ONGOING RESEARCH RELEVANT FOR SOLAR ASSISTED AIR CONDITIONING SYSTEMS

Technical Report

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

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

Task Participants

Austria
Wolfgan Streicher, TU Graz, Graz

Denmark
Jan Eric Nielsen, Solar Energy Center, DTI, Taastrup

France
Jean-Yves Quinette (Leader Subtask C), Tecsol, Perpignan
Daniel Mugnier, Tecsol, Perpignan
Rodolphe Morlot, CSTB, Sophia Antipolis

Germany
Hans-Martin Henning (Operating Agent), Fraunhofer Institute for Solar Energy Systems ISE, Freiburg
Uwe Franzke (Leader Subtask B), Institut für Luft- und Kältetechnik Dresden
Carsten Hindenburg, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg
Tim Selke, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg
Jan Albers, Institut für Erhaltung und Modernisierung von Bauwerken e.V. an der TU Berlin
Michael Kaelcke, ZAE Bayern, Munich

Greece (observer)
Constantinos A. Balaras, Group Energy Conservation, IERSD, National Observatory of Athens, Athens

Israel (observer)
Gershon Grossman, Technion, Haifa

Italy
Federico Butera, Polytecnic di Milano, Milano
Marco Beccali, University of Palermo, Palermo

Japan
Hideharu Yanagi, Mayekawa MFG.Co.

Mexico
Isaac Pilatowsky (Leader Subtask A), Universidad Nacional Autonoma de Mexico, Temixco
Roberto Best, UNAM, Temixco
Wilfrido Rivera, UNAM, Temixco

Netherlands
Gerdi R. M. Breembroek (Leader Subtask C), IEA Heat Pump Centre / Novem bv, Sittard
Rien Rolloos (now: Daniel Naron), TNO, Delft
Cees Machielsen, TU Delft, Delft

Portugal
Manuel Collares-Pereira, INETI-DER, Lisbon
Joao Farinha Mendes, INETI-DER, Lisbon
Maria Joaó Cavalhó, INETI-DER, Lisbon

Spain
Jordi Cadafalch Rabasa, Universitat Politècnica Catalunya, Terassa
Carlos David Pérez Segarra, Universitat Politècnica Catalunya, Terassa
Hans Schweiger, AIGUASOL Enginyería, Barcelona
Laura Sisó Miró, AIGUASOL Enginyería, Barcelona

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 adresses 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 form 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
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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1. Introduction

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 energy consumption is high;
- they cause high electricity peak loads;
- in general, they employ refrigerants with a considerable global warming potential.

The utilisation of solar energy to drive heat-driven cooling machines is a way to address these problems. These systems use solar heat to drive a heat-drive chiller or dehumidifier, such as ab- or adsorption chillers, and desiccant evaporative cooling systems. A well designed solar assisted air-conditioning system produces cooling with considerably less electricity demand than conventional air-conditioning systems. Furthermore, the working fluids used in sorption chillers and desiccant rotors will not contribute to global warming, contrary to most working fluids in conventional compression chillers.

IEA Solar Heating and Cooling Task 25 “Solar-assisted air-conditioning of buildings” aims to improve the conditions for market introduction of solar assisted air-conditioning systems. From 1999-2002, the project group has worked on the following issues:

- Establishing performance criteria (energy, economy) of solar assisted cooling systems;
- Identification and further development of promising solar assisted air conditioning technologies;
- Optimised integration of solar assisted cooling systems into the building and the HVAC system;
- Design tools and a solar-assisted air conditioning handbook for architects, planners and civil engineers.

This report is the result of the second task, to identify and promote further development of promising solar-assisted air-conditioning technologies. Purpose of the report is to summarise the results of the survey which the participants carried out in their countries. This shall help experts like scientists or engineers working in this field to achieve an overview about new opportunities of using solar thermal energy for air conditioning of buildings in the future. Furthermore the overview shall help to identify major future needs in the R&D field.

More information about the project in general can be found on the project Internet site [1].

2. Method of information gathering

The project team of IEA SHC Task 25 consisted of experts in solar air conditioning and related fields from Germany (task leader), Austria, Denmark, France, Greece, Israel, Japan, Mexico, the Netherlands, Portugal and Spain. These people were asked to identify finished or ongoing R&D projects relevant to solar-assisted air conditioning systems in their countries. Table 1 shows the results.

