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New technical solutions for energy efficient buildings

State of the Art Report

Solar heating & cooling

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Background

The European Directive to Promote Renewable Heating and Cooling calls for 25 % of EU heating and cooling to be supplied by renewables in 2020. To achieve these ambitious targets in each member state it is essential to increase the use of renewable energy sources in the heat market and this should be considered as a priority in many member states, coupled with efficiency measures (insulation etc.). Using Renewables should become the regular way of producing heat/cooling for households and a valuable fuel supplement for industries and district heating/cooling.

Worldwide the energy consumption for cooling and air-conditioning is rising rapidly. Usually electrically driven compressor chillers (split-units) consume most energy in peak-load periods during summer. Even in Europe in the last few years this has regularly led to overloaded grids. The market potential for solar cooling and thermal cooling is very large and still under development. These solutions are environmentally friendly because of their lower electricity demand. Furthermore operational costs are very low.

Solar Heating and Cooling - General remarks

Solar thermal energy is appropriate for both heating and cooling. Key applications for solar technologies are those that require low temperature heat such as domestic water heating, space heating, pool heating, drying process and certain industrial processes. Solar applications can also meet cooling needs, with the advantage that the supply (sunny summer days) and the demand (desire for a cool indoor environment) are well matched. To generate synergy effects in climates with heating and cooling demand combined systems should be used.

Solar Heating

Over 70% of the household's energy use goes into space and water heating. Covering a big part with a solar system leads to energy as well as financial savings. Solar heating is a well established renewable energy source and applied in numerous projects worldwide. Solar thermal systems consist of a solar collector, a heat exchanger, storage, a backup system and a load. This system may serve for both, space heating and tap water heating, known as combi system. [Fig 1]

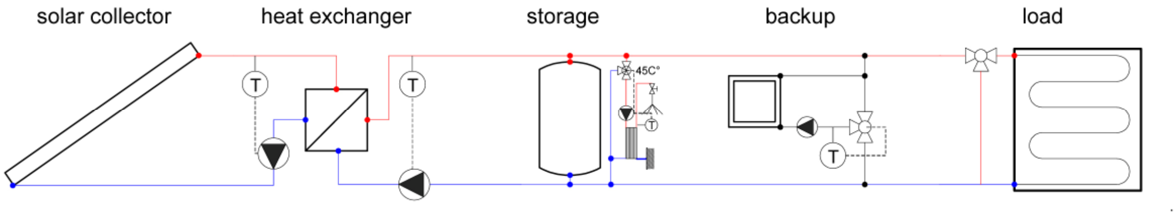

Fig. 1 Typical solar thermal system [1]

In most applications solar combi systems are used, generating energy for hot water and space heating. The three main components (Collector types, Storage systems and Domestic hot water preparation) are briefly described below:

Collector types

Flat-plate-collectors: Flat-plate collectors are the most used collectors on the market and therefore a popular application for domestic hot water production. The most critical issue affecting the performance of the collector is the coupling of the tubes (heat transfer circulation) with the absorber. Different solutions of manufacturing technologies are available on the market. Flat-plate collectors are installed on a simple supporting structure or can be integrated into a sloped roof.

Fig. 2 Flat-plate-collectors, www.greenonetec.com

Evacuated tube collectors: Evacuated tube collectors consist of single tubes which are connected to a header pipe. To reduce heat losses of the water-bearing pipes to the ambient air each single tube is evacuated . Besides different geometrical configurations it has to be considered that the collector must always be mounted with a certain tilt angle in order to allow the condensed internal fluid of the heat pipe to return to the hot absorber. [8]

