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Performance assessment and gained operational experiences of a residential scale solar thermal driven adsorption cooling system installed in hot arid area

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ABSTRACT

In this study, performance assessment of a residential scale size solar thermal driven adsorption cooling system installed in hot arid and dusty area at Upper Egypt, and, in operation since summer 2012 until now is carried out experimentally for four years in operation, moreover, the gained operational experiences are presented. The system performance is expressed in term of the solar collectors' field thermal efficiency, actual chiller chilling capacity, the temperature of cold-water outlet from the chiller, chiller coefficient of performance (COP) and cooling-water temperature outlet from the cooling tower. The system performance results show that the daily solar collector efficiency during the reported period was ranged from about 50% to 78%. While, the average chiller COP was varied from 0.4 to 0.64 in combination with average chilling power ranged from 3.6 to 6.42 kW and average chiller outlet cold water temperature ranged from 19 °C to 12.12 °C correspondence to cooling tower outlet cooling water temperature ranged from 31.4 °C to 23.4 °C, respectively. In the cooling session of 2014, a 50 kW cooling capacity wet cooling tower is integrated into the system, and the measurements show that the outlet water temperature from the cooling tower is about 23.4 °C at ambient air dry bulb temperature of 35.7 °C and wet bulb temperature of about 19 °C. Consequently, under this new heat rejection condition, the chiller average cooling capacity and COP reaches were 6.42 kW and 0.64 with a chilled water temperature of 15 °C. Clearly from the system operation period, the heat rejection through the re-cooling sub-system has the main significant impact on the system performance in the hot arid areas. Therefore, it should be based on alternative heat sink recourses with appropriate cost performance techniques.

1. Introduction

Energy demand in most of developing nations that located in the hot and arid environments, such as Egypt, is higher than production and represents one of major barriers to further national development. The building sector is the first electricity consumer in the Arab region (Egypt included) with a share exceeding 57% of the total demand in 2012 as reported by RECREE [1]. Electricity shortage is evident particularly in hot session due to extra power demand required to drive vapor compression air conditioners to cover the needs of buildings cooling load including the residential sector. Enteria and Mizutani [2] reported that conventional air conditioning systems (A/C) has a large contribution to the buildings energy consumption and represent more than 70% of building energy consumption in the Middle East. Nowadays there are many green energy technologies in use to drive to air conditioning systems utilizes renewable energy resources. Utlization of these technolgies could be one of a proposed solution to reduce the conventional power consumption combined by harmful greenhouse gasses emissions. Solar-driven cooling systems are one of these technologies, which gain its importance from being one of a significant application of solar energy in residential building sector due to the fact of the coincidence of buildings cooling load time distribution with the daily incident solar radiation profile. Egypt is located mostly in Sun Belt zone and classified geographically as a hot, arid area with one of the world highest solar radiation intensity in Upper Egypt. Therefore, most of the residential buildings in Upper Egypt need a mean of thermal comfort cooling for the residence most of the year. Consequently, solar-driven cooling system can be one of the alternative technology to cover residential buildings cooling demand. Solar-driven or assisted cooling systems are classified either electrically driven and/or thermally driven systems. Solar electrically driven systems is using the Photovoltaic (PV) technologies to

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Nomenclature

Latin letters

A_{cf}	Apparent total area of the solar collectors' field (m^2)
COP	Chiller coefficient of performance
C_p	Water specific heat (kJ/kg.°C)
G_T	Total measured incident solar radiation flux on the collectors' field surface (kW/m^2)
$\dot{m}$	Water mass flow rate (kg/s)
Q	Heat rate (kW)
Q_{chw}	Chiller chilling capacity (kW)
Q_{cll}	Collectors' field thermal output power (kW)
Q_{hw}	Chiller driving thermal power (kW)
T_m	Average means temperature of the water inside the collectors' field (°C)

Greek letters

ΔT	Temperature difference (°C)
η	Collector' field overall efficiency

convert a portion of solar radiation spectrum into electrical power, which is mostly used to drive the compressor of vapor compression refrigeration machine. While a solar thermal driven cooling system using the thermal energy output from the solar collectors' field to drive cooling devices such as sorption chillers or ejector systems. Solar thermal driven cooling sorption systems are classified into three main categories: absorption, adsorption, and desiccant cooling systems. Henning [3] cited that the absorption cooling systems are the most widely used for the case of solar thermal driven technology and represent 59% of the solar thermal driven cooling systems installed in Europe. While the solar powered adsorption cooling systems represent 11%, and solar driven desiccant cooling systems represent 23%, respectively. The absorption cooling systems have a higher specific cooling power and Coefficient of Performance (COP) than that of the adsorption cooling systems. However, adsorption cooling systems can run at low-temperature level heat source started from 55 °C. Despite this fact, the adsorption cooling systems has advantages over the absorption cooling systems that are: it does not need a liquid pump, has no crystallization problem appears at the beginning of each cooling session, noiseless, and most of the commercial systems have environmental friendly refrigerants (mostly water vapor). These advantages support the designer of the solar driven cooling system to recommend a solar thermal driven adsorption cooling system for use in the residential buildings sector. Balaras et al. [4], and, Wang and Oliveira [5] reported that for a small cooling capacity load, adsorption chillers in solar thermal driven cooling systems are thought to be more promising in mini-type building air conditioning systems.

