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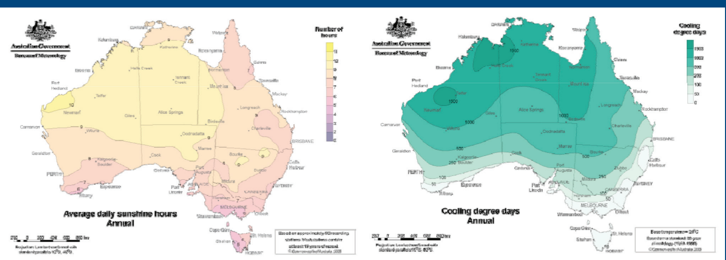
SOLAR AIR CONDITIONING: OPPORTUNITIES AND OBSTACLES IN AUSTRALIA



Warwick Johnston
The George Alexander Foundation/
ISS Institute Fellowship

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1. Executive Summary

What is Solar Air Conditioning?

Solar air conditioning is the application of solar thermal energy (heat) to production of conditioned air through a thermally-driven refrigeration process.

Why is Solar Air Conditioning Useful *and* Necessary for Australia?

Australia has a very sunny climate, with high demand for air conditioning. Air conditioning's impacts upon the electricity network and the environment threaten to affect our quality of life. On hot summer's days, the electricity grid increasingly faces the danger of overload due to air conditioner use, which would cause essential service disruption and severe economic impact. Associated with air conditioning's high use of energy is significant environmental pollution, namely in the form of greenhouse gas emissions – with the resultant climate change impacting not only upon our environment, but also our health and productivity.

Of the many ways of individually addressing air conditioning's impact upon the grid and environment, solar air conditioning (SAC or solar cooling) is one of the few solutions that provides cooling *and* addresses peak loading, and does so with reduced environmental impact.

Solar Air Conditioning Fellowship and Investigative Study

At present, there exists little awareness or understanding of solar air conditioning within Australia. A fellowship was undertaken to address solar cooling related skills deficiencies, with the intention of raising awareness, developing understanding, and providing a framework for a future Australian solar air conditioning market. This report forms one such dissemination activity.

Benefits of Solar Air Conditioning

The fellowship resulted in the understanding that solar air conditioning:

- can contribute to Australia's cooling requirements
- can also provide heating of living areas and domestic hot water
- can alleviate pressure upon the electricity network
- can provide environmental benefits
- can address the particularly high cooling demand of existing building stock
- can already be applied to commercial buildings and industrial applications, and will soon be readily applied to residential buildings
- has already successfully demonstrated itself in Europe, the USA, and Asia
- presents interesting opportunities of note to Australia
  - Application of rejected heat to swimming pools
  - Incorporation of biomass or cogeneration to deliver greenhouse gas-minimal operation
- holds particular promise in tropical environments, and therefore presents a domestic and export opportunity

Barriers to Implementation

There are barriers to be overcome if solar cooling is to live up to its market potential and supply a significant part of Australia's cooling and heating needs. The barriers relate to ignorance, market factors, social factors, buildings' characteristics, and environmental impact. However, the largest barrier at present is economic. Although a simple comparison of SAC and conventional A/C system prices is complex to perform, the economics of solar cooling are generally unfavourable when compared to conventional cooling systems. This is due to:

- Cost of solar collector
- System complexity
- Low energy prices in Australia because of cheap fossil fuel and unaccounted environmental costs
- Cross-subsidy for air conditioning, by which all energy users pay for electrical network infrastructure required to satisfy installation of new air conditioners, with a 2kW$_e$ air conditioner, which may cost $1000, requiring $6000 of infrastructure
- Lack of economic reward for producing or reducing energy during times of peak load
- Lock of incentive for building owners to install energy efficient equipment in leased buildings

Overcoming Barriers

Many of the aforementioned economic barriers are also faced in Europe, and are presently being addressed through research, development, and demonstration systems. However, addressing the market-related barriers requires some governmental intervention. The following measures improve the economic viability of solar air conditioners:

- To reduce collector costs, increased production volumes can be stimulated by further subsidies
- To simplify system design, standardised modules are being produced
- Cross-subsidies could be addressed by making air conditioner buyers pay the costs of infrastructure upgrades thus necessitated by their air conditioner use
- The peak load effect would be reduced by passing on peak costs to the user (interval metering), thereby also encouraging uptake of alternate cooling measures
- Building owners could be encouraged to install energy efficient systems by providing a market recognition mechanism such as an 'energy passport'
- Environmental costs that are presently excluded from energy prices could be addressed through a carbon tax or trading mechanism

Such measures would benefit solar cooling, as well as other Australian industries, particularly those related to sustainability in cities.

Table of Contents

2. Introduction

Solar air conditioning has the potential to address many of the problems caused by conventional air conditioning. Solar air conditioning has significant technical potential in Australia' sunny climate. However, there exists little understanding of solar air conditioning in Australia.

The author undertook a fellowship intended to bridge Australia's skills deficiency in solar air conditioning. This comprised an international tour in which solar air conditioning experts were consulted. Subsequently this report was written, as part of dissemination activities aimed at bridging the skills deficiency. Further activities intended to raise awareness of solar air conditioning will follow the report.

This report describes the fellowship, identifying the particular solar cooling related skills deficiencies known to exist.

It then proceeds to introduce solar air conditioning, examining why solar cooling is desirable for Australia, and outlining some of the challenges solar cooling faces if it is to live up to its potential.

Solar cooling is then described in brief technical detail, and applicable market sectors and opportunities evaluated.

The Australian and International contexts for solar air conditioning are presented, so that the Australian solar cooling market may be evaluated by interested parties within Australia and internationally. Factors including climate, air conditioning, electricity supply structure, buildings, public awareness, governance and knowledge are considered. Institutions active in solar cooling and related industries in the studied countries are presented.

The market analysis culminates in an assessment of the key issues and barriers facing solar cooling in Australia and worldwide. Technical, knowledge, environmental, market-based, social, buildings, and economics related barriers are analysed, and alternate solutions to solar cooling compared. Unique opportunities in the Australian market are presented.

The report concludes with recommendations of how the Australian solar cooling industry may be advanced by addressing market-related barriers, and a course of action for development of the local market is presented for industry actors. This encompasses recommendations to the industry, professional associations, government, education and training sectors, community, and the ISS.

The attachments include more detailed technical description of solar cooling enabling technologies, and material that addresses the identified skills deficiencies.

In this manner, this report achieves its aim of raising awareness of solar cooling and its potential in Australia, developing understanding of how solar air conditioning is achieved, identifying how an Australian solar cooling industry may be established, and bridging skills deficiencies to assist in this process.

3. Acknowledgements

3.1. Awarding Body - ISS Institute

We know that Australia's economic future is reliant upon high level skills and knowledge, underpinned by design and innovation.

Since 1989, International Specialised Skills Institute Inc (ISS Institute), an independent, national organisation, has provided opportunities for Australian industry and commerce to gain best-in-the-world skills and experience in traditional and leading-edge technology, design, innovation and management.

Carolynne Bourne AM, ISS Institute, CEO, uses her formula to illustrate the links, **skills + knowledge + good design + innovation + communication = competitive edge • good business**

Based on ISS Institute's initial market research in 1990, an important category emerged, that of 'skill deficiency'.

Skill deficiency is where a demand for labour has not been recognised and where accredited courses are not available through Australian higher education institutions. This demand is met where skills and knowledge are acquired on-the job, gleaned from published material, or from working and/or study overseas. This is the key area targeted by ISS Institute.

Other ISS definitions are:

- **Skill shortage** is when there is an unmet and recognised demand for labour.
- **Innovation** is creating and meeting new needs with new technical and design styles. [New realities of lifestyle.]
- **Design** is problem solving. From concept to production through to recycling. Design involves every aspect from the way the receptionist answers the phone, when invoices are sent out, where a machine sits on the factory floor, what trees are grown in the forest suitable for furniture or flooring, to whether the product is orange or blue, round or square, flat packed for export, displayed in a retail outlet and the market research to target customers' needs and wants - creating products or services.

Overseas Skill Acquisition Plan (Fellowship Program)

Skill deficiencies are filled by building global partnerships through ISS Institute's **Overseas Skill Acquisition Plan - Fellowship Program**. Australian Fellows travel overseas, or overseas Fellows travel to Australia.

Upon their return to Australia, Fellows pass on what they have learnt through education and training activities such as workshops, conferences, lectures, forums, seminars and events developed and implemented by ISS Institute, therein ensuring that for each Fellowship, many benefit - the multiplier effect.

ISS undertakes research, marketing, policy and advocacy.

The findings from the Fellows reports and those acquired through ISS Institute's research and education and training activities are made available to firms, industry, commerce, learning institutions and public authorities through ISS Research Institute's consultancy services – again, the multiplier effect.

ISS Institute operations are directed towards bringing skills (traditional and leading-edge technologies) and knowledge to Australian industries, education and government and, in turn, the community in general - new ways of thinking, new ways of working so as to create innovative products and services for local and global markets.

ISS Institute's holistic approach works across occupations and industry sectors and builds bridges along the way. The result has been highly effective in the creation of new business, the development of existing business and the return of lost skills and knowledge to the Australian workforce, thus creating jobs - whereby individuals gain; industry and business gain; the Australian community gains economically, educationally and culturally.

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3.2. Fellowship Sponsors

The George Alexander Foundation supports activities in the following two areas:

Education

- to help talented young people achieve their full potential in any endeavour
- to support programs designed to improve educational, employment and leadership opportunities for disadvantaged young people

Environment & Conservation

- to develop partnerships with communities, government and the private sector to prevent irreversible damage to the environment and to encourage the maintenance of biodiversity

I would like to thank the George Alexander Foundation for providing funding support for this fellowship.

In addition, I wish to thank my employer, Going Solar, for allowing me time to study and promote solar air conditioning, for their financial support of this pursuit, and for the opportunity to apply this knowledge in innovative projects.

3.3. Fellowship Supporters

The following people were key representatives of solar cooling at the organisations I visited in the overseas component of the fellowship, to whom I extend my deepest gratitude.

Representative	Organisation
Dr. Hans Martin-Henning	Fraunhofer-Institut für Solare Energiesysteme
Prof. Dr. Uwe Franzke	Institut für Luft- und Kältetechnik
Dr. Tim Selke	Arsenal Research
Roland Heinzen	Institut für thermische Energietechnik, Universität Kassel
Ursula Eicker	Fachhochschule Stuttgart
Raoul von der Heydt	Phoenix Sonnenwärmemeag
Eberhärd Lävemann	Bavarian Centre for Applied Energy Research, ZAE Bayern
Prof. Gershon Grossman	Energy Engineering Research Center, Israel Institute of Technology
Jesus Castro	Heat and Mass Transfer Technological Center, Universitat Politècnica Catalunya
Matthias Peltzer	L-DCS (Germany)
Michael Hinterbrander	L-DCS (Singapore)
Xabier Gorritxategi	Rotartica SA
Horst Streissnig	S.O.L.I.D

Walter Mittelbach	Sortech
Laura Siso	Aiguasol
Mattis Baumann	Conergy

Table 1 : Fellowship Supporters

In addition, the following people have assisted the solar air conditioning study, to whom I also extend my thanks.

Person	**Organisation**
Keith Baker	Australian Greenhouse Office
Dr Keith Lovegrove	Centre for Sustainable Energy Systems, Australian National University
Jenniy Gregory	Australian Business Council for Sustainable Energy
Michael Russell	Australian Business Council for Sustainable Energy
Terry Jones	Division of Energy Technology, CSIRO
Prof. Wasim Saman	University of South Australia
Dr. Michael Krause	University of South Australia
Alan Pears	Sustainable Solutions
Jeff Robinson	Connell Wagner
Christian Langen	Conergy
Peter Szental	Szencorp
Ken Guthrie	Sustainability Victoria
Sean McKinnon	Energy Control Systems
Craig Morgan	Hydro Tasmania
Paul Kohlenbach	CSIRO Energy Technology
Chris Bales	Solar Energy Research Centre, Dalarna University
Anthony Calderone	
Warwick Barnes	Air Solutions
Jordi Cadafalch	Heat and Mass Transfer Technological Center Universitat Politècnica Catalunya
Fred Kohl	Solitem
Joe Coventry	Australian National University
Per Olofsson	ClimateWell
Rakel Loubet	Rotartica
Inigo Aldekoa	Rotartica
Maider Usabiaga	Ikerlan
Dr. Tomas Nunez	Fraunhofer ISE
Edo Wiemken	Fraunhofer ISE
Dr. Joerg Waschull	ILK Dresden
Dr. Bodo Burandt	ILK Dresden
Dr. Uli Jakob	FHS Stuttgart
Dietrich Schneider	FHS Stuttgart
Dr. Jürgen Schumacher	FHS Stuttgart
Dr. Khaled Gommed	Technion
Dr. Dietrich Schmidt	Fraunhofer IB

Table 2 : Fellowship Assistants

4. The Fellowship Program

4.1. Fellowship Aim

The aim of the fellowship is to gain knowledge and understanding of solar air conditioning technology and applications, benefits, and limitations. With limited Australian experience in solar air conditioning, an international study tour was undertaken to address knowledge deficiencies. Prior to departure and upon return, interested parties in Australia were contacted for discussion, which assisted in shaping views of the Australian market.

The fellowship also aims to disseminate accumulated knowledge to interested parties within Australia. This report is one such dissemination action; the dissemination activities will also include articles in the press and seminars, as appropriate. It is intended that the fellowship assists in developing the solar air conditioning market in Australia, and makes a contribution to the network of solar air conditioning professionals internationally.

4.2. The Skills / Knowledge Gaps

The knowledge gaps regarding solar air conditioning within Australia are fairly broad. Most people tend to think of a photovoltaic (solar electric) panel linked to a conventional air conditioner when they first hear the words ‘solar air conditioning’. Few people are aware of the potential of solar thermal energy to provide space heating, space cooling, or even to generate electricity.

The skills required to design and implement a solar air conditioning system are also generally absent within Australia, chiefly because there is only one operational solar air conditioning system in Australia, installed in recent months. Most related knowledge is concentrated in the minds of a few key academics within Australia; one must typically look abroad for assistance with solar air conditioning system design. Internationally, there are few, if any, solar air conditioning systems that have been commercialised which could be applied off the shelf.

There is no opportunity to learn such information within Australia without studying a PhD, a process which delivers expert knowledge about a specific system and technology, but does not realistically allow the specification of a commercially applicable system.

The skills deficiencies are:

System Sizing and Engineering

Understanding the quantity of solar energy required to produce the desired cooling output, matched to building requirements, and ability to match with appropriately sized cooling device and storage vessel.

System Integration

Understanding the optimisation process of controlling the sub-system interactions in a simple manner without overcomplicating system control.

Technology Application Evaluation

Understanding the complexity of applying solar thermal energy to water heating, space heating, and space cooling.

Technology Choice Evaluation

Understanding the process of selection of appropriate cooling technology (absorption, adsorption, desiccant) for particular applications.

System Performance Comparison

Understanding how to technically compare system performance specification across applications and technologies. Research of performance and economic metrics used to justify inclusion in building projects.

Residential Application Issues

Technical and market related issues surrounding miniaturisation and mass-production to provide units suitable for residential application.

Market Comparison

Method of assessing the European market, including climate and technology, in order to appraise Australian market.

Combi-Systems

Understanding the additional complexities in designing space cooling and water heating (combi) systems.

These knowledge gaps are addressed in Section 11.2

4.3. Fellowship Methodology

The fellowship programme addressed the skills deficiencies through visits to selected educational institutions, applied research centres and product developers across the range of solar air conditioning's existing technologies and future directions.

Australia has a reasonable foundation in solar thermal energy and thermally driven chillers, pre-requisites for implementation of solar cooling systems. Harvesting and utilising solar thermal energy is generally well understood, although there are specifics associated with large collector arrays that require further experience. The operation of absorption chillers, adsorption chillers, and desiccant wheels is also thermodynamically understood, although there is not presently a significant Australian installation base of such products. Knowledge deficiencies were the target of the fellowship; in solar air conditioning these relate to system design and control, new technology developments, and market-related issues.

From a systems-level perspective, there is little Australian awareness of issues relating to the application of solar thermal energy to a thermally driven heat process. This includes the low-temperature and variability of supplied heat. Visits were made to institutions with experience in system control and operation to discuss such issues.

Also at the systems level, there is little understanding in Australia about how to successfully custom-design a solar cooling system to meet a building's specific cooling requirements. Visits were made to institutions with experience in system design to discuss such issues.

New developments in solar-compatible chillers, particularly those applicable to residences, are of interest to Australia. The requirements of a residential chiller are different to that of commercial chiller, and solar home cooling systems differ from systems suitable to commercial premises. Visits were made to product developers to discuss the barriers to residential application, their impact upon product design, and how they were being addressed.

Each cooling enabling technology is best suited to different applications and climatic conditions. The fellowship aimed to evaluate and compare each cooling technology for application in Australia. Visits were made to developers of absorption, adsorption, and desiccant coolers, and technology variations within each category were examined.

Market conditions impact upon solar cooling systems' configuration and viability. To assess market influence, barriers, and opportunities, visits included a strong emphasis on market considerations, particularly when meeting with commercial organisations. This fellowship component assisted in cross-comparison of the Australian and International markets.

To understand how the international solar cooling market development has occurred, interviews included discussion on programmes of international cooperation, so that best practises may be replicated in Australia. This will assist in accelerating the development of a local market.

Further details of visits made under the fellowship programme are presented in Section 8.2.

4.4. About the Fellow

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Contact	c/o International Specialised Skills Institute Inc Suite 101, 685 Burke Road Camberwell 3204 AUSTRALIA T +61 3 9882 0055 F +61 3 9882 9866 E issi.ceo@pacific.net.au
Positions Held	Project Development Engineer, Going Solar, 2005-present R&D Engineer, Redfern Broadband Networks, 2002-2004
Qualifications	Bachelor of Engineering (Computer) (Hons), Univ. of Melbourne, 2001 Bachelor of Science (Computer) (Hons), Univ. of Melbourne, 2001 Certificate in Green Building Design, RMIT Centre for Design, 2006
Memberships	State Treasurer, Australian & New Zealand Solar Energy Society Member of the International Solar Energy Society Member of the Alternative Technology Association
Awards	George Alexander Foundation/ISS Institute Fellowship Deans Honours, Engineering

Warwick's passion for nature, along with engineering aptitude and communication skills, found application in his position of Project Development Engineer at one of Australia's longest established solar energy and sustainable living companies, Going Solar. There Warwick has been responsible for the development of projects incorporating innovative aspects of renewable energy and sustainability, including such applications as PV, solar hot water, solar space heating, passive building design, rainwater harvesting, and system monitoring. In expression of a strong motivation to make a positive impact upon the world, Warwick has designed Australia's first solar powered freeway noise barrier, largest BIPV façade, and conducted a feasibility study for the incorporation of renewable energy into tsunami reconstruction efforts in the Maldives on behalf of the British Red Cross.

A fellowship from the George Alexander Foundation and ISS Institute has seen Warwick placed amongst Australia's top specialists in the field of solar air conditioning, and developed valuable ability to assess potential technologies in new markets.

Warwick's background includes a strong foundation in communications, through journalism and customer service, and excellence in applied technical engineering. His contribution to society has also included voluntary computer skills training for refugees and the underprivileged.

Warwick's other interests are travel, photography, surfing, cycling, camping, and the arts.

5. Air Conditioning Problems in Australia – a Solar Solution?

5.1. Air Conditioning Problems

Air conditioning is increasingly impacting upon the electricity grid and environment in ways recognised to be highly problematic. Large energy consumption associated with air conditioner use on hot days stretches the grid capacity to its limits, and blackouts are occurring with greater frequency. As the rate of air conditioner installation increases, so too does the impact upon climate change, reinforcing the public's demand for indoor climate control systems. As such, problems associated with air conditioner use need to be addressed in order to preserve energy security and our global environment.

Air conditioners are big consumers of electricity. An air conditioning unit able to cool the average family home consumes many kilowatts of electrical energy. When many households in a region run their air conditioner concurrently, as tends to happen on hot days, the demands placed on electricity generation lead to a scenario known as 'peak-load'. The peak load may be many times the base generation load and requires rapid response, on-demand generators, which charge high rates at peak times in order to recoup investment costs.

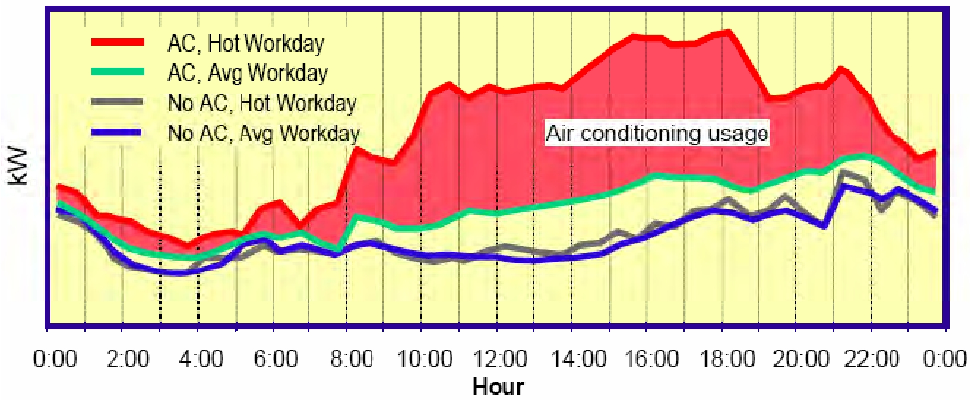


Figure 1 : Air Conditioner Contribution to Peak Load[1]

In Australia, peak load is increasing significantly faster than base load[2], largely the result of air conditioners. This is driven by an increasing penetration of air conditioners into new and existing houses nationwide (see Figure 2) as the population's wealth increases, a phenomenon not confined to the northern latitudes. People's comfort demand is also increasing, as air conditioning is no longer regarded as a luxury but an essential. Coupled with this is an increased frequency of air conditioner use as global warming increases average and peak outdoor temperatures.

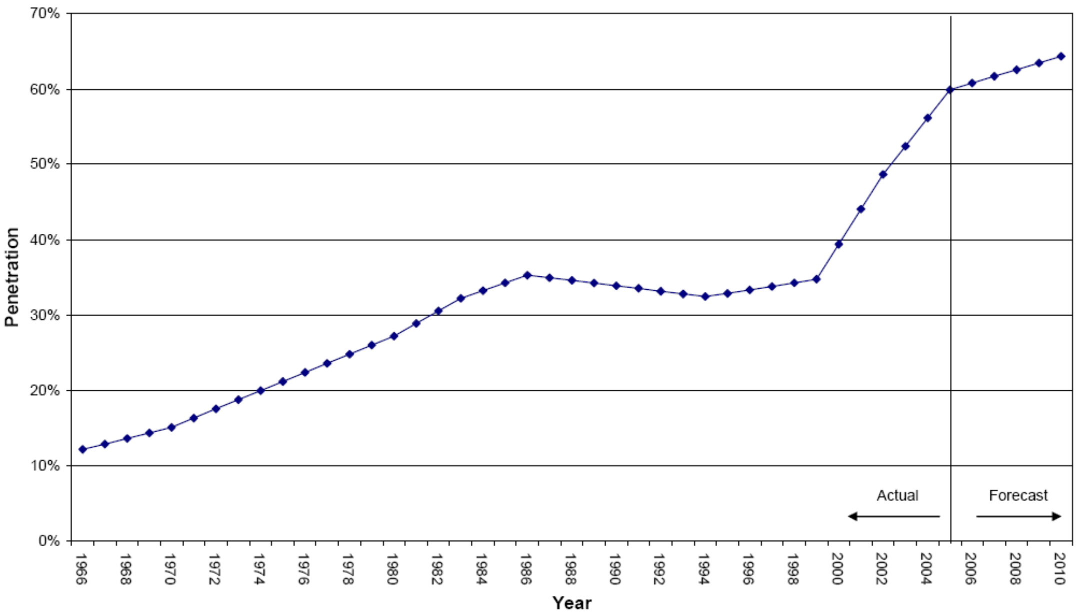


Figure 2 : National Penetration of Air Conditioners by Year[3]

This scenario places significant strain on the electricity network. Supplying ever-increasing peak load requires the installation of more and more generating infrastructure, at great cost. If the electricity supply does not meet demand, then grid failures result. This is expensive in terms of network damage, lost revenue, lost productivity, loss of essential services, and possibly even heat-related deaths. To recoup the costs, wholesale electricity prices at times of peak load are often hundreds of times more expensive than base load electricity prices[4]. This cost, borne by the energy retailer, is amortised over every retail customer, so as an increasing amount of energy use occurs during peak periods, the average cost of electricity rises[5]. As such, every householder pays for the infrastructure costs associated with air conditioners, regardless of whether they use an air conditioner or not. In effect, non-air conditioned households are paying a $70 P/A cross-subsidy to those that operate air conditioners[6]. The 'peak oil' phenomenon[i] will only act to increase electricity prices, making air conditioner operation an increasingly expensive exercise for every consumer. Taxpayers also foot the cost of subsidies given to companies in the energy supply chain, in addition to the currently unaccounted for environmental externalities.

Electricity supply in Australia is associated with large amounts of greenhouse gas (GHG) emission. Australia's per-capita GHG intensity is the highest in the world[7], in part due to our reliance on coal. Therefore, beyond increasing power stations' sulphur and particulate emissions, air conditioner use is contributing to climate change, with predictions of dire impact upon rainfall, drought, the land and oceans, biodiversity, public health, insurance, the economy, and business. The refrigerants used in air conditioners are many times more greenhouse-intensive than CO_2, and although careful steps are taken to minimise their release into the atmosphere, leakage in production, handling, and decommissioning grows inevitably as air conditioner sales rise. Add into this mix the incentive for privately-owned peak-electricity generators to quickly recoup costs and maximise profits by increasing their energy sales, and air conditioning is begetting a hot climate for the world.

