Hybrid concentrating solar thermal systems for large scale applications

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Executive Summary

This project developed and prototyped a new CSIRO-developed solar air conditioning technology, designed to provide high efficiency, low carbon heating and cooling for Australian commercial buildings. The novel technology has been specifically designed to operate using high temperatures to enable high efficiency operation. This increases the amount of cooling that can be achieved from the collected solar heat or, conversely, a smaller field can be used to provide the same cooling. This potentially represents a significant cost improvement as collector fields are typically a major component of the overall project costs.

This project aimed to verify the technical viability of the high temperature, solar heat driven two stage desiccant air conditioning system. The commercial partner (Stockland group) hosted a demonstration system at the Stockland Wendouree shopping centre in Ballarat, Victoria. A solar collector field and heat storage system was installed by NEP Solar incorporating solar heat collection with parabolic trough collectors, and heat storage in a thermal oil tank.

The chosen air conditioning design consists of two desiccant wheels to provide maximum dehumidification of the process air. A closed loop, solar heat driven, high temperature regeneration air stream is used for moisture removal from one wheel. The other wheel does not use any external heat. Heat cascaded from the high temperature wheel is used for regeneration of the low temperature wheel. As a result of the closed loop regeneration and heat cascading design, the unit is expected to provide higher thermal Coefficient of Performance (COP) compared with a single stage desiccant air conditioning system. This enables a smaller solar field to be used for the same cooling capacity, or alternatively, more cooling can be provided from a given size field.

Solar heat is obtained from concentrating trough collectors capable of providing 70 kW heat at rated conditions. Heat delivered by the collectors is stored in a $2m^3$ thermal oil tank. Collected solar heat is used for providing part of both the air conditioning and space heating needs of the shopping centre. Data shows that the collectors have been providing more than 1 MWh of heat every month and during winter months, more than 50% of heat delivered from the collectors has been used for space heating.

An 1100 m^3/hr air flow (10 kW cooling at rated conditions) two stage desiccant air conditioner was designed by CSIRO for installation on the roof of the Stockland Wendouree shopping centre. The two stage desiccant system functions either in the desiccant cooling mode or in IEC cooling mode based on ambient humidity (>40% RH) and storage tank temperature (> 140°C at top of the tank) set points. Typical desiccant mode operational data shows the performance of the two stage desiccant air conditioning system is as expected, with a mean thermal COP of 0.66 and an electrical COP of 7 in desiccant mode and 10 in IEC mode. There are opportunities to increase the thermal COP to a target COP of 1 through further system optimisation.

This project is a world first demonstration of the viability of a two stage desiccant air conditioning system that utilises high temperature closed loop regeneration for improving the thermal efficiency of the system. The project team estimates the Technology Readiness Level (TRL) of this demonstration to be between TRL3 and TRL4. This technology has significant potential to improve the efficiency of solar heat usage in commercial buildings and reduced the required solar collector area.

Project Overview

Project summary

The main objective of this project is to realise a practical, high temperature, high efficiency solar heat driven desiccant air conditioner. CSIRO, along with partners NEP Solar and the Stockland Group, secured funds from ARENA to demonstrate CSIRO's novel high efficiency solar air conditioning system at a Stockland site powered by NEP's trough solar collectors.

The developed design (Figure 1) consists of two levels of moisture removal of the process air as it moves through a low temperature wheel (state 1 to 2) and a high temperature wheel (state 2 to 3). A closed loop, solar heat driven, high temperature air stream is used for regenerating the high temperature wheel. There is no external heat source used for regeneration of the low temperature wheel. Heat for the low temperature regeneration is provided i) through a heat recovery wheel in the process air stream (state 3 to 4), and ii) heat recovered from the closed loop. As a result of the closed loop regeneration and heat cascading design, the unit is expected to provide a high thermal Coefficient of Performance (COP) (ratio of cooling provided per unit of heat input) compared with a conventional single stage desiccant air conditioning system. Sensible cooling of the process air is achieved when air goes through an Indirect Evaporative Cooler (IEC) (state 4 to 5).

