ONGOING RESEARCH RELEVANT FOR SOLAR ASSISTED AIR CONDITIONING SYSTEMS

Technical Report

IEA Solar Heating and Cooling
Task 25: Solar-assisted air-conditioning of buildings

October 2002
This report has been written through collaborative effort of the IEA SHC Task 25 project group “Solar assisted air conditioning of buildings”

Task Participants

<table>
<thead>
<tr>
<th>Country</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Wolfgang Streicher, TU Graz, Graz</td>
</tr>
<tr>
<td>Denmark</td>
<td>Jan Eric Nielsen, Solar Energy Center, DTI, Taastrup</td>
</tr>
<tr>
<td>France</td>
<td>Jean-Yves Quinette (Leader Subtask C), Tecsol, Perpignan</td>
</tr>
<tr>
<td></td>
<td>Daniel Mugnier, Tecsol, Perpignan</td>
</tr>
<tr>
<td></td>
<td>Rodolphe Morlot, CSTB, Sophia Antipolis</td>
</tr>
<tr>
<td>Germany</td>
<td>Hans-Martin Henning (Operating Agent), Fraunhofer Institute for Solar Energy Systems ISE, Freiburg</td>
</tr>
<tr>
<td></td>
<td>Uwe Franzke (Leader Subtask B), Institut für Luft- und Kältetechnik Dresden</td>
</tr>
<tr>
<td></td>
<td>Carsten Hindenburg, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg</td>
</tr>
<tr>
<td></td>
<td>Tim Selke, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg</td>
</tr>
<tr>
<td></td>
<td>Jan Albers, Institut für Erhaltung und Modernisierung von Bauwerken e.V. an der TU Berlin</td>
</tr>
<tr>
<td></td>
<td>Michael Kaecke, ZAE Bayern, Munich</td>
</tr>
<tr>
<td>Greece</td>
<td>Constantinos A. Balaras, Group Energy Conservation, IERSD, National Observatory of Athens, Athens</td>
</tr>
<tr>
<td>Israel</td>
<td>Gershon Grossman, Technion, Haifa</td>
</tr>
<tr>
<td>Italy</td>
<td>Federico Butera, Polytecnico di Milano, Milano</td>
</tr>
<tr>
<td></td>
<td>Marco Beccali, University of Palermo, Palermo</td>
</tr>
<tr>
<td>Japan</td>
<td>Hideharu Yanagi, Mayekawa MFG.Co.</td>
</tr>
<tr>
<td>Mexico</td>
<td>Isaac Pilatowsky (Leader Subtask A), Universidad Nacional Autonoma de Mexico, Temixco</td>
</tr>
<tr>
<td></td>
<td>Roberto Best, UNAM, Temixco</td>
</tr>
<tr>
<td></td>
<td>Wilfrido Rivera, UNAM, Temixco</td>
</tr>
<tr>
<td>Netherlands</td>
<td>Gerdi R. M. Breembroek (Leader Subtask C), IEA Heat Pump Centre / Novem bv, Sittard</td>
</tr>
<tr>
<td></td>
<td>Rien Rolloos (now: Daniel Naron), TNO, Delft</td>
</tr>
<tr>
<td></td>
<td>Cees Machielsen, TU Delft, Delft</td>
</tr>
<tr>
<td>Portugal</td>
<td>Manuel Collares-Pereira, INETI-DER, Lisbon</td>
</tr>
<tr>
<td></td>
<td>Joao Farinha Mendes, INETI-DER, Lisbon</td>
</tr>
<tr>
<td></td>
<td>Maria Joao Cavalhao, INETI-DER, Lisbon</td>
</tr>
<tr>
<td>Spain</td>
<td>Jordi Cadafalch Rabasa, Universitat Politècnica Catalunya, Terassa</td>
</tr>
<tr>
<td></td>
<td>Carlos David Pérez Segarra, Universitat Politècnica Catalunya, Terassa</td>
</tr>
<tr>
<td></td>
<td>Hans Schweiger, AIGUASOL Enginyeria, Barcelona</td>
</tr>
<tr>
<td></td>
<td>Laura Sisó Miró, AIGUASOL Enginyeria, Barcelona</td>
</tr>
</tbody>
</table>
THE IEA SOLAR HEATING AND COOLING PROGRAMME

The International Energy Agency (IEA) was formed in 1974 as an autonomous body within the Organisation for Economic Co-operation and Development (OECD). It carries out a program of energy co-operation, including joint research and development of new and improved energy technologies.