[i] Only loosely correlated with stationary energy prices

In the Business Roundtable on Climate Change, leaders in big businesses including BP, Visy, and Westpac[8] concluded that climate change presented a significant threat to the economic sustainability of our nation, and that actions should be taken immediately. One such action is to provide climatisation by alternate means to conventional air conditioning. In many places in Australia, passive means can significantly reduce or avoid altogether the amount of air conditioning required. However, in certain climates, and in particular building types or site locations that don't favour passive cooling, active cooling is necessary. Green building regulations are having some effect upon the energy performance of new buildings, but much needs to be done additionally to address the large energy requirements of existing building stock, which tends to perform poorly.

Therefore, bearing in mind the ever-increasing impact of air conditioning on the electricity grid, generating infrastructure, and the local and global environment, something must be done to address cooling and comfort requirements, without undue burden being placed on the environment and the consumer. Solar cooling is one such remedy.

5.2. A Solar Solution

Solar air conditioning (SAC or solar cooling), the process of converting solar thermal energy (heat) into conditioned air, has many favourable attributes and can provide climitisation with reduced impact upon both environment and electricity grid. Solar cooling enables climatisation with reduced electricity requirements, lower operational cost, and fewer GHG emissions. Providing maximum cooling when the sun is most hot is an elegant solution to air conditioning requirements; consequently SAC makes a smaller contribution to peak load, thus reducing the need for peak-supply infrastructure expansion and therefore offsetting electricity price rises. Solar cooling also has significant export opportunities to an increasingly wealthy Asian region.

A correctly designed SAC system provides cooling with lower fossil fuel energy consumption than conventional air conditioning. The sun's thermal energy (radiant heat) is harnessed in a thermally-driven cooling process. The process is not autonomous, requiring electricity for pumps, cooling towers, and coolth distribution network. A backup energy source, for when there is insufficient solar radiation to provide cooling, may also be considered and is generally supplied by a fossil-fuel-derived source. A solar cooling system needs to be correctly designed to therefore ensure that overall cost and energy savings are achieved (see section 9.1.3 for a more detailed explanation).

Because maximum cooling output is provided on sunny days (see Figure 3), solar air conditioning can strongly alleviate peak-load pressures associated with use of conventional air conditioners. Although peak load typically occurs mid-to-late afternoon, after the sun has reached its maximum intensity, solar cooling systems typically incorporate an element of storage that enables cooling to be provided when desired. On hot, humid days, a backup heat source (such as natural gas) may be used, or building thermal mass utilised, to provide cool conditions without impacting upon the electricity grid. Alternately, a modest sized conventional air conditioner could be employed as a backup source of cooling with lesser grid impact than a full-sized variant. Thus, a large uptake of solar cooling systems may reduce the stress on the grid that currently occurs on hot sunny days, and avoid electricity price increases by alleviating the need for peak-load supplying network infrastructure. As electricity prices continue to grow, solar air conditioning systems will be able to provide cooling increasingly more economically.

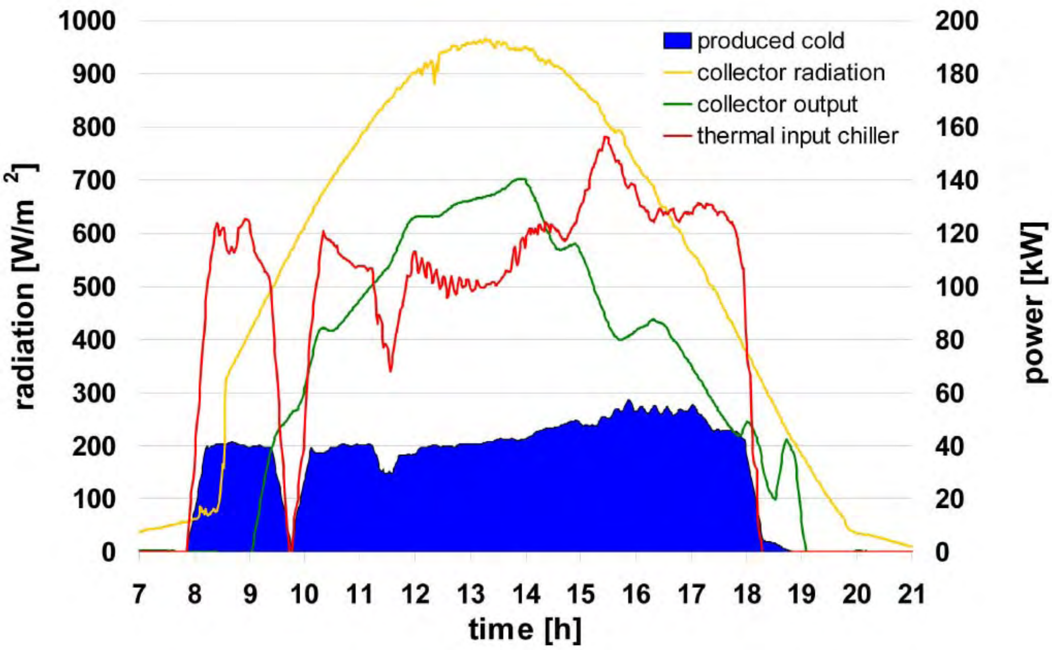


Figure 3 : SAC System Response w.r.t Available Radiation[9]

Solar cooling systems have a reduced environmental impact when compared to conventional air conditioners. The energy savings of a correctly designed solar cooling system translate into fewer greenhouse gases, sulphur, and particulate emissions associated with electricity production. Furthermore, the refrigerants used in solar cooling chillers are GHG benign, meaning their production, handling, and disposal does not significantly contribute to climate change. Solar cooling systems may employ green sources of heat – such as biomass or cogeneration – as backup when solar radiation is unavailable, resulting in the possibility of a carbon-neutral heating and cooling system.

Solar cooling is a key technology that may address the climatisation needs of existing building stock. Many older buildings have poor thermal performance and are unsuitable for renovation or passive design retrofit, and although new buildings are regulated to better standards of performance, new building stock represents only 2% of turnover per annum[10]. Meanwhile, many older residences are being retrofit with air conditioning, with the result that the property sector's impact upon climate change is going to get worse before it gets better. Hence there needs to be a highly energy-efficient climatisation option for existing buildings if there is to be a significant impact on the GHG emissions resulting from the property sector. Solar cooling is one such technology which neatly addresses existing building stock's cooling requirements, particularly as poorly performing buildings exhibit the strongest correlation of cooling need with solar radiation intensity.

New buildings present the opportunity to utilise solar cooling in its most energy-efficient form. The increasing amount of radiant cooling systems in new commercial buildings means that sensible cooling may be provided at higher temperatures (16°C rather than 6°C), at which solar cooling's energy efficiency is more favourable. Conventional air conditioning equipment then need only condition the fresh air content, often resulting in a smaller plant size. Alternately, solar cooling units that efficiently and directly treat latent cooling load of the fresh air intake can permit a smaller conventional plant to handle the sensible load, at higher cooling temperatures with increased efficiency. Residences are becoming increasingly airtight as they implement passive design principles, thus requiring forced ventilation to maintain levels of fresh air and address indoor air quality issues. Such systems present an opportunity for small solar cooling systems.

In addition to servicing a sizable local market, developing an Australian solar cooling product and/or service would present a significant export opportunity. Presently Australia has little experience with solar cooling systems, and if steps are not taken to address this skills deficiency, Australia risks losing profit and jobs to foreign companies when the solar cooling market eventuates. Developing a local product suitable to Australia's climatic conditions, particularly the tropical north, would open up markets in tropical Asia, where increasing wealth is driving air conditioner sales. In the land of the sun, servicing cooling requirements with solar energy seems highly appropriate, and exporting solar expertise would be wise.

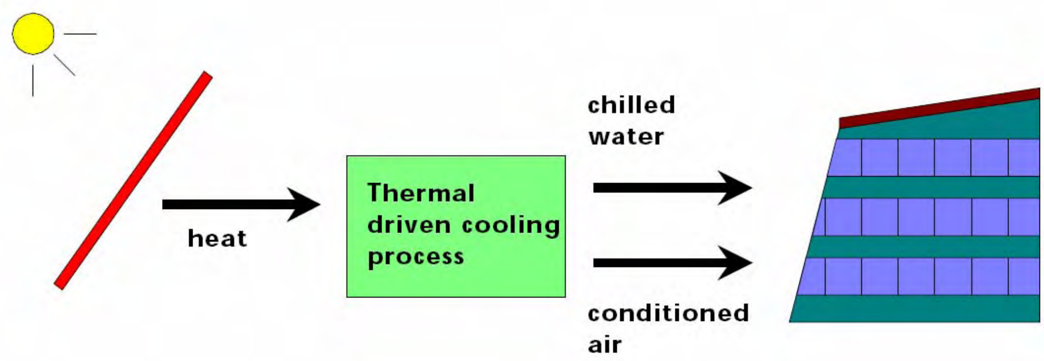
5.3. Challenges Ahead

Solar cooling faces significant hurdles to overcome if it is to live up to its potential, though all challenges are solvable. To reach a point where solar cooling can secure a modest market share of air conditioners, greater experience in the specification, design, installation, control, operation, and maintenance of solar cooling systems is necessary. Such experience will only come as the market demand for solar cooling grows, which requires awareness transfer to architects and building developers, and for market distortions to be addressed so that solar cooling becomes more economically favourable. First, solar cooling must establish itself as a feasible candidate for government support in the form of funding, market regulation, and measures to address current market barriers. This is a process already underway in Europe, as demonstration systems prove themselves, and niche markets are established. To enable solar cooling to grow to a level of self-sufficiency, government support will be necessary in early stages.

Solar cooling should not be regarded as being suitable for blanket application, nor is it the silver bullet solution to climate control. There are other solutions to climate control which are more favourable under similar circumstances, and other methods of addressing peak load issues and climate change. However, there is a large potential market, to which solar cooling could make a reasonable contribution. To this end, the optimism of solar cooling professionals is high.

6. Technology Overview

6.1. Overview



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Solar air conditioning is the task of converting solar thermal energy (heat) into conditioned air. In contrast to conventional air conditioning, which uses mechanical energy to transfer heat from one location to another via compression and expansion of a refrigerant, solar air conditioning uses the thermal energy (heat) collected from the sun's radiation to produce a cooling effect.

Cooling is achieved in closed cycle chillers through the expansion of a refrigerant that occurs when solar heat is applied; heat that is then rejected to the atmosphere and the refrigerant compresses. Subsequent exposure to ambient temperatures at low internal pressure causes re-evaporation of the refrigerant, absorbing heat and producing the cooling effect. The refrigerant is again cooled and re-condenses, completing the cycle. A**b**sorption chillers and a**d**sorption chillers are closed-cycle devices, and are described in Sections 6.2.1 and 6.2.2 respectively.

In contrast, open cycle chillers create conditioned air through direct contact of a dehumidifying desiccant with a fresh air stream. After the air is dried in this manner, it is evaporatively cooled to comfortable temperatures. Water is removed from the moisture-laden desiccant through application of solar heat. Desiccant coolers are open cycle devices, and are described in Section 6.2.3.

Each cooling device relies on thermal energy supplied at specific temperature, and is thus married to a solar collector with appropriate temperature output. The following are possibilities, listed in increasing order of output temperature provided:

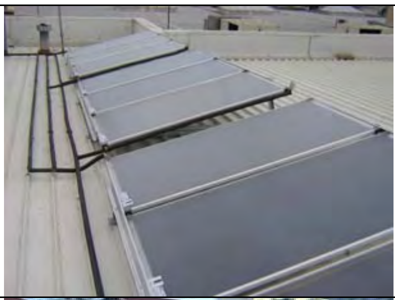
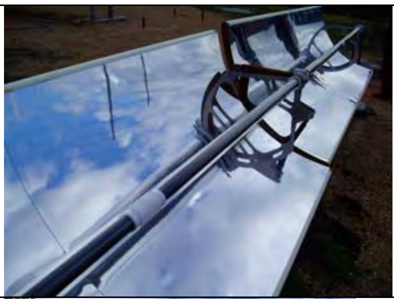
Solar Air Heater	 12
Flat Plate Collector	
Evacuated Tube Collector	 13
Parabolic Trough Concentrating Collector	
Parabolic Dish Concentrating Collector.	 14

Table 3: Solar Thermal Collectors

It is important to note that thermally driven coolers are able to be operated with any suitable heat source, including gas, biomass, waste heat, district heating, and solar energy, however the coupling of solar energy to a thermally-driven chiller is required for a system to be considered in this report.

Beyond the solar collectors and chiller, the balance of system typically consists of:

- A storage vessel to buffer against variations in solar energy and possibly provide extended hours of operation.

- A back-up means of cooling in periods when insufficient solar energy is available. This may be achieved by a conventional auxiliary chiller, or through a back-up source of heat, such as gas or biomass.

- Solution pumping equipment.

- Heat rejection equipment, such as a cooling tower.

Such a generic system is illustrated in Figure 4.

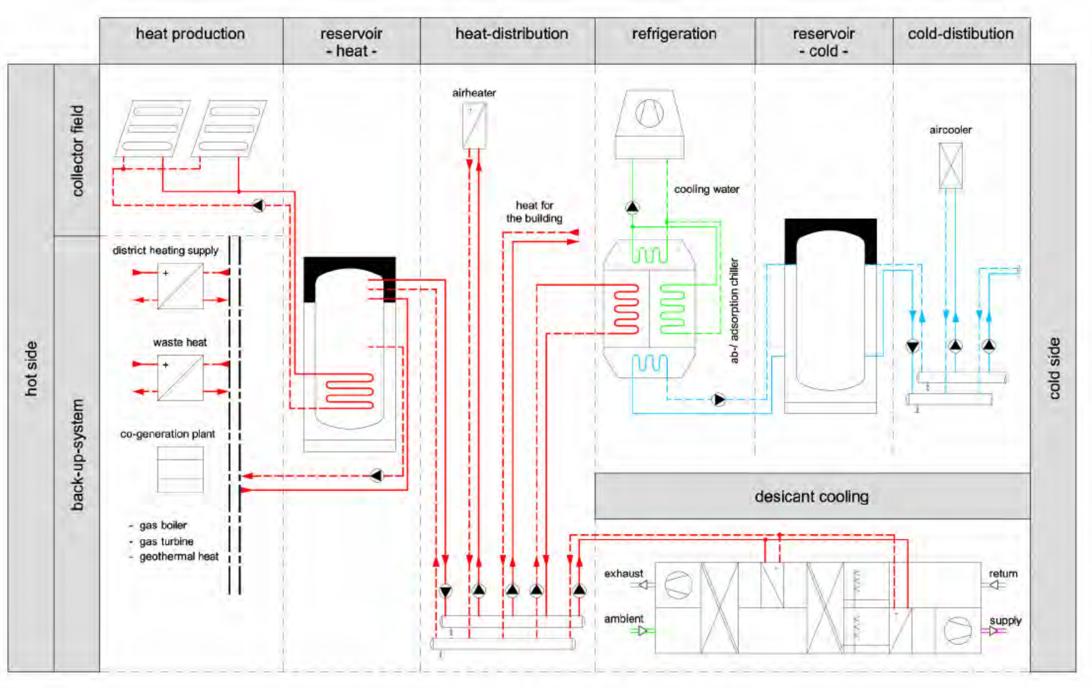


Figure 4 : Solar Cooling and Heating System[15]

The efficiency of a cooling device is measured by its coefficient of performance (COP), a value which indicates the amount of cooling energy output per input unit of heat energy. A higher COP is therefore a more efficient cooler. Thermally driven chillers have a COP ranging from 0.4 to 1.2.

In comparison, electrically driven air conditioners quote a far greater COP, typically 2.5 to 3.0. This measure relates the amount of cooling energy generated per unit of input electrical – rather than thermal – energy. This electricity was typically obtained from a thermal source – most often through firing of coal in Australia - converted at an efficiency of 40% or thereabouts, then suffers 13% further losses[16] during long distance transmission. In order to achieve a net energy saving, the primary energy (electricity and possibly gas) input into a solar powered air conditioner must be less than the corresponding electrical energy required to run a conventional air conditioner.

In addition, the collected solar energy can be used for heating of domestic hot water, and internal space heating in cooler months. Such a system is referred to as a combi-system.

6.2. Technologies

Each chilling technology is discussed briefly below. A more detailed technical description is provided in the appendices.

Technology	Ideal application	Benefits	Drawbacks
Absorption	Radiant Cooling	Constant, precise output	Higher temperature collectors required
Adsorption	Radiant Cooling	Lower temperature source.	Lower COP Typically heavier and more expensive
Desiccant	Humid environments High volumes of fresh air	Direct humidity treatment	Sensible cooling best handled by second device

Table 4: Cooling Technology Summary

6.2.1. Absorption Chillers

Absorption chillers:

- Use water as a refrigerant and Lithium Bromide (LiBr) as a sorbent. Under low pressure conditions, water evaporates at ambient temperatures to produce the useful cooling effect. To bring it to this state, solar energy is applied to evaporate the water from a LiBr-water solution, after which the vapour is cooled and condenses, then brought to a low-pressure state. After absorbing heat from the area to be air conditioned, the water vapour is absorbed by the concentrated LiBr solution to complete the cycle.

- May use ammonia as a refrigerant and water as a sorbent when operation below 4°C is required.

- May achieve a higher COP if a second stage is added, in which the heat that is rejected from the first stage acts as the energy input to the second stage. This requires higher initial driving temperatures, limiting its application to more efficient and correspondingly more expensive solar collectors such as parabolic troughs.

- Provide very precise continuous output temperatures.

- Have been in commercial production and operation for decades, often driven by natural gas.

- Existing commercial units are mostly high-capacity machines (>200kW) unsuitable for small buildings.

- Typically operate with temperatures of 90°C (single stage) to 150°C (double stage), which may be provided by evacuated tubes or concentrating collectors.

New developments in absorption chillers were observed during the investigative study tour, which are related in Section 8.2.

A technical description of how absorption chillers work is provided in Section 11.1.1.

Figure 5 : Absorption Chiller[17]

6.2.2. Adsorption Chillers

Adsorption Chillers:

- Use a dry sorbent (zeolite or silica gel) coated upon a heat exchanger. Water evaporates at low partial pressure to produce the cooling effect. The water vapour is adsorbed onto the sorbent, and the heat of condensation removed. The sorbent is regenerated by application of heat to evaporate the water, and the water condensed, again completing the cycle.

- Are periodic in output due to a quasi-cyclical nature of operation. As the two processes described above cannot occur in the same chamber simultaneously, two chambers are used – one cooling and one regenerating. They operate for 7-21 minutes before alternating, with a 20 second pause in between cycles.

- Tend to be large because a high surface area of sorbent is required. This makes adsorption chillers heaver and more expensive than absorption chillers.

- Operate at lower temperatures than an absorption chiller. Temperatures of 60-80°C are suitable, which may be supplied by a flat plate collector.

- Have a lower COP than absorption chillers.

- Have low operational energy usage.

- Are lower maintenance than absorption chillers.

New developments in adsorption chillers were observed during the investigative study tour, which are related in Section 8.2.

A technical description of how adsorption chillers work is provided in Section 11.1.2.

Figure 6 : Adsorption Chiller

6.2.3. Desiccant Coolers

Desiccant coolers:

- Directly treat fresh incoming air. Internal loads (sensible cooling) are handled by an auxiliary system, which then operates in a more efficient mode as it need not dehumidify.
- Dry the air, which is then evaporatively cooled, and are commonly called Desiccant Evaporative Coolers (DEC).
- Are air-only systems.
- Are best suited to handling latent cooling only.
- May use a solid desiccant coated upon a rotating wheel or a liquid desiccant sprayed onto a distributor.
- Require low regeneration temperatures, making them suitable for flat plate collectors or even solar air heaters.
- Presently require larger applications to be economically favourable. In the right conditions, desiccant dehumidification is of comparative cost to regular air conditioning.
- Offer interesting opportunities for liquid desiccant systems, including improved indoor air quality, split-systems, and lossless storage of potential cooling energy.

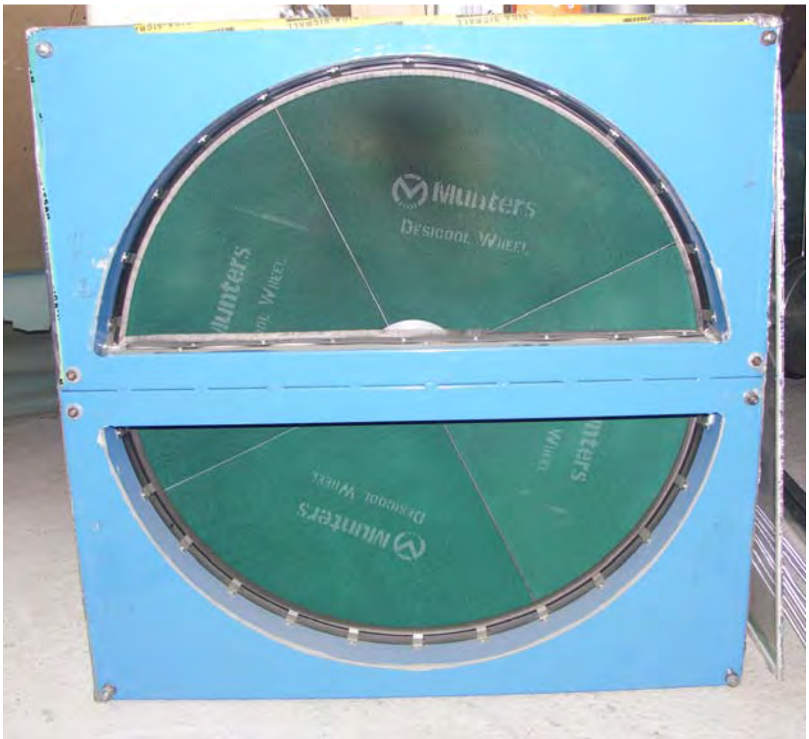


Figure 7: Solid Desiccant Wheel

6.3. Markets

Market	Prognosis	Best Opportunities
Industrial	Application suited to dry air requirements and harnessing of waste heat	Agriculture, pharmaceuticals, sweets
Commercial Buildings	Most favourable target for initial installations	Hotels, modest government offices (owner occupied or long-term lease)
Residential Buildings	Large market but hurdles relating to maintenance and defining system standard	Combi-systems (space and domestic water heating), Desiccant systems (in tropical Australia)

Table 5: Solar Cooling Market Summary

6.3.1. Industrial Market

Solar cooling typically struggles to compete in the industrial cooling market. This is because cooling is typically a critical process whenever it is required in an industrial scale. As such, reliability and quality of cooling is of paramount concern, and operation is not necessarily aligned with available solar radiation. This makes systems more complex and expensive, and reduces guarantees of energy savings.

It is difficult for solar cooling to compete against the cheap cost structures for energy in the industrial market. As bulk consumers, industrial users are given highly discounted rates for electricity, making any energy savings available with solar cooling of little value. Industrial processes may also be able to use lower grade fuels, and energy inputs are tax offsets in some countries.

There are certain applications in which solar cooling can be cost-competitive. These are in industries that require dry air, such as in agricultural product drying and pharmaceuticals, in which case a desiccant system is ideal. Alternative heat sources in such applications include waste heat from other processes, or the use of natural gas, the cost of which is more favourable than solar energy. However, such applications would support the further development of cooling technology compatible with solar air conditioning, and therefore are a favourable market stimulus.

6.3.2. Commercial Buildings Market

Current commercially-available solar-compatible chillers are of a high capacity, and as such are most suited to commercial buildings such as offices, hospitals, convention centres, and hotels. Hence, the commercial buildings market is the focus of most solar cooling demonstration systems. So long as the payback from use of a solar air conditioner is favourable, upfront cost is less of an issue in owner operated commercial buildings (as compared to residential buildings), though budget limitations may preclude additional cost regardless of favourable payback times. However, when the building is leased out, it becomes difficult for a building developer to make a return on investment on a more expensive but energy-efficient system – a quandary known as the ‘split incentive’.

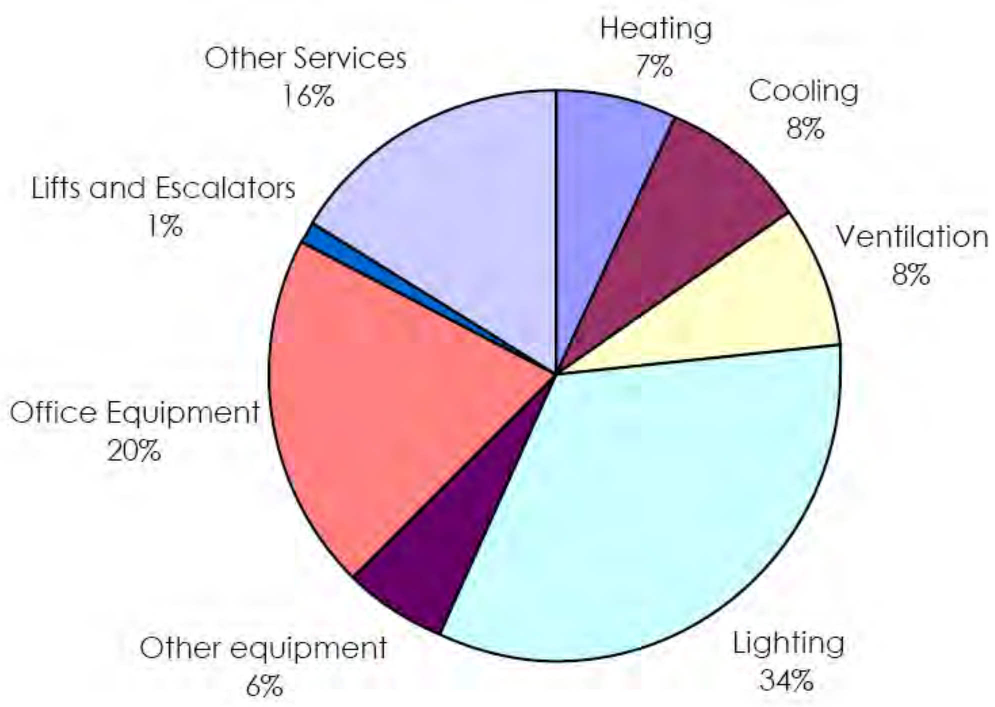


Figure 8: HVAC Energy Use in Commercial Buildings[18]

However, not every commercial building is a suitable candidate for solar cooling. There needs to be sufficient roof area for SAC to make a sizeable contribution to building cooling, which favours applications to buildings less than four to six storeys. Certain buildings are more favourable to solar cooling, namely those with large glass facades which exhibit high solar gain and therefore correspondence between cooling demand and available solar radiation, as well as those which have radiant cooling systems or output air temperature[ii] higher than is conventionally the case.