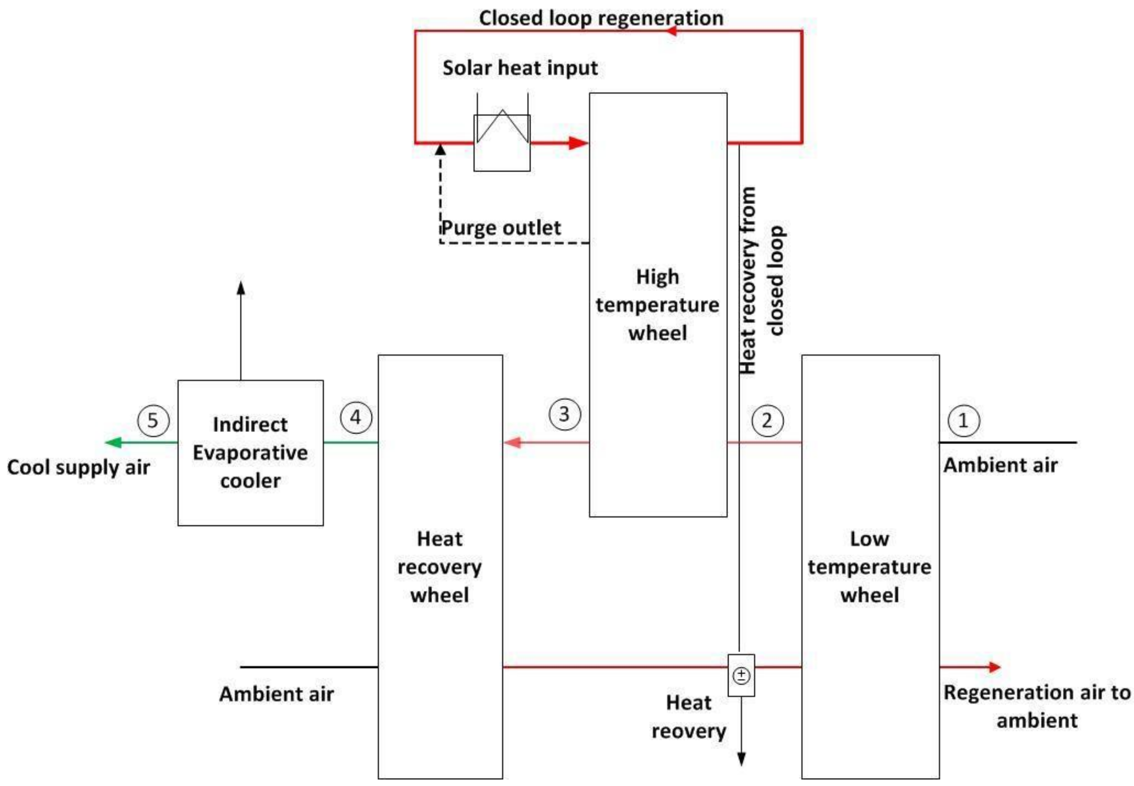

Figure 1 ***Process diagram for two stage desiccant air conditioning system. The system incorporates a heat cascading design for increasing the efficiency of the air conditioning system.***

The project progressed through three distinct tasks as listed in Table 1. The solar heat delivery system installation and commissioning was carried out by NEP Solar along with Stockland (Figure 2). NEP installed parabolic trough collectors capable of delivering 70 kW of heat at rated conditions along with a 2000 litre thermal oil storage tank. This system was integrated with the site space heating system and the solar air conditioning system so that solar heat can be utilised throughout the year.

Desktop design and evaluation of various desiccant air conditioning system concepts were carried out as a part of the second task. A key selection was whether to use superheated steam or moist air as the regeneration medium in the closed high temperature loop. Due to the simplicity of design, air was chosen as the medium for closed loop regeneration. Once the design was complete, an order was placed for building an 1100 cubic meter per hour air flow design, capable of delivering 10 kW cooling at rated conditions.

