FORUM

Solar Cooling in Australia: The Future of Air Conditioning?

Dr P. Kohlenbach, M.AIRAH, Solem Consulting and Dr M. Dennis, M.AIRAH, Centre for Sustainable Energy Systems, Australian National University.

ABSTRACT

This paper gives an outlook on the current and future situation of solar cooling in Australia. It discusses the current potential of energy and greenhouse gas savings by using alternative solar air-conditioning technologies. Economics are discussed using a comparison of photovoltaic vapour-compression cooling against solar thermal cooling with an absorption chiller and a grid-connected reference chiller. It was found that at current economical conditions and under the given financial and technical assumptions, a solar thermal cooling system has a lower lifetime cost than a PV-based system. However, both systems have higher lifetime costs than a grid-connected conventional system. A sensitivity analysis on electricity price showed that solar thermal cooling is more economic than PV-based cooling until the electricity price exceeds \$0.5/kWhel. A PV-based system becomes the most economic cooling alternative if the electricity price exceeds \$0.55/ kWhel. Greenhouse gas emissions were found to be lowest for the PV-based system due to the excess power being generated over the lifetime. The solar thermal system saves approximately 75 per cent of the emissions of the conventional system.

INTRODUCTION

Solar cooling replaces electricity with heat from the sun as the source of energy to drive a cooling or refrigeration process. Solar cooling technology largely comprises "off-the-shelf" heating, ventilation and air conditioning (HVAC) components, which are generally mature technology.

Combining these technologies into integrated systems has been proven feasible worldwide (mainly Europe) but the industry is still in its infancy in Australia, despite Australia being uniquely suited to the technology, with great solar resources and large air conditioning (AC) demand throughout the country.

The east coast of Australia receives between six to nine hours of sunshine a day, and an annual solar exposure between 1200-2400 kWh/m2/a. This is more than sufficient for solar applications.

The residential air conditioning market in Australia is around 800,000 units per year, and has increased significantly over recent years. In 2000, 35 per cent of all Australian households had air conditioning; in 2006 this number had doubled to around 70 per cent. The majority of these units are reversible wall-mounted split units.

Commercial air conditioning and refrigeration using chillers is a market of around 1,000 units per year, 80 per cent of which are dry-cooled. Together, residential and commercial refrigeration and air conditioning consumes approximately 20 per cent of the total electricity generated and contributes approximately 7 per cent to the country's GHG emissions [2-4].

The increasing popularity of domestic vapour compression air conditioning in Australia has resulted in peak electricity demand growing much faster than baseload demand, as noted by NEMMCO [5].

Transmission and distribution assets must be sized on the peak current transmission, and that capacity is used for a small proportion of the time. Thus there is a poor return on this investment, and so little incentive to upgrade the network in this way.

This is leading to supply security issues also noted by NEMMCO. Solar cooling is a distributed form of peak electricity reduction and has the unique ability to offset loads at source, thus reducing transmission requirements, and in particular, peak transmission requirements.

The large demand for AC in Australia, combined with the economic problem of infrastructure support, provides a basis for consideration of alternative technologies.

1 CURRENT SITUATION

The combination of good solar resource and a large air conditioning market seems like a perfect match for solar cooling and refrigeration applications in Australia. However, there are only few solar thermal cooling systems installed in Australia. At the time of writing there are three solar cooling systems in operation and three systems under tender or construction, as shown in Table 1.

The discrepancy between the great potential and the small number of installations is easily explained when economics are taken into account. Residential solar cooling systems (5-15 kWr) are exclusively imported from overseas and attract a considerably high price tag in Australia. With specific cost of approximately \$6,000-9,000/kWr they are an order of magnitude more expensive than conventional split systems, which are available at about \$600-\$800/ kWr (both costs for installed system, excluding GST) [6].

The situation is different for larger commercial or industrial applications (50-500 kWr). Economies of scale make larger units more economical, and the hours of operation are usually much greater in an industrial application compared to residential. However, other market barriers are also restraining the market in this segment.

