Development of Solar Cooling Technologies in China

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**Solar thermal industry in China**

In 2012, the annual production of solar collector is beyond 50 million m², the total solar collector area in use is more than 200 million m².

**Flat plate and Evacuated tube solar collectors**

In China, most of the installed solar collectors are evacuated solar collectors. In 2009, the ratio is about 95:5 for the two kind of solar collectors.
The newly completed construction area is huge in China; the heating, cooling and hot water production account for about 80% of the energy consumption in residential building section.

Solar thermal application in China

Solar thermal utilization in buildings

- Hot water
- Heating
- Cooling
- Hybrid system

Technologies in use: Demonstration and close to large scale application

The target technology
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**Target area**

- **Middle and lower reaches of Changjiang River area**: Energy for heating and cooling increases rapidly
- **South of China**: >40% electricity for AC demand
- **Demand of domestic hot water** increases

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**Background**

- Solar cooling matches the cooling load of the building well;
- The stronger the solar radiation is, the bigger the demand for cooling will be, and more cooling from solar can be produced.
- Solar cooling technology can efficiently cut off the power peak demand for cooling.
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Solar Cooling Research in SJTU

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Major technologies in China

- Adsorption chiller
- Two stage LiBr-H2O
- Single effect LiBr-H2O
- Rotary desiccant cooling
- Liquid desiccant cooling
- Double effect LiBr-H2O
Improvement in solar collectors

CPC solar collector

Flat plate solar collector

High temperature solar collector absorber

Evacuated glass tube with super conductivity heat pipe

Pressurized solar hot water system and selective coating

Two cycles solar hot water system

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Heat pipe and U tube solar collectors

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Medium temperature solar collector

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Recent development: Adsorption Cooling

- Solar adsorption Chiller
  - Powered by 55–85°C hot water;
  - Suitable to be driven by solar water heater or waste heat from other sources;
  - Small mass production
  - 5 kW, 10kW, 50kW, 100kW

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Performance</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling power</td>
<td>8.5</td>
<td>kW</td>
</tr>
<tr>
<td>Chilled water</td>
<td>10</td>
<td>°C</td>
</tr>
<tr>
<td>Chilled water flow rate</td>
<td>1.5</td>
<td>t/h</td>
</tr>
<tr>
<td>Cooling water inlet</td>
<td>32</td>
<td>°C</td>
</tr>
<tr>
<td>Cooling water flow rate</td>
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<td>t/h</td>
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<tr>
<td>Hot water inlet</td>
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<td>°C</td>
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<td>Hot water flow rate</td>
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<td>t/h</td>
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<tr>
<td>COP</td>
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<td></td>
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<tr>
<td>Weight</td>
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<td>t</td>
</tr>
<tr>
<td>Power AC</td>
<td>2Φ-220V-50Hz</td>
<td></td>
</tr>
</tbody>
</table>
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5 kW Adsorption chiller – Work by SJTU

<table>
<thead>
<tr>
<th>Hot water</th>
<th>Cooling water</th>
<th>Chilled water</th>
<th>Cooling capacity (kW)</th>
<th>Coefficient of Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>In (°C)</td>
<td>Out (°C)</td>
<td>In (°C)</td>
<td>Out (°C)</td>
<td>In (°C)</td>
</tr>
<tr>
<td>57</td>
<td>53</td>
<td>27</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>66</td>
<td>61</td>
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<td>32</td>
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<td>75</td>
<td>70</td>
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<td>80</td>
<td>85</td>
<td>29</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>91</td>
<td>86</td>
<td>26</td>
<td>32</td>
<td>7</td>
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</tbody>
</table>

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Solar cooling, heating hybrid system in a Green Building

- 2 silica gel water chillers
- 150 m² of U-type ETC;
- $T_{Gen.} = 55-85 \degree C$
  $\Rightarrow Q_C = 15 \text{ kW, Solar COP}=0.15$
Solar cooling used to cool a grain depot in China (2004)
- Solar powered water-heating unit:
- 50 m$^3$ of evacuated tube collectors
- 5 kW cooling

