Aquifer thermal energy storage systems ensuring continuous cooling in arid climates compared to applications in Europe

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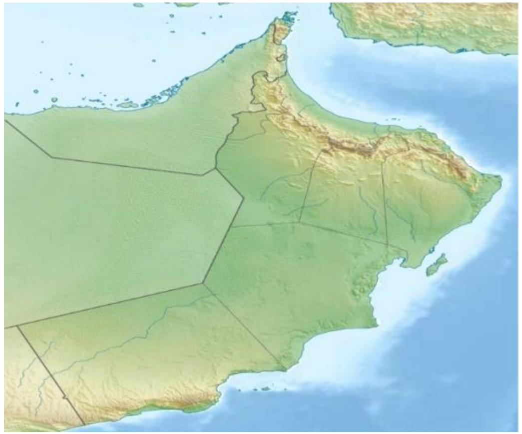
Energy consumption in Oman

Total power supplied in Oman
~25 TWh[a] (Germany ~650 TWh[d])

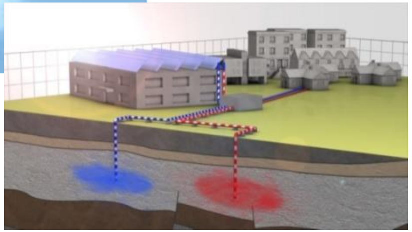


Total residential cooling use 2014
~11.6 TWh[a] (residential heating: Germany ~136 TWh[d])

Residential annual power used for cooling in Muscat
~5.8 TWh[a] (district heating Berlin ~8.5 TWh[e])

[a] *Authority for Energy Regulation, Oman*
[b] *Residential Energy Use In Oman: A Scoping Study, Trevor Sweetnam*
[e] *DIW ECON*
[c] *Energy Information Agency, USA*
[d] *International Energy Agency*

Concept for a continuously operating cooling system based on renewables



Absorption chiller requires water of 70–110°C to produce chill of 6–8°C

To ensure continuous cold supply a storage is required which can be installed in the underground

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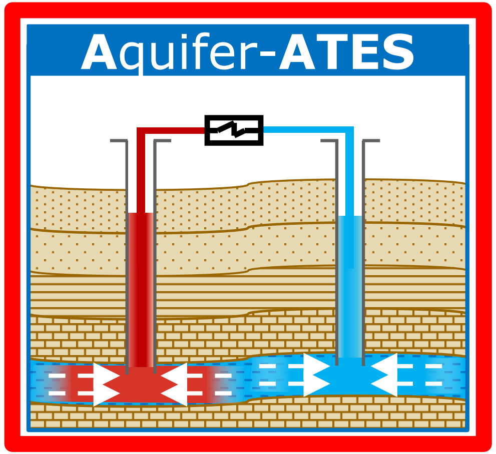
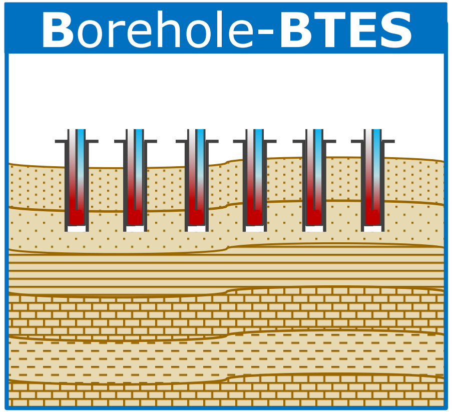
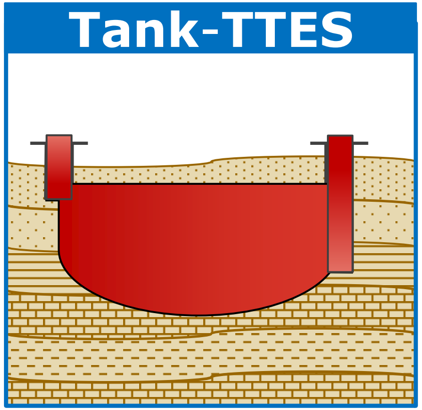
The Research Council
Towards an Effective National Innovation System

Different storage options

- Possibilities for thermal energy storage
  - Sensible heat storage
  - Latent heat storage
  - Thermochemical heat storage
- Options of thermal underground storage
  - Borehole thermal energy storage (BTES) - Tank thermal energy storage (TTES)
  - Aquifer thermal energy storage (ATES)







Concepts of ATES

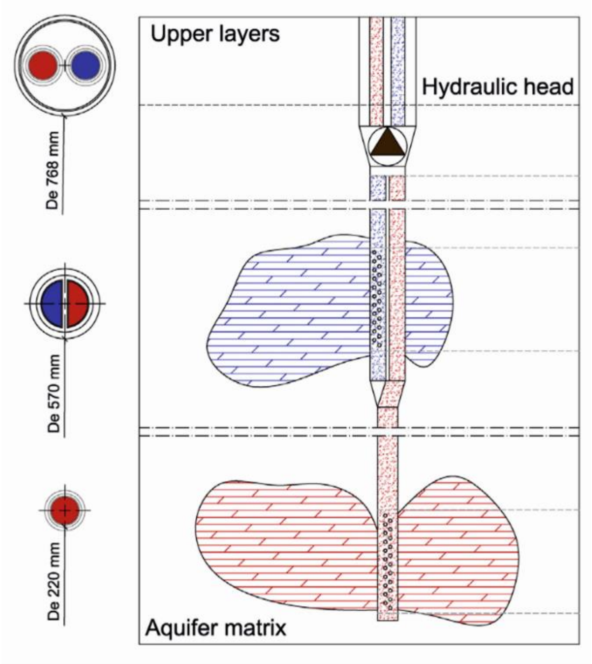
Doublet (group of wells)

