Adsorption closed cycles and machines

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Outline

- Adsorption principle
- Market overview
- Experiences in a realized installation
- Summary

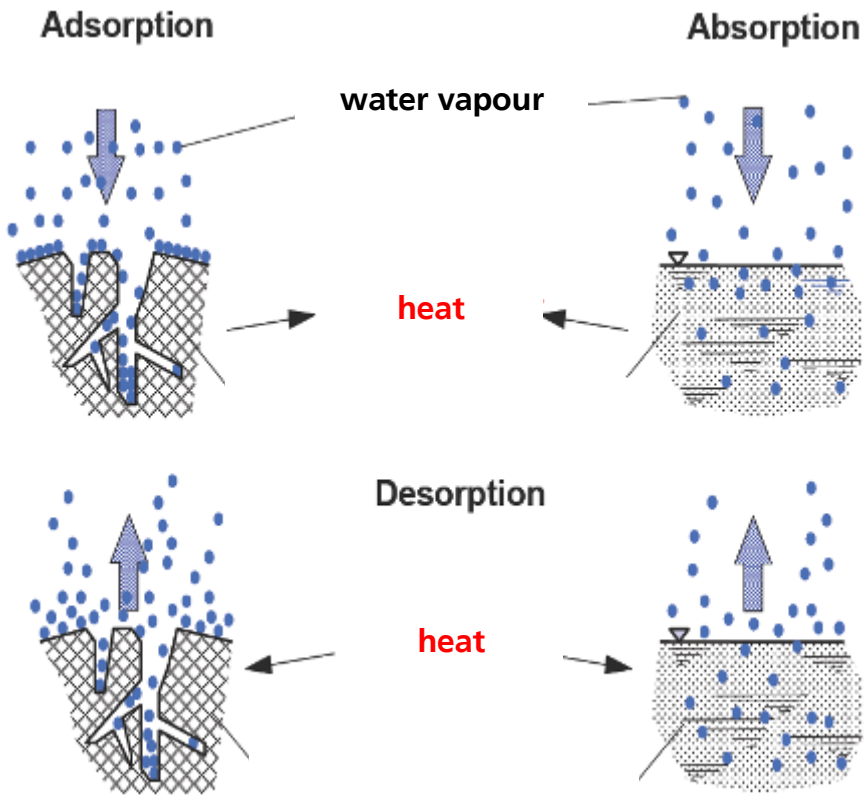
Solid sorption principle

Adsorption

- reversible bonding of gas molecules on the internal surface of highly porous solid materials

Absorption in solids

- reversible bonding of gas molecules in crystall structures, e.g. salt complexes



source: C. Hindenburg

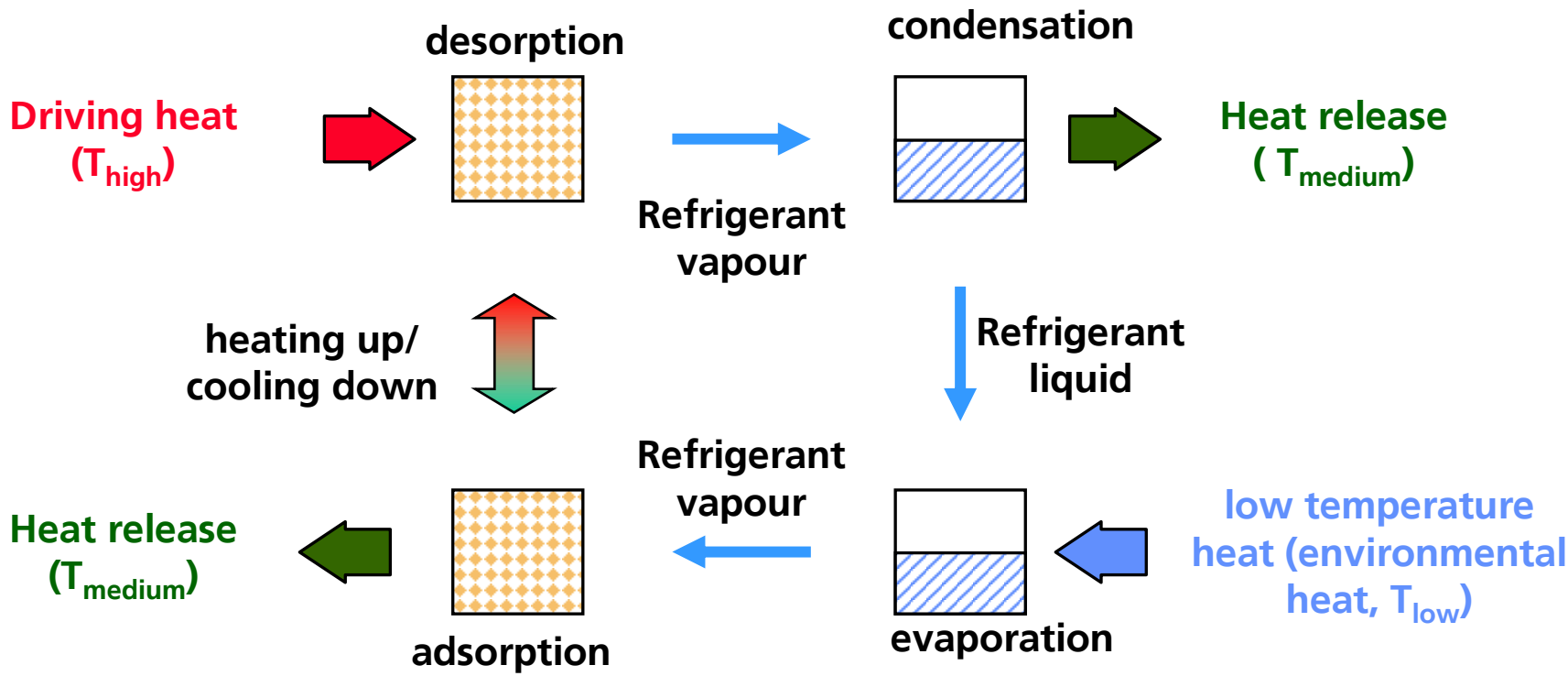
Technical adsorption materials

Typical pore size	5-20 Å
Typical materials	Silica gel, zeolite and similar materials, activated carbon, activated alumina
Possible refrigerants	Water, ethanol, methanol, ammonia
Bonding forces	Dominantly van-der-Waals forces
Internal surface area	300-1200 m^2 per g (210 – 840 sqft per gr); newly developed materials may provide up to 5000 m^2 per g (3500 sqft per gr)
Maximum water uptake	Approx. 60 mass-% (silica gel), approx. 35 mass-% (zeolite)

Use of adsorption for energy applications

Basic concept	Depending on actual value of refrigerant loading adsorption materials show a high affinity for refrigerant uptake
Thermodynamic cycle process	This phenomena can be used to create a closed thermodynamic cycle