Commercial buildings with large roof areas, such as supermarkets, shopping centres, and convention centres, have therefore been a focus of investigation for solar cooling. Shopping centres have been hesitant in seeing market advantage from embracing sustainability, and whilst supermarkets require large volumes of dry air (ideally suited to desiccant systems), they too have been reluctant to take on any risk. Convention centres are less ideally suited to solar cooling, as their usage pattern is unpredictable and not typically aligned with solar radiation, which imposes additional costs and inefficiencies associated with the need to store large quantities of energy.

Hotels are a more favourable application of solar cooling. In addition to large demand for cooling, hotels have a large hot water demand that may be serviced by solar panels. Hotels can also benefit from marketing to eco-conscious travellers, as a small percentage increase in occupancy can deliver significant financial return.

Hospitals require large volumes of fresh air for reasons of hygiene. Conventional air conditioning systems expend great quantities of energy in dehumidifying incoming air, in addition to needing to remove sensible load. Solar air conditioning systems that employ desiccant technology are able to directly treat incoming air with reduced energy requirements, and are most cost competitive in humid environments.

[ii] Such as displacement ventilation systems

6.3.3. Residential Buildings Market

Until recently, available solar-compatible chillers were high capacity, far in excess of the cooling requirements of a residential building. The larger producers of thermally-driven chillers perceived there to be no serviceable market in the residential capacity range, and the pumps required for system operation would be proportionally very expensive in lower capacity machines. Perception of a growing residential market for air conditioning in Europe combined with public awareness of solar energy have refocused research and development efforts towards small-capacity solar air conditioning.

Cost minimisation is the primary focus for small-capacity solar cooling developers. Some achieve this goal through elimination of components such as cooling towers (see Rotartica, p49), others employ unique thermodynamic processes to omit pumps (see FHS Stuttgart, p44) or achieve increases in performance. The result is a growing range of options in the 5-15kW cooling range, although not all systems are commercially available yet.

Although the cost-performance optimisation goal is the same as in any market, different boundary conditions apply in the residential market. Systems have to be zero maintenance to guarantee operation, must be quiet, and limited storage space must be considered. Generally a wet cooling tower is precluded on cost and maintenance grounds, which limits system performance. These and other boundary conditions make development of a product that satisfies the market quite challenging.

Residential solar cooling systems offer some interesting possibilities. Hot water demand in homes tends to be high, and many climates require winter space heating. The large solar array required for solar cooling can be put to use in providing domestic hot water and space heating in what is known as a combi-system. Many homes in Europe already have large solar arrays for space heating, making a solar cooling extension less expensive – though more driven by luxury than need in the relevant European climates. Upfront costs tend to be a greater limiting factor than payback in the residential market, although there exists a small but growing market of wealthy people with “green dollars” to spend on the latest environmentally friendly technology.

Incorporation of backyard swimming pools into the heating and cooling system is another interesting possibility presented by solar cooling. One possibility of addressing heat rejection issues is through the use of swimming pool heating, in which heat extracted from the conditioned room is added to the pool in addition to the solar energy harvested by the solar collectors. This could increase the efficiency of the cooling system whilst extending the duration of annual pool use for low operational cost. Application of such a system would be limited by the size and frequency of operation of the air conditioner, to ensure that the pool water does not overheat beyond comfortable temperatures.

6.4. Opportunities

As mentioned in Section 6.3.3, solar air conditioning presents opportunities beyond just the traditional cooling function. In climates in which it is warranted, the installed array of solar panels can be put to use in winter for space heating, and heating of domestic hot water, which is of year-round value. Solar air conditioning systems could be put to dual use in heating many of Australia's backyard swimming pools as they simultaneously cool the house.

Other unique opportunities exist for solar cooling. A solar cooling system that did not provide 'on-demand' cooling but rather took an approach of cooling when the sun is available could be appreciated by those wishing to come home to a pre-cooled house. Such a system would replace large costly storage vessels and instead store the coolth in the building thermal mass. The ability for liquid desiccants to store potential cooling energy without loss lends itself to split cycle machines and cooling distribution networks – in which the desiccant generator is located remotely from the dehumidifier. Concentrated liquid desiccant could also be generated and stored over winter months, trading a larger storage vessel for a smaller solar array, optimally tailored to the comparative costs of collector, storage, desiccant salt, and energy. These unique opportunities make the future exciting and quite possibly revolutionary for solar air conditioning.

New developments and refinements are presently being explored that ensure solar cooling's continued evolution. Thermo Chemical Accumulators[19] have unique characteristics in terms of integrated, dense energy storage and a high, stable COP. Phase Change Materials (PCM) can be utilised to provide high-density energy storage and constant output temperature. Special surfactants can be added to increase heat exchange surface wettability and thus performance, as can advanced surfaces. Materials science offers possibilities in new open cycle solid desiccant systems[20]. Such possibilities mean that solar cooling will have even more to offer in the future.

7. The Australian Context

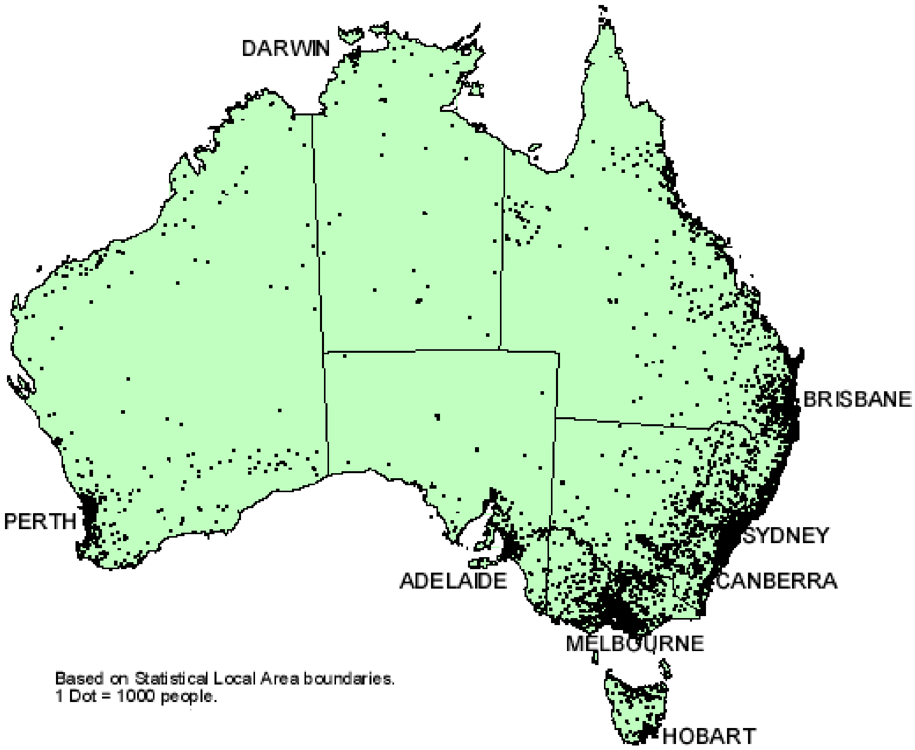


Figure 9: Australian Population Distribution[21]

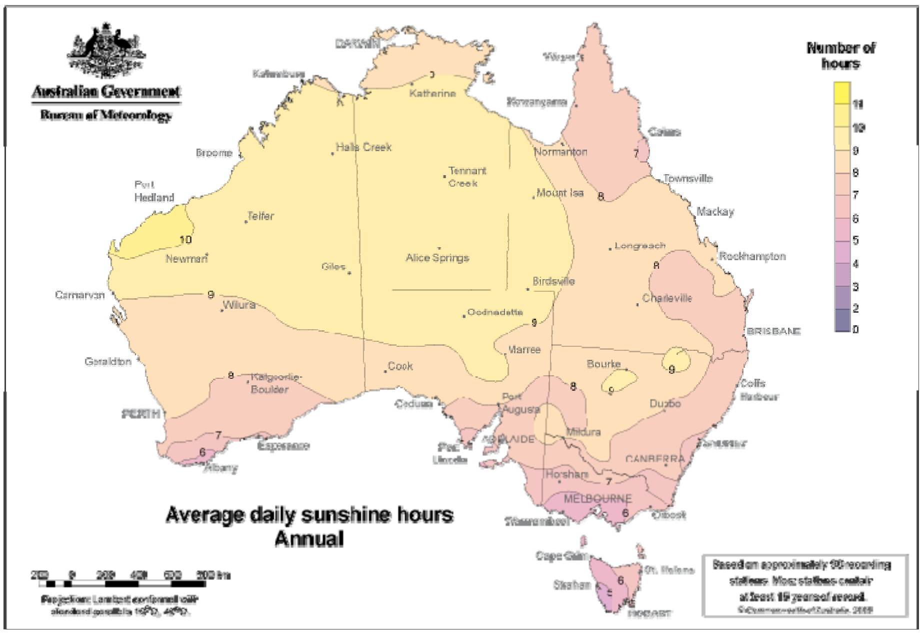


Figure 10: Average Daily Sunshine Hours[22]

7.1. Climate

The Australian continent has a wide range of climates, from the tropical north to the temperate south. The majority of the population lives in regions which require both winter heating and summer cooling, though there are also significant amounts of population living in areas which never require heating, and many occupying lands which seldom require cooling. In much of southern Australia, domestic residences could avoid the need for air conditioning through proper passive solar building design, and evaporative cooling could supply climitisation for much of inland Australia. However, the humidity of tropical regions within Australia requires that some air conditioning is required in northern residences in order to bring internal climate into the human comfort band.

Though the variation of Australia's climate is as significant as the difference between northern and southern Europe, Australia lies closer to the equator, meaning that there is a far greater demand for cooling than there is in Europe, and a similarly reduced heating demand. The upshot of this warm climate is that 10% of Australian households[23] have swimming pools in their back yard, which presents interesting opportunities for solar cooling – see Section 6.3.3.

The relevance of climate is that there is plenty of opportunity for solar air conditioning to provide the cooling needs of residences and commercial buildings throughout Australia, in addition to the heating needs of those in southern Australia. In much of Australia, dehumidification is the greater need than sensible cooling, though in those climates the value of heating is low. Other regions require significant heating and lower capacity coolers, akin to conditions in much of central Europe. The remainder of Australia requires either evaporative cooling only, or has cooling demand that would require larger solar arrays than could be utilised in winter.

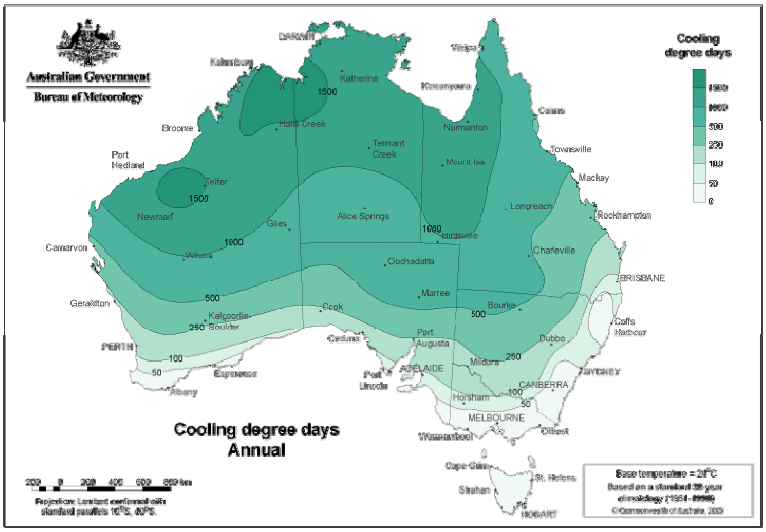


Figure 11: Cooling Degree Days (24°C) [24]

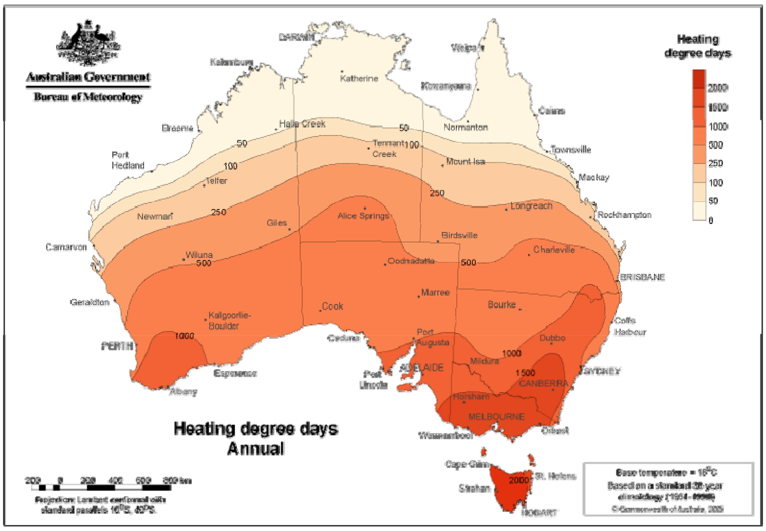


Figure 12: Heating Degree Days (18°C) [25]

7.2. Air Conditioning

Air conditioning is prevalent in Australia. 60% of Australian residences have at least one air conditioner[26], a proportion that is growing steadily as households become wealthier and have greater comfort demands; a scenario set to continue as global warming creates an increase in average and peak temperatures. Air conditioning is almost always installed in new commercial buildings as the internal loads together with external climate mean that even the best passive design in a commercial building still too frequently exceeds comfort bounds.

The usage of air conditioners tends to be highly correlated with incoming solar radiation. On hot days, more air conditioners run, and each person tends to run their air conditioner at the same time as their neighbour. This generates a surge in the electricity demand for an air-conditioned region that tends to occur towards the middle-to-later half of the day (see Figure 13).

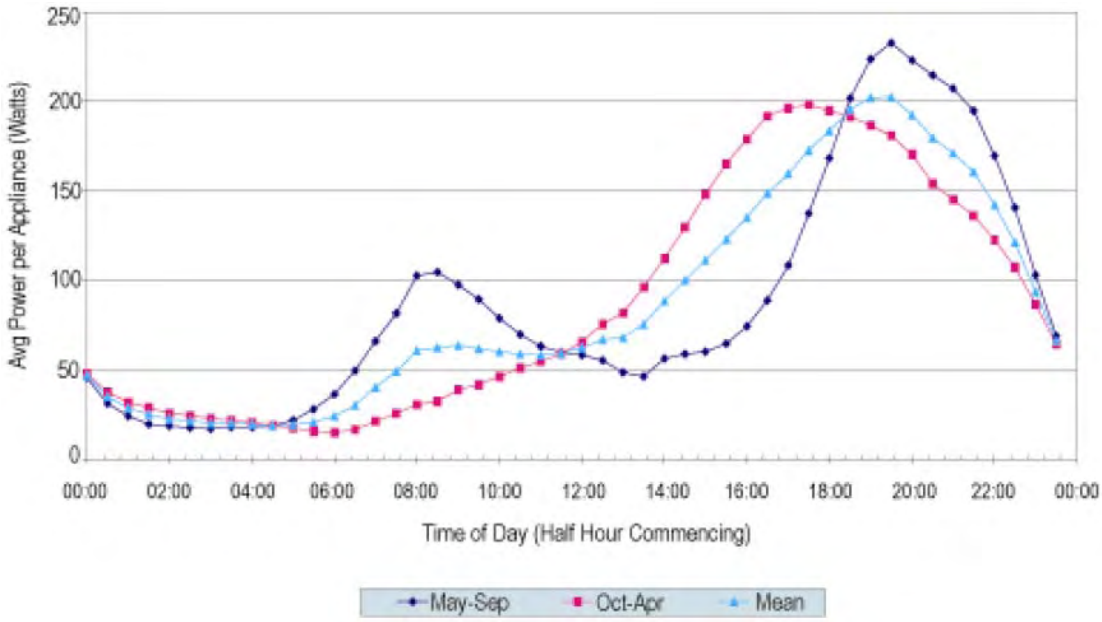


Figure 13: Average Power by Time of Day and Season[27]

The significant contribution of air conditioners to peak electricity demand (peak load) means that infrastructure must be built to satisfy air conditioner usage, infrastructure that sits idle during cooler periods of the day and year, but a resource that is able to charge hundreds of times the retail rate of electricity for operation of only a short period, as demand would otherwise outstrip supply. Air conditioning thus forces installation of additional infrastructure to satisfy peak load, infrastructure that needs to be operated in order for its investors to recoup its costs. Electricity network infrastructure investment required in Western Australia alone suggests that a 2kWe air conditioner, which may cost $1000, requires $6000 of network infrastructure investment[28], similar figures apply to other states[29]. There is therefore a pressure placed to run the infrastructure more often to generate and sell more electricity, a pressure at odds with society's need to reduce greenhouse gas emissions.

Present air conditioning loads are already straining the capabilities of Australia's electricity grid, with resulting blackouts already beginning to occur[iii]. In a market climate with uncertain future energy policy, as well as a long lead time in conventional electricity generation equipment commissioning, added to by contributing factors of the public's increased wealth and ability to purchase air conditioners, and the effect of global warming on the frequency and intensity of peak temperature days, peak electricity demand is growing faster than peak electricity supply can match. This continuation of the situation will result in more frequent blackouts, with each blackout costing millions of dollars in infrastructure damage, lost revenue, and possibly lives.

Such a situation presents an opportunity for solar air conditioning, whose reduced consumption of electricity can ease the impact of air conditioning needs upon peak load. There is a relatively small installation base of other alternatives such as gas-fired absorption chillers, or solar air conditioners in Australia[30]. This means that there is a deficiency of knowledge about thermally driven chiller specification, installation, operation, and maintenance in Australia.

[iii] Blackouts occurred on a 44° day in Adelaide in January 2006, blackouts which could have been far more widespread had industry been back from summer vacation.

7.3. Electricity Supply

Electricity in Australia tends to be generated by coal-fired power stations. Large scale hydro generation plants also contribute to Australia's stationary energy mix, as do gas fired turbines. There is no nuclear energy generation in Australia, and renewable energies presently contribute only a miniscule fraction of Australia's energy needs. The vast majority of Australia's stationary energy mix is fuelled by black or brown coal, with the result that Australia's greenhouse gas energy intensity is the highest in the world, Victoria harbouring the industrial world's most polluting generator.

This situation is unlikely to change in the near future, as Australia has hundreds of year's worth of coal reserves[31], large gas reserves and 40% of the worlds known uranium reserves[32]. With significant political power, those with vested interest in fossil fuels exert great influence upon the present conservative government, which consequently leans more towards investing in clean coal technologies and geosequestration than it does toward renewable energy solutions. A nuclear debate has been re-ignited by the Prime Minister, and though it unlikely that Australia will generate nuclear energy in the foreseeable future, it indicates that the government is considering climate change as worthy of a response.

Australia's energy prices are amongst the lowest in the world. A two-tiered pricing structure operates in the residential market, with peak electricity costing approximately 14 c/kWh (see Table 7, p53) and off-peak approximately 7.5c/kWh[33]. There is a movement towards interval metering supported by a mandated rollout of smart meters in Victoria[34] and the Solar Cities programme[35], both of which may eventually support residential energy charges reflective of peak generation prices. Electricity prices are forecast to increase only slowly by ABARE, Australia's principal (but typically conservative) energy forecaster. Australia has a deregulated energy market, with a national grid extending the length of the eastern seaboard, including Tasmania and Adelaide. The market is structured such that energy generators sell to energy distributors responsible for a specified location, from whom energy retailers purchase energy for on-sell to consumers.

This situation presents challenges and opportunities for solar air conditioning. Though it can be shown that reducing peak load is in the national economic interest, the electricity market structure creates only incentives to sell more electricity. Such cheap electricity makes it difficult for solar cooling to compete on economic terms with conventional air conditioning, as the financial value of reduced electricity usage does not justify any additional expenditure. However, there is great environmental reward for reducing usage of black and brown coal.

7.4. Buildings

Australia generally has energetically poor-performing buildings. Particularly in buildings of the last 40 years and largely the result of a moderate climate, insulation levels are low, thermal mass is unutilised, double glazing is almost unheard of, air gaps are common, and adoption of passive solar design principles is low. As a result, buildings tend to rely on fossil fuels for their heating and cooling, with large amounts of energy simply leaking out. Larger commercial buildings are equally notorious, having vast areas of single glazing, though often coated in a solar control film. Legionella is a concern driving developers away from wet cooling towers, but there is general acceptance that a properly maintained cooling tower poses no threat.

The problem of split incentives applies in leased buildings in Australia. Developers are unlikely to expend additional money or effort in producing a high-performance building if they are unlikely to see a return for this money. The result is a cheap building with an inefficient air conditioning system that is expensive for the tenant to operate.

This situation is changing somewhat as the general public and governments become more aware of the economic pain of shirking their environmental responsibilities. State- and nation-wide programmes to regulate and encourage passive solar, energy efficient, and environmentally sensitive building design have commenced in recent years. At a residential level, regulated minimums are enforced through ratings schemes such as Firstrate and BASIX, which may apply to the building shell and/or to internal fittings. The Australian Greenhouse Building Rating[36] (ABGR) programme gives commercial building developers incentive to build better performing buildings, putting local councils in the position of being able to drive markets by requiring Environmentally Sensitive Design (ESD) performance for planning approvals. A similar programme, Green Star[37], builds upon AGBR to include environmentally sensitive design, retrofit, and fit out in a range of specific applications, and offers buildings ratings which set them apart in the nation and internationally – a situation which alleviates some of the split incentive problems faced by eco-aware developers but which does not address the general market. These programmes address new developments, but not the existing building stock, which limits their impact. There is some talk of developing equivalent programmes and regulations for whenever existing buildings are renovated or extended.

In contrast to Europe, Australia has negligible installations of district heating, regarded by experts to provide efficient and inexpensive back-up heat for solar air conditioners. Australian use of hydronic radiators is consequently low; instead Australians often make use of ducted heating. Biomass and cogeneration – both energy resources that can offer support to solar cooling systems and markets – are largely unutilised. Energy generation from burning landfill gas is increasing within Australia, but without an installed base of district heating networks, the waste heat is not used for building heating. Radiant heating and cooling, which offer sound prospects for more efficient and effective utilisation of solar cooling, are uncommon in Australia, although AGBR and Green Star are creating more local knowledge and applications in this field.

Solar hot water systems are installed in 5% of residences in Australia[38]. Systems tend to consist of two or three flat plate collectors and 250-315L of storage, with many opting for instantaneous gas backup where appropriate. High quality flat plate collectors suitable for solar cooling application retail at approximately A$415/m^2, evacuated tubes retail at A$650/m^2 There are few examples of space heating combi-systems in Australia.

7.5. Public awareness

The environmental awareness of the Australian public is considered to be quite high. Residential collection of recycling has resulted in high public participation rates, and the Keep Australia Beautiful campaign has meant that most Australians thoughtfully dispose of their litter. People are aware of the health of our rivers and the impact of dryland salinity on our countryside. The public is aware of and concerned about the impact of global warming, although this is yet to significantly affect users' actions when they impact upon climate. A clever advertising campaign within Victoria, in which black balloons filled with 50g of CO_2 are emitted from cars, ovens, and appliances, eventually filling the sky, are gradually linking people's actions with their impact upon our atmosphere.

The Australian public is generally fearful of nuclear energy, though consideration of the environmental impact of global warming is changing the opinion of some of those that assume that nuclear energy will solve problems of CO_2 emissions[iv].

A decade-long drought affecting much of Australia is the most pressing environmental threat to have generated public response, with significant awareness and concern resulting in water restrictions across Australia and increasing numbers of rainwater tank installations. The general public may therefore prefer to save water than energy, hampering potential for evaporative cooling.

There is very little (though increasing) awareness of the existence or potential for other cooling technologies with reduced GHG footprint, including solar air conditioning, within Australia. Most people who are told about solar air conditioning observe the elegant association between requirement for cooling and a correlated solution, and are supportive of such a concept. However most do not understand how heat can create coolth.

In summary, background awareness levels about environmental issues are moderately high, and solar cooling can be expect to receive strong public support, both supportive factors for a future market in solar air conditioning.

[iv] There are (disputed) reports demonstrating that only 3 years of high-grade uranium ore exists, and that utilisation of low-grade uranium ore requires more energy to be spent in extraction, transporting, and refining the ore than is eventually generated. Certainly the belief that nuclear energy is CO_2 free overlooks the greenhouse gasses involved in its extraction, transportation, and processing.

7.6. Governance

Australia has had a conservative federal government for the past decade, which has not made a big priority of addressing climate change. Australia negotiated for an increase in GHG emissions under the Kyoto protocol and then followed the lead of the USA in refusing to ratify. Australia is a party to the Asia Pacific Partnership on Clean Development and Climate[39] involving the USA, India, China, South Korea, Japan, and Australia, known as the AP6. This agreement supports the development of new technologies and facilitates their transfer and implementation amongst the participants in a non-binding manner.

The Australian government's efforts to address climate change have been modest at best. A carbon tax is highly unlikely. A Mandatory Renewable Energy Target (MRET) stipulates that all energy generators must supply 2% of energy from new renewable resources[40]. This programme was so successful that the target was reached before programme completion and was un-renewed, leading to diving values of Renewable Energy Certificates – drastically reducing one of the rebates available to solar hot water systems. State governments have attempted to make amends, with the recent South Australian state government election featuring large commitments to GHG reduction (60% by 2050) and renewable energy generation (20% by 2014)[41]. The Victorian government recently legislated a local equivalent of MRET, requiring renewable energy generation of 10% by 2016.

