Energy Efficient Air-Conditioning
Technology Review and Decision Aid for Australian Telecommunications Sites

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Technology Review and Decision Aid for Australian Telecommunications Sites

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Abstract

Energy consumption is a major concern for telecommunications infrastructure companies with issues including government legislation, sharply rising costs of electricity and environmental impacts. Air-conditioning represents a significant proportion of the energy use at telecommunications sites but also provides some of the greatest potential for savings. This paper explores the available technologies and aims to aid engineers in making technology choices that maximise this potential.

The first section provides a technology review covering the major current technologies of today and those presenting significant potential in the future. For each technology the following sections are presented:

- A succinct description of the theory behind the technology with further information available in the appendices if required.
- A literature review discussing the technology's state of commercial development with case study reviews and where available.
- A review and analysis to provide clear examples of how this technology can be utilised on telecommunications sites.
- A list main advantages and disadvantages to summarise the findings and recommend the applications which present the greatest potential.

To aid in the paper's continued use, a decision aid has been developed to give the reader a tool for continual assessment of these ever evolving technologies. The primary aim of the decision aid is to provide a tool that will aid engineers in choosing the most suitable technology by guiding them through an assessment of relevant life cycle criteria. The decision aid is designed for comparison of site specific input data relevant at the time of use and is flexible in its application from high level first pass assessment to more detailed analysis. The decision aid also
has the ability to be applied in a generalised fashion to aid nationwide network planning and focus investment.
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1 Introduction

1.1 Context

“Australian retail electricity prices increased by an average of 30 per cent between 2006 and 2010, and by some estimates will have risen by at least 100 per cent from 2008 levels by 2015” (AIG, 2011). Statements from well-respected industry advisors and experts such as this from the Australian Industry Group are becoming common place in the Australian media and industry publications. Fuelling the concern further is the impact of carbon emissions on climate change and the uncertainty surrounding carbon price legislation. It’s of little wonder that many commercial enterprises are looking to invest in green technologies, energy efficiency and alternate supplies of energy to reduce business risk and costs.

Telecommunications companies and infrastructure owners are certainly included in the league of those concerned given that it’s one of their largest costs. Telecommunications companies are subject to strong competition in the market place so any reduction increases their competitive advantage. Infrastructure owners are often subject to long term fixed price contracts with limited opportunity to pass on the uncertainty and rising costs to their customers.

As a general rule, transmission equipment consumes the majority of the energy at a given site. However this design is often under the control of equipment vendors over which its customers have only limited control. This is especially true in the Broadcast Industry with equipment lifecycles spanning in excess of 20 years in most cases making efficiency driven upgrades unviable in many circumstances. Air conditioning represents a significant portion of these energy costs and is a more controllable cost.

Despite this focus and opportunity, the engineers in charge of system design are often limited in their ability to install the most efficient technology. Barriers include
a lack of knowledge of industry developments and time to invest in complex research, the resulting decision making process and a new design. Further, new designs bring with them inherent project risk and complexity. An engineer with time pressures from rollout deadlines or equipment downtime from existing system failures often tends towards the tried and true easy solution, despite the long term payback leaning towards an alternative.

1.2 Research Objectives

This report aims to reduce the impact of the following barriers to entry:

1. Knowledge and time consuming research through an industry specific literature review.

2. The difficult, multifaceted decision making process by developing a technology selection decision aid.

The primary aim of the decision aid is to provide a tool that will aid engineers to choose the most suitable technology by guiding them through an assessment of various technologies. The decision aid is designed for comparison of site specific input data relevant at the time of use. This assessment can be undertaken at any level required by the user from a very high level first pass to a more detailed analysis with engineered design inputs. The main controlling variable in this is the time and effort spent on the input data.

A secondary use of the decision aid is to give an overview of the technologies and their rating as a snapshot at the given point in time. The decision aid can then be taken a step further to give the user a national view of how these technologies rate when applied to typical climatic conditions. It provides a ranking which indicates the technology or technologies that are likely to present a valid alternative to conventional vapour compression systems.
1.3 Report Structure

The report is divided into the following key sections:

1.3.1 Section 2 – Technology review

This is the main body of the paper that reviews each technology individually. For each technology review the following general structure is followed:

1. Technology Brief – a succinct description of the theory behind technology to be discussed. Further detail for the majority of the technologies is available in the corresponding appendices.

2. Literature Review – a discussion covering the advantages, disadvantages and state of commercial development of the technology with case study reviews where available.

3. Possible Industry Applications – an appraisal following the literature review detailing how the technology could potentially be used at telecommunications sites.

4. Conclusions & Recommendations – a summary of the advantages and disadvantages of the technology followed by the author’s recommendation for trials and/or implementation.

1.3.2 Section 3 – Technology selection decision aid - Description

This section provides a detailed description of the decision aid, its objectives as outline in 1.2, use and how to interpret its outputs.

1.3.3 Section 4 – Technology selection decision aid – Demonstration

The primary purpose of the demonstration is to illustrate the decision aid’s use and effectiveness by evaluating a reduced number of technologies at a selection of “typical sites”. The demonstration is restricted in its direct application beyond a general overview by the following:

1. A large number of assumptions were required in order to define a “typical site” resulting in a lack of certainty.
2. The immature nature of the innovative technologies discussed and analysed restricts the information available for use when applying criteria ratings. Further, the sample size of that information is very restricted at this point in time.

Due to these issues, the reader should apply significant caution when reviewing the given results.

1.3.4 Appendices

The appendices are primarily aimed at providing the reader with guidance and tools to aid with the understanding, design and procurement of efficient air conditioning systems. The appendices contain:

- A review on the technologies for those readers who require a refresh or more detail. These appendices are designed to be read as a standalone reference and therefore may contain portions of repeated material from the main body.
- Extended detail on the decision aid and example illustrations.
- References to software.
- A list of potential manufacturers and system integrators at the time of publication to aid the engineer in finding a suitable vendor.
- A brief literature review on the major auxiliary system components review.
2 Technology Review

2.1 Indirect Evaporative Cooling

2.1.1 Technology brief

Evaporative cooling is a means of temperature reduction which operates on the principle that water absorbs latent heat from the surrounding air when it evaporates (RERC, 2011). Direct evaporative cooling draws air through wet evaporative pads thereby removing heat and adding moisture to the air (Bruno, 2008, 2009). Indirect evaporative cooling uses two air streams. One stream uses the conventional direct evaporative cooling method to remove heat from the wet stream connected to a heat exchanger and the other passes through the heat exchanger in a separate dry stream to remove the heat without adding extra moisture to the process air (Daou et al., 2006).

Further detail on how direct and indirect evaporative cooling works can be found in Appendix C.

Direct evaporative cooling has been omitted from this report as it introduces humidity into the air which is harmful to telecommunications equipment and the maximum cooling effect can only approach the wet bulb temperature. Whilst the systems can be cheaper and dehumidification techniques can be utilised, the technology is not considered on its own in this report.

2.1.2 Literature review

An evaporative cooling system can be implemented by Indirect Evaporative Cooling (IEC) or Direct Evaporative Cooling (DEC). DEC cools the process air directly by drawing it through drenched evaporative cores where the water is evaporated, thereby cooling the air to temperatures which may approach the wet bulb temperature of the incoming air. However, while the temperature is reduced with low energy consumption, DEC is an adiabatic process in which the
temperature of process air is lowered only at the expense of higher moisture content in the air, raising the humidity of the air, reducing comfort and reducing air quality for conditioned spaces sensitive to high humidity. Further, this cycle of evaporative cooling can only operate efficiently in dry climates (Bruno, 2008, 2009; Daou et al., 2006).

IEC utilises the low energy advantages of evaporative cooling to reduce the temperature of air without the addition of moisture. These technologies invariably use some form of heat exchange media between the evaporation of water process and cooling of air. The conditioned air is thereby cooled without the addition of moisture to the air stream (Bruno, 2008; Daou et al., 2006).

In relatively more humid climates, the IEC would rather be the better choice over DEC since it enables sensible cooling without adding moisture into the process air. The sensible cooling of air not only reduces the dry bulb temperature, but also its wet bulb temperature (Bruno, 2008, 2009). Furthermore, IEC allows the use of reduced air volume in comparison with what would be required in direct evaporative cooling (Daou et al., 2006). It should be clarified here that the inside humidity levels will be equivalent to the ambient conditions. Therefore if the ambient air humidity is considered too high for the conditioned space, additional measures must be taken to control it. IEC also suffers similar efficiency limitations as DEC in humid conditions.

The extent to which a particular cooler can approach the wet bulb temperature is its "wet bulb effectiveness". A well-made direct evaporative cooler will have an effectiveness of approximately 85% (Bruno, 2008, 2009). A simple single pass indirect evaporative cooler would be inferior to this due to losses in the heat exchange medium (Daou et al., 2006).
Counter flow heat exchangers use a double pass in adjacent wet and dry air passages to overcome this limitation. The configuration allows the outgoing air to approach the Dew Point of the incoming air which is considerably lower than the wet bulb temperature.

Figure 1 and Figure 2 below illustrate the difference between direct and indirect evaporative cooling in relation to the amount of humidity introduced into the air.

![Psychrometric Chart](image)

Figure 1 - Psychrometric chart of a direct evaporative cooling process (Bruno, 2008)
Two case studies are available for counter flow heat exchanger IEC systems as published by the University of South Australia for Seeley International. The first system studied was installed in a fresh air precooling configuration as illustrated in Figure 8 in section 2.1.3.2. It services an existing refrigerant based air-conditioning system for ETSA in Marleston, South Australia 35ºS. Unfortunately the increase in full system efficiency could not be measured due to the mixed air nature of the system along with the existing refrigerant cooling system being undersized.

However, gains were obvious and the cooling capacity increased such that the system now succeeds in meeting the cooling requirement during conditions that previously would have seen the system fail. Further, Figure 3 clearly shows that the air temperature into the refrigerant air conditioner located West consisting of precooled fresh air and building return air (AC West in the figure) drops over 3°C which would result in obvious energy savings on a correctly sized system, potentially up to 150 kWh per day. This is the end where the IEC unit is supplying fresh air into the plant room. There is no change at the other end (AC East) (Bruno, 2008).
Figure 3 - Temperatures from the ETSA indirect evaporative precooled plant on a hot day (max ambient temperature 35.4°C (Bruno, 2008))

The efficiency of the IEC precool units were able to be measured and were recorded as:

- Hot dry day, max temp recorded at 43.5°C - average cooling capacity for the day = 10.5 kW, average COP = 8.0
- Hot dry day with max 35.4°C - average cooling capacity for the day = 7.1 kW, average COP = 11.5
- Warm day max temp 28.3 - average cooling capacity = 7.2 kW, average COP = 6.4 (Bruno, 2009)

All the above Coefficient of Performance (COP) values can easily be identified as more efficient than the refrigerant air conditioning plant could realistically demonstrate that significant efficiency gains were made on the fresh air delivery portion of the system.

The second case study performed was on a standalone IEC systems installed in residential homes at Roxby Downs in far North South Australia 30.5°S, which has
a very dry hot climate. The cooling power of the two Climate Wizards was demonstrated to be as high as 10.8 kW (average over the day) with hot, dry conditions. The maximum average electrical COP was measured to be 11.8, compared with refrigerant air conditioner COP's of around 3.4 at the same operating conditions.

![Figure 4 - COP versus the dew point temperature of ambient air. Each point corresponds to the average (Bruno, 2009)](image)

As can be seen in Figure 4 above, COP has a strong inverse linear correlation to wet bulb temperature with a correlation coefficient of 0.94 for both units. This means performance in other climates can therefore be reliably predicted, given the temperature and dew point (Bruno, 2008).

An analysis has shown that for Roxby Downs, the Climate Wizard would have saved over 26% energy in comparison to a fixed speed refrigerant air conditioner, and over 17% energy in comparison to a modern inverter refrigerant air conditioner. In addition, the maximum power input for a Climate Wizard (approx. 1.7 kW) is significantly lower than a refrigerant based system (over 3 kW) (Bruno, 2008).
Further, Figure 5 and Figure 6 below illustrate how in hot and dry climates the IEC only gets stronger and more energy efficient as the temperature rises, while a refrigerant based air conditioner actually reduces its cooling capacity and COP (Bruno, 2009).

Figure 5 - Typical fixed speed refrigerant air conditioner input power, COP & cooling power vs. ambient temperature

Figure 6 - Typical "Climate Wizard" counter flow heat exchanger IEC input power, COP & cooling power vs. ambient temperature
Another IEC unit has been installed in the Broadcast Australia network which is retrofitted to an existing refrigerant air conditioning system to create a three stage cooling system. The system is configured to first utilise ambient air to ventilate the building followed by multiple stages of IEC cooling, which is backed up by staged refrigerant air conditioners if the space temperature or humidity rise above acceptable limits. The system is designed to achieve over 50% energy savings on an average yearly cycle. It has not been running for a sufficient time to allow for a thorough analysis to be performed and no independent study is available at the time of publishing this paper. Nevertheless, preliminary analysis indicates the system has increased the cooling performance of the site and has significantly reduced the running time of the refrigerant compressors. Figure 7 below tracks the system through initial setup. Since this required the system to be returned to its normal state with the IEC coolers switched off for certain periods, it clearly illustrates the advantages of the new system and its superior performance over that of the old system.

![Figure 7 - Mt Lofty IEC hybrid system performance](image-url)
Maintenance on an indirect evaporative cooler can be very significantly reduced if the right microbial control measures are undertaken. If microbial related maintenance is avoided using these measures, the maintenance regime for a plant with 24/7 operation is estimated at:

- Dust filter check/replacement – 30 mins/unit every 6 months – unskilled labour
- Check cores – 3 hours/unit every 12 months – skilled labour
- Water reservoir checks/cleaning – 2 hours/unit every 12 months – unskilled labour
- Pump strainers checks/cleaning – 2 hours/system every 4 months – unskilled labour
- Chlorinator plates checks/cleaning – 1 hour/unit every 4 months – skilled labour
- Water level probes checks/cleaning – 1 hour/unit – unskilled labour.

(Morton, 2011)

The above procedures sum to 15 man hours of unskilled labour per annum, per unit and 6 hours of skilled labour per annum per unit.
2.1.3 Possible industry applications

A description detailing likely optimal systems across Australia has been developed by Seeley International for Broadcast Australia which gives an indication of relative costs if installed in large regional centres i.e. excluding mobilisation costs. This analysis is summarised in Table 2 below. It should be noted that the cost estimates in this table are not intended as a quotation nor are they the maximum that might occur. They are based on experiences to date and the weather data from around Australia. However, they form a reasonable guide for comparison of system costs in different climates and for different system sizes which is the intention of this paper. Further, the 60 kW and above analysis based on a 4500l/s large capacity unit that is in development for high capacity applications but not yet commercially available.

Table 1 – Indirect evaporative cooling options overview for Australia (McBratney, 2011b)

<table>
<thead>
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<th>Geographical Location</th>
<th>0 - 10 kW</th>
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<td></td>
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<td>~ $</td>
<td>Suitability</td>
<td>~ $</td>
<td>Suitability</td>
</tr>
<tr>
<td>Nth QLD Coastal</td>
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<td>N/A</td>
<td>Not suitable</td>
<td>N/A</td>
<td>Not suitable</td>
</tr>
<tr>
<td>Nth QLD Inland</td>
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<td>$2.0k/kW</td>
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<td>Nth NT</td>
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<td>$2.3k/kW</td>
<td>Marginal</td>
<td>$2.3k/kW</td>
<td>Marginal</td>
</tr>
<tr>
<td>Nth WA</td>
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<td>$2.3k/kW</td>
<td>Marginal</td>
<td>$2.3k/kW</td>
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<td>South/central coastal QLD</td>
<td>Marginal</td>
<td>$2.3k/kW</td>
<td>Marginal</td>
<td>$2.3k/kW</td>
<td>Marginal</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------</td>
<td>----------</td>
<td>---------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>South/central NT</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
</tr>
<tr>
<td>Central WA</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
</tr>
<tr>
<td>South WA</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
</tr>
<tr>
<td>SA</td>
<td>Good to Very Good</td>
<td>$1.7k/kW</td>
<td>Good to Very Good</td>
<td>$1.7k/kW</td>
<td>Good to Very Good</td>
</tr>
<tr>
<td>Eastern NSW</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
</tr>
<tr>
<td>Western NSW</td>
<td>Good to Very Good</td>
<td>$1.7k/kW</td>
<td>Good to Very Good</td>
<td>$1.7k/kW</td>
<td>Good to Very Good</td>
</tr>
<tr>
<td>VIC</td>
<td>Good to very Good</td>
<td>$1.7k/kW</td>
<td>Good to very Good</td>
<td>$1.7k/kW</td>
<td>Good to very Good</td>
</tr>
<tr>
<td>TAS</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
<td>$2.0k/kW</td>
<td>Good</td>
</tr>
<tr>
<td>ACT</td>
<td>Very Good</td>
<td>$1.7k/kW</td>
<td>Very Good</td>
<td>$1.7k/kW</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

**NOTE:**
1. <10kW requires one machine, so minimum total applies.
2. Cost per kW cooling is indicative and not capped.
2.1.3.1 **STANDALONE COOLING SYSTEM IN DRY CLIMATES**

Provided that there is a water supply available and the correct (primarily low humidity) climatic conditions exist then when temperatures rise, indirect evaporative coolers can reliably be used as the sole source of cooling. Most systems can be applied in open or closed loop cycle depending on system requirements or efficiencies.

Further advantages can be realised where internal temperatures do not have to be constrained to levels at or below 27°C. Typically, refrigerant based coolers require a return air temperature below 27°C for continued reliable operation. IEC units however can control at higher temperatures or be designed such that temperatures can rise above this for periods of peak loading without impacting on unit performance or longevity. This advantage is an ideal solution in transmitter halls where higher temperatures can be permitted for short periods without unacceptable service risk. This design not only reduces energy consumption but also capital expenditure requirements by reducing the cooling capacity requirement to meet average load rather than peak.

2.1.3.2 **PRECOOLING OF AN AIR HANDLING UNIT**

![Diagram of Air Handling Unit](image)

**Figure 8 - Possible pre-cooling configuration (Bruno, 2008)**

Figure 8 above represents a system where the fresh air for an air handling unit for a conventional refrigerant mechanical cooling system is pre-cooled by indirect evaporative coolers, represented as the Dricool Units. The effect is reducing the load on the existing system, resulting in reduced consumption or if the system is
already overloaded, increased cooling capacity allowing the system to better meet its peak demands (Bruno, 2008).

2.1.3.3 **HYBRID STAGED COOLING**

![Diagram of IEC hybrid staged cooling](image)

**Figure 9 - IEC hybrid staged cooling**

The cooling system illustrated in Figure 9 above can either be added to an existing system to increase efficiency or cooling capacity. It is also ideal for climates where ambient conditions are predominantly hot and dry with periods of cool and dry but has the ability to accommodate those periods where humidity rises above acceptable equipment limits because the refrigerant air conditioning can be called upon to reduce humidity. Its operation can be described as below:
Stage 1: Ventilation only

When the ambient temperature is sufficiently cool, air is drawn directly into the room by the fans of the IEC cooler and exhausted through the vents. The cooling stages of the IEC are not engaged saving energy and water. This stage can be disabled if the internal humidity rises above acceptable limits.

Stage 2: IEC cooled air

As the ambient temperature rises above levels that can provide sufficient cooling of the conditioned space, the IEC unit coolers are engaged at various levels to cool the ambient air to the required temperature. This stage can be disabled if the internal humidity rises above acceptable limits.

Stage 3: IEC cooled air and refrigerant air conditioned

This final stage of cooling engages the existing refrigerant air conditioning compressors one by one to add additional cooling capacity to the system as required. The IEC coolers can also be disabled if the humidity rises to unacceptable levels leaving the refrigerant system to provide all cooling in a closed loop cycle.

2.1.3.4 *Hybrid system with a dehumidification system.*

See sections 2.6.2.2, 2.6.2.3 and F.2 for descriptions of these systems.

2.1.4 Conclusions & recommendations

2.1.4.1 Advantages

- Adds no humidity to the supply air
- Virtually unlimited return air temperatures
- Increased efficiency in extreme conditions that decrease the efficiency of vapour compression units
• Can be used for peak loading
• Can provide 24/7 cooling although dehumidification may be required in certain areas
• Can be utilised for pre-conditioning only if desired
• Easy to integrate/retrofit into existing systems

2.1.4.2 **DISADVANTAGES**

• Water supply required
• Performance is governed by wet bulb temperatures
• May require dehumidification
• Not efficient in all climates
• Potential for legionella build-up
• Relatively high maintenance required

2.1.4.3 **RECOMMENDATIONS**

Indirect evaporative cooling is one of the most attractive efficient cooling options on the market today, especially in hot and dry climates. It is recommended that these climates are targeted for installation either for new installations, remediation of aging systems or just where the payback is attractive.

2.2 **Gas Fire Driven Adsorption And Absorption Chillers**

Whilst gas driven absorption and adsorption chillers for backup or primary cooling systems are efficient especially when utilised in a trigeneration scenario they rely on gas supply and storage which is rarely available or practical at remote telecommunications sites. Therefore this technology has been omitted from this research paper.

2.3 **Solar Cooling - Overview**

Solar cooling as a technology group covers the following predominant, commercially available applications:
1. Adsorption chiller
2. Absorption chiller
3. Desiccant cooling
4. Ejector cooling

These applications are categorised in Figure 10 below.

Figure 10 - Overview on physical ways to convert solar radiation into cooling or air-conditioning. Processes marked in dark grey: market available (Henning, 2007)

All three of these applications require separate description and evaluation so they are treated separately by this paper in the subsequent sections. However, these three applications are commonly grouped in this small but rapidly growing industry sector and also have some significant commonalities which are better discussed collectively so are extracted here for efficiency and clarity. Further, solar collector and heat rejection technologies have been identified by the author as common and interchangeable components of any given solar cooling system, so whilst they will be touched on in this and the subsequent solar cooling sections, more in depth information can be found on these and their relevant design tools in:
2.3.1 Industry development

As illustrated in Figure 11, solar cooling appears to have achieved a level of commercialisation with installed unit figures doubling each year between 2004 and 2008. The industry is starting to show real promise and global prices are falling (see Figure 12 below) however further technology, policy and manufacturing improvements are required for prices to reduce and genuine competitive commercialisation to be realised (White, 2011d).