Basic process



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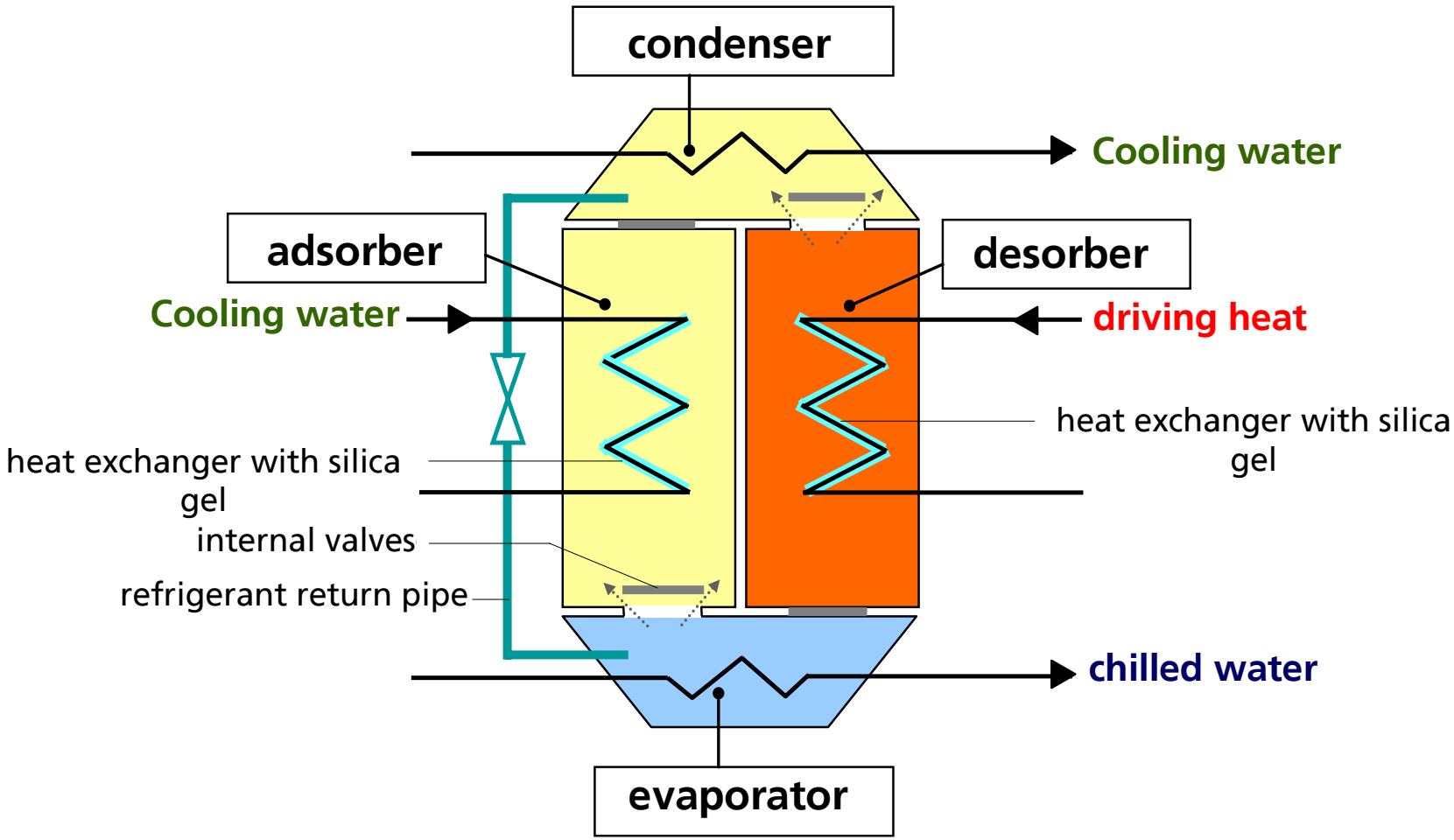
Scheme of an adsorption chiller



