Main presentation, part A (3 h, about 60 slides)

1. Load concepts and (solar) air-conditioning

2. The cold production sub-system
   a. Chillers (vapour compression, absorption and adsorption), including basics on chiller characterisation (dynamic test approaches for seasonal performance assessment)
   b. Desiccant cooling systems
   c. Heat rejection equipment

3. The heat production (solar) system (collectors and storage), including state of the art on concentrating and new collectors

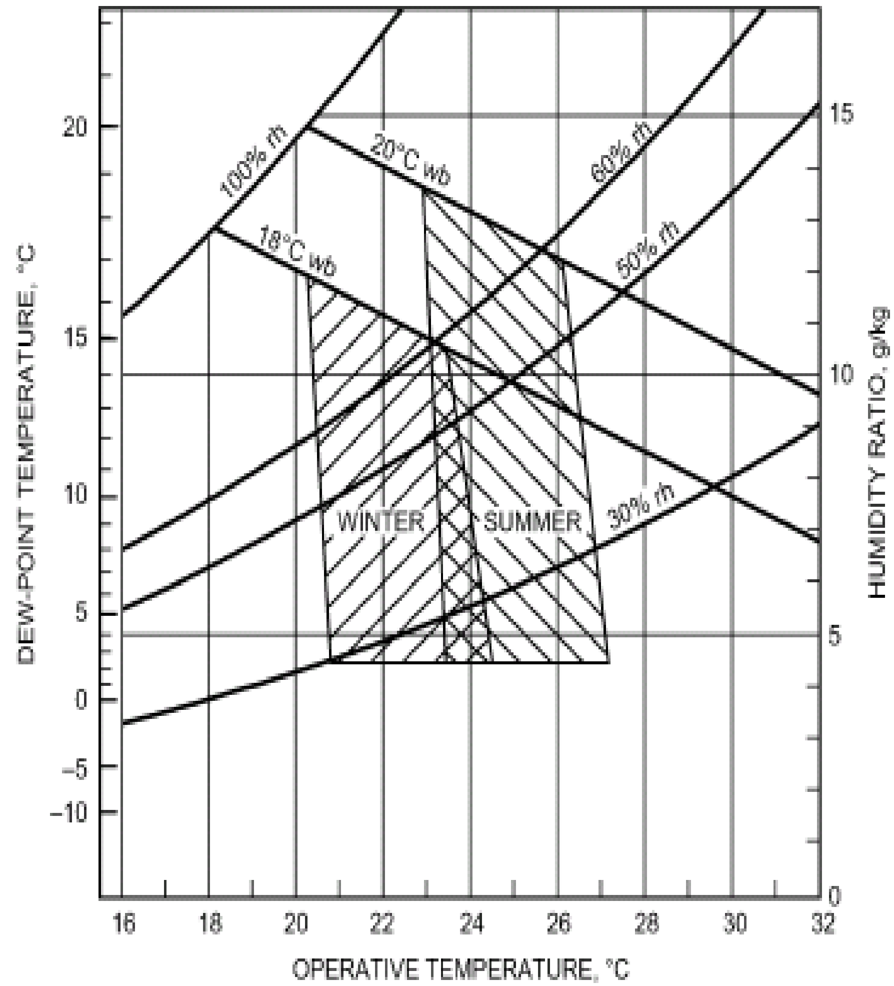
4. System configurations (solar assisted and solar autonomous systems) and control (including advanced control with self-detection of faults and malfunctioning). Solar district cooling.

5. Design approaches
   a. Preliminary design aspects, backup sources and efficiency benchmarks
   b. Dimensioning a solar cooling system (chiller size, collector area, storage volume)
   c. Quality assurance and lessons learned aspects

1. Load concepts and (solar) air-conditioning

The human comfort target

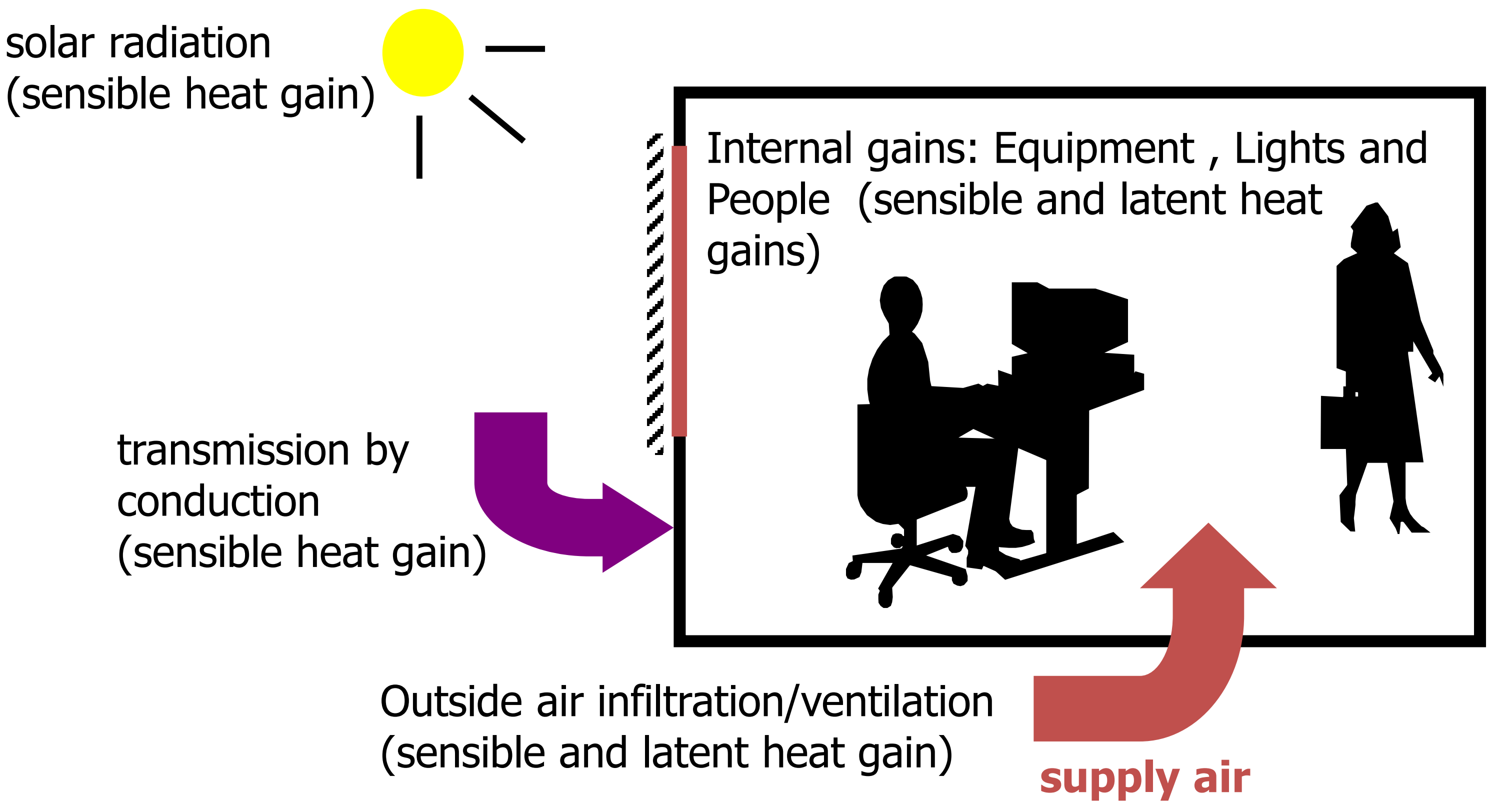
- Thermal comfort is influenced by
  - Air temperature
  - Air humidity
  - Surface temperature
  - Air velocity
  - Clothing thickness
  - Activity/ exertion
- Aim to remove heat to keep temperature and humidity inside the comfort window



Air-conditioning loads in summer

Sensible heat gains: lead to an increase in temperature

Latent heat gains: lead to an increase in humidity



Matching of demand with solar availability

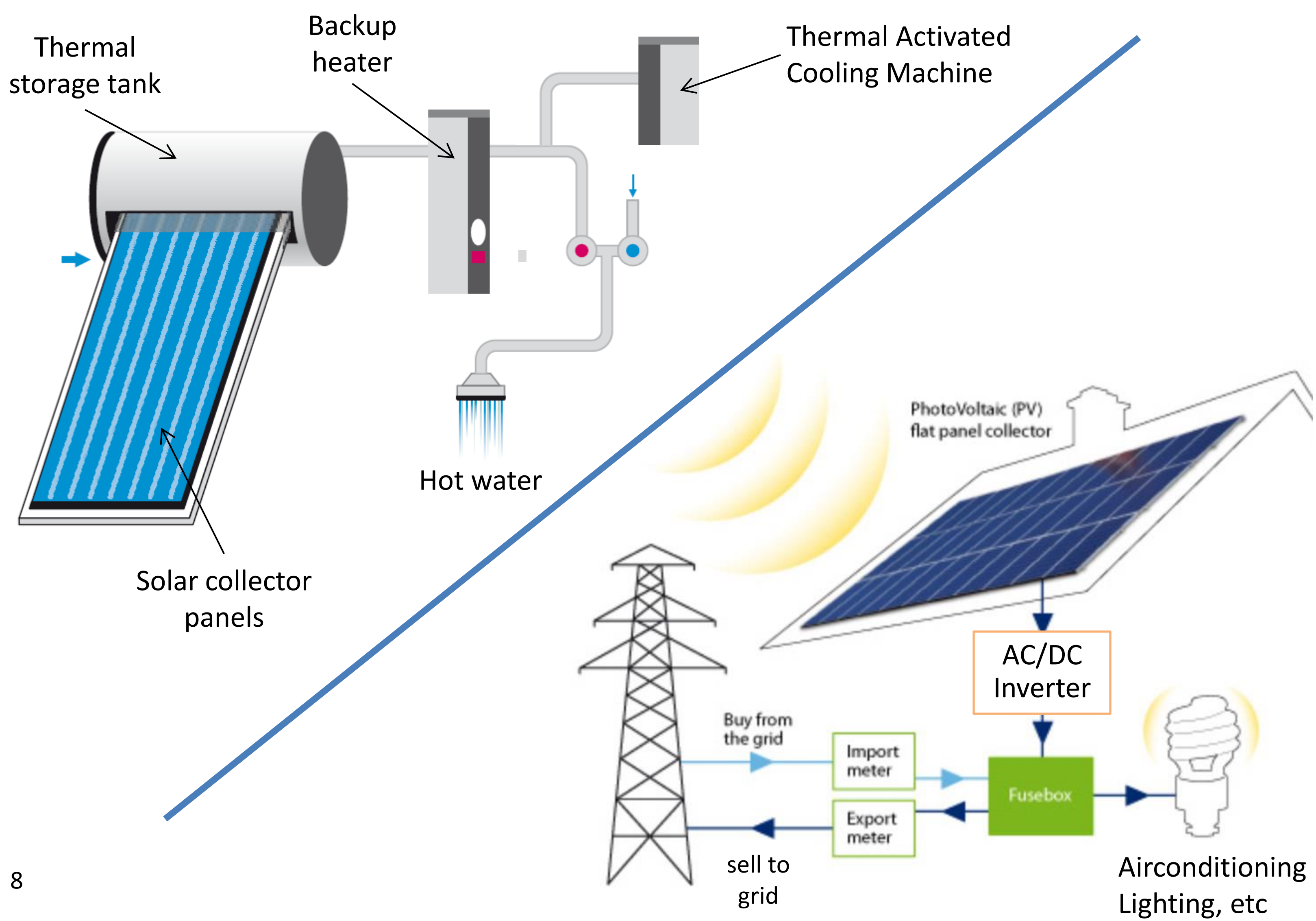
Source of Heat	Heat Type (sensible/latent)	Potential Magnitude	Correlation with Solar Availability
Sun shining through the windows	S	M/H	++
Heat conducting through the walls and windows	S	L	+
Computers, photocopiers, lights and other machines	S	M	+/-
People	S & L	M/L	+/-
Fresh air (infiltration or controlled ventilation)	S & L	H	++/-
Cooking	S & L	?	?

Hours of occupancy must also be considered

Removing heat and humidity

- Electricity driven vapour compression cooling
  - Cold production by chillers, package units or split system airconditioners
  - Cold transported to the room by air, water or refrigerant
  - Room air cooled below its dew-point to remove moisture
- Thermally activated cooling
  - Cold production by absorption chillers, adsorption chillers with cold transportation by chilled water
  - Dehumidification by cooling below dew point or by desiccant drying

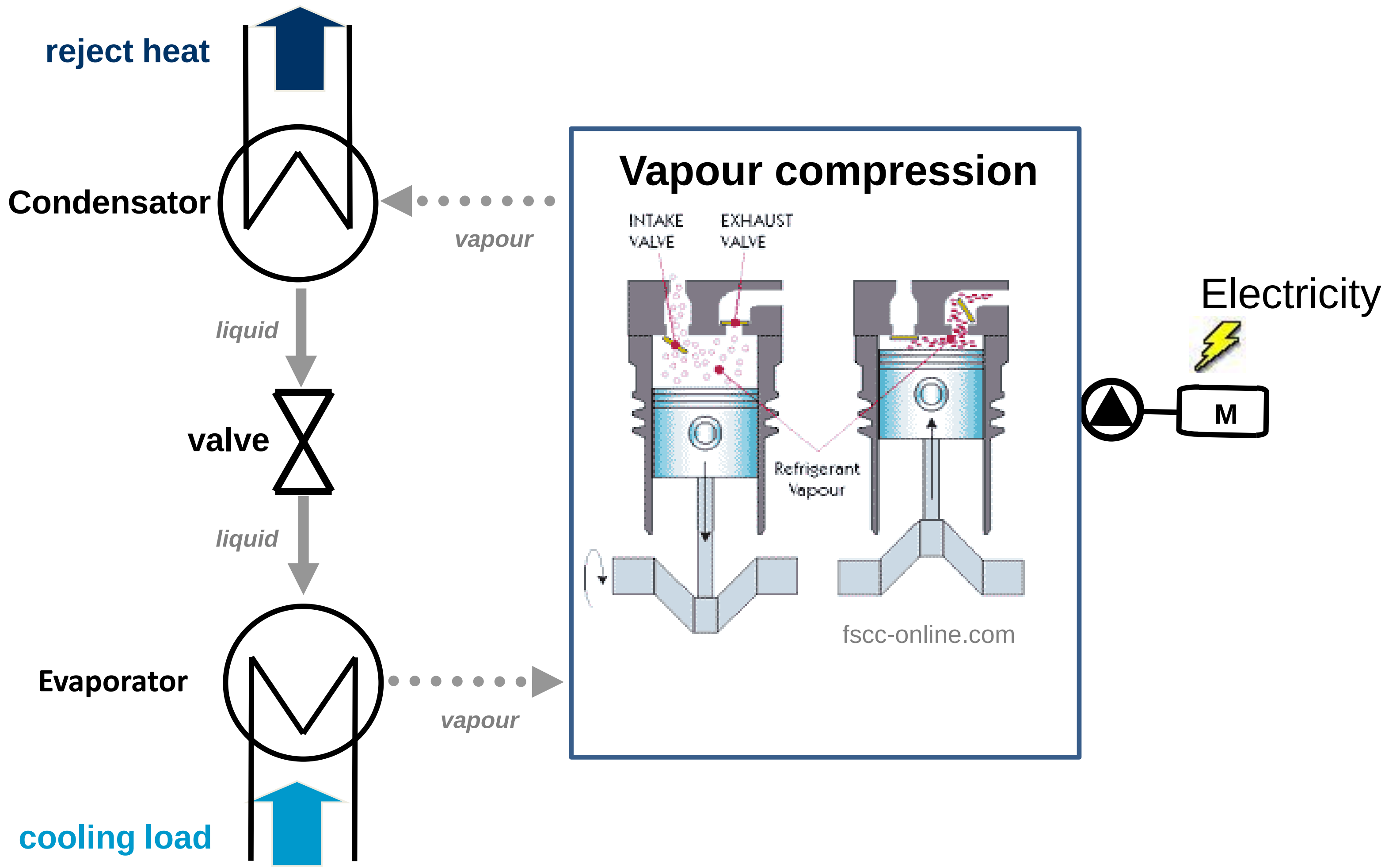
Solar PV or Solar thermal



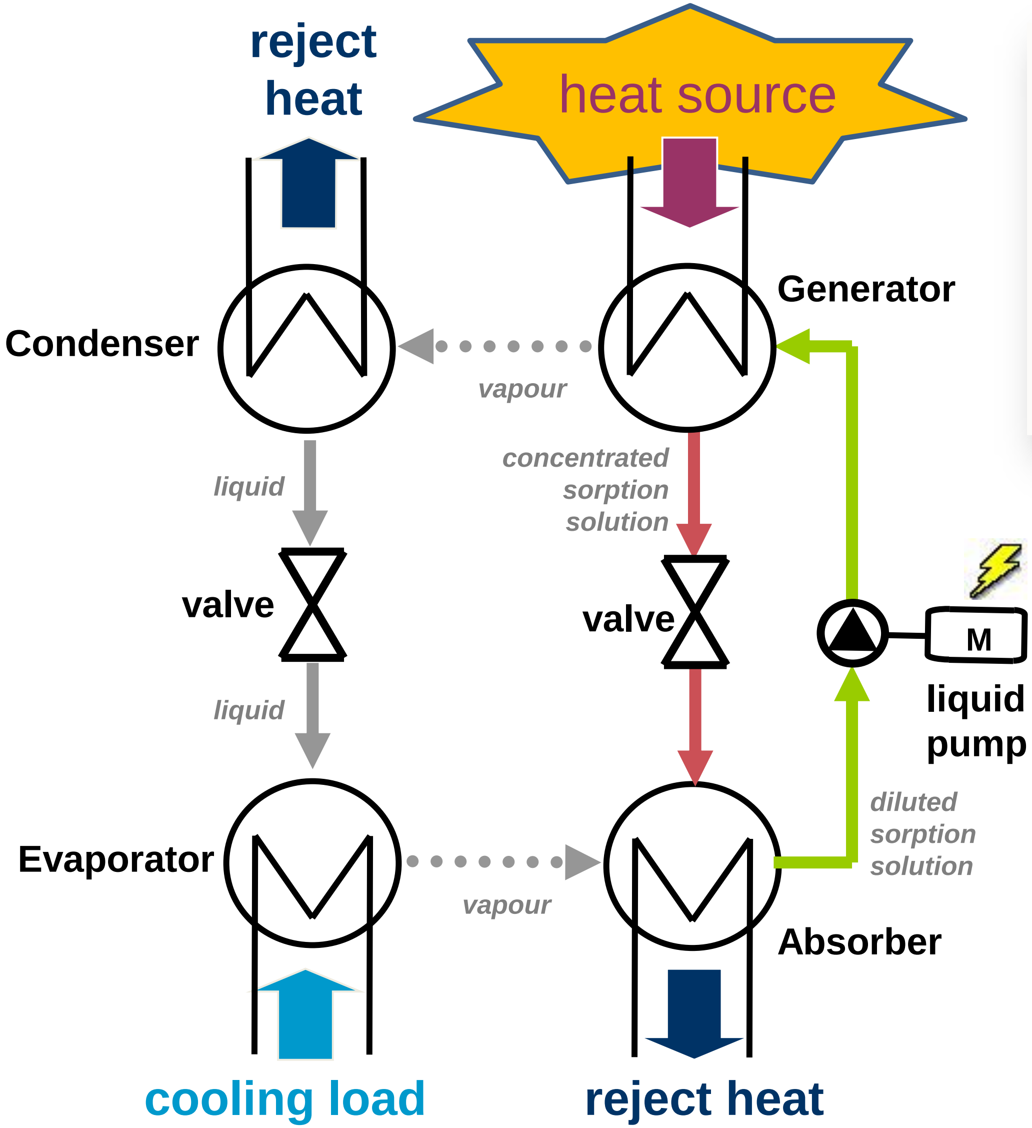
2. The cold production sub-system

a. Chillers (vapour compression, absorption and adsorption), including basics on chiller characterisation (dynamic test approaches for seasonal performance assessment)

Refrigeration principles: Vapour compression



Absorption refrigeration principle



Refrigerant/Absorbent pairs

- NH_3 / H_2O
  - Sub zero (food applications)
  - More expensive & less efficient
- H_2O / LiBr
  - Common for airconditioning

Parasitic Electricity

Task 48
Quality Assurance & Support Measures for
Solar Cooling Systems

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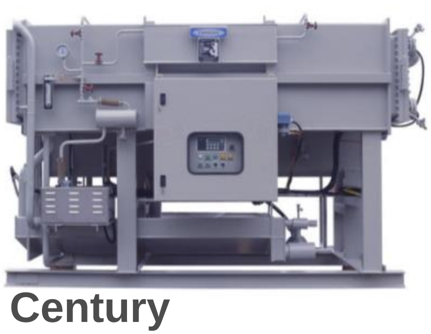
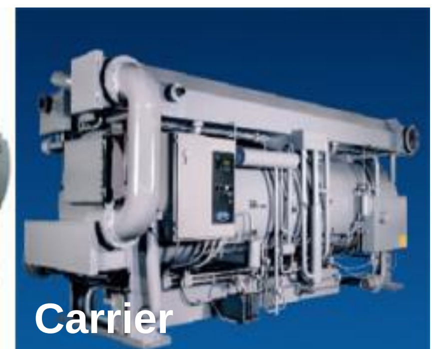
Large scale LiBr/ water absorption chillers

(Mature cost-effective technology, chilled water output)

Chiller	Coefficient of Performance (COP)	Required Heat Source Temperature
Single Stage	~0.7	80-120ºC
Two Stage	~1.3	160-180ºC
Three Stage	~1.8	200-240ºC