Location	Cooling capacity	Solar field size	Collector type	In operation since	Application
Ipswich, Qld	250 kWr	570 m2	Parabolic Trough	2009	Hospital
Logan City Council, Qld	tbd	tbd	tbd	Under tender	Office building
Alice Springs, NT	230 kWr	630 m2	Parabolic Trough	Scheduled for late 2010	Art gallery
Sydney, NSW	175 kWr	165 m2	Parabolic Trough	2007	Factory
Wyong, NSW	7 kWr	20 m2	Evacuated tube	2009	Café
Newcastle, NSW	230 kWr	350 m2	Parabolic Trough	Scheduled for mid 2010	Shopping mall

Table 1. Overview on existing solar thermal cooling systems in Australia

1.1 Market barriers

The main market barriers for solar cooling in Australia have been identified as: [7, 8]

- Low electricity prices
- Low-cost conventional air conditioning
- Cross-subsidy of conventional air conditioning system by all electricity customers who have to pay for network and generation infrastructure
- Most components manufactured overseas and imported
- Low number of installed systems
- System complexity
- Professionals involved lack training and experience with solar cooling
- Australia's large climatic variety makes it difficult for a standardised solar cooling system to be implemented.

There are no major unsolvable technical issues for the implementation of solar cooling. The main barrier for implementation is economic, not technical. There are sufficient installations in Europe where the technology has been proven feasible but the low electricity cost and cheap conventional AC units in Australia make competition difficult. Nevertheless, economics for solar cooling can become much more favourable for a range of building applications and locations with higher electricity cost, such as islands, remote locations and off-grid applications.

To help overcome the market barriers described above and support the introduction and market development of solar cooling in Australia, the Australian Solar Cooling Interest Group (ausSCIG) was founded in 2008 [21]. ausSCIG, an AIRAH special technical group, is an industry group made up of individuals who are interested in developing the solar cooling industry in Australia, with the aim of combating climate change by reducing greenhouse gas emissions (GHG) from the residential and commercial building sectors [7].

1.2 Market opportunities

Recently the situation for solar cooling has improved. Government measures towards intelligent use of energy, peak reduction and building upgrades have been implemented, as well as various funding programs for renewable energies. These include:

- Implementation of time of use (ToU) metering for end users (ordinary residences, not just high-consumption users), thus encouraging peak power savings.
- Building owners' recognition for energy efficient systems (Green Star and NABERS programs).
- Renewable Energy Credits (RECs) for solar thermal hot water systems
- Possible implementation of tradable certificates for energy saving activities (Energy Savings Certificates, ESCs, NSW only).

A solar cooling system will most likely generate hot water during operation and therefore becomes eligible for RECs. Users can trade the RECs for electricity saved by a solar hot water and cooling system at a rate of approximately $35/kWhel before tax. These measures do not significantly influence the economics of a residential solar cooling system but they make an impact on larger scale systems.

2 ECONOMIC COMPARISON

A competitive technology to solar thermal cooling is photovoltaic-based cooling using photovoltaic (PV) panels to generate electricity connected to a conventional air conditioner,. So far, this technology has been far too expensive due to the high cost for PV panels. Recent price drops of PV panels however have changed this and lead to the investigation presented in Figure 1.