One significant movement in the policy area is the proposed inclusion of solar cooling systems in the NSW Energy Efficiency white certificates scheme. However, greater barriers still exist such as:

- Currently, solar cooling has no access to a carbon value
• Solar cooling is not on a level playing field with other renewable energy
technologies for access to tradeable Renewable Energy Certificates
(RECs)
• There is currently no recognised or easy method for evaluating carbon
value
• Scale has not yet reached critical mass

(White, 2011d)

![Solar Cooling Kit price history](image)

Figure 12 - Solar cooling cost per kW trends (White, 2011d)

Figure 13 below illustrates the installed solar cooling systems in Europe as at
2006. Absorption chillers still dominate the market both in terms of number of
systems and installed capacity. It is likely that this is primarily due to the
technology’s maturity and resulting reliability and cost effectiveness on medium to
large scale systems. Desiccant systems, particularly dry rotor are the next largest
in terms of number of systems but the comparably low cooling capacity indicates
that they are most efficient at smaller scales or as precooling or conditioning for
larger systems. The key characteristic illustrated for adsorption is that it is still
relatively immature and expensive so fewer systems have been installed.
However, the systems installed are of a high capacity.
Different heat driven cooling technologies are readily available for large systems of 50 kW and above, generally driven by the gas fired and trigeneration market which can be used with solar thermal collectors. Until recently, many years have passed with no appropriate technology on the market for small scale systems in the 5 to 50 kW range. The first commercial systems are now available and development is continuing as driven by international programmes such as the framework of the Solar Heating and Cooling Programme of the International Energy Agency (IEA). The study provides a solid starting point for the review of high efficiency solar thermal collectors (Henning, 2007). In Australia, the Australian Solar Cooling Interest Group (AusSCIG) provides conduits for research and commercial development and general promotion of the industry through educational workshops and conferences (AusSCIG, 2011).

Figure 13 - Distribution of systems in terms of number of systems, cooling capacity and installed collector area.
2.3.2 Advantages and design considerations

Solar cooling capability trends on a daily time scale generally follows that of a typical solar PV system as illustrated in Figure 14 below. The primary advantage over PV as an energy source is solar thermal’s inherent mass and its reduced reliance on direct sunlight which smooths out much of the intermittency from localised cloud cover (Osbourne and Kohlenbach, 2011b).

![Figure 14 - Solar cooling capability relative to peak loads](image)

The energy producing hours largely map those of the peak electricity consumption trends observed in electricity networks and could therefore offset not only grid demand but also peak electricity costs. One challenge however is the ability for 24/7 operation, especially in industries where this is a vital requirement. In this situation, energy storage or alternate means of cooling are required. Energy storage technology is reported to be rapidly developing to the MWh range, however specifics are not readily available due to pending patent and intellectual property rights which restrict publication of findings (Taylor, 2011; Osbourne and Kohlenbach, 2011a). Until this technology develops, solar cooling will rarely be viable as a standalone application.
Design expertise is also a significant limitation for solar cooling as an industry. Critical mass must be achieved in order for these skills to become mainstream as they have for other technologies such as solar hot water. A general experience is that it is more important to install a robust system with less risk of malfunction than to increase the efficiency to the possible maximum (Osbourne and Kohlenbach, 2011b). Further, important observations from monitoring and system performance reviews are:

- In many cases the expected energy savings could not be realized completely in practice. In most cases the reason is a higher parasitic energy consumption of the poorly designed or inappropriately selected auxiliary components such as cooling towers or ventilators in desiccant systems (White, 2011b).

- In general a greater effort for system design and planning is necessary due to the higher complexity compared to conventional plants. For a list of currently available commercial and freeware solar cooling design tools see Appendix G (White, 2011b).

- A comprehensive commissioning phase is mandatory in order to test all possible operation conditions such as part load operations or backup heating systems (Henning, 2007; Osbourne and Kohlenbach, 2011b).

- Control system parameters are of paramount importance for performance with varying loads and heat sources (Henning, 2007; Osbourne and Kohlenbach, 2011b).

- Continuous automatic system monitoring such as web-based systems is recommendable in order to detect malfunctions or control problems (Henning, 2007; Osbourne and Kohlenbach, 2011b).

Stephen White in a recent conference on solar cooling drew some valuable comparisons between the major solar cooling technologies. This table is extracted
in Figure 15 for the benefit of the reader. It highlights the main applications and common drawbacks for consideration.

<table>
<thead>
<tr>
<th>Application Comments</th>
<th>Absorption (one stage)</th>
<th>Absorption (two stage)</th>
<th>Adsorption</th>
<th>Desiccant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Positive</strong></td>
<td>Most common to date. Mature technology. There are a number of small units being developed</td>
<td>Higher efficiency potentially reduces collector area and ancillary costs. Potential to use gas as a backup without GHG penalty</td>
<td>Robustness/simplicity is attractive in smaller applications. Better suited for flat plate collectors. A number of small scale units are being developed</td>
<td>Possibly the most economic of technologies available today. Uses cheap collectors. Can provide partial evaporative cooling without sun</td>
</tr>
<tr>
<td><strong>Negative</strong></td>
<td>Generally requires a cooling tower. Economics are unattractive. Limited room to improve.</td>
<td>Requires a cooling tower. Requires tracking collectors. Only available for larger applications. Complexity has not been fully resolved for robust systems</td>
<td>Poor efficiency limits suitability for large applications. Expensive</td>
<td>Possible problems achieving desirable room temperatures without chiller backup. Poor efficiency requires large collector area</td>
</tr>
</tbody>
</table>

Figure 15 - Solar cooling comparative advantages and disadvantage (White, 2011c)

A description detailing likely optimal systems across Australia has been developed by Australian Sun Energy for Broadcast Australia, which gives an indication of relative costs if installed in large regional centres. Whilst the geographic split is not detailed it does give an understanding of installation cost ratios between system sizes and indicates system suitability today which is largely limited to under 120 kW without backup or trigeneration. Note that the free-air solution is classified as a solar cooling technology because the systems used for comparison are powered by solar PV. This analysis is summarised in Table 2 below:
Table 2 - Solar cooling options overview for Australia (Taylor, 2011)

<table>
<thead>
<tr>
<th>Geographical Location</th>
<th>&lt; 10kW</th>
<th>10 - 60 kW</th>
<th>60 - 120 kW</th>
<th>120 - 200 kW</th>
<th>200 - 250 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Suitability</td>
<td>~ $</td>
<td>Suitability</td>
<td>~ $</td>
<td>Suitability</td>
</tr>
<tr>
<td>Northern states</td>
<td>Small Adsorption chiller, vacuum tube collectors, thermal battery.</td>
<td>$3.4k/ kW **</td>
<td>Absorption chiller, vacuum tube collectors, thermal battery.</td>
<td>$3.4k/ kW **</td>
<td>Single stage absorption chiller, Vacuum tube, thermal battery, off grid</td>
</tr>
<tr>
<td>Southern and central states</td>
<td>Free Air – 3 cooling solution</td>
<td>$7.1-9.7 k/kW **</td>
<td>Free Air – 3 cooling solution #3 - 5</td>
<td>$3.4k/ kW **</td>
<td>Single stage absorption chiller, Vacuum tube, thermal battery, off grid</td>
</tr>
</tbody>
</table>

*All Proposed solutions are subject to the availability of space on the site.

** Solar cooling price converted from per tonne of cooling to per kW.
2.4 Solar Cooling - Thermally Driven Adsorption Chillers

2.4.1 Technology brief

Adsorption chillers take advantage of two physical characteristics in order to achieve efficient cooling. First, liquids are easier to transfer between pressure levels than gases and therefore using less energy to do so. Secondly, at different pressures liquids have different evaporating temperatures, thus lowering the pressure on water also reduces its temperature (Sonneklima, 2011).

The adsorption cooling process utilises the properties of evaporation of a liquid as it adheres to the surface of the adsorbent. During this step, the temperature of the liquid phase becomes lower while the adsorbent temperature rises. Thermally driven adsorption chillers utilise this phenomenon (Dieng and Wang, 2001). An adsorption chiller generally consists of the two sorbent compartments, the evaporator and the condenser. While the sorbent in the first compartment is regenerated using heat from the external heat source, e.g., the solar collector, the sorbent in the second compartment (adsorber) adsorbs the water vapour coming from the evaporator. The adsorber has to be cooled in order to enable a continuous adsorption. The water in the evaporator is transferred into the gas phase being heated from the external water cycle. This is where the useful cooling is produced (Henning, 2007).

A further detailed description of the adsorption chilling process can be found in Appendix D.

2.4.2 Literature review

For reasons of clarity and reduced duplication, a review on solar cooling as a whole has been included in section 2.3. It is advised that the overview section should be read prior to the adsorption chiller specific literature review below.
Adsorption cooling is generally possible where a chilling capacity can be used for air-conditioning, process cooling and so on and where a lower temperature heat source is available, e.g. from waste heat, district heating or solar energy (Dieng and Wang, 2001). Driving temperatures as low as 50°C are possible with some commercially available units today although efficiency and capacity is significantly reduced at levels below the tipping point of the efficiency curve (see Figure 50 in Appendix K) (Sortech, 2010).

An advantage of solar cooling and its capacity profile is that it can increase the existing conventional chilling capacity with no significant increase in electricity consumption. A 100 kW Mycom adsorption chiller was installed for municipal services at Remscheid where 75% of the main driving heat is supplied by solar collectors, while the remaining heating energy is supplied by district heating. The system has a nominal chilling capacity at a chilled water temperature of 10°C and a hot water temperature of 70°C. The chilling process begins with a hot water temperature as low as 55°C.

Another capacity increasing system has been installed by a Japanese company, Nishydo: A 320 kW silica gel adsorption unit has been installed parallel to a conventional 260 kW chiller in a shopping centre named Koningsgalerie in Kassel, Germany. It supplies peak chilling capacity only, yet 78% of the annual chilling demand (450 MWh) is realized by the adsorption chiller (Dieng and Wang, 2001).

Over the last few years, further modernisation of the units and many more similar systems have been installed. Figure 16 below gives a visual indication of the size of modern units today.
2.4.3 Possible industry applications

As illustrated in 2.3 above, standalone cooling with solar driven thermal adsorption is not feasible without a backup heat source or thermal storage. As gas is the most economical backup and supply widely seen as an inhibiting factor at remote sites, then unless these problems and those technologies for storage are overcome, a hybrid system is the only realistic implementation model to date.

Waste heat sources that can be utilised for thermally driven adsorption on site are somewhat limited for adsorption chillers. On high powered broadcast or other sites where concentrated heat sources from equipment cooling is available, the heat can be used to assist the solar collectors and extend their operational hours or smooth out intermittency. On a broadcast site, the air cooled FM transmitter exhausts are an example of a usable heat source available. Water cooled digital transmitter circuits require more investigation. Telecommunications installations, especially in a data centre type applications can have a much higher concentration of waste heat per square metre. Particularly where liquid-cooled processors are utilised, this concentrated waste heat is also worth investigating further.

2.4.3.1 Hybrid peak electrical demand reduction

Figure 16 - Adsorption chiller examples (Osbourne and Kohlenbach, 2011a)
In sites with reduced electrical capacity or availability, electrical upgrade costs or requirements can be avoided by taking the site's cooling off the electrical energy demand. Increased cooling capacity is also achievable without significantly increasing the electrical demand which may be advantageous in different circumstances.

2.4.3.2 Hybrid Staged Cooler

Staged cooling would involve ventilation in the cooler periods and solar driven cooling when sufficient heat sources are available, all backed up by a conventional cooler or air conditioner.

2.4.4 Conclusions & recommendations

2.4.4.1 Advantages

- Relatively low maintenance requirements if the right adsorber/refrigerant pair is chosen
- No alternative resource impact considerations
- High potential for further development
- Correlation with peak load demands at sites with large solar gain
- Potential for the A/C load to be taken off the electricity supply altogether in the future
- Low temperature heat requirements

2.4.4.2 Disadvantages

- Relatively immature technology
- Still exhibiting high costs without attractive paybacks in most situations
- Not reliable for 24/7 operation
- Storage technology still very immature
- Large land areas required for collectors

2.4.4.3 Recommendations

Whilst solar thermally driven adsorption chillers have significant potential for energy savings in the future, it is the opinion of the author that it should be let
mature further and reach more competitive levels commercially before large scale implementation. Technically, the technology exhibits robust, low maintenance performance so if other factors such as restricted or expensive water and/or electricity supply are a factor at a given site then it should certainly be considered.

2.5 Solar Cooling - Thermally Driven Absorption Chillers

2.5.1 Technology brief

Like adsorption chillers, the absorption process takes advantage of two physical characteristics in order to achieve efficient cooling. First, liquids are easier to transfer between pressure levels than gases and therefore using less energy to do so. Secondly, at different pressures, liquids have different evaporating temperatures, thus lowering the pressure on water also reduces its temperature (Sonneklima, 2011).

Firstly the refrigerant (e.g. water) and solvent (e.g. lithium bromide) are separated. This desorption is facilitated by the refrigerant having a lower evaporation temperature than the solvent, so when the heat from the collectors is applied the water evaporates into the condenser. The heat is then removed from the refrigerant by a heat rejection unit and passed into the evaporator where it is evaporated again at a lower pressure and therefore lower temperature. This time it gets its heat for evaporation from the room air, thereby cooling it. Finally it is absorbed again into the solvent and the process restarts (Henning, 2007; Sonneklima, 2011).

2.5.2 Literature review

For reasons of clarity and reduced duplication, a review on solar cooling as a whole has been included in section 2.3. It is advised that the overview section should be read prior to the absorption chiller specific literature review below.
Absorption chillers are available on the market in a wide range of capacities and designed for different applications. As with adsorption chilling technologies, less choice is available in the smaller range below 100 kW, but products are constantly developing in this area with a few even below 30 kW (Henning, 2007; Osbourne and Kohlenbach, 2011a).

Absorption chillers can be used with a wide range of heat sources such as waste heat, district heat or heat from co-generation plants. The most common sorption pair water–Lithium Bromide is applied for air conditioning purposes. Hereby water is the refrigerant and Lithium Bromide the sorbent. The basic construction design applied is a single effect machine. Henning describes this as: “For each unit mass of refrigerant which evaporates in the evaporator one unit mass of refrigerant has to be desorbed from the refrigerant-sorbent solution in the generator. Under normal operation conditions such machines need typically temperatures of the driving heat of 80-100°C and achieve a thermal COP of about 0.7” (Henning, 2007).

Double effect cycle machines are also available. Two generators working at different temperatures are operated in series, whereby the condenser heat of the refrigerant desorbed from the first generator is used to heat the second generator. Henning claims that: “With this configuration, a higher thermal COP in the range of 1.1–1.2 is achievable. However, driving temperatures in the range of 140-160°C are typically required for these chillers. This type of systems is only available in the range of large capacities of some 100 kW and above” (Henning, 2007). This statement is still largely true today as little progress has been made double effect machine efficiency or development into small scale chillers (Kohlenbach and Osbourne 2011a).
A wide range of installs have been reviewed in Australia with results varying depending on location. Figure 17 below shows the relative advantages and energy savings of systems installed across the capital cities of Australia. The highest is in Melbourne likely due to the city's requirement to utilise heat in the winter in addition to cool in the summer. However savings approaching 40% should be achievable when cooling is required year round when you compare the warmer climates of Darwin and Brisbane who may only require minimal heat but require cooling for a high percentage of the time.

![Figure 17 - 3000m2 office block, 100% glazed, 90kW single stage absorption chiller, flat plate collectors, mechanical Ale backup (White, 2011b)'](image)

One of the most significant solar cooling installs in Australia to date is at Ipswich Hospital near Brisbane in Queensland. A summary of the 255 kW system that supplements a 4.5 MW cooling system can be found in Figure 18 below.
Figure 19 below gives a visual indication of the size of modern units today.

Figure 19 - Absorption Chiller Examples (Osbourne and Kohlenbach, 2011a)
2.5.3 Possible industry applications

As explained in section 2.3 above, standalone cooling with solar driven thermal adsorption is not feasible without a backup heat source or thermal storage. As gas is the most economical backup and supply widely seen as an inhibiting factor at remote sites then unless these problems and those technologies for storage are overcome a hybrid system is the only realistic implementation model to date.

The potential for using waste heat on site is somewhat increased with the use of absorption chillers over adsorption. However they are still generally limited to preheating as the temperatures are not high enough. On high powered broadcast or other sites where concentrated heat sources from equipment cooling is available, the heat can be used to assist the solar collectors and extend their operational hours or smooth out intermittency. On a broadcast site, the air cooled FM transmitter exhausts are one suitable heat source which is likely to be available beyond analogue switch off date, but ducting would likely have to be in a convenient location so as to reduce ducting costs. Water cooled digital transmitter circuits require more investigation.

2.5.3.1 HYBRID PEAK ELECTRICAL DEMAND REDUCTION

In sites with reduced electrical capacity or availability, electrical upgrade costs or requirements can be avoided by taking the site's cooling off electrical energy. Increased cooling capacity is also achievable without significantly increasing the electrical demand which may be advantageous in different circumstances.

2.5.3.2 HYBRID STAGED COOLER

Staged cooling would involve ventilation in the cooler periods, solar driven cooling when sufficient heat sources are available all backed up by a conventional cooler or air conditioner.
2.5.4 Conclusions & recommendations

2.5.4.1 ADVANTAGES

- Absorption chilling units are a mature technology with large amounts of
general experience in the industry
- No alternative resource impact considerations
- Correlation with peak load demands at sites with large solar gain
- Potential for the A/C load to be taken off the electricity supply altogether in
the future in smaller systems

2.5.4.2 DISADVANTAGES

- Still exhibiting high costs without attractive paybacks in most situations
- Not reliable for 24/7 operation unless gas backup is available
- Storage technology still very immature
- Large land areas required for collectors
- Cooling towers required for large systems which increases maintenance
requirements significantly or increases parasitic energy losses.

2.5.4.3 RECOMMENDATIONS

Solar thermally driven absorption chillers probably have the greatest potential
when used in conjunction with gas fired systems. Unfortunately this rules out the
majority of telecommunications sites. It is the opinion of the author that it should be
let mature further and reach more competitive levels commercially before large
scale implementation. Implementation should be restricted to energy savings
potential only as its not suitable for a large independent system without some form
of backup with today’s technology. Technically, the technology exhibits large
potential for energy savings and reliability if designed in a robust manner so if
prices fall in the near future it has strong potential, especially in the northern states
of Australia.
2.6 Solar Cooling - Desiccant Cooling Systems

2.6.1 Technology brief

Desiccant cooling refers to the cooling effect realised by the removal of moisture from the incoming process air. Daou clearly and succinctly describes the operation of desiccant systems so it has been extracted here “The desiccants are natural or synthetic substances capable of absorbing or adsorbing water vapour due the difference of water vapour pressure between the surrounding air and the desiccant surface. They are encountered in both liquid and solid states” (Daou et al., 2006).

“One of the typical arrangements consists of using a slowly rotating wheel (8–10 revolutions/h) impregnated or coated with the desiccant, with part of it intercepting the incoming air stream while the rest of it is being regenerated. Another arrangement uses the packing of solid desiccants to form a sort of adsorbent bed exposed to the incoming air stream, thus taking up its moisture. These beds need to be moved periodically in the direction of the regeneration air stream and then returned to the process air stream. Liquid desiccants are often sprayed into air streams or wetted onto contact surfaces to absorb water vapour from the incoming air. Like the solid desiccants, they need to be afterwards regenerated in a regenerator where water vapour previously absorbed is evaporated out from it by heating” (Daou et al., 2006).

Desiccants are rarely used standalone as it is their dehumidification rather than their cooling properties which are the strongest. Therefore the desiccant materials are used in diverse technological arrangements, many of which are discussed in the literature review with respect to their advantages and disadvantages. Further detailed description of the technical process can be found in Appendix F.

2.6.2 Literature review
Air conditioning loads can be divided into the sensible and the latent loads. In a conventional vapour compression air conditioner, the latent heat load is removed by reducing the process air down below its dew point so the moisture condenses out. The dehumidified air is then reheated to meet the required indoor temperature conditions. Thus, if the latent heat load is removed by other means then the requirement for super cooling and reheating is negated. Further, direct or indirect evaporative systems do not provide this function at all. Desiccants can perform the dehumidification process with much less energy consumption or when powered by free energy sources such as solar energy and waste heat, significantly reducing the operating costs (Daou et al., 2006).

Each liquid and solid desiccant system has its own advantages and shortcomings. Liquid desiccants require lower regeneration temperatures, have greater flexibility in utilisation and create a lower pressure drop on the process air stream. On the other hand, solid desiccants are compact and are less subject to corrosion and desiccant material carryover (Daou et al., 2006).

The various types of desiccants can be used in conjunction with other cooling systems in many different configurations which utilise their advantages. The main systems will now be discussed separately in each of the following subsections.

2.6.2.1 PRE-COOLING AND DEHUMIDIFICATION FOR CONVENTIONAL VAPOUR COMPRESSION AIR CONDITIONING

The desiccants can be coupled with the traditional air conditioning system to eliminate the overcooling and the reheat, thus downsizing the equipment and increasing its electrical COP. Because the latent load is handled independently by the desiccant dehumidifier, the need of cooling the ventilation air below its dew point is prevented. The increase in evaporator temperature or reduced latent load will entail the increase of the system’s electrical COP (White, 2011a). This configuration can be useful in humid climates. The result is (Daou et al., 2006) the ability to utilise a significantly reduced vapour compression air conditioner which is
sized to meet the sensible cooling load only thus enabling costs and energy savings (Daou et al., 2006).

