Aspects on solar thermally driven heating and cooling and PV supported energy supply in buildings

Results from a comparative study within the EVASOLK project

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www.ise.fraunhofer.de
EvaSolK - Chances and perspectives of solar thermal cooling in comparison to Reference and PV-supported systems

- Funded by BMU*
- Partners:
  - ILK Dresden
  - ZAE Bayern
  - Fraunhofer ISE (Co-ordination)
- Focus:
  - Reference technologies (e.g. monitoring)
  - Comparative study (buildings; closed cycle systems)

*Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Comparative study: Solar cooling in buildings (closed cycle techniques)

How does solar cooling perform?

- In different climate zones
  - Central-/South Europe, North Afrika

- In different utilizations
  - A (e.g. residential) —
  - B, B+ (e.g. office) —
  - C, C+ (e.g. hotel) —

- In different configurations
  - Type of collector
  - Type of chiller
  - Heat backup type
  - With/without cold backup
Comparative study: Solar cooling in buildings (closed cycle techniques)

- General approach

**General approach**

- Site 1
  - Absorption
    - FP
    - VTC
    - Size
  - Adsorption
    - FP
    - VTC
    - Size

- Site 2
  - Utilisation type

FP: flat-plate collector
VTC: evacuated tube collector

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Comparative study: Solar cooling in buildings (closed cycle techniques)

- General approach

```
.. site 1

Absorption
  - FP
  - VTC
  - Size

Adsorption
  - FP
  - VTC
  - Size

most promising configuration

Reference

Reference + PV (grid-con.)
```

- ST

utilisation type

```
.. site 2

....
```

FP : flat-plate collector
VTC : evacuated tube collector

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Sites

- Stationary collectors, 1-effect TDC
  - Freiburg (DE)
  - Toulouse (FR)
  - Madrid (ES)
  - Palermo (IT)
  - Athens (GR)

- Line concentrating collectors, 2-effect TDC (absorption)
  - Antalya (TR)
  - Bechar (DZ)

TDC : thermally driven chiller
Configurations

- **Standard configurations with solar thermal system  ST**
  - Cold backup (el. compression chiller: chilled water)
  - A, B: also considered without cold backup (in this case, solar thermal coverage of cooling load > 70%)
  - Heat backup: not used for operating thermally driven chiller

- **Reference**
  - Cooling:
    - multi split units (utilisations A, B, C)
    - electric driven compression water chiller (utilisations B⁺, C⁺)

- **Reference + PV**
  - Additional: grid-connected PV
  - Sizing of PV:
    \[ PV_p = 0.5 \times \text{nominal electric power demand of cooling system} \]
    \( \rightarrow 75-90\% \text{ self consumption of PV electricity in building} \)
Boundary conditions

- **Investment cost**
  - Cost curves for key components
  - No funding, no feed-in revenues
  - Installation, planning, maintenance: fixed %-rates of investment

- **Other conditions**
  - Country specific energy prices and conversion factors (primary energy, CO\(_2\) emissions)
  - Increase of operation costs: electricity 5%/a; gas 3%/a
  - 20 years life cycle (Life Cycle)
    (life span of solar and thermal units: 20a, of el. compression based units: 15a)

- **Evaluation: Standard approach primary energy reduction cost**
  - Costs per saved primary energy within life cycle \( (CPE_{LCC}) \)*
    - € per kWh saved primary energy
    - \( CPE_{LCC} > 0 \): additional costs compared to Reference

* Also defined for costs per avoided CO\(_2\) emission within life cycle
Results: costs and savings

- Most promising for ST:
  Systems with additional large DHW demand
  - Example: capacity of TDC decreased from 75% of max. cooling load to 33%
  - Still high PE savings possible, specific cost decrease
  - → Avoid layout on peak load

TDC: thermally driven chiller
Results: costs and savings

- Effect of cost projections
  - Different cost scenarios (decrease in component costs)
  - S3: strongest cost decrease prediction (Collector system: - 40%; TDC system: - 50%)
  - → economic competitive to Ref+PV, but higher environmental savings
Example: Sensitivity

