Main presentation, part B (1 ½ h, about 30 slides)

6. Performance figures
    a. Energy performance and primary energy balance, including COPel, electrical consumption of heat rejection and efficiency improvement potential for other components (e.g. pumps)
    b. Economic and environmental analysis, energy saving certification

6. Performance figures

a. Energy performance and primary energy balance, including COPel, electrical consumption of heat rejection and efficiency improvement potential for other components (e.g. pumps)

Primary energy analysis

Definition

thermal chiller driven by solar energy:

$$PE_{spec,solar} = \frac{\frac{Q_{backup}}{\varepsilon_{fossil}}}{Q_{cold}} + PE_{spec,coolingtower}$$
$$= \frac{Q_{backup}}{\varepsilon_{fossil}} \frac{1}{Q_{cold}} + PE_{spec,coolingtower}$$
$$= \frac{Q_{drivingheat}(1-F_{sol})}{\varepsilon_{fossil}} \frac{1}{Q_{cold}} + PE_{spec,coolingtower}$$
$$= \frac{(1-F_{sol})}{\varepsilon_{fossil}} \frac{Q_{drivingheat}}{Q_{cold}} + PE_{spec,coolingtower}$$
$$= \frac{(1-F_{sol})}{\varepsilon_{fossil}.COP_{thermal}} + PE_{spec,coolingtower}$$

where: $COP_{thermal} = \frac{Q_{cold}}{Q_{drivingheat}}$

cooling tower:

$$PE_{spec,coolingtower} = \frac{\frac{E_{coolingtower}}{\varepsilon_{elect}}}{Q_{cold}} = \frac{E_{spec,coolingtower} Q_{heatrejected}}{\varepsilon_{elect}} \frac{1}{Q_{cold}}$$
$$= \frac{E_{spec,coolingtower}}{\varepsilon_{elect}} \frac{(Q_{drivingheat} + Q_{cold})}{Q_{cold}}$$
$$= \frac{E_{spec,coolingtower}}{\varepsilon_{elect}} \left(1 + \frac{1}{COP_{thermal}}\right)$$

Source : RIDEF

Primary Energy Ratio

$$PER = \frac{Q_{cool}}{Q_{el} \cdot PEF_{el} + Q_{h,add} \cdot PEF_{gas}}$$

Cooling energy divided by the sum of consumed electricity and additional thermal energy multiplied by the PEF factors of 2.7 for electricity in Germany (GEMIS) and 1.1 for gas boiler.

Electric compression chillers, PER:	<1.0
Solar thermal cooling systems today:	1.0 – 1.7
Potential thermal for COPel = 10 -12:	3.5 – 4.5 *(where COPel = Qcool / Qel)*

Source : Zafh-NET

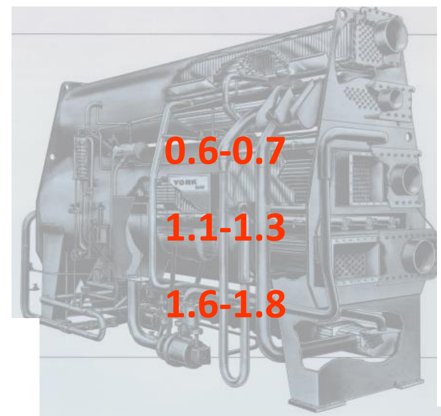
Energy Efficiency

Coefficient of Performance (COP) = Cold produced / Heat input

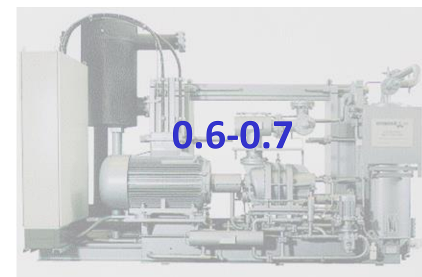
Desiccant Cooling

Closed Adsorption

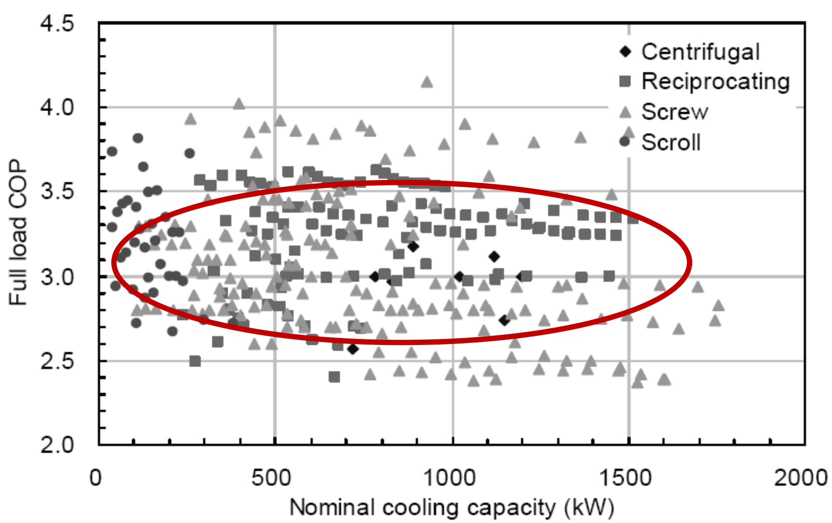
Absorption
H_2O - LiBr



Absorption
NH_3 - H_2O



Fa. GRASSO*KAB



Air cooled compression chiller
Source: F. W. Yu, and K. T. Chan
Department of Building Services Engineering,
Hong Kong Polytechnic University