- At least two wells
- Both wells tap the same aquifer
- „standard“ storage

Mono well - desing

- Just a single well required
- One well taps two aquifers
- Complex well design and completion
- Mixing of different groundwaters → effects?
- So far rarely implemented

Mono-well in two seperated aquifers



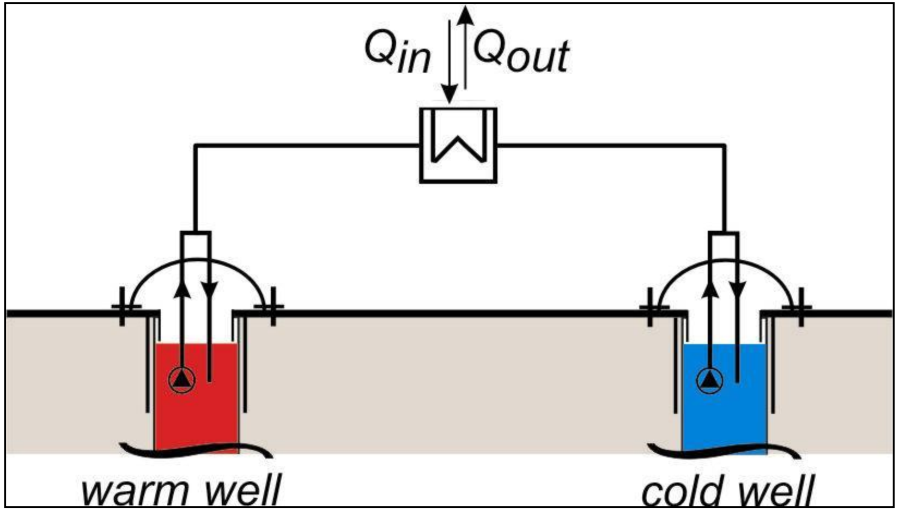
Zeghici et al., 2015[a]

[a]*Zeghici et al.,2015: Integrated assessment of variable density-viscosity groundwater flow for a high temperature mono-well aquifer thermal energy storage (HT-ATES) system in a geothermal reservoir*

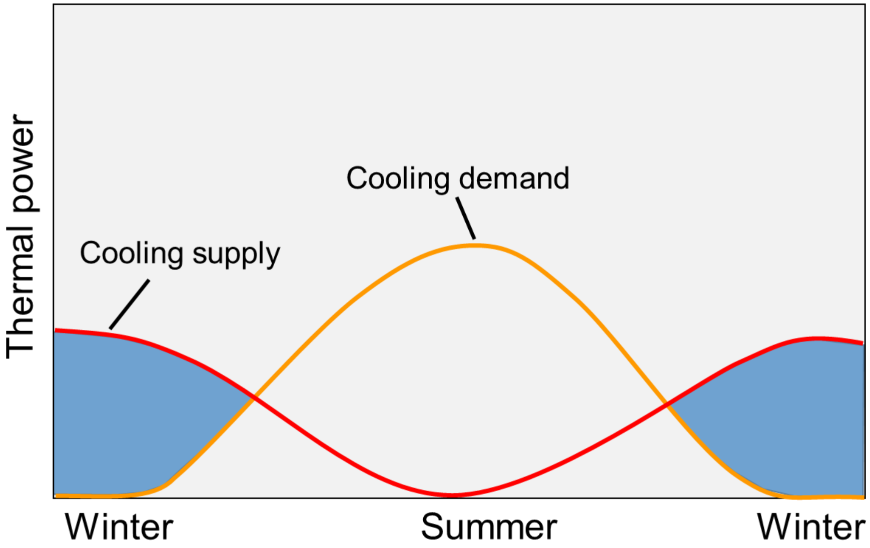
ATES

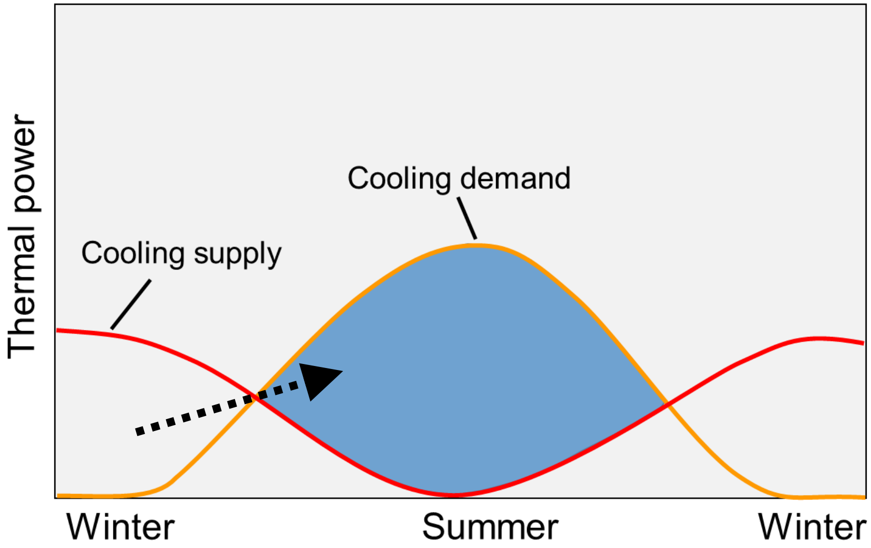
Depending on the temperature level three different types can be characterized (Drijver et al., 2012):

1. Low-temperature ATES with T < 30°C,
2. Mid-temperature ATES in the range of T = 30–60 °C and
3. High-temperature ATES with T > 60°C.



