

# SOLAR COOLING

## Overview and Recommendations



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**SOLCO**

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You may visit the SOLCO project at: [www.solcoproject.net](http://www.solcoproject.net) for detailed information on all the aspects of the project. We welcome feedback on this publication. If you have comments or questions please contact [islenet@skynet.be](mailto:islenet@skynet.be).

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# 1 Introduction

## The SOLCO Project

Cooling from renewable energies, particularly solar cooling (SC) technologies, represents a key issue within the European Union energy policy.

The higher temperatures experienced in Southern Europe widely attributed to climate change continue to increase the summer energy demand for air-conditioning. Employing the power of the sun (figure 1.1) can substantially reduce electricity peaks during the summer months and at the same time reduce CO<sub>2</sub> emissions.

Solar heating, a widely accepted concept for hot water production enjoys a high level of market penetration and is widely accepted by the general public. SC, however, although a mature technology, has rather low levels of market penetration and public acceptance. This is due to a number of non-technological barriers such as its relatively higher initial investment costs compared to traditional air conditioning installations.

**SOLCO's global aim is the removal of the non-technological barriers in an effort to improve the penetration and acceptance of SC technologies and chilling systems.**

In order to meet this objective the project endeavoured to achieve the following:

- the identification of the non-technological barriers that hinder the implementation and use of solar technologies and chilling systems
- the training of the market actors and potential users and
- the raising of awareness regarding these technologies and a large and targeted campaign of dissemination of information and results.

**The long term objective of the project is to encourage and facilitate the implementation of SC technologies and to support their use in Southern Euro-**

**pean insular territories and areas, particularly those associated with high levels of solar radiation.**

The dissemination of data and information, as well as the advice given during professional targeted training sessions and courses are expected to further support the wider and faster diffusion of this renewable energy source (solar energy).

### Project results

The results of the project are:

- Increased awareness of the benefits and opportunities offered by the wider penetration and utilisation of SC technologies
- Evaluation of solar technologies (including chillers)
- Market characteristics in each participating island
- A detailed analysis of the non-technical market barriers of both heating and cooling technologies and recommendations to overcome them
- Training of key market actors in insular areas and the development of a methodology and multilingual training material to train various categories of professionals involved in SC and chilling systems.

A database of solar collectors and chillers commercially available in the four islands participating in the project has been developed and is available online on the project web site.

### Local Action Committees

The development of SOLCO is based on effective and permanent communication between partners and all various categories of market actors and stakeholders. These key players were represented within four Local Action Committees (LAC) created at the beginning of the project in each insular partner area.

The members of the LAC are typically local designers, installers and equipment suppliers if they are locally present, SMEs, public bodies, such as the local government, the regional government, the chamber of commerce, and potential users, particularly hotels, resorts, hospitals and universities. Each key actor has provided useful contributions and input that have been critical for the success of the project.

There have been several meetings in the four islands participating in the project: Sicily, Crete, Canary Islands and Cyprus.

**The main findings derived from the LAC meetings are:**

- The subject matter is quite innovative and people feel that they need both technical and financial guidance to approach it and adopt it
- Financial aid is one of the main preoccupations of potential users
- SC technologies should be included in financial incentive schemes (national and European)
- One important barrier with respect to the success of financial schemes is the bureaucratic approval procedure
- Demonstration of the technology plays a crucial role, even if it is just in one building of the community
- Successful introduction of solar technologies should have strong links with the government's overall climate change policies and environmental priorities
- It is necessary to further develop solar technology design tools (advanced modelling and simulation tools) in order to improve the systems used and reduce costs of implementation
- Alternatives to the cooling tower should be developed in order to avoid the risk of legionnaires' disease and the related treatment which is quite costly
- There is a significant number of prime candidates for the implementation of SC technologies, such as hotels, resorts and hospitals in the Mediterranean area

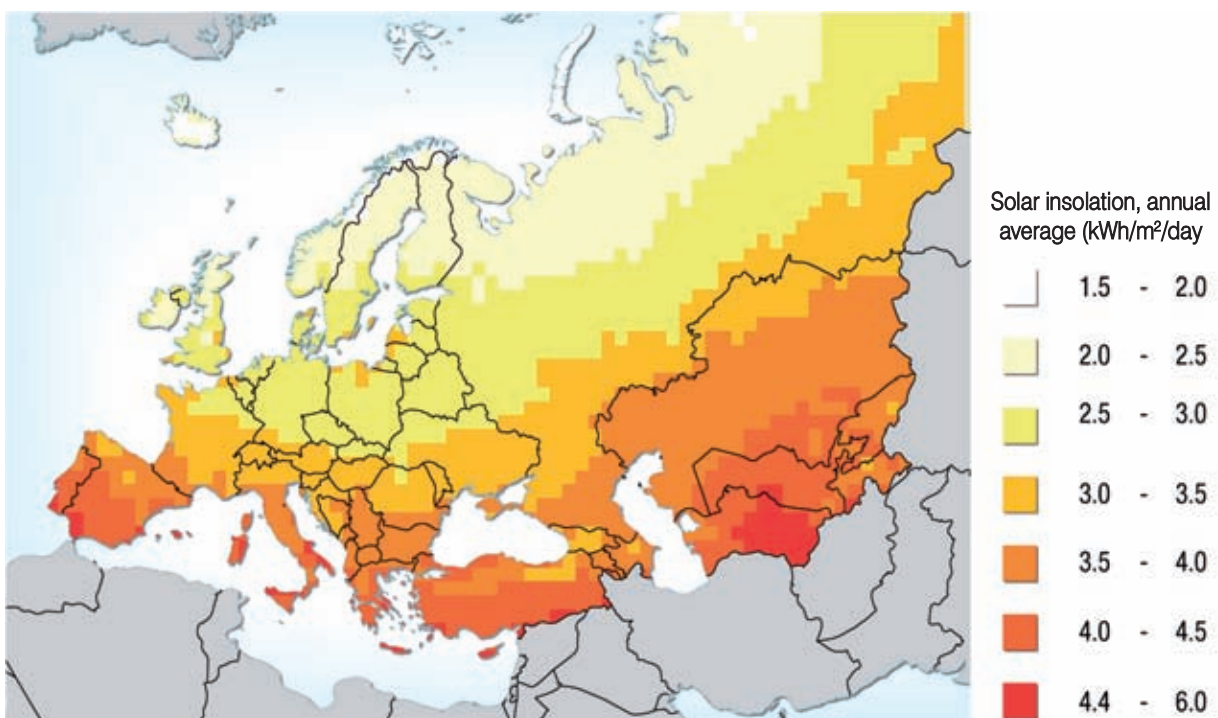


Figure 1.1: Solar Insolation in Europe. Source: GRID - Arendal

## Training Activities

Another important task of the SOLCO project was the development of training material and the organisation of training courses in each of the four partner areas. Each course has a maximum duration of 5 days and has been designed according to the needs and characteristics of the local actors it addresses:

- Designers
- Installers / Producers
- Private Potential users
- Public Potential Users

The general content of the training courses is as follows:

## Outline of Designers & Technical Experts Training

- Climatology (Solar Radiation, Air temperature) - Solar Collectors (Typologies, characteristics)
- Chiller Systems
- The Building - Normative Matters - Plant Design
- Financial Matters (cost evaluation, access to financing, supply contracts) – Case Studies
- Workshop - Final Test of Knowledge

## Outline of Potential Users Training

- The Building - Chiller Systems
- Climatology - Solar Collectors (Typologies, Characteristics)
- Normative Matters - Financial Matters
- Choice of Plant Layout - Case Studies
- Workshop

## Information dissemination

The dissemination effort has as its main objective to reach as many key stakeholders as possible and to inform the general public on the advantages of SC technologies. The main dissemination tools used were:

