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Research Paper

Solar-assisted absorption air-conditioning systems in buildings: Control strategies and operational modes

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HIGHLIGHTS

- A simulation model of a solar driven absorption chiller is developed in detail.
- Three control strategies were proposed in the solar loop of the plant.
- Series and parallel auxiliary heater arrangements were investigated.
- The results showed the auxiliary-heater in parallel outperformed the series one.
- Solar fraction can be increased by 20% by implementing the proposed configuration.

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ABSTRACT

Solar-assisted cooling technology has enormous potential for air-conditioning applications since both solar energy supply and cooling energy demand are well correlated. Unfortunately, market uptake of solar cooling technologies has been slow due to the high capital cost and limited design/operational experience. In the present work, different designs and operational modes for solar heating and cooling (SHC) absorption chiller systems are investigated and compared in order to identify the preferred design strategies for these systems. Three control scenarios are proposed for the solar collector loop. The first uses a constant flow pump, while the second and third control schemes employ a variable speed pump, where the solar collector (SC) set-point temperature could be either fixed or adjusted to the required demand. Series and parallel arrangements, between the auxiliary heater and the storage tank, have been examined in detail from an energy efficiency perspective. A simulation model for different system layouts is developed in the transient system simulation environment (TRNSYS, Version 17). Simulation results revealed that the total solar fraction of the plant is increased by up to 11% when a variable speed solar loop pump is used to achieve a collector set-point temperature adjusted according to the building load demand. Another significant finding of this study is that a parallel configuration for the auxiliary heater out-performs a conventional series configuration. The yearly performance of an auxiliary heater in parallel with the storage tank enhances the plant solar fraction, and the average collector efficiency, by up to 13% and 9%, respectively (as compared to the same components in series). Taken together, nearly 20% higher solar fraction (as compared to conventional designs) is possible through the control strategies and operational modes presented here without adding a substantial capital cost to the system.

1. Introduction

Air-conditioning represents a growing, worldwide market in the building sectors [1–4]. The use of renewable energy technologies in space-conditioning can reduce fossil fuel consumption and its associated environmental impacts. Solar power is the most promising renewable energy resource due to its abundance and distribution throughout the world compared to other types of renewable energy sources [5,6]. In recent years, solar heating and cooling (SHC) technologies have received considerable attention as an appealing alternative to conventional heating and cooling systems, as a result of world energy and environmental concerns [7–10]. Solar-assisted absorption chillers can serve both the heating and the cooling demand in buildings, improving the system efficiency as compared to those producing either chilled or hot water alone [11].

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Wide-ranging studies have been dedicated to the modeling, simulation and optimization of solar absorption air-conditioning systems [12–16]. In particular, many researchers have performed parametric studies to investigate the effect of such key design variables as the storage tank volume, the solar collector slope angle and area, on the energy performance of the solar absorption chiller system [17–20]. Several works have explored the potential of solar thermal absorption systems for use in different building types and climate zones [21–25]. Furthermore, a number of optimization studies have been carried out in the field of SHC systems, aiming at improving the system energetic performance and minimizing the system cost [26–29].

Solar absorption air-conditioning systems simply consist of solar thermal collectors, an absorption chiller as well as an auxiliary heater and a storage unit to overcome the mismatch between the solar availability and the load demand. Nevertheless, different configurations of these components can result in quite different performances from systems that otherwise use similar collectors and chillers. Thus, it is crucial to find the right arrangement of the system elements as well as a robust control approach to design a highly efficient SHC system.

Although there is a substantial body of research in the field of solar absorption chillers, surprisingly little has been written from this prospective. More specifically, a basic, yet controversial difference of opinion seen in the literature is whether the auxiliary heater and storage tank should be in series or in parallel. Initially introduced by Ward et al. [30] in 1977, the issue of series or parallel auxiliary heater arrangement has not yet been fully addressed since both configurations are seen in recent literature. As a case in point, Hang et al. [26,31], and Li and Sumathy [32] together with a few other researchers [33,34] have reported parallel auxiliary heater arrangements in their studies (i.e. where the heater supplies the full energy requirements whenever the storage temperature is too low to be utilized). This contrasts with a number of other studies [10,19,35–38] where the auxiliary heater was implemented in series to boost the temperature of the storage tank if the solar-derived heat does not meet the heating or cooling demand. Owing to no general agreement on this issue, one cannot be certain which auxiliary heater arrangement should be considered when designing SHC absorption systems.

