BOREHOLE THERMAL ENERGY STORAGE (BTES): LT AND HT BTES WITH CASE STUDIES

Charles MARAGNA, BRGM (c.maragna@brgm.fr)

GEOTHERMAL DHC
Towards Decarbonized Heating and Cooling!

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Géosciences pour une Terre durable
brgm

BOREHOLE THERMAL ENERGY STORAGE (BTES): LT AND HT BTES WITH CASE STUDIES

- Assumed definitions
- Examples of High-Temperature BTES
- Cost elements of High-Temperature BTES
- BTES as component of a thermal energy system
- Some concluding remarks

ASSUMED DEFINITIONS

- Low-Temperature BTES:
  - Indeed a reversible Ground-Source Heat Pump (GSHP) connected to a field of Borehole Heat Exchanger (BHE)
  - Suitable when heating and cooling needs are balanced
    → No long-term drift of ground temperature
    → Compact BHE fields possible
  - Assuming ground initial temperature $T_0 \approx 15$ °C, T oscillates between 5 °C (winter) and 25 °C (summer)
  - Free cooling (*geocooling*) may become possible
  - See presentation about UTES in 5GDHC grids

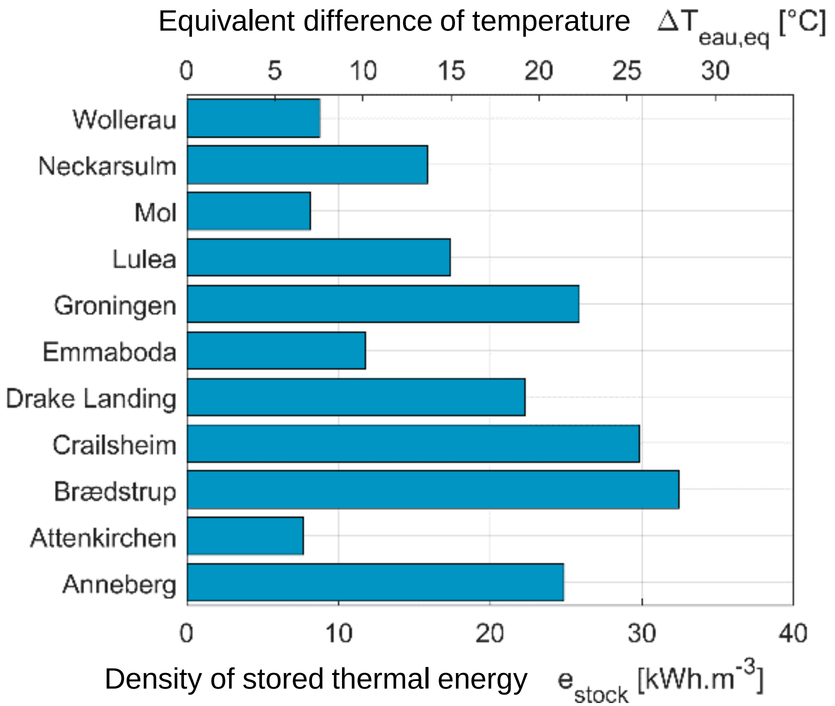
- High-Temperature BTES :
  - When available, a High Temperature source (e.g. solar or waste heat @80 °C) heats up the ground
  - The heat is retrieved from the ground up to the temperature flowing back from the DHN (e.g. 35 °C)
  - NB: not suitable if cooling is needed

HIGH TEMPERATURE BOREHOLE THERMAL ENERGY STORAGE: CASE STUDIES

- **Characteristics of some BTES**

BTES	Thermal source	Number of BHE	BHE depth [m]	Maximal temperature [°C]	Storage volume [×1000 m³]	Storage capacity [MWh]	Storage efficiency
Drake Landing	Solar	144	35	80	35	780	0,5
Lulea	Waste heat	120	65	65	115	2000	0,5
Emmaboda	Waste heat	141	149	45	323	3800	n/a
Anneberg	Solar	99	65	45	59	1467	0,46
Neckarsulm	Solar	528	30	55	63	1000	n/a
Crailsheim	Solar	80	55	30	38	1135	n/a
Attenkirchen	Solar + Heat Pump	90	30	30	10	77	
Brædstrup	Solar	48	45	45	19	616	0,61
Mol	Waste heat	144	30	30	16	130	n/a
Groningen	Solar	20	20	20	23	595	n/a
Wollerau	Gas (?)	36	120	n/a	40	350	n/a

