# Solar air-conditioning and refrigeration - achievements and challenges

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EuroSun 2010

September 28 – October 2, 2010

Graz - AUSTRIA

EuroSun 2010
International Conference
on Solar Heating, Cooling and Buildings

# Outline

- Components and systems
- Achievements
- Solar thermal versus PV?
- Challenges and conclusion

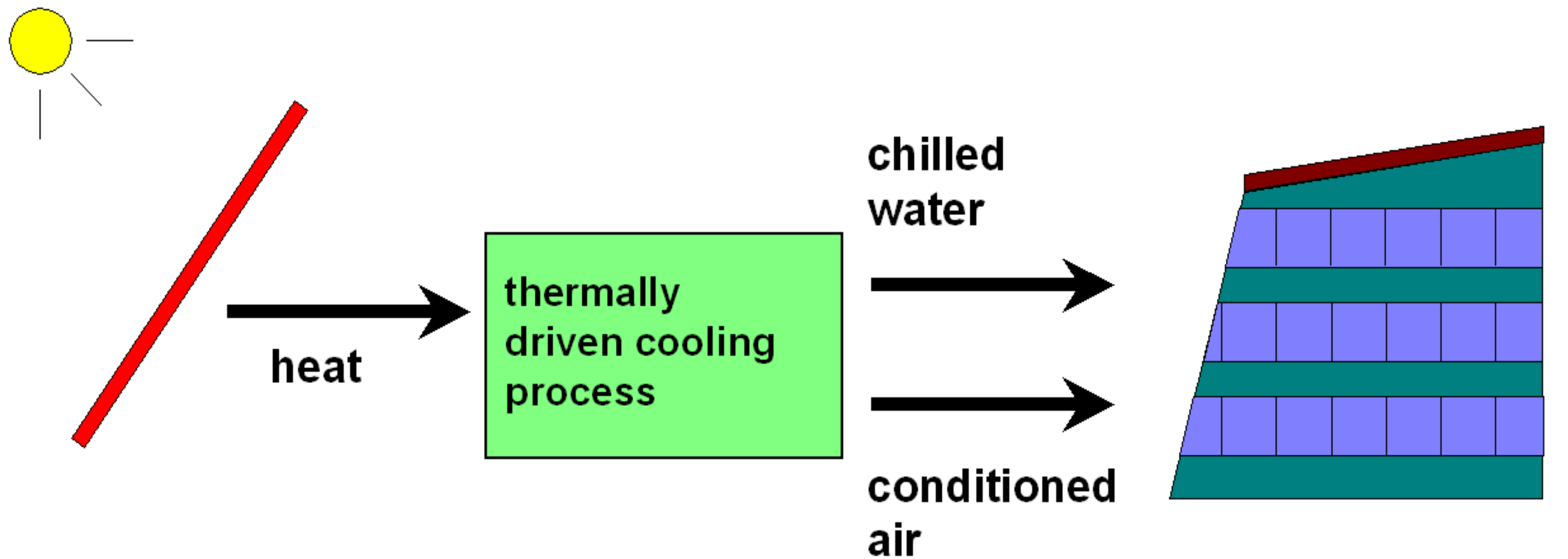
- **Components and systems**
- Achievements
- Solar thermal versus PV?
- Challenges and conclusion

# Overall approach to energy efficient buildings

- Assure indoor comfort with a minimum energy demand

| | |
|---|---|
| 1. Reduction of energy demand | Building envelope; ventilation |
| 2. Use of heat sinks (sources) in the environment | Ground; outside air (T, x) directly or indirectly; storage mass |
| 3. Efficient conversion chains (minimize exergy losses) | HVAC; combined heat, (cooling) & power (CH(C)P); networks; auxiliary energy |
| 4. (Fractional) covering of the remaining demand using renewable energies | Solar thermal; PV; (biomass) |

# Solar thermal cooling - basic principle




**Basic systems categories**

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

# Open cycles – desiccant air handling units

**Solid sorption**

- Desiccant wheels
- Coated heat exchangers
- Silica gel or LiCl-matrix, future zeolite

**Liquid sorption**

- Packed bed
- Plate heat exchanger
- LiCl-solution: Thermochemical storage possible


# Closed cycles – water chillers or ice production

*Turbo Expander/Compressor*
*AC-Sun, Denmark in TASK 38*

- Liquid sorption: Ammonia-water or Water-LiBr (single-effect or double-effect)
- Solid sorption: silica gel – water, zeolite-water
- Ejector systems
- Thermo-mechanical systems

# System overview

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

# System typology

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| | | ***Closed cycle:*** high temperature cooling system (e.g. chilled ceiling) |
| Medium (80-110°C) |  | ***Closed cycle:*** chilled water for cooling and dehumidification |
| | | ***Closed cycle:*** refrigeration, air-conditioning with ice storage |

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



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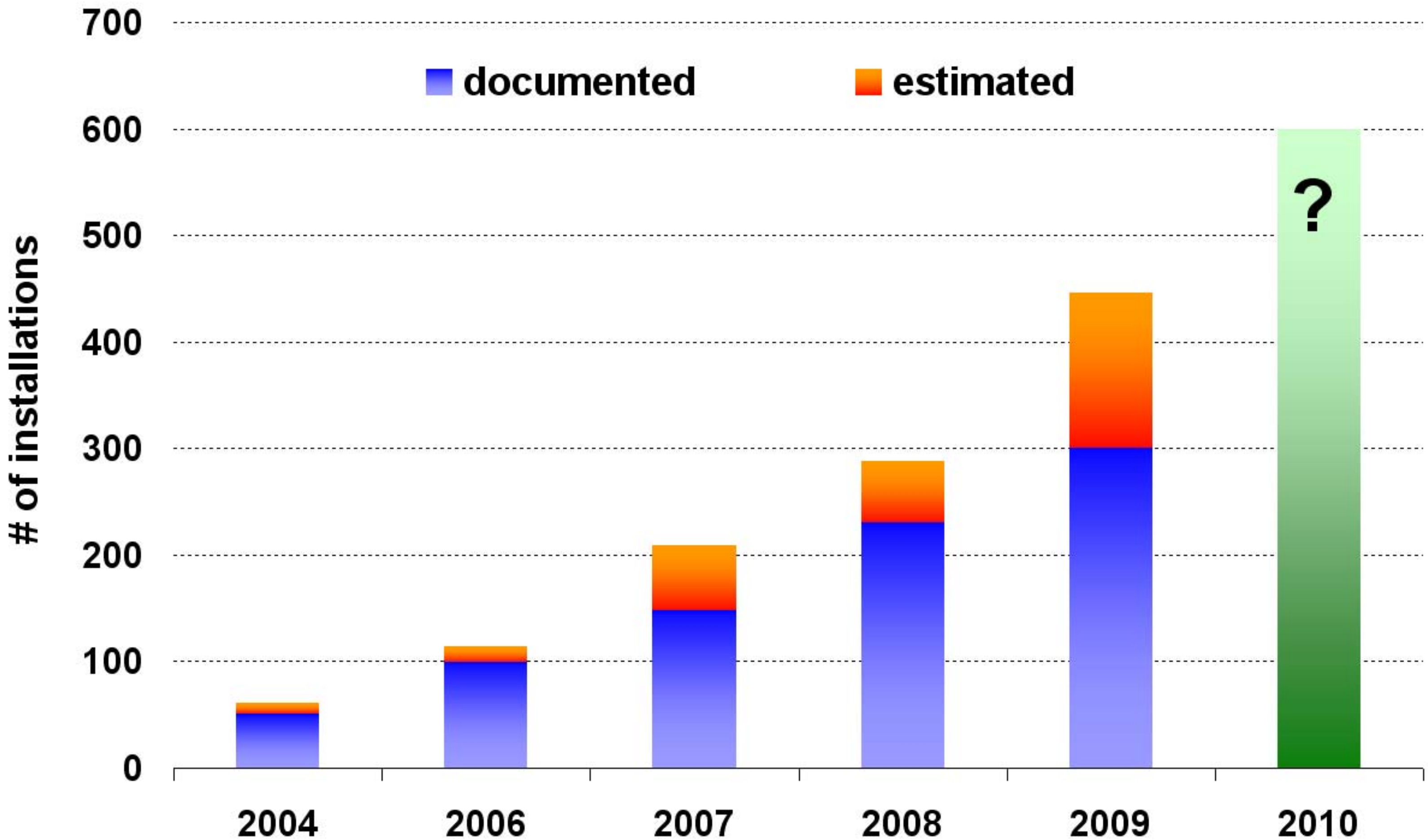
- Components and systems
- **Achievements**
- Solar thermal versus PV?
- Challenges and conclusion

