SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 48

Task 48

Quality Assurance and Support Measures for Solar Cooling

Solar Cooling Position Paper

September 2015

Contents

This document was prepared by Daniel Mugnier, Operating Agent of *Task 48: Quality Assurance and Support Measures for Solar Cooling* of the IEA Solar Heating & Cooling Programme.

Solar Cooling – Position Paper

Aim of the Position Paper

The purpose of this document is to provide an inside view for energy policy makers to understand why and how solar cooling systems should be supported and promoted.

Executive Summary

Increasing demand for refrigeration and air conditioning has led to a dramatic increase in peak electricity demand in many countries. In addition to increasing cost of electricity, brownouts in summer have been attributed to the large number of conventional air conditioning systems running on electrical energy. The increasing use of vapor compression cooling machines (more than 100 million units sold per year in 2014) also leads to increased 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 possibility to counter 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 of using solar thermal systems in combination with thermally driven sorption chillers is now a market ready technology.

The IEA Solar Heating and Cooling Program (IEA SHC) provides an overview of the state-of-the-art of available technologies and markets. And, it identifies the barriers and remaining shortcomings and how to overcome them.

More than 1,200 cooling systems have been installed in recent years, based on solar thermal collectors and thermally driven chillers. And the interest in these products continues to increase. This is most evident where solar thermal collectors can be used for cooling in summer and for heating in winter. As high prices for (peak) electricity and more frequent electricity outages occur, the attractiveness of solar thermally driven cooling systems will continue to grow.

The components for solar thermally driven cooling have reached a high level of maturity. Instead, the main technical problems today lie at the system level in the proper design and operational control of fully integrated systems.

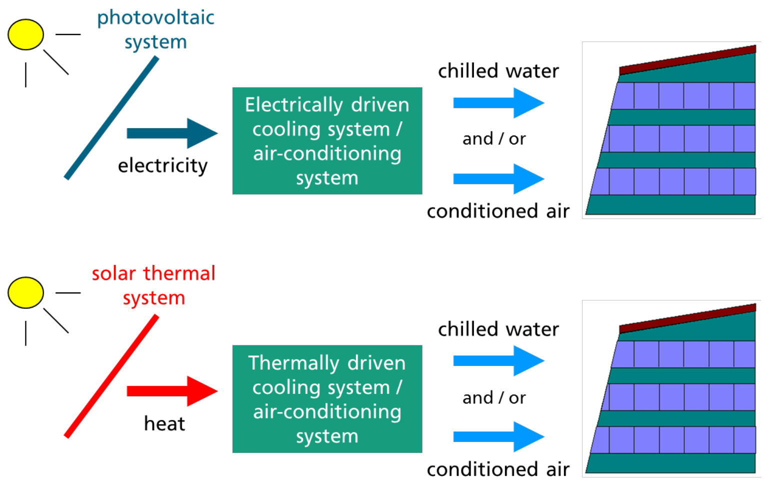
Both, public and private R&D efforts are needed to further improve solar thermally driven cooling at the system level. Research and development should focus on pre-engineered systems for the medium capacity range, which minimize design and planning effort, and the risk of installation errors. Specific focus on quality procedures for design, commissioning, monitoring and maintaining solar cooling systems, developed by SHC Task 48 experts, will enable a sustainable market for solar thermally driven cooling technologies to develop.

Unfortunately, economies of mass production have not yet been achieved for solar cooling. In order to fulfill it's environmental and electricity system cost reduction potential, solar cooling will likely require some form of Government policy support in the short term. Policy mechanisms should include both thermal (both heating and cooling) and electrical energy flows, so that solar heating and cooling can share support mechanisms with Solar PV on a level playing field basis. Regardless of the concrete support scheme (e.g., direct grants, tax incentives, minimum building renewable energy content), it is most important to avoid stop-and-go support, which usually hurts the market more than it helps.

Introduction and Relevance

Solar energy can be converted into cooling using two main principles:

- Electricity generated with photovoltaic modules can be converted into cooling using well-known refrigeration and air-conditioning technologies that are mainly based on vapor compression cycles.
- Heat generated with solar thermal collectors can be converted into cooling using thermally driven refrigeration or air-conditioning technologies. Most of these systems employ the physical phenomena of sorption in either an open or closed thermodynamic cycle. Other technologies, such as steam jet cycles or other cycles using a conversion of heat to mechanical energy and of mechanical energy to cooling are less significant.



