Exploitation in an unfair world:

Finding attractive markets for solar cooling

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Introduction

With over 700 installations world-wide (Mugnier and Jakob, 2012), solar airconditioning has achieved a level of maturity that demonstrates technical feasibility and greenhouse gas emissions savings, across a wide range of commercial installations. The International Energy Agency Solar Heating and Cooling Technology Roadmap (IEA, 2012) suggests that solar cooling could account for around 17% of world airconditioning by 2050. However, it is yet to be proven if solar airconditioning can be a cost-effective alternative to conventional airconditioning.

In the context of zero energy buildings, cost effectiveness is often compared against solar photovoltaic (PV) power. Otanicar et al., 2012, Kohlenbach and Dennis 2010, Henning 2010, and Ziegler 2011 have all compared solar cooling with solar PV. These studies have found that there is currently no compelling economic advantage for solar thermal cooling. Indeed, the familiarity and the flexibility of solar PV to produce electricity (particularly when space heating or cooling is not required in the shoulder seasons), makes solar PV a somewhat simpler and less risky investment.

It is instructive to consider the relative monetary value of a unit of collected solar heat when it is used for either heating or for cooling. A simple comparison is illustrated in Figure 1. It shows that a single effect absorption or adsorption chiller (COP=0.7) will, in general, *reduce* the relative value of the captured solar heat when that heat is converted into cooling. It would appear that, if the solar cooling application is to add value, then it should be done with a high efficiency

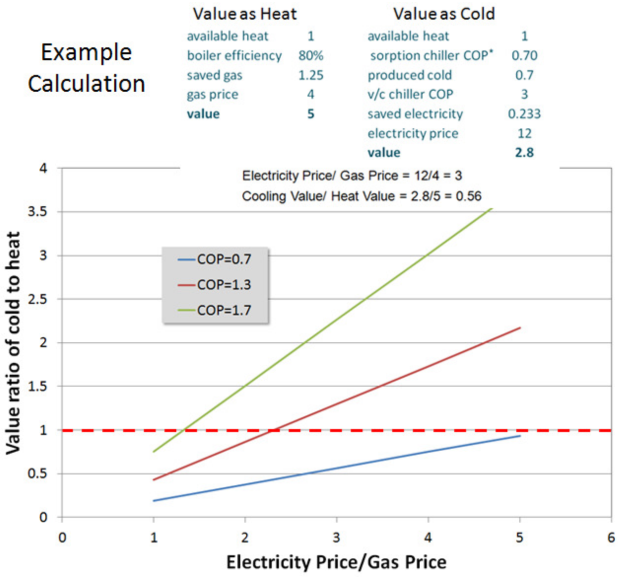

Figure 1: Influence of chiller COP and electricity to gas price ratio, on the relative value of solar cooling compared with solar heating

multi-effect absorption chiller. However, Pietruschka et al (2011) suggest that even this does not necessarily achieve a major improvement in annual primary energy consumption, when taking into account the backup energy needs during those times of the year when solar energy is not available.

These past studies treat solar airconditioning as a stand-alone investment, taking cooling to be the primary purpose/product delivered. As a result, the capital cost of the entire plant is justified against the operating savings from the space heating and cooling application alone, with limited success. An alternative view point is required.

One possibility is to explore niche applications where solar airconditioning has an "unfair" advantage as part of an economically viable larger system solution. In this way it may be possible to gain a "beach-head" market from which installation volumes can be increased, products refined, and costs reduced. The economics of such alternative applications, where solar airconditioning is a complementary but not primary product, have not been systematically analyzed.

This paper explores the potential for solar thermal cooling to succeed commercially, and more specifically, the application scenarios where this is most likely. This mainly philosophical contribution hopes to highlight directions for future research.

Current Solar Airconditioning Commercial Proposition

In the absence of a compelling financial case for stand-alone solar thermal airconditioning, the inclusion of a thermal cooling device may have commercial merit as an auxiliary to what is primarily a solar hot water system. This is illustrated in Figure 2, which compares the amount of heat required for a residential hot water system with the amount of heat that can be collected from a solar hot water system with different collector sizes.

When the cost of heat is high (eg hot water system with electric resistance heater or off-grid), it is advantageous to increase the size of the solar collectors as far as possible, to minimize the amount of fossil energy consumption. However, at some point, this increase in collector area leads to excess heat in the summer months. Inclusion of a thermal cooling device can then be an attractive option for utilizing the available "free" waste heat. The economics for the thermal cooling device become attractive because the solar collectors are paid for by the hot water application.

Further advantages of this approach are the potential for (i) reducing the temperature of the solar collector panels in summer when there is excess solar heat available (and so avoiding stagnation temperatures) and (ii) reducing the peak demand for cooling from a conventional airconditioner.