The Solar Heating and Cooling (SHC) Programme was one of the first IEA research agreements to be established. Since 1976, its members have been collaborating to develop technologies that use the energy of the sun to heat, cool, light and power buildings. The following 20 countries, as well as the European Commission are members of this agreement: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Mexico, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.

The mission of the SHC Programme is: “To facilitate an environmentally sustainable future through the greater use of solar design and technologies.”

Current Tasks of the IEA Solar Heating and Cooling Programme are:

Task 22: Building Energy Analysis Tools
Task 23: Optimization of Solar Energy Use in Large Buildings
Task 24: Solar Procurement
Task 25: Solar Assisted Air Conditioning of Buildings
Task 26: Solar Combisystems
Task 27: Performance of Solar Facade Components
Task 28: Solar Sustainable Housing
Task 29: Solar Crop Drying
Task 31: Daylighting Buildings in the 21st Century
TASK 25 Solar Assisted Air Conditioning of Buildings

Air-conditioning is the dominating energy consuming service in buildings in many countries. And in many regions of the world the demand for cooling and dehumidification of indoor air is growing due to increasing comfort expectations and increasing cooling loads. Conventional cooling technologies exhibit several clear disadvantages:

- Their operation creates a high energy consumption.
- They cause high electricity peak loads.
- In general they employ refrigerants which have several negative environmental impacts.

Task 25 'Solar Assisted Air Conditioning of Buildings' of the IEA Solar Heating & Cooling Programme addresses these problems. Therefore the utilization of solar energy for air-conditioning of buildings is covered by research, development and demonstration work. The main objective of the Task is to improve conditions for the market entry of solar assisted cooling systems.

The main objective of Task 25 is to improve the conditions for the market entry of solar assisted cooling systems in order to promote a reduction of primary energy consumption and electricity peak loads due to cooling.

Work in Task 25 is organized in 4 Subtasks
Subtask A: Survey of solar assisted cooling
Subtask B: Design tools and simulation programs
Subtask C: Technology, market aspects and environmental benefits
Subtask D: Solar assisted cooling demonstration projects

The current report was produced as part of the work in Subtask C.
Executive Summary

Solar-assisted air conditioning offers opportunities to meet the increasing cooling demand in buildings all over the world in an energy-efficient way. The potential of this technology is far from being realised. IEA Solar Heating and Cooling Task 25 “Solar-assisted air-conditioning of buildings” aims to improve the conditions for market introduction and development of solar-assisted air-conditioning systems. One of the activities of the Task 25 project group has been to identify and promote further research and development of promising technologies for solar-assisted air-conditioning systems.

This report presents an overview of ongoing and recently completed R&D work, relevant for solar-assisted air conditioning. Descriptions of the projects that have been identified by Task 25 participants form the backbone of this report. It further includes information from Internet searches and selected conference proceedings. The structure of the report reflects the solar-assisted air conditioning system itself, which consists of solar collectors on the one hand, and a heat-driven chiller/dehumidifier on the other.

Solar collectors
Solar-assisted air-conditioning systems in general require higher water temperatures than domestic hot water systems. Collectors that achieve this tend to be more expensive than conventional flat plate collectors. Two projects that aim to produce high water temperatures at low cost have been identified, but many more are ongoing, though not explicitly connected to solar-assisted air-conditioning systems. In general, it can be said that suitable collectors are already available. Cost reduction is not only desirable for the air-conditioning application.

Heat-driven chillers/dehumidifiers
Heat-driven chillers/dehumidifiers can be distinguished into the main groups: absorption chillers, adsorption chillers, desiccant cooling systems and other technologies.

A major challenge concerning absorption chillers is to develop smaller systems than currently available on the market (>35 kW), since the project group has identified a distinct market for small solar-assisted air-conditioning systems. Seven projects concerning absorption chillers have been identified, and most of them aim for small equipment.

Concerning adsorption chillers, the cost per kW cooling capacity is higher than for absorption chillers, but their efficiency at low driving temperatures is higher. Three projects have been identified. Two of them aim for improved efficiency at lower cost, and the other aims to improve the cyclic behaviour of the adsorption machine.

Little projects have been identified that were concerned with desiccant cooling systems and other technologies. The two desiccant projects both concerned liquid desiccant systems, which are highly interesting due to their intrinsic storage possibilities. Among other cooling technologies, there is one project concerning a jet cycle system. This system is characterised by low driving temperatures and low construction cost, but also by a low COP.

