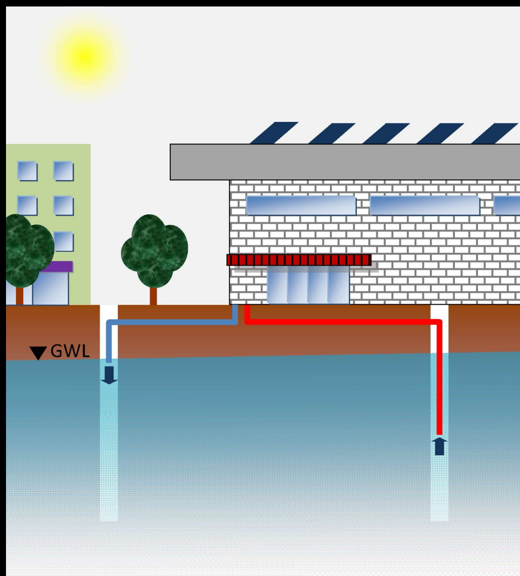
OPEN-LOOP GROUNDWATER HEAT EXCHANGER SYSTEMS



In an open-loop groundwater heat exchanger (GWHE), water is pumped from the ground and circulated through a heat pump – potentially with an additional intermediate heat exchanger – to exchange its sensible heat. The same flow is usually re-injected into the ground again. Free cooling without heat pump is generally possible under certain conditions.

1 PROVEN CONCEPTS

A HIDDEN POWER

Liquid water has one of the highest capacities of all available compounds on the Earth's crust to release or absorb sensible heat (c_p = 4180 J/kgK). For this reason, groundwater heat exchangers (GWHEs) are the best option over borehole heat exchangers (BHEs) (Figure 1), **when its exploitation is feasible**. Groundwater resources are not ubiquitous, and its use demands the most careful risk assessment among all non-storage SGE systems. However, there are several urban areas where a successful profit has been demonstrated with good aquifers, like in Zaragoza (Spain), with more than 100 MW_{th} of installed cooling capacity.

GWHE		BHE
1 l/s @ ΔT = 1 °C	=	105 m @ 40 W/m

Figure 1. Equivalent GWHE and BHE systems in terms of heat exchanging potential.

VERTICAL LIMITATIONS? GO HORIZONTAL

Horizontal injection wells are a good solution when there is a low hydraulic conductivity and limitations related to maximum drilling depth of the wells or a high extraction rate is wanted. A good example of its application can be found in the **Wirtschaftsuniversität Campus (Wien, Austria)**, where a set of 10 horizontal extraction wells provide a pumped flow of 150 l/s with a maximum drilled depth of 12 m (>3 MW_{th} installed).

WHY CHOOSING IF YOU CAN HAVE IT ALL?

Viertel Zwei district heating (Wien, Austria) has demonstrated that **GWHEs and BHEs can coexist successfully** in the same installation (210 kW_{th} and 450 kW_{th} installed, respectively). Moreover, additional heat sources/sinks are used, as wastewater and the Danube River itself using a surface water heat exchanger.

2 FUTURE CONCEPTS

"CLOSED-LOOP" GWHE

A recent new approach developed in Japan consists on installing **double U-Tube probes in artesian wells**. This is actually a closed-loop vertical BHE system, although it shows important differences. This scheme exploits the high upward flow of groundwater towards the surface, increasing the specific heat exchanging rate dramatically with respect to that of the soil surrounding the borehole (Figure 2).

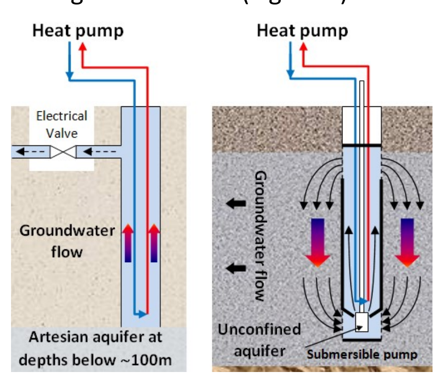


Figure 2. Left: BHEs in artesian wells (adapted from Shrestha et al., Energies 11 (2018) 1178). Right: Dynamic closed-loop solution.