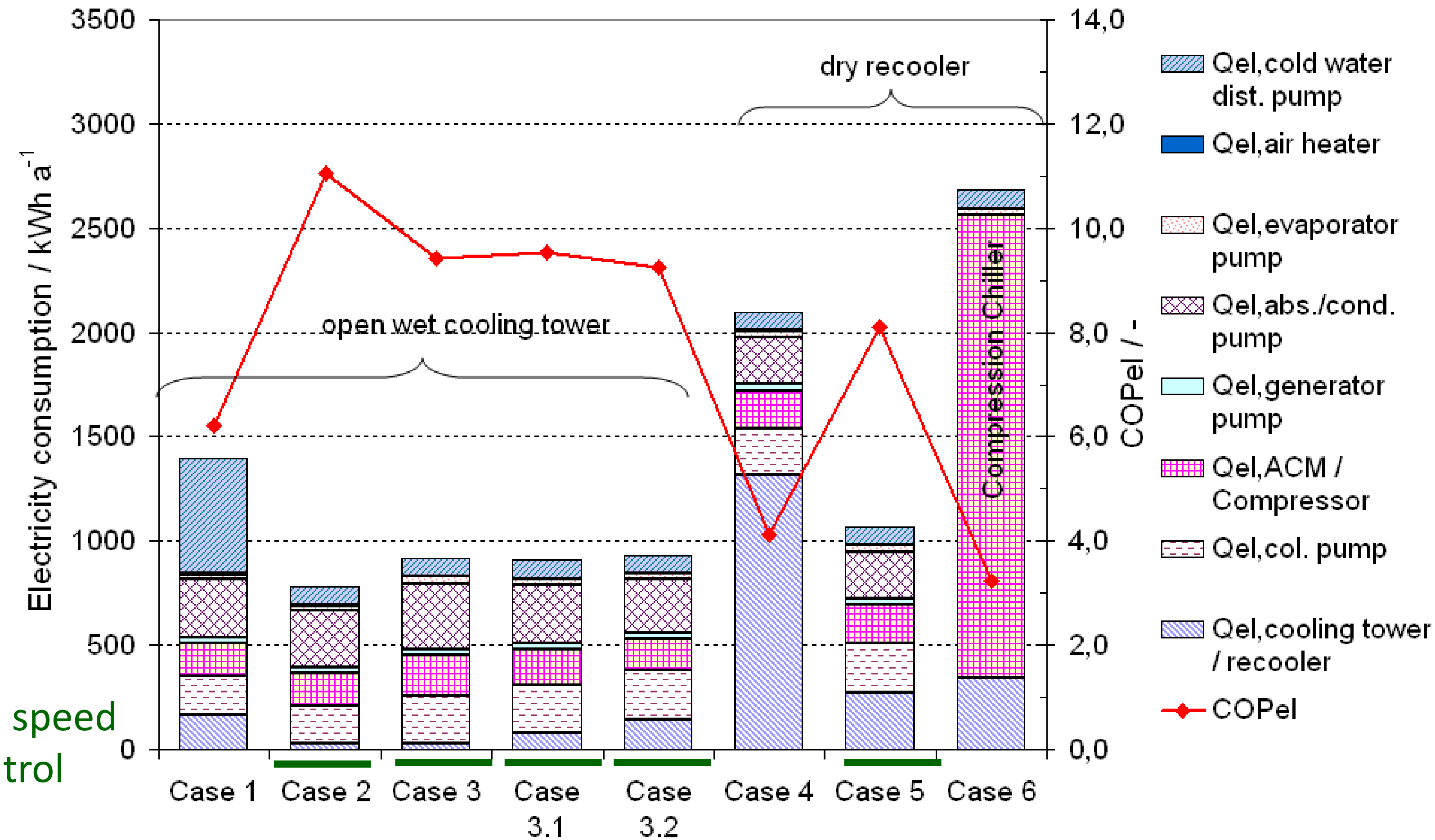
Source : Zafh-NET

Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Electricity consumption and COP_{el}



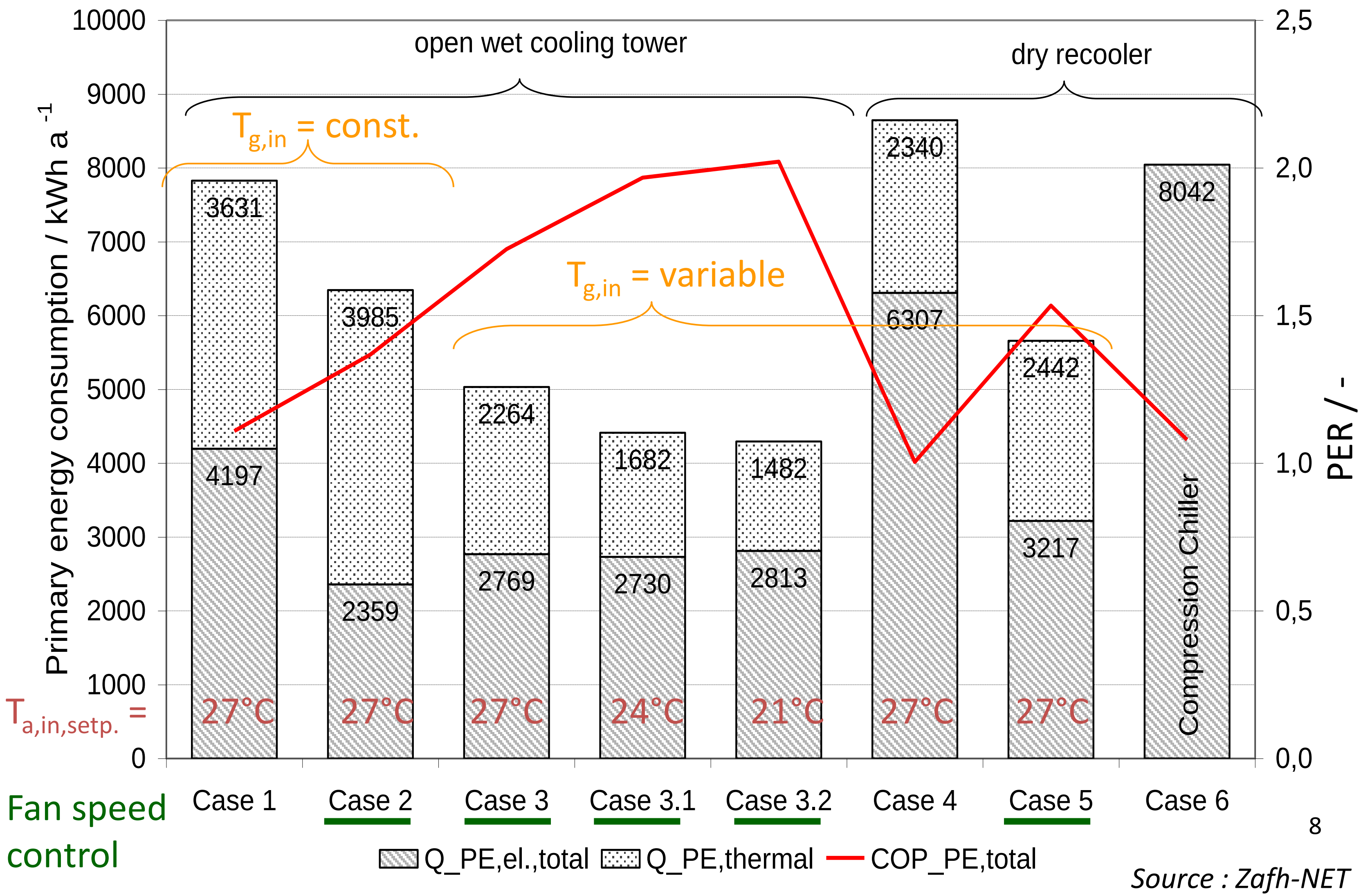
Fan speed control

$T_{a,in,setp.}$ = 27°C 27°C 27°C 24°C 21°C 27°C 27°C

(ambient temperature used for the heat rejection)

Source : Zafh-NET

Primary energy consumption & primary energy ratio PER



Source : Zafh-NET

Conclusions

- 20% increase in solar fraction only through optimised system control!
  - Variable generator inlet temperature 15 %
  - Cooling tower control 5 %

- Strong influence of control strategy on the electrical COP of the solar cooling system
  - simple control (Case 1): COPel = 6.1
  - optimised control (Case 2): COPel = 11.0
  (Electrical compression chiller COPel = 3.2)

- The primary energy ratio PER of the solar cooling systems varies according to the control strategy and type of cooling tower by a factor of two between 1.0 and 2.0
  (Electrical compression chiller PER = 1.1)!

