

## 1 Introduction

### 11 Why use this technology

The main goal of applying solar energy for air conditioning of buildings is to reduce the energy consumption and to make this task more environmentally friendly.

Using solar energy for air conditioning purposes is quite a new technology. Recently this topic raised new interest in many countries. The reasons therefore are manifold. Main issues are on the one hand increased consciousness about environmental problems which are created by use of fossil fuel consumption. Also the use of classical refrigerants with their ozone-depleting and/or global warming potential has become a serious environmental problem. After all also the increased influence of air conditioning on shortages in the electric power supply in electricity grids underlines the need for advanced, new concepts.

More and more experiences have been made with large installations using solar thermal collectors for heating purposes. In spite of a significant growing market penetration rate, the main bottleneck for a broad application of solar thermal collectors beyond their application in domestic hot water production has been the seasonal mismatch between heating demand and solar energy gains. The need of seasonal storage does not arise if solar thermal energy can be employed for air cooling and dehumidification.

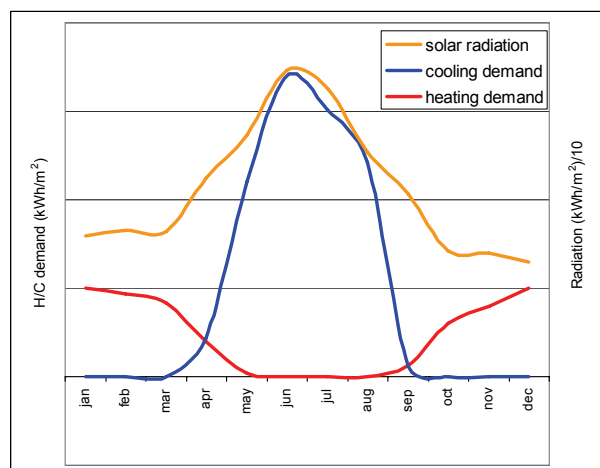


Figure 1: Example of cooling and heating load ( $\text{kWh/m}^2$ ) and available solar radiation for a site in southern Europe

The general "charm" of this concept is that at least on a seasonal level a high coincidence between cooling loads and solar gains exists; an example of the annual distribution of monthly heating and cooling load and the available solar radiation is shown in Figure 1. Using a Solar Heating and Cooling approach the installation of a Solar System is dedicated to the all year round climatisation of the building with favourable drawback on economic performance of them.

### 12 Requirements in regulations

European and National standards refer mainly on general issues of Air Conditioning Systems and Equipment and Indoors Comfort Conditions.

In the first case EN 14511 "Air conditioners, liquid chilling and heat pumps with electrically driven compressors for space heating and cooling" is the most representative standard among a large set of technical documents.

ISO 7730:2005 "Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria" is the worldwide accepted standard on this matter.

The issue of solar thermal systems for building climatisation is afforded up today in EN 15316 "Heating systems in buildings", while components performances and requirements are defined in EN 12975-1:2006 "Thermal solar systems and components", in EN 12976-2:2006 "Thermal solar systems and components - Factory made systems" and in EN 12977:2001 "Thermal solar systems and components - Custom built systems".

At the moment a standard on Solar Air Conditioning Systems is not programmed. A pre-standard activity is ongoing in the framework of International Energy Agency - Task 38 "Solar Air Conditioning and Refrigeration" activities".

## 2 Current practice

All air conditioning systems - no matter what type - increase the amount of energy required, the volume of investment, and the maintenance costs for a building. The prime aim of all building planners should therefore be to minimise the requirement of air conditioning. Yet in many

cases it is necessary to deploy active systems in order to control indoor temperature and air humidity. It is usually only possible to reliably control air conditioning in conference centres, theatres, department stores, multi-storey buildings, etc. with the aid of air handling units.

Apart from the heat and cold distribution scheme, heat is generally generated by combustion of fossil fuels (natural gas, oil, etc) while cold is produced through vapour-compression chillers. These solutions are today well established and their market is very mature. Costs of ordinary equipment are decreasing and, at the same time, more efficient appliances are available. The ozone-depleting refrigerants used in these systems have been replaced in recent years with CFC-free substitutes, although these agents are also not completely without their problems for the earth's climate.

What is more, compression chillers require a lot of electricity, which is primarily consumed at peak load times if no cold storage unit is used. During the last decades in most industrialised countries - even in heating dominating climates – the energy consumption for air conditioning purposes was increasing remarkably. In 1996 about 11.000 GWh of primary energy were spent in Europe alone for small room air conditioners up to a cooling capacity of 12 kW; it is expected that this value increases by a factor of 4 to about 44.000 GWh by 2020. This figure does not include all centralized air conditioning plants or chilled water systems as they are in general installed in large commercial buildings. However, the energy demand for summer air conditioning increases in all regions and most types of buildings also in temperate climates, like in Central Europe.

