Status and Prospects for Solar Cooling in Australia

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ABSTRACT

There has been a strong interest developing for solar cooling in Australia and this is leading to an increasing number of commercial solar cooling installations. It is timely to review the environment in which an emerging solar cooling industry must operate. This review begins with a look at world leading commercial and research activities in Europe and the benchmarking thus provided. A local context is then presented and this provides guidance for the growth of an Australian solar cooling industry.

The unique range of climates in Australia, the lack of design experience and the high cost currently provide market barriers to solar cooling. However, the worldwide deployed volume of systems is very low. Nevertheless, new performance metrics and targets are being proposed in the form of an Australian Standard.

An update on local activity is provided including industry coordination work through The Australian Solar Cooling Interest Group (AusSCIG), research activities and direction, local program funding and a review of local installations.

Keywords:* *Air-Conditioning, Solar Cooling

1. INTRODUCTION

The concept of a cooling system driven by solar heat has some appeal due to the causal relationship between solar radiation and cooling demand in buildings.

However, the installed capacity of solar cooling is limited to several thousand systems, predominantly in Europe. Experience with these systems has shown that the capital costs are high due to the requirement for a large solar collector. This experience and reputation has diffused to Australia and indeed there are only a dozen or so systems installed locally. Solar availability in Australia is nearly twice that of Europe and cooling demand in the majority of populated centres is moderate. Thus solar cooling could be well suited to Australian conditions and one might reasonably expect that there is a good opportunity for Australia to lead the world in implementation of solar cooling.

In this paper, a comparison is drawn between solar cooling activities in Europe and these in Australia. It is intended to both provide a review and propose some future directions for solar cooling in Australia.

2. THE INTERNATIONAL CONTEXT

In Europe a number of seminal programs have been completed over the last eight years. Their main objectives were to investigate the advantages of solar cooling and to provide guidelines for the design of solar cooling plants in practice.

The most significant program in the solar cooling context is the International Energy Agency (IEA) Solar Heating and Cooling Program. Within this program are a number of tasks. Initially, Task 25 □Solar-Assisted Air-Conditioning of Buildings□ ran from 1999 until 2004 and involved members from 10 countries (International Energy Agency Solar Heating and Cooling Project (IEA-SHC) 2011a). As a result of this project an free online design tool (SOLAC) was produced, which was available until October 2009, and a handbook for planners was published (Henning 2007). Task 38 □Solar Air-Conditioning and Refrigeration□ succeeded Task 25 from 2006 until 2010. Participants from 11 countries including Australia worked on the design of state-of-the-art small-scale applications, large scale custom-designed applications, system modelling and market analysis. Several reports of the different task groups are available online (International Energy Agency Solar Heating and Cooling Project (IEA-SHC) 2011b). An updated edition of the handbook for planners can be expected by the end of 2011. Also an online software tool (Tecsol 2011)was developed for rapid assessment of commercial solar cooling projects. This year, Task 48 □Quality Assurance and Support Measures for Solar Cooling□ was started and clearly now the focus of the IEA program is moving towards addressing commercial aspects of solar cooling. Again, Australia is represented in the Task workgroup (International Energy Agency Solar Heating and Cooling Project (IEA-SHC) 2011c).

Apart from IEA activities, some projects have been funded through the 5th and 6th Framework Programme of the European Commission. The focus of these programs is commercial readiness, demonstration systems and case studies.

- SACE (Solar Air Conditioning in Europe), 2002-2003 with the objective to investigate the market potential of solar air conditioning. Results were published through a set of guidelines for each solar cooling technology and supported by a number of case studies (SOLAIR 2011a) .
- ROCOCO (Reduction of Costs of Solar Cooling), 2004-2006 with the goal to identify the cost reduction potential of solar cooling systems in Europe. Participants were mainly industry start-ups and program funding was □500,000 (ROCOCO - Reduction of costs of Solar Cooling Systems 2008)
- REACt (Renewable Energy Air Conditioning), 2005-2010. Self-sufficient renewable energy air-conditioning systems for Mediterranean countries. Heating and cooling demonstration systems were installed in Morocco and Jordan (REACt 2011).
- MEDISCO (MEDiterranean food and agro Industry applications of Solar Cooling technologies), 2006-2009. Develop, test and optimize solar thermally driven cooling concepts in the food and agricultural industry (MEDISCO 2011).

