Task 53

The Future of Solar Cooling

The increasing demand for refrigeration and air conditioning has led to a dramatic increase in peak electricity demand in many countries. With the increase in demand comes the increase in the cost of electricity and summer brownouts, which have been attributed to the large number of conventional air conditioning systems running on electricity. As the number of traditional vapor compression cooling machines grows (more than 100 million units sold in 2014) so do greenhouse gas emissions, both from direct leakage of high GWP refrigerant, such as HFCs, and from indirect emissions related to fossil fuel derived electricity consumption. An obvious counter to this trend is to use the same energy for generation of cooling that contributes to creating the cooling demand—solar energy.

The distinct advantage of cooling based on solar energy is the high coincidence of solar irradiation and cooling demand (i.e., the use of air conditioning is highest when sunlight is abundantly available). This coincidence reduces the need for energy storage, as the cooling produced from solar energy is almost immediately used.

While many professionals, such as architects and installers think of photovoltaic systems in combination with conventional vapor compression cooling machines as the most obvious solar option, the alternative option – solar thermal systems in combination with thermally driven sorption chillers are now a market ready technology.

▲ **Figure 1: Solar cooling state-of-the-art *(does not claim to be a complete list).***

Status of the Technology and Industry

The status of solar assisted cooling (SAC) technology is described below by looking at the technical maturity, energy and cost performance, and the status of market deployment.

Technical maturity

The key components of SAC systems are the solar collector subsystem and the thermally driven cooling subsystem. Additional components are a heat rejection unit to reject the waste heat from the thermally driven chiller and a thermal storage system (hot, cold) to manage the intermittent availability of the solar resource.

Solar collectors and solar collector systems are common and have achieved a good status of technical maturity. For SAC systems that operate with temperatures below approximately 110°C there exists a good supply of robust, cost effective solar collectors. In the last few years, some new concepts for solar collectors have been developed that lead to increased safety and enhanced solar collection efficiency. Examples of solar collectors operated with water, include drainback systems and night recirculation.

Solar collector systems for higher temperatures, which are needed for multi-stage absorption chillers and high temperature lift applications, are still scarce. However, there are an increasing number of manufacturers entering the market with new products – typically single-axis tracking with optical concentration.

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Large thermally driven chillers and open sorption cycles have existed for many decades and are established in the market. Their main operation today is with waste heat (e.g., from a co-generation system or industrial waste heat) or directly gas-fired. Typically, they are designed for operation to provide base load cooling and are not specially optimized for operation with intermittent solar energy. Good system design should enable relatively smooth thermal flows to the chiller.

In the last decade, progress was made in the field of small capacity thermally driven chillers (up to approximately 35 kWcold) and SAC has significantly contributed to stimulating this development. Today, numerous systems from various manufacturers are offered on the market and have reached considerable technical maturity. However, most of the manufacturers are small start-up companies. Some of these companies have set up manufacturing capacity on an industrial scale.

Installation of thermal buffer storage is quite common in SAC installations. Sizes range from small buffers, to overcome short-term fluctuations, up to large buffer stores used to save solar gains for a number of hours (e.g., from noon to afternoon). Storage can be applied on the hot and/or cold side and are usually filled with water. In a few applications, ice storage has been applied on the cold side in order to increase the storage density (in applications with cooling demand at temperatures below 0°C). Other phase change materials are still not common in solar cooling.

Energy performance

Solar cooling systems have been proven to save energy in comparison to conventional technology. The achieved energy savings strongly depend on system design and operation. Key factors that determine the achieved energy savings are 1) the solar fraction of the heat needed to drive the thermally driven cooling device and 2) the overall electricity demand for auxiliary components, such as the fans (e.g., the fan in the cooling tower) and the pumps in the hydraulic circuits.

