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Comparison of mains versus standalone PV electricity to power a residential standalone solar absorption chiller in Australia

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Abstract

This study compares the cost of operating the auxiliary components of an optimised standalone hot water fired absorption chiller, using mains grid electricity and an optimised standalone photovoltaic system. The cheaper source was further compared with using mains electricity to operate a conventional reverse cycle air-air heat pump. Both types of air conditioners were sized to condition the same typical Australian house in three different Australian climate zones. The life-cycle cost of the electrical subsystem was determined for a house located in both a city and for a remote (grid-free) locations; the latter assumed the new connection could sustain the energy and power demands of the air conditioner. The operation and life-cycle costs are determined using TRNSYS 17. The results show that mains electricity attracts a lower cost than an optimised PV system for the chiller case; however, the standalone PV system offers a lower cost than mains, when operating a reverse cycle heat pump air conditioner. Finally, the paper shows that investing in a chiller system is better suited to houses in remote locations and in colder climate zones.

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Keywords: Solar air conditioning; standalone absorption chiller; standalone PV system.

1. Introduction

The use of thermally driven solar absorption chillers offers a potential alternative residential air conditioning option to conventional vapor compression air-air heat pumps. Absorption chillers have two attractive features: (i) they

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consume less electrical energy, which reduces primary energy consumption and subsequent greenhouse gas emissions [1, 2]; and (ii) they have a lower power demand, which in turn reduces the peak demand and ultimately potentially heavy investment required to augment the capacity of electricity infrastructures [3]. However, these two features can depend on the type and the size of the system's main components and how the components are configured and controlled [4]. To date, the majority of previous studies on solar hot water fired absorption chillers have focused on the technical or economic effects of using solar collected thermal energy to reduce the heat energy required by conventional energy sources to operate absorption chillers [1, 4, 5]. However, little attention has been paid to the potential of operating hot water fired chillers purely with heat from the sun. Furthermore, very few studies have sought to quantify the source and costs related to providing the electrical power requirements of such a system configuration, particularly one generated by a standalone photovoltaic system (SPVS).

In our previous study [6], the size of the components used to configure a standalone hot water fired absorption chiller (referred to hereafter as *chiller*) subsystem were optimised to meet the space conditioning demand of a single family house, where the subsystem was only powered by solar heat energy. In that study, the chiller subsystem still required electricity to operate the auxiliary components and the cost of the electricity was included as if it had been obtained from the mains. Conversely, this study focused on the cost of electricity required to operate the auxiliary components, i.e. the electrical subsystem. Specifically, it sought to evaluate the life cycle cost of electricity supplied from either an optimised SPVS or the mains for: a house located either in a city, or remotely. It was assumed that the electricity infrastructure capacity of the remotely located house was limited and that which the householder would need to fund the augmentation required to sustain the operation of the air conditioner, i.e. the peak power demand.

Based on current grid charges and SPVS component costs, the research aimed to determine the cheapest source of electricity to operate the chiller system in three Australian cities with vastly different climatic conditions, i.e. Brisbane, Adelaide and Melbourne. The lower cost electrical subsystem option was then compared to the cost of using mains electricity to operate a reverse cycle air-air heat pump (RC-AA-HP) air conditioner, referred to hereafter as *air conditioner*.

Nomenclature

PV	Photovoltaic
RC-AA-HP	Reverse cycle air-air heat pump
SPVS	Standalone photovoltaic system

2. Research methodology

The chiller and electrical systems configurations are shown in Fig. 1. The chiller thermal subsystem consists of the following main components: solar thermal collectors, a hot water storage tank, a cold water storage tank and an absorption chiller, whilst the auxiliary components included pumps, fans, a dry cooler and controllers. Information about the technical specification of these components and the capacity of the main components are detailed in [6].

The electrical subsystem is assumed to be sized such that it can sufficiently operate the chiller system from the mains or a SPVS. Additional infrastructure requirements were determined from the peak power demand profile over a 12-month period. The SPVS comprised of photovoltaic (PV) panels, a battery bank and an inverter; technical specifications and descriptions of components can be found in [7]. The battery capacity of the SPVS in each climate zone was sized such that it could supply the chiller's electrical energy demand 99.8% of the time.

The previously described system was modeled using TRNSYS 17 software [8] in two stages. First, the operation of the TRNSYS model for the chiller (previously configured in [6]) was simulated for one year in each climate zone using respective optimized components. The electrical energy load profile was printed to an external text file, which was used to size both the mains connection and the SPVS.