### 3 Innovative solutions

#### 31 General Overview

A crucial step towards the limitation of the disadvantages of the raising energy demand for air conditioning in both, economical and environmental sense, is the consumption reduction. Moreover, in the last thirty years and particularly in the last decade the growing environmental concerns and the consistent effort in research and product development opened the market for active solar systems. More and more experiences have been made with large installations using solar thermal collectors for heating.

At the same time, there is a growing interest in practice and applications of heat-driven cooling processes.

For example, gas-fired refrigeration machines still hold major market shares, above all in the USA and Japan. These systems take advantage of free capacities in the

gas grid in summer, thus reducing peak loads on the power grid. The high temperature level of gas firing allows refrigeration of up to 1.2 times the amount of heat input. In addition, there are several different processes available that take advantage of low temperature heat (<90°C) for refrigeration, for instance district heating, waste heat and solar heat. This is the way to make the solar thermal system suitable also for refrigeration and summer air-conditioning. Many processes are available to fulfil this task. Figure 2 shows the whole set of technologies today available to use solar energy for cooling.

Cooling effect in heat driven processes can be obtained through adsorption or absorption processes. The first one exploits the latent heat exchange occurring during ad-/desorption of vapour/water into a dry-saturated medium (i.e. silica-gel), the second one is based on the heat delivered and extracted from the ambient by a solution, by means of changing his concentration and pressure.

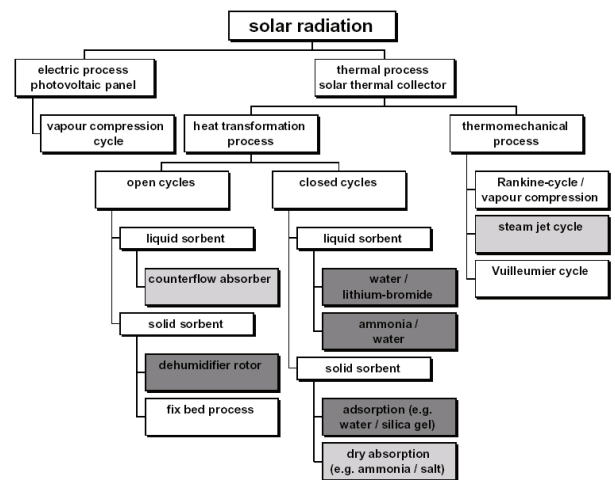


Figure 2: Overview on physical ways to convert solar radiation into cooling or air-conditioning. Processes marked in dark grey: market available technologies which are used for solar assisted air conditioning. Processes marked in light grey: technologies in status of pilot projects or system testing. [1]

In closed cycles, cold water is delivered by chillers. Open cycles are used for direct air conditioning of fresh air.

Closed systems are realised through adsorption and absorption chillers. Open refrigeration and dehumidifying processes are related to desiccant and evaporative cooling (DEC). Over the past few years, numerous systems have been built under pilot projects and demonstration projects to prove the feasibility of such systems. Many process-applications of solar cooling are close to reach commercial maturity.

### 32 Closed cycles

The most common types of thermally driven chillers, are absorption chillers and adsorption chillers. The coupling of these machines with solar thermal energy source is not a difficult task.

The working principle of an absorption system is similar to that of a mechanical compression system as far as the key components evaporator and condenser are considered. In the evaporator a low-pressure vaporising liquid extracts heat at a low temperature (cooling). Then the vapour can be absorbed by a suitable solution and compressed with a very slight energy to a higher pressure. Through the heat supply in the generator the refrigeration fluid is desorbed from the solution and condenses than at a higher temperature (heat dissipation). After this, the pressure of the liquid is reduced, and the cycle recommences from the beginning. In this way the mechanical energy input is substituted by a thermal energy input. In absorption machines the ability to circulate the absorbing fluid between absorber and desorber results into a continuous loop, that's why the process is called closed cycle..

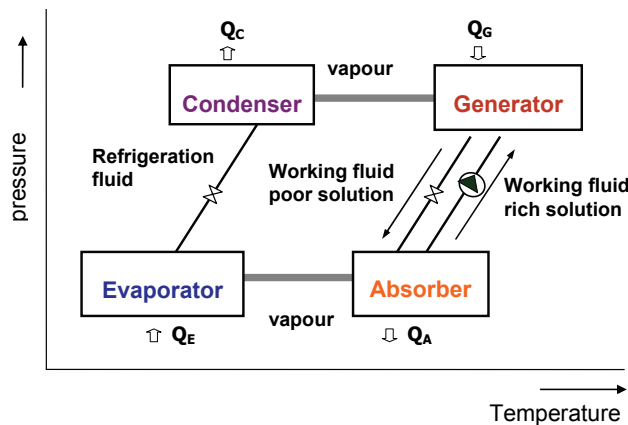


Figure 3: Schematic principle of thermal driven absorption chiller and performance indexes of a heat driven refrigeration machine

Instead of absorption of refrigerant in an absorbing solution, it is also possible to adsorb the refrigerant on the internal surfaces of a highly porous solid. This process is called adsorption. In adsorption machines the solid sorbent has to be alternately cooled and heated to be able to adsorb and desorb the refrigerant. The "cool production" occurs always in the evaporator.

