What is Geothermal Energy?

La géothermie à Bruxelles / Geothermie in Brussel
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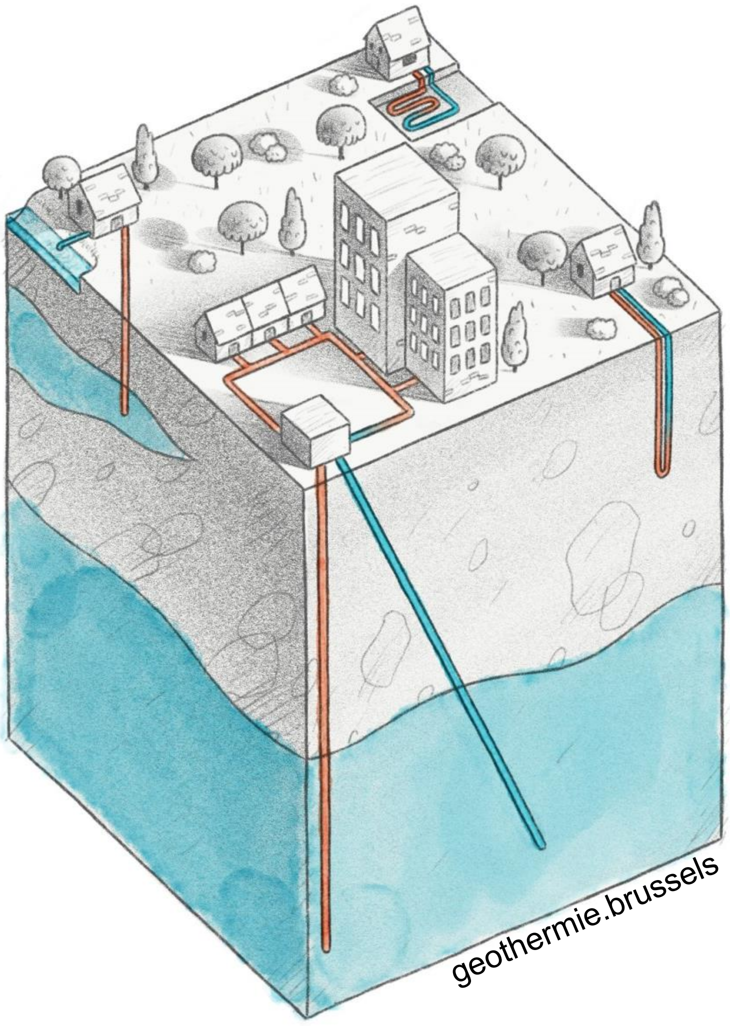
Geothermal energy
Introduction

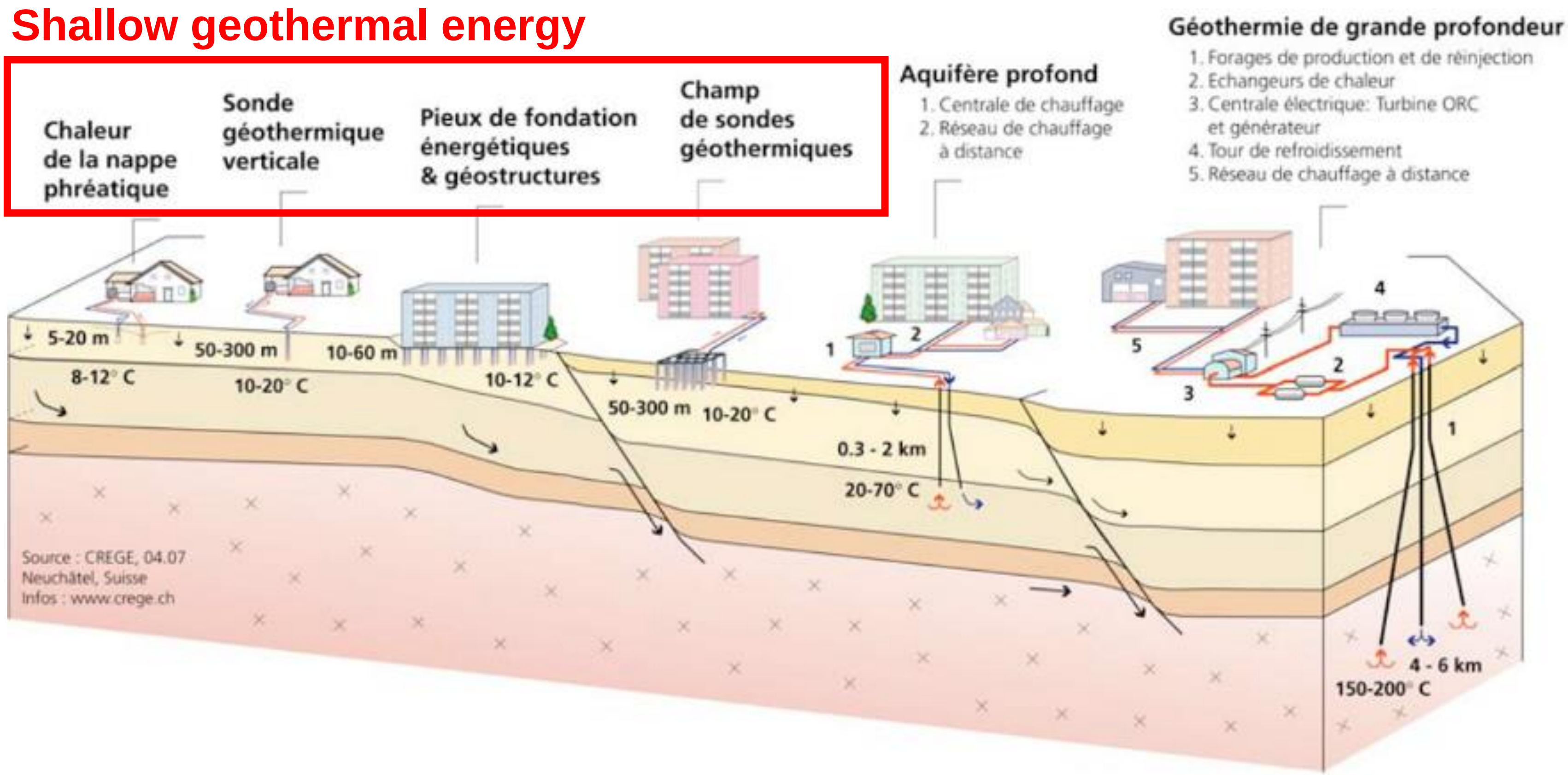
Geothermal energy systems aim at extracting heat from the ground for heating or electricity production.

By extension, it includes also the systems that dissipate heat into the ground, for cooling purpose.