- A fully dynamic website that contains all relevant project information as well as extensive information on SC technologies and equipment available in the four island-partners. The website has registered more than 100.000 hits during 2008
- Seven electronic newsletters
- A promotional leaflet in four languages (English, Greek, Italian and Spanish) and
- This technical brochure

In addition to the above tools the partners were involved in the following activities:

- participation in technical conferences and presentation of the SOLCO activities
- several visits to local SC plants, such as in Palermo, Italy and the SC installation of the ITC - Canary Islands Institute of Technology
- meetings with partners of similar projects, such as SOLAIR and SOLARCOMBI+, in order to exchange information and share know-how, and
- publication of articles in local newspapers and technical journals for the dissemination of the SOLCO work and the SC technology

*More details on the SOLCO project and its deliverables can be found at: [www.solcoproject.net](http://www.solcoproject.net)*



# 2 Layout of Solar Cooling Installations

A typical solar cooling system consists of a common solar thermal system made up of solar collectors, a storage tank, a control unit, pipes and pumps and a thermally driven cooling machine, as seen in figure 2.1. Most collectors used in solar cooling systems are high efficiency collectors available in the market today (often double-glazed flat plate collectors or vacuum tube collectors). A typical layout of a solar cooling plant is shown in figure 2.2:

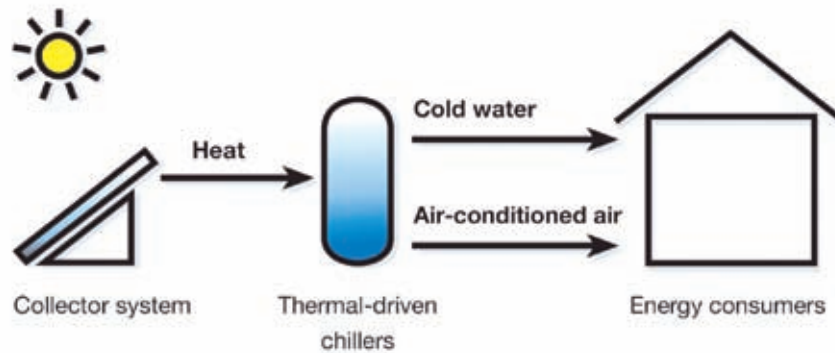


Figure 2.1: Solar cooling system

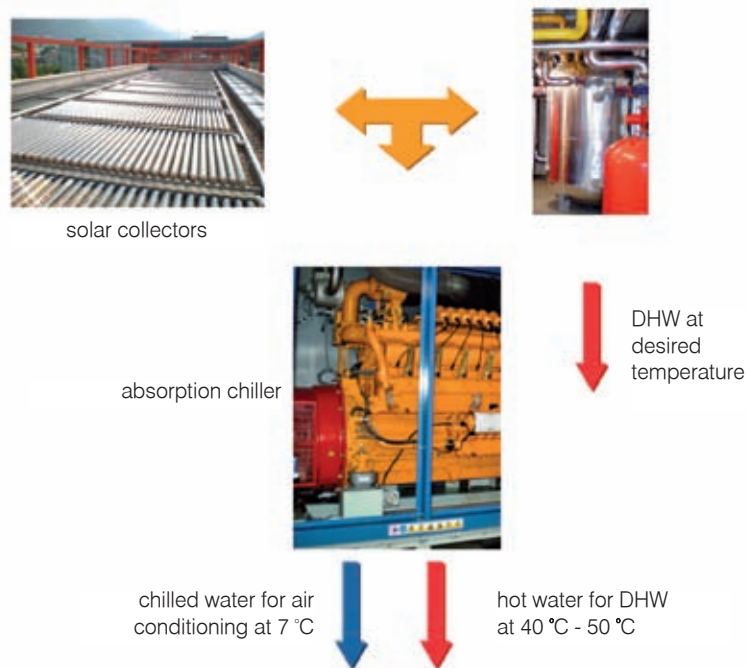


Figure 2.2: Layout of a typical solar cooling installation. Source: El Asmar, 2008



The available solar energy, in the form of solar radiation flux, is utilised by a solar panel, in order to produce a high temperature fluid (generally water) that is accumulated in a storage tank.

The chiller, the real heart of the process, uses the hot fluid of the storage tank to produce a cold fluid; the cold fluid can then be used in a normal cooling plant similar to an electric refrigerator.

On a typical day, the thermal storage tank acts as a buffer and enables the optimisation of the asynchronous heat absorption during the hours of solar radiation and the cooling that may be needed during a different time period making this component indispensable.

Another commonly used layout, that is very common for installations on which the plant has to be utilised during both winter (for heating) and summer (for cooling), is the one shown in figure 2.3. In this layout two tanks are necessary: one for the storage of hot water produced by the solar thermal panels and a second for the storage of cold liquid produced by the absorption machine (chiller). One conventional backup heat source (e.g. a natural gas boiler) is also present. The backup heat source makes the operating hours of the solar cooling plant independent from the availability of solar radiation.

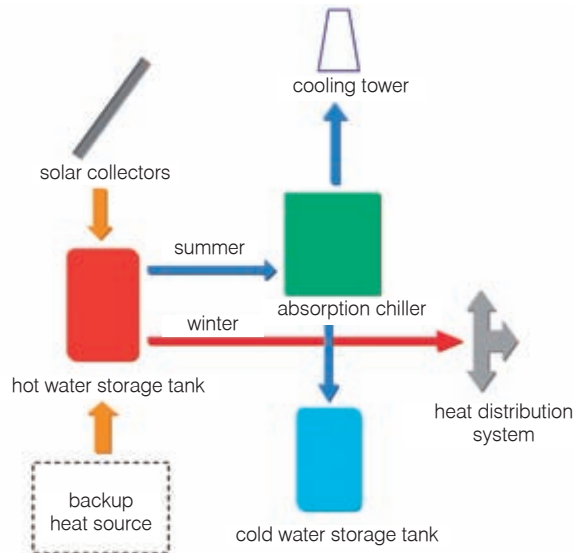


Figure 2.3: Basic layout of a solar cooling plant utilised during summer and winter

Solar assisted air conditioning systems may be classified into closed or open systems:

1. **Closed systems:** these are thermally driven chillers, which provide chilled water; that is either used in air handling units to supply conditioned air or that is distributed via a chilled water network to the designated rooms to operate decentralised room installations. Equipment available in the market for this purpose is of two types: absorption chillers and adsorption chillers (figure 2.4).