It has also been found if that a two stage desiccant cooling system requires lower regeneration temperatures from the solar source are required when compared with single stage units (Dai et al., 2009). This indicates that the extra investment in the second stage may be offset by the reduced cost of solar thermal collectors or backup heat sources.

In Jiangyin, China a solar hybrid desiccant air conditioning system, which combines the technologies of two-stage desiccant cooling and air-source vapour compression air-conditioning together has been installed. The desiccant system is designed to deliver 10 kW of cooling and is installed on the fresh air intake of the system. The regeneration is performed by a 90 m² flat plate solar collector array and a hot water storage tank. The vapour compression air conditioner has a cooling capacity of 20 kW and has the primary function of cooling the return air which is generally already dehumidified. Further detail can be found in section F.1 (Dai et al., 2009; White, 2011c).

The system was put into operation and its performance monitored during the summer of 2008 by the Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University. Under typical summer weather conditions for the region, it was found that the solar-driven desiccant cooling unit is energy efficient, achieving an average cooling capacity 10.9 kW with corresponding average thermal COP over 1.0 and electric COP up to 11.48. The cooling capacity of the hybrid air conditioning system is about 30.5 kW, of which 35.7% is contributed by solar-powered desiccant unit. In the test the system yielded a reduction in power consumption of 25.5% in comparison with traditional vapour compression system alone over a summer period (Dai et al., 2009).
Dieng and Wang claim that “Other studies have shown that combinations of sorption dehumidification (desiccant) with a conventional, electrically driven backup system allow for primary energy savings to 50% at low increased overall costs” (Dieng and Wang, 2001). Whilst the stated “low increased overall cost” is difficult to quantify and often not stated in current literature, the savings of 50% tend to indicate that a rapid payback is possible.

2.6.2.2 DEHUMIDIFICATION FOR EVAPORATIVE COOLING

Desiccant systems are most frequently used is with evaporative cooling. Evaporative coolers become inefficient in humid climates plus unusable if humidity in the conditioned space is detrimental to the occupants or equipment. One of the solutions is this issue is to dehumidify the incoming air through the use of a desiccant so that the evaporative cooler can operate more efficiently (Daou et al., 2006). This application is commonly employed in an open cycle configuration, most commonly with rotating desiccant wheels equipped either with silica gel or lithium-chloride as the sorption material. Most of the required components are common in buildings and commercial applications for many years (Henning, 2007; Daou et al., 2006) and are therefore well proven.

In systems which have to operate in higher humidity climates, an enthalpy exchanger, a rotor which enables total heat exchange, (i.e. exchange of sensible heat and humidity) can be added to the desiccant wheel system. Using this, ambient air component is precooled and pre-dehumidified using the return air from the building. After this, the conventional desiccant cycle can be employed although higher regeneration temperatures are necessary in order to enable sufficient regeneration of the desiccant wheel.

A solution for very high humidity applications is a desiccant cycle combined with two cooling coils supplied with cold water from a conventional chiller or indirect
evaporative coolers in the supply air stream. Either of these units will provide the sensible cooling required. Ambient air is pre-cooled and pre-dehumidified before it enters the desiccant wheel. Since the pre-dehumidification takes place on a high humidity level, high cold water temperatures are sufficient to cool the air below the dew-point. Sorption dehumidification with a desiccant takes place to adjust the supply air according to the desired supply air humidity (Henning, 2007). Given that the chilled water cooling coils provide sensible cooling only, indirect evaporative coolers could also be utilised in this configuration.

2.6.2.3 COUNTER FLOW PLATE HEAT EXCHANGER DESICCANT COOLER

Henning lists the following issues with conventional desiccant cooling systems:

- “Leakage between supply air and return air leads to reduced performance of rotor technology when applied at small capacity systems.
- The sorption process is not cooled (adiabatic process). This leads to a reduced dehumidification potential of the desiccant material compared to a cooled sorption process.
- Heat carry-over and the heat of adsorption leads to a high temperature of the process air leaving the desiccant wheel which is in contradiction to the primary goal of reducing the temperature of process air.
- The indirect evaporative cooling used in the standard desiccant cooling system does not make full use of the high potential of enthalpy uptake of the building return air” (Henning, 2007).

The counter flow heat exchanger desiccant cooler counters these disadvantages by taking the principle of the counter flow heat exchanger IEC unit described in section C.2, and adding a desiccant dehumidification step in the overall process. It is particularly intended as a desiccant cooling system for climates with high ambient air humidity. Further, the absence of moving components simplifies the process reducing maintenance and giving it the possibility to be used on smaller plants (Henning, 2007). The desiccant can be in liquid or solid form.
The main difference between these systems and that described in section C.2, is rather than the primary air being divided between supply air and the secondary wet channel, the return air from the conditioned space was used as secondary air to improve the secondary side performance. During tests in Brisbane, Australia it was found that the effectiveness of liquid desiccant evaporative cooling could reach 75% (Saman and Alizadeh, 2002). This is a good effectiveness value for an indirect evaporative cooling application however it still falls short of the 120% values reported by Bruno (2009). Although the tests were performed in significantly different climates the ratios still hold significance and potential can be seen for such a system to further improve on that 120% effectiveness when more recent advances in counter flow IEC technologies are applied. It has also shown that, depending on the primary air flow rate, the system could reach a good efficiency of humidity removal.

Liquid desiccant systems possess a certain number of advantages. Firstly, liquid desiccants can be regenerated at lower temperatures than solid desiccant systems making solar energy and waste heat viable options to drive it. Secondly, it is compact and another stage of evaporative cooler can be added to it in order to reach even lower indoor temperature (Daou et al., 2006), or counter flow IEC units such as those discussed in section C.2 could be utilised for the same end. Thirdly, this uncomplicated technology could be applied where abundant solar energy is available but technical expertise is not (Daou et al., 2006). Thus remote telecommunications applications where technical expertise is a great distance from the installation, local skills could be utilised at least as a first stage repair to keep the system operational until skilled labour can be sourced or returns for routine maintenance.
2.6.3 Possible industry applications

2.6.3.1 Pre-cooling and dehumidification for conventional vapour compression air conditioning

Desiccants precooling can be readily applied to telecommunications sites where fresh air is a requirement for human inhabitants or is a pre-set function of the existing system. If the system is completely closed loop and humidity is not adding significant latent load to the existing system then savings would be significantly limited.

Another possible application is for where ventilation systems were previously deemed unviable for primary cooling or energy saving due to the humidity transferred into the room. Desiccants can be seen to provide significant cooling capacity and could be utilised to assist a vapour compression air conditioner at night when ambient temperatures reduce. Desiccants installed in this way are reported to provide the most economically efficient way of solar cooling to date (White, 2011b).

2.6.3.2 Dehumidification for evaporative cooling

As described in section F.2, dehumidification for evaporative coolers can be performed in a number of different configurations. The simplest is illustrated in Figure 20 below and can be adapted to expand the application range for Indirect Evaporative Cooling across the majority of the country. In the opinion of the author, therein lays the largest potential for this technology.
2.6.3.3 **COUNTER FLOW PLATE HEAT EXCHANGER DESICCANT COOLER**

Very little reference to practical implementation of this technology can be found to date and therefore the potential for application cannot be properly evaluated. In the opinion of the author, with more development it could be applied in the future.

2.6.4 **Conclusions & recommendations**

2.6.4.1 **ADVANTAGES**

- Highest potential of the solar cooling technologies today for attractive payback periods
- Ability to pre-treat supply air for many system types
- Expands the usability of evaporative cooling technologies
- Low grade waste heat or cheap collectors usable for regeneration
Increases the potential for ventilation cooling in humid climates

Solid desiccants have low maintenance

2.6.4.2 DISADVANTAGES

- Significant collector area required
- Requires combination with another cooling technology in the majority of situations
- Technology still yet to be developed by many manufacturers

2.6.4.3 RECOMMENDATIONS

Once a commercially available product is found or developed, it is strongly recommended by the author that trials be set up to understand its full potential. This is especially true when combined with an indirect evaporative cooler. Further, trials for the expansion of ventilation only cooling into humid areas should be explored in more depth to assess viability.

2.7 Solar Cooling - Ejector Cooling

The ejector is a thermally driven compressor that operates in a heat pump refrigeration cycle as illustrated in Figure 21 below. The same principal applies as with an electrical heat pump system, but an ejector system uses heat rather than electricity to produce the compression effect (Dennis, 2010).

Ejector cooling is being investigated by research facilities such as the ANU but to date very little verifiable information is publically available with regards to its practical application and performance. For this reason, this paper only mentions its existence and notes that it appears to have great promise, especially in retrofit applications as it can simply bolt on* to an existing intercooler.
Figure 21 - Solar thermal driven ejector cooling cycle (Osbourne and Kohlenbach, 2011a)

2.8 Natural (Free) Convection

2.8.1 Technology brief

Free convection as described by Darwiche and Shaik (2008) can be designed such that it “does not require a power source because it functions on natural convection and energy storage capacity. This system consists of housings with insulation, sunshade, external and internal heat exchangers, heat storage tank and conveyance of the medium (mainly water), which must be designed for the specific application. The heat dissipated by the electronic equipment is absorbed by the internal heat exchanger and transferred to the water inside the tank by thermosiphon if the temperature differentials are sufficient.” In non-ideal conditions a pump can be utilised to assist the flow. At night, heat is dissipated by thermosiphon to the outside atmosphere (Darwiche and Shaik, 2008).

A more detailed description of this system can be found in Appendix G.

2.8.2 Literature review

It has been shown that the internal temperature of the shelter can be maintained as between 8.3°C and 11.1°C below ambient. Figure 22 shows the expected inside temperature of a passively cooled shelter located in a typical high ambient
The desert environment compared to the outdoor air. The tank and heat exchangers' temperatures are also shown on the same figure (Darwiche and Shaik, 2008)

![Temperature levels for a typical passive cooling system](image)

Figure 22 - Temperature levels for a typical passive cooling system (Darwiche and Shaik, 2008)

This system exhibits the following main benefits in optimal conditions where temperature differentials are sufficient:

- No energy is required to run it in optimal conditions
- There are no moving parts in optimal conditions

The system drawbacks include:

- The system’s performance is highly dependent on large temperature differentials between day and night

(Darwiche and Shaik, 2008).

Energy gains for such a system can be as high as 100% of the cooling load however these systems are typically only for small installations in desert climates.
2.8.3 Possible industry applications

2.8.3.1 STANDALONE CONVECTION COOLING

Implementing this as the sole cooling source as described in Appendix G below is a highly possible option for small remote or desert type shelters where the main heat load is from the sun. Further trials would have to be performed in order to prove system reliability and a minimum of a ventilation fan would be required as a backup cooling method.

2.8.3.2 PRIMARY COOLING METHOD WITH CONVENTIONAL AIR CONDITIONING AS A BACKUP

The free convection cooling system could be implemented as a primary cooling source to supplement the conventional air conditioning requirement at small sites in desert or temperate climates. Further, this system could be seen to reduce service risk at sites where temperatures are not guaranteed to drop significantly at night or until system reliability is sufficiently proven.

2.8.4 Conclusions & recommendations

2.8.4.1 ADVANTAGES

- Potential of 100% energy savings, at least for the periods of use
- Simple systems with few moving parts
- Potential to be retrofitted where space permits

2.8.4.2 DISADVANTAGES

- Large space requirements inside the transmission site
- Water flow required above sensitive equipment
- Appears to only be useful in limited climatic conditions
- Potential for small loads only and therefore small scale energy savings

2.8.4.3 RECOMMENDATIONS

The largest potential for this technology is at small sites where electrical capacity is limited and headroom can be achieved by removing or reducing the air conditioning on site. In order to be able to realise this potential some trials are required at sites where the existing air conditioning can still be relied upon until the
technology is sufficiently proven. These trials will also provide valuable information about its potential to be used as an energy savings measure when other opportunities are exhausted. Finding reliable expertise in the sector may however present a significant challenge.

2.9 Phase Change Materials – Bulk Storage Units

2.9.1 Technology brief

Phase Change Materials (PCM’s) are commonly referred to as latent heat storage materials that have a high heat of fusion. Exploiting their endothermic and exothermic relations using the latent heat of fusion, chemical bonds are used to store and release the heat as the material changes between solid and liquid form (Tyagi and Buddhi, 2007; Harland et al., 2010), much the same as ice but with significantly more potential to store energy in the process. This transition is called a change of state or phase.

This section reviews PCM being applied to an active heat and cold system, where the stored heat or cold is in containment thermally separated from the building by insulation. Therefore, the heat or cold is used only on demand, not automatically (Tyagi and Buddhi, 2007).

Section 2.10 then discusses passive use of distributed PCM storage in building materials.

2.9.2 Literature review

PCM heat and cold storage systems typically consist of a bulk storage container for the PCM material that acts as a heat exchanger. In cooling mode, the hot air from the building is passed over the PCM which removes some of the heat energy from the air and stores it. This heat is later removed either by cool ambient temperatures at night or by a heat rejection unit (Riffat et al., 2001; Maccracken, 1981).
The systems presented by Tumpenny (200,2001) and Maccracken (1982) describe novel cooling systems for larger buildings that require occupant comfort only. The results illustrate a potential for ten year payback in a low use office scenario. These systems are designed for limited period heat loads and are not directly suitable for 24/7 heat loads. However, the principals could potentially be adapted for assisted cooling in the day time if air conditioning or ventilation is used at night, thereby reducing the overall energy consumption.

Refrigeration systems assisted by PCM have also demonstrated significant savings with respect to COP as illustrated in Figure 23 from an experimental study performed on a system using PCM materials in conjunction with heat pipes (Riffat et al., 2001).

![COP vs Temperature of the Refrigeration Cabinet](image)

**Figure 23 - Comparison between performance of thermoelectric refrigeration system, with and without PCM material (Riffat et al., 2001)**

Another study has been performed for telecommunications infrastructure company, Broadcast Australia. The primary aim of the system was to reduce the electrical maximum demand but also had the added benefit of reduced
consumption overall. The studied site was Mt Clay near Portland in Victoria, Australia. At this site the design parameters were set at:

- Transmitter equipment operation - 24 hours a day, 7 days a week
- Peak heat load in the building (including solar radiation) - 20kW
- Total system capacity required - 24kW.
- Electrical power maximum demand limitation - 3.6kW.
- Target internal temperature - 27°C
- Internal temperature limit - 32°C

(Williams, 2009).

The system proposed by PCP Australia used a PCM tank which assisted a reduced sized chiller to supply chilled water to the air handling unit as illustrated in Figure 24 below. The PCM material was regenerated by the night air (Rizkalla and Kandadai, 2009).

![Figure 24 - PCM assisted air handling unit design schematic (Rizkalla and Kandadai, 2009)](image)

The proposed system utilised inorganic hydrated salts which they reported to ensure system longevity over many thousands of cycles. The design claimed

“HETAC provides stored energy for cooling during the hottest part of the day, using 90% less energy during this period, and providing greater than 50% energy
savings overall, when compared to conventional air conditioning”. The PCM chosen for the application was PC-17 which has a useful working temperature range of 14 to 20°C, a heat capacity of 180 kJ/kg/K and latent heat of fusion of 145 kJ/kg. By using PC-17, the lowest achievable supply air temperature was approx. 25°C which satisfied the internal temperature requirements of the transmitter enclosure. The total maximum power of 3.6 kW was reduced to 2.6 kW for the chiller alone in order to accommodate for water pump and fan power requirements which were estimated to be 0.75 – 1 kW. The designed system contained an air-cooled liquid inverter style chiller having a nominal cooling capacity of 10 kW and a water inlet/exit temperature of 16/11°C (Rizkalla and Kandadai, 2009).

The primary driver behind this system design was to avoid an electrical supply upgrade which was difficult to procure at the time of the study. Subsequent to the study being performed permission for the electrical upgrade was negotiated and this driver was therefore substantially reduced. At 50% energy savings, the system had a payback period in excess of 10-15 years and therefore did not represent sound economic investment for energy savings alone, so the system was never implemented.
2.9.3 Possible industry applications

2.9.3.1 **PCM ASSISTED CHILLER**

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**Figure 25 - Mt Clay PCM assisted cooling system schematic (Rizkalla and Kandadai, 2009)**

**Mode 1: Ventilation only**

Outside air temperature $T_{OA}<25^\circ C$ - Air is drawn through MD1 (MD3 is closed) and passes through Fan 1 & BD1 into the room and exhausted through MD2. The design indicated that this mode would be operational for almost 300 days in a year. If the ambient temperature is too low, the room temperature sensor (Tr) enabled VSD’s to reduce the speed of the Fan 1. The PCM tank in this mode is regenerated by cool outside air removing the heat and changing the PCM to a solid state ready for later utilisation.

**Mode 2: Open circulation cooling**

Outside temperature $25< T_{OA}< 32^\circ C$ - Air is drawn through MD1 (MD3 is closed) and passes through the PCM housing, Fan 2 and BD2 into the room and exhausted through MD2. The design indicated that this mode would be operational for almost 50 days in a year. The PCM is used to store heat from the external air in this mode and returns to mode 1 most nights for regeneration.
Mode 3: Closed circulation cooling

Outside air temperature $T_{OA} > 32^\circ C$ - MD1 and MD2 is closed. MD3 is open. Fan 2 is on. The room air is recirculated as return air is drawn through MD3 and the PCM housing to the Fan 2 and flows into the room. The design indicated that this mode would operational for approximately 10-15 days. The PCM is used to store heat from the external air in this mode and returns to mode 1 most nights for regeneration.

(Rizkalla and Kandadai, 2009).

2.9.3.2 STANDALONE PCM COOLING

If only small levels of cooling are required or a site with desert like climate, it is foreseeable that the PCM blocks could provide sufficient cooling on if the nights reach a low enough temperature and the heat load is predominantly from solar radiation. In this system, air could be passed over the PCM material during the peak solar periods during the day, melting the PCM and removing the heat from the air to cool the equipment building. At night, the PCM would be regenerated by releasing its heat energy to the atmosphere. This system would require very reliable climatic conditions that ensure very cool nights on the hottest days or considerable amounts of PCM to ensure the warm nights could be withstood without risk to service.

At the time of publication, discussion with local suppliers on this system revealed that it would only be commercially viable at ideal sites unless a fall in PCM system prices was to occur or a significant electrical upgrade was otherwise required.

2.9.4 Conclusions & recommendations

2.9.4.1 ADVANTAGES

- Potential for significant energy savings
- Able to be used in conjunction with existing systems
• Can reduce the amount of vapour compression air conditioning required on site thereby reducing maximum demands where electricity supply is restricted.

• No reliance on consumable alternative resources

• Relatively low maintenance requirements

2.9.4.2 DISADVANTAGES

• Reliant on localised climatic conditions so extra capacity or backup required in many cases

• Relatively immature technology that has few commercial projects demonstrating reliability

2.9.4.3 RECOMMENDATIONS

The case study demonstrated that PCM bulk storage could work as a primary or supplementary cooling system for telecommunications sites, in particular where electrical energy supply was limited or expensive. The main case study in the literature review was installed in a non-ideal climate and further developments in the industry have occurred since. In the future, PCM supply and install efficiencies may render the system worth reconsidering especially when coupled with rising electricity prices. A site specific trial with ideal climatic conditions and the ability to fall back onto an existing system should be investigated further for commercial viability.

2.10 Phase Change Materials – Impregnated Building Materials

2.10.1 Technology brief

Phase Change Materials impregnated in building materials use the same fundamental principles discussed for those used in bulk storage. In the same way, they store latent heat and utilising the latent heat of fusion, chemical bonds are used to store and release the heat as the material changes between solid and liquid form (Tyagi and Buddhi, 2007; Harland et al., 2010), much the same as ice
but with significantly more potential to store energy in the process. This transition is called a change of state or phase.

This section reviews utilising PCM by impregnating them into the building materials such as the walls, ceiling and/or roof. In this way the building fabrics take on the energy storage role in a distributed and passive way by using the ambient weather conditions to facilitate this energy storage and transfer to regulate the interior air temperature.

Active use of bulk centralised PCM storage is discussed in section 2.9.

2.10.2 Literature review

A building with PCM impregnated fabric has higher levels of thermal mass that can be utilised to reduce the peak power demand and down size the cooling or heating systems (Stetiu and Feustel, 1996; Khudhair and Farid, 2004). Khudhair and Farid go further to claim that “PCMs have two important advantages as storage media: they can offer an order of magnitude increase in thermal storage capacity, and their discharge is almost isothermal. This allows storing large amounts of energy without significantly changing the temperature of the sheathing (room envelope)” In an application requiring cooling, this is achieved by storing the heat from solar radiation during the day and releasing it at night predominantly into the cooler atmosphere but also into the building space. The main resultant advantages are reducing the peak loading of the systems and shifting the energy use from the more expensive peak tariff periods to the inexpensive off peak tariffs (Khudhair and Farid, 2004).

While limited experimental studies of PCM wallboard have been conducted or are available, a few general rules pertaining to the thermal dynamics of PCM wallboard have been observed and documented by Kudhair and Farid as below.
• “PCM wall is capable of capturing a large proportion of the solar radiation incident on the walls or roof of a building to be released when the temperature drops.

• Because of the high thermal mass of PCM walls, they are capable of minimizing the effect of large fluctuations in the ambient temperature on the inside temperature of the building.

• PCM impregnated materials can be very effective in shifting the heating and cooling load to off peak electricity periods.

• Gypsum wallboard impregnated with PCM could be installed in place of ordinary wallboard during new construction or rehabilitation of a building.

• PCM will provide thermal storage that is distributed throughout a building, enabling passive solar design and off peak cooling with frame construction.

• Optimal daytime heat storage occurs with a melt temperature 1-3°C above average room temperature.

• Little or no additional cost would be incurred for installation of PCM wallboard in place of ordinary wallboard.”

(Khudhair and Farid, 2004)

Figure 26 - Typical operation of PCM containing wallboard in a heat requirement scenario (Khudhair and Farid, 2004).
A practical study for a residential application conducted in Madison, Wisconsin, USA (43°N) has shown that a 120 m² house could save up to 4 GJ a year in heating and cooling (or 15% of the annual energy cost). Claims are made that PCM wallboards could save up to 20% of residential house space conditioning cost (Khudhair and Farid, 2004).