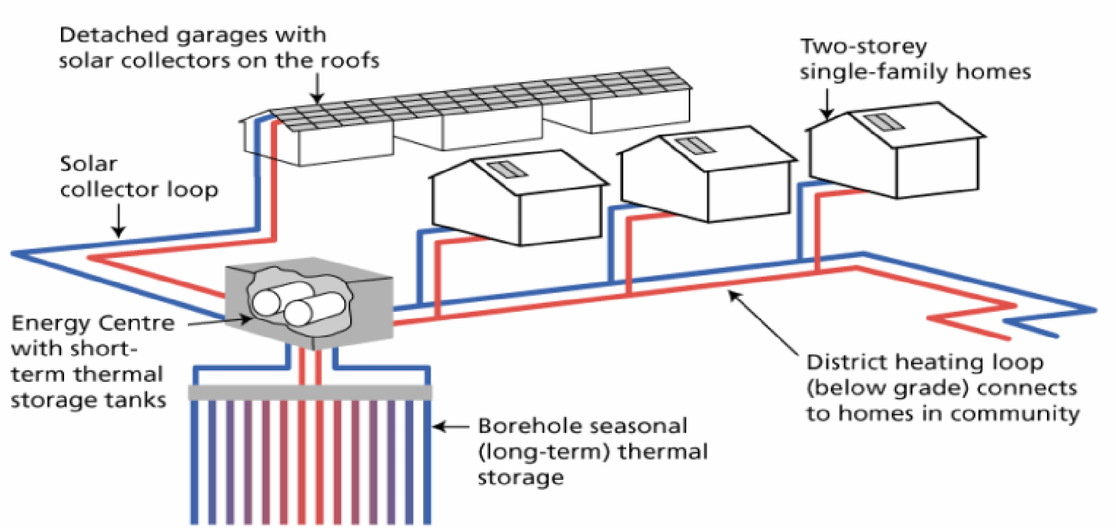
Source: Geothermica Heatstore project

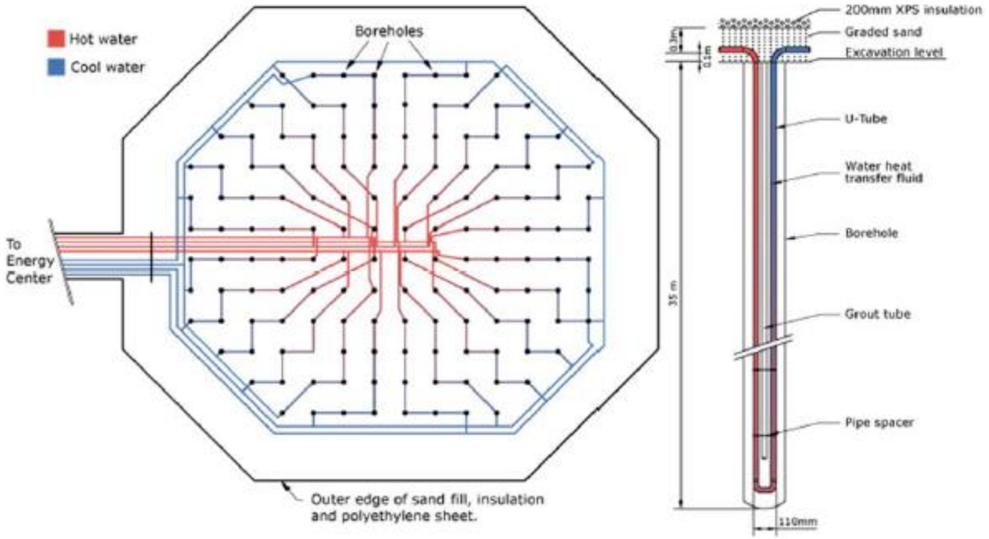


Density of stored thermal energy for 10 BTES. The upper axis accounts for an equivalent temperature difference applied on a mass of water

HIGH TEMPERATURE BOREHOLE THERMAL ENERGY STORAGE: CASE STUDIES

- **Solar Drake Landing BTES, Okotoks, Canada**
  - Providing heating and DHW to 52 individual housing through a micro DHN
  - NB: Very harsh climate (Heating Degree Days @18°C HDD_{18} = 4924 °C.day vs. HDD_{18} ≈ 2100 °C.day in Paris)
  - 2293 m² of solar thermal collectors
  - 144 BHE, 35 m deep (V_{BTES} ≈ 24 000 m^3)
  - 90% of the thermal need (≈750 MWh/y) covered by solar energy, either directly or through the BTES



