MW_{th} for heating and cooling, respectively)

DEEP SHALLOW or SHALLOW DEEP?

In areas where the use of SGE is a mature practice, there is a **growing need for drilling deeper**. This strategy partly overcomes possible thermal interaction with neighbouring installations. In addition, **deeper BHEs favour heat pump heating efficiency** thanks to the geothermal gradient (20 - 30 °C/km). In Sweden, the average borehole depth has doubled since 1995, from 100 to 200 m. In Sipoo (Finland), there is one of the largest SGE installations in Europe, with 319 boreholes 300 m deep each to supply a logistics centre.

2 FUTURE CONCEPTS

SMART GROUTS ENHANCE EFFICENCY

A new strategy for borehole grouting consists of embedding into the grout a high content of micro or macro-encapsulated phase-changing materials (PCMs) with melting temperatures in the range 10 - 60 °C. The idea is to **use latent heat instead of sensible heat within the boreholes**, so the minimum brine temperature could be raised in cold climates and the maximum brine temperature could be lowered in warm climates (figure 1), leading to an increase in heat pump efficiency.

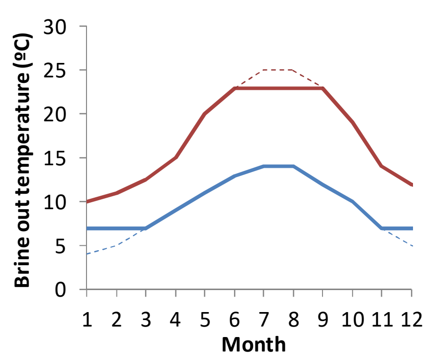


Figure 1. Hypothetic brine out temperature profiles corresponding to a cold climate (blue lines) and a warm climate (red lines). Dashed lines represent the temperature values achieved without PCMs in the in the borehole. Solid lines represent the ideal temperature profiles achieved thanks to PCMs.

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CARBON SEQUESTRATION IN HEAT PUMPS

Most common refrigerant fluids in geothermal heat pumps show global warming potential values about 2000 times higher than CO_2. But what if CO_2 itself was a good alternative as a refrigerant? In fact... it is! Active research is being carried out to use CO_2 in **direct-expansion ground source heat pumps** (DX-GSHPs). In DX-GSHPs, CO_2 can act both as the ground heat exchanging fluid and the refrigerant fluid in the heat pump.

3 GOOD EXISTING PRACTICES

INTERVIEW WITH THE GROUND

Thermal properties of the ground can be estimated from existing geological data, as e.g. geological surveys provide it, or it can be accurately measured by a thermal response test (TRT). The convenience of performing such tests increases with the projected capacity to be installed. **In small installations, uncertainty is usually compensated through oversizing**. However, the drilling costs and the TRT cost itself must be considered when taking the final decision, even for small-scale installations.

ROAD TO OPTIMUM DESIGN

An efficient design of a closed-loop BHE field must focus on (see Figure 2):

- **minimise total borehole length** (L_b)
- **minimise circulation pump power** (Q_{pump})
- **maximise heating and cooling seasonal performance factors** (SPF_h and SPF_c, respectively)

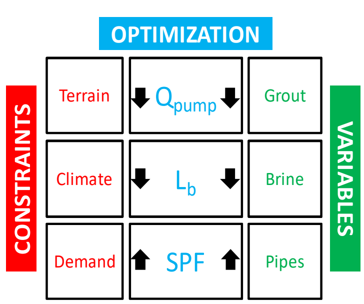


Figure2. Design aspects of a BHE

A trade-off must be carried out between the main variables of the system: the grouting of the BHE, the pipe material, geometry and the brine composition. On the side of the constraints, the ground characteristics, the climate and the demand of the building will impose their limits to the final design through the thermal ground conductivity (λ_g), the undisturbed ground temperature (T_{g0}) and the minimum and maximum brine temperatures (ELT_{min}; ELT_{max}), respectively. L_b impacts directly on the investment cost (and to a lower extent on the feasibility), while Q_{pump} and SPF impact on the operation cost, and therefore on the energy savings and the payback period.