The main requirements for achieving energy savings from a SAC system are:

- Keep the design as simple as possible in order to reduce risks of errors in implementation, operation, and maintenance.
- Carefully design and plan in order to define the optimal size of key components and an appropriate design fitting to the actual load profile, including strategies for efficient backup cooling when solar heat is not available.
- Auxiliary components (pumps and fans) should be highly energy-efficient.
- An operation and control strategy has to be developed that leads to energy-efficient operation under both full and part load conditions.
- A careful commissioning phase of the system is necessary to ensure system operation as planned. An ongoing monitoring ("continuous commissioning") program is also helpful in order to enable long-term operation at highest possible performance.

Economic viability and environmental benefits

As with other renewable energy systems, the first cost (investment cost including planning, assembly, construction and commissioning) of SAC systems is significantly higher than the corresponding cost of standard grid electricity based solutions. The first cost of realized SAC installations is between 2 and 5 times higher than a conventional state-of-the-art system depending on local conditions, building requirements, system size, and of course on the selected technical solution. In recent studies, first cost for total systems ranged from 2,000 per kWcold to 5,000 per kWcold and even higher in some particular cases. This large range is due to different sizes of systems, different technologies, different application sectors, and other boundary conditions.

A recent trend is the development of (solar) cooling kits – pre-engineered package solutions containing all of the main components of a system and where the components are well integrated with each other. These kits are mainly developed for small capacities, up to about 35 kW cooling capacity. Prices (excluding installation cost and distribution system to the building) for the package solutions dropped from about 6,000 per kW in 2007 to about 4,500 per kW in 2013.

The cost saving during operation very much depends on the boundary conditions. Boundary conditions that favor a short payback time are:

- High annual solar radiation leads to high gains of the solar system.
- A long cooling season leads to a large number of hours where the system is used.
- Other heat loads such as for sanitary hot water and/or process heating increase the usefulness of the solar system, particularly in the shoulder season where building heating and cooling loads are reduced.
- High prices of conventional energy make a solar alternative more competitive.

Looking at the overall life cycle cost of a SAC system (excluding any incentives or funds) in comparison to a conventional standard solution the situation looks much better than in the case of cost. Depending on the particular conditions SAC systems will in many

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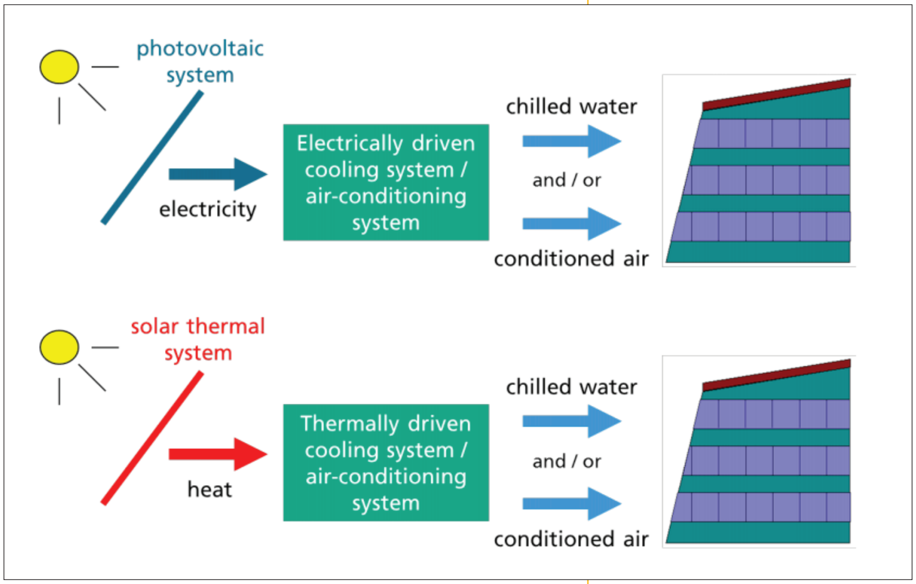
cases amortize within their lifetime. Under promising conditions payback times of ten years and less can be obtained. However, commercial companies often expect a payback time of five years or less in order to justify an investment. Such short payback times will only be achieved under very special conditions.