# Market




Source: climasol | Fraunhofer ISE | Rococo | TECSOL | TECSOL | estimate

# New small capacity chillers

ecosol

PINK
ENERGIE- & SPEICHERTECHNIK


invensor


SorTech AG

YAZAKI

EAW Energieanlagenbau Westenfeld GmbH


ClimateWell

no claim on completeness



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# High-temperature applications

Wine cooling in Tunisia (MEDISCO)

Solar cooling for a hotel in Turkey (SOLITEM)

- Increasing number of systems using single-axis concentrating collectors (parabolic trough, Fresnel) in combination with thermally driven chillers (150°C … 200°C)
  - Double-effect chiller with high conversion efficiency (Coefficient of Performance COP 1.1…1.3)
  - Single-effect chiller with high temperature lift for low cooling temperatures (e.g. ice production) and high heat rejection temperatures (dry cooling towers)
- Application in sunny regions for buildings (e.g. hotels) or industrial application (e.g. cooling of food, ice production)

# Large and very large installations (examples)

CGD Bank Headquarter

Lisbon, Portugal

1560 m$^2$ collector area

400 kW absorption chiller

Source: SOLID, Graz/Austria

FESTO Factory

Berkheim, Germany

1218 m$^2$ collector area

1.05 MW (3 adsorption chillers)

Source: Paradigma, Festo

United World College (UWC) (in planning)

Singapore

3900 m$^2$ collector area

1.47 MW absorption chiller

Source: SOLID, Graz/Austria

# Association for thermally driven cooling

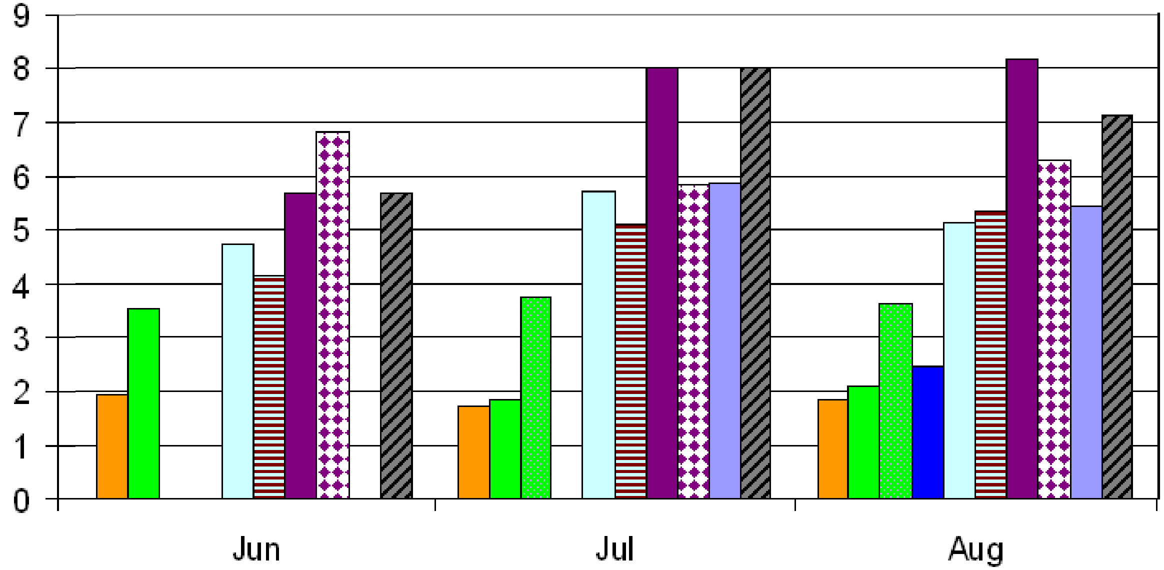
green chiller.eu
ASSOCIATION FOR SORPTION COOLING E.

- Greeen-Chiller association founded in 2009
- Goals
  - Promoting and developing of the solar and thermal cooling markets in Germany and Europe
  - Demonstration of different applications
  - Development of design tools
  - Standardisation of chillers and solar cooling / thermal cooling systems
- Application areas
  - Solar cooling
  - Cooling in combination with district heat networks
  - Using waste heat for cooling (industry, combined heat & power)

# System performance

- Significant progress in overall system performance
- Electric COP-values up to >8 shown in monitoring of Task 38 ➔ 8 kWh of cold production per 1 kWh of electricity for solar + cooling equipment (pumps, fans, heat rejection)

COP el cold - Task 38 Monitoring Systems Subtask A




Source: Dagmar Jähnig, AEE INTEC



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- Components and systems
- Achievements
- **Solar thermal versus PV?**
- Challenges and conclusion



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# Solar thermal versus PV?

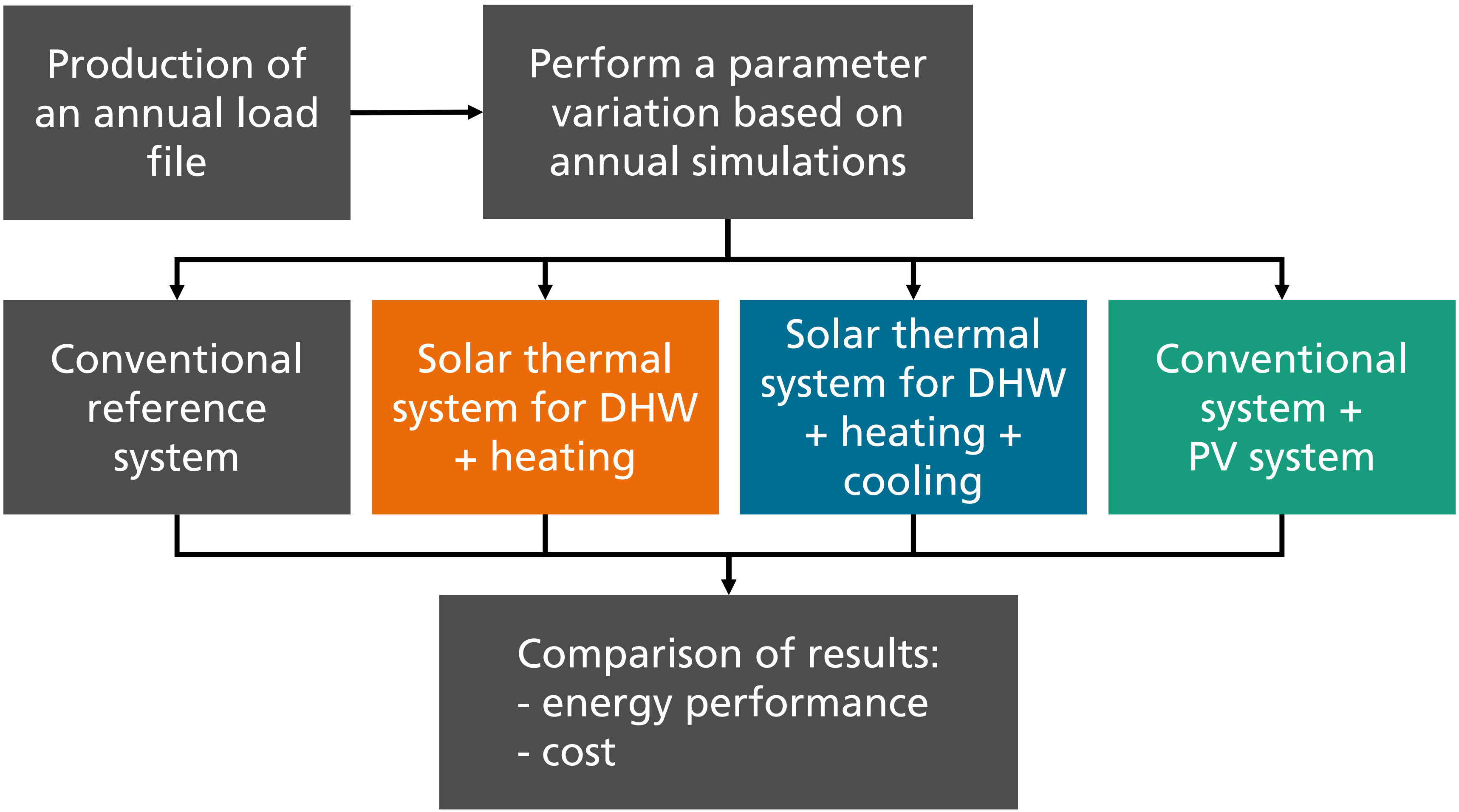
- How to use solar active systems in buildings in the best way?

