# SOLAR COOLING IN AUSTRALIA: THE FUTURE OF AIR-CONDITIONING?

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## 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 \$0.28/$kWh_{el}$. A PV-based system becomes the most economic cooling alternative if the electricity price exceeds \$0.54/ $kWh_{el}$. A solar thermal system becomes more economic than a conventional system for electricity prices above of \$0.67/ $kWh_{el.}$ 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. 75% of the emissions of the conventional system.

## 1 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. Figure 1 shows the average daily sunshine hours and the annual solar irradiation on a horizontal surface. It can be seen that the east coast of Australia receives between 6-9 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% of all Australian households had air-conditioning; in 2006 this number had doubled to around 70%. 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% of which are dry-cooled. Together, residential and commercial refrigeration and air conditioning consumes approx. 20% of the total electricity generated and contributes approx. 7% to the country's GHG emissions [2-4].

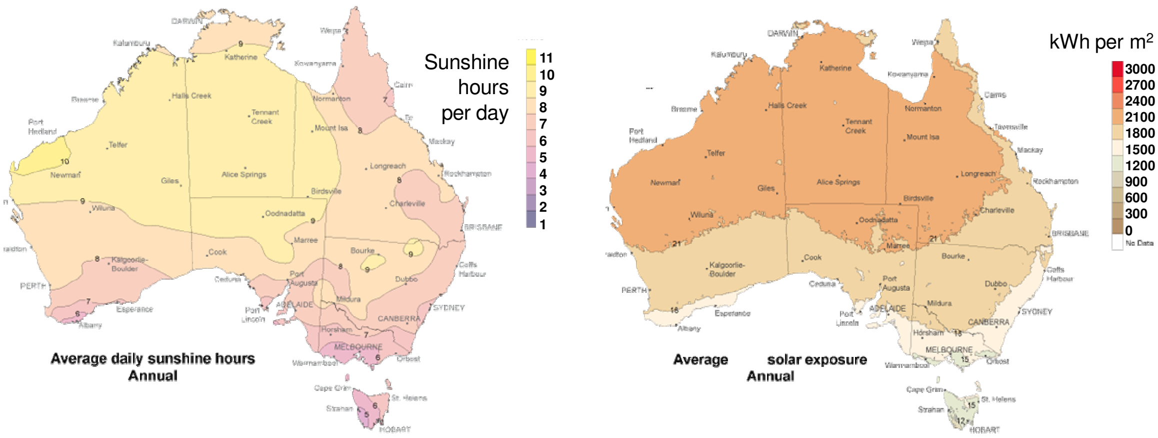



Figure 1. Sunshine hours and annual solar irradiation in Australia [1].

Recently, 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 is 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.

## 2 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 this paper there are four solar cooling systems in operation with a fifth under construction, Table 1.

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

| Location | Cooling capacity | Solar field size | Collector type | In operation since | Application |
|---|---|---|---|---|---|
| Ipswich, QLD | 300 $kW_r$ | 570 $m^2$ | Parabolic Trough | 2007 | Air-conditioning |
| Padstow, NSW | 175 $kW_r$ | 165 $m^2$ | Parabolic Trough | 2007 | Air-conditioning |
| Wyong, NSW | 7 $kW_r$ | 20 $m^2$ | Evacuated tube | 2009 | Air-conditioning |
| Newcastle, NSW | 18 $kW_r$ | 58 $m^2$ | Parabolic Trough | 2010 | Demonstration |
| Newcastle, NSW | 233 $kW_r$ | 350 $m^2$ | Parabolic Trough | 2010[1] | Air-conditioning |

[1] Under construction, expected operation mid 2010

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 $kW_r$) are exclusively imported from overseas and attract a considerably high price tag in Australia. With specific cost of approx.$ 6,000-9,000/$kW_r$ they are an order of magnitude more expensive than conventional split systems which are available at approx. $600-$800/ $kW_r$ (both costs for installed system, excluding GST) [6]. The situation is different for larger commercial or industrial applications (50-500 $kW_r$). Economies of scale make larger units more economic 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.

### 2.1 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 standardized solar cooling system to be implemented

These are no major unsolvable technical issues for the implementation of solar cooling, however 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 are hard to compete with. 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 and off-grid applications.

