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A state-of-the-art review of solar air-conditioning systems

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ABSTRACT

To reduce greenhouse gas emission, solar cooling is an attractive and environmentally friendly application since there is a direct match with cooling demand and peak incident solar radiation. In addition, solar absorption refrigeration technologies are regarded as a promising way to meet the growing refrigeration needs related to thermal comfort, vaccines, conservation of foods and medicines as well as crop drying. Presently, two systems in common used are, the single and double effects absorption chillers with the difference between the two systems being the operating temperature range. This comprehensive review looks at the available methods (theoretical modeling/simulation and experimental) that have been used for the powering of single and double effects solar absorption chillers, other solar cooling systems and their merits, system integration, design optimization and cost effectiveness of each system.

Furthermore, solar collector's area and efficiency needed for each load profile is reviewed. Higher temperature differential generated by concentrated augmented solar collectors appears to be economically viable for solar cooling systems, as peak incident solar radiations are a direct coincidence with peak solar cooling needs. Research has demonstrated that the use of evacuated tube and concentrated augmented solar collectors helps to improve the coefficient of performance of single and double-effect lithium bromide–water ($LiBr/H_2O$) absorption chillers. However, there is still the need for more research on system integration and optimization of concentrated augmented solar collectors powering single and double-effect lithium bromide–water ($LiBr/H_2O$) absorption chillers with thermal energy storage.

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1. Introduction

Solar cooling systems operating in the temperatures range of 70–120 °C is on the raise and becoming more common due to technological advancement and can be operated as stand-alone or integrated systems. There is a strong economic motivation and the need to investigate into the present technologies to determine the most appropriate systems based on cooling needs and to explore the possibility of harnessing solar thermal energy around the world. The use of conventional cooling technologies causes peak power demand with more energy consumption leading to negative environmental impacts resulting from the utilization of harmful refrigerants and greenhouse gas emission. The economy progress and development of each nation

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is dependent on it energy generation and usage ability. Air-conditioning and refrigeration systems while being used to either improve human thermal comfort levels and or preservation of food are great energy consumers.

The Commission of the European Communities, 2006 [1] reported that the world energy demand and CO_2 emissions are expected to rise by some 60% by 2030 and that the EU energy import dependency is forecasted to increase to about 70% by 2030. Energy related cooling demand on the other hand is expected to increase rapidly over the century due to global warming, with 1.1 °C to 6.4 °C rise in surface temperatures if emissions are not curbed (IPCC, [2]). The continuous use of conventional cooling technologies will further increase greenhouse gas (GHG) emissions, are energy intensive and often create high peak power demand. The direct match of the peak incident solar radiation with the solar cooling needs, both in seasonal and daily variations is a merit for the solar technology and the higher the collected incident solar radiation, the better the performance of the solar system for both the heating and cooling needs.

Initial solar cooling possibilities using solar field technological developments were reported by Tabor [3]. Solar cooling makes use of hot water produced by solar thermal collectors and or electricity generated from photovoltaic panels. The use of solar cooling results in energy conserving, reduction in GHG emission and thus preservation of the environment compared to conventional electrically driven compression systems. To meet the increasing cooling demand in an environmentally friendly manner, medium temperature applications (75–120 °C) like solar cooling and industrial process heat can be potentially met using current solar technology.

2. Solar thermal cooling schematics

Nkwetta and Symth [17] highlighted that, presently there are two most commonly used solar thermal driven systems, the single-effects absorption chillers operating in the designed temperature range of 75–90 °C and the double-effect absorption refrigeration systems needing input temperatures in the range of 90–120 °C. A schematic diagram of a domestic-scale prototype solar thermal absorption cooling systems, showing main system components and an experimental configuration reported by Agyenim et al. [4] is shown in Fig. 1. This figure brings out the need of numerous evacuated tubes to meet the cooling demand of single-effects absorption refrigeration systems operating in the designed temperature range of 75–90 °C. The absorption chiller is 4.5 kW and is driven by a 12 m^2 vacuum tube solar collector and a cold storage tank with a 6 kW fan coil. The system performance, as well as the performances of the individual components in the system, was evaluated based on the physical measurements of the daily solar radiation, ambient temperature, inlet and outlet fluid temperatures, mass flow rates and electrical consumption by component. They reported an average solar coefficient of performance of the system was 0.58 on a hot sunny day with average peak insolation of 800 W/m^2. Marcos et al. [5] defined water and air-cooled single and double-effect lithium bromide–water (LiBr/H_2O) absorption chillers. They stated that in water-cooled chillers, the water flows first through the absorber and then the condenser, transferring absorption and condensation heat to the cooling tower.