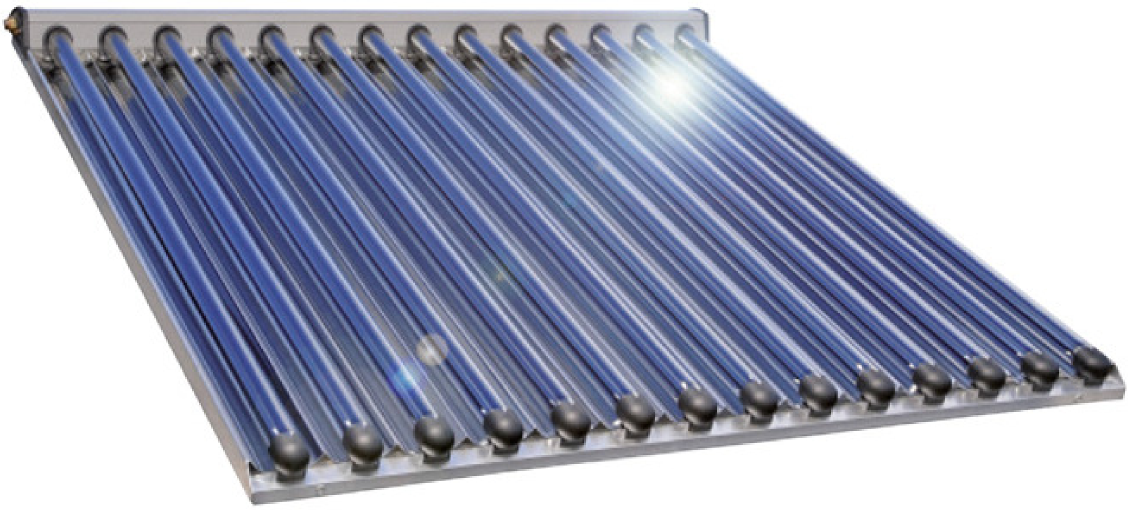

Fig. 3 Evacuated tube collector, www.greenonetec.com

Solar air collectors: The operating principle of solar air collectors is similar to flat plate collectors. The difference is that instead of liquid fluid an electric fan pumps air through the collector. This collector type is not very common in Europe (covers only 1-2% of the solar liquid collector market). Reasons for this might be on the one hand the lack of experience and the lack of knowledge of the end users. On the other hand this collector type cannot be used directly for domestic hot water production, which dominates the market today. [8]

Storage Systems

Hot water storage

The storage system is a key element in solar heating and cooling and fulfils several tasks:

- Delivering sufficient energy to the heat sink
- Decoupling mass flows between heat sources and heat sinks

- Storing heat from fluctuating heat sources for availability during times with no solar heat gain
- Extending operation times for auxiliary heating devices
- Reducing the needed heating capacity of auxiliary heating devices

Storing the heat at the appropriate temperature levels and avoiding mixing to reduce energy losses [8]

- Storage systems with phase change materials

Phase change materials absorb or release heat when the material changes its phases ("latent heat").

Main advantages of PCM compared to conventional water storage techniques:

- Higher thermal energy storage capacity
- Relatively constant temperature during charging and discharging
- Burner cycles for the back-up heat generation unit can be reduced

Disadvantages:

- Higher investment costs
- Peak power during discharge is limited in many cases
- Limited experience with long-term operation
- Risk of loss of stability of the solution and deterioration of the encapsulation material [8]

Domestic Hot Water (DHW) preparation

In solar combi systems without cooling functions, tap water is either heated inside the main heat store by means of an integrated heat exchanger or a tank-in-tank system or an external flat plate heat exchanger or a separate domestic hot water tank is used. [3]

Solar Cooling

Minimising the cooling demand by passive cooling strategies based on "bioclimatic design" (such as night ventilation, etc., further information can be found in the State-of-the-Art report on "Innovative cooling concepts for office buildings"[1],should be the first step before considering active cooling systems.

One of the main advantages of solar cooling is the fact that cooling demand and highest solar gains are at

[1] http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/State_of_the_Art_Report_Cooling.pdf

the same time (summer period). Especially in Mediterranean regions with high solar gains and high cooling demands solar cooling will become more and more an alternative to conventional cooling systems. For solar cooling in general two concepts are possible:

Cooling with PV collectors

A conventional vapour compression machine is operated by electricity provided by PV collectors. As the only difference to conventional cooling systems is solar produced electricity, as systems with thermal collectors are emerging and as systems with thermal collectors offer, promising approaches (both from energy efficiency and financial aspects) this report focuses only on systems with thermal collectors for cooling.