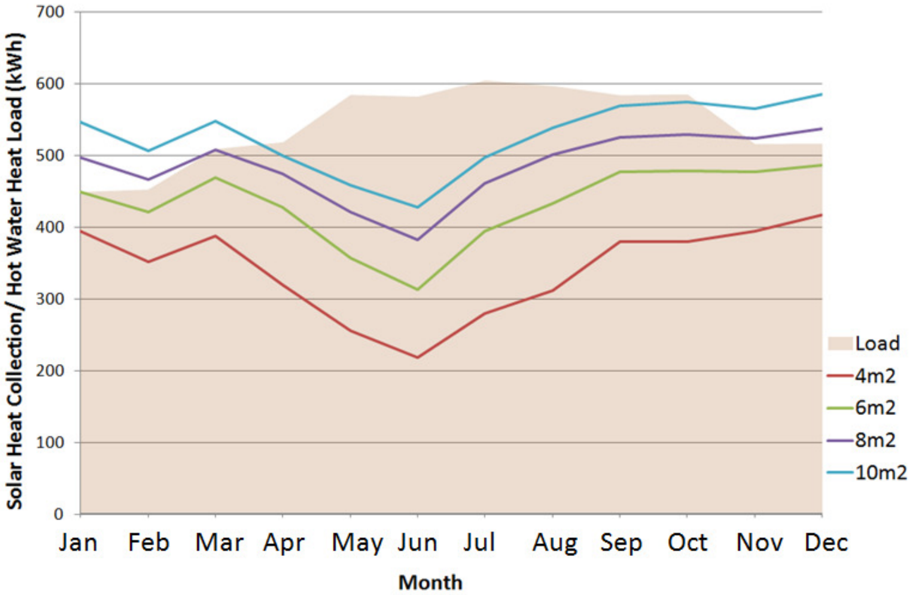

Figure 2: Comparison of monthly residential hot water demand and solar collection by collector area (southern hemisphere)

In warmer climates, airconditioning peak demand is often the primary driver of electricity infrastructure investment costs. To the extent that the solar airconditioning industry can partner with the electricity industry, the economics of this application would be based on (i) solar hot water production as the base economically attractive proposition, coupled with (ii) the additional chiller cost component paid for by electricity infrastructure avoidance rebates.

Interestingly the economics of this application is not based on the performance as a year-round airconditioning device, and a conventional vapour compression airconditioner is not normally avoided. Instead, this application particularly takes advantage of the ability for a solar thermal airconditioner to provide reliable peak demand reduction for the electricity grid (through gas backup or thermal storage), a feature that is not available from solar PV without expensive batteries.

Other Leveraged System-Based Solar Airconditioning Propositions

A number of other applications are potentially available, where solar airconditioning can form part of an integrated system, and where a significant fraction of the system cost is already paid for. Some examples are described below (superficially; noting that each is a research topic in its own right);

Solar assisted trigeneration: Trigeneration systems are becoming more common in Australia where the use of gas-engine based electricity generation, coupled with a waste heat fired absorption chiller, provides a low greenhouse gas emissions

solution relative to the predominantly coal fired electricity network. In this case, an absorption chiller, heat rejection and cold distribution network is already paid for. Consequently, solar airconditioning can be provided for the incremental extra cost of the solar collectors only.

Concentrated solar PV (CPV): A number of concentrated solar PV products are emerging on the market. By concentrating light on to a PV module mounted at the concentrator focal point, it is possible to obtain increased PV electrical conversion efficiency and reduce the size of the solar PV module. In order to manage the increased solar flux, the PV module is cooled. The heat collected from cooling the PV module is potentially available for solar airconditioning. In this case, the solar collectors are paid for by the production of electricity, and solar airconditioning can be provided at the incremental cost of the thermal cooling device and auxiliaries only. While further research is required in order to find the right combination of PV cell and thermal cooling technologies for this application, the application holds the potential for solar thermal and photovoltaic solutions to converge into a single solution, rather than be seen as alternative competing solutions.

Relaxing Performance Requirements

A further opportunity for improving the competitiveness of solar airconditioning is through relaxing target performance requirements in a hybrid solar/ fossil system. Whereas a conventional airconditioning system is required to provide the full comfort solution, it may be possible to divide the task up with a relatively easy task for the solar airconditioner, leaving the remaining (relatively difficult) task for the backup fossil fuel airconditioner. In this way the apparent performance/value of the solar airconditioner can be enhanced.

As an analogy, such an approach is commonplace in the concentrating solar power (CSP) industry when hybridizing solar with fossil fuel thermal power stations. In this case, the solar thermal contribution provides the required low-temperature, low-exergy heat portion, while fossil fuel sources provide the high temperature high-exergy heat. The low and high exergy heats are then valued/ remunerated equally on a first law of thermodynamics basis!

The airconditioning equivalent, in this analogy, is solar desiccant cooling (Figure 3). For summer design case ambient conditions, solar desiccant cooling is typically unable to achieve a complete comfort solution. This is because it is unable to reduce the temperature of the conditioned air low enough to satisfactorily remove all of the sensible heat from the occupied space.