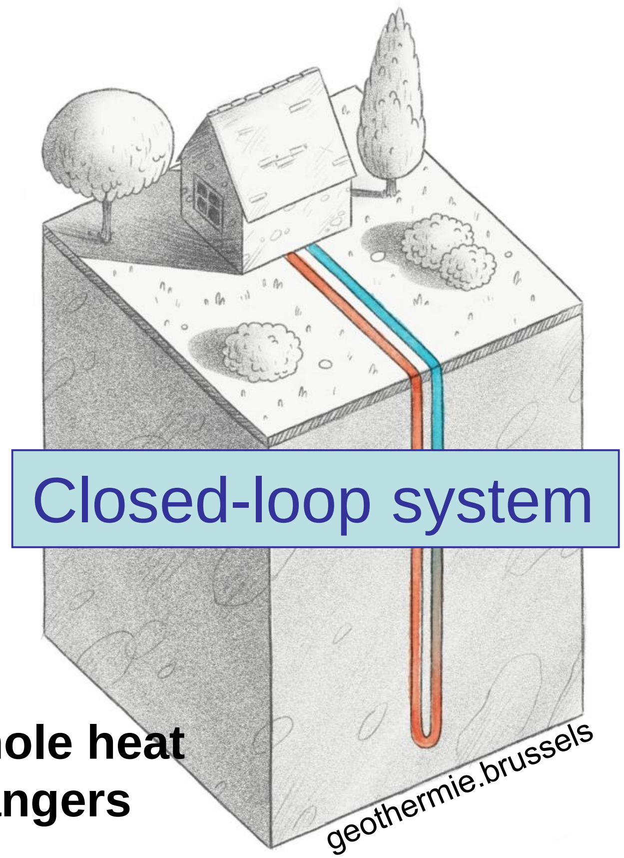
Geothermal energy
Introduction

Different systems for different applications,
in different geological contexts

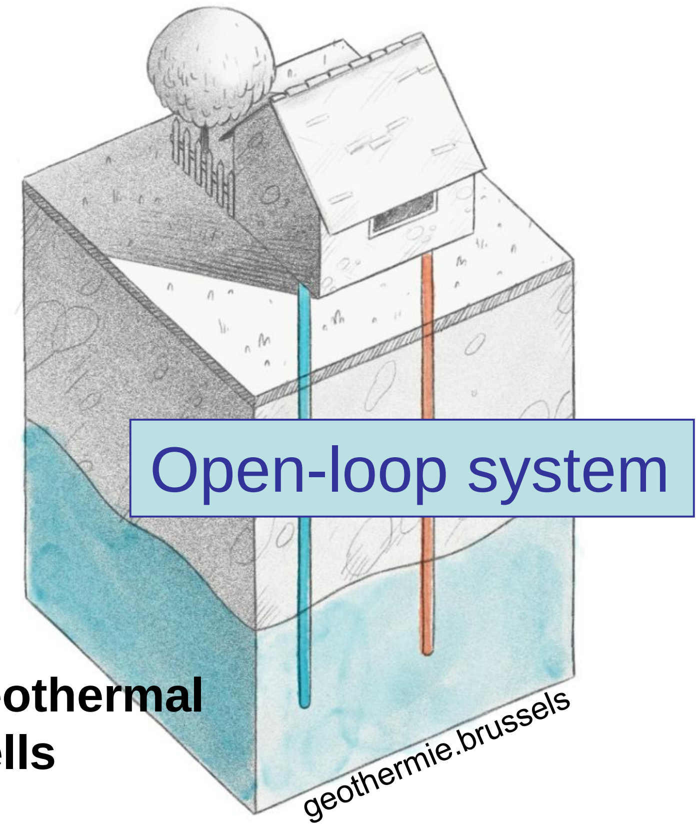


Source: *www.crege.ch*

Geothermal energy
Introduction



Borehole heat exchangers

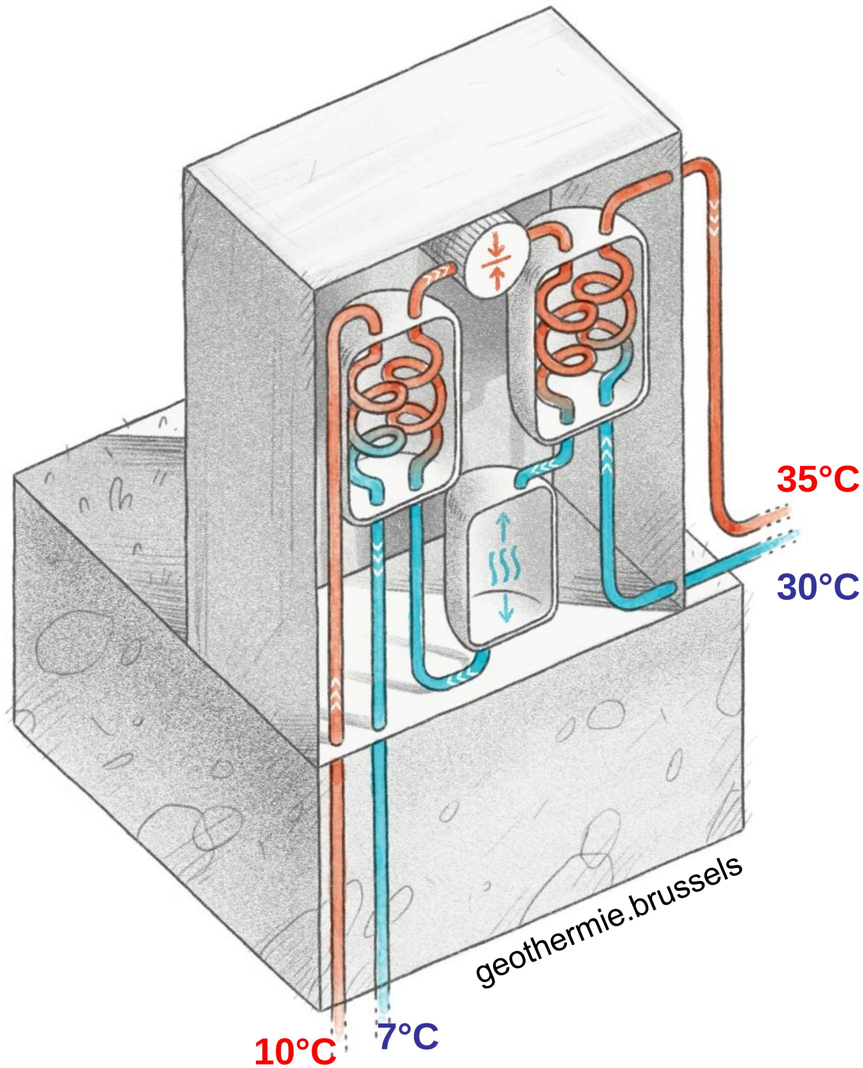


Geothermal wells

- **Heating and/or Cooling**
- **Energy Storage (ATES or BTES)**
- Sustainable (recoverable) heat source
- High performance of the heat pump (COP > 4) due to stable temperature

Geothermal energy
The heat pump

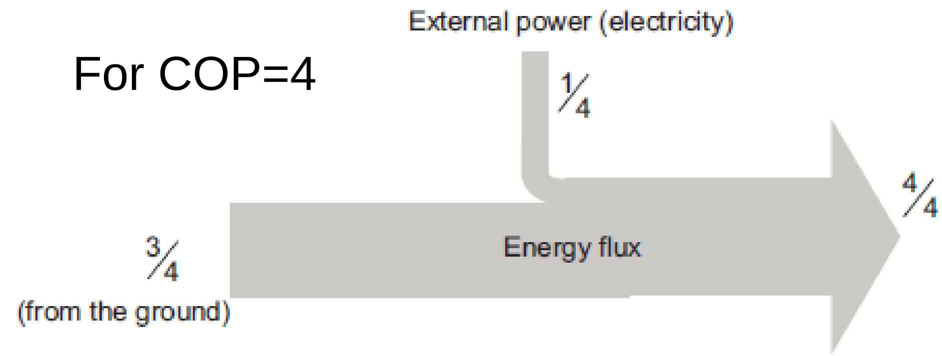
The **heat pump** allows an exchange of heat between the primary circuit (in the ground) and the secondary circuit (in the building).

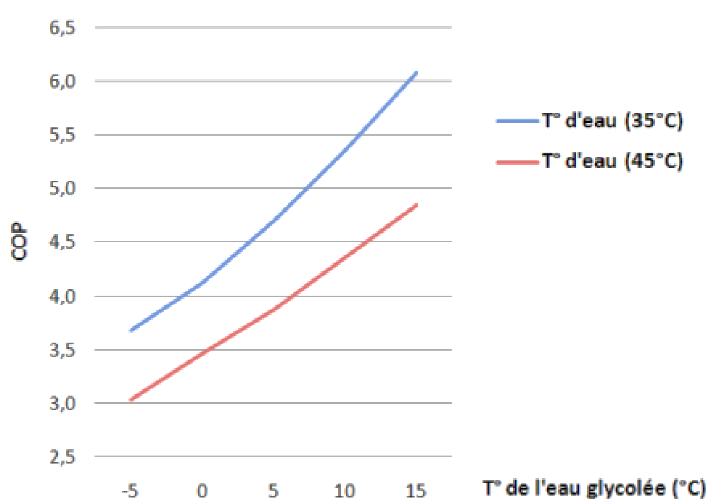


Geothermal energy
COP – Coefficient of performance

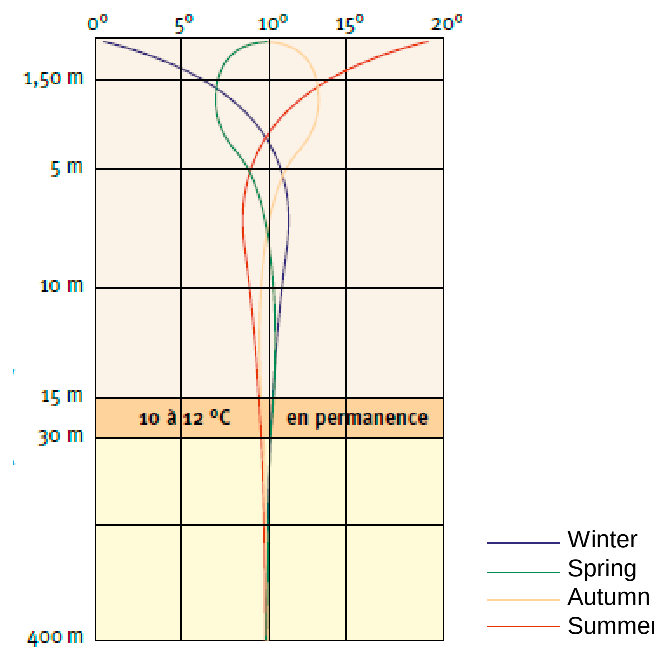
$$COP = \frac{\text{energy output after heat pump [kW]}}{\text{energy input for operation [kW]}}$$