The European Commission also supported an organisation called Intelligent Energy Europe also funded several solar cooling projects including:

- SOLCO (Solar Cooling), 2007 □ 2009 aimed to identify and remove the non-technological barriers to solar cooling technologies across southern European islands (SOLCO 2011).

- SOLAIR (Solar Air Conditioning), 2007 □ 2009, promoting the market implementation of small and medium scale solar air-conditioning applications in the residential and commercial sector. Among the outcomes are a best practice catalogue and guidelines for the design (SOLAIR 2011b).
- SOLAR COMBI+, 2007 □ 2010 was the promotion of standard system configurations for combined domestic hot water heating, space heating and space cooling systems up to 20kW. Solar cooling was provided by absorption chillers. Program funding was about □970,000 (Solarcombi+ 2011).

Across all the projects, the high capital cost of solar cooling has been apparent. This is mainly driven by the cost of the solar collectors, somewhat accentuated by the low annual solar radiation. The solar collector cost is typically 30-50% of the total investment for a solar cooling system.

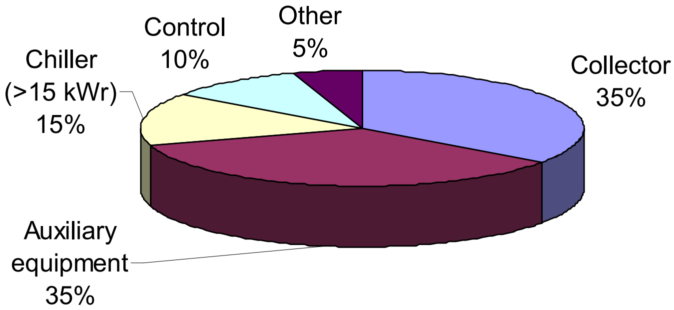

Figure 1 shows typical cost distributions for small and medium size solar cooling systems with absorption chillers larger than 15 kW_r. For domestic systems, the chillers are usually smaller than 15kW_r and the cost proportion can reach up to 30%.

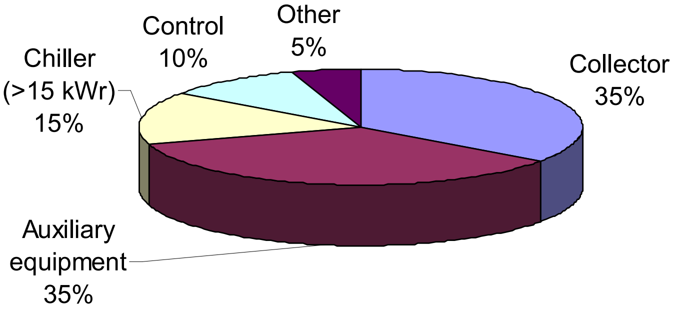

Figure 1: Investment cost distribution for chillers > 15 kW_r, (ROCOCO - Reduction of costs of Solar Cooling Systems 2008).

It is important to mention that thermal air conditioning is not restricted only to solar heat. Other sources can be utilized for example waste heat from tri- or co-generation power plants or geothermal heat. However, it is crucial for the cost-effectiveness of thermal cooling applications that the driving heat is of no extra cost, to keep the cost of operation low.

Worldwide, the installed capacity of solar cooling systems is less than 100 MW with approximately 600 solar cooling systems were expected to be installed by 2010, mainly in Europe. Around 85% of these system use Adsorption or Absorption chillers to generate chilled water (Mugnier 2011), the balance being solid or liquid desiccant systems. Most installations are commercial applications, e.g. office buildings, hotels or hospitals. Only 28% of all installations reported in 2009 were installations in the domestic sector (Sparber, Napolitano et al. 2009).

There has been some effort by solar cooling businesses to produce residential solar cooling systems in the form of kits. In this way, the complication of system design and integration is pre-packaged and therefore simple to install. Nonetheless, the cost of these systems is still high and they have not proved popular for this reason. In many cases, condenser cooling is achieved with water.