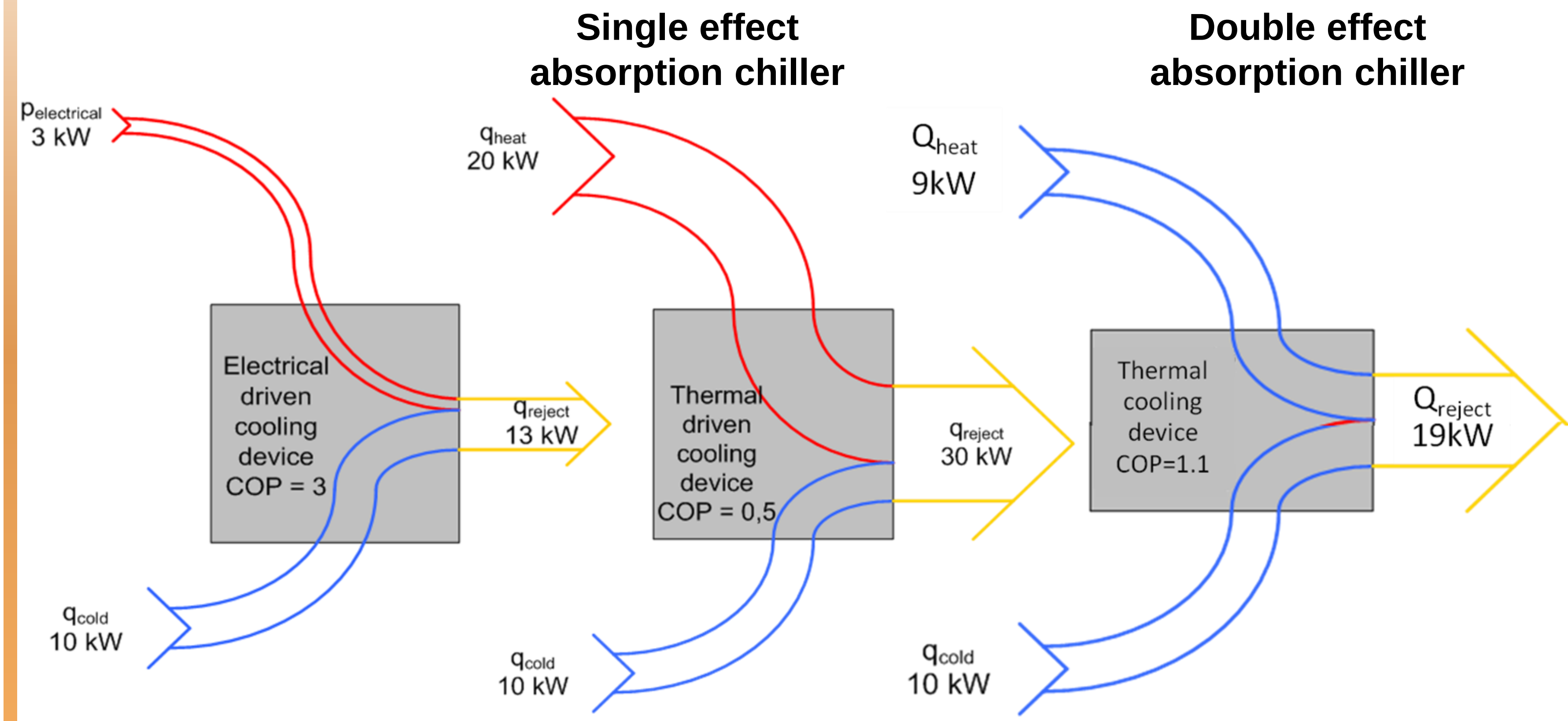
Source : Zafh-NET

Heat Rejection Considerations

- Absorption chillers almost always requires a wet cooling tower to achieve <35°C cooling water to prevent crystallisation on peak summer days
  - Availability of water
  - Maintenance, legionella
- Adsorption chillers and ammonia water absorption chillers can be air-cooled (don’t have crystallisation issues)
  - Can use a dry cooler, possibly with sprays for peak summer hours
  - Parasitic electricity consumption
  - Higher temperature lift with air cooler leads to higher heat source temperature requirement
- Desiccant systems don’t generally require heat rejection equipment but may require water for the evaporative cooler.
  - Evaporative water consumption is a little bit less than that required in the cooling tower of a high efficiency conventional mechanical chiller
  - Latent heat removal only system does not require water

Source : CSIRO

Heat rejection & parasitic electricity consumption



Inefficient single effect sorption chillers have a much greater heat rejection requirement

…but are using lower temperature solar energy !

Source : CSIRO

Parasitic Power consumption : lessons learnt

- Do use variable speed drives on the cooling tower/ dry cooler fans
- Do use high efficiency pumps
- Do minimise pipe runs
- Do ensure balancing of solar field is achieved without excessive use of pressure reduction valves
- Do measure it !!
- Do ensure pumps are not running when not required
- Consider double effect chiller if your application and climate allows it

Source : CSIRO

Parasitic Power consumption

(example single effect chiller, indicative numbers only)

	Full Load		Part Load Fixed Speed Fan		Part Load Variable Speed Fan	
	High Efficiency Pumps	Low Efficiency Pumps	High Efficiency Pumps	Low Efficiency Pumps	High Efficiency Pumps	Low Efficiency Pumps
Cooling (W)	8000	8000	4000	4000	4000	4000
Pump Power (W)	230	550	230	550	230	550
Fan Power (W)	650	650	650	650	100	100
COP_{el}	**9.1**	**6.7**	**4.5**	**3.3**	**12.1**	**6.2**

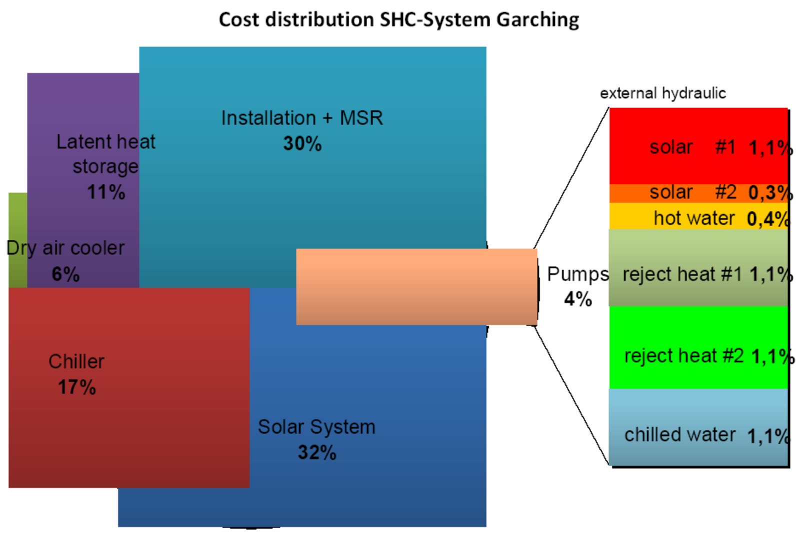
Conclusion :
- Use high efficiency ancillaries and variable speed drives
- Use higher efficiency cooling machine in the first place
- Don’t oversize your chiller/ explore variable speed on pumps