For COP=4





Source: www.ef4.be



Source: CSTC-NIT 259

Closed-loop systems
Various types

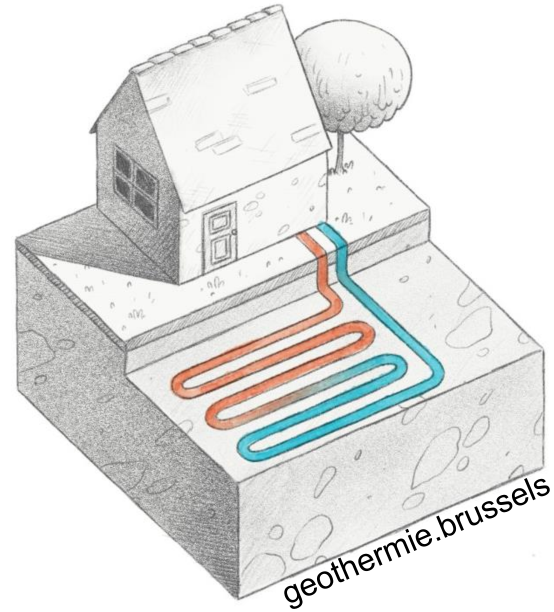
Sub-surface tubes

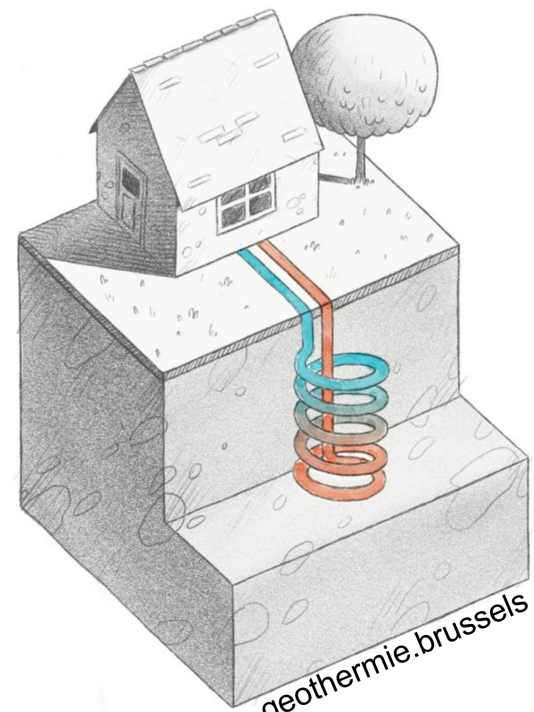
- **Tubes set up in a 3 to 5 m depth excavation**
- Closed loop: heat exchanger fluid in tubes
- Ground temperature affected by seasonal variations

  Tmax ≈ 14°C in September

  Tmin ≈ 7°C in April

- Need large surface : 1 to 2 times the heated surface of the building
- Interaction with roots and plants





Closed-loop systems
Various types

Sub-surface tubes

Source: www.lemoniteur.fr

Source: www.espace-eco-habitat.fr

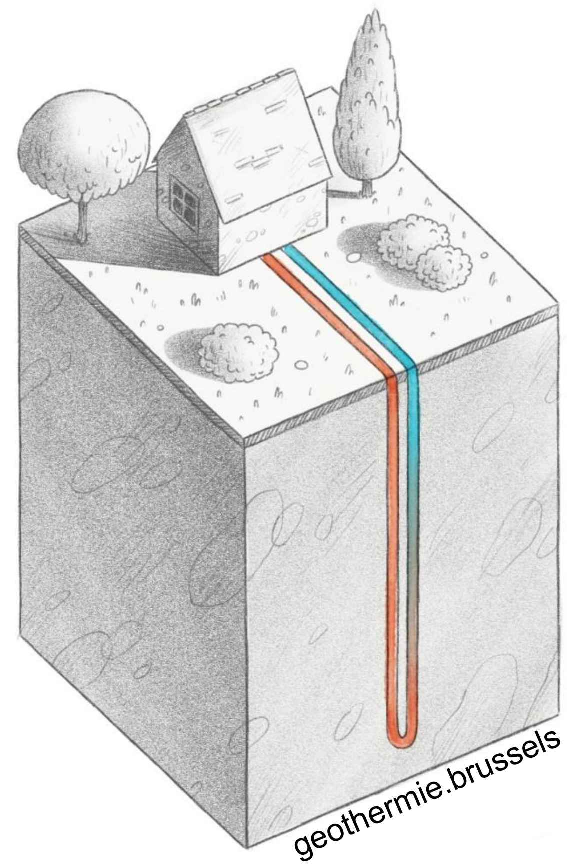
Closed-loop systems
Various types

Borehole heat exchanger

- Boreholes of ≈15 cm in diameter, 50 – 300 m in length
- **U tubes in borehole (closed loop)**
- Energy balance:

  ground ≈ 75-80 %

  electricity for heat pump ≈ 20-25 %
- Maximal power: 40 to 80 W / meter of probe



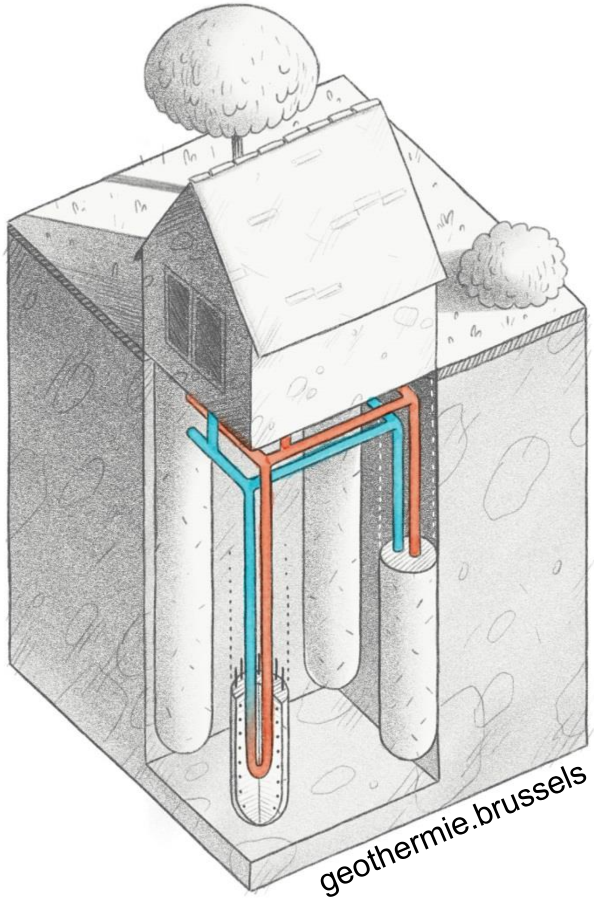
Closed-loop systems
Various types

Borehole heat exchanger

Source: *IBGE - Service Géologique de Belgique - Eurodrill*

Closed-loop systems
Various types

Heat exchanger geostructures



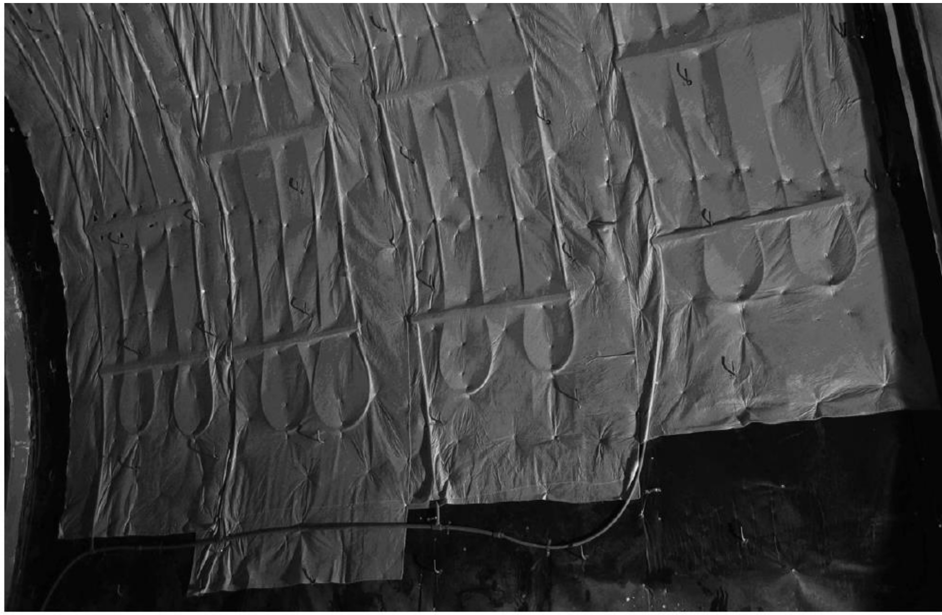
- **Structural role**
- No need of additional boreholes, the foundation is used as a heat exchanger
- **Piles, retaining walls, tunnels, pavements**
- U tubes in the geostructures
- Energy balance: ground ≈ 75 %

  electricity for heat pump ≈ 25 %
- Maximal power: 50 W / m of pile

Closed-loop systems
Various types

Heat exchanger geostructures

<u>Source:</u> *www.bine.info - © Katzenbach, Darmstadt*



<u>Source:</u> *Adam and Markiewicz, Géotechnique 2009*

Closed-loop system
Geothermal potential of the ground

Heat extraction in agreement with the geology

Underground	Specific heat extraction for 1800 h	Specific heat extraction for 2400 h
General guideline values:		
Poor underground (dry sediment) (λ < 1.5 W/(m · K))	25 W/m	20 W/m
Normal rocky underground and water saturated sediment (λ < 1.5–3.0 W/(m · K))	60 W/m	50 W/m
Consolidated rock with high thermal conductivity (λ > 3.0 W/(m · K))	84 W/m	70 W/m
Individual rocks:		
Gravel, sand, dry	< 25 W/m	< 20 W/m
Gravel, sand, saturated water	65–80 W/m	55–65 W/m
For strong groundwater flow in gravel and sand, for individual systems	80–100 W/m	80–100 W/m
Clay, loam, damp	35–50 W/m	30–40 W/m
Limestone (massif)	55–70 W/m	45–60 W/m
Sandstone	65–80 W/m	55–65 W/m
Siliceous magmatite (e.g. granite)	65–85 W/m	55–70 W/m
Basic magmatite (e.g. basalt)	40–65 W/m	35–55 W/m
Gneiss	70–85 W/m	60–70 W/m
The values can vary significantly due to rock fabric such as crevices, foliation, weathering, etc.		

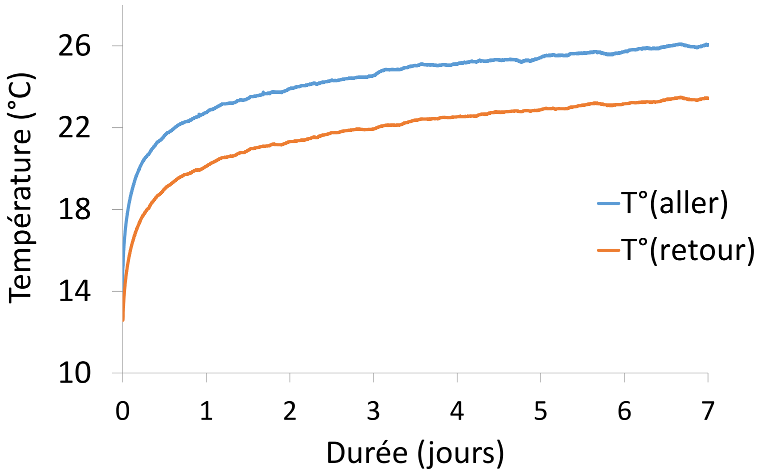
Source: *VDI (2004)*

Closed-loop system
Geothermal potential of the ground

Thermal response test (TRT)

The TRT apparatus provides a continuous water circulation inside a borehole heat exchanger with a constant heat input. The evolution of temperature of the fluid is recorded along time. It provides an average thermal conductivity of the ground.

Source: GeoLys



$$T_f(t) - T_o = k \cdot \ln(t) + m$$

$$\lambda = \frac{Q}{4 \cdot \pi \cdot H \cdot k}$$

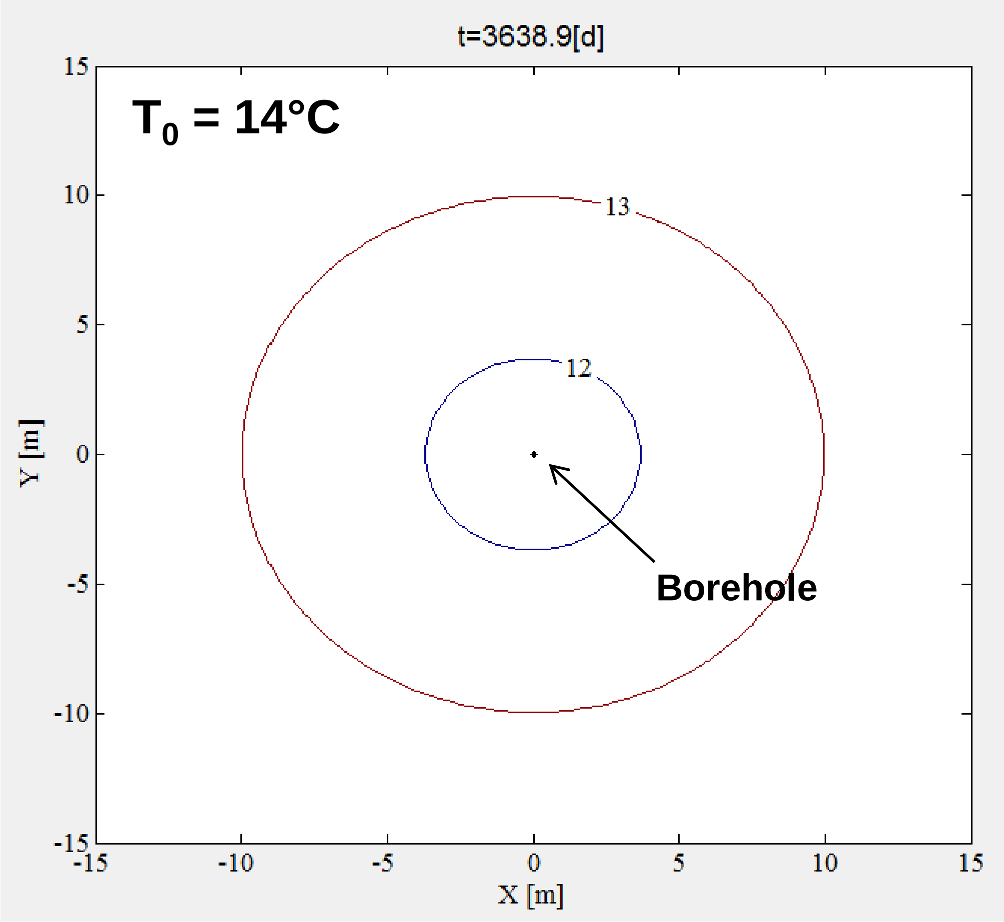
Closed-loop systems
Temperature during operation