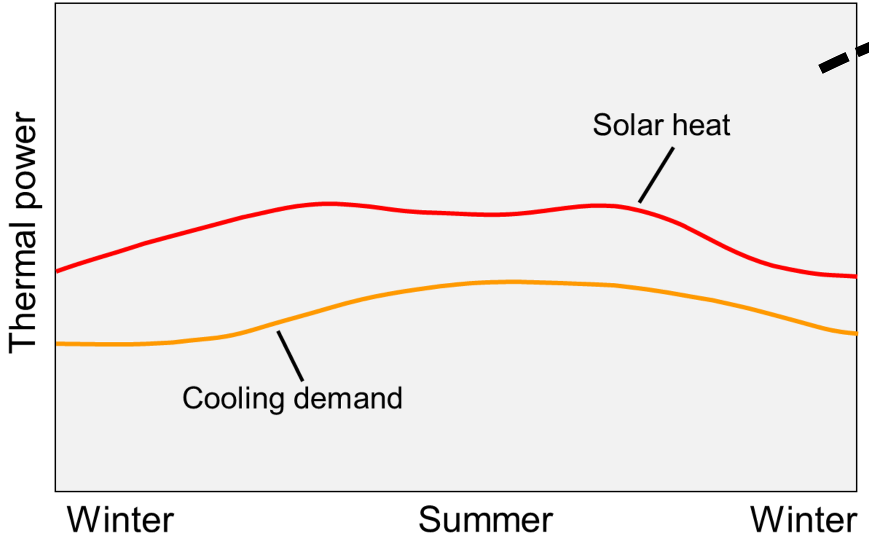
Motivation in Europe

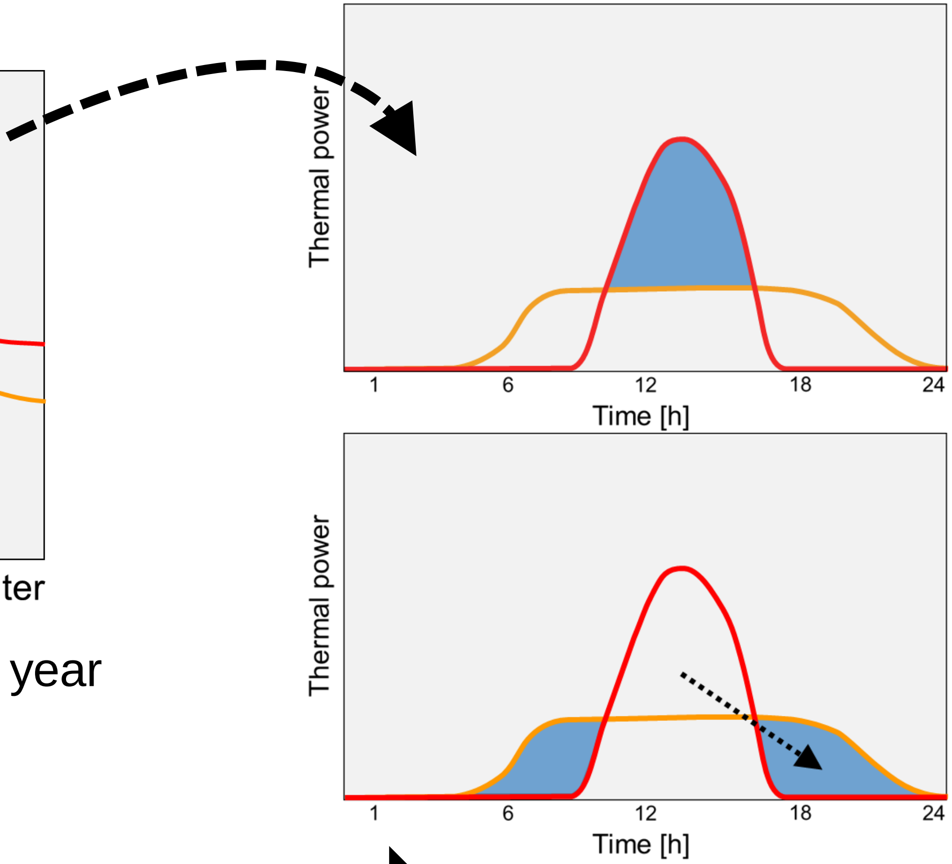




Bridging the gap between supply and demand ➡ **seasonal storage**

Motivation in an arid climate

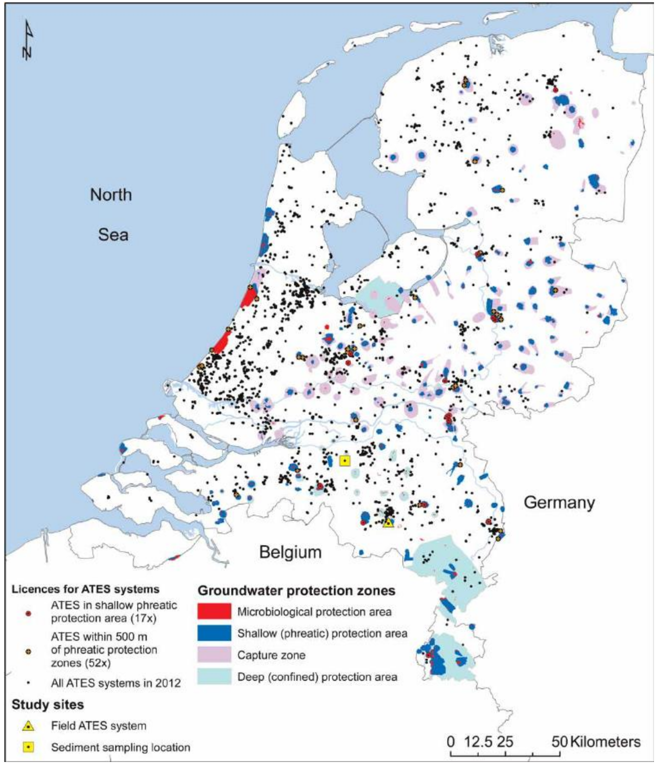




- Cooling demand over the whole year
- Minor seasonal changes

Bridging the gap between supply and demand ➡ **daily storage**

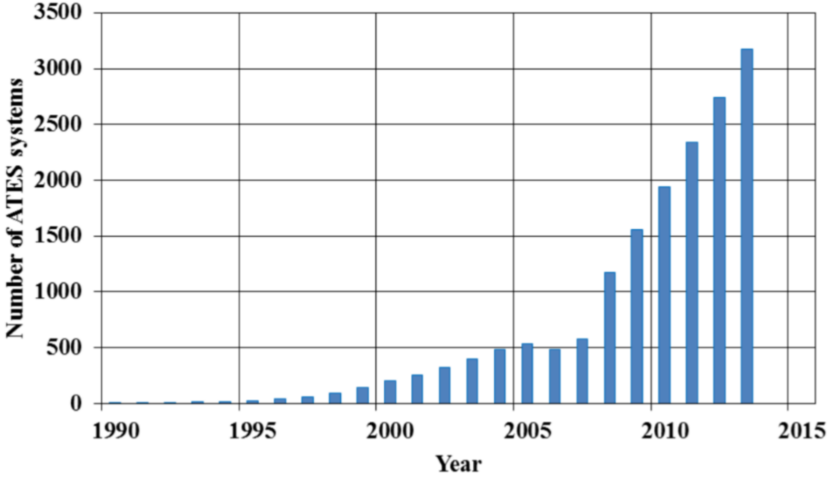
ATES in Europe



All licensed ATES systems in 2012[a]

Netherlands

- 2740 Registrated ATES systems in 2012 with a total estimated heat load of 1103 MW_{th}[b]



Amount of ATES systems in the utility sector[c]

[a]*Bonte et al.,2013: Environmental impacts of aquifer thermal energy storage investigated by field and laboratory experiments*

[b]*CBS, 2013: Hernieuwbare energie in Nederland 2012 (Renewable energy in the Netherlands 2012).*

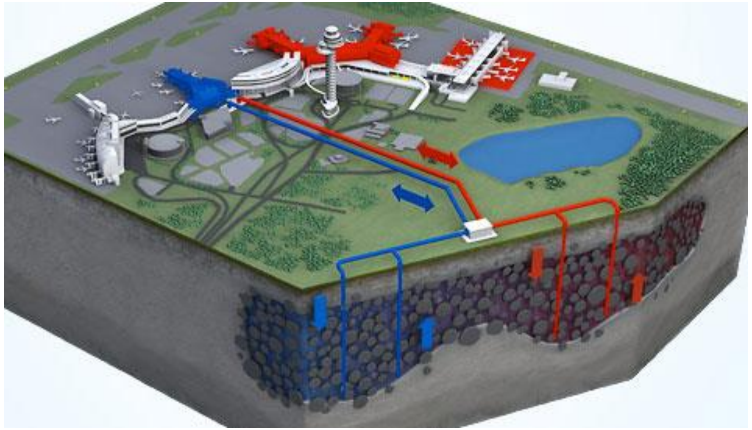