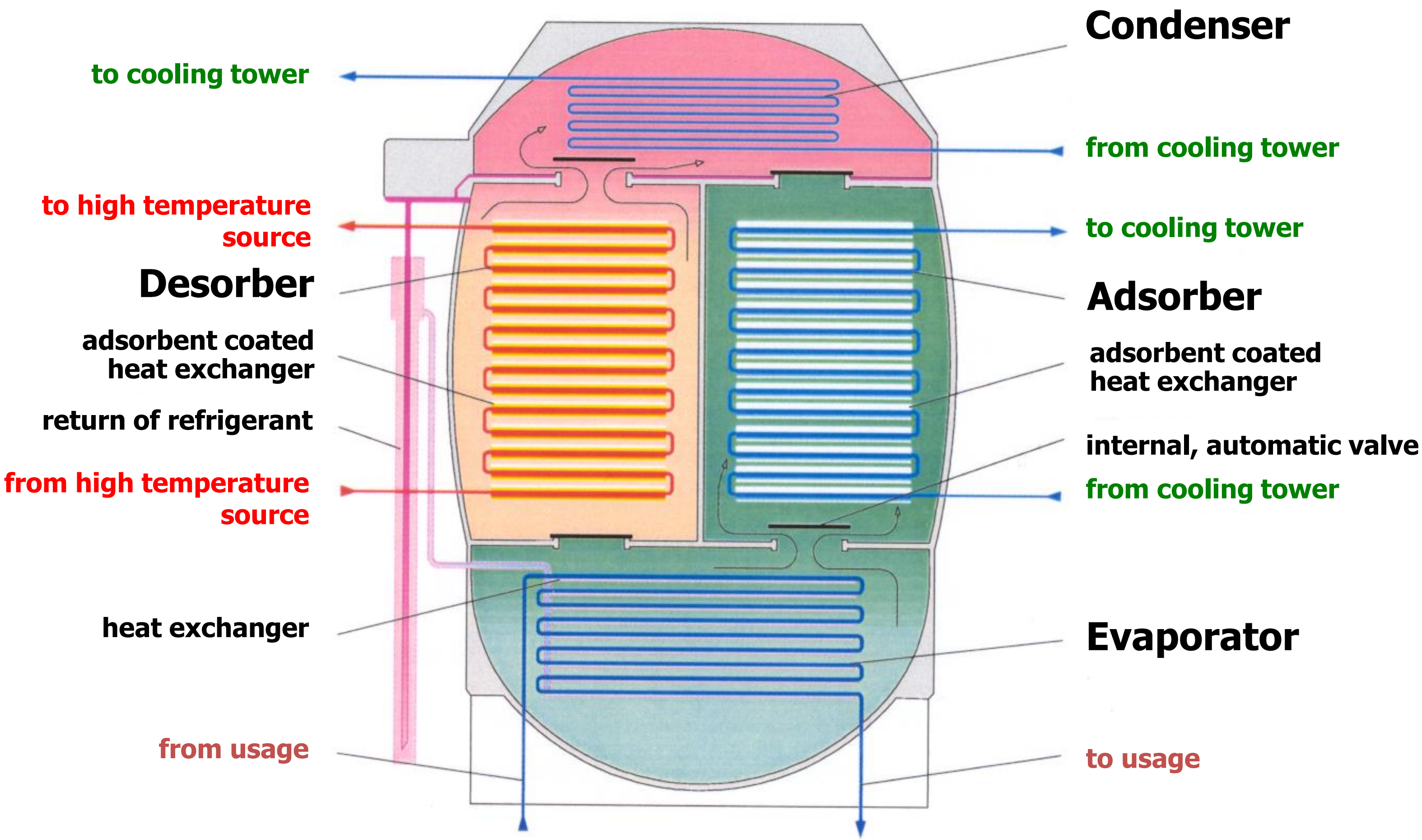




New developments

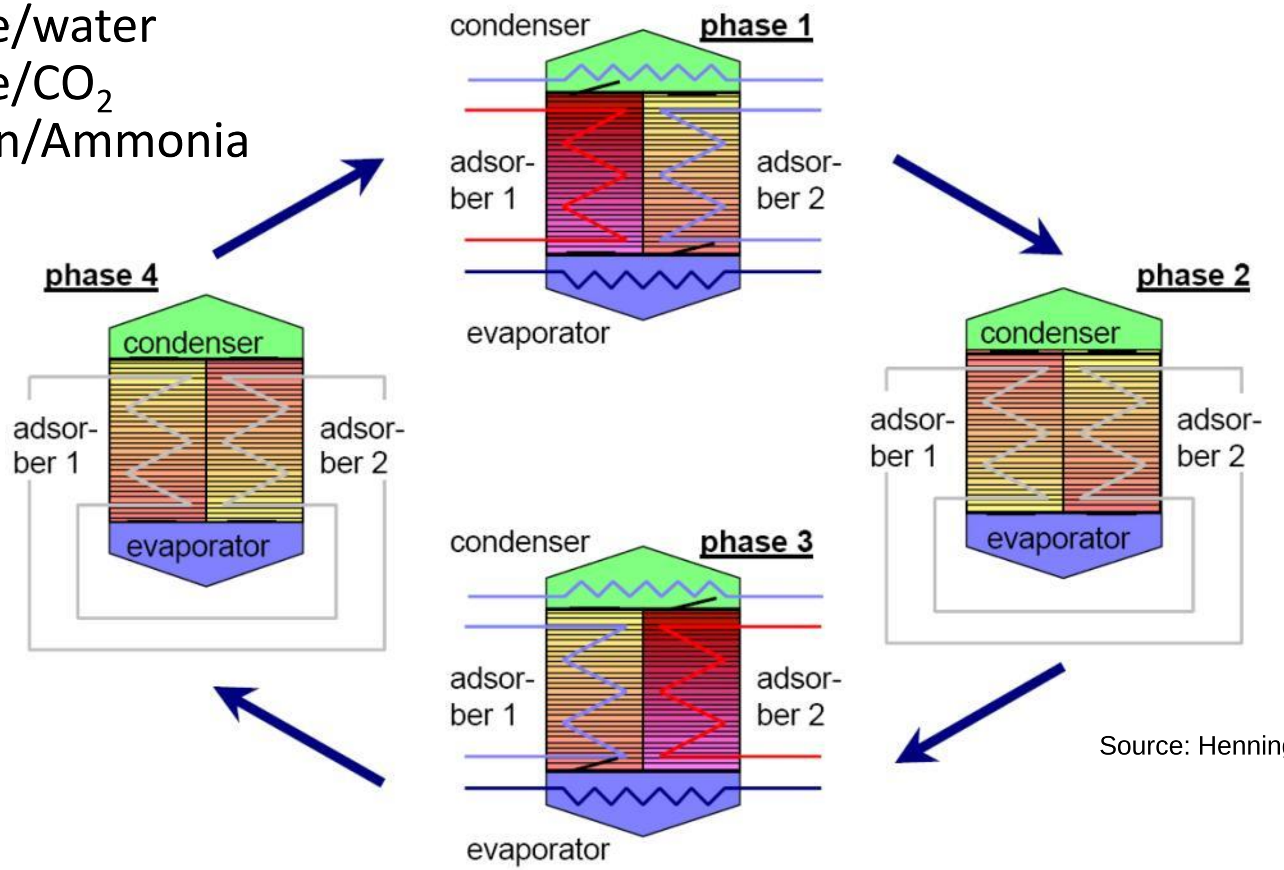
- Triple effect absorption chillers
- Double effect gas-fired with single effect solar boost
- Air cooled LiBr/H_2O absorption chillers
- Low temperature LiBr/brine absorption chillers

ADsorption machine schematic



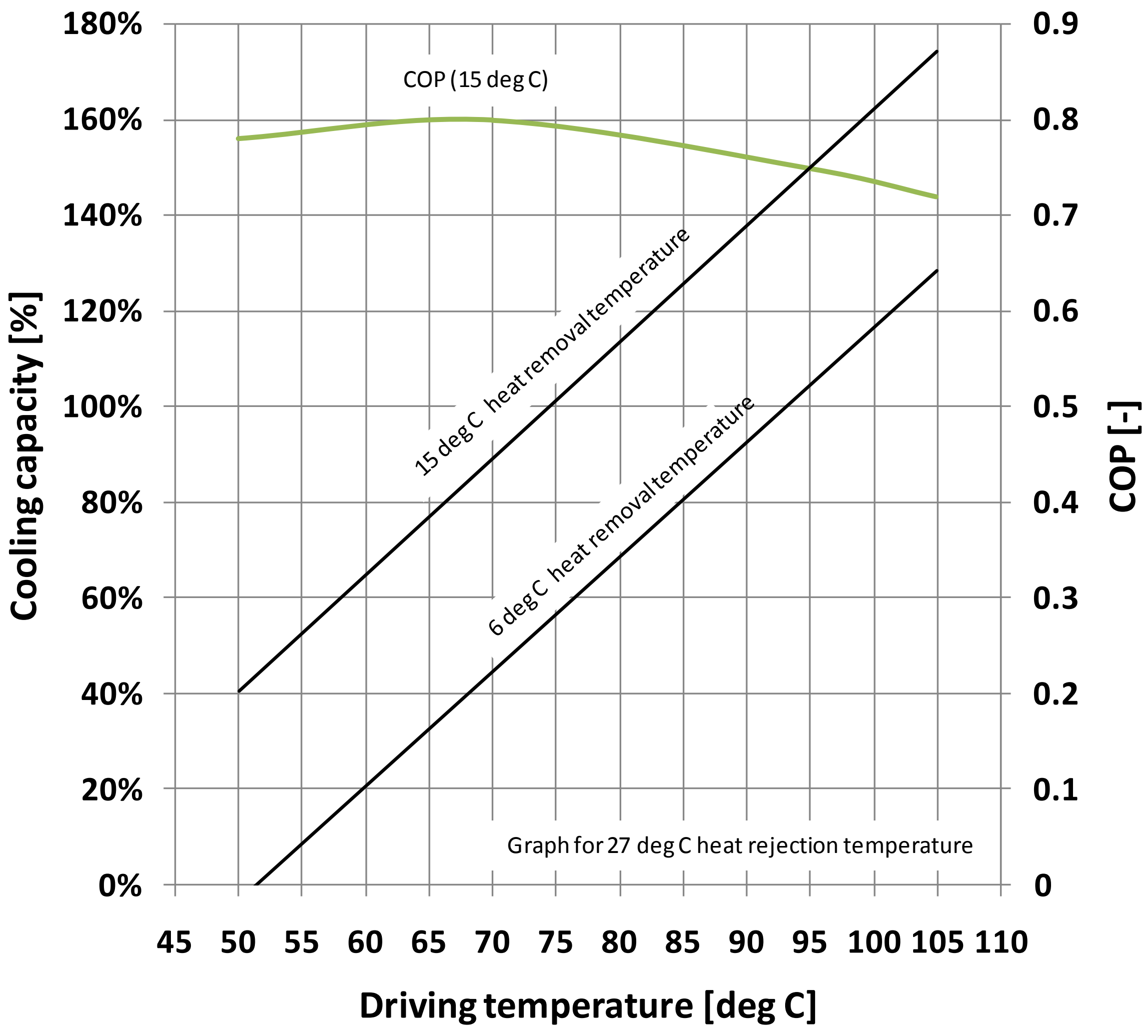
ADsorption refrigeration batch process

- Typical solid sorbent/ refrigerant pairs
  - Silicagel/water
  - Zeolite/water
  - Zeolite/CO_2
  - Carbon/Ammonia

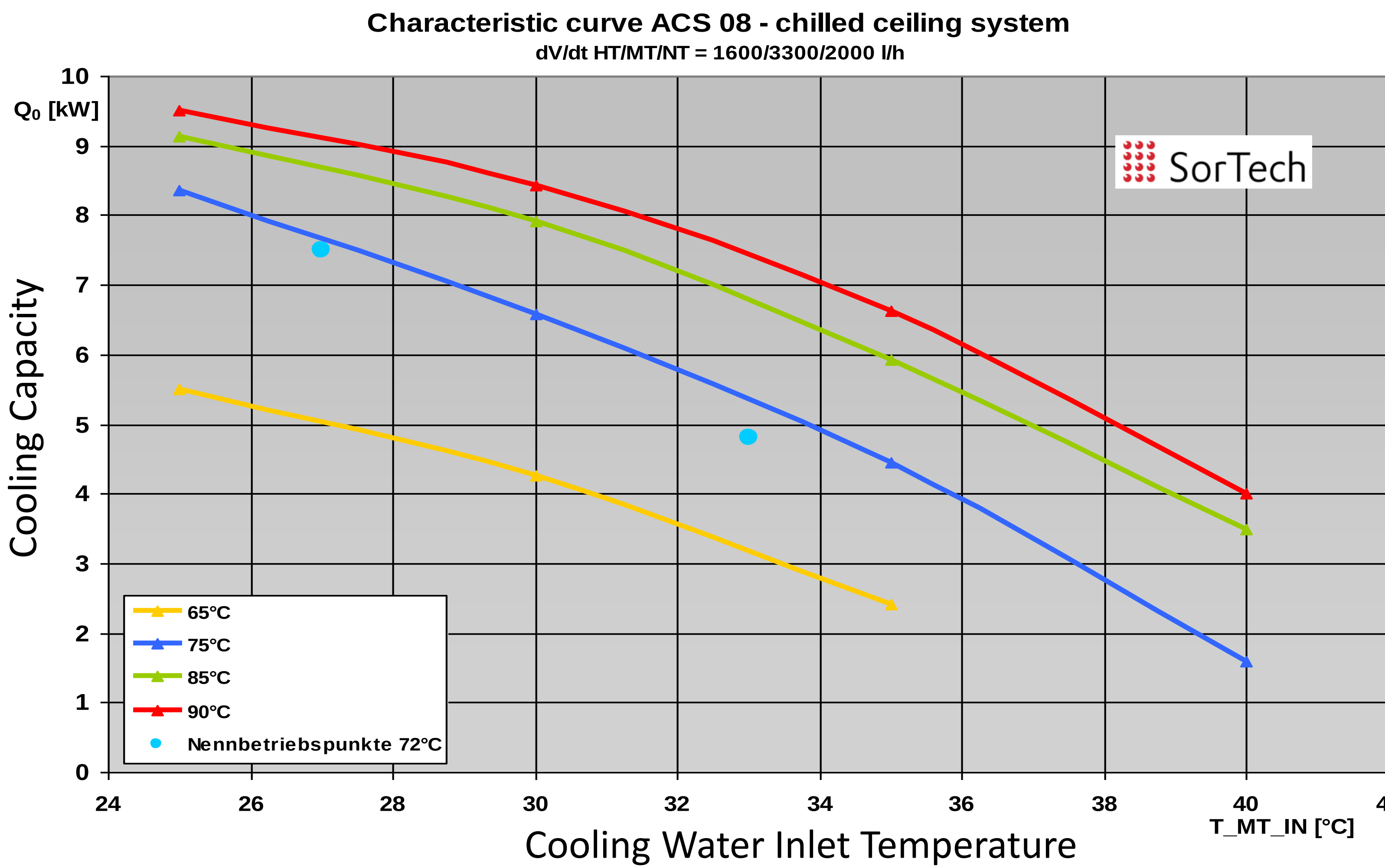


Source: Henning (2000)

Capacity and COP variation with driving temperature (single effect absorption chiller)



Capacity variation with heat rejection temperature (adsorption chiller)



Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

Some suppliers

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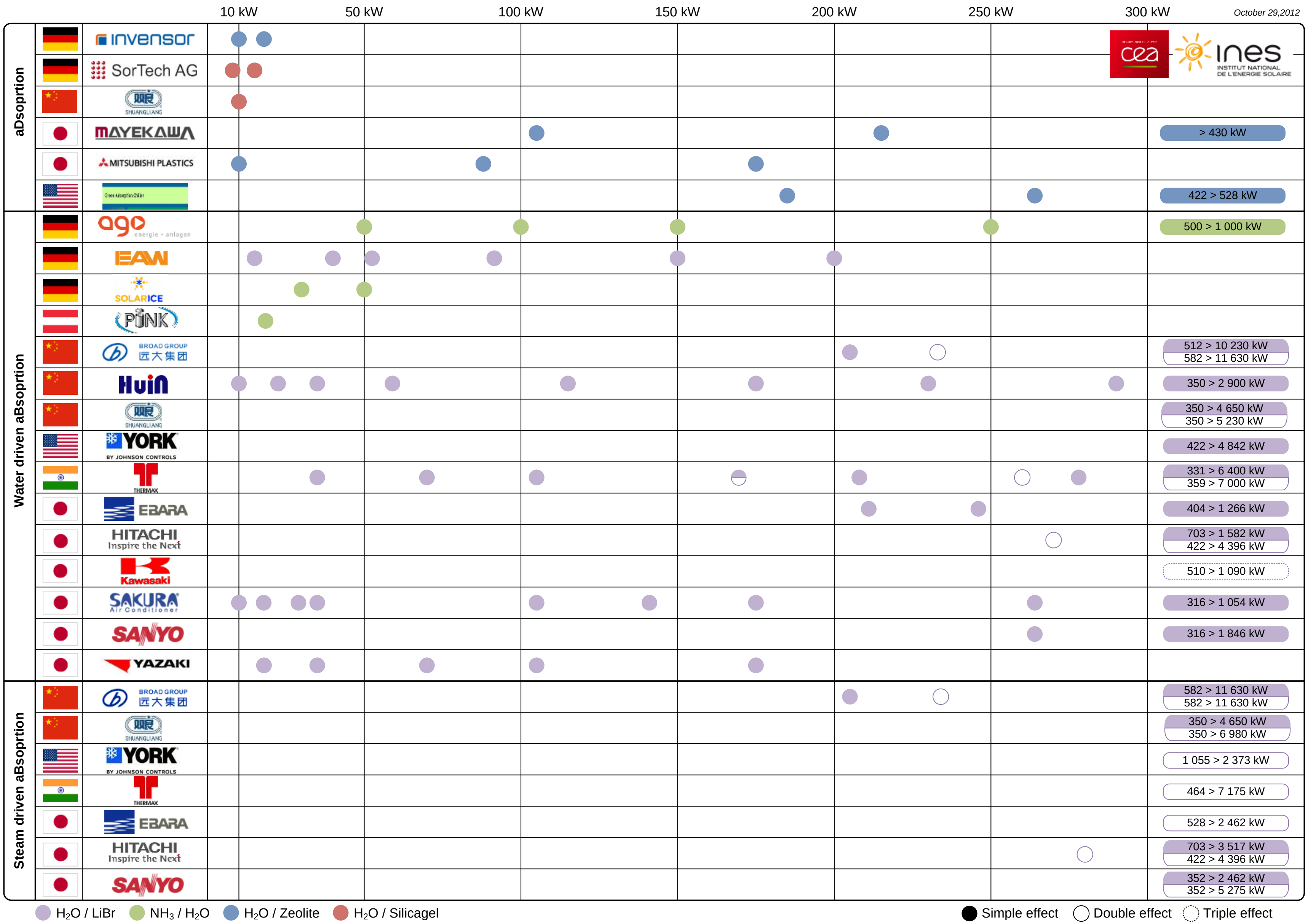
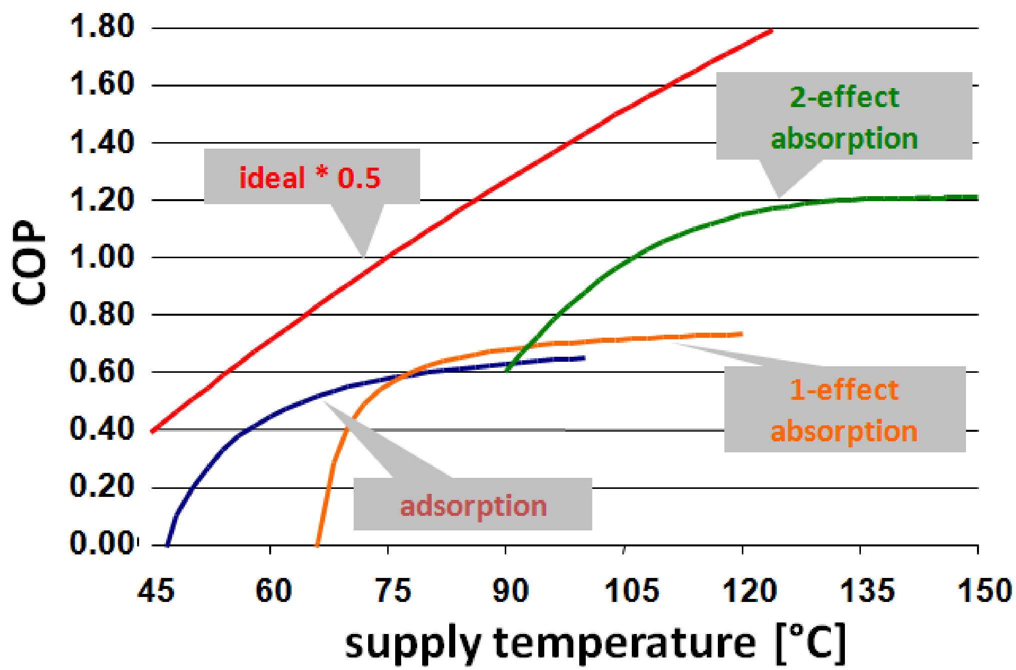


Comparing ad- and ab-sorption chillers

Adsorption generally has lower COP, larger size and higher cost, but

- Does not require a wet cooling tower
- Does not require management of solution chemistry
- Can run off a lower temperature heat source



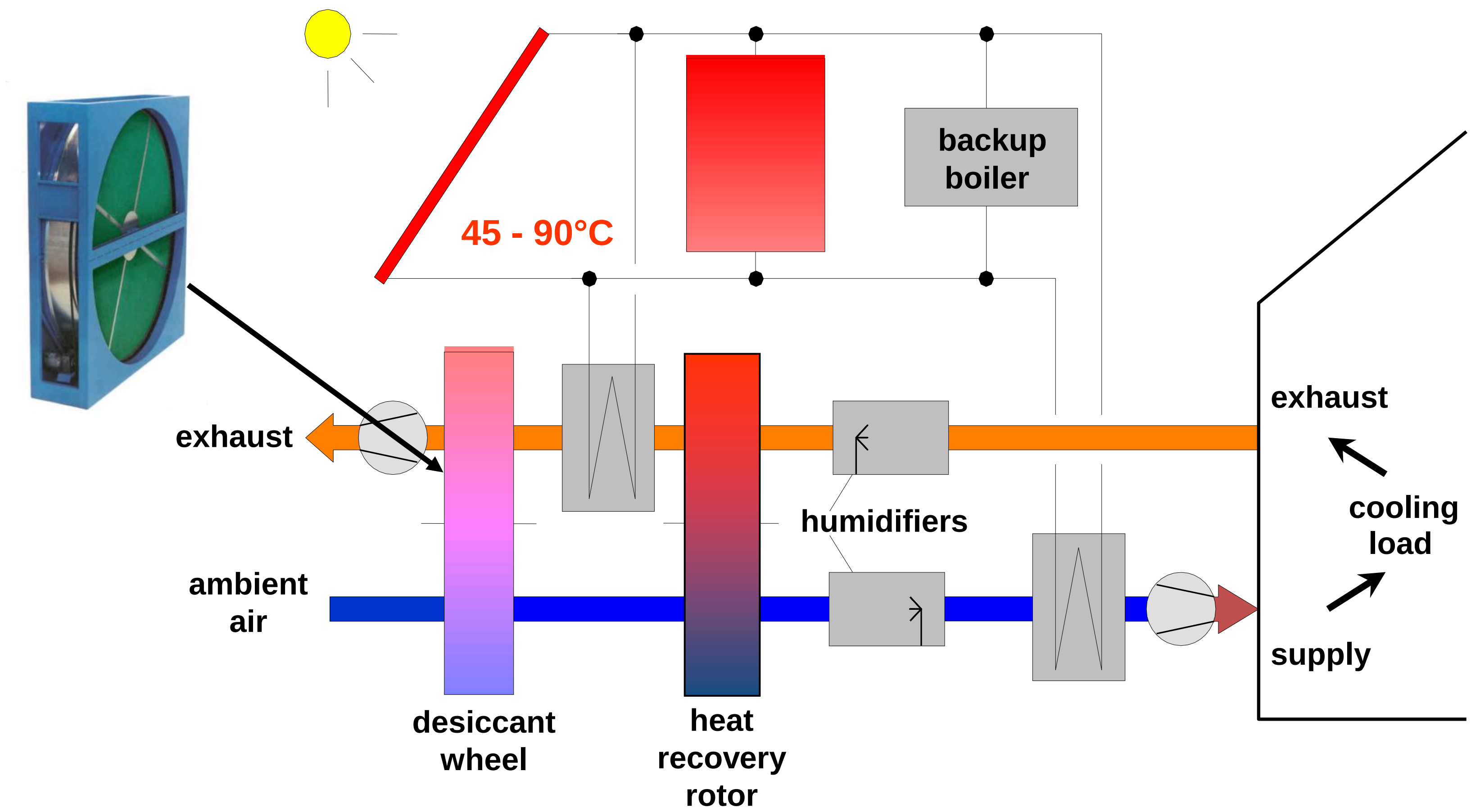
2. The cold production sub-system

b. Desiccant cooling systems

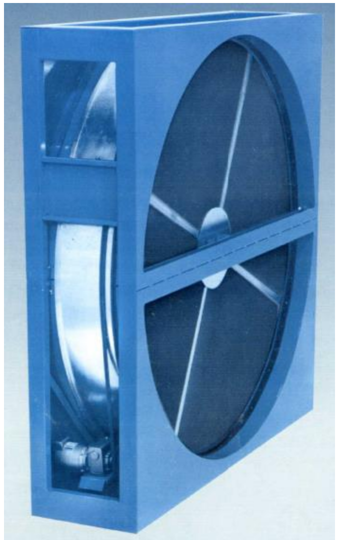
DEC systems (desiccant and evaporative cooling)