To help overcoming the market barriers above and support the introduction and market development of solar cooling in Australia, the Australian Solar Cooling Interest Group (ausSCIG) was founded in 2008. ausSCIG 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].

### 2.2 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, thus encouraging peak power savings

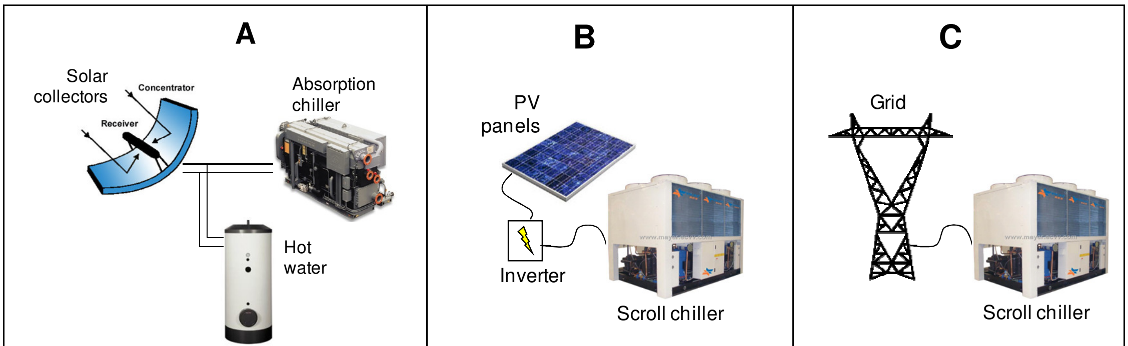
- Building owners recognition for energy efficient systems. (Green star and NABERS programs)
- Implementation of a carbon trading scheme to include for environmental externalities associated with electricity generation. (Carbon pollution reduction scheme).
- Renewable Energy Credits (REC's) for solar thermal hot water systems
- Implementation of tradable certificates for energy saving activities (Energy Savings Certificates, ESC's, NSW only)

A solar cooling system will most likely generate hot water during operation and therefore becomes eligible for REC's. Carbon tax credits apply to GHG emissions saved and in NSW users can trade the ESC's for electricity saved by a solar cooling system at a rate of $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.

## 3 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, Figure 2. 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 the following. Three scenarios have been compared to each other:

A. Solar thermal parabolic trough collectors and a double-effect absorption chiller
B. Photovoltaic panels and a scroll type vapour-compression chiller
C. Reference case: Grid-connected scroll type vapour-compression chiller




| | | |
|---|---|---|
| Solar thermal collectors & absorption chiller (STAC) | Photovoltaic panels & scroll chiller (PVS) | 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 230 $kW_r$ cooling capacity, this being a medium-sized industrial application for e.g. 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 8 hours/day over 5 five months/year (in total 1200 hours/yr)
- All cooling generated is used completely, ie no thermal/electrical storage

- No subsidies have been assumed for solar thermal cooling (no REC's, no ESC's, no carbon tax etc.)
- 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 (276 $MWh_{th}$/yr)
- Hot water provision is not taken into account

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.

Table 2. Financial assumptions for NPV calculations

| 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 | 0.17 $/kWh_{el}$ |
| Annual escalation rate electricity cost | 2 % |

Table 3. System specifications for NPV calculations

| System assumptions | STAC | PVS | REF |
|---|---|---|---|
| Total cooling power ($kW_r$) | 230 | 230 | 230 |
| Average annual COP chiller (-) | 1.1 | 4.0 | 4.0 |
| Heat required for cooling ($kW_{th}$) | 209 | - | - |
| Electrical power required for cooling ($kW_{el}$) | 15 | 58 | 58 |
| Solar thermal collector/PV area ($m^2$) | 508 | 391 | - |

Table 4. Cost assumptions for NPV calculations

| Cost assumptions | STAC | PVS | REF |
|---|---|---|---|
| Solar collectors/PV panel cost[2] | $ 335,506 | $ 301,440 | - |
| 230 $kW_r$ Chiller and air cooler cost | $ 154,000 | $ 119,600 | $ 119,600 |
| Balance of plant cost | $ 54,200 | $ 92,650 | $ 20,650 |
| Total equipment cost | $ 543,706 | $ 513,690 | $ 140,250 |
| Total engineering and installation cost[3] | $ 85,495 | $ 60,882 | $ 28,412 |
| **Total system cost** | **$ 629,201** | **$ 574,572** | **$ 168,662** |
| specific system cost | $/$kW_r$ 2,736 | $/$kW_r$ 2,498 | $/$kW_r$ 733 |
| Annual average O&M cost | $ 6,651 | $ 2,465 | $ 15,648 |

The solar thermal system (STAC) uses parabolic trough collectors with an annual average efficiency of 55%. A hot water storage tank of 1000 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].