Current government-funded programmes that could support solar air conditioning demonstrations and further installations include the following:

<u>LETA-SA</u>: the federal government's Low Emissions Technology Abatement – Strategic Abatement grant. Capped at $100,000, it may support the installation of an appropriate demonstration facility.[42]

<u>REDI</u>: the federal government's Renewable Energy Development Initiative grant could support development of Australian solar cooling technology components.[43]

<u>VSII</u>: Sustainability Victoria's Victorian Solar Innovation Initiative could contribute up to $100,000, matched dollar for dollar for an existing community centre which added solar air conditioning. A solar air conditioner would be a strong candidate for this funding.[44]

<u>RESF</u>: Sustainability Victoria's Renewable Energy Support Fund could contribute 20% of the capital cost of an installation of qualifying size.[45]

<u>CSHW</u>: Sustainability Victoria's Custom Solar Hot Water (SHW) grant may contribute up to $250/m^2 of flat plate collector and $450/m^2 of evacuated tubing when a system is used for domestic hot water.[46]

There are other funding opportunities in other areas of Australia, meaning the chance of state and/or federal government support for the first solar cooling demonstration systems should be strong. Subsequently, solar cooling would have to compete on its merits, though greater awareness of the externalities in fossil-fuel-based electricity generation (hidden subsidies and environmental externalities) and the installation of conventional air conditioners (infrastructure development requirements) may lead to direct support for solar cooling in order to create a level playing field. Involvement in the AP6 might lead the government to consider supporting the development of an Australian solar cooling product or service, which would have excellent export potential to our humid and rapidly developing Asian neighbours. The Victorian government has recently signed an MOU with India which includes the possibility for joint development of solar and biomass refrigeration equipment.

7.7. Knowledge

Knowledge of the specification, design, operation, and maintenance of solar air conditioning systems within Australia is very limited, as is knowledge and application of supportive systems and technologies. There is low uptake of cogeneration and biomass, with correspondingly few experts in commercial arenas. The same could be said for radiant heating and cooling, which offers possibilities for more efficient operation of solar cooling devices; although AGBR and Green Star mean that more of such systems are being installed, with an associated increase in local knowledge and experience of these technologies.

There are few research institutions that perform basic research into solar cooling. The University of South Australia has researched a liquid desiccant system and cooperates with the University of Kassel (Germany) and Queens University (Canada) on sharing of solar cooling knowledge. Queensland University of Technology has also published material relating to a liquid desiccant system. There are Australian centres of solar thermal expertise, including the Australian National University, the University of Sydney and CSIRO, all of whom are interested in solar cooling. But for the most part, solar cooling is not part of the syllabus for engineering, environmental, or architectural degrees, nor does it form part of continuing professional education.

One company is specifically active in solar cooling, Energy Conservation Systems (ECS)[47], which imports a solar cooling package from Broad (China). Such a system, consisting of sun-tracking concentrating parabolic dishes and a single or double stage absorption chiller, has been installed in a hospital in Ipswich.

A study into SAC was commissioned by the Australian Greenhouse Office (AGO), which resulted in the “Design Guide for Solar Cooling and Supplementary Heating of Commercial Buildings”.[48] This report highlighted market opportunities by demonstrating modest CO_2 emission savings and positive Net Present Value (NPV) in hotels and commercial building applications for absorption chillers in most climates. It also demonstrated that whilst desiccant systems were more expensive than conventional equivalents, 25% savings of greenhouse gas could be made in commercial buildings, hotels, and hospitals in certain climates. This report is now over three years old and is based upon then-existing technology and energy price assumptions. Newer technologies are becoming available, and as energy prices rise and carbon emissions are no longer considered externalities, the assumptions contained within this report should be revised, particularly taking into account the increasing impact of peak load as global warming increases temperatures.

7.8. Market Players

Beyond those market players directly involved in solar cooling, the local market players comprise those who import cooling machines, those that manufacture or import solar panels, those that perform research and development, organizations that support renewable energy, professional associations, and the environmental press. These have been identified below, alongside those that could benefit from solar cooling. This list does not claim to be exhaustive, but is a fair representation.

7.8.1. Active in Solar Cooling

Energy Conservation Systems (ECS) import a solar air conditioning package from Broad (China). They also import a liquid desiccant dehumidifier from Drycor (Israel), soon to be re-branded as Dewcool.
www.ecsaustralia.com/broad/broad.html

Conergy's Australian company has promoted the technology and performed market research in Australia.
http://conergy.com.au/Desktopdefault.aspx/tabid-359/529_read-4375/

Going Solar, through the ISS Institute fellowship, has an in-house solar cooling specialist.
www.goingsolar.com.au

University of South Australia has researched a liquid desiccant system and share knowledge with University of Kassel (Germany) and Queens University (Canada).
www.unisa.edu.au/sec

Queensland University of Technology has also has performed some research on liquid desiccant systems.
www.bee.qut.edu.au/research/projects/ldsac/

7.8.2. Import Thermally Driven Cooling Machines

In addition to ECS, the following companies are some of those that import thermally driven cooling machines suitable for integration with solar energy.

Air Solutions import Thermax absorption chillers from India.
www.airsolutions.com.au/products_thermax_ac.html

Munters supply desiccant dehumidifiers and evaporative coolers, imported from their overseas parent company.
www.munters.com.au/

7.8.3. Perform Related Research

CSIRO perform research and development activities on applications of solar thermal heat, and have developed the TrigenAir system.
www.csiro.au/csiro/content/standard/ps15e,,.html

University of Sydney performs research into applications of solar thermal heat.
www.physics.usyd.edu.au/app/research/solar/index.html

Australian National University carry out research into solar thermal energy, are commercialising their big dish and little dish parabolic concentrators through Wizard Power, and are host to the Australian Research Centre of Excellence for Solar Energy Systems.
engnet.anu.edu.au/DEresearch/solarthermal/

Basset Applied Research was engaged by the Australian Greenhouse Office to perform a study on solar cooling applied to Australian commercial buildings.
www.bassett.com.au

7.8.4. Manufacture or Import Collectors

The following companies manufacture or import solar panels in Australia

Company	**Activity**	
Rinnai / Beasley	Manufacture/Import FPC	www.beasley.com.au
Rheem/Edwards	Manufacture/Import FPC	www.edwards.com.au
Solarhart	Manufacture/Import FPC	www.solahart.com.au
SunplusCPC	Import ETC	www.sunpluscpc.com.au
Apricus	Import ETC	www.apricus-solar.com.au
Endless Solar	Import ETC	www.endless-solar.com
Alternative Fuels & Energy	Manufacture SAH	www.sunlizard.com.au
New Energy Partners	Develop low-cost PTC	www.newenergypartners.com
Solar Heat and Power	Liddell Power Station PTC	www.solarheatpower.com
Solar Systems	Parabolic Dish Power	www.solarsystems.com.au
Wizard Power	Parabolic Dish	www.wizardpower.com.au

Table 6: Australian SHW Collectors

USSS has worldwide exclusive rights to the intellectual property for many concentrating solar technologies developed at the University of Sydney.
www.usss.com.au

7.8.5. Other Associated Infrastructure

Muller Industries sell a '3C cooling tower' that has lower water consumption than a typical wet cooling tower, but better performance than a dry cooling tower.
www.mullerindustries.com.au/3c.htm

Packaged Environmental Systems provides portable and semi fixed infrastructure to address short and medium term including integrated power generation, water treatment, hot water generation, Heating Ventilation and Air Conditioning (HVAC) and fluid treatment.
www.pescorporation.com

7.8.6. Associations

Australian Business Council for Sustainable Energy is a member based industry association representing the sustainable energy industry in Australia.
www.bcse.org.au

Australian and New Zealand Solar Energy Society promotes scientific, social & economic development through the environmentally sound utilisation of solar energy.
www.anzses.org

Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH) is a specialist membership association for air conditioning, refrigeration, heating and ventilation professionals.
www.airah.org.au

The Royal Australian Institute of Architects (RAIA) is a national body consisting of 9000 members across Australia and overseas.
www.architecture.com.au

Archicentre is the building advisory service of the Royal Australian Institute of Architects.
www.archicentre.com.au

Green Building Council of Australia is a national, not-for-profit organisation with a mission to develop a sustainable property industry for Australia and to drive the adoption of green building practices through market-based solutions.
www.gbcaus.org

7.8.7. Government Agencies

Australian Greenhouse Office delivers the majority of programmes under the Australian Government's climate change strategy.
www.greenhouse.gov.au

Sustainability Victoria is the Victorian Governments sustainability body.
www.sustainability.vic.gov.au

Department of Energy, Utilities and Sustainability leads the NSW Government's sustainable energy and urban water agenda.
www.deus.nsw.gov.au

7.8.8. Related Media

Environment Management News:	www.environmentalmanagementnews.net/
Ecospecifier:	www.ecospecifier.org
Ecolibrium:	www.airah.org.au/ecolibrium.asp
CSIRO Sustainability Network Update	www.bml.csiro.au/SNnewsletters.htm

8. International Context

8.1. State of the Market

The solar air conditioning market is presently in its infant stages. The total number of installations is approximately 100, mostly concentrated in Germany and Spain. There is a minor amount of manufacturing of small-capacity systems in addition to the utilisation of existing thermally-driven chillers in larger demonstration projects.

There is a dedicated band of experts in solar air conditioning, typically engaged in research, product development, or system design and monitoring. Market development activities include forums and networks that assist in developing the industry, through sharing of information, approaches, and data. Such programmes also facilitate collective action to increase understanding and awareness amongst key decision makers. Funding for solar cooling projects and activities generally comes from EU funding bodies in conjunction with other research funds and commercial contributions.

More details about the state of the market are given in Section 8.3.

8.2. Program Content

The fellowship programme addressed the identified skills deficiencies through visits to a range of educational institutions, applied research centres, and product developers across the range of solar air conditioning's existing technologies and future directions.

The following site visits and meetings proved to be the most significant in providing information and inspiration:

Technion – Israel Institute of Technology,

Faculty of Mechanical Engineering
tx.technion.ac.il
Location: Haifa, Israel
Participants: Prof. Gershon Grossman, Dr. Khaled Gomed

Technion demonstrated an advanced prototype liquid desiccant plant that provided conditioned air to two office rooms (see Figure 14). The prototype was a refinement on previous iterations and was ready for commercialisation. It achieved the desiccant transfer through the use of a packed bed structure in cross-flow arrangement.

Figure 14: Technion's Liquid Desiccant Equipment

Stuttgart University of Applied Sciences (Fachhochschule Stuttgart)

Centre of Applied Research, Sustainable Energy Technology
zafh.net
Location: Stuttgart, Germany
Participants: Ursula Eicker, Uli Jacob, Jürgen Schumacher, Dietrich Schneider

The area of greatest expertise for Fachhochschule (FHS) Stuttgart appeared to be control strategies for solar air conditioning systems. Their advanced software, developed in-house, takes into account present and predicted solar radiation and building load, so that greater use of the sun's energy is able to be achieved.

The Fachhochschule also demonstrated three systems at various stages of advancement. Their diffusion absorption machine uses a helium catalyst to achieve non-mechanical fluid pumping through implementation of a bubble pump (see Figure 15). This avoids the use of a mechanical pump, which forms a significant component of the price in smaller capacity systems. As such, they feel that the diffusion absorption cooling machine will be price-competitive in the low-capacity market. A solid desiccant evaluation rig was being used to compare the desiccant wheels of various suppliers, and for testing and refining control strategies. They also had commenced experiments in liquid desiccant component prototypes.

Figure 15: DACM Prototype

Bavarian Centre for Applied Energy (ZAE Bayern)

Research Division: Technology for Energy Systems and Renewable Energy
www.zae-bayern.de
Location: Munich, Germany
Participants: Eberhard Lävemann

ZAE Bayern is a private applied research institution, with research areas including zeolite energy transportation, phase change materials, biomass, solar thermal energy, fuel cells, and cooling machines. Their extensive experience in liquid desiccant systems has resulted in commercialisation of a product through the company L-DCS. A site visit was made to a jazz club which contained a zeolite-based dehumidification machine and the first L-DCS liquid desiccant cooling demonstration installation (see Figure 16).

Figure 16: L-DCS System at Jazz Club

L-DCS

www.L-DCS.com
Location: Munich, Germany; and Singapore
Participants: Mattias Pelzer (Germany), Michael Hinterbrandner (Singapore)

L-DCS has commercialised a liquid desiccant cooling machine with modular structure, which offers advantages in scalability, manufacturing, maintenance, and redundancy. The site visit to a jazz club involved observing a demonstration system which dehumidified return air and increased the cooling potential of the supply air through an indirect evaporative cooling process. This visit discussed in detail the particulars of the design process, including the obstacles that were overcome along the way.

L-DCS' second installation was also visited, that on a factory in Singapore (see Figure 17). 500m^2 of collectors regenerate desiccant in a similar system configuration to that of the jazz club, albeit in much grander scale. This visit imparted wisdom relating to operational experience, planning, and local governance.

Figure 17: L-DCS System in Singapore

S.O.L.I.D. Solar Installation and Design

www.solid.at
Location: Graz, Austria (via telephone)
Participants: Horst Streissnig

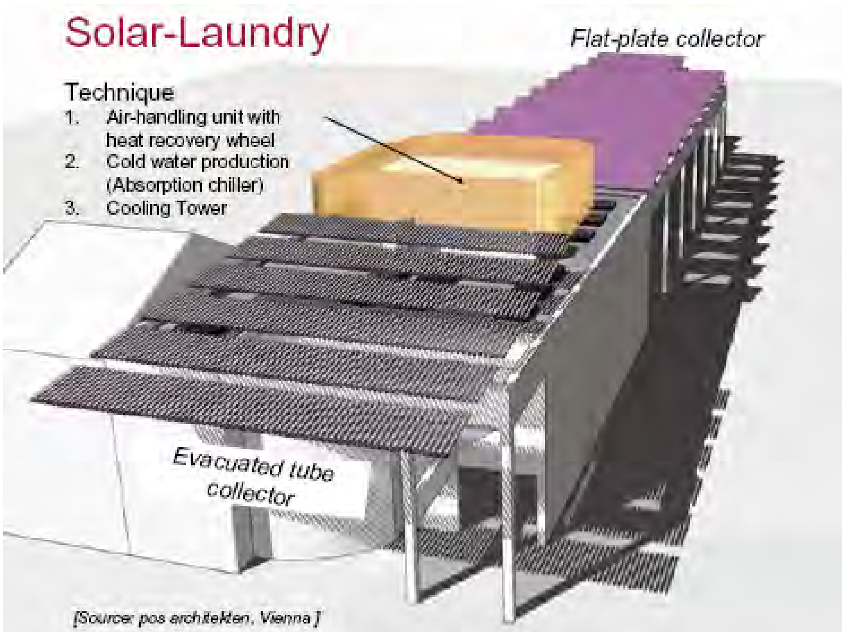
S.O.L.I.D. is a company which is seemingly furthest advanced in the ability to supply a full system to a client. S.O.L.I.D. has extended their abilities from experience in solar thermal energy applications to the field of solar cooling, and has now completed projects in Kosovo, the USA, China, Brussels, and Austria. After obtaining their first installation experience in a market, they are able to offer 3rd party financing models, and are investigating the possibility of leasing out solar cooling machines. This is based upon a present direction of supplying a 'container solution', a system pre-optimised for the client application and subsequently tele-monitored.

Conversations with S.O.L.I.D. imparted design objectives for future widespread applications, through identifying what's possible-and-assured to the customer, minimising storage and maintenance requirements.

Arsenal Research

Sustainable Energy Systems Division
www.arsenal.ac.at
Location: Vienna, Austria
Participants: Tim Selke

Arsenal Research has had involvement in three solar cooling plants. Arsenal has a strong architectural focus, drawing upon in-house expertise in this area, and is focussed on market requirements at the system level. Tim Selke emphasized the importance of educating architects about solar cooling possibilities, as architects are key players in the new building developments (see Figure 18). Arsenal is active in networking and promoting solar cooling, particularly acting as a bridge between the smaller companies that are prevalent in the Austria business landscape.



[49]

Figure 18: Arsenal Research's Solar Laundry Concept Drawing

ILK Dresden (Institute for Air Conditioning and Refrigeration)

Applied New Technologies Division
www.ilkdresden.de
Location: Dresden, Germany
Participants: Uwe Franzke, Bodo Burandt, Joerg Waschull

ILK Dresden has investigated of a wide range of solar cooling technologies as part of applied research in the fields of refrigeration & cryotechnology; air conditioning and energy technology; and new technologies including PCM, physics and chemical analysis. They co-developed a small capacity LiBr absorption chiller which is now commercialised through the company EAW. They also demonstrated a desiccant wheel in classic solar thermal configuration, however making good use of an electrical heat-pump to supply backup energy, a system which cooled their conference room. An adsorption machine installation was visited in a government-occupied building in Dresden, the use of which allowed the architect to design a glass-topped building whilst still maintaining modest conventional air conditioning requirements.

Additionally, ILK Dresden demonstrated a mechanical cooling device which used water as its refrigerant – water being the most inert refrigerant possible - and were the only company visited which demonstrated photovoltaic cooling applications, as applied to milk cooling, ice making, medicine cabinet refrigeration, and telecommunication devices.

Fraunhofer Institute for Solar Energy Systems (ISE)

www.ise.fraunhofer.de
Location: Freiburg, Germany
Participants: Hans-Martin Henning, Tomas Nunez, Edo Wiemken

The Fraunhofer ISE is widely considered to be the foremost centre for applied research in solar energy within Europe. Their research spans specialised solar glazing, stagnation research and selective coatings for solar thermal power plants, hydrogen technology, materials science, and photovoltaic development including concentrating PV. They are aware of system level issues including design, review, and monitoring, and conduct ongoing research into system components. Hans-Martin Henning has been a long-time staunch advocate for solar cooling.

The highlight of visiting the Fraunhofer ISE was witnessing their solar/biomass-cogeneration adsorption heat pump with ground-sunk heat rejection and fresh air pre-tempering through underground ducting (see Figure 19). By passing air underground before it is heated or cooled, it attains a moderate temperature and thus lessens the additional heating or cooling energy required. The system uses solar energy when available, and biomass-fired cogeneration heat otherwise, to supply energy to a large adsorption machine. Heat is very efficiently rejected to the ground, improving the overall system COP. The system may also be reversed to provide solar space heating with additional heat input from the ground, thus delivering what seemed to be the ultimate green source of cooling and heating.

Fraunhofer ISE has also developed a small scale adsorption machine, currently being commercialised by Sortech. They also have involvement with an open cycle dry sorbent system being refined in Milan (ECOS), which could have strong possibilities for the Australian market.

Figure 19: Evidence of Recent Trench Digging in front of Fraunhofer ISE Building,

Sortech

www.sortech.de
Location: Halle (Saale), Germany
Participants: Walter Mittelbach

Sortech are building adsorption heat pumps and simultaneously refining their product development in the laboratory and in the field (see Figure 20). A small capacity adsorption unit is the result of their focus on effectively coating a heat exchanger with zeolite.

The meeting with Walter Mittelbach impressed upon me the merits of development that is responsive to real market needs, which are still shifting as this infant market matures. As the European summer is quite short, the length of time for data collection is constrained. This led to the understanding that Australia can make a contribution to the development of the international solar cooling market.

Figure 20: Sortech's Adsorption Chiller

University of Kassel

Solar Technology Division
solar.uni-kassel.de
Location: Kassel, Germany
Participants: Roland Heinzen and Michael Krause (whilst at the University of South Australia), Dietrich Schmidt (Fraunhofer Instutut Bauphsik)

The University of Kassel's involvement with solar cooling started fairly recently and has been quite focussed on liquid desiccant systems. Michael Krause was seconded to the University of South Australia and undertook further research on liquid desiccant systems. Roland Heinzen is comparatively assessing solar cooling technologies, an approach which began to look at system level issues before discovering that there remains a lot of potential for improvement at a component level. For example, Roland introduced me to a third candidate for liquid desiccant salt.

The University of Kassel is involved in SolarNet, a European-wide solar cooling PhD programme, and cooperates with the University of South Australia and Queens University, Canada. My visit to the University of Kassel benefited my awareness of the studies and surveys that had been conducted in the field of solar cooling.

Aiguasol

www.aiguasol.com
Location: Barcelona, Spain
Participants: Laura Sola

Aiguasol is a small consultancy active in building design, software development, and energy systems with a focus on solar thermal systems and applications. They work on innovative projects with various energy sources, including district heating, biomass, cogeneration, and solar photovoltaic and thermal energy. Aiguasol has been involved in the monitoring of a solar cooling plant in a library, which incorporates air pre-heating through a photovoltaic façade before further heating in solar air heaters for use in a solid desiccant system.

Rotartica

Location: Bilbao, Spain
Participants: Xabier Gorritxategi, Inigo Aldekoa, Rakel Loubet, and Maider Usabiaga (Ikerlan)

Rotartica is manufacturing small capacity absorption chillers at the rate of 1 per day, making it the furthest progressed product developer in the small capacity market. Rotarica's units have a unique rotating mechanism (see Figure 21) that provides very good performance and enables an integrated dry re-cooling unit to be packaged with the system. Alternately, external connections may be made to a wet- or ground-re-cooler. A valuable visit was made to a Rotartica installation at Spain's Ikerlan technological research centre, which bridges the gap between the technology and the market. Ikerlan has also contributed to the commercial appearance of the Rotartica unit. Rotartica is currently developing a hydraulic module containing all the necessary pumps, backup heaters, and controls – a major step required for simple installation.

The visit to Rotartica revealed the significant number of combinations possible for solar cooling systems, and the effort required to correctly engineer and control each system component. The visit also revealed the value of advanced technology in achieving unique systems which will thus have competitive advantage in the future market.

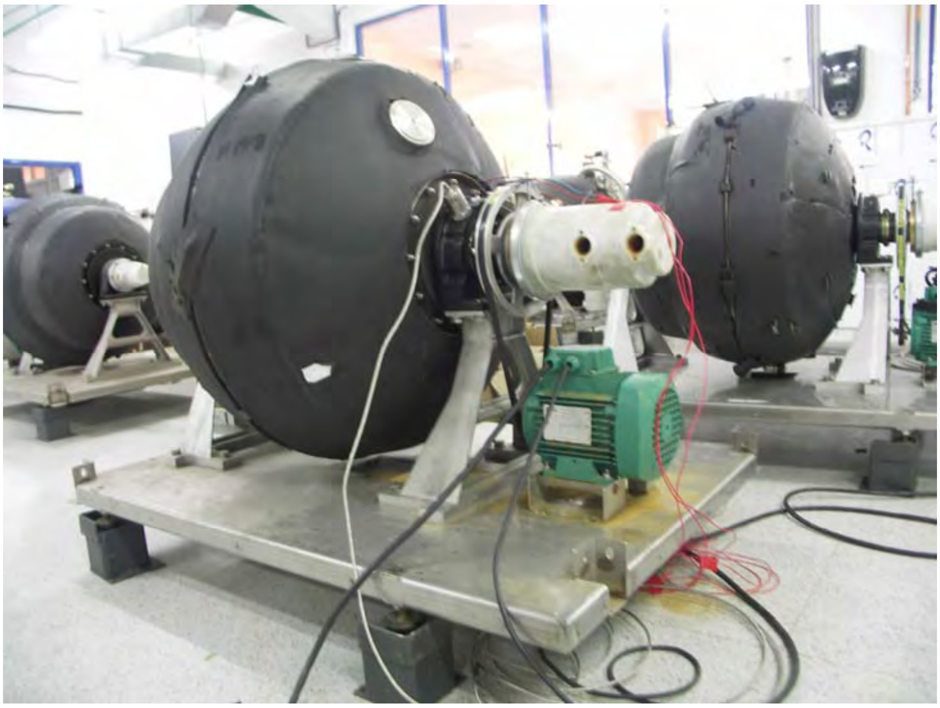


Figure 21: Inner Workings of Rotartica Absorption Chillers

Polytechnic University of Catalonia (UPC)

Heat and Mass Transfer Technological Centre (CTTC)
www.upc.es/lte
Location: Barcelona, Spain
Participants: Jesus Castro

UPC takes a highly theoretical approach to solar cooling. They have developed an air-cooled LiBr absorption chiller by drawing upon internal expertise in heat fin design, and extensively modelled its inner workings (see Figure 22). This enables them to effectively apply their theoretical understanding to the process of operational optimisation. They have also developed an ammonia-water air chilled absorption machine, and developed detailed theoretical models of advanced surfaces and surfactants, which hold promise for future efficiency improvement.

The visit to UPC revealed future technological advancements that may be possible beyond the time when machines evolve from their present form into more cost-effective models, and thenceforth compete on COP.

Figure 22: Air Cooled Absorption Chiller at UPC

Conergy

www.conergy.com.au
Location: Hamburg, Germany and Sydney, Australia
Participants: Mattis Bauman (Germany) and Christian Langen (Australia)

Conergy is a large German company, highly active internationally in PV, and also increasingly active in solar thermal, biomass, and other technologies including solar air conditioning. As a large company not tied to any one cooling technology, they have broad market awareness, and vested interests were lesser than with other smaller companies, enabling them to appraise market possibilities with economic rationality.

The visit to Conergy demonstrated that the solar air conditioning market is at present a niche market, and the possibilities for economic competitiveness are some time off, depending on internal market structures. Although Conergy has investigated the Australian market, for the time being the Spanish market seems to be the most lucrative. Subsequently, Conergy has taken the view of learning in the local Spanish market before then applying its knowledge to Australia.

8.3. International Market Analysis

Israel

Climate: Israel is a cooling-driven market, similar to much of temperate Australia. There is little demand for heating, but frequent need to dehumidify.

Awareness & Market Opportunity: Security concerns are far more prevalent than environmental concerns, with the result that solar air conditioning has little public awareness or government support.