Principles for solar driven cooling (source: Fraunhofer ISE)

Solar PV driven air conditioning (the first principle) is beginning to emerge through the small size segment (split air conditioners) in Asia. However, if such a system allows PV generated electricity to export to the grid then this would not normally be considered a "solar cooling system" since such a system is not materially different from most photovoltaic plants that are connected to the electric grid and are operated completely independent from the HVAC&R installation. Conversely, self-consumption-only solar PV driven air conditioning offers potential benefits to the electricity system and should be investigated further. This is particularly favorable in countries where photovoltaic system energy price is lower than the price that has to be paid for electricity from the grid.

Separately, SHC Task 48 focuses on the still more dominant technology for solar cooling in 2014, using the second principle – heat driven air-conditioning and refrigeration systems using solar thermal energy as the main driving energy.
The main arguments for solar assisted cooling (SAC) originate from both energy saving and electricity infrastructure cost saving perspectives:

- Application of SAC saves electricity and thus conventional primary energy sources.
- SAC also leads to a reduction of peak electricity demand, which is a benefit for the electricity network and could lead to additional cost savings of the most expensive peak electricity when applied on a broad scale.
- SAC technologies use environmentally sound materials that have no ozone depletion and no (or very small) global warming potential.

Other arguments originate from a more technical perspective:

- Solar energy is available almost at the same time as when cooling is needed, reducing the need for storage.
- Solar thermal systems used for production of sanitary hot water and heating (solar combi-systems) have large collector areas that are not fully used during summer. They can be used for SAC and thereby reduce risk of stagnation situations of the solar collector system.
- Comparatively low noise and vibration-free operation of thermally driven chillers.

After fifteen years of activity in the field of SAC, in particular within the IEA Solar Heating & Cooling Programme but also in many other national and European R&D projects, the market penetration of SAC remains small. Therefore, it is important to take a look at the achievements and the recent position of solar cooling technology. It is also important to understand the future prospects for this technology and formulate the needs related to both R&D and market stimulation in order to exploit its potential. It is also crucial to understand the potential for solar heating and cooling technologies (SHC) to contribute to the achievement of politically set targets for the reduction of energy consumption. The 20-20-20-targets of the European Commission are an example and it is important to identify the role of SHC within the suite of activities required to achieve these targets.

The following document describes the current position of solar cooling technology and develops an understanding of the potential and required actions.

Status of the Technology/Industry

The status of SAC technology is described 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 key 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, for 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.

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 kW_{cold}) 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.
- Careful design and planning is needed 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 kW_{cold} to 5,000 € per kW_{cold} 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; that are 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 in favor of a low 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 first cost. Depending on the particular conditions SAC systems will in many 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 and less in order to justify an investment. Such low values of payback time 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 may be important to be considered 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 CO_2 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.

Market status

Close to a 2,200 SAC plants have been installed worldwide in 2014, which cover all types of technologies and sizes. This is of course a very early market in comparison to the tens of millions of vapor-compression air-conditioning systems sold worldwide every year.

Recently, a number of large and very large installations have been built or are under development in the USA and Southeast Asia. And, even more importantly, a number of these projects have been completely driven by private investors without major incentives or funding programs to support them.

Some of these installations have been initiated in partnership with SAC RD&D activities, which has led to the establishment of a SAC community. An international bi-annual conference focusing on SAC R&D has held five conferences with a constant and dynamic number of participants and papers.

Today, there are still only a few companies that offer complete SAC solutions. Most systems are still composed of components or subsystems that are put together by a planning office for the particular project. There is still a great need for increased expertise and experience on the side of planners, installers, and other involved professionals.

Regarding the market for thermally driven chillers, a significant number of companies have been created in the last ten years that offer machines in the small capacity range (up to approximately 35 kW_{cold}). A significant increase in production rates can be expected with corresponding reductions in cost. These systems, which can be operated with relatively low driving temperatures, are not only operated in combination with solar thermal energy, but also as co-generation units (CHP), and in district heat networks and for industrial waste heat. Some of these companies have organized themselves into a worldwide association in the field of solar cooling and sorption chillers, the Green Chiller Association for Sorption Cooling in Germany, which promotes solar cooling and tri-generation.

Thus, the overall market for these thermally driven sorption chillers could be much larger than for solar cooling only. Today, there are mature products available and some first companies have started to establish a manufacturing capacity on an industrial scale. More companies will follow to enlarge the production capacity and thereby develop more automated production processes.

The next important step is to develop today's low volume market channels into a mass market and, at the same time, drive costs down further through standardization of concepts and design methods and development of reliable package solutions.