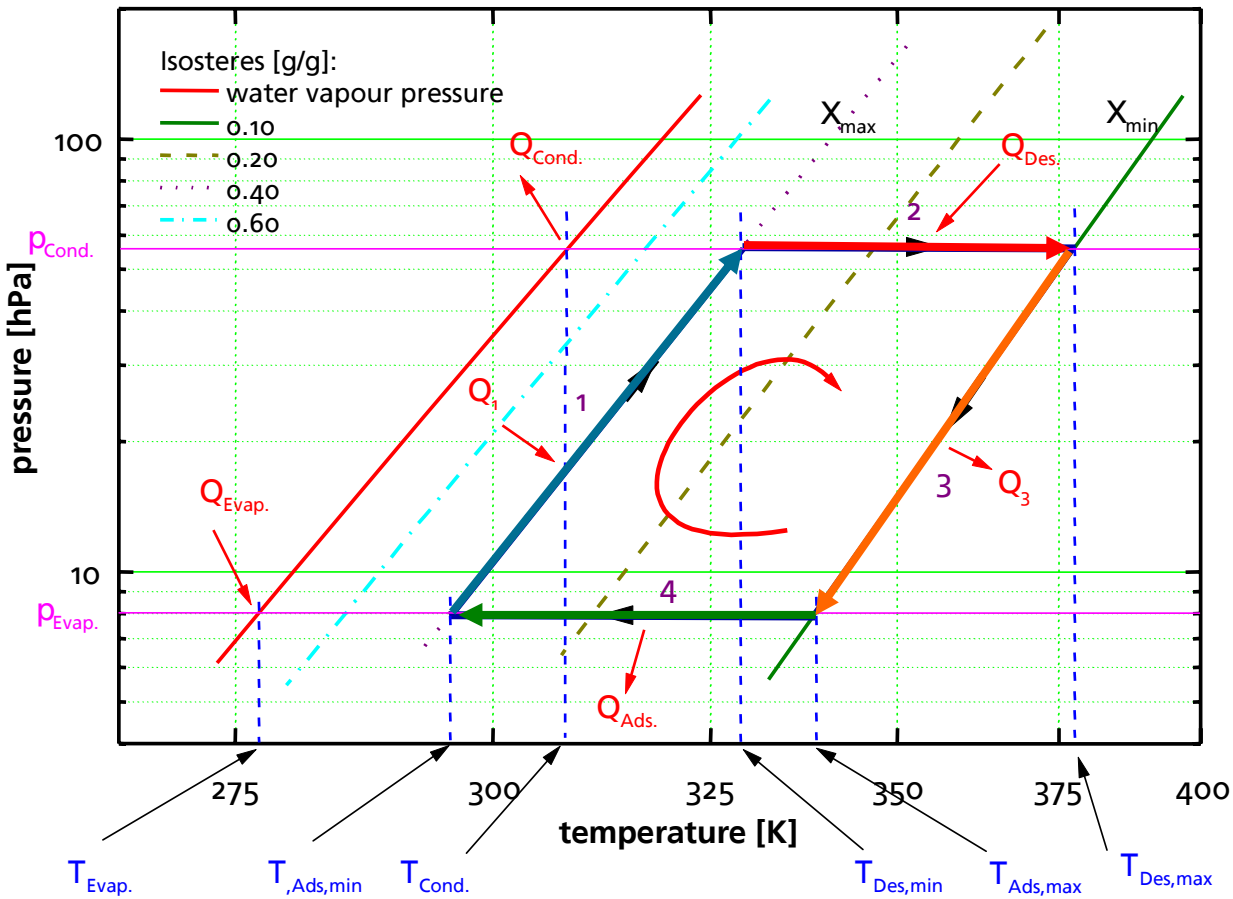
Ideal process cycle

isostere heating

desorption and condensation

isostere cooling

adsorption and evaporation



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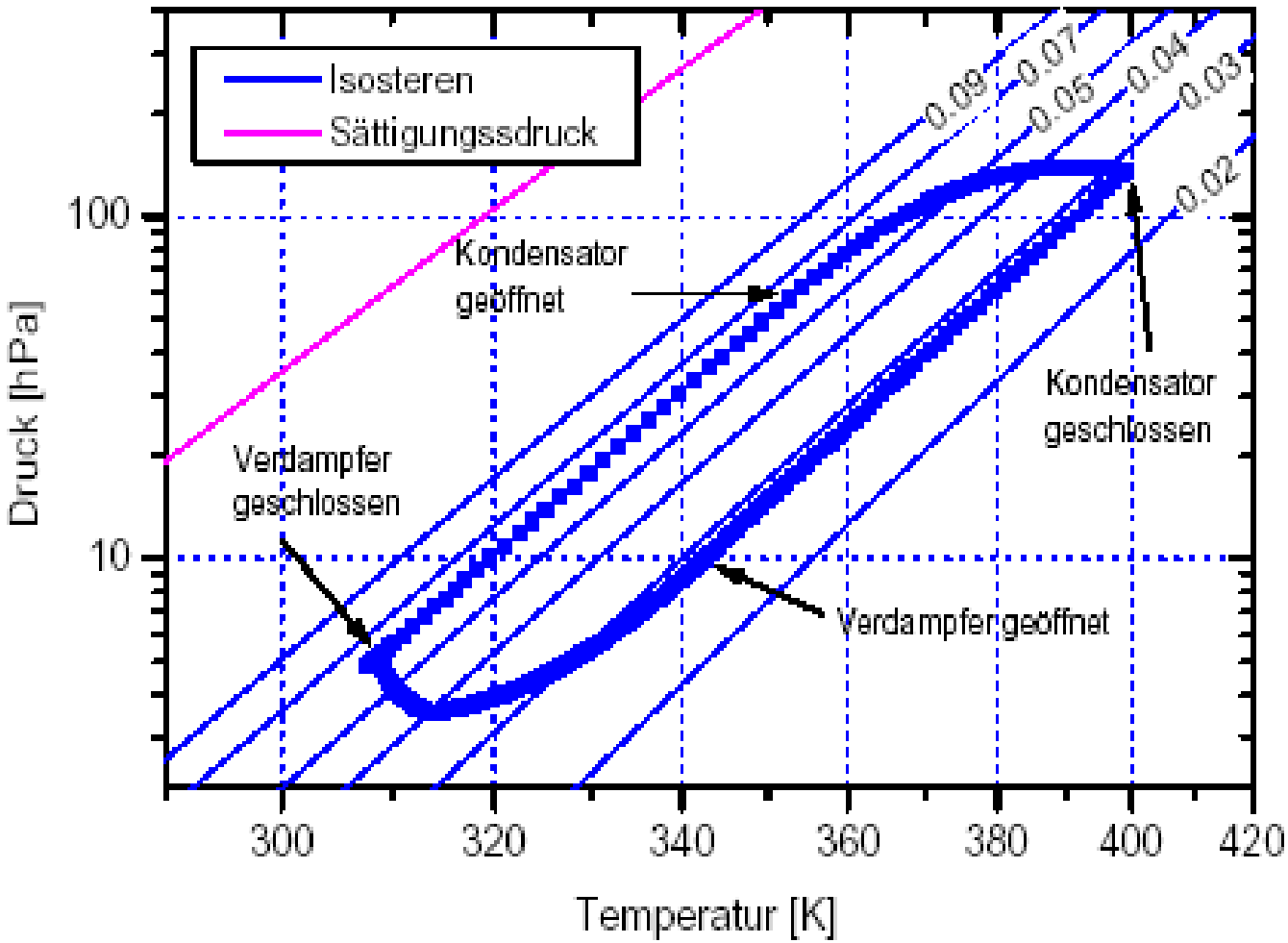
Real process cycle



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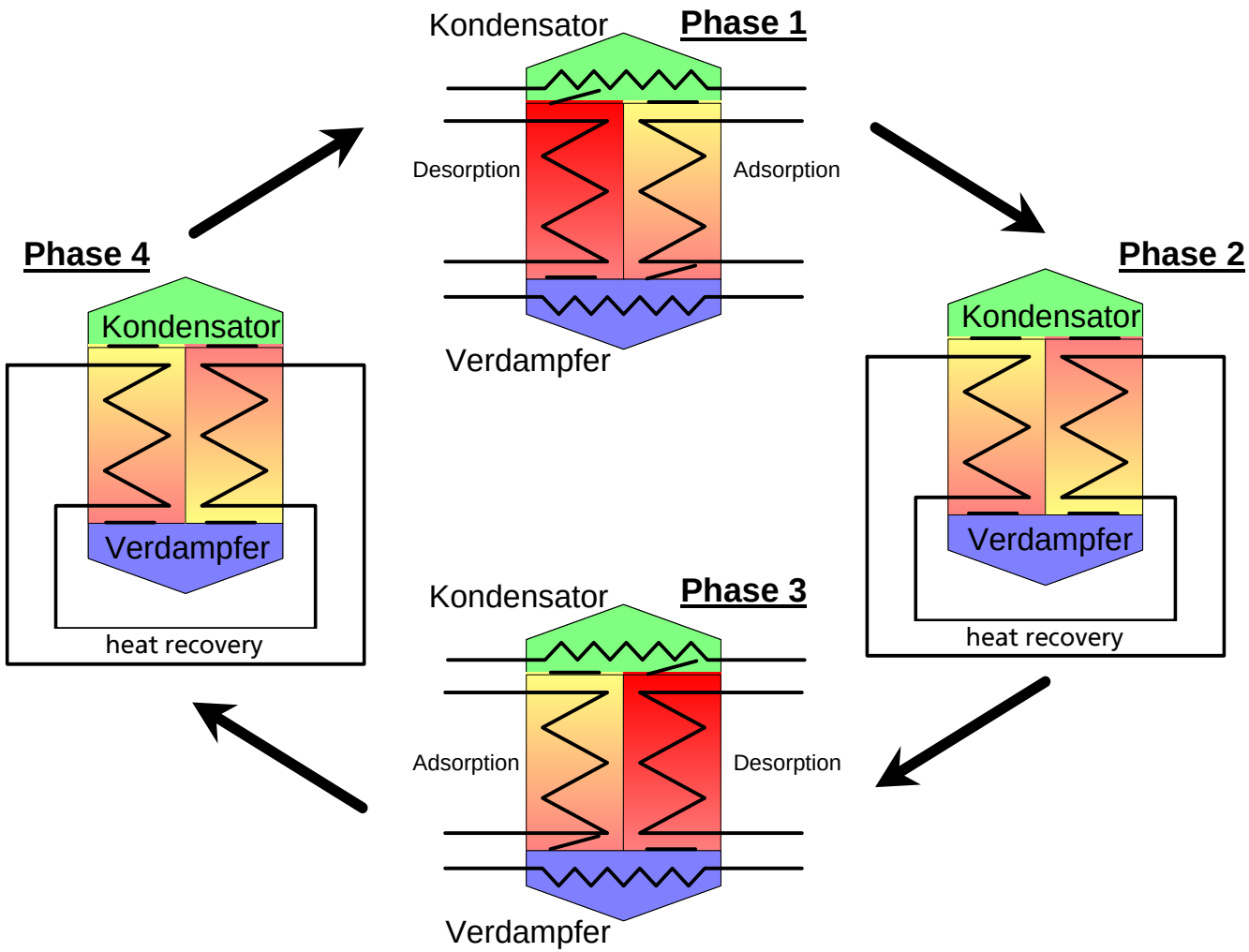
Tpyical machine with two sorption chambers



