

Design and simulation of solar powered cooling system in UAE

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Abstract—This paper aims to provide an optimum and reliable thermal design of a solar powered absorption cooling system in United Arab Emirates (UAE). A numerical algorithm was developed to compute the cooling capacity of the solar powered absorption system under the influence of several operating conditions, namely; hourly global radiation, flow rate, and the inlet generator temperature as well as investigating the associated environmental aspects. The proposed cooling system configuration consists basically of flat plate collectors, a stratified storage tank and an absorption chiller. A predictive model was programmed and simulated using INSEL software in order to analyse the performance of the system throughout summer season. A peak cooling demand of 20kW was estimated using Hourly Analysis Program (HAP) for a villa based in Dubai, UAE. The obtained results showed that a minimum of about 50% of the power from the peak demand can be provided by the solar system during high levels of radiation. Also the proposed system was successful to reduce the amount of carbon emission by 3690 kg during three months in the summer season.

Keywords—solar cooling, absorption chiller, INSEL.

I. Introduction

The statistics of electricity consumption in UAE show a major rise from 70 billion kWh in 2007 to 79 billion kWh in 2009 [1]. From the total electricity produced in the UAE, about 70 % is served for the purposes of air conditioning, heating systems and lightings in buildings [2]. One of the energy savings solutions for this issue is to use solar energy to run thermally operated cooling mechanisms such as an absorption cycle. In a survey carried out by the European Solar Thermal Industry Federation in Europe in 2006, it was shown that 67% of the solar cooling systems were by means of absorption cooling technology and majority of them were operated by flat-plate solar collectors [3]. A solar cooling feasibility study was carried out by A. Al-Alili et al. [4] in Abu Dhabi, UAE, using a 10 kW ammonia-water absorption chiller powered by evacuated tubes collectors. This study showed that the selected system required 47% less electrical energy compared with the regular vapour

compression cycles of the same cooling load. The system was found to reduce carbon dioxide emission by 12 metric tons per year. The main objective of this study is focused on the thermal design and simulation of a solar powered absorption cooling system for a known space. In this work, a villa located in UAE is considered as a representative case study.

II. System Description

Fig. 1 shows the schematic of the proposed setup of the solar cooling system. The solar collector receives energy from the sun which heats the water and stores the heated water in a storage tank where it is then supplied to the absorption cooling cycle at a constant flow rate. The heat gained from the solar system vaporises any water in the lithium bromide solution in the generator, thus leaving a strong concentrated solution in the generator. The water vapour produced is at a high temperature and pressure, which is passed through the condenser to cool it down and converts it to a liquid, followed by lowering the refrigerant pressure through an expansion valve. In the evaporator, the refrigerant is turned into vapour before entering the absorber. On the other hand, the concentrated solution in the generator flows through the heat exchanger and the reducing valve and fed to the absorber. In the absorber, the lithium bromide absorbs the refrigerant coming from the evaporator, as the lithium bromide dissolves in the water the temperature of the solution lowers. The diluted solution in the absorber is pumped through the heat exchanger into the generator where the process is repeated.

III. Thermal Model

The specifications of the solar collector used in the solar cooling simulation are provided in Table I. The solar collector modelling is carried out according to the formulation provided by Duffie and Beckman [5]. The useful energy gain by solar collectors, Q_u can be expressed as

$$Q_u = A_c F_R (G_t (\tau \alpha)_e - U_L (T_{fi} - T_a)) \quad (1)$$

where

G_t is the incidence solar radiation intensity (W/m^2).

τ is the transmissivity of the glass cover.

α is the absorptance of receiver's plate surface.

F_R is the heat removal factor.

T_{fi} is the inlet fluid temperature ($^{\circ}C$)

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T_a is the ambient temperature ($^{\circ}\text{C}$)
 A_c is the area of collectors (m^2)
 U_L is the collector overall loss coefficient ($\text{W}/\text{m}^2\text{ }^{\circ}\text{C}$)
 Also the outlet temperature from the solar collector, T_{fo} can be represented by

$$T_{fo} = \frac{Q_u}{\dot{m}C_p} + T_{fi} \quad (2)$$

where
 \dot{m} is the mass flow rate (kg/s)
 C_p is the specific heat of water ($\text{J}/\text{kg }^{\circ}\text{C}$)
 T_{fi} is the water inlet temperature, $^{\circ}\text{C}$

The solar collector efficiency is defined as

$$\eta_i = \frac{Q_u}{A_c G_t} \quad (3)$$

The Coefficient of Performance (COP) of the absorption chiller can be estimated by

$$COP = \frac{Q_c}{Q_g} \quad (4)$$

where Q_c and Q_g are the amount of cooling energy generated by the absorption chiller and the heat energy consumed by the generator, respectively.