The main recommendations from this report concern chillers and dehumidifiers. According to the project group, it is worthwhile to further pursue the development of small-size chillers, explore possibilities to integrate heat-driven and electrically-driven cooling equipment and benefit from the intrinsic storage possibilities of liquid desiccant systems.
Solar-assisted air conditioning systems studies are very important. Experience shows that many problems of real operation rise rather on a system level than on the level of single components. Only three projects have been described in this report, but it should be noted that many system studies are ongoing within the Task 25 work, particularly in Subtask D. However, these will be described in another publication. Important issues for system studies are control, primary energy savings and economy of the installations.

General conclusion
This report identifies a number of interesting research projects for the further development of the solar-assisted air-conditioning market. The emphasis is on suitable small-size (absorption) chillers and system studies. The projects will certainly help to promote solar-assisted air-conditioning.
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APPENDICES
(see separate File: Task25-SubtaskC2-Final_Report-Appendices.pdf)
Subtask C2 - Development of new technologies for solar assisted air conditioning

4. Title of development/project
Design of a Solar Driven Cooling Unit based on the diffusion absorption principle

2. Duration of project
Start Date: 01.04.1999  Termination Date: 31.03.2001

3. Short description of project (objectives, work program, background,....)
In the project a Diffusion-Absorption Cooling Machine (DACM) with 2.5 kW cooling power driven by solar thermal collectors was developed, constructed and tested.

The diffusion absorption process based on ammonia-water solutions and an inert gas for pressure equilibration has been known for about a century, but the only machines constructed so far use high temperature generators directly powered by gas or electricity. To use solar thermal energy with commercial vacuum tube collectors new generators had to be designed which can operate at temperature levels between 100°C and 150°C. The expensive mechanical solution pump has been replaced by the thermally driven generator which includes a gas bubble pump.

The objectives of the project were mainly centred around the development, construction and testing of the Diffusion-Absorption machine. A prerequisite for the development was a complete analysis of the process, which involves software development for heat transfer calculations and component design.

The cooling machine has been tested using solar thermal energy with varying temperature levels as the heating input and the evaporator performance has been tested for temperature levels corresponding to cold production and air-conditioning purposes. From the experience with the prototype development, a market near unit should be developed, which should be lightweight, should use low cost components and should work with stable operating conditions.
Appendix 2b
Solar-driven diffusion absorption chiller

4. Technical scheme (drawing)

![Diagram of the solar driven Diffusion-Absorption Cooling Machine (DACM)]

**Figure 1:** Principle of the solar driven Diffusion-Absorption Cooling Machine (DACM).
(Note: the dephlegmator is a specific type of rectifier)

5. Technical description

The main components of a DACM are the generator, condenser, evaporator and absorber (Figure 1). A solution heat exchanger in the solution circuit and a gas heat exchanger in the auxiliary gas circuit are also components of the DACM as well as a dephlegmator for the condensation of the evaporated solvent.

At low partial pressure in the evaporator the cooling agent evaporates and is absorbed in the absorber by the weak ammonia-water solution from the generator. In the indirectly solar powered generator with high heating temperatures the cooling agent is driven out of the rich ammonia-water solution and so a high cooling agent vapour pressure is generated which is enough for the condensation of the cooling agent in the condenser.

The usual mechanical solution pump of absorption cooling machines is replaced in a DACM by a thermal gas bubble pump. The circulation of the solution between the generator and absorber is maintained by vapour bubbles, which push up a liquid column. The pressure compensation between high and low-pressure level is realised by an inert auxiliary gas, helium or hydrogen. The auxiliary gas circulates between evaporator and absorber because of the temperature and density differences. In the whole cooling unit are no mechanically moving components and everywhere in the cooling unit is the same total pressure.
Appendix 2b
Solar-driven diffusion absorption chiller

6. performance characteristic (efficiency curve, COP curve, tables....)

The Diffusion-Absorption Cooling Machine was designed for air-conditioning with the following temperature and heating/cooling capacity parameters:

Heat flows and design temperatures of the DACM pilot plant:

- generator (required heating power) \( Q_H = 5.2 \text{ kW} \);
  \( T_{G,IS} = +101^\circ\text{C} \)
  \( T_{G,WS} = +112^\circ\text{C} \)

- dephlegmator (required cooling) \( Q_{Deph} = 0.9 \text{ kW} \);
  \( T_{Deph} = +50^\circ\text{C} \)

- condenser (required cooling) \( Q_C = 2.8 \text{ kW} \);
  \( T_C = +45^\circ\text{C} \)

- evaporator (designed cooling power) \( Q_0 = 2.5 \text{ kW} \);
  \( T_O = +5^\circ\text{C} \)

- absorber (required cooling) \( Q_A = 4.0 \text{ kW} \);
  \( T_A = +45^\circ\text{C} \)

