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ORIGINAL ARTICLE

Performance evaluation for solar liquid desiccant air dehumidification system

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TRNSYS;
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Saving energy

Abstract In this paper, a solar liquid desiccant air conditioning (SLDAC) system has been studied. The effect of changing evacuated tube collector area on the performance of the SLDAC system was fulfillment. This inquest was done over all a year in Borg Al-Arab city located in the Northern region of Egypt. Meteorological data, such as hourly average solar radiations and temperatures, were needed to achieve this research. The hourly cooling loads were determined by using Hourly Analysis Program (HAP) 4.7. These loads are wall, illumination, people, and equipment loads. Then, the hourly differences of different parameters such as amount of water absorbed in conditioner, amount of water desorbed in regenerator, hot water temperature and coefficient of the performance were calculated.

In addition, the maximum solar thermal energy was determined to meet the regeneration demand according to the hourly average solar radiation data. For 220 m^2 evacuated tube collector area, the maximum required heat energy is obtained as 38,286 kW h on December, while using solar energy, will save energy by 30.28% annual value.

1. Introduction

Humidity has a significant impact on indoor environments. High indoor humidity leads to uncomfortable and unhealthy environment. The basic problem is that all cooling coils, DX coil and chilled-water coil, are weak moisture removal devices. On the other hand, desiccants can be considered good devices to preserve comfortable and healthy indoor environments.

Desiccants are unique in that they can dry air without first cooling the air below its dew point. Once the desiccant is loaded with water, heat is used to return the desiccant to its "dry" state. The high electrical demand of the compressor in a conventional air conditioner is replaced by the need for thermal energy to regenerate the desiccant. This creates an important opportunity to use solar thermal energy for air conditioning. Liquid desiccant cooling is particularly well suited to solar applications as it requires low temperature heat (50–90 °C) and allows for high density loss and less energy storage in the form of concentrated desiccant. When comparing liquid desiccant systems to solid desiccant, or rotary wheel dehumidifiers, the ability to store energy is an important benefit for solar applications. The low cost of solar thermal energy makes SLDAC system become a competitive with natural gas desiccant air conditioning system [1]. This solar thermal energy can be provided by either flat-plate collectors or evacuated tube collectors. Flat-plate collectors are less expensive, as

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Nomenclature

c_p	specific heat at constant pressure, J/kg K
h	specific enthalpy, kJ/kg
h_{fg}	evaporation heat energy, kJ/kg
m^{o}	mass flow rate, kg/s
Q^{o}	heat energy, kJ
T	temperature, °C

Greek symbols

ω	humidity ratio of the air, $\mathrm{kg_w/kg_a}$

Subscripts

a	air
c	conditioner
hw	hot water
s	solution
v	vapor

Abbreviations

COP	coefficient of performance
dbt	dry bulb temperature
Eff	efficiency
LDAC	liquid desiccant air conditioner
TRNSYS	transient system simulation tool

evacuated-tube collectors will have an installed cost that is around 1.5 times that of a flat-plate collector. However, the required area for the flat-plate collectors to produce the same thermal energy is bigger than that of evacuated-tube collectors. The selection of the collectors for a solar cooling system is a trade-off between their cost and performance. In general, the Coefficient of Performance (COP) for desiccant regeneration—defined as the thermal energy needed to evaporate a unit mass of pure water divided by the thermal energy supplied to the regenerator to remove the same mass of water from the desiccant—increases at higher temperatures [2].

Many contributions have been made in the research for environmental-friendly and CFC-free alternative dehumidification techniques and systems. The annual operating energy performance of a desiccant cooling system was studied by Kim et al. [3]. They also proposed the operation model which was used to estimate the energy saving potentials. They also made an energy comparison between the proposed system and the conventional variable air volume (VAV) system. The recent researches on solar liquid desiccant cooling were reviewed by Buker and Riffat [4] for different climates. For appraisal of the saving energy, Ronghui and Lin [5] implemented the operation performance of the SLDAC of a building in Hong Kong. The results showed that LDAC, driven by electricity, was not suitable for the commercial building due to the fact that huge electricity was needed in regeneration process. On the other hand, SLDAC provides promising saving energy in case of the presence of an additional source of cooling as well as cooling towers. Burch et al. [6] submit a new district cooling system. This system was new in that continuously hot liquid desiccant (LD) solutions were distributed to each home. Also it lowers LD flow rates by storing LD in central and local storage. A SLDAC system was simulated for five cities representing the four main climate regions by Qi et al. [7]. Results showed that sensible heat ratio had a seriously effect on the system's performance. The electricity energy needed in SLDAC system was highly reduced in humid regions where sensible-total heat ratio (SHR) was low.

