Solar Thermal Energy
For Cooling and Refrigeration: Status and Perspectives

Dahran, Saudi Arabia, 20/02/2012

Daniel Mugnier
TECSOL
Contents

1. Introduction
2. Technical status
3. Energy performance
4. Market status
5. Economic viability
6. Perspectives and R&D challenge
7. Conclusion
Introduction

Estimated RAC/PAC Market Size in 2008 (units: million)
Air-Conditioning Split-Units up to 5 kW (1.4 RT)

USA 16
Europe 8.6
China 26.8
Central/Southamerica 4.7
Middle East 4.0
India 3.8
Japan 9.0
Africa 1.5
East Asia 7.4

Even now with a -10% market decrease market in 2009 and stagnation in 2010 and 2011

The World market is representing... 70 000 000 000 US$

Source: JARN

World total 2008: 82.3 million units

Source: Uli Jakob, SOLARNEXT 2009
Introduction

Overall approach to energy efficient buildings in Europe

- 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)
Introduction on Solar Cooling Evolution

From World exhibition in Paris: First ice block through solar energy (1878)

Source: Olynthus Verlag

To Banyuls sur Mer ... (1991)
Europe
52 kW – 130 m²
Still running nominally

Source: TECSOL

To UWCSEA in Singapore ... (2011)
1500 kW – 4 000 m²
Asia

Source: SOLID
Contents

1. Introduction
2. Technical status
3. Concepts & Energy performance
4. Market status
5. Economic viability
6. Perspectives and R&D challenge
7. Conclusion
Solar thermal cooling - basic principle

Basic systems categories

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

- Liquid sorption: Ammonia-water or Water-LiBr (single-effect, double-effect, future triple-effect)

- Solid sorption: silica gel - water, zeolite-water

- Ejector systems

- Thermo-mechanical systems
Open sorptive cycles - desiccant air handling units

Air treatment in an open cycle

- 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
**Technical status**

- **Mature components available** (both solar and refrigeration, A/C)

<table>
<thead>
<tr>
<th>Driving temperature</th>
<th>Collector type</th>
<th>System type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (60-90°C)</td>
<td></td>
<td>Open cycle: direct air treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closed cycle: high temperature cooling system (e.g. chilled ceiling)</td>
</tr>
<tr>
<td>Medium (80-110°C)</td>
<td></td>
<td>Closed cycle: chilled water for cooling and dehumidification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closed cycle: refrigeration, air-conditioning with ice storage</td>
</tr>
<tr>
<td>High (130-200°C)</td>
<td></td>
<td>Closed cycle: double-effect system with high overall efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closed cycle: system with high temperature lift (e.g. ice production with air-cooled cooling tower)</td>
</tr>
</tbody>
</table>
# Sorption cooling

<table>
<thead>
<tr>
<th>Type of system</th>
<th>Water chillers (closed thermodynamic cycles)</th>
<th>Direct air treatment (open thermodynamic cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical phase of sorption material</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Sorption material</td>
<td>Water</td>
<td>Lithium-bromide</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>Ammonia</td>
<td>Water</td>
</tr>
<tr>
<td>Type of cycle</td>
<td>1-effect</td>
<td>1-effect</td>
</tr>
<tr>
<td>COP range</td>
<td>0.5 - 0.75</td>
<td>0.65 - 0.8</td>
</tr>
<tr>
<td>Driving temperature range, °C</td>
<td>70 ... 100 120 ... 180(1)</td>
<td>70 ... 100 140 ... 180</td>
</tr>
<tr>
<td>Solar collector technology(2)</td>
<td>FPC, ETC, SAT(1)</td>
<td>FPC, ETC</td>
</tr>
</tbody>
</table>

1: high temperature lift  
2: FPC = flat plate collector; ETC = evacuated tube collector; SAT = single axis tracking collector; SAHC = solar air heating collector
Technical status

- **Mature components available** (both solar and refrigeration, A/C)

- **Thermax** (India)
- **YAZAKI** (Japan)
- **Nishyodo** (20-140 RT) (Japan)
- **Maekawa** (14-100 RT)
- **Dunham Bush** (Russia) 85 RT
Technical status

- **Mature components available** (both solar and refrigeration, A/C)

- **Main progress made in last decade**
  - Small scale heat driven chillers
  - Increasing number of high efficient double and recently triple effect absorption chillers
  - Development of systems using single-axis tracking solar collectors
New developments of small capacity water chillers

~3.28 ft

(2.5 RT)
High-temperature applications

- 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)
High-temperature applications

Example: Football Stadium in Dubai
Technical status

- **Mature components available** (both solar and refrigeration, A/C)