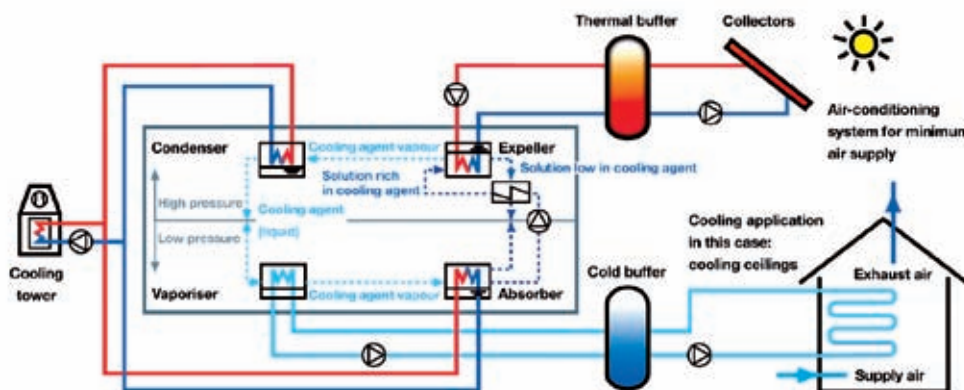


Figure 2.4: Closed systems

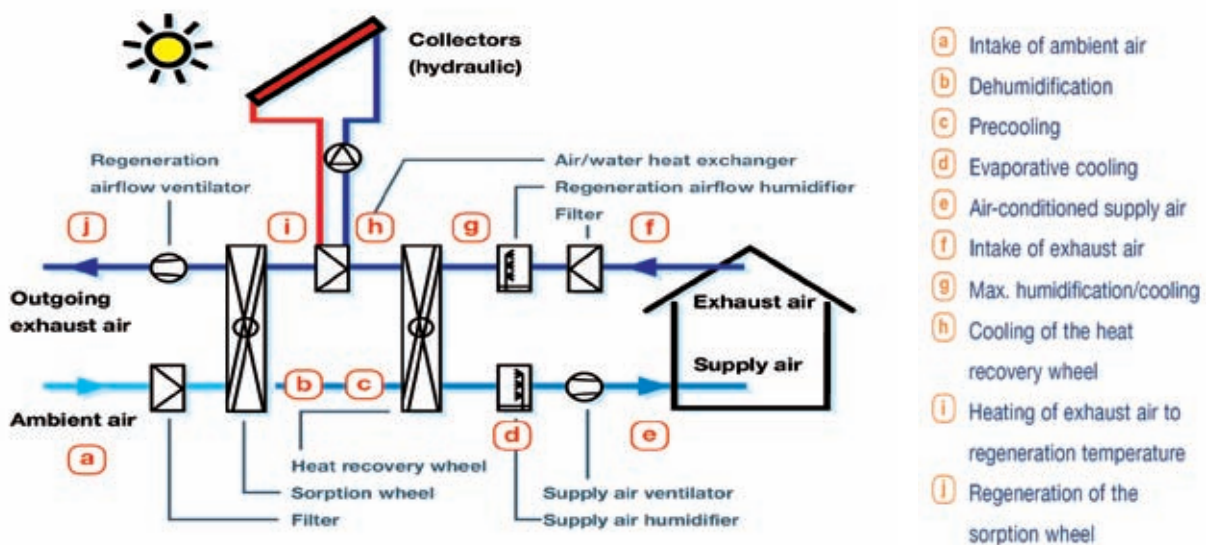


Figure 2.5: Open systems

**2. Open systems:** Desiccant cooling systems are basically open cycle systems, using water as a refrigerant in direct contact with air. The thermally driven cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant. For this purpose, liquid or solid materials can be employed. The term "open" is used to indicate that the refrigerant is discarded from the system after providing the cooling effect, and new refrigerant is supplied in its place in an open-ended loop. The common technology applied today uses rotating desiccant wheels, equipped either with silica gel or lithium-chloride as sorption material.

For the choice of the type of chillers, the following parameters have to be evaluated in advance:

- The operating temperatures of the absorption machine, as they affect the choice of solar collectors.
- The values of the coefficient of performance (COP) of the chiller, as they change according to the above mentioned temperatures and also according to the heat distribution system installed (e.g. fan-coils or radiant floor).

The choice of the type of solar collectors is not a difficult task. The functioning temperature of the absorption chiller determines the most suitable typology of collectors for different layouts. Dimensioning of the panels surface follows the same rules of domestic solar plants for hot water production, even though the fact that a solar cooling plant operates at higher temperatures has to be taken into account.

## 2.1 Solar collectors for solar cooling systems

Solar collectors transform solar radiation into heat and transfer that heat to a medium (water, solar fluid, or air). The solar heat can then be used for hot water, heating or cooling systems, or for heating swimming pools. Solar cooling technologies demand high temperatures (90-150°C); collectors that can achieve such temperatures are evacuated tube and selective coated flat-plate solar collectors. A solar collector array supplies hot water as a source of energy to the absorption chiller through a hot water storage tank.

### Flat-plate solar collectors

Flat-plate collectors are the most widely used kind of collectors for domestic water-heating systems and solar space heating/cooling. A typical flat plate collector consists of an absorber, transparent cover sheets, and an insulated box. The absorber is usually a sheet of high thermal conductivity metal such as

copper or aluminium, with tubes either integral or attached. Its surface is coated to maximise radiant energy absorption and to minimise radiant emission. The insulated box reduces heat loss from the back or the sides of the collector. The cover sheets, called glazing, allow sunlight to pass through the absorber but also insulate the space above the absorber to prevent cool air to flow into this space.

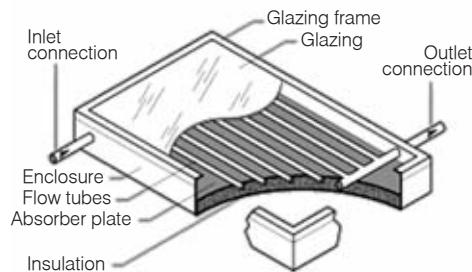


Figure 2.6: A flat plate collector

### Evacuated (or Vacuum) Tubes

Glass evacuated tubes are the key component of the Evacuated Tube Heat Pipe solar collectors. Each evacuated tube consists of two glass tubes. The outer tube is made of extremely strong transparent borosilicate glass (i.e. Pyrex) that is able to resist impact from hail up to 25mm in diameter. The inner tube is also made of borosilicate glass, but coated with a special selective coating, which possesses excellent solar heat absorption and minimal heat reflection properties. The air is evacuated from the space between the two glass tubes to form a vacuum, which eliminates conductive and convective heat loss.

The vacuum tube solar panel has been around for several years and has proved to be both reliable and dependable. The double wall glass Pyrex tubes have a space in the centre which contains the heat pipe.

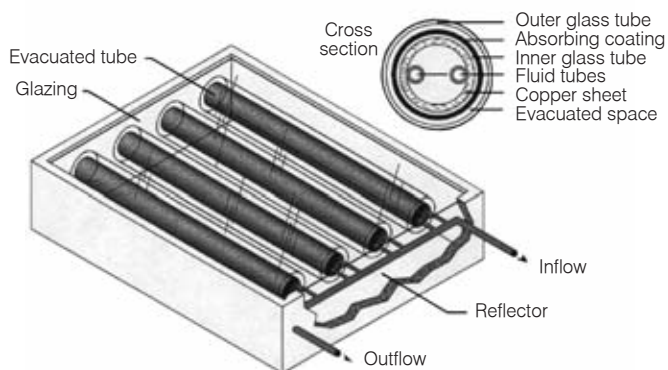


Figure 2.7: A vacuum tube collector

The solar radiation is absorbed by the selective coating on the inner glass surface, but is prevented from re-radiating out by the silver coated innermost lining which has been optimised for infrared radiation. This acts similarly as an one-way mirror.

This is very efficient: 93% of the sun light's energy hitting the tube's surface, is absorbed, whereas only 7% is lost through

reflection and re-emission. The presence of the vacuum wall prevents any losses by conduction or convection - just like a thermos flask. Because of this, the system will work even in very low temperatures, unlike traditional flat plate collectors.

The heat transferred to the tip of the heat pipe is in turn transferred to a copper manifold in which water circulates to heat the domestic hot water tank. If a tube is placed in direct sunlight on a summer day, the tip temperature can reach 250°C, so the system easily heats domestic hot water cylinders to 60°C even in cooler weather.

The manifold is heavily insulated with a 2" thickness of pre-formed rock wool. Unlike flat plates, these headers are so well insulated that they should not require antifreeze in normal operation - the temperature of the header is unlikely to fall below 10°C even in very cold weather.

## 2.2 Chillers

Chillers are the core of solar cooling plants. If solar panels provide the necessary energy input to the plant, chillers are those machines that are able to produce cooling by utilising the hot water coming from the solar panels. More precisely, a chiller is a machine that removes heat from a liquid via a vapour compression or absorption refrigeration cycle. Most often water is chilled, but this water may also contain ~20% glycol and corrosion inhibitors; other fluids such as thin oils can be chilled as well.