- DEC systems are used for the direct treatment of fresh air
- Process consists of a combination of evaporative cooling and dehumidification through hygroscopic materials
  - Liquid desiccant
  - Solid desiccant (most common)
- The potential of evaporative cooling is increased by the process of dehumidification of the air
  - Evaporative cooling available irrespective of solar availability
- A DEC system can be incorporated into a conventional air handling unit with or without a conventional compression chiller

Solar DEC system schematic



Desiccant wheels



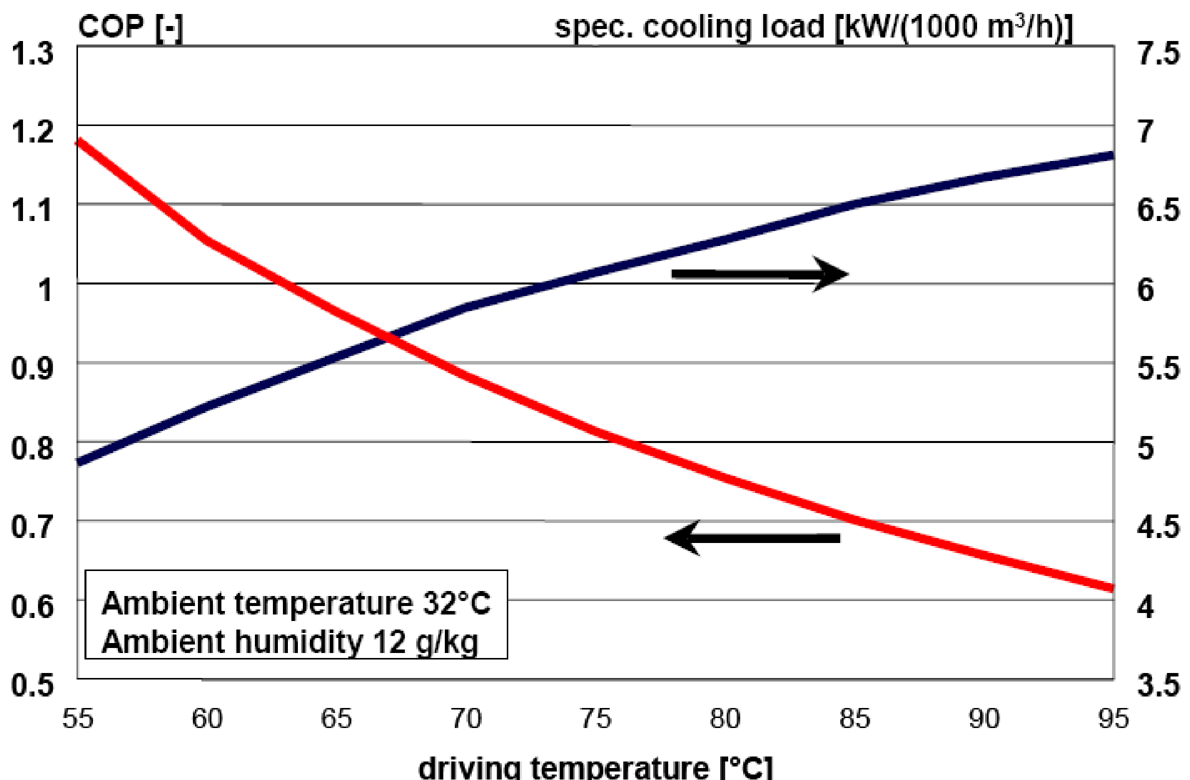
- Solid desiccant wheels are common in silica gel and zeolite
  - DRI/ Bryair
  - Seibu-Gieken
  - NovelAire
  - Klingenburg
  - Proflute

- Desiccant systems
  - Munters
- 50:50 process:regeneration air for high dehumidification/ low temperature
- 75:25 process:regeneration air for high capacity/ high COP

Desiccant cooling system performance

$$COP_{DEC} = \frac{h_{external} - h_{supply}}{\dot{Q}_{regeneration}}$$

Mix of „passive" (evaporative) and „active" (dehumidification + evaporative) cooling



Increasing temperature

- Increasing specific cooling capacity
- Lower temperature supply air
- Lower COP (due to lower fraction of passive cooling)

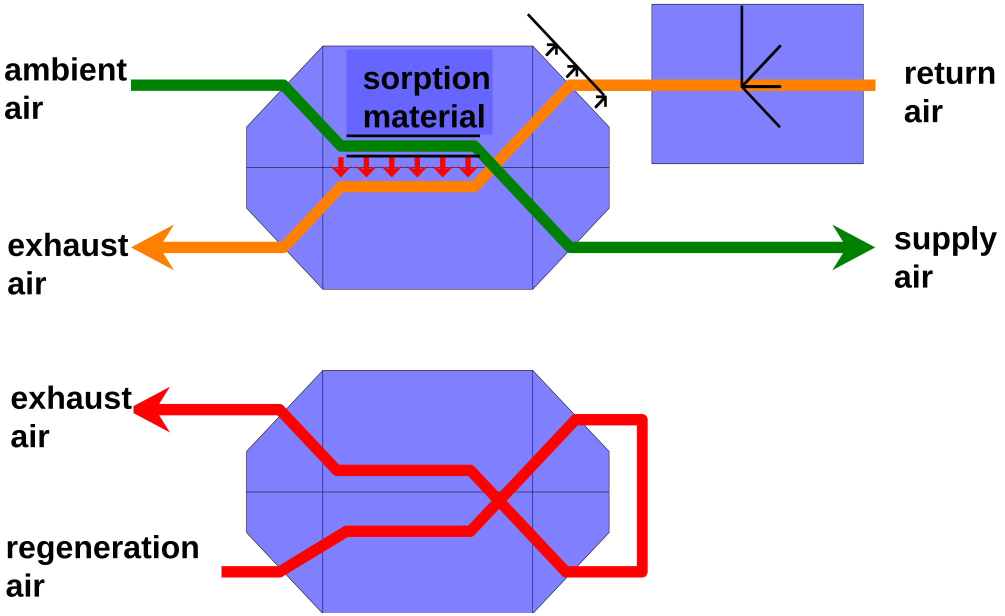
Comparing desiccant cooling with absorption cooling

DEC systems are

- Good for removing latent heat load (but may not achieve low enough supply air temperatures on hot days)
- Can operate over longer time periods in evaporative cooling only mode
- No cooling tower required (but does require water)
- Can use low temperature heat sources
- Efficiency is application specific
  - High COP (~1.0) when used as an advanced heat recovery unit for supply of required ventilation fresh air (recovering coolth from indoor air)
  - Low COP (~0.5) when supplying fresh air above that required for ventilation
- Easy to maintain, common AHU components
- Generally more cost effective

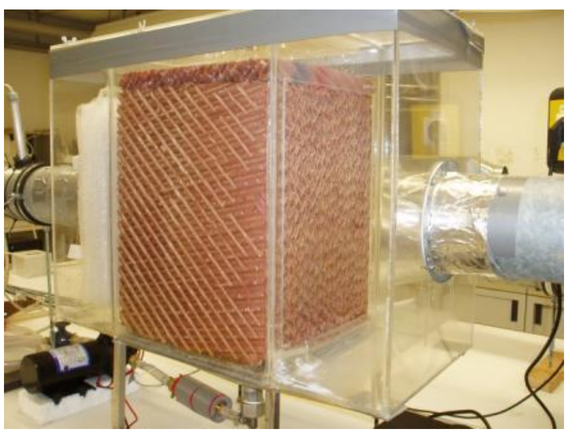
DEC system – new developments

- Cycles with indirect evaporative coolers
- New desiccant materials
  - Polymers
  - Impregnation with metal halides
- Cooled (non-adiabatic) desiccant coated heat exchangers
  - Simultaneous sensible and latent heat removal



DEC systems with liquid desiccants

- Aqueous LiCl or $CaCl_2$ solutions as liquid desiccant.
- Advantages:
  - Possibility of loss free storage of strong solution at high storage density
  - High dehumidification potential
- Disadvantages:
  - Problems with corrosion
  - High costs especially for LiCl
  - Possibility of liquid carryover





Some liquid desiccant system suppliers

AIL Research (35 - 93 kW)

Imtech Drygenic (Kathabar, 30 - 70 kW)

L-DSC Technology (200 - 350 kW)

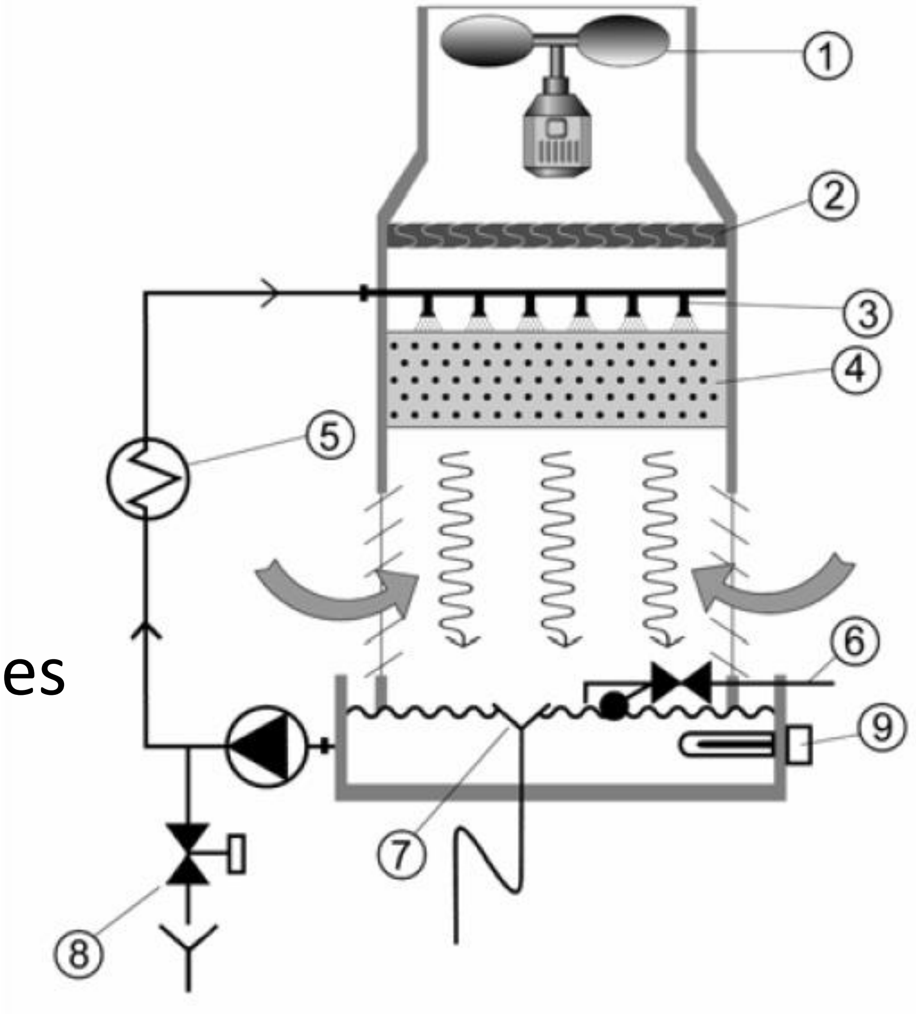
Menerga (20 - 100 kW)

2. The cold production sub-system

c. Heat rejection equipment

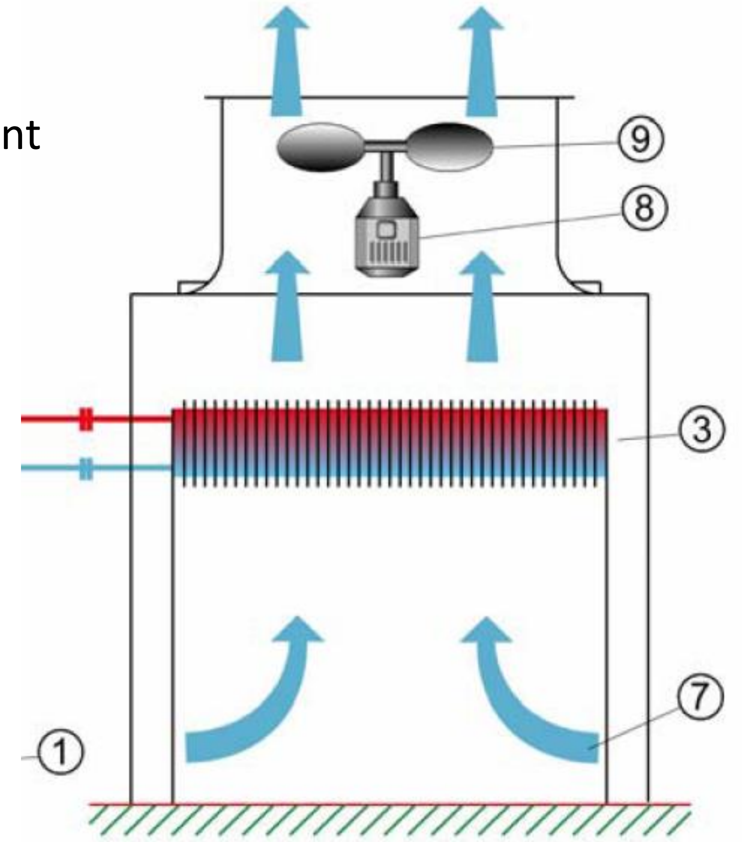
Wet Cooling Tower

- Efficient
- Water required
- Maintenance
  (chemical treatment, registration)
- Not available in small sizes
- Frost protection



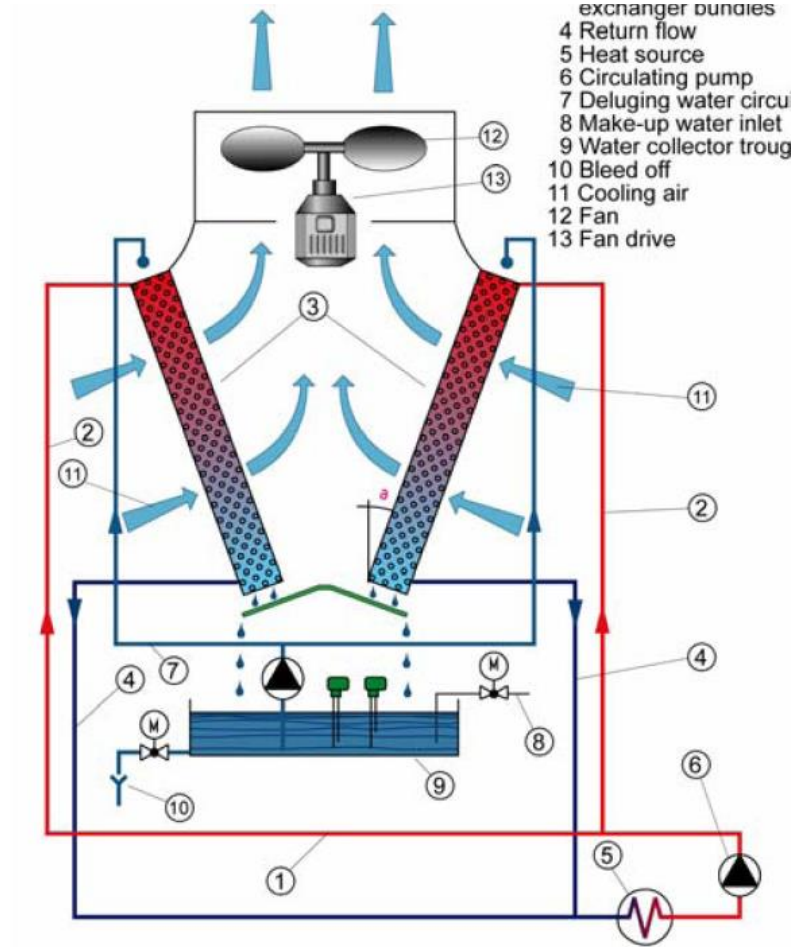
Dry Cooler

- No water required
  - Although sprays can be used for infrequent extreme conditions
- Higher/ more variable heat rejection temperature
- High parasitic power consumption



Evaporative Hybrid Cooler

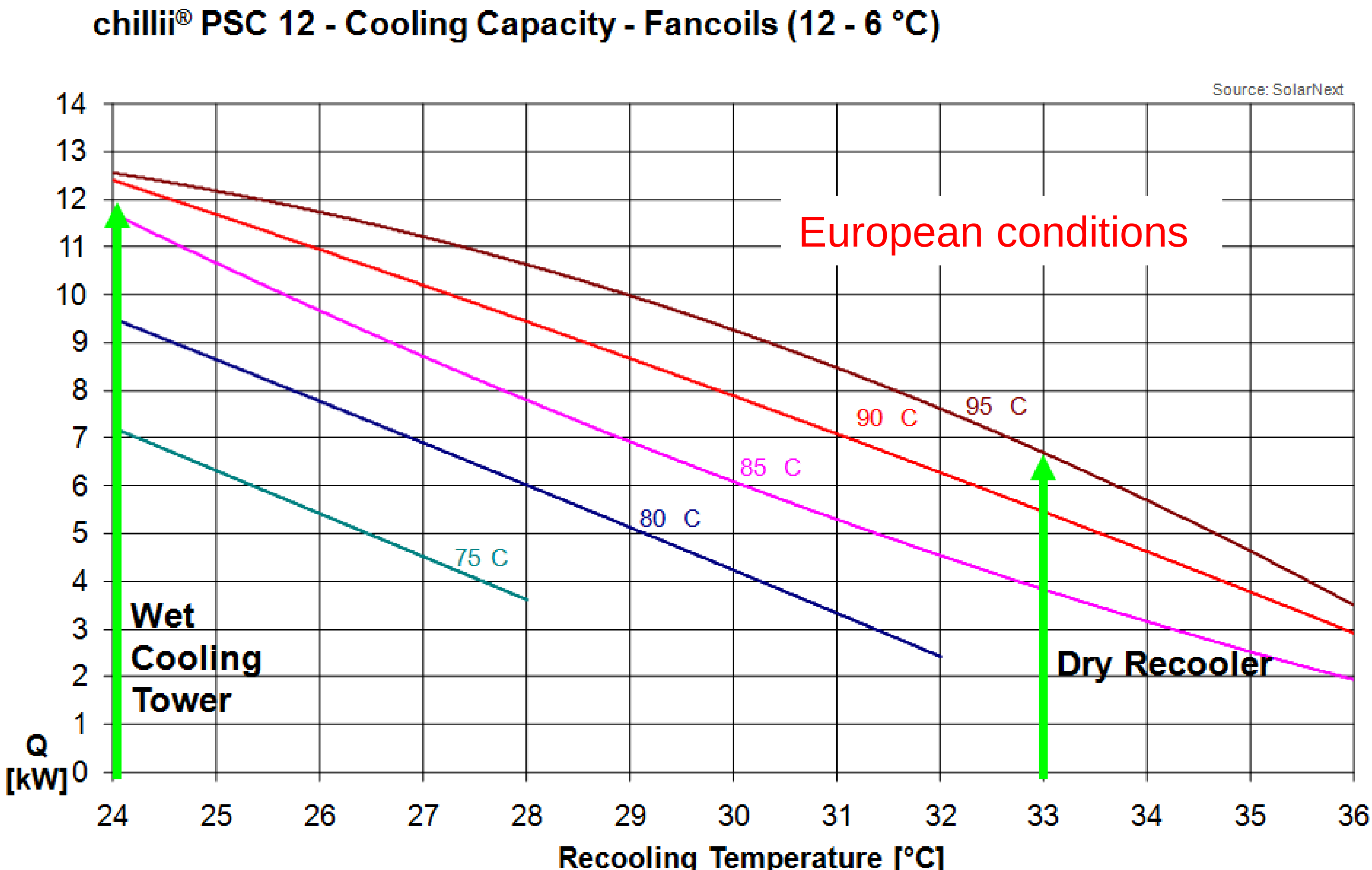
- Efficient but will still require maintenance
- Some variants
  - Can operate without water for some parts of the year
  - Evaporative curtain



Ground Source Heat Exchange

- Horizontal or vertical (reduced footprint and seasonal temperature variation)
- Efficient
- No water consumption
- Low parasitic power consumption
- Expensive

The heat rejection method matters



Performance Chart chillii® PSC12 (Fan coils)