Adriana et al. [8] used TRNSYS program to make a simulation and modeling of a hybrid liquid desiccant system (HLDS). They depend on performance tables to develop the modeling method. Kuala Lumpur city was chosen as a case study because it has high humidity and ambient temperatures throughout the year. A model, which predicts the regeneration rate, was inferred by Kim et al. [9]. This was done by statistically analyzing the experimental data measured from in fact liquid desiccant unit operated under different conditions. An optimization for central system parameters for different cities representing various climates was done by Qi et al. [10]. They depend on the Multi-Population Genetic Algorithm to get the optimal system performance. Data analysis elucidated that the climate changes had a large impact in choosing the operational system. Lowenstein et al. [11] made a comparison between a low flow LDAC air handling unit and a packed-bed liquid desiccant system when the ambient conditions were approximately 35 °C dbt and 16.9 $\mathrm{g_{water}/kg_{dryair}}$ humidity ratio.

The objective of the present investigation is to evaluate the performance of a solar liquid desiccant air handling unit using a numerical model. The scope of this study is aimed at studying the impact of changing solar collector area on absorption, desorption rates, and system coefficient of performance through summer season, also evaluating the annual energies consumption and the amount of energy saved by using the solar system with LDAC.

2. Materials and method

In Fig. 1, a schematic view of the SLDAC system is sketched. The main parts that the solar desiccant system consists of are evacuated tube collectors and a desiccant cooling device, which used the liquid desiccant to control humidity. Using evacuated tube collectors in SLDAC system has two benefits. First, it is simple construction, and second it is highly overall efficiency when installed with a SLDAC system.

2.1. Analyzing desiccant air condoning system

Fig. 2 shows the absorption and desorption process. It also labeled the inlet and the exit air or water temperatures as well as the liquid desiccant concentration through the absorber or desorber. The cooling or heating water flows inside each plate, with the desiccant falling down the plates in a thin film. Air is blown across the desiccant flow between the plates. Plate geometry is repeated with a 2.5 mm air gap between plates. The cross section of each absorber plate is 2.5 mm thick by 305 mm wide.

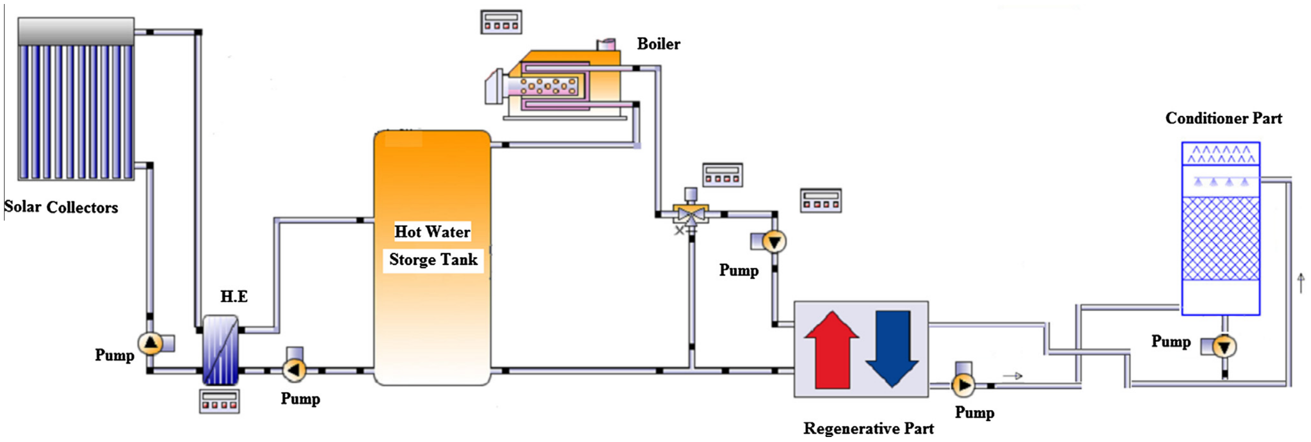

Figure 1 Components of solar liquid desiccant air conditioning (SLDAC) system.