In air-cooled chillers, forced ventilation is used and the absorber and the condenser are cooled, respectively. They further concluded that the condensation temperature is always higher than the final absorption temperature and that water-cooled single effect chillers are the most common in terms of market penetration. The differences between the solar thermal cooling schematics for the water and air cooled single-effect chillers reported by Marcos et al. [5] are illustrated in Figs. 2 and 3, respectively.

Henning [6] define the operating temperature range of single and double-effect chillers and reported that double effect system can be achieved by adding an extra stage as a topping cycle on the single effect cycle. As per the authors, the double-effect chillers have two generators rather than one use in the single-effect system and need

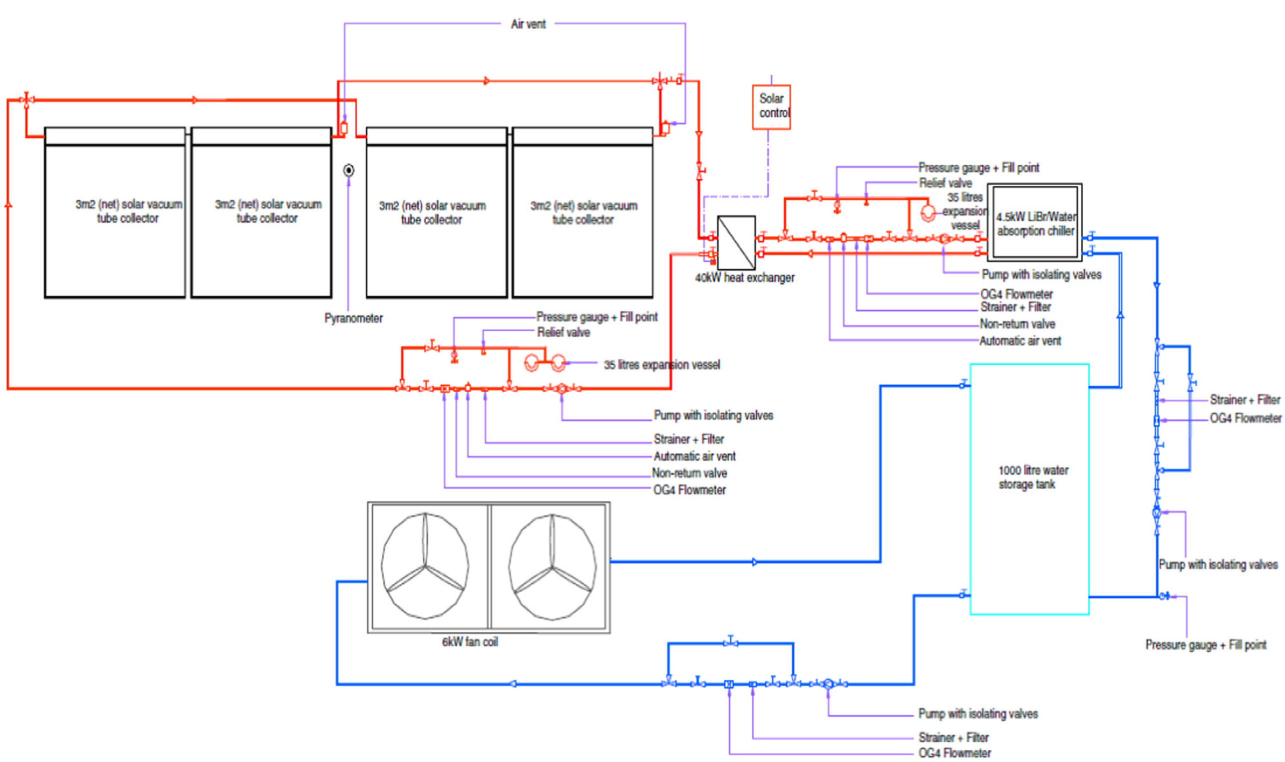

Fig. 1. A prototype solar thermal absorption cooling systems [4].