Example: Good design

10 years of operation

- Borehole length = 100 m
- Heat extraction = **8 kW (1800 h/year)**
- Averaged heat extraction = 16.4 W/m
- Thermal conductivity of the ground = **2.5 W/m (saturated sand)**
- No groundwater flow

T_{ground} = 11.5°C



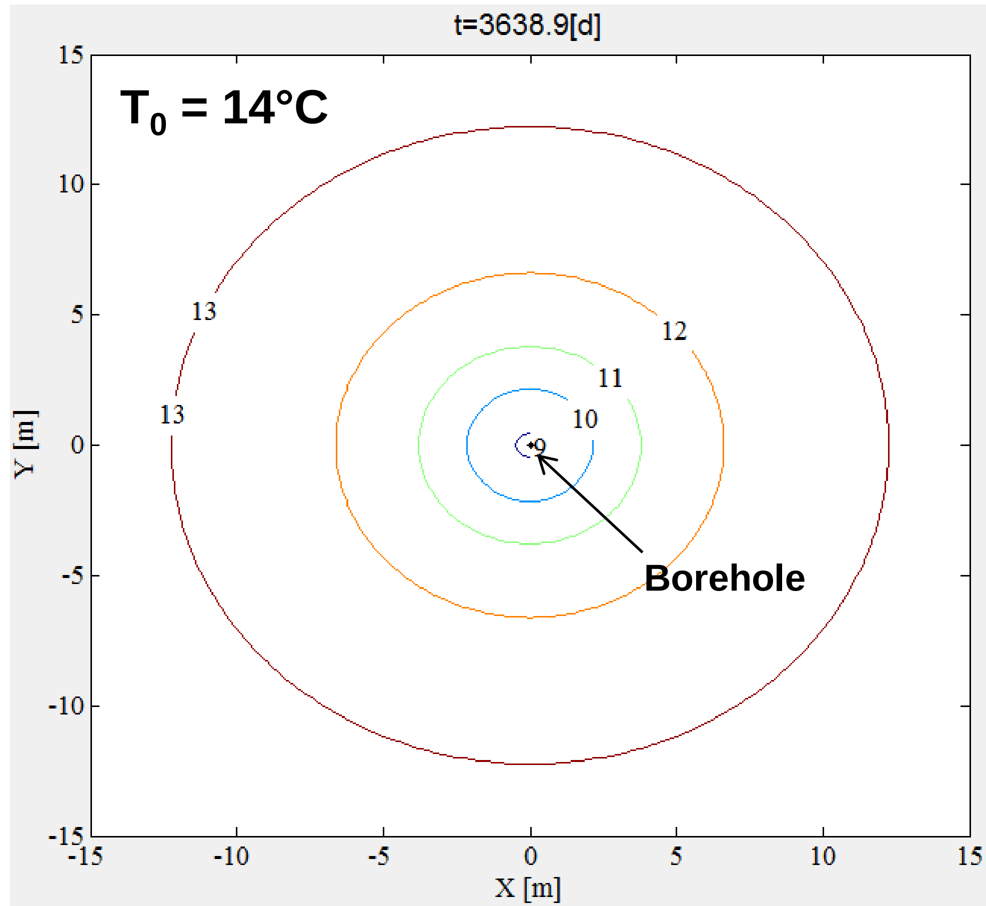
Closed-loop systems
Temperature during operation

Example: Quite good design

10 years of operation

- Borehole length = 100 m
- Heat extraction = **8 kW (1800 h/year)**
- Averaged heat extraction = 16.4 W/m
- Thermal conductivity of the ground = **1.4 W/m (clay)**
- No groundwater flow

T_{ground} = 8.5°C



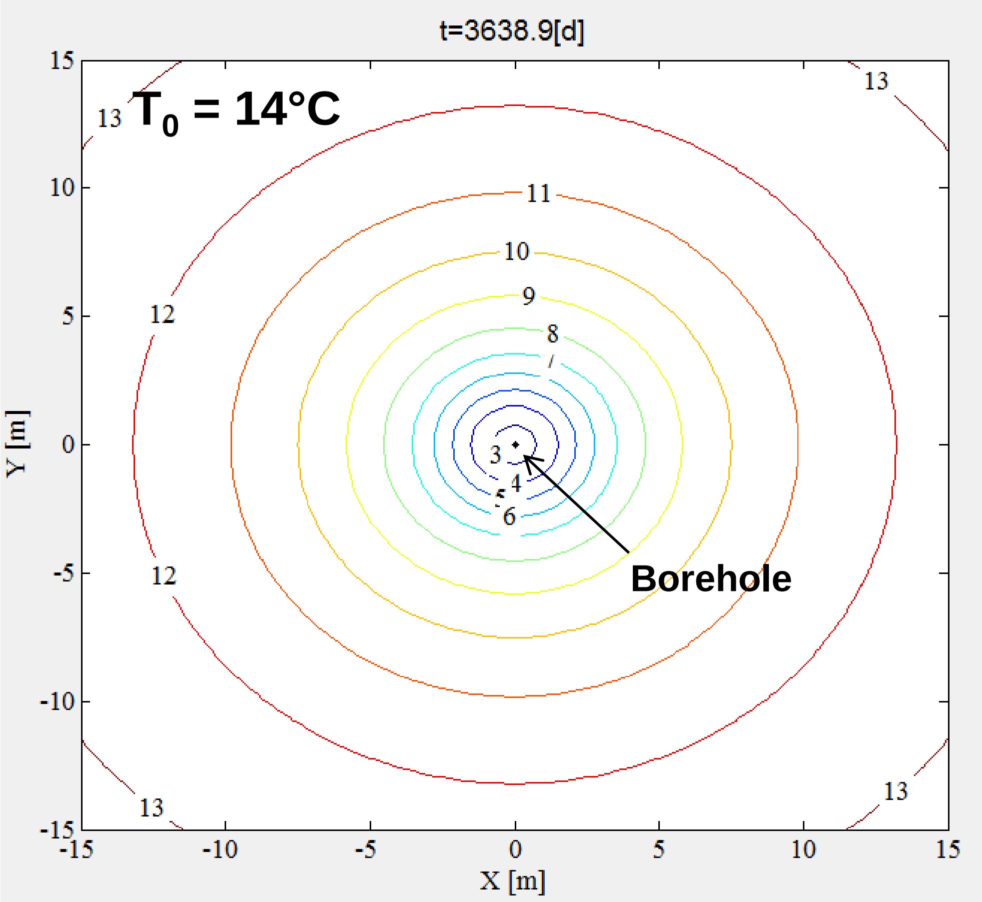
Closed-loop systems
Temperature during operation

Example: Bad design – Excessive use of the system

10 years of operation

- Borehole length = 100 m
- Heat extraction = **8 kW (3600 h/year)**
- Averaged heat extraction = 36.8 W/m
- Thermal conductivity of the ground = **1.4 W/m (clay)**
- No groundwater flow