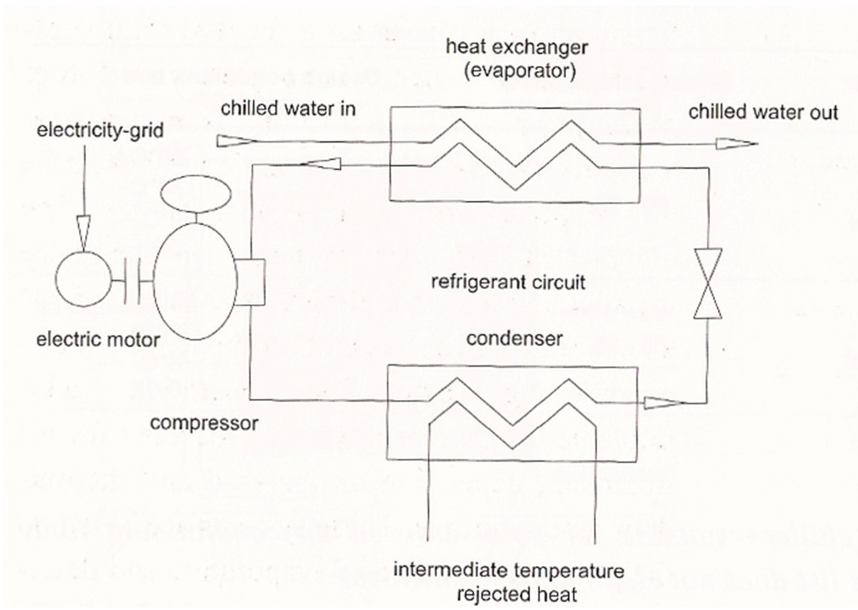

Fig. 4 Vapour compression chillers: This process employs a chemical refrigerant (e.g. R134a) and is the most common refrigeration process applied in air-conditioning.

Cooling with thermal collectors

There are three thermal driven systems:

- Absorption cooling with chilled water
- Adsorption cooling with chilled water
- Desiccant cooling for air based cooling systems

Solar assisted cooling systems usually involve solar thermal collectors connected to thermally driven cooling devices. They consist of several main components: the solar collectors, heat buffer storage, the air conditioning subsystem, including various forms of cold distribution, and auxiliary (backup) subsystems (see fig. 5)