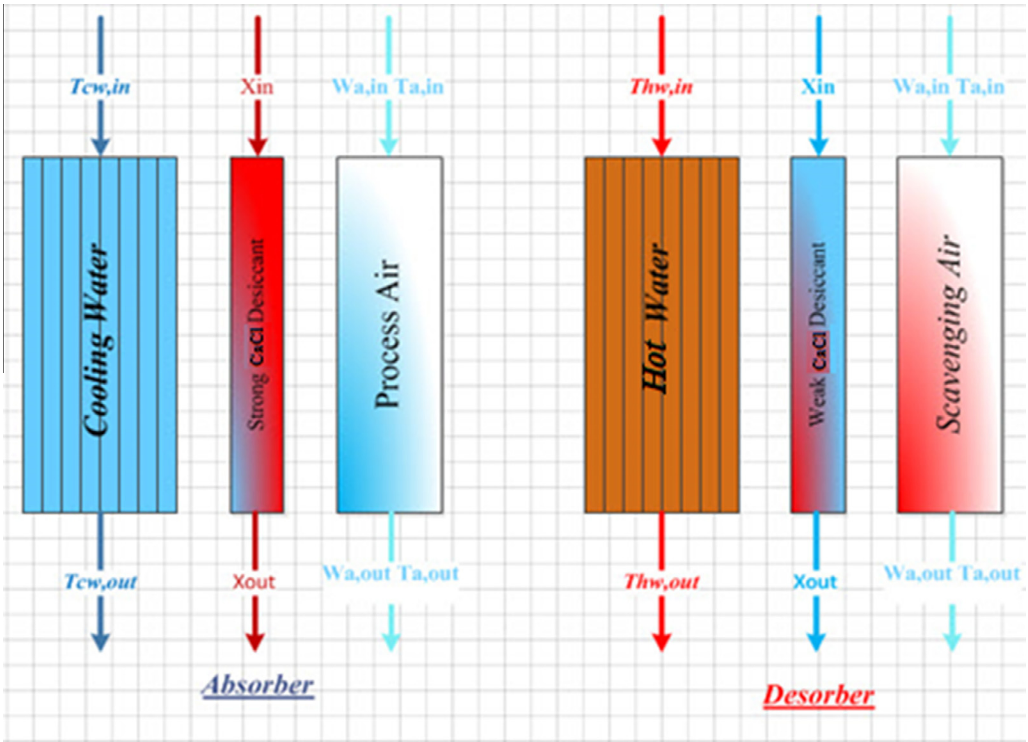

Figure 2 Process flow heat and mass transfer.

The absorber is operated such that water vapor from the air stream is absorbed by the desiccant solution. The air is dehumidified in by absorbing $m^{o}_{v,a}$ in the desiccant, resulting in a lower humidity ratio $\omega_{a,out}$. The exit humidity ration can be calculated by using the following equation [12]:

$$m^{o}_{a,c} \times \omega_{in,c} = m^{o}_{v,a} + m^{o}_{a,c} \times \omega_{out,c} \tag{1}$$

The solution will absorb $m^{o}_{v,a}$ from the air stream, lowering the concentration of the solution. This mass flow rate change is represented by equation [12]:

$$m^{o}_{s,out,c} = m^{o}_{v,a} + m^{o}_{s,in,c} \tag{2}$$

The regenerator component operates with heating water such that the temperature of the desiccant stream is elevated. This heated desiccant is brought into contact with an air stream. This air stream, called the scavenging air stream, carries away the desorbed water and is rejected back into the atmosphere.

The energy balance for the heating water in the regenerator is given by Eq. (3) [12] and accounts for the heat transfer between the heating water, the air and desiccant streams.

$$m^{o}_{hw} \times h_{hw,in} = Q^{o}_{hw,s} + Q^{o}_{hw,a} + m^{o}_{hw} \times h_{hw,out} \tag{3}$$

The thermal coefficient of performance of the regenerator is defined as the ratio of the amount of water desorbed from the solution expressed in terms of enthalpy to the amount of heat absorbed in the regenerator [12].

$$\mathrm{COP}_{reg} = m^{o}_{v,a} \times h_{fg} / m^{o}_{hw} C_{p\,hw} (T_{hw,in} - T_{hw,out}) \tag{4}$$

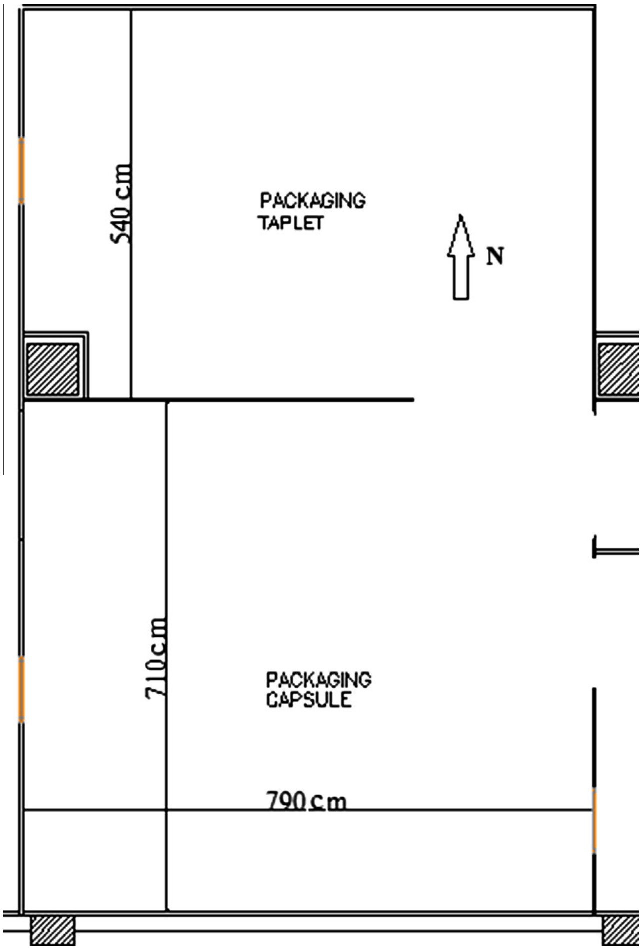

Figure 3 Schematic view of a packing area in a pharmaceutical factory.