Governance: As a result of a law stipulating that all new buildings have solar hot water, Israel has one of the highest per-capita usages of solar thermal energy. In Israel, cheap but low quality heating oil is used in many commercial and industrial applications, and the fuel is a tax-deductible business input, thus giving solar thermal energy applications little footing.

Germany

Climate: Germany has a heating-driven climate. Only for a couple of months of each year is air conditioning desirable, though hardly necessary except in poorly designed office buildings.

Awareness & Market Opportunity: Germany has a high awareness of, and support for, environmental initiatives. The success of the Green party in German politics may be in part attributed to this fact. In Germany, 25-30% of solar hot water installations are used for space heating, thus making solar air conditioning a less expensive addition. Germany's embrace of environmental technologies means that there is a niche market of early adopters and those with 'green dollars' willing to spend large amounts on solar air conditioning when a suitable product is available. Otherwise, due to lack of local demand for air conditioning, Germany finds itself far from a market for solar cooling – though Germany has long been an exporter of knowledge and technology.

Governance: Germany is a pioneer of solar energy, a result largely attributed to government leadership in this regard. Germany has developed a world leading market share of photovoltaic production and high local demand for photovoltaics largely by guaranteeing fixed payments for PV supplied energy – a “feed-in tariff”. Germany is now considering a feed-in tariff for solar thermal installations, which could further benefit solar air conditioning by generating an even larger installed base of sizeable solar thermal arrays, as well as drive costs down.

Austria

Climate: Austria’s climate is heating driven, more so than Germany’s. Air conditioning requirements are realistically only in commercial buildings with high internal and solar loads.

Awareness & Market Opportunity: In Austria, 35-40% of solar hot water installations are used to provide space heating. As in Germany, this installed base of SHW installations makes SAC a less expensive addition.

Spain

Climate: Spain’s climate varies significantly, including Mediterranean, desert and central European. As a result, many locations require both heating and cooling, though much can be served with passive means.

Awareness & Market Opportunity: Spain is considered to be a prime candidate for initial small-scale solar cooling applications, particularly as it is a country which needs some air conditioning, and one which is struggling to meet its Kyoto obligations. There is a Mediterranean market possibility for solar air conditioners, to supply wealthy retirees with climatisation and pool heating. Market opportunity may be limited in Spain due to Legionella fears placing great maintenance overhead upon the use of wet cooling towers, eating into cost savings achieved with solar cooling.

Governance: A combination of federal, regional, and local subsidies means that in many locations solar hot water panels are almost free. For example, the user may have to pay 20% upfront, 50% by a loan with interest rate lower than a housing loan, and 30% may be covered by the government – with local government subsidies applying additionally in some cases. Laws are about to come into effect that stipulate that a certain, regionally varying, percentage of hot water must be satisfied by solar energy, and guarantees made to prevent overheating.

Singapore

Climate: Singapore’s climate is hot and humid. Air conditioning is ubiquitous, and heating is unnecessary.

Awareness & Market Opportunity: Singapore’s interest in SAC has been aroused by the L-DCS installation. Although gas-fired DEC cooling systems may be economically competitive with vapour compression systems, there is limited availability of natural gas in Singapore, and the reticulated gas system contains gas of poor calorific value.

Governance: No known government sustainability programmes relevant to SAC were identified. However, Singapore does have an enterprise challenge programme, in which the government assists small-to-medium sized enterprises in implementing innovative ideas. The SAC installation in Singapore was supported by this programme.

8.3.1. Air Conditioning

In most of Europe, air conditioning is supplied by similar means to in Australia – by split systems in small dwellings (where desired or necessary), and by large chillers in commercial buildings. Heating is often provided by wall-mounted hydronic radiators, often fuelled by a district heating network. The source of this heat is varied but typically of fossil origin, although biomass is increasing its market share, and cogeneration offers possibilities.

Europe's peak electricity use tends to be in winter. As such, SAC has less to offer Europe in terms of reducing grid infrastructure investment. However, this is changing rapidly in southern countries such as Spain, Italy, and Greece, where air conditioner installations are skyrocketing. This is placing increasing pressure on the grid, with the threat and reality of blackouts becoming more ominous.

8.3.2. Electricity Supply

Overall, Europe's electricity supply comes from more varied sources than Australia's. These commonly include: coal, gas, hydro, and geothermal – and increasingly wind and solar (PV). There are trans-continental electricity networks with international agreements in place, though electricity prices vary considerably.

Country	Germany	Austria	Spain	Australia
Electricity A$/kWh[50]	0.292	0.232	0.150	0.135

Table 7: International Electricity Prices

Judging from interviewees' responses, off-peak electricity tariffs are not as prevalent as in Australia, nor does there appear to be a direction towards interval metering.

8.3.3. Buildings

Europe's building performance is very high. Centuries of habitation in a more extreme climate prior to the era of cheap hydrocarbons has generally resulted in an airtight building stock with double glazing, and high levels of insulation and thermal mass. This practise has slipped somewhat in recent years, particularly in highly-glazed office buildings which therefore have a large solar load.

Current directions in buildings in Europe are similar to that in Australia – passive designed houses are increasingly common and regulated. This means that buildings are becoming more airtight, which tends to mean mechanical ventilation (with heat recovery) is required for fresh air replacement and indoor air quality – an opportunity for SAC if a small desiccant system can utilize otherwise necessary infrastructure to provide cost effective air conditioning.

District heating is common in Europe, and regarded as far superior to ducted heating. Accordingly, radiant heaters are ubiquitous, as is knowledge about hydronic heating (and thus cooling) systems. District heating also lends itself nicely to acting as a highly efficient backup heat source for SAC, minimising infrastructure overhead when supplying a reliable thermally driven heating system without recourse to conventional air conditioners. District heating most favours adsorption chillers and desiccant regeneration, as they are typically of insufficient temperature to efficiently operate an absorption chiller. An appropriate market for summertime use of district heating is viewed favourably by district heating network operators keen to maximise utilisation of their resource. This is particularly the case when the district heating network is fuelled by waste incineration or landfill gas burning, which must occur year-round.

Because many of Singapore's warehouses are not designed for air conditioning, they are not sufficiently airtight to prevent infiltration of humid air. This limits cooling capacity of DEC systems. Typical lease agreements in Singapore include air conditioning as part of the lease amount, usually based on a per-m^2 conditioned area and irrespective of A/C usage. This means that there is no incentive whatsoever for tenants to reduce A/C use, and as provision of A/C is an unquestioned norm, owners typically do not apply energy efficiency measures as simple as making a building airtight.

8.3.4. Public Awareness

Although European's general levels of awareness about SAC are low, the public is becoming increasingly aware of solar air conditioning, largely a result of interaction of institutions, product developers, and market development associations with the media.

Levels of public awareness about environmental issues tend to be quite high in the countries visited, particularly in Germany where a Green party has been elected as part of the ruling coalition for over a decade. This has resulted in high levels of recycling, packaging minimisation, and organic waste collection[v]. Support for renewable energy amongst the community is quite high, and feed-in tariffs for photovoltaic installations, in which a higher rate than the supply rate is guaranteed for 20 years, have resulted in solar farms across the country.

Public awareness about climate change in Europe tends to be high, and the Kyoto protocol regularly features in newspapers. Due to high levels of public participation in environmental initiatives, the public is comparably well-informed about environmental issues, to the point where it affects their behaviour and decision making, at least more so than in Australia. Thus this is a market better conditioned for the introduction of solar cooling.

8.3.5. Governance

Europe has ratified the Kyoto protocol, forcing it to take great measures in reducing its CO_2 emissions. In part this is achieved through carbon trading amongst large industrial emitters with access to decreasing amount of carbon credits, though governments also take action to reduce carbon intensity of certain markets. In effect, by putting a price on CO_2 emissions, solar air conditioning can better compete with GHG-polluting conventional air conditioning.

One approach to reducing GHG emissions has been Germany's: to support the development of a world-leading industry in renewable energy generation, particularly photovoltaics. This has led to successful expertise, job creation and market advantage, in addition to reducing GHG emissions. Germany has achieved this largely through its feed-in tariff policy, in which green energy producers are guaranteed a higher price for the electricity they generate than that which they consume, the result being economically attractive investment in PV systems. Other European countries including France and the Czech Republic are currently in the process of mimicking the Germany's success by implementing their own feed-in tariff.

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[v] Only recently introduced to some councils in Australia – see www.carbonpartners.com.au

The feed-in tariff has not up until now supported solar thermal installations, though opinion is growing that a less efficient solar conversion product (PV) should not be given greater support than a more efficient one (solar thermal). Thus Germany is considering some kind of feed-in tariff for solar hot water systems, which could benefit solar cooling installations greatly if SHW panels are directly subsidised, as this reduces a solar air conditioning system's greatest cost component.

Another governance measure which builds the local market expertise and drives down collector prices is mandating SHW installation. Israel's long standing law requiring SHW installation on all new and newly renovated dwellings has resulted in a world leading per-capita use of solar thermal energy[vi]. In parts of Spain, due to national, state, and additional local rebates, SHW panels are almost free (see p52). Spain's national government has already legislated mandatory installation of SHW systems, with additional rebates explicitly available for solar cooling applications.

Torino, Italy, addressed its A/C-caused blackout problems by mandating a maximum power provision to each house. Whereas in the past, high consumers would pay increased rates past a certain instantaneous energy (kW) threshold, now they are no longer able to source the electricity. This often meant if residents desired air conditioning, they were forced to buy a gas fuelled thermally driven air conditioner. Such a policy also opens avenues for solar air conditioning.

Germany has addressed the split incentive problem through creation of an "energy passport". The energy passport gives occupants an idea of the energetic performance of their building, enabling easy comparisons between rented buildings. Consequently, owners are able to charge more rent for better performing buildings (and conversely lower rent for buildings that require significant fossil fuel inputs for heating and cooling) giving landlords an incentive to improve their building. Local governments – influential leaseholders – are then able to demand a highly efficient building, in doing so increasing the performance of the building stock. The energy passport may offer incentives for developers to install solar air conditioning systems in commercial buildings now, and in residential buildings as appropriately-sized SAC units become available.

8.3.6. Knowledge

Knowledge of SAC systems and components is concentrated in Europe, the USA, and Japan, although Europe tends to be most active. Those institutions and companies visited as part of the fellowship are a fair representation of the leaders in the field of solar cooling, though there are certainly others. SAC is still considered to be in its infancy, with less than 200 known installations, and consequently knowledge about SAC specification, design, installation, operation, and maintenance is quite low, and still evolving. Though the thermodynamics which lies behind the technology is well understood, the SAC industry is still attempting to match technological possibilities to market potentials, and no agreement has been reached upon the most viable application or configuration. As demonstrated by FHS Stuttgart, there is room for optimisation of design and operation of the equipment in response to local instantaneous and forecast climate.

There are still knowledge gaps in the area of large-field hydrodynamics. In larger installations it becomes critical to ensure the system is balanced so that one spot in the collector array does not become overheated; otherwise performance may be lost or heat transfer fluid damaged. Such large-field hydrodynamics design and precision installation knowledge is specialised; at present concentrated in the hands of those that design solar

[vi] Though this has also affected the general quality of product and installation.

thermal power (electricity) systems. Experience with such systems is increasing, and could reasonably be expected to be transferable to benefit further large scale solar cooling installations.

8.3.7. Market Development

Many market development activities occur in Europe, most of which are sponsored by the EU and national governments. This includes development programmes such as IEA-SHC Tasks 25 & 38, SolarThermie2000+, NEGST, in addition to symposiums and educational outreach activities. The result is a growing network of participants all interested in the mutual success of the industry, with significant acceleration of market development, not to mention greater lobbying power. There is no doubt amongst experts as to the market potential for solar cooling given the right conditions, and all feel that the market is sizeable enough to support all cooling technologies and existing companies, thus encouraging further cooperation.

The International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme initiated a task on solar cooling[51], task 25, headed by Dr. Hans-Martin Henning. The result was a design guide handbook and software, in addition to reports on the present state and directions of solar cooling. Task 38 is a follow-up task focussing upon accelerating market introduction of solar cooling systems, delivering reports upon key sectors (small package and custom large systems) with installation and maintenance guidelines, a software package for pre-design assessment, and call-for-tender models. Importantly, this task focuses upon market transfer activities. SolarThermie2000+ is a German programme which focuses upon solar thermal systems including solar cooling and combi-systems[52], whilst NEGST has investigated the NExt Generation of Solar Thermal systems, with the objective of reducing costs through networking, promotion, and rating systems[53]. This work builds upon other such programmes including the European Commission's 2003 SACE (Solar Air Conditioning in Europe) project[54]. A further example on the direct effectiveness of such proactive market development is ROCOCO[55], an Austrian network programme intended to reduce the cost of solar cooling, which builds upon previous activities including ExpertNet. These collaborations and market investigations foster relationships, accelerate technology development, reduce risks by learning from other's experiences, and thus accelerate the adoption of solar cooling technology.

Symposiums have similar effect in fostering networks and disseminating information. They are also an opportunity to attract press attention, and are evidence of a growing market in solar air conditioning. Such specialised symposiums include the upcoming 2nd international conference on solar air conditioning[56]. Other opportunities for market development include targeted workshops, such as those run for architects by Arsenal Research, which directly educate those with the greatest influence in building development.

Demonstration projects have been supported by national governments and by the EU, and are a way to promote solar cooling, develop skills, and disseminate real-life results that then assist in identifying market opportunities and market-reflecting technology developments.

Solar cooling in Europe is presently at the cusp of further market expansion, with sufficient demonstration projects already in operation to suggest that solar cooling must eventually stand of its own accord without significant additional financial contributions from governments. Already one company, S.O.L.I.D. has been able to offer 3rd party financing for solar cooling installations, so demonstrating that it is possible for solar cooling to be self sufficient. In order to get thus far, support has been needed to develop the technology and skills, and to establish a fair market and level playing field, so that solar cooling may compete on fair terms, and have its merits recognised.

At present, solar cooling is cost-competitive in niche environments, particularly where green dollars exist, or where power substation expansion can be avoided when installing a large new air conditioning plant. However, the market economics (increasing energy costs and a price on carbon) are moving in directions favourable to solar air conditioning, and product developers are achieving cost-reductions, so that future support need only assist in creation of economies of scale. Along the path to that end it is expected that solar cooling will initially focus upon medium-scale custom solar coolers for commercial buildings, until small-scale technologies become sufficiently developed and priced for mass-production to commence. Meanwhile, developers remain keen to exploit other compatible sources of heat, as the market for solar cooling technology will benefit from increased sales, installations, and experience.

Market development activities within Europe are fairly advanced and have demonstrated good results. Such development activities would be invaluable for the Australian market, implying governmental funding is worthwhile, and international cooperation highly beneficial.

8.3.8. Directions

At present, the solar air conditioning industry is focussed on cost reduction. It is generally accepted that a 10% increase in performance isn't going to blow open the market, though at a later stage this could offer competitive advantage. In addition, due to system complexity, reduction of the price of any single element will not result in a massive overall system cost reduction. Hence cost reductions across all aspects of the system are being pursued. Some, such as S.O.L.I.D, are focussing upon elimination of large storage vessels, by load matching data analysis and reliance on backup heat sources. Others, such as FHS, are reducing the costs of the chiller through elimination of expensive components (solution pumps). Rotartica is attempting to reduce engineering costs through system standardisation, installation costs through a pre-fabricated hydraulics & control unit, and production costs through larger production volumes. Rotartica and other air-cooled devices also offer reduced installation costs through avoidance of external chillers. L-DCS uses modularity to its production cost advantage, though is hampered by the large investment required for plastics moulding equipment. Many companies, aware that their product is particularly compatible with – but not limited to – solar energy, are looking at omitting the largest cost component – the solar array – by targeting alternative heat sources such as cogeneration[vii].

Other market-driven directions in solar cooling include Sortech's attempt to identify a single unit that will satisfy most market conditions. This is complicated by nonlinearity of the cost-performance space, sensitivity to energy prices, and variability of the boundary conditions. However, at this stage it is unclear in which direction the market will head, and which requirements are the most critical – making developer's lives difficult. However, two directions are certain within the SAC industry – that of developing a suitable small-scale unit suitable for residences and light commercial applications; and cost-performance optimisation of larger-scale systems.

[vii] For example, CSIRO's TrigenAir – a cogeneration system than incorporates cooling from waste heat, also provide cooling with reduced energy consumption and GHG emission. Also a potential competitor for solar cooling, although presenting interesting opportunities for cooperation. http://www.csiro.au/csiro/content/standard/pps6a,,.html

Beyond the immediate future lies exciting possibilities for solar air conditioning which are currently uneconomical, but which offer great scope for advancement. Further development of cooling machines continues: improving performance through use of surfactants or advanced surfaces (UPC), revisiting desiccant salts (Kassel) and new sorbents (ISE), improved system control or alternative cycles (FHS) – all offer opportunities for modest improvement in efficiency, performance boundaries, applications, and some may even open new markets and applications. A SAC system that challenges the conventional split system may be the result. Liquid desiccants may be used for seasonal desiccant storage, to provide storage of potential coolth with a larger (lossless) solution storage and smaller collector array that operates year round, or may be used to provide heat in winter. Alternative sources of heat may be identified, including combining fuel cells with liquid desiccant regeneration, or even the possibility of air conditioning trucks, trains or trams from recaptured waste heat.

9. Findings

9.1. Key Issues & Barriers

Undoubtedly the major barrier to market penetration of solar air conditioners is economic. For reasons explained below, solar cooling systems have trouble competing with conventional equivalents. There is a feeling amongst solar cooling professionals that, given the right economics, each barrier could be overcome; that although there are plenty of barriers, there would be incentive to overcome each – and this is certainly a strong possibility. Examination of each issue will demonstrate the barriers faced by solar cooling, and will lead to a greater understanding of why the economics are unfavourable at present. The barriers may be classified into technical, knowledge, market, environmental, social, buildings, and economics.

Key Issues	How to address	Opportunities
TECHNICAL		
No major unsolvable technical issues		Australian-developed product and expertise in liquid desiccant systems, pursued whilst liquid desiccant systems are in their infancy. Solar thermal excellence fostered
Inherent limitations of SAC	Awareness of non-blanket application	
Simple, effective system control which achieves promised energy savings	Further international development	Creation of standardised control module as SAC market matures
Heat rejection issues	Joint development with cooling tower companies, partnership with ground heat exchange experts	Highly efficient and low-maintenance systems tailored to solar cooling but which benefit all heat pumps
Hydrodynamics of large systems	Experience in solar thermal electricity plants	Fostering Australian solar thermal leadership to harness large solar resource could present export opportunities
KNOWLEDGE		
Ability to specify, design, install, and maintain systems needs to develop internationally in depth and breadth	Further experience on demonstration systems, dissemination of results supported by international cooperation	Access to Australian market and climate conditions is desired by European experts, offering the chance for rapid skills and knowledge transfer
ENVIRONMENTAL		

Reduced energy use and GHG emissions not guaranteed	Engineering design and quality installation on systems with conventional backup; solar standalone systems	Cooling-when-available systems integrating thermal mass pre-cooling
Water use may be increased	Dry heat rejection (energy and performance issues); Ground heat rejection	Generally very favourable environmental outcomes, thus likely to draw significant public support
	MARKET	
Complex Australian market due to wide range of climates	Further experience in sales and marketing of solar cooling	Liquid desiccant systems which can be used as evaporative coolers
Distance to market is of complicating factor for European developers	European companies establishing themselves in Australia as market conditions improve	Large local and regional market for Australian-made/designed desiccant systems
	SOCIAL	
Public doesn't conceptually understand how heat can create 'coolth'	Education required	Eventually people accept technology without needing to understand its inner workings
Appropriately designed system has differing response to conventional A/C	Public tends to readily accept limitations of solar energy, but expectations must be managed	Unique features of solar cooling cast in a positive light – "come home to a cool house"
	BUILDINGS	
Not every building appropriate for SAC	Simple questionnaire to filter interested applicants	SAC may address existing building stock
Split incentive is a barrier	Energy Passport, Green Star	Increase rental and resale value of building
	ECONOMICS	
Upfront cost favourable only in rare circumstances	All elements of system cost – design, solar collectors, chiller, controls – need reduction	Other sources of heat have lower upfront cost, and assist in market stimulation
Favourable NPV uncommon today	More favourable as collector costs fall and if energy prices rise	Invest in R&D now as market conditions will undoubtedly become more favourable, to be harnessed at the appropriate time by prepared companies and nations
Externalities from impact of A/C upon the grid hinder SAC payback time	Impose grid infrastructure expansion cost upon A/C installers	Commission study on impact of A/C on the grid that evaluates solar cooling as one possible solution
Externalities from impact of A/C upon the environment hinder SAC payback time	Implement carbon tax	Solar cooling's lesser use of fossil fuels will only become more valuable

COMPETITORS		
Strong competition faced by regular A/C so long as externalities remain unaccounted for	Small market niches are possible and likely	A large enough market potential to support many small solar cooling companies
Larger market penetration depends on economics of SAC when compared to climatisation and peak load addressing equivalents		See Table 10, p 70

Table 8: Summary of Key Issues

9.1.1. Technical

There are no major technical barriers to implementation of solar air conditioners. However, there are acknowledged technical issues that limit the performance of solar cooling machines. As seen from the following discourse, all are solvable, but the solutions impact on the system performance and hence overall economics. Though technical barriers may be addressed and improvements in performance made, system viability is more limited by economics than technical performance, though of course the two are related. Consequently, even a 10% improvement in performance is not going to radically improve SAC market viability.

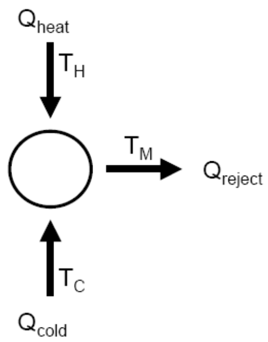


Figure 23: Thermodynamics of Heat Driven Cooling Devices[57]

There are certain thermodynamics laws that cap performance, dependant on the driving temperature source, rejection temperature, and desired output temperature, as illustrated in Figure 23. Thus, in order to achieve cooler supply temperatures, the amount of input energy must be greater, or the heat rejection effectiveness must improve. This can be achieved by a higher temperature source T_H or by increasing the temperature of heat rejection T_M, both of which options are limited. Alternately, the output temperature T_C can be increased. This explains why SAC performs better with applications such as radiant cooling or when handling sensible load only.

Even simply achieving theoretical performance in practise has its difficulties. To attain theoretical performance, heat and mass transfer must take place effectively, implying adequate and even surface wetting of sorbent (for liquid sorbents) or surface coating (for solid sorbents). In practise this is difficult to achieve, and is a focus of continued research.

Another aspect of delivering effective performance relates to the control of the solar cooling system, as suboptimal control strategies can lead to poor system performance or poor solar utilisation. During operation under part load, it is possible to change fluid flow speeds and temperatures to minimise cooling tower energy consumption and to maximise effectiveness of chillers, though this strategy is rarely implemented and requires some equipment modification. It is preferable under part load conditions to avoid frequent on-off cycling of machines, particularly adsorbent chillers, as thermal inertia should be taken into consideration – typically a cold buffer can assist in achieving this goal. FHS Stuttgart has demonstrated that a valuable improvement in system output can be achieved if present and forecast weather conditions are taken into account, though whether this additional performance is justified by the increase in system cost is doubtful at present. In contrast, it is highly desirable to keep the control strategy as simple as possible, as this minimises engineering design and component costs, as well as eliminating potential for complex interactions.

Rejecting the heat captured by the solar array and that extracted from the conditioned space is the role of the re-cooler. The re-cooler typically takes the form of a cooling tower, which may be wet or dry-based; alternatively the heat may be rejected to the ground. The problem with wet re-cooling is the amount of water used, of particular concern to the Australian public[viii]. Wet cooling towers also face Legionella concerns which, although simply addressed by appropriate maintenance schemes, may impose excessive maintenance costs beyond the value of the energy savings. Wet cooling towers also do not perform well in humid conditions, a problem which afflicts conventional air conditioners also. Dry cooling towers use far greater amounts of energy than wet cooling towers, which further eats into energy savings achievable with solar cooling. Dry cooling towers also have a larger footprint than wet cooling towers, problematic when roof space is at a premium, as it often is when large collector arrays are required. The alternative to cooling towers is to reject the heat via a ground-sourced heat exchanger. Because the ground temperature is cooler than the air temperature, increased effectiveness of heat rejection occurs, thus improving the performance of the chiller. However, ground heat exchangers are not suitable in all locations, and are expensive and of highly variable cost to install. There is also a possibility of a modest increase in local soil temperature[ix], with effect undocumented at this stage. Further development of cooling towers suitable with solar cooling systems is highly desired.

As noted in the previous section, the hydrodynamics design and installation of large solar panel fields is a specialised skill, and few practitioners have suitable experience, particularly within Australia. At this stage, the durability of newer technologies is uncertain, and it is too early to say how long they will perform. However, absorption and adsorption chillers and desiccant wheels have been in production for many years.

Some technologies face specific technical design and operational challenges. The salts used in liquid desiccant systems are highly corrosive, and must be prevented from carrying over into the air stream. This is typically achieved using low-flow air streams, which imposes large apertures and duct work. Mist eliminators may also be employed, which slightly increase the backpressure and thus required fan energy.

At a system level, as a result of the thermodynamic limitations and the not-insignificant amounts of electrical fan and pumping energy used, it takes careful design to ensure that primary energy savings are made – which is the main criteria of success. As shown in section 9.1.3, the cost savings may not be significant due to the comparative performance of conventional chillers, and primary energy savings may not be achieved if using thermal backup (e.g. gas) unless the system is carefully designed.

[viii] Though the author believes that CO_2 abatement is more important, as climate change will further reduce water availability in Australia.