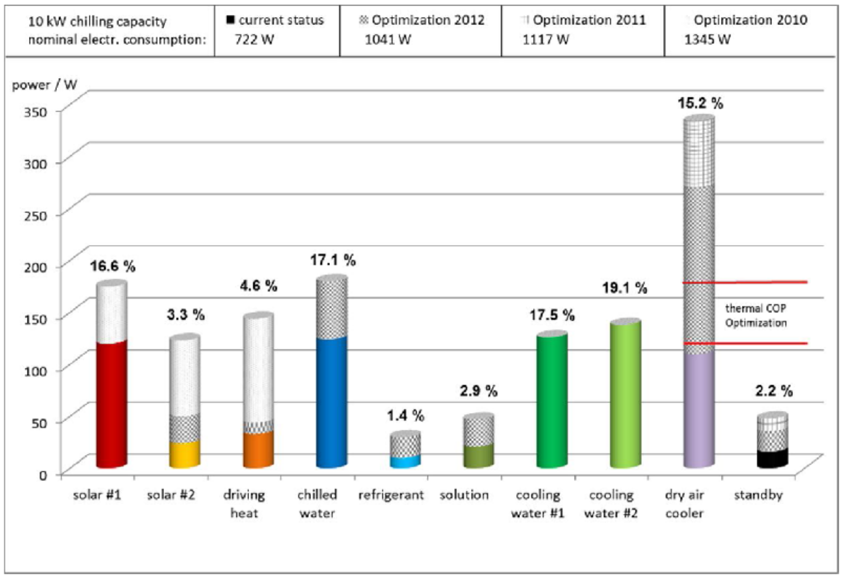
Source : CSIRO

Parasitic Power consumption

- Efficiency improvement potential for pumps

Example of a 10 kW absorption cooling system with dry heat rejection : investment and performances





Source : ZAE Bayern

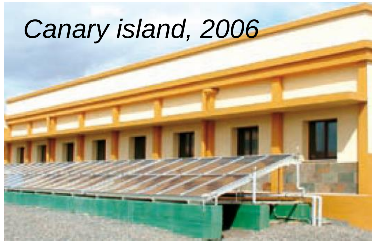
6. Performance figures

b. Economic and environmental analysis, energy saving certification

Economical context for solar cooling

- **Number of installations still limited**

(solcoproject Southern European Islands: about 20 installations, Austria with Roadmap Solar Air conditioning:19, world wide about 1000-1200 in 2013)



- **High initial investment cost**: payback times 10-20 years in best cases

- But.. **financial schemes** for support existing in some countries

- CO_2 trading might change the picture: California study 2020 for significance of CO_2 trading: 0 MW (no CO_2 price), 53 MW 123 $/t CO_2), 300 MW (CO_2 price high and COP=1.2) LBL, Chris Marnay, 3rd International Conference on Solar Air-Conditioning, September 30 – October 2, 2009, University Palermo, Sicily, Italy

- **Legislation** should support market introduction

(Renewable Heat laws make 15% solar heating and cooling mandatory in Germany in 2013)

Source : Zafh-NET

Economical context for solar cooling

Future Paybacks will be significant less as

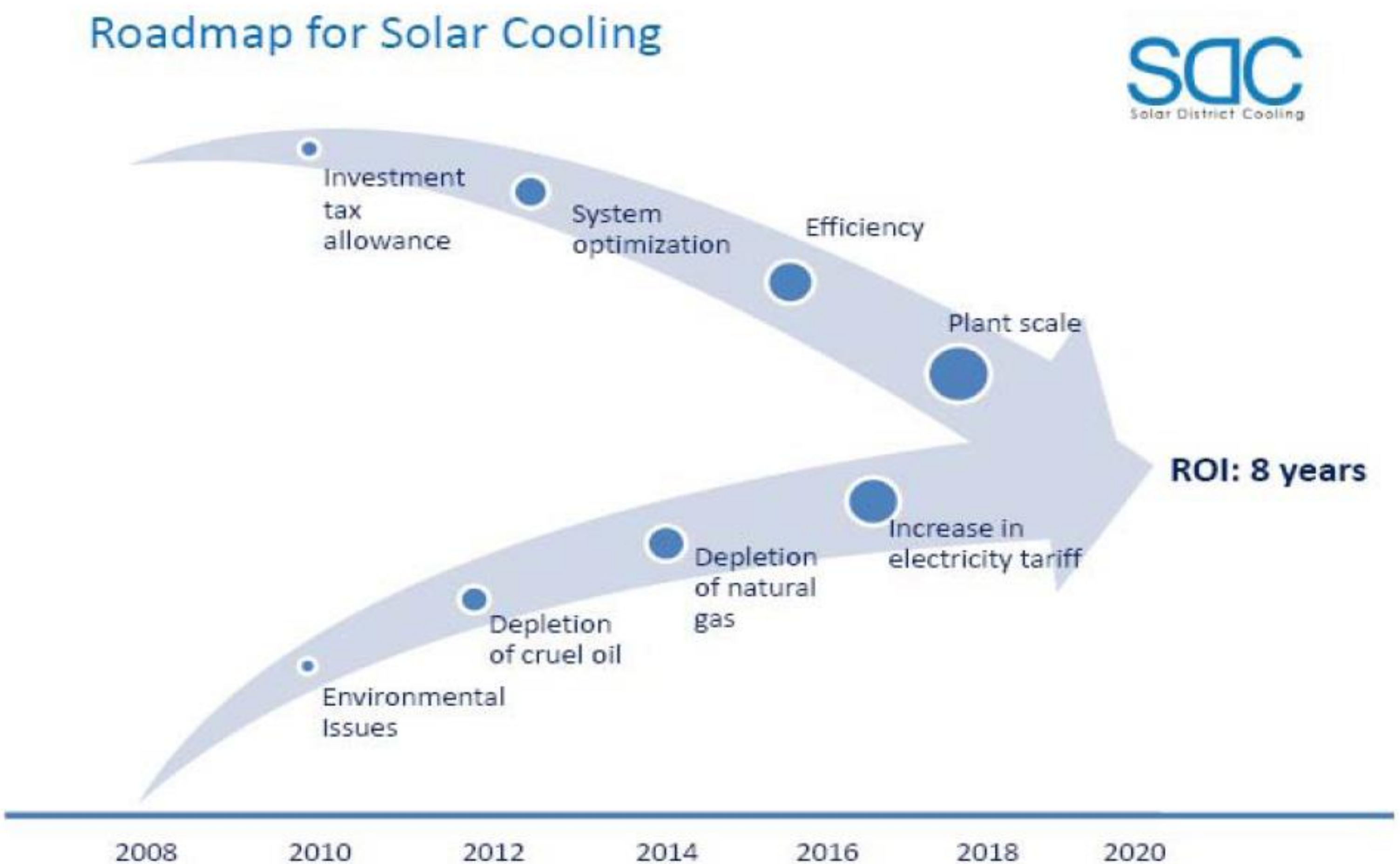
- Fuel and electricity get more expensive
- Solar cooling gets cheaper
- Carbon financing and environmental costs get implemented in investment schemes
- Refrigerants will phase out