Table 1. *List of the main tasks carried out as part of the hybrid concentrating solar thermal systems project*

Task	Participants
1) Solar heat delivery system installation and commissioning	NEP Solar, Stockland
2) Two stage desiccant air conditioning system design and order	CSIRO
3) Two stage desiccant system commissioning and overall system performance monitoring	CSIRO, Stockland, NEP Solar

Task three involved commissioning the system at the Stockland Wendouree site (**Figure 3**) and continuous monitoring to understand the performance of the system and the operational benefits of the system. The two stage desiccant system used high temperature heat at 150°C to deliver cooling to the facility. The system delivers cooling using the desiccant wheels, if the process air humidity is above 40% RH. Otherwise, the process air goes through only the indirect evaporative cooler. The novel solar air conditioning system has been operational for the past five months.

Figure 2 Parabolic trough collectors installed on the rooftop of the Stockland facility at Wendouree, Victoria

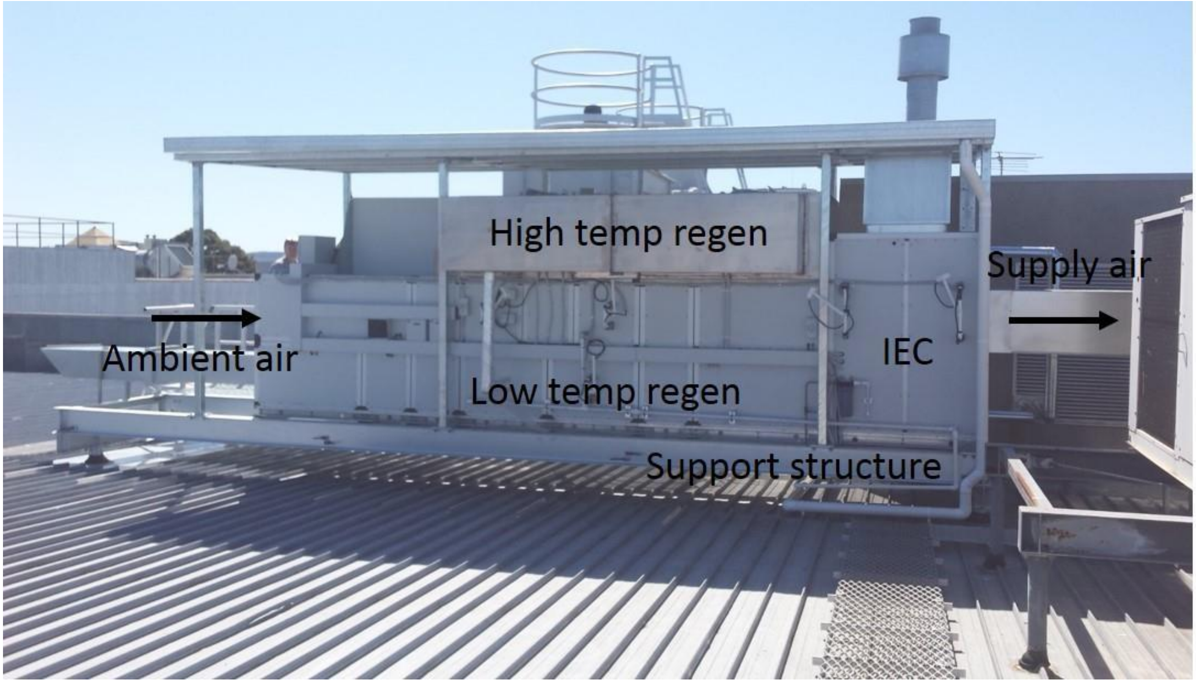

Figure 3 **Two stage desiccant air conditioning system at Stockland Wendouree showing the location of the IEC, and the high and low temperature regeneration paths**