Table 1: R&D relevant to solar–assisted air conditioning

Austria	Low temperature absorption chiller for solar cooling of buildings
Denmark	-
France*	Participation in SOLHEATCOOL (Costic) R&D on adsorption cycles (CNAM - F. Meunier) Thermochemical cascading systems (CNRS – B. Spinner) (NESSY)
Germany	Optical improvement of market available parabolic trough collectors Solar-driven diffusion absorption chiller $NH_3/SrCl_2$ absorption chiller 2-phase/2-component jet-cycle chiller Improved adsorption chiller Solar-driven liquid desiccant dehumidification of ventilation air Double effect absorption chiller driven by parabolic trough collectors
Greece	Absorption heat pump for solar assisted space conditioning of a small office
Israel	Solar cooling, dehumidification and air conditioning using liquid desiccants (part of ASODECO)
Italy	-
Japan	Hybrid adsorption cooling system with booster pump
Mexico*	Air-cooled GAX absorption heat pump, solar assisted.
Netherlands	-
Portugal	Residential solar air conditioning system (MAGESCLI)
Spain	Stagnation-proof transparently insulated flat plate solar collector (STATIC) Air-cooled H_2O/LiBr absorption chiller with a low capacity.(ACABMA)

*No detailed information available on projects from France and Mexico.

The project descriptions gathered by the Task 25 participants are given as appendices to this report.

Furthermore, several other sources such as conference proceedings and Internet have been consulted for additional information:

- Heat Powered Cycles 2001 [2];
- Absorption Conference 1999 [3];
- IEA Heat Pump Centre Newsletter, December 2001 [4];
- Cordis database of the European Commission [5].

3. Solar collectors

Solar collectors are the most specific part of the solar-assisted air conditioning system; the nature of the driving energy in this air conditioning system is the key difference to any other system. The goal of using solar collectors as heat source is to achieve primary energy savings. The challenge is that the efficiency of sorption systems – in particular absorption systems – benefits from high drive temperatures. However, collectors that achieve high temperatures (with an acceptable efficiency) tend to be more expensive than conventional flat plate systems.

The work within Task 25 has shown that both the price of the sorption machine/desiccant technology and the price of the required solar collectors determine the payback of a solar-assisted air-conditioning system [6]. In most cases a larger solar collector area leads to higher payback period, too. Therefore, collector cost efficiency is an issue.

In principle a solar collector is not designed for a certain application but for a certain operation temperature level. For solar cooling applications the temperature level is generally higher than for production of domestic hot water. Therefore, R&D on solar collectors relevant for solar cooling aims at improving the efficiency of solar collectors at higher temperature differences with low cost particularly when applied in large collector fields. The two projects described in this area are:

Title	**Main content**
Optical improvement of market available parabolic trough collectors *Description Appendix 1a.*	Improving reflectivity and integrating end-loss reflectors for IST (USA) collectors. Study performance.
Stagnation-proof transparently insulated flat plate solar collector (STATIC). *Description Appendix 1b.*	Flat plate collectors with honeycomb transparent insulation cover as a low cost alternative for evacuated tube and CPC collectors for temperatures of 80-160ºC.

The simulations shown in Appendix 1a show that the heat from parabolic trough collectors is cheaper than the heat from typical flat plate collectors at average fluid temperatures > 75ºC in the Copenhagen climate. The optical improvements are expected to further enhance these benefits.

The application of transparent insulation material enhances the efficiency of the flat plate collectors at higher temperatures. One of the prototypes, suitable for operation up to 120ºC, has an efficiency similar to vacuum tube collectors, but the production price would be lower. Currently, the results of this research are being adapted for commercial production.

The projects listed here were identified since the collector development is directly intended for application in a solar cooling system. Of course, work on improving the efficiency of solar collectors is going on in many countries. Different improvements, such as integration of anti-reflective glass covers, improved selective coatings, low-concentration non-tracking systems etc. are being introduced. In general, a crucial point is that these collectors achieve high stagnation temperatures which both the collector itself as well as the entire system must be able to stand. Therefore an important item in solar assisted cooling systems is to handle stagnation problems on a materials level but also on a level of control in order to be able to stand situations of high temperature and pressure in the solar circuit.

