
Solar Assisted Cooling: Technologies - Potential - Examples



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de Energia Solar*

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Outline

- *Solar assisted cooling technologies*
- *Energy saving potential*
- *Selected projects*
- *Summary & outlook*

Outline

➔ **Solar assisted cooling technologies**

- *Energy saving potential*
- *Selected projects*
- *Summary & outlook*

Design principles - general

Goal

- *Assure indoor comfort with a minimum of energy demand*

Approach

1. *Reduction of energy demand*
2. *Use of heat sinks (sources) in the environment*
3. *Efficient conversion chains (Minimize exergy losses)*
4. *(fractional) saving of the remaining demand using renewable energies*

Building envelope, ventilation

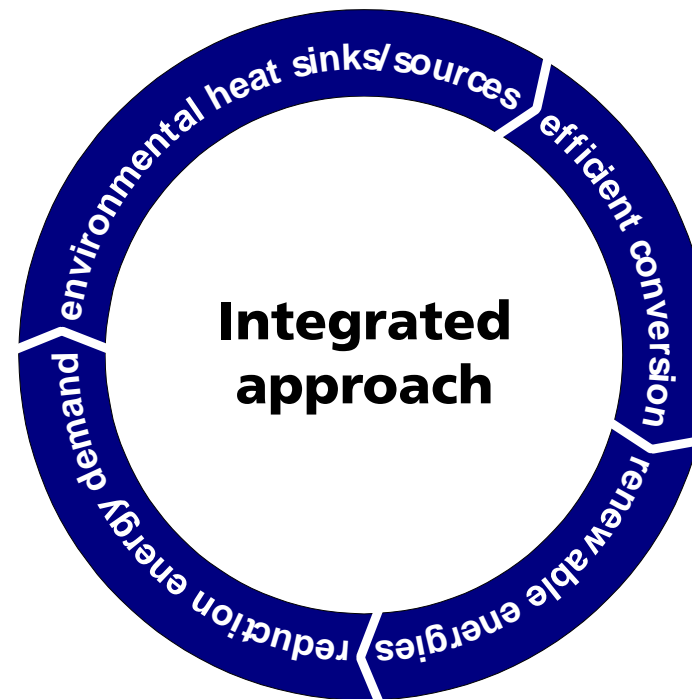
Ground, outside air (T, x) directly or indirectly; storage mass

HVAC, combined heat, cooling & power, networks, auxiliary energy

Solar thermal, PV, (biomass)

Design principles - general

Integrated approach needed, in particular when using solar active technologies integrated into the building envelope

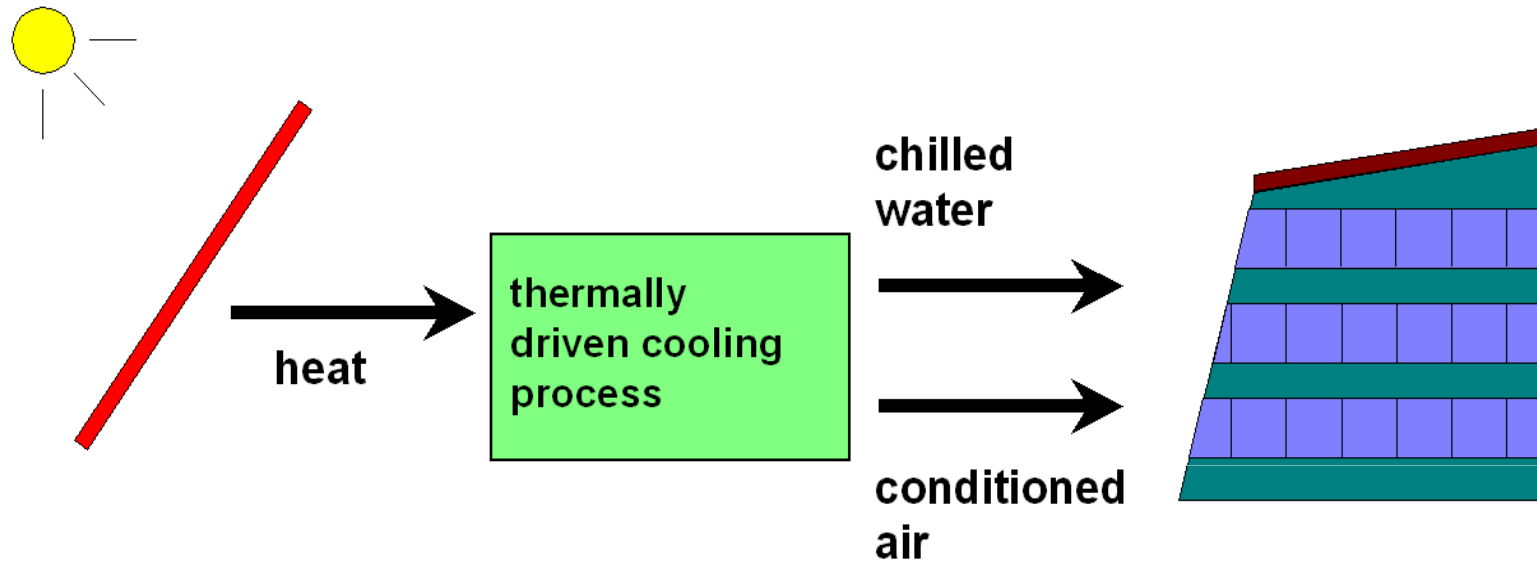


Bildnachweis: <http://www.uni-stuttgart.de/libk2/> (oben); Fraunhofer ISE (unten)

Design principles – air-conditioning with active systems

- *Separate of temperature control (cooling) and humidity control (dehumidification)*
- *Reduce air change rate to the hygienic needed minimum*
- *Treat sensible loads using high temperature systems (radiative cooling, chilled ceilings, chilled beams, thermally activated slabs, ...)*
- *Sorptive dehumidification of ambient air, if a low temperature heat source ($> 50^{\circ}\text{C}$) is available (co-generation, waste, district, solar)*
- *Otherwise: heat recovery in case of dehumidification by cooling air below the dew point*

