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Optimization of standalone solar heat fired absorption chiller for typical Australian homes

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Abstract

The increased penetration of residential air-conditioners (AC); specifically vapor compression types, is regarded as one of the foremost causes of a dramatic rise in critical peak electricity demands requiring corresponding upgrades of electricity infrastructures. These upgrades requires heavy investments, consequently, driving up electricity prices. Solar air-conditioning systems can reduce this trend, but current vapor-compression air-conditioners (VCACs) needs very large investments in both photovoltaic system and battery storage. Alternatively solar heat-driven absorption chillers need less expensive solar collectors and thermal storage, drawing only small amounts of electricity to overcome parasitic power. There are ample studies conducted previously on either the technical and/or economic feasibility of solar heat driven absorption chillers. But these studies are only focused on supplementing solar heat energy with an auxiliary heater. This study, examines the option of running the absorption chiller by solely relying on solar heat energy. It focuses on minimizing the life cycle cost of a solar heat driven absorption chiller through optimizing the size of all of its main components. The system is named the standalone solar heat fired absorption chiller (SA-SHF-ABS-CH) sized to sufficiently meet the space conditioning demands, both heating and cooling, of a typical Australian 6 star home. For the aims of this research, TRNSYS17 software was used in modelling and dynamically simulating the integrated system, while GenOpt software was used to carry out the optimization. The economic assessment on the most optimally sized system component configuration shows, firstly, the twenty-year lifecycle cost of the system with the most minimized cost is AU$ 53,387 in Brisbane, AU$ 51,639 in Adelaide and AU$ 32,816 in Melbourne. These investment costs in each of these cities appear higher than those incurred if the householder were to instead install a standard efficient inverter, ducted, reverse cycle air conditioner (IRC-AA-HP) powered by grid electricity; as follows: Brisbane at 77%, Adelaide at 58% and Melbourne at 28%. Secondly, the payback period was found to be longer than the twenty-year system service- life, which is far too long to justify the investment on such solar air-conditioner. However, when compared with IRC-AA-HP, in Adelaide and Melbourne, SA-SHF-ABS-CH consumed at least 50% less power, meaning it offsets half of the carbon dioxide emissions, furthermore, it draws 75% lesser critical peak kW_p power, which means it has strong potential to obviate the need for heavy investments in electrical infrastructures, ultimately contributing to mitigating rapid electricity price rises.

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1. Introduction

Space heating and cooling in Australia account on average for about 40% of total residential energy consumption **[1]**. Although only around 3% of this total energy is used in space cooling, energy for meeting space cooling demands remains significant since the energy demanded needs to be in the form of electricity, a need which is projected to grow with the global average temperature increase. Despite the fact that 5% of critical space air-conditioner demands for electricity occurs for only around 40 hours per year in most Australian states , reliability standard mandates that the entire electricity infrastructure needs to be sized for handling critical peak electricity demand **[2]**. Since the number of residential air-conditioner installations is growing, an ongoing heavy investment in extending the capacity of electricity infrastructures is needed. Since 2005, increased peak demands for air-conditioning electricity has been the main cause behind Australia's rapid electricity price rises **[3]**. Solar air-conditioning systems have the potential to decrease both electricity consumption and peak electricity demand, thereby, reducing greenhouse gas emissions and mitigating the investments needed to extend the capacity of electrical infrastructures, consequently, mitigating the cost of electricity price rises **[4]**. However, since powering conventional VCACs by solar requires a very large investment in both the photovoltaic (PV) system and the battery for storage **[5] [4]**; it is worthwhile bearing in mind the advantages of solar thermally driven air-conditioners. Sorption thermally driven chillers, specifically a single-effect, hot-water driven, lithium bromide/water absorption chiller, needs hot water at 75^{o}C and above to operate, a temperature which can be produced by low temperature solar collectors. The chillers needs only small amount of electricity to operate several pumps and a re-cooler. Of late, several manufacturers have presented small scale, highly pre-engineered chiller suitable for operation by solar energy in residential buildings. Although the market for such a small cooling capacity chiller exists mostly in European countries **[6] [7]**, the technology has the potential to spread to other countries such as Australia that have more sunshine. Previous studies conducted on this kind of chiller focused mostly on the solar-heat assisted types, meaning that auxiliary heat was required to back-up the chiller operation whenever available solar-heat energy was deficient. But these studies did not place enough focus on optimizing all the main system-components; namely, the chiller and the cold storage beside thermal collector and the hot buffer storage. In this study, our focus is on optimizing the size of these four main components to a level of operate the absorption chiller only by solar heat energy. The sizing criteria applied is the annual hour's loss in meeting building thermal load probability, sensible and latent cooling in summer and sensible heating in winter. These criteria enable matching the thermal capacity of the system well with building specific on-demand space conditioning. The yearly average hourly loss of thermal load probabilities considered as an optimization constraint, while the optimization objective was set to minimizing the life-cycle cost of the system. The system components sized will be optimized for a typical Australian house model and for three different climatic conditions. In order to justify the high investment in a solar system, in winter the collected solar-heat energy will be used to provide space heating. To rationalize the investment, the life-cycle cost will be compared with a basic conventional type of air-conditioner, the model chosen is a ducted inverter-driven reverse cycle air-air heat pump (IRC-AA-HP) sized for space conditioning the same house model.

Nomenclature

AC	Air-conditioner
A_{coll}	Thermal collector area
$C_{chiller}$	Chiller capacity
IRC-AA-HP	Inverter-driven reverse cycle air-air heat pump
NatHERS	Nationwide House Energy Rating Scheme
PV	Photovoltaic
SA-SHF-ABS-CH	Standalone solar heat powered absorption chiller
VCAC	Vapor compression air-conditioner