There are different types of chillers: absorption or adsorption chillers have been used for decades but have been powered mainly by electric motors, steam, or gas turbines. They produce their cooling effect via the "reverse-Rankine" cycle, also known as "vapour compression".

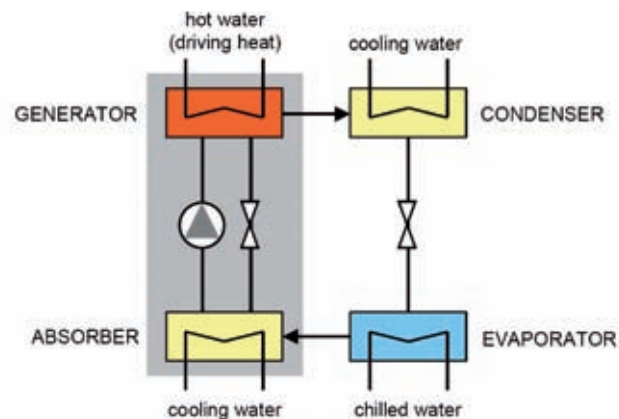


Figure 2.8 Principle of an absorption chiller. Source: ESTIF

**Absorption chillers'** thermodynamic cycle is driven by a heat source. This heat is usually delivered to the chiller via steam, hot water, or combustion but, in the sunny climates of South Europe, solar energy can be used to operate absorption chillers.

Compared to electrically powered chillers, they have very low electrical power requirements, very rarely above 15kW combined consumption for both the solution pump and the refrigerant. However, their heat input requirements are large, and their coefficients of performance (COP) are often 0.5 (single effect) to 1.0 (double effect). For the same tonnage capacity they require larger cooling towers than vapour compression chillers.

However, absorption chillers, from an energy efficiency point of view, excel where cheap heat is readily available such as heat provided by solar thermal panels in sunny regions.

Absorption chillers are the most widely used chillers throughout the world. A thermal compression of the refrigerant is achieved by using a liquid refrigerant/absorbent solution and a heat source, thereby replacing the electric power consumption of a mechanical compressor. For chilled water above 0°C, as is used in air conditioning, a liquid H<sub>2</sub>O/LiBr solution is typically applied with water as a refrigerant.

The main components of an absorption chiller are shown in the figure 2.8. The cooling effect is based on the evaporation of the refrigerant (water) in the evaporator at very low pressure. The vaporised refrigerant is absorbed in the absorber, thereby diluting the H<sub>2</sub>O/LiBr solution.

A few absorption chillers with capacities below 50kW are available. Typical chilling capacities of absorption chillers are several hundred kW.

**Adsorption chillers** apply solid sorption materials instead of a liquid solution. Systems available in the market today use water as a refrigerant and silica gel as a sorption material. The machines consist of two sorption compartments (denoted as 1 and 2 in figure 2.9), one evaporator and one condenser. Under typical operating conditions, at about 80°C, the systems achieve a COP of about 0,6, but operation is

possible even at heat source temperatures of approx. 60°C. The capacity of the chillers ranges from 50 to 500kW chilling power.

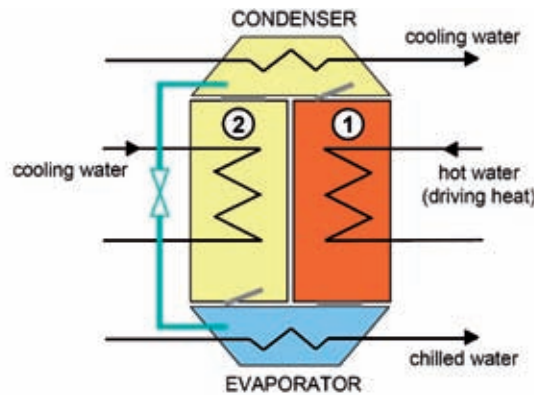


Figure 2.9: Principle of an adsorption chiller. Source: ESTIF

Table 2.1 compares the main sorption and desiccant technologies and summarises their advantages and disadvantages.

Table 2.1. Comparison of the main sorption and desiccant technologies		
Systems	Advantages	Disadvantages
<b>Absorption</b>	<ul style="list-style-type: none"> <li>• Only one moving part (pump) with possibly no moving part for a small system</li> <li>• Low-temperature heat supply is possible</li> </ul>	<ul style="list-style-type: none"> <li>• Low COP</li> <li>• It cannot achieve a very low evaporating temperature</li> <li>• The system is quite complicated</li> </ul>
<b>Adsorption</b>	<ul style="list-style-type: none"> <li>• No moving parts (except valve)</li> <li>• Low operating temperature can be achieved</li> <li>• Thermal Coefficient of Performance (COP) is quite high compared to other heat operating systems</li> </ul>	<ul style="list-style-type: none"> <li>• High weight and poor thermal conductivity of the absorbent</li> <li>• Low operating pressure requirement makes it difficult to achieve air-tightness</li> <li>• Very sensitive to low temperatures especially the decreasing temperature during night-time</li> <li>• It is an intermittent system</li> </ul>
<b>Desiccant</b>	<ul style="list-style-type: none"> <li>• Environmentally friendly, water is used as the working fluid</li> <li>• Can be integrated with a ventilation and heating system</li> </ul>	<ul style="list-style-type: none"> <li>• It cannot function properly in a humid area</li> <li>• It is not appropriate for an area where water is scarcity</li> <li>• Requires maintenance due to moving part in a rotor wheel</li> </ul>

Source: CLIMASOL project

The very scarce number of producers of solar assisted chillers within the global market is one of the reasons why solar cooling plants are still too few in spite of their environmental advantages in terms of low electricity consumption.

A survey of chiller machines available in Southern European islands participating in the SOLCO project is available on [www.solcoproject.net](http://www.solcoproject.net), in the section dedicated to project deliverables. Data sheets can be downloaded in order to get all the necessary technical information required for a SC plant dimensioning.

# 3 Solar Heating and Cooling: Basic Principles

This chapter briefly defines certain basic terms used in the design of solar cooling installations and describes the basic principles of the heat balance calculations that are necessary in order to ensure that the cooling capacity of the equipment is adequate.

## Solar Heating

The calculation of summer thermal gains in solar installations needs to consider the time variability of heat gains, due to quick variations of solar radiation across the whole day. Instantaneous thermal flux (defined as the heat that penetrates into a structure at any given point in time) entering a building does not turn itself immediately into a heating gain because of the thermal inertia of structures. It is therefore important to take notice of that in order to avoid errors when estimating cooling plant capacity.

The proper way to proceed in designing solar cooling installations is to calculate the cooling load as well as the exact heat extraction rate.



Figure 3.1: Solar Cooling installation

## Space heating gains

The thermal flux entering a space can be distinguished in two types:

### (i) Flux of direct heat

- Solar radiation through window frames (heat transmission by radiation)
- Transmission through window frames (heat transmission by conduction - heat transmission by convection)
- Transmission through the outside walls and roof (heat transmission by conduction or by convection)
- Transmission through the inside walls, ceilings and floors (heat transmission by conduction or by convection)
- Indoor heat generation (due to people, lights, electric instruments)
- External air infiltration
- Possible other contingent causes

### (ii) Flux of latent heat

- External air infiltration (with more specific humidity than indoor air)
- Steam due to indoor people
- Transmission through external walls and covering
- Steam due to particular processes or instruments located into the ambient

## Space cooling load

Space cooling load is the heat that has to be removed (or extracted) from a space in order to keep the desired temperature constant. As a matter of fact, heat transmission by radiation is not directly converted into space cooling load: radiant energy is first absorbed by all surfaces that delimit the space (walls, ceilings and floors) and then transferred to the air. Thus there is a lag between the thermal capacity of all surfaces fixes the rate of temperature increase, defining amplitude and delay time of each heat flux transferred to the space as opposed to the heat of instantaneous radiation.