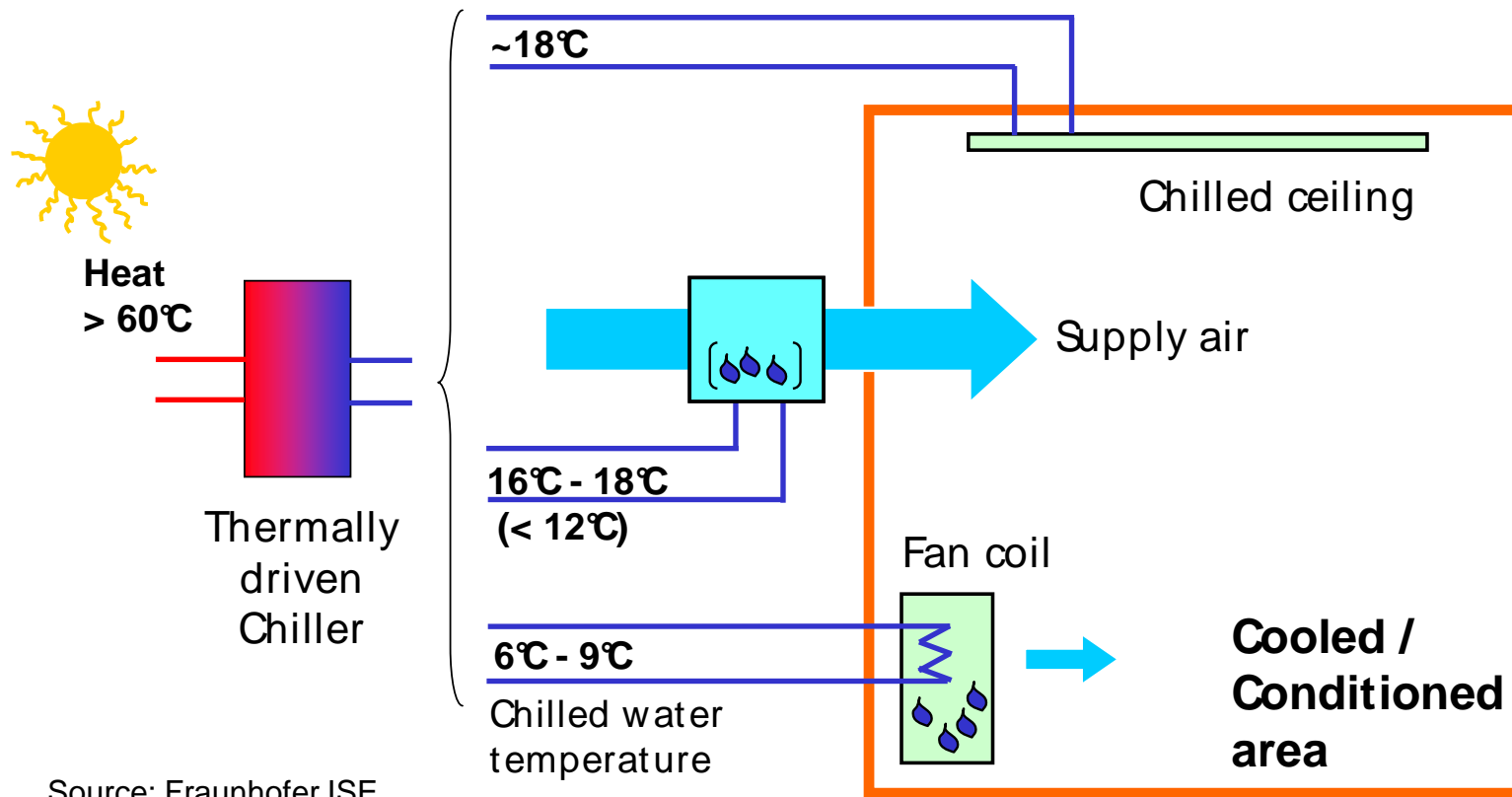
Basic process



Basic processes

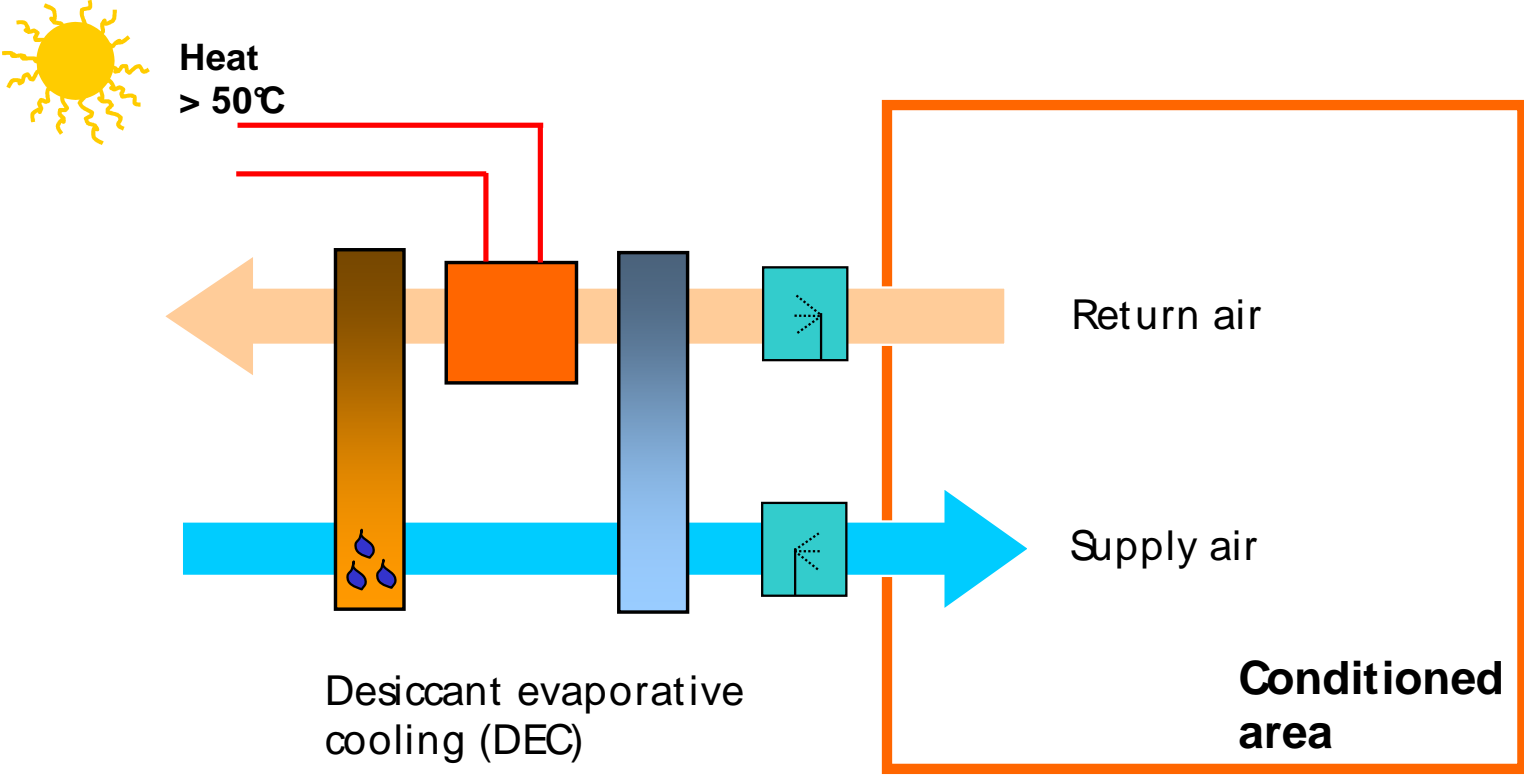
- *Closed cycles (chillers): chilled water*
- *Open sorption cycles: direct treatment of fresh air (temperature, humidity)*

Solar thermally driven cooling and air-conditioning - Closed cycles: distribution medium chilled water



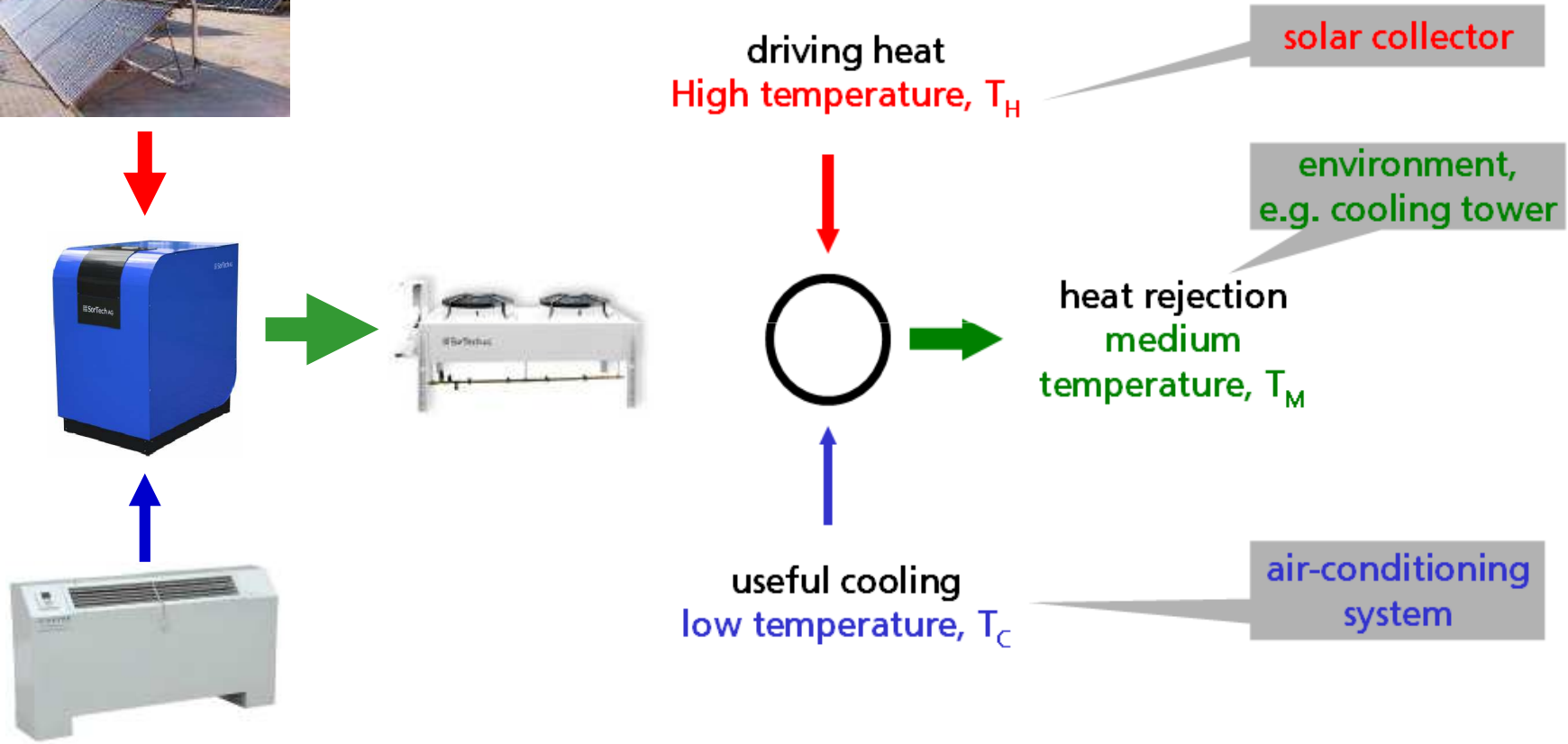
Source: Fraunhofer ISE

Solar thermally driven cooling and air-conditioning - Open cycles: distribution medium conditioned air



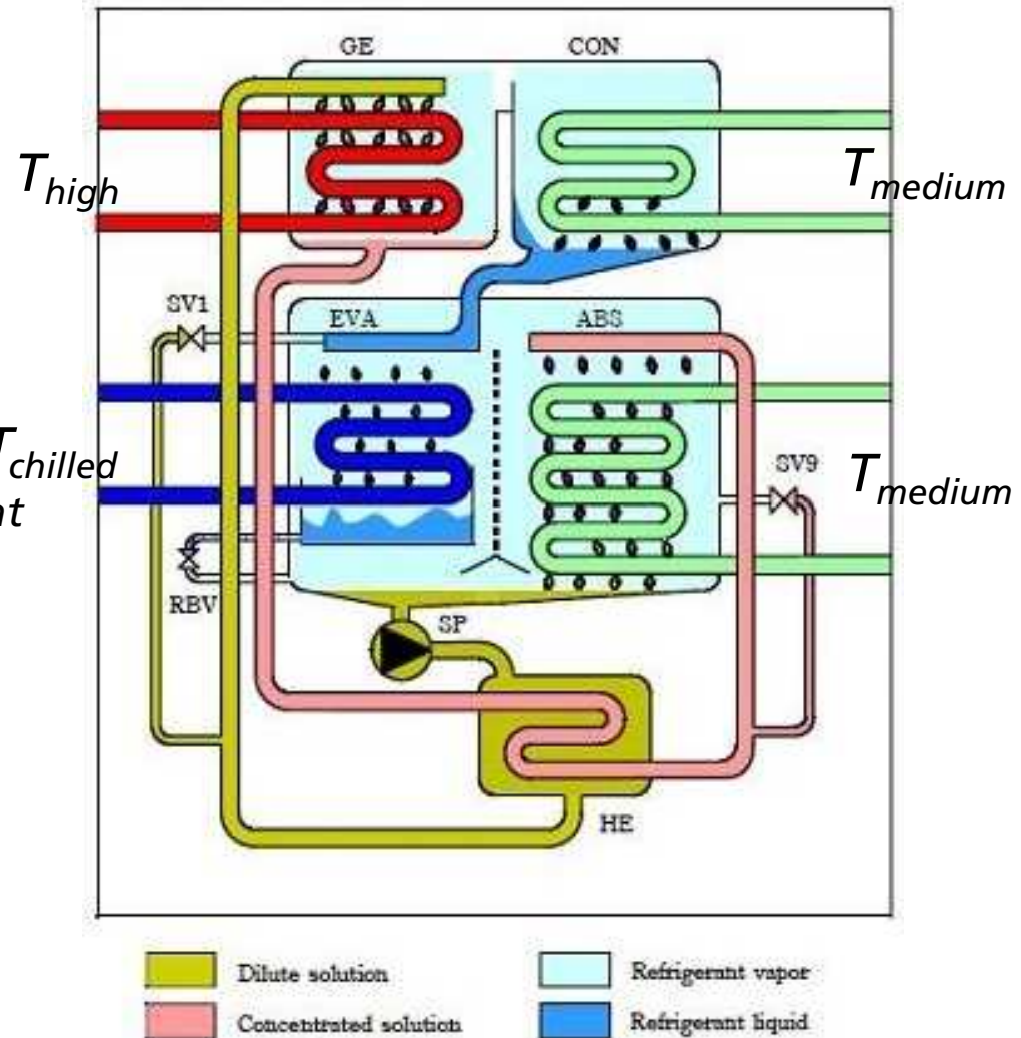
Source: Fraunhofer ISE

Closed cycles – general principle



Absorption chillers

- process discovered by Ferdinand Carré in 1858
- Two technologies:
 1. Lithium bromide – Water
 2. Water – Ammonia
- Four main elements:
 1. Generator (GE): solution is $T_{chilled}$ regenerated y the driving heat
 2. Condenser (CON): refrigerant is condensed
 3. Evaporator (EVA): refrigerant evaporates
 4. Absorber (ABS): refrigerant is absorbed by solution
- solution pump (SP) and heat exchanger (HE)