Project scope

Large commercial spaces such as that in shopping centres and hotels have high energy consumption due to their heating and cooling energy requirements. It is estimated that 50-60% of total energy consumption in commercial buildings is for Heating Ventilation and Air Conditioning (HVAC) needs. Roof mounted solar thermal collectors can offset a major part of this energy need by providing heat for winter space heating, hot water requirements and for cooling during summer months. Cooling is achieved through a heat energy assisted air conditioning system. Solar heat driven desiccant air conditioning systems are an attractive option to reduce HVAC electrical demand in commercial buildings due to their simplicity and their ability to provide humidity controlled fresh air into the buildings. Development of a high efficiency solar desiccant air conditioning system is expected to overcome the low efficiency of conventional single wheel systems.

This project is a practical step towards increasing the level of renewable energy that can be deployed in commercial buildings. This new desiccant system design has the potential to reduce the required collector area by 40% compared to a single stage desiccant system, providing valuable roof space that is normally a premium in commercial buildings.

This project has direct alignment with ARENA's investment focus area "renewable energy in residential and commercial buildings". It has resulted in demonstration of an innovative approach to reducing the cost of renewable energy usage in commercial buildings.

Outcomes

This project is the world's first demonstration of the viability of a two stage desiccant air conditioning system that utilises high temperature closed loop regeneration for improving the thermal efficiency of the system. This has been achieved through a partnership between CSIRO, NEP Solar and Stockland. Operational data shows that the system effectively produces heating and air conditioning to the Stockland facility. The installed collectors have delivered over 1MWh of solar heat per month. The desiccant air conditioning system delivered 10 – 12 kW of cooling when operating in the desiccant cooling mode and 5 to 6 kW of cooling when operating in the indirect evaporative cooling mode.

During this period, the unit operated with a mean thermal Coefficient of Performance (COP) of 0.66 and an electrical COP of 7 (desiccant mode), and 10 (IEC mode). The IEC component of the unit has been functioning consistently, providing the expected cooling to the building with wet bulb efficiencies of 80 – 100%.

The air conditioning system operated according to the design. High temperature solar heat delivered to the closed regeneration loop was used for drying the high temperature wheel. The low temperature wheel was regenerated using a regeneration air stream delivering 50-60°C heat without an external heat source. Heat cascaded from the high temperature side, to perform low temperature wheel regeneration, has resulted in higher thermal COP. There is scope for further optimisation of the system that can potentially increase the thermal COP to 1. The concepts developed and evaluated during this design phase have been claimed in an international patent application PCT/AU2015/00202.

Due to the intermittent nature of the solar resource, paying careful attention to the design of the solar heat delivery system is important. As demonstrated in this project, by careful design, a solar thermal system with thermal storage can provide a source of reliable heat into the building for both heating and air conditioning purposes.

Transferability

High efficiency two stage desiccant air conditioning systems are likely to be suitable for large scale commercial buildings that can utilise rooftop solar collectors, or industries that have waste heat or steam available for desiccant regeneration. Thus it is envisaged that these systems will target capacities in the range of 50-100 kW of cooling capacity. The demonstration prototype at Stockland Wendouree is the first demonstration of the technical feasibility of the high temperature, two stage desiccant air conditioning concept and has a rated cooling capacity of 10 kW. This is a proof of concept demonstration and the design can be scaled to higher capacities. Prototype demonstration of this concept provides an opportunity for various stakeholders to visit the site and experience the operation of the system. For example, Echuca regional hospital in Victoria has an operational solar assisted air conditioning system. Representatives from Echuca regional health visited the Stockland site in March 2016 to understand the operation of two stage desiccant air conditioning technology.