It would be reasonable to suggest that the European Union leads the push for solar cooling with well coordinated, well funded and highly participatory projects. Australian practitioners have been able to learn from these valuable programs but a local program would be beneficial to review the outcomes in an Australian context. A further missing element in the European programs is an examination of the potential for energy storage to make solar cooling both more effective and lower cost. This could be particularly relevant to Australia in the context of alleviating peak electricity grid demand from air conditioning.

3. AUSTRALIAN CONTEXT

3.1 Climate

In Australia, annual solar irradiance typically exceeds 2000 kWh/m^2-a with a high proportion of direct beam radiation (Figure 3). This is about twice as much radiation as in many countries in Europe. Furthermore, most of the local population lives in a mild coastal climate and this is reflected in the cooling demand, represented by cooling degree days (**Figure 3**). Thus, there is good potential for solar cooling to be practical in Australia. Nevertheless, passive cooling and demand reduction are valid techniques and should be considered before solar cooling (or any active cooling) is implemented.

Perhaps the most difficult climatic challenge is the variety of climates ranging from dry and hot to sub-tropical and humid.

The climatic context should also be considered in terms of the quality of the building stock. The right combination of climate and building structure provides the opportunity to support passive cooling through natural ventilation and diurnal temperature variation. In Australia, building thermal performance is poor and imposes a high cooling demand relative to the climate, compared to Europe. Although improved thermal performance is mandated in new housing, old housing stock will take a number of decades to turn over to improved energy efficiency. There is also good potential for cooling by natural ventilation since most of the population lives in coastal areas where sea breezes or night cooling are often available.

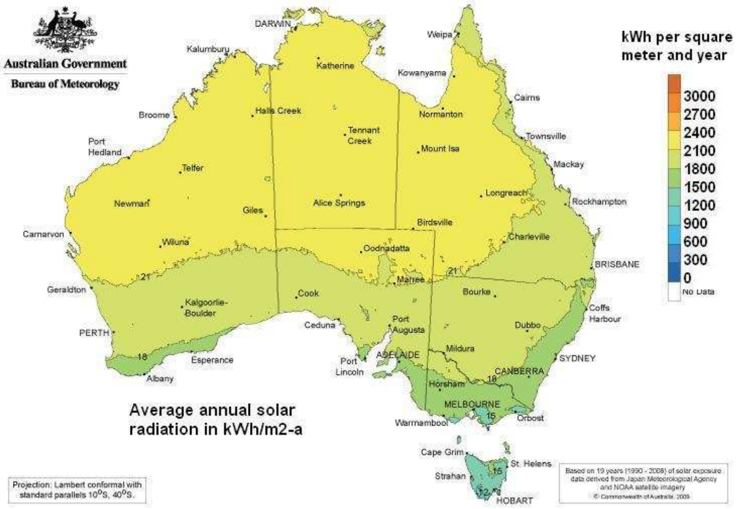

Figure 2: Average annual solar irradiation in kWh/m^2-a (Bureau of Meteorology (BOM))

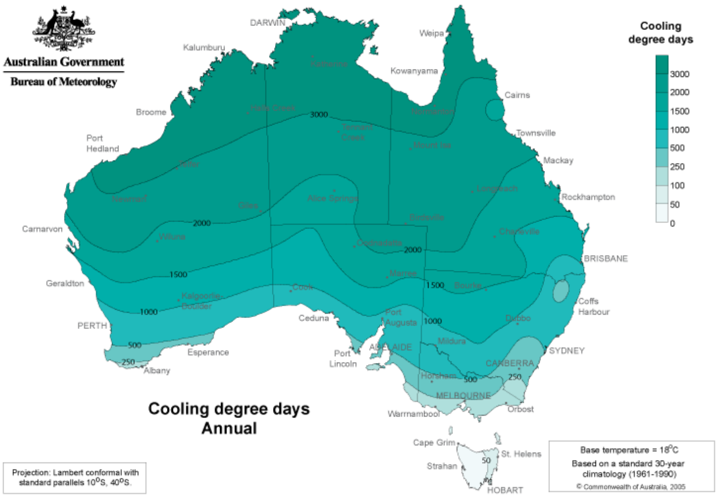

Figure 3: Cooling degree days in Australia, (Bureau of Meteorology (BOM))

3.2 Barriers to Growth in Solar Cooling in Australia

The main impediment to widespread uptake of solar cooling is the high capital cost relative to cheap electric and gas driven heat pumps. This high cost is largely driven by the cost of the solar collector. Furthermore, the cost of electricity is relatively low in conventional air conditioning systems. Solar cooling systems show a cost reduction over the life of the system and this advantage is likely to increase with volume production, transparent pricing for peak electricity and pricing for carbon emissions.