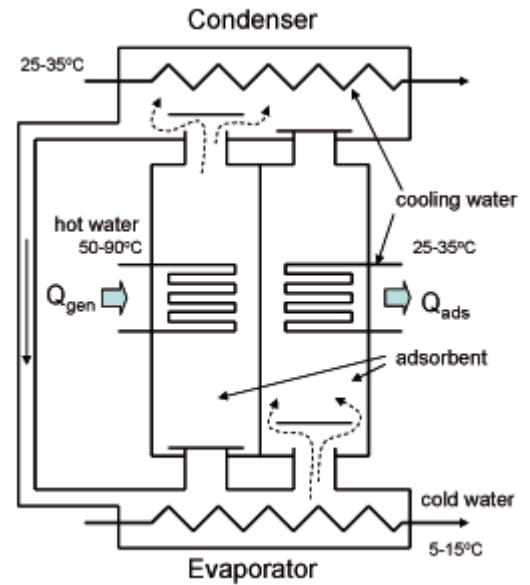


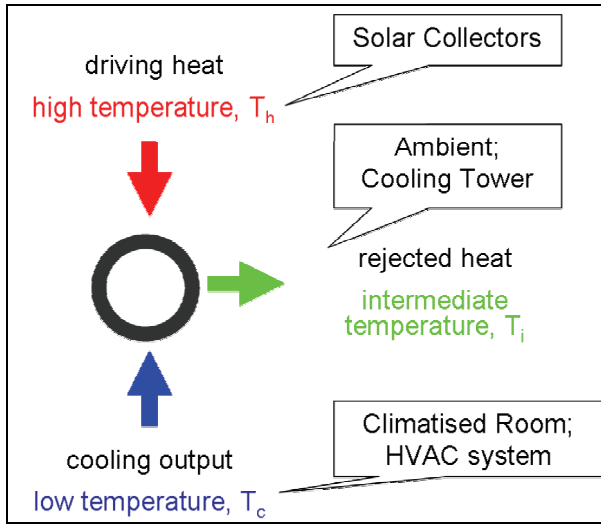
Figure 4: Schematic principle of thermal driven adsorption chiller

In most cases, a wet cooling tower is used for heat transfer.

Every thermally driven chiller is characterised by three temperature levels (see Figure 5):

- the high temperature level at which the driving heat is absorbed,
- the low temperature level at which useful cooling is delivered, i.e. the heat from the air conditioned room is absorbed, and
- the mean temperature level at which the heat is level at which the heat is rejected.

A key figure for describing the efficiency of thermally driven chillers is the thermal COP (coefficient of performance). It is defined as the ratio of cooling output to the required driving heat input (see Figure 5). However, a realistic comparison of different methods with regard to energy efficiency requires a consideration of the total energy expenditure including electricity consumption of pumps, etc.



$$\text{Coefficient of Performance} = \text{COP} = \frac{\text{cooling output}}{\text{driving heat input}}$$

$$\text{COP}_{PE} = \frac{\text{cooling output}}{\eta_{PE, \text{heat}} \bullet \text{driving heat input} + \eta_{PE, \text{el}} \bullet \text{electr demand}}$$

$\eta_{PE, \text{heat}}$  = efficiency of conversion (primary energy to heat)

$\eta_{PE, \text{el}}$  = efficiency of conversion (primary energy to electricity)

Figure 5: Schematic principle of thermal driven chillers and performance indexes of a heat driven refrigeration machine

By means of “primary energy” performance ratios ( $\text{COP}_{PE}$ ) it is possible to compare in the right way a conventional chiller with a heat driven chiller (see Figure 5 for the main equations). The conversion efficiencies of primary energy (mainly for electricity generation) strictly influence the overall performance of the system. As it will be shown in the next chapters, there are many case where conventional chillers are more efficient than the heat driven chillers. Anyway it is necessary to take into account the way the heat is generated. If waste or solar heat is utilised, it requires null or very little consumption of primary energy and  $\text{COP}_{PE}$  becomes very high.

In closed processes, chillers deliver cold water that may be used in a variety of ways for air conditioning purposes. Obviously, according to thermodynamics laws, COP depends on working temperatures. For given high and intermediate temperatures, the lower the cold water temperature the lower the COP.

The required temperature of the cold water closely depend on whether it is necessary to supply equipment that is also used for air dehumidifying (latent loads) or whether the room components connected to the system are only used to carry off sensible loads, i.e. to control temperature. In central air conditioning equipment or decentralised fan-coils that are used to control temperature and indoor air humidity, the humidity is reduced by cooling down the air below dew point, whereupon water vapour condenses and absolute humidity drops.

Cold water temperatures of 6-9°C are required in order to ensure adequate dehumidifying. However, if the chiller is only used to carry off sensible loads, far higher cold water temperatures of 15-20°C are sufficient. Examples of such room components include chilled panel systems such as chilled ceilings, floor cooling systems, in-wall capillary tube mats, building component cooling and concrete core cooling or other systems of passive cooling such as air recirculation coolers working on the basis of natural air circulation.