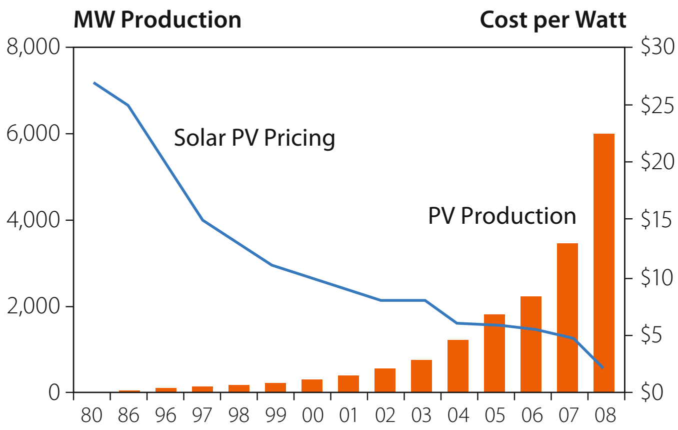
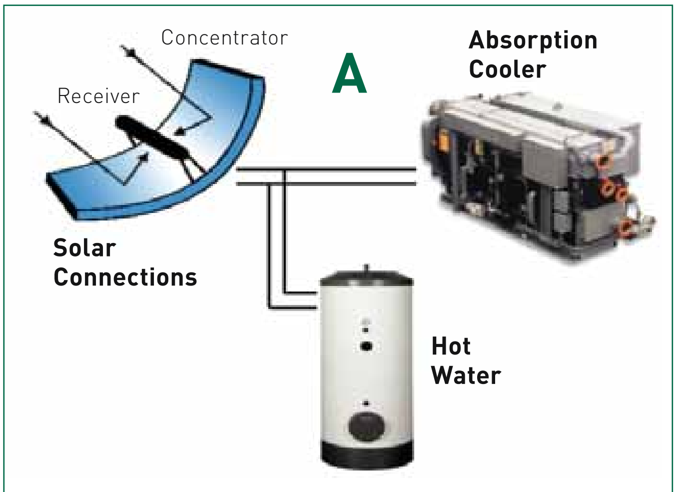


Figure 1. Global PV production and PV panel price from 1980 – 2008 [20].

The price per Watt peak of photovoltaic panels was approx. $300/Wp in 1956. In 1980 the price had dropped to approx. $27/Wp and current panel prices are around $2/Wp (~$4/Wp including installation).

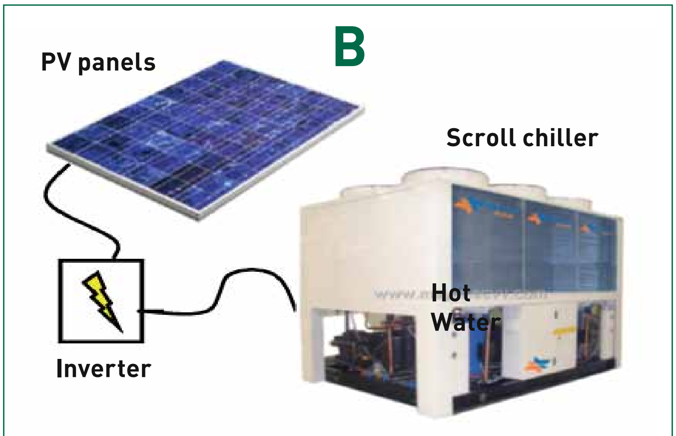
Three scenarios have been compared to each other:

A. Solar thermal parabolic trough collectors and a double-effect absorption chiller



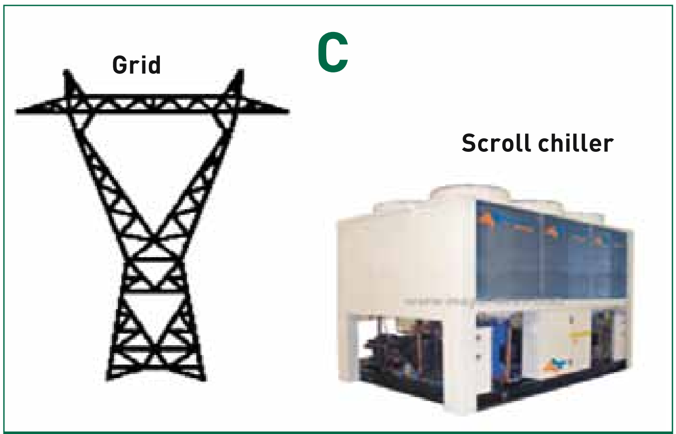
Solar thermal collectors and absorption chiller (STAC)

B. Photovoltaic panels and a scroll type vapour-compression chiller



Photovoltaic panels & scroll chiller (PVS)

C. Reference case: Grid-connected scroll type vapour-compression chiller



Grid-connected scroll chiller (REF)

Figure 2. Scenarios for comparison of solar cooling technologies [9–13].