Consequently, desiccant cooling is much better suited to the task of reducing the heat load on a building (by reducing the enthalpy of the ventilation air being provided to the occupied space) rather than doing the complete airconditioning task. In this case, rather than providing high exergy chilled water at ~7°C, it preconditions air at the relatively low exergy cooling temperature of ~20°C.

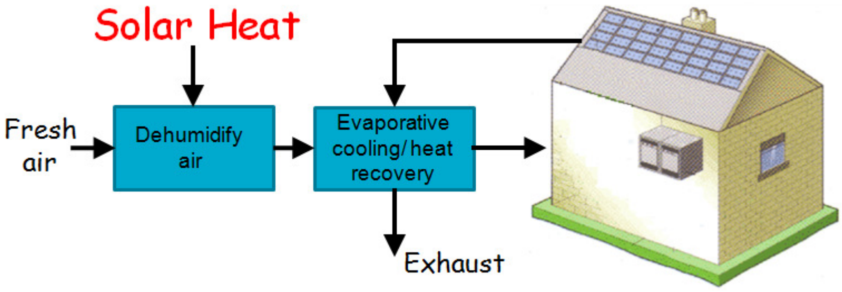

Figure 3: Schematic of the solar desiccant cooling process

Furthermore, desiccant cooling can benefit from passive evaporative and/or heat recovery cooling potential, even when solar heat is unavailable. As a result, it is possible to bypass the desiccant wheel and operate the evaporative cooling/ heat recovery step to provide a partial level of cooling to the building 24 hours a day. This allows for a solution that benefits from the availability of the solar heat that might be available in the peak summer months, but does not rely on solar availability for large parts of the year where the heat is better applied to water heating applications (as illustrated in Figure 2).

TRNSYS modelling of this application was performed for a typical 160m^2 "5 star" residential house in Brisbane Australia. Conduction, radiation and air infiltration heat loads were modelled, along with sensible and latent heat loads due to appliances, cooking, lighting and people applied according to a daily schedule based on a two adult, two child household.

A range of alternative airconditioning approaches were modelled, each with a nominal 10 kW rated cooling capacity. 1) AC: Conventional 10kW vapour compression unit. 2) DEC+GAS+AC: 5kW desiccant cooling system with a backup 5kW vapour-compression air-conditioner, and with gas used in the desiccant cooler as required to maximise comfort. 3) DEC + AC: 5kW solar only desiccant cooling system with a backup 5kW vapour-compression air-conditioner (i.e. no gas backup).

Modelling results are illustrated in Figure 4, as a trade-off between gas and electricity running cost and the hours of discomfort outside of the target temperature and humidity threshold (27°C and 14g/kg). (Note, the temperature criteria alone was generally achieved by all options)

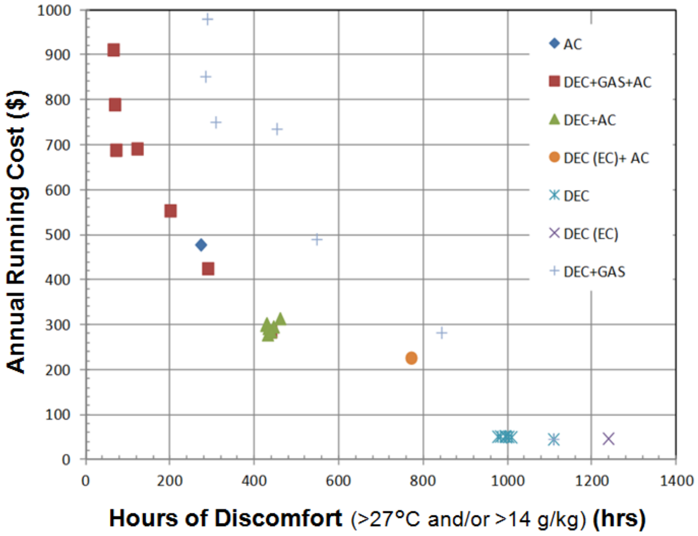

Figure 4: Impact of alternative hybrid cooling solutions on running cost and comfort

This analysis shows that desiccant cooling can improve comfort over the conventional vapour compression airconditioning solution, if heat is always available. However, if gas provides that heat then the running cost is high. When relying on solar heat only, energy consumption (and cost) can be reduced by around 40%. This is achieved predominantly through the indirect evaporative cooling/ heat recovery step of the desiccant cooling process.

Conclusion

In the absence of a compelling financial case for *stand-alone* solar thermal cooling using current technology, the industry must look to more nuanced application-specific solutions where solar airconditioning has an "unfair" advantage. Attractive options proposed in this paper include (i) leveraging existing (paid for) equipment as part of a broader system solution and (ii) relaxing performance criteria for the solar element of a hybrid solution. In this way, it should be possible to gain a "beach-head" market from which installation volumes can be increased, products refined, and costs reduced.

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