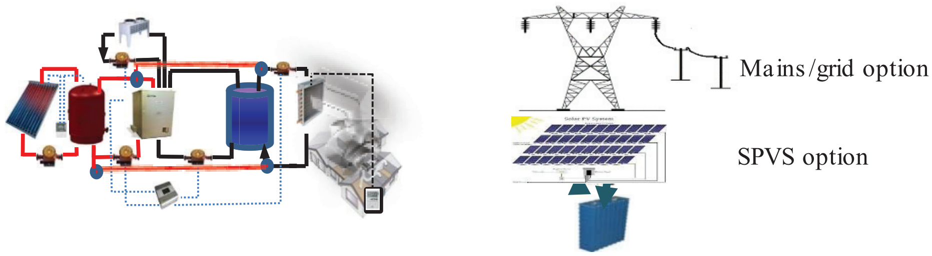

Fig. 1. Simplified schematic diagrams of the (a) chiller, and (b) electrical supply.

The economic criterion used to evaluate the system was the life cycle cost over a 20 year period. All cash flow was discounted by a 7% real interest rate. The SPVS life cycle cost comprised the cost of the battery, the PV panels and the inverter. The parameters used to calculate the cost of the SPVS were identified using recent online retail pricelists and suppliers based mainly in Australia; cost details can be found in [7]. Calculating the life cycle cost of the mains connection required two parameters, firstly the electrical energy charge (AU$/kWh) was required to calculate the discounted 20-year cost of the electrical energy consumption charge. To calculate this cost, the charge assumed was 34 c/kWh in Brisbane, 35c/kWh in Adelaide and 33 c/kWh in Melbourne; these are estimations based on the standing offers found in [9]. Second, the cost of the electricity infrastructure capacity in (AU$/kW) required to sustain the delivery of the maximum peak power demands of the air conditioners. The cost of the full electricity infrastructure, including generation, transmission and distribution, was based on the average long run marginal cost suggested by the productivity commission [10] which estimate the cost to be 325 AU$/kW.Year.

3. Results and discussion

3.1. Chiller operated from Mains electricity scenario

The cost of the mains connection required to reliably operate the chiller, which is to be paid by individual householders, was quantified as the sum of (i) the twenty year discounted cost of electricity consumed, and (ii) the electricity infrastructure capacity cost. The annual electrical energy consumption by the chiller was found to be 1,379 kWh in Brisbane, 842 kWh in Adelaide and 271 kWh in Melbourne. From these annual electrical energy consumption, the twenty year discounted cost of electricity that would need to be purchased from the main grid in each city is presented by the blue columns shown in Fig.2. This figure also shows the cost of the electricity infrastructure capacity in red columns. These are based on the maximum power demand of the chiller which, and were determined from the monitored power demand profile. The maximum power demands were 1.2 kW in Brisbane, 0.8 kW in Adelaide and 0.5 kW in Melbourne.

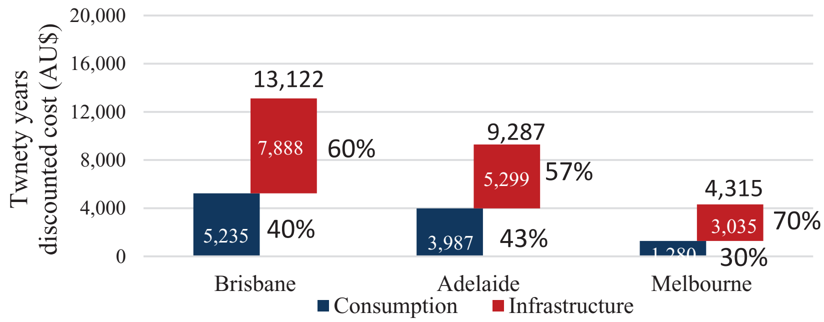

Fig. 2. The 20-year discounted electricity consumption and infrastructure capacity costs, related to chiller operation in three Australian cities.

The costs shown in Fig.2 indicate that for each location, the cost of infrastructure exceeds the operational (energy consumption costs), and that these costs are higher for hotter and more humid climate zones. This signifies the importance of accounting not only for the cost of the energy consumed by an air-conditioner, but also the cost of the infrastructure capacity needed to deliver the maximum power demand. This becomes increasingly important for houses in remote locations and or at the edge of the grid, as the cost of adding or constructing new electrical infrastructure capacity can significantly exceed the cost of the electrical energy consumed by the air-conditioner.