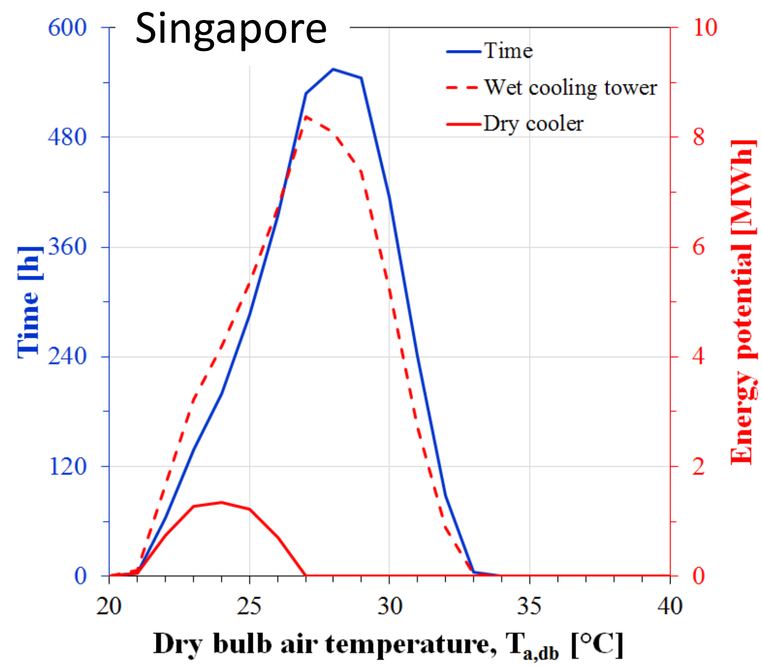
SOLARNEXT clean energy for you

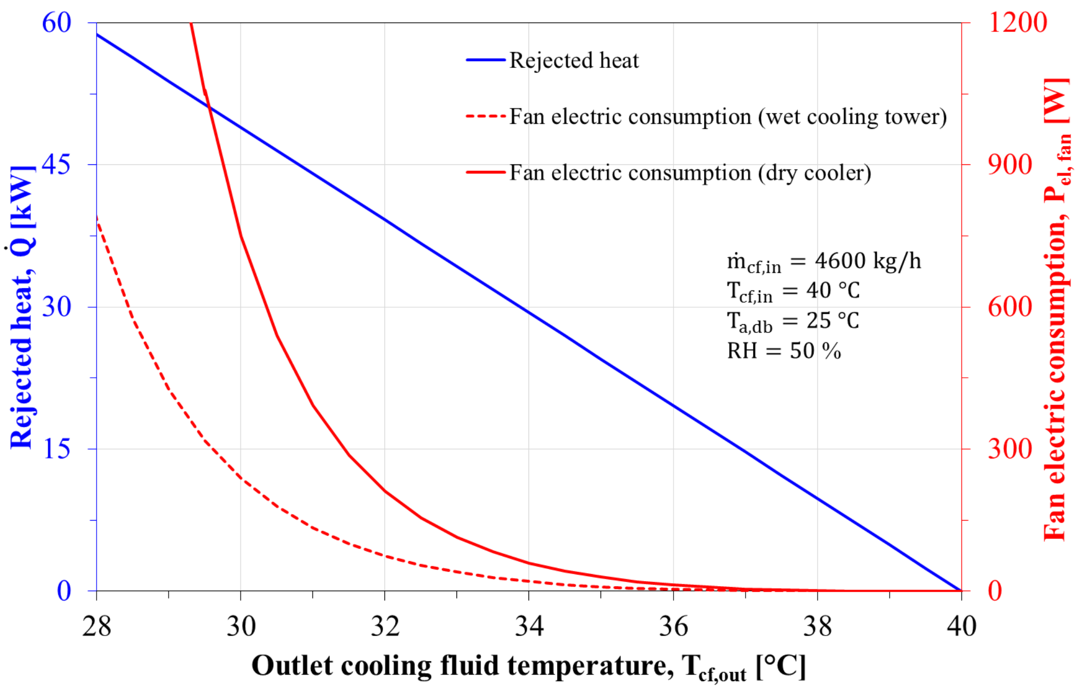
Task 48

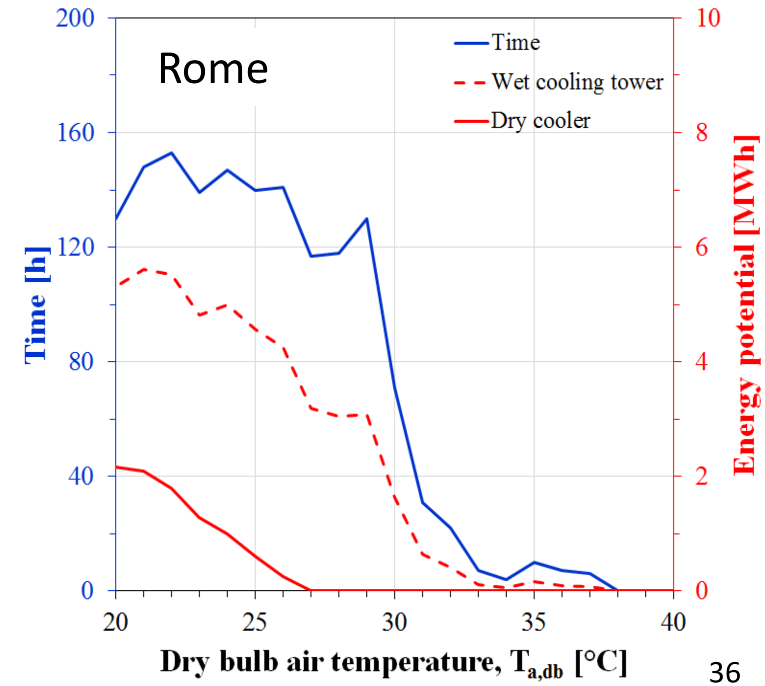
Quality Assurance & Support Measures for Solar Cooling Systems

Comparing wet and dry heat rejection in warm climates

- Fan power increases exponentially as exit temperature approaches ambient
- Wet cooling maintains performance closer to nameplate rating over a wider range of ambient conditions



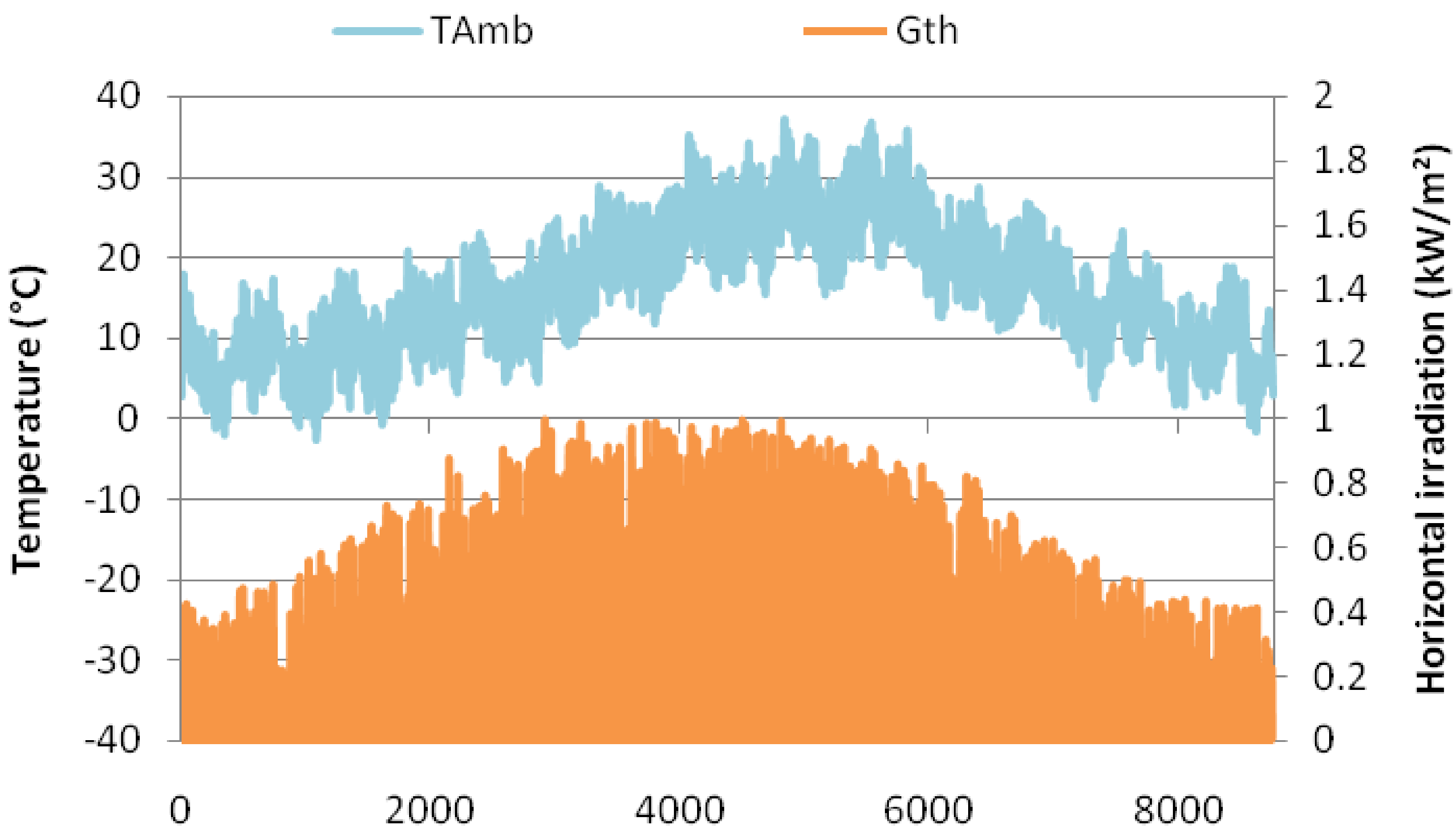




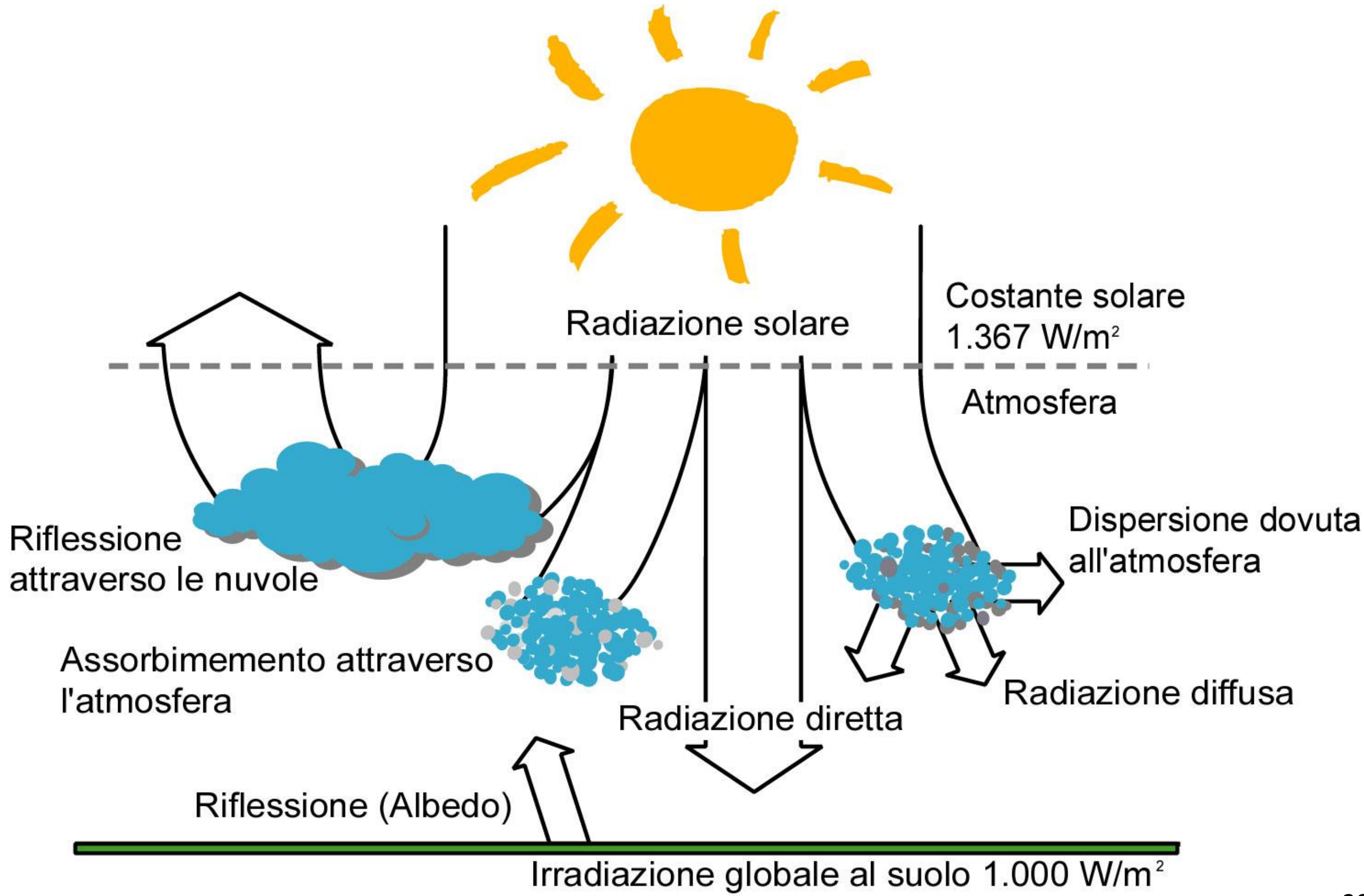
3. The heat production system

a. The heat production (solar) system (collectors and storage), including state of the art on concentrating and new collectors

Seasonal weather variations

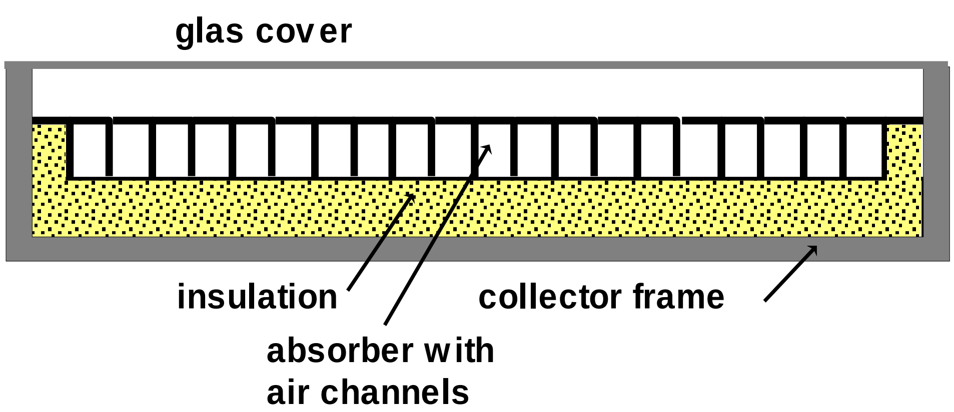


Solar radiation



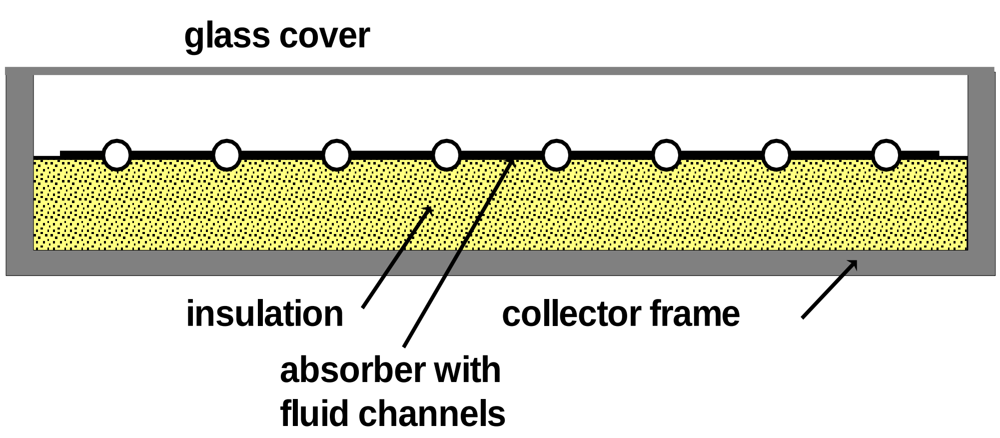
Air collectors

- Direct heating of the air
- Normally used to pre-heat the supply air. Requires ventilation system e.g. industrial buildings
- Possible combination with open-cycle systems e.g. DEC for desiccant material regeneration



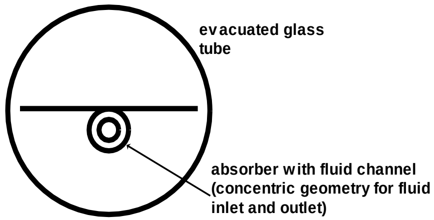
Flat plate collectors

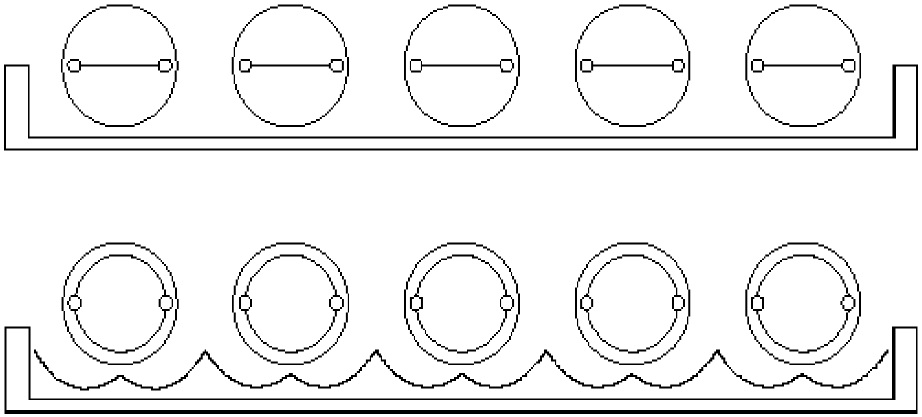
- Heating of the heat transfer fluid (water and anti-freeze component, e.g. Glycol)
- Major use, domestic hot water production
- Dominates the production of collectors in Europe
- Selective surface treatment necessary to achieve temperatures suitable for use for Solar Cooling systems



Evacuated tube collectors

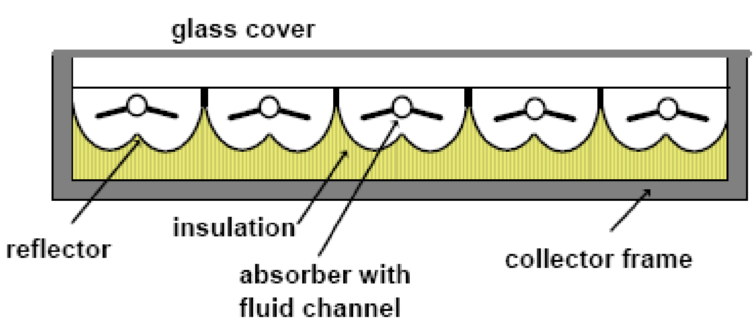
- Evacuated tubes for the reduction of thermal energy losses (convection, conduction)
- Different construction types available:
  - heat-pipe or direct flow (U tube) or water filled
  - single glass tubes or double wall (Dewar)
  - with / without concentrator
- Dominates the production of collectors in China which is the largest exporter

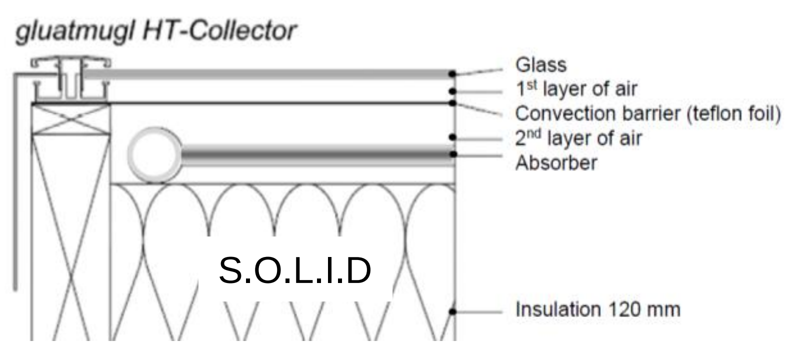




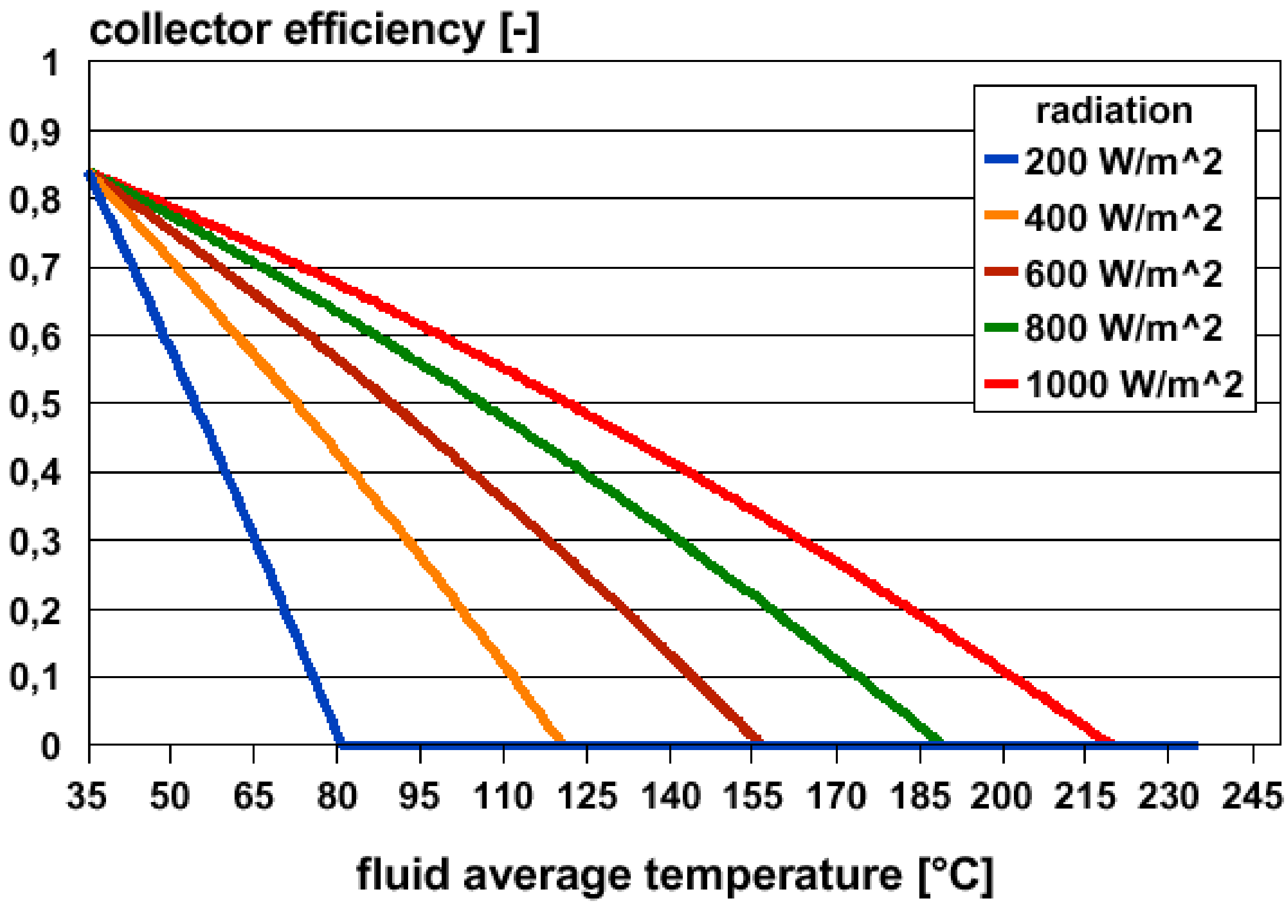
Other variants for high efficiency/high temperature (without tracking the sun)

- Double glazed or convection retarding flat plate collectors with selective coating
- Compound parabolic collectors (stationary concentrating collectors (~2 suns))





Instantaneous solar collector efficiency



$$\text{Collector efficiency} = \eta_o + a_1 \frac{(T_{fluid} - T_{ambient})}{G} + a_2 \frac{(T_{fluid} - T_{ambient})^2}{G}$$

Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

SOLAR HEATING & COOLING PROGRAMME
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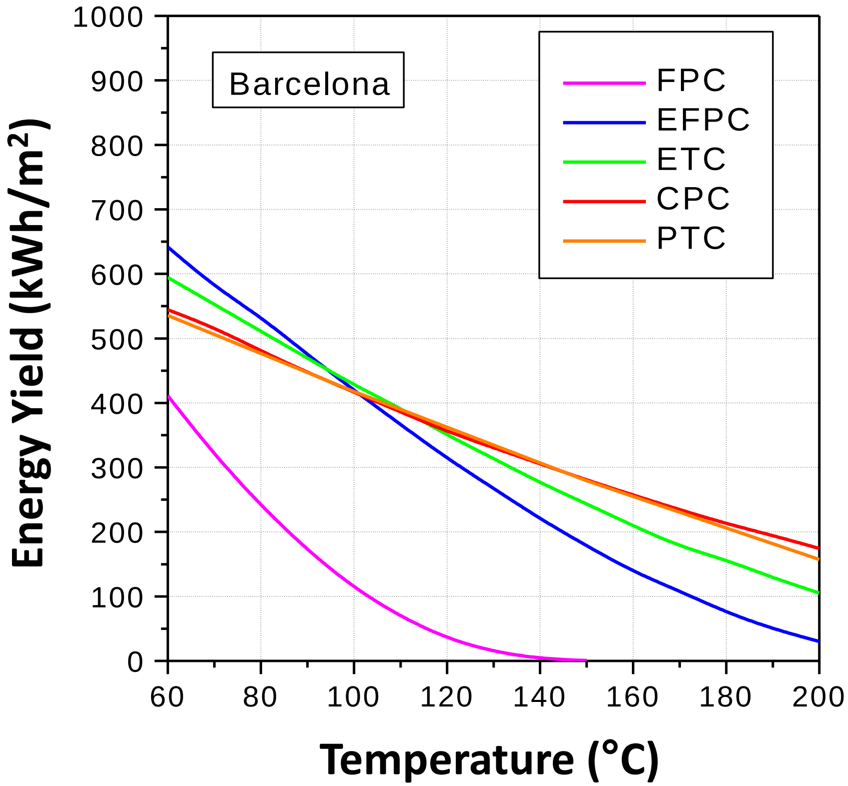
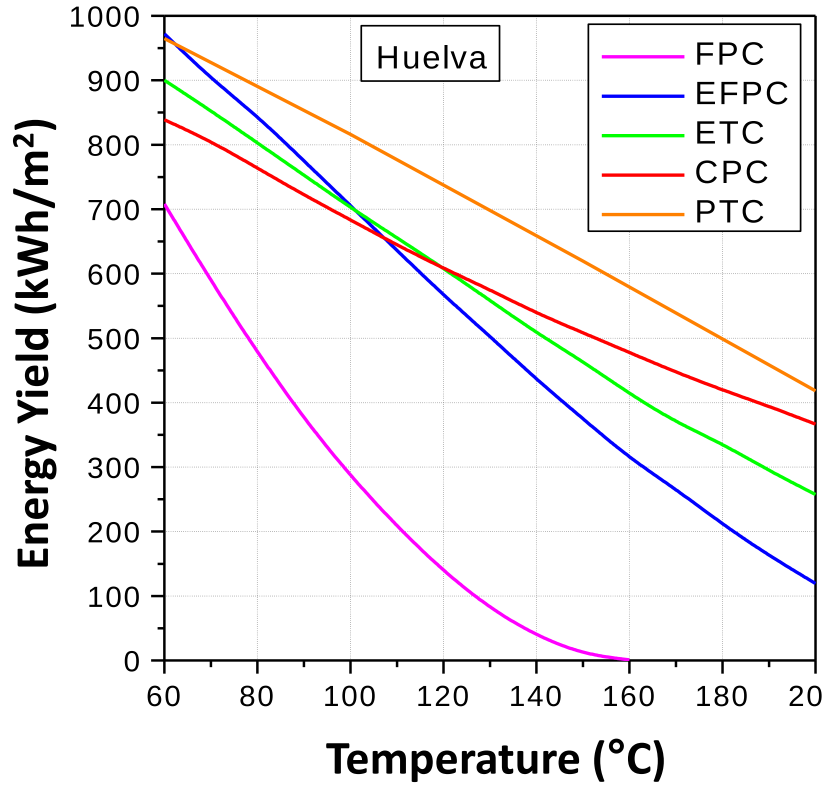
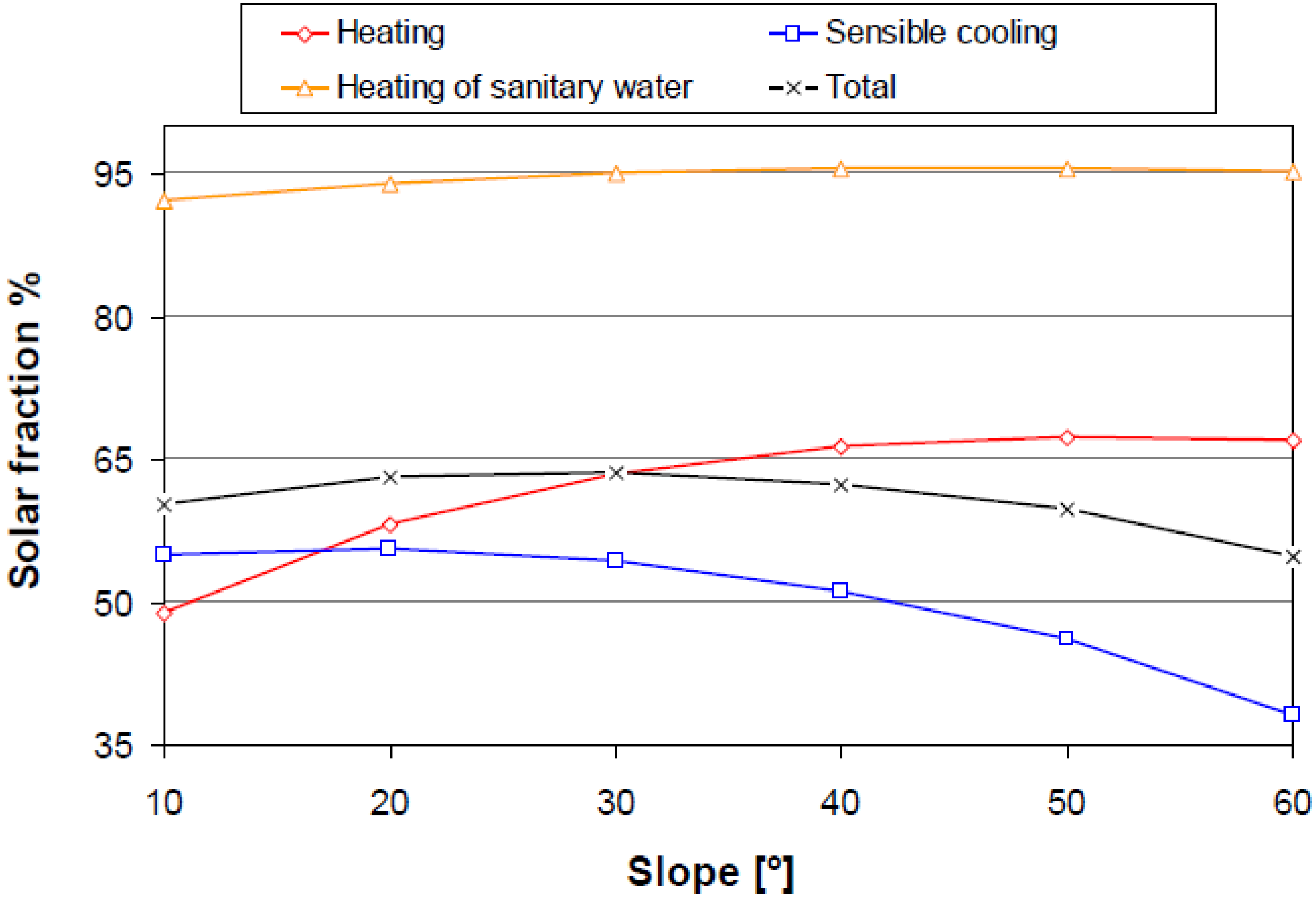
Annual solar production





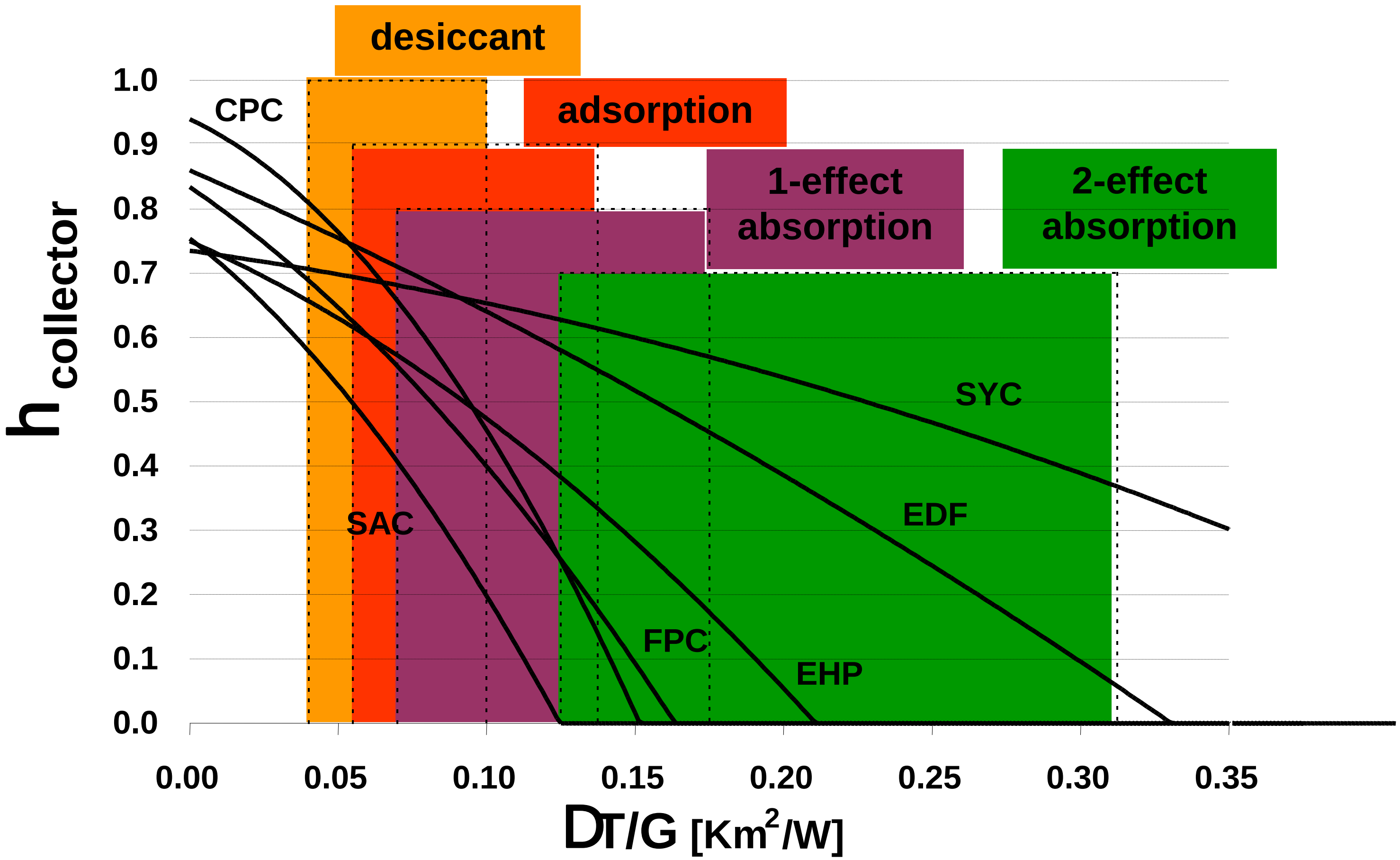
FPC: flate plate collector
EFPC: flate plate collector with concentrating parabolic compound (CPC)
ETC: vaccum tube collectors
CPC: vaccum tube collectors with concentrating parabolic compound (CPC)
PTC: parabolic trough collector

Influence of collector tilt angle



Source: Cejudo, Solar Energy, Volume 86, Issue 1, Pages 1-680 (January 2012)

Solar collector efficiency and TDC fit



SAC = air collector
CPC = stationary CPC
FPC = flat plate, selective surface

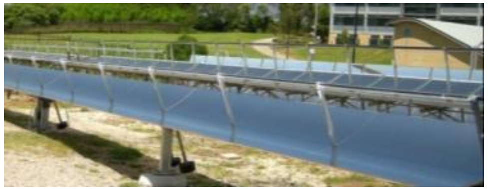
EHP = evacuated heat-pipe
EDF = evacuated direct flow
SYC = stationary concentrator, Sydney-type

Concentrating Collectors (direct radiation only)

1. IST/Abengoa – Spain

2. Solitem - Turkey

3. NEP Solar - Australia



4. Sopogy – USA

5. Solarlite – Germany

6. Industrial Solar – Germany

7. Chromasun - Australia

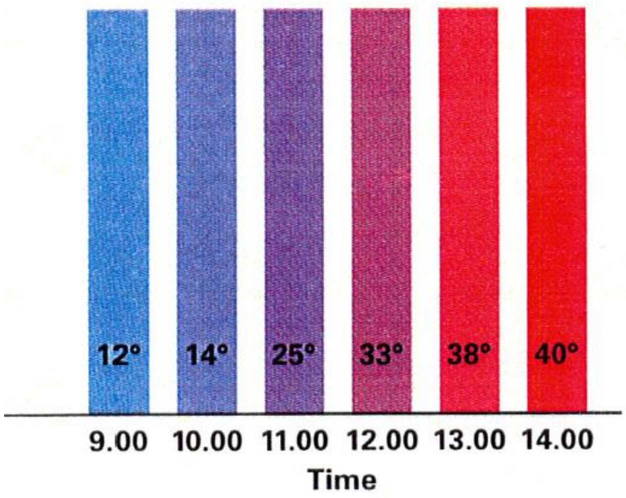
8. Thermax - India

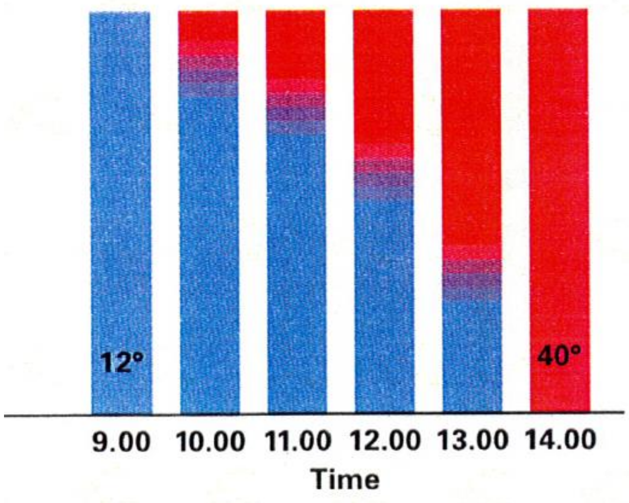
Thermal storage tank mixing

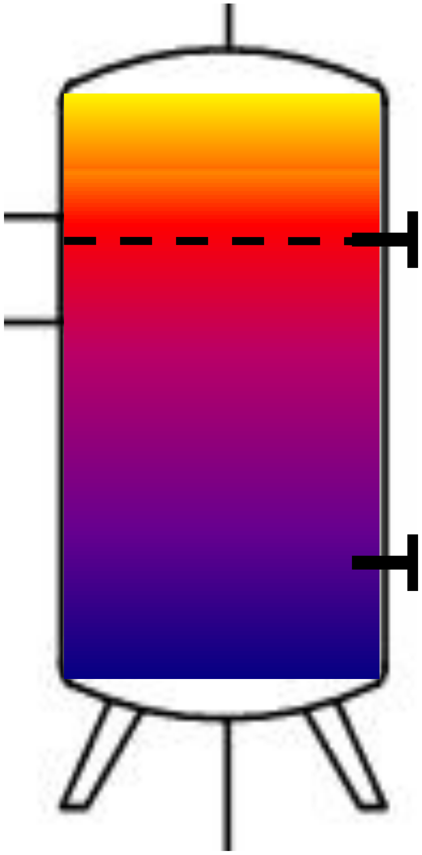
- Fully mixed

vs

- Stratification

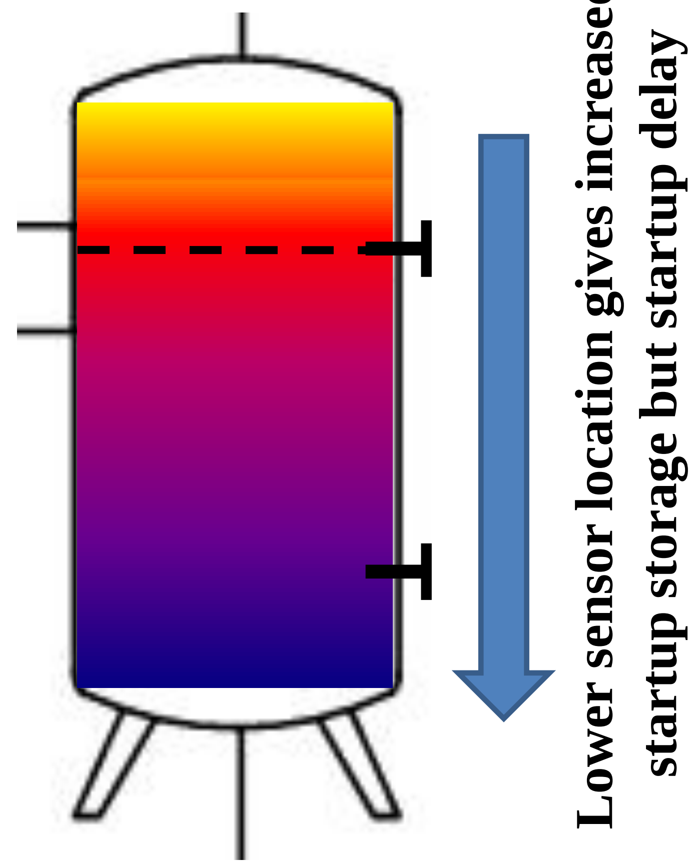






Storage tank functions

- Thermal stratification is your friend
  - It directs the coldest fluid to the collectors (increased efficiency)
  - It directs the hottest fluid to the application (increased efficiency and capacity)
  - It provides buffer capacity without loss of temperature
  - It reduces chiller cycling



Thermal storage tanks

Empty tank

- low cost
- may have mixing

"Combi" tank with coil

- potable water & heating
- temperature reduction

Stratified tank

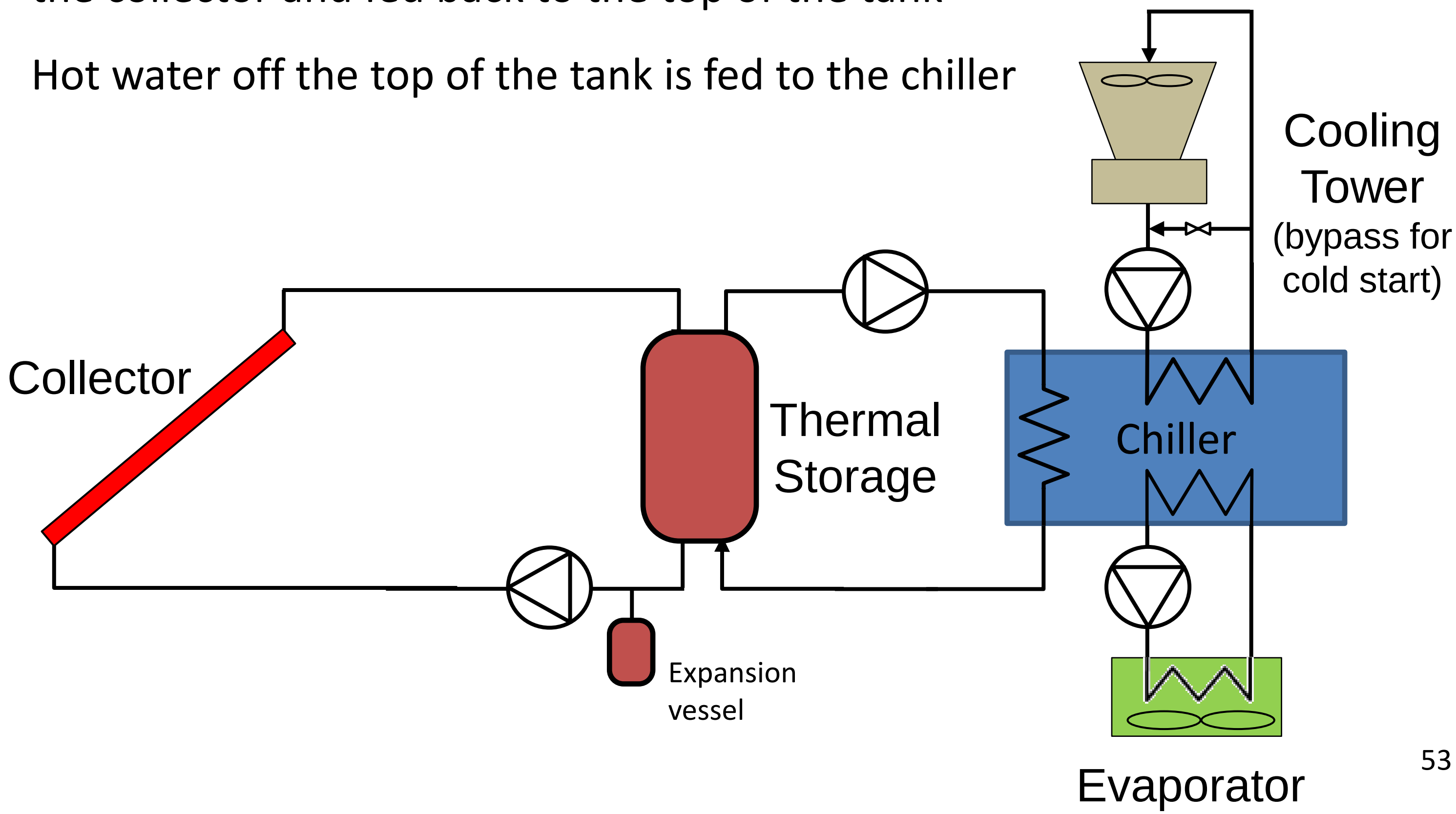
- low mixing loss

4. System configurations and control

a. System configurations (solar assisted and solar autonomous systems) and control (including advanced control with self-detection of faults and malfunctioning). Solar district cooling.