In general it can be said, that concerning solar-assisted air conditioning, the need for system studies (discussed in chapter 5), and the need to develop a market, are more pressing than the need to develop more efficient collectors at high temperature differences. There is no "best" collector for solar cooling, since the local climate, the collector output temperature, efficiency and cost, and cooling machine driving temperature, efficiency and cost all determine the efficiency of a solar-assisted cooling system.

A list of additional projects on solar collectors:

- *Refrigeration, heating and air-conditioning using an absorption refrigeration system heated by transparent insulated solar collectors*. EESD project, end date August 2003. Prime contractor ITELSA, Salamanca, Spain. ITELSA is a solar energy company [5].

4. Cooling and dehumidification technologies

4.1. Absorption chillers

Absorption chillers are applied in most solar-assisted air conditioning systems which are in operation today. The main challenges to achieve a further penetration of absorption chillers in solar-assisted air conditioning systems are the following:

1. The machines on the market are intended for large-scale applications but there is also a demand for smaller solar-assisted air-conditioning systems;
2. LiBr absorption chillers need a cooling tower;
3. Efficiency and capacities are small at low driving temperatures;
4. More expensive collector types (e.g. vacuum tubes, CPCs) are required in combination with absorption chillers to guarantee a sufficient efficiency.

Research relevant for solar air conditioning systems aims to address these challenges. The following projects identified by Task 25 participants concerned absorption systems:

Title	**Main content**
Residential solar air conditioning system (MAGESCLI). *Description Appendix 2a.*	Development of a 5 kW cooling capacity, 9-10 kW heating capacity NH_3/H_2O absorption chiller. Rectifier inside generator.
Solar-driven diffusion absorption chiller. *Description Appendix 2b.*	Development and testing of a 2.5 kW cooling capacity $NH_3/H_2O/He$ diffusion absorption chiller.
$NH_3/SrCl_2$ absorption chiller. *Description Appendix 2c.*	NH_3 absorbs into a $SrCl_2$ impregnated surface. Batchwise operation. Regeneration at 69ºC, therefore suitable for solar heat. Prototype 1-3 kW planned.
Low temperature absorption chiller for solar cooling of buildings. *Description Appendix 2d.*	Scaling-up to 30-50 kW cooling capacity of the 400 W AAAC “Advanced Ammonia Absorption Cooling” $NH_3/H_2O/He$ diffusion absorption chiller. Has an additional heat exchanger for higher efficiencies.
Absorption heat pump for solar assisted space conditioning of a small office (SOLHEATCOOL). *Description Appendix 2e.*	10 kW single-stage H_2O/LiBr absorption heat pump.
Air-cooled GAX absorption heat pump, solar assisted. *No full description available.*	10.6 kW GAX (Generator absorption heat exchanger) absorption heat pump with some simplifying modifications. Air-cooled.
Air-cooled H_2O/LiBr absorption chiller with a low capacity.(ACABMA) *Description Appendix 2f.*	Air-cooled H_2O/LiBr absorption chiller for residential use. Driving heat 75-90ºC.

- The capacities of the machines in this overview are mostly around 10 kW, whereas market available equipment starts at 35 kW (Yazaki).
- Most of the machines are air-cooled, except the "SOLHEATCOOL" machine.
- Many machines reach a (modeled) COP of 0.70-0.75 under favourable conditions. It should be noted that little measurements are available yet. The efficiency of the $NH_3/SrCl_2$ is apparently lower – as well as the potential driving temperature.
- Most of these machines are intended for driving temperatures below 100ºC, so that they could operate without expensive collector types.

The ongoing research indeed aims to address the challenges to promote absorption technology for use in solar assisted air conditioning systems. There is little explicit attention for the cost of the systems compared to other alternatives for small applications (Yazaki machine, 35 kW; or compression chillers, though these cannot be solar-heat driven).