3.2. Chiller operated from Standalone PV system scenario

Table 1 displays the optimal capacity of PV and battery components that attract the least SPVS cost in each city. There is a large disparity in the component capacities for each location, as the minimum required component size for each city was mostly determined by the maximum daily energy demand, the number of consecutive days of high demand and the season in which that demand occurred. The large battery and PV capacity required in Adelaide was due to the high space-cooling demand that occurs during heat waves.

Table 1. The optimal capacities of PV panels and battery banks for configuring the SPVS.

Location	PV (kW_e)	Battery (kWh)
Brisbane	2.5	4.5
Adelaide	3.0	10.0
Melbourne	2.0	5.5

Fig. 3 shows the life cycle cost of the SPVS and a break down of the cost attributed to each of the components summarized in Table 1. The life cycle cost varied in each city, and was the highest in the hot and dry climate zone (Adelaide), whilst the life cycle costs for Melbourne and Brisbane were almost similar, despite proportions of the cost varying. Regardless of this, it is clearly shown that the battery makes up the majority of the cost, due to the assumption that this will be replaced after (an expected life) of 10 years.

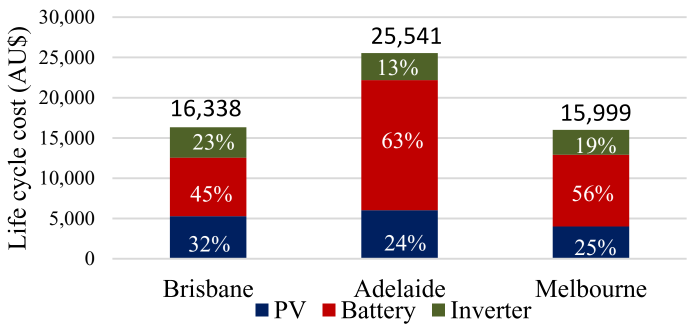

Fig. 3 The 20-year life cycle costs of the optimized SPVS in three Australian cities

3.3. Standalone PV vs. Mains electricity

The above information was used to determine which electricity source offered the lowest cost to operate the auxiliary components of the chiller system. Fig. 2 and Fig. 3 suggest that if a dwelling was located on a site where there is sufficient infrastructure capacity, the householder would only be required to pay for the grid energy consumed, and subsequently purchasing energy from the mains was the lower cost option. This was 24 %, 14 % and 7 % cheaper than the cost of a SPVS in Brisbane, Adelaide and Melbourne, respectively. In addition, if a house was located in a region where the electricity infrastructure capacity was not reachable or was limited (e.g. a remote site or at the edge of the grid), obtaining the electricity from the mains was cheaper than obtaining it from SPVS by 45 % in Brisbane, 27 % in Adelaide and 21 % in Melbourne. Obviously, across all climates, using mains electricity to power the chiller was much cheaper than using the SPVS regardless of whether the house was located in a city or remotely. However, in Brisbane, when the grid infrastructure was not available, the difference between the costs of using the mains and a SPVS were small (and insignificant). These results confirmed that using the SPVS to power the chiller could be deemed almost feasible in hot humid climates where cooling is required for a long period. Given the current trend and future projected decline in battery costs, and expected rising cost of electricity, using a SPVS instead of mains to power the chiller, may become a more attractive option in the near future.

3.4. Reverse cycle heat pump operation from Mains electricity scenario

It was contended that installing a chiller instead of conventional a reverse cycle air conditioner would be feasible if its required mains costs were used as the comparator. To undertake this comparison, the RC-AA-HP was also modeled using TRNSYS, and its cooling capacity was correctly sized to meet the space conditioning demand of the typical 6 star rated house, in each of the three climate zones. This allowed the annual electrical energy demand profiles for the air conditioners to be determined, and it was found that the annual power consumption of the RC-AA-HP was 1,046 kWh in Brisbane, 2,013 kWh in Adelaide and 2,658 kWh in Melbourne; the peak power demands were: 2.2 kW in Brisbane, 4 kW in Adelaide and 3.5 kW in Melbourne.

The resulting cost of mains electricity for a 20-year periods are shown in Fig. 4. This shows that the highest energy consumption cost was attributed to space heating in Melbourne. It also showed the highest infrastructure cost occurred for Adelaide to sufficiently handle the high peak space cooling demands experienced during heat waves.