In parallel, a Spanish company (DCL Geoenergia S.L.) is already implementing an **analogous**

solution called "Dynamic closed-loop" (DCL) designed for unconfined aquifers. In this case, a submersible circulating pump is installed in the borehole under the U-Tube probes (more than one loop per borehole), forcing a convective flow, which enhances the specific heat exchanging rate (more than 300 W/m is claimed for a single borehole).

3 GOOD EXISTING PRACTICES

SENSIBLE HEAT IN A SENSITITVE RESOURCE

A municipal measuring/testing point network is the key for an efficient management of groundwater as an energy resource:

- **Groundwater quality** (pH, hardness, alkalinity, calcium content). Water chemistry influences corrosion, scaling, fouling and potentially clogging of pipes and/or heat exchangers. It must be a guide for materials selection and **impacts feasibility, CAPEX and OPEX**. Contaminants and subsoil biological activity are also important aspects.
- **Groundwater temperature**. Below 10 °C free cooling is possible. Above 15 °C, HPs work efficiently in heating mode, **concerning efficiency and pay-back time**.
- **Piezometric level**. A smart network of measured values determines the flow direction of groundwater. Extraction wells should be located upstream. Neighbouring installations should be along the perpendicular direction to groundwater flow to minimise thermal interferences. **This must be considered in the design**.

OPTIMUM FLOW - MAXIMUM EFFICIENCY

The thermal energy exchange rate with groundwater (Q_{gw}) can be estimated by the well-known expression:

$$Q_{gw} = c_p \cdot \rho \cdot q_{gw} \cdot \Delta T_{gw}$$

Where c_p and ρ are, respectively, the specific heat capacity and density of water. q_{gw} is the groundwater flow and ΔT_{gw} is the difference between entering and leaving groundwater.

Compressors in heat pumps require less power consumption when ΔT_{gw} is low. But this implies an increase of q_{gw} to keep the same value of Q_{gw}. The higher q_{gw}, the higher the power consumption of well pumps. Hence **a smart design should find an optimium value for q_{gw}** that minimises the combined power consumption of heat pumps and well pumps (Figure 3).

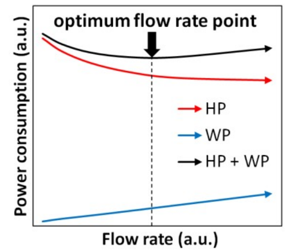


Figure 3. The flow rate is ideal when combined electrical power consumption of heat pump (HP) and well pump (WP) is at its minimum.

4 LESSONS LEARNED

A BUNCH OF GOOD ADVICES

The groundwater loop is often isolated from the building loop by means of **an intermediate heat exchanger** to keep corrosion/scaling problems away from the most expensive equipment and building pipes. Non-metallic pipes are then preferred for the groundwater loop.

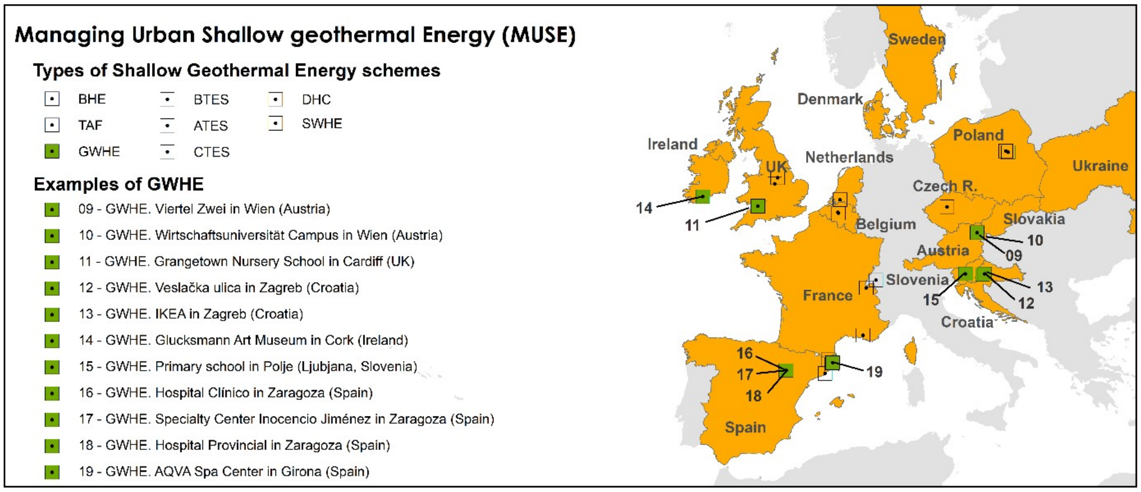
Injection temperature should be always above a safe threshold to avoid excessive condensation or even freezing and below the admissible temperature value for drinking water (5 - 20 °C).