4 LESSONS LEARNED

USE HIGH QUALITY GEO-SERVICES

Not considering existing and **readily available hydrogeological information** can lead to unexpected drilling problems involving environmental hazards, building/ infrastructure damage or inadequate SGE exploitation schemes. Most frequent omitted aspects are:

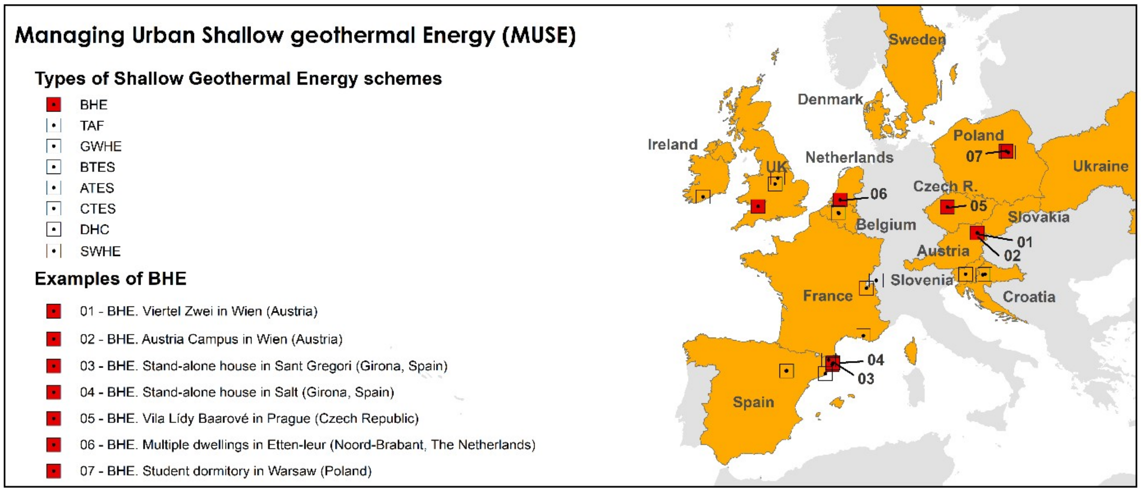
- The existence of artesian aquifers.
- Areas with high groundwater flow.
- Existence of contaminated soils.
- Presence of karstified rocks.
- Presence of thermal anomalies.

It is also important to consider **access of drilling** machinery in densely packed urban areas, as well as limitations imposed by the building **structural stability** or by **the architecture itself**.

BOREHOLES NEED THEIR SPACE

Especially in urban areas, the possible **thermal interference between adjacent installations** must be considered, since the addition of a new installation can create "lose-lose" scenarios between existing and forthcoming customers. Therefore, public databases of existing boreholes and their characteristics are extremely helpful.

5 EXAMPLES



BHE-1. Viertel Zwei in Wien (Austria)

WIEN PILOT AREA

Location (WGS84 coordinates): N 48.212830 E 16.415016

	heating (15/18)	cooling (21/24)
Degree-days$_{2017\text{-}18}$ [ºC·days/year]	2377	229

Undisturbed T_{ground} [ºC]: 12.1
Minimum T_{brine} [ºC]: 5.4 (simul.)
Maximum T_{brine} [ºC]: 22 (simul.)

Number of Boreholes: 165
Total length [m]: 23100

	Heating	Cooling
Capacity installed [kW]	450	1200
Demand [MWh]	5.6	2.4
Seasonal performance (SPF_{H2})	4.5	5.5

This shallow geothermal energy installation is part of a smart anergy grid, which combines borehole and groundwater heat exchangers, as well as wastewater and waste heat utilization, providing space heating, domestic hot water and cooling (with floor heating system and concrete core activation) to a complex of residential and office buildings (District Heating). Shallow geothermal energy alone meets 70% and 95% of the heating and cooling demands in the complex, respectively.

BHE-2. Austria Campus in Wien (Austria)

WIEN PILOT AREA

Location (WGS84 coordinates): N 48.223196 E 16.394030

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	2377	229

Undisturbed T_{ground} [ºC]: 12.8
Minimum T_{brine} [ºC]: no data
Maximum T_{brine} [ºC]: no data

Number of Boreholes: 207
Total length [m]: 30593

	Heating	Cooling
Capacity installed [kW]	918	569
Demand [MWh]	No data	No data
Seasonal performance (SPF_{H2})	No data	No data

The Austria Campus is a business district consisting of offices, underground parking, a hotel, health and conference centre, and areas for restaurants and retail (Rental space: 20 hectares). Apart from the borehole heat exchanger (BHE) field (what this factsheet is about), thermo-active foundations (TAFs) were implemented: slurry (diaphragm) walls, auger piles and parts of the base plate are geothermally activated through absorber pipes for the purpose of heating and cooling in the building complex. As an innovation, the installation of geothermal energy cycles into unreinforced piles was realized by means of a specially developed distribution system. Combined it is one of the largest geothermal projects in Austria.

