Solar Thermal or Photovoltaic Cooling?

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Solar cooling systems

Intersolar Europe 2012
Prof. Dr. Ursula Eicker
PV Module Prices Development 2009 - 2011

Source: www.solarserver.de
Methodology: Simulation studies in planning phase

- Location
- Building characteristics
- Thermal solar system characteristics

Production of annual load and weather data

TRNSYS

TRANSOL

INSEL

Thermal solar cooling system (absorption chiller)

Electrical solar cooling system (compression chiller + PV modules)

Reference system (compression chiller)

Comparison of results:
- Energy performance
- Costs
Small office building European conditions

Task 25 Office building in three climates (Palermo, Madrid, Stuttgart)

- Absorption 35 kW (COP = 0.7) versus Compression 30 to 50 kW
- Backup CCM 10kW (COP= 3.5)
- Flat plate/vacuum tube collectors – Monocrystalline Silicon
- Heat storage (5m³)
- Cold storage (1m³)
- Wet cooling tower
Compressor performance model

- COP (Tin cond = 25°C)
- COP (Tin cond = 30°C)
- COP (Tin cond = 35°C)
- COP (Tin cond = 40°C)
- COP sim (Tin cond = 25°C)
- COP sim (Tin cond = 30°C)
- COP sim (Tin cond = 35°C)
- COP sim (Tin cond = 40°C)
- Pel (Tin cond = 25°C)
- Pel (Tin cond = 30°C)
- Pel (Tin cond = 35°C)
- Pel (Tin cond = 40°C)
- Pel sim (Tin cond = 25°C)
- Pel sim (Tin cond = 30°C)
- Pel sim (Tin cond = 35°C)
- Pel sim (Tin cond = 40°C)
Cooling loads

<table>
<thead>
<tr>
<th>Case</th>
<th>City</th>
<th>Uwall (W/m² K)</th>
<th>Internal loads</th>
<th>Sun Protection</th>
<th>Annual cooling load (kWh/m²)</th>
<th>Annual heating load (kWh/m²)</th>
<th>Maximum cooling load (W/m²)</th>
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<td>54</td>
<td>2</td>
<td>30.2</td>
</tr>
</tbody>
</table>

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Solar fraction for PV and ST cooling
Electrical energy requirement

![Graph showing electrical COP vs. annual cooling load](https://example.com/graph.png)

- **Stuttgart (Uwall = 1.1 W/Km²)**
- **Madrid (Uwall = 0.66 W/Km²)**
- **Palermo (Uwall = 1.1 W/Km²)**
- **Stuttgart (Uwall = 0.41 W/Km²)**
- **Mad PV (Uwall = 0.41 W/Km²)**

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Reduction of auxiliary energy by optimised control

Annual electricity consumption / kWh kW⁻¹

Case 1 Case 2 Case 3 Case 3.1 Case 3.2 Case 4 Case 5 Case 6

Compression Chiller

dry recooler

open wet cooling tower

COPel / -

Qel, cold water dist. pump
Qel, air heater
Qel, evaporator pump
Qel, abs./cond. pump
Qel, generator pump
Qel, ACM / Compressor
Qel, col. pump
Qel, cooling tower / recooler

COPel
Primary energy savings for cooling

- Compr.+PV
  - Palermo (45.79 kWh/m²) low - CASE 1
  - Palermo (61.15 kWh/m²) low - CASE 2
  - Palermo (94.24 kWh/m²) high - CASE 3
  - Palermo (140.99 kWh/m²) high - CASE 4
Total annual costs

- Stuttgart (8.4 kWh/m²) low - CASE 9
- Stuttgart (16.76 kWh/m²) low - CASE 10
- Stuttgart (31.28 kWh/m²) high - CASE 11
- Madrid (33.93 kWh/m²) low - CASE 5
- Madrid (35.64 kWh/m²) low - CASE 6
- Palermo (45.79 kWh/m²) low - CASE 1
- Stuttgart (54.11 kWh/m²) high - CASE 12
- Palermo (61.15 kWh/m²) low - CASE 2
- Madrid (88.34 kWh/m²) high - CASE 7
## Cost of cooling production

### Photovoltaic Cooling System

<table>
<thead>
<tr>
<th>CASE</th>
<th>PV Export Grid</th>
<th>Feed in tariff</th>
<th>Thermal Solar Cooling System</th>
<th>Heat use</th>
<th>Heat price</th>
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<td>No</td>
<td>-</td>
<td>-</td>
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<tr>
<td>B</td>
<td>yes</td>
<td>Germany 0.2455 €/kWh</td>
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<td>Spain 0.1855 €/kWh</td>
<td>Spain 0.0506 €/kWh</td>
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<td>C</td>
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<td>Germany 0.42 €/kWh</td>
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<td>Germany 0.114 €/kWh</td>
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<td>Spain 0.4 €/kWh</td>
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<td>Spain 0.1855 €/kWh</td>
<td>Spain 0.101 €/kWh</td>
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</tbody>
</table>

### Cost of Cooling Production

\[
\text{cost of cooling production} = \frac{\text{annual total costs of solar system}}{\text{total cooling energy produced}}
\]
Design project Baden Württemberg State Ministry

Motivation:
strong summer overheating, no night ventilation
Renewable heat law: 15 % solar thermal for heating and cooling (of public buildings)