- **Main progress made in last decade**
  - Small scale heat driven chillers
  - Increasing number of high efficient double and recently triple effect absorption chillers
  - Development of systems using single-axis tracking solar collectors

- **Main technical shortcomings are still on system level**
  - Energy efficient heat rejection system
  - Energy management
  - Bottleneck: good trained technical staff almost not available
Contents

1. Introduction
2. Technical status
3. Concepts & Energy performance
4. Market status
5. Economic viability
6. Perspectives and R&D challenge
7. Conclusion
Influence of solar fraction of driving heat

- High energy saving compared to conventional system
- Negative energy saving compared to conventional system

Target zone for system design

Solar fraction of driving heat to operate thermally driven cooling

- Low temperature single-effect
- Low temperature double-effect
- High temperature double-effect

Low, Medium, High
Influence of electricity consumption of auxiliary components

Overall electricity consumption of auxiliary components (fans, pumps, ...) is low in optimal conditions, medium in average conditions, and high in suboptimal conditions. High temperature double-effect processes tend to be more energy efficient compared to low temperature single-effect processes. Best practice is also found in practice.
Cold production and Temperature “lift”: arid regions

- Arid Regions
  - $T_M = 40°C$

- Continental climate
  - $T_M = 28°C$

- High T lift
  - $T_c = +5°C$

- Low T lift
  - $T_c = -10°C$

Heat rejection
- Medium temperature, $T_M$

Heat supply
- High temperature, $T_H$

Cold production
- Low temperature, $T_C$
Energy performance

- **Many systems lead to measurable energy savings** when compared to a best practice conventional reference solution.

- **Best values of overall electric COP range up to 6-8**, which means that 6-8 kWh of useful cooling are produced with 1 kWh of invested electricity.

- **Target value for electric COP > 10**

- **However**: also many systems do not achieve these values in practice due to:
  - Non-optimal design
  - Non-optimal operation (e.g. control, part load)
Example of performing concept in 2011

Building block in Montpellier, France
2 parts: building A & B (mini district)

Building A: 11,000 m² for offices and shops
Building B: 10,600 m² with 167 dwellings

Both production of Domestic Hot Water and Cooling

Safe solar production: drainback strategy (freeze & overheating protections)

Energy performance: Electrical COP of... 17!
Task 48: Quality assurance & support measures for Solar Cooling

Solar production

DHW distribution

Drainback system

Cold production

Anti legionella adiabatique cooling tower
Contents

1. Introduction
2. Technical status
3. Concepts & Energy performance
4. Market status
5. Economic viability
6. Perspectives and R&D challenge
7. Conclusion
Market - estimated > 800 systems worldwide

About 150 new installations in 2010 and 2011 (+30%)
Market analysis: Europe / World

Mainly US, China and Australia

Total amount of installed Solar Cooling systems in Europe and the World

Sources: Climasol, Fraunhofer ISE, Rococo, Tecsol
Market share (2009)

- Absorption: 71%
- Adsorption: 14%
- Dec solid: 13%
- Dec liquid: 2%

Percentage of use of different technologies for thermally driven chillers within 113 large scale systems.

Absorption representing nearly 85% ...
Task 48: Quality assurance & support measures for Solar Cooling

- Air-conditioning of a production hall in Greece
- Air-conditioning of a meeting room and cafeteria in Freiburg/Germany
- Wine cooling in southern France
- Air-conditioning and process heat production for a hotel in Turkey
- Wine cooling in Tunisia
Recently large and very large installations (examples)

**CGD Bank Headquarter**
Lisbon, Portugal
1560 m² collector area
400 kW absorption chiller

Source: SOLID, Graz/Austria

**FESTO Factory**
Berkheim, Germany
1218 m² collector area
1.05 MW (3 adsorption chillers)

Source: Paradigma, Festo

**United World College (UWC)**
Singapore
3900 m² collector area
1.47 MW absorption chiller

Source: SOLID, Graz/Austria
Examples of Custom made system manufacturers

(Australia, Europe)
(Middle East, North Africa)
(USA)
(USA)
(Middle East, Europe, USA)
(Europe, USA, Caribbean, Asia)
(Europe, Middle East)
(Europe, North Africa, Middle East)

Source: GreenChiller, TECSOL
Contents

1. Introduction
2. Technical status
3. Concepts & Energy performance
4. Market status
5. Economic viability
6. Perspectives and R&D challenge
7. Conclusion
Economic viability

- **First cost 2-5 times higher than for conventional technology**

- **Total first cost found in realized installations**: 2000 – 5000 € per kW of cold production (for entire system including solar collector field)

- **Payback time depends strongly on boundary conditions**
  - Annual numbers of use (cooling, heating, hot water, …)
  - Conventional energy cost
  - Climatic conditions

- **Best conditions: payback < 10 years possible**
**Example of specific total costs of solar cooling kits in Europe**

* Solar cooling kits generally include: solar thermal collectors, hot water storage, pump-set, chiller, re-cooler, cold water storage, system control.