**Absorption chillers
products < 5 RT (18 kW);
no claim to be exhaustive**

 **YAZAKI**











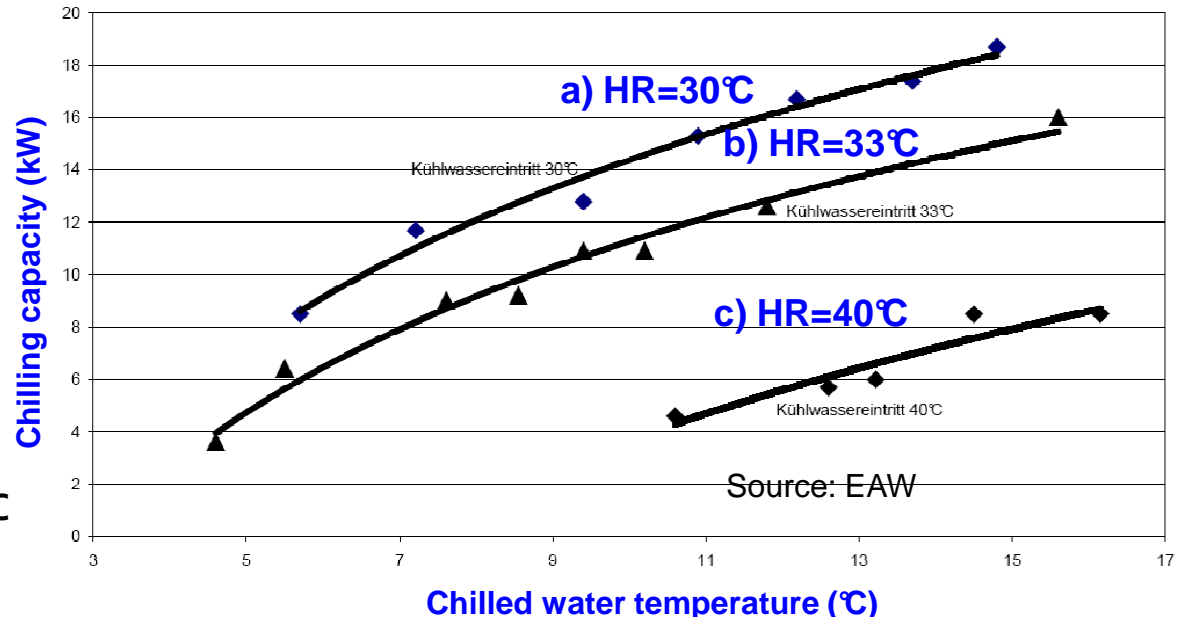




SK SonnenKlima GmbH

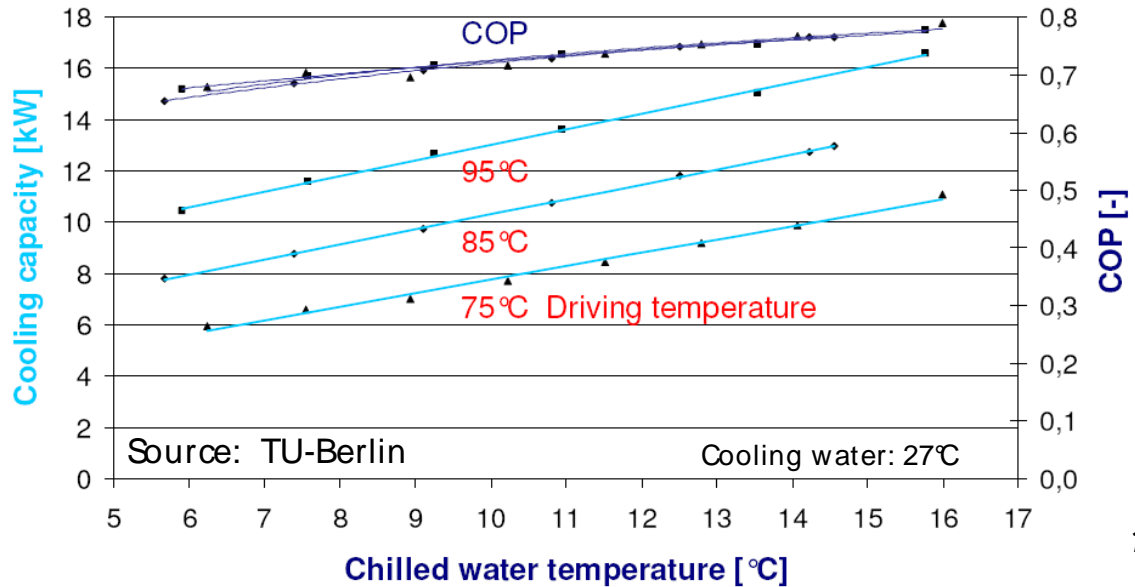
Absorption chiller performance

Example:
 dependency of capacity on heat rejection;
 cooling water inlet temperature:
 a) 30°C
 b) 33°C
 c) 40°C
 Source: EAW, nominal capacity 4.3 RT (15 kW);
 hot water inlet temperature 90°C



Example:
 dependency of COP and capacity
 on driving temperatures

Source: TU-Berlin, Sonnenklima;
 nominal capacity 2.8 RT (10 kW)
 cooling water inlet temperature:
 27°C



Absorption technology

■ Advantages

- ◆ Continuous operation through liquid circulating sorption fluid, therefore constant temperatures
- ◆ With ammonia-water technology refrigeration $< 0^{\circ}\text{C}$ possible
- ◆ In general higher COP's than achieved in adsorption chillers
- ◆ 2-effect machines with COP's > 1.0 exist
- ◆ Combination possible with stationary collectors, for refrigeration and 2-effect chillers with concentrating collectors
- ◆ Many manufacturers, since a few years also in the small capacity range

■ Disadvantages

- ◆ Danger of crystallisation with H_2O -LiBr chillers; high internal control effort required to avoid crystallisation
- ◆ Solution pump required
- ◆ Typically, higher driving temperatures than for adsorption technology

Absorption chiller suppliers

Supplier	Type of components	Technology	Application	Remarks	Available in Brazil	Origin, web link
Broad	single-effect Absorption chillers > 230 kW, double-effect Absorption chillers > 230 kW	H ₂ O-LiBr	> 5°C chilled water	Inbetween, one of the worlds leading producer of absorption chillers	Worldwide distribution, but no target market in Brazil for absorption technology Exclusive representative for BROAD in Brazil: TUMA	China www.broad.com www.tuma.com.br
YORK	single-effect Absorption chillers > 400 kW, double-effect Absorption chillers > 700 kW	H ₂ O-LiBr	> 5°C chilled water	Classical manufacturer of large scale products, mainly compression chillers; International distributed by Johnson Controls	Worldwide distribution and manufacturing (also in Brazil), but no target market in Brazil for absorption technology Several dependencies of Johnson Control exist in Brazil, focus on compression chiller technology	USA www.york.com www.johnsoncontrols.com
Carrier	single-effect Absorption chillers > 260 kW, double-effect Absorption chillers > 350 kW	H ₂ O-LiBr	> 5°C chilled water	Classical manufacturer of large scale products, mainly compression chillers	Worldwide distribution, but no target market in Brazil for absorption technology	USA www.corp.carrier.com www.commercial.carrier.com
Trane	single-effect Absorption chillers > 460 kW, double-effect Absorption chillers > 390 kW	H ₂ O-LiBr	> 5°C chilled water	Classical manufacturer of large scale products, mainly compression chillers	Worldwide distribution and manufacturing (also in Brazil), but no target market in Brazil for absorption technology	USA www.trane.com
Thermax	single-effect Absorption chillers > 35 kW, double-effect Absorption chillers > 350 kW	H ₂ O-LiBr	> 5°C chilled water	Producer of HVAC and refrigeration systems	Worldwide distribution, but no target market in Brazil for absorption technology A dependency exists in Rio de Janeiro	India www.thermaxindia.com www.thermaxdobrasil.com.br
Thermax	Absorption chillers > 175 kW for refrigeration	NH ₃ -H ₂ O	0°C to -50°C chilled medium	Producer of HVAC and refrigeration systems	Worldwide distribution, but no target market in Brazil for absorption technology A dependency exists in Rio de Janeiro	India www.thermaxindia.com www.thermaxdobrasil.com.br
Colibri	Absorption chillers > 150 kW for refrigeration	NH ₃ -H ₂ O	0°C to -50°C chilled medium	Classical producer of ammonia-water absorption refrigeration plants	Worldwide distribution, but no target market in Brazil for absorption technology	Netherlands www.colibri-bv.com

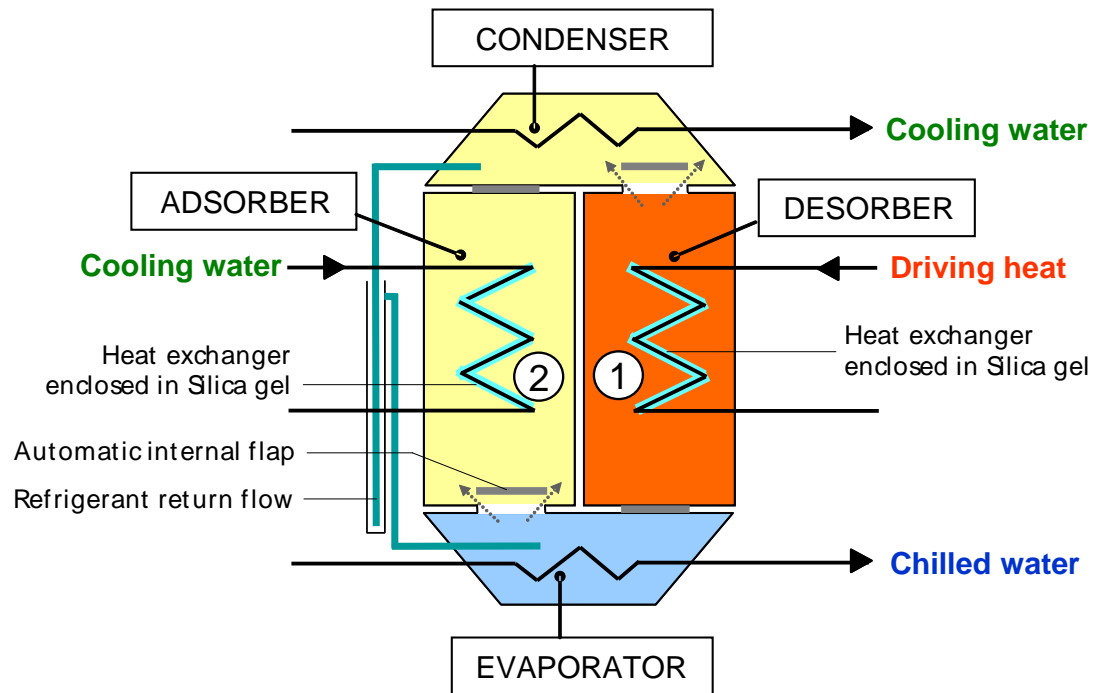
Absorption chiller suppliers

Supplier	Type of components	Technology	Application	Remarks	Available in Brazil	Origin, web link
Yazaki Energy	single-effect absorption chillers > 17.5 kW	H ₂ O-LiBr	> 5°C chilled water	Absorption chillers are a minor production line; main business is electric distribution systems, automotives	Worldwide distribution, but no target market in Brazil for absorption technology A representative is available in Brazil	Japan www.yazakienergy.com
EAW	single-effect absorption chillers > 15 kW,	H ₂ O-LiBr	> 5°C chilled water	Manufacturer of absorption chillers up to 200 kW; CHP units	Central market: Europe	Germany www.eaw-energieanlagenbau.de www.wegra-anlagenbau.de
Sonnenklima	single-effect absorption chillers 10-15 kW,	H ₂ O-LiBr	> 5°C chilled water	New company since a few years for production and marketing of small scale absorption chillers	Actually focusing on European markets; in near future worldwide available	Germany www.sonnenklima.de
ClimateWell	single-effect absorption chiller 10 kW	H ₂ O-LiCl	> 5°C chilled water	Main product: small absorption chiller. On the market since a few years. Series manufacturing since 2008 (Spain)	In principle worldwide available; actually focusing on South European market	Sweden www.climatewell.com
Ago	Absorption chillers > 30 kW for refrigeration	NH ₃ -H ₂ O	> 0°C to -30°C chilled medium	Energy processing in heat, cold, CHP	Central market: Europe	Germany www.agogroup.com
Robur	Absorption chiller 13 kW for refrigeration	NH ₃ -H ₂ O	> 0°C to -10°C chilled medium	Gas driven heat pumps and chillers; one gas-driven chiller modified for operation with thermo-oil	Worldwide distribution, but no target market in Brazil for absorption technology	Italy www.robur.com
Pink	Absorption chiller 12 kW for refrigeration	NH ₃ -H ₂ O	> 0°C to -10°C chilled medium	Main business: Storage technologies	Worldwide available through distribution partners, no target market in Brazil for absorption technology	Austria www.pink.co.at