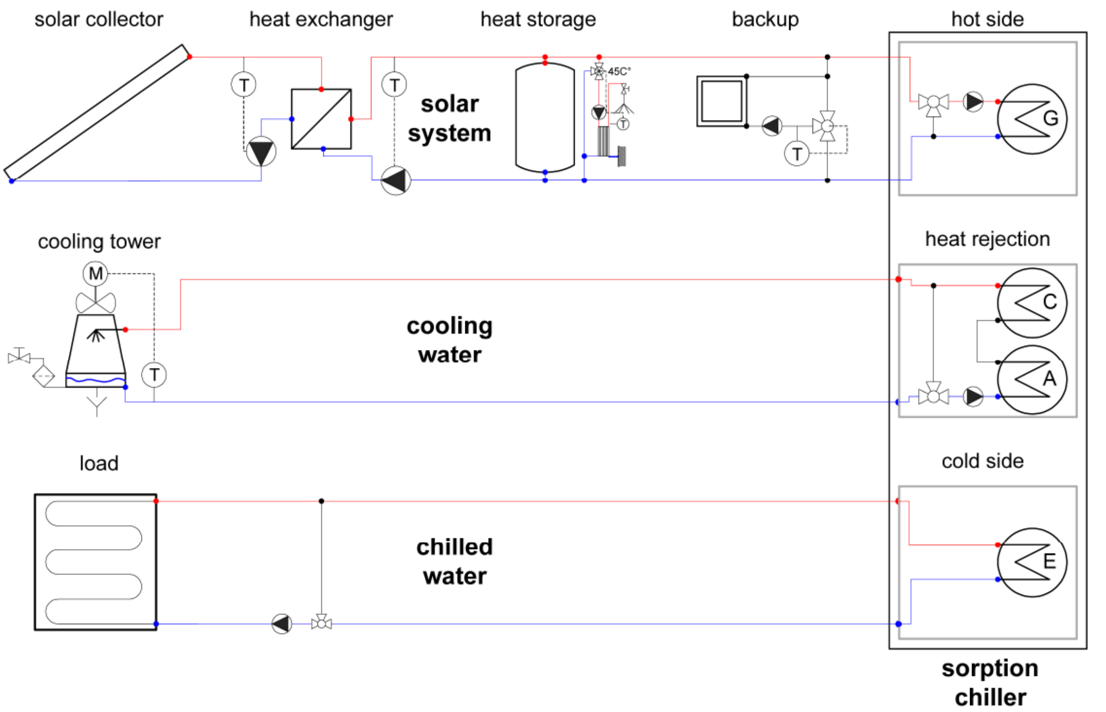

Fig. 5 Solar assisted cooling systems: Thermally driven chillers coupled to solar thermal system, cooling water loop and chilled water loop [1]

Main advantages of solar cooling are

- The availability of high solar radiation during the time when cooling is needed
- the applicability of thermal energy as driving energy
- low operating costs
- low electrical power rating
- Durability and environmental compatibility [5]

The disadvantage of solar cooling systems are the still high installation costs, the space needed for heat storage and the additional backup system necessary[2].

The technical development of solar thermal cooling systems has progressed in recent years and performed in numerous pilot projects. To give an overview on this very complex system three principle

[2] in residential buildings it is possible to reduce the additional back-up system.

technologies are described below: absorption and adsorption chillers and desiccant cooling systems:

Absorption chillers

Solar powered absorption chillers use hot water from solar collectors to absorb already pressurized refrigerant from an absorbent/refrigerant mixture (such as water/lithium bromide and ammonia/water). Condensation and evaporation of the refrigerant vapour provides the same cooling effect as that provided by mechanical cooling systems. Although absorption chillers require some electricity for pumping the mixture, the amount is very small compared to that consumed by a compressor in a conventional electric air conditioner. Absorption chillers are the most widely used chillers throughout the world although most of the installations are located in countries with mild climate such as southern Europe, China and the Mediterranean. [6]

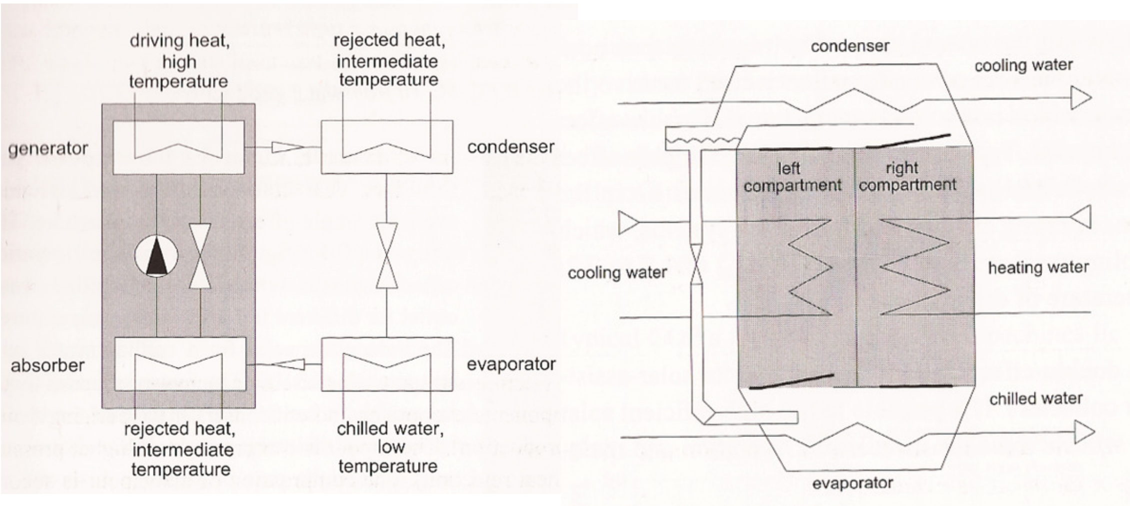

Fig. 6 Schematic scheme of an absorption chiller (left) and adsorption (right) [8]

Adsorption chillers

Here, instead of a liquid solution, solid sorption materials are applied. Market available systems use water as a refrigerant and silica gel as a sorbent. The machines consist of two sorbent compartments, one evaporator and one condenser.

