Solar-Reports:

Solar-assisted heating and cooling of buildings: technology, markets and perspectives

by Björn Nienborg
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Even if the future still holds a few hurdles that will have to be overcome, developments in the field of solar-assisted heating and cooling show that solar air-conditioning is moving ahead. Thermal cooling has the further potential of increasing the utilisation of combined heat and power units (CHP). Another field of application that is currently being analysed is that of connecting to remote heating grids since these are often not fully utilised during summer. In the February 2010 Solar Report Björn Nienborg, scientist at the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg, provides an overview of the future perspectives of air-conditioning with solar heat in anticipation of the upcoming summer. But also in the extremely cold winter 2009 these contents may be of relevance, since the operation of a chiller as heat pump in winter can further increase the degree of utilisation of a solar heat system and its economic viability.
Solar-Report as PDF-Document

Photos: Single-family residential house in Alzenau, Germany. *Chiller: Sortech ACS08. Source of power: 24 m² of flat solar heat panels. Reverse chilling: dry reverse cycle chiller with fresh water spraying system (RCS 08). Cooling: cooling distribution through a central ventilation system with ceiling fans (fresh air cooling and forced air cooling). Planning & implementation: SolarNext AG / Rimsting (Germany)*

Growing energy demand for air-conditioning of buildings

Approximately 40% of energy consumption in Europe is utilised in buildings, just over half of this being consumed in private households [1]. The area-specific energy consumption for heating decreased over the last 20 years as a result of increased energy efficiency in the provision of heating as well as modern construction methods, but consumption for air-conditioning of buildings is strongly increasing. The reasons for this are the increased thermal loads in buildings caused by electrical devices, the increased expectations of comfort regarding the ambient climate, as well as the architectural trend to utilise more large light-transmissive surfaces. By 2020 it is anticipated that the number of electrical climate-controlling devices installed in European residential houses will increase annually by over 10% [2].

Air-conditioning with solar heat and solar power

On the basis of solar radiation and air-conditioning demand peaking at the same time, it is sensible to resort to solar cooling and thus to cover a considerable portion of the load with low emissions. In practice the following processes are applied:

- Solar collectors convert solar radiation to heat that is then fed into a thermally driven cooling process or into a direct air-conditioning process;
- Particularly in special applications, for example for cooling medication in remote areas that are not connected to the grid, a photovoltaic generator transforms solar radiation to solar power that then drives a refrigeration process – usually in the form of a compression chiller.

For cooling and climatising of buildings, only solar-*thermally* driven processes are used – this edition of the Solar Report will focus on these.

Photo: Climatisation of a building of the University of Sevilla. *Chiller: Double-stage BROAD BZH 15 IX, China. Source of power: 352 m2 linear-concentrated Fresnel collectors (Mirrox, Germany). Reverse chilling: Cooling tower. Cooling: cooling distribution through a central ventilation system. Photo source: Mirrox GmbH.*

Solar thermics save electricity and avoid CO2 emissions

In comparison to conventional, electrically driven compression cooling technology, solar cooling boasts a number of advantages. The machines generally utilise environmentally friendly refrigerants. In most cases water is utilised which, compared to refrigerants used in compression cooling machines, has no greenhouse potential (e.g. R134a: GWP=1300).

Because the systems merely provide auxiliary energy for the operation of pumps, reverse chilling, etc. they utilise significantly less power when adjusted correctly. Thus, besides the resulting CO2 savings, the electricity grid is also relieved – in some southern countries this constitutes a significant advantage, since the mass operation of electrical air-conditioners in summer occasionally leads to severe strain on the electricity grid. In addition to cooling, the solar collector system can also provide thermal energy to heat water and to support heating systems which in turn leads to a further reduction of emissions. Furthermore, noise emissions are significantly lower since the machines work without compressors.

Thermally driven chillers

The thermally driven cooling and air-conditioning process is at the heart of every solar cooling system. Thermally driven air-conditioning and cooling processes available on the market have in common that they utilise absorption and adsorption processes, the so-called desiccant evaporative cooling (DEC). A liquid or a gaseous substance either accumulates on the surface of a solid, porous substance (adsorption) or is taken up by a liquid or a solid substance (absorption). In some processes supply air is directly conditioned, i.e. treated in terms of temperature and humidity. Since this air is generally external air that is not recirculated, this process is referred to as open cycle. In a closed cycle, however, water that circulates in a closed hydraulic circuit is cooled.

Research is currently developing further technologies, e.g. steam jet chilling or thermally driven compressors, which will not be further discussed at this point.