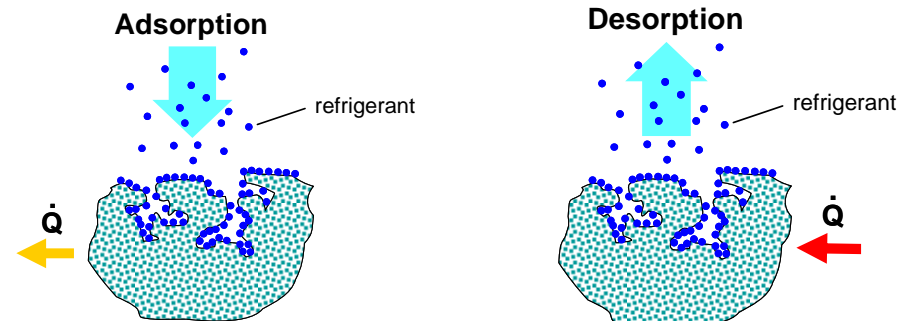
Adsorption chillers: internal components

Principle:

- heat is applied to desorb the refrigerant (water) from the sorption material (compartment 1)
- desorbed refrigerant vapour is condensed in the condenser and returns to the evaporator
- refrigerant (water) is evaporated in the evaporator, thereby taking up evaporation heat from the chilled water circuit (cold production)



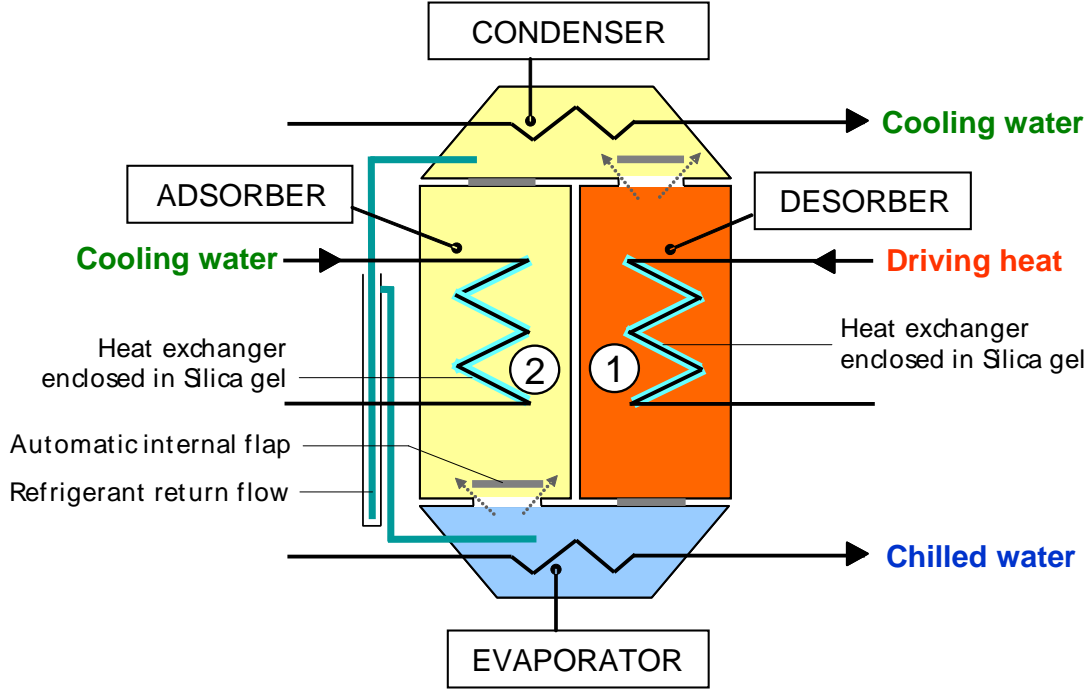
Source: Fraunhofer ISE



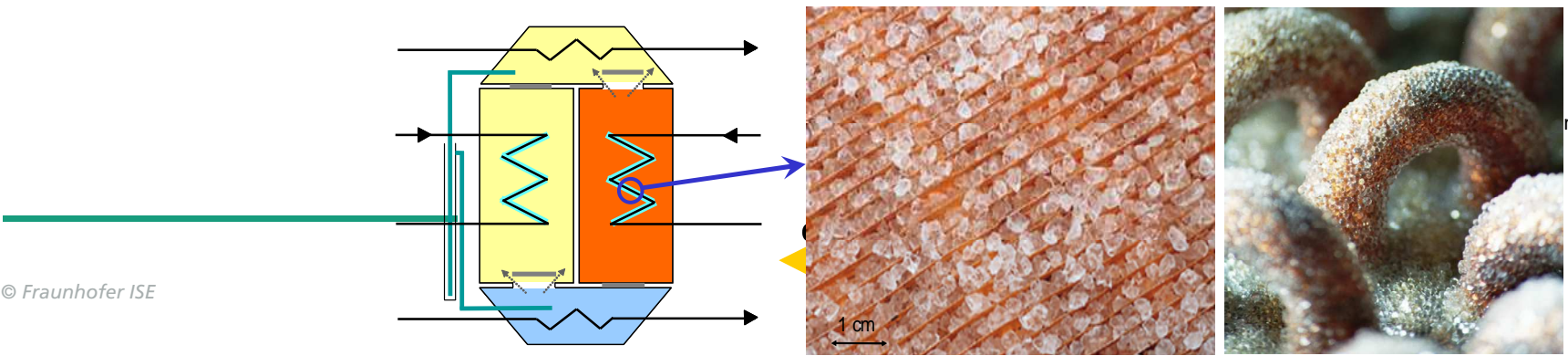
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Source: Fraunhofer ISE



Adsorption chillers typical products; no claim to be complete



Nishiyodo NAK
70 kW chilling capacity
Installation: University hospital Freiburg, Germany

Sortech ACS
2.1 RT and 4.3 RT capacity
(7.5 kW and 15 kW capacity)



Invensor
2 RT and 2.8 RT capacity
(7 kW and 10 kW capacity)



Adsorption technology

■ Advantages

- ◆ Environmentally friendly materials
- ◆ No solution pump, few moving parts only
- ◆ No danger of crystallisation
- ◆ Low driving temperatures > 60°C
- ◆ Less requirements on collectors than absorption chillers
- ◆ Very low noise level
- ◆ High potential for cost reduction (basically simple construction)

■ Disadvantages

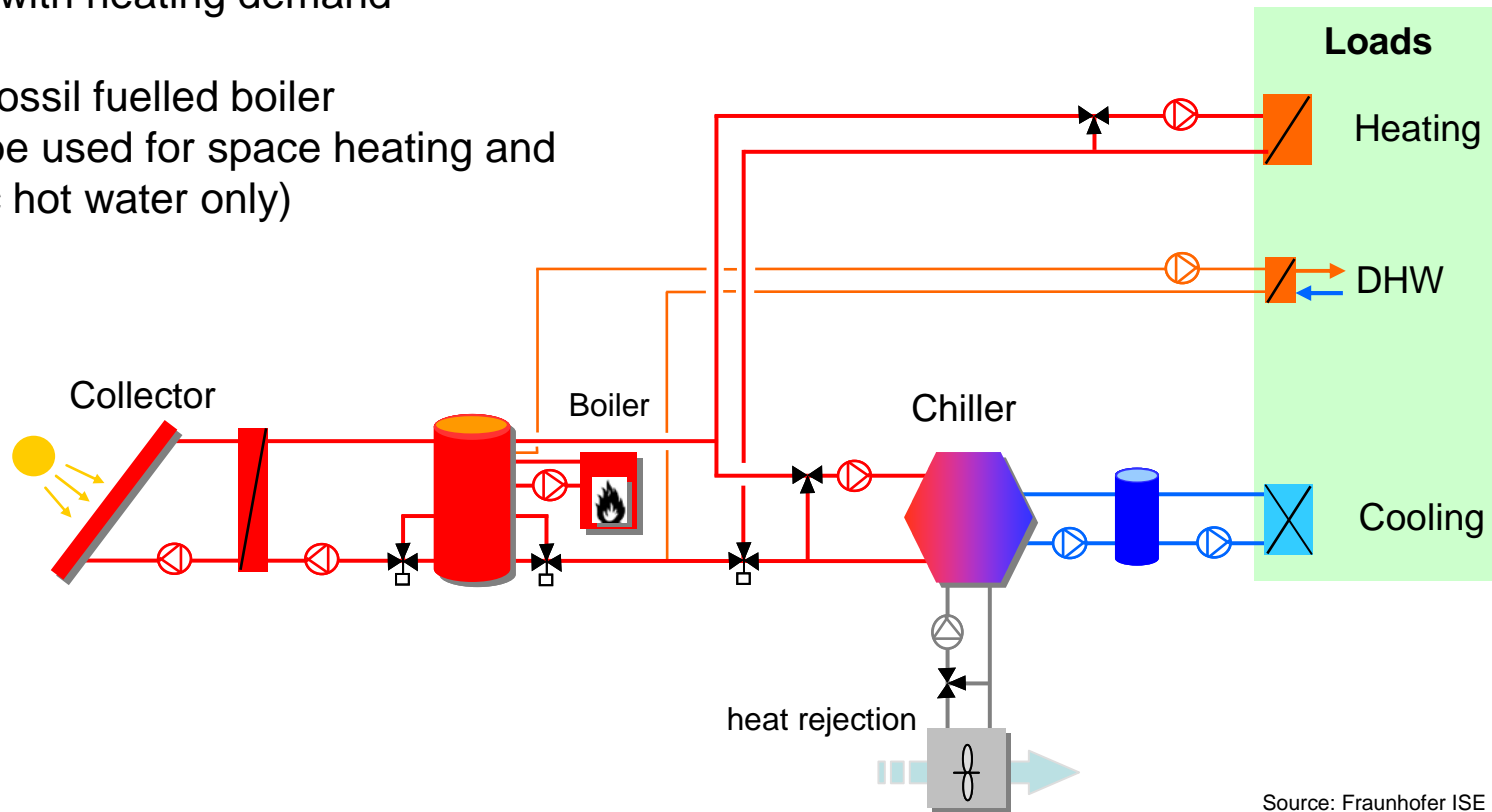
- ◆ High requirements on vacuum tightness
- ◆ Avoidance of formation of non-condensable gasses
- ◆ Lower COP as of absorption chillers
- ◆ Cycling temperature fluctuations in hydraulic circles
- ◆ Currently few manufacturers only
- ◆ Not available for refrigeration (minimum chilled water temperature approx. 5°C)

Adsorption chiller suppliers

Supplier	Type of components	Technology	Application	Remarks	Available in Brazil	Origin, web link
Mayekawa	Adsorption chillers > 108 kW	H ₂ O-Zeolite	> 5°C chilled water	Adsorption chillers are a minor production line; main business are traditional HVAC products	Worldwide distribution, and representatives in Latin America, but no distribution of adsorption chillers in Brazil so far.	Japan www.mayekawa.co.jp www.mycom.com.br
SorTech	Adsorption chillers > 8 kW,	H ₂ O-Silica gel	> 5°C chilled water	Manufacturer of adsorption chillers, currently 8 and 15 kW; on market since a few years	Current central market: Europe Available through distributors in Europe and Orient, but also installation in China	Germany www.sortech.de
Invensor	Adsorption chillers > 7 kW,	H ₂ O-Silica gel	> 5°C chilled water	New company on the market since 2008 for production of small scale adsorption chillers	Current central market: Europe Available through distributors in Europe, but also installation in Australia	Germany www.invensor.com