Projects from other sources that deal with topics related to application in solar assisted air conditioning systems but from which no project summary form is available, are:

- *Air-cooled, solar (or gas) driven NH_3/H_2O absorption system for air conditioning and other cooling applications using a compound parabolic collector.* EESD project, end date September 2001. Prime contractor: CEERAN, the Netherlands. Focus was on developing a 10-50 kW air-cooled absorption chiller [5].
- *Identification and evaluation of advanced GAX cycles for space conditioning,* G. Anand, D.C. Erickson. Focuses on designing alternative GAX cycles, with a better cooling COP than the basic GAX cycle (which has a better COP for heating than conventional absorption systems) [3].
- *Single effect/double effect chiller: operational experience and prospect.* C. Schweigler et all. ZAE, Germany. Describes operating experience with three chillers, especially designed for operation on CHP waste heat. Hot water supply at 95-85ºC; return at 65-60ºC. COP around 0.6; Cooling capacity fo these machines ranging from 300-2500 kW [3].
- *Development and operation of a high performance 10 kW absorption chiller,* R. Lorton et all. The "Interotex" technology uses a burner for regeneration and metal hydroxides/H_2O as the working media. The system is a highly integrated double effect heat pump with the key processes enhanced by rotation. In a second step the development aims on use of hot water as driving heat which replaces the direct heating with gas. The size of the chiller is interesting.
- *Thermodynamic cycle for solar thermal power,* D.Y. Goswami et all. University of Florida, USA. Concerns a hybrid Rankine and absorption refrigeration cycle, with simultaneous production of power and cooling, driving by solar heat (~100ºC). Ammonia-water is the working fluid [12]. The researchers aim at a household-scale appliance of 5 kW electricity.

Other absorption heat pump research focuses on controls, new working pairs, heat and mass transfer, additives for enhanced heat and mass transfer, etc. [3]. Solar-driven refrigeration research can be interesting for solar assisted air conditioning as well. A recent example was presented at the Heat Powered Cycles conference [2].

4.2. Adsorption chillers

Adsorption chillers have a higher efficiency at low driving temperatures than absorption chillers. Adsorption technology has a few weaknesses:

- They are more expensive per kW cooling capacity than absorption chillers;
- There is a limited market choice (only two manufacturers);
- The process has a cyclic nature, which requires more effort in design and control;
- The machines are big and heavy.

Research included here aims to cancel the weaknesses or improve the benefits of adsorption technology. Related projects are:

Title	Main content
Hybrid adsorption cooling system with booster pump. *See Appendix 3a.*	Booster pump facilitates desorption process and enables high efficiencies at lower driving temperatures.
Four-bed adsorption chiller. *See Appendix 3b.*	Four-bed adsorption chiller delivers steadier cooling than two-bed systems. 17.6 kW prototype has been built. COP will be ~ 0.6.
Improved adsorption chiller. *See Appendix 3c.*	Development of modular machine 10 kW – 1 MW, improved heat exchangers, rotating switching system, optimised control. Investment cost < € 250/kW cooling.

The adsorption cooling system with booster pump reaches efficiencies > 10, defined on electricity input. The interesting fact of this system is that an integrated hybrid system is provided in which solar produced heat serves to save electricity for the production of chilled water. The improvements to the adsorption chiller, as presented in appendices 3b and 3c, will increase the market choice and improve the characteristics of adsorption systems. No results of these efforts are available yet.

Projects from other sources that deal with topics related to adsorption chillers:

- *Adsorption heat pump technology – possibilities and limits;* F. Meunier [3]. The basic one-adsorber cycle consists of an adsorber, an evaporator, a condenser and valves. Various working pairs can be used, such as silicagel-water, but also activated carbon-ammonia etc. A high affinity adsorbent yields a low COP but enables a high temperature lift. Advanced sorption systems focus on low-temperature driving heat, high efficiencies and/or continuous cold production. Additional topics are (heat) transfer intensification in the adsorber and weight reduction.
- *New working materials for sorption cooling/heating driven by low temperature heat: properties;* Yu. L. Aristov et all. [3]. This focuses on the properties of various salts on various host materials. These sorbents can be highly competitive to the common working materials and the power density of the machines would be increased due to a much higher refrigerant loading for given operation conditions.
- *Solar-gas solid sorption heat pump;* L.L. Vasiliev et all. [3]. Research to develop a small scale (< 10 kW) solar-assisted absorption heat pump. Evaporator was placed in the focus of a parabolic solar concentrator, but direct evaporation in vacuum tube collectors was

also used. Generator temperatures 85-100ºC. NH_3 and active carbon are the working pair. In a subsequent research project, a salt-impregnated active carbon fiber sorber was used [2].