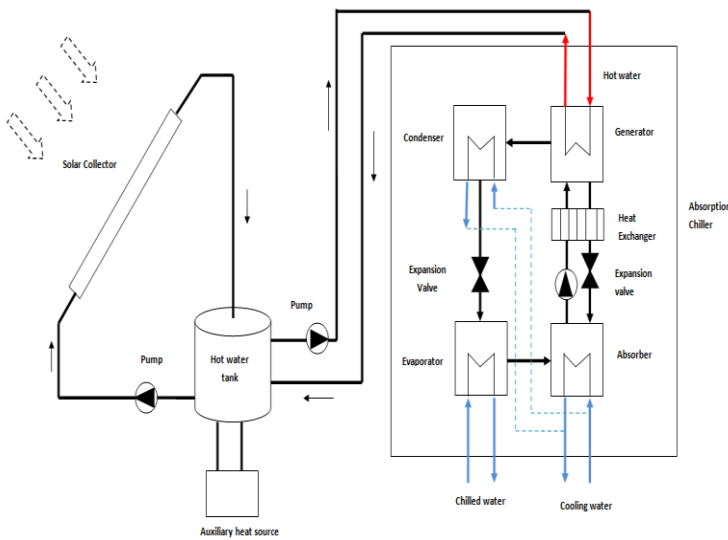


Figure 1. Schematic of the proposed solar cooling system

TABLE I. SOLAR COLLECTOR TECHNICAL DATA

Parameter	Value	Unit
Area of a single flat plate collector, A_c	2.5	m^2
No. of collectors	65	----
Collector overall loss coefficient, U_L	4.23	$\text{W}/\text{m}^2\text{ K}$
Overall mass flow rate, \dot{m}	0.333	kg/s
Specific heat capacity water, C_p	4181	$\text{J kg}^{-1}\text{ K}^{-1}$

The solar insulations for a typical summer season in Dubai are presented in Table II. The flat plate collector is set at an angle of 25° which is the optimum angle of incidence for solar radiation to be received on the solar collectors in UAE during the summer season.

IV. Case Study

A hypothetical two bedroom residential villa located in Dubai with a finish floor space of 131 m^2 (1413 ft^2) was considered. The net floor area of the simulated zones is about 86.3 m^2 (929 ft^2) and the average ceiling height is 3.05 m (10 ft). The two bedroom villa floor plan is shown in Fig. 2.

TABLE II. SOLAR INSOLATION, G (W/M^2)

Hour	May	July	September
8:00	616.7	524.2	442.14
9:00	756.03	610.7	589.5
10:00	849.2	716.3	680.8
11:00	864.64	766.5	721.8
12:00	889.74	775	714.7
13:00	817.9	705.4	614
14:00	700.7	664.5	508.4
15:00	544.14	487.3	412
16:00	366.02	323.01	262.6
17:00	233.53	229.1	172.1



Figure 2. Villa layout

V. Numerical Simulation

The simulation of the solar powered cooling system was carried out using INSEL [6]. Detailed program structure is shown in Fig. 3. The investigation of the system starts with the SCETA block which simulates a solar collector. Each flat plate collector has water flow rate of 0.005 kg/s and the outlet heated water is stored in a storage tank that is the TANKST block. The DO block simulates the time in seconds with a constant hourly increment. The current approach implies that the tank is charged for 5 hours at an overall mass flow rate of 0.333 kg/s which is provided by 65 flat plate collectors. As long as the value 18000 seconds which defined by the CONSTANT block is greater than or equal to the output of the DO block, the GE block output is unity. This signal allows the heated water into the tank and into the chiller. Once the DO block crosses the storage time then the GE block outputs zero and no more water is given into the tank. The zero signal passes through INV block which inverts the input signal logically thus discharging the hot water at the same mass flow rate. The LE block notes whether the input signal is less than or equal to the minimum operating temperature that is 76 degree Celsius. When the solar energy is not sufficient to run the absorption chiller, the auxiliary heater is switched on which supplies the minimum inlet generator temperature to continue operation of the absorption chiller. The PLOT block generates a graphical output of the results through a GNU plot which shows the temperature profile inside the stratified tank and the resulting cooling capacity of the absorption chiller as shown in Fig.3.