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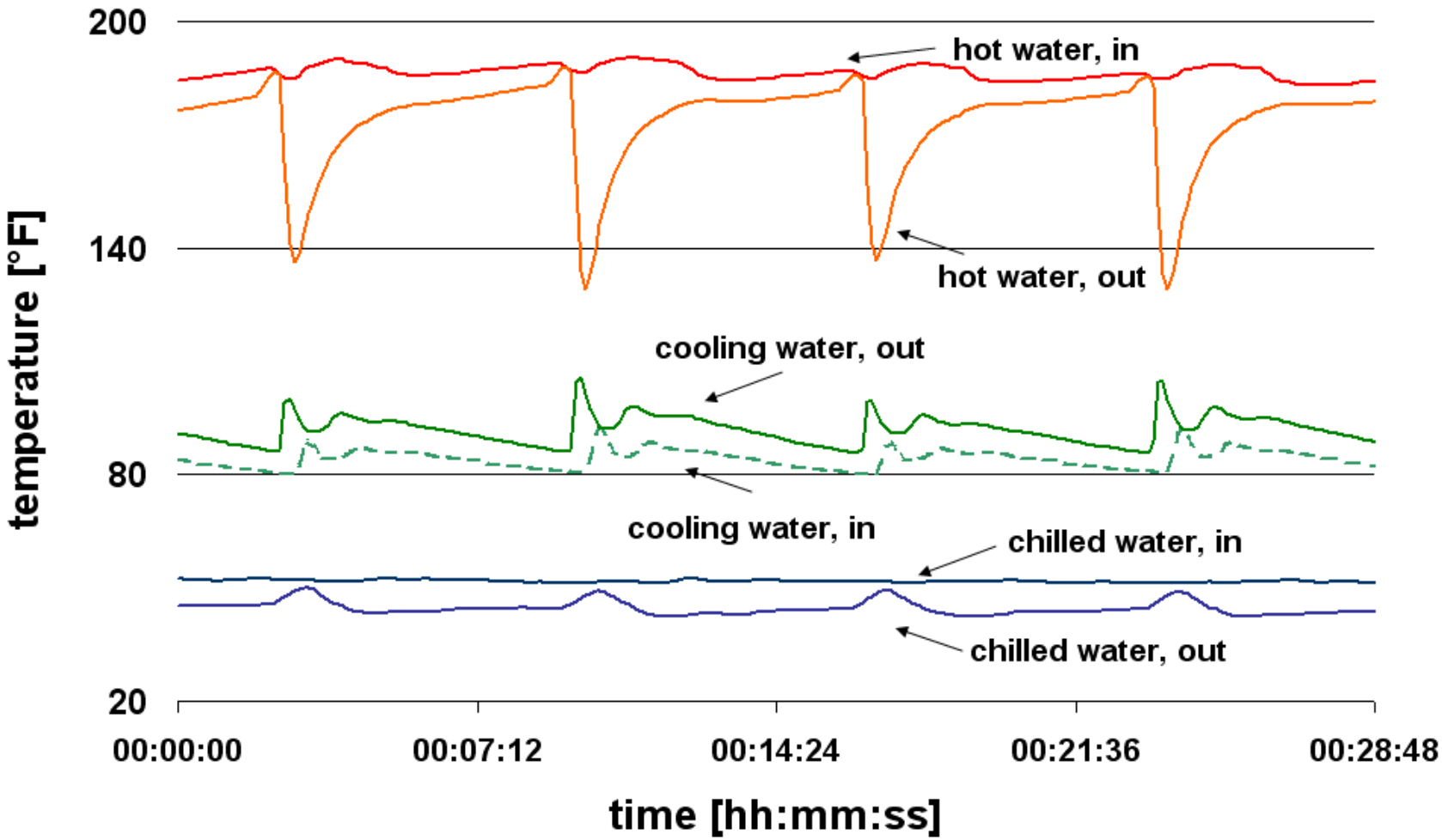
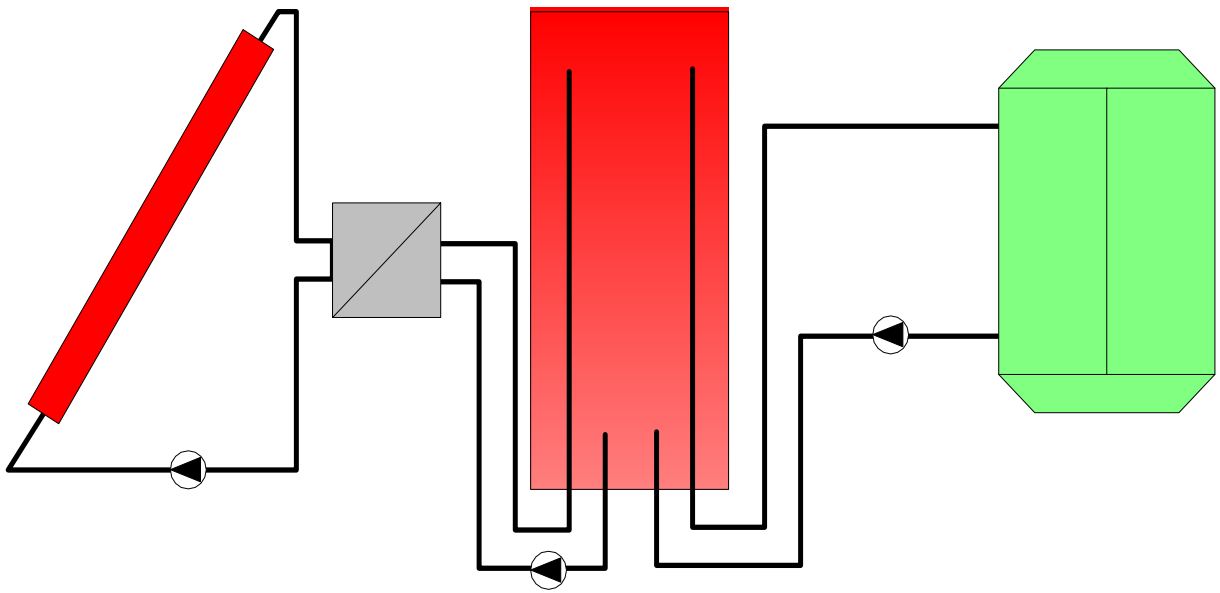
Temperature history



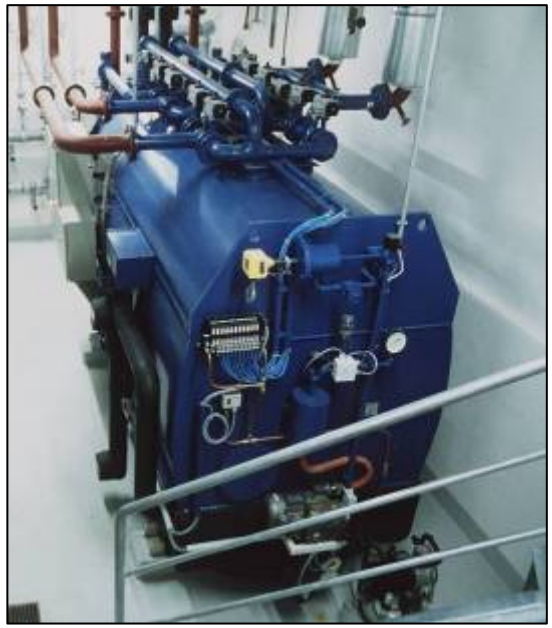
Temperature variations ⇔ hydraulic concept