- Main criteria
  - Technical maturity, robustness
  - Energy saving
  - Cost

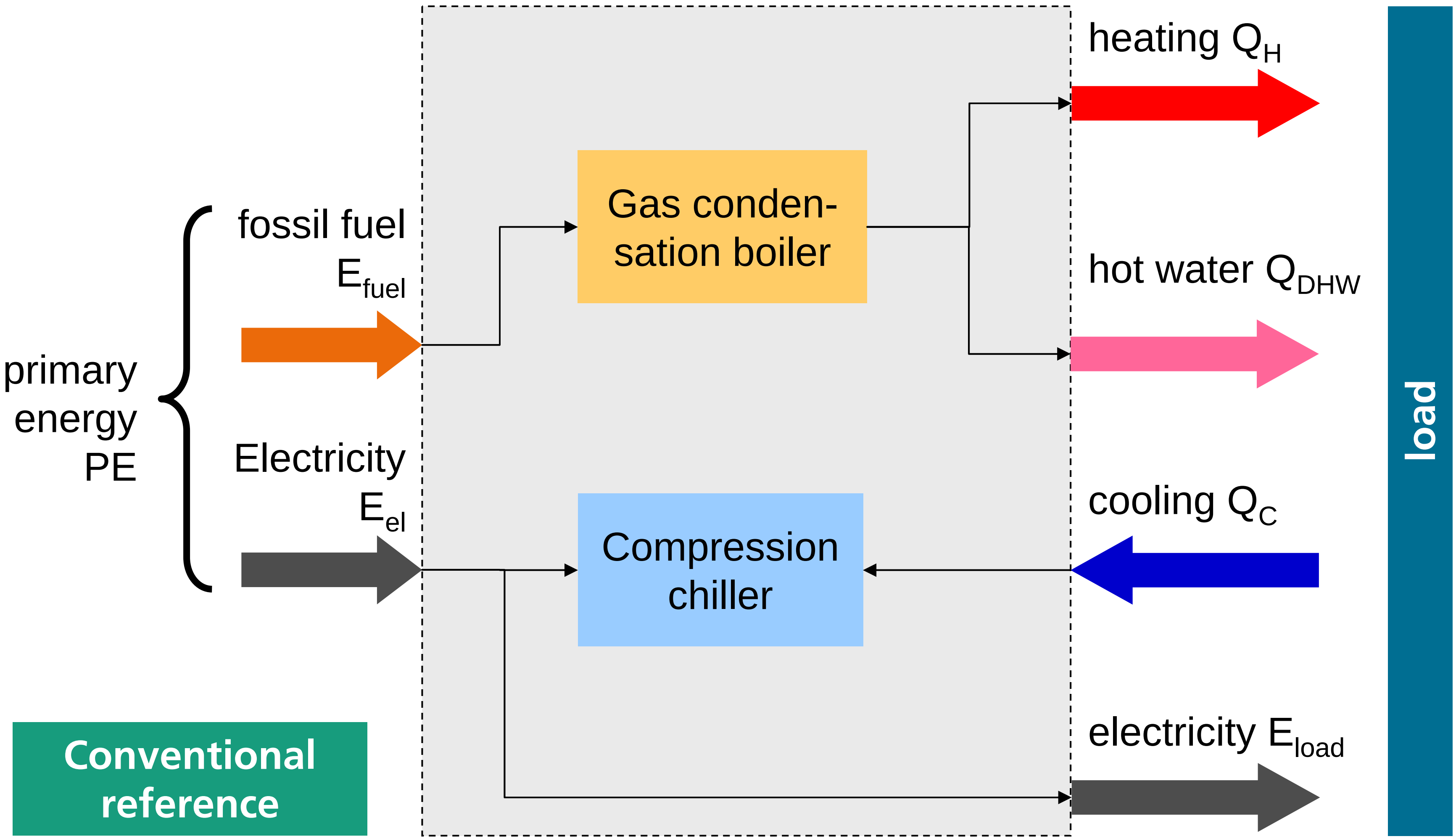
# Solar thermal versus PV?

- How to use solar active systems in buildings in the best way?
- Main criteria
  - Technical maturity, robustness
  - → **Energy saving**
  - → **Cost**
- Example: simulation study for a hotel in Madrid