The basic flow-sheet: Putting it all together

- Separate flow circuits for the chiller and collectors enables independent charging and discharging
  - Cold water off the bottom of the thermal storage tank is heated by the collector and fed back to the top of the tank
  - Hot water off the top of the tank is fed to the chiller

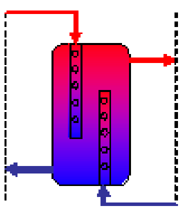
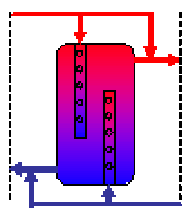
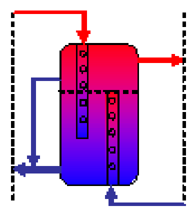
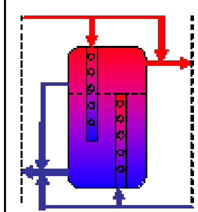
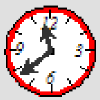
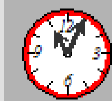
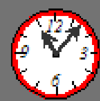
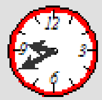
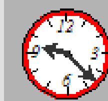
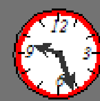
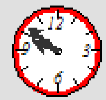
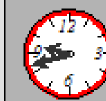
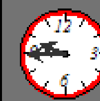
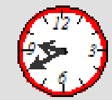
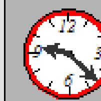
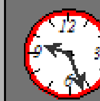


Tank bypass options

21st June 2008 Hot summer Day with single clouds 

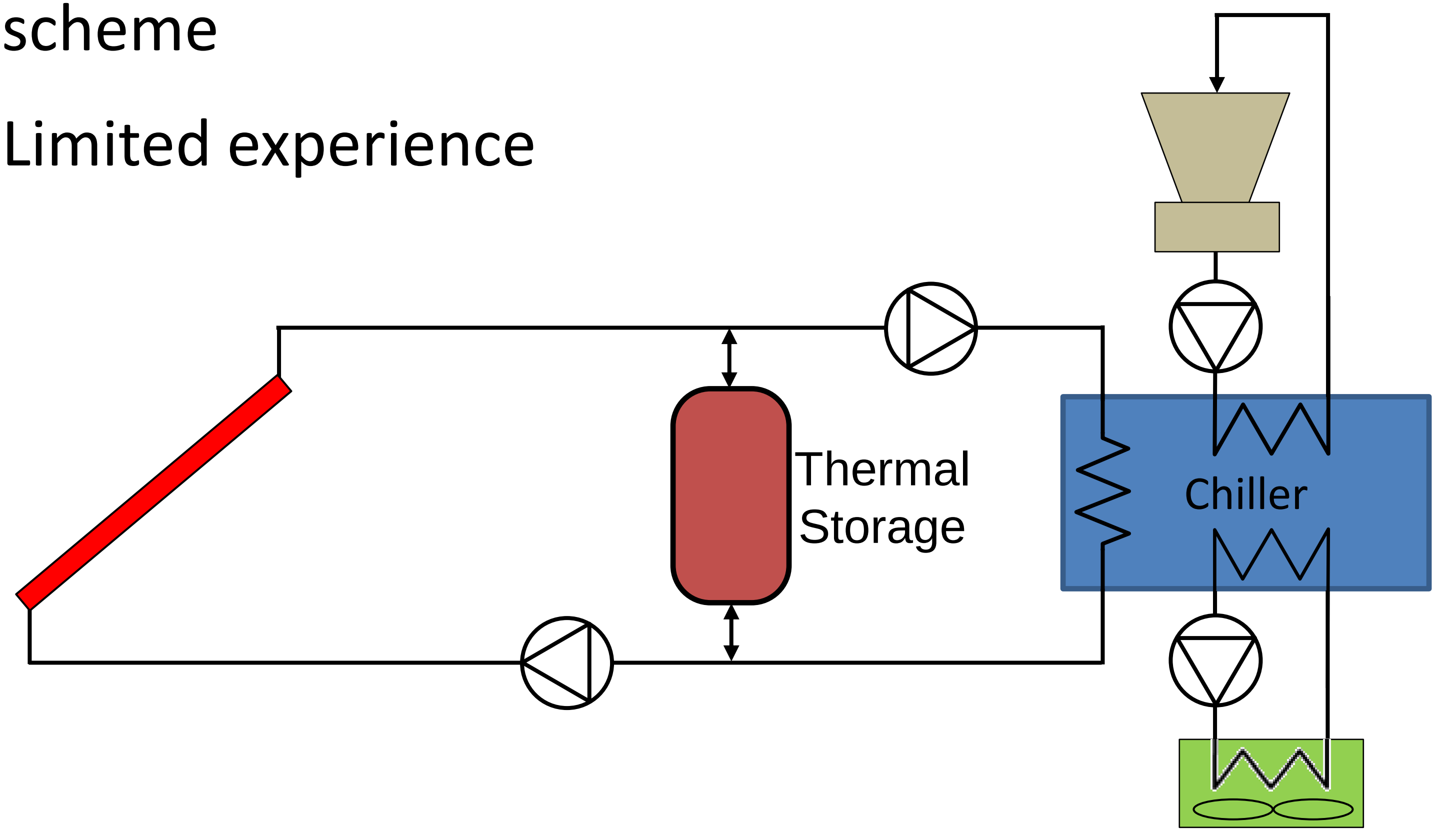
10th July 2008 Hot summer day with almost clear sky 

11th July 2008 Hot summer day, some clouds in the early morning and thunderstorm in the afternoon  

Storage charge and discharge control options	Case1  Full storage always used			Case 2  Full storage with bypass			Case 3  Partitioned storage with 300 l top volume			Case 4  Partitioned storage with 300 l top volume and bypass		
Analysed day	21st June	10th July	11th July	21st June	10th July	11th July	21st June	10th July	11th July	21st June	10th July	11th July
Start up time of ACM												
Coverage of cooling load	72%	73%	61%	89%	86%	83%	88%	84%	80%	90%	86%	84%
COP_{th} [-]	0.66	0.68	0.64	0.66	0.68	0.65	0.66	0.68	0.65	0.66	0.69	0.65
COP_{el} [-]	7.07	8.51	7.50	7.26	8.49	7.69	7.07	8.47	7.42	7.06	8.39	7.18

Another buffer tank flow arrangement

- Better stratification
- Requires variable speed drives and associated control scheme
- Limited experience



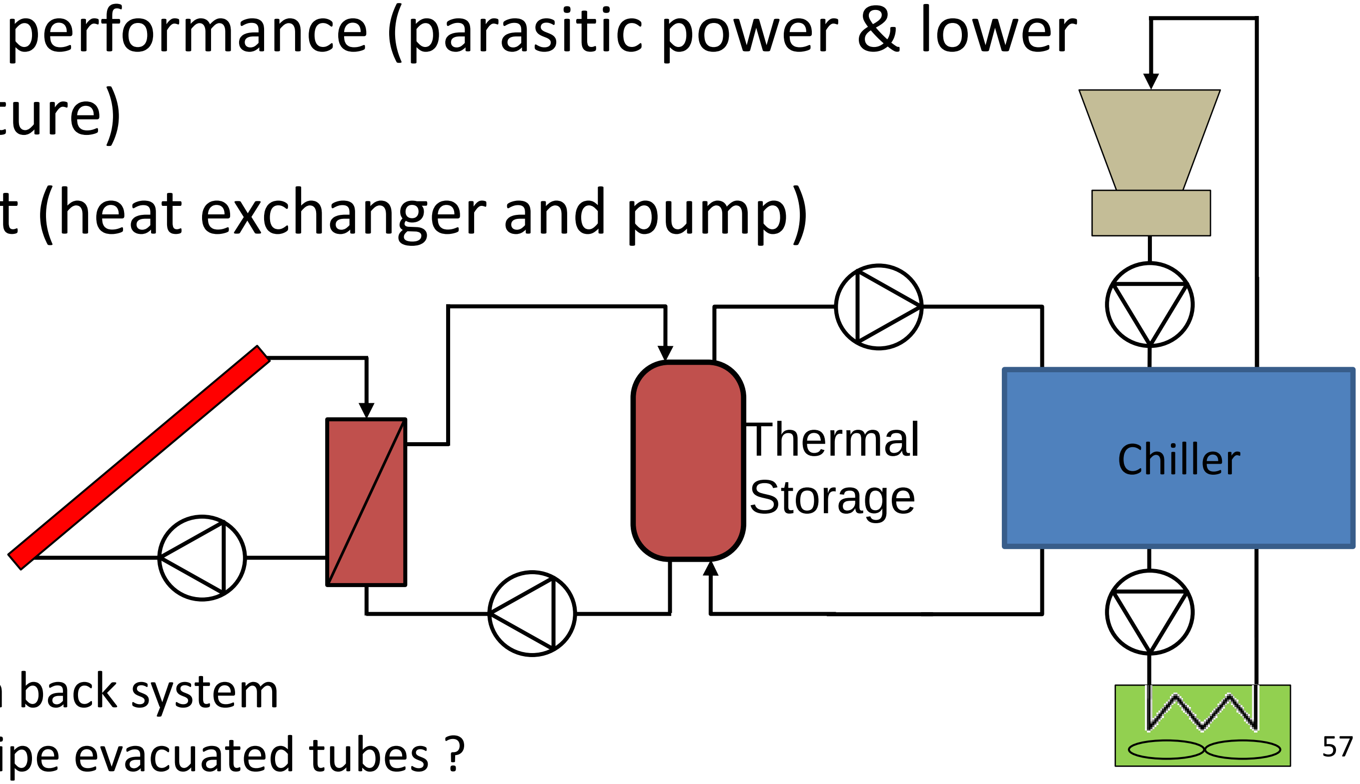
Chilled water buffer?

- Suggest as per normal air conditioning requirement
  - Hot water buffer is required for management/ control of intermittent solar heat supply (cant be eliminated) – hence chilled water buffer is duplication of storage need and increases cost
  - Hot water has higher specific energy storage (hot water storage ΔT is higher than cold water ΔT)

Although (i) chilled water suffers from lower heat losses and (ii) high hot water ΔT leads to less efficient solar collectors and (iii) hot water converts to cold at COP<1 (for single effect chillers)

Frost protection

- Secondary heat transfer fluid
- Heat exchanger (or in tank coil) on the collector or chiller side of the tank
- Reduced performance (parasitic power & lower temperature)
- Extra cost (heat exchanger and pump)



or

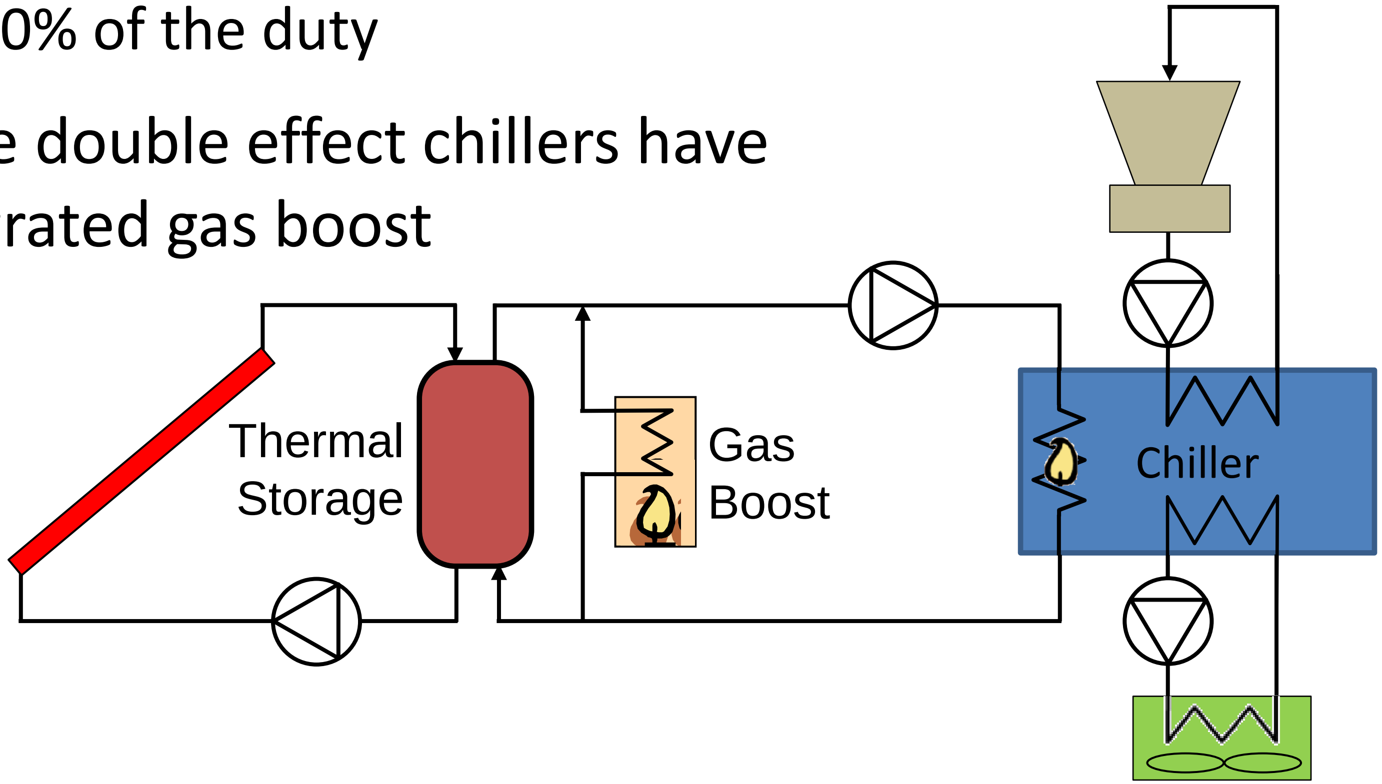
- a drain back system
- heat pipe evacuated tubes ?

Heat transfer fluid above 100°C

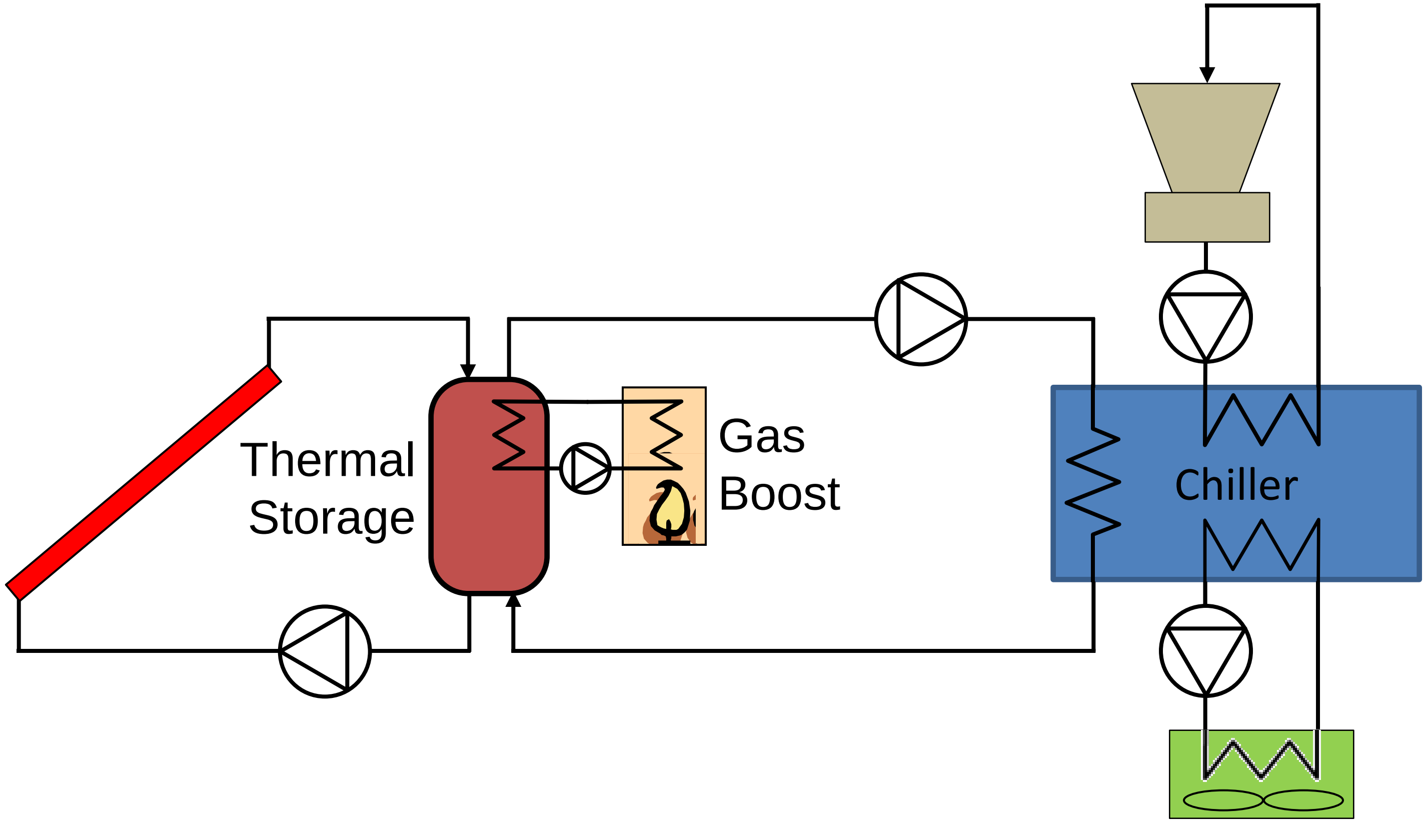
- Pressurised hot water
  - Pressure vessels for the thermal buffer
- Thermal oil
  - Atmospheric pressure but
    - Bunding ?
    - Cost of thermal buffer fluid
    - Contamination – oxygen, water
    - Viscosity differences between 20°C and 180°C
    - Chiller performance degradation
    - Absorption chiller manufacturers requirements
- Stagnation temperatures can be very high
    - Defocus concentrating collectors
    - Pressure relief
    - Drain-back

Gas boost

- Gas boost in parallel preferred
  - Boost while the solar store is charging (not both together) to prevent gas charging the thermal store and taking 100% of the duty
- Some double effect chillers have integrated gas boost

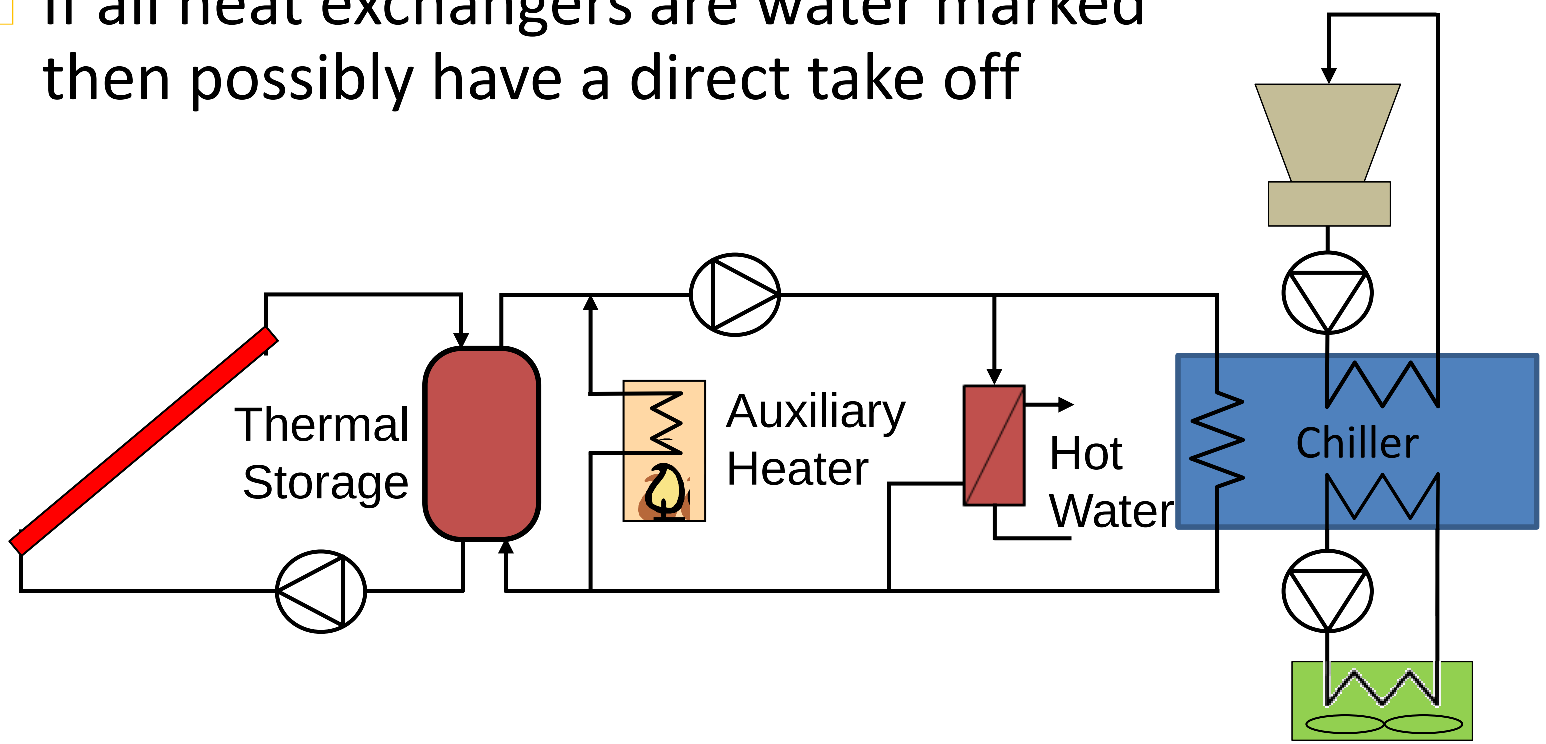


Or this



Potable hot water production

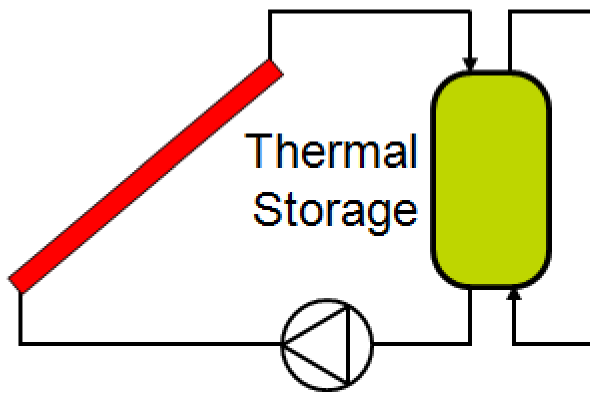
- High temperature for solar cooling can cause scale issues.
  - If scale is not an issue then in-tank coil is ok
- If all heat exchangers are water marked then possibly have a direct take off



Control of collector fluid circulation loop

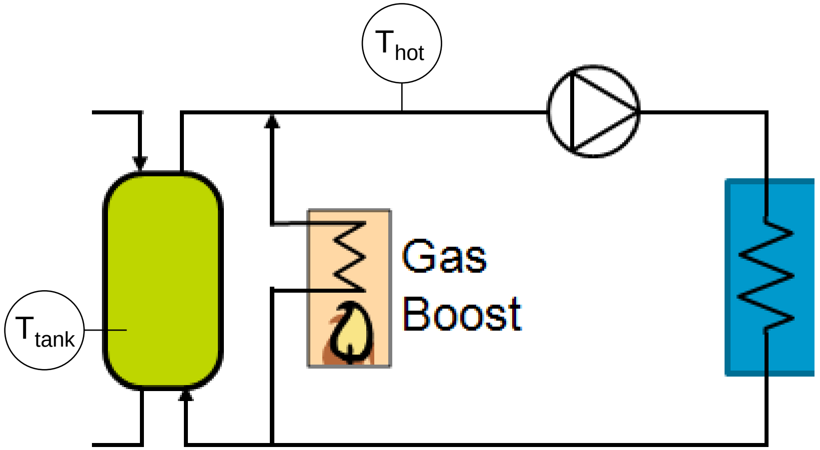
- Method 1 (generally for smaller systems with fixed speed pumps)
  - Start pump when $T_{coll,out} - T_{coll,in} > x\ °C$
  - Stop pump when $T_{coll,out} - T_{coll,in} < y\ °C$ (hysteresis reduces pump starts)
- Method 2 (generally for larger systems with variable speed pumps)
  - Start pump when PV cell output > x W
  - Vary pump speed to maintain
    - $T_{coll,out} - T_{coll,in}$ = constant °C – captures the most solar heat

    or
    - $T_{coll,out}$ = constant °C – higher driving temperature = capacity from chiller



Control of chiller heat supply loop

- When chiller requests cooling....
  - For gas boost application
    - Pumps (heat supply, cooling water, chilled water) turn on
    - Switch to solar thermal store when $T_{tank} > x$ °C, switch off gas
    - Switch to gas boost when $T_{hot} < y$ °C, switch off solar
  - For compression chiller application
    - Pumps turn on when solar thermal store $T_{tank} > x$ °C
    - Pumps turn off when $T_{hot} < y$ °C