### 33 Open processes (sorption assisted methods)

Open methods are usually based on a combination of adsorptive dehumidification (vapour/water, first contained in the air, is deposited on a porous material with a large internal surface) and evaporative cooling. They are referred to as Desiccant Cooling or Desiccant and Evaporative Cooling (DEC). The dehumidification process uses either liquid or solid desiccants. Systems working with solid desiccant materials use either rotating wheels (figure 6) or periodically operated, fixed-bed systems.

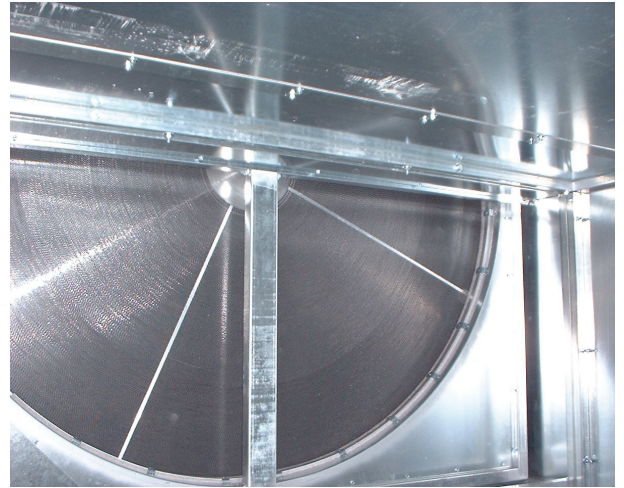


Figure 6: Rotating desiccant wheel

Alternatively, if the desiccant cooling process is combined with standard vapour compression technology, it leads to higher efficiency because the part of dehumidification is assumed by the desiccant wheel, and the evaporator temperature of the compression cycle can be increased (only for sensible cooling).

Regeneration heat must be supplied in order to remove the adsorbed water from the desiccant material. The required heat is at a relatively low temperature, in the range of 50 to 100°C, depending on the desiccant material and the degree of dehumidification.

Of particular interest is the coupling with thermal solar energy. The components of such systems are generally installed in an air-handling unit and are activated according to the operation mode of the air conditioning system. These operation modes implement different physical processes for air treatment, depending on the load and the outdoor air conditions. This allows that only in the



case of maximum load all components of the system are working, and in a part of the operation time the auxiliary (conventional) components are out of service (no consumption of conventional energy).

Figure 7 shows a “standard” solar assisted DEC system.

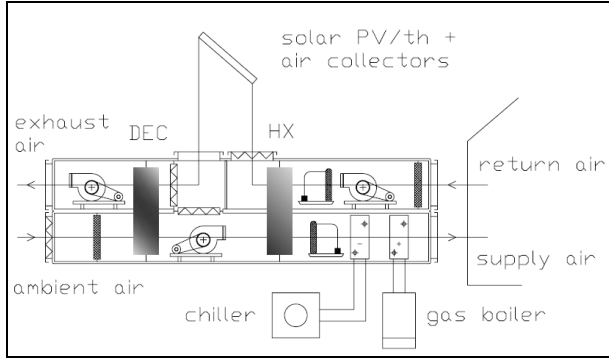


Figure 7: Operation of a solar standard desiccant cooling system with electric chiller as back-up energy source

The definition of the COP for open air conditioning methods and of refrigeration capacity and room cooling capacity are summarized in Figure 8.

For DEC systems it is equally true that a realistic comparison regarding energy efficiency requires a consideration of all energy consumptions.

|                        |  |
|------------------------|--|
| refrigeration capacity | $P_{cold} = \dot{V} \cdot \rho_{air} \cdot (h_{amb} - h_{supply})$ |
| cooling capacity       | $P_{cool} = \dot{V} \cdot \rho_{air} \cdot (h_{ret} - h_{supply})$ |
| specific enthalpy      | $h = (c_{air} + c_{w,v} \cdot x) \cdot T_{air} + x \cdot r_0$      |

$Coefficient\ of\ Performance = COP = \frac{cooling\ output}{driving\ heat\ input}$

$\dot{V}$  = air flow rate,  $\rho_{air}$  = density dry air

$C_{air}$  = specific heat capacity of humid air

$C_{w,v}$  = specific heat capacity of water vapour

$T_{air}$  = air temperature,  $x$  = absolute humidity

$r_0$  = specific enthalpy of evaporation

Figure 8: Capacities and COP of open cooling processes.

With open systems, the electrical energy powering the fans is of particular importance as a high number of additional components are usually installed compared to conventional ventilation systems, thus entailing greater loss of pressure and therefore more electricity to move the air. For these reasons a calculation of  $COP_{PE}$  is required to assess the global performance of the systems.

## 4 Advantages/disadvantages

### 41 Good design necessary for good performances

The main aim of exploiting solar energy is to save primary energy. Any energy consumption balance for solar assisted air conditioning systems must take all energy

flows into account in order to provide a realistic picture. This includes the energy for all pumps, e.g. in the solar circuit and in the return flow circuit, the electrical energy driving the fan in the cooling tower, and the energy used to provide refrigeration when insufficient solar heat is available.