But we need to start today

- To create knowledge
- To create a critical mass

Source : Zafh-NET

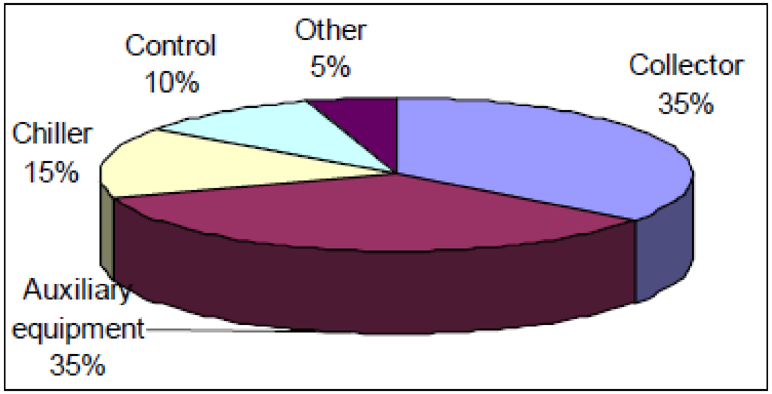
Possible path toward competitiveness for solar cooling



Source : Zafh-NET

Cost comparison absorption – compression (1/3)

Model	Absorption	Compression
Cooling performance	150 kW	150 kW
Energy input	214 kW_{th}	50 kW_{el}
COP	0.7	3.3
Investment costs	59,308 €	33,205 €
Specific investment costs	395 €/kW	233 €/kW
Dimension re-cooling tower	364 kW	195 kW
Costs re-cooling tower	10,238 €	6,990 €
Costs peripheral equipment[5]	50,623 €	40,498 €
Specific water consumption	5 m³/MWh	-



Source : Zafh-NET

Cost comparison absorption – compression (2/3)

	Type of unit	Absorption chiller 150 kW, 1,000 full-load hours, 5 € cent/kWh heat	
1	Energy cost, Water cost in total	15,850	Euro/yr
2	Electricity	-	Euro/yr
3	Heat	-	Euro/yr
4	Water	-	Euro/yr
5	Annual costs of repairing and service in total	2,008	Euro/yr
6	Cost of investments in total	132,186	Euro
7	Annual annuity from investment (6%, 15 years)	13,610	Euro/yr
8	Cooling production cost in total	31,468	Euro/yr
	Specific costs	209.79	Euro/MWh

	Price in the first year	Annual price increase
Heat price [€ cent/kWh]	5,00	1%
Heat base price [€/a]	100,00	1%
Power price [€ cent/kWh]	12,00	2%
Water [€/m³] incl. treatment	2,00	1%

Source : Zafh-NET

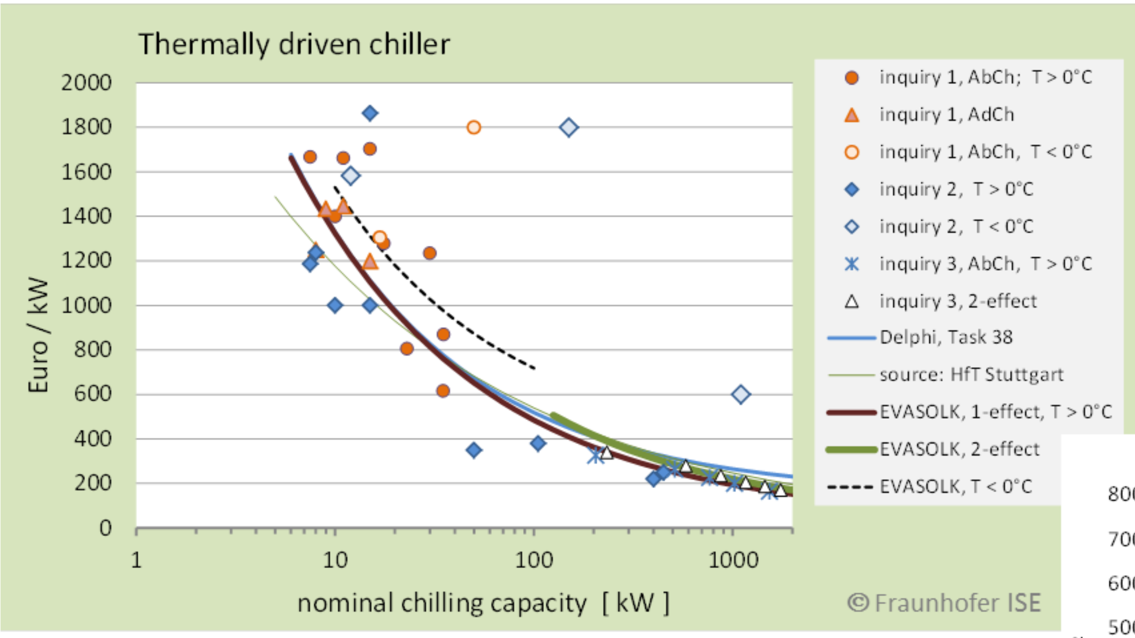
Cost comparison absorption – compression (3/3)

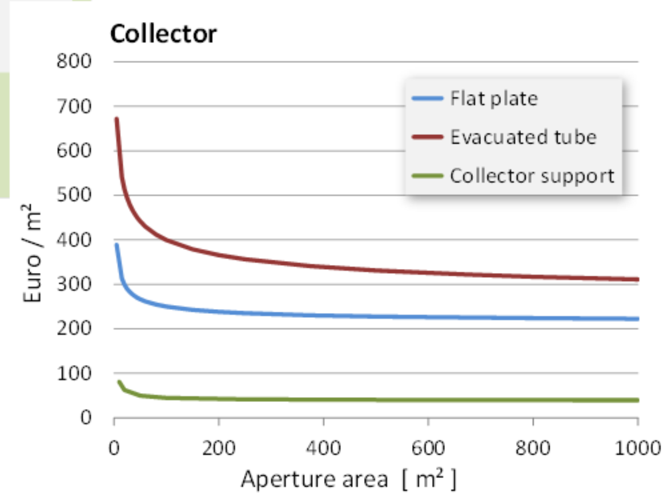
	Type of unit	Compression chiller 150 kW, 1,000 full-load hours	
1	Energy cost, Water cost in total	6,840	Euro/yr
2	Electricity	-	Euro/yr
3	Heat	-	Euro/yr
4	Water	-	Euro/yr
5	Annual costs of repairing and service in total	3,744	Euro/yr
6	Cost of investments in total	88,763	Euro
7	Annual annuity from investment (6%, 15 years)	9,139	Euro/yr
8	Cooling production cost in total	19,724	Euro/yr
	Specific production costs	131.49	Euro/MWh

