Solar Air-Conditioning Systems

in small - medium scale applications

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The problem

- **Ozone layer depletion**
  CO$_2$ higher now than in last 400,000 years
  CO$_2$ emissions are expected to increase 20-fold from 1990 to 2010, only in the EU

- **IPCC predicts temperature rise of 1.5 - 5.8 degrees**
  Humans: 150,000 deaths directly attributable to climate change in 2000
  Climatic zones shifting 7 times quicker than plants can follow

- **New directives on air quality**
  2008/50/EC, ‘Ambient air quality and cleaner air for Europe’
  2008/1/EC, ‘Integrated pollution prevention and control’

- **Inefficient conventional a/c units**
  - VCS operate at a temperature colder than the supply air dew-point temperature, so the air is overcooled and needs reheating before entering indoors
  - Energy consumption in commercial and residential buildings: 40% of Europe’s energy bill

- **Global increase in air-conditioning demand**
Solar Air-Conditioning

- Higher living / working standards
- Adverse outdoor conditions in urban environments
- Reduced prices of air-conditioning units
- Installed a/c has increased 5-fold in the last 20 years in Europe
- Total a/c floor space: 30 million m² in 1980, over 150 million m² in 2000.
- Annual energy use of room a/c was 6 TJ in 1990, estimated 160 TJ in 2010.

We need an a/c system that controls temperature and provides air of high quality, with high efficiency and low CO₂ emissions!
The solution: Solar-driven air-conditioning

- **Radiation** supply from sun carries a 5 billion year guarantee
- Annually, the sun provides $1.5 \times 10^{18}$ kWh, that is more than 10,000 times the energy that human race needs.

Source: *Planning & Installing Solar Thermal Systems: A guide for installers, architects & engineers*, EarthScan publications
Solar radiation is in tune with air conditioning demand

Source: TECSOL for SOLAIR project
Annual solar irradiance (sum of direct and diffuse) in Greece is approximately \textbf{1,600 kWh/m}^2. This amount of energy, corresponds to \textbf{160 lt oil}.

Daily solar irradiance for 3 representative dates (in winter, summer and spring) is shown in the next diagram. The area that receives the biggest amount of radiation has an inclination of \textbf{60° in December} and \textbf{0° in June}.

Source: CRES, PVGIS
**Optimum collector angle**: depends on the geographical location and the system’s type of use.

- **Winter use**: geographical latitude of area + 15°
- **Summer use**: geographical latitude of area - 15°
- **Annual use**: collector angle = geographical latitude

### RESULTS OF INCIDENT RADIATION ON COLLECTORS (FROM TSOL)

**Place**: Athens  
**Azimuth**: 0

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<thead>
<tr>
<th>From:</th>
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<th>0</th>
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</tbody>
</table>

| Sum YEAR | 1567 | 1658 | 1706 | 1716 | 1718 | 1711 | 1697 | 1670 | 1635 | 1593 | 1540 | 1477 | 1409 | 1334 | 1252 | 1165 | 1075 |

- **hotels season**: 1/4 to 1/11
- **heating season**: 1/11 to 1/4

"winter": 1/12 to 1/3

Source: T-SOL
Solar Air-Conditioning

Energy yield

Optimum angle: 1700-1800 kWh/m²
Horizontal surface: 1300-1400 kWh/m²

Source: PVGIS
Properties
- Middle cost: more expensive than unglazed, but cheaper than vacuum
- Higher operation temperature
- Thermal insulation on back & edges
- Fragile, heavier: 20-32 kg/m²
- Absorber: black paint or spectral-selective coating (black chrome, black nickel, blue titanium)
- Spectral-selective coating: conversion of short-wave solar radiation into heat (light absorption capacity) is optimized, while thermal emissions are kept low. Absorption rate: 90-95%, emission rate 5-15%
- Stagnation temperature: 160-200°C

Applications
- Space heating
- Solar air conditioning (selective coating)
Vacuum collectors