## Space heat extraction rate

As the ambient temperature does not remain constant and stable across the day, the amount of heat to be removed will be different from the cooling load. These proportions change in relation to internal and external condition changes (fig. 3.2). The space heat extraction rate is equal to the space cooling load only in the case when the room temperature is kept constant. This, however doesn't happen frequently.

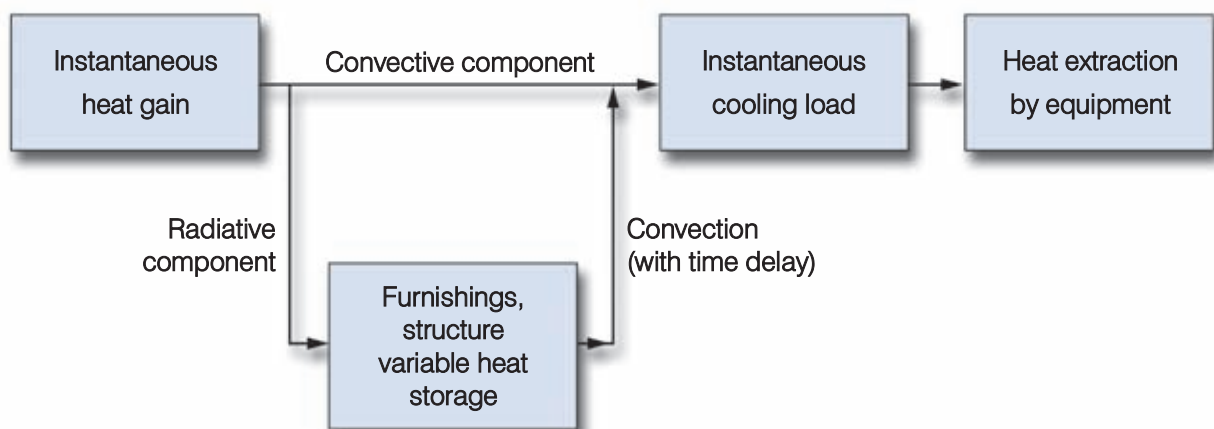


Figure 3.2: Schematic representation of the relation among thermal flux, cooling load and heat extraction rate

# 4 Solar Cooling Installations - Case Studies

This chapter presents a number of successful solar cooling installations that have been designed in three Mediterranean islands participating in the project and in Bolzano, Italy.

## 4.1 Solar Cooling at the Technological Institute of Canary Islands

Since 2006, this installation is used to produce chilled water which acts as a refrigerant for the air conditioning units used to chill an office building of 400m<sup>2</sup>



Figure 4.1: Solar collector field

The solar collector field consist of nine flat plate collectors model Wagner LB 7,6. These solar collectors have a selective surface. As they are of high performance, they can reach 80°C. The collector surface is 68,4m<sup>2</sup>. The installation has two tanks, a 3.000l hot water storage tank and a 1.000l chilled water storage tank. The absorption process takes place in the Yazaki absorption chiller (model WFC-SC10), whose nominal power is 35,2 kW. In the following photographs (figure 4.2 - 4.3) the absorption chiller and the cooling tower are presented.



Figure 4.2: Absorption Chiller



Figure 4.3: Cooling Tower



## 4.2 L' Amor Rouge Bakery, Nicosia, Cyprus

The bakery is located in the industrial area of Ergates in Nicosia. The building is composed of the bakery, the confectionery and the offices with total surface of 627m<sup>2</sup>. L' Amor Rouge Bakery has been using the first solar cooling and heating system in Cyprus since May 2006, with autonomy higher than 59%. The system consists of 120m<sup>2</sup> vacuum tube collectors tilted 25° from the horizontal, a 6,8m<sup>3</sup> hot water storage tank, a 70,3kW nominal power absorption chiller (LiBr-H<sub>2</sub>O) and a 212kW nominal power cooling tower. Several technical and economical data are presented in the following tables:



Figure 4.4: First solar airconditioning system in Cyprus, L' Amor Rouge Bakery

Table 4.1: Annual Requirements of Installation

Annual needs of energy (Hot water, space heating and cooling)	213,65 MWh
Back up heat source	oil
Annual consumption of back up heat source	21.191 L/year
Back up heat source cost	0,77 €/L

Table 4.2: Solar System features

Number of collectors	40
Type of collectors	Vacuum Tubes
Area of the absorber	3 m <sup>2</sup>
Total area of the collectors	120 m <sup>2</sup>
Efficiency of the collector	0,73
Average daily radiation in plane of solar collector	5,94 kWh/m <sup>2</sup> /day

**Environmental and Economic Data:** The total investment cost was 134.489€ and the percentage of the grant/subsidy was 40% (53.796€). The payback time was calculated equal to 8,1 years. The solar fraction was estimated at 59,34%. Finally, the overall primary energy savings was estimated at 63,4MWh per annum and the total CO<sub>2</sub> savings at 22,44Mg per annum.

## 4.3 Solar cooling plant in Bolzano, Italy

In Bolzano, the capital town of South Tyrol, three buildings are equipped with solar collectors assisted by one Combined Heat and Power generator. One of the buildings houses the European Academy's EURAC Research Centre. In this same building a sophisticated monitoring system that is capable of collecting a large amount of data has been installed since 2005. The main features of the EURAC energy facility are reported in Table 4.3. Figures 4.5 and 4.6 show the plant layout respectively for winter and summer operation mode.

Table 4.3: Main features of the SHC-CHP installation in EURAC, Bolzano		
Heat production facility	Solar collectors- Gross area	615 m <sup>2</sup>
	1 Cogeneration Unit	180 kWe/ 330 kWth
	2 Condensing boilers	350 kWth each
Cold production facility	1 Absorption chiller	300 kWc
	2 Compression chillers	315 kWc each
Storage tanks	2 Solar tanks	5.000l each
	1 Cold tank	5.000l

Solar vacuum tube collectors, with a gross absorber surface of 615m<sup>2</sup>, provide heat not only for heating purposes and sanitary hot water production, but also for feeding the absorption chiller during the summer. One cogenerator and two condensation boilers supply the heating requirement which exceeds the solar fraction. Cooling is provided by the absorption chiller being assisted by two compression chillers, covering the peak demand. The monitoring system includes 13 heat meters and 3 electricity meters. Values are measured every minute and gathered at a central server.

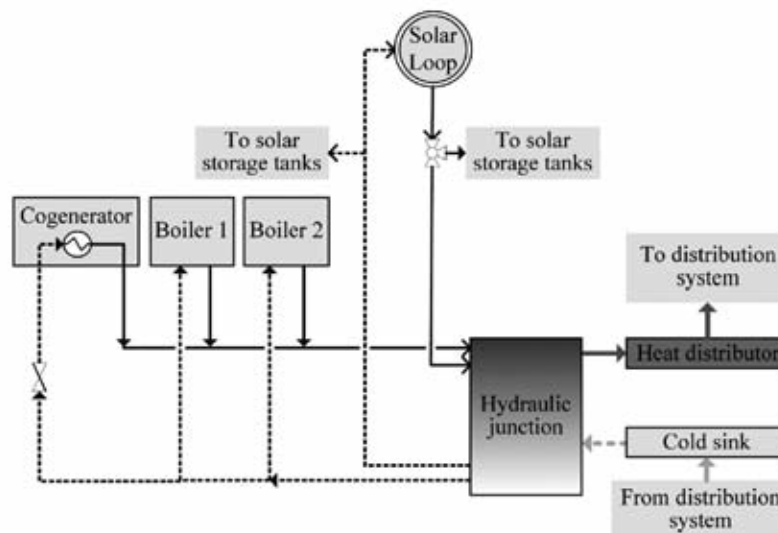


Figure 4.5: Layout of the SHC-CHP installation at EURAC, Bolzano: winter operation mode. (SHC-CHP: Solar Heating and Cooling + Combined Heat and Power). Source: Napolitano et al.