The comparison in this paper is made for a commercial system of 230kWr cooling capacity, this being a medium-sized industrial application for office buildings, shopping malls, art galleries, hotels and the like. The following general assumptions have been made:

- All three scenarios have been investigated for two different climate zones: Zone 3 (eg Sydney/NSW) and zone 2 (eg Brisbane/Qld) in Australia.
- Cooling is needed for eight hours/day over five months/year (in total 1200 hours/yr or 276 MWhth/yr). This has been assumed conservatively for zone 3, most likely the air conditioning demand will be greater in zone 2.
- Heating/hot water is provided whenever cooling is not needed.
- No subsidies have been assumed for solar thermal cooling (no RECs, no ESCs, no carbon tax and the like.)

Financial assumptions	All Scenarios
Lifetime of scroll chiller	12 yrs
Lifetime of absorption chiller, collectors & PV modules	20 yrs
CPI (inflation rate)	2.5 %
Discount rate	8 %
Electricity cost[1]	0.17 $/kWh$_{el}$
Annual escalation rate electricity cost	2 %
Natural gas cost	$6/GJ
Annual escalation rate natural gas cost	1 %

Table 2. Financial assumptions for NPV calculations

– No feed-in tariff has been assumed for photovoltaic power generation.

– All three systems have been designed to provide 100% of the annual cooling load.

The comparison was made by calculating investment and O&M cost and calculate the net present value (NPV) for a lifetime of 20 years. Table 2 shows the financial assumptions for NPV calculations. The system specifications are given in Table 3 and the costing in Table 4. Figure 2 shows the breakdown of system costs.

System assumptions	STAC	PVS	REF
Total cooling power (kWr)	230	230	230
Average annual COP chiller (–)	1.1	4.0	4.0
Heat required for cooling (kWth)	209	–	–
Electrical power required for cooling (kWel)	15	58	58
Solar thermal collector/PV area (m^2)	508	391	–
Backup system for heating/hot water	none	gas boiler[2]	gas boiler

Table 3. System specifications for NPV calculations

Cost assumptions	STAC	PVS	REF
Solar collectors/ PV panel cost[3]	$330,200	$301,440	–
230 kWr Chiller and air cooler cost	$154,000	$119,600	$119,600
Balance of plant cost	$69,200	$137,650	$65,650
Total equipment cost	$553,400	$558,690	$185,250
Total engineering and installation cost[4]	$86,658	$60,882	$28,412
Total system cost	$640,058	$619,572	$213,662
Specific system cost	$/kWr 2,783	$/kWr 2,694	$/kWr 929
Annual average O&M cost	$6,893	$3,981	$17,163

Table 4. Cost assumptions for NPV calculations

1 Gas boiler efficiency was assumed at 85%.
2 Parabolic collectors have been assumed at $650/m², the PV panels at $4.20/Wp.
3 Cost estimates for installation and engineering have been taken from [14].

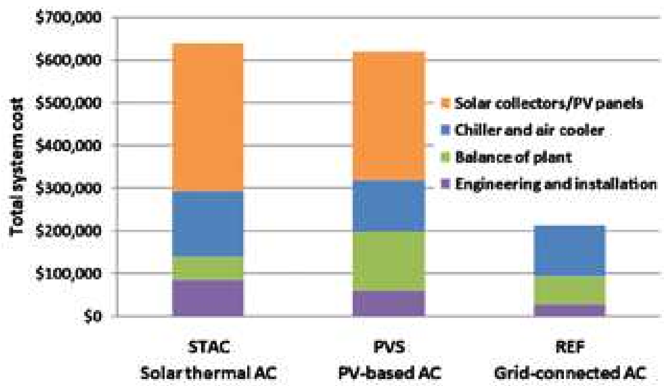


Figure 3. Breakdown of system equipment and installation costs.

It can be seen in Table 4 and Figure 3 that the solar thermal cooling system (STAC) has the highest upfront investment cost of all systems; however, the PV-based system (PVS) is only about $20k cheaper. The reference system (REF) is approximately 65% cheaper than both the STAC and PVS systems.

The solar thermal system (STAC) uses parabolic trough collectors with an annual average efficiency of 55%. A hot water storage tank of 5,000 litres is used as a buffer tank. The absorption chiller is an air-cooled double-effect chiller with an annual average COP of 1.1. The solar thermal system yield has been calculated using Meteonorm data for the two climate zones [15] in a TRNSYS simulation.