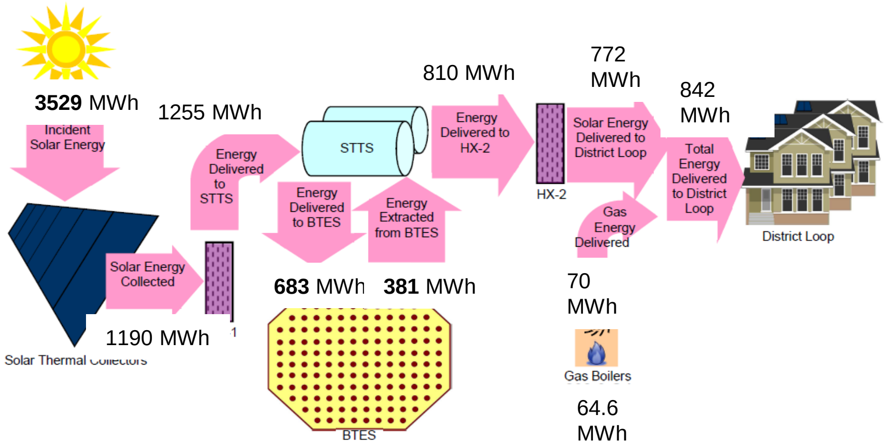


Source: The Drake Landing Solar Community Project - Early Results

HIGH TEMPERATURE BOREHOLE THERMAL ENERGY STORAGE: CASE STUDIES

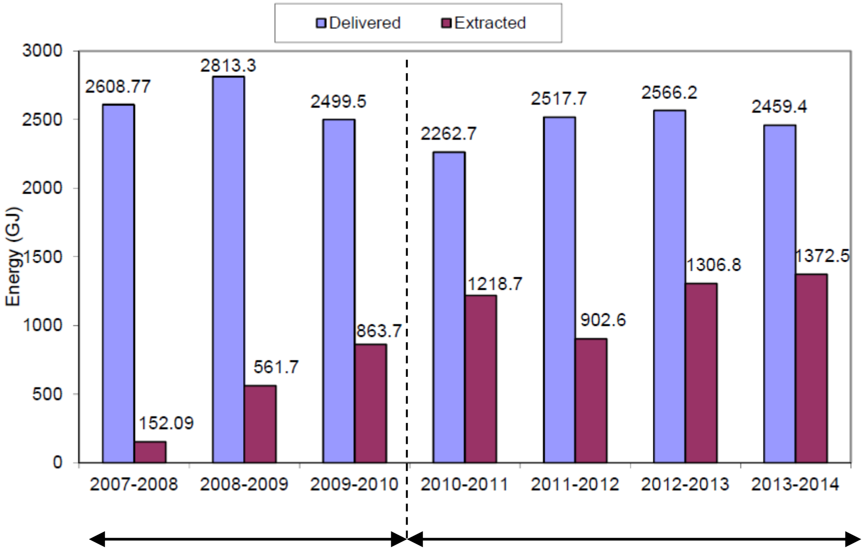
- **Solar Drake Landing BTES, Okotoks, Canada**
  - Sizing based on a dynamic model of the whole installation implemented in TRNSYS ; predictions turned out to be reliable (e.g. solar fraction estimated to be 89 % at year #4 vs. 86% measured)
  - A well documented & monitored installation.

Sankey diagram (2014)



Source: Drake Landing Solar Community Energy Report 2014

Yearly balances on BTES



Transient regime

Periodic regime
Average efficiency ≈ 49%

HIGH TEMPERATURE BOREHOLE THERMAL ENERGY STORAGE: CASE STUDIES

- **Crailsheim BTES, Germany**
  - Operational since 2008
  - 7300 m² of solar thermal collectors
  - 80 BHE, 55 m deep (V_{BTES} ≈ 37 500 m^3)
  - A 3D discretized model of the BTES was developed in Feflow®, including the hydraulic properties of the geological layers and the hydrogeological conditions
  - It enlightened the influence of the underground water flow upon the feasibility of a HT-BTES, even at low velocities (v_{Darcy} ≈ a few m/y)

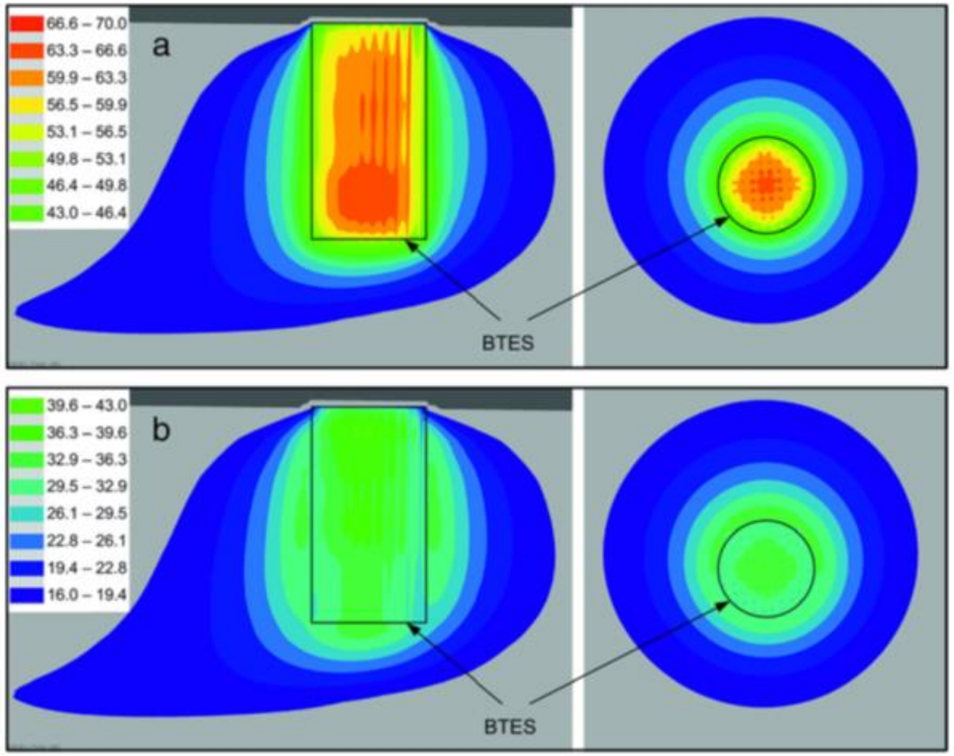


Figure 9 Computed temperature profiles of the BTES in the 30th year of operation. Completely charged **(a)** and completely discharged **(b)**; left: vertical cross section parallel to the aquifer flow direction; right: horizontal cross section at approximately 40-m depth; temperature scale in degrees Celsius.