# Methodology



# System boundary and energy balance



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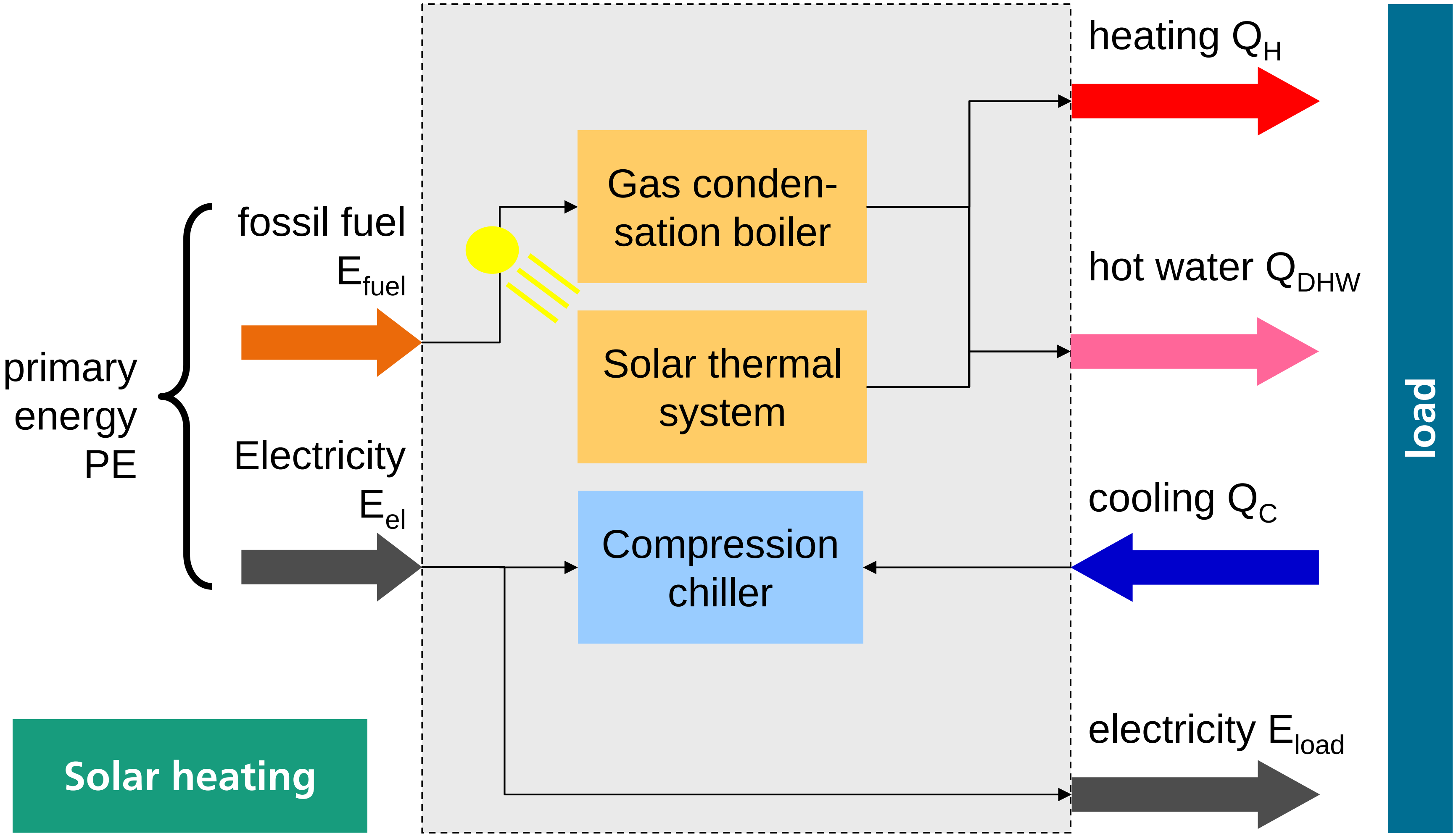


Solar heating



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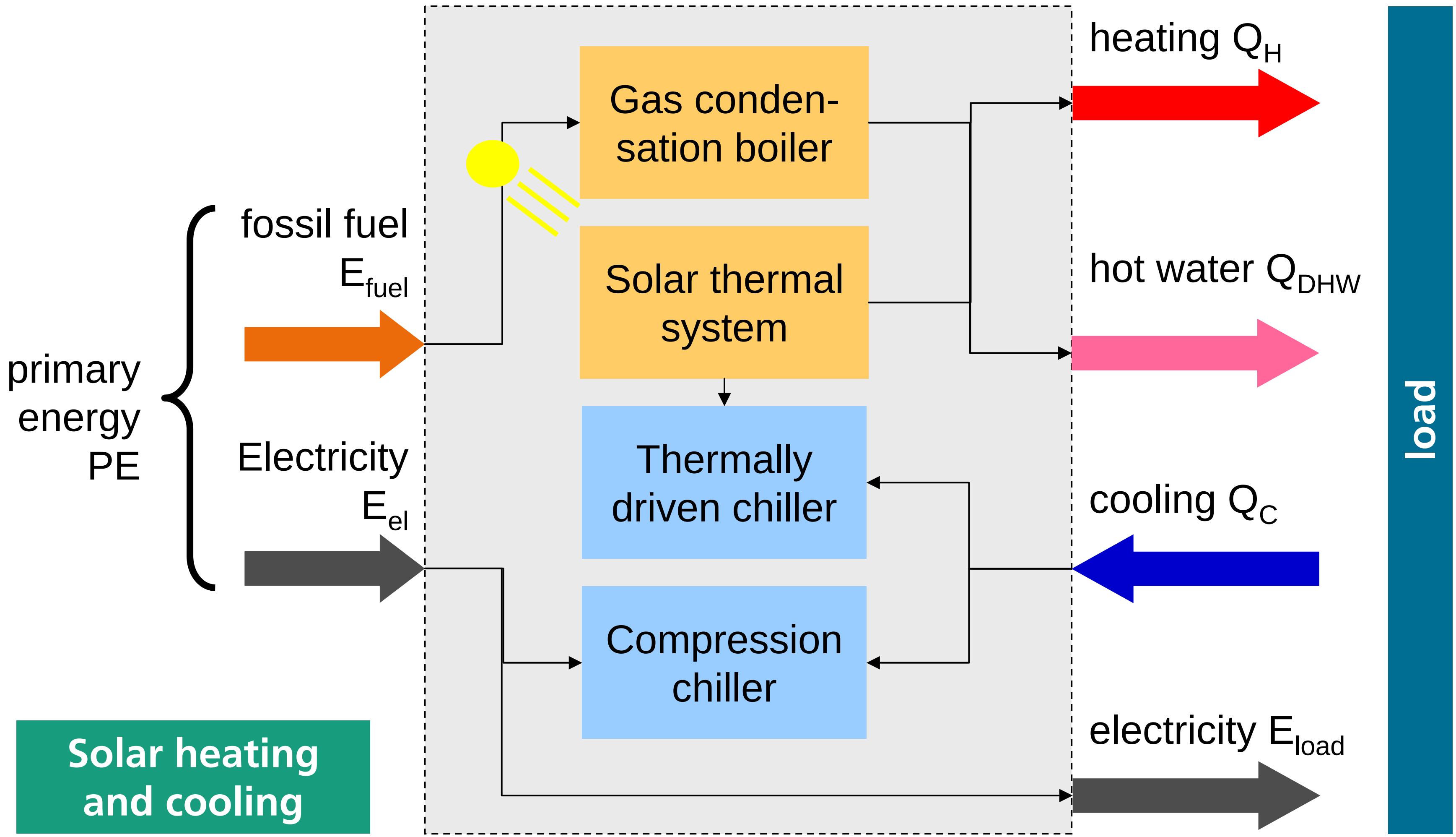
# System boundary and energy balance