<table>
<thead>
<tr>
<th>Change</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase electricity price</td>
<td>5 %/a</td>
</tr>
<tr>
<td>Increase gas price</td>
<td>3 %/a</td>
</tr>
<tr>
<td>Cost projection</td>
<td>none</td>
</tr>
<tr>
<td>Life time multi-split unit</td>
<td>15 a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Change</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase electricity price</td>
<td>10 %/a</td>
</tr>
<tr>
<td>Increase gas price</td>
<td>6 %/a</td>
</tr>
<tr>
<td>Cost projection</td>
<td>S2</td>
</tr>
<tr>
<td>Life time multi-split unit</td>
<td>10 a</td>
</tr>
</tbody>
</table>

### Collector System
- Collector system: -10%
- TDC system: -25%

### Life Time
- Collector system: 10 a
- TDC system: 25%

### Example: Sensitivity

**A, without cold backup**

- Freiburg
- Palermo
- Toulouse
- Madrid
- Athen
- Madrid, Ref+PV
- Athen, Ref+PV

**B, without cold backup**

- Freiburg, Ref+PV
- Palermo, Ref+PV
- Toulouse, Ref+PV
- Madrid, Ref+PV
- Athen, Ref+PV

**ST**
Estimations on grid interaction

- Physical effects on grid frequency and voltage in local supply node: not investigated within EVASOLK
- Approach similar to Net Zero Energy Buildings (NZEBr):
  - Grid interaction index $f_{\text{grid}}$ (annual value)*:
    standard deviation of grid exchange fluctuations (normalized to average of grid load)**
  - The less $f_{\text{grid}}$, the smaller the ‘stress’ on the grid

* $f_{\text{grid}} = \sigma \left( \frac{P_{\text{Grid},i}}{\langle |P_{\text{Grid},i}| \rangle} \right)$

** normalization different than in NZEB aproach

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Grid interaction

- Utilisation type A
  - Decrease in peak-load from grid with solar thermal cooling, especially in configuration without cold backup
  - Increase of grid stress with Ref+PV

**Configuration:**
Gas boiler as heat backup

n ... size of PV compared to chiller capacity
Expert survey (I) “Trends and developments in cooling technologies”

- Conducted by ZAE Bayern and ILK Dresden (2012 – 2013)
- 30 experts of air-conditioning and refrigeration contacted, feedback from 19

Interviewed persons
Expert survey (II)  
“Trends and developments in cooling technologies”

- Market trends

Expected lifetime of mono-split unit (hardware store quality, normal use in Central Europe)

Expected lifetime of mono-split unit (brand quality, normal use in Central Europe)

Expected yearly increasing sales rates of air-conditioning units

Expected maximum future increase of sales rates related to today's rates

Do you expect a medium-/long-term saturation of the market?

How do you expect a distribution of non-brand and brand quality units?
**Expert survey (III)**

**Technology trends**

- Expected technology (chilled water units or direct evaporation) for existing building stock in private household in Europe

- Expected technology (chilled water units or direct evaporation) for hotel sector in Europe

- Expected technology (chilled water units or direct evaporation) for office sector in Europe

- Which technology (chilled water units or direct evaporation) is expected to be advantageous concerning EER / COP?

- Which future role plays the efficiency in development and marketing?

- Expected future leakage rates of refrigerants

- Expected influence of permanently decreasing PV-module prices on the development of air-conditioning units
Expert survey (IV)
“Trends and developments in cooling technologies”

- Expected EER of split units in 10 years

Question:
Today, an EER > 3.2 is required to get the A-rating for a split-unit. A large number of units already reach nominal values of EER between 3.5 and 4.5.
What do you expect as the typical EER of a split-unit in 10 years?
(boundary conditions: ambient temperature 35°C, room air temperature 27°C)
# Monitoring results of compression chillers
(by ZAE and ILK, operated in Germany)