Options

- Include buffer in return line of adsorption chiller
- Buffer between heat production and adsorption chiller



Adsorption Chillers



Nishiyodo NAK
70 kW capacity

the two “old” manufacturers (from Japan)

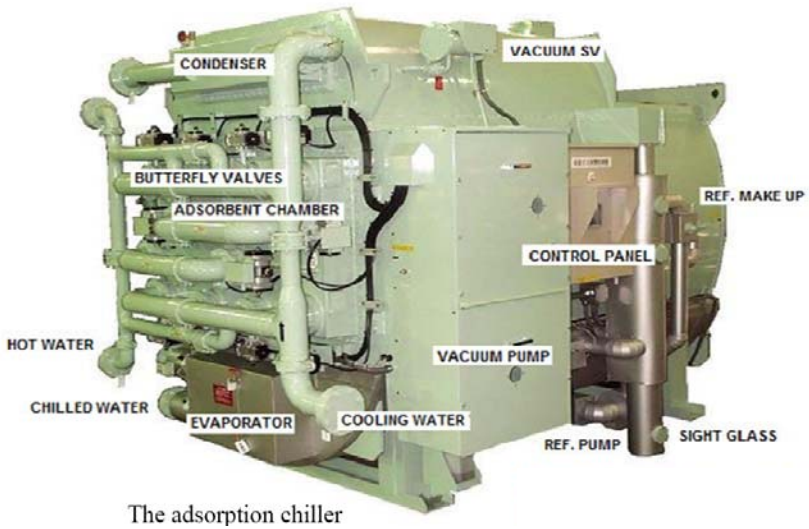
- Nishyodo (70-500 kW; 20 – 143 RT)
- Mayekawa (50-350 kW; 14.3 – 100 RT)

Mayekawa / Mycom ADR
350 kW capacity

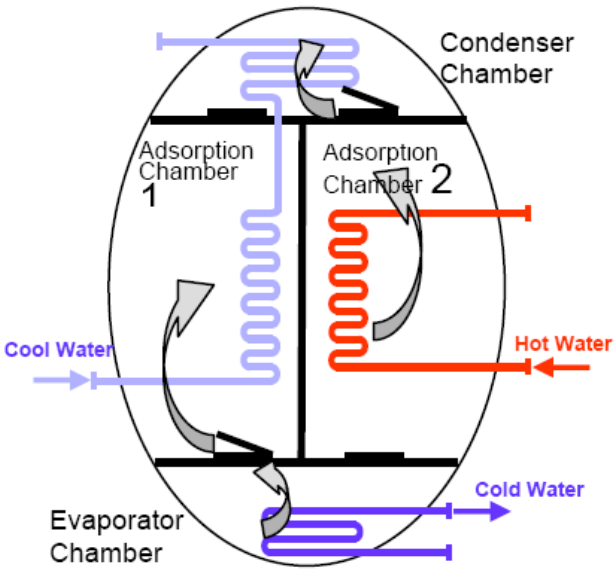
approx. 25 installations in Europe

Adsorption chiller in US

ECO-MAX
adsorption chillers
...for global cooling



The adsorption chiller



Power Partners, Inc.
ECO-MAX Adsorption Chillers
200 Newton Bridge Rd.
Athens, GA 30607
1.800.545.3121

http://www.eco-maxchillers.com

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Adsorption chillers

SorTech AG

Sortech AG (Germany):
7.5 kW (2 RT) and 15 kW (4 RT)

H_2O/silica gel

COP ≈ 0,6

$T_{generator}$: 72/65°C (161/149°F)

$T_{evaporator}$: 18/15°C (65/59°F)

$T_{condenser}$: 27/32°C (81/90°F)

Weight (7.5kW; 2 RT): 260 kg (573 lb)

also offered by SolarNext AG with the brands chillii® STC8 and chillii® STC 15

Sortech ACS 08
7.5 kW nominal capacity

Sortech ACS 15
15 kW nominal capacity

Features of the Sortech machine

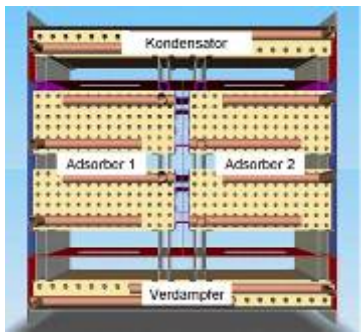
Coating technology

Heat exchanger surface coated with silica gel using epoxy resin as adhesive

Fast heat transfer
Improved mass transfer

Compact and light construction

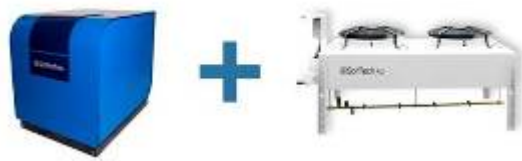
- Support of the vacuum envelope on the inner components enables to use stainless stell sheets for the containment.
- No moving parts



Low material use
Less weight and volume

Optimized system approach

- Chiller & re-cooler as package
- Integrated control of the re-cooler by the chiller
- Use of efficient EC fans and tap water spraying for peak temperatures



Low electricity consumption
Reduced water consumption
Simple system integration

Adsorption chillers

H_2O / zeolite

- New manufacturer
  Invensor (Berlin): first prototype in 2008

  nominal capacity: 10 kW (2.9 RT)

  COP ≈ 0.5

  T generator. : 85/77°C (185/170°F)

  T evaporator. : 18/15°C (65/59°F)

  T condenser. : 27/33°C (81/91°F)

  Weight: 370 kg (815 lb)

Invensor
10 kW nominal capacity

also offered by SolarNext AG with the brands chillii® ISC10

Adsorption chillers

SWAC-10 (China) : 8.5 kW

上海交通大學 Shanghai Jiao Tong University

Nominal capacity: 8.5 KW (2.5 RT)

COP : 0,4

T generator. : 85°C (185°F)

T evaporator. : 5°C (41°F)

T condenser. : 32°C (90°F)

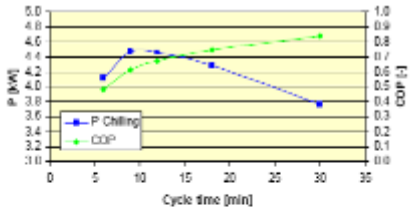
Weight: 1.5 t (3300 lb)

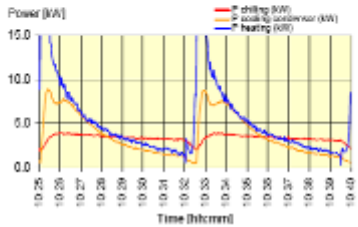
H_2O/silica gel

not yet fully commercially available

Adsorption chillers: recent new developments

ECN (Netherlands)
2.5 kW (0.7 RT)





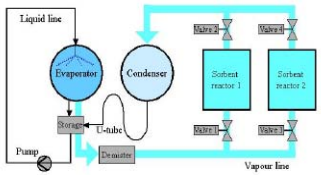


Figure 2: Basic lay-out (left) and basic design drawing (right) of the thermally driven chiller for the Socool project.

