

## **Performance Analysis of a Solar Powered Adsorption Cooling System**

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### **Abstract**

*With the increasing global cooling demand and in order to keep up with the recommendation of the Montreal Protocol and global warming concerns, there is an increasing need for alternative cooling technologies powered by renewable sources, to take over. Adsorption cooling technology is one such emerging technology which can harness solar thermal energy for cooling needs, with the distinct advantage of having lesser corrosive and maintenance issues than the absorption counterpart. The present study carries out a detailed analysis of a solar evacuated tubular collector powered adsorption cooling system for a room cooling application using TRNSYS software. The room cooling load considered is of 3 tons peak capacity, and varies with the time of the day and season, over the non-winter duration of March-October, for the local weather conditions of Delhi. The performance analysis of the system has been done with varying collector areas and hot water storage tank sizes, in terms of overall COP and cooling capacity. Appropriate hot water storage sizes have been identified for the collector areas varying from 10m<sup>2</sup> to 100m<sup>2</sup>, based on the maximum solar COP obtained. The cooling capacity of the system increases from 5755.29 MJ to 42107.62 MJ with increasing collector area and the solar COP varies between 0.143 to 0.087, with a decreasing trend albeit minor fluctuations.*

**Keywords:** Adsorption cooling, Evacuated tubular collector, TRNSYS, Solar cooling, COP

### **1. Introduction**

With an increase in the standard of living of people, the demand for refrigeration and air conditioning systems has increased very much in the recent years especially in developing countries like India [2]. With the increasing demand for refrigeration and air conditioning systems, the use of ozone-depleting HCFCs and high Global Warming Potential (GWP) HFCs has increased. In order to keep up with the guidelines of Montreal Protocol and to reduce the dependency on fossil fuels, the use of alternative energy powered cooling systems has to take place, for a sustainable solution. Adsorption cooling technology is an upcoming technology that can harness the solar potential for cooling application. Besides, it has the distinct advantage of having less corrosion and absence of crystallization issues in comparison with its absorption counterpart.

The adsorption cooling systems can be broadly classified into intermittent cooling and continuous cooling systems. This work focuses on the development of solar-powered continuous cooling systems, which can serve a broader range of applications than the intermittent systems. Based on the literature review, the research on continuous solar cooling systems can be classified into two categories. The first kind is a thermodynamic study, which deals with the performance aspects of the adsorption chillers under different operating conditions like hot source temperatures, ambient conditions, etc. ([3]; [4])). The second kind is an overall system performance study, where the predetermined thermodynamic performance characteristics of a cooling system are utilized for determining overall system performance with various collector configurations, storage capacities, locations, etc. ([1]; [5]; [7]) or a feasibility study for a particular application [6]. TRNSYS is a widely used software for solar applications, which is helpful for integrating different subsystems such as solar collector, storage tank, cooling load, adsorption chiller etc., in order to

do an overall study of the solar cooling system. In the current work, the effects of collector area and storage tank capacities are intended to be studied on a solar adsorption cooling system for a room cooling load application, using TRNSYS.

## 2. System description

A 3-ton adsorption cooling unit has been modeled in TRNSYS for a room cooling load of 3-ton peak capacity. The adsorption chiller unit is powered by ETC collectors coupled to a thermal storage. There is also another chilled water storage tank which couples the room cooling load with the adsorption chiller, as shown in Figure 1.