The PV modules in the PVS system have been assumed with an annual average efficiency of 14%. A degra¬dation of the module efficiency of – 15% over the 20-year lifetime has been assumed. The PVS system yield has been calculated using a zone-based yield factor of 1.382 MWh/kWp/a for Sydney and of 1.536 MWh/kWp/a for Brisbane, including a 15% loss due to annual self-shading of the panels [16].

Excessive power generated by the PVS system is accounted for as net export to the grid. The scroll chiller is air-cooled and has an annual average COP of 4.0. For the reference (REF) system the same chiller as for the PVS system is assumed. No electrical storage has been assumed.

3 RESULTS AND DISCUSSION

The lifetime cost calculations over 20 years lifetime (replacement of scroll chiller in scenarios PVS and REF after 12 years) are given in Figure 4 and Table 5. Greenhouse gas emissions are shown in Figure 5 and Table 6.

It can be seen that the solar thermal cooling system (STAC) has significantly lower lifetime costs than the PV-based system (PVS) under the given assumptions. The cost difference between systems STAC and PVS is approx. $114k over 20 yrs. The reference case (REF) has the lowest lifetime cost of all three systems.

Greenhouse gas (GHG) emissions have been calculated over the lifetime using indirect emission factors for consumption of purchased electricity from the grid, Table 6. Emission factors for both NSW and Qld are given as 0.89 kg CO2-e/kWhel, emissions for natural gas have been assumed as 200kg CO2e/MWhth[17].

Exported electricity into the grid from the PV system has been accounted for as emissions avoided using the same factors. It can be seen that the reference case (REF) has the highest GHG emissions of all three systems. The solar thermal cooling system (STAC) has approx. 78% less GHG emissions than the reference system (REF) under the given assumptions.

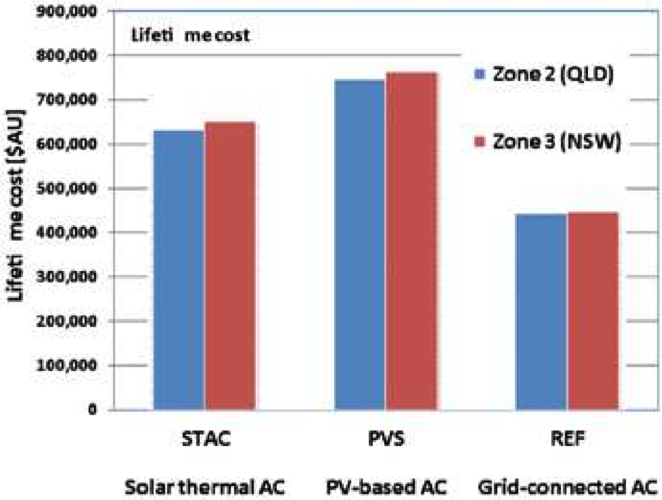


Figure 4. Lifetime cost of all systems

The PVS system has only 5% of the reference GHG emissions in zone 3 (Sydney) and no operational GHG emissions in Zone 2. This is due to the excess electricity generated over the lifetime, which makes its GHG emissions negative. The excess electricity generated in zone 2 (Brisbane) is slightly higher than in zone 3 (Sydney) due to higher annual solar radiation in zone 2.