A range of PCM’s are used, each with varying melting points and enthalpies. A combination of the enthalpy and melting point must be chosen for the desired application. According to Tyagi and Buddhi (2007) there is currently a lack of PCM in the 5 to 25°C range. A particular gap is evident in the 15 to 20°C range where enthalpy levels are very low.

A study in 1991 found that the economic payback time for a PCM impregnated wall board was ten to twenty years depending on the location, due to reduced energy costs. With the rising energy costs of recent and future years it could be anticipated that the payback time would be reduced. However, this research appears to have been based on the immersion bath technique for impregnating the board which has since been shown to fail due to evaporation. Estimated costs for supply of Smartboard in New Zealand from Knauf in Germany indicate it to be about ten times the cost of regular gypsum board (Harland et al., 2010). Given this, the 1991 study payback figures are unlikely to be realised and also counters the no additional cost bullet point recorded above from (Khudhair and Farid, 2004).

2.10.3 Possible industry applications

The requirement to replace internal walls is common in aging infrastructure due to the presence of asbestos fibres so this requirement could be taken advantage of and has a PCM product put in its place. To take full advantage of the PCM materials, the air conditioning system would need to be set above the melting point of the material thereby achieving a “backup” system which only uses the air-conditioning where the PCM board cannot achieve the required cooling. Savings
could however be distorted when comparing it to the alternative standard plasterboard walls because of the thermal properties of asbestos.

### 2.10.4 Conclusions & recommendations

#### 2.10.4.1 ADVANTAGES

- Passive and maintenance free

#### 2.10.4.2 DISADVANTAGE

- Difficult to quantify savings
- Unknown and seemingly expensive supply chain available
- Much of the energy use is simply shifted to another part of the day potentially resulting in cost savings but reduced energy savings
- Low quantum of energy savings compared to other technologies.

#### 2.10.4.3 RECOMMENDATIONS

A building integrated with distributed thermal storage materials could shift most of the load coming of residential air conditioners from peak to off peak time periods. This shifting of energy demand also has the potential to reduce the peak heat load of the building thereby reducing the cooling system size required or peak loading on extreme days. Whilst the theoretical advantages are clearly evident, the actual potential to make significant energy savings are limited for internal fixtures of a 24/7 heat load because it means large amounts of the energy is dissipated back into the building during the night achieving cost savings rather than energy savings. Given the PCM product is a level of magnitude more expensive than the standard product, the cost benefit is unlikely to be worthwhile. However the potential for use where walls or insulation is being replaced for other reasons such as asbestos contamination or age should be investigated further.
3 Technology Selection Decision Aid - Description

3.1 Decision Aid Objectives

Air conditioning upgrades, remediation and green fields installations are often undertaken without due consideration of new, more efficient air conditioning technologies. Attention to timely delivery is often the primary focus with project pressures making the time to properly research all available technologies largely restricted for the average project engineer making the decisions. Further, with the ever evolving quest for energy efficiency, technology is advancing at a rate where proper re-assessment is a constant burden. Therefore, the engineer with time constraints will often be forced to make the choice for the easier, standard vapour compression system installation which is well known and trusted but often far less efficient option.

Whilst the technology review section aims to summarise current literature and give a snapshot of available technologies today, the decision aid aims at providing a tool that can guide the engineer through a high level assessment of various technologies for a site specific application.

3.2 Decision Aid Use

3.2.1 Criteria rating and specification

As illustrated in Table 3 below, the decision aid guides the user through a number of selection criteria and asks them to give an appraisal on a simple 1-5 rating scale. The criteria have been selected to aid the user in considering the main life cycle facets of air conditioning design from installation costs and complexities through to environmental impacts and ongoing maintenance requirements. The general definitions of the criteria and corresponding rating specifications are outlined in the Main Criteria Key worksheet as extracted in Table 4 below. The level of information available at the time of decision aid use will dictate the accuracy of the
output. However, the decision aid is designed to be quite flexible so that multiple passes can be made as better information becomes available through the life of the project.

Each technology assessment is undertaken on a separate worksheet in the decision aid. A worksheet is provided for each technology discussed in the Technology Review section of this paper. Extra sheets are provided for further technologies that may be considered or arise in the future. As each criterion is assessed, the user is required to enter the rating in the light pink cells of the main table for each technology with the exception of criteria which are a composite of sub criteria ratings. Maintenance Intensity and Alternate Resource Impact are two such criteria. The ratings for these must be entered in the evaluation table which is then automatically calculated into the main table. An example of one technology’s worksheet can be found in Appendix A.

For design validation and tracking the Evaluation Justification columns of the input table are provided to track and log the decision making process and level of rigour undertaken by the user.
### Table 3 – Technology selection criteria ratings

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</tr>
<tr>
<td>Victoria</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Tas</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

* Rating based on regional modelled average  
** Rating based on Average Annual Solar Expo  
*** Rating based on mean max and min temper
Table 4 – Technology Selection Ratings Specifications

<table>
<thead>
<tr>
<th>Criteria</th>
<th>General Definition</th>
<th>Rating Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payback</td>
<td>Expected simple payback for the chosen system installed at the &quot;typical&quot; site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.</td>
<td>&gt; 20 years</td>
</tr>
<tr>
<td>Net Energy savings</td>
<td>Expected net energy savings for the chosen system installed at the &quot;typical&quot; site.</td>
<td>0-20%</td>
</tr>
<tr>
<td>Retrofit Capability</td>
<td>The ability for the chosen system to be retrofitted into the existing system at the &quot;typical&quot; site.</td>
<td>Not Possible - the system is almost exclusively only viable in new installations</td>
</tr>
<tr>
<td>Current Level of Commercialisation</td>
<td>Research - High technical and commercial risk. No Scale up demonstrated</td>
<td>Development - high technical risk, some commercial and scale up potential demonstrated in Pilot(s)</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Commercialisation Potential</td>
<td>The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.</td>
<td>&gt; 20 years - Most research and reviews show that the technical and commercial potential is not very high</td>
</tr>
</tbody>
</table>
**Design Suitability for 24/7 Heat Load**

The ability for the chosen system to be designed to deliver the total heat load 24 hours a day seven days a week at the "typical" site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.

| Score | Almost Never - Rarely to meet the 24/7 demand and very little technology development initiated to counter issues | >20% / Some Potential - Able to meet the 24/7 demand >20% the year and some technology development initiated to counter issues | >50% / Demonstrated Potential - Able to meet the 24/7 demand >50% of the year and technology to solve issues in demonstration phase of commercialisation | >80% / Very High Potential - Able to meet the 24/7 demand >80% the year and technology currently available to solve the remaining issues but may be at reduced reliability or high cost | 100% Today - Can stand alone as a cooling solution for 100% of the year |

---

**Maintenance Intensity**

Maintenance requirements as defined by minimum frequency someone has to attend site, complexity and resources required and total duration p.a.. The rating is calculated based on an average of these three subcategories.

<table>
<thead>
<tr>
<th>Score</th>
<th>Min Frequency ≤ 2/1.6 months</th>
<th>2/1.6 &lt; Frequency ≤ 4/2.1.3 months</th>
<th>4/2.1.3 &lt; Frequency ≤ 6/3.2 months</th>
<th>6/3.2 &lt; Frequency ≤ 12/6.4 months</th>
<th>Frequency &gt; 12/6.4 months</th>
</tr>
</thead>
</table>
criteria. The frequency sub
criteria are weighted in a 3/2/1
ratio for small/medium/large
sites respectively. The duration
sub criteria are weighted in a
1/2/3 ratio for
small/medium/large sites
respectively. e.g. a small site
should require 1/3 of the
maintenance of a large site and 3
times less often.

<table>
<thead>
<tr>
<th>Alternate Resource Impact</th>
<th>Complexity - all specialised personnel or equipment</th>
<th>Complexity - 75-95% specialised personnel or equipment</th>
<th>Complexity - 50-74% specialised personnel or equipment</th>
<th>Complexity - 25-49% specialised personnel or equipment</th>
<th>Complexity - &lt; 25% specialised personnel or equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration &gt; 6.5/10/20 man days p.a.</td>
<td>Duration ≤ 3/5/10 &lt; Duration ≥ 6.5/10/20 man days p.a.</td>
<td>Duration ≤ 1.5/2.5/5 &lt; Duration ≥ 3/5/10 man days p.a.</td>
<td>Duration ≤ 0.3/0.5/1 &lt; Duration ≥ 1.6/2.5/5 man days p.a.</td>
<td>Duration ≤ 0.3/0.5/1 man days p.a.</td>
</tr>
</tbody>
</table>

1. Not practical - see subcategories
2. High - see subcategories
3. Medium - see subcategories
4. Low - see subcategories
5. Very low - see subcategories

The chosen system's reliance on alternative finite resources and their availability without significant storage requirements. The variables are quantity of consumption and availability. The final rating eliminates this technology as an option with a rating of 1. The rating is

<table>
<thead>
<tr>
<th>Consumption - &gt; 50 average Australian households</th>
<th>Consumption - 30-49 average Australian households</th>
<th>Consumption - 10-29 average Australian households</th>
<th>Consumption - 1-9 average Australian households</th>
<th>Consumption - &lt; 1 average Australian household or is renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
calculated based on an average of these two sub criteria. The consumption sub criterion is weighted in a 3/2/1 ratio for small/medium/large sites respectively. e.g. a small site should require 1/3 of the maintenance at a large site.

<table>
<thead>
<tr>
<th>Climates Performance</th>
<th>Availability - Design performance in the required site's climatic conditions. If site specific ratings are not available the Climate Ratings worksheet may provide assistance.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Not Suitable - &lt;40% of optimal efficiency 2. Marginal - 40-59% of optimal efficiency 3. Good - 60-79% of optimal efficiency 4. Desirable - 80-95% of optimal efficiency 5. Optimal - able to achieve optimal efficiency as per design within a tolerance of 5%</td>
</tr>
</tbody>
</table>

Availabilty - Capex and NPV of operational requirement represents 101-200% of the capital investment

Availabilty - Capex and NPV of operational requirement represents 20-100% of the capital investment

Availabilty - Capex and NPV of operational requirement represents <20% of the capital investment
3.2.2 Multiple system evaluation option

The user is given the flexibility to analyse up to 3 system designs or sizes at once through the use of the Small, Medium and Large entries. Whilst they are listed as sizes for simplicity and guidance these criteria can be adjusted by the user in the “typical system” description shells at the bottom of the main worksheet which is then copied into each technology worksheet to give continued guidance through the process for consistency. An example of this is given in Table 5 below:

Table 5 - Example use of the Small Medium and Large fields on the Main Criteria Key worksheet

| "Typical" Small Site | - 2-4 small split system units  
| | - Sealed system (no existing fresh air supply)  
| | - < 30 kW cooling load  
| | - No existing centralised logic or assume needs to be replaced.  
| | - Set temperature = 25°C  
| | - Max rel humidity internal = 75% @ 23°C  
| | - Existing system COP = 2.5 |

| "Typical" Medium Site | - 2-4 large split system units  
| | - Sealed system (no existing fresh air supply)  
| | - 30-100 kW cooling load  
| | - Centralised relay logic control system with reprogrammable PLC  
| | - Set temperature = 28°C  
| | - Max rel humidity internal = 75% @ 23°C  
| | - Existing system COP = 3.0 |

| "Typical" Large Site | - 2-4 large package units  
| | - Supply and return air divisible with ducting  
| | - Sealed system (no existing fresh air supply)  
| | - > 100 kW cooling load  
| | - Relay logic control system with reprogrammable PLC  
| | - Set temperature = 28°C  
| | - Max rel humidity internal = 75% @ 23°C  
| | - Existing system COP = 3.0 |

3.2.3 Criteria Weighting
The Criteria Weighting worksheet in the decision aid provides the user with a customisable percentage allocation for each of the criteria. Default weighting values and justification fields are provided to guide the user however these are not required to be adhered to.

3.2.4 Climate Ratings

The Climate Ratings worksheet provides example climatic performance ratings for each the main technology categories in each of the main regional areas of Australia. As seen in Table 4 above, climatic ratings of a technology in a given region of Australia are rated as a percentage of site specific design performance as compared to its optimal design climate. The example ratings are meant only as a guide for the initial stages of evaluation and should be adjusted for site specific use when those details are known. The basis for these ratings is thus:

- **Evaporative** – to be used for all evaporative cooling technologies the ranking is based on a percentage of optimal electrical COP in Australia (McBratney, 2011a).

- **Solar Thermal** – to be used for all thermally driven solar cooling technologies. The ranking is based on a percentage of optimal daily solar exposure as measured in MJ/m² (BOM, 2008).

- **Phase Change Materials/Free Convection** – both PCM and free convection technologies rely heavily on temperature differentials between the minimum and maximum temperatures of a 24 hour period. The ranking is based on a percentage of optimal mean max to mean min temperatures (BOM, 1990).

3.3 Decision Aid Output

3.3.1 Results – Site Specific

The output of this page is the primary use for this decision aid. When the required worksheets are completed, the technology scores are weighted against their priorities and a weighted average is returned for each of the Small, Medium and
Large options of the systems as required. The score returned indicates the
technologies applicability to the chosen site or scenario. These scores are then
ranked against each other, providing a clear indication of the best technology
option.

3.3.2 Results – National

A secondary use of the decision aid is to give a snapshot overview of the
technologies and their rating against the criteria as described above. The decision
aid is then taken a step further to give the user a national view of how these
technologies rate when applied to typical climatic conditions and which technology
or technologies are likely to present a valid option.

Note: The user must apply extreme caution when using the decision aid in this
fashion. Assumptions made must first be clearly defined and applied evenly across
all the technologies. Further, the assumptions must be checked and to ensure they
apply when evaluating or applying the results. The results of the national decision
aid are intended for high level planning purposes ONLY. It is highly recommended
that a site specific evaluation be performed before any of the results are applied to
a specific project or site.
4 Technology Selection Decision Aid – Demonstration

4.1 Demonstration Purpose, Scope and Limitations

The primary purpose of the following demonstration is to illustrate the decision aid’s use and effectiveness. The original objective of the demonstration was to give a clear overview of each technology and its current ranking as a usable technology across all the climatic regions of Australia. During the preparation of this demonstration it became apparent that much of the information required to thoroughly complete the decision aid with verifiable information was not possible due to:

1. A large number of assumptions were required in order to define a “typical site”. The resultant generalisation of these lost a significant amount of academic and professional detail required to apply the outputs of the decision aid with an acceptable amount of certainty.

2. As a consequence of the immature nature of the innovative technologies discussed and analysed, the information available for use when applying criteria ratings and the sample size of that information is very restricted at this point in time. This results in broad decision aid input assumptions and therefore unreliable output results to some degree. As the technologies mature and further verified information becomes available the decision aid outputs will become more reliable. In order to increase the certainty to even an acceptable level, the results of the technologies without sufficient information available have been excluded from this demonstration.

Due to these issues, the reader should apply significant caution when reviewing the results given below. Whilst much diligence was applied when obtaining the input information, significant amounts of them are based on engineering experience of the author or those industry experts that were willing to provide their own experiences for the sake of promoting the industry. These unverifiable results
are marked with an asterisks "**" under the relevant rating in the main table. These
and other assumptions or justifications are summarised in the Evaluation
Justification column of the details table for each technology as entered in
Appendix B.

4.2 Demonstration Inputs

The technologies chosen for the demonstration were:

1. Indirect Evaporative Cooling
2. Solar Cooling – Thermally driven adsorption chiller (small only)
3. Solar Cooling – Thermally driven absorption chiller
4. Solar Cooling – Desiccant precooling and dehumidification
5. Phase change Materials – Bulk storage unit (small system only)

Three different “typical sites” were chosen. The site characteristics were chosen to
represent varying telecommunications site sizes. Very Large exchanges were
excluded from the chosen demonstration but that is not as a result of the decision
aid’s limitations rather they were seen as requiring a different level of analysis that
was beyond the skill set of the author. The site characteristics are defined in Table
6 below.

<table>
<thead>
<tr>
<th>&quot;Typical&quot; Small Site</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- 2-4 small split system units</td>
<td></td>
</tr>
<tr>
<td>- Sealed system (no existing fresh air supply)</td>
<td></td>
</tr>
<tr>
<td>- &lt; 30 kW cooling load</td>
<td></td>
</tr>
<tr>
<td>- No existing centralised logic or assume needs to be replaced.</td>
<td></td>
</tr>
<tr>
<td>- Set temperature = 25° C</td>
<td></td>
</tr>
<tr>
<td>- Max rel humidity internal = 75% @ 23° C</td>
<td></td>
</tr>
<tr>
<td>- Existing system COP = 2.5</td>
<td></td>
</tr>
</tbody>
</table>
"Typical" Medium Site
- 2-4 large split system units
- Sealed system (no existing fresh air supply)
- 30-100 kW cooling load
- Centralised relay logic control system with reprogrammable PLC
- Set temperature = 28°C
- Max rel humidity internal = 75% @ 23°C
- Existing system COP = 3.0

"Typical" Large Site
- 2-4 large package units
- Supply and return air divisible with ducting
- Sealed system (no existing fresh air supply)
- > 100 kW cooling load
- Relay logic control system with reprogrammable PLC
- Set temperature = 28°C
- Max rel humidity internal = 75% @ 23°C
- Existing system COP = 3.0

Further assumptions were made for each system analysed for the demonstration. Care was taken to choose systems that were broadly comparable in size and application. The details of these chosen systems are described in Table 8 through Table 11 below.

**Table 7 - Decision Aid Demonstration IEC Systems**

| Chosen System at Small Site | - 2 x 10 kW Seeley Climate Wizard counter flow indirect evaporative coolers
|                           | - Supplementing 75% of total cooling load (covers base load)
|                           | - Assumed 1/3 installation complexity and cost of Mt Lofty |
| Chosen System at Medium Site | - 6 x 15 kW Seeley Climate Wizard counter flow indirect evaporative coolers
|                           | - Supplementing 75% of total cooling load (covers base load)
|                           | - Direct example of Mt Lofty, Adelaide |
| Chosen System at Large Site  | - 3 x 45 kW Seeley Climate Wizard counter flow indirect evaporative coolers
|                           | - Supplementing 75% of total cooling load (covers base load)
|                           | - Conservatively assumed 1.5 times installation complexity and cost of Mt Lofty. |
Table 9 - Decision Aid Demonstration Solar Absorber System

| Chosen System at Small Site | - 20 kW Absorption chiller supplementing a 27 kW cooling load, |
|                           | - Vacuum tube collectors |
|                           | - Thermal battery. |
|                           | (Taylor 2011) |
|                           | - Assumed 12 hr. per day operation |
|                           | - Supplementing 75% of total cooling load (covers base load) |

| Chosen System at Medium Site | - 90 kW Absorption chiller supplementing a 120 kW vapour compression system, |
|                             | - Vacuum tube collectors |
|                             | - Thermal battery. |
|                             | - Off grid |
|                             | (Taylor 2011) |
|                             | - Assumed 24 hr. per day operation |
|                             | - Supplementing 75% of total cooling load (covers base load) |

| Chosen System at Large Site | - 150 kW Absorption chiller supplementing a 200 kW vapour compression system, |
|                            | - Parabolic trough concentrated collectors |
|                            | - Assumed half sizing of the Ipswich Hospital project in Brisbane with a 50% cost loading for lack of existing infrastructure such as cooling towers and water system (DEEDI, 2010) |
|                            | - Supplementing 75% of total cooling load (covers base load) |

Table 10 - Decision Aid Demonstration Solar Desiccant Systems

| Chosen System at Small Site | - Desiccant cycle example from Jiangyin, China added to the IEC system already evaluated. |
|                           | - 10 kW (2600 m³/h) two stage desiccant rotor with inter-cooling (+20kW air cooled mechanical cooling) |
|                           | - 72 m² flat plate collectors, 4000 l hot water buffer |
|                           | - Average summer COPth -1.24, COP elec -11.48 (Dai et al, 2009) |
|                           | **IEC system:** |
|                           | - 2 x 10 kW Seeley Climate Wizard counter flow indirect evaporative coolers |
|                           | - Supplementing 75% of total cooling load (covers base load) |
|                           | - Assumed 1/3 installation complexity and cost of Mt Lofty |
**Chosen System at Medium Site**

- Solid desiccant rotor system with negligible cooling capacity added to the IEC system already evaluated for dehumidification only
- Insufficient example systems available so savings from Jiangyin, China example scaled up
  
  **IEC system:**
  - 6 x 15 kW Seeley Climate Wizard counter flow indirect evaporative coolers
  - Supplementing 75% of total cooling load (covers base load)
  - Direct example of Mt Lofty, Adelaide

**Chosen System at Large Site**

- Solid desiccant rotor system with negligible cooling capacity added to the IEC system already evaluated for dehumidification only
- Insufficient example systems available so savings from Jiangyin, China example scaled up
  
  **IEC system:**
  - 10 kW (2600 m³/h) two stage desiccant rotor with inter-cooling (+20kW air cooled mechanical cooling)
  - 72 m² flat plate collectors, 4000 l hot water buffer
  - Average summer COPth -1.24, COP elec -11.48
    
    (white, 2011c)
  - Assumed to be used to supply fresh air on a system already supplied with an economiser or free air mode

**Table 11 - Decision Aid Demonstration PCM Bulk Storage System**

<table>
<thead>
<tr>
<th>Chosen System at Small Site</th>
<th>Transmitter equipment operation - 24 hours a day, 7 days a week</th>
<th>Peak heat load in the building (including solar radiation) - 20kW</th>
<th>Total system capacity required - 24kW.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equipment power maximum demand limitation - 3.6kW.</td>
<td>Target internal temperature - 27°C</td>
<td>Internal temperature limit - 32°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Williams, 2009).</td>
</tr>
</tbody>
</table>

### 4.3 Demonstration Results

#### 4.3.1 Generic Technology Results

Table 12 below shows the output of the decision aid on the site specific worksheet.

