State of the Art in Solar Cooling

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CSIRO Energy Technology
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Content

• Solar cooling technology developments
• Market developments & barriers
• Some solar cooling selection examples
• Cautionary tales
Solar Cooling

Solar cooling uses heat from the sun to drive a thermal cooling process.

This displaces the use of fossil fuel derived electricity that would otherwise be used in the conventional mechanical cooling process.

A New Technology?

World Exhibition 1878 in Paris - A. Mouchot Produced the First Ice Block With Solar Energy
Key Elements of Solar Cooling

Solar Heat Collection

Thermal Cooling Process

Cold Delivery & Building Integration

The Core Solar Cooling Technologies

Solar Heat Collection
- Air collectors
- Flat plate collectors
- Evacuated tube collectors
- Tracking collectors

Thermal Cooling Process
- Absorption chillers
  - One stage
  - Two stage
- Adsorption chillers
- Desiccant cooling
  - Solid
  - Liquid

But auxiliary equipment items (cooling towers, buffer tanks, heat exchangers etc) are also very important.
Large Scale LiBr/ Water Absorption Chillers
(Mature technology, chilled water output)

<table>
<thead>
<tr>
<th>Chiller</th>
<th>Coefficient of Performance (COP)</th>
<th>Required Heat Source Temperature</th>
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</thead>
<tbody>
<tr>
<td>Single Stage</td>
<td>0.7</td>
<td>80-120°C</td>
</tr>
<tr>
<td>Two Stage</td>
<td>1.2</td>
<td>160-180°C</td>
</tr>
</tbody>
</table>

Medium Scale Absorption Chillers
(Single Stage Only)

- **Yazaki, Japan** (35 - 105 kW)
- **Thermax, India** (70 - 175 kW)
- **EAW, Germany** (30 - 200 kW)
- **AGQ, Germany** (30 - 500 kW)
Small Absorption Chillers
(Single Stage Only)

- Yazaki (17.5 - 35 kW)
- EAW (17.5 - 30 kW)
- Rotartica (4.5 kW)
- Pink (12 kW)
- Thermax (17.5 kW)
- Sonnenklima (10 kW)
- Climatwell (10 kW)

ADSorption Chillers Too...

- Sortech (8 - 15 kW)
- Invensor (7 - 10 kW)
- Mayekawa (50 - 350 kW)

**Lower COP, 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
Desiccant Systems (Open Cycle)

- Removes moisture from fresh air entering the building
  - Avoid humidity problems in humid climates (partial airconditioning solution)
  - Augments evaporative airconditioning in dry climates and/or at certain times of the year (possibly a total airconditioning solution)

- Solid desiccant wheels are common
  - Low temperature heat source, robust, no cooling tower
  - Possibly (probably) high efficiency

Liquid Desiccant Systems are Emerging

- AIL Research (35 - 93 kW)
- Imtech Drygenic (Kathabar, 30 - 70 kW)
- L-DSC Technology (200 - 350 kW)
- Menerga (10 - 100 kW)
CSIRO Solid Desiccant Cooling Product

Residential solar cooling heating & hot water

- Reduce household energy consumption by around 50%

Solar Thermal Collectors

<table>
<thead>
<tr>
<th>Type of Collector</th>
<th>Concentration Ratio</th>
<th>Typical Working Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat plate collectors</td>
<td>1</td>
<td>≤70</td>
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<tr>
<td>High efficiency flat plate collectors</td>
<td>1</td>
<td>60-120</td>
</tr>
<tr>
<td>Fixed concentrators (non-imaging)</td>
<td>3-5</td>
<td>100-150</td>
</tr>
<tr>
<td>Parabolic trough collectors</td>
<td>10-50</td>
<td>150-350</td>
</tr>
<tr>
<td>Parabolic dish collectors</td>
<td>200-500</td>
<td>250-700</td>
</tr>
<tr>
<td>Central receivers</td>
<td>500-&gt;3000</td>
<td>500&lt;1000</td>
</tr>
</tbody>
</table>

Source: Goswami 1999
Australian Solar Collector Developments

- NEP Solar Polytrough 1200
- Sola-Mate Air Collector
- Chromasun Microconcentrator
- AUSRA Linear Fresnel

Recent European Small Scale Solar Cooling Kit Suppliers (<50kW)

