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Worldwide overview of solar thermal cooling technologies

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ABSTRACT

In this paper, a brief overview of different available and actually installed solar thermal driven technologies used for cooling or air-conditioning purposes have been presented. A review analysis has been performed taking into account research on experimental and simulated solar cooling systems in terms of COP, area of collector (A_c) per unit chiller capacity (P_{ch}) and volume of storage tank (V) per unit area of collector. The COP of absorption chillers lies between 0.6 and 0.8 for simulated and 0.40–0.85 for experimental systems for generator inlet temperature between 70 and 100 °C with dominance in the market. Adsorption chillers have lower COP in the range of 0.2–0.6 both for simulated and experimental systems. However, adsorption chillers can work at lower generator inlet temperatures in the range of 45–65 °C. The ratio of A_c to P_{ch} presents a wide spread ranging from 1.5 to 11.5 $m^2\ kW_{ch}^{-1}$. It shows that some installation may have additional area of collector installed resulting in higher thermal energy losses and initial cost of the system while others may have lower A_c installed resulting in lower solar fraction and lesser primary energy savings. Similarly, the ratio of V to A_c also shows a large variation in both simulated and experimental systems ranging from 5 to 130 $l\ m^{-2}$. However, most of these systems lie in the range of 20–80 $l\ m^{-2}$. The range of storage volume is suggested between 50 and 110 $l\ m^{-2}$ but at a first glance it seems that keeping fixed storage volume linked to area of collector may not be an economical solution for large collector areas. Although these installations are designed for solar cooling/air-conditioning purposes only but utilization of these installations further for space heating and sanitary hot water production so called multi-purpose solar thermal systems (MPSTS) will provide better results of primary energy savings.

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1. Introduction

The increasing global energy demand and CO_2 emission is expected to increase almost 60% by 2030 in comparison to the beginning of this century. The European Union (EU) energy import dependency is expected to increase approximately 70% by 2030 which was 50% in 2000 [1].

The energy demand for cooling/air-conditioning is increasing continuously [2] due to growing thermal loads, changing building architectural modes, and especially due to increasing occupants indoor comfort demand resulting in higher electricity demand notably during peak loads. This increasing electricity demand is resulting in higher consumption of primary energy and emission of Green House Gases (GHG) due to electricity generation from primary energy sources e.g. fossil fuels. An exciting alternative to reduce the peak electricity consumption is the possible use of renewable energy or waste heat to run thermally driven cooling machines instead of using vapor compression (VC) machines [3]. Solar heat can contribute significantly to the global energy need for heating purposes. The global energy demand for heat represents 47% of final energy use in OECD countries, higher than both the final energy need for electricity (17%) and transports (27%) [4]. Therefore, solar heat can make substantial contribution in meeting climate change and energy security objectives especially during the peak cooling demand in summer. Fortunately, the availability of surplus amount of solar radiation offers an opportunity to utilize solar thermal (ST) technologies to meet the cooling demand during summer season and partially the heating demand during winter time. The real challenge lies in the selection of suitable and efficient technology to utilize maximum heat from the sun to fulfill the required energy demand [5]. In addition to replace primary energy or fossil fuels that is directly burned to produce heat, solar thermal technologies can replace electricity used for hot water production and space heating. Solar thermal cooling technology can further reduce electric grid load at peak cooling demand period by partially or fully replacing electricity needed for conventional vapor compression chillers or room air-conditioners (RAC). Solar cooling technologies are beneficial particularly due to strong correlation between supply of the solar resource and demand for cooling during day time, while efficient heat storage technique can also fully or partially cover cooling demand during night time [6].

Solar thermal driven cooling/air-conditioning systems usually consist of solar thermal collectors connected to thermal driven chillers [7]. The main components of the complete solar cooling system include solar thermal collectors to produce heat from available radiation, a buffer heat storage tank to store heat for extended hours of use, the heat distribution system for supply to sorption chiller, the thermal driven cooling machine to produce chilled water, cooling towers (dry or wet type) to reject heat to the ambient, the air conditioning system for cold distribution, and auxiliary (backup) heating system (electric, gas or oil boiler) during scarce or no radiation, pumps to regulate the flow rate and controllers for the automatic operation of the complete system.