A second barrier is that no solar cooling technologies are produced locally. Most of the components have to be imported with varying quality of local support and knowledge. This leads on difficulties in the design and system integration of solar cooling installations. Neither engineers nor tradespeople have specific experience in solar cooling although this is being incorporated into TAFE programs of late.

For any emerging technology, it is important to establish codes of practice and standards associated with the use of that technology. For solar cooling systems, there is currently no Australian standard, although one is now being developed as an extension to AS4234 for solar water heater performance.

3.3 Demonstration Systems

There are only a few systems installed in Australia (Table 1). The systems consist of either parabolic trough collectors or evacuated tube collectors combined with an imported absorption chiller.

Information from these initial installations has been freely shared by the Engineering consultants responsible for the projects. In some of the early installations, they reported difficulties in designing the system, delays in installation and cost overruns. More recently, the projects rapidly adopted knowledge from previous projects and total project costs are approaching $4/kWr. This is already much less than costs in Europe. Furthermore, the specific cooling cost is also low due to the higher solar collector yield in Australia, even without subsidies for solar cooling.

Table 1: Installed solar cooling systems in Australia

Location	*Year*	*Capacity*	*Collector*
Brisbane, QLD (Hospital)	2007	290 kW$_r$ Absorber	570 m^2 Parabolic Trough
Padstow, NSW (Air-Cond.)	2008	175 kW$_r$ Absorber	165 m^2 Parabolic Trough
Wyong, NSW (Air-Cond.)	2009	7 kW$_r$ Absorber	20 m^2 Evacuated Tubes
Charlestown, NSW (Cinema)	2010	230 kW$_r$ Absorber	350 m^2 Parabolic Trough
Newcastle, NSW	2007	18 kW$_r$ Absorber	50 m^2 Parabolic Trough
Echuca, VIC (Hospital)	2011	500 kW$_r$ Absorber	442 m^2 Evacuated tubes
Araluen, NT (Art Gallery)	2010	230 kW$_r$ Absorber	450 m^2 Parabolic Trough

3.4 Industry Standards and Performance Measurement

Although solar cooling is included into the European □Thermal solar systems and components□standards (European Committee for Standardization 2011), there are only standards for some solar cooling components in Australia (e.g. solar collectors and storage tanks). A standards development process for solar cooling systems has only started this year in Australia. The aim of the new standard is to describe a methodology by which the energy and greenhouse gas savings from a solar cooling system might be determined. The methodology adopts the principles of AS4234 for solar water heaters, using TRNSYS thermal modelling software to predict system performance. The standards development process is expected to be complete in late 2012.

In this way, a rebate scheme might be supported for solar cooling systems in the future.

The performance metrics of direct energy saving and greenhouse gas saving are of primary importance for solar cooling. These relate to the system effectiveness. It is important to note that performance metrics for solar cooling should focus on annual aggregated cooling performance rather than instantaneous Coefficient of Performance (COP) since the operating and environmental conditions vary throughout the year.

Further performance metrics might also be developed. These metrics could consist of an environmental index, a financial index and possibly of a human comfort index incorporating the effects of the building structure.

The environmental index might account for the green house gas emission over the life cycle and the water consumption. The TEWI is a well accepted measure to account for direct and indirect GHG emissions (Fischer 1993). The indirect GHG emissions are due to electricity or gas consumption for backup solutions or parasitic energy consumption (pumps, fans etc.). The direct GHG emissions are due to the global warming potential of the refrigerant used and are determined by leaking rate and recycling rate. The GHG emissions factors vary through out the states of Australia and therefore the GHG saving potential of solar cooling applications is also different in each state. The impact of water consumption is also very much related to the location since some areas in Australia suffer from water scarcity especially in summer.