[c]*Sommer, 2015: Modelling and monitoring of Aquifer Thermal Energy Storage*

ATES in Europe

Sweden

- Systems in operation (2016): 170
- Overall heat load:
  ~ 650 MW_{th}
- Overall storage capacity:
  ~ 1700 GWh/a
- Low-temperature ATES systems:
  - 12-16 °C at warm side
  - 2-4 °C at cold side[a]

Stockholm-Arlanda Airport[b]



- Storage temperature:
  - 2-3 °C at cold side
  - 20-25 °C at warm side
- 5 cold and 6 warm wells in 15-30m depth
- Cooling/heating load between 6-7 MW_{th}
- Storage capacity: 20 GWh_{th}/a
- In operation since 2009[a,c]

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[a]Gehlin and Anderson, 2016: Geothermal Energy Use, Country Update for Sweden
[b]Wigstand, 2010: The ATES project – a sustainable solution for Stockholm airport
[c]Anderson, 2009: The ATES project at Stockholm Arlanda Airport

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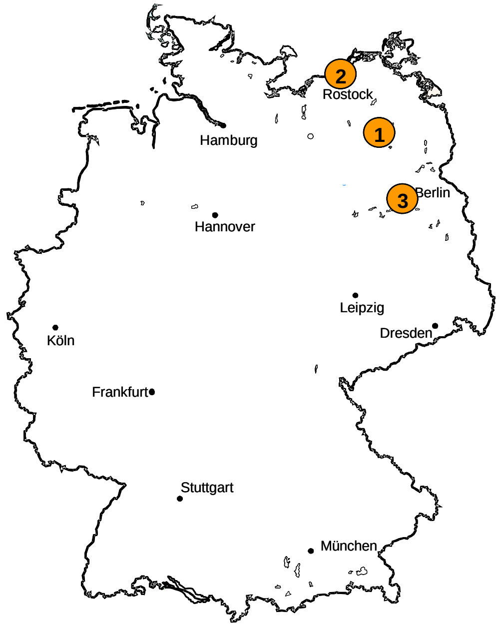
ATES in Germany