[ix] Unless a heat pump configuration is achieved, in which the heat rejected in summer can be equal to the heat extracted in winter. See Fraunhofer ISE Section 8.2

9.1.2. Knowledge

Knowledge, experience, and familiarity with solar cooling systems is very low at present, a situation which applies worldwide, and also an area in which Australia lags behind Europe and Asia. The knowledge required to specify, design, install, and maintain a solar cooling system is very specialised, largely due to the system complexity. Currently, every system must be purpose engineered, as there is a strong need to size system components correctly to achieve desired performance. Though at some future stage standard units will be available to suit a given load, for the meanwhile engineers must be involved; a fact which is already quite typical in large-system HVAC design, but which is compounded by the additional specialised skills required by SAC.

Installation and maintenance are other areas requiring specialised skills. A sub-quality installation will grossly under-perform, and the present lack of experienced installers is compounded by the need for solar-familiar plumbers to come together with thermally-driven-chiller HVAC installers to achieve a quality installation.

The lack of knowledge extends to two critical areas – that of architects and the general public. Generally it is architects that specify cooling systems, and a lack of awareness and familiarity means that they will be hesitant to recommend solar cooling, even if they are aware of the technology. This issue may be addressed in methods employed by Arsenal Research, through facilitation of workshops with architects and supported by a simple sizing tool to assist in the understanding of system components. The general public remains quite unaware of solar air conditioning, and though they are typically quite supportive of the concept, most implicitly assume that solar air conditioning means photovoltaics rather than solar hot water, solar space heating and air conditioning. Certainly the concept of obtaining coolth from heat is difficult to fathom for most of the public. The expectations of the public must also be managed, as described in Section 9.1.5.

Universities are another area lacking in knowledge of solar cooling. Few research departments worldwide have conducted research into solar cooling, and as such it is yet to make its way to the core syllabus of engineers, architects, or planners.

Knowledge is a barrier that is best overcome through direct experience with systems. This may be achieved in early phases of nationwide adoption through the commissioning of demonstration projects. Initial projects can draw upon international experts until locals have sufficient experience.

9.1.3. Environmental

One of the key reasons for installing solar air conditioning systems is reduced GHG emissions. These come as a result of using less fossil fuel energy to provide coolth, but to achieve savings the system must be designed for a high solar fraction[x] or have conventional backup chillers. One problem faced by solar cooling is that for each thermal kW of cooling offset, only ¼ of a kW of electricity is saved, owing to the high electrical COP of conventional air conditioners, as well as the parasitic electrical energy associated with pumps and cooling towers. In comparison, 1kW of solar heating may offset 1kW of thermal energy from gas (or approximately 0.4kW of electricity in a reverse cycle air conditioner), making heating comparatively more valuable, although less well aligned with source and demand. Because of the lower conversion efficiency of thermally driven chillers (0.6-0.7) when compared to vapour compression systems (2.5-3.0), if a thermal

[x] A high proportion of energy supplied by the sun when compared to the fossil energy required to run the system

energy backup source such as gas is used to provide cooling in periods of insufficient solar radiation, a greater amount of primary energy may be consumed if backup is required often – with an associated increase in GHG emissions. For these reasons it is important to design the system for a high solar fraction, and preferable to use mechanical chillers as backup in order to ensure environmental benefit.

Solar cooling typically consumes more water than its mechanical equivalent. For DEC cooling, water is consumed as part of the evaporative cooling process, whereas a wet cooling tower uses the evaporative effect to assist in heat rejection. Although there are alternative options including dry re-coolers, they use more energy to operate. In a country whose drought frequency and intensity is predicted to increase due to climate change, water consumption is perceived very negatively amongst the public and politicians. When a trade-off between water and energy use exists, saving energy is rationally more economically advantageous, and climate change's effects will reduce water availability. However, public opinion is not necessarily based on logic.

Other environmental considerations include the impact of manufacturing and disposal of the refrigerants and sorbents (LiCl, LiBr, NH_3), which should be the study of a sustainability Life Cycle Analysis. Should there be a massive implementation of solar coolers, the effect of less reflected sunlight and greater rejected heat upon the local urban environment may need to be considered – although as such arguments are typically ignored for other urban development, pre-emptively applying them to solar cooling would be inequitable.

9.1.4. Market

There are some interesting market-related issues faced by the Australian SAC industry. For each climate band, a differing solar air conditioning technology and system is most appropriate. A solar cooling system that can provide space heating is of little value in northern Queensland, whilst a desiccant cooler is unnecessary inland. Consequently, the range of climates within Australia makes giving the public a simple solution troublesome, with associated future marketing challenges for those companies involved in sales. European manufacturers of residential solar coolers are as yet uncertain of the exact market requirements of a solar cooling system[xi], so adding further climate bands makes market analysis even more difficult.

Distance to market is a problem faced by the Europeans who were visited. Most of the technology expertise lay in Germany, whilst the initially most favourable market for closed cycle machines (absorption or adsorption chillers) is in Spain. Hot, humid climates where desiccant cooling becomes highly valuable lie further afield, though the proximity of a large Asian market to Australia's borders may offer great opportunities for exporting systems or services to the region.

The solar cooling market in Australia is already many steps behind that in Europe. In order to secure future economic benefits, it is important to act swiftly, whilst easy entry to an infant market is possible. It is likely that European companies will eventually manufacture in Asia, reducing construction and shipping costs to Australia and lessening the opportunities for local industry. Unless Australia is able to rapidly develop a liquid desiccant system, which offers greatest possibilities in Australia and the region and is

[xi] System parameters can be adjusted to meet differing solutions, such as different temperature collectors or types of heat rejection, but they can only be adapted at manufacturing time. The initial solution may suit the present market needs, which are likely to evolve.

least developed, Australia risks being relegated to a service provider, and only then if concentrated efforts to build local expertise in system design are made.

In order to achieve this, Australian governments must realise the value of solar cooling as a way of reducing pressure on peak electrical infrastructure and a simultaneous opportunity to reduce GHG emissions. Acting against this cause may be those with vested interests in current regime – those who manufacture conventional air conditioners as well as those who profit from selling energy including those associated with the fossil fuels that generate electricity, well recognised in Australia as a powerful lobby group.

9.1.5. Social

Social perception and behaviour may present issues for solar cooling. A lack of understanding is the first barrier. Most people assume solar air conditioning involves PV rather than solar thermal energy, and people don't conceptually understand how heat can generate 'coolth'. People may expect the same performance or operation as they have in a conventional system, or may overuse the system in the belief that it's 'free' cooling. Should a system fail for any reason, even though performance depends on a number of system components the chiller is likely to be perceived as the culprit, however unfairly. Eventually systems may be installed which fall below appropriate standards and earn the industry a bad name. As such, social expectations need to be managed.

At present, people are familiar with the operation of the on-demand, instant response of conventional air conditioners, and may expect solar air conditioning to provide the same characteristics or performance. To supply instant on-demand response requires an oversized system that is more likely to rely on fossil-fuel input, thus increasing system cost and also reducing environmental benefit. A smaller system which stored energy in building thermal mass rather than an oversized liquid storage vessel would be less expensive, use less operational energy, and could be configured to "cool when the sun is shining". Carefully controlled to prevent unnecessary operation, such a configuration could offer the public the opportunity of coming home to a cool house instead of having to wait for the air conditioner to 'kick in'.

This indicates the need to shift and manage the public's expectation, something that implies education is necessary. A critical aspect of this is preventing misuse, ensuring that the operator does not over-use their air conditioner in the false belief that it's free or 100% green, thus overlooking the electricity required to run pumps, fans, and re-coolers. A sufficiently large solar collector and chiller may provide the necessary cooling 90% of the time required but be unable to satisfactorily provide cooling in the remaining 10% of hot cloudy days. If the client has chosen to avoid the additional cost of a conventional backup system for such occasions, then their expectations must be moderated by unambiguous methods to ensure understanding and satisfaction.

In future it is likely that if a solar air conditioning market booms, a small percentage of installations may be of lesser quality, particularly if corners are cut and inferior collectors are used. In such cases it is likely that the customer will point the finger at the cooling machine, even if the fault lies in elsewhere. Even though education may reduce such occurrences, it is likely that to protect brand name, cooling device manufacturers will need to take some responsibility for the overall system.

A final aspect of public opinion which must be managed is the public dislike towards cooling towers. Whilst residential systems are unlikely to include a wet cooling tower, as its maintenance requirements are likely to go unheeded, cooling towers are a performance necessity on larger systems. This is a minor hindrance, as most architects and engineers recognise the necessity of a cooling tower and understand that a properly maintained cooling tower poses no health threat. Even so, if governments follow Spain's lead in imposing overly restrictive regulations upon cooling towers, then the solar air conditioning industry has an issue on its hands.

9.1.6. Buildings

Buildings themselves present issues for solar cooling. Buildings to which solar air conditioning may be applied are limited to those with sufficient roof area and preferably those with aligned solar load and cooling demand, which incorporate radiant surfaces, and are reasonably airtight. Finding such combination in new or existing building stock is quite rare.

A building's roof area must be sufficiently large to hold the solar collector array. A rule of thumb is that every m^2 of collector area is able to condition a 4-6m^2 space. This limits solar cooling to buildings less than six storeys high – higher than this and the solar contribution becomes less significant and the maintenance of an extra system makes the concept less workable.

Solar cooling is ideally suited to buildings with high correspondence between solar load and cooling demand. Such buildings allow systems with reduced water storage volume, resulting in simpler, more responsive, and cheaper systems. However, such applications are typically limited to highly glazed, poorly performing buildings, of which fewer and fewer are being built as building designers become more energy conscious.

One of solar cooling's strengths is its ability to be retrofit to address the excessive solar-related cooling needs of existing building stock. However, the system performance is improved with airtight buildings with radiant cooling surfaces, the likes of which are more commonly installed in new building stock build to achieve greater ESD standard. In such buildings, whilst solar cooling can make a sound contribution, it must compete with efficient modern cooling systems (see 9.1.8).

Although solar cooling may find a significant residential market within Australia, there are system optimisation boundary conditions that constrain the solution set of solar cooling systems. A residential system needs to be lightweight, easily installed, require little maintenance, and take up little room (including the storage tank). Less stringent conditions apply to commercial systems, in which required maintenance is assumed, and size is less of an issue.

The split incentive is a problem faced by solar cooling, and applies equally to all environmentally beneficial technologies that are more expensive than conventional counterparts. When a building is to be leased, there is little incentive for the developer or owner to install equipment with lower running cost but greater upfront cost, when ongoing costs are borne by the leaser. Until some return on green investment is facilitated, through such mechanisms as advertised star ratings and (even better) an energy passport, solar cooling will only find niche markets amongst green-conscious building owners and long-term leaseholders.

9.1.7. Economics

Although a simple comparison of SAC and conventional A/C system prices is difficult to achieve, the economics of solar cooling are generally unfavourable when compared to conventional cooling systems. In a limited number of circumstances, SAC system upfront costs may be smaller, though generally the cost is greater and has simple payback period of 10-20 years or greater. It is likely that as energy prices increase and component costs decrease, solar cooling's economics will improve considerably.

Unfortunately, it is difficult to compare solar and conventional system costs without detailed computational analysis. The type of the chiller affects the unit cost of the solar array that needs to serve it, and the system capacity directly affects the collector area, chiller capacity, and cooling tower capacity (if required). The amount and therefore cost of storage is dependent upon the building and application, and the complexity of the system affects the cost of design, control, and installation. System cost generalities have been drawn below, and the only existing comparative study into Australian solar cooling system costs (the Basset report) is referenced below. However, in order to provide an indication of system and component costs, the following table is presented.

Manufacturer	Type	Capacity	Cost	Notes
Components				
Phoenix	Absorption	10kW	A$13,500 (€8,000)	Plus solar collector, pumps, cooling tower, controls, installation
Rotartica	Absorption	5kW	A$8,400 (€5,000)	Plus solar collector, pumps, controls, installation
Rotartica	Absorption	8kW	A$10,000 (€6,000)	Plus solar collector, pumps, controls, installation
Broad	Absorption Chiller		A$685/kW (400€/kW)	Plus solar collector, pumps, cooling tower, controls, installation
Thermax	Absorption Chiller		A$900/kW (534€/kW)	Plus solar collector, pumps, cooling tower, controls, installation
General	Absorption chillers		A$420/kW (250€/kW)	Plus solar collector, pumps, cooling tower, controls, installation
Alternatives				
General	Reverse Cycle Split System		A$128-389/kW [58] upfront (A$3,000/kWe infrastructure)	Plus Installation
PV		2.5kWe	A$31,000 installed	Plus A/C & installation. Provides 5kWth equivalent cooling at 4pm with COP=2.5
Systems				
Rotartica	Solar cooling system	5kW	A$35,200 (€21,000) installed	
Rotartica	Solar cooling and heating system	5kW	A$50,000 (€30,000) installed	

Table 9: Cost Indications for Selected A/C Components and Systems

In most cases, solar cooling installations have greater upfront cost than conventional equivalents. This is largely due to solar collector array, which typically forms the greatest part of the system cost. The greater cost per kW of thermally driven chillers when compared to mechanical equivalents also increases comparable system cost, and a larger cooling tower is also required. Furthermore, system complexity presently imposes the need for design to be performed by a specialist engineer, and installed by specialist service technicians. Therefore, the energy savings achieved by a solar air conditioning system must justify its additional cost, in order for a building owner-occupier to justify its installation.

Cheap energy prices in Australia tend to lengthen the payback time of solar cooling systems. Until cross-subsidies removed from installations of conventional air conditioners, and subsidies are removed from – and environmental externalities incorporated into – energy prices, the energy savings possible with solar air conditioning will be undervalued.

There are applications, however, in which the upfront system cost of a SAC system is comparable to that of a conventional system. These tend to occur in desiccant systems in humid environments, in which a reduced size conventional chiller handles sensible load only, and at greater efficiency. A sub-station upgrade might also be avoided by installation of a smaller electrical chiller, of benefit to comparative costs of an SAC system.

Even when upfront cost of a solar cooling system is greater than a conventional equivalent, it is possible to achieve favourable payback. The Basset report performed an NPV analysis on solar cooling installations in Australian capital cities, and identified locations and applications with favourable cost and environmental outcomes. Modelled commercial buildings in Adelaide, Brisbane, Darwin, Perth, and Sydney, as well as hotels in Brisbane, Darwin, Melbourne, and Perth had favourable NPV and reduced GHG emissions (see Figure 24). Desiccant systems for such buildings were found to have the greatest potential to reduce GHG emissions in most applications, however were found to have less desirable NPV. This study should be revisited in light of technology advancements and the rising costs of electricity owing to rising fossil fuel prices, carbon signals, and increasing impact of air conditioner cross-subsidy in a warmer environment. A similar study of the potential of solar air conditioning systems in residences should be conducted to identify the necessary pricing conditions in which such systems become favourable to the home-owner. A triple bottom line analysis should be also performed in such a study to establish whether government support or market intervention to achieve such conditions is desirable for Australia's economy and environment.

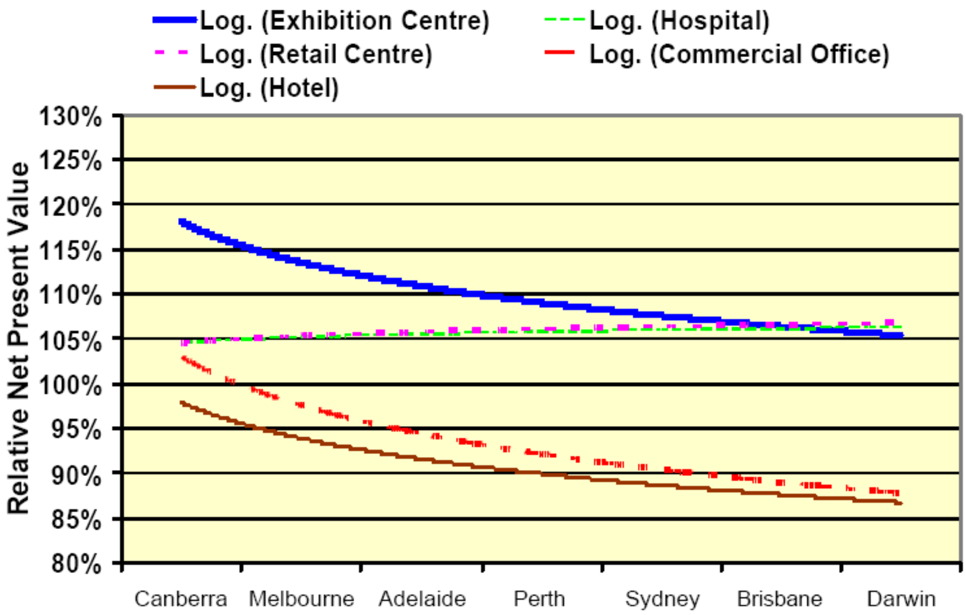


Figure 24: Relative NPV for 50% Absorption System[59]

The major cost component which limits the economic attractiveness of solar cooling systems at present is the cost of the collectors. Although continued cost-savings are being sought in thermally driven chillers[xii], they have less-significant impact on system cost than a proportional decrease in collector cost. As the solar hot water market grows in Australia and worldwide, the collector's cost can be expected to decrease, however it is likely that less dramatic savings will apply to the high-performance collectors used in non-desiccant solar cooling systems as they will continue to be components produced in comparatively low-volumes. By buying in bulk, overheads are minimised and thus one method of reducing the cost per unit area of the solar collector array is to increase its size. This faces complications when the solar field becomes large enough for hydrodynamic considerations to impact upon the system, beyond which point specialist design services are required (See section 9.1.1).

The analysis performed in the Basset report was limited to high-capacity coolers. A standardised domestic system has not yet emerged, so only the expected costs of cooling components are presented in Table 9, p67, alongside some indicative system costs.

9.1.8. Competitors

Any system that provides a ventilated space within human comfort boundaries acts as a competitor to solar air conditioning. For solar air conditioning to be chosen over other forms of climate control, it must have superior performance in economic, energetic, and environmental terms. Its competitors in this area include conventional air conditioning in addition to passive buildings and energy efficient air conditioning. Solar cooling's other benefits – avoided energy consumption at peak times – may also be achieved by other means including photovoltaic systems, load shedding, and load shifting. In addition, solar cooling must compete with other applications of solar thermal energy such as seasonal thermal storage. In order to win a major market segment necessary for solar cooling to fulfil its potential, a strong case must be made for the benefits of solar cooling technologies in comparison to alternatives.

[xii] Including by tapping alternate sources of heat, to increase sales and experience.

Competitor	Pros	Cons
ALTERNATIVE CLIMATISATION		
Reverse cycle A/C	Economical installation, high energy use, established, ease of installation	Split incentive and short-sightedness suggest that without intervention, reverse cycle A/C will continue to dominate
Passive building design	Avoidance or minimisation of energy requirements in (heating and) cooling No operational cost, and equivalent upfront cost if appropriately employed. New buildings only	Employ passive building design in preference to active cooling, but there are always some climates, sites, and building applications that will require some active cooling. SAC can address existing building stock
Energy efficient A/C	Typically simpler and more cost effective than solar cooling	Split incentive applies Peak load only slightly lessened
PEAK LOAD MITIGATION		
Load Shedding	Simple method of addressing peak load strain. Interval meters, which assist in load shedding in residential settings, will also benefit solar cooling	Significant economic impact and little reduction in GHG emissions
Load Shifting	Cost effective	Increases use of energy and associated environmental impact
PV installation	More straightforward, offsets network infrastructure costs. Both PV and SAC stand to benefit from interval metering	Less directly coupled peak load and PV output. No hot water or heating benefits
OTHER SOLAR THERMAL APPLICATIONS		
Seasonal Thermal Storage	Of comparable energy efficiency as solar cooling. Technologically less challenging	Doesn't address peak load concerns. Most suitable to regions that require winter heating with district heating networks
Seasonal Desiccant Storage	Variant on solar cooling applicable to climates with shorter cooling season, or for use in creating hot dry air for industrial use. Possibly an opportunity for liquid desiccant systems to expand in southern markets	Limited by relative costs of solar array, desiccant salt, and storage vessel
Solar Cooling	Competition amongst technologies will eventually occur, although each technology ideally suited to different applications, and there is sufficient market for all technologies to coexist	

Table 10: Summary of Competitors to Solar Cooling

Conventional Air Conditioners

Climate control may be provided in means other than through solar air conditioning. Conventional air conditioners are very cheap the world over, both at the residential and commercial scale, and it is highly improbable that solar cooling systems will ever be cheaper than conventional residential reverse cycle air conditioners. As such, the significantly increased price of solar air conditioners must be justified through acceptable payback times in order for solar cooling to secure reasonable market share. Although cheaper air conditioners tend to be less efficient and thus consume significant amounts of energy, the energy savings made possible with solar air conditioning aren't valued significantly enough by today's inexpensive electricity prices. So long as the impact of conventional air conditioners upon the grid remains unaddressed (see Section 5.1), and environmental impacts remain as externalities, it will take dramatically reduced solar air conditioning system prices, in conjunction with higher energy prices, for solar cooling to achieve short enough paybacks to warrant large-scale deployment.

Another method of achieving comfortable internal conditions removes the need for air conditioning altogether. Passive buildings are able to self-regulate internal temperatures through a mix of site selection, building orientation, insulation, high thermal mass, air-tightness, and window and eave design. Such elements of passive design typically cost less than an air conditioning system and have no operational costs. As such, it is universally agreed that such buildings should be chosen in preference to a poorly performing building supplied with solar air conditioning. However, whilst passive design is effective when designing a new building on a suitable site, there are always sites that do not meet preferred design criteria which will need some active cooling system. In addition, there is a plenitude of existing building stock which solar cooling may supply more cost-effectively than retrofitting passive design measures. In addition, there are many building sites and applications (especially commercial buildings with high internal loads) that require active cooling. Furthermore, in tropical climates passive means are unlikely to remove the need (or desire) for air conditioning in many building types. Hence, in buildings and environments poorly suited to passive building design, and notably existing buildings, solar cooling is appropriate.

One of the benefits of solar cooling is its ability to provide climatisation with reduced energy consumption. This benefit can also be achieved through highly energy-efficient air conditioning systems, the likes of which are being increasingly installed in green commercial buildings recognised by AGBR and Green Star ratings schemes in Australia. Such systems include air conditioning systems with COP of 5 or greater, as well as displacement ventilation, often in conjunction with mixed mode ventilation. Such systems out-compete solar cooling in high-rise commercial building, in which a reduced plant area is of constraint. In shorter buildings, solar cooling may be applicable, though must then compete against energy efficient air conditioning systems on the basis of upfront cost, as their energy savings are more marginal. In hot, dry climates, evaporative cooling is often more cost effective and energy efficient than regular air conditioning; it follows that solar air conditioning is even less viable in such climates.

Peak Load Mitigation

Removal of load from an electricity grid facing peak demand enables A/C use without grid disruption. This is commonly achieved by paying large electricity users to remove their load at peak times. Load shedding already occurs in many locations, for example the Alcoa factory in Victoria consumes a significant proportion of the State's electricity. Turning off this plant alleviates the strain placed on the grid by the numerous air conditioners running on hot sunny days. This has commercial ramifications for the power company, the load-shedding company involved, and the State's productivity. Such a concept may also be applied in a distributed manner, by rewarding or forcing suitable electricity consuming devices, such as refrigerators, to power save during periods of peak load[xiii]. However, this faces technical challenges and is reliant upon regulation or incentives. Load shedding doesn't provide air conditioning directly, but allows use of air conditioners without causing grid failure. Additionally, load shedding has only marginal environmental benefits, but remains the most often considered method of addressing peak load.

Load may also be shifted to other periods of the day. By creating and storing coolth at non-peak times, for later use during times of peak demand, air conditioning may be provided without straining the electricity grid. Typically, ice is manufactured in off-peak times when electricity costs are halved, for later reuse in cooling air. However, although this achieves cost savings and reduces strain on the grid, the inefficiencies involved mean that more energy is used overall, with consequently greater GHG emissions. As such, there are drawbacks to widespread implementation of this approach as it's a solution driven by economic rather than environmental benefit.

One approach that alleviates strain upon the grid at times of peak demand, thereby enabling air conditioner usage at such times, is the installation of photovoltaic (solar electricity) systems. Although PV systems may be configured to directly connect to a suitable air conditioner, in most applications connecting the PV system to the grid would be most sensible. The power output of the PV system may be designed to match the power consumption of the air conditioner, thus offsetting the energy usage of the air conditioner at times strongly correlated to peak demand. However, the PV system will not perform in cloudy humid conditions, a scenario in which a solar cooling system with storage or thermal-mass activation would deliver comfortable conditions, and consequently the user must either forgo cooling in such conditions or again place a strain on the grid. Such a system has different benefits to a solar cooling system; in place of domestic water heating and winter space heating (mainly useful in southern latitudes), a grid-connected PV system provides year-round electricity generation. Similarly to solar cooling, PV systems would benefit from recognition of the value of offset peak electricity, whether by interval metering and/or by recognition of avoided cost of peak-load infrastructure. To address the infrastructure costs associated with conventional air conditioning use, those who install new air conditioners could be required to install an equivalent amount of PV.

[xiii] As has been successfully trialled in Glenelg: http://www.etsautilities.com.au/media_release.jsp?xcid=1075

Other Solar Thermal Applications

The same resource that is being used to provide cooling – solar heat – can also be used to other means. Seasonal thermal storage is the process of storing the sun's heat harvested in spring, summer and autumn, for use in winter space heating. Due to the longer solar harvesting period, a smaller solar array is possible, though a significantly larger storage vessel is required to be insulated and placed underground. Although solar cooling combi-systems are able to provide space heating and domestic water heating, seasonal thermal storage systems have similar efficiency in delivered energy, and similar costs. The required temperatures are lower than those required for absorption chillers, meaning collectors are cheaper and more efficient, and losses in storage of about 50% are comparable to the COP of adsorption chillers. As such, the energetic efficiency of such systems in delivering winter heat is equivalent to that of comparable systems delivering summer coolth. However, the suitability of such systems is limited to heating-driven climates. Additionally, such systems typically are of such scale that district heating networks are required, the likes of which are rare in Australia.