Utilising the guidelines provided by ARENA, the project team considers the Technology Readiness level (TRL) of this demonstration at TRL3 or TRL4, incorporating a few elements of TRL5. CSIRO is open to work with commercial partners towards scaling up the prototype and working with a commercial partner regarding licensing and other technology transfer options. The solar thermal system can be integrated into numerous building and industrial processes, where heat up to a temperature level of 250 °C is required. This heat is generally provided by the burning of fossil fuels. Due to the transient nature of the solar resource, the solar system can be applied as a fuel saver or in some cases as a primary heat source with backup from an alternative heat source.

Conclusion and next steps

This project has demonstrated the successful design, integration of high temperature solar heat (150°C to 200°C) and operation of a building space heating and air conditioning system. The project has provided a pathway for realising a world first high efficiency solar thermal desiccant air conditioning system. CSIRO, along with its partners, will continue monitoring the operation of the system over one annual cycle to establish long-term operation of this design. The next activities towards commercialising the technology will involve progressing the technology to TRL6 by engineering an optimal design and collecting long term performance and life cycle assessment data in a relevant environment. CSIRO is seeking commercialisation investment to carry out these investigations and to further optimise the design for realising a thermal COP of 1.

Lessons Learnt

Lessons Learnt Report (A): Integration cost of concentrating collectors for rooftop installations

Project Name: Hybrid concentrating solar thermal systems for large scale applications

Knowledge Category:	Technical
Knowledge Type:	Construction
Technology Type:	Solar Thermal
State/Territory:	Victoria

Key learnings

Installation of trough collectors and the desiccant air conditioner prototype on the roof required adding super structures to the roof to distribute the load onto the existing concrete columns in the roof. Structural consultants were brought in to resolve this problem. This resulted in additional project cost and time.

Implications for future projects

There are potentially significant costs involved with integrating solar systems onto an existing building rooftop. These costs are easily underestimated. Careful selection of the installation site is required. Cost and time associated with structural assessments, building approvals and cost of a super structure should be included, with some contingency in the project plan, to ensure cost-effective installation of heavy solar systems. This assessment could be conducted along with the site solar resource assessment if a system design is well understood.

Knowledge gaps

1. Establishing the suitability of a roof for structurally supporting solar thermal systems (particularly in the initial stages of site assessment when detailed site-specific design is yet to be completed)
2. Standardised mounting accessories for solar collectors with high loads (due to dead weight and more importantly wind load) based on the existing building rooftop types
3. Reducing the overall weight and size of the high temperature desiccant air conditioning system prototype

Background

Objectives or project requirements

Demonstration of the high temperature solar heat assisted air conditioning system required installation of solar collectors onto the roof of the Stockland Wendouree shopping centre. The solar heat delivery system was required to be mounted closer to the air conditioning system to reduce system heat loss and installation cost. These collectors need to be affixed to the building roof to avoid any uplift during high wind periods.

Process undertaken

The host site commissioned a structural consultant to investigate the structural integrity of the existing roof and examine options for collector field placement. This initial assessment indicated that the roof structure could accommodate the solar collectors. Following selection of the solar collectors, the structural consultant appointed by NEP Solar reviewed the collector load details (dead weight, wind load) and the existing building roofing details (roofing sheet, existing rafters, concrete column details) and suggested installing the collectors on a super structure to distribute the load onto existing concrete columns. As a result of this exercise, a super structure was designed and installed on the roof to mount the solar collectors. The cost of the additional structural elements on the roof is significant and accounted for more than 20% of the solar thermal system cost.

Lessons Learnt Report (B): Remote site installation and monitoring

Project Name: Hybrid concentrating solar thermal systems for large scale applications

Knowledge Category:	Logistical
Knowledge Type:	Operation and maintenance
Technology Type:	Solar Thermal
State/Territory:	Victoria

Key learnings

HVAC tradespeople do not have expertise in emerging technologies such as desiccant systems and indirect evaporative coolers. This meant that CSIRO engineers needed to visit the site for initial troubleshooting more often than originally planned. This resulted in additional project cost and time.