2.2. Analyzing solar heating system

Sunlight, the zero-cost energy, is converted directly into heat energy by using evacuated tube solar collector modules. The efficiency of a solar thermal collector [13] is defined as the ratio of useable solar thermal energy per unit area (Q_u) to the total incident radiant energy on the collector (G_T) as shown in Eq. (5):

$$Eff_{Collector} = Q_U / A_C G_T \tag{5}$$

The usable solar thermal energy [13] is given by

$$Q_u = A_C F_R [S - U_L (T_i - T_a)] \tag{6}$$

where

A_C total collector array aperture or gross area.

U_L is the total heat loss coefficient of the collector.

F_R is the heat removal factor, equivalent to the effectiveness of a conventional heat exchanger.

3. Air conditions and case study model

In this research, the weather data measured at the Borg Al-Arab scientific city meteorological station were used. This station is located in the North of Egypt on the geographical coordinates of 31.22° North latitude, 29.92° East longitude and sea level altitude. One of these measured climatic data is the hourly solar radiation I (kW/m^2) which reaches its maximum values at noon. As a result of the increasing or decreasing solar irradiation, an auxiliary heating system must be used to insure 24 h operation. The Solar radiation and atmospheric air temperature are varied all around the year with the same behavior but with different magnitudes and the maximum values observed were in summer.

The case used in this study was a Tablet and Capsule packing area at Pharmaceutical Factory (Borg Al-Arab, Egypt). Fig. 3 shows a sketch of this area. This area has a 98.75 m^2 floor area. The factory wall consists of brick and other layers and the total thickness of each wall is 0.15 m. The indoor air conditions shall be 19 ± 2 °C dry bulb temperature and 50 ± 5% relative humidity. An Hourly Analysis Program (HAP) 4.7 was used to calculate the building cooling loads including wall, lighting, occupancy, and devices loads. The fresh air required for the ventilation is 20 air changes per hour. The internal loads were 10 person and 234 kW equipment load.

A beta prototype Calcium chloride (CaCl) desiccant air handling unit was used. This air handling unit can be modelled at full scale with proper consideration. A TRNSYS program was designed to analyze the solar liquid desiccant air conditioning system. The complete TRNSYS system model is shown graphically in Fig. 4.

4. Results and discussion

According to the model, it is required around 190 m^2 of evacuated tube with 5 m^3 storage tank to get 87 °C hot water temperature using reactivated CaCl solution. Also, flat plate collector can be used, but the area will be higher than evacuated tube approximately 300 m^2 with the same volume of storage tank to get the same temperature of hot water. According to the area, the evacuated tube was chosen to use. The effect of changing area of evacuated tube on different parameters was recorded. Fig. 5 represents the annual solar thermal energy entering to the system.

4.1. Effect of changing evacuated tube collector area

To study this effect, the evacuated tube collector area will be changed, while the difference between outlet and inlet processing air dry bulb temperature is approximately 3 °C. The following assumptions are considered when studying SLDAC system: Kinetic and potential energies are neglected. Each component is studied as a steady state control volume. All the flows through the heat exchangers are at constant pressure. No irreversibilities over the absorber and regenerator are disregarded. Inlet and outlet desiccant concentration through conditioner and regenerator will be 45%, 40%, 40%, and 45%, respectively. Amount of processing mass flow rate and scavenging mass flow rate are 9875 m^3/h, and 1900 m^3/h, respectively. Inlet and outlet cold and hot water temperatures assumed are 29 °C, 35 °C, 87 °C and 77 °C respectively. The effect of changing evacuated tube collector area on amount of water vapor absorbs and desorbs, and regenerator thermal C.O.P will be studied.