BHE-3. Stand-alone house in Sant Gregori (Girona, Spain)

GIRONA PILOT AREA

Location (WGS84 coordinates): N 41.90693 E 2.761794

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	1718	219

Undisturbed T_{ground} [ºC]: 16.5
Minimum T_{brine} [ºC]: no data
Maximum T_{brine} [ºC]: no data

Number of Boreholes: 3
Total length [m]: 300

	Heating	Cooling
Capacity installed [kW]	11	11
Demand [MWh]	1.52	1.05
Seasonal performance (SPF_2)	7.1*	

The SGE installation consists of an oversized BHE field (300m for 9kW installed capacity), since it is expected to meet additional demand from adjacent dwellings in the near future. The electricity production is aided by a rooftop photovoltaic installation (3 kW_p) and a set of Li-ion batteries (6 kWh of storage capacity). The electricity surplus activates the ground source heat pump (GSHP) automatically to produce domestic hot water (DHW) at 65ºC (this represents a thermal energy battery). During the warm season, the heat rejected from the building is profited to produce DHW, which enhances the overall efficiency of the SGE installation. The hybrid installation generates >100% of the dwelling total demand.
The total CAPEX (including PV and batteries) is 31000€, and the estimated pay-back period is 11 years.

** This value accounts for (E_h+E_{DHW}+E_c)/E_e, from April to September 2019. E_{DHW} and E_c are produced simultaneously most of the time, where E - energy, h - heating, c-ccoling, and DHW - domestic hot water*

MUSE GeoERA GEO-ENERGY

BHE-4. Stand-alone house in Salt (Girona, Spain)

GIRONA PILOT AREA

Location (WGS84 coordinates): N 41.968048 E 2.788189

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	1718	219

Undisturbed T_{ground} [ºC]: 16.5
Minimum T_{brine} [ºC]: no data
Maximum T_{brine} [ºC]: no data

Number of Boreholes: 2
Total length [m]: 200

	Heating	Cooling
Capacity installed [kW]	12	12
Demand [MWh]	31.8	no data
Seasonal performance (SPF_{H2})	4.2	no data

This is a retrofitted building. The shallow geothermal energy installation consists of a 12 kW ground source heat pump coupled to a 2-borehole heat exchanger field. The installation meets entirely the cooling, heating and domestic hot water demand. It substitutes a previous gas-fired boiler system.

BHE-5. Vila Lídy Baarové in Prague (Czech Republic)

PRAGUE PILOT AREA

Location (WGS84 coordinates): N 50.1091636 E 14.3816253

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	2855	77

Undisturbed T_{ground} [ºC]: 12.8
Minimum T_{brine} [ºC]: -7
Maximum T_{brine} [ºC]: 20

Number of Boreholes: 3
Total length [m]: 240

	Heating	Cooling
Capacity installed [kW]	25.6	6.7
Demand [MWh]	51.8	no data
Seasonal performance (SPF_{H2})	no data	no data

Refurbished building. A new SGE installation was implemented to meet the entire demand of heating, domestic hot water production and cooling. The distribution system consist of radiant floor combined with existing cast iron radiators. A fan-coil unit is used for cooling.

Vila Lídy Baarové is a well-known building in an exposed and historically protected area. The reconstruction took place under the strict supervision of the Heritage department.

BHE-6. Multiple dwellings in Etten-leur (Noord-Brabant, The Netherlands)

ETTEN-LEUR AREA

Location (WGS84 coordinates): N 51.590329 E 4.659573

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	2435	25

Undisturbed T_{ground} [ºC]: 11.0
Minimum T_{brine} [ºC]: 0
Maximum T_{brine} [ºC]: 15
Number of Boreholes: >2000
Total length [m]: >180000

	Heating	Cooling
Capacity installed [kW]*	5	6.7
Demand [MWh] *	8-12	1-2
Seasonal performance (SPF_{H2})*	3.5-4.0	25

2005-2015 new housing development of 1500 homes in the municipality of Etten-Leur. All electric infrastructure (no gas) with individual vertical closed-loop systems for heating and domestic hot water production. In summertime free cooling potential of ground loop is used to provide cooling to the homes. Prior to the start of the development a feasibility study was carried out and over the last 8 years the soil temperature has been monitored at various depth's in 30 observation wells.

** Average values per dwelling unit*

BHE-7. Student dormitory in Warsaw (Poland)

WARSAW PILOT AREA

Location (WGS84 coordinates): N 52.251829 E 21.032445

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

Undisturbed T_{ground} [ºC]: 11.8
Minimum T_{brine} [ºC]: 6
Maximum T_{brine} [ºC]: 16
Number of Boreholes: 100
Total length [m]: 2300

	Heating	Cooling
Capacity installed [kW]	190	250
Demand [MWh]	60	6
Seasonal performance (SPF_{H2})	no data	no data

The student dormitory (public building) is a new building constructed in 2015 and is integrated into an historic urban area of the city. Due to the lack of space all the borehole heat exchangers (BHEs) were drilled and installed within the building perimeter, so the access to them is done at the basement (parking). The system of active space heating and cooling of this multi-storey hotel building uses a cascade of ground source heat pumps achieving a total capacity of 200 kW. Additional 100 kW of heating are available from the existing district heating. The building is equipped with a building management system to control and monitor ventilation as well as water and electric energy use.