T_{ground} = 2.5°C

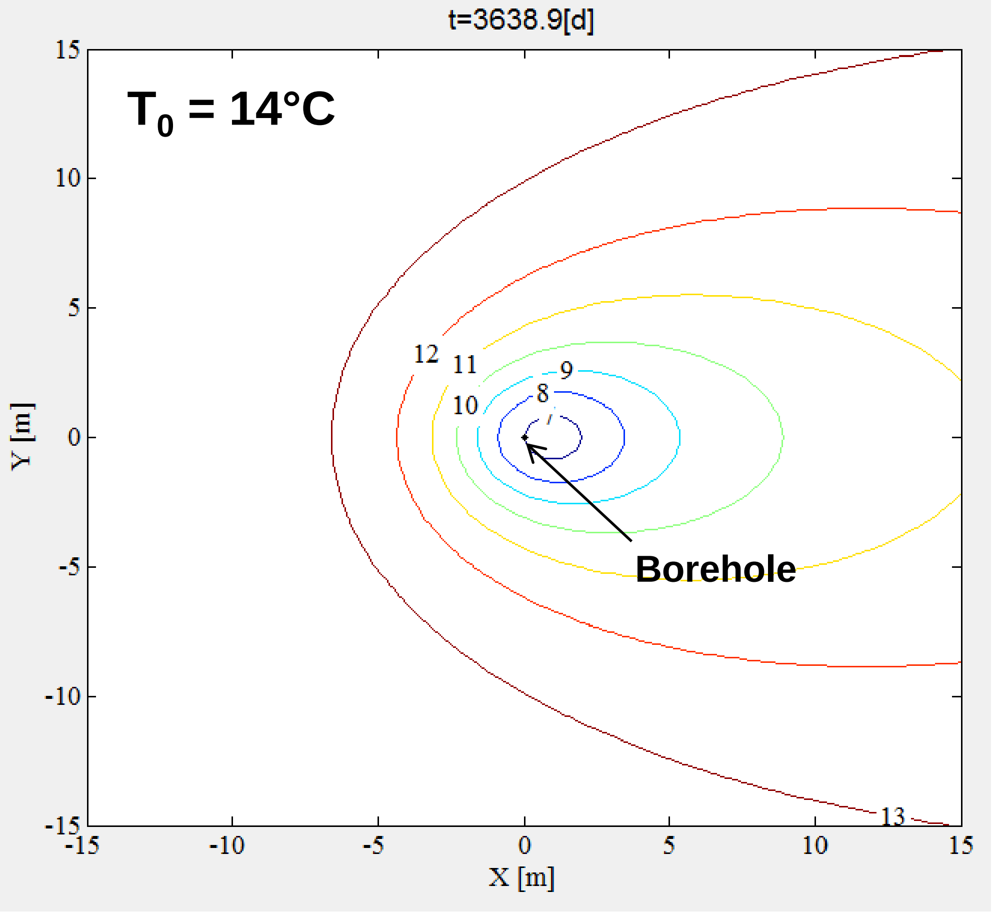


Closed-loop systems
Temperature during operation

Example: Quite good design

10 years of operation

- Borehole length = 100 m
- Heat extraction = **8 kW (3600 h/year)**
- Averaged heat extraction = 36.8 W/m
- Thermal conductivity of the ground = **1.4 W/m (clay)**
- **Groundwater flow = 10^{-7} m/s**

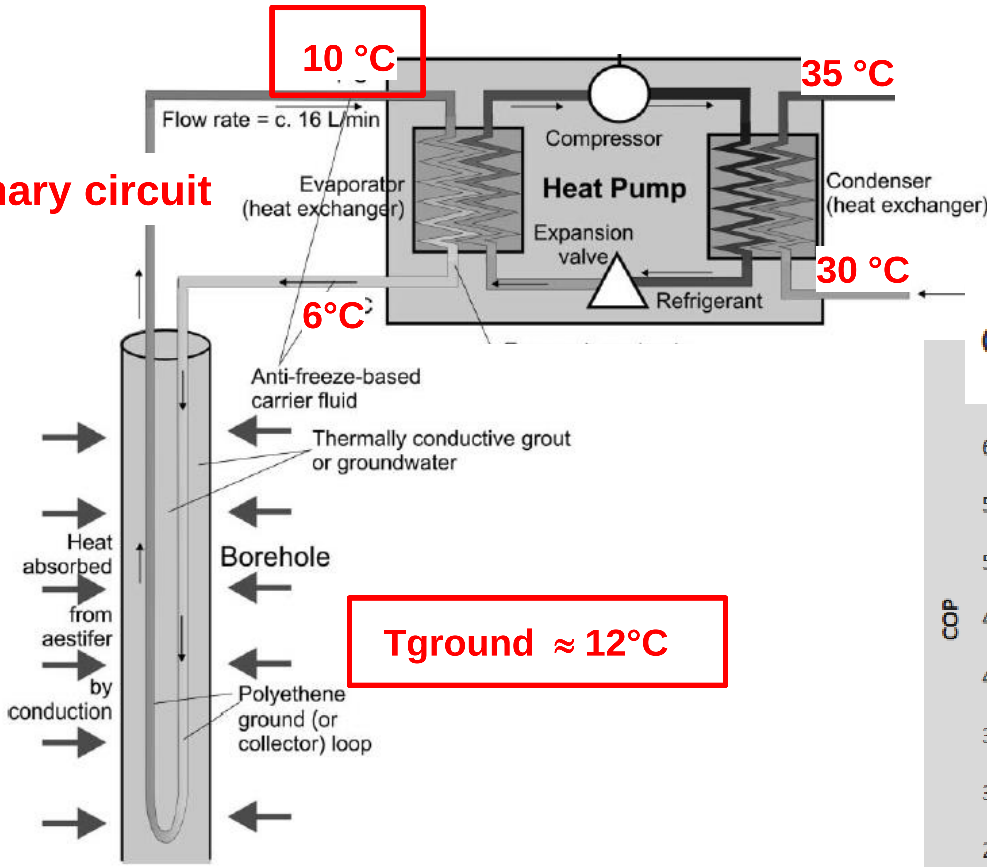


T_{ground} = 7°C

Closed-loop systems
Temperature during operation

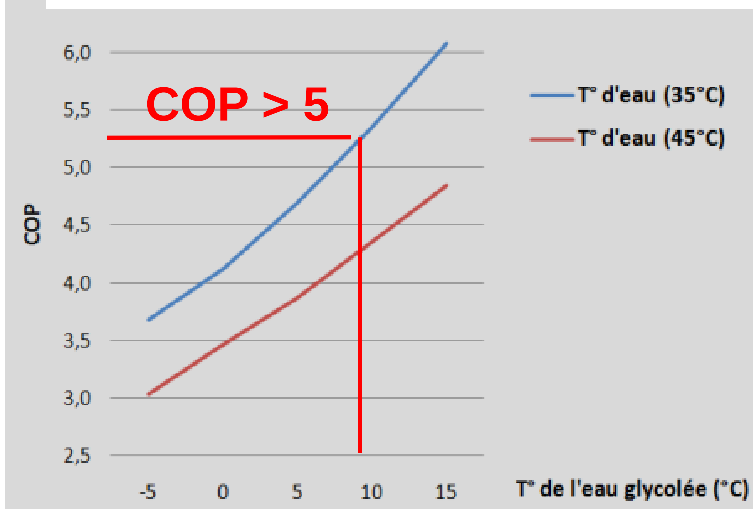
Example: Good design

Primary circuit



Secondary circuit

$$COP = \frac{\text{energy output after heat pump [kW]}}{\text{energy input for operation [kW]}}$$

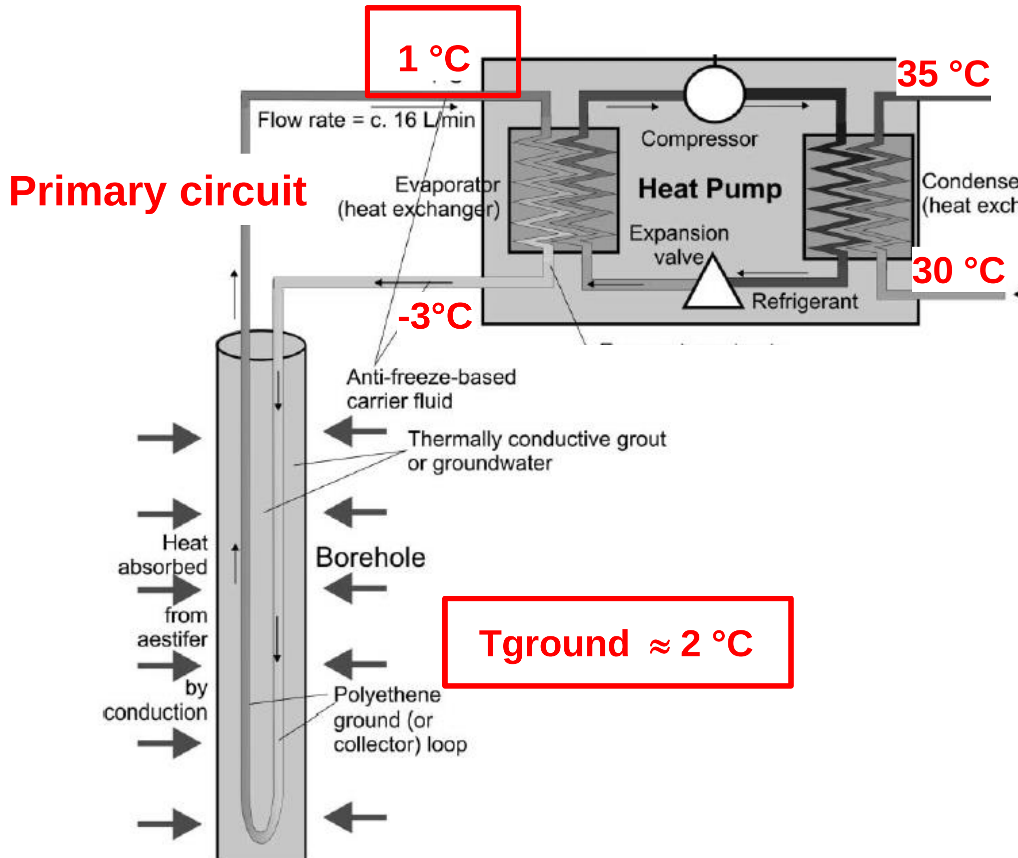


Source: adapted from Banks (2009)