### 2.1. Components

The components considered in this simulation have been taken from the TRNSYS and TESS libraries. The major components of the solar room cooling layout are listed below:

#### Solar collector

The TRNSYS inbuilt Type1288 Evacuated Tube Collector was used for providing thermal energy input to the adsorption cooling system. The efficiency equation for the collector is given by the following equation [8]:

$$\eta = F_R(\tau\alpha)_n - a_1 \frac{(T_{in} - T_{amb})}{I} - a_2 \frac{(T_{in} - T_{amb})(T_{in} - T_{amb})}{I} \quad (1)$$

Where  $T_{in}$  is the fluid inlet temperature,  $T_{amb}$  is the ambient temperature,  $I$  is the incident radiation on the collector and the collector parameters  $F_R(\tau\alpha)_n$ ,  $a_1$  and  $a_2$  are considered with their default values of 0.6, 2.99 kJ/hr.m<sup>2</sup>.K and 0.01 kJ/hr.m<sup>2</sup>.K<sup>2</sup> respectively. The tilt angle of the collector has been taken to be zero degrees for the current study.

#### Storage Tank

The Type 60C vertical cylindrical storage tank component has been used as a storage tank, which integrates solar collector circuit with the adsorption chiller circuit. The heat loss coefficient of the tank has been reported as 0.833 W/m<sup>2</sup>.K. The height to radius ratio of the tank has been maintained constant at 3.5, while the tank's storage capacity or volume has been varied for the performance study.

#### Adsorption chiller

The Type 909 adsorption chiller component of 3-ton capacity has been used in this simulation. This component calculates the output chilled water temperature, cooling capacity and Coefficient of Performance (COP) based on the interpolation from its data file containing the experimental results recorded over a range of hot water, cooling water and chilled water temperatures. In addition to the water pumps required for circulating hot, chilled and cooling water through the chiller, a cooling tower is required for heat dissipation of the cooling water returned from the chiller. The cooling tower's air to water flow rates ratio has been fixed at 400, in accordance with the design data of the cooling tower, while the sump volume and air flow fan capacities are 0.35 m<sup>3</sup> and 1.5 kW respectively.

#### Cooling load

Type 686 synthetic building cooling load generator has been used for generating a cooling load for the adsorption chiller. Hourly cooling loads are generated during the period of March-October, excluding the four winter months of the year, with a peak cooling load of 10.5 kW. The time-of-day and seasonal variation in the cooling loads are taken care by modifiable sine wave functions. Besides these hourly and daily noise fluctuations in the cooling load can be incorporated by specifying the standard deviation value of this component. This component is connected to the Type 682 component of TRNSYS library, which imposes the cooling load generated by Type 686 on a water flow stream through it. The chilled water circuit of the adsorption chiller is connected to the cooling load generator circuit using a chilled water tank of 100 L capacity, whose sole purpose is to take care of sudden temperature fluctuations occurring due to the cooling load.

### 2.2. Control strategy

Besides the basic components mentioned in section 2.1, pump controllers and safety relief valve are required in the solar room cooling layout to reduce thermal losses from the solar collectors, ensure an energy efficient operation of the chiller as well as to maintain the pressure safety limits within the thermal storage tank. There are 3 pump controller

units in the system as can be seen by a differential controller (Type 2b) and two aquastatic controllers (Type 2), apart from the tank relief valve (Type 13), in Figure 1. The purpose of these controllers is as follows:

#### Differential temperature controller (Type 2b)

This controller ensures that water circulates through the solar collector pump, only when the temperature of the collector outlet fluid is at least 2°C above the temperature of the thermal storage water. This reduces the thermal losses from the storage tank.

#### Cooling mode aquastat (Type 2-AquastatC)

This controller turns on the adsorption chiller including all of its pumps, only when the temperature of water in the thermal storage is in the operable range of the chiller (65-100°C). This controller ensures the saving of the pumps', cooling tower's and the chiller's electrical energy consumption.

#### Heating mode aquastat (Type 2-AquastatH)

This controller ensures that the water pump coupled with the room cooling load, runs only when the water temperature in the storage unit is below the maximum chilled water temperature of 12°C as per the standard working conditions of the chiller. The chilled water tank is recoupled back to the cooling load only when the tank attains the minimum chilled water temperature of 6.67°C.