Because these are not site specific results due to the generic “typical site” assumptions detailed above, the results given are generalised and have not had climate performance taken into account. At this point each technology is assumed to be installed at a “desirable” location and given the optimal rating to cancel out
any variables that might be observed. Climatic performance variables are applied in the next stage of modelling.

### Table 12 - Decision Aid Demonstration Technology Generic Results

<table>
<thead>
<tr>
<th>Technology</th>
<th>Small Score</th>
<th>Small Rank</th>
<th>Medium Score</th>
<th>Medium Rank</th>
<th>Large Score</th>
<th>Large Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Evaporative Cooling</td>
<td>3.95</td>
<td>1</td>
<td>4.2</td>
<td>1</td>
<td>4.2</td>
<td>1</td>
</tr>
<tr>
<td>Solar Cooling - Thermally driven adsorption chillers</td>
<td>3.14</td>
<td>5</td>
<td>2.37</td>
<td>4</td>
<td>2.37</td>
<td>4</td>
</tr>
<tr>
<td>Solar Cooling - Thermally driven absorption chillers</td>
<td>3.19</td>
<td>4</td>
<td>3.29</td>
<td>3</td>
<td>3.32</td>
<td>3</td>
</tr>
<tr>
<td>Solar Cooling - Desiccant cooling systems</td>
<td>3.72</td>
<td>3</td>
<td>3.72</td>
<td>2</td>
<td>3.42</td>
<td>2</td>
</tr>
<tr>
<td>Phase Change Materials – Bulk Storage Units</td>
<td>3.83</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

#### 4.3.2 Climate Adjusted Generic Technology Results

The default climatic ratings in Table 13 below were calculated as described in section 3.2.4 above were applied to the generic results with the aim of providing an overview of where the technologies are best applied across the country.
### Table 13 - Default Climatic Ratings

<table>
<thead>
<tr>
<th>Region</th>
<th>Evaporative *</th>
<th>Solar Thermal **</th>
<th>PCM/Free Convection ***</th>
</tr>
</thead>
<tbody>
<tr>
<td>North QLD Coastal</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>North QLD Inland</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Sth QLD Coastal</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sth Central QLD</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>North NT</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>South/Central NT</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>North WA</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Central WA</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>South WA</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Nth SA</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Sth SA</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Eastern NSW</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Western NSW</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>ACT</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Victoria</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Tas</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

In the results displayed in Table 14 through Table 16 below show the decision aid output for a generic national analysis. This output is a snapshot and current at the time of publishing only. It is important to reiterate here as previously indicated that significant assumptions have been made. These should be reviewed in Appendix B by the reader to gauge whether the results are applicable to their specific application(s).

---

1 The asterisks in Table 13 are for reference purposes in the decision aid only. Applicable description of how these ratings were derived can be found in section 3.2.4.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
<th>Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Evaporative Cooling</td>
<td>2.5</td>
<td>5</td>
<td>4.0</td>
<td>2</td>
<td>3.0</td>
<td>5</td>
<td>4.0</td>
<td>1</td>
<td>3.0</td>
<td>5</td>
<td>4.0</td>
<td>1</td>
<td>3.5</td>
<td>5</td>
<td>4.5</td>
<td>1</td>
</tr>
<tr>
<td>Solar Cooling - Thermally driven adsorption</td>
<td>3.6</td>
<td>3</td>
<td>3.6</td>
<td>5</td>
<td>3.1</td>
<td>4</td>
<td>3.1</td>
<td>5</td>
<td>4.1</td>
<td>3</td>
<td>3.1</td>
<td>5</td>
<td>4.1</td>
<td>3</td>
<td>2.6</td>
<td>5</td>
</tr>
<tr>
<td>Solar Cooling - Thermally driven absorption</td>
<td>3.6</td>
<td>2</td>
<td>3.6</td>
<td>4</td>
<td>3.1</td>
<td>3</td>
<td>3.1</td>
<td>4</td>
<td>4.1</td>
<td>2</td>
<td>3.1</td>
<td>4</td>
<td>4.1</td>
<td>2</td>
<td>2.6</td>
<td>4</td>
</tr>
<tr>
<td>Solar Cooling - Desiccant cooling systems</td>
<td>3.9</td>
<td>1</td>
<td>3.9</td>
<td>3</td>
<td>3.4</td>
<td>2</td>
<td>3.4</td>
<td>3</td>
<td>4.4</td>
<td>1</td>
<td>3.4</td>
<td>3</td>
<td>4.4</td>
<td>1</td>
<td>2.9</td>
<td>3</td>
</tr>
<tr>
<td>Phase Change Materials – Bulk Storage Units</td>
<td>3.4</td>
<td>4</td>
<td>4.4</td>
<td>1</td>
<td>3.4</td>
<td>1</td>
<td>3.9</td>
<td>2</td>
<td>3.9</td>
<td>4</td>
<td>3.9</td>
<td>2</td>
<td>3.9</td>
<td>4</td>
<td>4.4</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 14 - Climate Adjusted Demonstration Results – Small Systems**
## Table 15 - Climate Adjusted Demonstration Results – Medium Systems

<table>
<thead>
<tr>
<th>Technology</th>
<th>Climatic Rating - Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North QLD Coastal</td>
</tr>
<tr>
<td>Indirect Evaporative Cooling</td>
<td>2.6</td>
</tr>
<tr>
<td>Solar Cooling - Thermally driven absorption chillers</td>
<td>3.6</td>
</tr>
<tr>
<td>Solar Cooling - Desiccant cooling systems</td>
<td>3.9</td>
</tr>
</tbody>
</table>
## Table 16 - Climate Adjusted Demonstration Results – Large Systems

<table>
<thead>
<tr>
<th>Technology</th>
<th>Climatic Rating - Large</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North QLD Coastal</td>
</tr>
<tr>
<td>Indirect Evaporative Cooling</td>
<td>2.6</td>
</tr>
<tr>
<td>Solar Cooling - Thermally driven absorption chillers</td>
<td>3.7</td>
</tr>
<tr>
<td>Solar Cooling - Desiccant cooling systems</td>
<td>3.7</td>
</tr>
</tbody>
</table>
4.4 Demonstration Analysis

4.4.1 Decision Aid:

Successes – The decision aid has:

- Provided a general overview for planning
- Aided targeted technology development
- Provided a starting point for further analysis

Limitations – The decision aid:

- Has limited use for network wide analysis.
- Should be reviewed with more detailed information before application of results.

4.4.2 Demonstration

The results presented clearly show that:

- Indirect evaporative cooling exhibits the highest potential in more situations than any other technology.
- PCM bulk storage systems are proposed as the optimal solution for small applications in southern WA and second in many other applications.
- The solar cooling technologies are shown to have potential only in the far northern and western areas of Australia.
- Solar cooling technologies have scope limited to the far northern and western areas of Australia.
- Relatively low scores for solar cooling indicate that even though they are the most attractive options in their option regions, they are still unlikely to be viable.
5 Conclusions

5.1 Literature Review

Indirect evaporative cooling is one of the most attractive efficient cooling options on the market today, especially in hot and dry climates. It is recommended that these climates are targeted for installation either for new systems, remediation of end of life systems or capacity increases. Further review of the trial at Mt Lofty is required before retrofitting on functioning systems is considered for energy savings alone.

Whilst solar thermally driven adsorption chillers have significant potential for energy savings in the future, it is the opinion of the author that it should be let mature further and reach more competitive levels commercially before large scale implementation. Technically, the technology exhibits robust, low maintenance performance so if other factors such as restricted or expensive water and/or electricity supply are a factor at a given site then it should certainly be considered.

The case study demonstrated that PCM bulk storage could work as a primary or supplementary cooling system for telecommunications sites, in particular where electrical energy supply was limited or expensive. The main case study in the literature review was installed in a non-ideal climate and further developments in the industry have occurred since. In the future, PCM supply and install efficiencies may render the system worth reconsidering especially when coupled with rising electricity prices. A site specific trial with ideal climatic conditions and the ability to fall back onto an existing system should be investigated further for commercial viability.

The literature review has revealed a few technologies that are on the cusp of commercial viability and a number that show large amounts of potential with further development. It can be seen that there is value in telecommunications
companies to become familiar with these technologies and review them for large scale implementation on a site by site basis however there appears to be limited scope for retrofitting systems on sites with non-end of life conventional systems already installed. Focus should be on utilising these new technologies for remediation rather than straight out replacement until the technologies become more commercially competitive.

This literature review as with most studies of this nature provides only a current state of the market and technology development. It is recommended that this review always be considered in light of the latest developments especially as significant period of time lapse from publication.

5.2 Decision Aid
In cases where the assumptions are considered accurate or sufficiently similar to the required application, the decision aid has succeeded in providing an overview that will aid in planning exercises for the purpose of targeting technology development in certain regions. Site specific information should then be applied to the decision aid before implementation.

Whilst the decision aid can be seen to provide a strong start towards the development of a decision making tool, further development is required before wide scale use in the industry. It is also recognised that the decision aid has been developed with the aim of providing a tool for generic application across many kinds of sites and locations. Further research may find that separate decision aids are required for various types of sites or even industry sectors.

5.3 Demonstration
The results presented clearly show that indirect evaporative cooling exhibits the highest potential in more situations than any other technology. PCM bulk storage systems are proposed as the optimal solution for small applications in southern
WA and second in many other applications. The solar cooling technologies are shown to have potential only in the far northern and western areas of Australia.

Even though they are the most attractive options there, they are still unlikely to be viable given their relatively low scores. Overall, the decision aid results favour indirect evaporative cooling in more climates and being that it is the most mature and cost effective of the technologies the author recommends investment the most significant investment be focused in these areas. Application of the other technologies is recommended but should be limited to smaller scale trials as a secondary priority.

This demonstration has given a very high level snapshot in time and should be reviewed on a site specific basis before actual application of the decision aid’s outputs.
6 Bibliography


http://www.sciencedirect.com/science/article/B6V4S-428DKJ0-B/2/b9eb1b0da77e5d2fe0e692c9a13e09b


Stetiou, C., and HE Feustel. 1996. Phase change wallboard as an alternative to compressor cooling in californian residences.


White, Stephen. 2011b. Modelling, Results and Dos and Dons. In ausSCIG Solar Cooling Workshop. Canberra, Australia: CSIRO.


### Appendix A: Decision Aid Blank Worksheet Example

#### Table 17 - Example Blank Evaluation Worksheet

<table>
<thead>
<tr>
<th>New Technology 1</th>
<th>Potential categories - High Score = 5, Low Score = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Payback</td>
</tr>
<tr>
<td>&quot;Typical&quot; System Size</td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>Enter Valid Rating 1 through 5 or '1'</td>
</tr>
<tr>
<td>Medium</td>
<td>Enter Valid Rating 1 through 5 or '1'</td>
</tr>
<tr>
<td>Large</td>
<td>Enter Valid Rating 1 through 5 or '1'</td>
</tr>
<tr>
<td>Further Details</td>
<td>General Definition</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Payback</td>
<td>Expected simple payback for the chosen system installed at the &quot;typical&quot; site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.</td>
</tr>
<tr>
<td>Net Energy savings</td>
<td>Expected net energy savings for the chosen system installed at the &quot;typical&quot; site.</td>
</tr>
<tr>
<td>Retrofit Capability</td>
<td>The ability for the chosen system to be retrofit into the existing system at the &quot;typical&quot; site.</td>
</tr>
<tr>
<td>Current Level of Commercialisation</td>
<td>The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).</td>
</tr>
<tr>
<td>Commercialisation Potential</td>
<td>The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.</td>
</tr>
<tr>
<td>Design Suitability for 24/7 Heat Load</td>
<td>The ability for the chosen system be designed to deliver the total heat load 24 hours a day seven days a week at the &quot;typical&quot; site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.</td>
</tr>
</tbody>
</table>
### Thesis
Energy Efficient Air-Conditioning - Technology Review and Decision Aid for Australian Telecommunications Sites

<table>
<thead>
<tr>
<th>Maintenance Intensity</th>
<th>Maintenance requirements as defined by minimum frequency someone has to attend site, complexity and resources required and total duration p.a.. The rating is calculated based on an average of these three sub criteria. The frequency sub criteria is weighted in a 3/2/1 ratio for small/medium/large sites respectively. The duration sub criteria is weighted in a 1/2/3 ratio for small/medium/large sites respectively, e.g. a small site should require 1/3 of the maintenance of a large site and 3 times less often.</th>
<th>Frequency</th>
<th>Complexity</th>
<th>Duration</th>
<th>Total</th>
</tr>
</thead>
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</tr>
<tr>
<td>Alternate Resource Impact</td>
<td>The chosen system's reliance on alternative finite resources and their availability without significant storage requirements. The variables are quantity of consumption and availability. The final rating eliminates this technology as an option with a rating of 1. The rating is calculated based on an average of these two sub criteria. The consumption sub criterion is weighted in a 3/2/1 ratio for small/medium/large sites respectively, e.g. a small site should require 1/3 of the maintenance at a large site.</td>
<td>Consumption -</td>
<td>Availability -</td>
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</tr>
<tr>
<td>Climatic Performance</td>
<td>Design performance in the required site's climatic conditions. If site specific ratings are not available the Climate Ratings worksheet may provide assistance.</td>
<td>For the purposes of the model demonstration for this thesis, a common rating of 5 has been chosen for each technology to assume optimal climatic conditions as this weighting will be distributed in the overview. For future site specific use the rating should always be applied.</td>
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</table>
Appendix B: Decision Aid Demonstration Details

B.1 Indirect Evaporative Cooling

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</thead>
<tbody>
<tr>
<td>Small</td>
<td>3</td>
<td>5-10 years</td>
<td>4</td>
<td>Minor or no Modifications</td>
<td>4</td>
<td>5</td>
<td>&lt; 2 years</td>
<td>4</td>
<td>&gt;80% / Very High Potential</td>
<td>5</td>
</tr>
<tr>
<td>Medium</td>
<td>4</td>
<td>2-5 years</td>
<td>4</td>
<td>Minor or no Modifications</td>
<td>4</td>
<td>5</td>
<td>&lt; 2 years</td>
<td>4</td>
<td>&gt;80% / Very High Potential</td>
<td>5</td>
</tr>
<tr>
<td>Large</td>
<td>4</td>
<td>2-5 years</td>
<td>4</td>
<td>Minor or no Modifications</td>
<td>3</td>
<td>4</td>
<td>2-5 years</td>
<td>4</td>
<td>&gt;80% / Very High Potential</td>
<td>5</td>
</tr>
<tr>
<td>Further Details</td>
<td>General Definition</td>
<td>Evaluation Justification</td>
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</tr>
<tr>
<td>Payback</td>
<td>Expected simple payback for the chosen system installed at the &quot;typical&quot; site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.</td>
<td>The calculations were based on payback periods achieved at Broadcast Australia's South Australian Mt Lofty site excluding internal project costs (4.8 years) and weighted on the $/kW figures given by McBratney (2011). It is assumed that these energy savings are indicative of an average design in a desirable climate. The system's ability to be independent of the existing cooling system means that it will integrate easily regardless of existing system configuration. Small - 4.8 x 1.7 / 1.3 = 6.3 years = rating 3 Medium - 4.8 x 1.3/1.3 = 4.8 years = rating 4 Large - 4.8 x 1.3 / 1.3 = 4.8 years = rating 4</td>
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<td></td>
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<tr>
<td>Net Energy savings</td>
<td>Expected net energy savings for the chosen system installed at the &quot;typical&quot; site.</td>
<td>These calculations are based on Mt Lofty which was designed to deliver 75% of the cooling capacity which at the time of install represented the optimal size technically. It is assumed that these energy savings are indicative of an average design in a desirable climate. The COP of the Mt Lofty vapour compression A/C system is 3.0, therefore the ratings are weighted against a ratio of 3.0 to the typical site's COP. Small - 65 x (3.0/2.5) = 78% = rating 4 Medium - 65 x (3.0/3.0) = 65% = rating 4 Large - 65 x (3.0/3.2) = 61% = rating 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Retrofit Capability</td>
<td>The ability for the chosen system to be retrofit into the existing system at the &quot;typical&quot; site.</td>
<td>The works required to retrofit the system into the existing consisted primarily of interfacing with the existing controls which was priced at 8% of the total capital expenditure. The ducting was kept completely separate of the existing system and is therefore seen as the same required for a greenfield site. This ratio has been assumed as the same for all typical site types. 8% = rating 5</td>
<td></td>
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</tr>
<tr>
<td>Current Level of Commercialisation</td>
<td>The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).</td>
<td>For small and medium systems literature review revealed that whilst many units are commercially available and in production, a limited number of vendors are in the market especially ones that achieve the effectiveness of the case study sites. A significant number of full scale commercial systems have been commissioned. Therefore it is deemed by the author that IEC is in the early stages of deployment = rating 4. Large units are less developed and therefore have been given a demonstration rating of 3.</td>
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</tr>
<tr>
<td>Commercialisation Potential</td>
<td>The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.</td>
<td>The commercialisation potential can be seen as very high given that many of the technical issues have been resolved and some units are approaching dew point temperatures which lends greatly to competitiveness. With its sister technology of evaporative coolers being quite well developed, the potential to become mature within a decade can be seen to be realistic. Small - Rating 5 Medium - Rating 5 Large - Rating 4</td>
<td></td>
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</tbody>
</table>
The ability for the chosen system be designed to deliver the total heat load 24 hours a day seven days a week at the “typical” site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.

IEC can meet 100% of a 24/7 heat load year round. The main limiting factor is external humidity such that if it rises above 75% @ 23°C the units should shut down to protect the equipment as per the typical site requirements. It has not been tested how often this could happen so an assumption of 5% (18 days p.a.) of the time has been made until the results from Mt Lofty are available to give a benchmark. Therefore the systems must be down rated the system to 4.

### Design Suitability for 24/7 Heat Load

<table>
<thead>
<tr>
<th>Maintenance Intensity</th>
<th>Frequency - Mt Lofty maintenance schedule specifies 2 months. Rating = 1</th>
<th>Duration - 21 hours per unit (Morton, 2011). Assume 2 x 10kW units = 42 hours p.a. = 5.25 days p.a. Rating = 2.</th>
<th>Complexity - 6hrs skilled / 15 hours total = 28.6%. Rating = 4.</th>
<th>2 Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Frequency - Mt Lofty maintenance schedule specifies 2 months. Rating = 2</td>
<td>Duration - 21 hours per unit (Morton, 2011). Assume 6 x 15kW units = 126 hours p.a. = 15.75 days p.a. Rating =1.</td>
<td>Complexity - 6hrs skilled / 21 hours total = 28.6%. Rating = 4.</td>
<td>2 Total</td>
</tr>
<tr>
<td>M</td>
<td>Frequency - Mt Lofty maintenance schedule specifies 2 months. Rating = 3</td>
<td>Duration - 21 hours per unit scaled up for larger units by 1.5. Assume 3 x 45 kW units = 94.5 hours p.a. = 11.8 days p.a. Rating = 2</td>
<td>Complexity - 6hrs skilled / 15 hours total = 28.6%. Rating = 4.</td>
<td>3 Total</td>
</tr>
</tbody>
</table>
**Alternate Resource Impact**

The chosen system’s reliance on alternative finite resources and their availability without significant storage requirements. The variables are quantity of consumption and availability. The final rating eliminates this technology as an option with a rating of 1. The rating is calculated based on an average of these two sub criteria. The consumption sub criterion is weighted in a 3/2/1 ratio for small/medium/large sites respectively. e.g. a small site should require 1/3 of the maintenance at a large site.

<table>
<thead>
<tr>
<th>Size</th>
<th>Consumption - Water consumption at Mt Lofty estimated at 150 kL p.a. Assume 1/3 size = 50,000 L p.a.. Average household = 419.5 kL p.a.. Rating = 5</th>
<th>Availability - Water availability varies greatly between sites. Whilst in capital city sites it is commonly available, remote sites in dry areas have little chance even for rainwater harvesting. Assumed rating of 3 to represent 50% of sites.</th>
<th>4 Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Consumption - Water consumption at Mt Lofty estimated at 146,220 L p.a. Average household = 419.5 kL p.a.. Rating = 5</td>
<td>Availability - Assumed rating of 3</td>
<td>4 Total</td>
</tr>
<tr>
<td>M</td>
<td>Consumption - Water consumption at Mt Lofty estimated at 146,220 L p.a. Assume 2x size = 300,000 L p.a.. Average household = 419.5 kL p.a.. Rating = 5</td>
<td>Availability - Assumed rating of 3</td>
<td>4 Total</td>
</tr>
<tr>
<td>L</td>
<td></td>
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</tr>
</tbody>
</table>

**Climatic Performance**

Design performance in the required site’s climatic conditions. If site specific ratings are not available the Climate Ratings worksheet may provide assistance.