- coolySun, 7.5 and 15 kW
- Kingspan Climate System, 10 kW
- Suninverse, 10 kW
- LB Cooling System, 15 and 30 kW
- chilli® Cooling Kit, 7, 7.5, 10, 12, 15, 17.5, 30, 35 and 50 kW
- Alaska-Set, 7.5, 15, 30 and 54 kW

Source: Solar Next
Market Developments and Barriers

Market Drivers for Solar Cooling in Australia

1. Reduce Greenhouse Gas emissions (lower energy costs)
2. Achieve higher building star rating (access to green tenants)
3. Benefit to the electricity system (reduced demand charges)
4. Compliance with minimum renewable energy targets (planning permission/ satisfy aspirational targets)
Solar Cooling Market in Europe

- **Source:** SolarNext

Growing Interest is Mirrored in Australia

- 4 solar cooling systems installed in Australia in the last two years
- ~3 more are going to tender now and more are in negotiation

Source: ECS
Capital Costs

Wide variety of reported numbers
• $3000 to $9000/\text{kW}_{\text{cooling}}

Source: ROCOCO Project

Small Systems - Kit Cost

Solar Cooling Kit price history
• 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

Source: Solar Next

Without installation costs and cold distribution
### Benchmarking Against Other Renewables

**Wholesale**

- Black coal pf (super critical) 0.5
- Gas combined cycle 1.5
- Coal CCS 1.5
- Wind 2
- Solar thermal 2
- Solar PV 3.5
- Solar cooling 3

**Retail**

- Wholesale Target Market Price in 2010 = 4.26c/kWh
- Retail Target Market Price in 2010 = 15c/kWh

AUD10,500 kW avoided less AUD3,000 kW for conventional system, 20% utilisation factor.

### Barriers

- **Scale has not yet reached critical mass**
  - Lack of trained engineers, architects and installers
  - Industry visibility and confidence
  - Government visibility

- **Technical Risk**
  - Few standardised systems
  - Potential for failure not necessarily recognised by providers

- **Cost**
Barriers

- Access to industry/technology development support
  - Ad-hoc and time consuming
- Access to carbon value
  - Not a level playing field with other renewable energy technologies for access to tradeable Renewable Energy Certificates (RECs)
  - Opportunity with new State based tradeable white certificate schemes (targeted at building energy efficiency)
  - No recognised or easy method for evaluating carbon value

Australian Solar Cooling Interest Group (ausSCIG)

>170 members

Work-groups
- Technology Roadmap & Barriers Assessment
- Education, Training and Communication
- Demonstration, Funding and Research
- Standards Development

www.ausSCIG.org
daniel.rowe@ausscig.org.au
Solar Cooling Selection Examples

Selection Considerations

- Climate and building heat load
  - Requirement for dehumidification
  - Night time cooling required
  - Potable hot water demand
- Cold distribution method
  - Chilled ceilings
  - Chilled water fan coils
  - Packaged units
- Heat rejection method
  - Availability of water
  - Maintenance, legionella
  - Parasitic electricity consumption
- Backup cooling
  - Gas burner supplementing solar heat for the sorption cooler
  - Conventional electric chiller
  - Thermal storage
  - Autonomous
- Cost
1. House/ Light Commercial in Central Europe

- Local practices & climate suggests
  - Dehumidification is not required
  - Radiant panels (chilled ceilings) for cooling are attractive

- Small scale suggests
  - Maintenance of a cooling tower would be difficult
  - Dry or hybrid cooler is preferred

- Wide availability and low cost of flat plate collectors is attractive which further suggests
  - Must be able to run off low temperature ~80°C heat

Result: Adsorption chiller with flat plate collectors and a dry (or hybrid cooler), providing chilled water to radiant panels. Autonomous or electric backup

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Perpignan, France

Source: Tecsol

- CNRS Lab building 180 m² floor area
- 7.5 kW Sortech adsorption chiller
- 25 m² double glazed flat plate collectors
- Dry cooler with sprays (used 10 days in summer only)
- Average summer $\text{COP}_{\text{th}} \sim 0.4$, $\text{COP}_{\text{elec}} \sim 4.0$
Single Stage Design Parametric Study (Naples)

<table>
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<th>Coll. type</th>
<th>H.R. type</th>
<th>Coll. area [m²/kW]</th>
<th>Storage Vol. [/m²]</th>
<th>TOT. Solar fraction [%]</th>
<th>PE Saved [%]</th>
<th>Gross Solar Yield [(W)/anno/m²]</th>
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</table>