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Solar grain cooling (adsorption chiller) (2005) (almost the same as 2004)
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Solar adsorption cooling in grain depot (2006)


Pavilion of National state power company

2 adsorption chillers are used
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Adsorption Ice maker for Waste heat or solar heat utilization

CaCl2 hybrid adsorbent + NH3 adsorption refrigerator

130°C vapor driven adsorption refrigeration 10kW/-15°C COP=0.3

Potential applications: Waste heat refrigeration for chemical process engineering
Ice maker for fishing boat

Absorption cooling
Two-stage LiBr water absorption chiller

70kW two stage absorption chiller
(Guangzhou, China, 1994)

Solar driven two stage absorption cooling project in Jiangmen, Guangdong, China (1997)

- solar flat plate collectors: 500m²
- Hot water: 75°C
- chilled water: 9°C
- Cooling capacity: 100kW
- Auxiliary heat source: Oil boiler
Solar absorption air conditioning demonstration in Rushan, Shandong Province

- collector aperture area of 540 m²
- cooling and heating capacity of 100 kW
- air-conditioning construction area of 1000 m²
- hot water supply of 32 m³ per day.
- 88°C hot water
- the effective solar cooling time is usually limited to 3-4 hours daily.

Solar absorption cooling (single effect) in Tianpu Co., Beijing, China (2003)

Sketch map for new energy of the building
Solar absorption cooling (singel effect) in Beijing Solar energy institute

Solar cooling Project in Qingdao

360kW solar cooling project (heat pipe solar collector)

Solar +waste heat absorption cooling project in QingDao Olympics center (2008)

- solar flat plate collectors: 600 m²
- Sanyo single effect absorption chiller
- Hot water: 75-90 °C;
- chilled water: 12-15 °C
- Cooling capacity: 600 kW
- Auxiliary heat: waste heat from power station
Solar air conditioning in Himing Group

Collector area: 9188m²
Single effect Absorption chiller

It is not so successful and stopped till now.

Broad solar absorption cooling (double effect)
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System Performance

Daily solar thermal efficiency of the collector is about 40%.

Temperature increase is about 12-15°C.

COP is about 1.0.
Roof solar collectors

Number: 703 units, Area: 1040.8 m²

03/05/2011

Solar heating and cooling system in Auhua Co., Ltd.

3F integration building (3层综合楼)
Office building (7层办公楼)
System design (Sino – Denmark joint Project)

Solar driven air cooled absorption cooling

- Solar driven hybrid
  Air cooled absorption chiller + VC air conditioning system
- Trough collector is about 135 m²
- About 25kW air cooled absorption chiller
- Vanke real estate Co., research center
Solar cooling in Shanghai Electric Co.

- 550 m² Fresnel solar collector; (150 ~ 200°C)
- Salt thermal energy storage (PCM, 146°C)
- Double/Single effect absorption chiller (100kW)

Air cooled NH₃-H₂O absorption chiller Vicot Co.

Gas boiler as back up; COP is about 0.7
2.5~200 RT capacity range

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Project in the factory

Huineng Co., Small size solar absorption chiller

- 23 kW
- 35 kW
- 58 kW

23, 35, 58 kW single effect absorption chiller
Match well with evacuated solar collectors
Desiccant cooling

Hybrid VCS/Two-stage desiccant cooling driven by solar flat plate water collector

- Cooling capacity of TSDC: 10 kW
- Flat plate solar collector
- Collector area: 90 m² (72 m² was used during test)
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Two-stage Solar DCS Installed in Jiangsu, China

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10 kW Flat plate solar collector & two stage solar desiccant cooling, SJTU, applied in Jiangyin, China

<table>
<thead>
<tr>
<th>Average water temperature (°C)</th>
<th>Average cooling water temperature (°C)</th>
<th>Average temperature (°C) and moisture ratio (g/kg DA) of supply air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>Outlet</td>
<td>Inlet</td>
</tr>
<tr>
<td>67</td>
<td>55.6</td>
<td>28.1</td>
</tr>
</tbody>
</table>