Fig. 6 exposes the relation of evacuated tube collector area vs. amount of absorbs water vapor, respectively. It can be observed that increasing evacuated tube collector's area does not affect the amount of absorbs water vapor, because it mainly depends on ambient conditions and the required humidity ratio. Fig. 7 shows the accompanying change in the amount of water vapor desorbed through the regenerator. According to the obtained results, it can be observed that increasing the evacuated tube collector's area leads to a slight increase in desorption rate and amount of desorbs water vapor, because of increasing the temperature of CaCl solution which leads to increase the density of the desiccant. Fig. 8 illustrates the relationship between the collector area and the inlet heating water temperature. It is seen that increasing evacuated tube area leads to increase inlet heating water temperature as a result of increasing the solar thermal energy. Also, Fig. 9 presents the effect of changing collector area on regenerator thermal C.O.P during the period from April to September. It is

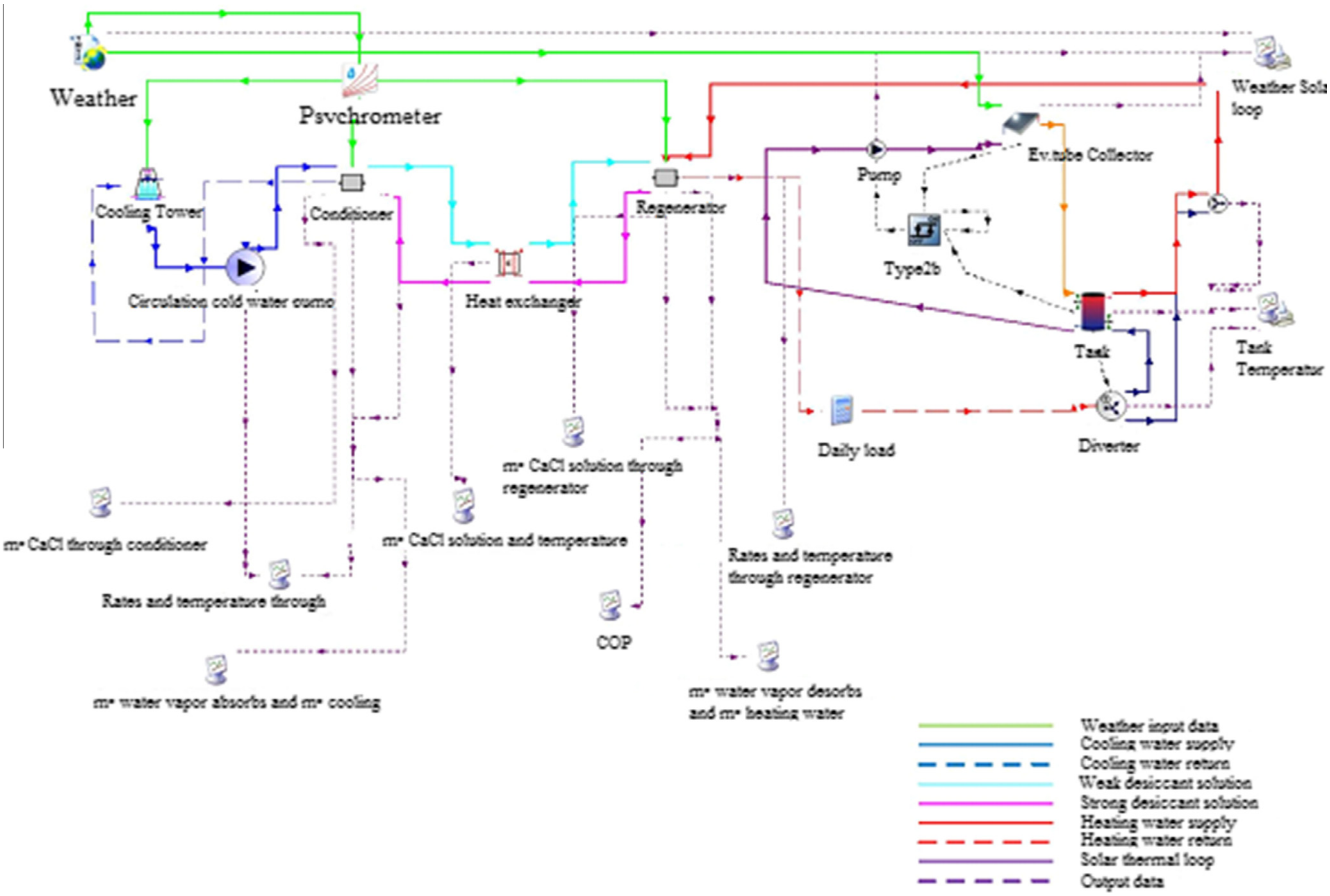

Figure 4 Schematic of TRNSYS model.