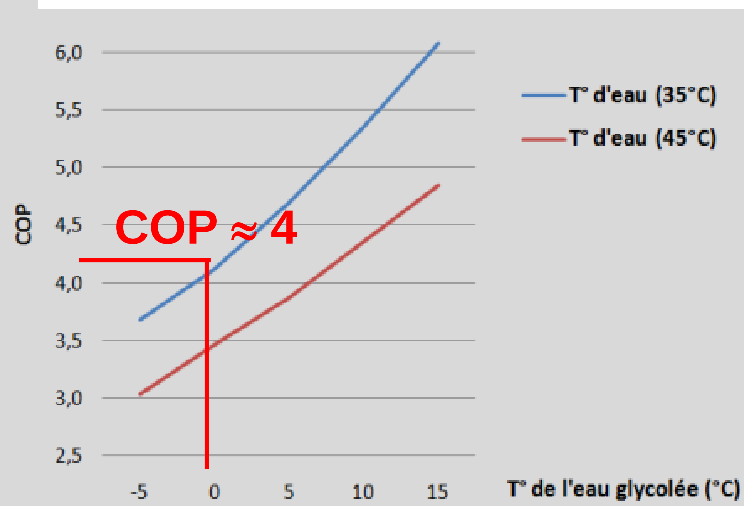
Source: www.ef4.be

Closed-loop systems
Temperature during operation

Example: Bad design – Excessive use of the system



$$COP = \frac{\text{energy output after heat pump [kW]}}{\text{energy input for operation [kW]}}$$



Source: adapted from Banks (2009)

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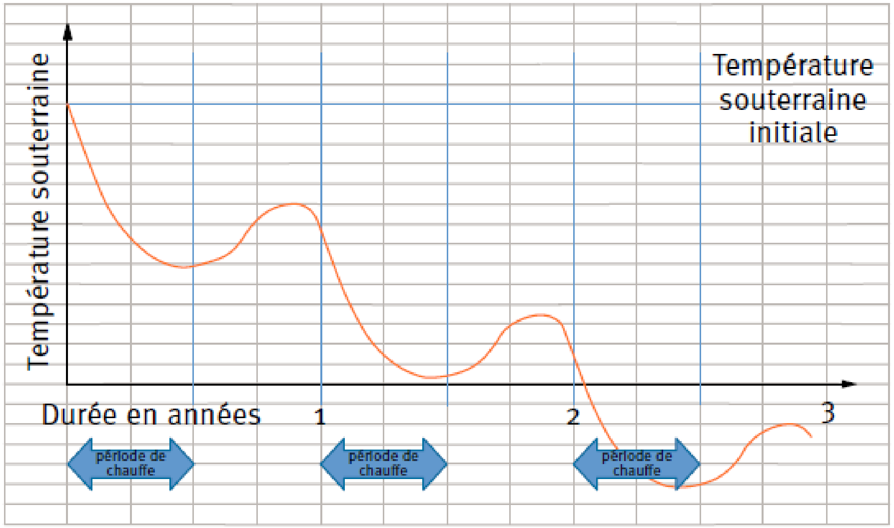
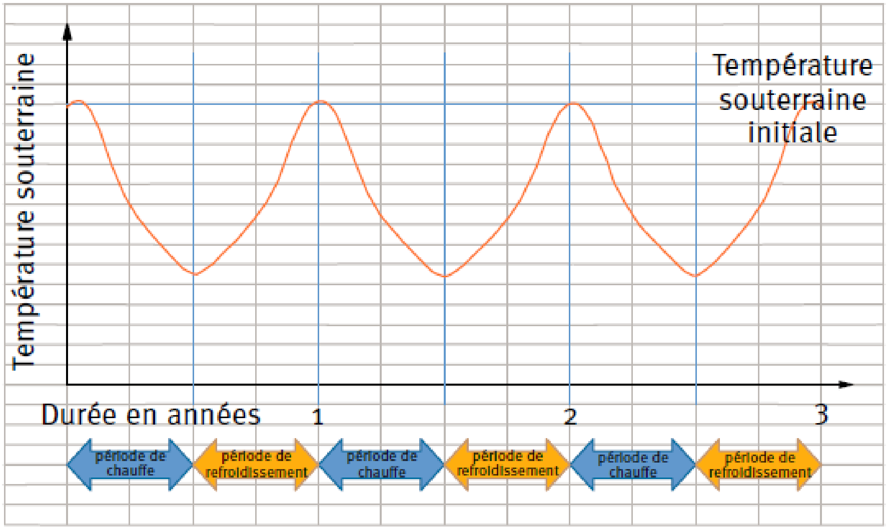
Closed-loop systems
Temperature during operation

Unbalanced system



Well - balanced system



Source: CSTC-NIT 259

Due to low thermal properties of ground and/or excessive use of the system

Due to thermal recharge during recovery period and/or reversible heating/cooling

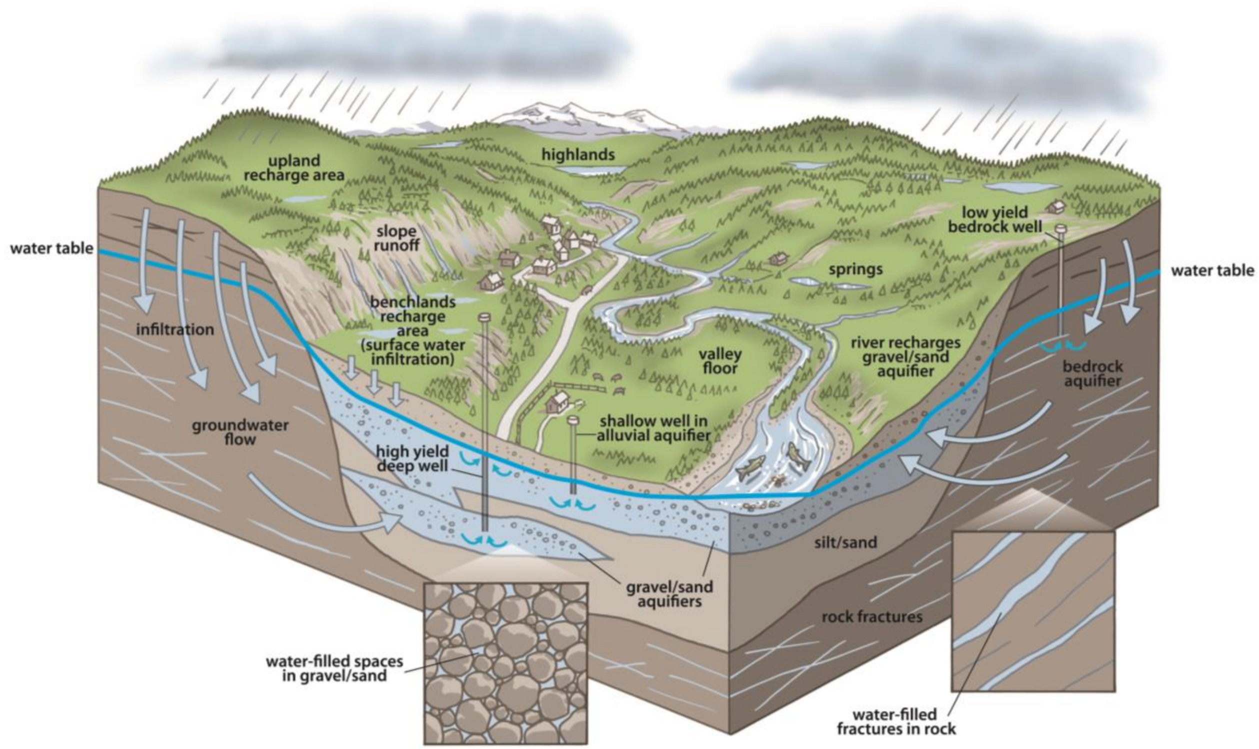
Closed-loop systems
Partial conclusions

- Closed-loop systems are **possible (almost) everywhere**
- The efficiency of the system depends on **the ground characteritics** and the good design of the system
- The design must be done in agreement with the ground and the need of the building
- **Reversible heating/cooling** strongly improves the efficiency of the system (BTES)
- **Coefficient of perfomance** larger than 5 can be expected (when well designed)