- ambient \( T_{ambient} = +32^\circ\text{C} \)

- collector outlet \( T_{Cell, out} = +127^\circ\text{C} \)
- collector inlet \( T_{Cell, in} = +117^\circ\text{C} \)

Total pressure (given by condenser temperature): \( p = 18.5 \text{ bar} \)

Degassing wide in the generator (rich to weak solution): 5 \%

- NH3-concentration rich solution \( X_{IS} = 42 \% \)
- NH3-concentration weak solution \( X_{wS} = 37 \% \)

For the investigations of the DACM the pilot plant was filled up with a 38 percent ammonia-water solution and helium as auxiliary gas. The complete pilot plant of the solar powered DACM is run and tested in the laboratory of the University of Applied Sciences Stuttgart with an indirect liquid heating circuit. Modelling of the performance of the DACM (Figure 2) resulted in a COP of 0.53 and with heat recovery of the rectification losses of about 0.72 for the design operating conditions.

Figure 2: Coefficient of performances (COP) of the DACM with/without heat recovery for evaporator temperatures from -20 up to +20°C and for \( T_A = T_C = 45^\circ\text{C} \) (simulations).
7. project status (prototype production, pilot production, market introduction, unsolved problems,....)

In this JOULE-CRAFT project “Design of a Solar Driven Cooling Unit based on the diffusion absorption principle”, contract JOE3-CT98-7045, an innovative solar thermally driven absorption cooling machine of 2.5kW cooling power was designed and constructed. The indirectly heated generator with a thermally driven gas bubble pump as the main new component of the cooling machine was designed using computer simulation tools and tested on a new experimental facility with alternative material combinations (methanol/water).

Standard components such as condenser, absorber, gas and solution heat exchangers has been scaled up from the known power range for small refrigerators (<100W) to medium power levels. Extensive calculations had to be done to determine the heat exchange properties of these components in the presence of helium as an inert gas. Experiments on the completed prototype unit showed that stable system operation is critically dependent on temperature levels and heat flux densities and continuous operation can only be achieved if special algorithms for system control are used. The temperature levels required from the solar collectors for stable operation were 150°C.

Measurements were done with different evaporator temperature $T_e$ from 0°C up to +25 °C. The reached evaporator capacities were in a range between 0.2 and 1.5 kW and the heating capacities were between 4.0 and 13.5 kW depending on flow rates or heating temperatures. The condenser and absorber cooling capacities were between 1.0 and 3.5 kW and the dephlegmator cooling capacity was 1.0 kW. Up to now the best ever reached cooling capacity of the pilot plant amounted to 1.5 kW. However, the results are very difficult to reproduce and a detailed analysis of the process stability and reproducibility has to be done. For increasing of the cooling capacity to the designed value of 2.5 kW, a further optimisation of the fluid cycles and a reduction of the heat losses is necessary. For the improvement of the performance from the latest reached COP of 0.20 to 0.25 to the calculated COP of the aggregate of 0.5 the internal fluid circulations and the single components generator, evaporator and gas heat exchanger have to be optimised.

As all components of the prototype were custom designed and constructed in the workshops of the University of Applied Sciences Stuttgart, the prototype had a weight of 800kg at 3.7m height. The main task of the development of a market near unit was the redesign of most components (apart from the generator) with the main criteria of cost, weight and height reduction. The final market near unit uses plate heat exchangers for the standard components (condenser, gas and fluid heat exchanger) and a common shell evaporator/absorber construction. The final aggregate could thus be reduced to a 2m high unit of 290kg weight, which can be easily placed in buildings.

An application for a national German Patent was done for the cooling machine and extended to a PCT patent application, which covers the European member states and additionally Australia, China, India, Japan, Canada and the United States.

8. participating companies and institutions

<table>
<thead>
<tr>
<th>8.1 company’s name</th>
<th>Fachhochschule Stuttgart - Hochschule für Technik – Joseph-von-Egle Institut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsible person</td>
<td>Prof. Dr. Ursula Eicker / Dipl.-Ing.(FH) Uli Jakob</td>
</tr>
<tr>
<td>Address</td>
<td>Schellingstrasse 24, 70174 Stuttgart, Germany</td>
</tr>
<tr>
<td>Phone</td>
<td>+49 / (0)711 / 121-2831 / -2889    fax -2698</td>
</tr>
</tbody>
</table>
## Appendix 2b
Solar-driven diffusion absorption chiller