Result:
25-50% solar fraction with thermal cooling system
Recommendation for small systems

PV most cost effective – but low solar fractions of 20-30%
Solar thermal cooling for base load to reduce costs
Peak loads with electric compression + PV with grid feed in
Large solar cooling systems for mediterranean climates

Cairo office building
15100 m² surface
52 W/m² cooling load
130 kWh/m² cooling energy demand
### Comparison of large multi-effect systems

<table>
<thead>
<tr>
<th>Case</th>
<th>Chiller Type</th>
<th>Cooling Capacity</th>
<th>Collector Type</th>
<th>Collector Area</th>
<th>Storage Tank</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>brut</td>
<td>hot</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>aperture</td>
<td></td>
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<tr>
<td>Case 1</td>
<td>Single Effect</td>
<td>422 kW</td>
<td>Vacuum Tube</td>
<td>2025 m²</td>
<td>20 m³</td>
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<td></td>
<td></td>
<td>1350 m²</td>
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<tr>
<td>Case 2</td>
<td>Double Effect</td>
<td>500 kW</td>
<td>Linear Fresnel</td>
<td>2050 m²</td>
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<td></td>
<td></td>
<td>1320 m²</td>
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<td>Case 3</td>
<td>Triple Effect</td>
<td>563 kW</td>
<td>Linear Fresnel</td>
<td>1280 m²</td>
<td>-- m³</td>
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<td></td>
<td></td>
<td></td>
<td>800 m²</td>
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</table>

**THERMAX, single effect**

- ProChill LT12C

**Shuangliang, double effect**

- 500 kW

**Kawasaki Sigma, triple effect**

- Ace CF01-10-0001

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Absorption Cooling Fraction and Solar System Efficiency

<table>
<thead>
<tr>
<th>System</th>
<th>ACM Fraction</th>
<th>Solar System Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single effect ACM + vacuum tube collectors</td>
<td>37%</td>
<td>91%</td>
</tr>
<tr>
<td>Double effect ACM + Fresnel collectors</td>
<td>40%</td>
<td>31%</td>
</tr>
<tr>
<td>Triple effect ACM + Fresnel collectors</td>
<td>27%</td>
<td>27%</td>
</tr>
</tbody>
</table>

ACM fraction / %
Solar system efficiency / %
Heating Energy Consumption and Average $\text{COP}_\text{th}$

- Single effect ACM + vacuum tube collectors: 1050 MWh a⁻¹, $0.70$
- Double effect ACM + Fresnel collectors: 972 MWh a⁻¹, $1.31$
- Triple effect ACM + Fresnel collectors: 534 MWh a⁻¹, $1.83$

Heating energy consumption / MWh a⁻¹
$Q_{h\_solar}$ $Q_{h\_additional}$ $\text{COP}_\text{th}$
Primary Energy Efficiency

The chart shows the primary energy consumption and energy ratio PER for various solar energy systems. The systems are categorized into single effect, double effect, and triple effect systems, with different combinations of collectors and energy storage.

- Single effect: ACM + vacuum tube collectors
- Double effect: ACM + Fresnel collectors
- Triple effect: ACM + Fresnel collectors
- CCM with PV collectors, grid as ideal storage
- CCM with PV collectors, electricity directly used
- Reference system with compression chiller only

The primary energy consumption and PER values are as follows:

<table>
<thead>
<tr>
<th>System Type</th>
<th>Primary Energy Consumption / MWh a⁻¹</th>
<th>PER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single effect, ACM + vacuum tube</td>
<td>183</td>
<td>1.43</td>
</tr>
<tr>
<td>Double effect, ACM + Fresnel</td>
<td>443</td>
<td>1.50</td>
</tr>
<tr>
<td>Triple effect, ACM + Fresnel</td>
<td>462</td>
<td>1.60</td>
</tr>
<tr>
<td>CCM with PV collectors, grid as ideal storage</td>
<td>692</td>
<td>1.59</td>
</tr>
<tr>
<td>CCM with PV collectors, electricity directly used</td>
<td>640</td>
<td>1.37</td>
</tr>
<tr>
<td>Reference system with compression chiller only</td>
<td>1240</td>
<td>1.04</td>
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</tbody>
</table>

Electricity, Additional heating, Additional cooling, PER
Overall Cooling Costs / Office Building in Cairo, Egypt

Prices:
- Gas = 0.0174 €/kWh
- Electricity = 0.062 €/kWh
- Water = 1.6 € / m³

Source: www.worldtribune.com

Inflation rate = 5.6%/a
Discount rate = 6%/a
Overall Cooling Costs / Office Building in Cyprus

Prices:
- Gas = 0.101 €/kWh
- Electricity = 0.230 €/kWh
- Water = 4.0 € / m³

Inflation rate = 5.6%/a
Discount rate = 6%/a

Operational cost annuity
System cost annuity
Cooling costs [€/MWh]
Annual cooling costs [€/a]
Conclusion

- Solar thermal and photovoltaic cooling allows for primary energy savings of 30 to 50% in typical office building projects.
- Good partial load control is important for primary energy savings.
- For reduced feed in tariffs and increasing heat costs the total costs of PV and solar thermal cooling are comparable.
- For long operating hours solar cooling is competitive with conventional cooling.
- The primary energy efficiency of solar thermal cooling is comparable or higher than photovoltaic cooling, especially when double or triple effect chillers are used.