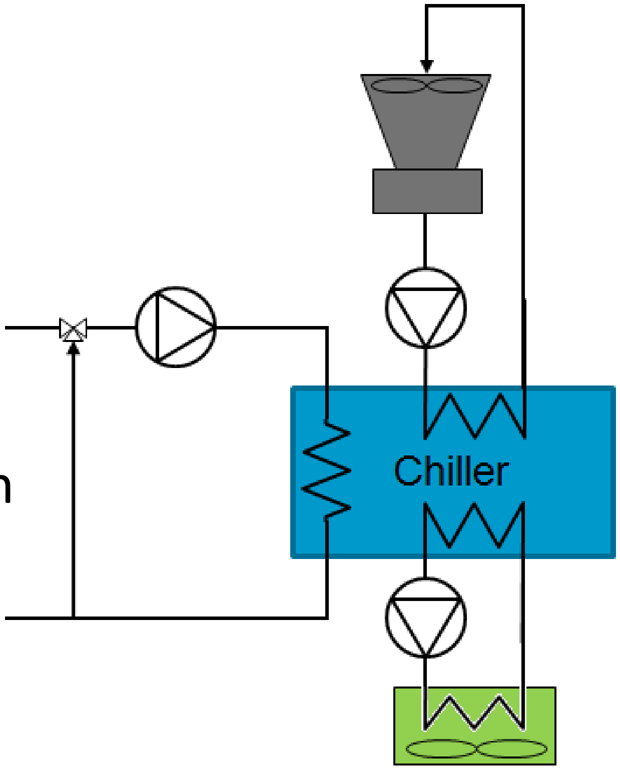


Control of chiller part load

- Reduce heat source temperature to reduce chiller capacity
  - Mix hot water supply and return

Or

- Increase cooling water temperature
  - Reduce cooling tower fan speed (within manufacturers limits, allowing for slow response)
  - Most energy efficient

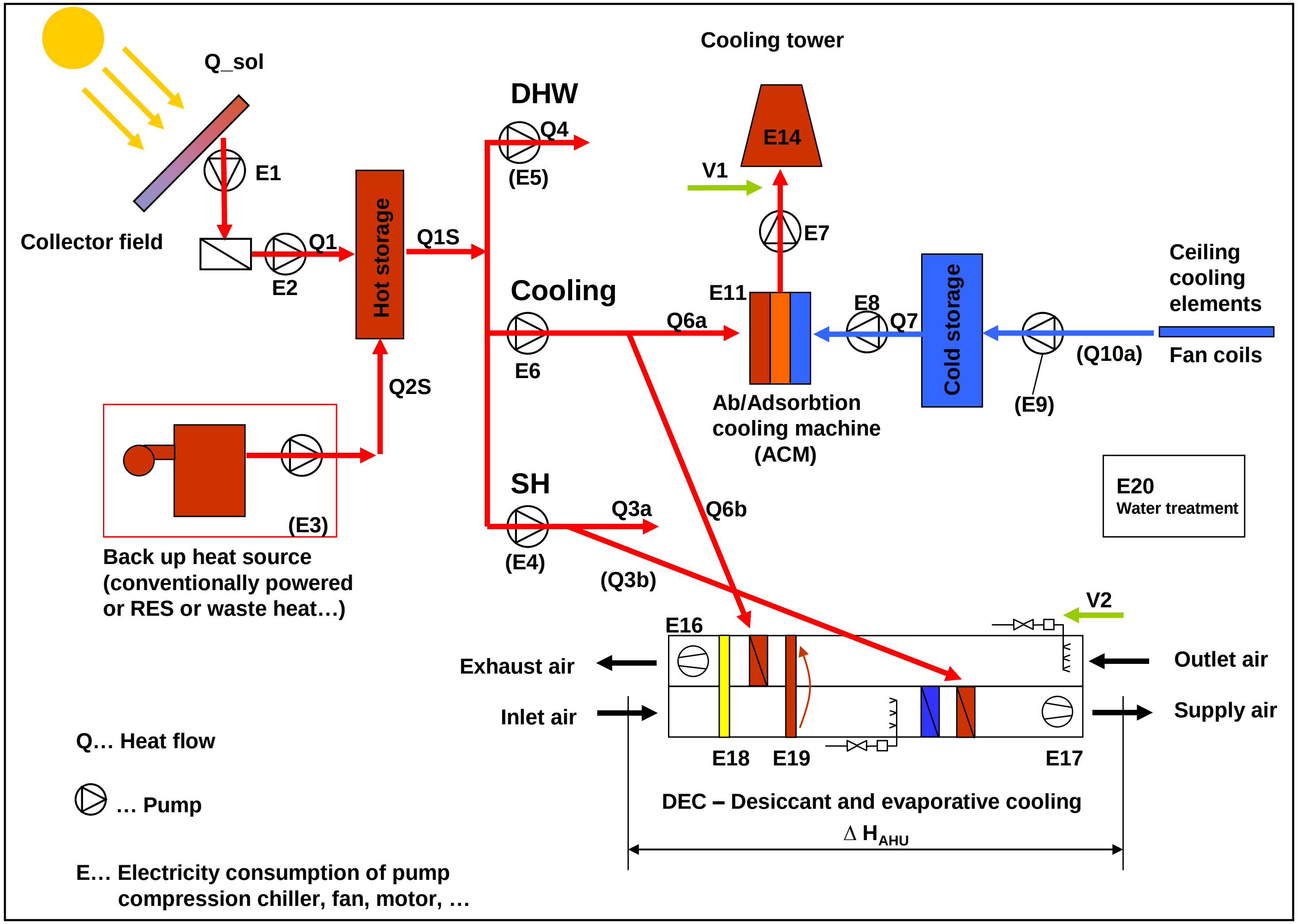


Note: In autonomous operation, when heat source temperature is insufficient to deliver full load, chilled water temperature can increase to maintain chiller capacity

5. Design approaches

a. Preliminary design aspects, backup sources and efficiency benchmarks

Task 38 monitoring concept



Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

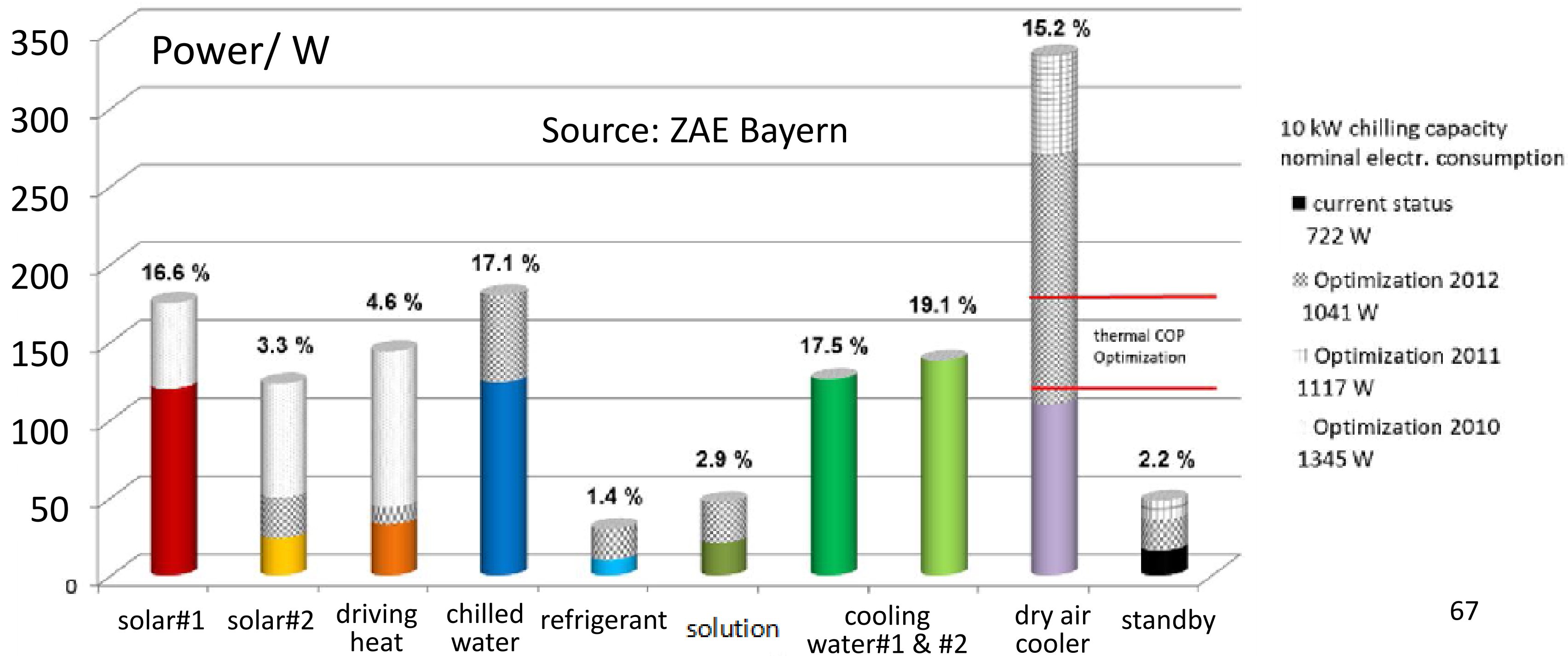
SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Electrical efficiency

$$COP_{el} = \frac{\text{Cold Produced}}{\text{Electricity Supplied}}$$

Energy and emissions savings vs vapour compression chillers

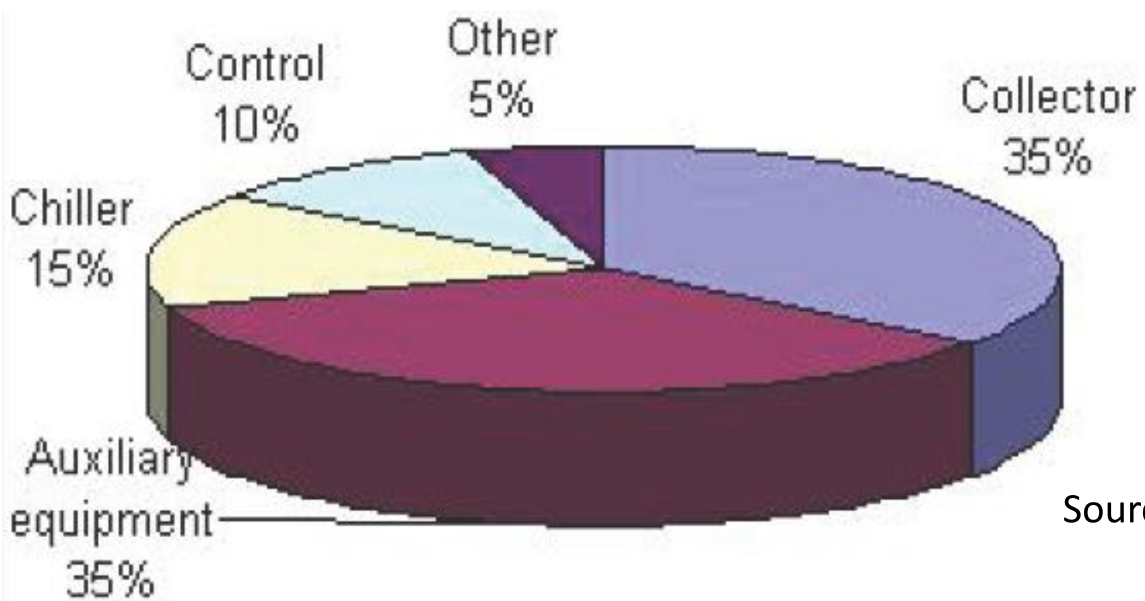
- Electrical consumption from parasitic loads
  - Chiller pumps & controls
  - Pumps (solar, process, cooling tower)
  - Fans (cooling tower)



Thermal efficiency

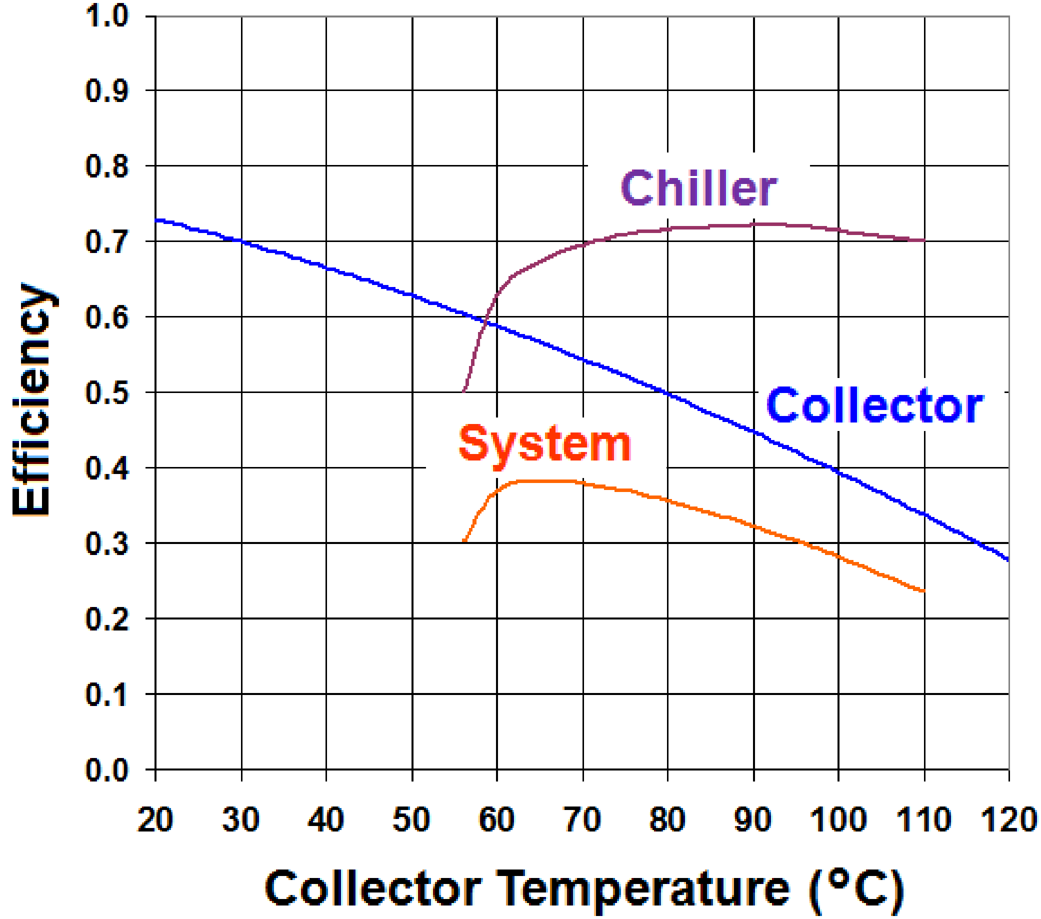
$$COP_{th} = \frac{\text{Cold Produced}}{\text{Heat Supplied}}$$

- Increasing efficiency
  - Reduced greenhouse gas emissions (when running on gas as a thermal backup)
  - Reduced collector area and capital cost



Source: AIT

System thermal efficiency



$$\text{Collector area} = \frac{\text{Design Load (kW)}}{\text{Design Radiation (kW/m}^2\text{) * System Efficiency (-)}}$$

Annual system performance metrics

(Combining solar, electrical and backup energy sources)

- Primary Energy Ratio (PER) (solar + backups)

$$= \frac{\text{All useful (heating, hot water, cooling) delivered energy}}{\text{All supplied fossil (primary) energy}}$$

$$PER_i = \frac{\sum Q_{i,out}}{\sum\left(\frac{Q_{el,i,in}}{\varepsilon_{el}} + \frac{Q_{i,in}}{\varepsilon_{in}}\right)}$$

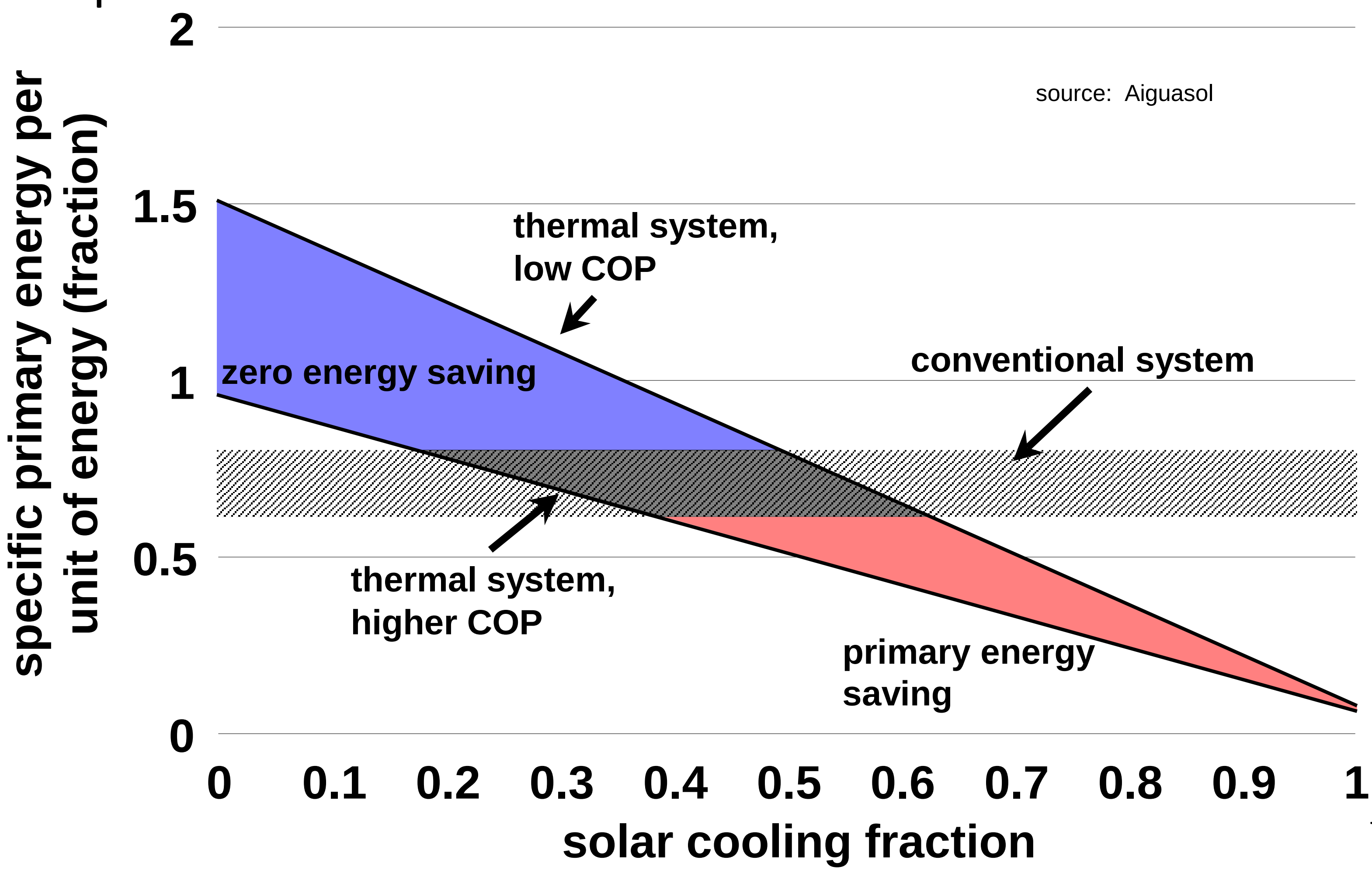
- Incremental change in SPF ($\Delta SPF_{\text{electrical equiv}}$) due to solar

$$= \frac{\text{Useful (heating, hot water, cooling) energy } \textit{from} \text{ solar}}{\text{Parasitic electricity + electrical equivalent PE to chiller}}$$

PE conversion factor: electricity – 0,41; fossil fuels – 0,9

Comparing primary energy consumption

Single effect solar absorption chiller with gas backup vs compression chiller



Greenhouse gas emissions from backup

	Backup Fuel GHG Intensity	COP/EER	GHG (kg/kWh_{cold})
No backup (autonomous/ thermal storage only)	na	na	0.09 (1 stg chiller) 0.07 (2 stg chiller)
Gas backup (absorption chiller)	~0.24 kg/kWh	0.7 (single effect absorption chiller)	0.43
		1.2 (double effect absorption chiller)	0.27
Coal fired electricity (compression chiller)	~1.07 kg/kWh	3 (air cooled)	0.36
		6 (water cooled)	0.22

- Includes parasitic electricity to run cooling tower fans at 0.03 kWh/kWh of heat rejected and 0.01 W/W of cold for the absorption chiller
- Cogeneration / trigeneration could also be used as backup for large GHG savings

Design summary for efficiency

- Gas backup
  - High values of "Solar Fraction" (SF) are needed for low COP_{th} systems with fossil fuel backup
  - Low values of SF are acceptable if you use air conditioning systems with high COP_{th}
- Conventional compression chiller backup
  - will always reduce the PE
- No backup (solar autonomous)
  - will always reduce the PE but there is no guarantee of maintaining comfort conditions.
- Trigeneration backup should also save PE
- In any case solar heating and domestic hot water saves PE

5. Design approaches

b. Dimensioning a solar cooling system (chiller size, collector area, storage volume)

Design approaches

1. Design point sizing with rules of thumb
   - Gives: Rough sizing of key components and capital cost
   - Does not give: Annual energy savings, payback, control analysis, backup chiller sizing

2. Simplified sizing tool with annual energy savings
   - Gives: Preliminary sizing of key components, sizing sensitivity, capital cost, annual energy savings and payback *for pre-specified solar cooling solutions*
   - Does not give: Hydraulics, parasitic electricity and control analysis. Flexible system design (eg process steam draw)

3. Full system model
   - Gives: Complete component sizing and sensitivity (including hydraulics), capital cost, annual energy savings, payback, and control analysis for conceived system
   - Does not give: Guarantees

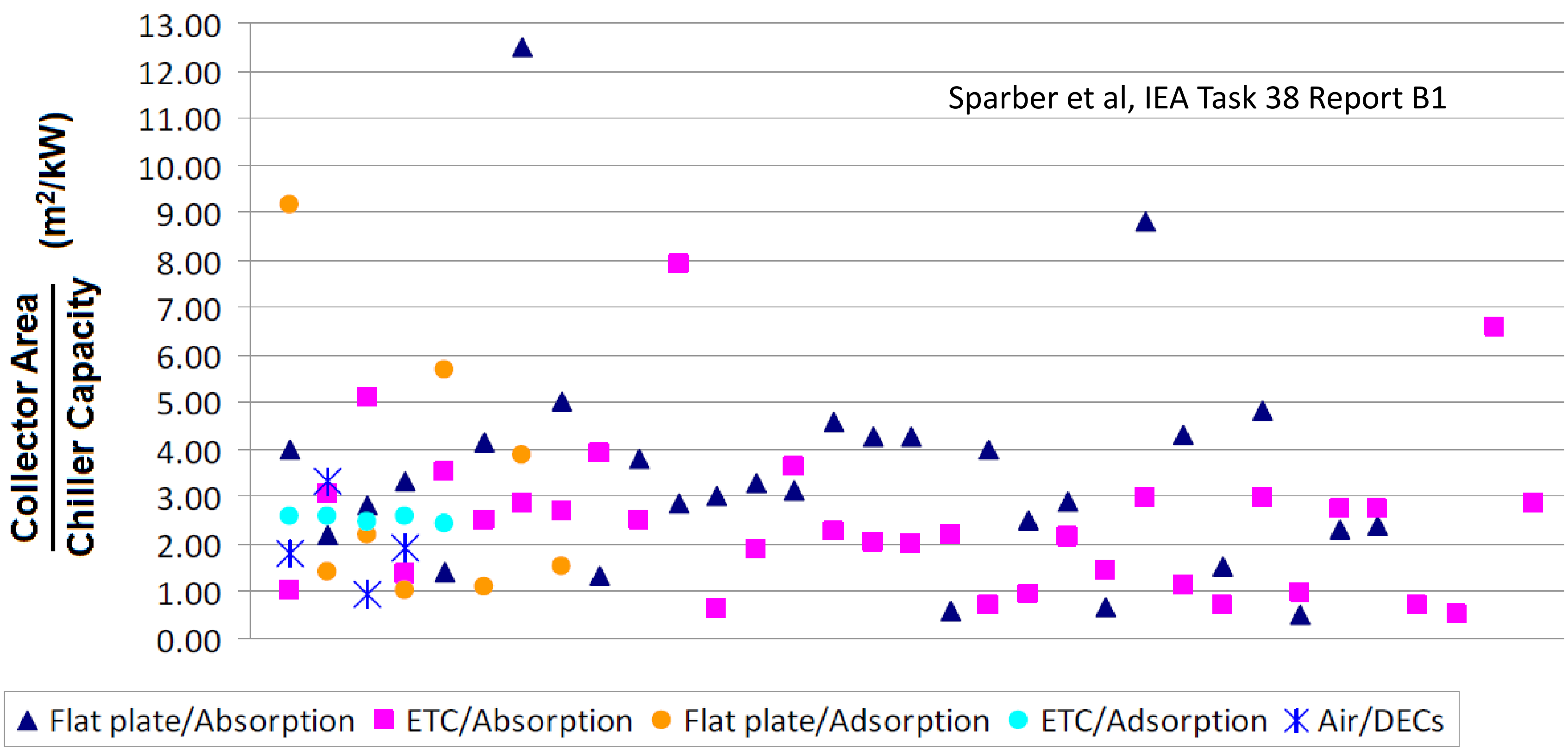
1. Design point sizing

$$\text{Collector area} = \frac{\text{design load (kW)}}{\text{radiation (kW/m}^2\text{)} * \text{COP}_{th} * \text{collector efficiency}}$$