Injection of used groundwater back to the aquifer is (and should be) the predominant option. It **avoids aquifer depletion** over time, **prevents subsidence** and contributes to a sustainable use of the resource.

Open water tanks for groundwater storage in surface must be **totally disregarded**. This could promote the entrance of oxygen (fouling ↑) and let dissolved CO_2 to escape (pH ↓, corrosion↑).

Hydrodynamics and water chemistry may change over time. **Favourable groundwater** analysis at the beginning of the project might **not be enough to guarantee a trouble-free operation** during the predicted lifetime of an installation.

5 EXAMPLES



GWHE-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$_{2017-18}$ [ºC·days/year]	2377	229

Maximum flow [m^3/h]: 36
Minimum T_{gw} [ºC]: 5
Maximum T_{gw} [ºC]: 18

Depth of extraction [m]: 10 (2 wells)
Depth of injection [m]: 10 (2 wells)

	Heating	Cooling
Capacity installed [kW]	210	210
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.

GWHE-2. Wirtschaftsuniversität Campus in Wien (Austria)

WIEN PILOT AREA

Location (WGS84 coordinates): N 48.213532 E 16.408565

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

Maximum flow [m^3/h]: 540
Minimum T_{gw} [ºC]: unknown
Maximum T_{gw} [ºC]: unknown
Depth of extraction [m]: 12
Depth of injection [m]: 10

	Heating	Cooling
Capacity installed [kW]	3000	3000
Demand [MWh]	unknown	unknown
Seasonal performance (SPF_{H2})	unknown	unknown

Over 70 percent of the required energy in the WU campus is generated by shallow geothermal energy from the groundwater and it is one of the largest installations of its kind in Austria. Up to 150 liters per second are pumped from a set of 10 of horizontal filter wells. Heating is produced mainly with heat pumps, while cooling is carried out mainly as "free cooling". Peak loads and high temperature-heating is provided by a district heating network. Peak loads of the cooling demand are covered by heating/cooling machines and conventional heat exchangers.

GWHE-3. Grangetown Nursery School in Cardiff (UK)

CARDIFF PILOT AREA

Location (WGS84 coordinates): N 51.463459 W 3.179977

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	2329	4

Maximum flow [m^3/h]: 1.52
Minimum T_{gw} [ºC]: 8
Maximum T_{gw} [ºC]: 10
Depth of extraction [m]: 22
Depth of injection [m]: 18.6

	Heating	Cooling
Capacity installed [kW]	22	na
Demand [MWh]	93.3	na
Seasonal performance (SPF_{H2})	6.0	na

This groundwater heat exchanger installation used for active heating of a school building. The well doublet has a 20m spacing between extration and injection wells. Groundwater pertains to a confined shallow gravel aquifer, where water is pumped from a depth of 15 m and reinjected at a depth of 10m.
Overall heating output capacity is 22kW using two 11kW Dimplex heat pumps. The distribution system is based on wall mounted radiators. Additional back-up heating unit is an old gas boiler.
It is an example of public installation where performance and long term environmental impact on aquifer is being actively monitored and analysed.