[2] Parabolic collectors have been assumed at $650/$m^2$, the PV panels at $4.20/$W_p$.

[3] Cost estimates for installation and engineering have been taken from [14].

The PV modules in the PVS system have been assumed with an annual average efficiency of 14%. A degradation 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.

## 4 RESULTS AND DISCUSSION

The life time cost calculations over 20 years lifetime (replacement of scroll chiller in scenarios PVS and REF after 12 years) are given in Figure 3 and Table 5. Greenhouse gas emissions are shown in Figure 3 and Table 6.

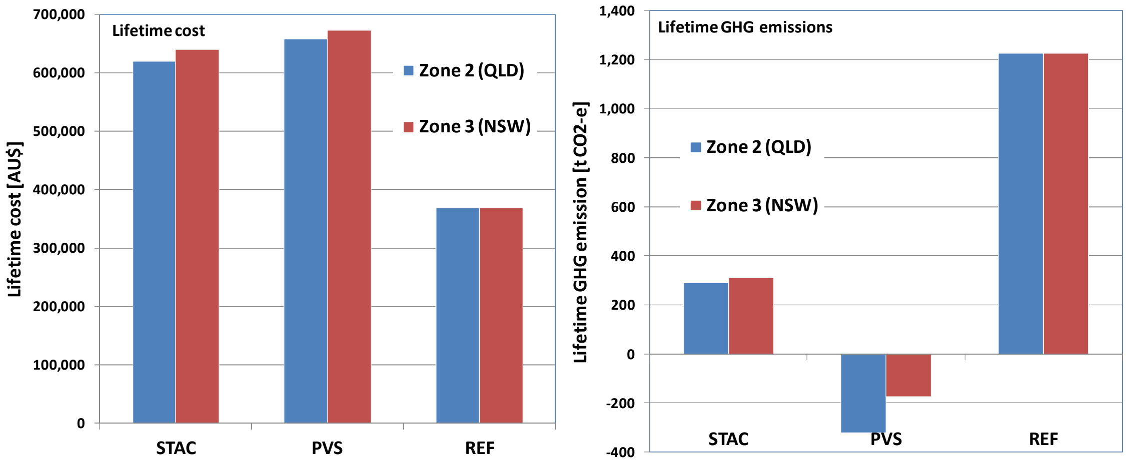



Figure 3. Lifetime cost (left) and greenhouse gas emissions (right).

Table 5. Results of lifetime cost calculations

| | NPV results | STAC | PVS | REF |
|---|---|---|---|---|
| Zone 2 (Brisbane) | Lifetime cost | $ 620,928 | $ 658,061 | $ 370,724 |
| | Difference to reference case | 167% | 178% | 100% |
| Zone 3 (Sydney) | Lifetime cost | $ 640,148 | $ 673,014 | $ 370,724 |
| | Difference to reference case | 173% | 182% | 100% |

Table 6. Lifetime greenhouse gas emissions

| | GHG emissions | STAC | PVS | REF |
|---|---|---|---|---|
| Zone 2 (Brisbane) | Lifetime GHG emissions (t $CO2_e$) | 293 | -320 | 1228 |
| | Difference to reference case | 24% | -26% | 100% |
| Zone 3 (Sydney) | Lifetime GHG emissions (t $CO2_e$) | 312 | -174 | 1228 |
| | Difference to reference case | 25% | -14% | 100% |

It can be seen that the reference case (REF) has the lowest lifetime costs of all three systems. The solar thermal cooling system (STAC) has lower lifetime costs than the PV-based system (PVS) under the given assumptions. The differences between systems STAC and PVS are however rather small compared to the overall system cost.