Source : Mielke et al. Thermal effect of a borehole thermal energy store on the subsurface. *Geothermal Energy* **2**, 1–15 (2014).

COST ELEMENTS OF HT-BTES

- **Pit Thermal Energy Storage (PTES)**
  - Denmark ahead
  - Volume ranges from 10 000 à 203 000 m^3 (Vojens, Southern Jutland, 2015)
  - Maximum temperature = 90°C
  - The quality of the insulation of the top layer deeply impacts the efficiency (50-90%)
  - Large PTES are affordable (20-40€/m3)
  - Main challenge is the care taken in the PTES construction

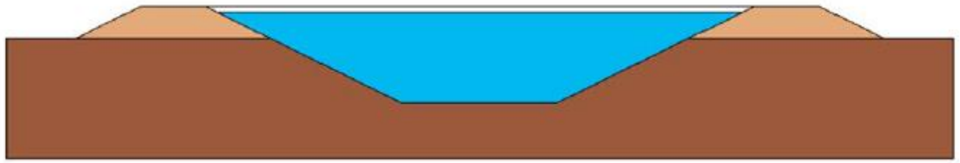
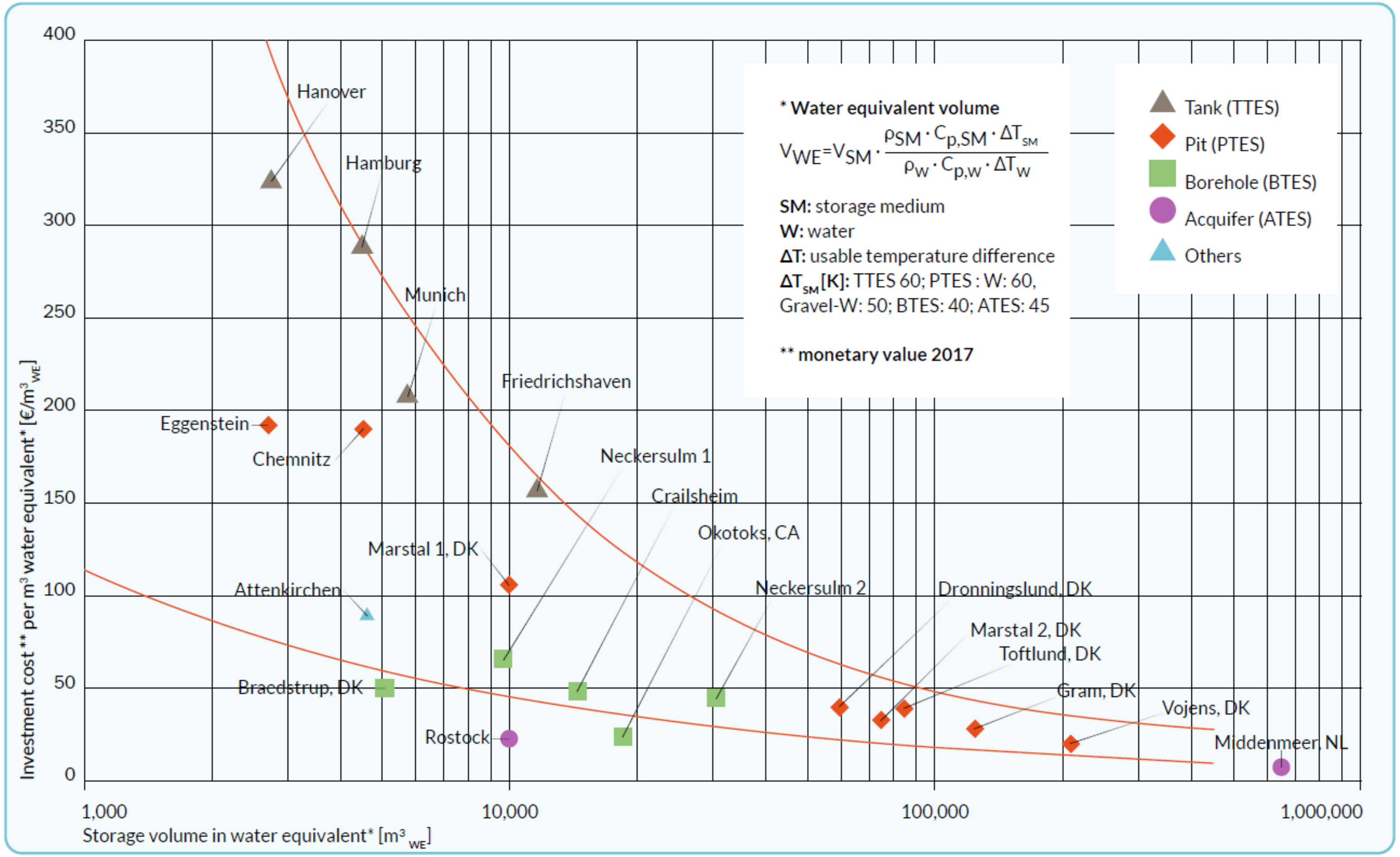


Figure 4.5 Danish PTES concept with soil balance shaped as a truncated pyramid placed upside down.