GWHE-4. Residential building in Zagreb (Croatia)

ZAGREB PILOT AREA

Location (WGS84 coordinates): N 45.788304 E 15.956723

	heating (15/18)	cooling (21/24)
Degree-days$_{2017\text{-}18}$ [ºC·days/year]	2348	157

Maximum flow [m^3/h]: Unknown
Minimum T_{gw} [ºC]: unknown
Maximum T_{gw} [ºC]: unknown
Depth of extraction [m]: 9
Depth of injection [m]: 9

	Heating	Cooling
Capacity installed [kW]	Unknown	Unknown
Demand [MWh]	unknown	unknown
Seasonal performance (SPF_{H2})	unknown	unknown

This is a new residential building with 119 dwellings with individualised heating systems based on heat pumps. The heat source is the groundwater from a shallow aquifer. 2 wells are used for the extraction and 3 wells for injection.

GWHE-5. Glucksmann Art Museum in Cork (Ireland)

CORK PILOT AREA

Location (WGS84 coordinates): N 51.894827 W 8.490414

	heating (15/18)	cooling (21/24)
Degree-days$_{2017\text{-}18}$ [ºC·days/year]	2537	0

Maximum flow [m^3/h]: 36
Minimum T_{gw} [ºC]: unknown
Maximum T_{gw} [ºC]: unknown
Depth of extraction [m]: 12
Depth of injection [m]: 12

	Heating	Cooling
Capacity installed [kW]	200	170
Demand [MWh]	384.5	112
Seasonal performance (SPF_{H2})	4	3

Shallow geothermal energy installation used for simultaneous heating and cooling. The building has an area of 2350 m^2. The heat source is the underlying Sand and Gravel aquifer with elevated temperatures (~15 ºC) associated with the urban heat island effect. A groundwater heat exchanger system pumps water from a depth of 20 m. The open loop system is rated 170 kW and 200 kW for cooling and heating respectively against corresponding loads of 130 kW and 190 kW. Groundwater is used alternatively for toilet flushing and garden irrigation. Excess water is discharged to the nearby River Lee. Additional systems are: air handling units, an ancillary plant (two equally rated cold and hot loop circulating submersible pumps set at a depth of 12 m), ventilation and air circulation units, two gas boilers, and underfloor heating. Pay-back period was 6 years.

GWHE-6. Primary school in Polje (Ljubjana, Slovenia)

LJUBJANA PILOT AREA

Location (WGS84 coordinates): N 46.055133 E 14. 587578

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	2649	93

Maximum flow [m^3/h]: 60
Minimum T_{gw} [ºC]: 11.3
Maximum T_{gw} [ºC]: 12.5
Depth of extraction [m]: 7.4
Depth of injection [m]: 7.4

	Heating	Cooling
Capacity installed [kW]	195.5	N.A.
Demand [MWh]	434.9	N.A.
Seasonal performance (SPF_{H2})	No data	N.A.

This is a very recent shallow geothermal energy installation (operated since 2019), which is used for heating (radiators with T_{in}=55 ºC) and domestic water production in the building (5202 m^2). Groundwater level is on average 10.9 m below the surface and the estimated thickness of saturated zone is 20 m. Water is reinjected into the same aquifer. Additional heating unit is a gas boiler (200 kW). 70% of the heating demand is met by the groundwater heat exchanger system.

GWHE-7. Hospital Clínico in Zaragoza (Spain)

ZARAGOZA PILOT AREA

Location (WGS84 coordinates): N 41.643574 W 0,903282

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	1790	269

Average flow [m^3/h]: 161.8
Minimum T_{gw} [ºC]: 25.0/19.2/8.4*
Maximum T_{gw} [ºC]: 35.5/29.0/35.0*
Depth of extraction [m]: 28
Depth of injection [m]: 24.3

	Heating	Cooling
Capacity installed [kW]	NA	8589
Demand [MWh]	NA	13290
Seasonal performance (SPF_{H2})	NA	2.9-3.6/3.5**

There are 4 production wells (3 in operation) and 2 discharge wells. The mean (undisturbed) temperature is 19ºC. There are two circuits in operation (cooling only): one for continuous operation (hospital) and one for discontinuous operation (external offices). The total installed power is 8.6 MW, although the maximum cooling capacity achieved so far has been 4.7 MW (oversized heat pump units).