The financial index must take into account the levelised cost of cooling over the life time. To allow solar cooling applications to become financially competitive with conventional air conditioners and generate electricity savings, European case studies indicate that they have to be carefully designed, controlled and installed.

The building structure plays an important role in solar cooling effectiveness, since the building thermal response to a climate provides a time offset between peak solar radiation and peak requirement for indoor cooling. The building fabric also allows some opportunity for storage of cooling effect. Therefore, in system without additional air conditioning back up, a factor to describe the thermal comfort should be included in the performance measure.

3.5 Peak Industry Bodies

As solar cooling industry per se does not currently exist in Australia and in the long term, there is no need for a specific solar cooling industry. However, in the short term, it is necessary to establish solar cooling as a mature and viable proposition.

One major initiative is the establishment of a peak body to coordinate the emerging industry. The Australian Solar Cooling Interest Group (AusSCIG) was established in 2008 and currently has about 200 members. The membership is well balanced between engineering consultants, practitioners, policy makers, researchers and architects. The group is active in policy development, road mapping, standards development, outreach activities and in attracting industry funding.

AusSCIG is associated with the Australian peak body for air conditioning, refrigeration and heating (AIRAH) and the International Institute of Refrigeration (IIR). Thus AusSCIG has a direct communication path to the entire air conditioning industry. AusSCIG and AIRAH are active peak bodies and are well respected.

In the longer term, solar cooling should become another energy efficiency technology option for the existing industry to offer to customers as standard practice and indeed there should be no long term need for a specific industry or peak body for solar cooling.

3.6 Policy Support

The Australian federal government has progressed sporadically in its support for solar energy over the last decade. State governments have also supported a range of initiatives although there are no federal or state programs that specifically encourage solar cooling systems.

The most significant federal program is the Mandatory Renewable Energy Target (MRET) which mandates energy retailers to provide a proportion of their electricity from renewable sources by surrender of certificates. Since this program has a focus on renewable electricity, solar cooling systems are not eligible to participate.

Recently, a cost on greenhouse gas emissions has been proposed. This is expected to come into force in July 2012. Income from a carbon tax will be used to support a number of initiatives to move Australia to a reduced carbon intensity economy.

Within the framework of the Renewable Energy Target, the $5 billion Clean Energy Initiative (CEI) will support research and development of renewable energy and clean energy technologies.

- Clean Technology Innovation Program ($200M) support for research, development and commercialisation of new low pollution products, processes and services.
- Clean Technology Investment Program ($800M) helping industry to invest in energy efficiency and low pollution technologies, processes and products.
- Clean Technology Food Processing Investment Program ($150M) - helping the trade-exposed food processing industry to invest in energy efficiency and low pollution technologies, processes and products.
- Clean Technology Focus for Supply Chain Programs ($5M) -
- Support for Small Business Grants of $6500 for investment in energy efficiency

Unfortunately the programs within the scheme focus mainly on large scale electricity generation or carbon capture and storage.

Until recently, initiatives such as the Solar Flagships program and the Australian Solar Institute have exclusively funded solar electricity production. The potential solar cooling can provide in the context of electricity grid stability has been neglected.

The Clean Energy Initiative provides greater scope for solar cooling. The membership of AusSCIG must raise awareness of the capabilities of solar cooling to government and the public, in particular its value in mitigating peak electricity demand in summer, thereby mitigating expensive electricity infrastructure upgrades and helping to stabilise electricity charges (Department of Resources, 2011).

There is an opportunity through the Clean Energy Initiative to support a local solar cooling program through AusSCIG in a similar manner to the European programs. Such a program might incorporate building local research capacity, disseminating local case studies, producing design guides, running a local conference and supporting a full time program coordinator.

3.7 Research Directions for Solar Cooling in Australia

There is not a great deal of solar cooling research in Australia.

- Research activities in Australia focus mainly on residential systems. The CSIRO in Newcastle continues to develop a small-scale desiccant system and operates an advanced solar cooling test facility which is available to industry (CSIRO 2011) .
- The Australian National University is working on improvements to ejector solar cooling technology and is developing a cold storage system using gas hydrates (CSIRO 2011; Dennis 2011).