Seasonal desiccant storage is a similar application to seasonal thermal storage, in which potential energy may be stored in the (liquid-) desiccant salt in a lossless manner. Stored desiccant may be used to heat and dry air, or to dry and then evaporatively cool air for summer cooling. A reduced solar array size is then able to harvest heat over a longer period of the year, for use in a briefer cooling period. The reduction in solar array size and cost must be balanced with the expense of greater volume of storage tank and desiccant salt. The application of such is therefore limited by the salt's cost, and local climate.

SAC technologies must eventually compete for market share amongst one another, both across and within the technology categories. The industry consensus is that, if there is a market for solar cooling, the market is big enough to sustain all current solar cooling technologies. There is no clear-cut universal solar cooling configuration appropriate to all buildings and climates, although certain technologies are favourable under particular circumstances. As such, it seems that, at least initially, all forms of solar air conditioning may cooperate without need to compete. However, the market will decide which technology dominates within each sector and climate on the basis of which technology can supply the cooling function in the most cost-effective manner. As such the solar cooling technologies will eventually find competition amongst one another. Companies willing to invest in solar cooling should consider the likelihood of eventual competition from China and India. Although there are presently market niches in which there is no suitable cooling device compatible with solar energy, when such markets are demonstrated it is certain that the interest of existing and new players will be aroused, and low-cost devices will follow. In such eventuality, only chillers containing unique technologies will be able to differentiate themselves from more basic competitors, although eventually the best performer per dollar is likely to dominate the market. Though this point is some time off into the future, it is then that local actors within the solar cooling market should focus on service-, rather than product-, delivery.

9.2. Opportunities

Australia has some interesting characteristics which make it a large, but quite unique market. These relate to the climate, wealth, and location of Australia. Investors and Governments soon need to decide whether Australia chooses to develop local solar cooling product and expertise before opportunities are missed and Australia is relegated to playing the role of product importer and having services provided by European companies.

Australia has a large market for residential-sized air conditioners. In contrast to much of Europe, in which air conditioning is primarily required in large offices only, most Australian offices require air conditioning throughout, and air conditioning is installed in a high proportion of residences throughout Australia. This presents an opportunity for mass-manufacturing to reduce system costs. Due to Europe's population density, Australia's residential air conditioning market may be of comparable size, although Australia's more humid and tropical climate means that mass-manufactured European models are less likely to best suit Australian conditions. Thus, while European operators continue to develop a mass-manufactured product in their local market, there exists the potential for establishing a home-grown alternative that is particularly suited to Australian conditions[xiv].

In addition to the local market, there exists on Australia's doorstep a large, increasingly wealthy population with growing demands for cooling and escalating impact on the global environment. The climatic requirements of the tropical Asian market are more akin to Australia's tropical north than Europe's temperate south or the Middle-East's dry heat. As such, any expertise developed in Australia could readily be applied to our region. Australia could provide locally-developed product to Asia, and could certainly provide solar cooling services regardless of which regional nation manufactured the product. Australia could therefore reap the rewards offered by proximity to market in technology specifically appropriate to the tropics. The AP6 may provide the perfect forum for regional cooperation in development and transfer of technology and services.

Solar cooling professionals in Europe are eager to build upon their operational data set in new climates, and as such are keen to assist in monitoring Australian solar air conditioning installations. Participating in such programmes as the IEA-SHC Task 38 would greatly benefit the knowledge and skills transfer to Australia, and provide access to an international network of experts. Development of the worldwide solar cooling industry would also benefit from Australia's participation, as access to data throughout the whole year (northern and southern summers) would then be available. As such, now is an opportune moment to engage with Europe and to develop Australian solar cooling expertise.

Currently the solar cooling industry is quite young. At present the most promising technology for the Australian climate, liquid desiccant, is only emerging and holds significant promise of further development. It is therefore possible for Australia to rapidly accelerate its expertise in solar cooling, to become a leader in liquid desiccant technology and systems, and to do so before it becomes too late. Such knowledge also opens gateways to other opportunities of transforming heat into cooling, such as landfill gas, cogeneration systems, fuel cells, and trams and trains. Should Australia, through lack of investor interest and Government support, fail to capitalise on this present moment opportunity, it may find itself importing product from Asia and services from Europe, thus exporting the profit of all services except that of installation. It would be more beneficial to take advantage of Australia's climate, more similar to Asia's than Europe's, in developing local solar cooling expertise and product appropriate to the tropics.

[xiv] A home-grown solution may incorporate heating of Australia's ubiquitous backyard swimming pools, a possible method of addressing heat rejection difficulties.

10. Recommendations

For solar cooling to realise its full potential, the combined efforts of industry and government are necessary in order to overcome technical and market barriers. The benefits of addressing such issues reverberate far beyond solar cooling, and are important for Australia's energy security and for the global environment. The strategy for development of solar air conditioning in Australia relies upon active promotion of solar cooling and installing systems wherever appropriate. Beyond initial systems in niche applications however, eventual government support is required in order to overcome significant market distortions skewed towards the current energy paradigm. Only then will solar cooling be able to compete economically and establish a reasonable market share in which its benefits may be realised.

Action	Benefit	Who
INDUSTRY		
• Identify and pursue most favourable applications	Economical application	Solar cooling specialists
• Demonstrate system's technological feasibility and establish costs	Provide government with incentive to support industry and address barriers. Develop the industry	Solar cooling specialists and solar hot water panel producers
• Promote technology to architects	Encourages specification and uptake of systems	Solar cooling specialists
PROFESSIONAL ASSOCIATIONS		
• Advocate for removal of market distortions and recognition of value of peak energy. Support SAC	Benefit the whole solar energy industry by increasing value of energy generated at peak times	BCSE
• Adopt SAC as a marketed candidate for ABGR recognition	Increase awareness and uptake of solar cooling	Green Building Council
GOVERNMENT		
• Provide financial support for SAC demonstration systems	Reduce risk barrier to first installations. Gain valuable insight and experience. Access monitoring data	State Government sustainability agencies
• Commission inquiry on impact of peak load and its relationship with air conditioning	Fully understand impact of air conditioners upon the grid, with associated social, economic and environmental problems. Determine suitable methods of addressing cause of problem	State Government energy agencies

• Apply tariff related to grid infrastructure expansion cost to every air conditioner installation • Offset tariff when PV is installed	Reduce rate of air conditioner installation. Reduce rate of infrastructure expansion. Reduce GHG emissions. Support the renewable energy industry. Level the playing field	State Government energy agencies
• Implement energy passport to address split incentive in leased buildings	Provide incentive for owners to improve energy efficiency of leased buildings. Stimulate the property market, address existing building stock	Federal Government
• Mandate occupancy of energy efficient buildings for all government bodies	Stimulate the property market and address energy efficiency of existing building stock	Local, State, and Federal Governments
• Implement a Carbon Tax and/or ratify the Kyoto protocol	Internalise GHG emissions. Support renewable energy and energy efficiency industries	Federal Government
	EDUCATIONAL INSTITUTIONS	
• Include solar cooling as course component of architecture, mechanical engineering, building services, and sustainability courses	Raise awareness of solar cooling	Universities and TAFEs
• Include solar cooling as a detailed subject studied optionally in mechanical engineering	Develop understanding of designing solar cooling systems	Universities with solar expertise
• Research and develop liquid desiccant systems	Develop applied expertise and an Australian solar cooling product	Universities with solar expertise
	COMMUNITY	
• Demand action on climate change. Make climate change an election issue	Demonstrate to government that there is public demand for a full-scale response to climate change	General public

Table 11: Summary of Recommendations

10.1. Industry

Ultimately, responsibility for the establishment of a local solar air conditioning industry lies with the present industry actors themselves. For only when governments have confidence in solar cooling will they support it directly. As such it is up to the industry to convince the government of the merits of directly supporting solar cooling, and of addressing barriers associated with present market structure.

To achieve this, present actors in solar cooling in Australia will best assure governments of solar cooling's technical viability by demonstrating the technology in the facilities of early adopters. Although there are presently no specific funds that explicitly support solar cooling installations, more general funds such as VSII and RESF[xv] could provide assistance and client incentives for initial installations of solar air conditioning systems.

For initial systems, prior to explicit government financial support and before the removal of market barriers, and long before an established industry is able to compete unsupported, the most favourable scenarios for solar cooling need to be identified and exploited. Although solar cooling is one of the few methods of addressing existing building stock, initial installations may be more straightforwardly applied to new buildings. Solar cooling systems perform better in such buildings where there is opportunity to provide radiant cooling, also buildings in which ground-sourced heat pumps are being considered may be favourable for solar cooling. Other opportunities may include multi-purpose centres incorporating swimming pools. Greatest demonstration value, as well as technical and economic feasibility, will be found in larger-scale applications. The most technologically and economically favourable solar cooling installation sites should be identified and pursued so that initial systems may demonstrate their viability. Industry members such as ECS, Conergy, and Going Solar should continue to perform this action on an ongoing basis, and mutual cooperation would be in the industry's interest at this stage. Those with a strong vision for the future should join the IEA-SHC Task 38. These steps will assist in the industry development, provide technical assurance, highlight a potential market, and hopefully facilitate further government assistance in developing a large industry.

Hand in hand with the requirement to demonstrate systems is the need to promote them. Raising awareness amongst specifiers of HVAC systems is crucial, and architects in particular should be targeted. Simple supporting software tools will benefit architects' understanding of the application, implications, and limitations of solar cooling. Presentations to the RAIA in particular should be made, possibly enlisting the support of the AIRAH. Sustainability and Environment arms of government, including SV and the AGO should be made aware of all solar cooling development activities and opportunities. Incorporation of the press to stimulate public awareness would also be worthwhile.

Beyond initial systems, low hanging fruit should be identified and pursued, although under current economic conditions few have been identified thus far. However each installation increases the industry's self-sufficiency and merit for support. Future development of an Australian-made solar cooling technology should also be explored as a possibility. This may take the form of a partnership with an existing company, and may be supported by a REDI grant.

10.2. Professional Associations

In addition to direct advocacy by individual actors, industry representative bodies such as the BCSE should be utilised to advocate on the industry's behalf. This is particularly the case as they are representative of such existing solar cooling participants as ECS, Conergy, and Going Solar. Additionally, many other members of the BCSE stand to benefit from addressing the market distortions identified as barriers to solar cooling specifically, but also sustainable energy in general. The BCSE should make appropriate submissions to national and state governments. Additionally, the Australian Building Rating Scheme should be approached to ensure that solar cooling is a promoted technology recognised as suitable for building star-rating systems.

Professional associations directly representative of the HVAC industry, such as AIRAH, may also be engaged to advocate on solar cooling's behalf. However, as they represent

[xv] See Governance, p53

the broad spectrum of conventional and non-conventional air conditioning technologies, they are less likely to promote one at the expense of the other. However, educational material including seminars and articles in member magazines should draw support.

10.3. Government

Many of the barriers faced by solar air conditioning may be addressed by government directives. Such directives should assist in addressing peak load concerns, split incentives, and climate change, and would benefit not only solar cooling but sustainable energy in particular and quite possibly the market as a whole.

The first aspect of government support is to provide explicit funding for solar cooling demonstration systems. An AGO study has already concluded that solar cooling is viable in particular climate and application combinations, yet there is little evidence of further action on supporting solar cooling systems from the Federal Government. Some of the state governments, most notably the Victorian Government, have renewable energy demonstration funds which could be applied to solar air conditioning systems, however there is broad scope for the expansion of similar programmes into other states, and for earmarking funds specifically to solar cooling systems. State-based support schemes would allow tailoring of funding to relevant climate-specific attributes, and a distribution of systems and technologies is probably necessary before the federal government throws its support behind solar cooling in any considerable manner. Alleviating peak load should be addressed by state agencies with energy, sustainability, and environmental responsibilities by communicating with energy suppliers and solar cooling companies in order to develop an appropriate support fund that may alleviate the effects of peak load upon the grid, economy, and environment. Such a fund may specifically earmark funds for solar cooling demonstration projects, though it should fairly be accessible to other forms of load reduction.

At a national level, a detailed enquiry should be commissioned into solar air conditioning's potential to solve problems associated with peak load[xvi], so that energy, economic, and environmental effects may be quantified. However, so long as the wholesale price of peak energy is hidden from the consumer, then demand for air conditioner use by the general public will continue to rise. The best method of passing price signals to the consumer is through interval metering, and these should undergo an accelerated rollout, particularly in regions of high air conditioner penetration. A suitable pricing strategy, simple to understand yet reflective of peak electricity prices, should be implemented in those regions, and may be paired with automated load shedding and/or consumer feedback. In this way, the public are made aware of the costs of running their air conditioner and may choose to lessen the load on the grid by turning off appliances, switching to air conditioning alternatives, or paying for the impact they are having on the grid. A reduction in peak demand is the likely result, one that will see avoidance of further peak electrical infrastructure installation, with associated environmental and national economic benefits. In addition, the value of generating electricity at peak times may be recognised through rewarding PV-generated power with tariffs which reflect actual wholesale generation costs. Such a move is likely to decrease the payback time for PV systems, thus leading to further installations with environment and renewable energy industry benefits. The federal or state governments should therefore promptly regulate the accelerated uptake of interval metering.

[xvi] Studies into energy efficiency standards and demand management as responses to problems associated with conventional air conditioners have been performed, though they have not considered solar air conditioners. As an example, see http://www.energyrating.gov.au/library/pubs/200422-ac-demandmanagement.pdf

To further address the cause of peak load – air conditioner use – the true cost of an air conditioner installation could be passed onto those that install air conditioners. In this manner, the hidden subsidy is removed so that the user pays the network expansion cost rather than the taxpayer and all electricity customers. Such a move would lessen the installation of air conditioners and halt the increase in peak load demand. The consumer may elect to install a PV system of equal capacity to their air conditioner instead of paying this money directly to the government, thus addressing peak load issues in tandem with providing environmental and sustainable energy industry benefits. A study into the true energy, economic, and environmental effects of peak load and air conditioning should consider this possibility.

Property managers should be rewarded for the installation of energy conservation measures, thus creating a market for more efficient HVAC and lighting systems. The current split incentive that applies hides the operational cost of rented properties from occupants, and provides no return on investment to the owner that installs more expensive but energy efficient equipment. Implementing an 'energy passport' in the same manner as Germany will improve the energy efficiency of leased properties, further stimulate the market for green buildings, and deliver energy savings to renters and owner-occupiers alike, with associated reduction in GHG emissions. Solar cooling would benefit from an energy passport, although it would have to compete with other energy efficient HVAC systems in this technology-neutral approach favoured by market purists. The federal government should rapidly implement an energy passport, possibly to be administered by the Green Building Council of Australia, and draw upon German experience.

Governments Australia-wide have a responsibility to mandate improvements to average building performance. In part this is being achieved through home rating, AGBR, and Green Star schemes. However, for the large part existing building stock is not being addressed, and the schemes are unlikely to have significant impact in the near future with present building turnover rates. The energy passport is also an effective means of addressing the plethora of existing building stock that underperforms. Solar cooling, as a potential method of addressing existing building stock, stands to benefit from such an approach, as does the environment and a stimulated and more energy-efficient economy. By mandating occupation of minimum energy-passport rated buildings, governments at all levels throughout Australia can stimulate significant improvements in the average building performance throughout Australia.

Australia's Federal Government has elected not to ratify the Kyoto protocol, instead opting for the non-binding AP6 agreement. With no firm commitment to addressing the cause of climate change, and with businesses lacking price signals that force them to take environmental impact into consideration, Australia risks continuing to operate without regard to climate change prevention. The Business Roundtable on Climate Change demanded the government adopt GHG pricing signals, which would benefit all renewable energies by making them more cost-competitive. Australia's status as environmental pariah may also be lessened by this act, and opportunities for engagement with Kyoto countries may be reopened. Implementing a carbon tax, or at least ratifying the Kyoto protocol, would benefit solar cooling, sustainable energy, and the environment directly and increase investor confidence in the sector.

10.4. Education and Training

Universities and training organisations recognise the vast solar resource available within Australia, having areas of expertise in PV and solar thermal energy. However, solar cooling is barely mentioned in most relevant courses, let alone the fundamentals taught. This situation could be addressed by including solar cooling as a course component of sustainability, energy, and engineering courses, initially as a single lecture to develop awareness and stimulate student interest. However, for more substantial inclusion in undergraduate engineering courses to occur, there needs to be a demonstrable market. So too, to develop the solar cooling industry beyond the initial installations there needs to be local specialists with appropriate training. Thus, once initial installations are in place, there needs to be specific masters of engineering courses with detailed solar cooling components, as well as more technical training in installation of combined solar hydraulic and HVAC systems, necessary to ensure qualified installers perform quality installations. This training will likely involve the in-house expertise of solar thermal energy engineers. However, until this point is reached, awareness raising within sustainability, mechanical engineering, and building design courses should focus upon guest lecturers.

Further research and development is required in solar cooling, if Australia is to have the ability to train local experts and develop local products. Solar cooling technologies, in particular liquid desiccant, have significant scope for refinement and development, and are of particular relevance to tropical regions of Australia and Asia. PhD projects in such technologies should be encouraged as part of broader solar cooling programmes within chosen centres of excellence. Such centres could also work together to further improve cooling towers compatible with solar cooling systems.

10.5. Community

The community is generally uninformed of the significant amounts of energy consumed by air conditioners, and ignorant of their impact on grid infrastructure. Although the public is gradually associating energy use with greenhouse gasses, on-demand comfort generally takes greater priority. Even though the public is increasingly interested in SHW and PV, upfront costs remain as major barriers.

As solar cooling has a high upfront cost, it is unlikely that the general public will exhibit strong demand until energy prices rise significantly. In such event, faced with less complex alternatives, consumers are more likely to purchase a simple, known solution such as PV in preference to complicated solar air conditioning, at least until system refinement and simplification occurs.

The best role the public can play is demanding solutions to GHG emissions from governments. Recent campaigns by Greenpeace were successful in making climate change a state election issue in South Australia, with the result that commitments to GHG reduction and renewable energy targets have been legislated. This grass roots campaign focussed upon direct representation to local MPs, a tactic which should be repeated in all upcoming state and federal elections.

10.6. How ISS Institute can be involved

The International Specialised Skills Institute can convene a seminar on environmentally friendly cooling technologies, to be targeted towards architects and sustainability organisations.

Through articles in the press and networking opportunities, the ISS Institute can assist in building public awareness of solar cooling.

The ISS Institute can support the further development of solar air conditioning in Australia by supporting the visit of a distinguished specialist with technical expertise as well as experience in advocacy and market development.

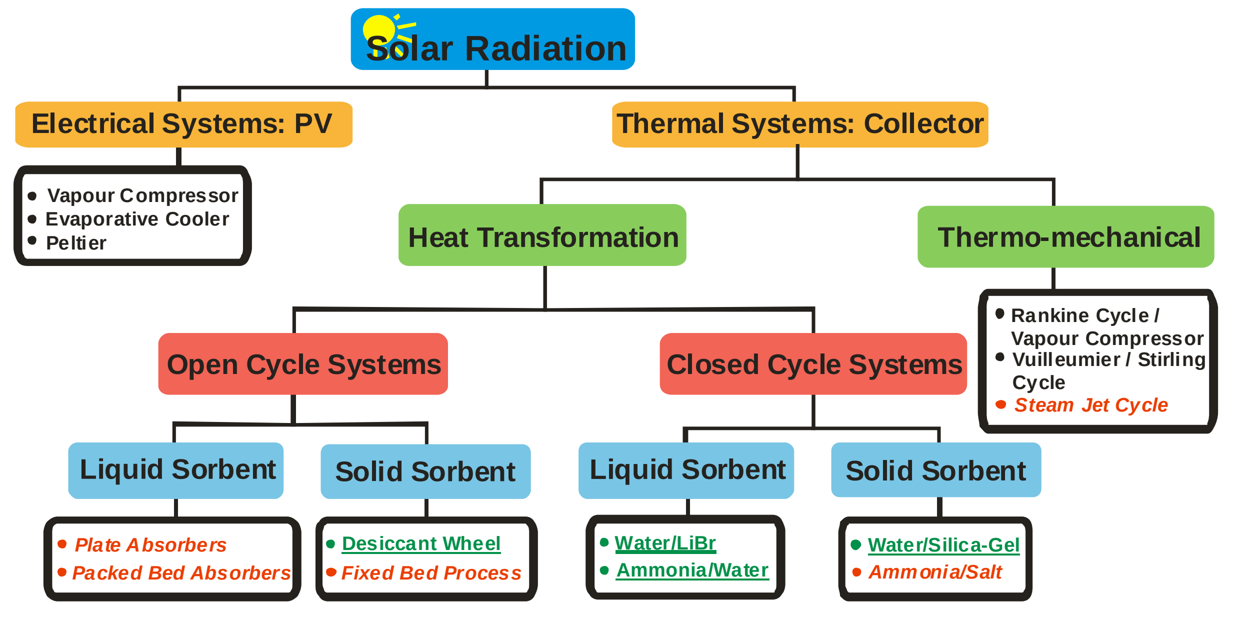
10.7. Further Skill Gaps

No amount of theoretical understanding is a substitute for experience in application of knowledge. Ultimately, hands-on experience for engineers is required in the fields of specification, design, installation, and project management. Skill gaps that relate to the design, manufacturing, and operation of a liquid desiccant system need to be addressed in order for Australia to develop a product of its own. In future, skills gaps will exist that relate to the experienced installation of solar air conditioning systems. Although such skills generally exist in separate disciplines, the installation and commissioning of interacting solar, chiller, and coolth distribution components would best be performed by personnel experienced in whole system operation.

11. Attachments

11.1. Thermally Driven Chillers: Technical Description

This section is intended to give a more detailed description of the most commonly used technologies and the variations available within each.



Underlined systems are market available and suitable for the use with solar collectors, systems in italics are still in the R&D phase.

Figure 25: Classification of Solar Cooling Technologies[60]

11.1.1. Absorption Chiller

A (mechanical) conventional chiller achieves the transfer of heat from indoors to outdoors by the expansion and compression of a refrigerant; an absorption chiller achieves the same function through the thermally-driven expansion and contraction of a refrigerant.

1. The refrigerant is boiled off from a refrigerant-absorbent solution by the application of (solar) heat in the Generator.

2. The vapour is then re-condensed to a concentrated solution by extracting its heat using cooling water in the Condenser.

3. The concentrated refrigerant solution absorbs heat from a low temperature solution because of the low pressure conditions of the sub-enclosure in the Evaporator. This chills water which is used to extract heat from the room.

4. The refrigerant vapour is absorbed in the concentrated absorbent solution in the Absorber, from which it flows back to the generator, completing the cycle.

To increase the thermal efficiency of the process, heat in the concentrated absorbent fluid leaving the generator is transferred to the diluted fluid flowing from the absorber back to the generator. Figure 25 depicts the whole process graphically.

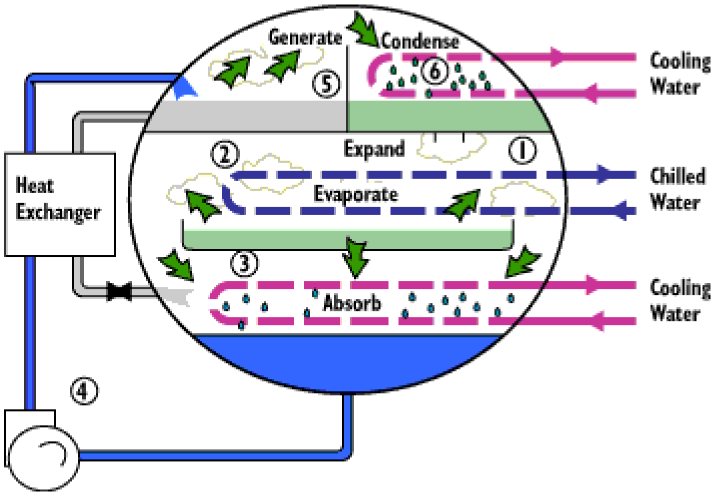


Figure 26: Absorption Chiller Process[61]

Water is typically used as the refrigerant and Lithium Bromide (LiBr) as the absorbent. Such systems are suitable for generating temperatures down to 4°C, below which the use of water as a refrigerant prevents further cooling. Systems which require temperatures below water's freezing point employ Ammonia as the refrigerant and use water as the absorbent, as it is then only exposed to moderate temperatures.

Described above is the operation of a single-stage absorption chiller. The thermal efficiency of operation may be increased substantially by reusing the rejected heat from one cycle to fuel a second stage. Such dual-stage absorption chillers require higher temperatures, the likes of which must be produced by concentrating parabolic troughs if they are to come from solar energy. Alternative high-temperature heat sources may also be employed, making triple-stage absorption chillers also possible, though incompatible with solar heat.

The flow of the fluid through the absorption chiller is achieved by use of a solution pump. However, novel ways may be employed to omit the need for this solution pump, and thus reduce system costs. Rotartica's rotating absorption chiller achieves this by rotating the whole enclosure and using centripetal force to transfer fluids from one stage to another. This has the effect of achieving a high surface wettability; consequently the heat transfer is optimal. The use of dry re-cooling is thus enabled, which, when taken in conjunction of minimum maintenance due to a sealed and pump-free unit, has benefits in residential applications (see Section 11.2.6). A bubble pump also has cost benefits for small-scale chiller applications, and as no moving parts are used, nor pumping energy consumed in the chiller, maintenance and operational costs are also minimised. FHS Stuttgart has developed such technology.

Moving beyond the traditional cycle, the energy storage density associated with a liquid-gas process may be increased by incorporating the solid phase of absorbent, as is achieved in Climate Wells Thermo Chemical Accumulator, which offers other interesting and unique benefits.

11.1.2. Adsorption Chiller

An adsorption chiller, similarly to an absorption chiller, achieves the function of pumping heat from one area to another through the thermally driven expansion and compression of a refrigerant, in conjunction with use of a sorbent. Here however, an adsorbing process is used with a solid sorbent, typically silica gel or zeolite.

As depicted in the diagram,

1. Solar heat is applied to evaporate a refrigerant that had been adsorbed in the Generator (right chamber in the image).