#### Tank relief valve (Type 13)

This valve prevents steam accumulation in the thermal storage tank by discarding the excess input thermal energy, whenever the temperature of the top segment of the storage tank exceeds the boiling temperature.

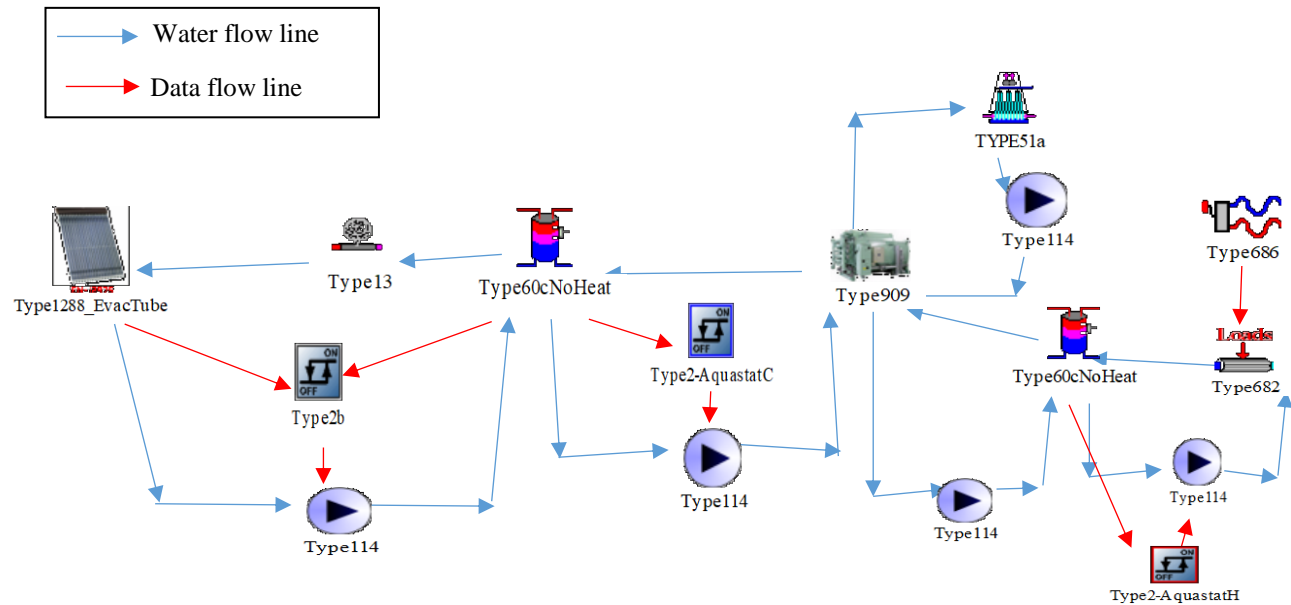


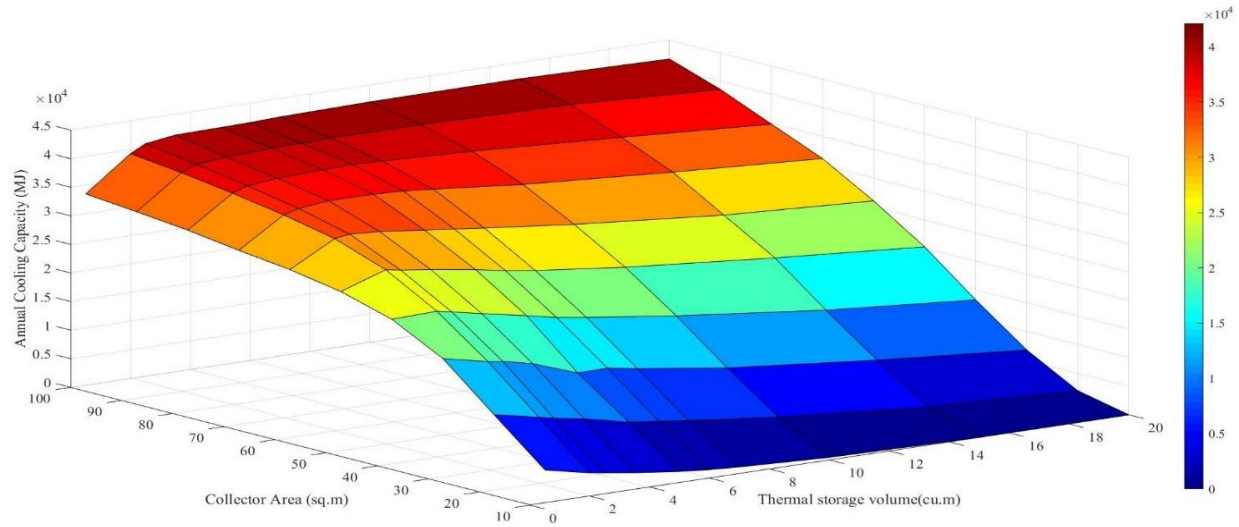
Fig. 1. TRNSYS layout of solar adsorption room cooling system