Open-loop systems

Aquifer Thermal Energy Storage (ATES)

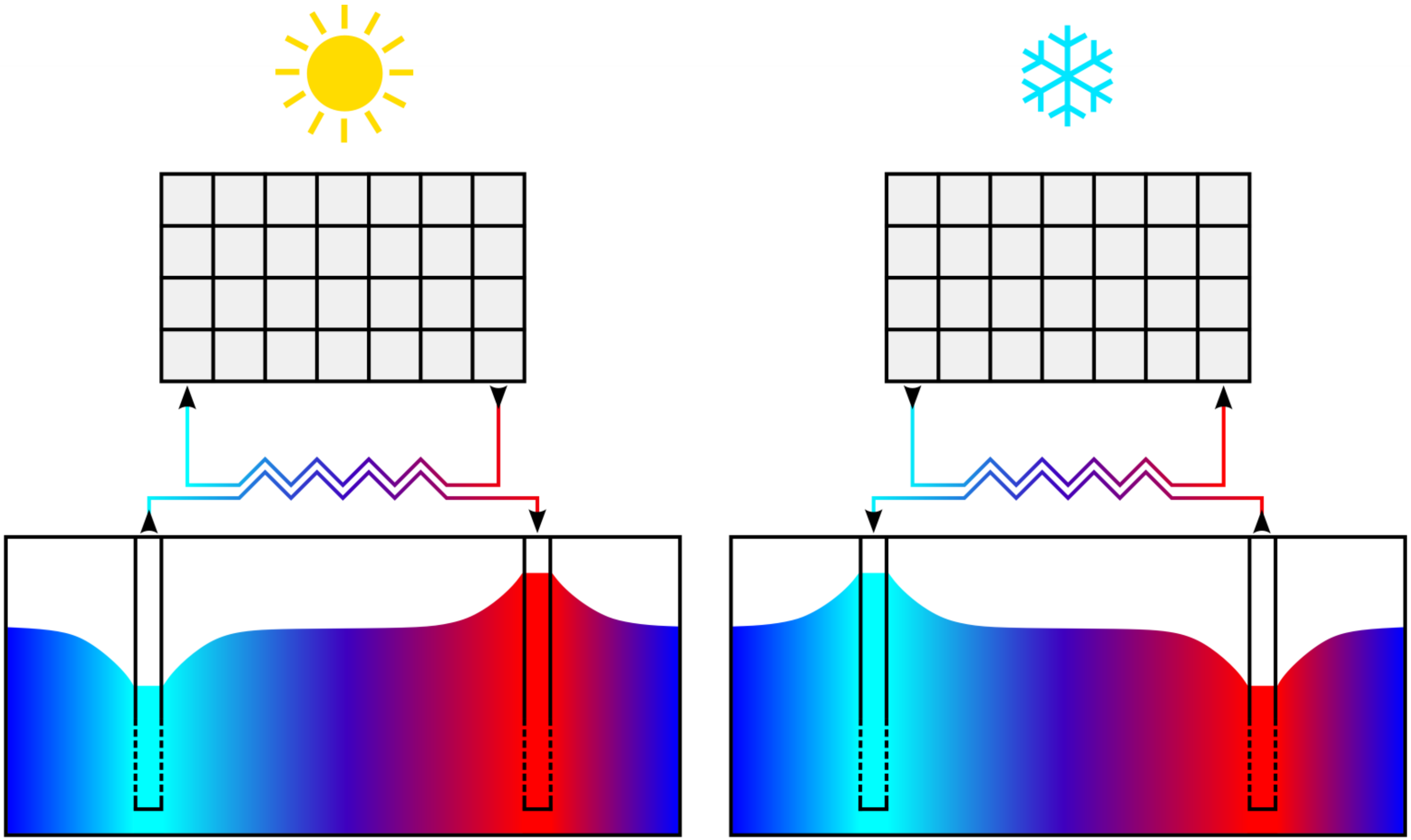
- Store energy in aquifer
- Open connection to the groundwater
- Pumping and injection wells
- Depths of several tens of meters to approximately 200m



(watershed-watch.org)

Open-loop systems

Aquifer Thermal Energy Storage (ATES)



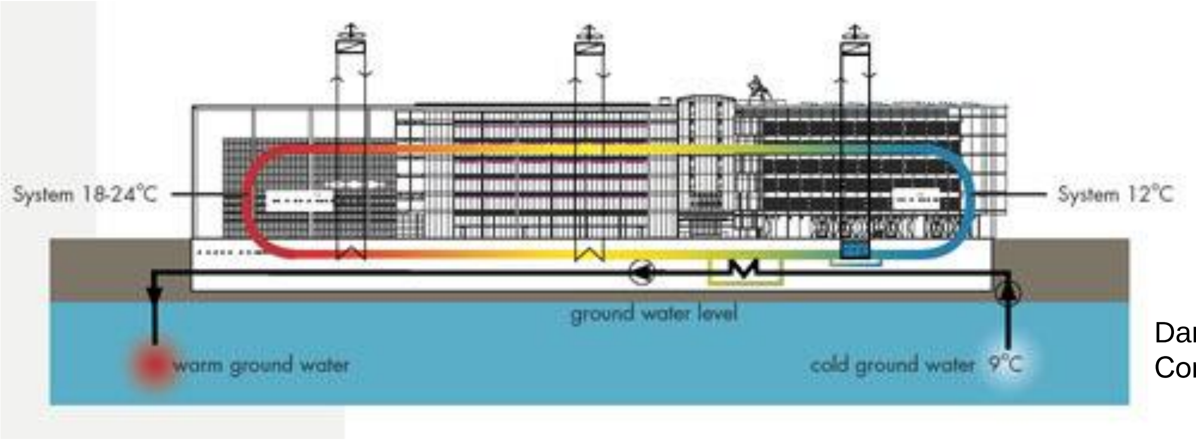
(Mathias Possemiers, 2015)

Open-loop systems

Aquifer Thermal Energy Storage (ATES)

Applications

- Energy savings and CO_2 reduction
- Larger buildings (offices, hospitals, shopping centers, …)
- Horticulture
- from 200-300 kW
- Energy savings up to 85-95% for cooling and 40-60% for heating



Danish Broadcasting Corporation's Media House

Open-loop systems

Aquifer Thermal Energy Storage (ATES)

Factors influencing feasibility and efficiency

- Geology and hydrogeology
    - Saturated thickness of aquifer
    - Hydraulic conductivity of aquifer
    - Depth of aquifer
    - Groundwater flow velocity
    - Redox conditions
- Legislation

Assessment	Criteria
Favourable	Aquifer >15 m thickness.
	Aquifer depth between 5-80 m.
	Ground water flow <0.2 m/day.
	Static head between 5 and 20 m below grade
Acceptable	Aquifer thickness is 2-15 m.
	Aquifer depth is 80-150 m.
	Ground water flow is 0.2-0.3 m/day.
	Static head is 20-50 m, or between 5 m and 5 m above grade

Ford and Wong, 2010

Open-loop systems

Aquifer Thermal Energy Storage (ATES)

Environmental impacts and risks

- Mixing of groundwater
- Interference with soil and groundwater pollution
- Effects of groundwater level changes on ecology and subsidence
- Temperature effects limited in case of limited temperature range
- Interference with other systems

Questions?

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