SOLAR COOLING

Dr. Herena Torio

Outline

INTRODUCTION
- Cooling market
- Psychrometric processes
- Basic principle

AVAILABLE TECHNOLOGIES
- Compression chillers
- TDCs:
  - Absorption chillers
  - Adsorption chillers
- Desiccant systems

- Principles
- Thermodynamic analysis
- System performance

Thermally driven compression chiller Principle

Principle:

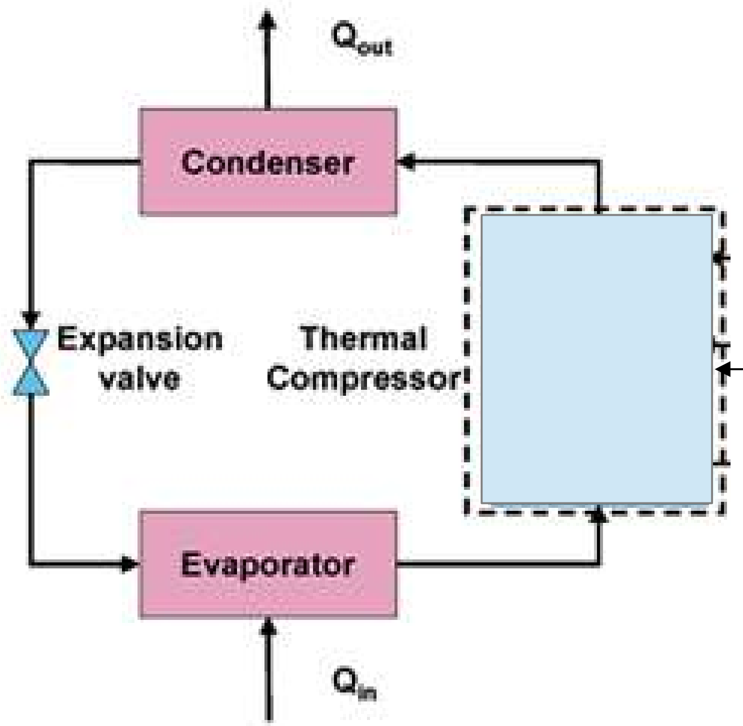
Substitute **mechanical compression**

by

thermal compression

➡ **ABSORPTION**

➡ **ADSORPTION**



Electric compressor

P_{el}

Thermally driven compression chiller Principle

Principle:

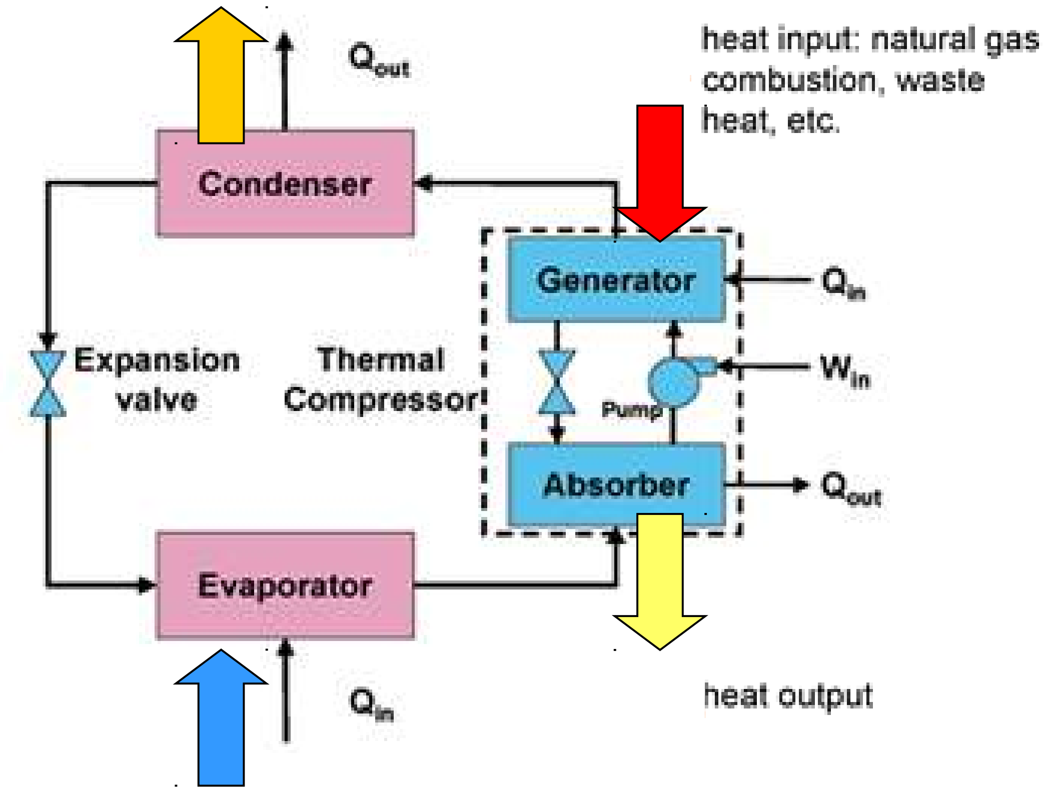
Substitute mechanical compression

by

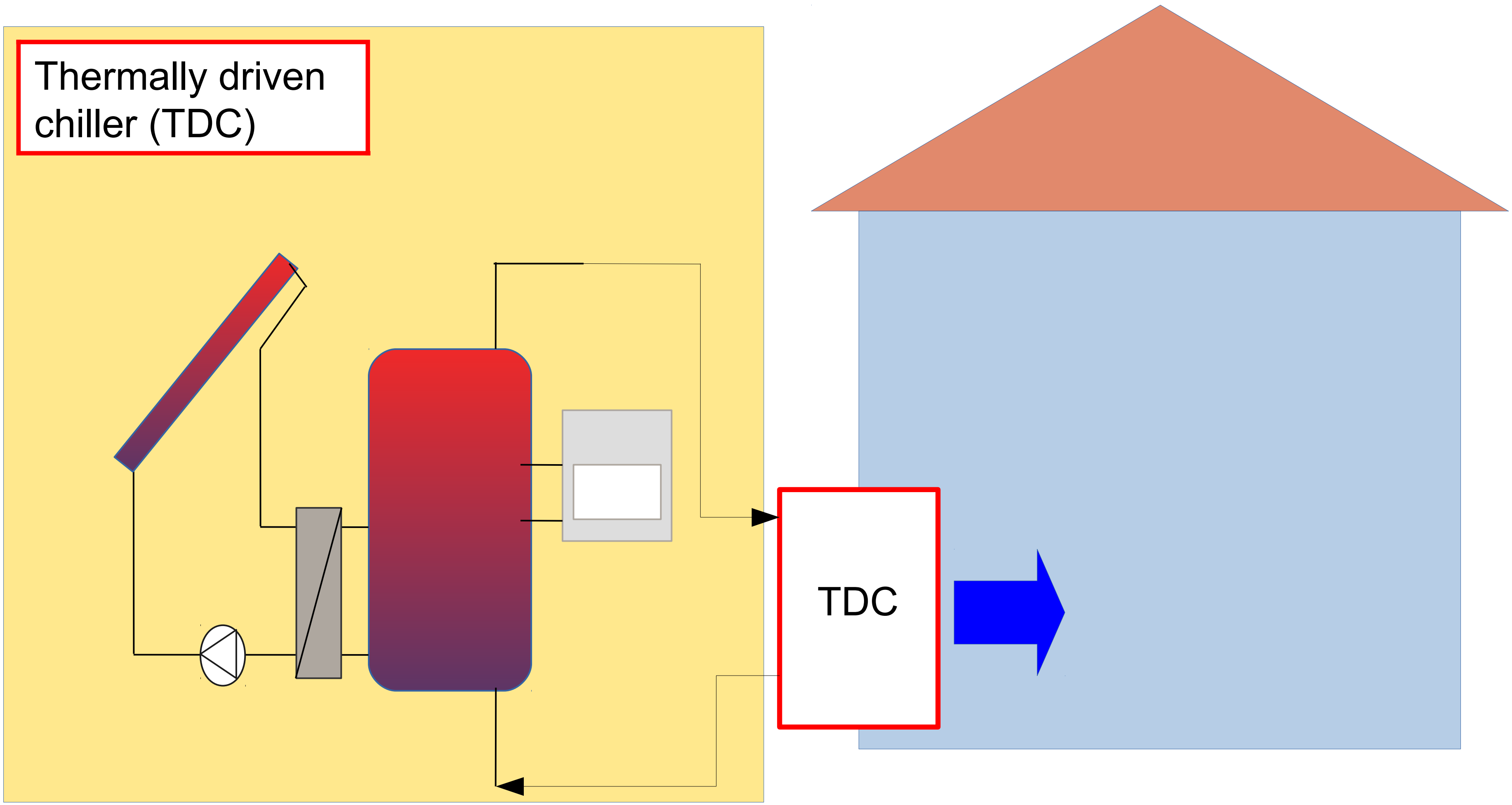
Thermal compression

ABSORPTION

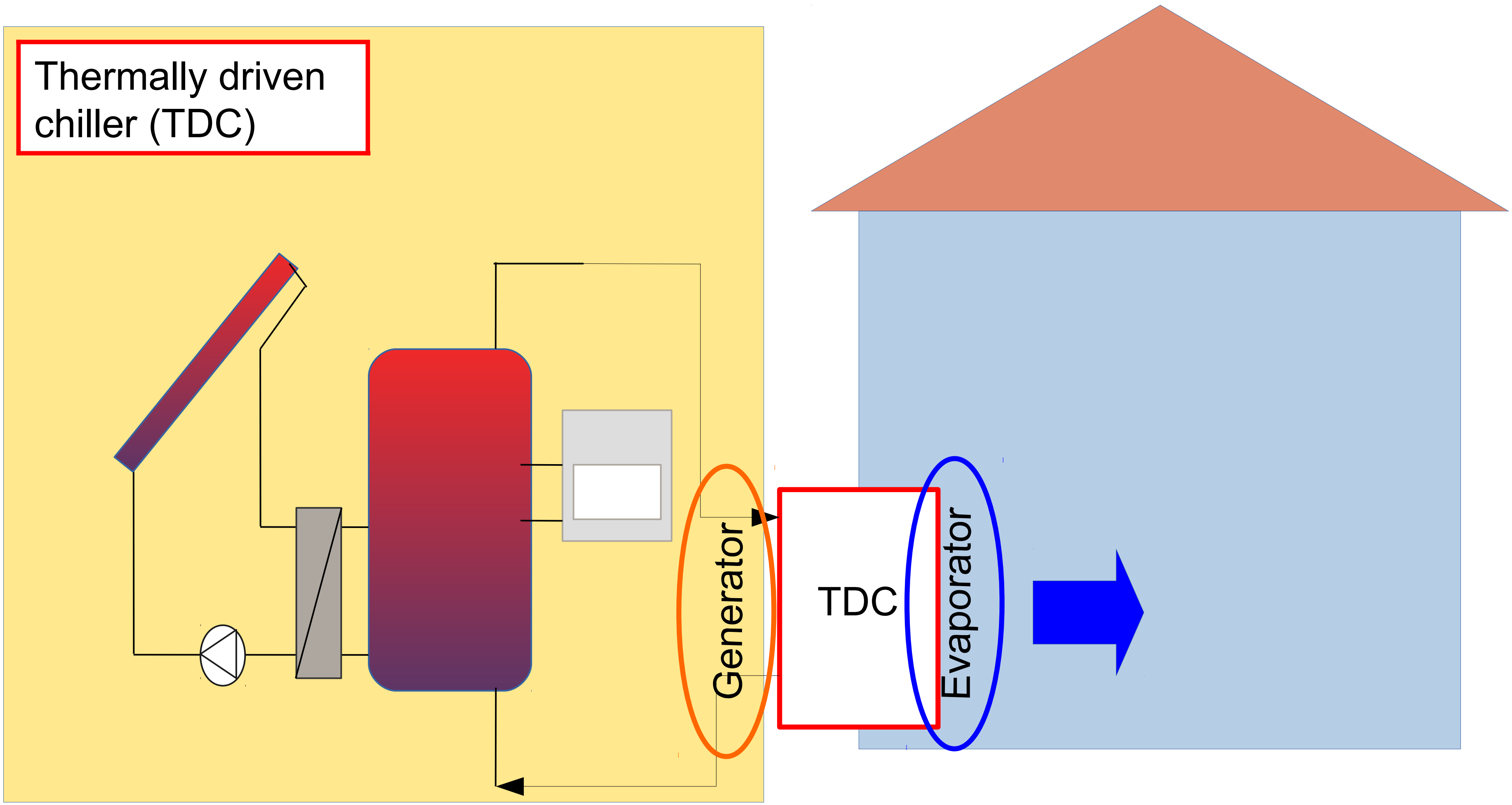
ADSORPTION



Thermally driven compression chiller
...within the whole system



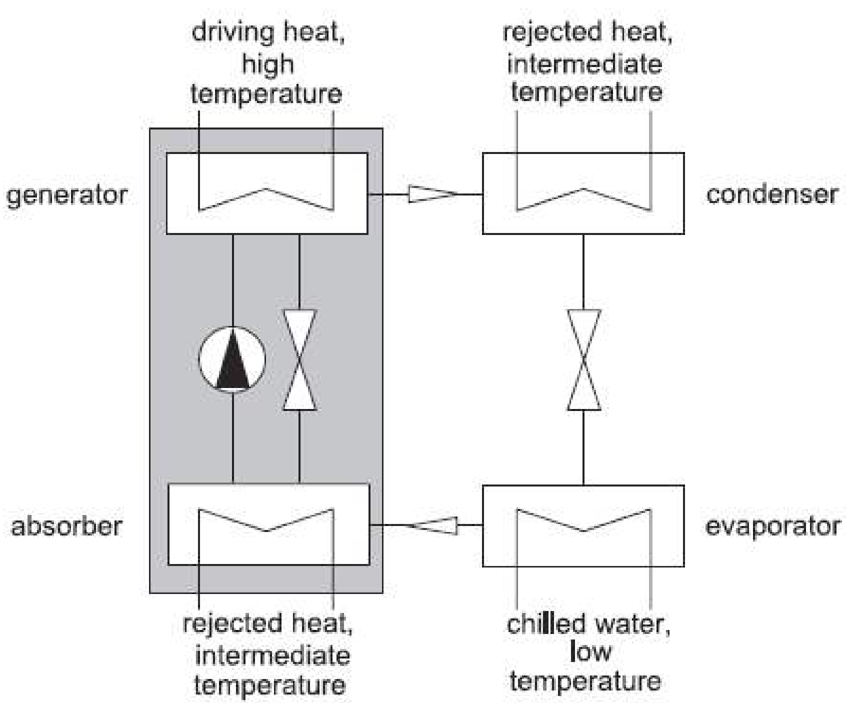
Thermally driven compression chiller ...within the whole system

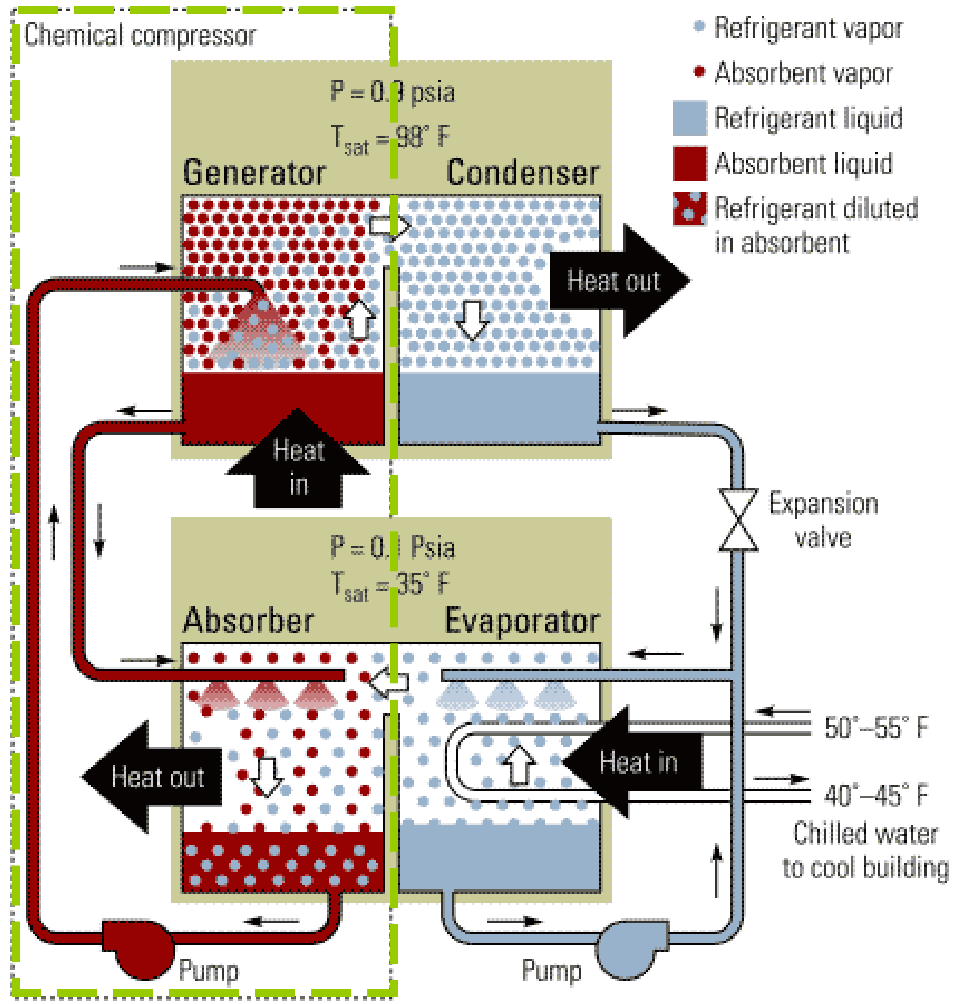


Absorption chillers: principle

Refrigerant: Water

Absorbent: LiBr





Source: Henning, 2003

Absorption chillers

LiBr – Water (refrigerant): if $T_{chilled}$ (T_{evap})>5°C

- Water cooled
- Water freezes at 0°C -> lower limit for Tcool!!
- LiBr soluble in water if ist concentration > 70% -> max. T_{middle} (absorber temperature)

Ammonia (refrigerant) – Water : if $T_{chilled}$(T_{evap})<5°C

- Water or air cooled

Electric power consupmtion (pumps) 1-5% of cooling power

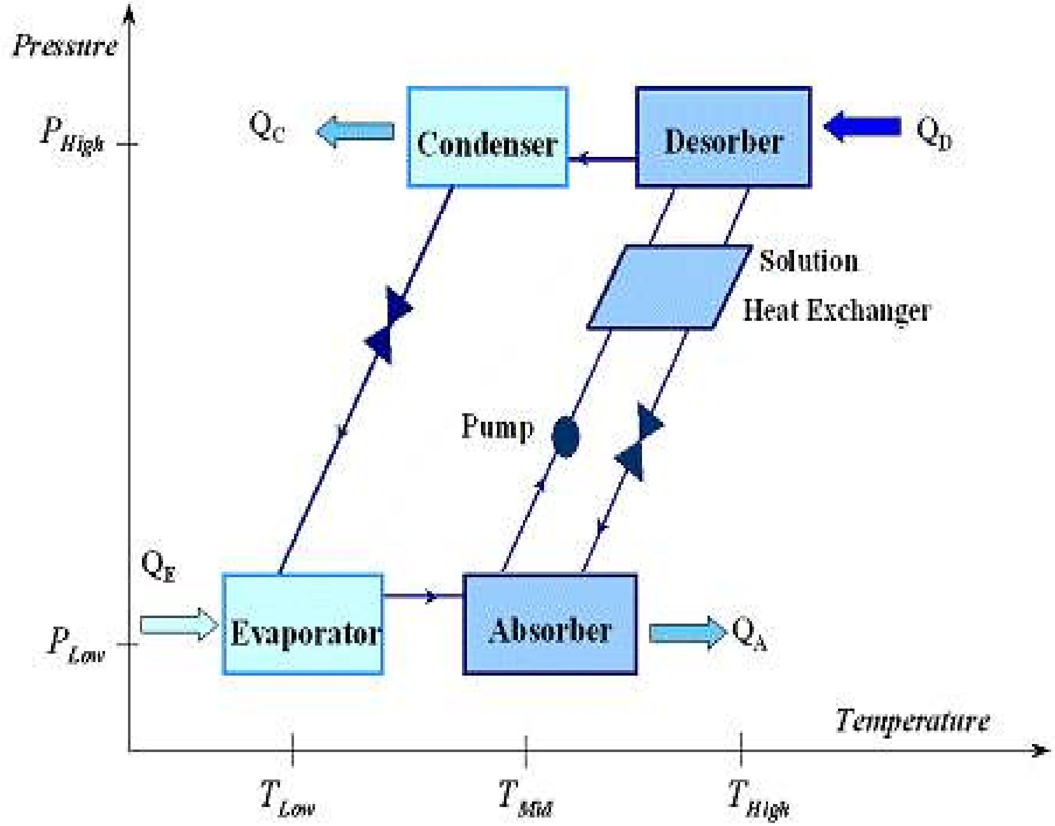
$T_{middle} = T_{cond}$ = 27 - 32 °C

$T_{chilled} = T_{evao}$ = 5 - 16°C

Absorption chillers

Single-effect

- COP: 0.7-0.8
- $T_{driving}$ = 75-90°C



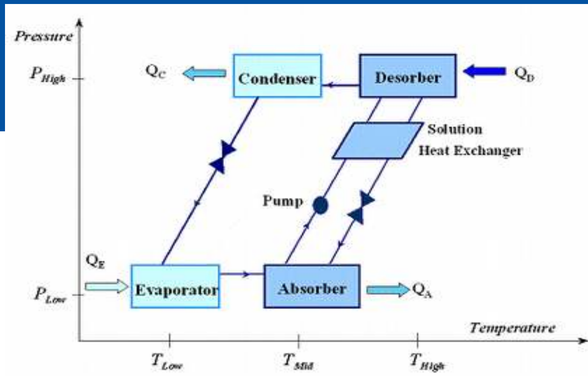
Source: APEP-UCI, 2017

Absorption chillers

Single-effect

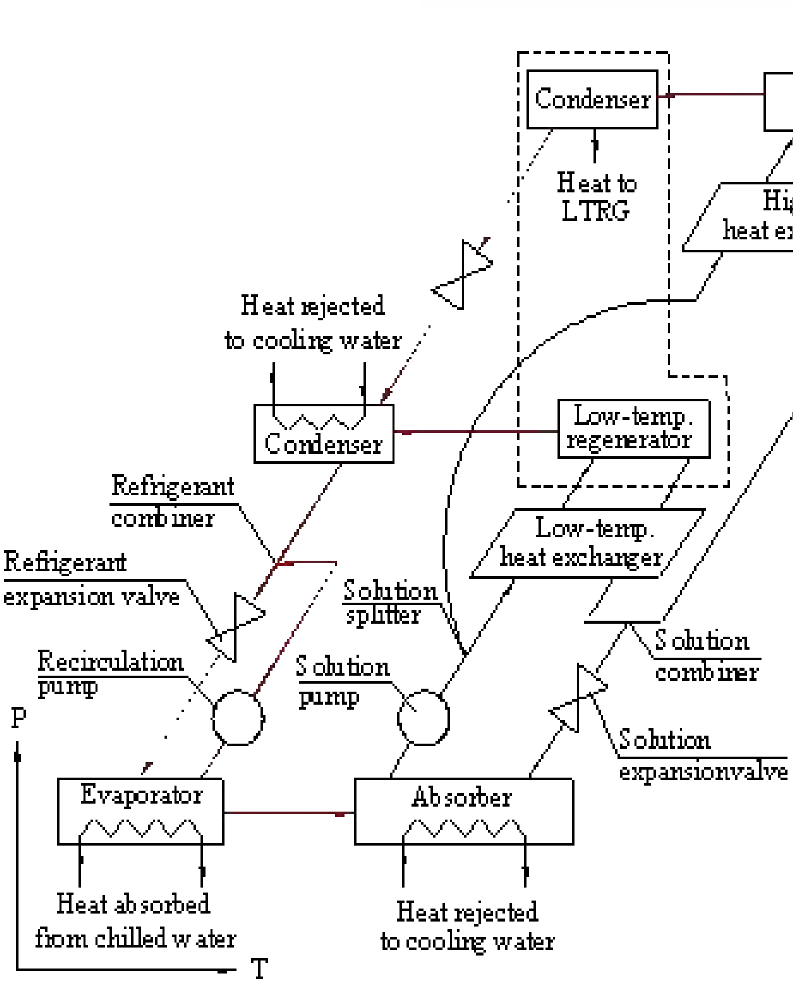
COP: 0.7-0.8

$T_{driving}$ = 75-90°C



Double-effect

- COP: around 1.1
- $T_{driving}$ = 140-160°C



Source: cmu.edu, 2017

Outline

INTRODUCTION
- Cooling market
- Psychrometric processes
- Basic principle

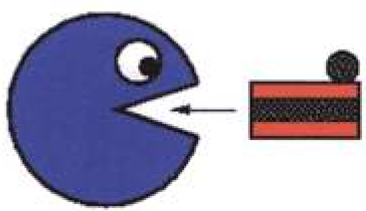
AVAILABLE TECHNOLOGIES
- Compression chillers
- TDCs:
  - Absorption chillers
  - Adsorption chillers
- Desiccant systems