<table>
<thead>
<tr>
<th>System</th>
<th>Nom. cooling capacity</th>
<th>SEER</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment for room air-conditioning</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono-split</td>
<td>2.6 kW</td>
<td>3.5 – 4.1</td>
<td>- 2 summer seasons</td>
</tr>
<tr>
<td>(hardware store quality, not regulated)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono-split</td>
<td>5 kW</td>
<td>4.5</td>
<td>- Cooling season only</td>
</tr>
<tr>
<td>(modulating)</td>
<td></td>
<td>3.6</td>
<td>- Whole year operation incl. standby</td>
</tr>
<tr>
<td>Multi-split</td>
<td>40 kW</td>
<td>3.1 – 4.4</td>
<td>- 3 seasons operation</td>
</tr>
<tr>
<td>(often part load operation &lt; 5 kW)</td>
<td></td>
<td></td>
<td>- without internal unit</td>
</tr>
<tr>
<td>Chilled water system</td>
<td>46.6 kW</td>
<td>3.6 / 3.1</td>
<td>- without chilled water pump</td>
</tr>
<tr>
<td>(with 2 units)</td>
<td></td>
<td>3.0 / 2.5</td>
<td>- with chilled water pump</td>
</tr>
<tr>
<td>Chilled water system</td>
<td>54 kW</td>
<td>4.4 / 2.8</td>
<td>- without chilled water pump</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- with chilled water pump</td>
</tr>
<tr>
<td><strong>Equipment for cold storages</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling chamber (&lt;10°C)</td>
<td>2 kW</td>
<td>1.2</td>
<td>- overall system</td>
</tr>
<tr>
<td>Brine chiller</td>
<td>17.4 kW</td>
<td>2.3</td>
<td>- without brine pump</td>
</tr>
</tbody>
</table>
Monitoring results of compression chillers – example for cold storage applications
(by ZAE and ILK, operated in Germany)
Conclusions (I)

Solar thermally driven cooling is still not on a par with grid connected PV system technology due to the small market penetration, this results in comparatively high investment costs for thermal options.

A differentiated evaluation of the technical approaches is necessary:

**Solar thermal driven system options**

- Environmental beneficial effects are high → high primary energy and CO₂ savings are possible

- Favourable applications: high full load hours of cooling equipment (>> 500 h/y), high radiation sums

- Compensation of electricity only with solar thermal options are difficult in terms of economics with present costs (and even with moderate cost decrease forecasts), especially in comparison to the option Ref+PV;

  pre-conditions for an economic use of solar thermally driven cooling are rathermore:
Conclusions (II)

Solar thermal driven system options

- Pre-conditions for an economic use of solar thermally driven cooling are rathermore:

  - Optimised use of collector system throughout the year covering additional heat demands, e.g., high domestic hot water demand (hotels, hospitals, production, ..) ⇒ utilisation chain of solar heat
  
  - Accurate planning and layout in large capacity systems ⇒ no layout of thermal driven cooling components on peak-load
  
  - Whenever compatible with requirements on room air states: waiving of cold-backup installation
  
  - Moderate to distinct cost decrease (or proportional funding) in collector and thermally driven cooling system
  
  - 2-effect cooling systems at appropriate sites
  
  - Whenever possible: use of heat rejection circuit for pre-heating feed water (large quantities, e.g., production facilities)
Conclusions (III)

Option Reference + PV

A) regarding costs and environmental benefits

- In applications with dominating electricity consumption (little fossil fuel input for heating only):
  → advantages of Ref+PV in economic and environmental terms

- In applications with high additional thermal power demands (DHW):
  → lower environmental effects than solar thermal options; smaller differences in costs

B) regarding grid interaction, grid-stress (qualitative)

- In general: increase of grid stress → to be considered in ‘weak’ public grids

- In some application types: higher peak electricity exchange with grid compared to solar thermal driven option → to be considered in ‘weak’ public grids

Please, note:

- Only standard, marketable solar cooling solutions and configurations are considered
Conclusions (IV)

Monitoring of compression chillers

- Best results of SEER (equal to manufacturer’s data) at systems without additional planning and installation demand
- Main reasons for worsening of SEER
  - Non-optimised operation (control) of cold water distribution pump and standby operation
  - Oversizing of the chiller results in inefficient part load operation or stop and go operation
Final remarks

- EVASOLK was funded by the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (FKZ 0325966ABC)

- Final public report (German language):
  - TIB (Technische Universitätsbibliothek Hannover)
    www.tib-hannover.de
  - or
  - www.solare-kuehlung.info
Thank you for your attention!

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