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2015 J. Phys.: Conf. Ser. 596 012016

(http://iopscience.iop.org/1742-6596/596/1/012016)

Performance study of a heat recovery desiccant cooling system

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Abstract: The comparison between the experimental and theoretical simulations of a desiccant cooling system under various climatic conditions (outdoor temperature and relative humidity) on the system performance has been presented. The performance of the system is evaluated using Cooling Capacity (CC) parameter. The system under a typical summer day of hot and humid climate was tested. A remarkable decrease about 40-65% in the specific humidity and with a supply air temperature lower than 25°C of the proposed system was observed. The study is important and helpful to improve the effectiveness of this kind of liquid desiccant system in hot and humid places.

1. Introduction

The development of air conditioning to improve the living conditions leads to an increase in energy consumption with problematic effects on the environment. Therefore, in recent years the liquid desiccant cooling technology has been studied, focusing on applications such as cooling of human houses, commercial buildings and hospitals.

Liquid desiccant cooling system (LDC) is operated based on liquid desiccant, which has strong affinity to water to control air temperature, reduce humidity and provide high quality air. There are a lot of studies on the performance of LDC systems in different climatic conditions are carried.

Some of these studies have been carried out with hybrid liquid desiccant systems which eliminate the latent heat of vapor condensation before entering in the conventional air conditioning systems. Ma et al. [1] studied a combining system the system of desiccant cooling liquid and a solar system of adsorption.

Hellmann and Grossman investigated a novel cooling system which used a renewable energy such as solar energy [2].

Mei and Dai [3] gave a detailed account of the general features of the major desiccant dehumidification techniques and configurations of the related systems. They concluded that this kind of systems can realize the independent control of process air humidity and temperature, but it has the potential drawbacks which are big dimension and unstable operation.

Other systems comprise a dehumidifier and a regenerator working together to dehumidify and cool the fresh air entering to buildings. The liquid desiccant solutions are used a fluid of operation. Shuli Liu [4] studied a novel heat recovery/cooling system leads by a solar collector and a turn of cooling to carry out low energy cooling with the low emission of CO_2. This system is very useful for a hot and wet climate with the abundance of solar energy.

Grossman and Gommed [5,6] studied and examined a desiccant cooling system for solar cooling and dehumidification, the system including a novel Heat/Mass Exchanger (HME), is designed to be used as desiccant reserve of solution with the regenerator and the dehumidifier, allowing the mass transfer between them with losses thermal minimum of transfer and eliminates the need for exchanger of external heat of recovery. P. Mavroudaki and C.B. Beggs [7] reviewed the application of desiccant dehumidification cooling systems in northern Europe and concluded that there was potential to utilize these technologies in the southern European countries.

Nomenclature			
C	Specific heat capacity (J/kg.°C)	Subscripts	
CC	Cooling Capacity (W)	Cool	Cool
COP	Coefficient of performance	El	Electrical
M	Flow rate (kg/s)	Exp	Experimental
Q	Rate of heat transfer (W)	Heat	Heat
W	Humidity ratio (g/kg)	S	Dry air
Greek letters		Sol	Solution
Θ	Temperature (°C)	Theo	Theoretical

In this paper we present the comparison between a theoretical simulation and experimental results of the influence of climatic parameters in the coefficient of performance and cooling capacity of a desiccant cooling system. The project aims at assessing the effectiveness of this kind of a heat recovery/desiccant cooling technologies under hot and humid climate.

2. Description system

The liquid desiccant system is designed to serve as open-cycle absorption system that can operate with low grade solar heat. The system consists of six components: a dehumidifier, a regenerator, two heat exchangers (water-to-solution), a heat exchanger (solution-to-solution), and air-to-air heat exchanger, a schematic description of a system is given in Figure 1.