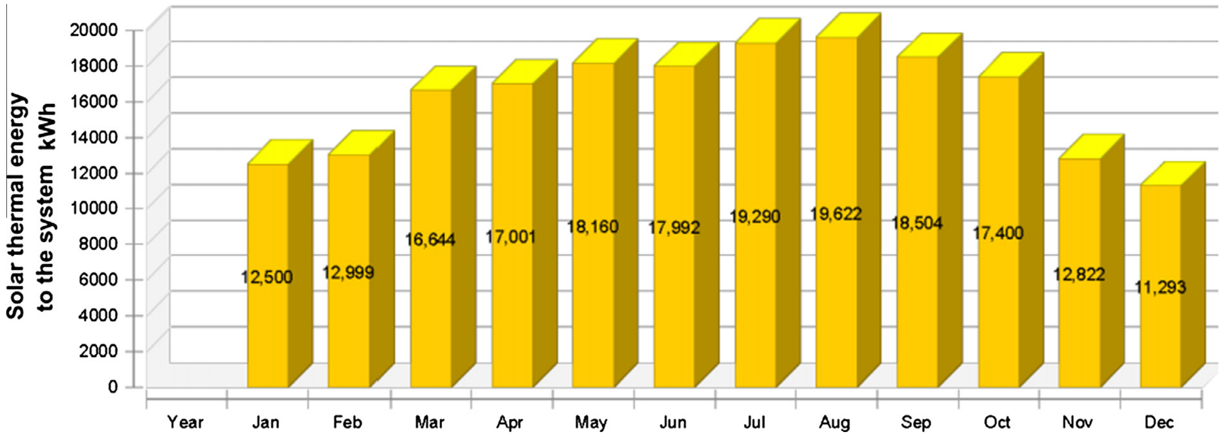

Figure 5 Annual solar thermal energy inlet to the system.

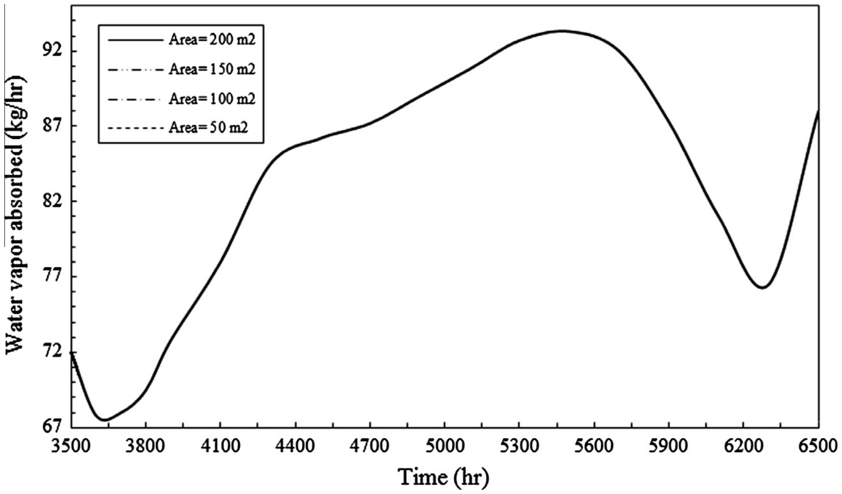

Figure 6 Effect of changing evacuated tube collector area on amount of absorbs water vapor.

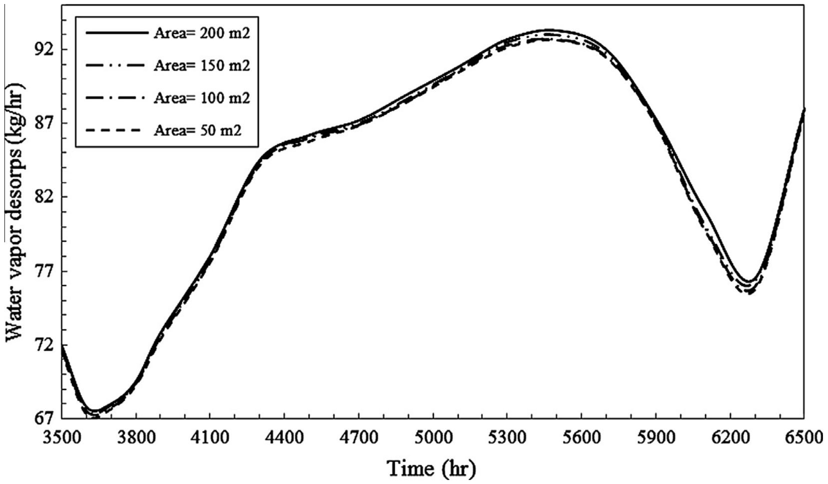

Figure 7 Effect of changing evacuated tube collector area on amount of desorbs water vapor.