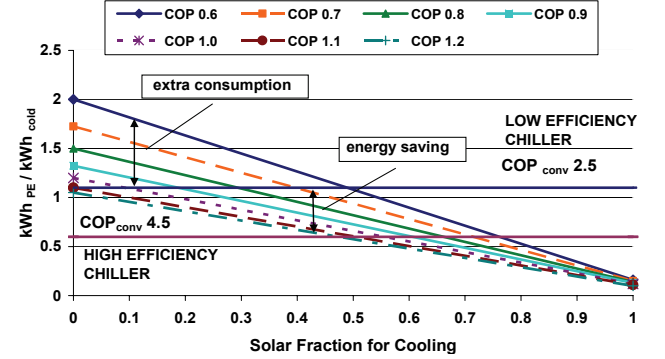


Figure 9: Comparison among conventional chillers and solar assisted absorption chillers; PE is the primary energy consumption per unit of cooling effect [2]

Figure 9 shows the primary energy required per kWh refrigeration as a function of the percentage of solar coverage for various COP values of the thermally driven refrigeration process.

Figure 9 highlights that energy saving (or extra consumption) depends not only by the solar fraction but also by the reference system the solar assisted absorption chiller are compared with. In any case the designer must choose the right solar collector area (to achieve SF)

The diagram only provides a general picture and illustrates that a detailed energy balance is necessary in the design-phase to planning a system. Figure 10 shows the results expected, based on computer simulations, for a standard DEC system in comparison with a typical air conditioning application in Palermo (Italy). The reference systems are two. A conventional air handling unit with COP 2.5 and a modern unit with enthalpy recovery wheel and overall COP 3.5.

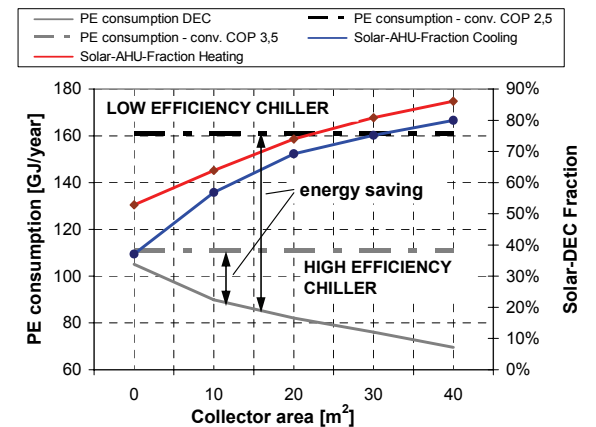


Figure 10: Comparison of the primary energy consumption and the energy fraction covered by the solar and the DEC system among conventional Air Conditioning Systems and Solar DEC systems. (max. cooling load 16,4 kW, air mass flow 500 kg/h)

This example shows the relevant potential of energy saving even with small collector areas and with small Solar Fraction (SF). Also the Solar-DEC-Fraction in Heating season is considered.

## 42 How to achieve saving and avoid extra consumption

In practice it has evolved that many systems fail to achieve possible energy savings. The reasons for this are too complex hydraulic layouts and often insufficient control. With regard to design and operation, it follows that:

- The hydraulic system should be as simple as possible and as complex as necessary.
- The efficiency and capacity of both solar systems and thermal refrigeration or air conditioning processes depend on the operating temperatures. Demand-based control of driving temperature as well as of refrigerant temperature and of recooling temperature can significantly increase overall efficiency. But this requires a complex control system that should only be implemented after thorough testing.
- A rigorous commissioning phase with subsequent recording and analysis of operating data is essential in order to achieve the targeted energy savings.

In practice, it is clear that in order to take advantage from the technologies and avoid risks of inefficient operation some basic guidelines must be followed:

- Solar cooling processes with a low COP and fossil fuel backup require a high percentage of solar coverage.
- A low percentage of solar coverage is sufficient for thermally driven refrigeration processes with a high COP.
- An alternative is to use a conventional refrigeration system (compression chillers) as a backup; this is generally acceptable for systems with a high installed capacity.
- Savings on primary energy are possible when using autonomous solar-thermal systems; in this case, however, it is not possible to guarantee adherence to prescribed indoor air conditions.
- In any case, the level of utilisation of the solar system should be maximised by incorporating other thermal consumers (heating, domestic hot water).

## 5 Costs

### 51 Investment costs

Solar assisted air conditioning systems require more technical apparatus than conventional systems. Furthermore, they additionally require the entire thermal solar

system. The recooling system is larger in thermally driven chillers as the COP of thermal methods is lower than the COP of electrically driven compression systems. This means that the amount of heat to be removed is greater. Also the specific costs of thermally driven chillers in terms of refrigeration are higher than the costs of conventional systems. All these factors results in higher investment cost for solar cooling.