**Properties**
- High cost
- Minimal convection thermal losses (tube pressure < \(10^{-5}\) bar)
- Low radiation losses
- High efficiency, even with low radiation
- Low weight
- Average annual efficiency 45-50% (with 1000 kWh/m\(^2\) irradiation, the energy yield is 450-500 kWh/m\(^2\)a)
- Stagnation temperature: 200-350\(^0\)C

**Applications**
- Solar air conditioning
- Industrial applications (steam generation)

*Planning & Installing Solar Thermal Systems: A guide for installers, architects & engineers, EarthScan publications*
**Vacuum types**

- **Direct-flow:** Internal U-tube, South-oriented.
- **Concentrated:** Double tube (external tube: absorber surface, internal tube: U-type), 2 external reflector surfaces
- **Heat-pipe:** Horizontal absorber area placed inside a vacuum tube. The tube is connected to an evacuated heat pipe with a solution inside. The solution evaporates ($T_{\text{evaporation}} = 25^\circ\text{C}$) and its heat is transferred through a heat exchanger in the medium.

**Dry connection:** the heat transfer takes place from the condenser via the tube wall to the medium, so defective tubes are replaced without emptying the solar circuit.

**Wet connection:** the condenser is immersed in the medium, so defective tubes are replaced by emptying the solar circuit.

*Planning & Installing Solar Thermal Systems: A guide for installers, architects & engineers, EarthScan publications*
## Collectors comparison

<table>
<thead>
<tr>
<th>Collector type</th>
<th>Application</th>
<th>Performance (kWh/m²a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unglazed</td>
<td>Pool heating</td>
<td>300</td>
</tr>
<tr>
<td>Flat plate (black paint)</td>
<td>Pool heating, Hot water</td>
<td>650</td>
</tr>
<tr>
<td>Flat plate (selective coating)</td>
<td>Hot water, space heating, solar a/c</td>
<td>700</td>
</tr>
<tr>
<td>Vacuum</td>
<td>Solar a/c, industry</td>
<td>850</td>
</tr>
</tbody>
</table>
Performance

Temperature difference collector - environment

- Unglazed
- Vacuum
- Flat plate

- 0 - 20 K: Pool heating
- 20 - 100 K: DHW & space heating
- > 100 K: Industrial applications

Planning & Installing Solar Thermal Systems: A guide for installers, architects & engineers, EarthScan publications
Solar-driven air-conditioning systems

Systems
- **Open cycle DEC**
  Production of air conditioned air
  Dehumidification and evaporative cooling
- **Closed cycle**
  Production of chilled water for space cooling through fan coil, chilled ceiling, floor heating
  Absorption (liquid)
  Adsorption (solid)

Characteristics
- Air conditioning load in tune with the solar radiation
- Solar systems can be integrated in existing air-conditioning units (fan coils, floor heating systems)
- Small scale solar a/c systems: under research
- Small scale chillers (<30kW): High initial cost, 2,000 €/kW.
<table>
<thead>
<tr>
<th>Method</th>
<th>Closed cycle</th>
<th>Open cycle</th>
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</thead>
<tbody>
<tr>
<td>Refrigerant cycle</td>
<td>Closed refrigerant cycle</td>
<td>Refrigerant (water) is in contact to the atmosphere</td>
</tr>
<tr>
<td>Principle</td>
<td>Chilled water</td>
<td>Dehumidification of air and evaporative cooling</td>
</tr>
<tr>
<td>Phase of sorbent</td>
<td>solid</td>
<td>liquid</td>
</tr>
<tr>
<td>Typical material pairs</td>
<td>water - silica gel</td>
<td>water - lithium bromide, ammonia - water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>water - silica gel, water - lithium chloride</td>
</tr>
<tr>
<td></td>
<td></td>
<td>water - calcium chloride, water - lithium chloride</td>
</tr>
<tr>
<td>Market available</td>
<td>Adsorption chiller</td>
<td>Absorption chiller</td>
</tr>
<tr>
<td>technology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical cooling</td>
<td>50 – 430 kW</td>
<td>15 kW – 5 MW</td>
</tr>
<tr>
<td>capacity (kW cold)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical COP</td>
<td>0.5 – 0.7</td>
<td>0.6 – 0.75 (single effect)</td>
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<tr>
<td>Driving temperature</td>
<td>60 – 90 °C</td>
<td>80 – 110 °C</td>
</tr>
<tr>
<td>Solar collectors</td>
<td>Vacuum tubes, flat plate collectors</td>
<td>Vacuum tubes</td>
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</tbody>
</table>