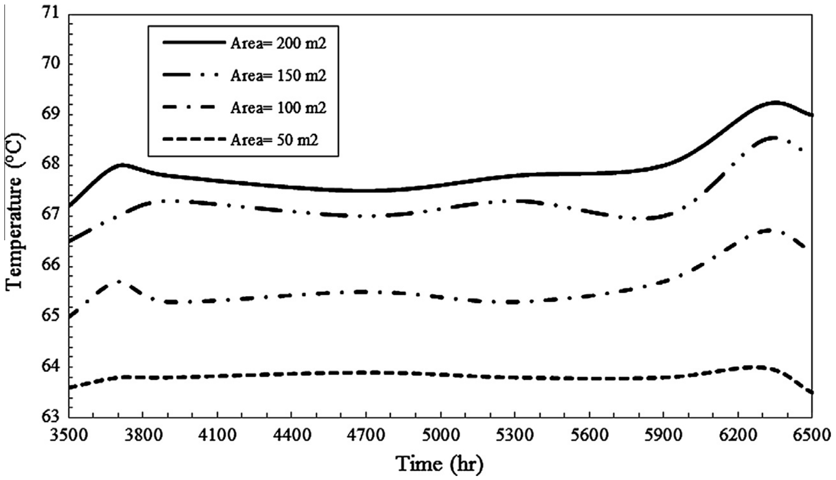

Figure 8 Effect of changing evacuated tube collector area on inlet heating water temperature.

seen that increasing solar collector area will increase the regenerator thermal C.O.P because of increasing the enthalpy of the water desorbed through regenerator, and the amount of heat absorbed in the regenerator.

4.2. Determination of annual saved energy and the annual energy consumption

The heat energy consumption in the regenerative process was calculated at different months. Eq. (3) is used to determine the required daily total heat consumption in regenerator (kW h/day). Also, Eq. (6) was used to calculate the daily total solar Energy (kW h/day) produced from the evacuated tube panels. This solar energy provides a part of the required regenerative energy.

For 220 m^2 evacuated tube collector area, Fig. 10 gives the annual total heat generated by the boiler for different months. As can be seen from the results according to the months, the highest and lowest required heat energies are respectively obtained as 38,286 kW h on December and as 30,652 kW h on June. According to the obtained results, the required heat decreases as the outside air temperature increases as a result of increasing the solar intensity. As shown in Fig. 11 the cumulative evacuated tube heat production is not enough to meet the cumulative regenerator heat consumption. For that a thermal energy produced from the boiler was needed. But using solar energy saved energy by 30.28% annual value.

5. Conclusion

The solar liquid desiccant air conditioning system, studied in this research, was investigated for various evacuated tube collectors and months in Borg Al-Arab city of Egypt. The following points can be noted from this research:

- In Borg Al-Arab city, the maximum hourly solar radiations happen on August and produce maximum solar energy with a magnitude of 19,622 kW h.
- In July and August, the water vapor desorbed in the regenerator is the highest during all the year.

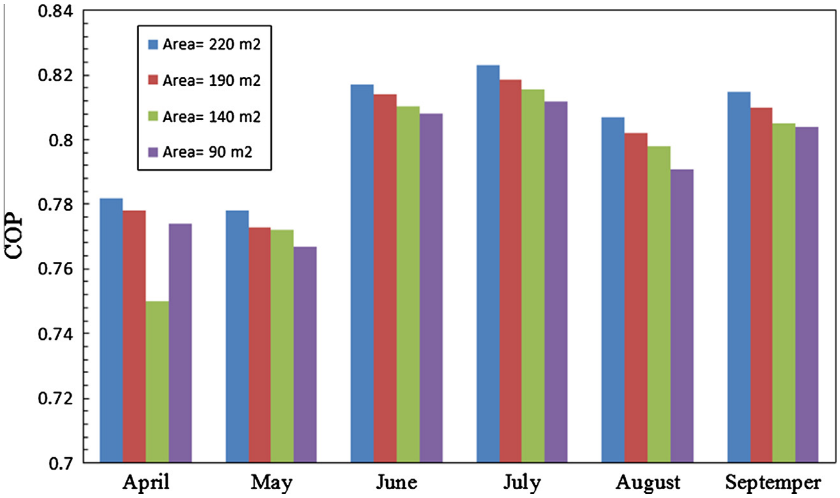

Figure 9 Effect of changing evacuated tube collector area on thermal regeneration C.O.P.