Figure 4.1 Picture of Dronninglund Pit Storage under construction. Dronninglund District heating; 37,573 m^2 of solar collectors and a 62,000 m^3 water in pit heat storage (PlanEnergi)

COST ELEMENTS OF HT-BTES

- **Specific storage cost of UTES demonstration plants**. Including all necessary costs for building the storage device, without design, without connecting pipes and equipment in the heating plant without VAT.



Source: Solites, republished in "Roadmap for flexible energy systems with underground thermal energy storage towards 2050", Geothermica Heatstore project

BTES AS COMPONENT OF A THERMAL ENERGY SYSTEM

- Whatever the UTES technology, the « cut-off temperature » (i.e. the temperature of the water flowing back from the DHN ≈ the UTES inlet temperature when unloading) is a critical parameter
- The lower the cut-off temperature, the higher the amount of unloaded heat

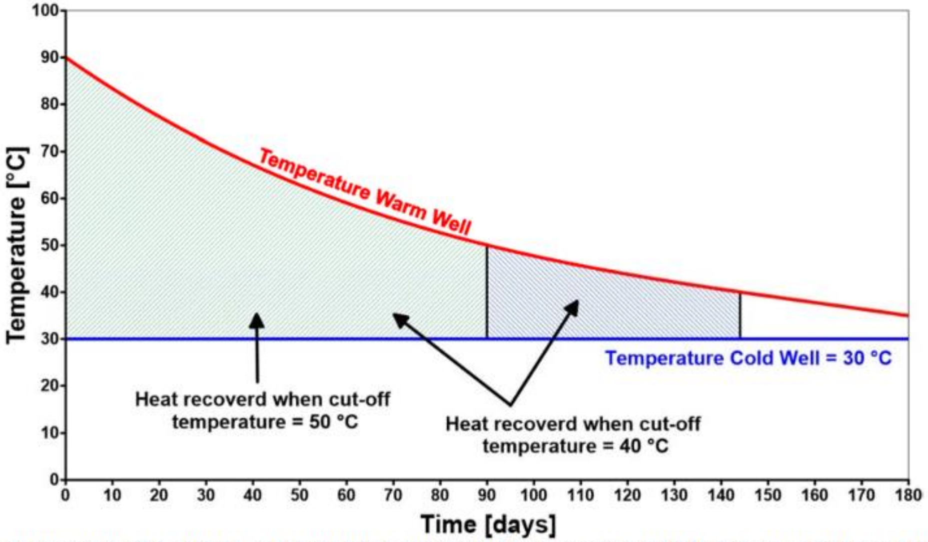


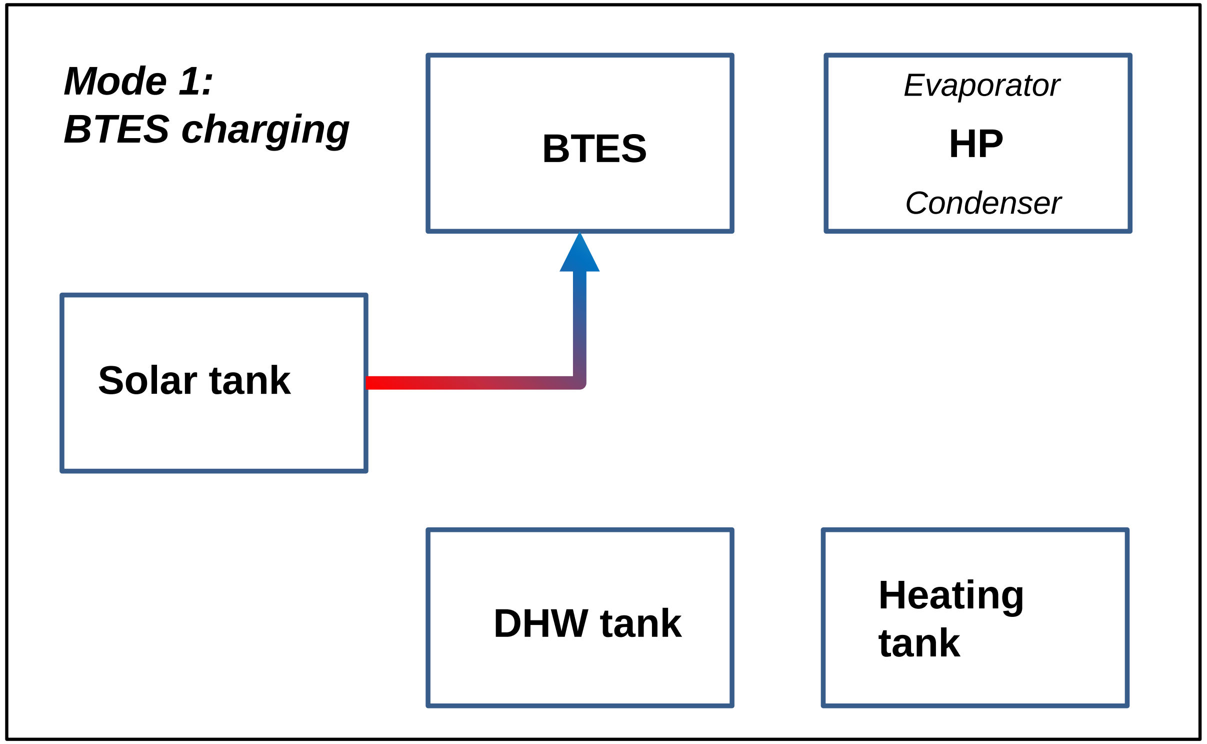
Figure 2.9 The relationship between cut-off temperature and the amount of heat that can be extracted from the subsurface with heat storage at 90°C (IF Technology)