Under typical operation conditions, with a driving heat temperature of about 80°C, the systems achieve a thermal COP[3] of about 0.6, but operation is possible even at heat source temperature of approx. 60°C.

[3] Thermal COP (Coefficient of Performance): A key figure to describe the performance of a thermally driven chiller is the thermal Coefficient of Performance (COP), defined as the produced cold per unit of driving heat.

The capacity of the chillers range from 50 to 500 kW chilling power. The simple mechanical construction of adsorption chillers and their expected robustness is an advantage. There is no danger of crystallization and thus no limitations in the heat rejection temperatures. An internal solution pump does not exist and hence only a minimum of electricity is consumed. A disadvantage is that they are much heavier. A large potential for improvements of the heat exchangers in the adsorption compartments is expected. [6]

Desiccant cooling system

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, i. e. a hygroscopic material. For this purpose, liquid or solid materials can be employed. Only water is possible as a refrigerant since a direct contact to the atmosphere exists. The common technology applied today uses rotating desiccant wheels, equipped with silica gel or lithium-chloride as sorption material. Solar assisted desiccant cooling uses solar thermal energy to dry out or regenerate the desiccant.

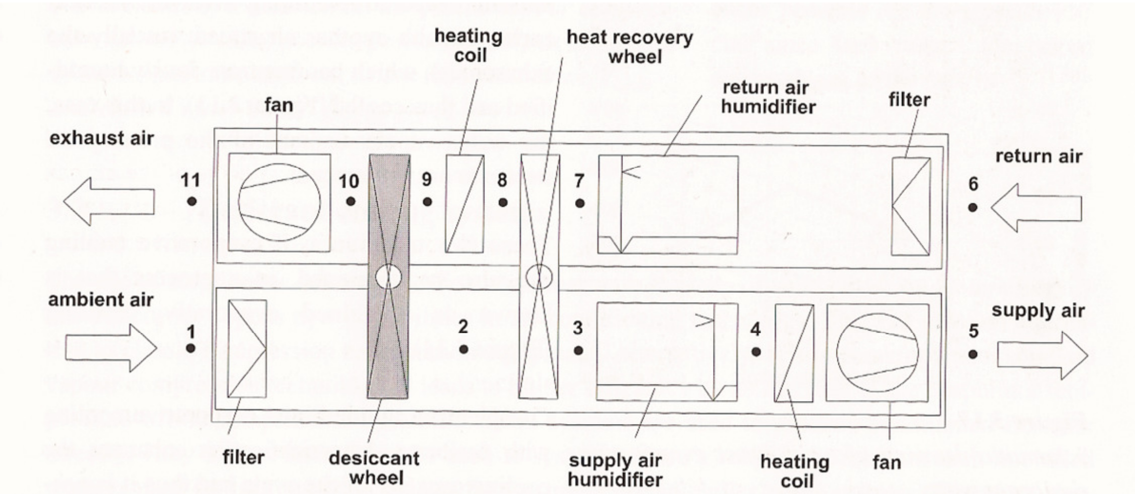

Fig. 7 Schematic drawing of a desiccant cooling air-handling unit [8]

Major benefit: increased comfort (since temperature and humidity are controlled independently), lower operating costs, heat recovery options, improved indoor air quality and reduced building maintenance as a result of high humidity levels. [6] Desiccant systems are used to produce conditioned fresh air directly. Therefore, they can be used only if the air-conditioned ventilation system includes some equipment to remove the surplus internal loads by supplying conditioned ventilation air to the building. [8]

Examples

Cooling systems above 40 kW cooling load

Different heat driven cooling technologies are available on the market, for systems above 40 kW, which can be used in combination with solar thermal collectors. The main obstacles for large scale applications, beside the high initial cost, are the lack of practical experience and knowledge among architects, builders and planners with the design, control and operation of these systems. [1]

54 projects for solar cooling have been analysed within the scope of the "SACE project (Solar Air Conditioning in Europe)" to examine environmentally friendly air conditioning and to assess the potential of various heat driven cooling technologies for use with solar thermal systems. [5]

The study of the 54 projects demonstrated that the average specific solar collector area for all the reviewed projects was 3.6m^2/kW cooling capacity, but with a high variety ranging from 0.5 to 5.5m^2/kW. Adsorption and absorption systems require a specific solar flat plate collector area higher than 2m^2/kW and usually lower than 5m^2/kW.