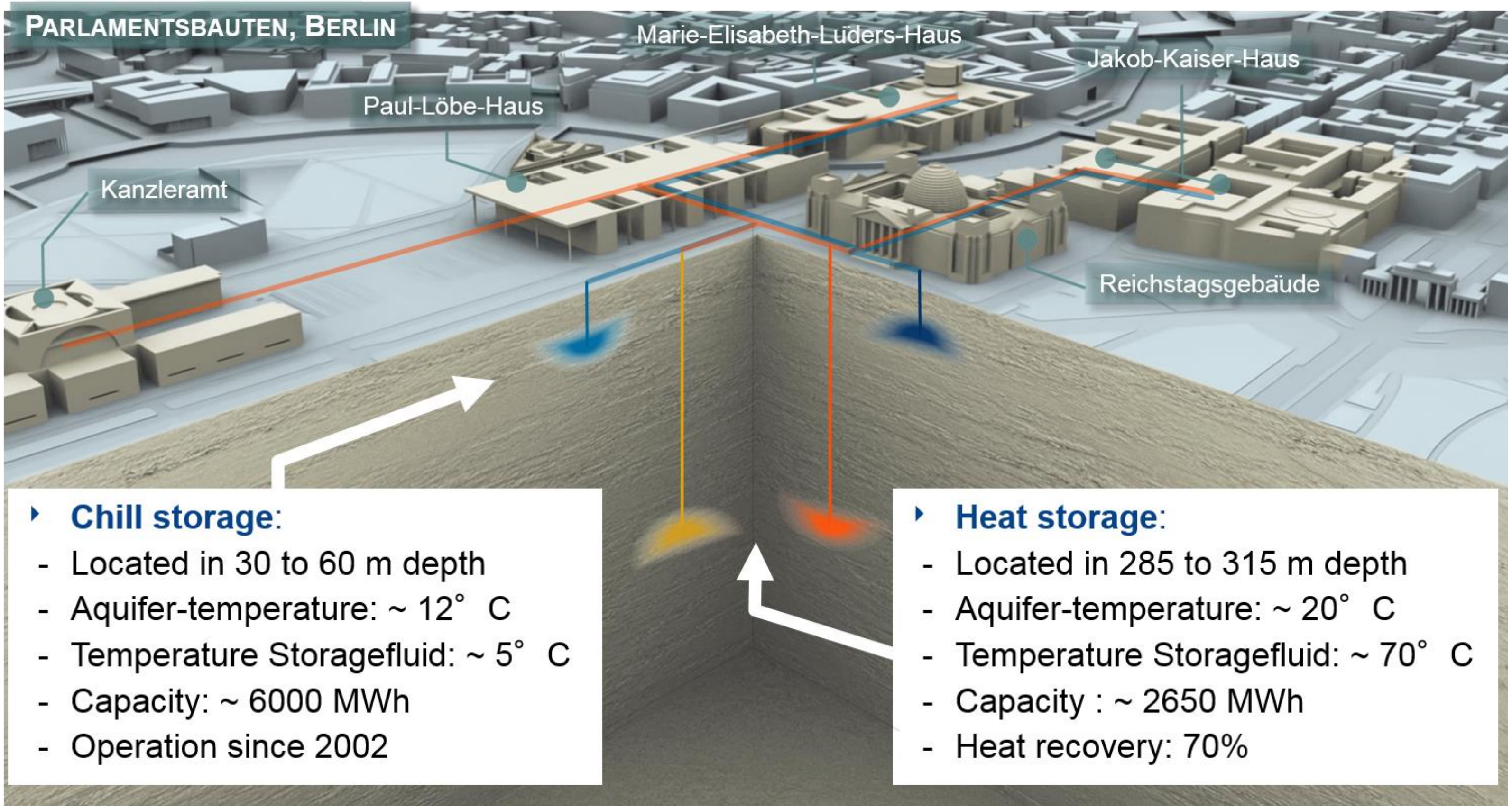
1. Neubrandenburg
   - ➢ In operation since 2005
   - ➢ Gas and steam turbine heat and power plant, waste heat is fed into the underground
   - ➢ High-temperature ATES used for heating

2. Rostock-Brinkmannshöhe
   - ➢ In operation since 2000
   - ➢ solar heating plant with ATES
   - ➢ Low- to mid temperature storage used for heating

3. Berlin- German parliament buildings



ATES German parliament buildings in Berlin



- **Chill storage**:
  - Located in 30 to 60 m depth
  - Aquifer-temperature: ~ 12° C
  - Temperature Storagefluid: ~ 5° C
  - Capacity: ~ 6000 MWh
  - Operation since 2002

- **Heat storage**:
  - Located in 285 to 315 m depth
  - Aquifer-temperature: ~ 20° C
  - Temperature Storagefluid: ~ 70° C
  - Capacity : ~ 2650 MWh
  - Heat recovery: 70%