Source : Zafh-NET

Cost curves derived from various cost data

without taxes, peripheric components (e.g., cooling tower), installation





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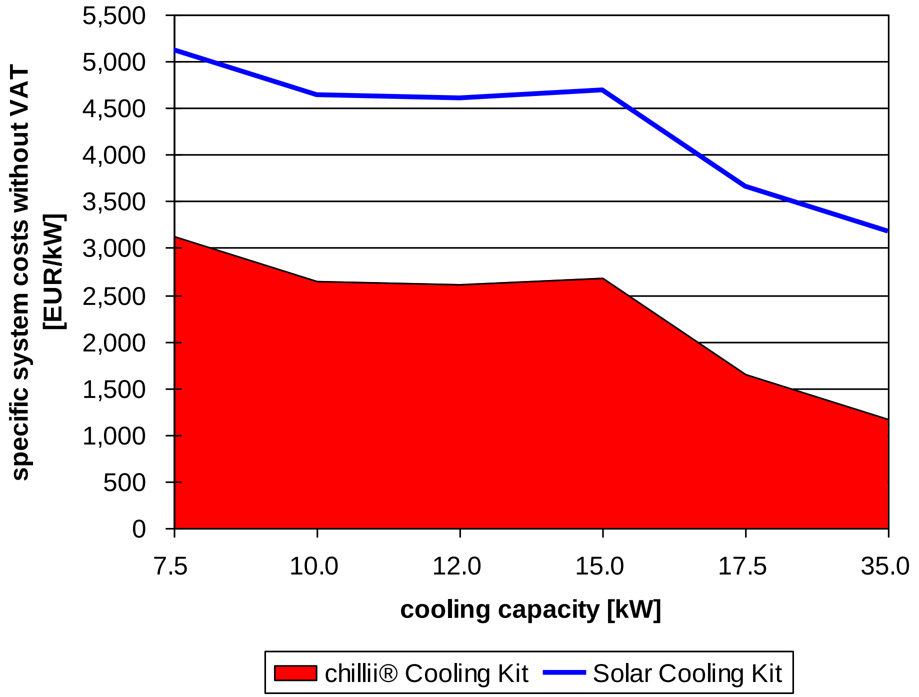
Source : Fraunhofer ISE, 2013

Potential for cost reduction

Component / Parameter	Development until the year 2015 compared to 2010	
	Absorption	Adsorption
Expenses for installation & integration	- 13 %	- 14 %
Expenses for maintenance	- 10 %	- 18 %
Thermal COP	+ 7 %	+ 9 %
Machine lifetime	+/- 0 %	+/- 0 %
Price of re-cooling system	- 20 %	
Electricity consumption of the periphery (pumps, fans)	- 28 %	

Source : Zafh-NET

Specific Costs of Low Capacity Solar Cooling Systems



SOLARNEXT

Specific Costs of Solar Cooling Kits in Europe:

- 5,000 to 8,000 EUR/kW in 2007
- 4,000 to 4,500 EUR/kW in 2008
- 3,500 to 4,500 EUR/kW in 2009
- **About 3,500 €/kW in 2012-2013 (2,500 €/kW only cooling kit)**

Without Installation Costs and Cold Distribution

Source : Zafh-NET

Systematic economic analysis

Hypothesis

INVESTMENT COST VARIATION
Solar thermal collectors:
LOW 100 €/m², MEDIUM 300 €/m², HIGH 500 €/m²
Sorption chiller system costs:
LOW 500 €/kW, MEDIUM 1500 €/kW, HIGH 3000 €/kW
Installation and system integration:
LOW 10%, MEDIUM 20%, HIGH 30% of investment

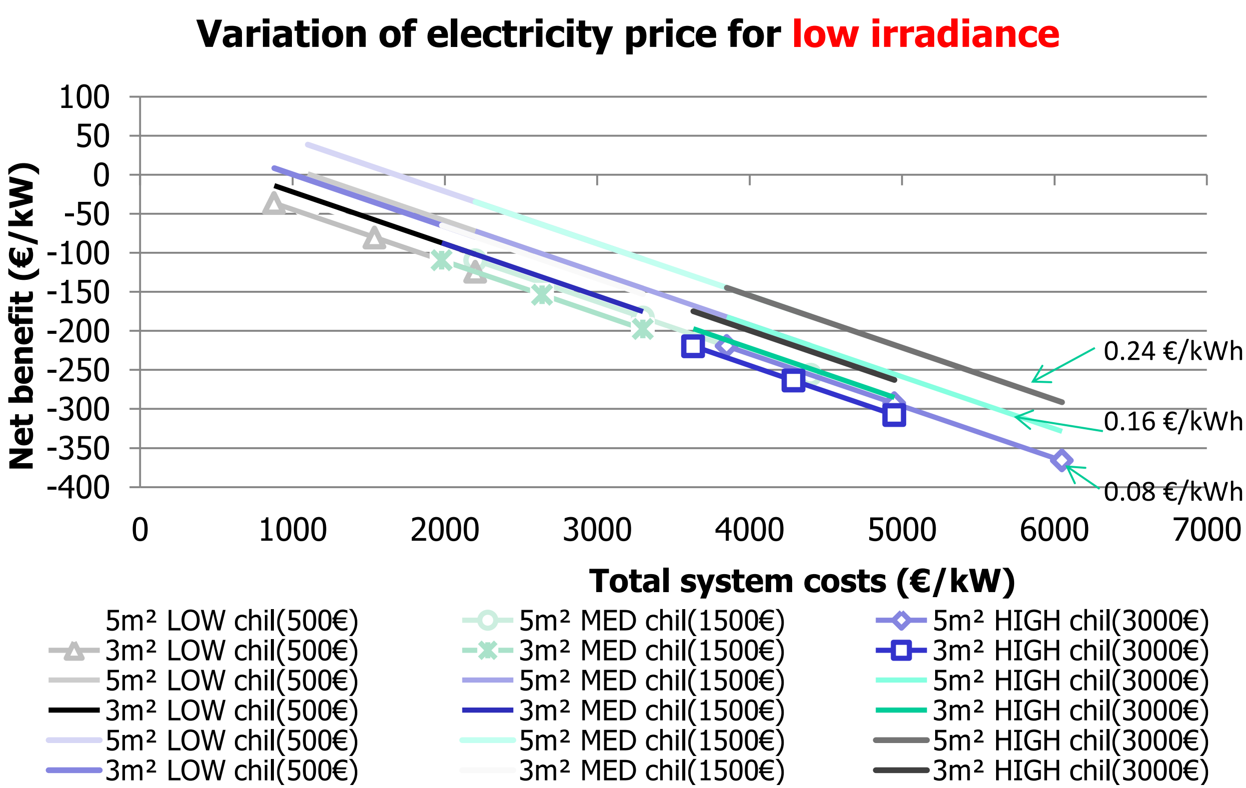
ELECTRICAL PRICE
LOW elec: 0,08 €/kWh
MED elec: 0,16 € /kWh
HIGH elec: 0,24 €/ kWh

IRRADIANCE VARIATION
LOW irr 1000 kWh/m² (Northern European)
MED irr 1750 kWh/m² (Southern European - MEDIUM)
HIGH irr 2500 kWh/m² (Sahara-HIGH).