Univ. Warwick (GB)
Compact HXs

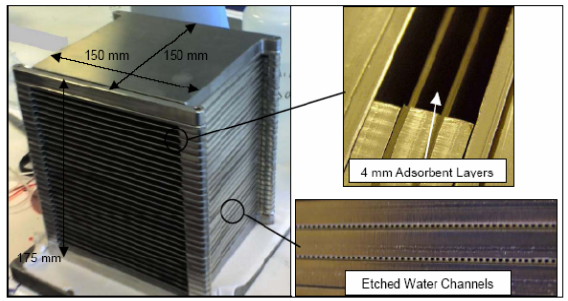
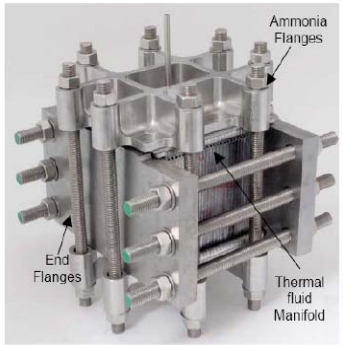


Figure 5: Plate heat exchanger generator design



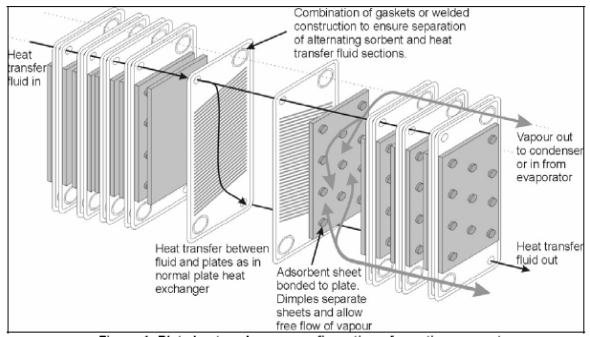


Figure 1: Plate heat exchanger configuration of sorption generator

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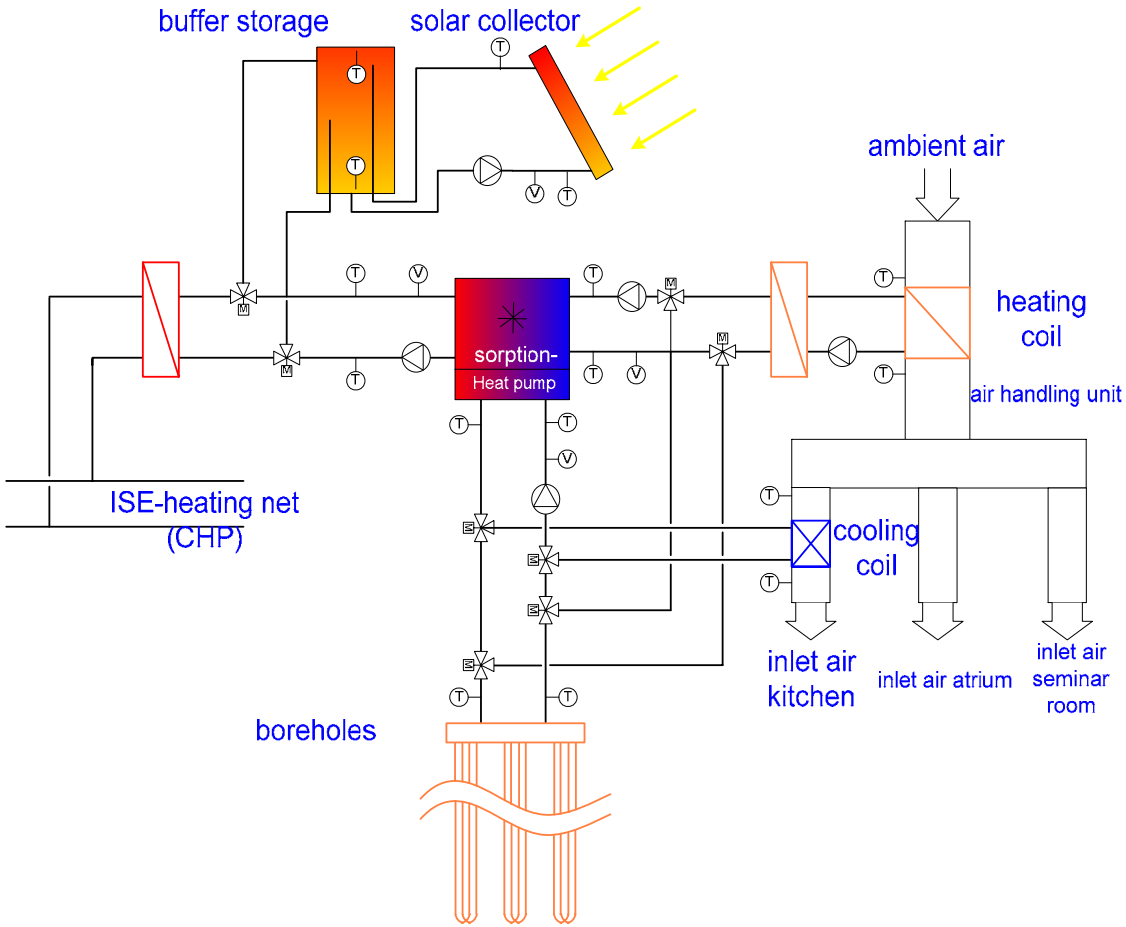
Example: System at Fraunhofer ISE in Freiburg/Germany

Central components:

- Adsorption heat pump / chiller: SorTech ACS05 5kW cooling / 12kW heating
- Solar system (20m²/ 215 sqft) flat plate collectors, 2m³ / 70 cf) buffer storage)
- Borehole system (3 x 80m / 262 ft)
- Connection to heating net of ISE (CHP)
- Heating coil in central AHU
- Cooling coil in the kitchen inlet air