- *A four-bed regenerative adsorption chiller design;* H.T. Chua et all, Singapore/Japan. This chiller works at driving temperatures of 85ºC [3].
- *A prototype adsorption heat pump/chiller using forced convection heat transfer and the active carbon/ammonia pair*; R. Thorpe, University of Warwick, UK. This concerns an adsorption machine with a novel and compact geometry which optimises thermal regeneration. However, heat input is at 225ºC [2].

Other research on adsorption systems concentrates on heat and mass transfer in the adsorption blocks. A monolithic adsorber has been proposed, as well as an adsorber of aluminum sheets [3]. This work does not consider the regeneration efficiency at low regeneration temperatures. An adsorption system, using methanol and activated carbon as a working pair, with integration of heat transfer and adsorption, and connected, twin active beds, has been developed in the UK, University of Bristol [2]. Regeneration temperature is 100ºC.

4.3. Desiccant systems

Desiccant evaporative cooling (DEC) systems have the advantage that they can treat latent loads separately. They can replace a conventional ventilation system in which the cooling/dehumidification function is realised by a conventional electrically driven vapour compression chiller.

It is striking that there is little research on solid desiccant wheels or DEC systems. The project partners have identified two research projects that deal with *liquid* desiccant systems. Liquid desiccant systems can be cheaper than solid desiccant wheels, if current market-available products are compared.

Title	**Main content**
Solar-driven liquid desiccant dehumidification of ventilation air. *See Appendix 4a.*	Space conditioning for 5000 m^2 office building. Cooling by well water, dehumidification by liquid desiccant system. Regeneration of desiccant by solar heat.
Solar cooling, dehumidification and air conditioning using liquid desiccants (part of ASODECO). *See Appendix 4b.*	Space conditioning for 35 m^2 office building. Additional conventional chiller. Regeneration by solar heat (flat plate).

Results of these projects are not available yet, since both systems are still in the construction phase.

One of the advantages of liquid desiccant systems is, that the stocks of concentrated and dilute solution can serve as buffers. When solar heat is available, a stock of concentrated solution can be prepared. The liquid desiccant system has a cleaning effect on the supply air.

Other projects:

- *A novel desiccant cooling system using needle impeller rotors.* Joule project, completed June 2000. Prime contractor: University of Nottingham. Needle impeller rotors are expected to increase heat and mass transfer and reduce manufacturing cost. Furthermore, a heat recovery unit based on heat pipes and a novel absorbent have been applied [5].
- *Advanced commercial liquid-desiccant technology development study,* Andy Lowenstein et all.. This is a completed study which identifies the following required technology improvements for liquid desiccant systems: zero-carryover, internal cooling, and double effect regeneration [7]. Both zero-carryover and internal cooling are features of the Drykor commercial product that is on the market now [8].
- *Analysis of an innovative HVAC plant based on an open cycle absorption system.* R.M. Lazzarin et all. This concerns a liquid desiccant system, intended for a building of the University of Padua, Italy. The system dehumidifies exhaust air – to be mixed with fresh air in summer, and to heat fresh air in winter. Regeneration with fossil-fuel fired boiler.

4.4. Other air-conditioning technologies

There are a number of other heat-driven cycles of interest to solar-assisted air conditioning. One of them is the jet cycle.

Title	**Main content**
2-phase/2-component jet-cycle chiller *See Appendix 5a.*	Construction and testing of a 0-20 kW NH_3/H_2O jet cycle chiller using heat < 80ºC as driving energy.

The 2-phase/2-component jet-cycle chiller only required some pump energy and produced temperatures between -5ºC - 5ºC at the evaporator. Its size would make it suitable for small commercial applications. The modelled efficiency is slightly above 0.2.