One critical aspect within this plant is the presence of a hydraulic junction where all the hot and cold streams are mixed, in particular the ones of the cogenerator and the solar loop which often have different temperatures, especially in winter.

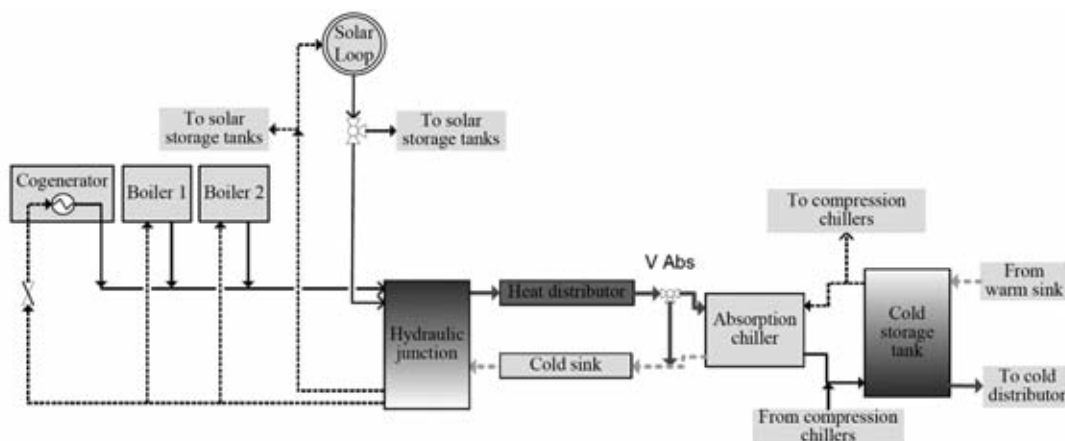


Figure 4.6: Layout of the SHC-CHP installation at EURAC, Bolzano: summer operation mode. Source: Napolitano et al.

The monitoring system has demonstrated that the control strategy influences the performance of the single devices, in particular of the solar collectors, the cogeneration unit and the absorption chiller.



Figure 4.7: Solar vacuum tube collectors installed on EURAC roof

#### 4.4 N. Kazantzakis town hall, Heraklion, Crete

This is a town hall building consisting of a basement, a ground floor and one storey with total surface of 2.500m<sup>2</sup>. The building's profile was developed through the SimCad software (fig. 4.8). Initially the heating and cooling loads were estimated and presented on a monthly basis through a 12-month period (fig.4.9).

The suggested solar cooling system consists of 300m<sup>2</sup> of flat plate selective collectors tilted 15° from the horizontal, a 20m<sup>3</sup> hot water storage tank, a 125kW nominal power absorption chiller (LiBr-H<sub>2</sub>O), a 35kW nominal power compression chiller, a 130kW oil back up heat source and a 250kW nominal power cooling tower.

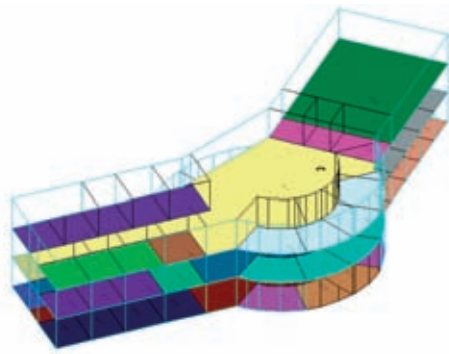


Figure 4.8: Building profile and thermal zones definition

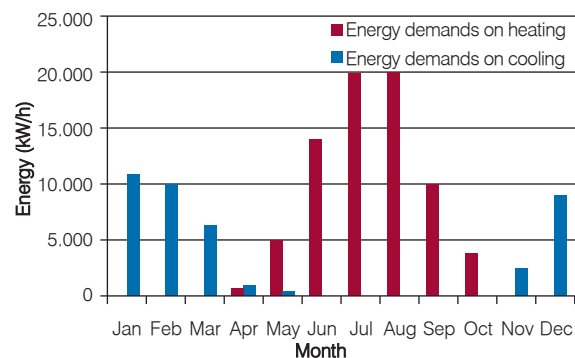


Figure 4.9: Heating & cooling loads on monthly base

The basic assumptions made during the economic evaluation were:

- Maintenance costs: conventional: 2% of investment costs, solar: 1% of investment costs
- Operating costs associated with the solar process include the cost of electricity for the pumps operation, interest charges on funds borrowed to purchase the equipment and other
- Installation costs: 12% of the equipment cost
- The energy inflation is taken equal to 2%
- Energy prices: electricity: 0,18€/kWh, oil: 600€/t (2007)

Several technical features and the equipment cost are presented in table 4.4.

Table 4.4: Technical features and the cost of equipment

Equipment	Cost
FPC selective	466 € (2,6m <sup>2</sup> )
Absorption Chiller LiBr-H <sub>2</sub> O (COP=0,7)	400 €/kW
Conventional chiller (COP=2,5)	310 €/kW
Back up heat source (n=85%)	50 €/kW

**Environmental and Economic Data:** The total investment cost was estimated to be 163.352€ and the total annual operating cost: 4.109€. The payback time was also calculated equal to 18,5 years. The solar fraction was estimated at 87,8%. Finally, the overall primary energy savings was estimated at 87.944kWh and the total CO<sub>2</sub> savings at 32.337kg.

## 4.5 General Hospital of Sitia, Crete

The building is part of the facilities of the General Hospital of Sitia. Building B has an overall surface of 1.250m<sup>2</sup> and consists of 3 areas. It accommodates the maternity clinic on the ground floor, the cardiology and the pathology clinic on the first floor and the paediatrics clinic on the second floor. This building was selected mainly for three reasons: the high importance that the General Hospital attributes to management, the problems in the existing conventional AC system, and its operation as a clinic.



Figure 4.10: General Hospital of Sitia

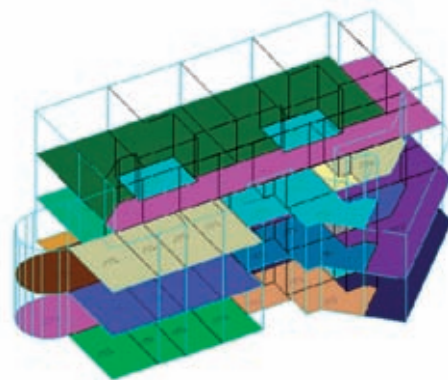


Figure 4.11: Profile of the building created in SimCad

The annual required energy of heating is 34.205kWh and the annual required energy of cooling is 123.911kWh.

The suggested system consists of 500m<sup>2</sup> flat plate selective collectors tilted 15° from the horizontal, a 15m<sup>3</sup> hot water storage tank, 70kW nominal power of absorption chiller (LiBr-H<sub>2</sub>O), 50kW nominal power of compression chiller, 87kW oil back up heat source and 170 kW nominal power cooling tower.

**Environmental and Economic Data:** The assumptions made during the economic evaluation were almost the same with the previous case. Only two parameters concerning energy prices were changed: electricity: 0,25€/kWh and oil: 1.200€/t (2008). The total investment cost without funding subsidies is 173.992€ and the total annual operating cost: 6.473€. The payback time was also calculated equal to 11,5 years. The solar fraction was estimated at 74,73%. Finally, the overall primary energy savings was estimated 113.581kWh and the total CO<sub>2</sub> savings at 45.535kg.

*Note: Case studies 5.4 and 5.5 have been designed by the Renewable and Sustainable Energy Systems Laboratory, Environmental Engineering Department, Technical University of Crete.*

# 5 Barriers and Recommendations

Nowadays solar cooling technologies are neither as well known, nor as widespread as they should be. They have not yet enjoyed a significant level of penetration into the air conditioning market in Southern Europe. One of the main objectives of the SOLCO project is to identify the non-technical barriers preventing further penetration of solar cooling technologies. This section identifies these barriers and proposes ways to overcome them.