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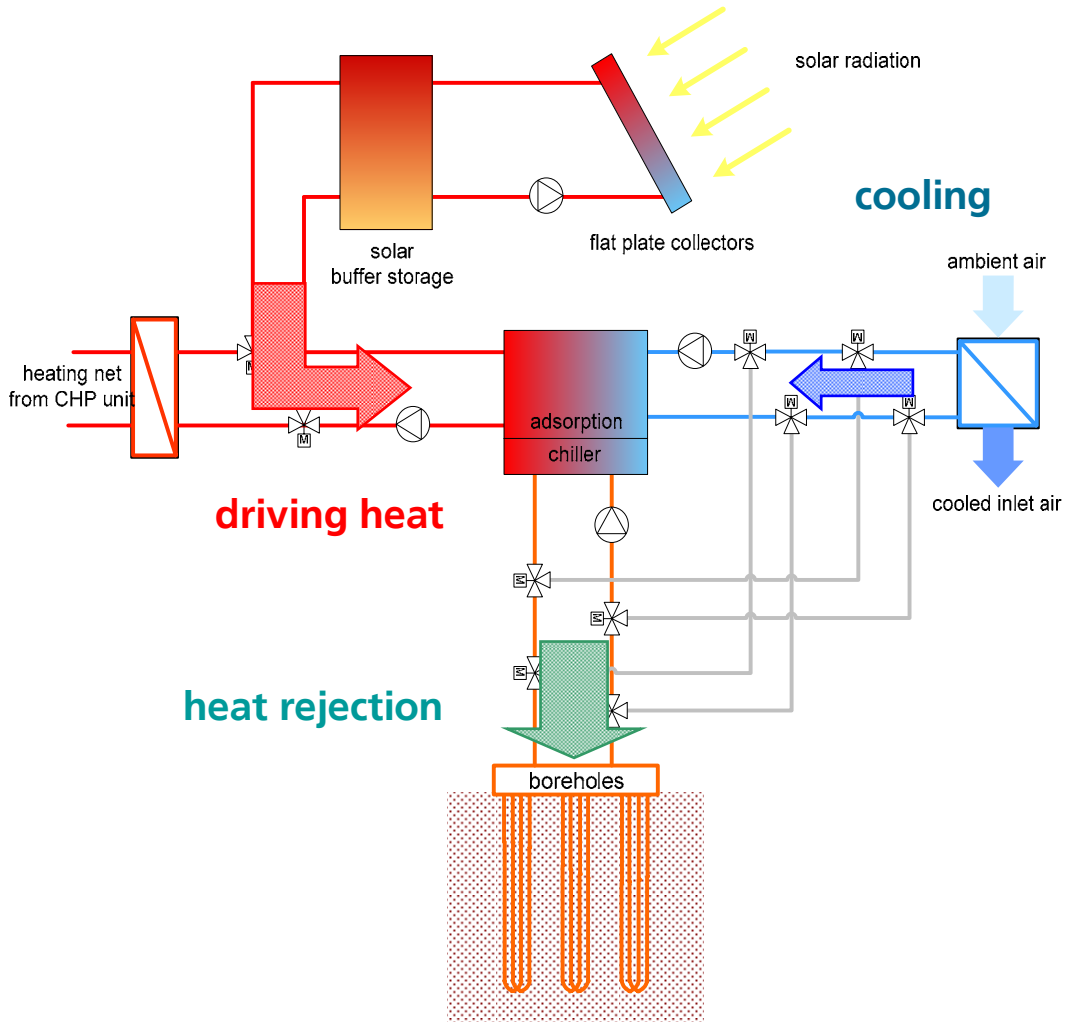
Summer mode: Solar cooling

Cooling operation

- Adsorption machine working as chiller
- Solar system provides driving heat
- Heating net of ISE (CHP) used as back-up driving source
- Borehole system used as heat rejection unit
- Cooling provided to cooling coil in the kitchen inlet air



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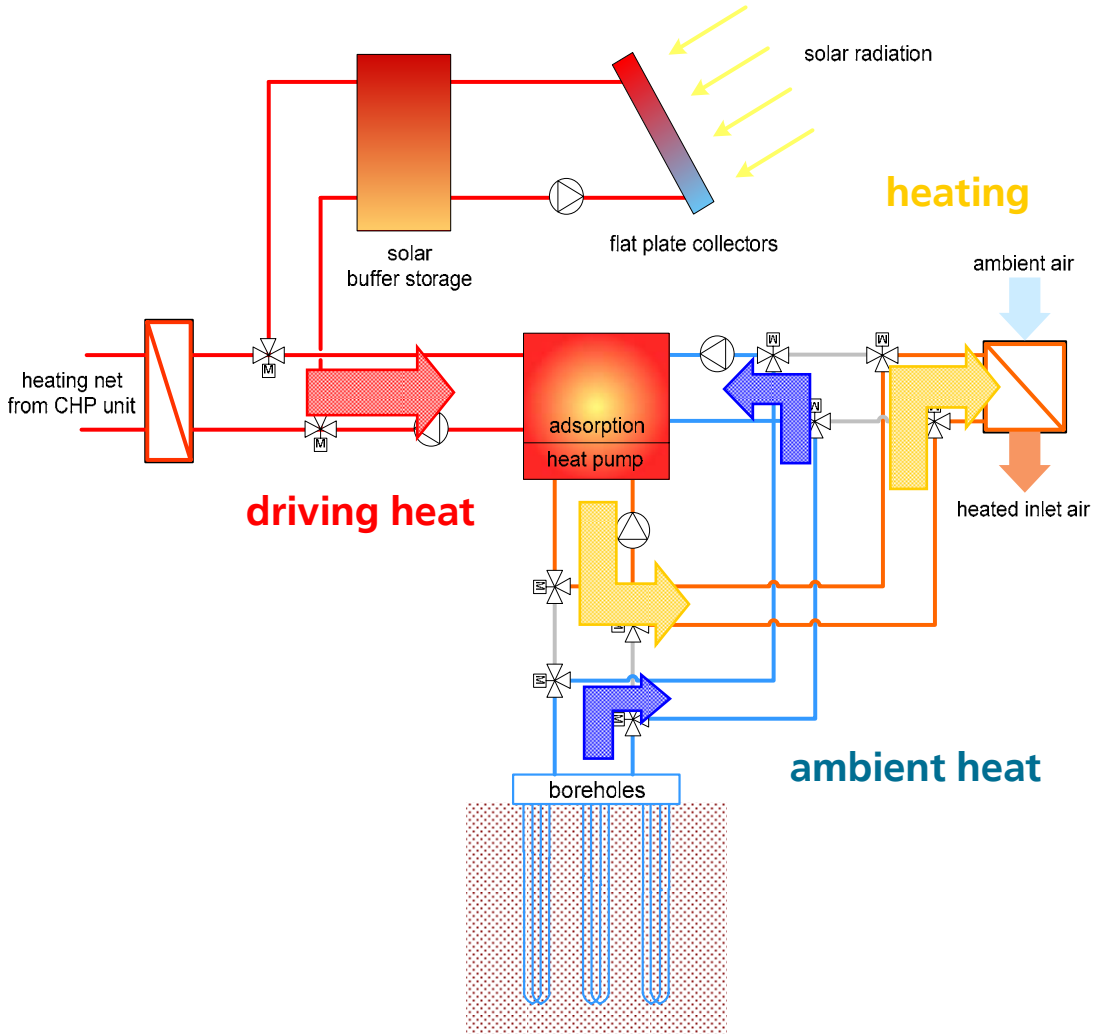
Winter mode: Heat pumping

Heating operation

- Adsorption machine working as thermally driven heat pump
- Heating net of ISE (CHP) provides driving heat
- Solar system may provides driving heat in favourable conditions
- Borehole system used as low temperature heat source (ambient)
- Heating provided to the main duct of AHU