### 3. Results and discussion

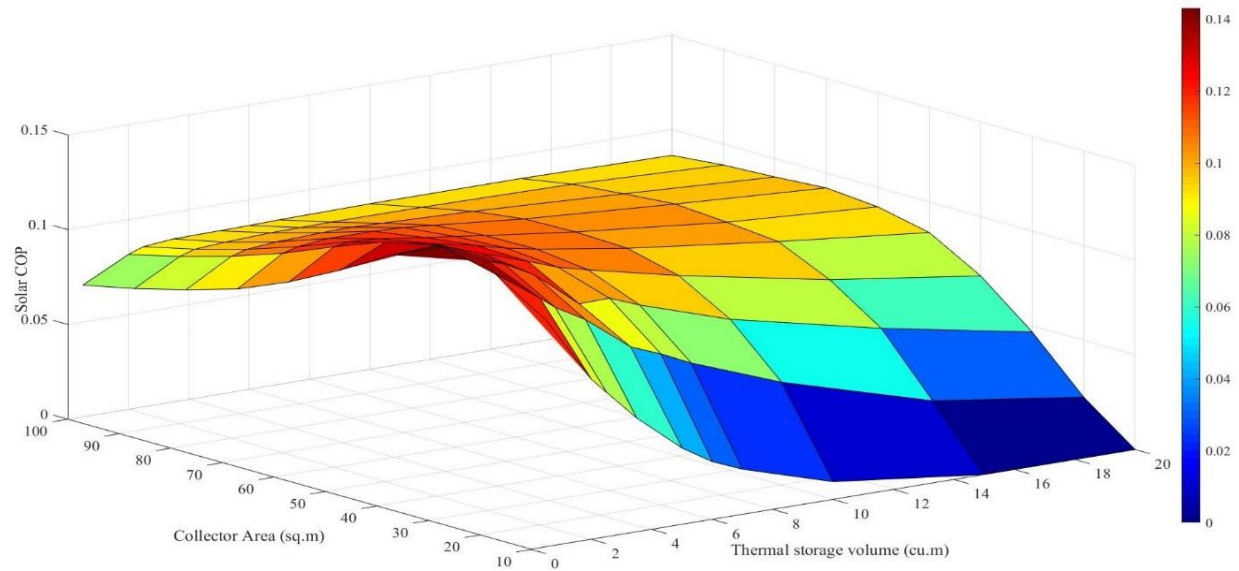
The system performance has been studied under the local weather conditions of New Delhi, during the months of March-October. The remaining 4 winter months of the year haven't been considered for the room cooling application. The system's performance has been assessed in terms of Solar COP and cooling capacity primarily, where solar COP is given by:

$$\text{Solar COP} = \frac{\text{Annual Cooling capacity generated by chiller}}{\text{Annual solar insolation incident on the collector}} \quad (2)$$

The cooling capacity and solar COP variations with various collector areas and hot water thermal storage volumes is shown in Figure 2 and Figure 3 respectively.