This paper presents a brief overview on the state-of-the-art and potential of solar assisted cooling and air conditioning technologies along with the analysis of worldwide simulated and experimental (real) systems in terms of hot water inlet temperature to the chiller and coefficient of performance (COP), area of collector (A_c) installed per unit chiller capacity (P_{ch}) and volume of storage tank (V) installed per unit area of collector.

2. Technologies for solar thermal driven cooling and air-conditioning

In solar thermal cooling/air-conditioning systems, solar thermal collectors along with auxiliary heating unit (backup boiler in case of scarce or no radiation and during night time) are used to deliver heat to thermally driven cooling machines for producing chilled water used for cooling purposes or air-conditioning of the buildings. Thermally driven technologies can be classified into two main categories. Those are: (1) closed cycles (chilled water systems) and (2) open cycles (direct treatment of air for temperature and humidity control).

In closed cycle processes thermally driven sorption chillers produce chilled water being used for space cooling or air-conditioning of buildings using different types of conditioning equipments e.g. fan-coils, air handling units, chilled beams, chilled ceilings etc. The general scheme to produce chilled water in closed cycles is shown in Fig. 1 [8,9]. Two types of sorption machines are more common; namely absorption and adsorption chillers based on their working principle.

In open cycle process, also referred to as Desiccant Evaporative Cooling (DEC) system we use water as refrigerant and a desiccant (a hygroscopic material; moisture absorbing material) as the sorbent for producing conditioned air directly in ventilation system. The basic scheme of open cycle system is shown in Fig. 2 [8,9].

The closed and open cycle processes are further classified depending on their working principle as given below [3,10]:

1. Closed cycles: (i) liquid sorption (absorption): water–lithium bromide (H_2O–LiBr) or ammonia–water (NH_3–H_2O) (single effect or double effect), (ii) solid sorption (adsorption): H_2O–Silicagel or H_2O–Zeolite [11], and (iii) ejector system.
2. Open cycles based on solid sorption: (i) desiccant wheels, (ii) coated heat exchanger, and (iii) silica-gel or LiCl-matrix.

Open cycles based on liquid sorption: (i) packed bed, (ii) plate heat exchanger, and (iii) LiCl solution.

A brief description of commonly used sorption technologies is as follows.

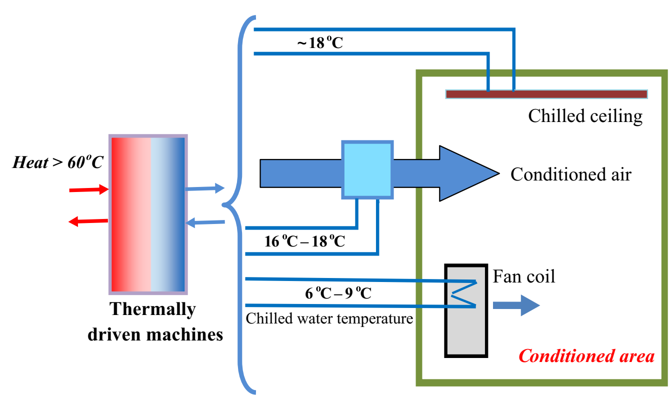

Fig. 1. Basic scheme of a chilled water system (closed cycle) [8,9].

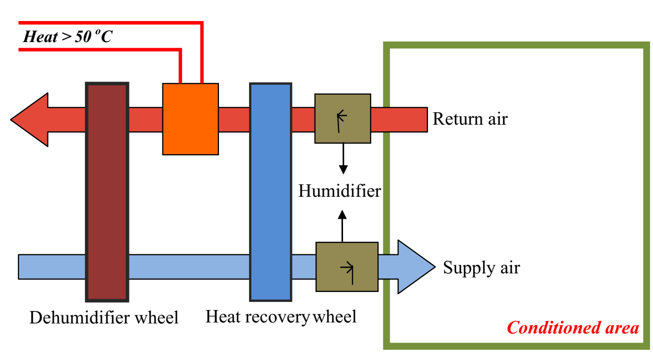

Fig. 2. Basic scheme of an open cycle (DEC) system [8,9].