For the purposes of the model demonstration for this thesis, a common rating of 5 has been chosen for each technology to assume optimal climatic conditions as this weighting will be distributed in the overview. For future site specific use the rating should always be applied.
### B.2 Solar Cooling – Thermally Driven Adsorption Chiller

#### Solar Cooling - Thermally driven adsorption chillers

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</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>1 &gt; 20 years</td>
<td>1 0-20%</td>
<td>Minor or no Modifications</td>
<td>3 Demonstration</td>
<td>3 5-10 years</td>
<td>2 &gt;20% / Some Potential</td>
<td>3 Medium</td>
<td>5 Very low</td>
<td>Optimal</td>
<td>3.14</td>
</tr>
<tr>
<td>Medium</td>
<td>1 &gt; 20 years</td>
<td>1 0-20%</td>
<td>Not Possible</td>
<td>1 Research</td>
<td>2 10-20 years</td>
<td>1 Almost Never</td>
<td>1 Not Practical</td>
<td>5 Very low</td>
<td>Optimal</td>
<td>2.37</td>
</tr>
<tr>
<td>Large</td>
<td>1 &gt; 20 years</td>
<td>1 0-20%</td>
<td>Not Possible</td>
<td>1 Research</td>
<td>2 10-20 years</td>
<td>1 Almost Never</td>
<td>1 Not Practical</td>
<td>5 Very low</td>
<td>Optimal</td>
<td>2.37</td>
</tr>
<tr>
<td>Further Details</td>
<td>General Definition</td>
<td>Evaluation Justification</td>
<td></td>
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<tr>
<td>Payback</td>
<td>Expected simple payback for the chosen system installed at the &quot;typical&quot; site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.</td>
<td>Small - No payback possible at this time without offset of capital costs for an existing system replacement. (White, 2011) More information required.</td>
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<tr>
<td></td>
<td></td>
<td>Medium &amp; Large - Not viable with existing technology</td>
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<tr>
<td>Net Energy savings</td>
<td>Expected net energy savings for the chosen system installed at the &quot;typical&quot; site.</td>
<td>Small - COP 4 in Germany (White 2011c) scaled by 1.5 for Australia to 6. Operating 6 hrs per day. Saves 41.6% when operational = 10-15% total.</td>
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<tr>
<td></td>
<td></td>
<td>Medium &amp; Large - Not viable with existing technology</td>
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</tr>
<tr>
<td>Retrofit Capability</td>
<td>The ability for the chosen system to be retrofit into the existing system at the &quot;typical&quot; site.</td>
<td>Estimated as very simple given the system would run as a supplement to the existing with little interconnection required.</td>
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</tr>
<tr>
<td>Current Level of Commercialisation</td>
<td>The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).</td>
<td>Small - Very early demonstration</td>
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<tr>
<td></td>
<td></td>
<td>Medium &amp; Large - Not viable with existing technology</td>
<td></td>
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<td></td>
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<td>(White, 2011d; EPRI, 2010)</td>
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<tr>
<td>Commercialisation Potential</td>
<td>The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.</td>
<td>A small number of small scale units are being developed White (2011d) - still requires significant development but industry ramp up should assist.</td>
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<tr>
<td>Design Suitability for 24/7 Heat Load</td>
<td>The ability for the chosen system to be designed to deliver the total heat load 24 hours a day seven days a week at the &quot;typical&quot; site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.</td>
<td>Storage capability is still very infantile so the risk is perceived as very high to not possible.</td>
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<tr>
<td>Maintenance Intensity</td>
<td>Frequency - Stated as 12 monthly by industry experts</td>
<td>Complexity - No specific information available but large amounts of the maintenance is assumed mainly centred around the absorption chiller which is skilled labour ~ 90% skilled</td>
<td>Duration - 0.5 days p.a. maintenance on the adsorption chiller as anecdotally advised by industry experts.</td>
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<td>S S</td>
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<tr>
<td>M 0</td>
<td></td>
<td>Complexity - No specific information available but large amounts of the maintenance is assumed mainly centred around the absorption chiller which is skilled labour ~ 80% skilled</td>
<td>Duration - 2 days p.a. maintenance on the absorption chiller as anecdotally advised by industry experts.</td>
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<tr>
<td>L 0</td>
<td></td>
<td>Complexity - No specific information available but large amounts of the maintenance is assumed as simple routine mechanical tasks. ~ 30% skilled</td>
<td>Duration - Based on the Ipswich Hospital maintenance of $1400 p.a. at $65 per hour this equates to approx. 3 days p.a.</td>
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</tr>
</tbody>
</table>

Maintenance requirements as defined by minimum frequency someone has to attend site, complexity and resources required and total duration p.a.. The rating is calculated based on an average of these three sub criteria. The frequency sub criteria is weighted in a 3/2/1 ratio for small/medium/large sites respectively. The duration sub criteria is weighted in a 1/2/3 ratio for small/medium/large sites respectively, e.g. a small site should require 1/3 of the maintenance of a large site and 3 times less often.
### Alternate Resource Impact

The chosen system’s reliance on alternative finite resources and their availability without significant storage requirements. The variables are quantity of consumption and availability. The final rating eliminates this technology as an option with a rating of 1. The rating is calculated based on an average of these two sub criteria. The consumption sub criterion is weighted in a 3/2/1 ratio for small/medium/large sites respectively. e.g. a small site should require 1/3 of the maintenance at a large site.

<table>
<thead>
<tr>
<th>Site</th>
<th>Consumption - apart from the renewal of the absorption material, the systems primarily use Solar radiation.</th>
<th>Availability - Renewable</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>S</td>
<td>5</td>
<td>5 Total</td>
</tr>
<tr>
<td>M</td>
<td>Consumption - apart from a small amount of water and the renewal of the absorption material, the systems primarily use Solar radiation.</td>
<td>4</td>
<td>5 Total</td>
</tr>
<tr>
<td>L</td>
<td>Consumption - apart from a small amount of water and the renewal of the absorption material, the systems primarily use Solar radiation.</td>
<td>4</td>
<td>5 Total</td>
</tr>
</tbody>
</table>

### Climatic Performance

Design performance in the required site’s climatic conditions. If site specific ratings are not available the Climate Ratings worksheet may provide assistance.

For the purposes of the model demonstration for this thesis, a common rating of 5 has been chosen for each technology to assume optimal climatic conditions as this weighting will be distributed in the overview. For future site specific use the rating should always be applied.
### B.3 Solar Cooling – Thermally Driven Absorption Chiller

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>1</td>
<td>&gt; 20 years</td>
<td>0-20%</td>
<td>5 Minor or no Modifications</td>
<td>Demonstration</td>
<td>4 2-5 years</td>
<td>&gt;20% / Some Potential</td>
<td>3 Medium</td>
<td>Very low</td>
</tr>
<tr>
<td>Medium</td>
<td>1</td>
<td>&gt; 20 years</td>
<td>21-40%</td>
<td>5 Minor or no Modifications</td>
<td>Demonstration</td>
<td>4 2-5 years</td>
<td>&gt;20% / Some Potential</td>
<td>3 Medium</td>
<td>Very low</td>
</tr>
<tr>
<td>Large</td>
<td>2</td>
<td>10-20 years</td>
<td>0-20%</td>
<td>4 Medium Modifications</td>
<td>Demonstration</td>
<td>4 2-5 years</td>
<td>Almost Never</td>
<td>3 Medium</td>
<td>Very low</td>
</tr>
</tbody>
</table>
## Further Details  

### General Definition

**Payback**
- Expected simple payback for the chosen system installed at the "typical" site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.

**Net Energy savings**
- Expected net energy savings for the chosen system installed at the "typical" site.

**Retrofit Capability**
- The ability for the chosen system to be retrofit into the existing system at the "typical" site.

**Current Level of Commercialisation**
- The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).

**Commercialisation Potential**
- The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.

**Design Suitability for 24/7 Heat Load**
- The ability for the chosen system be designed to deliver the total heat load 24 hours a day seven days a week at the "typical" site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.

### Evaluation Justification

**Payback**
- Small & Medium - No payback possible at this time without offset of capital costs for an existing system replacement. (White, 2011) More information required.  
- Large - Adjusted figures according to typical system description takes a 8 year payback at the Ipswich Hospital to a

**Net Energy savings**
- Small - COP 4 in Germany (White 2011c) scaled by 1.5 for Australia to 6. Operating 6 hrs per day. Saves 41.6% when operational = 10-15% total.  
- Medium - Little information available on this so assuming an average of the large and small savings but increased due to 24 hr. operation.  
- Large - Direct figures are not available for the Ipswich Hospital however based on claimed savings of the overall system, net energy savings are in the order of 13% of a gas fired absorption chiller (COP=5). Adjusted for a COP of 3 on the existing system and assuming 75% of load the savings are estimated at ~17%.

**Retrofit Capability**
- Estimated as very simple given the system would run as a supplement to the existing with little interconnection required.

**Current Level of Commercialisation**
- Demonstration (White, 2011d; EPRI, 2010)

**Commercialisation Potential**
- Given the industry ramp up illustrated by White (2011d) with year on year doubling of installed systems and price reductions stronger levels of commercialisation potential can be seen. Indications from some industry experts predict systems will be price competition under 5 years to realise commercially attractive paybacks.

**Design Suitability for 24/7 Heat Load**
- Storage capability is still very infantile so the risk is perceived as very high to not possible.
### Maintenance Intensity

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
<th>Frequency</th>
<th>Complexity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>4-6 monthly by industry experts</td>
<td>No specific information available but large amounts of the maintenance is assumed mainly centred around the absorption chiller</td>
<td>1 day p.a. maintenance on the absorption chiller as anecdotally advised by industry experts</td>
<td>3 Total</td>
</tr>
<tr>
<td>M</td>
<td>4-6 monthly by industry experts</td>
<td>No specific information available but large amounts of the maintenance is assumed</td>
<td>2 days p.a. maintenance on the absorption chiller as anecdotally advised</td>
<td>3 Total</td>
</tr>
<tr>
<td>L</td>
<td>Complex with moving parts - Monthly maintenance potentially required</td>
<td>No specific information available but large amounts of the maintenance is assumed</td>
<td>Based on the Ipswich Hospital maintenance of $1400 p.a. at $65 per hour</td>
<td>3 Total</td>
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</tbody>
</table>

### Alternate Resource Impact

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
<th>Frequency</th>
<th>Complexity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Consumption - apart from a small amount of water and the renewal of the absorption material, the systems primarily use Solar radiation</td>
<td>Renewable</td>
<td>5 Total</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Consumption - apart from a small amount of water and the renewal of the absorption material, the systems primarily use Solar radiation</td>
<td>Renewable</td>
<td>5 Total</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Consumption - apart from a small amount of water and the renewal of the absorption material, the systems primarily use Solar radiation</td>
<td>Renewable</td>
<td>5 Total</td>
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</table>

### Climatic Performance

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
<th>Rating</th>
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<tbody>
<tr>
<td>S</td>
<td>For the purposes of the model demonstration for this thesis, a common rating of 5 has been chosen for each technology to assume optimal climatic conditions as this weighting will be distributed in the overview. For future site specific use the rating should always be applied.</td>
<td>5 Total</td>
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</table>
## B.4 Solar Cooling – Desiccant Precooling and Dehumidification

**Solar Cooling - Desiccant cooling systems**

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<tbody>
<tr>
<td>Small</td>
<td>3</td>
<td>5-10 years</td>
<td>4</td>
<td>Medium Modifications</td>
<td>2</td>
<td>Development</td>
<td>4</td>
<td>2-5 years</td>
<td>5</td>
<td>100% Today</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
<td>5-10 years</td>
<td>4</td>
<td>Medium Modifications</td>
<td>2</td>
<td>Development</td>
<td>4</td>
<td>2-5 years</td>
<td>5</td>
<td>100% Today</td>
</tr>
<tr>
<td>Large</td>
<td>3</td>
<td>5-10 years</td>
<td>4</td>
<td>Medium Modifications</td>
<td>2</td>
<td>Development</td>
<td>4</td>
<td>2-5 years</td>
<td>5</td>
<td>100% Today</td>
</tr>
</tbody>
</table>
### Further Details  | General Definition  | Evaluation Justification
--- | --- | ---
**Payback**  | Expected simple payback for the chosen system installed at the "typical" site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.  | Insufficient data is available on capital costs on installed desiccant systems although most references in the literature review indicate a "small" or "minor" increase in capital outlay. Therefore a 20% cost and maintenance increase on the IEC systems is assumed for the model's demonstration. The calculations were based on payback periods achieved at Broadcast Australia's South Australian Mt Lofty site excluding internal project costs (4.8 years) and weighted on the $/kW figures given by McBratney (2011). It is assumed that these energy savings are indicative of an average design in a desirable climate. The system's ability to be independent of the existing cooling system means that it will integrate easily regardless of existing system configuration.
Small - 4.8 x 1.7 / 1.3 * 1.2 = 7.6 years = rating 3
Medium - 4.8 x 1.3/1.3 * 1.2 = 5.8 years = rating 3
Large - 4.8 x 1.3 / 1.3 * 1.2 = 5.8 years = rating 3  |
**Net Energy savings**  | Expected net energy savings for the chosen system installed at the "typical" site.  | the IEC system chosen is designed to perform at an average COP of 8-9 in desirable climatic regions. The desiccant system chosen is reported to perform at "up to" 11.4. It is therefore assumed that no increase in energy saving is realised with the addition of a desiccant cycle in desirable climates. Therefore the IEC energy savings calculations are directly transferable as below:
These calculations are based on Mt Lofty which was designed to deliver 75% of the cooling capacity which at the time of install represented the optimal size technically. It is assumed that these energy savings are indicative of an average design in a desirable climate. The COP of the Mt Lofty vapour compression A/C system is 3.0, therefore the ratings are weighted against a ratio of 3.0 to the typical site’s COP.
Small - 65 x (3.0/2.5) = 78% = rating 4
Medium - 65 x (3.0/3.0) = 65% = rating 4
Large - 65 x (3.0/3.2) = 61% = rating 4  |
**Retrofit Capability**  | The ability for the chosen system to be retrofit into the existing system at the "typical" site.  | It is assumed that the desiccant system is integral to the IEC system so retrofit is identical to the IEC system as below:
The works required to retrofit the system into the existing consisted primarily of interfacing with the existing controls which was priced at 8% of the total capital expenditure. The ducting was kept completely separate of the existing system and is therefore seen as the same required for a greenfield site. This ratio has been assumed as the same for all typical site types. 8% = rating 5
<table>
<thead>
<tr>
<th>Current Level of Commercialisation</th>
<th>The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).</th>
<th>Whilst desiccant dehumidifiers are readily available from a few suppliers, their commercial application to IEC and other cooling systems have not appeared in the market or in research in any significant numbers. Therefore the technology cannot be seen as in demonstration in the opinion of the author. Therefore a rating of development has been granted for the purposes of the model demonstration.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercialisation Potential</td>
<td>The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.</td>
<td>With the relative maturity of the desiccant systems as a standalone application and the apparent interest of IEC system manufacturers, the author believes that this is the next logical step to the expansion of IEC systems. With further application potential in fresh air pre-conditioning for vapour compression systems as an additional driving force to push the technology commercialisation, it can be seen that deployment within 5 years is achievable. Small - Rating 4 Medium - Rating 4 Large - Rating 4</td>
</tr>
<tr>
<td>Design Suitability for 24/7 Heat Load</td>
<td>The ability for the chosen system be designed to deliver the total heat load 24 hours a day seven days a week at the “typical” site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.</td>
<td>Desiccant pre-conditioning of an IEC system not only expands its climatic application range but also its ability to provide cooling 24/7, especially on mountain top sites or regions prone to mist and fog. Desiccant dehumidification can be seen to provide a more reliable system that can potentially run 24/7.</td>
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<td>IEC can meet 100% of a 24/7 heat load year round. The main limiting factor is external humidity such that if it rises above 75% @ 23°C the units should shut down to protect the equipment as per the typical site requirements. It has not been tested how often this could happen so an assumption of 5% (18 days p.a.) of the time has been made until the results from Mt Lofty are available to give a benchmark. Therefore the systems must be down rated the system to 4.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The addition of desiccant dehumidification can be seen to provide a more reliable system that can potentially run 24/7.</td>
</tr>
<tr>
<td>Maintenance Intensity</td>
<td>Frequency - Desiccant systems will not increase frequency of maintenance on previous IEC assumptions. Mt Lofty maintenance schedule specifies 2 months. Rating = 1</td>
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<td></td>
<td>Duration - 20% increase on IEC maintenance is assumed. Therefore a duration of 21 hours per unit (Morton, 2011) is increased to 25.2. Assume 2 x 10 kW units = 50.4 hours p.a. = 6.3 days p.a. Rating = 2</td>
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<tr>
<td></td>
<td>Complexity - The 20% increase on IEC maintenance is assumed to be 80% skilled. Therefore 6+4.2hrs skilled / 25.2 hours total = 40.5%. Rating = 4</td>
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<td></td>
<td>2 Total</td>
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<tr>
<td>S 1</td>
<td>Frequency - Desiccant systems will not increase frequency of maintenance on previous IEC assumptions. Mt Lofty maintenance schedule specifies 2 months. Rating = 2</td>
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<tr>
<td></td>
<td>Duration - 25.2 hours per unit (Morton, 2011). Assume 6 x 15 kW units = 151.2 hours p.a. = 18.9 days p.a. Rating =1</td>
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<tr>
<td></td>
<td>Complexity - The 20% increase on IEC maintenance is assumed to be 80% skilled. Therefore 6+4.2hrs skilled / 25.2 hours total = 40.5%. Rating = 4</td>
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<tr>
<td></td>
<td>2 Total</td>
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<tr>
<td>M 2</td>
<td>Frequency - Desiccant systems will not increase frequency of maintenance on previous IEC assumptions. Mt Lofty maintenance schedule specifies 2 months. Rating = 3</td>
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<tr>
<td></td>
<td>Duration - 25.2 hours per unit scaled up for larger units by 1.5. Assume 3 x 45 kW units = 113.4 hours p.a. 14.2 = days p.a. Rating = 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complexity - The 20% increase on IEC maintenance is assumed to be 80% skilled. Therefore 6+4.2hrs skilled / 25.2 hours total = 40.5%. Rating = 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 Total</td>
<td></td>
</tr>
</tbody>
</table>

Monitoring requirements as defined by minimum frequency someone has to attend site, complexity and resources required and total duration p.a.. The rating is calculated based on an average of these three sub criteria. The frequency sub criteria is weighted in a 3/2/1 ratio for small/medium/large sites respectively. The duration sub criteria is weighted in a 1/2/3 ratio for small/medium/large sites respectively, e.g. a small site should require 1/3 of the maintenance of a large site and 3 times less often.
### Alternate Resource Impact

The chosen system's reliance on alternative finite resources and their availability without significant storage requirements. The variables are quantity of consumption and availability. The final rating eliminates this technology as an option with a rating of 1. The rating is calculated based on an average of these two sub criteria. The consumption sub criterion is weighted in a 3/2/1 ratio for small/medium/large sites respectively. e.g. a small site should require 1/3 of the maintenance at a large site.

<table>
<thead>
<tr>
<th>Consumption - Negligible change on consumption over IEC, therefore: Water consumption at Mt Lofty estimated at 150 kL p.a. Assume 1/3 size = 50,000 L p.a.. Average household = 419 kL p.a.. Rating = 5 Available - Water availability varies greatly between sites. Whilst in capital city sites it is commonly available, remote sites in dry areas have little chance even for rainwater harvesting. Assumed rating of 3 to represent 50% of sites.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption - Negligible change on consumption over IEC, therefore: Water consumption at Mt Lofty estimated at 146.220 L p.a. Average household = 419 kL p.a.. Rating = 5 Available - Assumed rating of 3</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Consumption - Negligible change on consumption over IEC, therefore: Water consumption at Mt Lofty estimated at 146.220 L p.a. Assume 2x size = 300,000 L p.a.. Average household = 419 kL p.a.. Rating = 5 Available - Assumed rating of 3</td>
</tr>
</tbody>
</table>

### Climatic Performance

Design performance in the required site's climatic conditions. If site specific ratings are not available the Climate Ratings worksheet may provide assistance.

For the purposes of the model demonstration for this thesis, a common rating of 5 has been chosen for each technology to assume optimal climatic conditions as this weighting will be distributed in the overview. For future site specific use the rating should always be applied.
### B.5 Phase Change Materials – Bulk Storage Unit

#### Phase Change Materials – Bulk Storage Units

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</thead>
<tbody>
<tr>
<td>Small</td>
<td>3</td>
<td>5-10 years</td>
<td>3</td>
<td>Minor or no Modifications</td>
<td>3 Demonstration</td>
<td>2 10-20 years</td>
<td>Medium</td>
<td>3</td>
<td>Very low</td>
<td>Optimal</td>
</tr>
<tr>
<td>Medium</td>
<td>N/A</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>Medium</td>
<td>3</td>
<td>N/A or Not Definable Today</td>
<td>Enter Valid Rating 1 through 5 or ‘-’</td>
</tr>
<tr>
<td>Large</td>
<td>N/A</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>N/A or Not Definable Today</td>
<td>Medium</td>
<td>3</td>
<td>N/A or Not Definable Today</td>
<td>Enter Valid Rating 1 through 5 or ‘-’</td>
</tr>
<tr>
<td>Further Details</td>
<td>General Definition</td>
<td>Evaluation Justification</td>
<td></td>
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<tr>
<td>Payback</td>
<td>Expected simple payback for the chosen system installed at the &quot;typical&quot; site. Considerations include capital expenditure, operation and maintenance costs assuming zero mobilisation.</td>
<td>Small - Based on the quoted 50% savings and an A/C load of 15 kW at night and 20 kW in the day, savings would be around $10,000 p.a. The quoted installation capex was $120,000 therefore a 12 year payback is assumed. This figure is improved by 20% to allow for the fact that the system was not installed in a desirable climatic region. Final payback = 9.6 years, rating = 3.</td>
<td></td>
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<tr>
<td>Net Energy savings</td>
<td>Expected net energy savings for the chosen system installed at the &quot;typical&quot; site.</td>
<td>Small - 50% (Rizkalla and Kandadai, 2009) improved by 20% to allow for the fact that the system was not installed in a desirable climatic region. Final savings = 60%, rating = 3</td>
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<tr>
<td>Retrofit Capability</td>
<td>The ability for the chosen system to be retrofit into the existing system at the &quot;typical&quot; site.</td>
<td>Small - the system controls are quite simple as the technology works in isolation and only calls upon the vapour compression system when it cannot provide the required cooling load. Rating = 5</td>
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<tr>
<td>Current Level of Commercialisation</td>
<td>The level of commercial advancement of the technology in general in Australia. Criteria defined by EPRI (2010).</td>
<td>Small - The technology has a number of full scale demonstrations so this level of commercialisation can be assumed. Rating = 3</td>
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<tr>
<td>Commercialisation Potential</td>
<td>The foreseen timeframe for the technology to achieve a late stage of deployment or better level of commercialisation.</td>
<td>Small - Whilst there are a number of demonstrations around, the technology has been at this level for some time and it is the opinion of the author that this may stay the case for some years to come unless the price reduces significantly. Rating = 2</td>
<td></td>
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<tr>
<td>Design Suitability for 24/7 Heat Load</td>
<td>The ability for the chosen system be designed to deliver the total heat load 24 hours a day seven days a week at the &quot;typical&quot; site assuming climatic conditions are desirable and alternate resources are available. If standalone 24/7 operation is a requirement then a poor score here should preclude its use and the user should disregard this technology as an option in the first instance.</td>
<td>Small - the system design claimed to support the site for 365 days of the year however a full trial has not been witnessed by the author nor is there published reference to a similar system so the rating has been downgraded to a 4.</td>
<td></td>
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</tbody>
</table>
### Maintenance Intensity

Maintenance requirements as defined by minimum frequency someone has to attend site, complexity and resources required and total duration p.a.. The rating is calculated based on an average of these three sub criteria. The frequency sub criteria is weighted in a 3/2/1 ratio for small/medium/large sites respectively. The duration sub criteria is weighted in a 1/2/3 ratio for small/medium/large sites respectively. e.g. a small site should require 1/3 of the maintenance of a large site and 3 times less often.