A**d**sorption chillers

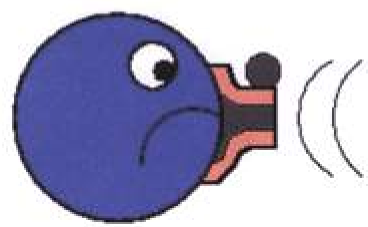
Absorption = Molecules are taken up by the volume

Adsorption = Molecules are take up by the surface

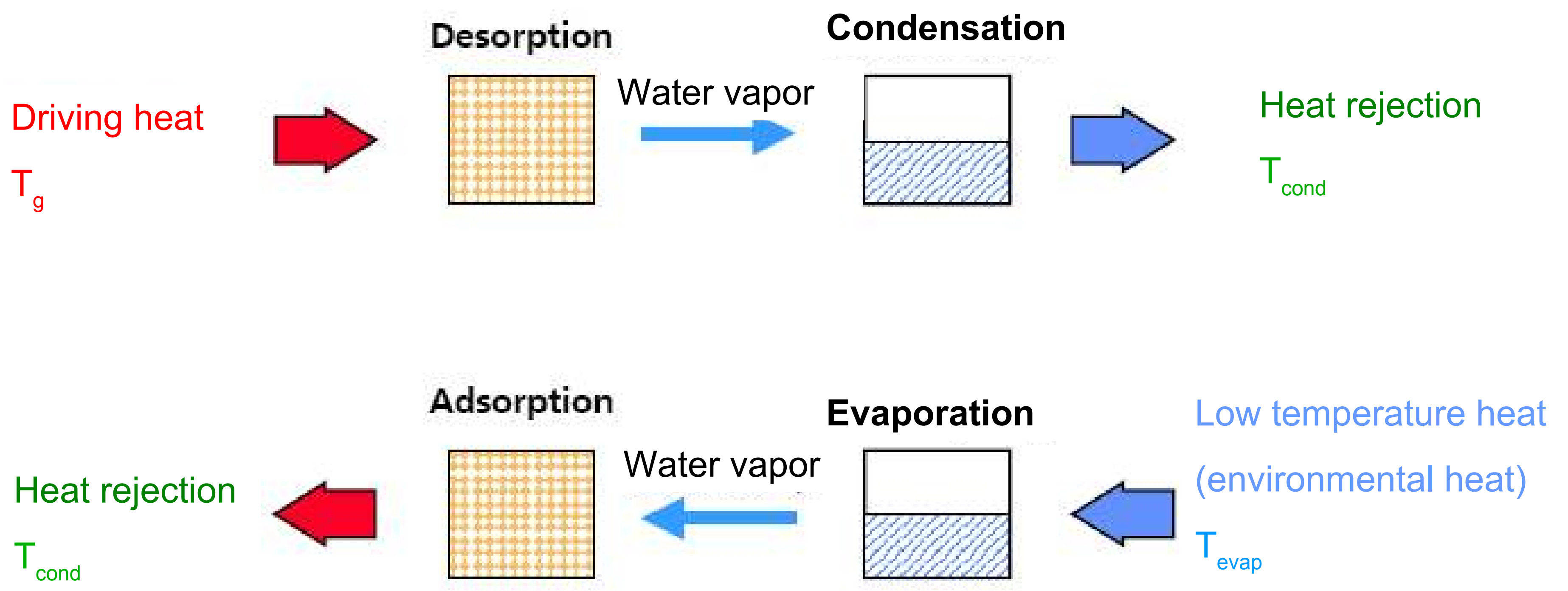
Absorption



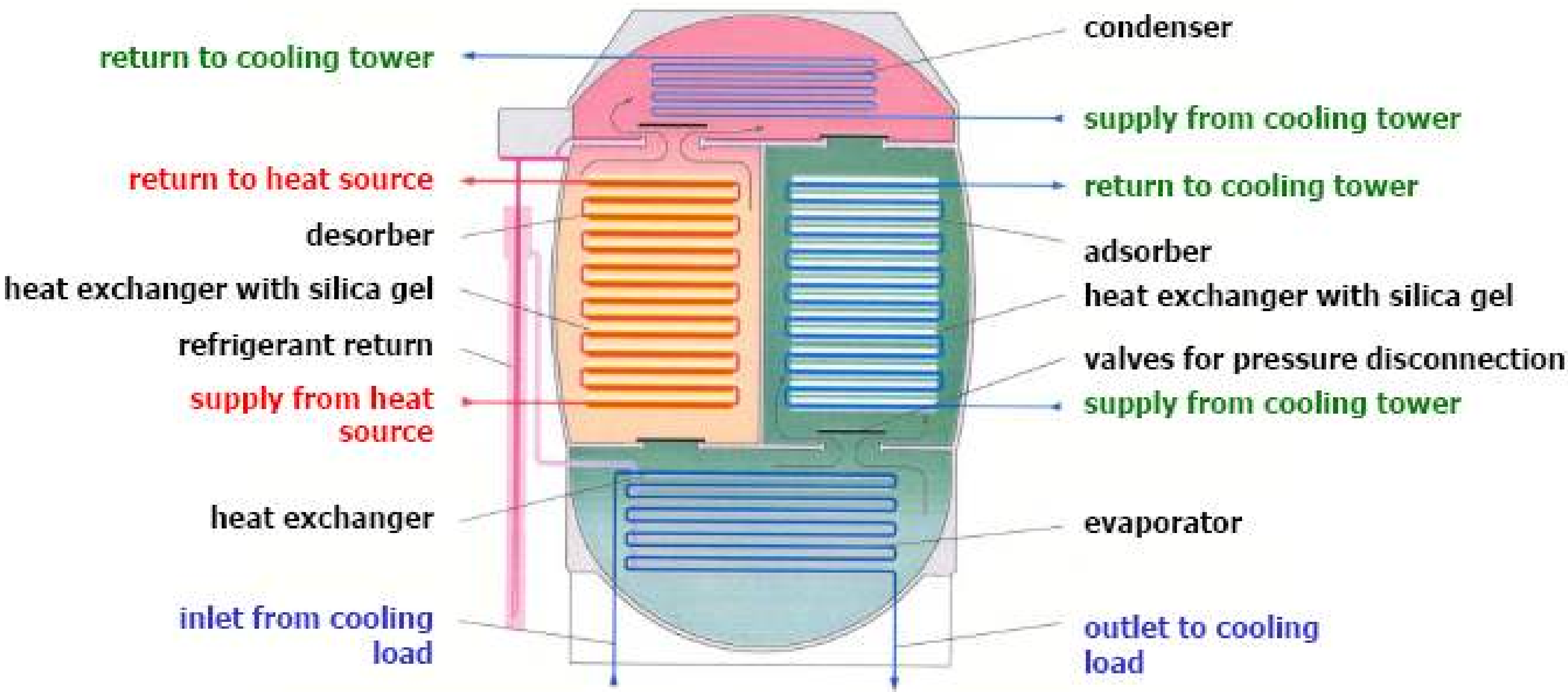
Adsorption



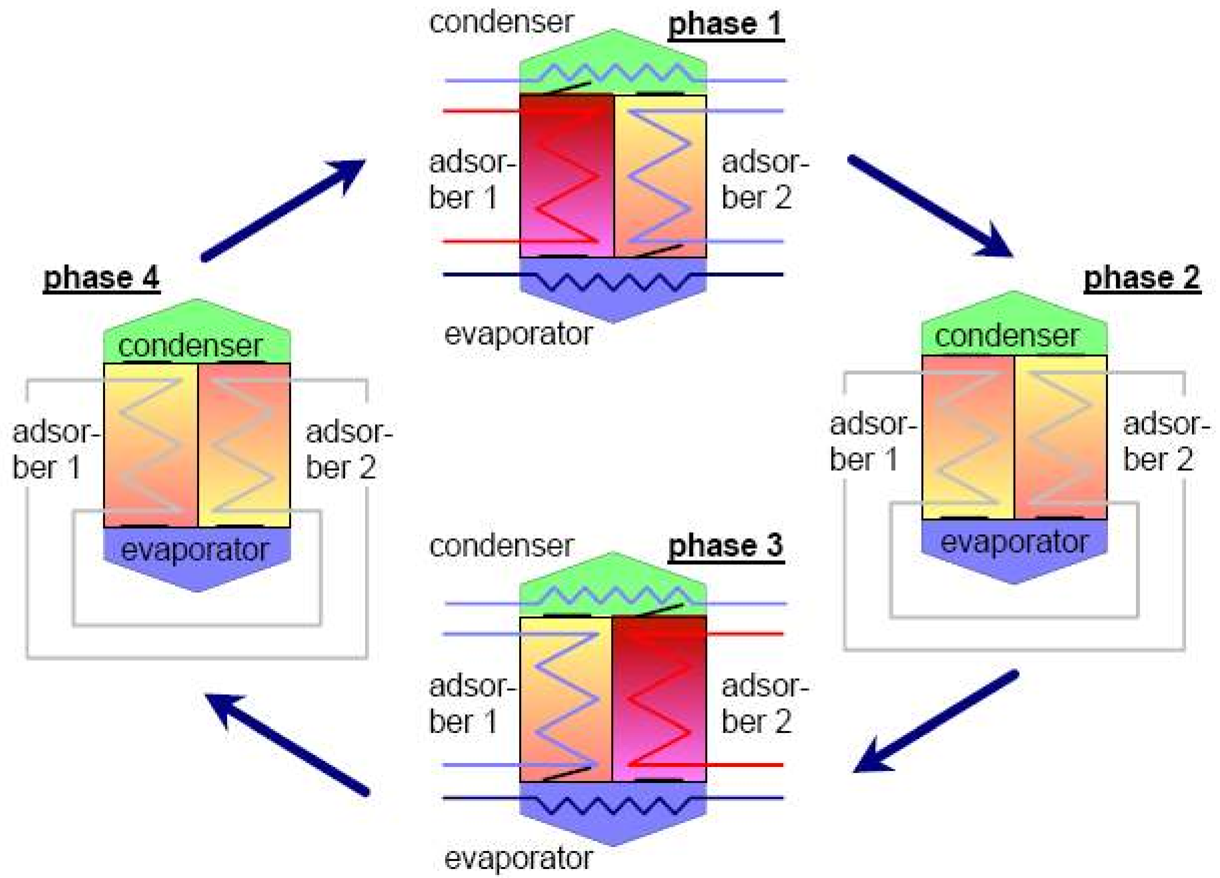
Adsorption chillers



Adsorption chillers



Adsorption chillers



Comparison: ab**s**orption and a**d**sorption chillers

Single effect absorption: >100kW (few<100kW)

water/LiBr or ammonia/water

COP ca. 0.7; T_{drive} =75-110°C

Double effect absorption: no product <100kW)