Furthermore the initial cost of the evaluated projects range from 1.286 to 8.420 €/kW[4]. The costs are related to the type of heat-driven device employed and particularly to the stage of development of its technology and working principle. However the cost is influenced more by the cooling capacity and the solar collector type. Small cooling capacities and tracking solar collectors increase the cost significantly. Furthermore systems that require larger collector areas are usually more expensive too.

[4] This is the overall system costs excluding ductwork from system to application and application equipment as fan coils and induction units per installed cooling capacity in kW

Collector type	Collector area per $kW_{chiller}$ (m^2/kW)	Heat storage volume (m^3)	Chiller type	Backup type	Total annual costs (k€)	Primary energy saving (%)	Value of saved primary energy (€ ¢/kW h)
–	–	–	el. compr.	–	10.1	–	–
FPC	2.99	12.6	ads	heat	13.5	38	13.6
StCPC	2.99	16.8	ads	heat	14.4	52	12.7
ETC	2.13	15	ads	heat	14.9	47	15.7
FPC	2.99	12.6	ads	el. compr.	16.2	47	19.6
StCPC	2.99	12.6	ads	el. compr.	17.2	53	20.3
ETC	2.13	15	ads	el. compr.	17.7	53	22.1
FPC	2.99	12.6	abs	heat	11.7	36	6.8
StCPC	2.13	9	abs	heat	11.8	30	8.2
ETC	2.13	12.6	abs	heat	12.9	45	9.5
FPC	2.99	12.6	abs	el. compr.	14.5	46	14.7
StCPC	2.13	12	abs	el. compr.	14.6	43	15.7
ETC	2.13	18	abs	el. compr.	16	53	17.0

Fig. 8 Results of comparison of different systems for solar assisted air conditioning and heating for an office building (room area 930 m^2) in Madrid [5][5]

Figure 8 presents a comparison of different system configurations to provide solar assisted air conditioning (and heating) to an office building in Madrid, Spain[6]. The primary energy savings compared to a conventional state-of-the-art reference system[7] are listed. Therefore the cost for the primary energy saving serve as a measure for the value of energy saving and can be used during design for comparison of different energy saving measures. [5]

Cooling systems under 30 kW cooling load

The main technology for solar cooling systems with small scale cooling capacity (< 30kW) are absorption and adsorption cooling. They are mostly used as central air conditioning systems with decentralised fan coils or cooled ceilings. During the last few years especially in Europe various new sorption chillers with small-scale and medium-scale cooling capacity have been developed. Many of these sorption chillers have passed over from prototype stadium into small serial production. [1]

[5] FPC = flat plate collector (280€/m^2), StCPC = stationary concentrating parabolic collector (400 €/m^2), ETC = evacuated tube collector (620€/m^2)

Investigated chillers: abs = absorption chiller (400€/m^2); ads =adsorption chiller (800€/m^2) el.compr. = electrically driven compression chiller (310 €/m^2)

[6] The cooling capacity of the chiller for this particular building is 47 kW. Standard values have been used for all parameters (i.e. technical components as well as energy prices).

[7] electrically driven compression chiller with a COP of 3.0 for cooling and a conventional gas burner for heating

Absorption chillers with capacities from 7.5 kW to 15 kW cooling capacities are listed in the table below with the different applications for the different chillers. The adsorption chiller *chillii STCR* with a cooling capacity of 7.5 kW is mainly for residential buildings, the 12 kW ammonia/water absorption chiller *chilli PSC12* is for office buildings or process cooling e. g. milk cooling and the 15 kW water/silica gel absorber *chilli STC 15* as well as the water/lithium bromide absorber *chilli WFC 18* (17.5 kW cooling capacity) are for air conditioning e. g. of office buildings, hotels, banks, bakeries, public and administration buildings. [7]