Potential

The potential for broader market penetration of SAC technology is composed of (1) further development of the technology in terms of improved performance, (2) reduction of cost and thus improvement of economic returns and (3) identifying preferred applications and business models for the market.

Technical potential

The potential on the technical level range from new and advanced materials through to improved components for more efficient and reliable systems.

The main ongoing R&D on the material level is aiming to improve materials for adsorption and absorption (tailor-made absorbents e.g., Ionic liquids) or absorption cycles and composites mainly using adsorption materials. These materials and compounds have the potential to allow for more compact systems with advanced heat and mass transfer and thus will lead to lowering the cost for installation and broadening the application range. Completely different solutions, such as new thermo-mechanical cycles, promising a significant increase in efficiency, are under development but have not yet left laboratory scale.

Work on components includes both advanced cooling cycles and advanced solar collectors, which are tailored to the needs of thermally driven cooling. Some important R&D activities addressing advanced components include:

- Integration of the generator of a thermally driven cooling machine in the solar collector with the aim of reducing heat transfer losses and creating more compact systems requiring less space in the plant room. Overall, such concepts aim at high efficiency and reduced system cost.
- Double-effect and triple-effect cycle absorption technology, which achieves high efficiency at high operation temperatures, will be extended also for the small capacity range and thus offer solutions with high overall efficiency for applications in the range of small capacity.
- Single-axis tracking and/or non-tracking evacuated solar thermal concentrating collectors to produce heat at temperatures in the range of 150°C to 250°C are still a rather new technology and important cost savings

may be achieved by developing advanced materials (e.g. for reflectors) and advanced production technologies.

- Non-tracking collectors have achieved a high level of technical maturity. However, improvements towards higher operation efficiency at temperatures of 80°C to 110°C are still possible and advanced production technologies will allow for reduction of cost.

Important work on the system level is required in order to achieve more reliable systems and high quality in the whole delivery chain of projects ranging from design, planning, construction, and assembly to operation. This work includes measures such as training and education to increase knowledge and experience among professionals active in design and installation of HVAC systems. Task 48 has done a lot on the R&D side on these quality topics, including design reports on heat rejection, pumps, innovative collectors, fast design software tool, LCA analysis tool, overall economic assessment tool, self-detection procedures, incentive schemes review as well as monitoring guidelines.

Costs and economics

On the component level, the main cost reductions are particularly expected to be for small capacity thermally driven sorption cooling machines. Both technology improvements and mass production on an industrial scale will certainly lead to a lower cost for this key component. In principle, a noticeable potential also exists for cost reduction of solar thermal collectors. However, prices of solar thermal collectors have remained almost static over the last decade, which is mainly due to unstable market development and market policies.

Another major component is the heat rejection unit. Today, units mainly exist in the large capacity range. The development of heat rejection systems specially designed for use in SAC will lead to reduced component cost, in particular for small capacity units (e.g., below 100 kW of cooling power).

On the system level two main market areas have to be distinguished:

- *Pre-engineered systems*. Pre-fabricated standard packages will be developed mainly for applications in the small capacity range, such as residential buildings and small commercial applications. This pre-fabrication minimizes the effort on both the planning construction side, which also leads to minimized risk of errors in assembly and installation. A significant cost reduction of these pre-fabricated systems (kits) has already been observed and will certainly continue to take place with growing markets.
- *Custom-made systems*. For large buildings and industrial applications, custom-made systems will remain the appropriate approach. Cost reductions on the system level are also expected for custom-made systems with increased design and construction experience.

Increased experience among involved professionals is an important need. Guidelines and software tools for the design and layout of systems will help to reduce the effort during design and planning. In particular, standardized measures to assure a high quality of installations is required in order to increase the certainty of energy savings and related operation cost savings.

As pointed out in the introduction, systems using electrically driven vapor compression cycles combined with photovoltaic systems may be an alternative for using solar energy for air-conditioning or refrigeration, particularly for small scale systems. Photovoltaic modules have experienced a continuous cost reduction resulting from a growing market over the last two decades. Under today's price conditions both solar solutions, that is a solar thermally driven heating and cooling system compared to a conventional heating and cooling system plus a photovoltaic system, lead to a similar economic performance, if no funds or incentive are taken into consideration. Therefore, a decision on the one or the other alternative has to be made based on local conditions, requirements and incentives.