mainly water/LiBr

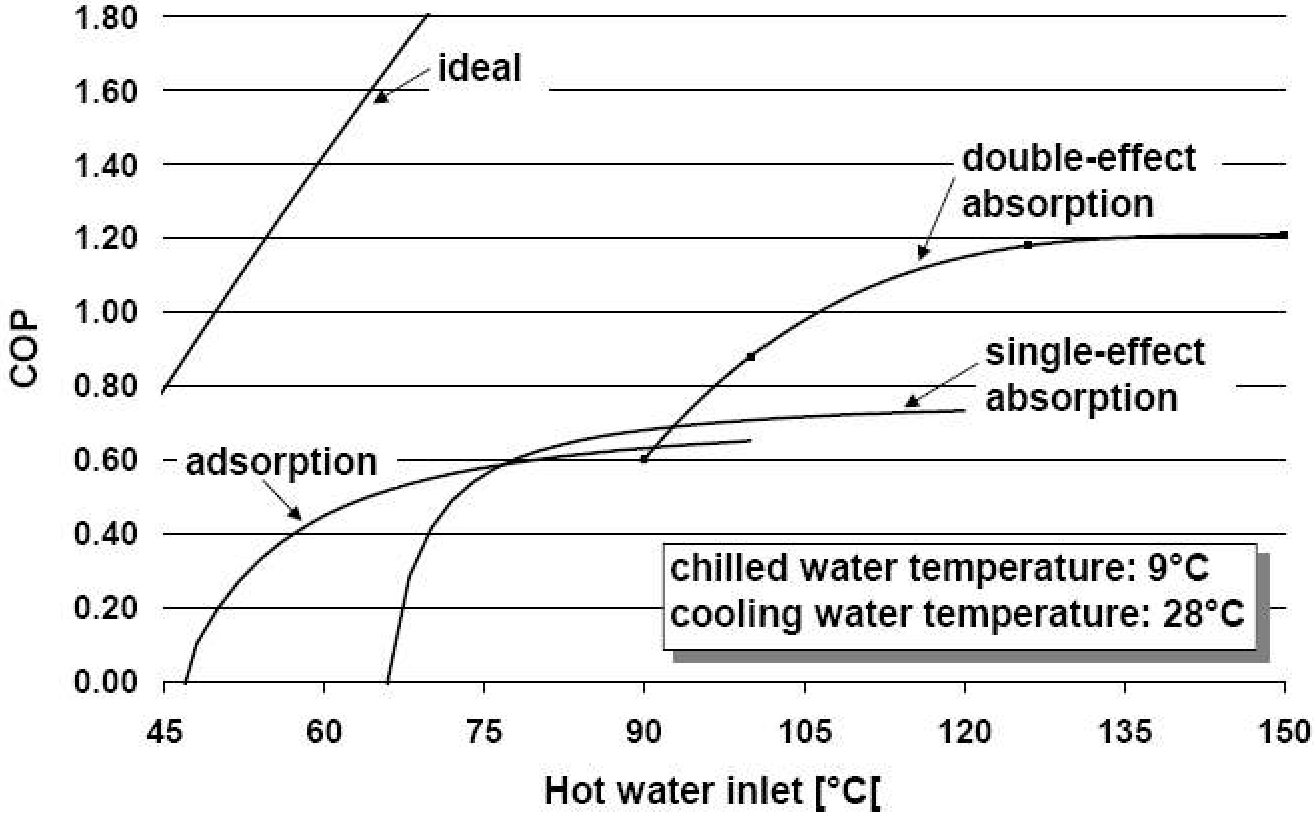
COP ca. 1.1-1.3; T_{drive} =140-160°C

Adsorption: few products (large and heavy)

water/silica gel or zeolite/water

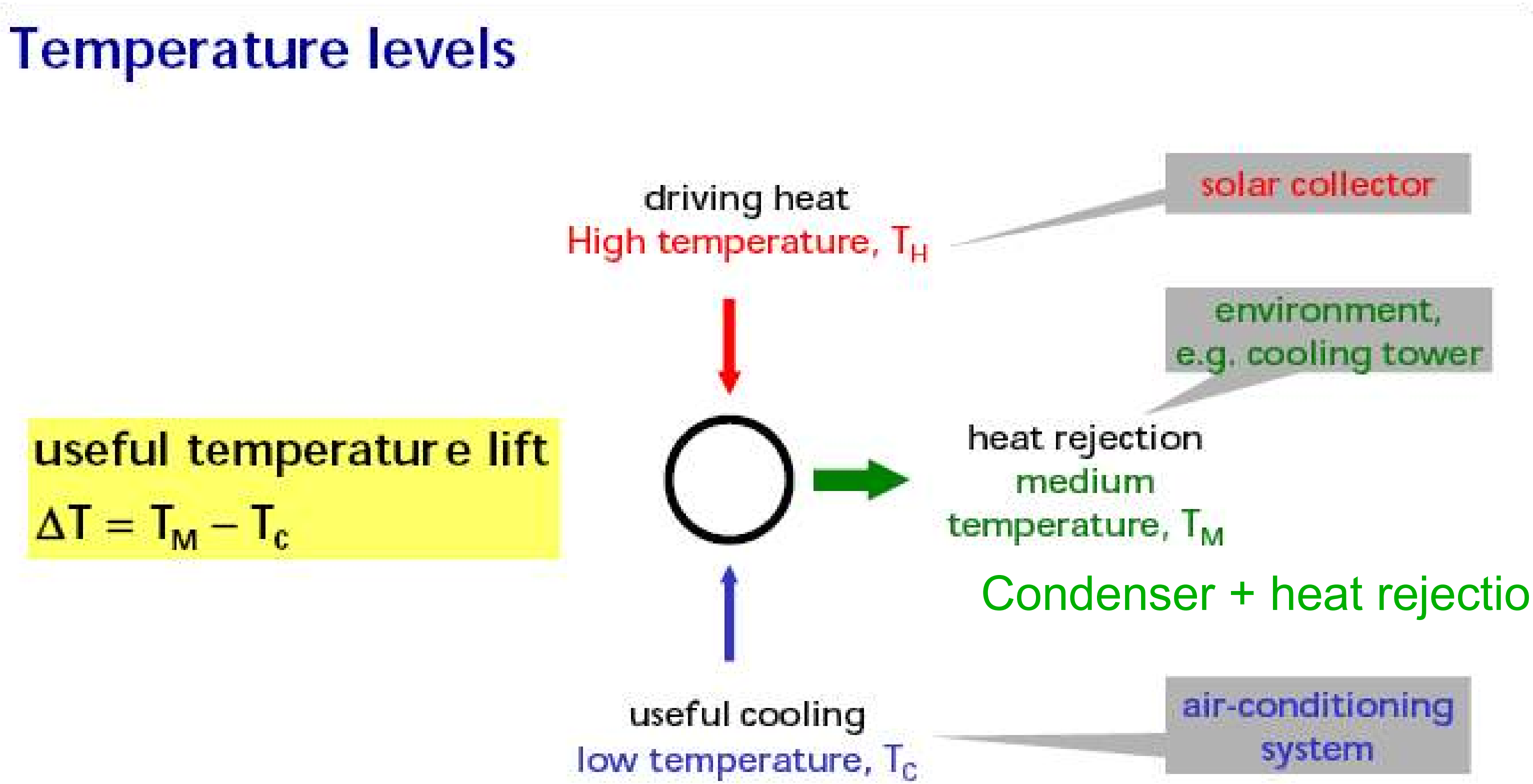
COP ca. 0.6 - 0.7; T_{drive} =65-95°C

Comparison: ab**sorption and a**d**sorption chillers



Source: Henning 2003

Thermodynamic analysis



Condenser + heat rejection

Evaporator

Source: Henning 2007

Thermodynamic analysis

- Coefficient of performance COP

$$COP = \frac{\text{useful cooling}}{\text{driving heat}}$$

- Carnot efficiency factor

$$\xi_{Carnot} = \frac{COP_{real}}{COP_{ideal}}$$

- Reversible COP_{ideal}

$$COP_{ideal} = \frac{T_C}{T_H} \cdot \frac{T_H - T_M}{T_M - T_C}$$

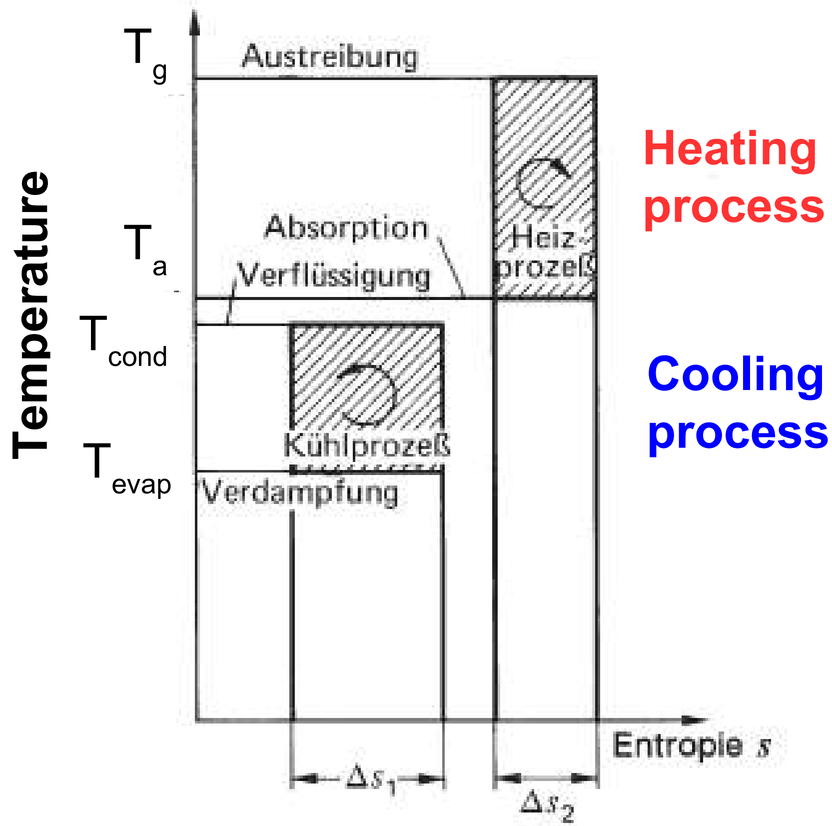
- Typical range of ξ_{Carnot} for real machines:

$$0.3 \leq \xi_{Carnot} \leq 0.4$$

Source: Henning, 2007

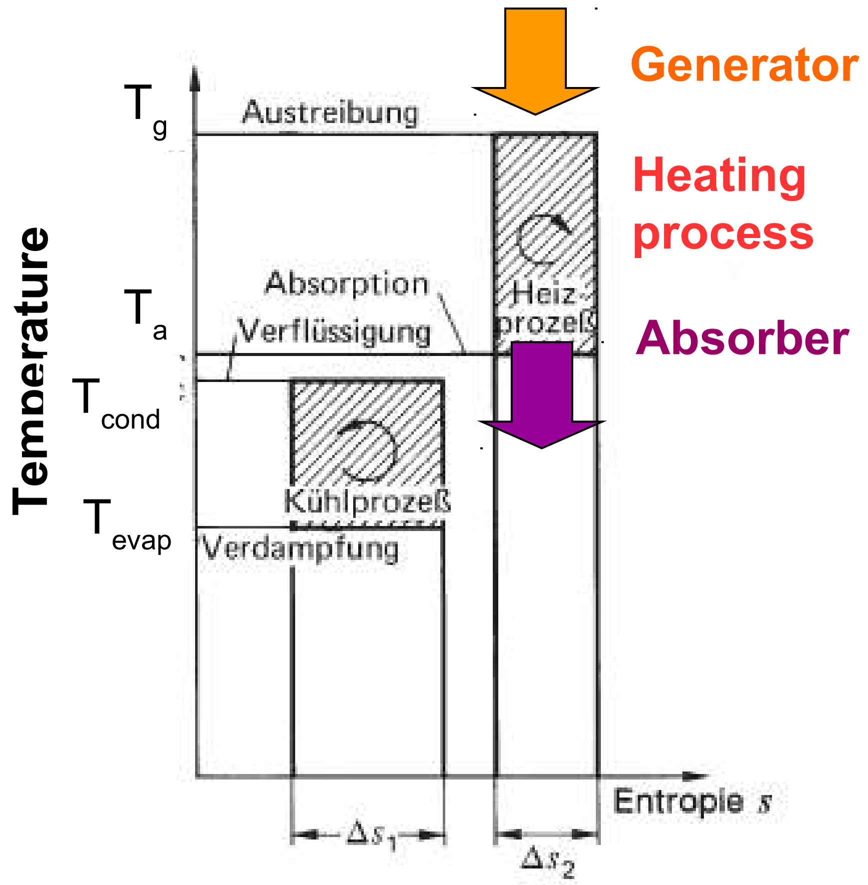
Thermodynamic analysis

Absorption chiller



Thermodynamic analysis

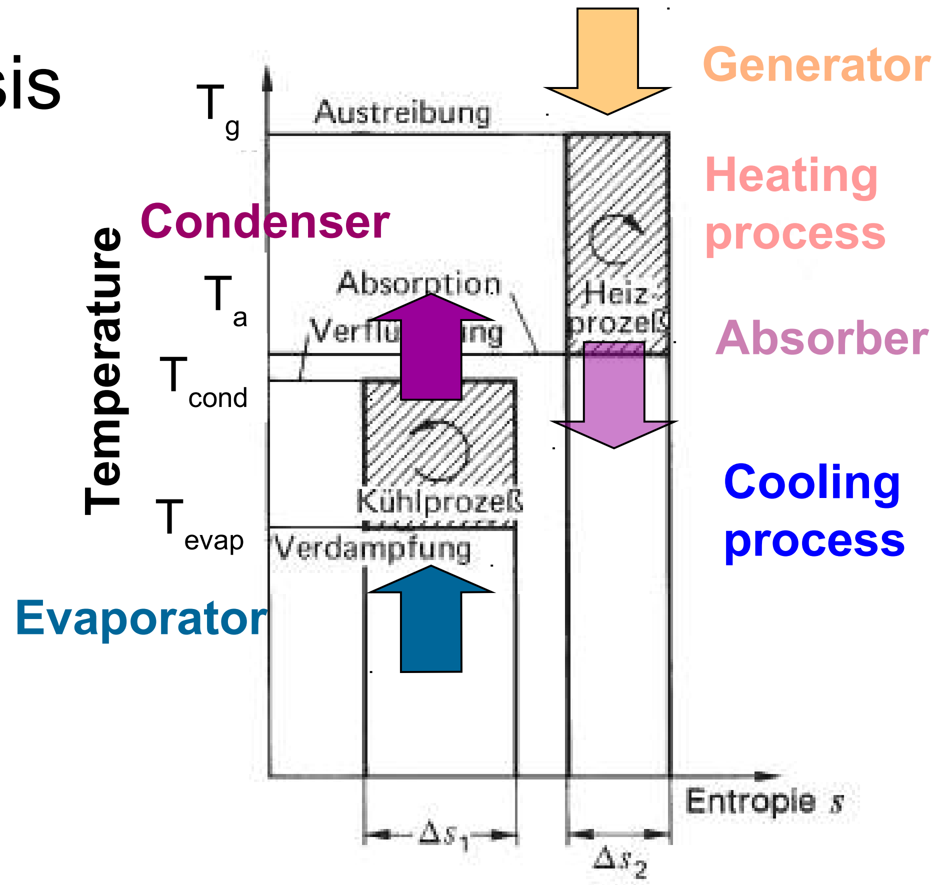
Absorption chiller



$$COP_{cool} = \frac{Q_{evap}}{Q_g} = \frac{T_g - T_a}{T_g} \cdot \frac{T_{evap}}{T_{cond} - T_{evap}}$$