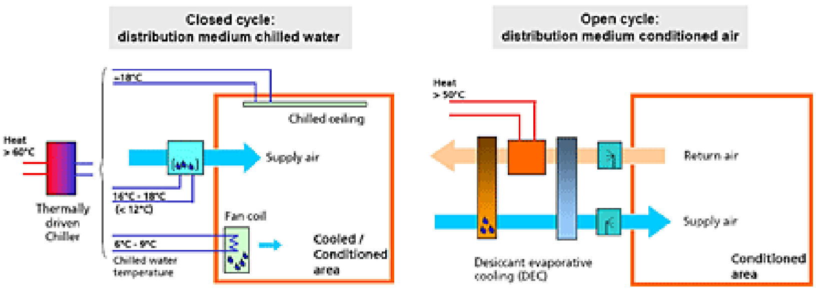

Image 1: Comparison of open-cycle and closed-cycle cooling systems; Source: Fraunhofer ISE

Open processes for buildings with high moisture loads and high air exchange rates

In these processes which are also referred to as desiccant evaporative cooling (DEC), outside air is dehumidified through sorption and is then brought to the desired temperature through heat recovery as well as direct and indirect evaporative cooling. Usually dehumidifying is achieved in a rotor containing the desiccant material silica gel or lithium chloride, but increasingly processes of liquid desiccants (desiccant material: lithium chloride) are becoming the focus of attention. Various companies are already offering this technology. Heat is required for the regeneration of the absorption/adsorption unit.

The use of open-cycle systems is promising in buildings with high humidity loads and high air exchange rates. The installation of a net for the supply air and the return air, as well as a heat recovery unit is required. In principle, the process can be combined with chilling water in a closed-cycle system (e.g. in order to remove sensitive loads from rooms through, for example, chilled ceilings).

Closed-cycle systems for chilling water

Closed-cycle desiccant evaporative cooling systems are based on the following desiccant processes:

- **ad**sorption: which works on the basis of solid desiccants. Customary material pairs are silica gel or zeolith as desiccant and water as refrigerant.
- **ab**sorption: here the desiccants are liquid. Commercially available machines utilise the material pairs of lithium bromide as desiccant and water as refrigerant, or water as desiccant and ammonium as refrigerant. With the latter material pair, temperatures of below 0°C can be achieved.

More information on closed-cycle and open-cycle processes can be found, for example, under [3], as well as in the directive on solar climatisation [6]. In the following we will be focussing on the systems for water chilling, i.e. on closed-system processes.

Lowering the system and operating costs by increasing the COP

The efficiency of thermal chillers is determined by way of the Coefficient of Performance (COP). Analogous to the energy efficiency ratio (EER) of electrical compression chillers this is defined by output over input, i.e. of cooling achieved in comparison to the heat required in the process. Typical values for single-stage machines range between 0.5 and 0.8. These values, however, cannot be compared to those achieved by compression chillers, since these are electrically powered. The COP strongly depends on the input temperature, the required temperature of the chilled water and the temperature of the cooling water in the reverse chilling cycle. In Image 2 it can be seen that an increase of the COP, which can achieved through more efficient technologies or technical measures on the operational side (e.g. through higher chilled water temperatures), leads to a decreased demand for solar process heat and thus also a decreased demand for reverse chilling. This has a positive effect on system and operating costs.

The technologies described have already been used for many years in the field of large-scale cooling (>100kW), thus numerous manufacturers are operating in the field. Small-scale machines (<20kW) have only recently become available on the market. Table 1 provides an overview of the nominal operating data. When making a product choice, it is essential that the framework conditions be taken into consideration and that the respective data be requested from other manufacturers when required.

Table 1: Overview of chillers with a nominal cooling output of below 20kW available on the market

Manufacturer	**Yazaki**	**EAW**	**Sortech**	**Pink**
Designation	WFC-SC5	Wegracal SE 15	ACS15	chillii PSC12
Technology	Absorption	Absorption	Adsorption	Absorption
Desiccant pair	LiBr/H2O	LiBr/H2O	Silikagel/H2O	H2O/NH3
Cooling output [kW]	17.5	15	15	12
COP	0,7	0.71	0.6	0.63
Hot-water temperature	88/83°C	90/80°C	72/65°C	75/68°C
Cooling water temperature	31/35°C	30/35°C	27/32°C	24/29°C
Cold water temperature	12.5/7°C	17/11°C	18/15°C	18/15°C
Electrical input required	48W (max. 72)	300W	14W	300W
Special characteristics			- WP-mode1	