INTEREST RATES
LOW inter: 0%
MED inter 4%
HIGH inter 8%

Source : Zafh-NET

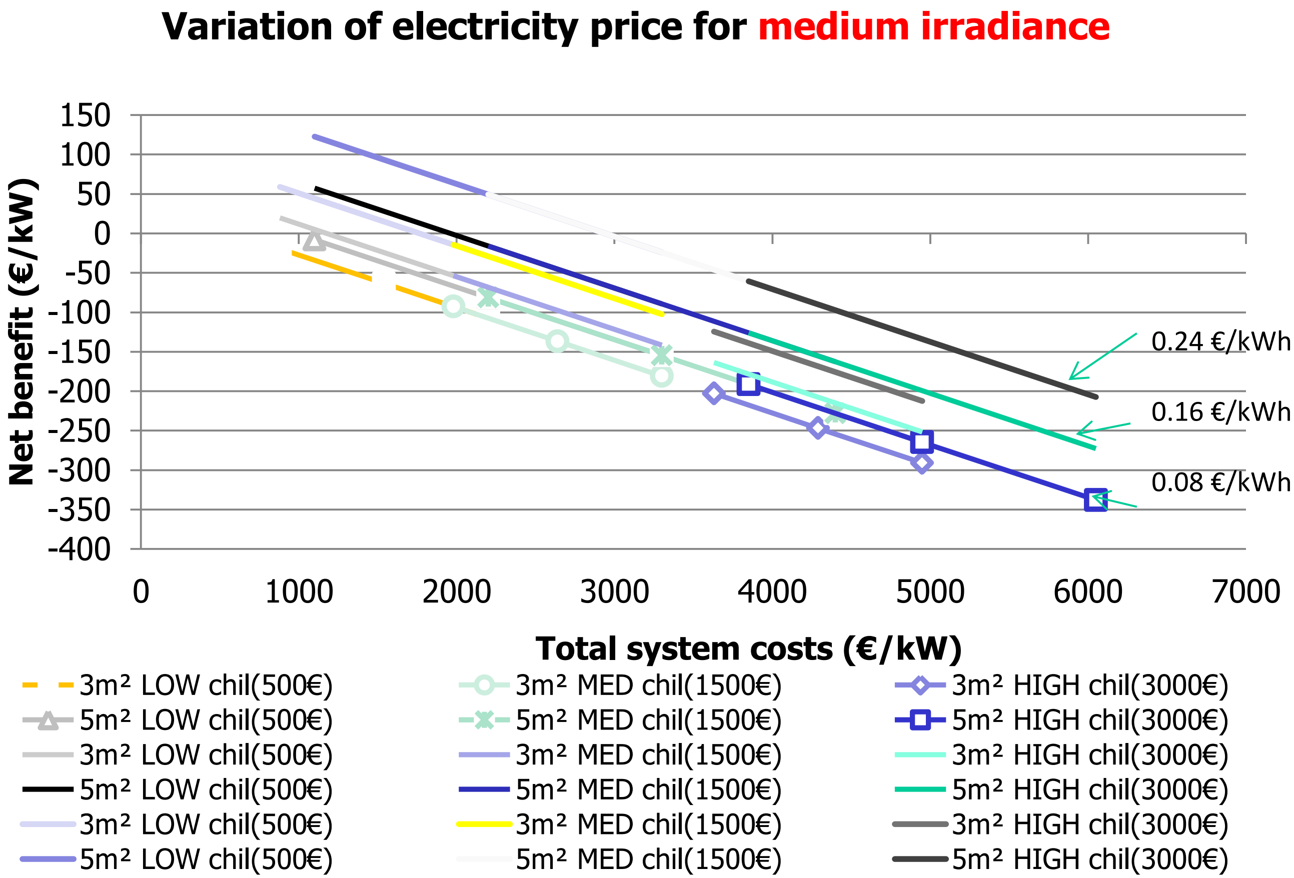
Summary economics for low irradiance conditions



Economical performance only at high electricity price
and system costs around 1000 €/kW

Source : Zafh-NET

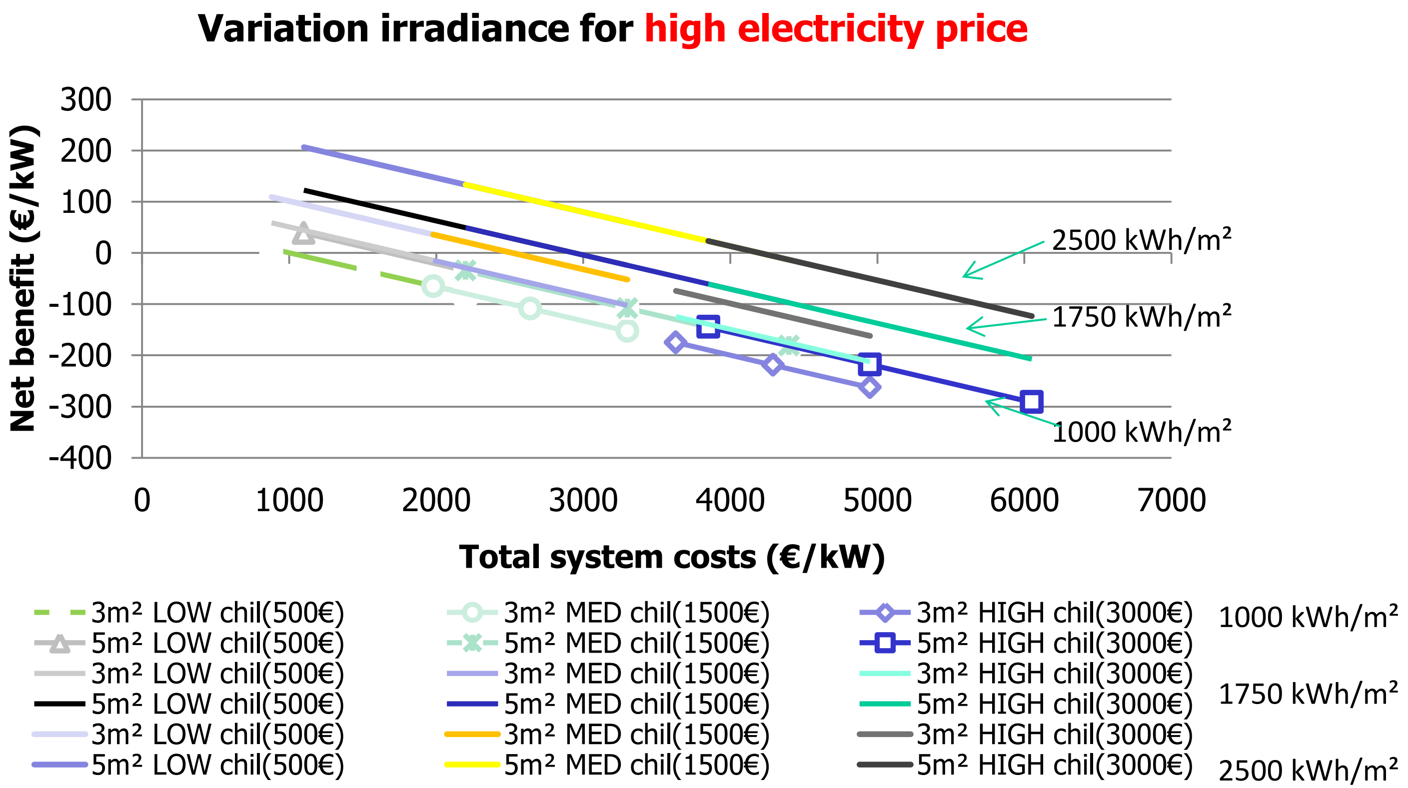
Medium irradiance conditions



Economical performance for medium electricity price up to 2000 €/kW system costs, for high electricity prices up to 3000 €/kW