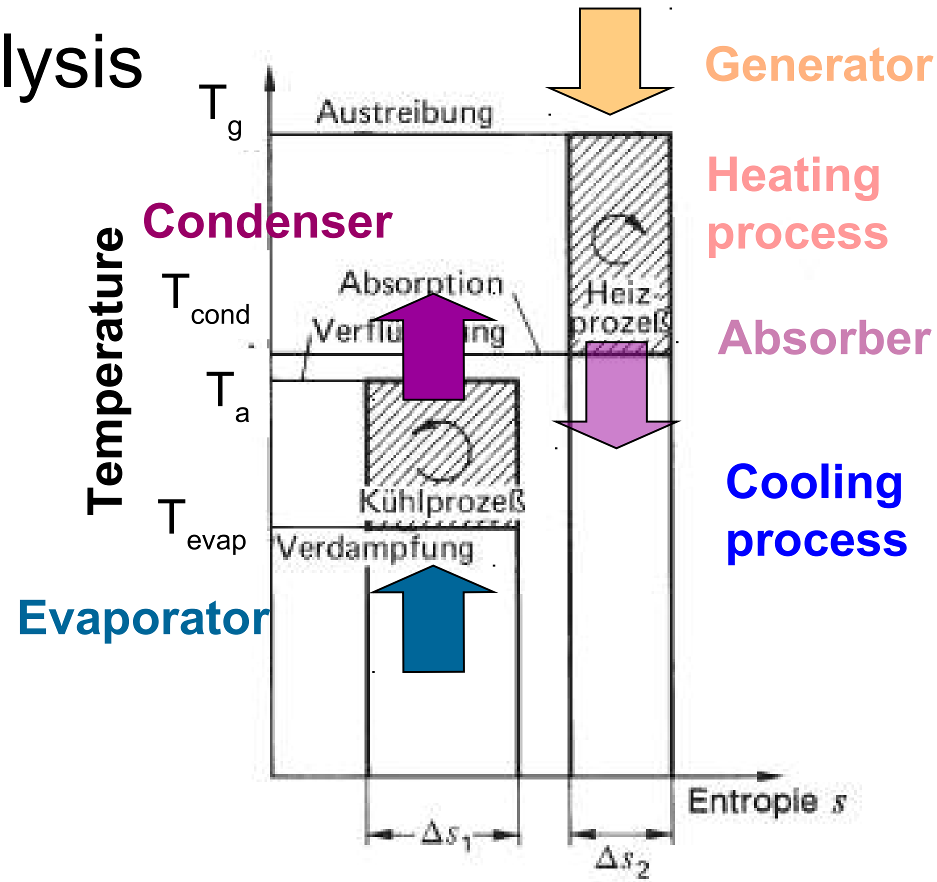
Thermodynamic analysis

Absorption chiller



Thermodynamic analysis

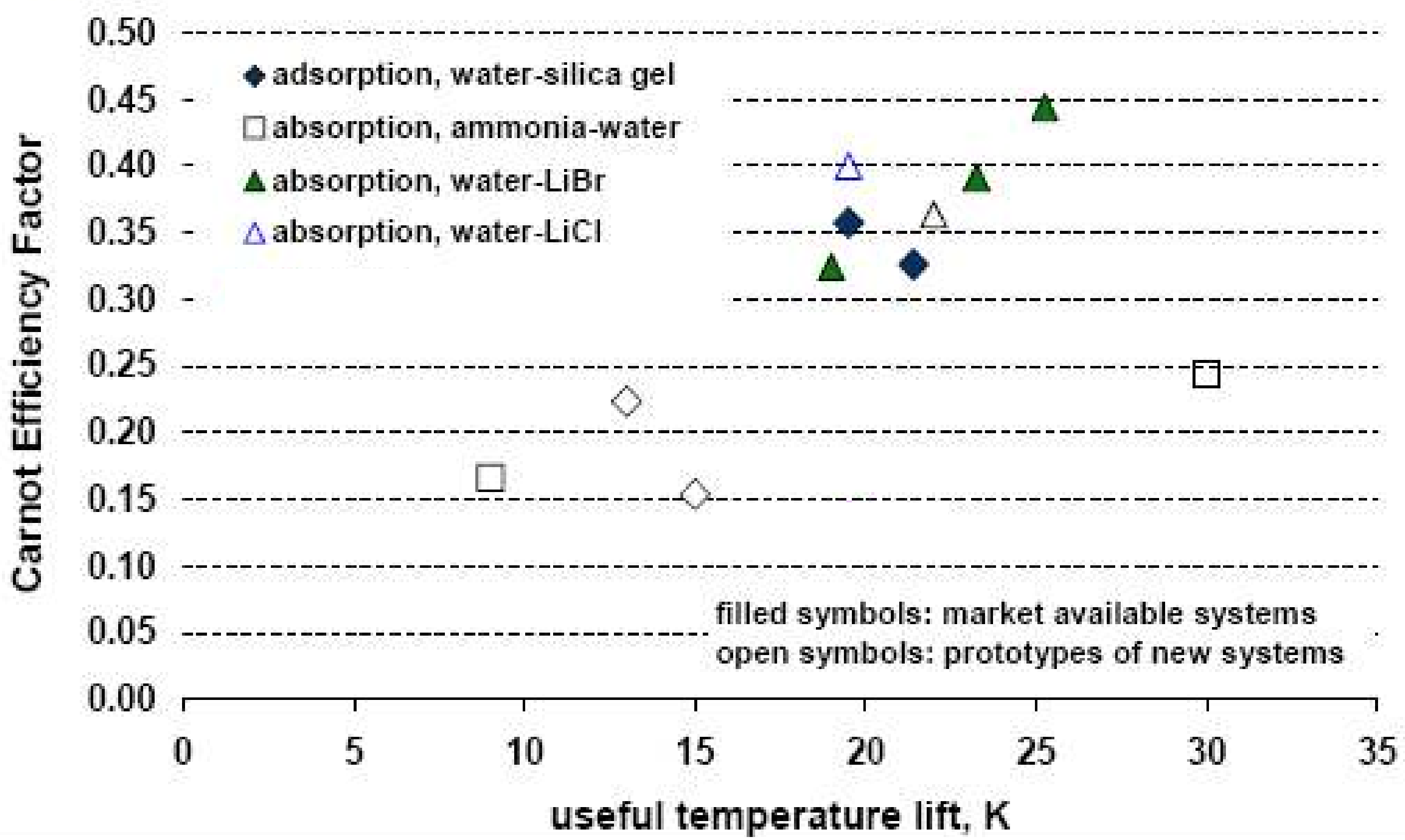
Absorption chiller



$$COP_{cool} = \frac{Q_{evap}}{Q_g} = \frac{T_g - T_a}{T_g} \cdot \frac{T_{evap}}{T_{cond} - T_{evap}}$$