## 5.1 Barriers for the wide adoption of solar cooling technologies

During the implementation of the SOLCO project a number of market barriers was identified and verified, such as:

### (i) Awareness and know-how

- Lack of awareness in potential users (hotels, hospitals, and others) about the possibilities and benefits of using solar driven cooling plants;
- Most of the technical actors are not familiar with SC technologies, and they do not suggest them as a solution to potential users;
- Most engineers are not completely educated in this technology;
- The suppliers of the plants are mainly engineering consultants and installers; they need additional support through training, design tools (software) and control systems in order to do their job better;
- Lack of packaged solutions is a serious problem not only during setting-up but also during the life of the installation (maintenance); the installation and M&O need specific knowhow;

### (ii) Demonstration

- A rather limited number of demonstration plants; by the end of 2007 there were approximately 300 Solar Cooling systems in operation worldwide; only a few of them are monitored and as a result there is limited information about their performance;

### (iii) Cost

- Relevant market actors claim that the high investment cost limits widespread application;
- Today's sorption technologies are, still, more expensive in comparison to conventional chillers; this is more evident in the case of small scale sorption chillers (residential, small trade centers etc). Significant effort is required to develop the existing technology in order to reduce the cost of system;
- The use of sorption chillers requires in most cases the existence of wet cooling towers, which are covered by specific legislation to avoid the legionnaire's disease. The maintenance of such installations is more expensive and most of the potential users prefer to avoid them;

### (iv) Market availability

- Although there is an important increase in the size of this market, today there is limited or no market availability of small capacity systems;

**(v) Policy and incentives**

- Tax exemptions and other financial incentives for solar thermal systems are limited and clearly not sufficient to promote the technology;
- A roadmap for solar-assisted cooling systems at national and/or European levels is missing; these installations are often forgotten in today's financial incentive schemes for solar thermal plants.

## 5.2 Recommendations to overcome the barriers

Despite the fact that the adoption of solar technologies is recognized as a realistic response to the energy and environmental problems that are attracting the attention of the public, economic evaluations are often unfavourable. Critical factors that will ensure the spreading of solar cooling systems are technological maturity and improved economic viability.

Economic analyses of solar cooling systems indicate that these systems will not be competitive compared with standard cooling systems at present energy prices. There is a strong need both for investment incentives and a fair environmental tax to reflect the full environmental costs of conventional fuels.

In order to overcome the multitude of obstacles and barriers faced by the solar cooling technologies the project partners identified the following remedial actions:

**(i) Information-dissemination**

- Develop a strong Europe-wide campaign of the SC technology to create broad awareness and new and better market implementation activities to decision makers and potential users;

**(ii) Demonstration**

- A large number of demonstration projects is necessary and overall, real data about the performance of monitored plants is absolutely necessary. The existing solar cooling installations show a high cost reduction potential for the next generation of cooling plants;

**(iii) Training**

- As indicated by the extensive training activities carried out during the life of the SOLCO project, specific training courses for professionals (installers) and inclusion of solar cooling technologies into standard education for engineers is a must; development of advanced modelling and simulation tools for designers and installers is also absolutely necessary;

**(iv) Quality, O&M**

- Improvement of components with respect to their performance (increasing the COP in the case of chillers and the efficiency of solar collectors) is also required; at the same time this improvement must reduce the cost of the components in order to make solar driven cooling plants more attractive;
- Standardisation in the field of solar driven cooling plants, design guidelines, proven operation and maintenance concepts is necessary;

**(v) Policy**

- Introduction of legislation that requires Member States to keep statistics on energy demand for cooling purposes;
- Inclusion of solar cooling into financial incentive schemes and subsidies for solar thermal at national and European level;
- There is still a need for subsidies to support the implementation of solar cooling technologies in order to ensure their effective penetration into the cooling market;
- Establishment of an accreditation process based on specific training together with a good track record of successful installations and client references.

# 6 Economic & Financial Considerations

Further to the barriers identified in the previous section, the higher investment costs -required for solar cooling installations- need a very careful analysis of the economic and the financial aspects of the project. This analysis has to start with a feasibility study that will seek to establish the technological, financial and environmental viability of the project. Once there is enough evidence that the project is feasible, a more detailed financial analysis has to be carried out, in order to establish the financial structure of the project and identify all available sources of financing.

## 6.1 Feasibility study

There is a need for a new perspective in valuing solar energy technologies. The need for new economic cost perspectives derives from the fact that these technologies have vastly divergent financial risk characteristics; additionally the unpredictability of conventional fuel prices over long periods should be taken into account.

The first crucial steps in developing a solar cooling project are to ensure that it can be realised from a technological, financial and environmental point of view. Before the actual commitment to implementation, most projects have to undergo a detailed feasibility assessment.

A feasibility study should include a technical evaluation of all potential alternatives. It should also contain a concrete summary of the financial aspects; a reliable feasibility study is a valuable tool in order to identify and attract the financing resources needed for a successful project implementation. After a pre-screening of preferred and alternative options, there is a need for a comparison of the alternative solutions against quality and quantity issues, land costs, local social, environmental and economic impacts, necessary permits, profitability etc.

Conducting the feasibility study, the following steps - as presented in figure 6.1 - should be followed.

**Background information:** This step summarises the motivation for carrying out the project, as well as the rationale on how this project fits within the sustainable energy strategy of the community. A general description is an additional required task. This step also identifies project objectives and incorporates fundamental information about facility size and design considerations.

**Technology choice:** This step focuses on the recommended technology; how it would fit with the existing facility, what benefits the system would provide and how these benefits would be exploited. It would also outline and compare with alternative options that could be used instead. It is important

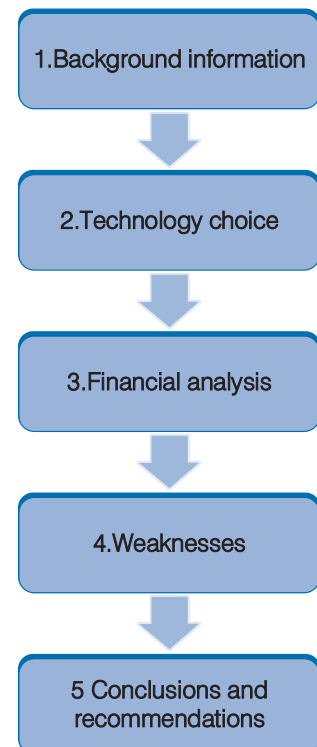


Figure 6.1: Steps in the Feasibility Study

to develop the most suitable project that best fits the vision, needs, and current conditions. An initial screening of the financial, environmental and social costs, as well as the benefits coming from alternative energy technologies is recommended in this stage.

**Financial analysis** evaluates the system's costs and illustrates how the owner would pay for it. This step should also include a cost effectiveness evaluation that would detail social, environmental, and avoided cost benefits in addition to the simple payback period calculation.

**Weaknesses:** This step concentrates on the identification of major problems, obstacles and prospective barriers concerning the project. It should also suggest solutions and provide recommendations on how to address these issues.

**Conclusions and Recommendations:** This final step of the feasibility study offers the main conclusions and judgments regarding whether or not the project should proceed.