Source: EU Altener Project Climasol
Solar Air-Conditioning

Initial cost – Collector area needed, 2007

**Open systems**
- Liquid DEC: $4500 \, \text{€}/\text{kW}, \, 5 \, \text{m}^2/\text{kW}$
- Solid DEC: $3500 \, \text{€}/\text{kW}, \, 0.5 \, \text{m}^2/\text{kW}$

**Closed systems**
- Absorption: $2000 \, \text{€}/\text{kW}, \, 4 \, \text{m}^2/\text{kW}$
- Adsorption: $5500 \, \text{€}/\text{kW}, \, 2.5 \, \text{m}^2/\text{kW}$

Efficiency – Operational temperature, 2007

**Open systems**
- Liquid DEC: $T = 60^\circ\text{C}, \, \text{COP} = 0.7$
- Solid DEC: $T = 80^\circ\text{C}, \, \text{COP} = 0.5$

**Closed systems**
- Absorption: $T = 75^\circ\text{C}, \, \text{COP} = 0.7$
- Adsorption: $T = 55^\circ\text{C}, \, \text{COP} = 0.5$

Solar Cooling Systems installed in Europe
- Absorption: 58%
- Solid DEC: 23%
- Adsorption: 12%
- Liquid DEC: 4%

PENA, Lavrio
Solar cooling **Solid DEC system**
Demo & research application for CRES

<table>
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<th>In operation since</th>
<th>2007</th>
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<tr>
<td>Air conditioned area</td>
<td>84m²</td>
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<tr>
<td>Collector type</td>
<td>10 m², Calpak flat-plate</td>
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<td>Collector fluid</td>
<td>water-glycol</td>
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<td>Operation temperature</td>
<td>60°C</td>
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<tr>
<td>Nominal air flow rate</td>
<td>1100 m³/h</td>
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<tr>
<td>Min. air volume flow rate</td>
<td>373 m³/h</td>
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<tr>
<td>Desiccant cooling system</td>
<td>solid LiCl</td>
</tr>
<tr>
<td>Brand of desiccant unit</td>
<td>Klingenburg</td>
</tr>
</tbody>
</table>

Source: CRES
Solar cooling of a production site for cosmetics
- In operation since 1999
- One of the largest installations in the world
- 2,700 m² flat plate collectors (SOLE)
- 2 adsorption cooling machines, with 350 kW cooling power each
- 3 compression cooling machines with 350 kW air cooling and fan-coils
- Concept: economisation of electricity (Power and Work)

Source: CRES
In operation since 20/08/00
Solar air-conditioning system, fan coils
Air-conditioned area 1000 m²
450m² flat plate collectors (SOLE)
**Absorption chiller** LiBr, 105 kW\(_c\)
Performance: COP\(_{\text{thermal}}\) =0.6,
COP\(_{\text{electrical}}\) =0.52
Initial cost: 146,000 € (2000)
Annual electrical energy savings: 70,000 kWh (7,000 €)
Annual oil savings: 20,000 lt (8,000 €)
Payback in 10 years, without incentives.
870,000 kg less CO\(_2\) annually

Source: SOLE
Solar Cooling is not yet widespread in Greece
- 8% of the solar thermal market
- lack of real incentives

However, there is large growth potential, because
- only 25% of the buildings are equipped with a solar thermal system (>90% of the owners are satisfied)
- steady increase in demand for a/c units

Law modernization
solar cooling system project study compulsory for every large building

Financial incentives
to cover part of investment & construction costs
Thank you for your attention!

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