**Solar heating and cooling**



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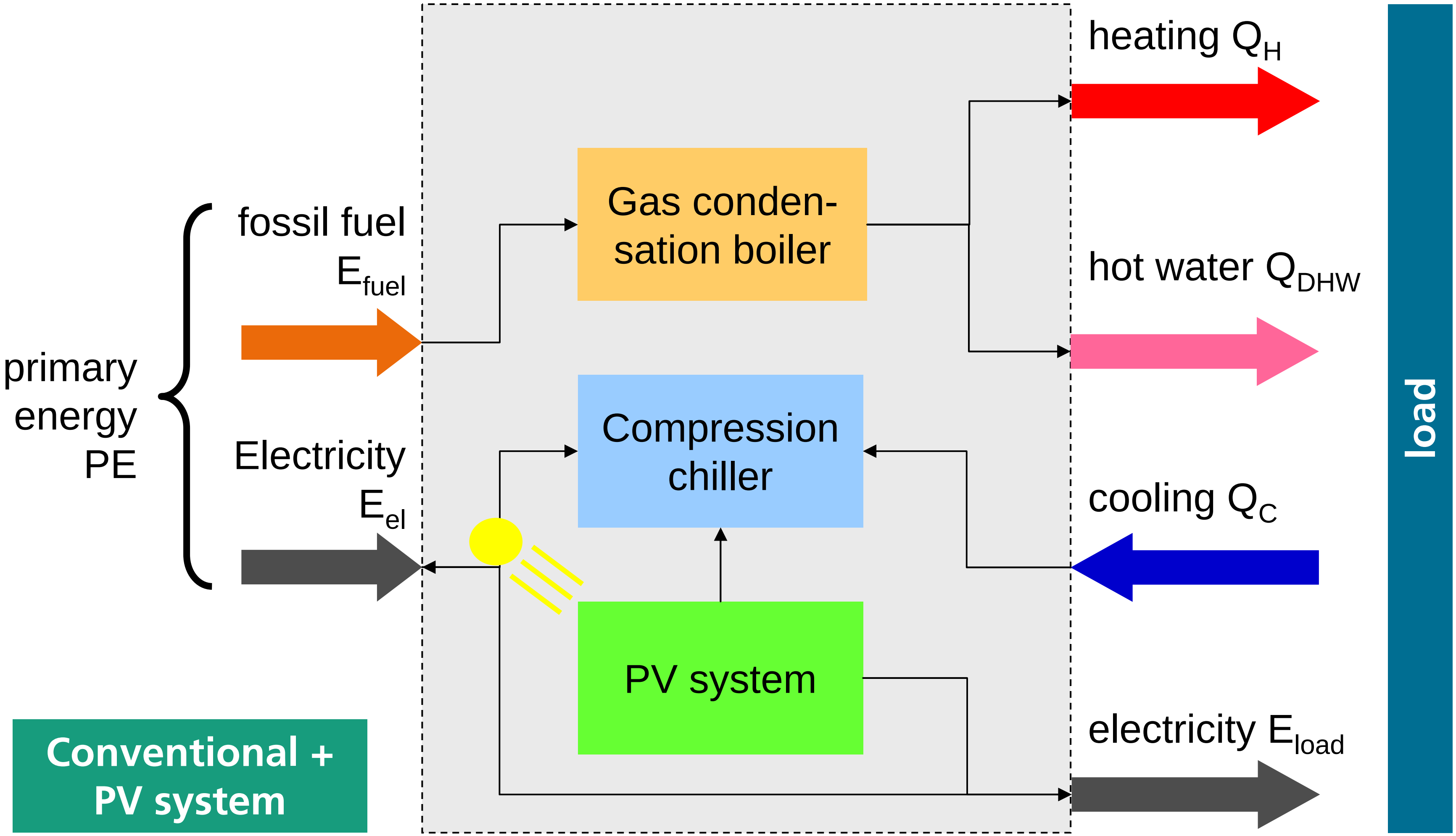
# System boundary and energy balance




**Conventional + PV system**

# Methodology and made assumptions

- Annual simulation based on hourly load and meteo data
- Load: Hotel in Madrid (4 zones) ➔ hourly load file
- Components
  - Advanced flat plate collector tilted 30° towards south (variation from 100 $m^2$ … 500 $m^2$)
  - Heat buffer storage (variation from 30 litre/$m^2$ … 80 litre/$m^2$)
  - Thermally driven chiller with average thermal COP of 0.68 (variation from 0 kW … 40 kW)
  - Cooling tower with a nominal COP of 25 (i.e. 25 kWh of rejected heat per 1 kWh of consumed electricity)
  - Vapour compression chiller with average EER of 3.0
  - Natural gas boiler with efficiency of 0.9

# Assumptions and methodology

- PV system
  - Mono-crystalline Si-wafer PV modules tilted 30° towards south (variation from 8 $kW_{peak}$ … 80 $kW_{peak}$); cost 3 € per $W_{peak}$ (including planing + installation)
  - Electricity produced higher than actual electricity load is fed into grid; reimbursement 50 % of the tariff for which electricity is purchased
- For all systems: no incentives, no subsidies, no tax reduction
- Operation strategy solar thermal system
  1. Cover heating demand
  2. Cover sanitary hot water demand
  3. Cover cooling demand in combination with thermally driven chiller



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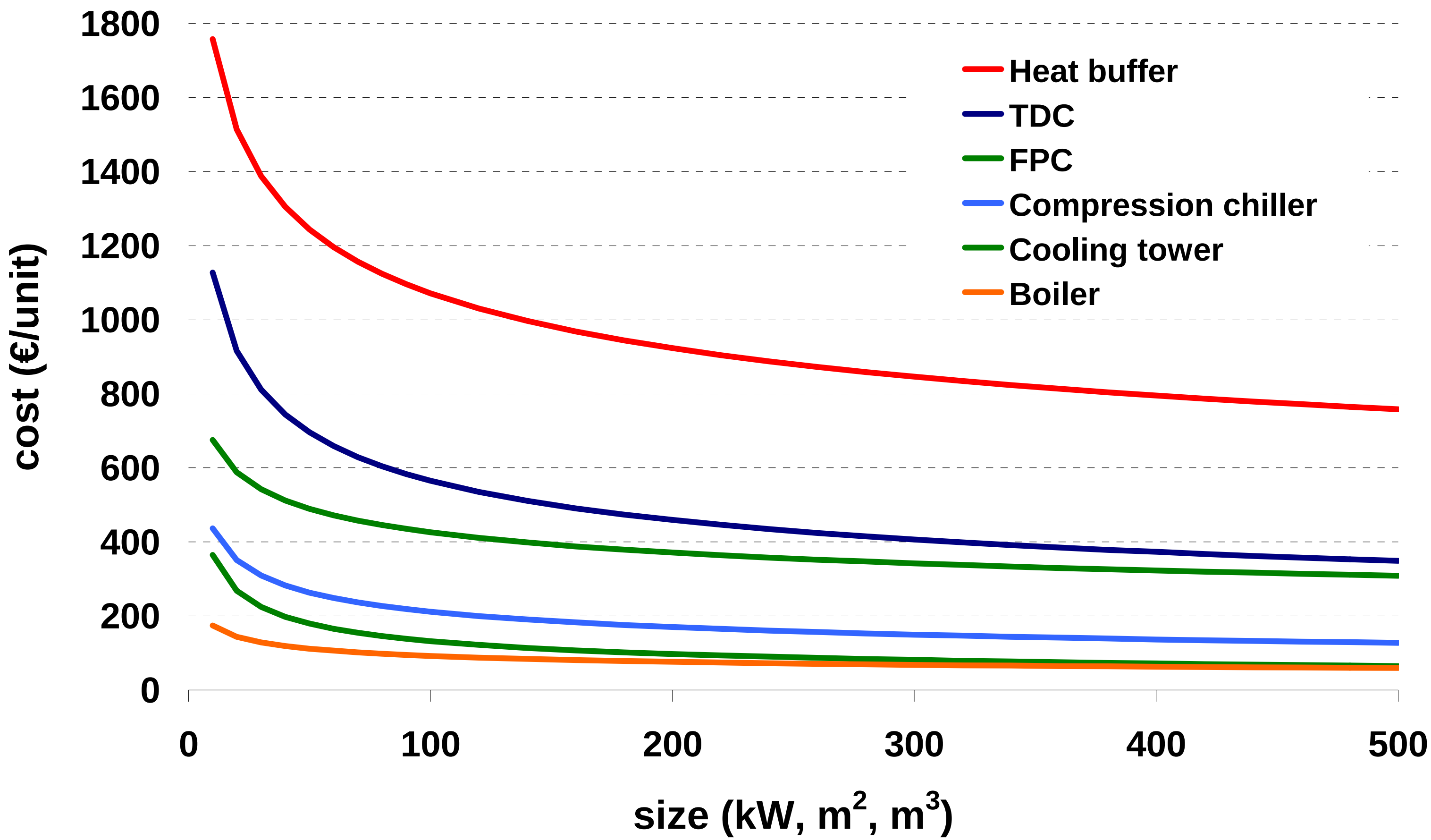
# Cost curves of key components




*Source for most cost curves: new cost models provided by Aiguasol/Spain within Task 38*