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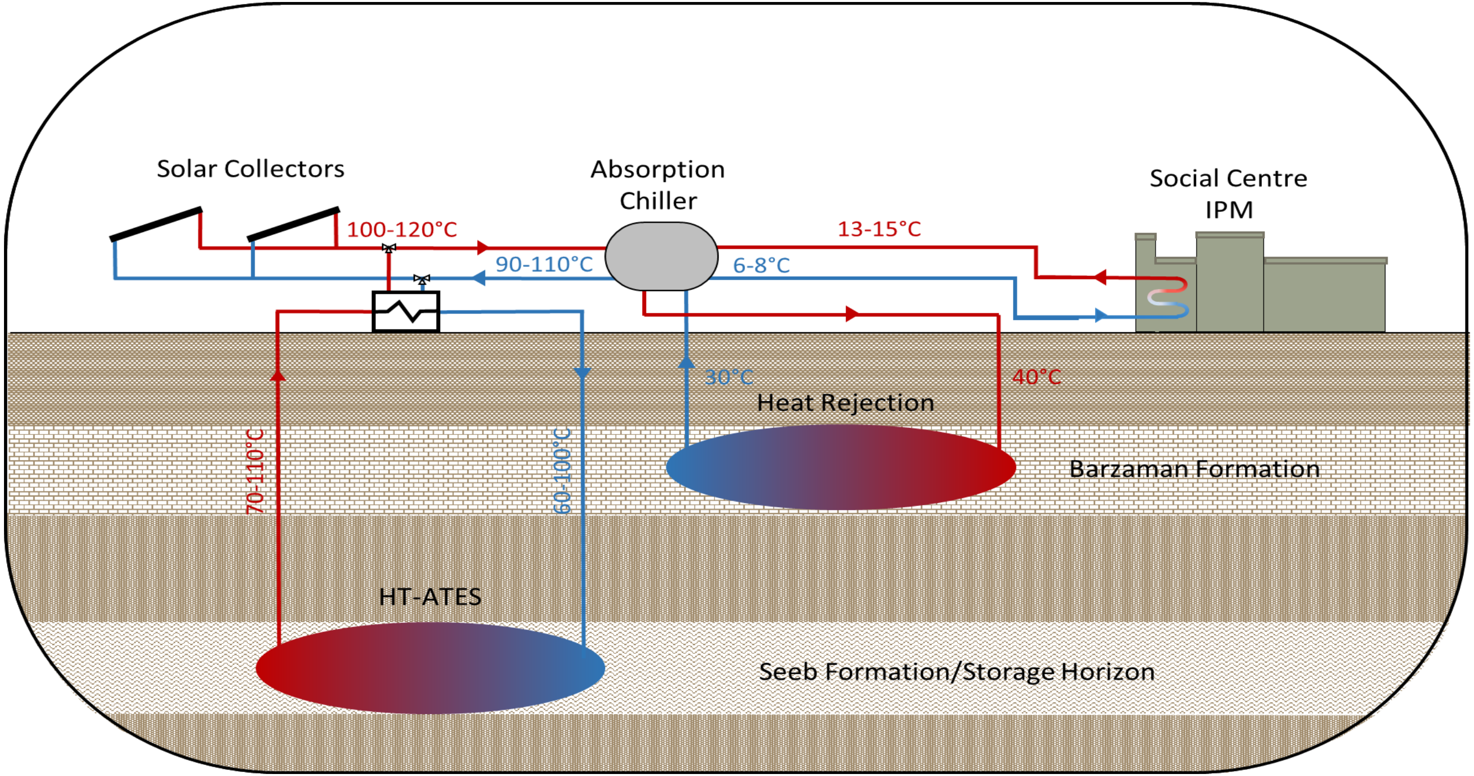
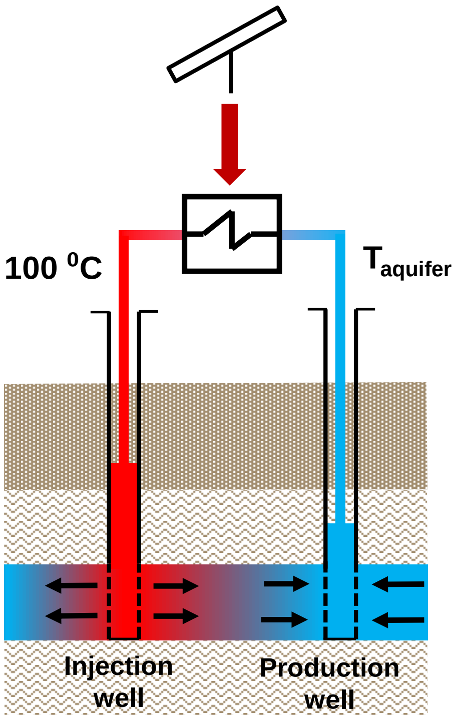
Cooling system Oman - combined with HT-ATES