## 6.2 Funding Opportunities and Financing Instruments

Financing for solar cooling projects can come from multiple sources, including up-front equity, debt financing, incentives schemes (including subsidies, low-interest loans, grants and tax incentives). A brief overview of the most common available types of funding follows:

- **Equity Financing:** For private companies or Public-Private-Partnerships developing solar projects, it is important that they have a sound financial structure. No granting agency or financial institution will proceed with the approval of grants or debt financing if the owners are not willing to risk their own capital in the project. It is therefore essential that in preparing the financial structure, and before any application for external financing, the owners establish their own equity by creating an appropriate equity capital structure that will provide the basis for further financing from outside sources, such as banks, government agencies and other lending institutions.
- **Debt Financing:** Even if a project receives public funding, some of the funds should probably come from financial institutions through debt financing. Before visiting the banks, project developers should prepare the project's plan and feasibility study, and gather all available site and financial data presented in a comprehensive "proposal to finance". In cases where the project objectives include selling power to the local utility, it is necessary to conclude a power purchase agreement with the utility; this will help the bank assess the financial viability of the project and evaluate the potential payback period.
- **Governmental Incentive Payments:** These may appear in the form of direct or indirect subsidies, tax incentives, low VAT rates, energy tax exemptions, public subsidies for environmental investments, or as production payments. Eligibility and availability of incentive schemes are frequently subject to change, so any project that relies on incentive payments should verify that the incentives under consideration are still available at the project's inception.
- **Public (European and National) Loans and Grants:** Beyond production incentives, there may exist loan or grant programmes available to help finance renewable energy projects. Schools, social houses, municipalities and other government units may be eligible for Community Support Framework (CSF) funding.
- **EU grants:** They provide funding opportunities and are awarded to co-finance specific projects or objectives, usually through calls for proposals. EU grants cover a whole range of EU policy areas for sustainable, competitive and secure energy and environmental protection, such as: electricity production from RES, RES share in energy mix, energy efficiency etc. The form of application depends on the type of funding:
  - structural funds are managed at national or regional level and, as a result, applications are submitted to and evaluated by national or regional authorities;
  - for EU grants, application procedures are set out in the calls for proposals for specific programmes, and applications are sent directly to the European Commission or an executive agency which runs the programme in question.



Table 6.1 illustrates the main EU financing instruments, which could benefit a solar cooling project:

Table 6.1: Main EU financing instruments
<p><b>1. Framework Programme - CIP (2007-2013) Competitiveness and Innovation</b>  <a href="http://ec.europa.eu/cip">http://ec.europa.eu/cip</a></p> <p>1.1. Intelligent Energy - Europe Programme 2007-2013  <a href="http://ec.europa.eu/energy/intelligent/call_for_proposals/index_en.htm">http://ec.europa.eu/energy/intelligent/call_for_proposals/index_en.htm</a></p> <p>1.2. LIFE + (2007-2013)  <a href="http://ec.europa.eu/environment/life/funding/lifeplus.htm">http://ec.europa.eu/environment/life/funding/lifeplus.htm</a></p> <p>1.3. Marco Polo Programme (2003-2010)  <a href="http://ec.europa.eu/transport/marcopolo/index_en.htm">http://ec.europa.eu/transport/marcopolo/index_en.htm</a></p>
<p><b>2. Seventh Framework Programme - FP7 (2007 to 2013)</b>  <a href="http://ec.europa.eu/research/fp7">http://ec.europa.eu/research/fp7</a>, <a href="http://www.cordis.lu/fp7">http://www.cordis.lu/fp7</a></p>
<p><b>3. EU Structural Funds</b>  <a href="http://www.eugrants.org/frame-template.html">http://www.eugrants.org/frame-template.html</a></p> <p>3.1. European Regional Development Fund - ERDF  <a href="http://ec.europa.eu/regional_policy/funds/feder/index_en.htm">http://ec.europa.eu/regional_policy/funds/feder/index_en.htm</a></p> <p>3.2. European Agricultural Fund for Rural Development - EAFRD 2007-2013  <a href="http://ec.europa.eu/agriculture/rurdev/index_en.htm">http://ec.europa.eu/agriculture/rurdev/index_en.htm</a></p>

## 6.3 EU legislation and policy

The following table provides an indicative list of the European Union legislative and supporting initiatives that foster the increase of RES share in electricity and the efficiency of energy use, encouraging the reduction of total energy consumption, at national, regional and local level.

Table 6.2: Indicative list of the current EU policy, legislative and supporting initiatives
<ul style="list-style-type: none"> <li>• New Directive on the promotion of the use of energy from renewable sources (COM(2008)19 final)</li> <li>• Energy for a Changing World - An Energy Policy for Europe, (COM(2007)1 final)</li> <li>• Integrated energy and climate change package (COM(2007)1 final) and the Presidency Conclusions of the Brussels European Council (8/9 March 2007)</li> <li>• Green Paper follow-up action - Report on progress in renewable electricity (COM(2006)849 final)</li> <li>• Renewable Energy Road Map - Renewable energies in the 21<sup>st</sup> century: building a more sustainable future (COM(2006)848 final)</li> <li>• Towards a European Strategic Energy Technology Plan (COM(2006)847 final)</li> <li>• Green Paper - A European Strategy for Sustainable, Competitive and Secure Energy (COM(2006)105 final)</li> <li>• Directive on the energy performance of buildings (2002/91/EC)</li> <li>• Renewable Electricity Directive (2001/77/EC)</li> <li>• Green paper on security of energy supply (COM(2000)769)</li> <li>• White Paper on Renewable Energy Sources (COM(97)599 final)</li> </ul>

More information for European legislation currently in force or in preparation can be found or downloaded from EUR-Lex, the portal to European Union law. EUR-Lex provides direct free access to European Union law, in all official languages; <http://eur-lex.europa.eu>.

Copies of the above documents can be also downloaded from the following websites:

- [http://ec.europa.eu/energy/energy\\_policy/index\\_en.htm](http://ec.europa.eu/energy/energy_policy/index_en.htm) (energy and climate change package)
- [http://ec.europa.eu/energy/res/legislation/index\\_en.htm](http://ec.europa.eu/energy/res/legislation/index_en.htm) (renewable related legislation)
- [http://ec.europa.eu/energy/demand/legislation/index\\_en.htm](http://ec.europa.eu/energy/demand/legislation/index_en.htm) (energy efficiency related legislation)
- [http://europa.eu.int/eur-lex/en/lif/ind/en\\_analytical\\_index\\_07.html](http://europa.eu.int/eur-lex/en/lif/ind/en_analytical_index_07.html)

# 7 Conclusions

Nowadays, Solar Cooling is both possible and reliable. Exploitation of solar thermal energy for cooling is an efficient, intelligent and environmentally friendly way to use renewable energy sources to meet our air conditioning needs.

However, applications of solar cooling are actually too few. This is both the cause and the result of the low levels of penetration of this technology, even in markets where solar radiation is relatively high, namely those of Southern Europe.

**SOLCO is reporting the following major findings in the diffusion of solar cooling technologies:**

- At local level there is a real need for the implementation of solar cooling and the public is willing to use the technology for air conditioning applications in the residential, commercial and public sector, including private enterprises, hotels and hospitals.
- The investment cost of solar cooling installations is higher than conventional air conditioning systems. As a result, relatively few installations are in place and this in turn keeps the cost of components (such as chillers) relatively high due to the absence of economies of scale.
- There is a lack of widespread specialised knowledge of solar cooling technologies amongst designers, installers and maintainers who in their majority continue to design and promote conventional non-solar installations.

**In order to overcome existing non-technical barriers and improve the penetration of SC technologies in the European market, SOLCO's main recommendations are:**

- Training of technical market actors (designers, installers, maintainers) is crucial in order to overcome the knowledge barrier.
- Financial support schemes at national and European level are essential in order to overcome the financial barrier and make SC technologies competitive, improve market penetration and exploit economies of scale. These schemes can be in the form of grants, subsidised interest rate loans, and/or tax incentives.
- Dissemination of information on the advantages of solar cooling is vital. A Europe-wide campaign, with emphasis in Southern Europe, is central in order to improve the understanding and acceptance of solar cooling technologies by the general public.



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