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# Further parameters

| | | | |
|---|---|---|---|
| **Other cost** | Planning | % of invest | 20.0% |
| | Installation | % of invest | 30.0% |
| | Maintenance | % of invest p.a. | 1.5% |
| **Energy cost** | Electricity | € / kWh | 0.15 |
| | Peak electricity cost | € / kW | 50.00 |
| | Fuel | € / kWh | 0.07 |
| | Increase rate electricity cost | % p.a. | 3% |
| | Increase rate fuel cost | % p.a. | 3% |
| **Other parameters** | Lifetime | a | 20 |
| | Interest rate | % | 5.0% |
| | PE factor electricity $f_{PE,el}$ | $kWh_{PE}$ / $kWh_{el}$ | 2.7 |
| | PE factor fuel $f_{PE,fuel}$ | $kWh_{PE}$ / $kWh_{fuel}$ | 1.1 |

# System comparison: alternative versus reference

- Saved primary energy

$$f_{PE,saved} = \left( \frac{PE_{reference} - PE_{alternative}}{PE_{reference}} \right) \cdot 100 \qquad [\%]$$

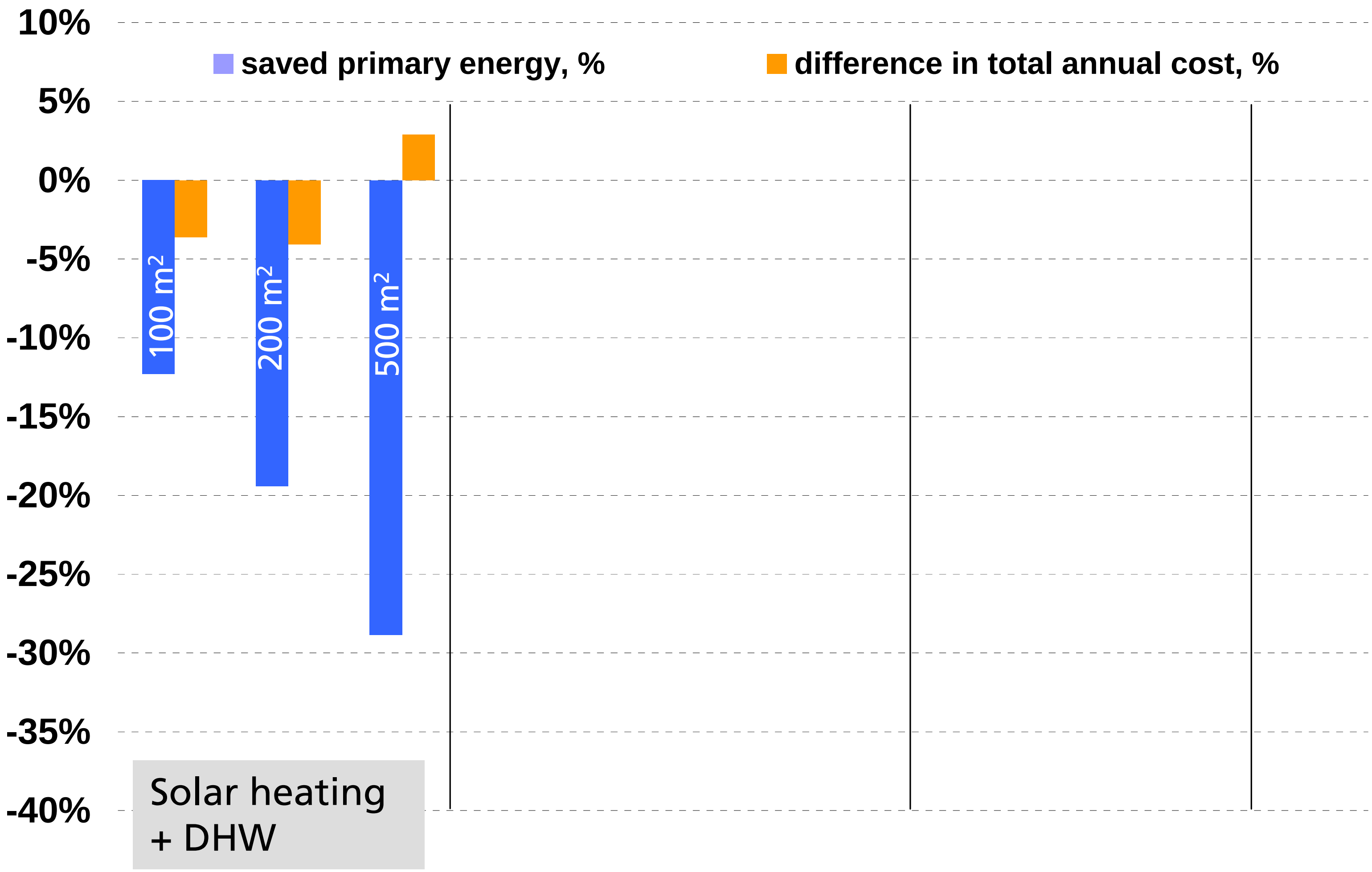
- Total annual cost ( = life cycle cost divided by lifetime)

$$C_{total,annual} = C_{capital,annual} + C_{maint\,enance,annual} + C_{operation,annual}$$