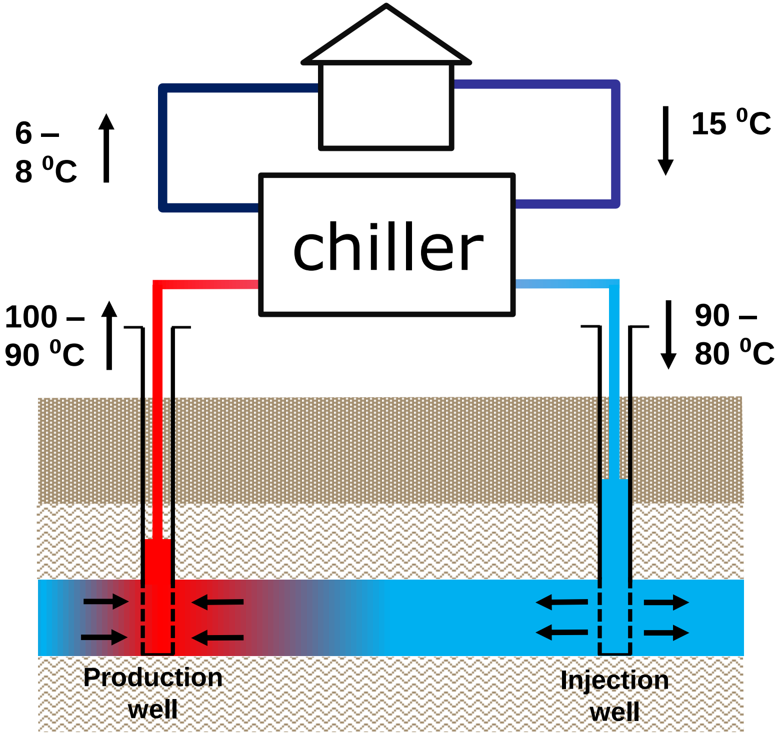


HT-ATES System

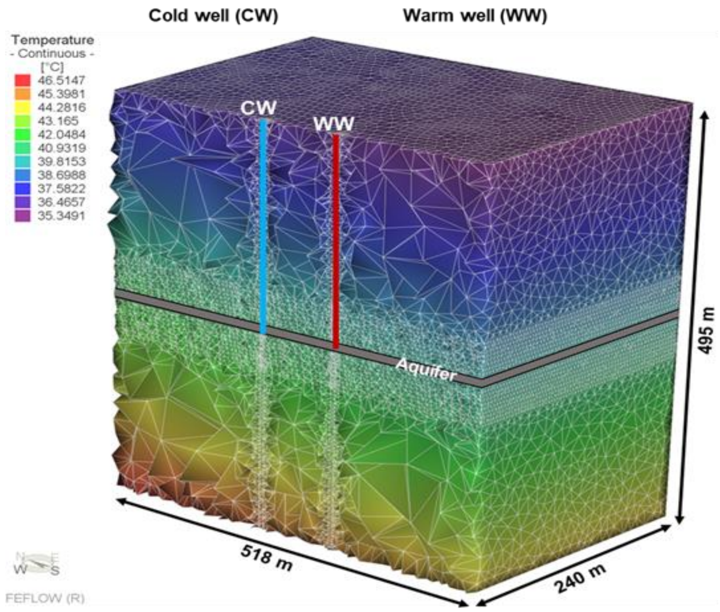
loading (heat surplus)



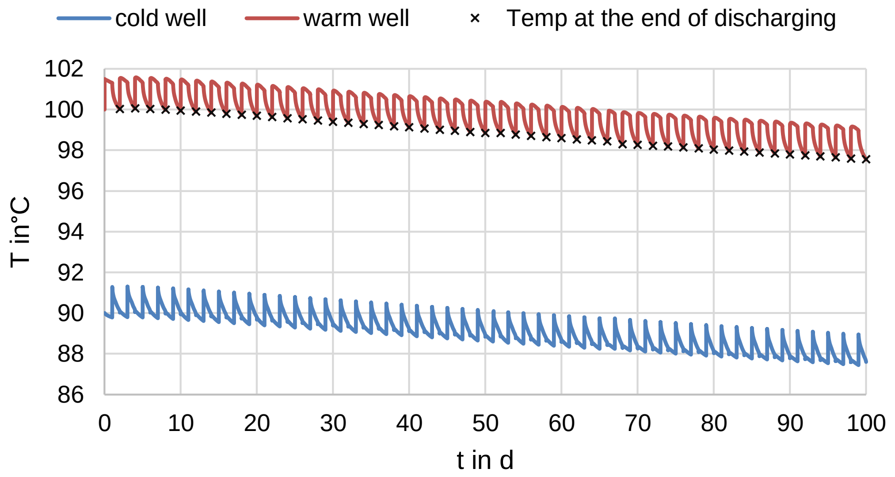
unloading (heat deficit)



Numerical simulation of a daily storage



Parameter	charging/supply	discharging/demand
Q [kW]	82	71
ΔT [K]	11.5	10
ṁ [m³/d]	146	146
T [°C]	100	≥ 90
v[m/d]	0	0



heat surpluses and heat deficits for one representative day were calculated and implemented to the model

Conclusion ATES

- HT-ATES can be used in an arid climate to stabilize a cooling system if the geological conditions are suitable
- The storage has to fuction in a daily rhythm. Seasonal changes are playing a minor role.

➡ Especially the high temperatures required for absorption cooling are a challenge, further research is required

- ATES in Europe is already succesfully proven

➡ further facilitation and stimulation is required especially in Germany to increase the number of sites