<table>
<thead>
<tr>
<th>Sub-Criteria</th>
<th>Frequency</th>
<th>Complexity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total Rating**: 3

### Alternate Resource Impact

The chosen system’s reliance on alternative finite resources and their availability without significant storage requirements. The variables are quantity of consumption and availability. The final rating eliminates this technology as an option with a rating of 1. The rating is calculated based on an average of these two sub criteria. The consumption sub criterion is weighted in a 3/2/1 ratio for small/medium/large sites respectively. e.g. a small site should require 1/3 of the maintenance at a large site.

<table>
<thead>
<tr>
<th>Sub-Criteria</th>
<th>Consumption</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
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<td>L</td>
<td></td>
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</tbody>
</table>

**Total Rating**: 5

### Climatic Performance

Design performance in the required site’s climatic conditions. If site specific ratings are not available the Climate Ratings worksheet may provide assistance.

For the purposes of the model demonstration for this thesis, a common rating of 5 has been chosen for each technology to assume optimal climatic conditions as this weighting will be distributed in the overview. For future site specific use the rating should always be applied.
Appendix C: Indirect evaporative cooling process description

An evaporative cooling system can be implemented by Indirect Evaporative Cooling (IEC) or Direct Evaporative Cooling (DEC). DEC cools the process air directly by drawing it through drenched evaporative cores where the water is evaporated thereby cooling the air to temperatures which may approach the wet bulb temperature of the incoming air. However, while the temperature is reduced with low energy consumption, DEC is an adiabatic process in which the temperature of process air is lowered only at the expense of higher moisture content in the air, raising the humidity of the air, reducing comfort and reducing air quality for conditioned spaces sensitive to high humidity. This effect is illustrated in Figure 27 below. Further, this cycle of evaporative cooling can only operate efficiently in dry climates (Bruno, 2008, 2009; Daou et al., 2006).

![Psychrometric Chart](image)

**Figure 27 - Psychrometric chart, Direct evaporative cooling (Bruno, 2008)**

C.1 IEC – Single pass heat exchanger

IEC utilises the low energy advantages of evaporative cooling to reduce the temperature of air without the addition of moisture. These technologies invariably use some form of heat exchange media between the evaporation of water process
and cooling of air. The low temperatures created by the evaporation of water provide a temperature differential to enable the cooling of air across a heat exchange barrier, which enables the transfer of heat from the air stream to be cooled without any direct contact with wet surfaces. The conditioned air is thereby cooled without the addition of moisture to the air stream. This technology is generally known as indirect evaporative cooling (Bruno, 2008; Daou et al., 2006).

Figure 28 below shows schematically a simple single pass example of indirect evaporative cooling. It comprises of a number of chambers separated by a heat conductor plate. In one chamber, water is sprayed in the secondary air stream which is cooled by direct evaporative cooling. The primary air is passed through a heat exchanger, generally in the form of cooling fins closely coupled to the secondary chambers transferring its heat to the secondary air through the separating plate, thus realising the indirect evaporative cooling. The cool, dry primary air is used to cool the space and the warmer, humid wet secondary air is dumped into the environment (Daou et al., 2006). The warm water is generally waste but could be recycled through a heat rejection unit or used for other purposes.
In relatively more humid climates, the IEC would be the better choice over DEC since it enables a sensible cooling without adding moisture into the process air. The sensible cooling of air not only reduces the dry bulb temperature, but also its wet bulb temperature (Bruno, 2008, 2009). It also allows the use of reduced air volume in comparison with what would be required in direct desiccant cooling (Daou et al., 2006). It should be clarified here that the inside humidity levels will be equivalent to the ambient conditions, therefore these must be within the acceptable limits of the conditioned space or additional measures must be taken to control this. IEC also suffers similar efficiency limitations as DEC in humid conditions.

C.2 IEC – Counter flow heat exchanger

The extent to which a particular cooler can approach the wet bulb temperature is its "wet bulb effectiveness". A well-made direct evaporative cooler will have an effectiveness of approximately 85% (Bruno, 2008, 2009). A simple single pass
indirect evaporative cooler would be inferior to this due to losses in the heat exchange medium (Daou et al., 2006).

Equation 1 below illustrates how a direct or indirect single pass evaporative cooler is limited in its cooling ability by the wet bulb temperature.

\[
\text{Wet Bulb Effectiveness} = \frac{\text{Temperature drop}}{\text{Maximum temperature drop}} = \frac{T_{\text{wb, in}} - T_{\text{wb, out}}}{T_{\text{wb, in}} - T_{\text{in}}} \%
\]

**Equation 1 - wet bulb effectiveness - single pass IEC or DEC (Daou et al., 2006)**

This limitation can be overcome with a different configuration of the indirect evaporative cooler. Counter flow heat exchangers use a double pass in adjacent wet and dry air passages. The configuration allows the outgoing air to approach the dew point of the incoming air which is considerably lower than the wet bulb temperature.

![Indirect evaporative cooler schematic diagram - counter flow heat exchanger](image)

**Figure 29 - Indirect evaporative cooler schematic diagram - counter flow heat exchanger (Bruno, 2008, 2009)**

In a counter flow heat exchanger, a proportion of the air which has been heat exchanged to a lower temperature is returned along the wet channel as illustrated
schematically in Figure 29 above. Since the air returned has a depressed wet bulb temperature, evaporation on the wet surfaces of the wet channel will produce temperatures approaching the now lower wet bulb temperature. This significantly lower temperature then further intensifies the heat exchange to the dry channel, further reducing the wet bulb temperature of the proportion returned to the wet channel. The cooling process is represented on a psychrometric chart in Figure 30 below.

**Figure 30 - Psychrometric chart – Indirect evaporative cooling (Bruno, 2008)**

This process continues throughout the heat exchanger matrix continually intensifying the heat exchange and evaporation processes until the exit temperatures start to approach the dew point of the incoming air. (Bruno, 2008, 2009). This process therefore potentially increases the wet bulb Effectiveness above 100% as per Equation 2 above where the $T_{wb,in}$ is replaced by the lower $T_{wb, out}$.

$$\text{Wet Bulb Effectiveness} = \frac{\text{Temperature drop}}{\text{Maximum temperature drop}} = \frac{T_{db,in} - T_{db,air}}{T_{db,in} - T_{wb, out}} \%$$

**Equation 2 - wet bulb effectiveness – counter flow heat exchanger IEC**
Appendix D: Solar driven adsorption chiller process description

Continuous adsorption processes are generally realised in two main chambers containing the adsorbate material which are connected by an evaporator and condenser. In these cycles, a quasi-continuous operation, these two compartments are operated in parallel and their functions are exchanged through four stages. The four process chambers are connected to each other by internal, automatically functioning steam valves. These valves influence the directional flow of the evaporated coolant into adsorber chamber 1 or 2 and the condenser, depending on the phase of the process (Henning, 2007; Dieng and Wang, 2001; Sortech, 2010). This process will be described below.

D.1 Phase 1

Ref Figure 31

Hot water from the solar collector or alternate heat source is connected to chamber 1 such that desorption takes place to regenerate the adsorbent. The coolant which has accumulated on the inner surface of the adsorbent is expelled as vapour and it rises up into the condenser. The condenser is connected to a heat rejection unit which cools it allowing the coolant to returns to liquid form. The now cooled liquid falls to the evaporator where the heat from the return or fresh air causes it to evaporate at low pressure into chamber 2 which is currently the adsorber. Here the coolant adheres to the adsorbent extracting the heat from the coolant (enthalpy of evaporation). The heat is removed through the re-cooling circuit (Henning, 2007; Dieng and Wang, 2001; Osbourne and Kohlenbach, 2011a; Sortech, 2010).
D.2 Phase 2

Ref Figure 32

Phase 2 represents the stage where the sorbent in chamber 1 has been completely regenerated and the sorbent in chamber 2 has become saturated. The driving heat source is then switched onto chamber 2 and this then becomes the desorber. The re-cooling is now connected to chamber 1 and it is the adsorber (Henning, 2007; Dieng and Wang, 2001; Osbourne and Kohlenbach, 2011a; Sortech, 2010).

Figure 32 - Phase 2: Switching phase 1 (Osbourne and Kohlenbach, 2011a)
D.3 Phase 3

Ref Figure 33

In phase 3 the process from phase 1 is repeated except the functions of the chambers are interchanged such that chamber 1 is now the desorber and chamber 2 the adsorber (Henning, 2007; Dieng and Wang, 2001; Osbourne and Kohlenbach, 2011a; Sortech, 2010).

![Figure 33 - Phase 3: Chamber 1 = Adsorber, Chamber 2 = Desorber (Osbourne and Kohlenbach, 2011a)](image)

D.4 Phase 4

Ref Figure 34

Phase 4 represents the second stage where the system returns back to the original configuration. The sorbent in chamber 1 has become saturated and the sorbent in chamber 2 has been completely regenerated. The driving heat source is then switched onto chamber 1 and this then becomes the desorber. The re-cooling is now connected to chamber 2 and it is the adsorber. The process now continues in phase 1 (Henning, 2007; Dieng and Wang, 2001; Osbourne and Kohlenbach, 2011a; Sortech, 2010).
Figure 34 - Phase 4: Switching phase 2 (Osbourne and Kohlenbach, 2011a)
Appendix E: Solar driven absorption chiller process description

Absorption chillers take advantage of two physical characteristics in order to achieve efficient cooling with reduced energy compared to vapour compression units. First of all it takes less energy to transfer liquids between pressure levels than gases. Secondly, at different pressures, liquids have different evaporating temperatures, thus lowering the pressure on water also reduces its evaporating temperature (Sonneklima, 2011). Absorption chillers can be used with a wide range of heat sources such as waste heat, solar thermal heat, district heat or heat from co-generation plants. The most common sorption pair water–Lithium Bromide is applied for air conditioning purposes where water is the refrigerant and Lithium Bromide the sorbent (Henning, 2007).

The basic construction design applied is a single effect machine. Henning describes this as: “For each unit mass of refrigerant which evaporates in the evaporator one unit mass of refrigerant has to be desorbed from the refrigerant-sorbent solution in the generator. Under normal operating conditions such machines typically need temperatures of the driving heat of 80-100°C and achieve a thermal COP of about 0.7”. At these temperatures cheap solar thermal collectors can be used (Henning, 2007). In the high pressure chambers of the chiller, the refrigerant and solvent are separated as illustrated by vessels 1 and 2 in Figure 35 below. This desorption process is driven in vessel 1 by the high temperature introduced by the heat source (e.g. from solar collectors or waste heat). In vessel 2, the condenser, a heat rejection unit (e.g. wet or dry cooling tower) removes the heat from the water vapour condensing the refrigerant (Sonneklima, 2011).
Figure 35 - Operation principal of an absorption chiller (Sonneklima, 2011)

After condensation, the liquid refrigerant is led into vessel 3, which is the low pressure chamber of the chiller (the evaporator). Here it evaporates at temperatures between 5 and 15°C. The energy for this process is taken from the room return air therefore supplying cool air back to the room as a result (Sonneklima, 2011).

In vessel 4, the absorber, the refrigerant vapour from vessel 3 will be absorbed by the solvent and energy (heat) is released. The solution is then pumped back into the high pressure chamber and the process is restarted (Sonneklima, 2011).

Double effect cycle machines are also available. Two generators working at different temperatures are operated in series, whereby the condenser heat of the refrigerant desorbed from the first generator is used to heat the second generator.
Henning claims the following which was further supported by Osbourne and Kohlenbach (2011a): “With this configuration, a higher thermal COP in the range of 1.1–1.2 is achievable. However, driving temperatures in the range of 140-160°C are typically required for these chillers.” (Henning, 2007).
Appendix F: Solar thermally regenerated desiccant cooling process description

F.1 Pre-cooling and dehumidification for conventional vapour compression air conditioning

Air conditioning loads can be divided into the sensible and the latent loads. In a conventional vapour compression air conditioner, the latent heat load is removed by reducing the process air down below its dew point so the moisture condenses out. The dehumidified air is then reheated to meet the required indoor temperature conditions. Thus, if the latent heat load is removed by other means then the requirement for super cooling and reheating is negated. If the desiccant system is to be fitted to a vapour compression unit without an adjustable evaporator temperature, significant savings will be observed due to the reduced latent load such that the refrigerant returns to the unit at much the same temperature. Further, if the installed system is such that the temperature of evaporation can be adjusted up to 15°C from its generally practiced level of 5°C for the traditional vapour compression system, additional savings can also be realised as the system does not have to drive to this lower temperature in the first place (White, 2011a; Daou et al., 2006).

In humid climates, a desiccant system would be applied to the fresh air supply only if the return air from the building had a minimal latent load. These systems are best applied where an air handling unit is used so this mix can be readily separated or controlled. Figure 36 depicts a two stage desiccant assisted vapour compression system schematically with the desiccant being regenerated by solar thermal energy. As seen, it can be divided into three subsystems, namely the solar thermal subsystem, desiccant subsystem and vapour compression air conditioning subsystem. Being driven by the hot water from the heat collecting subsystem, the desiccant subsystem dehumidifies and cools the ambient fresh air supply. Then
the air is then further cooled by mixing with the processed air from vapour
compression subsystem (Dai et al., 2009).

![Diagram of a two stage desiccant wheel aided vapour compression air conditioning system](image)

**Figure 36 - Schematic of a two stage desiccant wheel aided vapour compression air conditioning system (Dai et al., 2009)**

Further savings could potentially be realised with the addition of an indirect evaporative cooler. A schematic illustration of a desiccant dehumidifier with an evaporative cooler pre-treating a vapour compression system can be seen in Figure 37 below.
The aim of desiccant pre-dehumidifying the air for an evaporative cooling system is to increase the evaporative cooler’s efficiency or increase the number of climates that it can be used in. It also provides a dehumidification process to protect equipment (Daou et al., 2006). This application is commonly employed in and open cycle configuration, most commonly with rotating desiccant wheels equipped either with silica gel or lithium-chloride as the sorption material. Most of the required components are common in buildings and commercial applications for many years (Henning, 2007; Daou et al., 2006) and are therefore well proven.

F.2.1 Standard Cycle

In temperate climates the standard cycle using a desiccant wheel can be employed as illustrated in Figure 38 below by showing a schematic diagram and psychrometric chart of the air properties. With the use of indirect evaporative cooling the application areas are greater still. The points below describe each part

Figure 37 - Schematic of liquid desiccant aided vapour compression air conditioning (Henning, 2007)

1 → 2 sorptive dehumidification of supply air
This is an almost adiabatic process and the air is heated by the adsorption heat and desiccant wheel heated by the regeneration side.

2 → 3 pre-cooling of the supply air
A heat recovery wheel is employed in counter-flow to the return air from the building.

3 → 4 evaporative cooling of the supply air
The diagram illustrates the use of a direct evaporative cooling system to cool the supply air. This process would be used for cheap comfort conditioning of a space. The humidity of the supply air at point 4 could be kept to the same as point 3 with an indirect evaporative cooler.

4 → 5 Pre-heating of supply air
The heating coil is used only in the heating season for pre-heating of air.

5 → 6 fan forcing the air
A small temperature increase is caused by the fan blowing the air into the conditioned space

6 → 7 Cooling of conditioned space
Supply air temperature and humidity are increased by means of internal loads. Again the diagram is based on a comfort conditioning scenario so the humidity in the conditioned space would not likely increase, but the temperature would likely increase more for a telecommunications facility due to the equipment heat dissipation.

7 → 8 cooling of return air
The return air from the building is cooled using evaporative cooling close to the saturation line. IEC may be a better alternative in telecommunications applications or may be able to be removed altogether.
8 → 9 Preheat of return air

Heat is extracted from the supply air to preheat the return air in preparation for desiccant regeneration. This is performed by means of a high efficiency air-to-air heat exchanger, e.g., a heat recovery wheel.

9 → 10 Heat source added

Regeneration heat is provided for instance by means of a solar thermal collector system.

10 → 11 Regeneration

The water bound in the pores of the desiccant material of the dehumidifier wheel is desorbed by the hot air.

11 → 12 Exhaust

Exhaust air is blown to the environment by means of the return air fan.

Figure 38 - Standard desiccant cooling cycle (Henning, 2007)
F.2.2 Enthalpy pre-cooled desiccant cycle

In systems which have to operate in higher humidity climates, an enthalpy exchanger, a rotor which enables total heat exchange, (i.e. exchange of sensible heat and humidity) can be added to the desiccant wheel system. Using this, ambient air component is precooled and pre-dehumidified using the return air from the building. After this, the conventional desiccant cycle can be employed although the added humidity requires higher temperatures to regenerate the desiccant wheel (Henning, 2007).

Figure 39 – Standard desiccant cooling cycle with enthalpy heat exchanger (Henning, 2007)
F.2.3 Standard desiccant cycle with sensible cooling

A solution for very high humidity applications is a desiccant cycle combined with two cooling coils supplied with cold water from a conventional chiller or indirect evaporative coolers in the supply air stream. Either of these units will provide the sensible cooling required. Ambient air is pre-cooled and pre-dehumidified before it enters the desiccant wheel. Since the pre-dehumidification takes place on a high humidity level, high cold water temperatures are sufficient to cool the air below the dew-point. Sorption dehumidification with a desiccant takes place to adjust the supply air according to the desired supply air humidity. Since the air temperature behind the heat recovery unit will still be too high to enter the room directly, another cooling coil is employed which has to cool down the air. This may not be required for indirect evaporative cooling as a single cooler could handle the entire cooling requirement. Figure 40 below illustrates this type of system (Henning, 2007; Bruno, 2008).
F.2.4 Counter flow plate heat exchanger desiccant cooler

The counter flow heat exchanger desiccant cooler takes the principle of the counter flow heat exchanger IEC unit described in section C.2 and adding a desiccant dehumidification step in the overall process (Henning, 2007). The desiccant can be in liquid or solid form.
When utilising liquid desiccant dehumidification, the air leaving the primary dry air channel is concurrently dehumidified through a cross flow contact with the desiccant solution sprayed using nozzles. Since the liquid desiccants can be regenerated at lower temperatures than solid desiccant systems, solar energy and waste heat viable options to drive it (Saman and Alizadeh, 2002; Daou et al., 2006).

**Figure 41 - Counter flow plate heat exchanger desiccant cooler – Liquid Desiccant (Saman and Alizadeh, 2002; Daou et al., 2006)**

For solid desiccant applications, the heat exchanger is divided in primary sorptive dry air (black line in Figure 42, top) and secondary wet cooling channels, which are physically separated but in thermal contact. The sorption material is fixed on the heat exchanger primary dry channels performing dehumidification on the supply air. One exchanger is used in cooling mode while the other is regenerated with a 60-90°C hot air stream (Henning, 2007).
The main difference between these systems and that described in section C.2 is that rather than the primary air being divided between supply air and the secondary wet channel, the return air from the conditioned space was used as secondary air to improve the secondary side performance.
Appendix G: Natural (Free) Convection process description

Free convection as described by Darwiche and Shaik (2008) can be designed such that it "does not require a power source because it functions on natural convection and energy storage capacity. This system consists of housings with insulation, sunshade, external and internal heat exchangers, heat storage tank and conveyance of the medium (mainly water), which must be designed for the specific application. The heat dissipated by the electronic equipment is absorbed by the internal heat exchanger and transferred to the water inside the tank by thermosiphon if the temperature differentials are sufficient." In non-ideal conditions a pump can be utilised to assist the flow. At night, heat is dissipated by thermosiphon to the outside atmosphere (Darwiche and Shaik, 2008).

In places without guaranteed large day/night temperature differentials, some manufacturers have added small pumps, to help the free convection. In instances where the difference in temperature between the shelter and the outside temperature is not sufficient to invoke natural convection, these pumps work to circulate the fluid between the heat exchangers (Darwiche and Shaik, 2008).
Figure 43 - Free convection passive cooling during the day and night (Darwiche and Shaik, 2008)
Appendix H: Solar cooling design tools

The following are links to simplified and more complex HVAC design tools which incorporate calculation for solar cooling. No comment or recommendation is implied as it is only meant as a reference for available tools at the time of publishing for the reader’s reference.