Extra costs could be very variable. Cooling systems with absorption machines can cost up to 1,5-2 times more than a conventional one. A fully equipped solid desiccant Air Handling unit can cost up to 1,3 to 2 times more than a standard unit. Solar collector field has a cost of about 5000 € for every 1000 m<sup>3</sup>/h of handled air or 1500 € for every cooling kW.

### 52 Potential of energy costs saving

Although higher investment costs are required, the potential reduction of operating costs is relevant. This becomes particularly noticeable when the maximum electricity used by conventionally cooled buildings is due to their refrigeration/air conditioning systems. In this case, using thermally driven methods – depending on the current power price – can result in significant cuts in operating costs. Although exact statements regarding the economic efficiency of a solar cooling system always depend on the specific case in question, today the annual costs – i.e. the total costs including capital costs, operating costs, maintenance costs, etc. - of solar thermal methods are usually higher than the costs of conventional technologies. In order to be able to dimension a solar system taking into account also the economic variable, it is useful to refer to primary energy (PE) and thus to consider the costs of the primary energy saved ( $C_{PE}$ ).

This figure must be calculated by comparing PE and annual costs (AC) of the solar system and of reference system. The variable is measured in [€/kWh] and defined as follows:

$$C_{PE} = \frac{(AC_{\text{solar system}} - AC_{\text{reference system}})}{(PE_{\text{reference system}} - PE_{\text{solar system}})}$$

Figure 11 presents an example of a sensitivity analysis conducted for an absorption machine application for an hotel in Spain (Fraunhofer ISE/Freiburg, IEA SHC Task 25). The aim was to select the best collector surface and storage volume combination. A minimum of  $C_{PE}$  is expected for the system layout of 140 m<sup>2</sup> collector area and a volume of the hot water storage unit of 90 m<sup>3</sup>. This layout saves 36 % on primary energy compared to the comparable system.

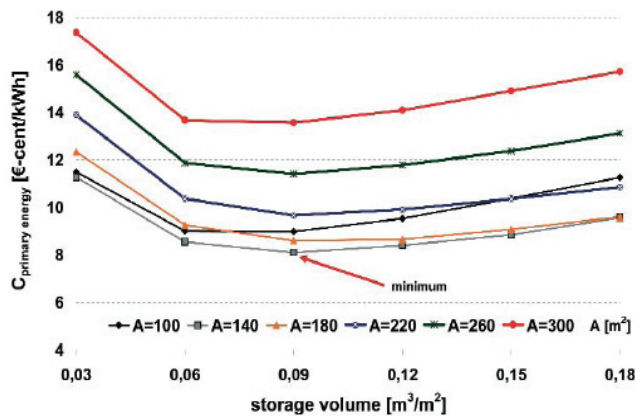


Figure 11: Cost of Conserved Energy as a function of collector area and storage volume for a reference absorption chiller

Similar studies conducted for Solar DEC systems assessed  $C_{PE}$  for could close to zero if the system is well designed and operates in sunny climates.

## 6 Maintenance and service

Solar assisted cooling systems have a more complex layout than conventional HVAC systems. This requires an additional skill for their operation. Otherwise their maintenance is no more different from a conventional system apart from some required operation in some equipment.

## 7 Best practice example

### 71 System with sorption rotor: Pompeu Fabra Library in Mataró

The system built and implemented in the public library Mataró /Spain is a desiccant cooling system with air as the only heating and cooling fluid. The unit is coupled to a PV-solar air heating system.

The system is working according to year seasons based on the following physical principles:

- Summer – desiccant cooling system with thermal solar energy used to regenerate the system (by heating for releasing humidity);
- Winter – using a heat recovery wheel, thermal solar energy is indirectly used for heating.

The system also incorporates auxiliary coils for cooling and heating, respectively, which will cover the heat needs when solar energy is not sufficiently available or there are exceptional critical loading conditions. From monitoring performed during the 2002 summer period at the new solar air conditioning system at Pompeu Fabra library in Mataró, the following conclusions have been obtained:

- Water consumption is high so it would be necessary to introduce any system for water recycling, and the regulation of humidifiers could be optimised.
- The performance of the air treatment unit, the solar system and the regulation and control system are as predicted in the design period.



Figure 12: Solar collectors and DEC unit mounted on the roof at Mataró Library (source: Aguasol)

### 72 System with absorption chiller: Office Building in Guadeloupe

The office building has been built in Guadeloupe, at Basse Terreand, and is in operation since 2003. This Building, of high environmental quality, includes a solar assisted cooling system employing an absorption chiller. Figure 13 shows the layout of the system. Cooling power is distributed by means of a chilled-water circuit and is produced according to the following principle:

- Pre-cooling of the chilled water circuit (nominal temperatures: 7 - 12°C) by an absorption chiller (30 kW), driven by vacuum tube solar collectors, and connected to a water-based open cooling tower.
- The back-up cooling energy is supplied by a vapour compression chiller (liquid based cooling plant with 55 kW capacity), with air cooling of the condenser.