Solar thermally driven chilled water systems

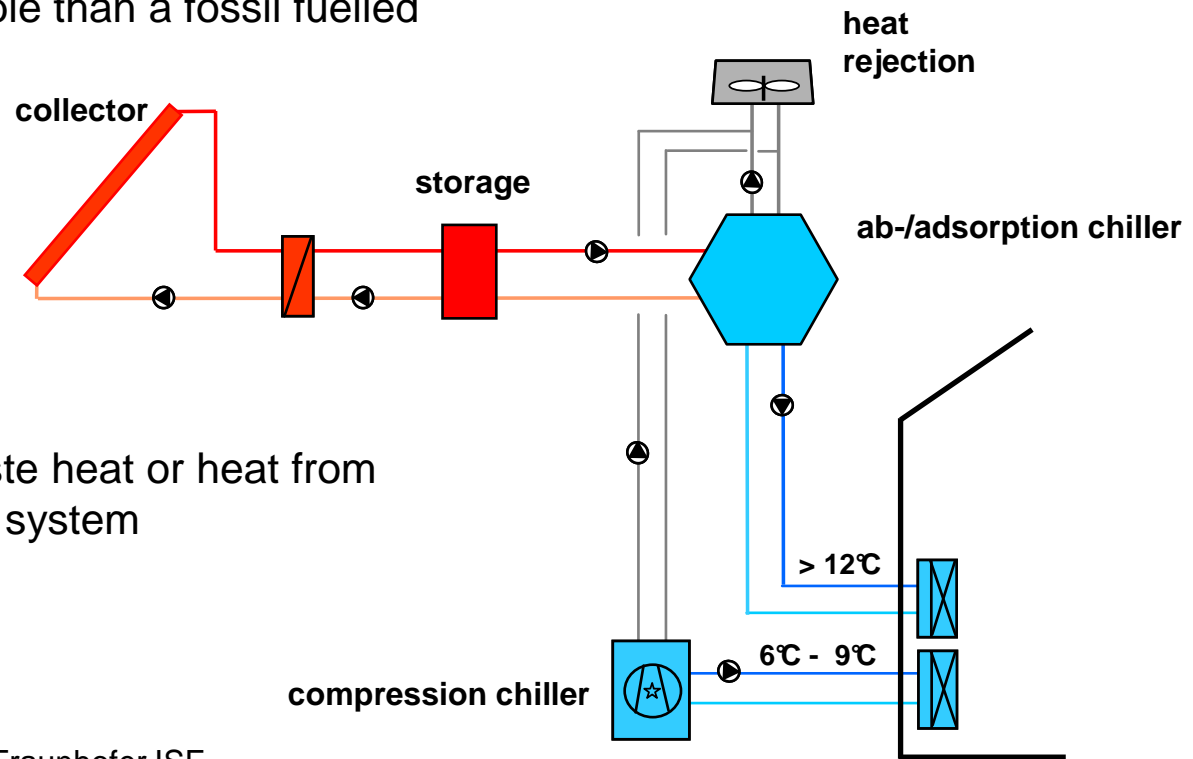
- Possible system scheme for building cooling and air-conditioning in temperate climates with heating demand
- Critical: fossil fuelled boiler (should be used for space heating and domestic hot water only)



Source: Fraunhofer ISE

Solar thermally driven chilled water systems

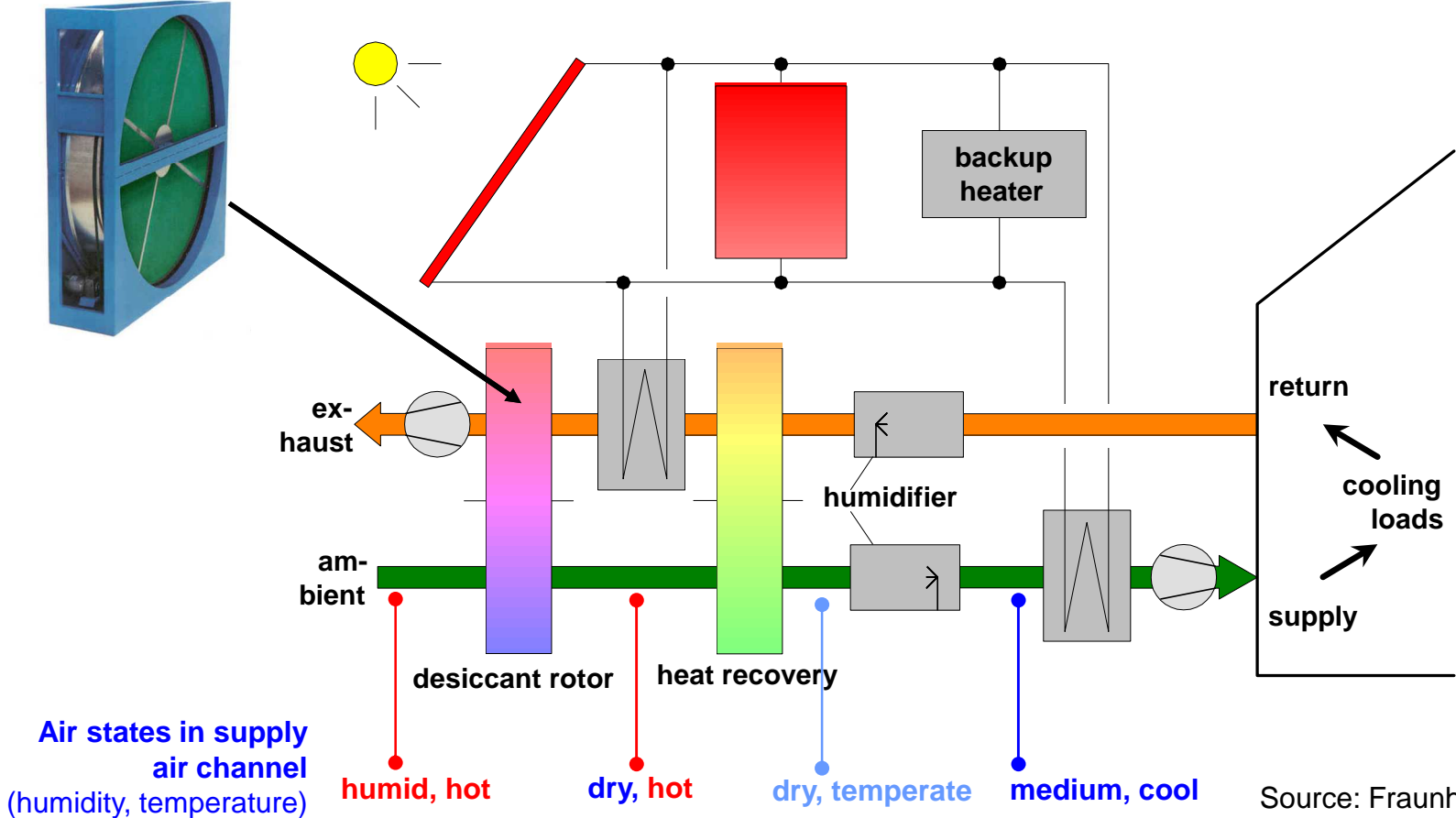
- In case a back-up system is required (e.g., for cooling in the evening or during night), a compression chiller is from primary energy aspects more favourable than a fossil fuelled heat back-up



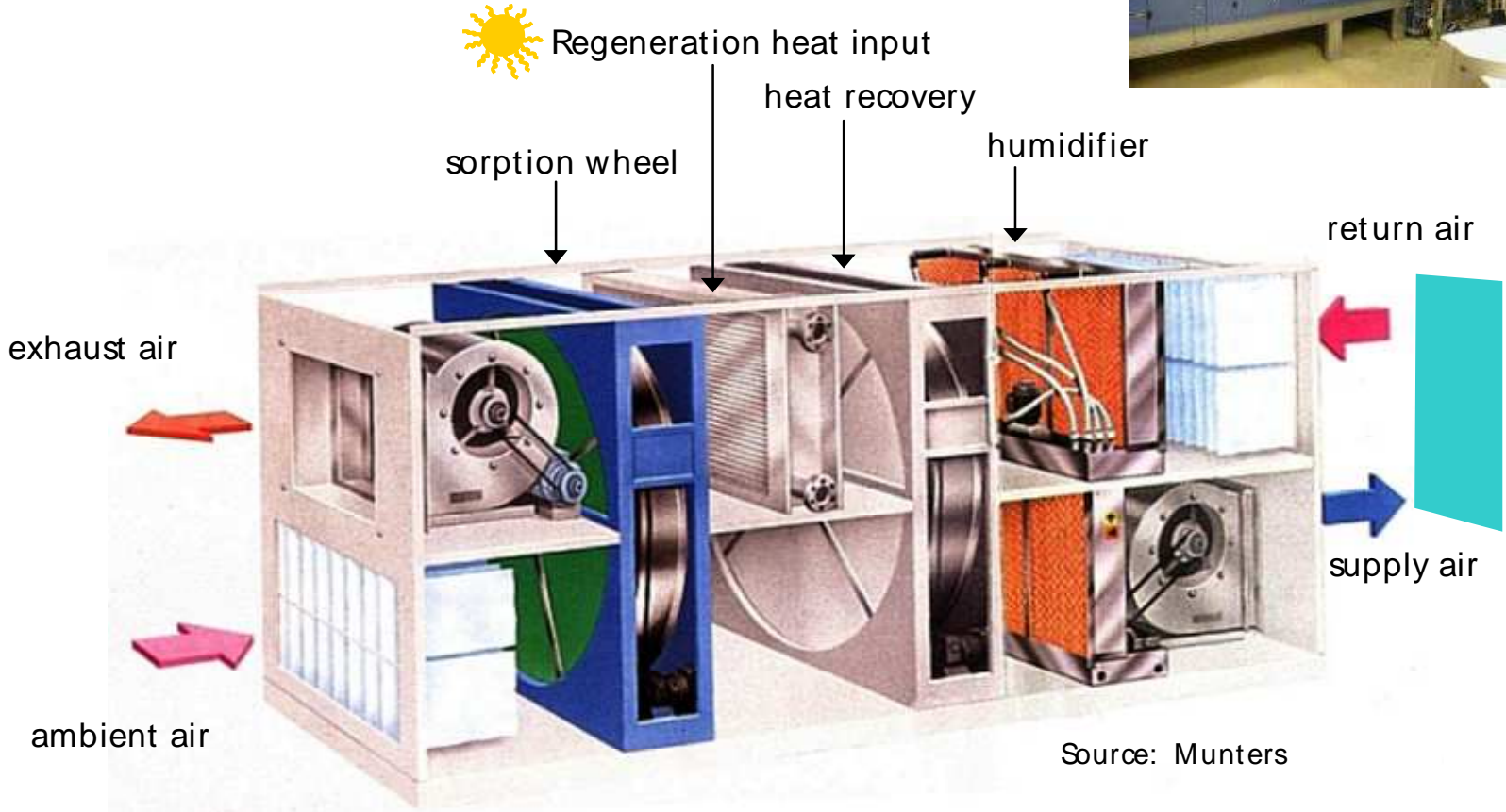
- Alternative: use of waste heat or heat from efficient co-generation system

Source: Fraunhofer ISE

Open cycle solid desiccant cooling system (standard configuration)