Company	SorTech	SolarNext	SorTech	Yazaki
Product name	chillii® STC8, (ACS 08)	chillii® PSC12	chillii® STC15, (ACS 15)	chillii® WFC 18 (WFC-SC5)
Technology	adsorption	absorption	adsorption	absorption
Working pair	water/silica gel	ammonia/water	water/silica gel	water/lithium bromide
	 (source: SorTech)	 (source: Pink)	 (source: SorTech)	 (source: Yazaki)
Cooling capacity	7.5 kW	12 kW	15 kW	17.5 kW
Heating temperature	75 / 68°C	85 / 78	75 / 69	88 / 83°C
Recooling temperature	27 / 32°C	24 / 29°C	27 / 32 °C	31 / 35°C
Cold water temperature	18 / 15°C	12 / 6°C	18 / 15°C	12.5 / 7°C
COP	0.56	0.62	0.56	0.70
Dimensions (LxDxH)	0.79 x 1.06 x 0.94 m³	0.80 x 0.60 x 2.20 m³	0.79 x 1.35 x 1.45 m³	0.60 x 0.80 x 1.77 m³
Weight	260 kg	350 kg	510 kg	420 kg
Electrical power	20 W	300 W	30 W	72 W

Fig. 9 Small scale sorption chillers for solar cooling systems [7]

The solar cooling systems basically contain solar thermal collectors with hot water storage, pump-sets, a chiller, a re-cooler, partly cold water storage and a control unit. The cooling kits are developed for the European market, whereas other re-coolers can be offered according to the country (e.g. in Spain a dry re-cooler).

3.5 to 4.5 m^2/kW cooling capacity specific collector surface can be considered as a reference value for thermal driven absorption and adsorption chillers. These values are only rough references and can't replace the detailed design and simulation of a system. The specific total costs of installed solar cooling systems in Europe have been between 5.000 and 8.000 Euro/kW (2007). In the future 3.000 Euro/kW are expected.

Solar combi systems and cooling

As most solar systems are combi systems for space heating and domestic hot water preparation, in the following chapter the main aspects for the integration of cooling application in combi systems are mentioned. Common components of solar combi systems (as already discussed under “Solar Heating”) have been screened and their purpose for solar cooling systems reviewed.

Collector

The driving temperature is determined by the heat-driven cooling device, and influences the system performance, with a different range of driving temperature[8] supplied by different types of solar collectors. If the driving temperature is in the range of 60-90°C, a common flat plate solar collector can be used. Figure 8 shows the different efficiency of the different collector types.

Storage and DHW

The most common storage system is a hot water buffer tank in the heating cycle of the thermally driven cooling equipment. This is the case for desiccant cooling systems. However, when using absorption or adsorption chillers two possible places (see Figure 10) for integrating thermal storage exist. [8]

[8] The driving temperature is defined as the average temp of the heating fluid between inlet and outlet of the heating section with temp expressed in Kelvin.

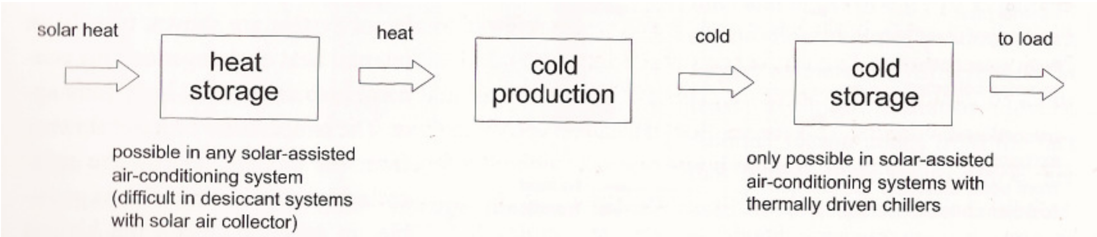

Fig. 10 Energy storage typologies in a solar-assisted air conditioning system [8]

If a thermally driven cooling machine is added to a combi system the main aspect is the DHW preparation. Therefore the an “integrated heat exchanger” and a “tank-in-tank system”) are not suitable for solar cooling as most manufacturers recommend limiting the tank temperature to 60° to avoid scaling and calcification. [2]