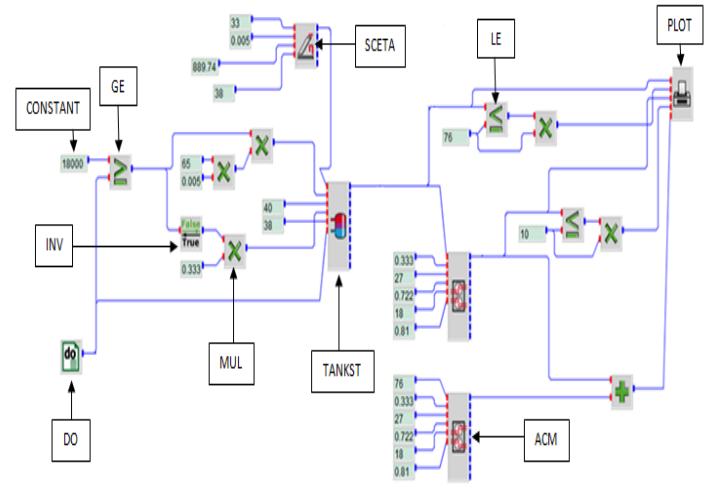


Figure 3. Solar absorption cooling system simulation

VI. Results and Discussion

The internal cooling load was estimated using Hourly Analysis Program (HAP). The selected villa is assumed to be occupied throughout the week where an average people activity, occupancy, overhead lighting and electrical appliances contribute to the total cooling load were considered. The appliances and lighting loads are based on the occupancy schedule. The simulation showed that the required total conditioning to be 19.8 kW (67508 Btu/hr). Two 10 kW absorption chillers were selected to meet the cooling load requirement. Table III provides the specifications of the absorption chiller [8]. Before evaluating the cooling capacity produced by the solar cooling system, the solar collector area is sized according to the mass flow rate required by the absorption chiller.

TABLE III ABSORPTION CHILLER TECHNICAL DATA

Specification	Unit	Operation with
Refrigerating capacity nominal/maximal	kW	10/15.8
Generator temperature nominal/maximal	°C	75/95
Hot water mass flow	kg/s	0.33

The first step in this analysis is to predict the optimum amount of mass flow rate which should be fed into the collectors while providing sufficient hot water for the generator in terms of mass flow rate and temperatures. Fig. 4 shows the variation of the outlet temperature from the flat plate collector at various mass flow rates which were investigated at an average radiation level. It was observed that at a mass flow rate of 0.003 kg/s or lower, the water is turning into steam. On the other hand, the mass flow rate of above 0.0055 kg/s does not provide the minimum operating temperature for the absorption cycle (i.e. 75 °C). Thus, it was concluded that the mass flow rate of 0.005 kg/s is sufficient to match this operating condition.

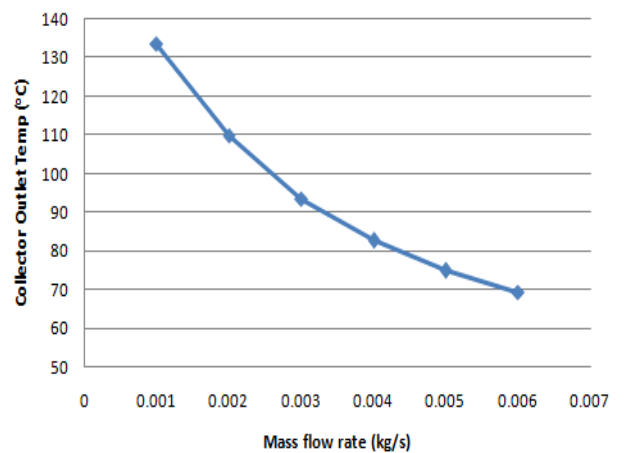


Figure 4. Effect of mass flow rate on the collector outlet temperature.

Fig. 5. shows the temperature distribution of the water in the tank versus time. Initially the temperature is at 25 °C, once the tank starts receiving hot water from the solar collector the temperature of the water increases gradually in the tank. As the temperature provided by the collector falls below the required value, the tank inlet valve is switched off and no more water is let into the tank.

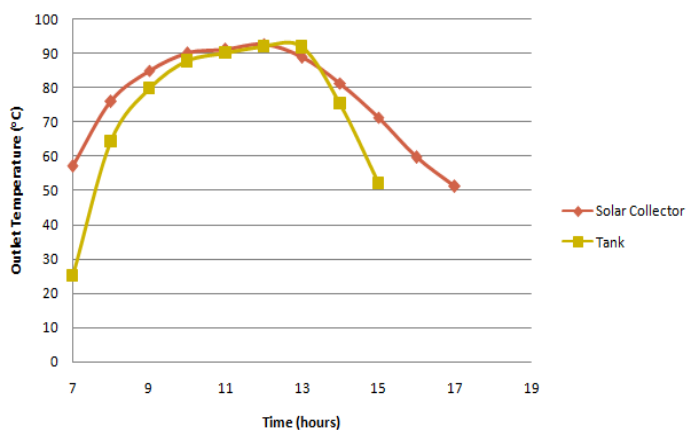


Figure 5. Hot water collected in storage tank from collector

Fig. 6 shows the graphical output result of the solar absorption cooling system and the corresponding mode of operation. This simulation was carried out for a single day in the summer season. The Y axis represents the temperatures for the lines #1 and #2 whereas the same axis also represents the refrigerating capacity for line #3 and #4. The X axis displays the time when the whole system starts to operate. Line #4 represents a separate absorption chiller which is working independently and sums up with line #3 to provide the maximum cooling load. The simulation shows the system operates on solar energy for approximately 4 hours at least. The minimum power required to be generated by the solar powered absorption chiller is 10 kW. The solar fraction achieved is a minimum of 50% during the peak hours of radiation. The average cooling power generated by the absorption chiller for selected months throughout the summer season is shown by Fig.7. It was found that the maximum power generated by the solar powered system during May can reach up to 15 kW (i.e. about 75% of the total required cooling load).