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Installed system

buffer sto

g net

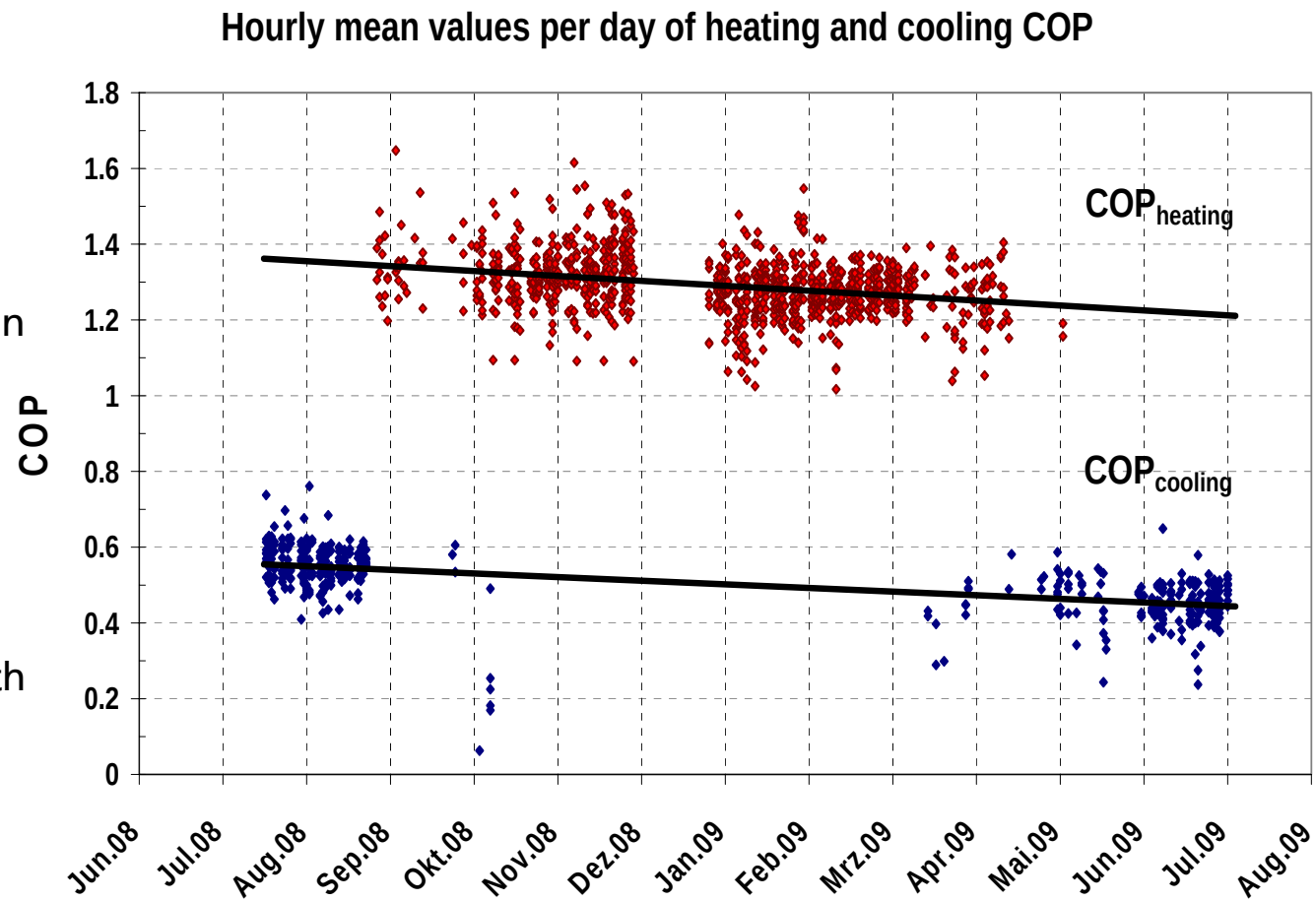
cooling

inlet air
kitchen

Machine performance

Results

- overall results as expected
- thermal COP within expected range (0.46 cooling, 1.25 heating)
- new system: modified coating technology in the present ACS08 with improved performance



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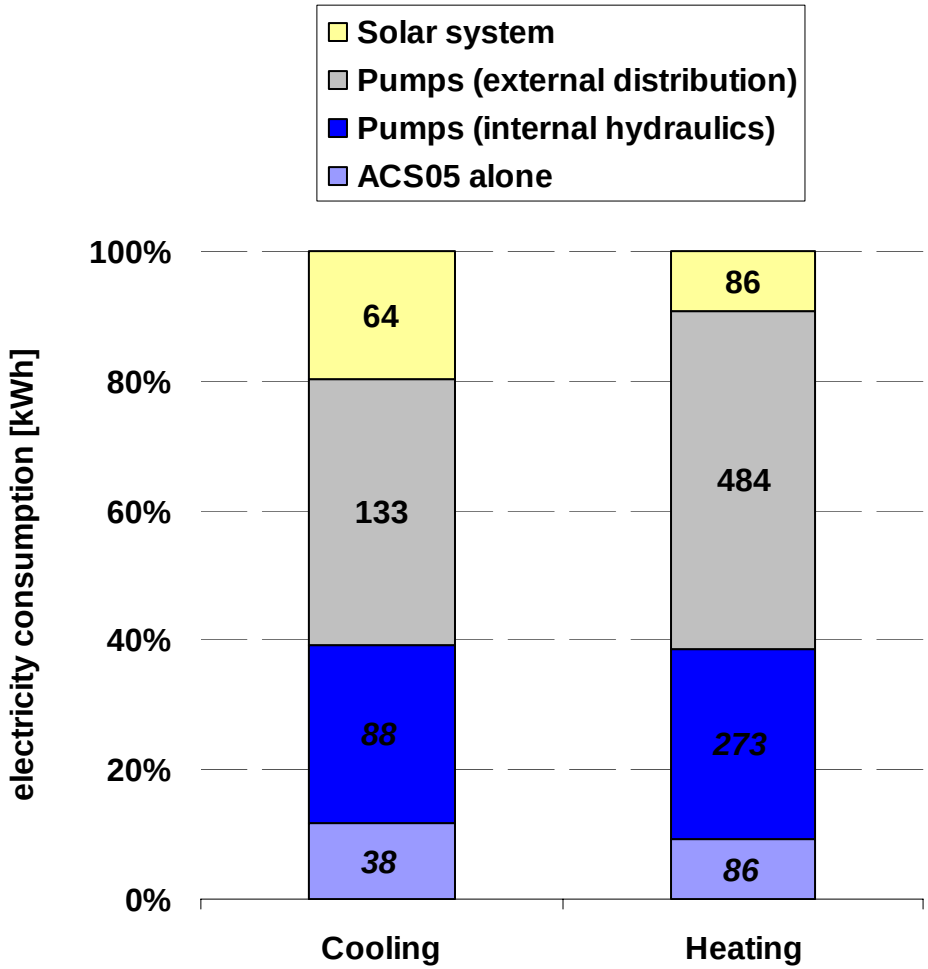
Thermal and electric performance



➔ **thermal and electric COP**

$$COP_{th} = \frac{Q_{heat/cold}}{Q_{driving}}$$

$$COP_{el,ACS/sys} = \frac{Q_{heat/cold}}{E_{tot,ACS/sys}}$$

	cooling	heating
COP_{th}	**0.46**	**1.25**
$COP_{el,ACS}$	**16.1**	**45.6**
$COP_{el,sys}$	**6.3**	**17.7**

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Adsorption – pro's and con's

Pro

- Environmentally sound materials (refrigerant, adsorption material)
- No solution pump; almost no moving parts
- No risk of cristallisation
- Large potential for cost reduction; in principle very simple construction
- Silent operation (no moving parts, except possibly refrigerant pump)
- Overall, a very robust process

Con

- Important to guarantee high tightness (vacuum in case of water as refrigerant)
- Avoid formation of non-condensibles
- Somewhat lower COP when compared to single-effect absorption (more difficult to achieve high efficient heat recovery)
- Cyclic variations of temperature in hydraulic cycles (particular heating)

Summary

Adsorption technology is promising for thermally driven cooling

- Low driving temperatures starting at approx. 55°C (130°F) possible
- Robust process
- Large optimization potential
  - Optimally designed adsorption materials
  - Advanced compound materials of adsorption materials and HX substrate
- In particular interesting for small capacity range
- Significant cost reduction potential for large production rates

… thank you very much for your attention