- The University of South Australia has developed a liquid desiccant system to be tested in a home in 2012 (Sustainable Energy Centre 2011).

There are persistent technical issues relating to poor thermal efficiency of solar cooling machines at standard conditions which have not been overcome despite a volume of research effort. This leads to the requirement of a large solar collector which increases the capital cost per unit of cooling and also the roof area necessary to host the collectors. Engineers must therefore use intelligent design and system integration to overcome the performance limitations relative to conventional air conditioners and such approaches now coming out of research efforts appear to be attractive.

A promising solution is to design hybrid solar thermal systems whereby the solar collector is more fully utilised. In such a configuration, the same collector is used for winter space heating and year round water heating, thereby significantly increasing the value of the solar collectors. Little research has been done on this concept in the Australian climate, although the European Solar Combi+ program has developed designs for European climates.

System integration with solar cooling is difficult. Although handbooks exist, industry experience with designing and installing these systems is limited. The design is complicated somewhat by poorly defined load characteristics and the lack of a minimum performance standard. However, there is a rich and available set of case studies and design guides available from Europe that are directly relevant to Australia and indeed the practicality and cost of solar cooling machines continues to improve by demonstration.

In the Australian context, condenser cooling using water is likely to be replaced with air cooling. In the local climate, ambient summer temperatures extremes further reduce solar cooling performance (as with any heat pump) and require a very large condensor. An emerging technology to improve dry re-cooling efficiency is the integration of a condenser heat store. Such a device ((Rodriguez 2009)) is designed in a way that condenser heat is stored during the day and released overnight. By morning, the condenser heat store is at a temperature much lower than the peak ambient temperature range of the day, thereby accentuating the solar cooling system performance. This technology is particularly promising to the areas with large diurnal temperature swing.

Since there is a time delay between peak solar cooling capacity and peak cooling demand due to the building thermal response, it is desirable for a solar cooling system to have cold storage. Properly sized, this would also enable solar cooling to have effect into the evening and cover periods of solar intermittency. Ice or low-temperature chilled water storage are commonly used for this purpose although undesirable due to their detrimental effect of chiller thermal efficiency. Properly sized cold storage could benefit annual solar cooling yield (Dennis and Garzoli 2010), making investment in solar cooling economically more attractive. An ideal device would use phase change material that operates at close to evaporating temperature of the cooling device with a large enthalpy of fusion. Research has been conducted on various materials such as paraffin wax, salt hydrates, and gas-hydrates, while the industry is still yet to see any commercialised product.

Storage of high temperature heat at around 100°C to drive a solar cooling system is less attractive since the storage losses will be high relative to storing cold, but sorption chillers require stable operating conditions and so this is a requirement for solar cooling systems using sorption technology to ensure stable operation of the generator.

Finally, there have been preliminary investigations into photovoltaic powered conventional heat pumps as a solar cooling solution. A study done in 2010 (Kohlenbach, 2010) suggests that lifecycle costs of solar thermal cooling and solar electric cooling were similar for direct cooling only. However, thermally driven systems are more adept to storage and hybridisation and are thus likely to be more attractive in a real scenario.

4. FUTURE STRATEGY

The establishment and growth of a local solar cooling industry has value to Australia in that it can:

1. Reduce greenhouse gas emissions associated with building space conditioning and water heating
2. Reduce peak electricity grid loading
3. Create local employment

Peak bodies currently exist for solar cooling, air conditioning and water heating and so it would seem that coordinating the growth of solar cooling is in hand. By funding permanent position(s) in AusSCIG, a local solar cooling program could be developed with the aim of □localising□the outcomes of the European programs. This would be a logical extension of the existing activities of AusSCIG and would be a key enabling strategy for solar cooling in Australia.

In addition to the existing AusSCIG programs previously noted, the following new initiatives would be desirable:

- Identification of appropriate niches for solar cooling
- Identifications of the most appropriate system configurations for local conditions
- Production of case studies from local demonstration sites, featuring key performance metrics relating to cost, peak electricity and greenhouse gases.
- Research activity in system integration and energy storage

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