Incentives have the potential to achieve perverse outcomes. For example, when an attractive feed-in tariff for electricity produced by photovoltaic systems exists, the most probable outcome will be in favor of a solar photovoltaic-only system exporting all electricity into the grid, and operating completely separate from any heating and cooling system. Unfortunately, this will lead to an increased share of electricity production from fluctuating renewable sources on the grid with potential stability issues. Some jurisdictions are already experiencing grid level problems and are restricting the amount of PV that can be installed in sections of the grid, a problem that could be avoided by a self-consumption solar air conditioning system. Incentive programs that apply rebates evenly to both thermal (heating and cooling) and electrical energy flows, is preferred so that solar thermal and electrical technologies can be treated on a level playing field basis.

It is difficult to assess which of the two main solar driven heating and cooling solutions – thermal driven or electricity driven – will be more competitive under such conditions. Obviously, the thermally driven system always provides a local system solution and thus will always lead to a reduced dependence on conventional energy and never have a negative impact on the grid. Also, the low cost of thermal energy storage compared to electrical storage is in favor of thermally driven cooling systems from a system integration point of view.

Market opportunities

Generally speaking, the most favorable conditions for successful market implementation of SAC systems are:

- Applications with a high need for heating and cooling (and sanitary hot water).
- Places with high solar energy resource.
- Conditions characterized by a high coincidence of loads and solar gains since this reduces the need for storage.
- Places with high cost of conventional energy.

A major obstacle is that in many of the places that fulfill the above requirements, there is no or very little experience with solar energy use, and often HVAC and refrigeration installations are of a comparatively low standard. Nevertheless, under such conditions the best economic performance can be expected. Companies that offer overall solutions and have the capability to provide maintenance services (e.g., using remote control approaches) will be able to exploit this market opportunity.

A major argument for the installation of SAC systems is their environmental soundness due to reduced consumption of conventional energy and employment of environmentally friendly refrigerants. This can be an important argument for an investor even if the system is not yet economically competitive, that is the return on investment is above the normal expectations for commercial investments.

More specifically, market opportunities are seen in the following:

- *Tertiary buildings, such as office buildings and hotels, in regions with sufficient solar gains*. Typical applications will involve technologies employing non-tracking solar collectors and the solar system will be used for heating, cooling and sanitary hot water (if needed).
- *Production in sunny regions that need cooling for industrial processes (e.g., in the food industry).* Depending on the required temperature level of the cooling process either non-tracking solar collectors or single-axis tracking solar collector technologies will be employed. Large factory roofs can serve to place the collectors but also systems installed on the ground will be usual, in particular in areas where ground is not a limiting resource.
- *In sunny regions in particular, a potential exists for application of SAC in residential houses*. Heating and cooling solutions making use of solar thermal energy for single family houses as well as for multi-family houses are particularly interesting in new buildings and in combination with highly energy efficient buildings that allow for radiative solutions (e.g., using the floor and/or the ceiling for heating/cooling). High domestic hot water requirements in residential applications provide year round high utilization of solar thermal energy.

Overall, renewable energy will play an increasingly important role in future energy systems due to the strong need to limit CO_2 emissions originating from conventional energy sources. SAC technology is one of the important solutions applicable on the demand side. Thus, this technology provides a market opportunity for many involved stakeholders, including building owners, planners, manufacturers and installation companies.

Current Barriers

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, which results in a high overall electricity consumption of auxiliary components. A particular area where mistakes are made is the heat rejection subsystem, which in the past has often not received sufficient attention. Another mistake made is that many systems are far too complex and as a result create non-optimal control and require significant maintenance.

The main problem areas, observed from practical experience with installations, are:

- Heat rejection: cooling towers often need too much electricity and are not controlled for part load. Small capacity wet cooling towers are relatively expensive and need an inappropriate high effort for maintenance. Dry cooling towers need more electricity and often the re-cooling temperatures are too high for the solar thermally driven chillers. Hybrid systems (dry/wet) seem to be a promising solution, but very few systems are available on the market and they are not optimized for combination with thermally driven chillers.

- High efficiency auxiliary components and careful hydraulic design are essential. This is particularly important, as solar cooling systems need more hydraulic loops than standard solutions.
- Another technical barrier concerns the integration of all components into a complete system. The overall system design requires various professional skills for the different subsystems – solar energy at medium temperature (higher than that used for standard sanitary hot water application), hydraulics with pressurized and medium temperature water, and air-conditioning or industrial cooling.

The second main shortcoming of SAC already identified in this paper 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 this 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 internalizing electricity system costs into the upfront purchase price of solar cooling systems.

Actions Needed

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 the 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 the regional and national level. They should first be promoted in regions in the world where cooling is an important issue (Middle East, Southeast Asia, Sun Belt in the USA, and 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 and these tools should be widely promoted and used in the next years.