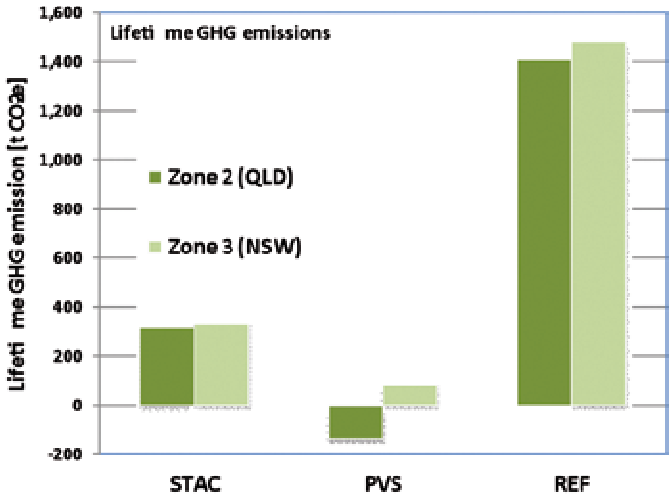


Figure 5. Lifetime greenhouse gas emissions of all systems

It is obvious from the analysis that the lifetime cost difference between a solar cooling system (PVS and STAC) and a grid-connected cooling system (REF) is still quite large, despite the recent price drops in PV module price and collector cost. However, the cost difference between a solar thermal system and a PV-based system is significant under the current assumptions.

Therefore it has been investigated which escalation in grid electricity price is required to make a PV-based cooling system competitive with a solar thermal cooling system. Also, it has been investigated at which electricity cost both solar driven cooling systems become competitive with the grid connected scroll chiller system. Figure 6 shows the results.

	NPV results	STAC	PVS	REF
Zone 2 (Brisbane)	Lifetime cost (20 yrs)	**$631,879**	**$745,959**	**$443,098**
	Difference to reference case	143%	168%	100%
Zone 3 (Sydney)	Lifetime cost (20 yrs)	**$652,292**	**$764,767**	**$446,953**
	Difference to reference case	146%	171%	100%

Table 5. Results of lifetime cost calculations

	GHG emissions	STAC	PVS	REF
Zone 2 (Brisbane)	Lifetime GHG emissions (t $CO2_e$)	**317**	**-139**	**1410**
	Difference to reference case	22%	-110%	100%
Zone 3 (Sydney)	Lifetime GHG emissions (t $CO2_e$)	**332**	**81**	**1481**
	Difference to reference case	22%%	5%	100%