<table>
<thead>
<tr>
<th>E-mail</th>
<th>role in project</th>
<th>8.2 company's name</th>
<th>Responsible person</th>
<th>Address</th>
<th>Phone</th>
<th>e-mail</th>
<th>role in project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Schneider &amp; Partner Ingenieurgesellschaft für Energie und Umwelttechnik GbR</td>
<td>Dipl.-Ing. Dietrich Schneider</td>
<td>Im Junoweg 3, 70565 Stuttgart, Germany</td>
<td>+49 / (0)711 / 7450-134</td>
<td><a href="mailto:sup-stuttgart@t-online.de">sup-stuttgart@t-online.de</a></td>
<td>SME coordinator and SME partner; planning, construction, development prototype</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schneider &amp; Partner Ingenieurgesellschaft für Energie und Umwelttechnik GbR</td>
<td>Dipl.-Ing. Dietrich Schneider</td>
<td>Im Junoweg 3, 70565 Stuttgart, Germany</td>
<td>+49 / (0)711 / 7450-134</td>
<td><a href="mailto:sup-stuttgart@t-online.de">sup-stuttgart@t-online.de</a></td>
<td>SME coordinator and SME partner; planning, construction, development prototype</td>
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</tr>
<tr>
<td>8.3 company's name</td>
<td>SQG Bau GmbH</td>
<td>Ulrich Barth</td>
<td></td>
<td>Magnolienweg 5, 63741 Aschaffenburg, Germany</td>
<td>+49 / (0)171 / 4436988</td>
<td><a href="mailto:sup-stuttgart@t-online.de">sup-stuttgart@t-online.de</a></td>
<td>SME partner; construction, plans of market near unit</td>
</tr>
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</tr>
<tr>
<td>8.4 company's name</td>
<td>Colibri bv</td>
<td>IR. Reinhard Schneider / IR. Heiner Veelken</td>
<td>Tentstraat 5a, 6291 bc Vaals, The Netherlands</td>
<td>+31 / (0)43 / 306-6227</td>
<td><a href="mailto:colibri@mail.cobweb.nl">colibri@mail.cobweb.nl</a></td>
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<tr>
<td></td>
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<td></td>
<td>SME partner; planning, development prototype</td>
</tr>
<tr>
<td>8.5 company's name</td>
<td>Energy Consulting</td>
<td>Dr. Emanuele Negro</td>
<td>1260, Chemin de Bibemus, 13100 Aix en Provence, France</td>
<td>+33 / (0)429 / 650-21</td>
<td><a href="mailto:negro@energy-consulting.com">negro@energy-consulting.com</a></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>SME partner; simulation, visualisation</td>
</tr>
<tr>
<td>8.6 company's name</td>
<td>AXIMA Refrigeration GmbH Lindau (former: Sulzer-Escher Wyss GmbH)</td>
<td>Dr.-Ing. Martin Bierer / Dipl.-Ing.(FH) Werner Diepolder</td>
<td>Kemptener Strasse 11-15, 88131 Lindau, Germany</td>
<td>+49 / (0)8382 / 706-284</td>
<td><a href="mailto:Martin.Bierer@axima.eu.com">Martin.Bierer@axima.eu.com</a> / <a href="mailto:Werner.Diepolder@axima.eu.com">Werner.Diepolder@axima.eu.com</a></td>
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<td>RTD partner; calculation, planning, construction of market near unit</td>
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Ongoing research relevant for solar-assisted air-conditioning systems
Appendix 2b
Solar-driven diffusion absorption chiller

<table>
<thead>
<tr>
<th>8.7 company's name</th>
<th>Universität Stuttgart – Institut für Thermodynamik und Wärmetechnik</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsible person</td>
<td>Dr.-Ing. Klaus Spindler / Dipl.-Ing. Thomas Brendel</td>
</tr>
<tr>
<td>Address</td>
<td>Pfaffenwaldring 6, 70550 Stuttgart, Germany</td>
</tr>
<tr>
<td>Phone</td>
<td>+49 / (0)711 / 685-3533 / -3552</td>
</tr>
<tr>
<td>e-mail</td>
<td><a href="mailto:spindler@itw.uni-stuttgart.de">spindler@itw.uni-stuttgart.de</a> / <a href="mailto:brendel@itw.uni-stuttgart.de">brendel@itw.uni-stuttgart.de</a></td>
</tr>
<tr>
<td>role in project</td>
<td>RTD partner; calculation and dimensioning of prototype</td>
</tr>
</tbody>
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9. references


Appendix 2b
Solar-driven diffusion absorption chiller

10. funding (national, EU, ...)

This project was funded in part by the European Commission in the framework of the Non Nuclear Energy Programme JOULE-CRAFT (contract number: JOE3-CT98-7045).