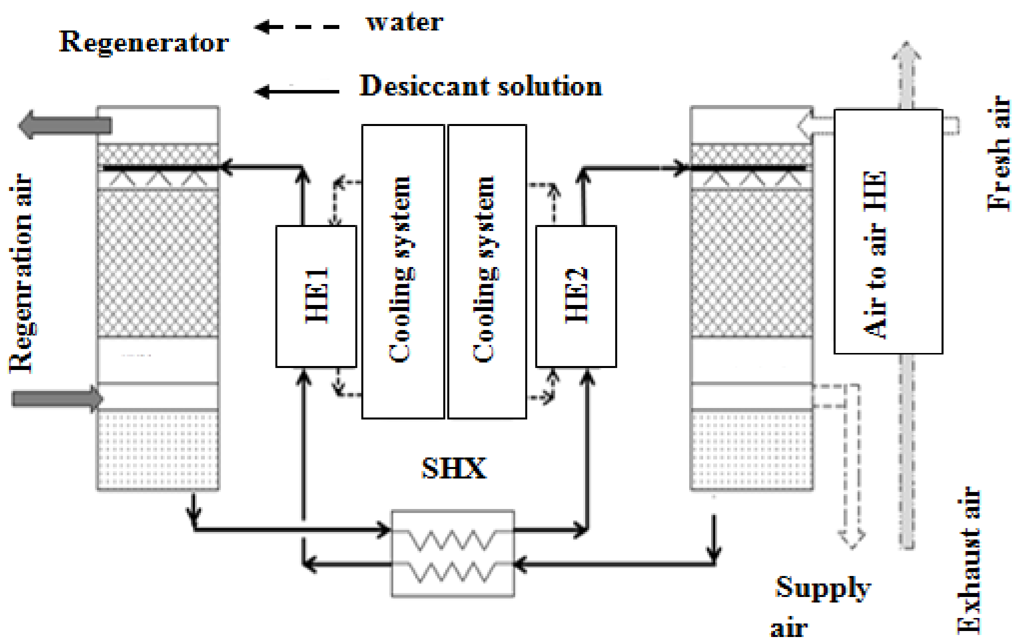

Figure 1. Description of liquid desiccant system.

When the fresh air enters the system, first it is cooled in the heat exchanger recovery (air-to-air heat exchanger), then it enters into the dehumidifier, it makes contact with the concentrated and cool liquid desiccant, where it is dehumidified and cooled.

The liquid desiccant cycle is started by pumping the solution at the bottom of the dehumidifier, passes through the solution to solution heat exchanger (SHX) to preheat it, then it is heated to attain regeneration temperature by solar energy, and finally sprayed in the regenerator to compress.

3. Theoretical analysis

Many researchers have developed mathematical models of the coupled heat and mass transfer processes in the dehumidifier or/and regenerator of most of models were solved numerically [4].
The output energy (cooling capacity CC) is energy reduction from the fresh air to supply air as shown in the following:

$$CC = m_{air} * C_s * \left(\theta_{freshair} - \theta_{\mathrm{supplyair}}\right) \quad (1)$$

The temperature of cooled water leaving the cooling system (cooling tower) is assumed to be lower than the solution temperature .entering in the heat exchanger (HE2). The heat transfer rate (**Q_{cool}**) transferred from the solution to the cold water is calculated:

$$Q_{cool} = m_{sol4} * C_{sol} * \left(\theta_{sol4} - \theta_{sol5}\right) \quad (2)$$

The temperature of heated water leaving is assumed to be higher than the solution temperature entering in the heat exchanger (HE1). The heat transfer rate (**Q_{heat}**) transferred from the hot water to the solution is calculated:

$$Q_{heat} = m_{sol1} * C_{sol} * \left(\theta_{sol2} - \theta_{sol1}\right) \quad (3)$$

Electrical energy (Qel) consumed in this system, we take the electrical consumption of the example of Shuli Liu system [4], which require a small amount of energy with the maximal value of about 500W (There are 6 pumps (30W) and 3 fans (100W)).

We present the coefficient of performance (COP) to describe the working performance of the global system. It is defined as the ratio between the cooling capacity and the total primary energy consumption in the whole liquid desiccant system. We taken the same equation used by Shuli Liu to compare the theoretical results with her experimental results. The COP of the whole system is:

$$COP = \frac{CC}{Q_{cool} + Q_{el} + Q_{heat}} \quad (4)$$

4. Numerical results

We present a comparison between the experimental results of Shuli Liu and our theoretical simulation of the heat recovery desiccant cooling system. The input conditions to the theoretical simulation were the same input values of experimental testing conditions used by Shuli Liu [4].

4.1. Influence of fresh air humidity

The experimental and the theoretical simulation were effectuated to examine the air humidity's influence on the cooling capacity and the coefficient of performance of the whole system.
The average cooling water temperature was equal to 16°C and the flow rate was 0.23kg/s. the average heating water temperature was equal to 63°C with the flow rate of 0.15kg/s. With the same fresh and return air flow rates were 509m^3/h and the fresh air temperature equal to 30°C, the testing and theoretical results indicate that the fresh air humidity have an effects in the CC of the system.
The results of the experimental and theoretical CC of the system are shown in Figure 2. When the fresh air humidity increases from 11.43g/kg to 16.84g/kg, it provoked the increase of the experimental **CC_{exp}** from 2.83 to 4.14kW [4] and the theoretical **CCt_{heo}** from 3.24 to 3.8kW.
The highest of CC values due to the increase of enthalpy difference between the fresh and leaving air from the system. The average CC difference percentage between the theoretical and the experimental results is 10%. This average difference percentage is acceptable for the whole system and it is caused by some simulation errors.