The operating parameters that are affecting the performance of the solar thermal driven adsorption cooling system are many such as the temperature variations of the driving heat source due to variation in the incident solar radiation intensity throughout the day. Wang et al. [6] experimentally investigated the influences in a variation of drive heat source temperature on the performance of the adsorption chiller. They reported that the rapid changing rate in the hot water temperature led to a significant drop in the system cooling capacity and coefficient of performance. Luo et al. [7] experimentally investigated the effects of operating parameters on performance of a solar driven silica gel-water adsorption chiller. They reported that the COP and the chilled power of the solar driven adsorption system could be improved significantly by optimizing the key operation parameters such as driving temperature, heating/cooling time and chilled water outlet temperature. Zhai et al. [8] reported that the solar adsorption cooling system with heat storage operated stably because of the regulating effect of the heat stored in the hot water tank. It is known that higher initial capital cost is one of the hindrances for widespread of solar thermal driven cooling technologies in the residential buildings sector. In order to be competitive for integration in residential buildings Clausse et al. [9] cited that, solar thermal driven sorption systems have to be as simple as possible to lower their installation cost which is one of their main drawbacks for market penetration. Fasfous et al. [10], Sim [11] and El-Sharkawy et al. [12] investigated the potential use of the adsorption solar cooling systems working under the hot arid climate conditions of the Middle East region.

Throughout the literature, there are numerous pilot and demonstration solar thermal driven and/or assisted cooling systems constructed and in operation worldwide with only a few reported investigation for the potential use of this system in the hot arid region. However, to the best of the knowledge, none of those reported research available on open literature identify the system performance and the gained operation experience for a longer period under real operation in hot and arid areas. Therefore, for further development and implementation of solar thermal driven cooling systems and toward penetration of this system into the residential sector market in the hot and arid area; it is important to assess, report, and interpret based on actual measurement with the full-scale system in operation for a longer period the factors influence on solar thermal driven cooling system performance. Moreover, the gained operational experiences from a real full-scale system in operation in hot arid and dusty area need be clarified. Therefore, this study aims to report performance assessment as well as the gained operational experiences for a residential scale solar thermal driven adsorption cooling system in operation in hot arid and dusty climate since summer 2012 until now at Assiut, Egypt.

2. Solar driven cooling system, measurements and control, data reduction and experimental error analysis

2.1. Solar cooling system

A hybrid schematic and photos diagram of solar thermal driven adsorption cooling system supplies the cooling demand for a space of 80 m^2 floor area with a height of 3.55 m in Assiut University, Egypt (27.18 ^{oo}N latitude and 31.19 ^{oo}E longitudes) is shown in Fig. 1. The system consists of the following main numbered components: (1) evacuated tube solar collector field with an apparent area of 36 m^2 and each collector has a modified back high reflective parabolic surface under the vacuum tubes. The collator's field facing south direction and tilted by 22° angle with the horizontal and is arranged in two sub-fields each consist of three parallel arrays and each array contains a set of three collectors connected in series to provide the required driving thermal power at a specified hot water temperature. (2) A hot water storage (buffer) tank that has an active volume of 1.8 m^3 and gross internal dimensions of 1 m inner diameter and 2.75 m height. This tank also works as a thermal buffer to avoid fluctuation in the temperature inlet to the chiller and store the excess hot thermal energy outlet from the collectors' field. (3) Adsorption chiller has 8 kW nominal cooling capacity (tow beds silica gel-water) at a nominal driving hot water temperature of 85 °C and cooling water temperature of 30 °C as reported by the manufacturer. This chiller can operate with hot water supply temperature ranges from 60 °C to 95 °C, and cooling water ranges from 27 °C to 32 °C. (4) A chiled water storage tank with an active volume of 1.2 m^3. It has gross internal dimensions of 0.75 m inner diameter and 2.4 m height. It is the system cold thermal energy storage and buffer to avoid fluctuation in the temperature inlet to the load (fan-coils) as well as to store the excess