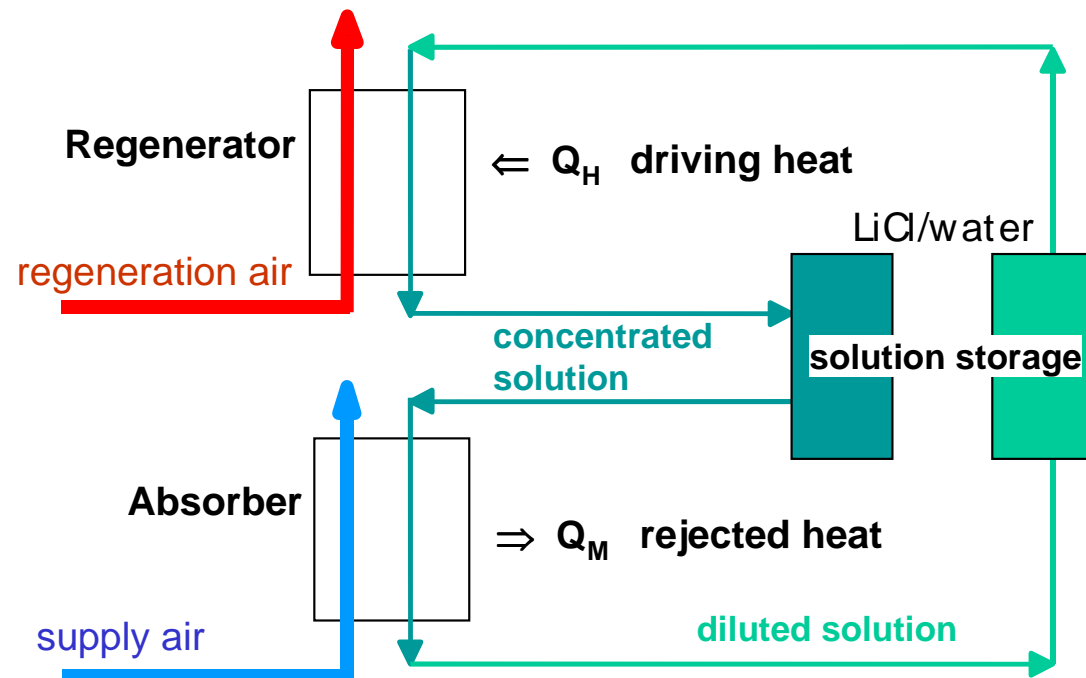


Open cycle solid desiccant cooling system (standard configuration)



Open cycle liquid desiccant cooling system

- liquid sorption integrated in indirect evaporative cooling systems; Germany: Menerga
- driving temperature: 60-90°C
- high density energy storage, decoupling of cooling and regeneration
- pilot plants in operation



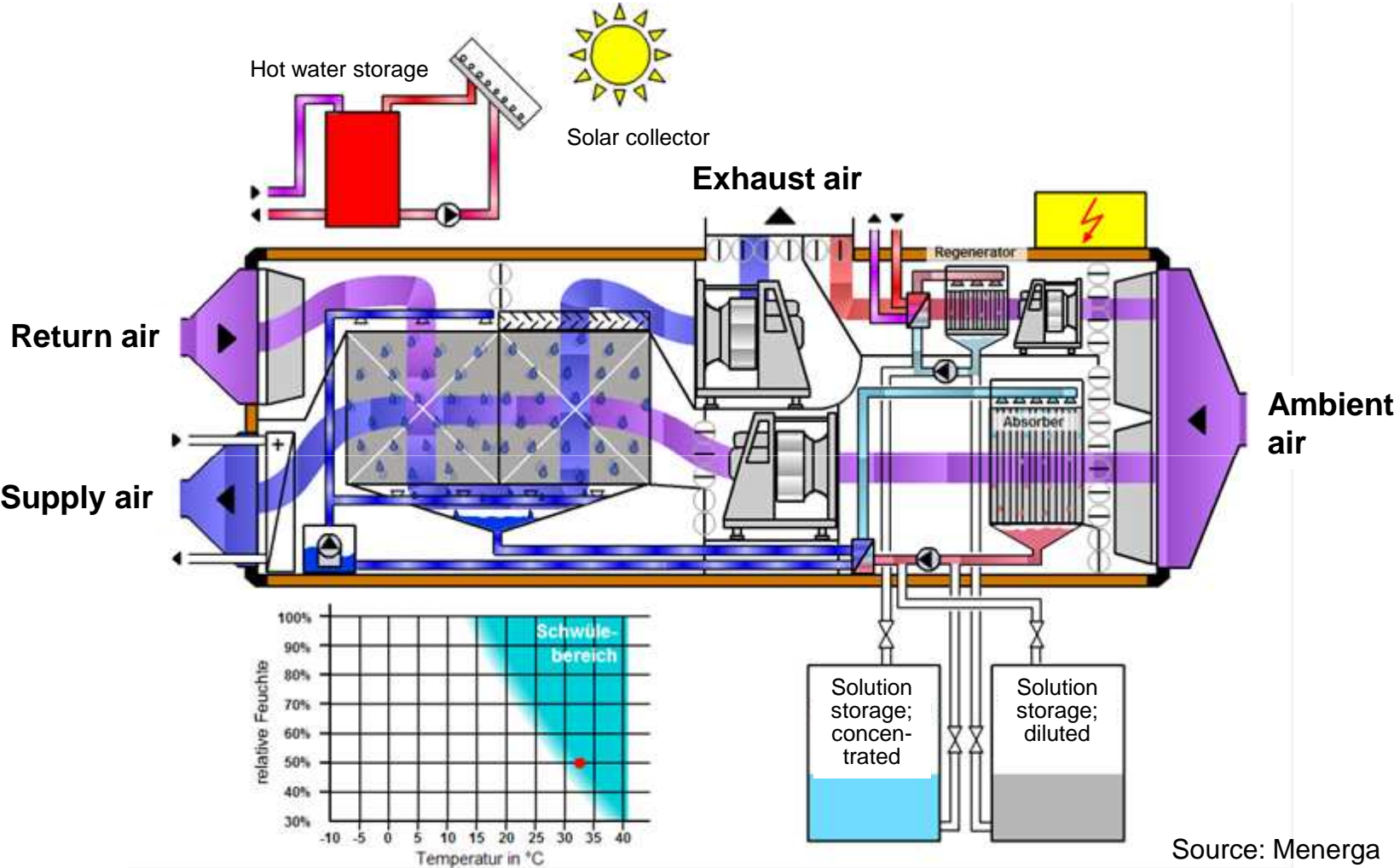
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Open cycle liquid desiccant cooling system




Desiccant cooling - overview

	Solid desiccant systems	Liquid desiccant systems
Typical material pair	Water/ silica gel Water/ lithium chloride	Water/ calcium chloride Water/ lithium chloride
Available technology	available on the market, several installations with solar heat	Available on the market, few installations with solar heat
Cooling capacity	typically 20 - 350 kW	> 5 kW
Air flow rates	typically > 5000 m ³ /h	> 1000 m ³ /h
Typical COP (COP=cooling capacity / regeneration heat)	0.5 - >1	0.5 - > 1
Typical driving temperatures	50 – 80°C	50 – 70°C
Type of collector when applied with solar heat (typical)	Flat plate collector, Flat plate air collector	Flat plate collector



Desiccant cooling component and system suppliers

	Solid desiccant systems	Liquid desiccant systems
Sorption rotors (non exhaustive)	<p>Munters (Sweden)</p> <p>Seibu Giken (Japan)</p> <p>Nichias (Japan)</p> <p>DRI (India)</p> <p>Klingenburg (Germany)</p> <p>ProFlute (Sweden)</p> <p>Rotor Source (USA)</p> <p>NovelAire (USA)</p>	Not applicable
Systems providers (non exhaustive)	<p>Klingenburg GmbH, Germany www.klingenburg.de worldwide sales</p> <p>Munters AB, Sweden www.munters.com worldwide sales, dependency in Brazil (Curitiba)</p> <p>robatherm GmbH Wärme- und Klimatechnik, Germany www.robatherm.de worldwide sales, focus: Asia; sales partners in USA, Canada</p> <p>Siegle + Epple GmbH & Co. KG, Germany www.siegleundepple.de worldwide sales, focus: Europe, Asia</p>	<p>Menerga Apparatebau GmbH, Muelheim, Germany www.menerga.com</p> <p>Kathabar Inc., New Brunswick, NJ, USA www.kathabar.com</p> <p>Ficom Pty Ltd., Glenelg, Australia</p> <p>L-DCS Technology GmbH, Ismaning, Germany www.L-DCS.com</p> <p>Ail Research Inc., Princeton, NJ, USA www.ailr.com</p> <p>AEX - American Energy Exchange Inc., Holland, USA www.aexusa.com</p>




Summary – system typology

Driving temperature	Collector type	System type
Low (60-90°C)		<i>Open cycle: direct air treatment</i> <i>Closed cycle: high temperature cooling system (e.g. chilled ceiling)</i>

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<p><i>Medium</i> (80-110°C)</p>		<p><i>Closed cycle: chilled water for cooling and dehumidification</i></p>
		<p><i>Closed cycle: refrigeration, air-conditioning with ice storage</i></p>

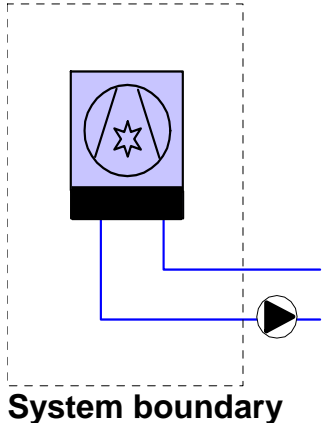
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		<p><i>Closed cycle: refrigeration, air-conditioning with ice storage</i></p>
<p><i>High</i> (130-200°C)</p>		<p><i>Closed cycle: double-effect system with high overall efficiency</i></p>
		<p><i>Closed cycle: system with high temperature lift (e.g. ice production with air-cooled cooling tower)</i></p>

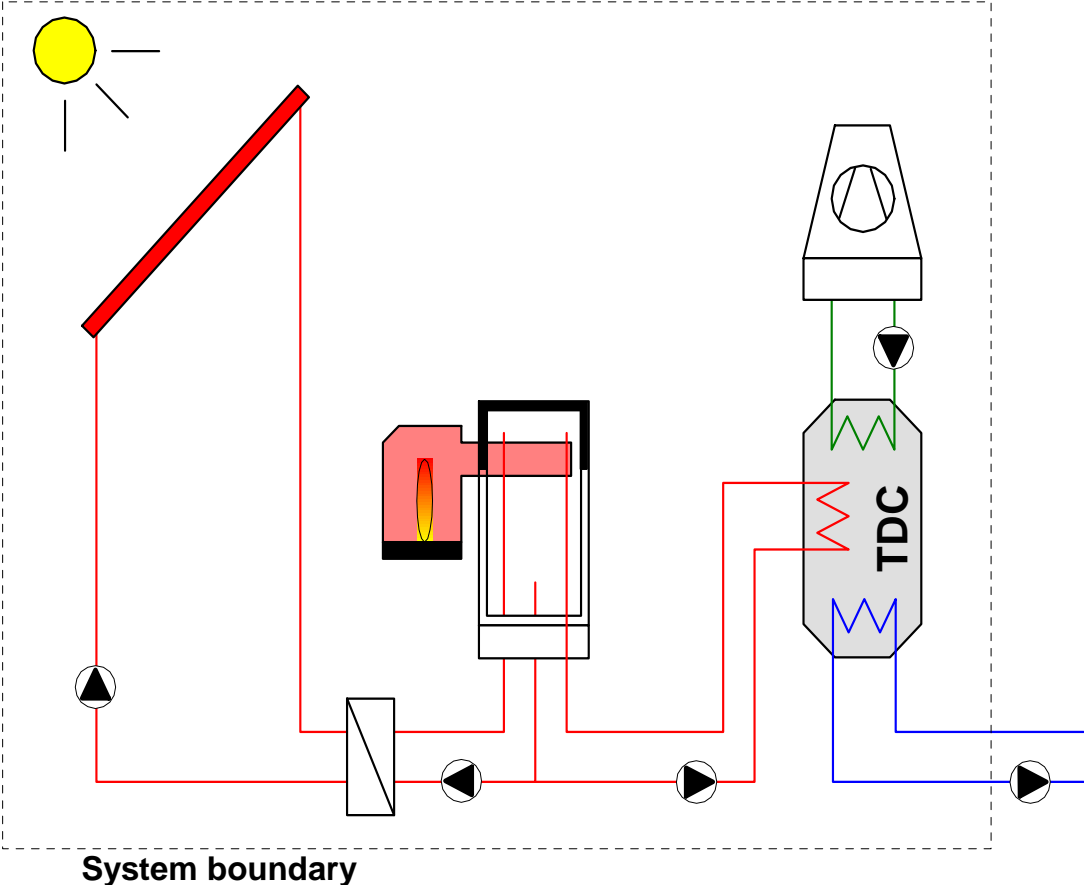
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Compared systems