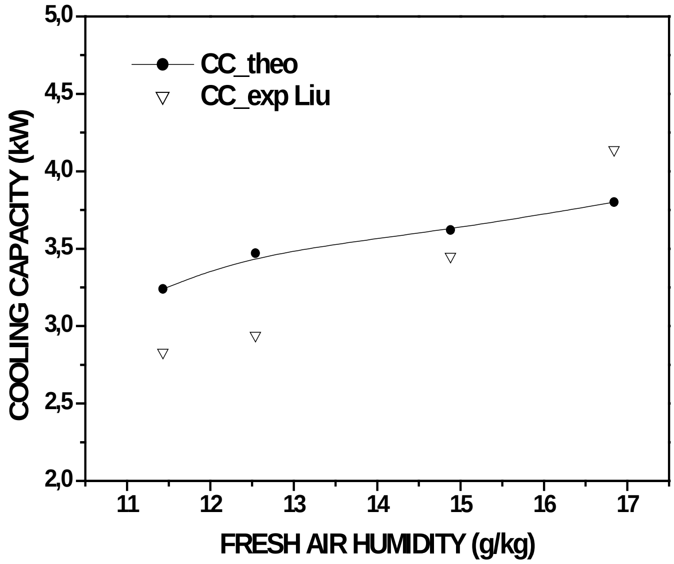

Figure 2. Influence of fresh air humidity on the cooling capacity.

4.2. Influence of fresh air temperature

The experimental and the theoretical simulation were carried to present the fresh air temperature's influence on the CC system. The average cooling and heating water temperature used in the experimental tests are 17°C and 61.5°C respectively. The fresh and return air flow rates were 509m^3/h and the cooling and heating water flow rates were 0.15kg/s and 0.16kg/s respectively [4].

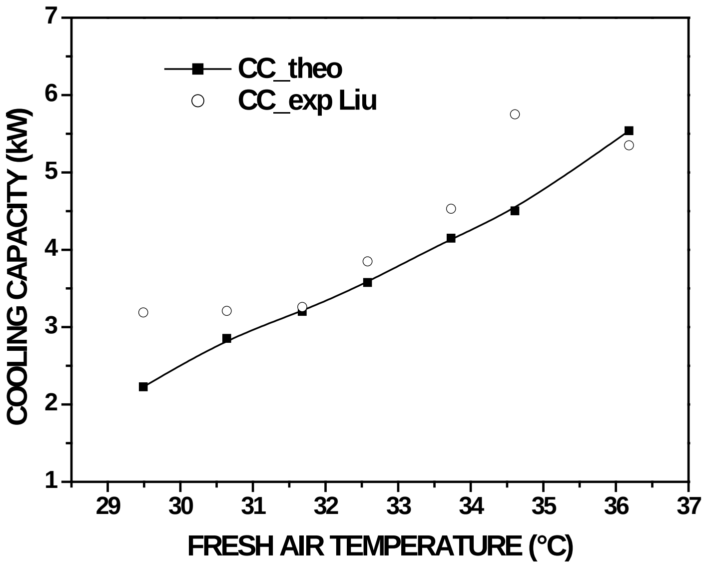

Figure 3. Influence of fresh air temperature on the cooling capacity.

In Figure 3, The experimental and theoretical results show that the CC of the system increase when the fresh air temperature increase, the highest fresh air temperature from 29.5°C to 36.18°C resulted the increase of the theoretical $\mathbf{CC_{theo}}$ of the system from 2.22kW to 5.53kW and the highest value of experimental $\mathbf{CC_{exp}}$ are about 5.35kW respectively are shown in Figure 3.
This increase is due to difference between the air enthalpy at the inlet and outlet of the dehumidifier in the whole system. According to these results, the liquid desiccant system is efficient in the hot and humid climates. The theoretical simulation results indicate the same increase in the experimental test with an average CC difference percentage is 14.5%.