Tabelle 1 (continuance): Overview of chillers with a nominal cooling output of below 20kW available on the market

Manufacturer	**ClimateWell**	**Invensor**	**Sortech**	**Invensor**
Designation	ClimateWell SolarChiller	HTC 10	ACS08	LTC 07
Technology	Absorption	Adsorption	Adsorption	Adsorption
Desiccant pair	LiCl/H2O	Zeolith/H2O	Silikagel/H2O	Zeolith/H2O
Cooling output [kW]	n/a	10	8	7
COP	n/a	0,5	0,6	0,54

Hot-water temperature	n/a	85/77°C	72/65°C	65/59,5°C
Cooling water temperature	n/a	27/33°C	27/32°C	27/31°C
Cold water temperature	n/a	18/15°C	18/15°C	18/15°C
Electrical input required	18W	20W	7W	20W
Special characteristics	-Internal chem. storage unit - WP-mode1		- WP-mode 1	

This list is not exhaustive.
1 WP= heat pump

Structure of solar cooling systems

The fundamental functioning of a solar cooling system is presented in Image 3. The collector field transforms solar radiation into heat with which the storage unit is then loaded. Upon demand this then supplies 'consumers' with energy: the desiccant cooling machines for cooling, the heating system as well as the water heating system. If solar heat is insufficient (e.g. on cloudy days, during winter) a conventional water heater can provide heat. For the system to work efficiently it is important to select suitable components, to install them adequately, to take them into operation and to implement a finely adjusted regulation concept.

Flat plate or vacuum tube collectors for different cooling processes

The efficiency of standard flat plate collectors rapidly decreases when temperatures increase. Thus they are mainly suitable for adsorption cooling machines that are reliable at relatively low temperatures (from 65°C) as well. All other cooling processes generally require input temperatures of over 75°C. These can be provided either by improved flat plate collectors (with anti-reflective coating and/or double glass) or by vacuum tube collectors. Generally, 3 to 5 square metres of collector surface are installed for every kilowatt of cooling output [3]. This surface area was surely calculated as a compromise between solar coverage on the one hand and a limitation of investment costs and minimisation of stagnation risk on the other hand. However, the exact size of a collector depends on its location as well as the load profiles of its application and would thus form part of system planning.

Partially contradictory requirements for storage units

The storage unit is the central interface of the system and must at times fulfil contradictory requirements. During cooling season it is to rapidly achieve the starting temperature of the cooling machine, in which case its small volume is of advantage. However, in order to ensure continuous operation even if clouds move by, large capacities are required – together with auxiliary heating. In addition it is to provide stable temperature coating regardless of high volume flows. Practice has shown that sizes of about 50 litres per square metre of installed collector surface are practicable.

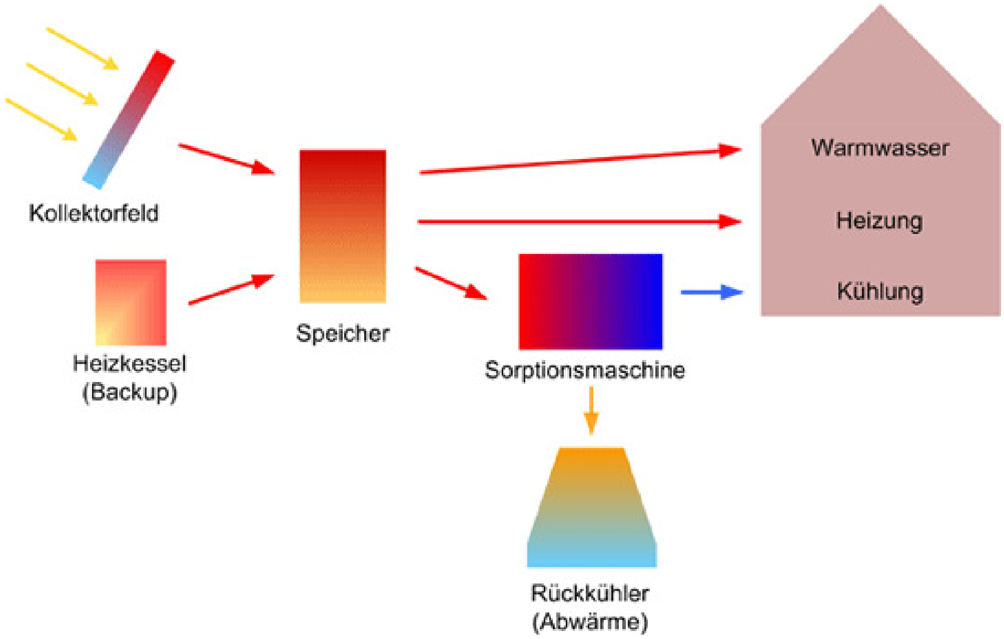

Image 3: Schematic presentation of the structure of a solar cooling system; Source: Fraunhofer ISE. Wording: Kollektorfeld: Solar thermal collectors; Heizkessel: Water heating system; Speicher: Storage unit; Sorptionsmaschine: Sorption chiller; Rückkühler: Reverse chiller; Warmwasser: Domestic hot water; Heizung: Heating; Kühlung: Cooling