SAC applications have some other advantages that are often difficult to translate into an economic advantage, but are important for consideration by policy makers:



- SAC systems can contribute to reducing electricity infrastructure costs (and hence reduce electricity tariffs) in regions where a considerable share of peak electricity consumption from the grid is from air-conditioning with conventional techniques. Similarly, it may contribute to grid stability in regions where electricity infrastructure is insufficient to meet demand.
- Application of SAC systems may lead to (primary) energy savings and thus help to reduce the dependence of finite energy fuels, which have to be imported in many countries.
- Correspondingly, application of SAC systems will lead to reduced CO2 emissions and thereby contribute to a reduction of climate change and related effects.
- SAC systems using thermally driven cooling cycles show additional environmental benefits since they typically employ refrigerants with no ozone depletion potential and no or a very small global warming potential.
- SAC systems can be used also for all heating applications in a building or industry. The large solar collector field also provides heat for other purposes than cooling and thus helps to avoid consumption of fuel (or electricity) for heating applications.

Current Barriers

Currently, the main shortcoming of SAC from a technical perspective lies in system level integration. Many systems fail to achieve the planned energy savings because of shortcomings in proper design and energy management of systems that result in a high overall electricity consumption of auxiliary components. A particular area where mistakes are made is the heat rejection subsystem, which often has not received sufficient attention in the past. Another mistake made is that many systems were far too complex and as a result created non-optimal control and have required significant maintenance effort.

The second main shortcoming of SAC is the economics. The first cost of realized SAC installations is between 2 and 5 times higher than a conventional state-of-the-art system, and so must be reduced. The two major possibilities to overcome that barrier are 1) to focus on medium to large system sizes, which lead to economies of scale, and 2) to standardize as much as possible the systems to reduce on site efforts and risks. An important focus should also be on policy strategies that enable a cost reflective means of internalising electricity system costs into the upfront purchase price of solar cooling systems.

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Challenges for Solar Cooling

SAC technology is at a critical stage. Mature components are available and many installations have been realized. The technology has shown that significant energy savings are possible, and it has reached a level of early market deployment. However, the financial risk for parties involved in SAC business is still too high.

The following actions should lower this risk:

- Development of systematic quality assurance requirements and standards for SAC systems: Currently, there are no international ISO/EN standards or norms specifically relating to solar cooling. Such standards would help give users the necessary confidence in the level of energy savings and related cost savings. They could also provide a rigorous basis for allocating funding or tax credit schemes to stimulate market development
- Deployment of specific training for actors involved in SAC projects: most planners and installers have little experience with SAC technology and thus the effort – and related cost – to install those systems is higher than for standard systems.
- Implement industry development support schemes that provide like for like incentives to SAC technology as to solar PV, and additionally reflect the unique benefits of SAC to the electricity system: These support schemes would help to avoid perverse incentives in electricity system investment decisions. And it would help build the market to achieve economies of scale and a competitive supply chain.

Measures to support sustainable market development are most important. This includes establishment of large-scale demonstration programs with both 1) incentives and 2) quality assurance requirements that combine to encourage adoption and lower the risk.

These actions should be organized at regional and national level. They should be firstly promoted in regions in the World where cooling is an important issue (Middle East, South East of Asia, Sun Belt in the USA, Australia for example) and where environmental issues are a major concern (impact of pollution due to greenhouse gas emissions).

Quality procedures that cover all phases of a project are most critical in order to satisfy the expectations of all involved stakeholders. This work has been widely covered by the work of IEA SHC Task 48: Quality Assurance & Support Measures for Solar Cooling Systems of the IEA SHC Programme and these tools should be widely promoted and used in the next years.

This article was contributed by Daniel Mugnier, the Operating Agent for SHC Task 48: Quality Assurance & Support Measures for Solar Cooling Systems and SHC Task 53: New Generation Solar Cooling and Heating. For more information visit the IEA SHC website, www.iea-shc.org or contact Daniel Mugnier, daniel.mugnier@tecsol.fr.