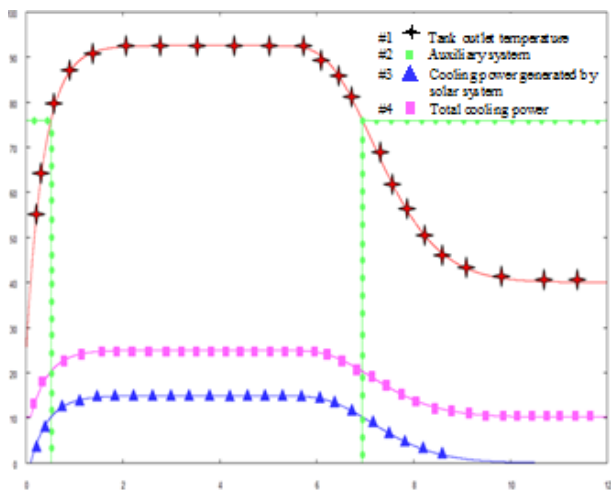


Figure 6. Complete solar cooling system simulation plot

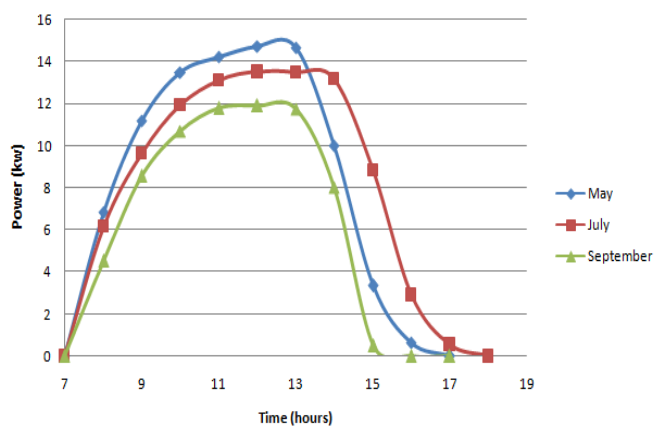


Figure 7. Refrigerating capacity under solar radiation

In order to verify the positive impact of the solar-powered cooling system on the environment, the amount of carbon dioxide savings were predicted in case of replacing the conventional cooling system by the proposed solar cooling system as shown by Fig. 8. It was found that about 3690 kg of equivalent carbon dioxide can be reduced if the solar powered cooling system has been utilized for a period of three months.

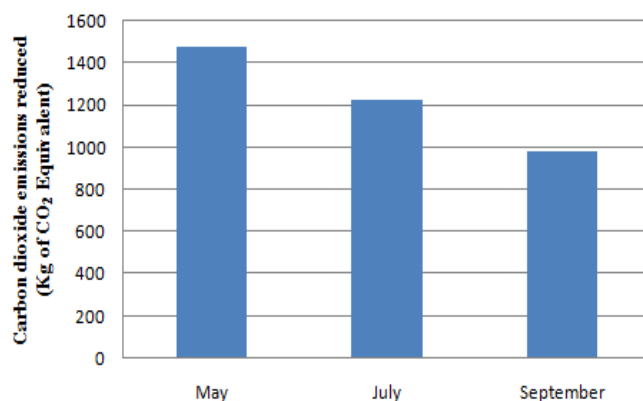


Figure 8. CO₂ reduction by using solar cooling system

VII. Conclusion

In this paper the design and simulation of the solar cooling system was investigated under UAE climatic conditions. A numerical model was developed and simulated using INSIL software in order to study the effects of several operating conditions on the performance of the system such as the mass of flow rate in the collector , temperatures of hot water in the tank and the generator inlet temperature. Also this simulation shows the recommended mode of operation (i.e. solar system and/or auxiliary system) during the day hours. The proposed model was implemented to analyze the feasibility of installing solar powered system for a villa located in Dubai. The obtained results showed that the proposed system was sufficient to provide 50 % of the cooling load (i.e. 19.8 kW) at overall collectors’ mass flow rate of 0.333 kg/s during the operating hours in summer season. On the other hand, the current study showed that using solar cooling system instead of conventional cooling



system can contribute to the environment by reducing the carbon dioxide emissions by amount of 3690 kg during summer season.

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