- Low-temperature emitters (e.g. heating floors @35 °C) are necessary
- A Heat Pump (HP) can unlock large amounts of heat below the cut-off temperature (e.g. @5°C to 35 °C)

BTES AS COMPONENT OF A THERMAL ENERGY SYSTEM

GEOTHERMAL DHC Towards Decarbonized Heating and Cooling!

- Example of a system combining Solar Thermal Collectors, a BTES and a Heat Pump (HP)
  - Expected synergies between the components:
    - Solar recharge → much more compact BTES
  - Principles:
    - Only the excess solar heat is stored into the BTES
    - When heating or DHW is needed, the best thermal source (solar or BTES) is selected.
    - This source is used as long as its temperature is high enough. If too low, then the HP is activated to meet the desired temperature. If still too low, gas boilers are activated.
  - → 9 modes of operations are possible :
    - 1 mode for “Solar heat storage into BTES”
    - 2×2×2 = 8 modes of production
  - System modelled in TRNSYS software, with time step = 7.5 minutes over 7 years
  - Control strategy based on a “differential controller”: The current mode of operation is selected based on comparison between temperatures



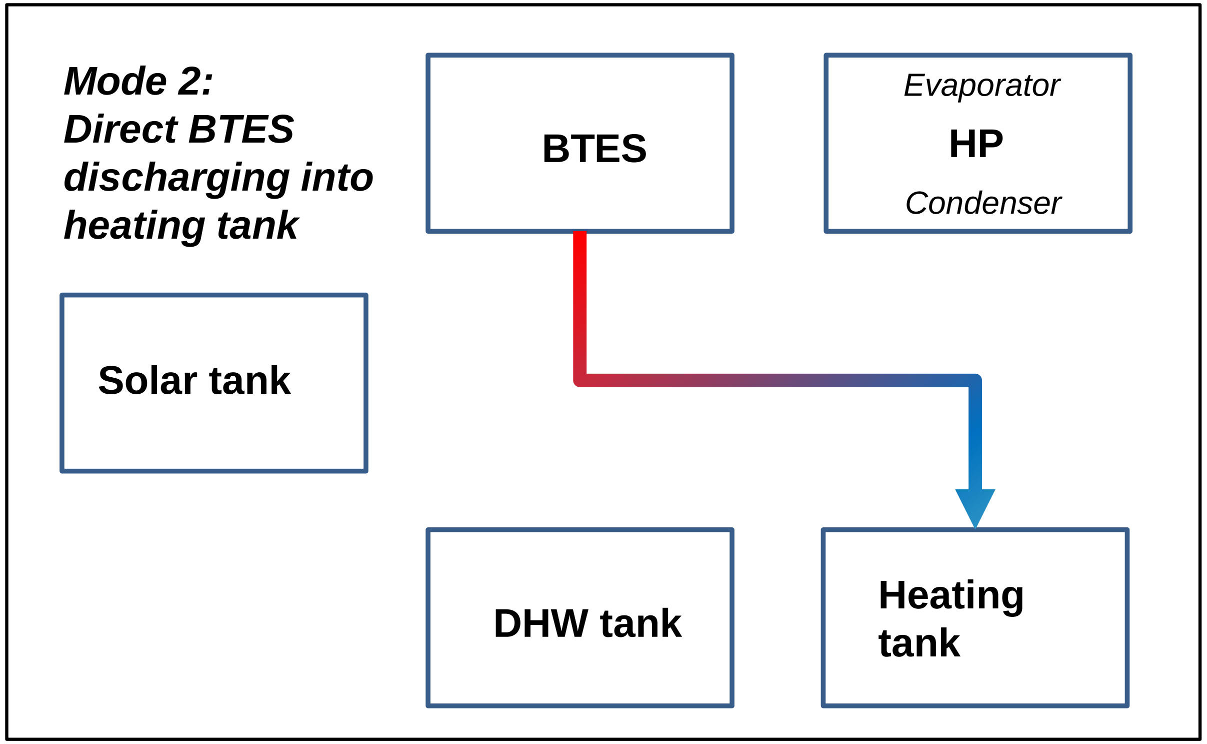
Maragna, C., Rey, C. & Perreaux, M. A novel and versatile solar Borehole Thermal Energy Storage assisted by a Heat Pump. Part 1: System description. Renewable Energy 208, 709–725 (2023).