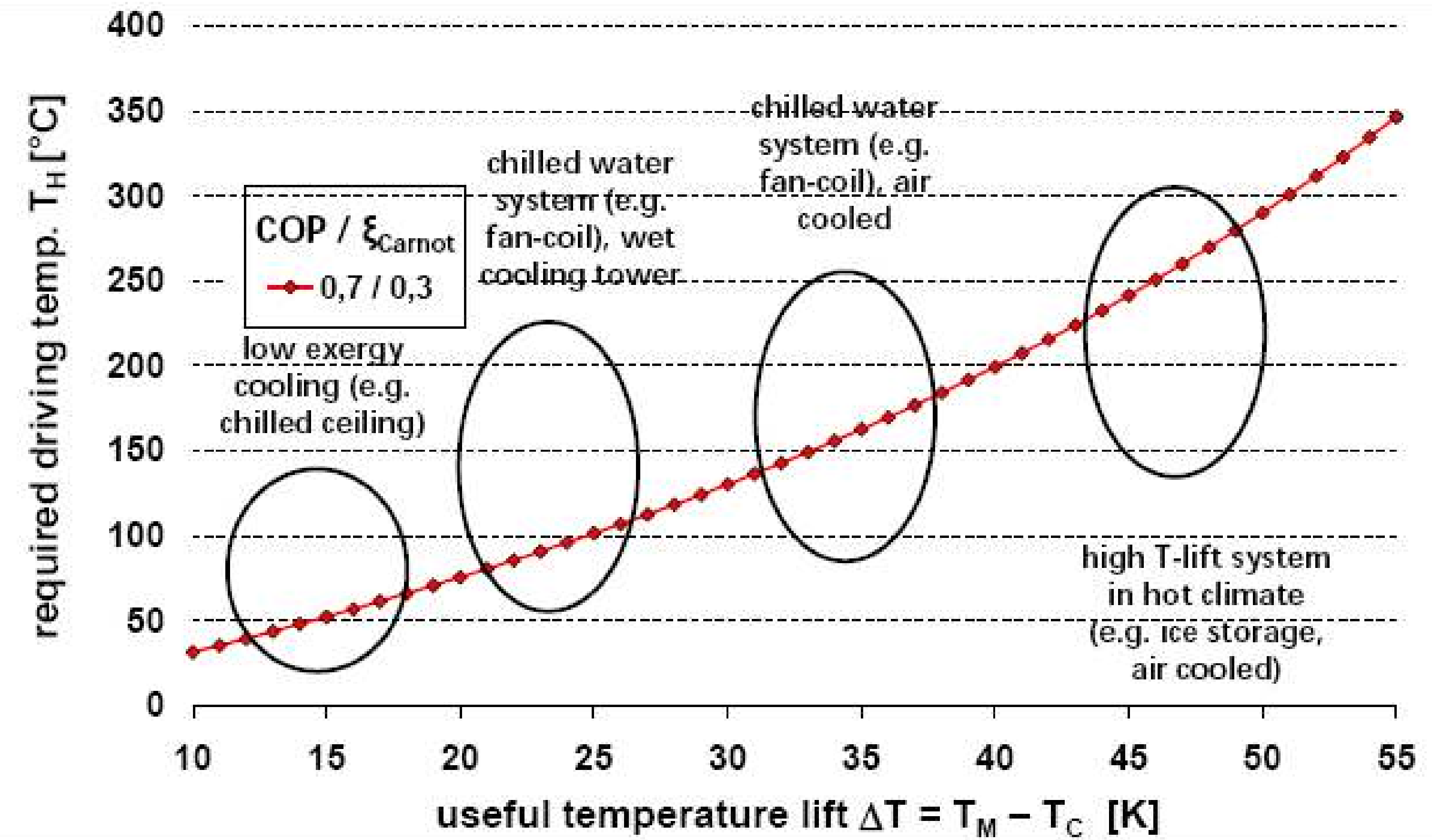
Thermodynamic analysis

Comparison of a**b**sorption and a**d**sorption chillers



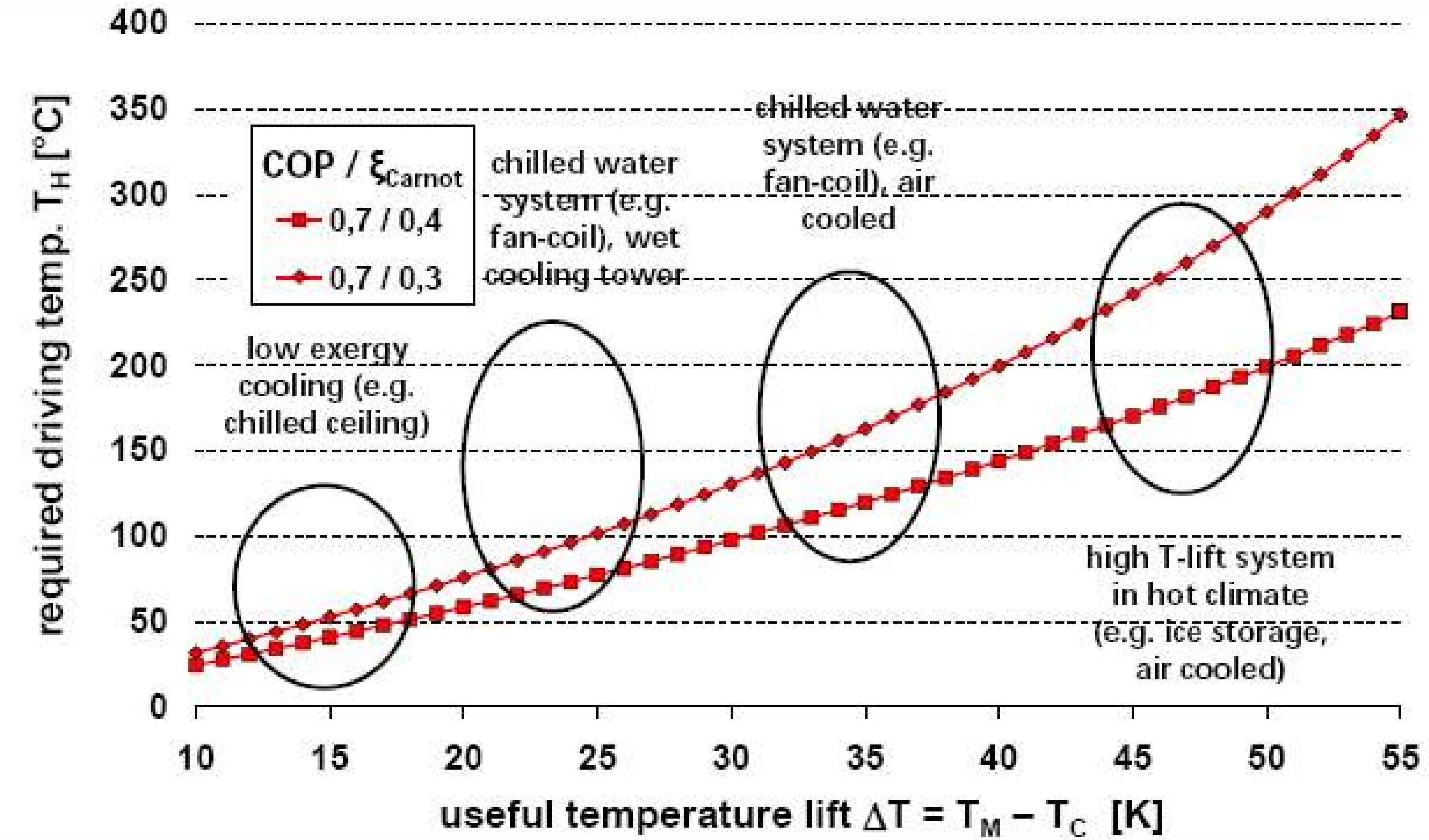
Source: Henning 2003

Thermodynamic analysis



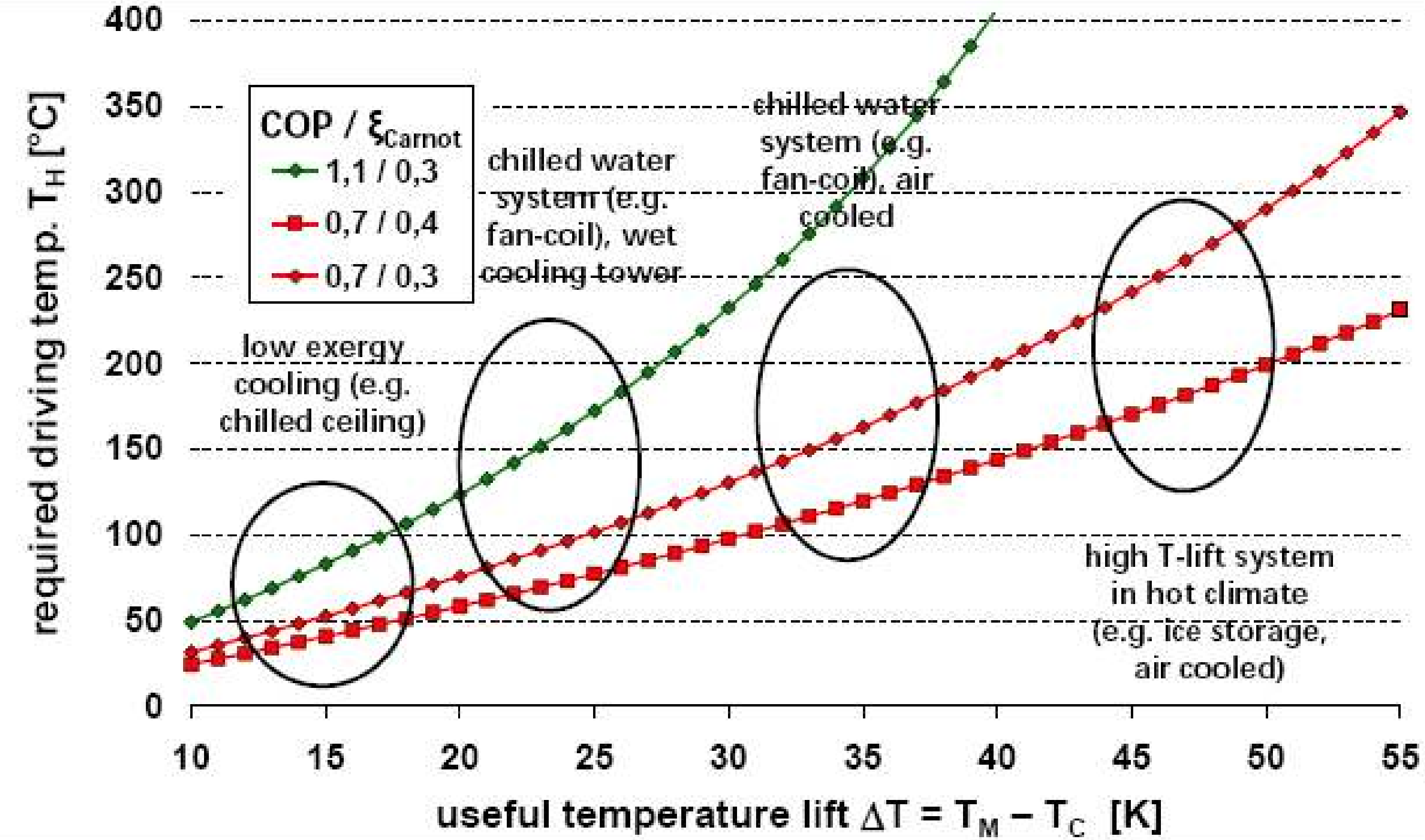
Source: Henning 2003

Thermodynamic analysis



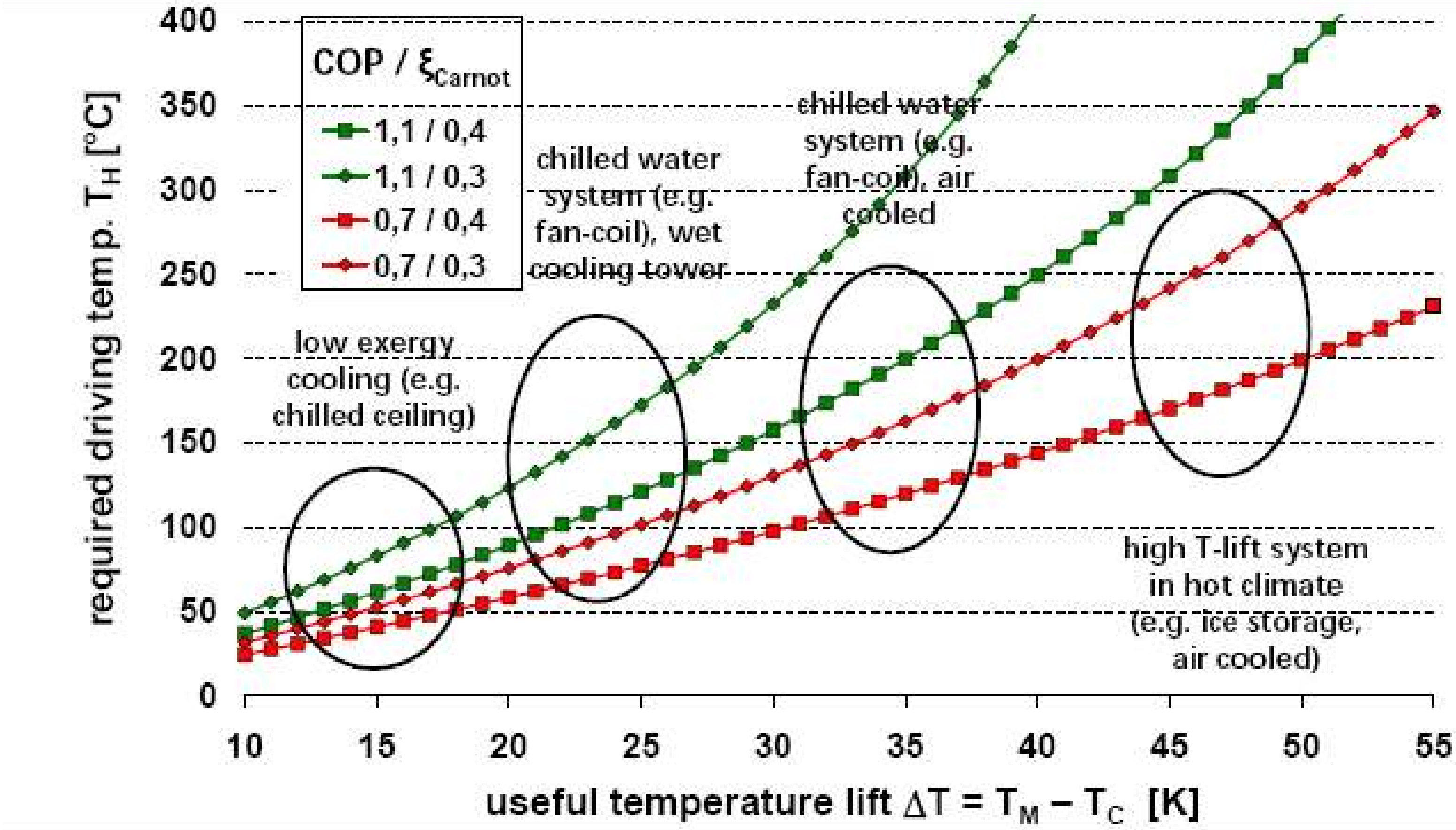
Source: Henning 2003

Thermodynamic analysis



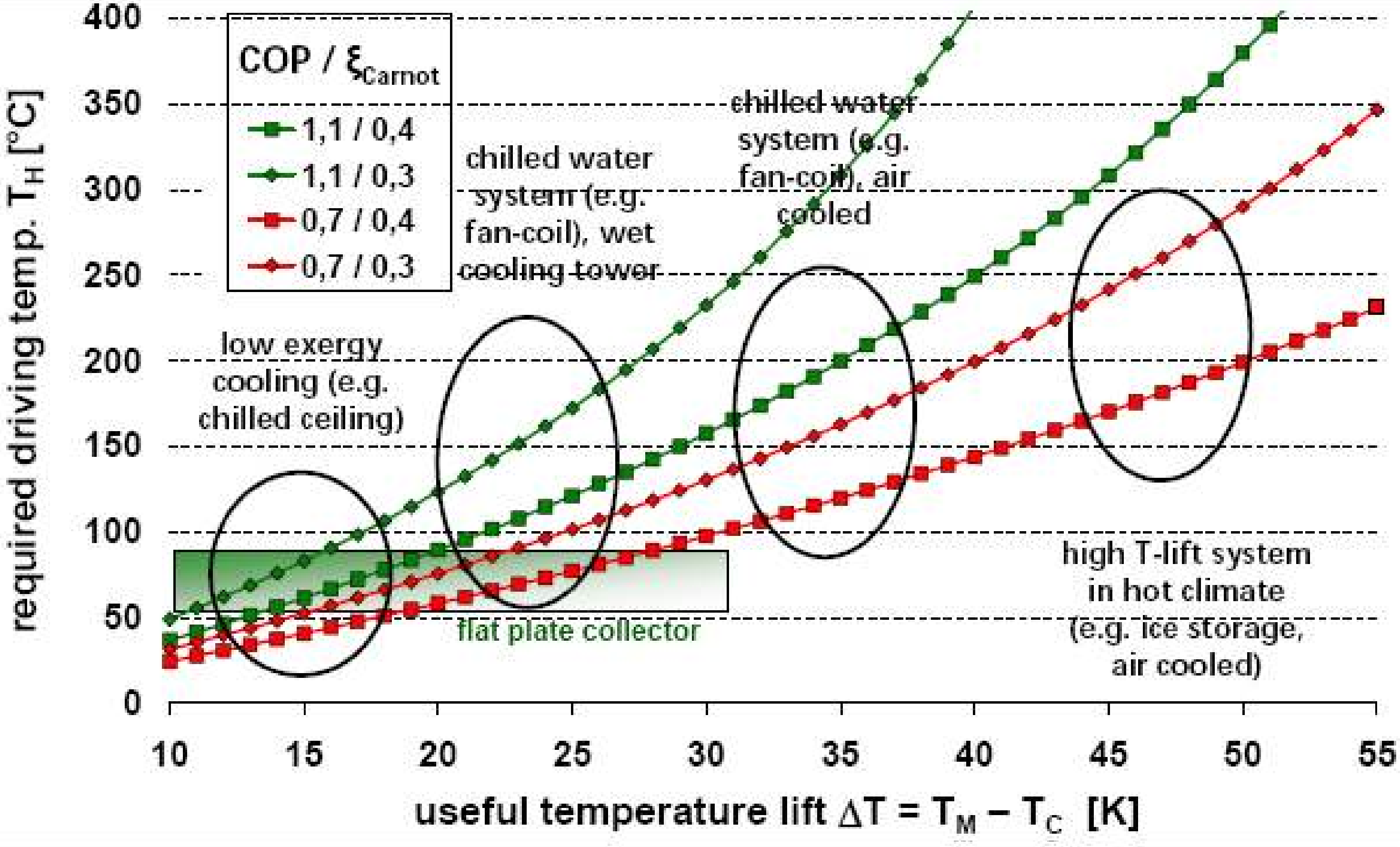
Source: Henning 2003

Thermodynamic analysis



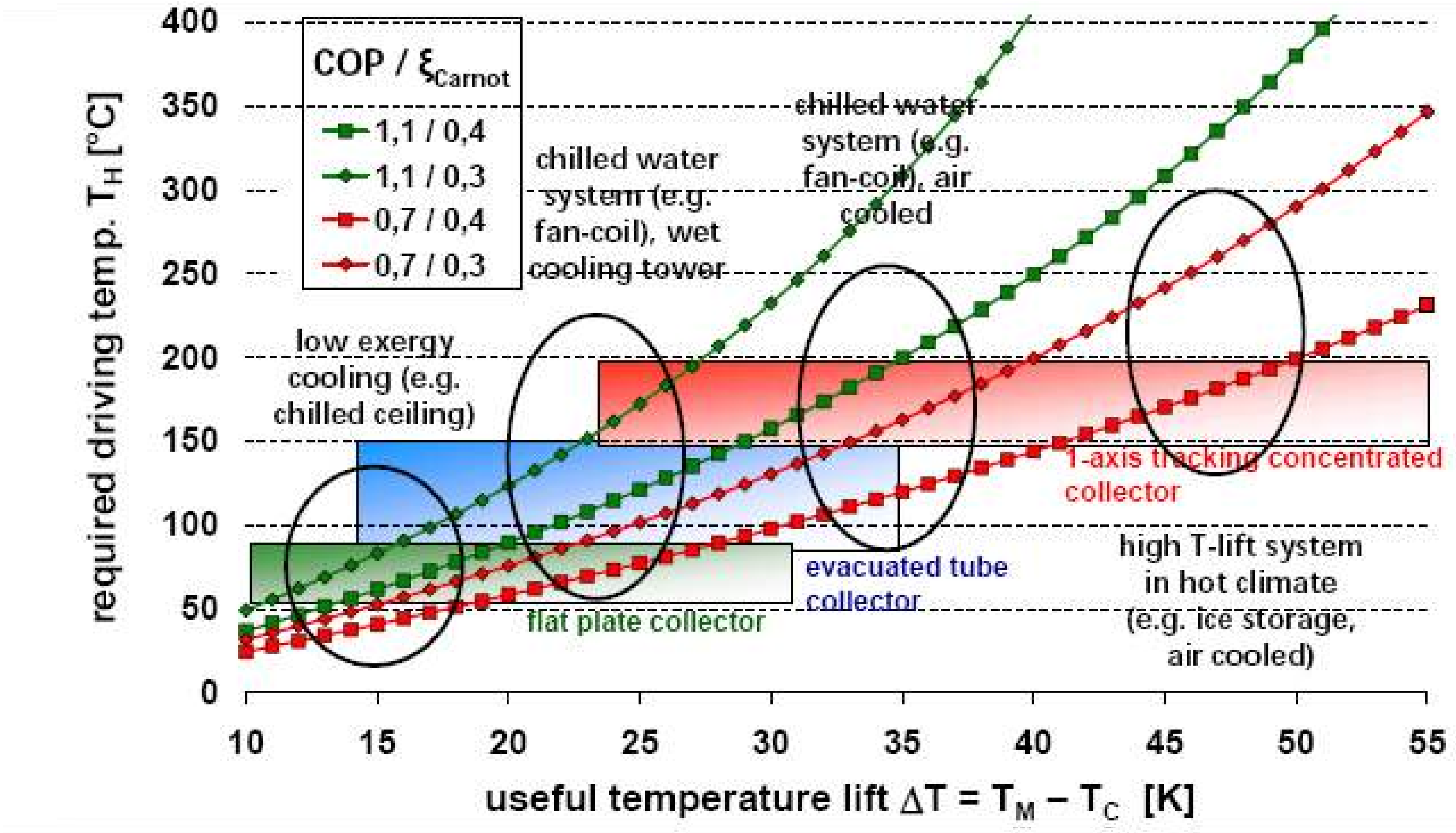