- Scenario 4 is fan coil unit. Other three are chilled ceiling
- 3 to 5 m²/kW cooling
- 25 to 75 l hot water buffer/ m² collector

Source: Solar Combi+ Project

2. Large Institutional Building in Australia

- Local practices & climate suggests
  - Chilled water and VAV air distribution
  - Chilled water at ~7°C for dehumidification

- Scale suggests cost and performance optimisation is most important
  - High efficiency two stage absorption chillers are available and attractive
    - Smaller collector area and cost
    - Reduced roof space required for collector area
    - Can use gas as a backup without excessive greenhouse emissions penalty
    - Less heat rejection (and associated parasitic power consumption)
    - Smaller hot buffer tank

- Two stage absorption chiller suggests
  - Need a cooling tower
  - Need tracking concentrating solar collectors

Result: Two stage absorption chiller with tracking concentrating collectors and a cooling tower providing chilled water to one or more AHUs
Brisbane, Australia

Source: ECS

- Small fraction of total capacity required for a large hospital
- 300 kW Broad absorption chiller
- 574 m² parabolic trough collectors (max 225kW_{th} @ 180°C)
- 6000 l buffer tank

Two Stage Design Parameters/ Results (Alice Springs)

- 233 kW chiller
- Thermal oil buffer
3. Office Ventilation Air in China

- Local practices & climate suggests
  - Minimum ventilation rates create high heat loads in humid climates

- Desiccant systems are good for pre-cooling/ pre-dehumidifying ventilation air
  - Good seasonal efficiency due to “free” evaporative cooling
  - Allow low cost flat plate collectors
  - No cooling tower required (depending on technology selection)

Result: Desiccant cooling system with flat plate collectors providing 100% fresh air. Sensible heat removed by a backup mechanical chiller

Jiangyin, China

- ~10 kW (2600 m³/h) two stage desiccant rotor with inter-cooling (+20kW air cooled mechanical cooling)
- 72 m² flat plate collectors, 4000 l hot water buffer
- Average summer COPₚₜ ~1.24, COPₑₒₑ ~11.48

Source: Shanghai Jiao Tong University
Cautionary Tales 1 - Cycling

- Absorption chillers are steady state machines
  - 40 min cold start + dilution cycle shut down
- Factors influencing start-up/shutdown include
  - Chiller sizing – don’t add a safety margin
  - Buffer tank sizing & control – use simulation

<table>
<thead>
<tr>
<th>Case</th>
<th>V' (m³)</th>
<th>V'_{avg} (m³)</th>
<th>T_{in} (°C)</th>
<th>Abs. chiller cooling (MWh/a)</th>
<th>Operating days/year</th>
<th>Days with &gt;0 warm starts</th>
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<tbody>
<tr>
<td>1</td>
<td>6</td>
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<td>595</td>
<td>255</td>
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Cautionary Tales 2 – Parasitic Power
(Example adsorption chiller)

<table>
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<th></th>
<th>Full Load</th>
<th>Part Load Fixed Speed Fan</th>
<th>Part Load Variable Speed Fan</th>
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<td></td>
<td>High Efficiency Pumps</td>
<td>Low Efficiency Pumps</td>
<td>High Efficiency Pumps</td>
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<tr>
<td>Pump Power (W)</td>
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<tr>
<td>Fan Power (W)</td>
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<td>570</td>
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<tr>
<td>COP_{elec}</td>
<td>9.0</td>
<td>6.7</td>
<td>5</td>
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Conclude:
- Use high efficiency ancillaries
- Use higher efficiency cooling machines
Conclusion

• Huge interest in the opportunity
• Lots of new systems are being developed
• Operational experience is being gathered, prices are dropping, issues are being identified and problems solved
• Viable products are looking likely
• But market lacks critical mass and government support
• Bad installations at this point could be a major blow to the future of the industry
  • Allow for increased planning at the beginning
  • Insist on independent monitoring and evaluation

This extra effort/ risk requires Government support

Energy Transformed Flagship
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"Energy for Buildings" Stream Leader

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Thank you
Cooling Demand Matches Solar Availability

Diurnal Load Match
3. Impact of Air-conditioning on Peak Demand

Sydney West Bulk Supply Point Load Profile

30 Jan 2003 (44°C Max)

15 Jan 2003 (28°C Max)

Integral Energy, 2004 Electricity Network Review