Harsh weather conditions in Oman

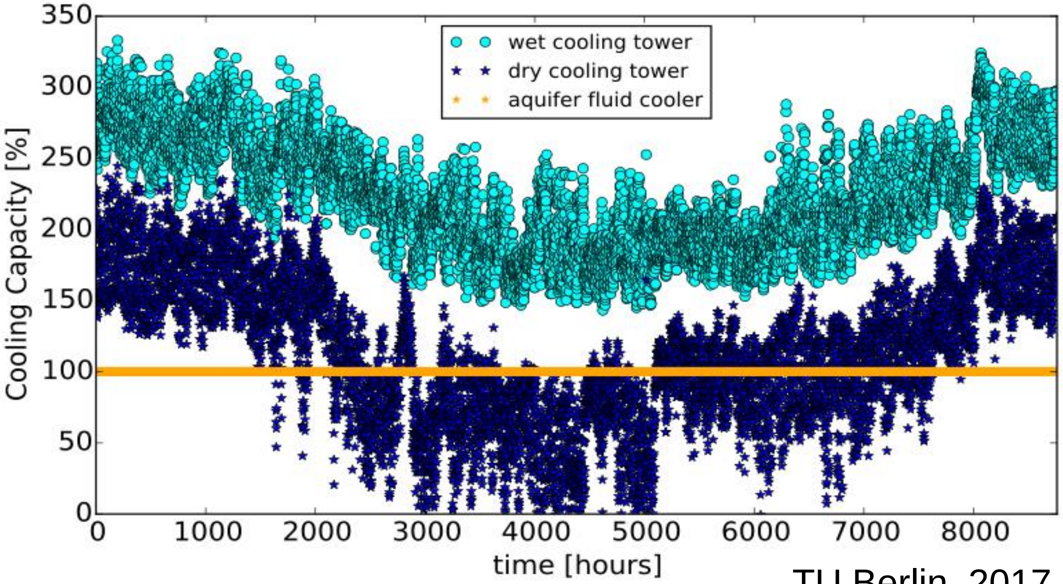
- Average annual temperature in Muscat: 29°C
  - May, June, July are the hottest months

➡ temperature can rise to 50°C

The ambient air temperature of Oman is too high to efficiently reject the waste heat of an absorption chiller to the surrounding environment

Waste heat management in Oman

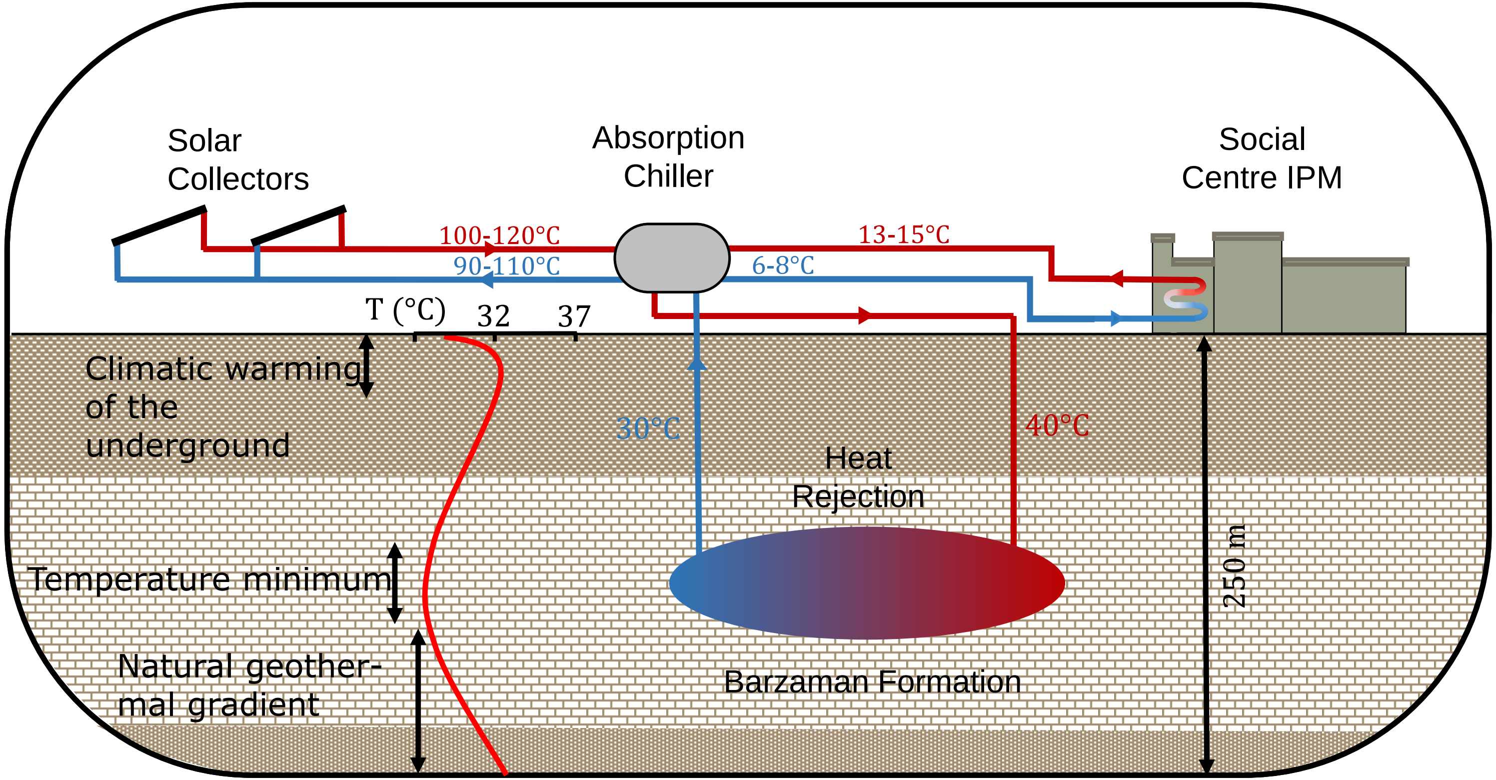
➢ stable temperature below 35° C is required to efficiently reject the process waste heat of an absorption chiller



TU Berlin, 2017

- cooling demand over the whole year
- dry cooling tower during summer time insufficient
- wet cooling tower and underground heat rejection for waste heat management sufficient

Waste heat management



Conclusion waste heat management

The rejection of process waste heat to the underground is a relevant topic for the whole Arabian Peninsula and also for other countries in arid climates:

- The underground offers stable conditions over the whole year
- In case the geological conditions are suitable it is an efficient and cheap alternative to the conventional options