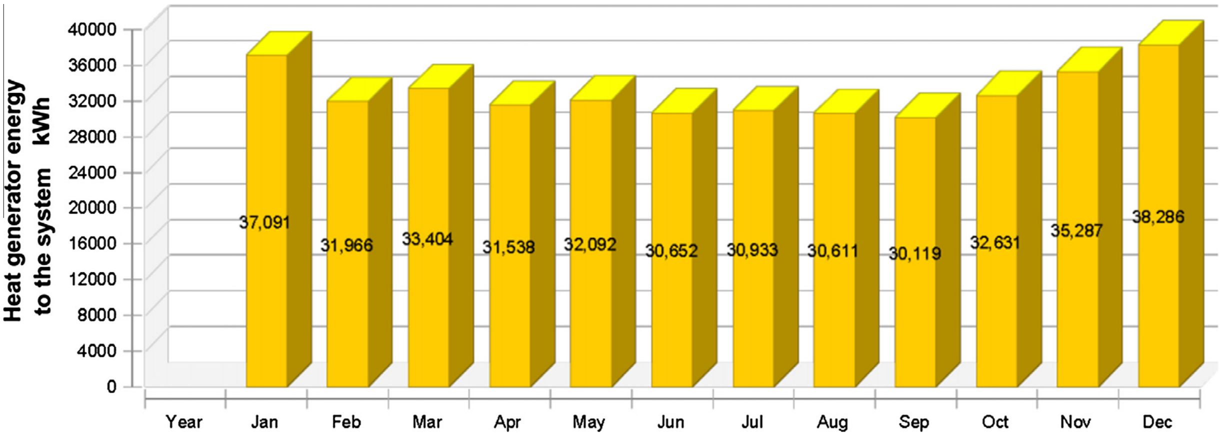

Figure 10 Annual heat generator energy.

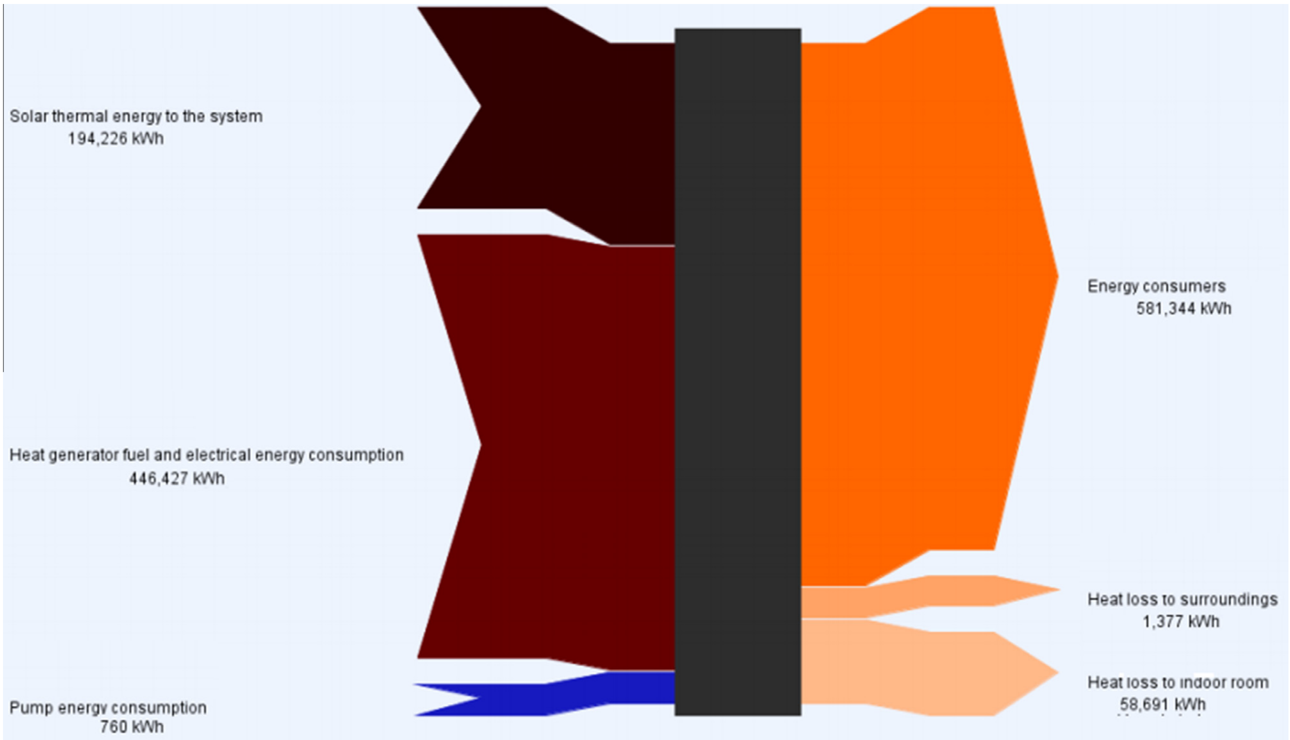

Figure 11 Energy flow diagram (annual balance).

- Changing evacuated tube solar collectors area has no effect on the amount of water vapor absorbed in the conditioner.
- The rate of water desorbed in regenerator of the SLDAC system increases as the solar collector area increases. According to the obtained results, this effect is small due to increasing CaCl density.
- Increasing the solar collector area will increase the regenerator COP which will also increase with increasing the outside temperature. The thermal COP reaches its maximum value in July.
- The thermal COP of the system for different liquid desiccant can be evaluated to determine the most suitable choice.
- Using SLDAC system will be more applicable as the result of lowering the cost of solar panels.
- Eventually, analyzing the obtained results from proposed SLDAC system driven by solar evacuated tube panel can successfully be operated in the selected province in Egypt.

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