Furthermore, it is also of interest to improve the energy performance of the solar absorption chillers through a suitable control strategy. Albers [39], for example, developed a new control strategy to govern the cooling capacity of absorption chillers by changing the hot and cooling water temperatures simultaneously, leading to a 5% reduction in the operating cost of the system. Labus et al. [40] also proposed a control strategy for absorption chillers using artificial neural networks. Although an increasing amount of research is devoted to the control strategies of absorption machines [41,42] and heat rejection devices [43–45], less attention has been paid to the control approaches within the solar collector loop. In particular, many authors have used constant speed pumps on the solar collectors [11,17,18,46,47], while only a few works have stressed the importance of variable speed pumps [10,15,48]. Since the cost of variable speed devices has significantly dropped in recent years, the use of variable speed pumps and fans has become much more widespread in air-conditioning systems [49,50]. Due to the transient nature of solar energy, a variable speed pump would appear to be even more important in solar HVAC than in conventional HVAC, thereby achieving a desired solar collector set-point temperature and enhancing the system overall energy efficiency.

As several alternative options have been reported in literature, this study conducts a comprehensive analysis to determine which one is the best configuration and control strategy. This is done using a complete dynamic simulation model for different SHC absorption system layouts within the TRNSYS software (version 17) environment [51]. Three control scenarios are introduced for the solar collector loop. The first uses a constant speed pump, while the second and third strategies employ a variable speed pump. The collector outlet set-point temperature in the third strategy, unlike the second one, is not constant but can vary according to the building required demand. Considering these three control strategies, the performance of the modeled system is systematically examined under two different arrangements of the auxiliary burner and the storage tank – series and parallel. The yearly performance results from the parametric study of the different configurations are compared in order to select the most efficient configuration and control scheme.

2. System description

The solar-assisted heating and cooling absorption system analyzed in this study was modeled in the TRNSYS environment, a widely used modular simulation program for energy systems. The software consists of sub-routines that represent system components, or 'types', which work as modules in the system. As schematically illustrated in Fig. 1, the plant consists of solar thermal collectors (SCs), a pressure relief valve (PRV), a thermally stratified hot water storage tank (ST), an auxiliary heater (AH), a single-effect LiBr—H_2O absorption chiller (ACH), cooling and heating coils, a cooling tower (CT), pumps, valves and control equipment.

The following is a brief description of the SHC cycle flow diagram shown in Fig. 1.

The solar collector array is hydraulically connected to the stratified storage tank where the collected solar thermal energy is stored. During the day, the solar loop pump (P1) draws water (the working heat transfer fluid) from the bottom of the tank to the collector inlet. Passing through the collector field, water is then heated and directed to the top of the tank. A pressure relief valve is utilized in the main delivery pipe from the collector array to release water vapor if the fluid begins to boil. Hot water accumulated in the tank can be supplied either to the absorption chiller or to the heating coil unit for space cooling and heating in the building. An on–off controller is used to activate the cooling and heating equipment when space-conditioning is required. During the cooling season, when the temperature in the tank is above the required value, hot water from the top of the tank is drawn by pump 2 (P2) to drive the absorption chiller. This temperature is required to boil off the refrigerant (water vapor) from the lithium bromide–water solution in the generator. When the solar input is not adequate, the auxiliary heater is switched on to meet the requested demand. The chiller is also connected to a closed circuit cooling tower loop equipped with a single speed pump (P3) to transfer the rejected heat from the coolant to the surrounding environment. In the chilled water circuit, chilled water is directly supplied to the cooling fan coil using a fixed flow pump (P4), thus cooling the building. When space heating is required, the harvested solar energy is used to supply hot water to the heating fan coil unit. Analogously, the auxiliary heater can also be activated when the tank outlet temperature falls below a fixed set-point.

3. Control strategy and system layouts

The SHC absorption chiller plant requires a robust control scheme to ensure all components operate properly, thereby enhancing system performance and minimizing the use of fossil fuels. As such, the following control philosophies are explored in order to achieve the optimal operation of the system subject to varying solar radiation intensity and varying cooling and heating demand.

3.1. Solar collector loop

The solar collector loop can use either a constant or variable speed pump between the collectors and the storage tank. From these two options, one can suggest the following control scenarios for the collector loop.