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 $CO_{2\text{-}e}/kWh_{el}$ [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 (C) has the highest GHG emissions of all three systems. The solar thermal cooling system (STAC) has approx. 75% less GHG emissions than the reference system (REF) under the given assumptions. The PVS system has no operational GHG emissions at all and the electricity generated over the lifetime makes its GHG emissions negative.

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. Therefore it has been investigated which escalation in grid electricity price is required to make a solar cooling system competitive with a grid connected scroll chiller system under the given assumptions, Figure 4.

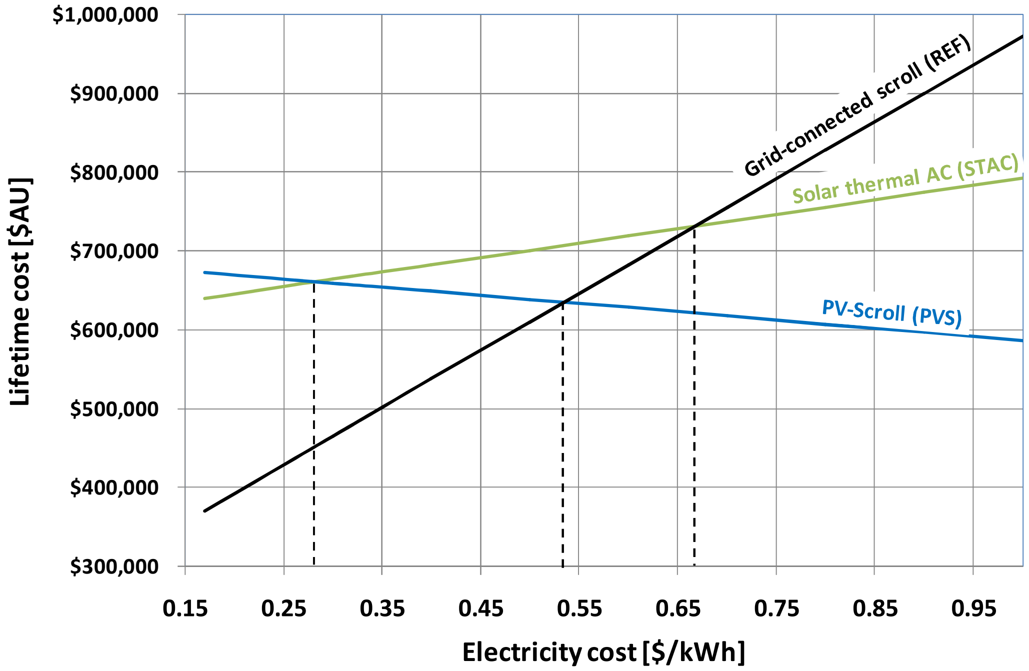



Figure 4. Sensitivity analysis on electricity price to reach lifetime cost parity between reference and solar cooling systems.

A few conclusions can be drawn from Figure 4. Firstly, at current conditions ($0.17/kWh$_{el}$) solar thermal cooling (STAC) has a lower lifetime cost than PV-based cooling (PVS). This is true until the electricity price reaches $0.28/kWh$_{el}$, then the PVS system has lower lifetime cost. Secondly, up to an electricity price of $0.54/ kWh$_{el}$ a grid connected chiller (REF) has always lower lifetime cost. Above $0.54/ kWh$_{el}$ the PVS system becomes more economic. Thirdly, a solar thermal cooling system breaks even with a grid connected chiller at an electricity cost of $0.67/ kWh$_{el}$.

## 5 SUMMARY AND OUTLOOK

Solar cooling still is 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 summarizes 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.

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 \$0.28/$kWh_{el}$. A PV-based system becomes the most economic cooling alternative if the electricity price exceeds \$0.54/ $kWh_{el}$. A solar thermal system becomes more economic than a conventional system for electricity prices above of \$0.67/ $kWh_{el.}$

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. 75% 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. The authors recommend more detailed modelling using transient solar simulation software such as TRNSYS.

# 6 NOMENCLATURE

| **Variables** | | **Subscripts** | |
|---|---|---|---|
| *COP* | Coefficient of performance | th | Thermal |
| *CPI* | Consumer price index | el | Electrical |
| *GHG* | Greenhouse gas | r | Refrigeration |
| | | p | peak |

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