The specific costs are without cold distribution and installation costs.
System costs: example

Solar cooling installation - 10 tons abs. - France - 2009

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (w/o tax)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar collectors</td>
<td>130,000</td>
</tr>
<tr>
<td>Technical room</td>
<td>15,080</td>
</tr>
<tr>
<td>Cold production</td>
<td>57,200</td>
</tr>
<tr>
<td>Electricity</td>
<td>13,000</td>
</tr>
<tr>
<td>Monitoring</td>
<td>6,500</td>
</tr>
<tr>
<td>Starting up</td>
<td>1,950</td>
</tr>
<tr>
<td>Engineering</td>
<td>19,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>243,230</strong></td>
</tr>
</tbody>
</table>

$/ton 24,323

Source: TECSOL
Cost Reduction Potential of Solar Cooling Kits

- **Solar Plant (Collectors and Storage):**
  max. 10% Cost Reduction Potential in the next 2-3 years

- **Small-Scale Sorption Chillers:**
  max. 20% Cost Reduction Potential till 2013, from 2011 up to 50% if Serial Production is started (Production Capacity larger than 500 Units)

- **Recooler:**
  Cost Reduction Potential between 40-50%

- **Control:**
  min. 60% Cost Reduction Potential, Increasing of the System Performance

- **Installation:**
  10-30% Cost Reduction Potential through Standardized Solar Cooling Kits

*Source: Uli Jakob, SOLARNEXT*
Task 48: Quality assurance & support measures for Solar Cooling

How do reduce costs?

High performance flat plate collectors + drainback

Performing, safe and cheap Evacuated Tube collectors

Source: Viessmann

Compact packages solutions

And above all...

Large scale production

Source: EDF Optimal Solutions
Contents

1. Introduction
2. Technical status
3. Concepts & Energy performance
4. Market status
5. Economic viability
6. Perspectives and R&D challenge
7. Conclusion
Perspectives (1/2)

- **Systems using non-tracking solar collector technology**
  - Solar heating & cooling (+ DHW) → summer use of large collector fields
  - Application in buildings: residential, tertiary sector
  - Significant cost reductions in particular for small scale thermally driven chillers (> 50 % possible)
  - Increasing level of standardization
  - Pre-fabricated systems for small capacity
  - Custom-made systems for commercial buildings
  - Desiccant systems in particular for air dehumidification in humid climates
Perspectives (2/2)

- **Systems using single-axis tracking with optical concentration**
  - Medium and large capacity range in regions with high direct solar radiation
  - Applications with dominant use of cooling (e.g. industrial refrigeration)
  - Installation either on the ground or large flat roofs of industrial buildings
  - High efficient cooling cycles using double- or triple-effect
  - Applications which require a high temperature-lift (e.g. food conservation with dry cooling tower)
**R&D challenges**

- **Heat rejection**: full integration, lower O&M costs => application as add-in for residential buildings for 100% solar houses in Southern European countries

- **New and small capacity open cycles** to be integrated in ventilation systems for residential sector

- **Demonstration activities for large solar cooling packaged systems** (more than 100 kW) => cost reduction and guarantee results. Application: industry, cooling networks and large buildings.

- **Quality assurance measures for solar cooling** (T48 SHC-IEA), among others:
  - Automated failure detection & monitoring
  - Systems testing & characterization
  - Control strategies optimization
Quality assurance & support measures for Solar Cooling

Duration: 3.5 years (October 2011 – March 2015)

Subtask A: Quality procedure on component level
Subtask B: Quality procedure on system level
Subtask C: Market support measures
Subtask D: Dissemination and policy advice

Participating Countries: Australia, Austria, Canada, Belgium, France, Germany, Italy, Singapore, South Africa, Spain, and USA (no claim for completeness)

Participating Manufacturers and Companies: Aiguasol, Climatewell, Industrial Solar GmbH, Invensor, Sortech, SOLEM, SOLID, TECSOL, Thermosol (no claim for completeness)

http://www.iea-shc.org/task48/
Conclusion & outlook

- Solar heating and cooling (SHC) systems will play a significant role in our future energy system.

- They provide an energy saving solution on the demand side without negative (possibly positive) impact on the electricity grid.

- **Main challenge** is to assure **high quality of installations in broad market**.

- From **technology** companies toward **sales companies & powerful lobbies**...

Thank you for your attention !!!

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