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Géosciences pour une Terre durable brgm

BTES AS COMPONENT OF A THERMAL ENERGY SYSTEM

- Example of a system combining Solar Thermal Collectors, a BTES and a Heat Pump (HP)
  - Expected synergies between the components:
    - Solar recharge → much more compact BTES
  - Principles:
    - Only the excess solar heat is stored into the BTES
    - When heating or DHW is needed, the best thermal source (solar or BTES) is selected.
    - This source is used as long as its temperature is high enough. If too low, then the HP is activated to meet the desired temperature. If still too low, gas boilers are activated.
  - → 9 modes of operations are possible :
    - 1 mode for "Solar heat storage into BTES"
    - 2×2×2 = 8 modes of production
  - System modelled in TRNSYS software, with time step = 7.5 minutes over 7 years
  - Control strategy based on a "differential controller": The current mode of operation is selected based on comparison between temperatures



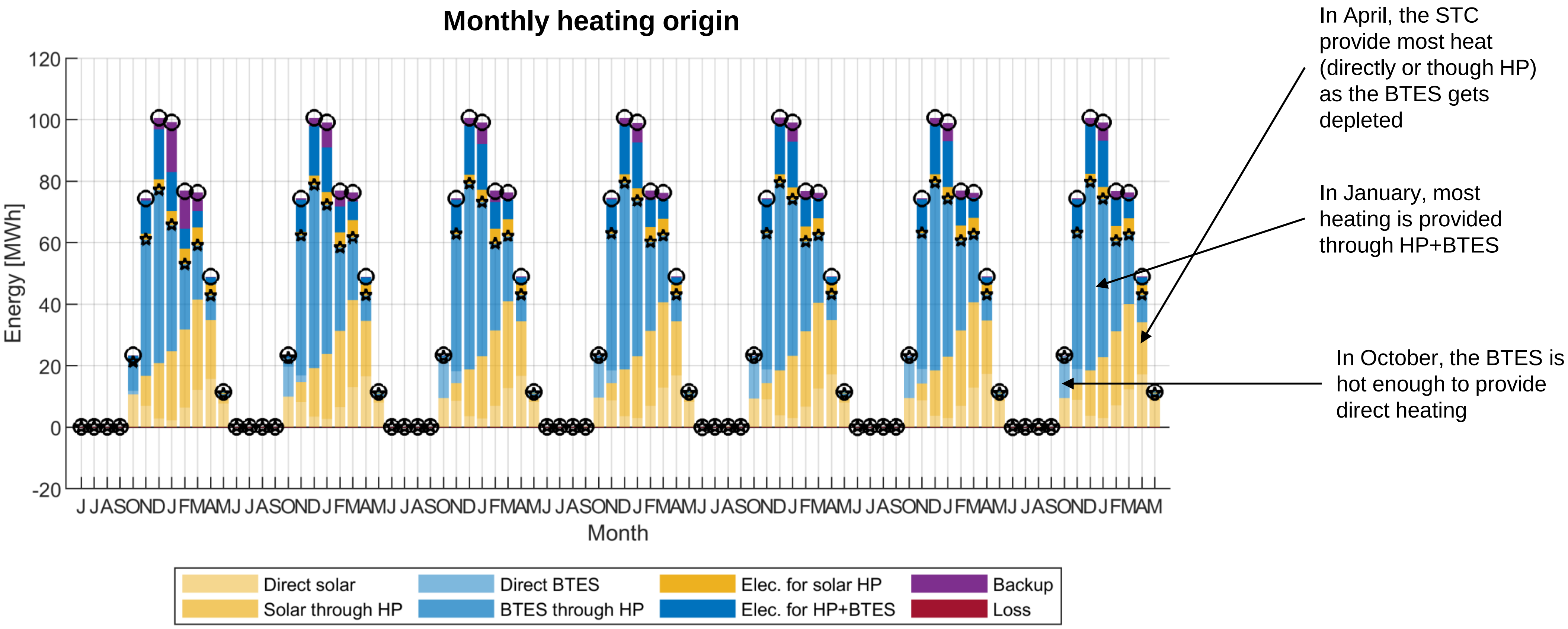
Maragna, C., Rey, C. & Perreaux, M. A novel and versatile solar Borehole Thermal Energy Storage assisted by a Heat Pump. Part 1: System description. Renewable Energy 208, 709–725 (2023).