Table 6. Lifetime greenhouse gas emissions

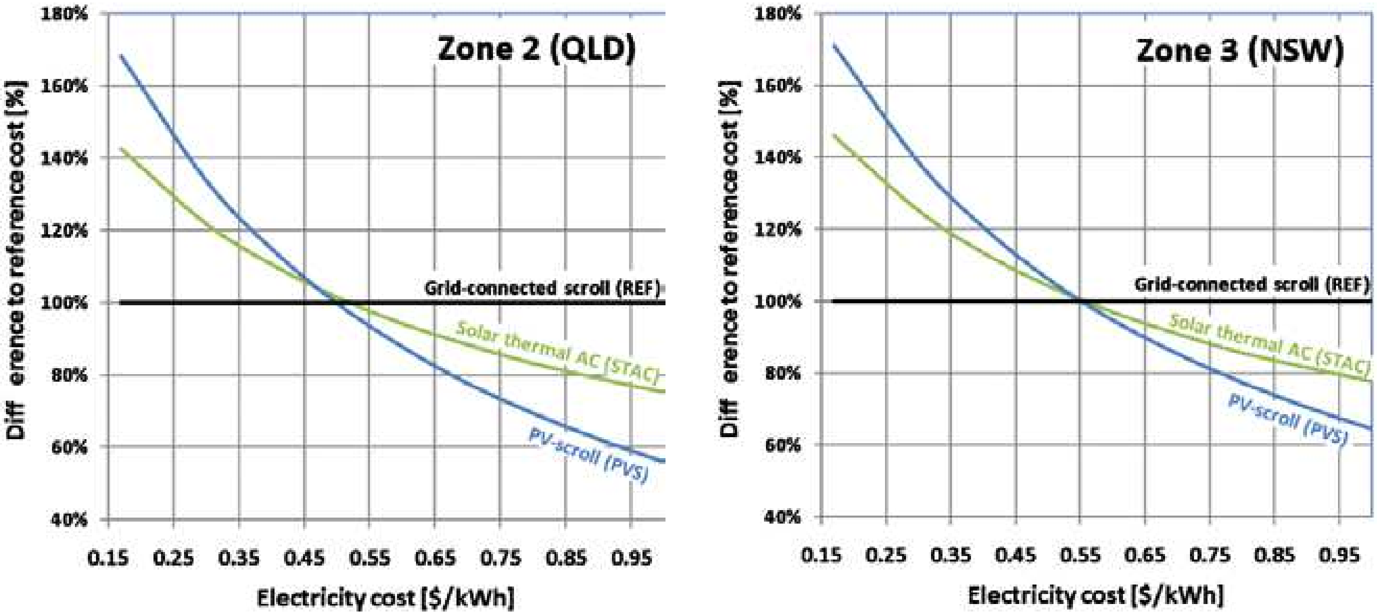


Figure 6. Sensitivity analysis on electricity price to reach lifetime cost parity between reference and solar cooling systems.

A few conclusions can be drawn from Figure 8. At current conditions ($0.17/kWhel) solar thermal cooling (STAC) has a lower lifetime cost than PV-based cooling (PVS) in both zones. In zone 2 (Qld) the STAC and PVS systems have an equal lifetime cost at an electricity price of $0.47 /kWhel. The PVS system has lower lifetime costs than the REF system at electricity price higher than $0.50 /kWhel and the STAC system at electricity cost lower than $0.52 /kWhel. In zone 3 (NSW) the break-even between STAC and PVS occurs at $0.55 /kWhel. Both STAC and PVS have lower lifetime costs than the REF system at electricity prices higher than $0.55 /kWhel.

4 SUMMARY AND OUTLOOK

Solar cooling is still a niche technology in Australia, despite good solar resources and a large air conditioning and refrigeration market. Mostly economic, multiple market barriers prevent the technology from achieving bigger market shares. This paper summarises the market barriers and opportunities for solar cooling. It further investigates the economics of a solar thermal, a PV-based and a conventional cooling system over a 20-year lifetime.

The main market barriers for solar cooling in Australia are:

– Low electricity prices
– Low-cost conventional air conditioning
– Cross subsidy of conventional air conditioning system by all electricity customers who have to pay for network and generation infrastructure
– Most components manufactured overseas and imported
– Low number of installed systems
– System complexity
– Professionals involved lack training and experience with solar cooling
– Australia's large climatic variety makes it difficult for a standardised solar cooling system to be implemented.

The main opportunities for solar cooling are:

– Implementation of Time of Use (ToU) metering, thus encouraging peak power savings
– Building owners recognition for energy efficient systems. (Green Star and NABERS programs)
– Implementation of a carbon trading scheme to include for environmental externalities associated with electricity generation. (Carbon pollution reduction scheme).
– Renewable Energy Credits (RECs) for solar thermal hot water systems
– Implementation of tradable certificates for energy saving activities (Energy Savings Certificates, ESCs, NSW only)

It was found that at current economical conditions and under the given financial and technical assumptions, a solar thermal cooling system has a lower lifetime cost than a PV-based system. However, both systems have higher lifetime costs than a grid-connected conventional system. A sensitivity analysis on electricity price showed that solar thermal cooling is more economic than PV-based cooling until the electricity price reaches approx. $0.50/kWhel. A PV-based system becomes the most economic cooling alternative if the electricity price exceeds $0.55/ kWhel, beating the reference and solar thermal system in lifetime cost.

Greenhouse gas emissions were found to be lowest for the PV-based system due to the excess power being generated over the lifetime. The solar thermal system saves approx. 78% of the emissions of the conventional system.

The authors acknowledge that the results of this study are subject to the modelling assumptions and to some degree a snapshot in time. Changes in PV panel cost will influence this study as well as changes in investment cost for solar thermal collectors and absorption chillers.

5 NOMENCLATURE

Variables		Subscripts	
COP	Coefficient of performance	*th*	Thermal
CPI	Consumer price index	*el*	Electrical
GHG	Greenhouse gas	*r*	Refrigeration
AC	Air-conditioning	*p*	peak
PV	Photovoltaic		

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About the authors

Dr Paul Kohlenbach, M.AIRAH, is directior of Solem Consulting. Contact him at paul@solem.com.au

Dr Mike Dennis, M.AIRAH, is a senior research fellow at the Centre for Sustainable Energy Systems, Australian National University. Contact him at Mike.Dennis@anu.edu.au