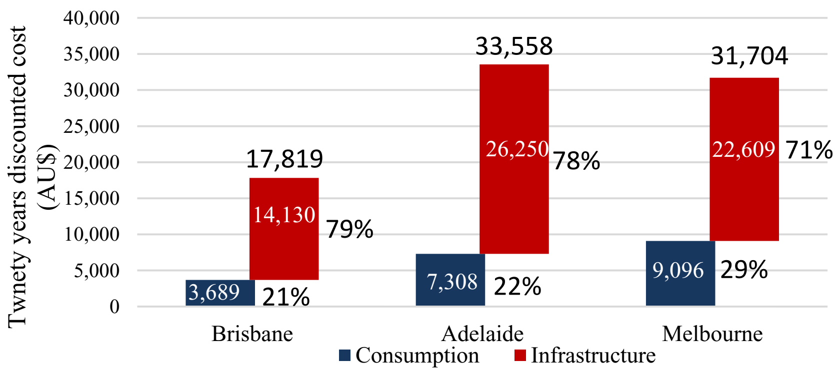

Fig. 4 The 20-year discounted electricity consumption costs and infrastructure capacity costs for the RC-AA-HP in three Australian cities

A comparison between the costs of using mains electricity to operate a chiller (Fig. 2) and an air conditioner (Fig. 4), show that the operational (purchased energy) costs of the latter is most expensive in Melbourne and cheapest in Brisbane. This is opposite for the operating costs for the chiller, hence installing a chiller is more attractive for householders in colder climate zones. In addition, the infrastructure cost to operate an air conditioner was much higher in remote locations for all climate zones, and householders could install a chiller to defer the need to build (or upgrade) the electrical infrastructure. As such, the total (operational and electricity infrastructure capacity costs) for houses located in remote locations, is much higher to operate the air conditioner compared to the chiller; the lowest cost occurs for the Melbourne climate zone.

A comparison between the costs of the SPVS required to reliably operate the chiller (Fig. 3) with the cost of the mains electricity required to operate the air conditioner (Fig. 4), indicates that despite the high investment cost in a SPVS, this is lower than the investment cost using mains to operate the air conditioner. Thus, given the electricity costs in all climate zones, using either the mains or a SPVS to operate the chiller is a cheaper than using mains electricity to power an air conditioner, especially in remote locations.

Finally, it should be noted that this study focused only on the cost of the electrical subsystem part of air conditioners. However, a decision to invest in a chiller should also consider the costs of the thermal components. Currently, these components such as the flat plate collector, sorption chiller, two thermal storage tanks and the control system, are relatively high. However, previous studies suggest that there is high potential for reduction in the cost of both small residential scale absorption chillers [11] and the solar thermal collectors [2], implying, that the difference between the complete costs of installing a chiller and an air conditioner is projected to decrease. If the capital costs of both systems are similar, investing in a chiller will be more attractive due to the lower cost of the mains or SPVS supply needed to power its auxiliary components, compared to the cost of the mains required to operate the air conditioner compressor.

4. Conclusion

This study examined the cost competitiveness of using electricity from either the mains or a standalone PV system to operate the auxiliary components of an optimized chiller sized to condition a typical Australian house in three cities with very different climatic conditions (i.e. Brisbane, Adelaide and Melbourne). In evaluating the mains costs, both the electrical energy consumption costs and infrastructure costs were taken into consideration; the latter included the upfront charges for houses remotely located or houses located on the edge of the grid (that were assumed to have no or limited available infrastructure). The study was performed using TRNSYS and systems were assumed to operate for a 20-year life cycle. The costs of the components were obtained from online retailers, whilst electricity and infrastructure costs were obtained from recent reports. The conclusions from the analysis include:

- The investment needed to construct electricity infrastructure (capacity) to supply the power to operate the chiller was higher than the electricity consumption (energy) costs.
- The operational costs of the chiller with mains electricity was less expensive than operating it with electricity obtained from an optimized SPVS, regardless of house location (city or remote area).
- The investment in the SPVS to operate the chiller was less than the cost of the mains electricity if it was used to operate a conventional reverse cycle air conditioner.
- The investment costs for operating a chiller was more attractive, particularly for houses in remote locations, located in colder climate zones such as Melbourne.

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