Source: Henning 2003

Thermodynamic analysis



Source: Henning 2003

Thermodynamic analysis



Source: Henning 2003

Thermodynamic analysis
Driving temperatures: solar collectors

SAC = solar air coll.

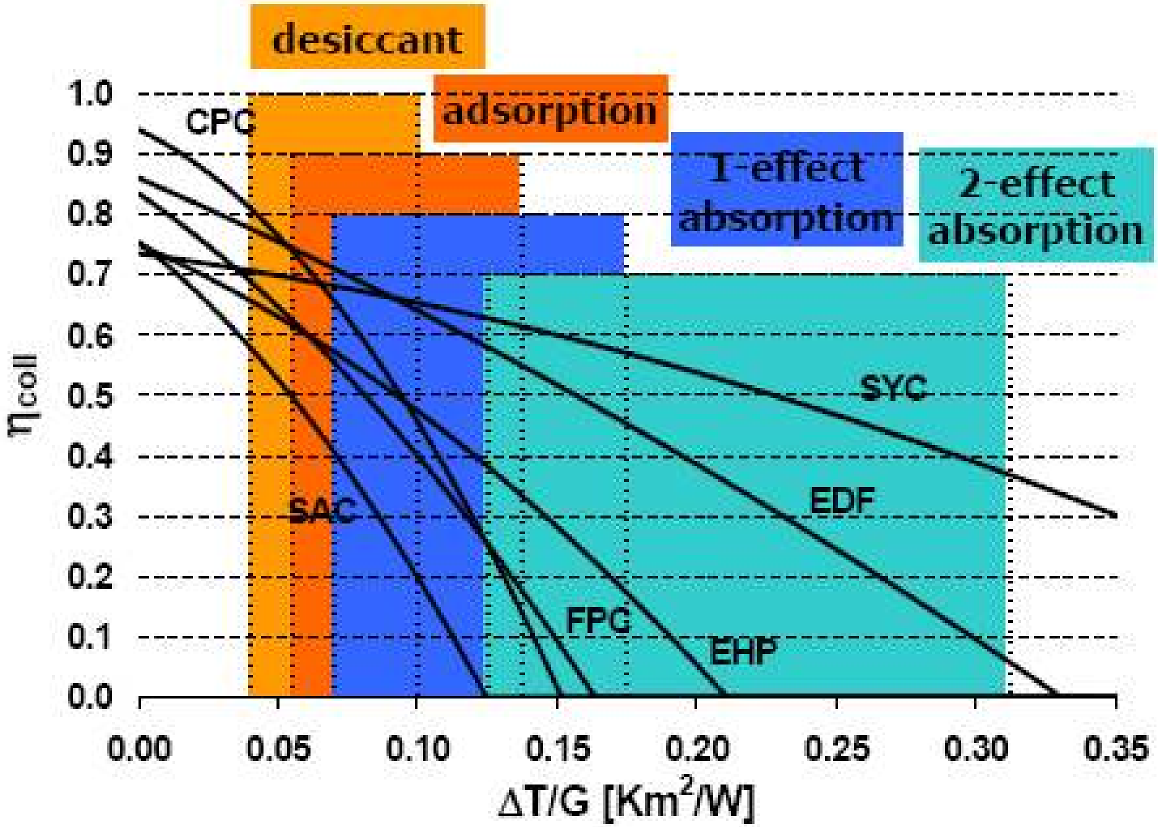
CPC = stationary CPC

FPC = selectively coated flat plate

EHP = evacuated heat-pipe

EDF = evacuated, direct flow

SYC = stationary concentrated, Sydney-type



Source: Henning 2007

System performance
Efficiency of cold generation

Example:

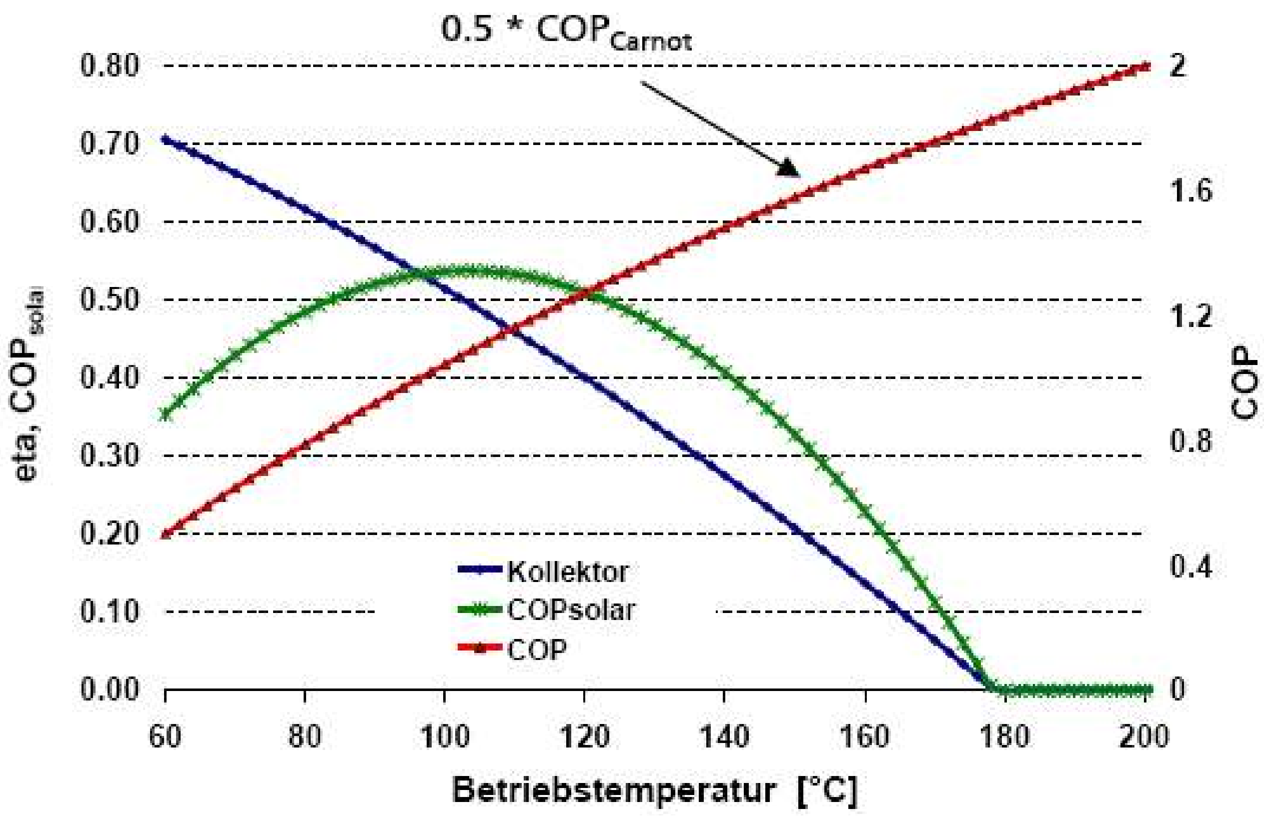
Flat plate collector

Radiation= 1000 W/m²

$COP_{sol} =$

$COP_{thermisch}$ *

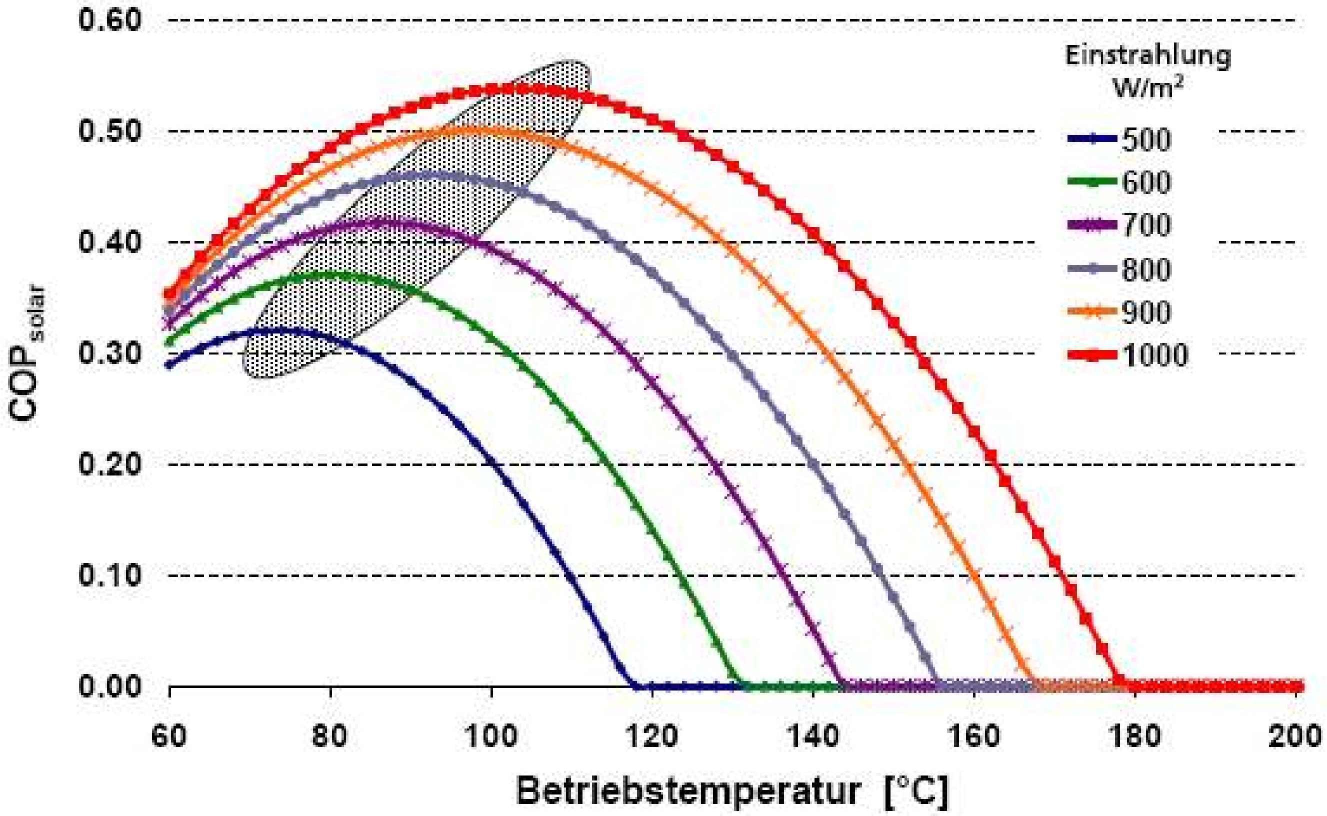
$\eta_{Kollektor}$



Source: Henning 2007

System performance

Efficiency of cold generation



Optimal driving temperature for solar-cooling system depends on the incident radiation
strahlung ab

$$COP_{solar} = \eta_{coll} * COP_{TDC,carnot}$$

Source: Henning 2007

System performance
Primary energy balance

$$E_{PE} = Q_{bu} / \varepsilon_{fossil} + E_{elec} / \varepsilon_{elec}$$

$$E_{PE,save} = \boxed{E_{PE,reference}} - \boxed{E_{PE,solar}}$$

$$E_{PE,save,rel} = \frac{E_{PE,save}}{E_{PE,reference}} \qquad E_{PE,save,spec} = \frac{E_{PE,save}}{A_{coll}}$$

$$PE_{spec,conv} = \frac{1}{(\varepsilon_{elec} \cdot COP_{conv})}$$

$$PE_{spec,sol} = \frac{1}{\varepsilon_{fossil} \cdot COP_{thermal}} \cdot (1 - SF_{cool}) + PE_{spec,cooling\ tower}$$

$E_{spec,cooling\ tower}$

6-10 $W/kW_{cooling,power}$ (axial)

10-20 $W/kW_{cooling,power}$ (radial)

$$PE_{spec,cooling\ tower} = \frac{E_{spec,cooling\ tower}}{\varepsilon_{elec}} \cdot \left(1 + \frac{1}{COP_{thermal}}\right)$$

$$Q_{use} = Q_{tot} - Q_{bu}$$

System performance

Primary energy balance

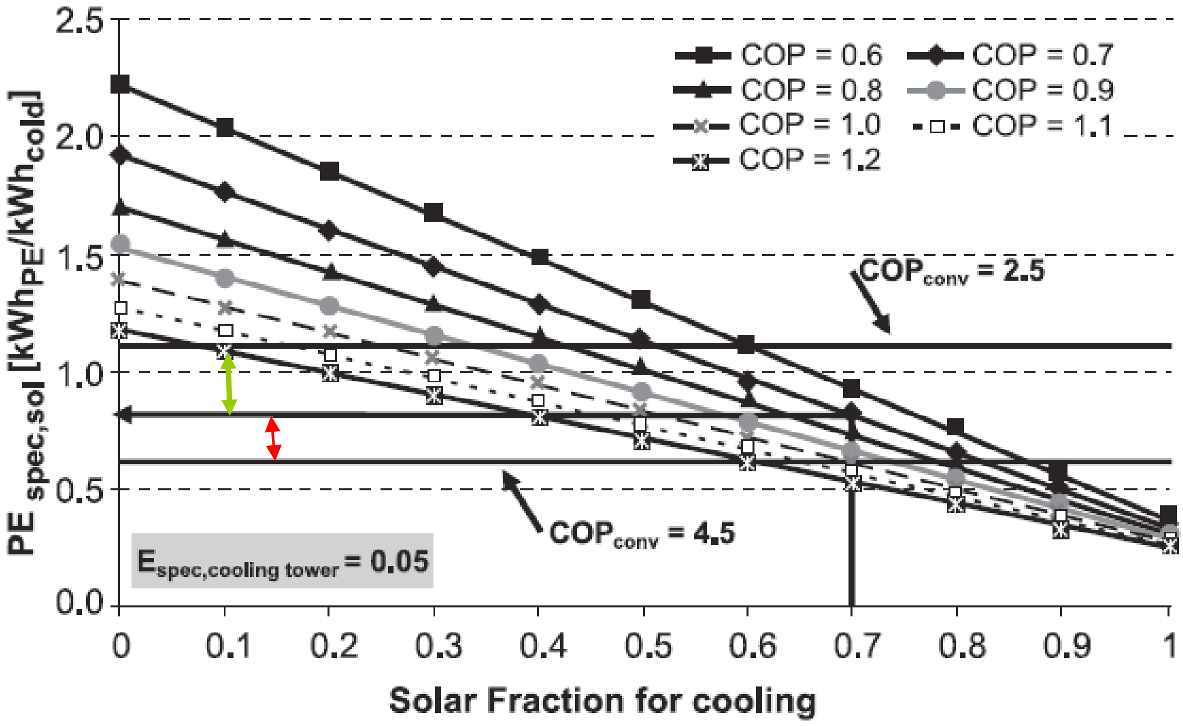
Example:

Cooling tower: 0,05 kWh_{el}/kWh_{cool} ;COP = 0,7 ; F_p=2,7 (ε =1/f_p)

Solar fraction: 0.7

27% lower

32% higher



Source: Henning 2003

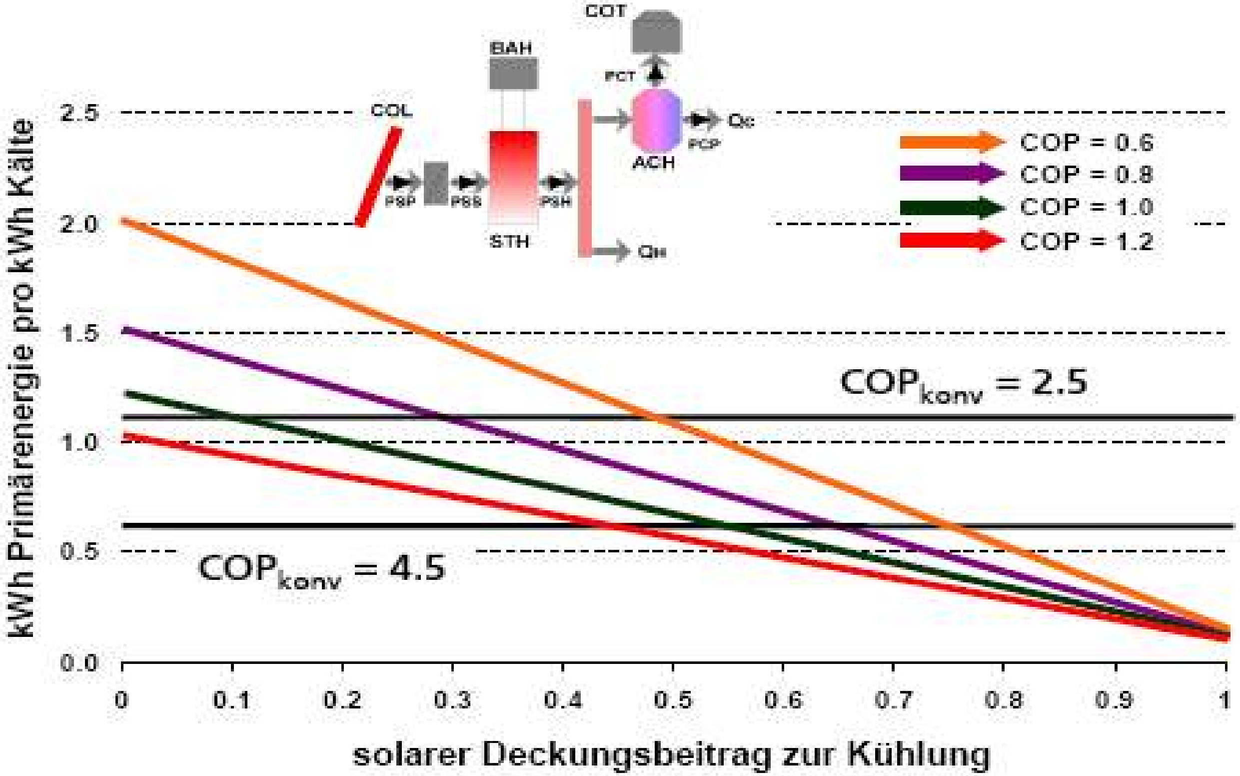
University logo: Carl von Ossietzky Universität Oldenburg

System performance
Primary energy balance

Solar energy + back up boiler (fossil fueled)

Primary energy conversion factor electricity: 0.36

Primary energy conversion factor for heat: 0.9



Source: Henning 2004

CARL VON OSSIETZKY universität OLDENBURG

References

- Henning, H.M. (Ed.) 2003. Solar-Assisted Air-Conditioning in Buildings - A Handbook for Planners. Springer-Verlag/Wien (Austria). 2003.

- Henning H-M., 2007. Solar cooling. SES Solar World Congress 2007 Beijing International Convention Center (BICC). Beijing, CHINA – September 19, 2007

- Henning H-M., 2004. Solare Klimatisierung: Stand der Entwicklung. Tagung „Solares Kühlen“ Wirtschaftskammer Österreich, Wien. 7. Mai 2004

- Cmu.edu, 2017. http://www.cmu.edu/iwess/components/steam_absorption_chiller/flow-diagram.html
Last visited: 18.09.2017

- APEP-UCI, 2017. http://www.apep.uci.edu/der/buildingintegration/2/Technologies/WasteHeatRecovery.aspx
Last visited: 18.09.2017