Source : Zafh-NET

High electricity price conditions



At high electricity prices and high irradiance, system costs up to 4000 €/kW are possible

Source : Zafh-NET

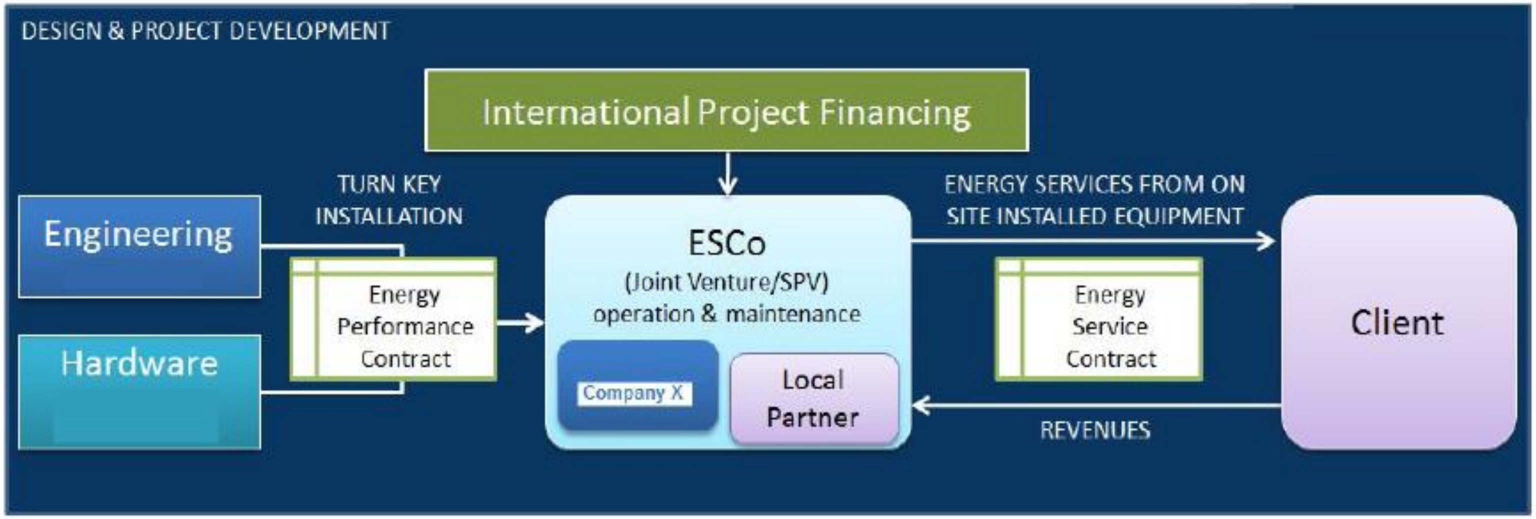
Conclusions

- **Costs are still high** due to low number of installations: important are reduced investment costs, low heat prices and high full load hours
- **Large systems are closer** to economical performance
- For system prices of 1000 €/kW paybacks of 2 to 13 years are possible for long operating hours and heat costs close to zero
- **For Mediterranean irradiance conditions solar cooling systems are economically feasible** at medium electricity prices (0.16€/kWh) up to 2000 €/kW system costs, for high electricity prices (0.24 €/kWh) up to 3000 €/kW

Source : Zafh-NET

Contracting models

Energy performance contracting (EPC)



For further explanations :

Final report on Contracting Models for Solar Thermally Driven Cooling and Heating Systems (***Task 48 - C6 activity final report)***

(see http://task48.iea-shc.org website and Publications section)

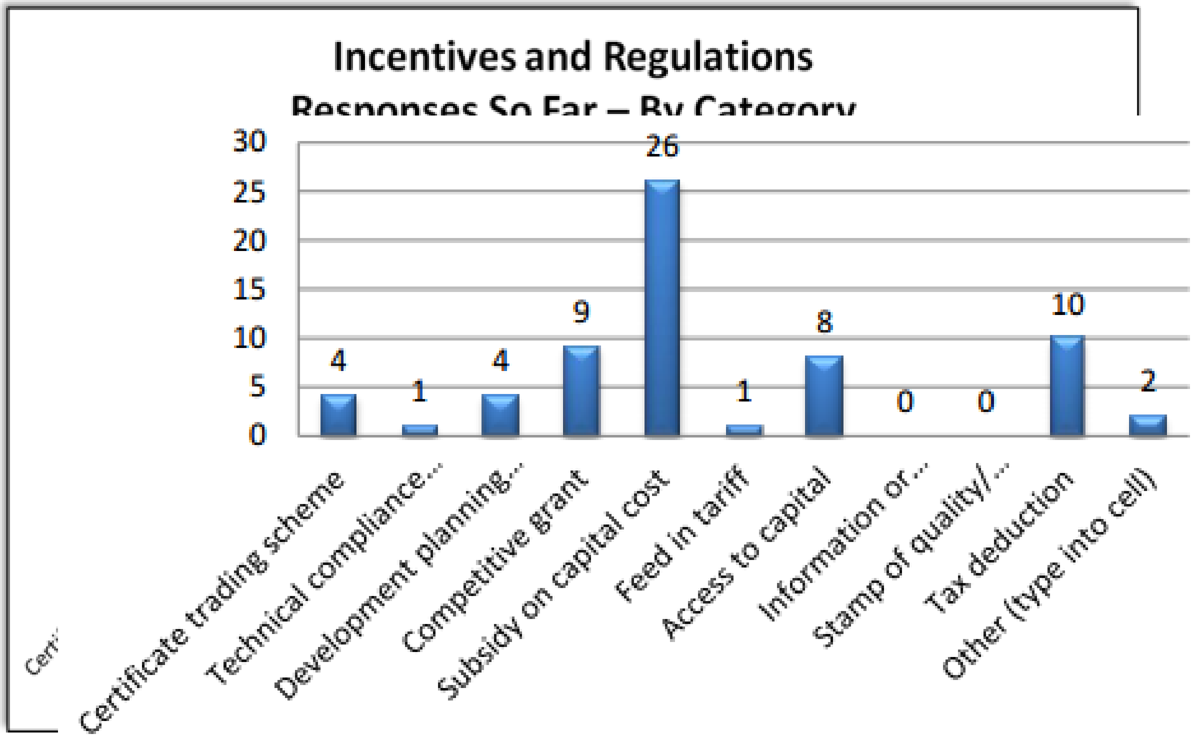
Task 48

Quality Assurance & Support Measures for Solar Cooling Systems

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Incentive schemes

Review of relevant international standards rating and incentive schemes



For further explanations :

Review of relevant international standards rating and incentive schemes

Task48 - Activity C1 Report

(see http://task48.iea-shc.org website and Publications section)