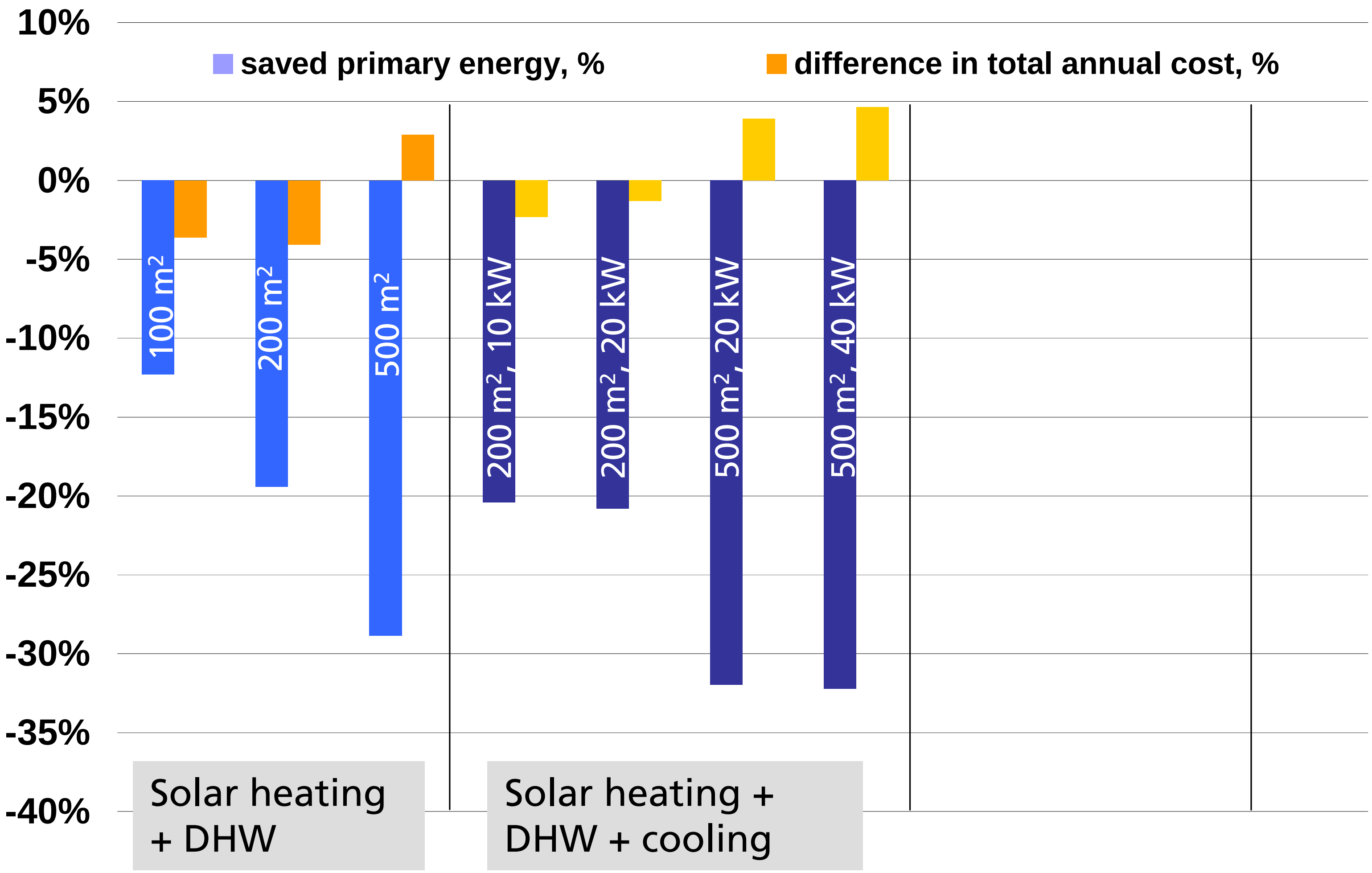
- Difference in total annual cost

$$\Delta C_{total,annual} = C_{total,annual,alternative} - C_{total,annual,reference}$$

# Results


10%
5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
saved primary energy, %
difference in total annual cost, %
100 m²
200 m²
500 m²
Solar heating
+ DHW

# Results



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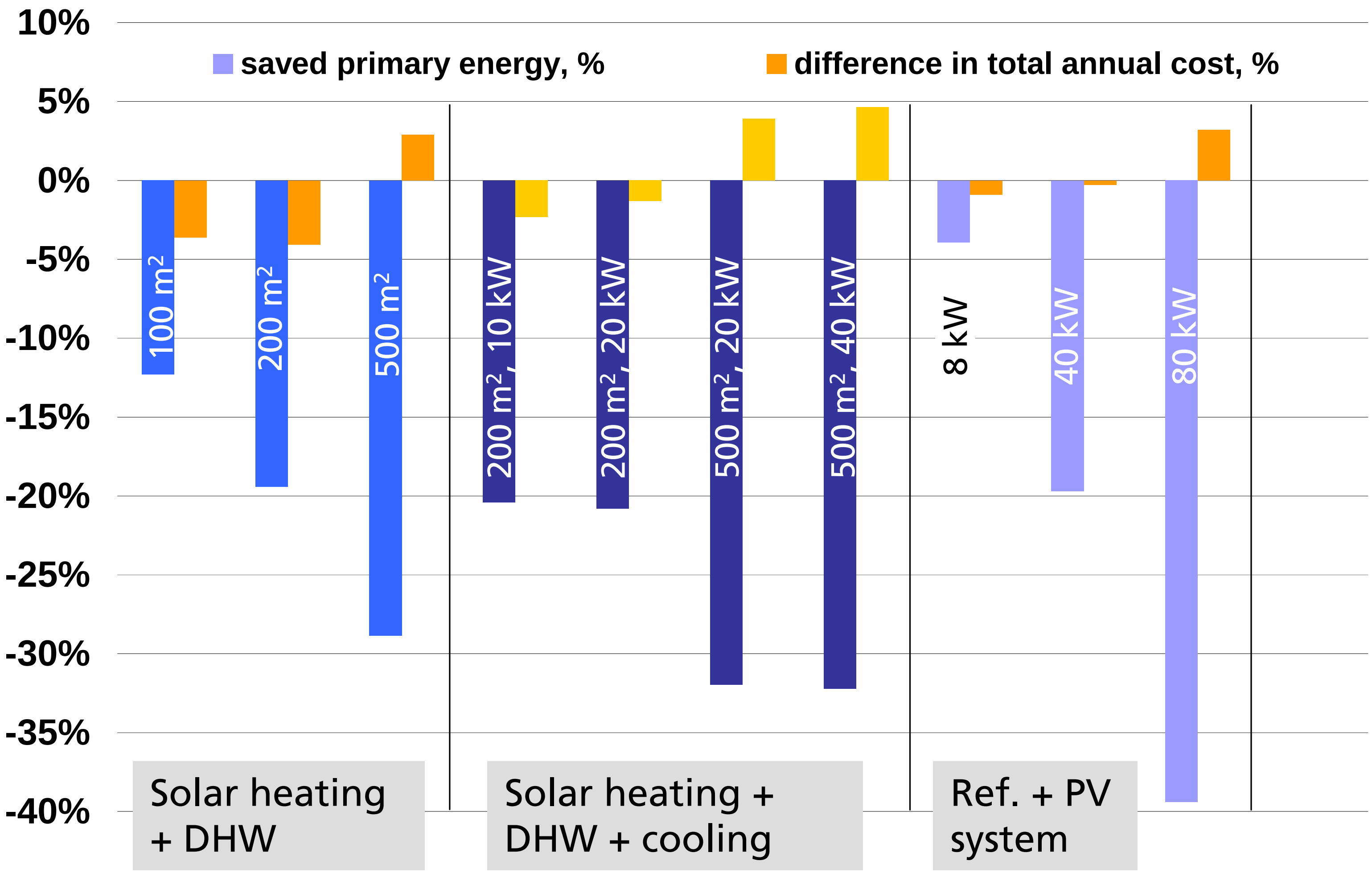