Recommendations for solar heating and cooling

- Before considering active cooling systems the first step is to reduce the cooling load. This can be done very effectively by intelligent building design. Passive cooling strategies based on “bioclimatic design” (such as orientation and size of windows, reduction of solar gains by sunblind, implementation of thermal mass, night ventilation, etc.). Due to this a simplified assessment of cooling loads in early design stages (e. g. architectural competitions) should be done. More detailed information can be found in the State-of-the-Art report “Innovative cooling concepts for office buildings”[9].
- If solar heating and/or cooling is planned, solar collector areas need to be considered in early design stages, as they will have huge impact on the building design. This has to be taken into account by procurers especially for architectural design competitions.
- In climates with heating and cooling demand, combined systems (solar heating and cooling) make sense.
- Comparisons/assessment of the environmental impact of solar heating and cooling systems should be done on the primary energy level and on CO_2- emissions. If possible technical specifications in tendering documents should deal with benchmark values of primary energy and CO_2-emissions. It is recommended to use primary energy savings as a measure for the value of energy saving and using it during design and in the tendering process for comparison/assessment of different bids.
- As from the technical and economical point of view a 100% cooling fraction with solar cooling

[9] http://www.sci-network.eu/fileadmin/templates/sci-network/files/Resource_Centre/Innovative_Technologies/State_of_the_Art_Report_Cooling.pdf

systems is very rarely feasible, the environmental performance of the system is strongly influenced by the type of backup system.

- A key figure to describe the performance of a thermally driven chiller is the thermal Coefficient of Performance (COP), which is defined as the produced cold per unit of driving heat, or the annual thermal COP (ratio of the annual cold production in kWh and the annual heating input in kWh). So tendering documents should include a COP in the technical specifications.
- Against solar combi systems for heating and DHW, which are already state of the art all over Europe, knowledge and implementation of solar systems for cooling (especially for cooling capacities above 20 kW) is not widespread. In case of this high quality expertise for the tendering process is required.
- An amount of solar coverage rate of min. 70% of the total cooling demand is recommended.
- Only high quality collectors with a selective absorber coating are suitable for solar cooling.
- As the calculation of costs (like payback times) in comparison to conventional heating and cooling systems is quite complex, expert input is required. Generally speaking costs (payback times) are effected by following aspects:
    - Solar radiation on the site
    - Efficiency of the HVAC system for heating and cooling
    - Construction costs for the HVAC system for heating and cooling
    - Additional construction costs for the implementation of the solar panels in the building structure
    - Operation costs of the HVAC system
    - Future development of interest on borrowings
    - Future development of energy prices
- Standard design procedures and regulations are currently under preparation (further information: SHC Task 38 Solar Air-Conditioning and Refrigeration).
- In the European research project "SACE - Solar Air Conditioning in Europe" [5 + 9], user guidelines with detailed aspects concerning costs and technical issues and a simplified evaluation tool for building professionals, such as engineers, architects, building owners, planners and consultants can be found. Below some recommendations of this guidelines are stated:
    - The Electricity consumption of the necessary fans and pumps needs to be considered when choosing a specific collector type, as they have huge impacts on operation costs and environment (primary energy consumption, CO_2 -emissions). The average electric energy consumption for auxiliary fans and pumps of the systems evaluated in the SACE projects was about 225 W per kW cooling capacity.
    - Systems for solar heating and cooling with a cooling capacity below 20 kW should be as much pre-engineered as possible. That means that the entire system layout

and the size of all components are pre-defined by the manufacturer or seller of the system. To install such a system there is no detailed planning process necessary. It can be bought “off the shelf” designed for a given heating and cooling load and can be installed by an HVAC installer. Unfortunately, only few companies offer this kind of pre-engineered system up to now.

- In particular, for southern European and Mediterranean areas, solar assisted cooling systems can lead to primary energy savings in the range of 40–50%. Related cost of saved primary energy lies at about 0.07 €/kWh for the most promising conditions.
- Small cooling capacities and tracking solar collectors increase the cost significantly.
- A simplified evaluation tool called "Easy Solar Cooling" was developed for assessing the cost performance of different technologies and system designs. The tool assists the user to identify the most promising technologies under different operating conditions and establishes the most preferable conditions. The tool (and other materials) can be downloaded under following link: http://www.solair-project.eu/218.0.html

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