Implications for future projects

Commissioning of R&D prototypes and remote monitoring could involve significant efforts in troubleshooting at the client site. Easy access to the site, the availability of local expertise and a contingency margin for additional time and cost should be considered during planning and budgeting stages. Additional system testing at R&D labs and customisation before site installation could also avoid onsite troubleshooting.

Knowledge gaps

1. HVAC contractor training regarding emerging technologies such as the indirect evaporative cooling and desiccant air conditioning may enable more efficient project delivery

Background

Objectives or project requirements

The project aimed to demonstrate a novel solar heat driven air conditioning system at a client site and deliver useful heating and cooling to the building. Project partner (the Stockland Group) identified the shopping centre in Ballarat as the target demonstration site and CSIRO carried out both the design and some small scale desiccant wheel testing at its facilities in Newcastle, NSW. Thus the desiccant system was installed at Ballarat, Victoria, over 1000 km away from the CSIRO site at Newcastle, NSW.

The project required reporting of the summer operation of the system. This required remotely accessing the operation of the desiccant system and carrying out any troubleshooting by CSIRO.

Process undertaken

CSIRO has previous experience working on remote site demonstration projects of this nature and learnings from previous projects have been incorporated in this installation. For example, the CSIRO team added an additional data logger with multiple sensors for monitoring the system performance. CSIRO also enabled remote access to the controller so that any control logic changes can be implemented without a site visit. CSIRO awarded the desiccant air conditioning prototype commissioning contract to a Ballarat based HVAC contractor with significant experience in HVAC system design and installations.

However, system hardware related modifications required site visits by CSIRO engineers to resolve issues related to water flow distribution in the IEC and checking if the installed sensors were functioning correctly.

Some of the site visits and resultant delays could have been avoided if the desiccant air conditioner prototype was fully tested at CSIRO facilities and troubleshooting was carried out before installation at the client site. Unfortunately, time constraints due to the international construction of the prototype required the unit to be shipped to the site directly.

Lessons Learnt Report (C): First prototype construction cost in technology demonstration projects

Project Name: Hybrid concentrating solar thermal systems for large scale applications

Knowledge Category:	Financial
Knowledge Type:	Technology
Technology Type:	Solar Thermal
State/Territory:	Victoria, NSW

Key learnings

CSIRO's desiccant air conditioning system prototype is between TRL3 and TRL4 and has not been built before. As a result, when HVAC contractors were asked to quote for building a prototype, they built significant costs for 'unknown' risks in their quotes. It is recommended that projects include a substantial contingency margin when budgeting for building prototypes that are at early TRL levels (less than TRL5) and requiring a client site installation. This margin should be facilitated by the project financier.

Implications for future projects

When budgeting for client site installation projects that are in early TRL levels, careful consideration of costing is required. R&D organisations can help industry partners early on to address the various component level performance details and ensure adherence to industry standards in the prototype construction.

Knowledge gaps

First time prototype builds require higher levels of technical design competence to overcome knowledge gaps, and higher levels of metering is required to ensure performance is analysed in detail. R&D organisations can provide these additional skills and can document learnings for industry to follow.

Background

Objectives or project requirements

The project aimed to demonstrate a novel solar heat driven air conditioning system at a commercial building rooftop. Due to the commercial site installation of this prototype, CSIRO decided to engage an Australian HVAC industry supplier to build the prototype to ensure a high quality product finish and adherence to industry standards.

Process undertaken

Once the prototype design was ready, CSIRO asked HVAC contractors in Australia to quote for the building of the prototype. Unfortunately Australian industry is quite conservative. Consequently, the quotes received were significantly (200%) higher than estimates, based on component level costs of the system. This appears to be a reflection of unknown risks involved in constructing the prototype. As a result, CSIRO was forced to choose an international supplier with expertise in desiccant systems design. This brought down the prototype construction cost within the project budget. However, when the unit arrived in Australia, a few non-compliant items were found in the prototype (with reference to specific Australian standards). These were identified and rectified before site installation of the prototype.