H.1 Simplified Design Tools

SHC Software tool (NGEST Project)

SACE
http://www.solair-project.eu/218.0.html#c1010

H.2 Complete System Modelling Tools

Colsim5
http://www.colsim.de

Energy Plus
http://apps1.eere.energy.gov/buildings/energyplus/
Appendix I: List of manufacturers and consultants

Table 18 - Flat plate and evacuated tube solar collectors (Osbourne and Kohlenbach, 2011a)

<table>
<thead>
<tr>
<th>Type</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuated tube</td>
<td>Endless Solar/Hill solar</td>
</tr>
<tr>
<td>Evacuated tube</td>
<td>Apricus</td>
</tr>
<tr>
<td>Evacuated tube</td>
<td>Urban Energy/Sundra</td>
</tr>
<tr>
<td>Evacuated tube</td>
<td>Greenland</td>
</tr>
<tr>
<td>Evacuated tube</td>
<td>Solar Lord</td>
</tr>
<tr>
<td>Flat Plate</td>
<td>Edwards</td>
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<td>Flat Plate</td>
<td>Conergy</td>
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<tr>
<td>Flat Plate</td>
<td>Rheem</td>
</tr>
<tr>
<td>Flat Plate</td>
<td>Solar Energy GmbH (SEG)</td>
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<tr>
<td>Flat Plate</td>
<td>Schueco</td>
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</table>

Table 19 - Desiccant wheel/cassette manufacturers and licensees (Wurm et al., 2002)

<table>
<thead>
<tr>
<th>Company</th>
<th>Country of Origin</th>
<th>Desiccant</th>
<th>Wheel Size</th>
<th>Disposition</th>
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</thead>
<tbody>
<tr>
<td>Muners USA</td>
<td>US</td>
<td>SiGel, AlTi Silicates, New Proprietary</td>
<td>0.25 – 4.5 m</td>
<td>Own use</td>
</tr>
<tr>
<td>Muners AB</td>
<td>Sweden</td>
<td>SiGel, AlTi Silicates, New Proprietary</td>
<td>0.25 – 4.5 m</td>
<td>Own use</td>
</tr>
<tr>
<td>Seibu Giken</td>
<td>Japan</td>
<td>SiGel, AlTi Silicates, New Proprietary</td>
<td>0.1 – 6 m</td>
<td>Own use, export: US, South America and Europe</td>
</tr>
<tr>
<td>Nichias</td>
<td>Japan</td>
<td>SiGel, Mol. Sieves</td>
<td>0.1 – 4 m</td>
<td>Export</td>
</tr>
<tr>
<td>DRI</td>
<td>India</td>
<td>SiGel, Mol. Sieves</td>
<td>0.3 – 4 m</td>
<td>Own use, Export</td>
</tr>
<tr>
<td>Klingenburg</td>
<td>Germany</td>
<td>Al oxide, LICI</td>
<td>0.6 – 5 m</td>
<td>Export, to OEMs</td>
</tr>
<tr>
<td>ProFlute</td>
<td>Sweden</td>
<td>SiGel, Mol. Sieves</td>
<td>0.5 – 3 m</td>
<td>to OEMs</td>
</tr>
<tr>
<td>By-Air</td>
<td>US</td>
<td>SiGel (pellets)</td>
<td></td>
<td>Own use</td>
</tr>
<tr>
<td>Rotor Source</td>
<td>US</td>
<td>SiGel, Mol. Sieves</td>
<td>0.5 – 3 m</td>
<td>to OEMs</td>
</tr>
<tr>
<td>NovelAire</td>
<td>US</td>
<td>SiGel, Mol. Sieves</td>
<td>0.5 – 3 m</td>
<td>to OEMs</td>
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</tbody>
</table>
Table 20 - Concentrating solar collectors manufacturers (Osbourne and Kohlenbach, 2011a)

<table>
<thead>
<tr>
<th></th>
<th>Manufacturer</th>
<th>Country</th>
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<td>1</td>
<td>IST/Abengoa</td>
<td>Spain</td>
</tr>
<tr>
<td>2</td>
<td>Solitem</td>
<td>Turkey</td>
</tr>
<tr>
<td>3</td>
<td>NEP Solar</td>
<td>Australia</td>
</tr>
<tr>
<td>4</td>
<td>Sopogy</td>
<td>USA</td>
</tr>
<tr>
<td>5</td>
<td>Solarlite</td>
<td>Germany</td>
</tr>
<tr>
<td>6</td>
<td>Mirroxx1</td>
<td>Germany</td>
</tr>
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</table>
### Table 21 - Chiller suppliers and manufacturers (Osbourne and Kohlenbach, 2011a)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Process/Working pair</th>
<th>Capacity [kW]</th>
<th>Driving heat source</th>
<th>Product name</th>
<th>Driving heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGO</td>
<td>1-1 Water-NH3</td>
<td>50</td>
<td>Hot water</td>
<td>cogelco</td>
<td>115 degC</td>
</tr>
<tr>
<td>BROAD</td>
<td>2-D LIR-water</td>
<td>233-11,630</td>
<td>Gas/oil</td>
<td>BYZ</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2-1 233-11,630</td>
<td>Steam</td>
<td>BYZ</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 233-11,630</td>
<td>Hot water</td>
<td>BHE (BHE)</td>
<td>180 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 233-11,630</td>
<td>Excess gas</td>
<td>RE</td>
<td>600 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 233-11,630</td>
<td>Steam</td>
<td>BYDG</td>
<td>0.1 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 209-1,138</td>
<td>Hot water</td>
<td>BYPD</td>
<td>98 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 233-11,630</td>
<td>Excess gas</td>
<td>BYDE</td>
<td>300 degC</td>
<td></td>
</tr>
<tr>
<td>Carrier</td>
<td>2-D LIR-water</td>
<td>362.274</td>
<td>Gas/oil</td>
<td>TASA-18K</td>
<td>620 degC</td>
</tr>
<tr>
<td>(ex Sanyo, McQuay)</td>
<td></td>
<td>345-4,662</td>
<td>Steam</td>
<td>TASA-16K</td>
<td>0.78 MPa</td>
</tr>
<tr>
<td></td>
<td>1-1 264-1,846</td>
<td>Steam</td>
<td>TASA-16K</td>
<td>96 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 263-3,481</td>
<td>Steam</td>
<td>TASA-14K</td>
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<td></td>
</tr>
<tr>
<td>Century</td>
<td>2-D LIR-water</td>
<td>70-5278</td>
<td>Gas/oil</td>
<td>AR-F</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2-1 246-1,800</td>
<td>Steam</td>
<td>AR-W</td>
<td>9.8 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 100-2,185</td>
<td>Hot water</td>
<td>AR-D</td>
<td>96 degC</td>
<td></td>
</tr>
<tr>
<td>ClimateWell</td>
<td>1-1 LIR-water</td>
<td>6-20</td>
<td>Hot water</td>
<td>OW 16, OW 20</td>
<td>80 degC</td>
</tr>
<tr>
<td>ColtIrt</td>
<td>1-1 Water-NH3</td>
<td>150-1,500</td>
<td>Hot water</td>
<td>na</td>
<td>120-200 degC</td>
</tr>
<tr>
<td>CAV</td>
<td>1-1 LIR-water</td>
<td>15-200</td>
<td>Hot water</td>
<td>WEGRAKAC</td>
<td>95 degC</td>
</tr>
<tr>
<td>Elara</td>
<td>2-D LIR-water</td>
<td>140-2,462</td>
<td>Gas/oil</td>
<td>RCD/RCP</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2-1 528-2,462</td>
<td>Steam</td>
<td>RCWIFAW</td>
<td>0.78 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 158-1,566</td>
<td>Hot water</td>
<td>RICH</td>
<td>90 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 334-5,134</td>
<td>Steam</td>
<td>16JH</td>
<td>0.04-0.15 MPa</td>
<td></td>
</tr>
<tr>
<td>Energy Concepts LLC</td>
<td>1-1 Water-NH3</td>
<td>50-1,500</td>
<td>Hot water</td>
<td>ThermoSofter, HeatChiller</td>
<td>98 degC</td>
</tr>
<tr>
<td>Inventor</td>
<td>1-1 Zootherm-water</td>
<td>7-10</td>
<td>Hot water</td>
<td>LTCT, HTC10</td>
<td>65-85 degC</td>
</tr>
<tr>
<td>Kawasaki: Thermal Engineering</td>
<td>3-D LIR-water</td>
<td>510.1,196</td>
<td>Gas/oil</td>
<td>Sigma Ace/Midy</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2-D 141.2,462</td>
<td>Steam</td>
<td>Sigma Ace 3.9</td>
<td>0.78 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 282-3,462</td>
<td>Steam</td>
<td>Sigma Ace 12.1-4</td>
<td>120-200 degC</td>
<td></td>
</tr>
<tr>
<td>LS Mtron</td>
<td>2-D LIR-water</td>
<td>352.6,275</td>
<td>Gas/oil</td>
<td>LDF</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-1 352-3,462</td>
<td>Steam</td>
<td>LS-H-S</td>
<td>0.8 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 352-3,813</td>
<td>Hot water</td>
<td>LDF-R</td>
<td>180 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 180-3,978</td>
<td>Hot water</td>
<td>LHV-W</td>
<td>95 degC</td>
<td></td>
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<tr>
<td>Misties</td>
<td>1-1 Water-NH3</td>
<td>80-3,000</td>
<td>Steam</td>
<td>AK</td>
<td>0.5 MPa</td>
</tr>
<tr>
<td>Mayekawa, Mycom SA</td>
<td>1-1 Silicap-water</td>
<td>50-350</td>
<td>Hot water</td>
<td>ADR</td>
<td>75 degC</td>
</tr>
<tr>
<td>Neiboyko</td>
<td>1-1 Silicap-water</td>
<td>88-468</td>
<td>Hot water</td>
<td>RHE</td>
<td>90 degC</td>
</tr>
<tr>
<td>Pink</td>
<td>1-1 Water-NH3</td>
<td>11-15</td>
<td>Hot water</td>
<td>PEC 12</td>
<td>85 degC</td>
</tr>
<tr>
<td>Robur</td>
<td>1-1 Water-NH3</td>
<td>11-88</td>
<td>Gas</td>
<td>ACF-RTCF</td>
<td>-</td>
</tr>
<tr>
<td>Shuangjiang</td>
<td>1-1 Water-NH3</td>
<td>290-2,480</td>
<td>Hot water</td>
<td>XH</td>
<td>300 degC</td>
</tr>
<tr>
<td></td>
<td>2-1 350-3,650</td>
<td>Hot water</td>
<td>HSC, HS 55</td>
<td>130 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 350-4,900</td>
<td>Steam</td>
<td>SS</td>
<td>0.1 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 350-4,650</td>
<td>Hot water</td>
<td>HSA</td>
<td>130 degC</td>
<td></td>
</tr>
<tr>
<td>Solarcon</td>
<td>1-1 Water-NH3</td>
<td>25-40</td>
<td>Hot water</td>
<td>AAC</td>
<td>95 degC</td>
</tr>
<tr>
<td>SunTech</td>
<td>1-1 Zeritha-water, 58, 515</td>
<td>6.15</td>
<td>Hot water</td>
<td>ASCB, ATC15</td>
<td>75-85 degC</td>
</tr>
<tr>
<td>TransThermal</td>
<td>2-D LIR-water</td>
<td>390-3,893</td>
<td>Gas/oil</td>
<td>Ecohill</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2-1 390-5,925</td>
<td>Steam</td>
<td>BK-ED</td>
<td>0.78 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 390-5,825</td>
<td>Hot water</td>
<td>BK-SD</td>
<td>180 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-1 417-1,398</td>
<td>Steam</td>
<td>BK-4</td>
<td>0.1 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 70-220</td>
<td>Hot water</td>
<td>CoGenie</td>
<td>90 degC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 701-343</td>
<td>Hot water</td>
<td>ProCH</td>
<td>90 degC</td>
<td></td>
</tr>
<tr>
<td>Yazaki</td>
<td>2-D LIR-water</td>
<td>105-700</td>
<td>Gas</td>
<td>CHJ-CH-MG</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-1 18-106</td>
<td>Hot water</td>
<td>WPC-SC</td>
<td>90 degC</td>
<td></td>
</tr>
<tr>
<td>York Johnson Controls</td>
<td>2-D LIR-water</td>
<td>70-3,372</td>
<td>Gas/oil</td>
<td>VPC-A</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1-1 250-3,373</td>
<td>Steam</td>
<td>VPC-2</td>
<td>0.8 MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 420-4,842</td>
<td>Steam</td>
<td>Y-9ST</td>
<td>90 kPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1-1 420-4,842</td>
<td>Hot water</td>
<td>YIA-I-HW</td>
<td>130 degC</td>
<td></td>
</tr>
</tbody>
</table>
### Table 22 - Small scale chiller manufacturers (Osbourne and Kohlenbach, 2011a)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product name</th>
<th>Distributors</th>
<th>Sorbent</th>
<th>Refrigerant</th>
<th>Nominal Cooling capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climatrontell (S)</td>
<td>CW 20</td>
<td>Ultimate well, Sonnenkraft</td>
<td>LiCl/LiNO₃</td>
<td>6 kW</td>
<td></td>
</tr>
<tr>
<td>SorTech AB (GER) *</td>
<td>STC08</td>
<td>SolarNext (retail), SorTech (wholesale)</td>
<td>LiCl/LiNO₃</td>
<td>8.5 kW</td>
<td></td>
</tr>
<tr>
<td>ARKM (GFR)</td>
<td>Suninverse</td>
<td>Sonnenklima</td>
<td>LiBr/H₂O</td>
<td>10 kW</td>
<td></td>
</tr>
<tr>
<td>Fisk (AUS) *</td>
<td>Chilli PSC 12</td>
<td>SolarNext</td>
<td>H₂O/NaOH</td>
<td>10 kW</td>
<td></td>
</tr>
<tr>
<td>Inversor (GER) *</td>
<td>ISC 10</td>
<td>SolarNext (retail), Inversor (wholesale)</td>
<td>ZnCl₂/H₂O</td>
<td>10 kW</td>
<td></td>
</tr>
<tr>
<td>Evl (GER)</td>
<td>Viegasod Ste 15</td>
<td>BAW, SolarNext Solution</td>
<td>LiBr/H₂O</td>
<td>15 kW</td>
<td></td>
</tr>
<tr>
<td>SorTech AB (GER) *</td>
<td>STC015</td>
<td>SolarNext (retail), SorTech (wholesale)</td>
<td>LiCl/LiNO₃</td>
<td>15 kW</td>
<td></td>
</tr>
<tr>
<td>Yazali Energy (J) *</td>
<td>WFC S65, WFC LB</td>
<td>Yazali Europe, Sonnenkraft, Von SolarNext</td>
<td>LiBr/H₂O</td>
<td>17.5 kW</td>
<td></td>
</tr>
<tr>
<td>Thermax (IND) *</td>
<td>LT 05</td>
<td>Thermax</td>
<td>LiBr/H₂O</td>
<td>17.5 kW</td>
<td></td>
</tr>
<tr>
<td>Rotherd *</td>
<td>n.a</td>
<td>Rotherd</td>
<td>H₂O/NaOH</td>
<td>17 kW</td>
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</tbody>
</table>

### Table 23 - Heat rejection suppliers (Osbourne and Kohlenbach, 2011a)

<table>
<thead>
<tr>
<th>Heat Exchanger Type</th>
<th>Nominal Thermal Capacity (kW)</th>
<th>Internal Flow Rate (l/min)</th>
<th>Mean Outdoor Temperature (°C)</th>
<th>Air Volume Flow (m³/h)</th>
<th>Electricity Consumption (kWh/yr)</th>
<th>Heat Exchange Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation Towers</td>
<td>35</td>
<td>500</td>
<td>32.26</td>
<td>7.21</td>
<td>0.03</td>
<td>320</td>
</tr>
<tr>
<td>Dry Air Coolers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAT ASHRAE 1000</td>
<td>25</td>
<td>300</td>
<td>35.27</td>
<td>25</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>ASHRAE 1000</td>
<td>25</td>
<td>300</td>
<td>35.27</td>
<td>25</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>Queensland</td>
<td>20.5</td>
<td>500</td>
<td>45.40</td>
<td>32</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>Queensland</td>
<td>20.5</td>
<td>500</td>
<td>45.40</td>
<td>32</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>Central</td>
<td>30</td>
<td>500</td>
<td>43.56</td>
<td>30</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>Central</td>
<td>30</td>
<td>500</td>
<td>43.56</td>
<td>30</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>Hybrid Coolers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRYTECH</td>
<td>20</td>
<td>300</td>
<td>31.927</td>
<td>24</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>DRYTECH</td>
<td>20</td>
<td>300</td>
<td>31.927</td>
<td>24</td>
<td>0.03</td>
<td>120</td>
</tr>
<tr>
<td>DRYTECH</td>
<td>20</td>
<td>300</td>
<td>31.927</td>
<td>24</td>
<td>0.03</td>
<td>120</td>
</tr>
</tbody>
</table>
Table 24 - System integrators (Osbourne and Kohlenbach, 2011a)

1. Simons Green Energy Solutions (NSW) - SorTech AG chillers
2. Ecokinetics (QLD) – Climatwell chillers
3. Urban Energy (VIC) – InverSor chillers
4. ECS (NSW) – BROAD chillers
5. IPS Australia (NSW) – Solitem system
6. Air Solutions (VIC) – Thermax chillers
7. Coolgaia (QLD) – InvenSor chillers
8. CSIRO (NSW) – Desiccant systems
9. Bright Generation (WA) – Desiccant systems
10. Endless Solar (NSW) – Ejector system
Appendix J: Heat rejection technologies

All thermally driven chillers require powerful and efficient re-cooling of both the driving energy supplied and the cooling energy “generated.” This can be performed by a number of different methods which each have their advantages and disadvantages. The three main and most well established methods for re-cooling are a wet cooling tower, dry air re-coolers and hybrid re-coolers (Sortech, 2010; Koller et al., 2009). The lesser utilised geothermal exchanger is also reviewed here but its scope for use is less than the other methods in Australia due to different soil temperatures.

J.1 Dry cooling tower

A dry cooling tower consists of a cooling fan and air to liquid heat exchanger. The liquid transfers the heat from the heat rejection circuit and through the exchanger to be cooled. Here, the heat that is generated is released to the surrounding area at the middle temperature level. Dry re-coolers can be designed to meet the special requirements of adsorption chillers but cannot cool below ambient dry bulb temperature. However, they can also be fitted with fresh water sprinklers to add cooling capacity when the external temperatures are too high to obtain the required re-cooling temperature drops. Generally, these coolers are more efficient Air-conditioning Technology Review and Decision Aid for Australian Telecommunications Sites
expensive per Watt of cooling power than a wet cooling tower and cheaper than a hybrid. They are also the highest energy consumers of the three (Koller et al., 2009; Osbourne and Kohlenbach, 2011a; Sortech, 2010).

J.2 Open wet cooling tower

This series of re-coolers features a fresh water sprinkler system and rotation speed-controlled EC fans. Cooling is possible below the dry bulb temperature as near saturation evaporative cooling is performed. These coolers are the most economically efficient with a significantly lower capital expenditure in the first place. However, operational costs can be extensive to control legionella especially at remote unmanned sites (Koller et al., 2009; Osbourne and Kohlenbach, 2011a; Sortech, 2010).

![Diagram of Open Wet Cooling Tower]

Figure 45 - Open Wet Cooling Tower (Koller et al., 2009; Osbourne and Kohlenbach, 2011a)

J.3 Hybrid cooling towers

Hybrid cooling towers are a combination of dry and wet cooling towers. In most operating conditions the tower acts essentially as a dry air cooler. However, during extreme heat the wet cooling cycle can be invoked as illustrated in Figure 46 below, which is more expensive but much more effective than a small sprinkler...
system over a normal dry cooling tower. Whilst it can achieve cooling approaching the effectiveness of a wet cooling tower, legionella can also be easily controlled (Osbourne and Kohlenbach, 2011a).

1. primary cooling circuit
2. inlet flow
3. finned tube heat exchanger
4. return flow
5. heat source
6. circulating pump
7. deluging water circuit
8. make up water inlet
9. water collector
10. bleed off
11. cooling air
12. fan
13. fan drive

Figure 46 - Hybrid cooling tower (Koller et al., 2009; Osbourne and Kohlenbach, 2011a)

Since fresh water is sprinkled only periodically, a permanent liquid film cannot develop on the lamellae. Further, build-up in the pipework and tank system can be prevented with periodic draining and temperature surveillance. The danger of microbial growth is thus effectively prevented (Sortech, 2010).
J.4 Geothermal heat exchanger

Geothermal heat exchangers take advantage of the ground’s constant temperatures and ability to consistently transfer energy. The heat exchange pipes can be installed in a horizontal configuration as pictured in Figure 47 above or vertically (Osbourne and Kohlenbach, 2011a).

Horizontal ground heat exchangers are buried at a depth between 0.5 to 2 m into the ground. They can achieve cooling capacities of 10 W/m² of soil surface for dry solid soil, 20 to 30 W/m² in moist solid soil or 40 W/m² for a water saturated soil. Typical run lengths are a horizontal distance of 50 m in moist soil and about 80 m in dry soil (Osbourne and Kohlenbach, 2011a).

Vertical boreholes take advantage of the even more constant temperatures found deeper down. Below 15 m depth the soil temperature is constant within 10°C over
the season and temperature increases only 1°C with every 30 m increase. Cooling capacities of 30 W/m in dry soil, 55 W/m in schist and similar stone, 80 W/m in solid rock and 100 W/m in a soil with significant ground water flow can be expected. Further, a minimum distance of 5 m is recommended between two or more boreholes (Osbourne and Kohlenbach, 2011a).
Appendix K: Solar collector technologies

![Solar collector types](image)

Figure 48 - The three most common solar thermal collectors for solar cooling (Osbourne and Kohlenbach, 2011a)

The success of solar cooling is strongly dependent on the availability of low cost and high performance of solar collectors. Choosing the right solar collector is largely dependent on application but also on price. The most common collector types are listed below roughly in cost and performance order, but discussion on the relative advantages and disadvantages of each of these technologies is beyond the scope of this paper. It must be considered that the choice of solar collector is usually strongly dependant on the cooler technology chosen as illustrated in Figure 49 below (Henning, 2007; Osbourne and Kohlenbach, 2011b, 2011a).

The solar technologies considered relevant are:

- flat plate collectors
- evacuated tubes
- stationary non-imaging concentrating collectors such as CPC
- dish type concentrating collectors
- linear focusing concentrators

(Henning, 2007).
Figure 50 further emphasizes the point that the collector must be matched to the application. A higher performance and also priced collector will not increase your system’s performance significantly once over its design temperature e.g. there’s no point in paying extra money for a 100°C evacuated tube collector when a cheaper 75°C flat plate collector will result in similar performance (Osbourne and Kohlenbach, 2011a).

Figure 50 - COP-curves of sorption chillers and the theoretical upper thermodynamic limit (ideal) (Henning, 2007; Osbourne and Kohlenbach, 2011b, 2011a; White, 2011c).