**Fig. 2.** Cooling capacity variation with varying collector areas and thermal storage volumes



**Fig. 3.** Solar COP variation with varying collector areas and thermal storage volumes

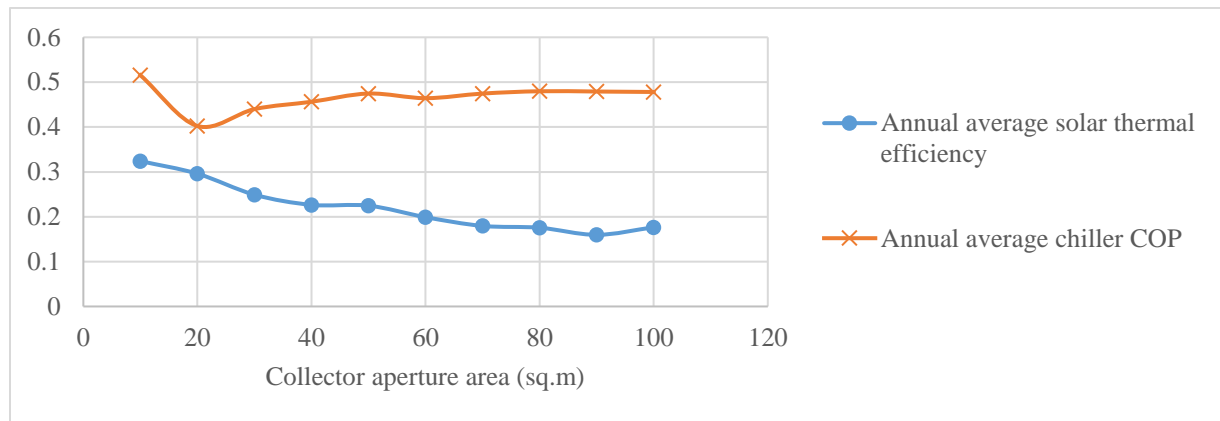
The optimum storage tank size for each collector area so as to yield a maximum solar COP, has been tabulated in Table 1.

**Table 1.** Optimum thermal storage volume with the corresponding solar COP data for various collector areas

Collector Area (sq.m)	Storage Tank volume (cu.m)	Annual Average Solar COP
10	0.5	0.119
20	0.5	0.136
30	0.5	0.143
40	1	0.134

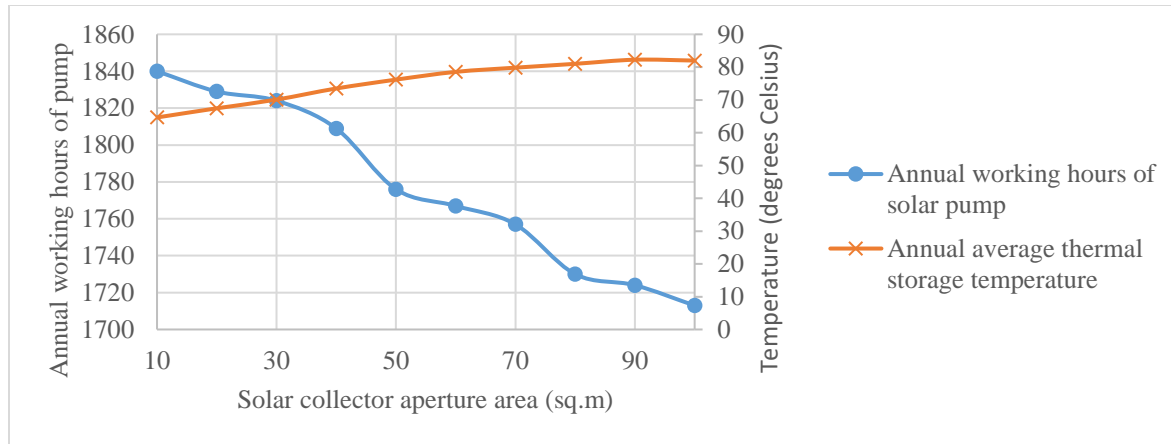
50	2	0.126
60	2.5	0.117
70	3.5	0.109
80	6	0.101
90	7	0.093
100	15	0.087