BTES AS COMPONENT OF A THERMAL ENERGY SYSTEM

- Example of a system combining Solar Thermal Collectors, a BTES and a Heat Pump (HP) : Some reference case
  - Thermal need (block of residential buildings, Paris suburb):
    - Heating (@ 35°C) : $E_{heating}$ = 510.5 MWh.y^{-1} & $P_{heating,max}$ = 250 kW
    - Domestic Hot Water E_{DHW} = 226.7 MWh.y^{-1}
  - BTES :
    - BTES volume V_{BTES} = 15000 m^3
    - Spacing between adjacent boreholes d_{BHE} = 3 m
    - Number of boreholes N_{BHE} = 55
    - Ground thermal conductivity λ_m = 2.0 W.K^{-1}.m^{-1}
    - Initial ground temperature T_0 = 12 °C
    - No insulation at the top surface
  - STC :
    - Area S_{STC} = 2500 m^2 ;
    - Solar tank volume $V_{tank,sol}$ = 100 m^3
  - HP :
    - Nominal calorific power = 250 kW

BTES AS COMPONENT OF A THERMAL ENERGY SYSTEM

- Example of a system combining Solar Thermal Collectors, a BTES and a Heat Pump (HP)

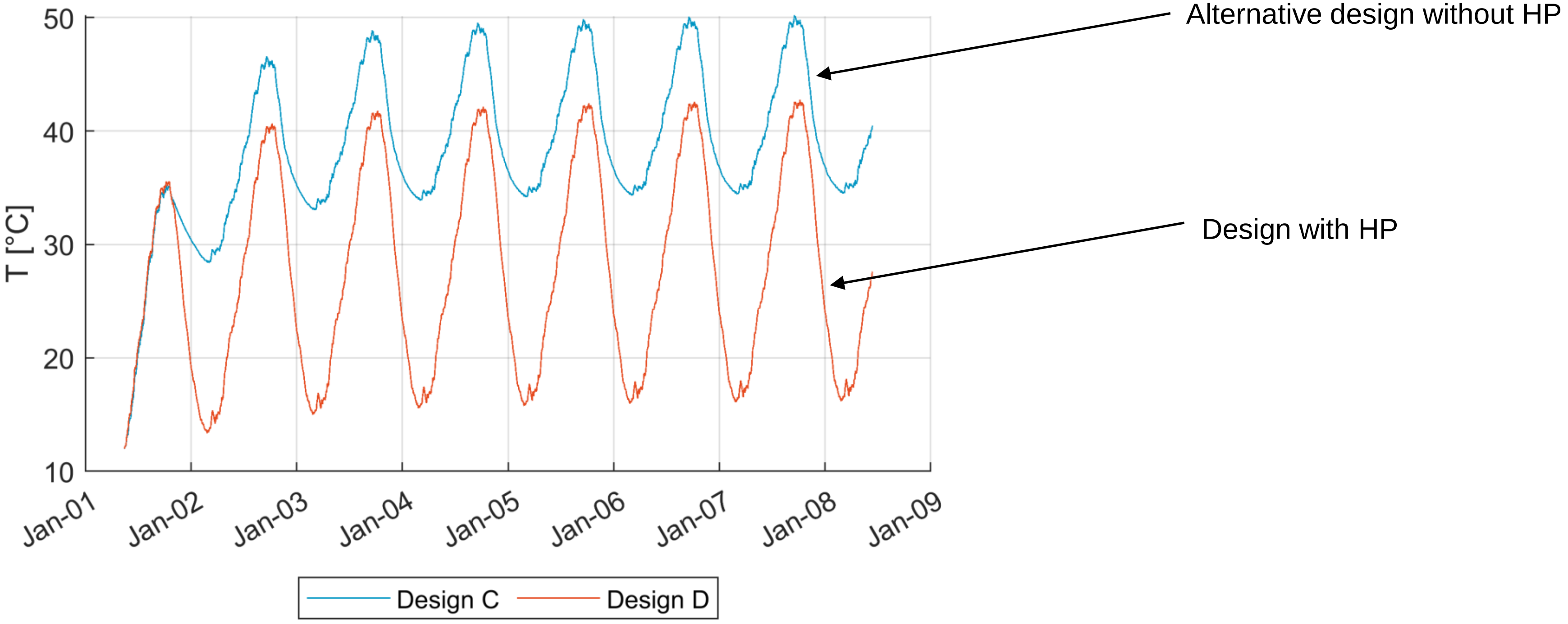


NB: the black stars accounts for the cumulated solar and underground energy (i.e. not gas or electricity)

BTES AS COMPONENT OF A THERMAL ENERGY SYSTEM

- Example of a system combining Solar Thermal Collectors, a BTES and a Heat Pump (HP)
  - The HP allows the operation of the BTES on a much larger temperature range, allowing about twice more energy to be retrieved from the BTES, at the expense of a small amount of electricy.

Average BTES ground temperature



Maragna, C., Rey, C. & Perreaux, M. A novel and versatile solar Borehole Thermal Energy Storage assisted by a Heat Pump. Part 1: System description. Renewable Energy 208, 709–725 (2023).

SOME CONCLUDING REMARKS

- HT-BTES:
  - Constraints:
    - Enough space for the installation of STC, nearby available waste heat
    - Hydrogeological context with no moving groundwater
  - Opportunities:
    - Coupling with HP to increase the potential of the technology

Acknowledgement to COST Action CA18219 “Geothermal DHC”, supported by COST (European Cooperation in Science and Technology), www.cost.eu & https://www.geothermal-dhc.eu/