Hybrid coolers or dry coolers with fresh water spraying systems combine the advantages of liquid and dry cooling

Reverse chilling greatly affects performance and efficiency of the chiller. In most systems the waste heat is passed into the environment through dry coolers or wet cooling towers. The former are suitable for moderate climate zones that only occasionally have high outside temperatures (>30°C). Wet reverse cycle chilling has the advantage that cooling water temperatures of below outside temperature can be obtained. However, it only works if relatively high humidity allows for evaporation cooling. In regions with a shortage of water it is also unsuitable. In addition, some countries have imposed strict hygiene regulations on wet cooling towers which make the operation of small systems economically unviable. Hybrid coolers or dry coolers with fresh water spraying systems combine the advantages of both technologies. All four technologies have in common that the ventilator constitutes an important part in the auxiliary energy demand of the system. Thus it is recommended to utilise efficient EC motors. To further reduce electricity consumption, these should be adjusted according to operating conditions and cooling demand. Depending on the respective local conditions waste heat can also be disposed of in other ways, e.g. through earth probes, swimming pools or borehole water. Ideally waste heat should be utilised in some way.

In the cold-water circuit of the cooling machine, high temperatures will benefit performance. Thus module activation and chilled ceilings are particularly suitable for distribution. When dealing with air-cooling, often higher temperatures can be used than in conventional climate technologies that usually utilise the 7/12°C split, which would also achieve a higher efficiency. For this purpose convectors would have to be of larger dimensions.

In order to keep the use of electrical auxiliary energy for pumps at a minimum, tube sections in all hydraulic circuits must adhere

to manufacturers' specifications. It is also recommended that high-efficiency pumps be used.

When selecting components, the component mix as well as their application must be considered. Furthermore, it is essential to be aware of the fact that surrounding conditions which deviate from the nominal conditions, can negatively affect the performance of the cooling machine. If the system is not adjusted to the nominal operation point, the relevant operating data must be obtained from the manufacturer. Then, for example, a dry reverse cycle chiller can also be used in warm climates if the solar thermal system is adapted accordingly.

Photos: Single-family residential home in Chiclana de la Frontera, Spain. *Cooling machine: ClimateWell 10. Source of power: 36 m² flat plate collectors. Reverse cycle cooling: swimming pool. Cooling: Distribution through chilled floors. Planning & implementation: "8'17".*

Load profile is essential for efficient solar cooling, additional benefits through the heating of water or heating support

The decision whether solar cooling is sensible at all is influenced strongly by the load profile. Radiation and cooling demand must be fine-tuned, since the use of fossil fuels for the operation of the cooling machine is disadvantageous from a primary energetic point of view and should be avoided. In order to achieve the highest possible solar degree of utilisation, applications that also require heat for heating water or for the heating system outside the cooling season are recommended. Thus residential buildings and small office buildings are most suitable. If cooling is required throughout the entire year (process chilling, server rooms) the solar cooling system can be used merely as a fuel-saver for conventional air-conditioning. In such a case free cooling directly through the reverse cycle chiller might be an option in the cooler seasons.

Market situation

So far as to the technological side – but what is the market potential like? In attempting to find an answer to this question, a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) was conducted within the framework of the EU project "SolarCombi+". In this study the position of solar cooling was investigated under technical, financial, market-related and legislative aspects [4].