Without the absorption machine, this plant would have required a power input of 90 kW. The heat supply for the absorption chiller is required in a temperature range of 85 - 95°C. This dictated the choice of vacuum tube collectors from the beginning of the project.

The system is not equipped with a full-size hot-water storage tank. Instead, the collectors are connected to the generator of the absorption chiller by a small buffer tank (< 100 litres). The cooling output (30 kW) was established so that it would always be slightly less than the load at all times during sunny periods. In this way, the absorption chiller can operate directly with the sun, and use all the energy supplied by the solar collectors for cooling. When the load is higher, the conventional chiller makes up the difference.

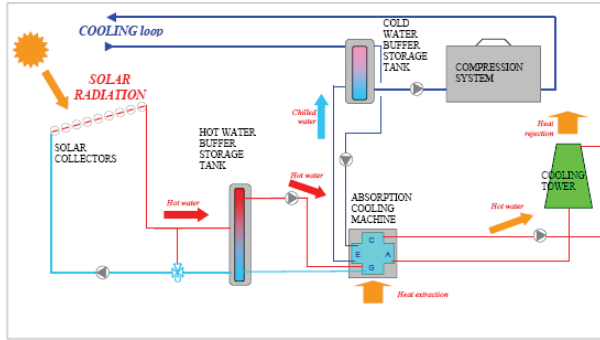


Figure 13: Plan of the solar assisted cooling system employing an absorption chiller at the office building in Guadeloupe. (Source: Tecsol)

This system is expected to save one third of the electricity billed for air-conditioning every year. It is then compared to a conventional compression system, which would have a size of 90 kW. This illustrates both the cost distribution and the initial cost breakdown for this solar-assisted cooling system. An additional cost of 18.000 € for system design should be added for the part concerning the solar cooling equipment. The solar collectors represent more than 40 % to the overall cost.

### 73 Solar DEC coupled with chilled ceiling: SunLab installation at University of Palermo (Dept. DREAM), Italy

Solar desiccant cooling systems operating in the climatic conditions of the Mediterranean area can achieve good primary energy savings in comparison to conventional HVAC systems. Recent researches carried by authors about the performances of several air treatments cycles using solar energy (including different kind of desiccant cooling units, air, hybrid (photovoltaic/thermal air) and liquid collectors) have highlighted achievable energy savings up to 100% in comparison to a conventional air handling units when particular design and operation schemes are applied.

As a result of this theoretical research a solar desiccant cooling system equipped with liquid solar collectors and coupled with a radiant ceiling has been installed in Palermo. The climatized room is part of the SunLab, the solar energy test facility of the University of Palermo. The radiant ceiling is designed to meet the sensible load in case of moderate people occupation of the rooms [2]. The AHU will meet latent and part of the sensible load in case of higher occupation patterns.

The SunLab is situated on the roof floor of the Department of Energy and Environmental Research (DREAM). The components are designed for a conditioned ambient with a volume of about 450 m<sup>3</sup>.

The following table lists the mean data of the project.

|   |                     |      |
|---|---------------------|------|
| Peak thermal load winter                        | [kW]                | 11   |
| Peak thermal load summer                        | [kW]                | 28,8 |
| Sensible part of load                           | [kW]                | 12.7 |
| Latent part of load                             | [kW]                | 16.1 |
| Minimal ventilation air mass flow               | [m <sup>3</sup> /h] | 1250 |
| Active area of the radiant panels               | m <sup>2</sup>      | 76.1 |
| Absorber surface of solar flat plate collectors | m <sup>2</sup>      | 22,5 |
| Heat storage capacity                           | L                   | 600  |
| Heating capacity auxiliary boiler               | kW                  | 11   |
| Cooling capacity of water chiller (15°C/55°C)*  | kW                  | 24.3 |
| Expected thermal COP of the process             | -                   | 0.86 |

\* chilled water temperature/condensation temperature

Table 1 – Main figures of the SunLab HVAC project

The design occupation is 60 persons, which means high latent loads coming either from people either from external air. The maximum air vapour content is 24 g/kg in summer.



Figure 14 – The SunLab plant at University of Palermo (source: DREAM-UNIPA)

During the test campaign the internal load will be simulated in different intensities by the means of heaters and humidifiers displaced into the rooms. The AHU is designed as a special desiccant cooling plant for primary air. The desiccant cooling system in summer operation basically provides dehumidification of external air by means of the desiccant wheel (silicagel) which is regenerated from solar heat. In this special design further dehumidification and cooling of the supply air are achieved by means of two cooling coils (figure 15). The first coil makes possible a pre-dehumidification of the air although the supply water temperature is relatively high (15°C). The second one controls the air temperature when the heat recovery cooling (indirect evaporative cooling) is not sufficient for this task. The supply temperature is the same for the two coils and for the radiant ceiling. In this way, a good COP of the chiller can be achieved.