The system has little moving parts and provides sensible cooling. It is too early, at this stage, too say if it will be competitive compared to adsorption chillers, that can operate at higher efficiencies on hot water of similar temperatures. This machine would potentially be cheaper.

5. Solar-assisted air-conditioning systems

As already pointed out in chapter 3, the economical and energy efficiency of a solar-assisted air conditioning system does not depend on the maximum efficiency of the constituting parts only, but on their interaction and also the interaction with the load. Furthermore, different climates will favour different choices.

A number of solar-assisted air-conditioning demonstration projects will be monitored in detail within the working package of IEA SHC Task 25 (Subtask D – Demonstration projects). More information will be published in the Task 25 final report, in the handbook on solar air conditioning and in a specially dedicated web site.

Title	**Main content**
Double effect absorption chiller driven by parabolic trough collectors *See Appendix 6a.*	Hotel in Turkey. Newly designed parabolic trough collectors supply 180ºC water for driving a double effect chiller + laundry etc.
Solar-driven liquid desiccant dehumidification of ventilation air. *See Appendix 4a.*	See section 4.3
Solar cooling, dehumidification and air conditioning using liquid desiccants (part of ASODECO). *See Appendix 4b.*	See section 4.3

The solar-assisted air conditioning systems presented here are all quite different. For the Turkish situation, calculations have shown that a (more efficient) double effect absorption chiller and a limited parabolic trough collector area was economically more attractive than a single effect absorption chiller.

Liquid desiccant systems have a high flexibility. The system layout in these two projects is quite different, with an additional chiller in one case, and sensible cooling with well water in the other.

The reports given in the Appendices do not discuss the energetic and environmental efficiencies of these systems. Neither do any of the summaries say much about process control. It is clear that the systems design is of major interest for solar air conditioning systems. Economic and energetic advantages or disadvantages of the systems should be estimated and disseminated. More work on this topic will be part of the Task 25 handbook and the web site.

Other projects:

- *Hybrid Solar Liquid Desiccant Air Conditioning*, ongoing research at university of Florida [9]. A LiCl liquid desiccant system for dehumidification plus a conventional system for sensible cooling, operated in a test house. Regeneration of the LiCl with solar heat. Results indicate that the system has a payback of 9 years for (Florida) residences, and of less than 2 years for commercial applications.
- *Solar air conditioning for buildings; demonstration, analysis and assessment* [SOLARCLIM]. EESD Project, end date 2004. Prime contractor Tecsol. This demonstration project involves building and analysing 10 representative solar air

conditioning systems in Spain and France. Market available vacuum-tube collectors, and absorption chillers will be used [5]. Some of the projects are part of the demonstration Subtask D of Task 25.

- *Adsorption cooling of buildings with integrated PV/solar air heating facades* [AIRCOOL]. EESD project, end date September 2002. Prime contractor Fachhochschule Stuttgart. Design and implementation of a low cost desiccant cooling system. Regeneration with heat from integrated PV/solar air collectors. Aims include control strategies [5]. Monitoring results will also be part of the Subtask D.
- *Micro tri-generation system for indoor air conditioning in the Mediterranean climate.* EESD project, end date September 2003. Prime contractor: AMG Palermo. A system for heating and cooling of residences, micro-CHP and desiccant cooling, is being developed. One of the partners (Fiat Research Center) is working on a new liquid dehumidification process using a semi-permeable membrane.
- *Demonstrating the efficiency of solar space heating and cooling.* EESD project, end date December 2002. Prime contractor: NTUA Athens, Greece. Desiccant systems with solar regeneration will be integrated in 7 commercial buildings (Cyprus, Spain, Israel, Germany and further project partners) [5].
- *Solar powered adsorptive desiccant-based air-conditioning systems for the hot and humid climate of Japan.* A two-stage system layout that provides the necessary dehumidification and cooling, even in the hot and humid climate of Japan [10].
- *A numerical study on dynamic behaviour of a solar absorption cooling system,* S. Jeong, Korea. Models one-day operation of a solar single-effect absorption cooling system [3].
- *APASCUE: Advanced passive and active solar cooling for European cities,* M. Santamouris et all. [11]. Aims include an assessment of energy saving potential through solar cooling in Europe, the legislative framework, evaluation of case studies in Greece and Spain and a reference manual with design guidelines. Case studies include Sarantis, Boiotia, Greece (2700 m^2 flat plate collectors, two 350 kW adsorption chillers) and Hotel Belroy, Benidorm, Spain (328 m^2 vacuum tube collectors, single-effect 125 kW absorption machine).
- *The solar desiccant cooling cycle,* S. Halliday, C.B. Beggs, P.A. Sleigh, UK. A study demonstrates that solar-assisted desiccant cooling systems are viable in the UK.
- *Solar air conditioning in Europe SACE.* European Accompanying Measures Project. The project intends to review the state-of-the-art and to provide a picture of the potential, the future needs and the overall perspectives of solar assisted air conditioning technology. Project leader: Technical University of Delft.
- *Promoting Solar Air-conditioning – CLIMASOL.* EU-Altener-Project: Main content is the promotion and dissemination of ways of combining the reduction of cooling needs by passive or semi-passive measures and installing solar air conditioning components in order to reduce energy consumption and CO_2-emissions. Project leader: Rhônalpénergie-Environnement.