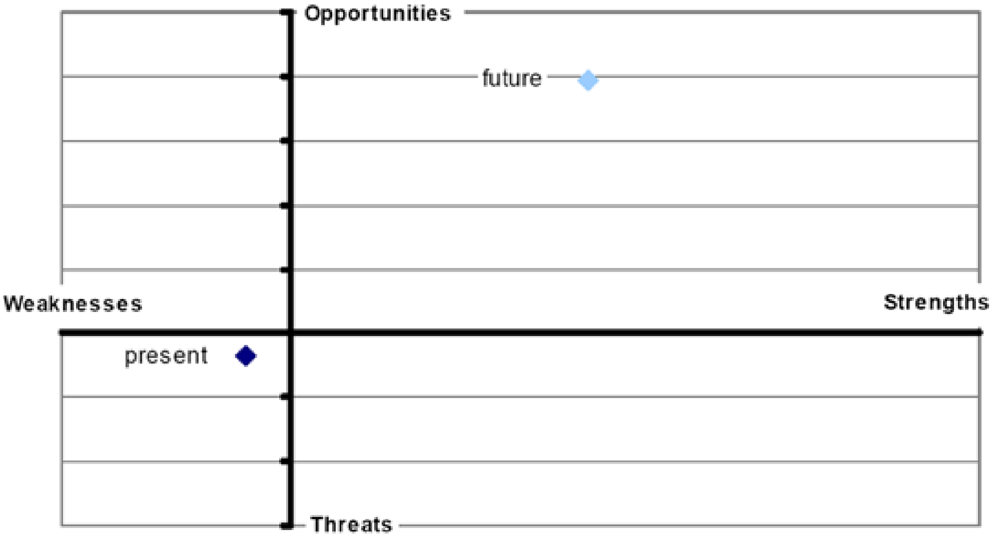

Image 4: Current and potential future position of SolarCombi+ systems in terms of the SWOT analysis; Source: SolarCombi+

Market introduction programme should compensate high investment costs

Currently some challenges still exist: the complexity of the system technology brings with it the risk of installation errors and faulty operation, the same applies to the fine-tuning of adjustments. In addition, a lack of knowledge on the side of planners has a negative impact. Because of the complexity and the fact that hardly any standard systems have been developed, systems are often individualised. This results in comparably high planning costs. In addition, investment costs of between 3.200 und 5.100 Euro per kilowatt of cooling output in small systems [5] are still high. Besides the required large collector surface, chillers contribute significantly to the high prices, the reason being that they are usually manufactured only in very small series. Initial costs thus play an important role, because so far no market introduction programme that supports the complete system exists for cooling as it does for renewable energy production (e.g. in the renewable energy production act in Germany). Furthermore, the technology is still largely unknown which causes the demand to be low.

In spite of the existing problems the future holds significant potential for solar air-conditioning. The target set at the Global Climate Conference in Copenhagen that global warming should not exceed 2°C, requires strong reductions of emissions – also in cooling, although the cooling demand is expected to rise. The increasing costs of fossil fuels further increase the relevance of lowered energy consumption and thus lower operating costs.

Manufacturers of cooling machines are aiming for mass production and pre-configured systems

Manufacturers of chillers are aiming at utilising this market opportunity. The Swedish company ClimateWell has recently erected a factory with a manufacturing capacity of up to 1 000 chillers per year in the Spanish town of Olvega. Sortech AG in Halle, Germany, is also in the process of changing to industrial series production. Furthermore, some companies are already offering preconfigured solar cooling kits (e.g. Solarnext AG, Solution Solartechnik GmbH). At the same time various companies are working together in national and international projects to develop and optimise such combined kit solutions. In the SolarCombi+ project an extensive simulation study was done in this regard. A database containing the results of the best configurations is available on the website of the project [6]. The low level of knowledge of such systems as well as the particularities of their structure are being addressed by way of specialised seminars for architects, planners and fitters. In particular, the EU project SOLAIR aims at filling knowledge gaps. In addition, the website contains among many other useful information a planning guideline for solar cooling systems in different languages at no cost [7].

International Solar Heating and Cooling Programme; "GreenChiller" association in Germany

With 52 companies and institutes from 11 countries worldwide the Task 38 "Solar Air-Conditioning and Refrigeration" is the largest association of actors from the field of solar cooling in the Solar Heating and Cooling Programme of the International Energy Agency (IEA) [8]. In their six-monthly meetings extensive exchange of experiences in the field of planning and operation of solar cooling systems takes place. The results of these activities are then included in a revised edition of the handbook for planners of solar-assisted cooling systems. Discussions are also held on strategies for and progress in the distribution of this technology, an area in which progress can be seen: in the German-speaking region seven companies and two research institutes have joined to form the GreenChiller e.V. association which is campaigning for political support [9]. In France, complete systems can be financed through state subsidies of up to 70% since the beginning of this year and also the costs for operation monitoring are covered for the first two years. In order to qualify for such subsidies, systems need to comply with various requirements, e.g. a feasibility study must forecast a specified minimum output of thermal energy [10].

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