Calculate peak building heat load → For selected T_{CHW} , T_{CW} , T_{Gen} determine COP_{th} & capacity → For selected T_{Gen} determine h_{coll} → For climate zone design radiation calculate area

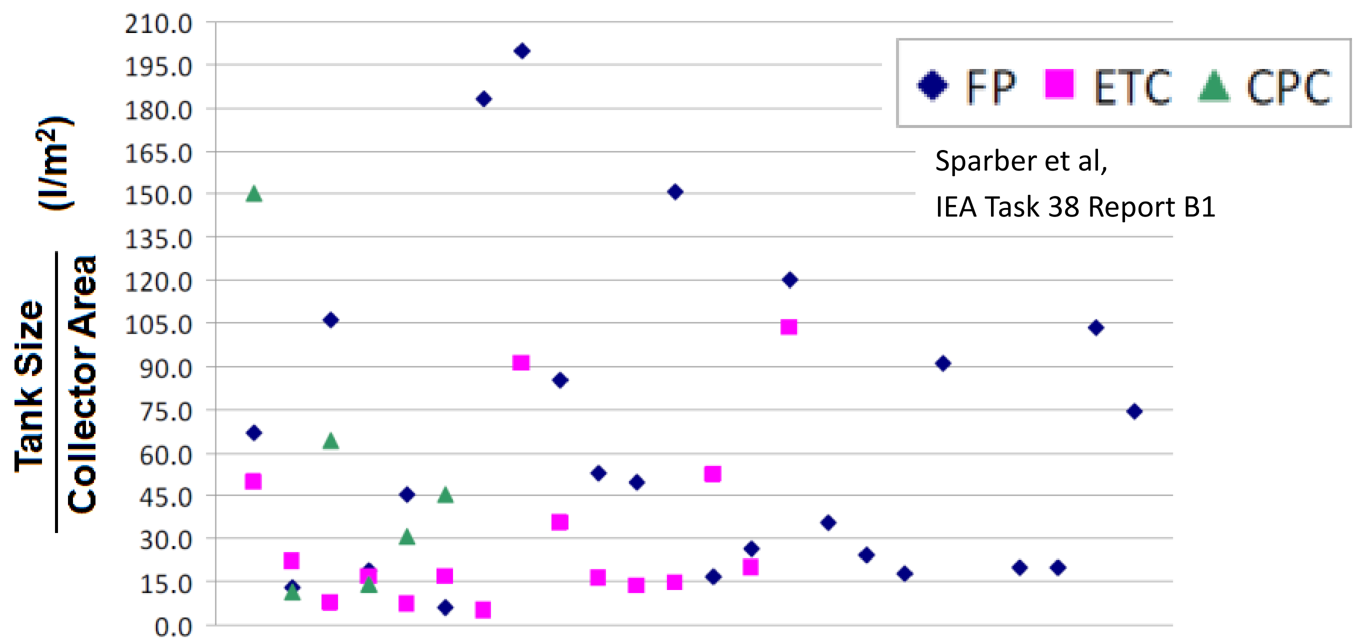
- ~3 m²/kW for single effect absorption chiller
- ~2 m²/kW for double effect absorption chiller
- ~8 m²/(1000 m³/h) for desiccant cooling
- Tends to underestimate collector area for achieving high solar fraction
- May need more area for hot water or other service

Some actual installations



Thermal storage sizing

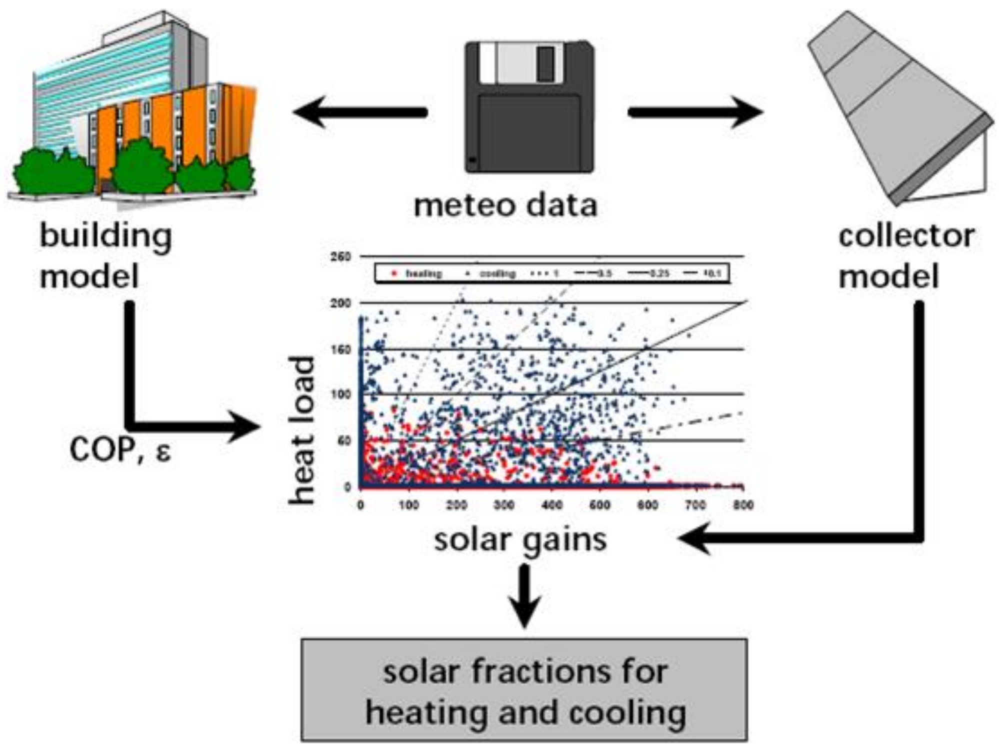
- Storage for shifting morning sun into evening demand
  - Only if you have high collector area (relative to chiller size)
- Storage for start-up and stable operation through cloudy periods (particularly in autonomous solar designs)
  - Absorption chillers are a slow start-up (~30mins) base-load machines



Why modelling ?

- Variable source of energy to drive the cooling process
- Variable demand for cooling required from the building

These need to be balanced hour by hour throughout the year



Task 48

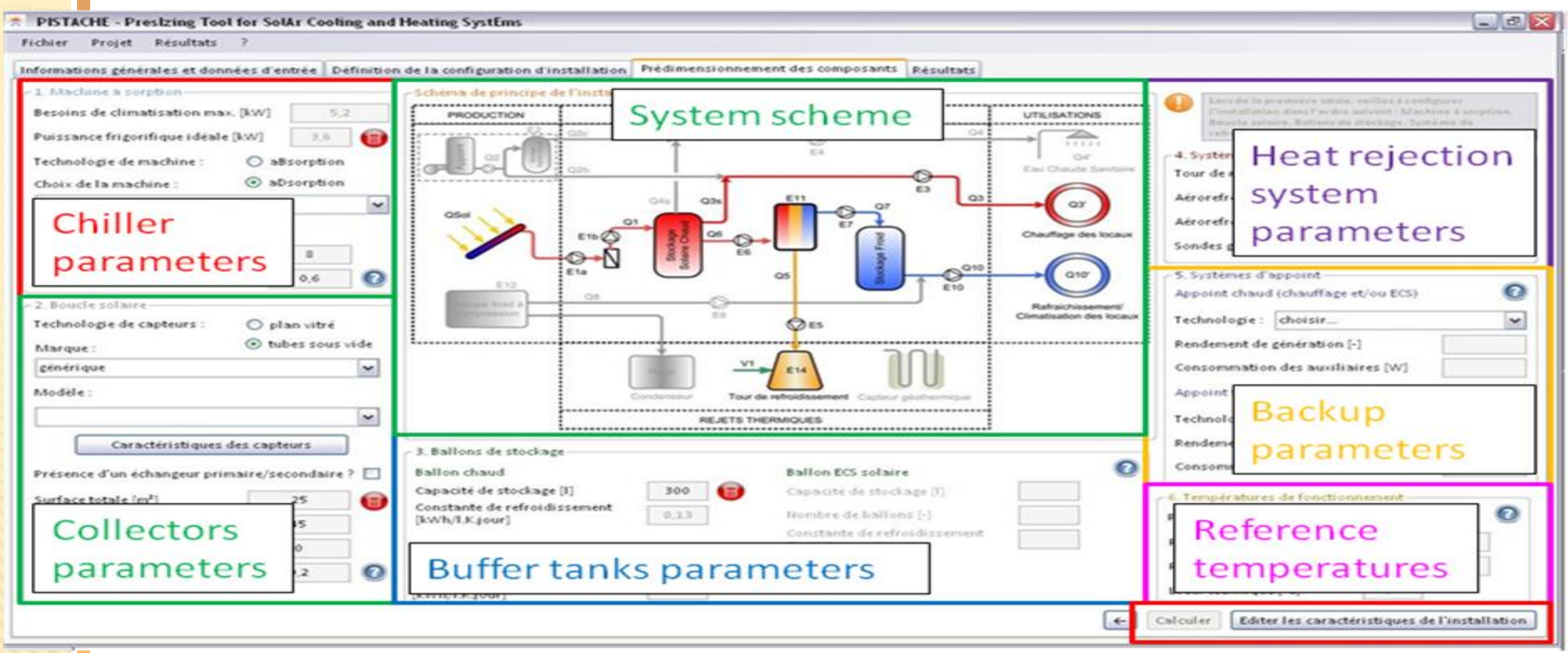
Quality Assurance & Support Measures for Solar Cooling Systems

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

2. Simplified sizing tools

Pre-simulated building heat loads with matching weather

- Pistache: Available on request http://task48.iea-shc.org/tools
- SACE: http://www.solair-project.eu/218.0.html
- SolAC: http://www.iea-shc-task25.org/english/hps6/index.html



3. Full dynamic simulation software

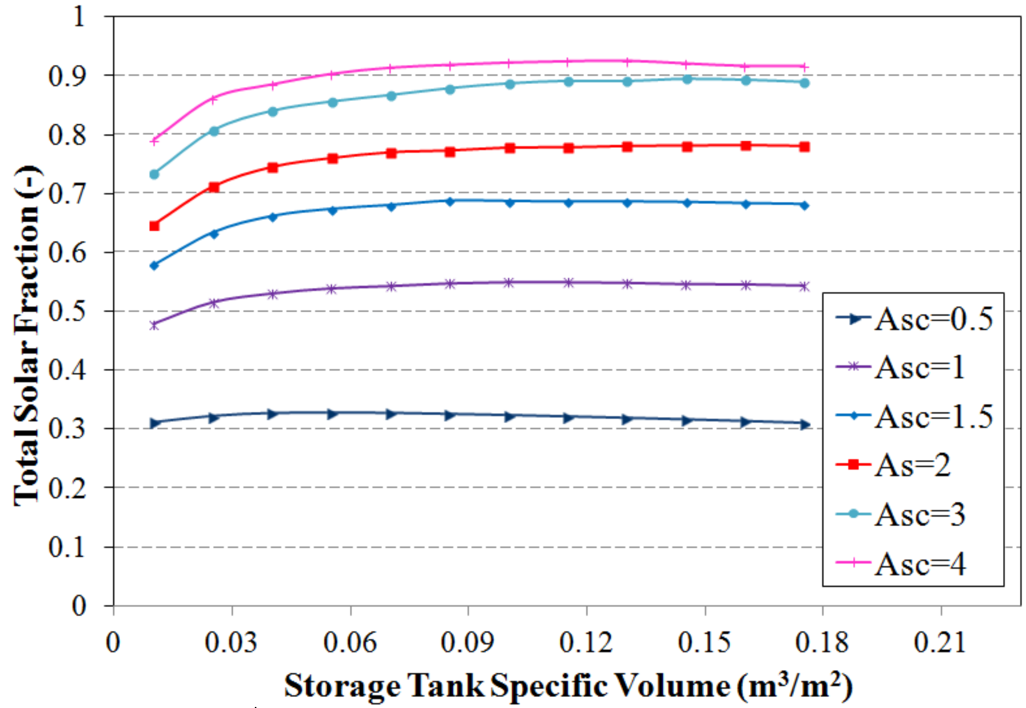
- calculation of generic energy systems
  - TRNSYS - www.sel.me.wisc.edu/trnsys/
  - ColSim - www.colsim.de
  - Insel - http://www.inseldi.com/index.php?id=21&L=1
  - Transol 3.0 - www.aiguasol.coop
- calculation of buildings
  - Energy plus - www.eere.energy.gov/buildings/energyplus/
  - ESP-r – FREE - http://www.esru.strath.ac.uk/Programs/ESP-r.htm

Software	Solar components	AC components	New components	Free download	Open source
TRNSYS	Yes	Yes	Yes	No	Yes
ColSim	Yes	Yes	Yes	N.A.	Yes
Energy Plus	Yes	Yes	Yes	Yes	N.A.
INSEL	Yes	Yes	Yes	No	No

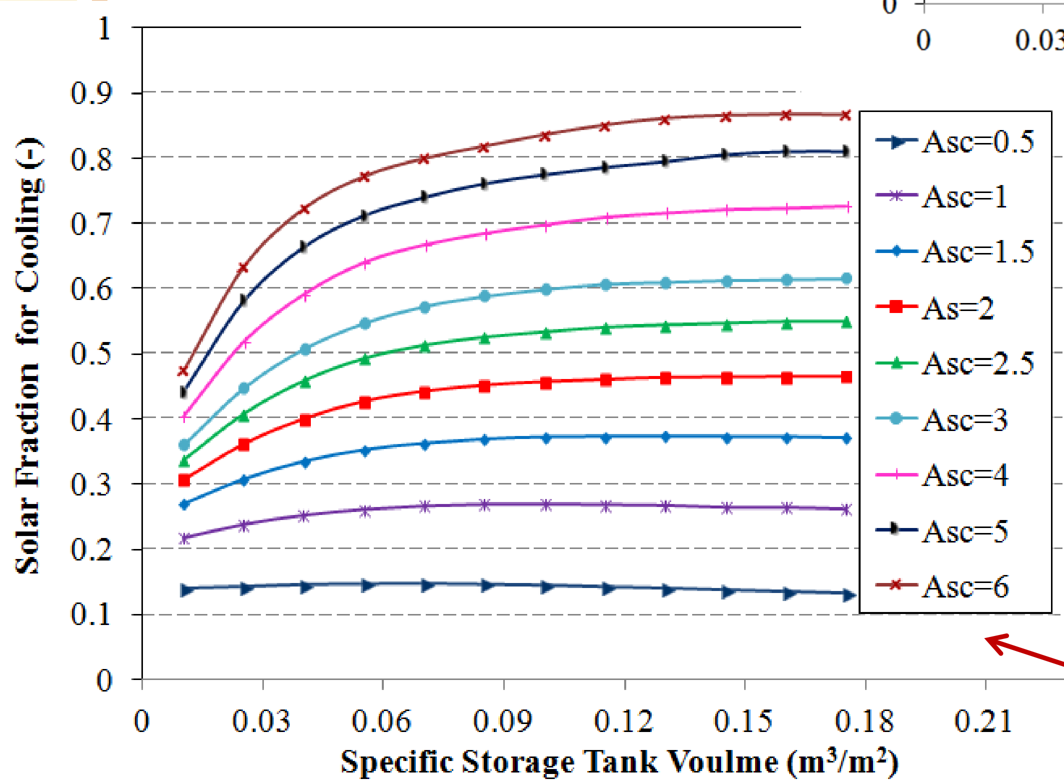
Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

Sensitivity analysis



11 hour airconditioning load

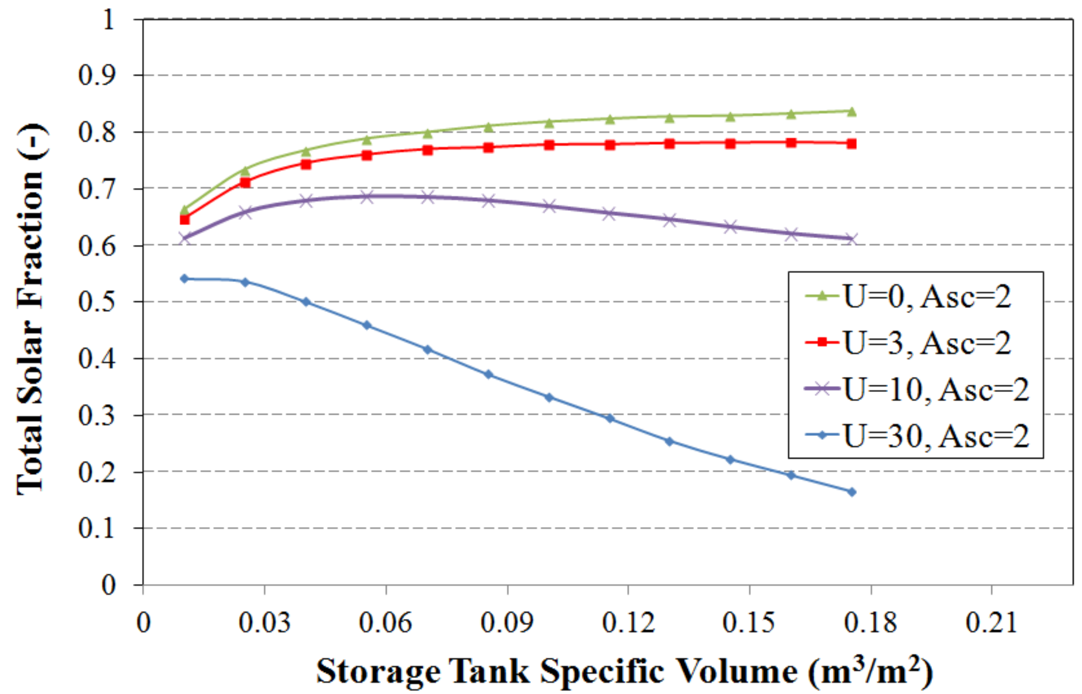


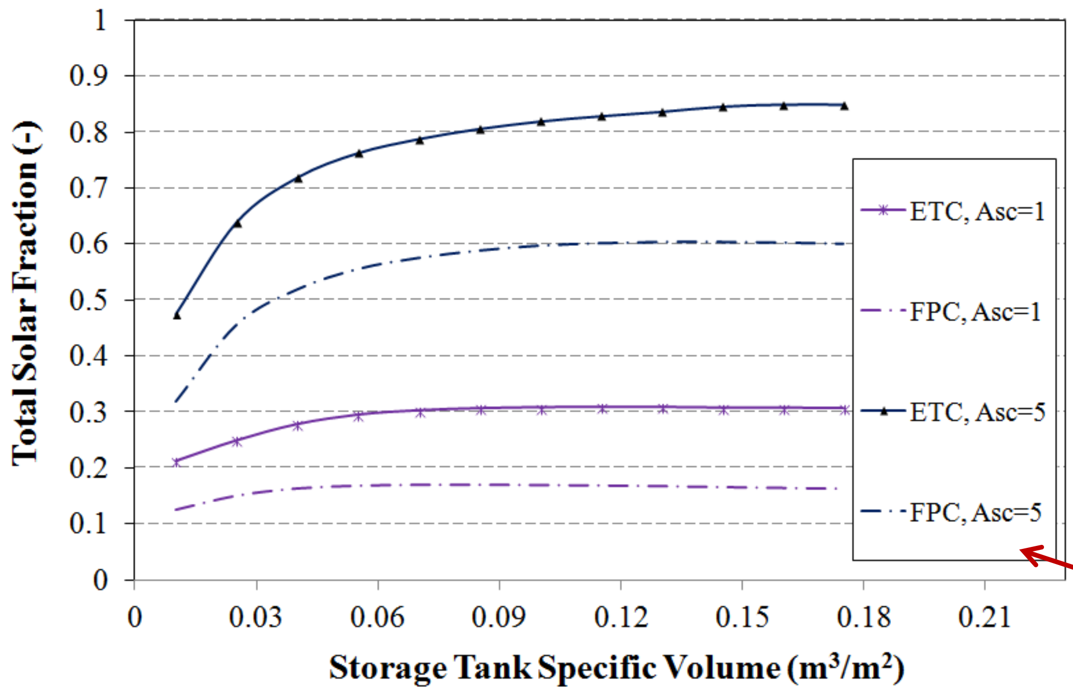
24 hour airconditioning load

Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

Sensitivity analysis #2





Impact of insulation

Impact of collector

5. Design approaches

c. Quality assurance and lessons learned

Chiller considerations

- When using gas as a backup, its probably best to select a two stage absorption chiller
- Cooling water needs to be kept inside temperature limits.
- Absorption chillers are steady state machines
  - ~30 min cold start + dilution cycle shut down
  - So don’t add a “safety margin” to chiller sizing
    - Larger chiller may <u>reduce</u> energy savings
    - Can cause cycling resulting in heat losses and poor diurnal availability

Heat collection considerations

- Aim for equal flow through panels for full use of available collector area
  - Balancing valves (but watch for parasitic power from pumps)
  - Tickleman layout
- Insulate pipes to minimise heat loss
- Allow for possible freezing and over-heat stagnation eventualities
- Err on over-sizing of solar side heat exchangers to minimise temperature reduction

Buffer tank considerations

- Thermal stratification is your friend
- So look to
  - maximise temperature lift across solar collectors (low flow)
  - avoid circulating excessive volumes of fluid through the tank
  - consider use of baffles/ special stratification tanks
  - avoid situations where a back-up boiler takes over heating of the tank (in place of the solar system)
  - put in more temperature sensors at different levels and consider optimal placement to obtain a reliable control signal

Monitoring and commissioning checks

- Past experience suggests sub-metering is required to evaluate and enforce contractor compliance on
  - Parastic power – pump and fan efficiencies
  - Heat losses – insulation effectiveness
- Monitor and adjust control strategies/ thermal storage management strategies across all seasons.