2. The refrigerant vapour is then condensed by extracting its heat using cooling water in the Condenser.

3. The refrigerant absorbs heat from a low temperature solution because of the low pressure conditions of the sub-enclosure in the Evaporator. This chills water which is used to extract heat from the room.

4. The refrigerant vapour is adsorbed onto the solid adsorbent in the Adsorber (left chamber in the image), and the heat of condensation is extracted with cooling water.

Because a solid sorbent is used, once the sorbent has reached saturation, the process must be reversed by adjustment of valves and redirection of solar heat and cooling water flows. Thus the process is semi-cyclical, imposing some additional control requirements. Because there is no solution pump and the all system control is external (compressed air actuates the valves), maintenance requirements are minimal, with consequent benefit for residential applications (see Section 11.2.6). However, because there is no opportunity for heat exchange between the adsorbents, the COP is lower than for absorption cooling (where heat exchange is possible).

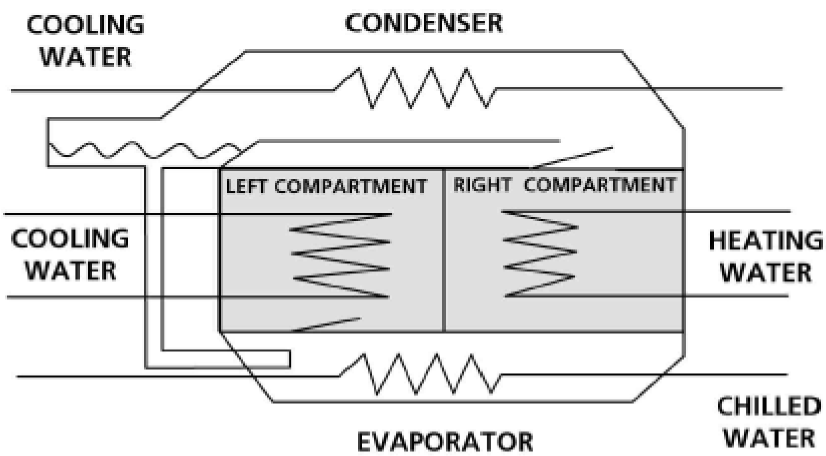


Figure 27: Adsorption Chilling Process[62]

11.1.3. Desiccant Cooler

Desiccant coolers achieve their cooling function by drying the air and thus increasing its evaporative cooling potential. It is an open cycle system, in which incoming fresh air is directly treated and eventually expelled, rather than a closed cycle ab/adsorption chiller which may work on fresh and recycled air. Desiccant coolers are therefore best suited to treatment of the latent load of the incoming fresh air; they are less efficient – both in economic and energy terms – at handling sensible load than conventional or ab/adsorption chillers.

A desiccant cooling system may use a solid desiccant, attached to a rotating wheel, or a liquid desiccant that flows over a heat exchanger. The solid desiccant system operates on the following principles:

1. Incoming air is dehumidified by a desiccant wheel. This absorbs moisture from the air, a process which heats the air.

2. The incoming air is then cooled by heat exchange with the cooler outgoing air.

3. The air is evaporatively cooled, its temperature decreases and humidity increases to the level required to satisfy human comfort.

4. The outgoing air, already having had its temperature raised by heat exchange with the incoming air in step 2, is further heated by application of solar thermal energy (or a backup heat source if solar is unavailable).

5. The heated air then flows through the desiccant wheel, evaporating the water (humidity) absorbed in step 1, before being exhausted.

Depending on the fresh air conditions, dehumidification or evaporative cooling may be unnecessary. A control system measures the fresh air conditions, and applies the following procedure:

1. If the air can be brought within comfort bounds simply by heat exchange with the outgoing air, only the heat exchanger operates.

2. If the incoming air is hot but dry, the evaporative cooler in conjunction with the heat exchanger suffices.

3. However, if the incoming air is hot and humid, the dehumidifier, heat exchanger, and evaporative cooler operate.

As demonstrated by the FHS Stuttgart, such a linear control mechanism, although simple to implement, may result in sub-optimal use of solar energy. Instead, by pre-cooling building thermal mass when solar energy is available, use of conventional heat sources may be avoided on cloudy days.

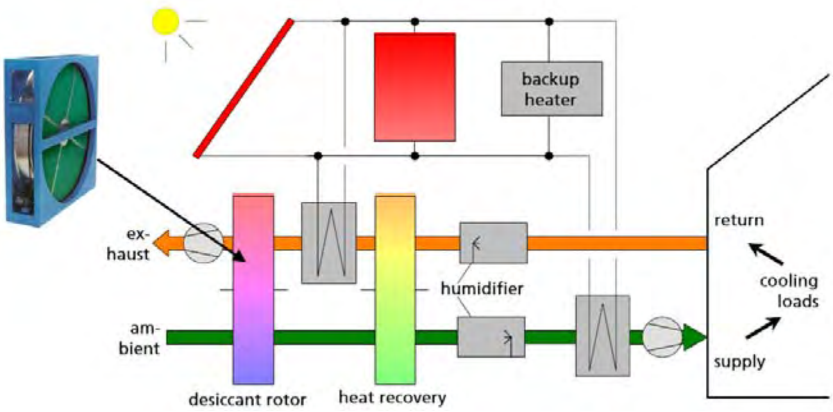


Figure 28: Desiccant Evaporative Cooling Process[63]

A liquid desiccant is the alternative to a solid desiccant wheel, and offers several key advantages. The operational principles and stages are similar:

1. Incoming fresh air is dehumidified by direct contact with a concentrated liquid desiccant flowing over a heat exchanger in the Absorber. As moisture is absorbed from the fresh air, the desiccant heats up, decreasing its moisture holding capacity. Cooling water in the heat exchanger increases the achievable dehumidification and reduces the air temperature.

2. The air is then evaporatively cooled. A similar unit to the absorber can achieve evaporative cooling, as the air flows in direct contact with water, evenly distributed over a surface.

3. In the Regenerator, the desiccant is regenerated by the return air which has been heated by solar energy. The air flows over the liquid desiccant and evaporates its water content, increasing the concentration of liquid desiccant back to the level where it readily absorbs humidity.

Liquid desiccants offer a significant advantage over solid desiccants, notably lossless high-density storage of potential cooling energy. As such they can be generated during the daytime for use even at night, a possibility that must incorporate hot water storage if a solid desiccant is to be used. They may also be stored for lengths on the order of seasons, providing coolth in summer using a smaller solar array over a longer harvest period. The relative merits of this approach depend on the duration of storage, as well as the relative costs of liquid desiccant salts versus water, and the size and costs of the storage vessel, but seasonal desiccant storage merits further exploration. Another advantage of the liquid desiccant is its ability to be remotely generated and then distributed, opening up possibilities for split-cycle units and even liquid desiccant distribution networks. Liquid desiccants also improve the indoor air quality, as they destroy bacteria in the air.

One major drawback of liquid desiccants is their corrosive nature. The salts used – typically Lithium Chloride, but Calcium Chloride and Klimat-3930 are alternatives – are highly corrosive, which has implications for the material selection, price, and manufacturability of liquid desiccant units. The system must also be designed to prevent carryover, something typically achieved with low-velocity air flow, implying large aperture ducting.

Another interesting desiccant cooling technology that is emerging is the coating of a solid desiccant onto a stationary heat exchanger, with semi-cyclical operation similar to an adsorption chiller. This process, ECOS, opens up interesting possibilities for materials science to offer breakthroughs thought unachievable for other thermally driven coolers.

11.2. Addressing Knowledge Gaps

11.2.1. System Sizing and Engineering

Skill deficiency: Understanding of quantity of solar energy required to produce desired cooling output, matched to building requirements, and ability to match with appropriately sized cooling device and storage vessel.

A SAC system is typically sized according to the building it is cooling. This is currently a specific process tailored to each building, as most applications are in commercial buildings in which this process is necessary and warranted. Advanced simulation tools are employed; most commonly the TRNSYS program is used. A building model is made, and typical hourly climate data is applied. A solar collector array and cooling technology model is incorporated into the software simulation, and then optimised in terms of performance and cost.

This is a complex procedure that takes into account performance curves of collector, chiller, and re-cooler at varying ambient, operational, and rejection temperatures in providing cooling to a building with a defined internal and external load profile. Operation and control considerations are also taken into account, as these impact upon the performance, system complexity, and cost.

There are less sophisticated software approaches that use more basic building and equipment models. These tools, such as SOLAC[64] and SolarCoolingLite[65], assist designers in exploring system options and alternatives, thus enabling system pre-evaluation.

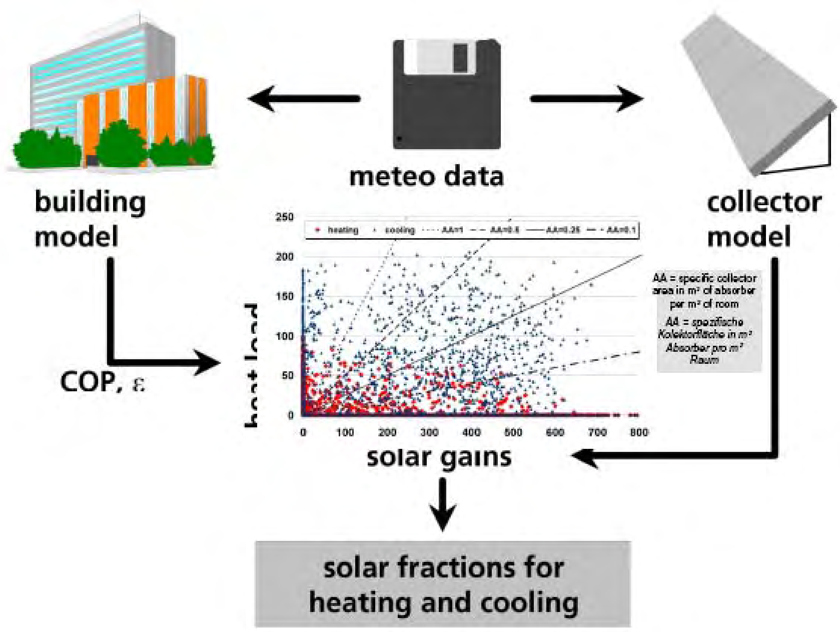


Figure 29: Computer Modelling in Solar Cooling[66]

The most basic approach uses rules of thumb based upon the experience of demonstration systems already in existence. These rules are provided in the handbook "Solar-Assisted Air-Conditioning in Buildings"[67] The rules of thumb are based upon the following process, which is generally followed in all of the above methodologies, in varying levels of detail.

Given a cooling demand, the solar array is sized from the cooling demand divided by the COP of the chiller and then again by the efficiency of the collector panels. This then specifies the kW output of the collector array, which is converted into an area by dividing by typical solar radiation of 800W/m^2. Storage is then also required, the quantity of which given by rule of thumb and dependant on the correlation between solar radiation and cooling load.

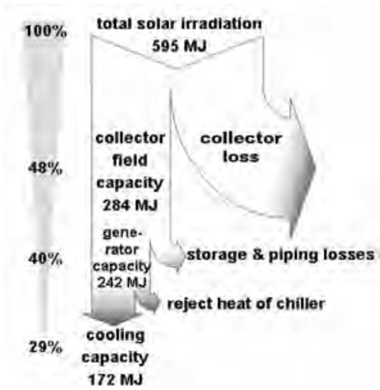


Figure 30: Energetic Processes in Solar Cooling[68]

11.2.2. System Integration

Skill deficiency: Understanding the optimisation process of controlling the sub-system interactions in a simple manner without overcomplicating system control.

The control system governs the operations of the

- solar array pumps based upon storage temperatures and available radiation,
- chiller based upon storage temperature,
- re-cooler based upon the cooling demand,
- and backup heat source or alternate chiller when insufficient solar radiation is available.

The application of solar energy to domestic water heating and space heating is also done by the control system. Although heat and mass flow is usually set at the time of installation, a system that is responsive to partial loads and available solar radiation (achievable temperature) can achieve worthwhile performance improvements[xvii]. However, the additional capability required of valves and electronics, and increased system complexity may impose substantial additional costs and introduce non-linear dynamics into system operation.

[xvii] On-off cycling of absorption and adsorption machines is preferably avoided, as frequent interruptions to thermal inertia will reduce performance.

Another example of operational complexity occurs in solid desiccant systems. Solid desiccant systems can also operate in heat exchange (only) mode, heat exchange and evaporative cooling mode, and heat exchange with desiccant dehumidification and evaporative cooling mode, depending upon the ambient conditions. However, a linear approach to system control can underutilise the solar resource, when cooling could be applied to building thermal mass in anticipation of future load in the absence of solar radiation, if such factors are predictable. FHS Stuttgart has demonstrated significant increases in utilisation of available solar energy with a control system that integrates weather forecasts and employs building pre-cooling, although it remains to be seen whether the energy savings justify the additional cost.

Achieving the right operational balance, with the ability to minimise operational energy but also achieve inexpensive installation and simplified operation, is a delicate task. This process is generally fine tuned in computer simulations, with the objective of finding a solution set that provides adequate system performance under most operational conditions.

Presently, with each system is tailored to its client's needs, individual control systems must be built that make use of commonly available components. Currently, research is being performed into a simplified solar controller capable of achieving these goals in a configurable manner on more standardised systems. This task will be of particular importance in a mass-produced residential market, and is of pertinence for Rotartica as they begin to manufacturer hundreds of units.

11.2.3. Technology Application Evaluation

Skill deficiency: Understanding the complexity of applying solar thermal energy to water heating, space heating, and space cooling.

Many options are possible when applying solar thermal energy to the tasks of heating and cooling. A solar hot water system is the most straightforward application, one seen all over the world. Install a larger array and it becomes possible to provide space heating through simple water-based radiators. On cloudy winter days, the choice then becomes whether to use the available solar energy for space heating or for water heating – generally water heating is favoured. However, a large solar array is required to provide space heating, as generally the need for heating is inverse to the available radiation – thus a large array with large storage volume is required to be able to produce heating effect on cloudy days. A combi-system designer must also choose whether to direct available solar energy directly to the building thermal mass, or to store it for another day. Choices are limited by the energy storage density of water in comparison to the space it must heat, and the fact that most passive designed homes already make use of winter sun (when available), thus adding extra heat on such days may make the home uncomfortably warm.

With such a large solar array, the question becomes 'what to do with the heat in summer?' Leaving the system idle is a waste of potentially useful solar energy, and the temperature of the stagnant system may exceed specified levels and therefore cause damage. Of the couple of solutions to this dilemma, directing the solar energy towards a thermally-driven cooling device makes greatest utilisation of the sun; for this reason solar air conditioners could be considered as "solar heating systems with efficient excess heat utilisation (cooling)" rather than "solar cooling systems able to make use of their energy harvest in winter". This subtle distinction, combined with the fact that 3kW of air conditioning offsets only 1kW of electricity, when it could offset 3kW of heating energy (gas)[xviii], means that in economic terms a system in a heating driven climate may perform better than a system in a cooling driven climate. Thus, optimal climate bands with high heating demand and lesser cooling demand may exist, of which parts of Australia are ideally located. In contrast, desiccant systems, which directly treat the air's humidity, are considered separately to this statement as they offer strong advantages in humid climates, and can also enable more efficient operation of conventional air conditioners which then need only handle the sensible load.

Then, if an absorption or adsorption chiller is installed, it is also possible to provide space heating in winter by operating the chiller as a heat pump, and extracting heat from the storage vessel (or ground) and supplying it to the room in addition to that harvested from the sun. Such a system becomes significantly more complex, and the performance improvements may not be justified in most applications whilst energy prices remain low.

11.2.4. Technology Choice Evaluation

Skill deficiency: Understanding the process of selection of appropriate cooling technology (Absorption, Adsorption, Desiccant) for particular applications.

This skill deficiency is discussed in Section 6.2 and summarised in Table 4, p23. In addition to the climate, the type, cost, and aesthetic aspect of the collectors can influence the choice of technology, as can available roof area and maintenance requirements.

11.2.5. System Performance Comparison

Skill deficiency: Understanding how to technically compare system performance specification across applications and technologies. Research of performance and economic metrics used to justify inclusion in building projects.

The performance of absorption and adsorption chillers is generally rated by COP. This performance measurement specifies, for a nominated temperature, the thermal cooling energy output as a fraction of the input heat energy. However, whilst the maximum COP for absorption chillers is higher than that achievable by adsorption chillers, for a given solar supply temperature adsorption chillers may be more efficient, as seen by the following figure.

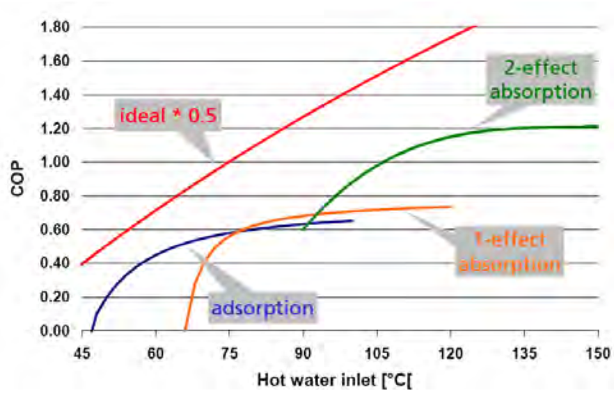


Figure 31: COP of Selected Cooling Technologies[69]

[xviii] This applies less so for reverse cycle air conditioners, which can provide electricity-efficient heating

Ultimately the system's primary energy (*electrical + gas)*, not thermal, performance that must be evaluated – its ability to provide cooling as a proportion of the fossil-fuel-derived energy input to the system. The objective is to provide cooling with less primary energy usage than when compared to a conventional air conditioner; electricity is consumed by pumps, cooling towers, and air handling units, and a backup heat source may be of fossil origin. Though it is possible to compare performance curves of individual system components, ultimately all must be interconnected, in a manner that balances energy savings with upfront cost.

The solar fraction is another term of reference for comparing SAC systems. It measures the amount of the cooling energy that is provided by solar means, as a fraction of the total energy input (including backup heat source). In order to achieve energy savings when compared to conventional air conditioners, a solar fraction of 0.7-0.8 or greater is recommended. However, in a stand-alone SAC system (one without backup heat source and instead relying upon conventional A/C or without supplementary cooling), the solar fraction is always high.

It is difficult to compare the performance of a desiccant system to that of a closed-cycle system, for desiccant systems directly condition the air and are typically used in applications in which the air change rate is the design goal rather than the instantaneous cooling power. The COP of desiccant system can be calculated in terms of the latent energy removed from the air, but is not directly comparable to closed cycle systems. Further, although the instantaneous power of a desiccant system can be calculated – again in terms of the rate of latent energy removal – this figure is somewhat arbitrary as the design goal (m^3/hour ventilation) is not directly comparable to closed-cycle systems' design goal (kW).

System and component costs are difficult to compare. The type of the chiller affects the unit cost of the solar array that needs to serve it, and the system capacity directly affects the collector area, chiller capacity, cooling tower capacity (if required). The amount and therefore cost of storage is dependent upon the building and application, and the complexity of the system affects the cost of design, control, and installation. A standardised domestic system has not yet emerged, so only the expected costs of cooling components can be presented, alongside some indicative system costs. The available figures are presented in Table 9, p67.

11.2.6. Residential Application Issues

Skill deficiency: Technical and market related issues surrounding miniaturisation and mass-production to provide units suitable for residential application.

Although it was initially understood that there are technical issues regarding crystallisation of LiBr in absorption chillers in the small apertures of possible small-scale chillers, no such technical obstacles were uncovered during discussions with solar cooling experts. The issues relating to residential application of solar cooling are primarily related to market conditions and the technical implications thus imposed upon systems.

Limited available space is one constraint in the residential market. Available roof area is one such issue that may preclude blanket application for solar collectors. There must also be room for a storage tank alongside or inside buildings, and the recommended 1000L tank is larger than most existing hot water tanks.

The residential market imposes other constraints, most particularly those relating to maintenance. On commercial building applications, a maintenance regime can be expected; householders however cannot be expected to routinely maintain their unit. Thus, low maintenance units – such as those produced by Rotartica (fully sealed) and Sortech (external valves only) – are more favourable in these situations. Dry re-cooling is the most likely method of heat rejection, as wet cooling towers require maintenance – consequently air-cooled units are more applicable to the residential market.

Upfront cost is a major issue in the residential market, a greater issue than payback when compared to the commercial buildings market. The solution pumps on absorption chillers form a greater part of the total component cost as a chiller's capacity decreases. Thus, avoiding a mechanical solution pump – achieved by Rotartica's rotating absorption chiller and FHS Stuttgart's bubble pump – can reduce the minimum achievable cost of small-scale chillers. Yet a 10% decrease in chiller cost will not open up the market until the costs associated with collector, storage, and system complexity can be addressed.

There are expected to be few issues with component mass production. However, the difficulty comes in the design criteria selection for the off-the-shelf component, as the market has not yet matured sufficiently to be able to identify what a 'standard' residential solar cooling system will comprise of: collector type, power output, and re-cooling method. Further quandaries are faced in specifying an off-the-shelf system, as the system needs to provide high performance under most operating conditions, rather than being able to be tailored to individual building's requirements.

11.2.7. Market Comparison

Skill deficiency: Method of assessing the European market, including climate and technology, in order to appraise Australian market.

The market comparison has been addressed in sections 7 and 8.3.

11.2.8. Combi-Systems.

Skill deficiency: Understanding the additional complexities in designing space cooling and water heating (combi) systems.

This skill deficiency has been addressed in the discourse in Section 11.2.3.

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13. Acronyms

A/C	Air Conditioning
AGBR	Australian Greenhouse Building Rating
AGO	Australian Greenhouse Office
AIRAH	Australian Institute of Refrigeration Air Conditioning and Heating
AP6	Asia Pacific 6 (Asia Pacific Partnership on Clean Development and Climate)
BCSE	(Australian) Business Council for Sustainable Energy
COP	Coefficient of Performance
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEC	Desiccant Evaporative Cooler
ECS	Energy Conservation Systems
ETC	Evacuated Tube Collector
FPC	Flat Plate Collector
GHG	Greenhouse Gas
HVAC	Heating Ventilation and Air Conditioning
IEA-SHC	International Energy Agency Solar Heating and Cooling programme
ISS Institute	International Specialised Skills Institute
MOU	Memorandum of Understanding
MRET	Mandatory Renewable Energy Target
NEGST	Next Generation of Solar Thermal Systems programme
NPV	Net Present Value
PCM	Phase Change Material
PTC	Parabolic Trough Collector
PV	Photovoltaic (Solar Electricity)
R&D	Research and Development
RAIA	Royal Australian Institute of Architects
REDI	Renewable Energy Development Initiative
RESF	Renewable Energy Support Fund
SAC	Solar Air Conditioning
SAH	Solar Air Heater
SHW	Solar Hot Water
SV	Sustainability Victoria
TAFE	Technical and Further Education
VSII	Victorian Solar Innovation Initiative

Table 12: Acronyms

1 http://www.eraa.com.au/db_uploads/ERAAsubmissiontoProductivityCommissionInquiryonEnergyefficiencyNov04.pdf

2 http://www.energy.wa.gov.au/cproot/603/2759/Air%20conditioning%20paper.pdf

3 http://www.energyrating.gov.au/library/pubs/200509-ac-aust.pdf

4 http://www.dpmc.gov.au/publications/energy_future/chapter8/images/8_fig_5.gif

5 http://www.eraa.com.au/db_uploads/ERAAsubmissiontoProductivityCommissionInquiryonEnergyefficiencyNov04.pdf

6 http://www.eraa.com.au/db_uploads/ERAAsubmissiontoProductivityCommissionInquiryonEnergyefficiencyNov04.pdf, p7

7 http://www.aius.org.au/indicators/sectiontype.cfm?ThemeID=4&SectionTypeID=2

8 See http://www.businessroundtable.com.au/

9 http://www.iea-shc-task25.org/english/hps6/pdf/poster08_ads_example.pdf

10 http://www.archmedia.com.au/aa/aaissue.php?issueid=200507&article=4&typeon=1

11 www.eduvinet.de/servitec/henninge.pdf

12 http://www.alternativefuels.com.au/gippsland.htm

13 http://www.endless-solar.com/installation_photos.htm

14 http://www.wizardpower.com.au/solar_technology.html

15 http://www.iea-shc-task25.org/english/hps6/pdf/poster02_technical-overview_new.pdf

16 http://www.abs.gov.au/ausstats/abs@.nsf/b06660592430724fca2568b5007b8619/1dd46a713657ba33ca256e000075736b!OpenDocument

17 http://www.rotartica.com/pub/marcos_1024.htm

18 http://www.bassett.com.au/media/files/Design%20Guide%20for%20Solar%20Cooling.pdf

19 See ClimateWell www.climatewell.com/

20 http://www.ise.fraunhofer.de/english/fields/field1/mb3/solar_cooling/publications/pdf/HPC-Motta.pdf

21 http://www.inaustralia.com.au/images/population%20distribution.gif

22 http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/sunshine-hrs.cgi

23 http://www.energyrating.gov.au/library/pubs/200412-mepspools.pdf

24 http://www.bom.gov.au/climate/averages/climatology/heating_cooling_degree_days/hdd_cdd_gifs/cddgif/cdd24ann.png

25 http://www.bom.gov.au/climate/averages/climatology/heating_cooling_degree_days/hdd_cdd_gifs/hddgif/hdd18ann.png

26 http://www.energyrating.gov.au/library/pubs/200509-ac-aust.pdf

27 http://www.energyrating.gov.au/library/pubs/200509-ac-aust.pdf

28 http://www.energy.wa.gov.au/cproot/603/2759/Air%20conditioning%20paper.pdf

29 http://www.eraa.com.au/db_uploads/ERAAsubmissiontoProductivityCommissionInquiryonEnergyefficiencyNov04.pdf, p8

30 http://www.airah.org.au/downloads/2002-03-01.pdf

31 http://www.australiancoal.com.au/vitalabundant.htm

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