Average Cooling capacity kW  
10.9

Coefficient of performance (dehumidification) COPth  
1.1

Coefficient of performance (electric) COPe  
8.3

Performance summary of air-source heat pump air-conditioning system

<table>
<thead>
<tr>
<th>Electrical condition</th>
<th>Average temperature (°C) and moisture ratio (g/kg DA) of supply air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (A)</td>
<td>Electrical power (kW)</td>
</tr>
<tr>
<td>15.7</td>
<td>5.97</td>
</tr>
</tbody>
</table>

Average Cooling capacity kW  
17.7  
Coefficient of performance (electric) COPe  
12
**10 kW Flat plate solar collector & two stage solar desiccant cooling, SJTU, applied in Jiangyin, China**

<table>
<thead>
<tr>
<th>Desiccant</th>
<th>Power consumption of the desiccant AC system (kW)</th>
<th>Coefficient of performance (electric) of the desiccant AC system COP&lt;sub&gt;e&lt;/sub&gt;</th>
<th>Cooling capacity of the desiccant AC system (kW)</th>
<th>Coefficient of performance (electric) of the integrated system COP&lt;sub&gt;e&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.31</td>
<td>8.3</td>
<td>10.9</td>
<td>3.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air cooled water chiller</th>
<th>Power consumption of the air-source heat pump system (kW)</th>
<th>Coefficient of performance of the air-source heat pump system COP&lt;sub&gt;e&lt;/sub&gt;</th>
<th>Cooling capacity of the air-source heat pump system (kW)</th>
<th>Power-saving-ratio of the solar power system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.97</td>
<td>2.96</td>
<td>17.7</td>
<td>24.50%</td>
</tr>
</tbody>
</table>

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**20 kW Air solar collector & two stage solar desiccant cooling, SJTU, applied in Himin Solar company**

- Cooling capacity: 20 kW
- 140m² solar air collectors
- Dehumidification: 11.9g/kg
- Thermal COP: 0.95
- Electric COP: 5.9

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30 kW Air solar collector & two stage solar desiccant cooling, SJTU, applied in Tianjin Business College, China

- Cooling capacity: 30 kW
- Heat pipe collector + Heat storage collector
- Collector area: 200 m²

Solar driven ORTS desiccant cooling

- Thermal COP > 1
- Convert more than 50% solar radiation to capability of dehumidification

50℃～90℃ heat resource
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A novel chiller with desiccant dehumidification and regenerative evaporative cooling

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Performance in producing chilling water

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Comparison between the supply air condition of the novel cycle and that of the conventional cycle under high humid climate (1130.6 m3/h, 674.2 m3/h, 1.04 m3/h, July 22, 2011)
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Desiccant heat exchanger units

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Liquid desiccant cooling

- Heat source: heat from heat pump
- Design fresh air: 4000 m³/h
- Cooling area: 300 m²
- EER: 6.5-7.3 in summer, 7.5.0 in winter

- Heat source: waste heat from BCHP system
- Design fresh air: 30 m³/h/person
- COP of liquid desiccant sub-system: about 1.0
- CO₂ emission is reduced by 40%
- 2 years is required to recover the extra initial cost for liquid desiccant subsystem

- Hybrid system: two 10 kW adsorption chillers (driven by 150 m² solar collector), and liquid desiccant dehumidification subsystem (driven by the condensing heating at about 80 °C)
- Performance is 44.5% and 73.8% higher than conventional vapor compression system at the latent load of 30% and 43%, respectively.

Tsinghua University  Tsinghua University  Tsinghua University and Shanghai Jiao Tong University

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Solar air conditioning system in GEL

- Solar adsorption cooling
- Desiccant cooling
- Solar assisted CO2 heat pump
- Micro CCHP
- Water resource heat pump
- Ground source heat pump

Main system

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Solar Cooling Future

- This sustainable cooling technology will be more competitive with the increased fuel price;
- With the development of solar collector technology, the improvement of the cooling machines suitable for solar energy utilization, solar cooling will be more popular;
- It will play an important role in the regions with hot climate and good irradiation.
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Thanks for your attention
谢谢！