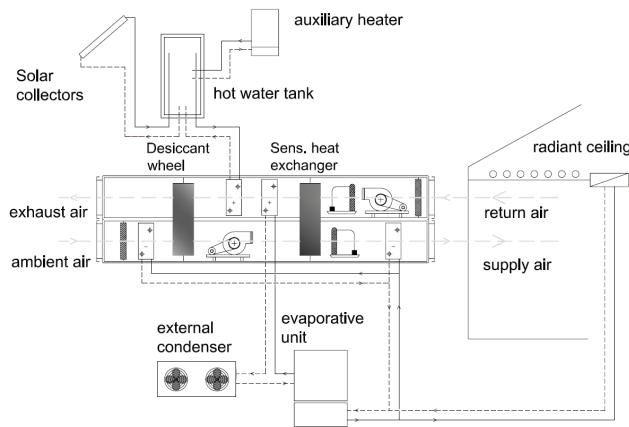


Figure 15 – Functional scheme of the SunLab plant

This system implements an innovative configuration based on the way of integration of a back-up water-to-air chiller onto the air treatment process. The heat rejection is in fact partially operated through a condensing coil displaced in the return air path. In this way part of the heat is delivered to the air stream for the regeneration of the desiccant wheel.

## 8 Calculation tools

To assess the feasibility of a solar assisted air conditioning system, to find an appropriate system design or to investigate the advantages of selected technical solutions, computer based design tools have to be applied. Different types of design tools exist to meet the different requirements in the planning phase. Not in any case, a detailed simulation of a solar assisted air-conditioning system is required from the very beginning. On the other hand, there is no tool which meets all requirements at different levels of the planning phase.

In the framework of IEA Solar Heating and Cooling Task 25 activities, a new software has been developed [9]. The aim was to produce a user-friendly tool, which would allow the user to design a system without extensive software training.

The simulation program calculates the hourly energy demand of the solar-assisted air-conditioning sub-systems. The calculations are performed on an hourly basis and are summed up to calculate the annual energy demand.

The outputs of the software include the following: electrical energy demand for fans, pumps and compressors; energy demand of the (thermal) back-up system; water consumption.

The annual total costs of the system are calculated based on the annual energy demand of the components and their investment, maintenance and capital costs.

The building loads can be calculated or imported if evaluated through building simulation programs like e.g. TRNSYS, EnergyPlus, ESP-r. Several solar assisted air-

conditioning technological solutions can be simulated using this tool. Numerous types of solar collectors are available in a selection diagram that already includes all the necessary coefficient/performance settings and a minimum storage capacity calculation routine. The user can define the collector area and orientation. In general, the routines dealing with the solar energy supply allows a detailed calculation of the performance capability of the plant.

The refrigeration module enables calculation of the following types of cold water production: Vapour compression machine, absorption system, adsorption system, free cooling by means of cooling tower, use of well water. Calculations can be made for air-based systems as well as for combined water-air systems. Depending on the selected systems (with/without air handling unit, with/without chiller), the conditioned space can be supplied with mechanical ventilation or infiltration only, and chilled ceiling or fan-coil systems are possible for sensible cooling.

The task of the simulation software is above all fast calculation of useful layout variations in order to determine the ideal solution for the specific application.

The software is distributed by ILK Dresden. After rigorous testing under Task 25, it is available to interested users. at: <http://www.iea-shc-task25.org/english/hps6/index.html> Documentation of the software is also available when downloading.

Another pre-design software was developed in the framework of European Project "SACE: Solar air conditioning in Europe" [10]. The objective of this software is to allow a quick feasibility study of solar assisted air conditioning systems. The annual solar fraction for heating and cooling is calculated based on an hour-by-hour comparison of needed heat for a thermal driven cooling and available solar heat. It performs parametric studies and allows the comparison of conventional Air Conditioning systems with Solar Assisted Air Conditioning systems. For calculations it needs a load file (heating and cooling load) and a weather file with hourly values. The solar system is mainly characterized by collector efficiency parameters. The building is represented by its area and the HVAC equipment by two operating temperatures (heating and cooling), efficiency of heating system and COP of thermal chiller.

It is worth noting that for a reliable detailed design of Solar Cooling systems it is suggested to perform dynamic analysis with hourly energy simulation softwares such as DOE-2, Trnsys and Energy Plus (see Energy Tools Guidelines for more references). As the source code of the program modules which reflect the model components is open in these tools, the source can be modified or self written components may be added because of individual requirements. For example, advanced models for thermally driven chiller cycles could be integrated into the

programme library of the simulation environment. The time step in the system simulation is in general adjustable, enabling thereby the user to implement and test more sophisticated control strategies in the modelled system. A detailed energy flow study including the part-load behaviour is possible with simulation tools of this type.

As a disadvantage in the use of these open simulation platforms it should be mentioned that the setup of a desired system model requires much more effort compared to the aforementioned programs.

## 9 References

### 9.1 Compilation

This guideline is written as a part of the project BRITA in PuBs – Bringing retrofit innovation to application in public buildings, EU 6th framework program Eco-building (TREN/04/FP6EN/S.07.31038/503135).

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The professional editing was closed in April 2008.

### 9.2 Further reading

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## 10 Disclaimer

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