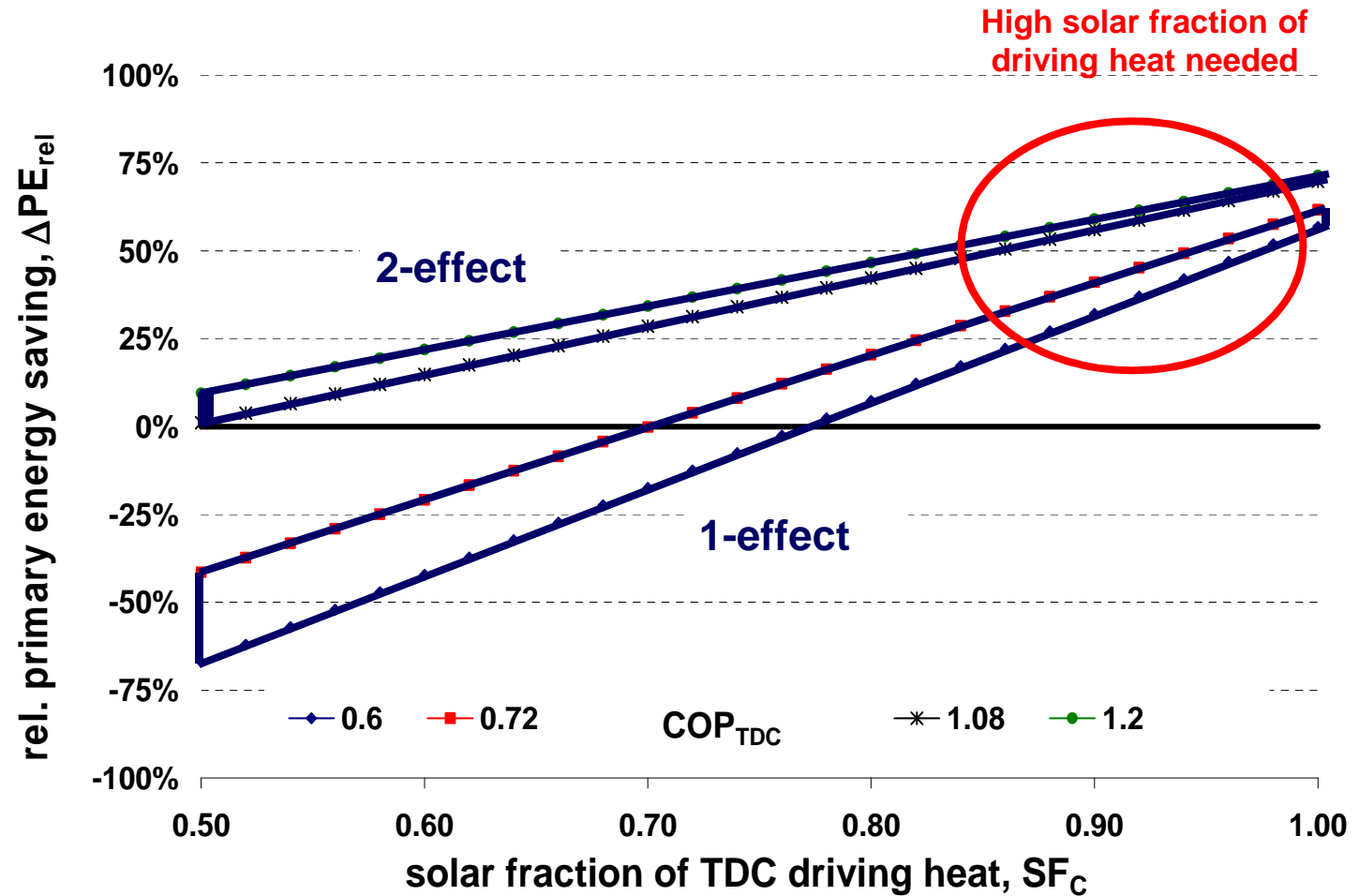


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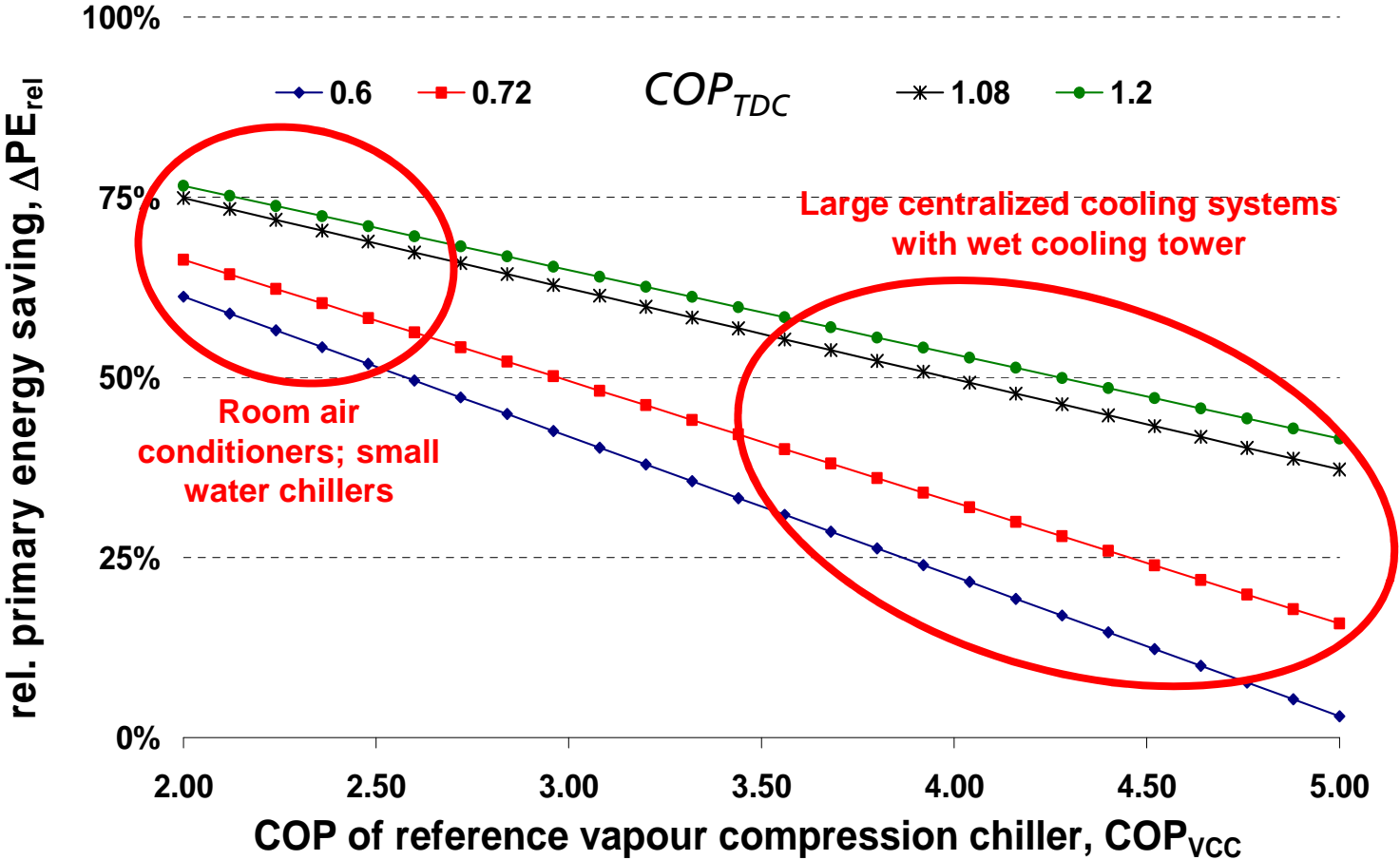


solar

Primary energy saving - solar fraction of driving heat



Primary energy saving - COP of conventional vapour compression chiller



Conclusions from energy balance

- *No fossil fuel as back-up heat for cooling*
- *Most careful design of all components using parasitic power*
 - *Variable speed pumps*
 - *Variable speed fan (cooling tower, air handling unit)*
 - *Thermally driven chiller with low power needs*
- *Optimized control in order to minimize electric parasitic consumption*
 - *Adjustment of heat rejection temperature (follow cooling demand, not stable temperature)*
 - *Use storage to level peaks*

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Examples

A Chilled water applications; driving temperatures < 100°C

Solar thermal cooling of a wine storage at Banyuls, France

- Cooling of a wine storage building (3 million bottles) with three ventilation systems
- Two absorption chiller with total 52 kW (15 RT) capacity
- Wet-cooling tower
- 130 m² Vacuum tube collectors, 1 m³ buffer storage
- No backup, small storage (load-side storage)
- Reliable operation since 1991
- Mediterranean hot summer



Source: Tecsol

Solar assisted office air-conditioning at Guadeloupe, France, Caribbean Sea

- Office building with 570 m² air-conditioned area
- Absorption chiller 35 kW (10 RT) capacity, wet cooling tower; back-up: compression chiller with 55 kW (16 RT) capacity
- 100 m² evacuated tube collectors
- In operation since 2004
- Tropical climate



Source: Tecsol

Solar assisted air-conditioning at Inofita Viotias, Greece

- Chilled water for supply air cooling and fan coils in a cosmetics production factory
- 2 adsorption chillers with 350 kW (100 RT) capacity each
- 2700 m² flat plate collectors
- Wet cooling tower
- Back-up: 3 compression chiller with 350 kW (100 RT) capacity each
- Concept: electricity saving (prior operation of adsorption chiller)
- In operation since 1999
- Mediterranean hot summer



Solar assisted air-conditioning for offices in Lisbon, Portugal

- Office building of the CGD bank, 100 000 m² office area
- Approx. 1600 m² HT-flat-plate collectors
- 545 kW (155 RT) absorption chiller
- Back-up: thermal, 700 kW
- In operation since 2008
- South European, Atlantic climate, hot summer



Source: S.O.L.I.D.