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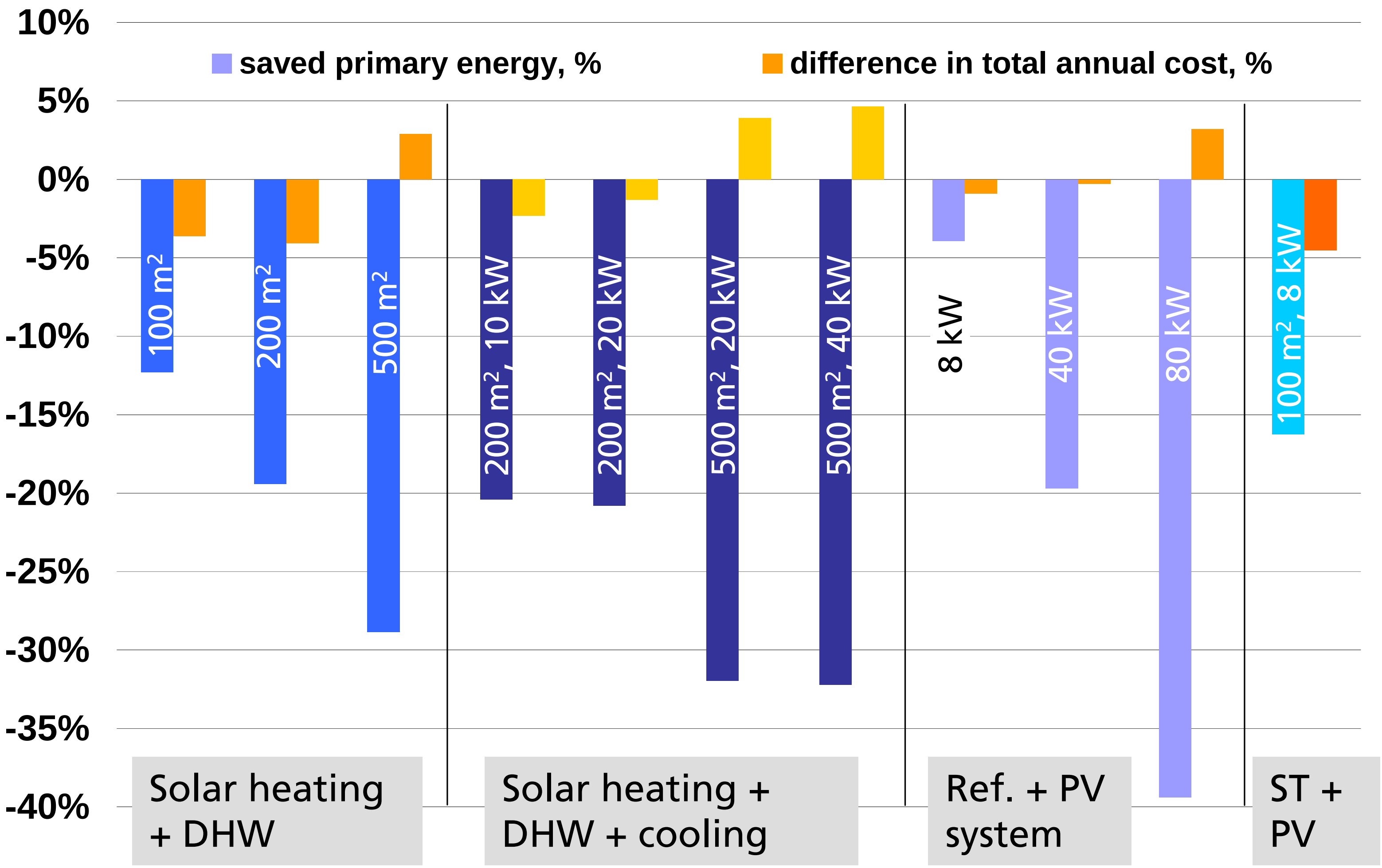
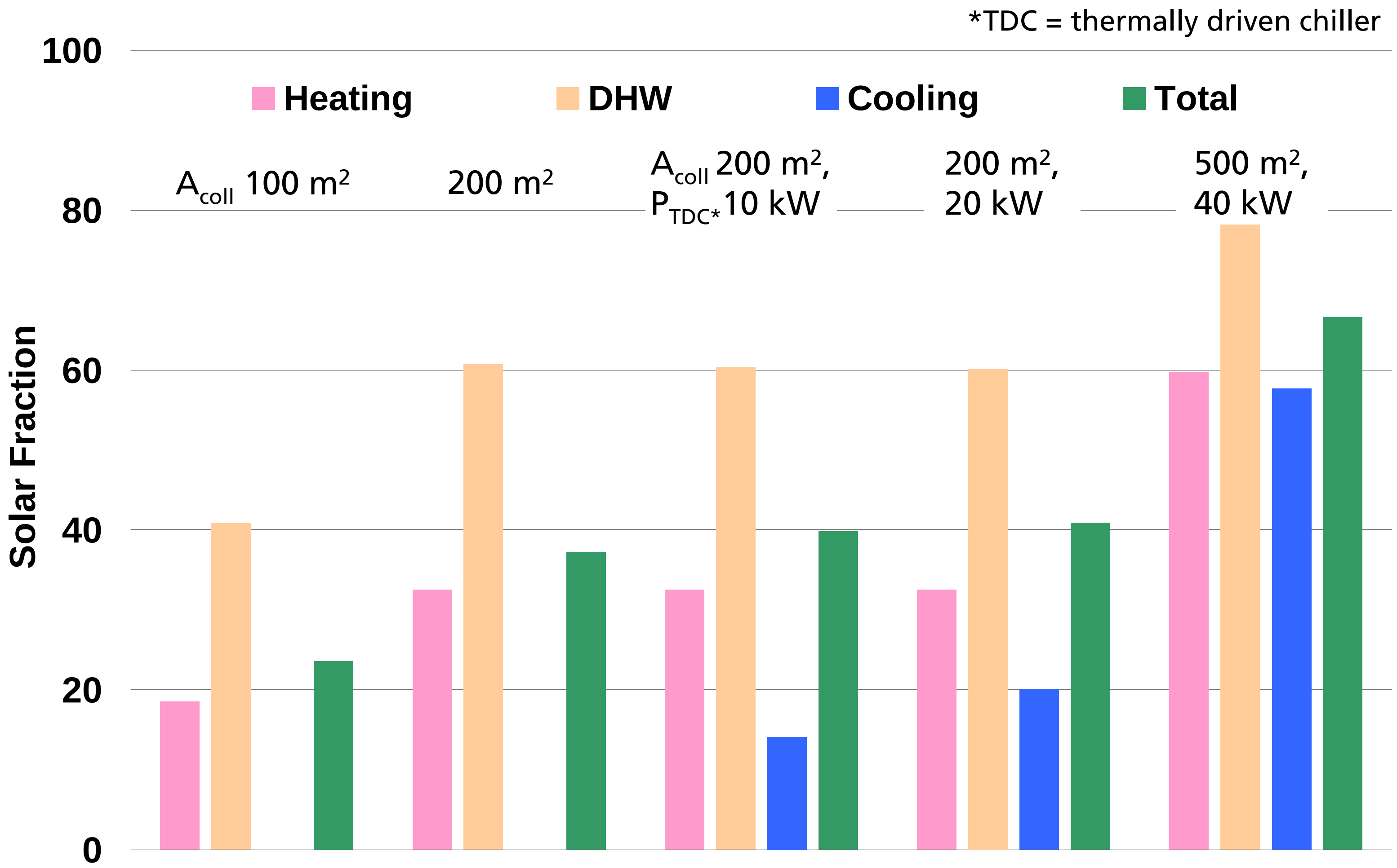

10%
5%
0%
-5%
-10%
-15%
-20%
-25%
-30%
-35%
-40%
saved primary energy, %
difference in total annual cost, %
100 m²
200 m²
500 m²
200 m², 10 kW
200 m², 20 kW
500 m², 20 kW
500 m², 40 kW
8 kW
40 kW
80 kW
100 m², 8 kW
Solar heating + DHW
Solar heating + DHW + cooling
Ref. + PV system
ST + PV

# Solar fractions



# Results

- Many systems are cost efficient under the assumptions made (considering complete life cycle cost; 3 % increase in energy prices (electricity, natural gas))
- Solar thermal system (small to medium size) without cooling is first priority (lowest cost of saved primary energy)
- A large solar heating & cooling system (overall solar fraction about 65 %) leads to an increase of total annual cost compared to reference (4 %)
- A large PV field (similar area) leads to a higher primary energy saving at lower increase of total annual cost
- However, this requires that electricity generated by PV which can not be used in the building can be fed into the electricity grid
- The large solar thermal heating & cooling system is the only system which leads to a reduction of peak electricity consumption (about 8 %)

- Components and systems
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# Challenges, conclusion

- Future buildings have to be highly energy-efficient and make use of locally available renewable energies, mainly solar
- Integrated solutions for heating, cooling and hot water adapted to specific buildings / load profiles / applications and climatic (solar) conditions are needed
- Solar heating and cooling (SHC) systems will play a significant role, since they provide an energy saving solution on the demand side without affecting the electricity grid
- For SHC considerable potentials for further reduction of cost and increase of efficiency exist on both, component and system level
- Main challenge is to assure high quality of installations in broad market
- Development of quality procedures for all phases of projects are essential: Design ➔ Installation ➔ Commissioning ➔ Operation / Maintenance / Monitoring



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# IEA Task 38 Solar Air-Conditioning and Refrigeration


Task 38 ends in December 2010

Many reports already on www.iea-shc.org

Among them

- Solar Cooling Position Paper (soon)
- 3rd completely revised edition of Handbook for Planners (mid next year)

**… thank you for your attention.**



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