The current groundwater heat pump was installed to replace the previous air-to-air unit. Other factors apart from the economic one were considered for the feasibility of the project. For example, the new configuration guarantees a null risk of legionella proliferation.

** The three values correspond to each of the 3 production wells / ** Hospital circuit and External offices circui, respectively*

GWHE-8. Specialty Center Inocencio Jiménez in Zaragoza (Spain)

ZARAGOZA PILOT AREA

Location (WGS84 coordinates): N 41.656434 W 0.909370

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	1790	269

Maximum flow [m^3/h]: 39.5/26.3*
Minimum T$_{gw}$ [ºC]: unknown
Maximum T$_{gw}$ [ºC]: unknown
Depth of extraction [m]: 10
Depth of injection [m]: 5

	Heating	Cooling
Capacity installed [kW]	1454	1306
Demand [MWh]	740	640
Seasonal performance (SPF$_{H2}$)	unknown	unknown

This installation comprises two wells for extraction (35 m) and two more for injection (20 m). In Zaragoza there is an important deployment of grounwater heat exchanger systems, but mostly for cooling, which poses a risk of an excessive temperature rise of the groundwater. Installations like this help to equilibrate the heat exchanged with the groundwater through a well balanced heating and cooling loads.

**Heating and cooling flow rates, respectively*

GWHE-9. Hospital Provincial in Zaragoza (Spain)

ZARAGOZA PILOT AREA

Location (WGS84 coordinates): N 41.652275 W 0.887119

	heating (15/18)	cooling (21/24)
Degree-days$_{2017-18}$ [ºC·days/year]	1790	269

Average flow [m^3/h]: 38.3
Minimum T$_{gw}$ [ºC]: 18.5**
Maximum T$_{gw}$ [ºC]: unknown
Depth of extraction [m]: 30 / 33*
Depth of injection [m]: 34.8

	Heating	Cooling
Capacity installed [kW]	NA	1400
Demand [MWh]	NA	1200
Seasonal performance (SPF$_{H2}$)	NA	No data

In Hospital Provincial 2 production wells and 2 injection wells are used in the groundwater heat exchanger installation. A wellhead siphon is used to prevent air entry into the groundwater circuit.

**Injection 1 and 2, respectively / ** Value at the beggining of the exploitation, in 2011*

GWHE-10. AQVA Spa Center in Girona (Spain)

GIRONA PILOT AREA

Location (WGS84 coordinates): N 41.989106 E 2.825784

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

Maximum flow [m^3/h]: 8
Minimum T_{gw} [ºC]: 14.4
Maximum T_{gw} [ºC]: 15.4

Depth of extraction [m]: 18 / 20*
Depth of injection [m]: 18

	Heating	Cooling
Capacity installed [kW]	80	80
Demand [MWh]	No data	No data
Seasonal performance (SPF_{H2})	No data	No data

This a very unique groundwater heat exchanger system for several reasons. There are 4 wells (2+1 for production and 1 for injection) drilled in a very reduced space (8x25m^2). The Spa center was built from the remains of a ancient building located in the historic part of Girona city (it dates from Roman times). Simultaneous cooling, heating (dehumification) and domestic hot water is carried out by the installation (6-pipe system). The system is capable of meeting the entire demand, although it has a gas-boiler as a back-up unit. Two storage tanks (cool and warm water, 2500 liters each) and the air-treatment unit adds to heating/cooling infrastructure. Nevertheless, the system is totally integrated within the building boundaries, with no visible parts from outside. The extraction zone of the wells are not cased, since the soil is a consolidated rock formation (Limestone).

**Values correspondingto the 2 wells used for extraction (there is an additional well but it is currently unused with extraction depth at 18m)*