B Open cycle desiccant cooling systems

Solar air-conditioning with liquid DEC system in Freiburg, Germany

- *Pilot plant in Solar Info-Center building, Freiburg*
 - *Liquid DEC-system: Menerga*
 - *Dehumidification with aqueous LiCl-solution*
- *Air-conditioning of 310 m² Office area*
- *1500 m³ air volume flow rate*
- *17 m² flat plate collectors*
- *1.5 m³ buffer storage*
- *In operation since 2004*
- *Solar autonomous operation in summer*

Source: Fraunhofer ISE



Solar DEC system at University Palermo, Italy

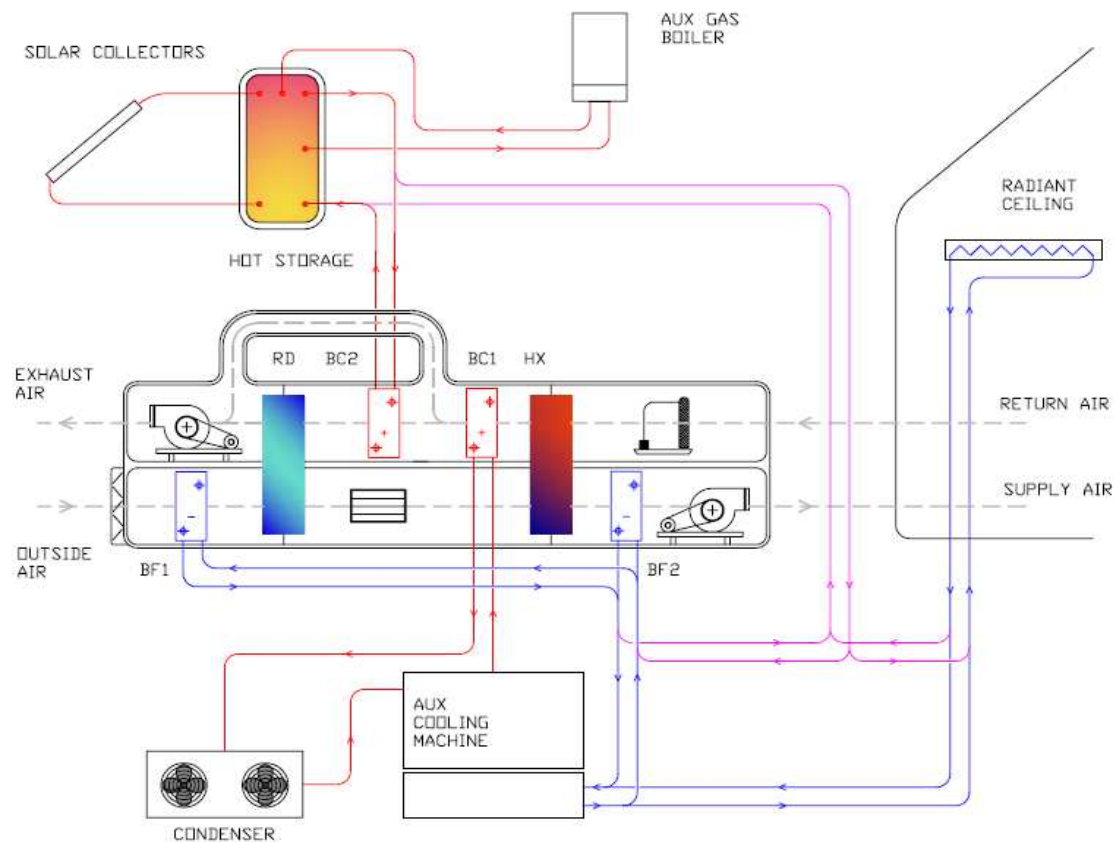
- Building: DREAM, University of Palermo
(Dipartimento di ricerche energetiche ed ambientali)
- System
 - DEC-System (1500 m³/h)
 - 22.5 m² flat-plate collectors
 - Cold-side backup 24.3 kW
 - Gas boiler 11 kW
(for winter operation)
- In operation:
since July 2008
- Mediterranean hot,
humid climate



Source: DREAM

Solar DEC system at University of Palermo, Italy

- *Special configuration for hot and humid climate: when necessary, vapour compression chiller for pre-dehumidification and additional supply air cooling;*
→ *efficient operation at high chilled water temperatures*



Source: DREAM

C Chilled water applications; driving temperatures > 100°C

Solar assisted hotel air-conditioning Dalaman, Turkey

- Parabolic trough collector with 180 m² aperture area for hot water 180°C provision;
heat exchanger for steam generation
- 2-effect absorption chiller with 116 kW (33 RT) capacity; 4 bar steam, COP > 1.2, manufacturer: Broad
- Air-conditioning of hotel and steam for hotel laundry
- Back-up: LPG operated boiler for steam operation
- In operation since 2004
- Mediterranean hot summer

Source: SOLITEM



Solar assisted 2-effect absorption cooling in Sevilla, Spain

- Demonstration system at the University Seville for building air-conditioning
- 1-axis tracked Fresnel-collector with 350 m² aperture area (PSE/Mirroxx)
- 2-effect absorption chiller (Broad) with 175 kW (50 RT) capacity
- Collector fluid: pressurized water (approx. 180°C)
- In Operation since 2008
- Mediterranean hot summer



Source: AICIA



Source: PSE

Solar assisted refrigeration with ammonia-water chiller in Grombalia, Tunisia

- Demonstration of solar assisted process cooling in a wine fabrication; annual production: 600,000 l
- Chilled water: - 5°C
- Dry heat rejection high temperature lift (between chilled medium and heat rejection)
- Ammonia-water absorption chiller (Robur) with 12.8 kW (3.7 RT) capacity
- Linear concentrating Fresnel collector; 88 m² aperture area; pressurized water; 110°C – 180 °C
- Back-up: compression chillers
- In operation since 2008
- Mediterranean hot, arid summer

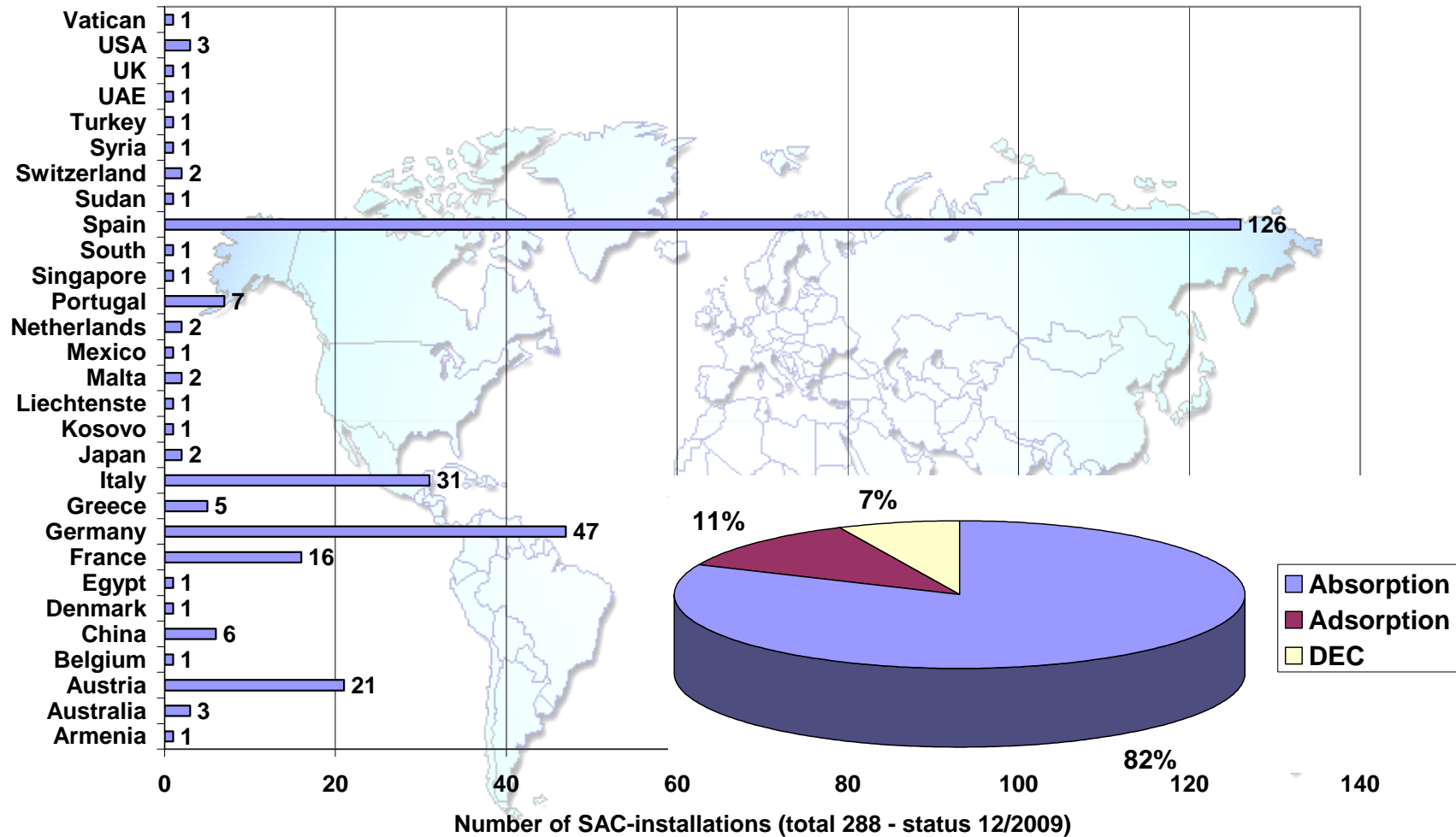


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- In operation since 2008
- Mediterranean hot, arid summer



SAC-installations worldwide – overview in IEA Task 38



Source: W. Sparber, A. Napolitano (EURAC research)

Experiences with installations - Summary

- *Primary energy saving possible*
- *Need for careful design with particular focus on minimizing parasitic electric demand*
- *High quality needed during design, installation, commissioning and operation (many realized systems still fail)*
- *Best niches for market introduction: places with high electricity cost and insecure electricity supply (e.g. hotels on islands)*
- *First cost 2-4 times higher than for conventional state-of-the-art technology*
- *ROI mainly depends on climatic and load conditions (number of operation hours) and cost of conventional energy sources*
- *Payback < 10 year possible under favourable conditions*

Outline

- *Solar assisted cooling technologies*
- *Energy saving potential*
- *Selected projects*
- ➔ **Summary & outlook**

Outlook



Systems using non-tracking solar collector technology

- *Solar heating & cooling (+ DHW)*
- *Solar dehumidification in warm-humid climates*
- *Application in buildings*
- *Significant cost reductions in particular for small scale thermally driven chillers (probably > 50 % compared to recent cost values)*
- *Increasing level of standardization*
- *Pre-fabricated systems for small capacity*
- *Custom-made systems for commercial buildings*

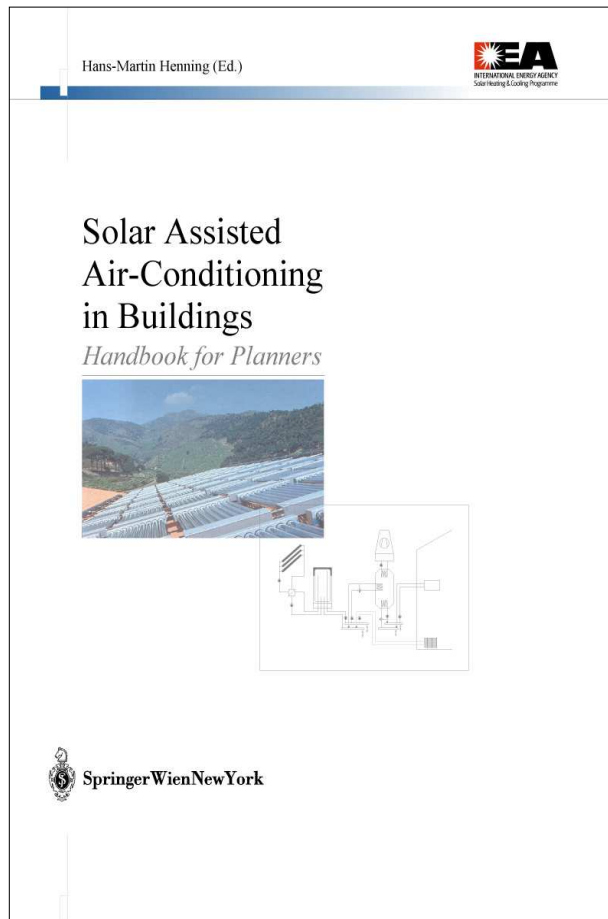
Outlook (cont'd)



Systems using single-axis tracking with optical concentration

- *Medium and large capacity range in regions with high direct solar radiation*
- *Applications with dominant use of cooling (e.g. industrial refrigeration)*
- *Installation either on the ground or large flat roofs of industrial buildings*
- *Double-effect or high T-lift*
- *Operation temperatures 150-250°C*

Main source of information today



1. Introduction

PART I - COMPONENTS

2. *The load sub-system - air-conditioning equipment*
3. *The cold production sub-system*
4. *The heat production sub-system*

PART II – SYSTEMS

5. *System configurations: examples, control and operation*
6. *Design approaches*
7. *Performance figures*
8. *Design examples*
9. *Summary*

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