It can be seen that though the cooling capacity of the plant increased with increasing collector areas for all the storage tank sizes, the trend isn't the same for the solar COPs. Table 1 shows that the solar COP follows a decreasing trend besides a minor fluctuation between 10-30 m<sup>2</sup>, with the increasing collector areas. The solar COP is primarily determined by solar collector thermal efficiency and chiller COP apart from the heat losses from the hot and chilled water tanks. Figure 4 shows the annual average solar collector thermal efficiencies and chiller COPs obtained for the solar COPs shown in Table 1.



**Fig. 4.** Annual average solar thermal efficiency and chiller COP data for various collector areas

The thermal efficiency follows an overall decreasing trend with increasing collector area from 10 m<sup>2</sup> to 100m<sup>2</sup>. The average thermal efficiency, in turn, depends on two factors, viz., the average operating temperature of hot water storage tank and annual number of running hours of the solar pump. Figure 5 shows the effects of the variation of these two parameters obtained for the thermal efficiencies shown in Figure 4.



**Fig. 5.** Annual solar pump working hours and average thermal storage temperature data for various collector areas

The annual working hours of the solar pump tend to decrease with increasing collector area. This is due to the temperature differential controller (Type 2b) and tank relief valve (Type 13) in the solar collector circuit. The temperature differential controller doesn't allow the pump to run if the temperature of the collector outlet is above a certain specified margin over the storage tank's temperature. With increasing collector area and the proportionate thermal storage size, the time taken for the collector outlet temperature to rise up to the specified margin over the storage tank's temperature also increases, leading to the increase of the non-working hours of the solar pump. With the increasing collector area, the time duration for which the collector outlet temperature rises above 100°C also increases which increases the solar energy discarded by the pressure relief valve (Type 13) in the form of steam. The solar collectors of higher aperture areas operate at higher average circulating water temperatures due to the higher thermal storage temperatures, thereby having greater heat losses in comparison with the collectors of lower aperture areas. The chiller average solar COP, on the other hand, doesn't seem to follow a definitive trend. Out of the three determining parameters of chiller COP, viz. hot, cooling and chilled water temperatures, the effect of cooling water temperature on COP variance is smaller, in comparison to the effects of annual average hot and chilled water temperatures. With increasing collector aperture area, the annual average hot water temperature increases, which increases the capability of the chiller to meet the cooling demand with a relatively lower chilled water temperature. While the increasing hot water temperature has a positive effect on the chiller COP, decreasing chilled water temperature has a detrimental effect, thus making it difficult to predict the trend of chiller COP.

#### 4. Conclusion

- A TRNSYS based performance analysis of a solar integrated adsorption cooling system has been done for a room cooling application, with varying collector areas and thermal storage tank sizes.
- With increasing collector areas, though the cooling capacity increased, the solar COP largely had a decreasing trend, in spite of identifying appropriate thermal storage sizes. The decreasing solar thermal efficiency due to the reduced number of solar pump working hours and increased thermal storage tank temperatures, have been identified to be the main reasons for decreasing solar COP.
- Critical underlying reasons of the performance trends of a solar coupled adsorption cooling system have been identified by this study, which hope to help project developers and researchers to address them and plan accordingly.
- This study could be further extended for various other aspects like optimum solar collector tilt determination, internal temperature monitoring for cooling space, etc., for a more accurate sizing of the solar collector and thermal storage systems to meet the desired load.

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