6. Conclusions and recommendations for further work

From the analysis of ongoing R&D projects it becomes obvious that a major lack for a broader application of solar assisted air conditioning is that no small systems (2-15 kW) are available on the market, though there is a demand for solar assisted air conditioning in this size range. Many different groups have identified this lack. As a result, there is a number of projects in which small-scale absorption chillers or adsorption chillers are being developed. A number of ongoing research projects in this and other areas are highly interesting for solar-assisted air conditioning. Other heat-driven cooling technologies are attracting attention, too. Among these, liquid desiccant systems stand out, with two demonstration projects ongoing.

Concerning future R&D on chillers for application in solar-assisted air-conditioning systems, the most important recommendations are:

- there is still need for further R&D on small systems (chillers, desiccant air handling units) which operate reliably at low temperatures; the need for low temperatures rises on the one hand from the collector efficiency but on the other hand from the fact that in most systems a heat store is recommendable and therefore the usable temperature level should be as far away from 100°C as possible;
- based on the primary energy analysis of solar assisted air conditioning systems (see e.g. the handbook) it turns out that from an energy point of view it would be extremely interesting to have integrated hybrid systems available which work with both a heat driven cycle and a compression cycle. Only one project was identified in which such an approach is taken up. Different technical solutions are possible for this purpose, e.g. cascaded compression/absorption or compression/adsorption cycle with different refrigerants; internal cascaded compression/absorption or compression/adsorption cycle with the same refrigerant; parallel employment of sorption with compression like in a desiccant air handling unit with backup chiller. In such a system solar energy is used as a ‘fuel-saver’ or better ‘electricity-saver’ in a combined process;
- Interesting new options come from the liquid desiccant cycles. One effect is the possibility to use the concentrated desiccant as energy storage for air conditioning. Another is that it is possible to cool the absorber and thereby to increase the potential for dehumidification remarkably. Such a process could also be combined with the solid desiccant cycle in order to increase its dehumidification potential and COP.

The number of relevant projects where solar collectors are developed is lower. Main reason is that solar collectors for all temperature ranges including those needed to drive absorption or adsorption chillers are available on the market. Many manufacturers offer many different products, including selectively coated flat plate collectors and/or evacuated tube collectors. Related to the application in solar assisted air conditioning systems the main need for the solar collector is further reduction of their costs in order to increase the competitiveness of the entire system. Of course, this is desirable not only for the air-conditioning application.

Solar assisted air-conditioning *system studies* are very important. Experience shows that many problems of real operation rise on the system level rather than on the level of the components. Many system studies are ongoing as well – many of them within the framework of IEA SHC Task 25 “Solar-assisted air conditioning of buildings”. These specific projects will be discussed in another publication. The evaluation of successful design strategies and successful system layouts in different climates will be an important output of the Task 25 effort.

In general, the projects aim to develop an energy-efficient technology and do not discuss the price of the system or the energetic advantages compared to competing technologies. For a further market development of solar-assisted air conditioning systems, these themes should be better integrated into the research projects or in subsequent studies.

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APPENDICES

(see separate File: Task25-SubtaskC2-Final_Report-Appendices.pdf)