4.3. Typical summer day results

The experimental and theoretical results show that this kind of system is very efficient in the hot and humid climate. Tunisia is situated on the Mediterranean coast of North Africa; it lies between latitudes 30° and 38°N, and longitudes 7° and 12°E [8]. It has a high level of solar power with an average direct irradiation which varies from 2 kWh/m^2 /d in the extreme north to 6 kWh/ m^2/d in the zones of the extreme south [9]. Tunisian climate characterized by a hot and humid climate in the summer. In this part we test the system under a summer Tunisian day.
Figure 4 presents the solar radiation and ambient (fresh) air temperature of a sunny day representative in the August month chosen from data file. In summer, it is expected that the temperature of the fresh humid air that enters the cooling system is higher than the inlet air temperature in the build. At 13h, the ambient air temperature is about 40°C with a humidity ratio equal to 23.9 g/$kg_{dry\ air}$ and a global solar radiation is more than 800 W/m².

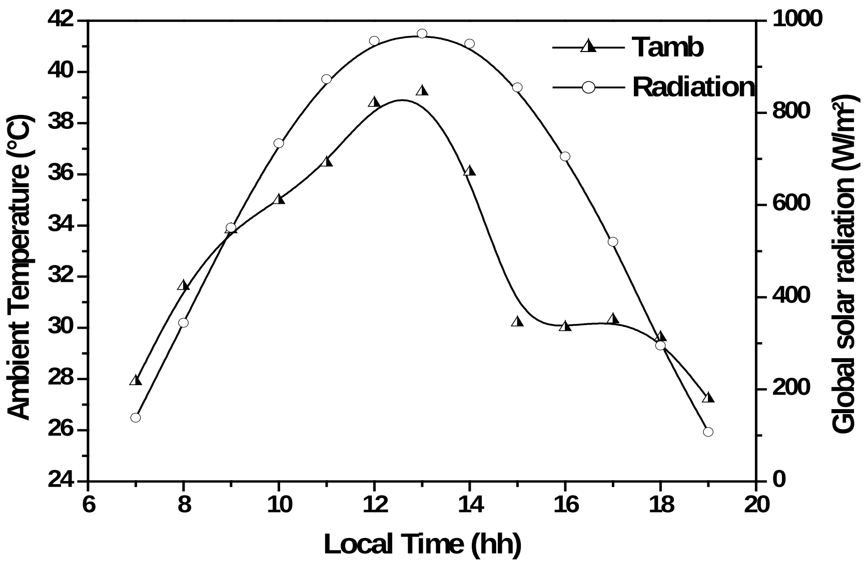

Figure 4. The solar radiation and ambient air temperature of a summer Tunisian day.

Figure 5 shows the air specific humidity at the inlet (fresh air) and outlet (supply air) of the cooling system under the indicated summer climatic day. The air specific humidity decreased between 40-65 %, this deference between inlet and outlet is proportional to moisture transfer during an air dehumidification process.

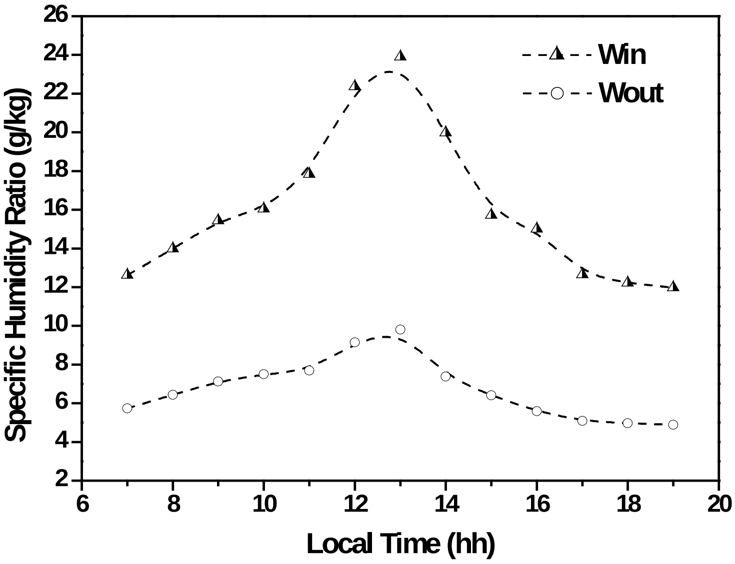

Figure 5. Air specific humidity at the inlet and outlet of the cooling system.

The air temperature at the inlet (fresh air) and outlet (supply air) of the cooling system under the indicated climatic conditions are shown in Figure 6. The supply air temperature is expected to lower than the summer comfort condition (25°C) due to the contact of the air stream with the cool and strong desiccant solution. This is confirmed with the experimental data [4].

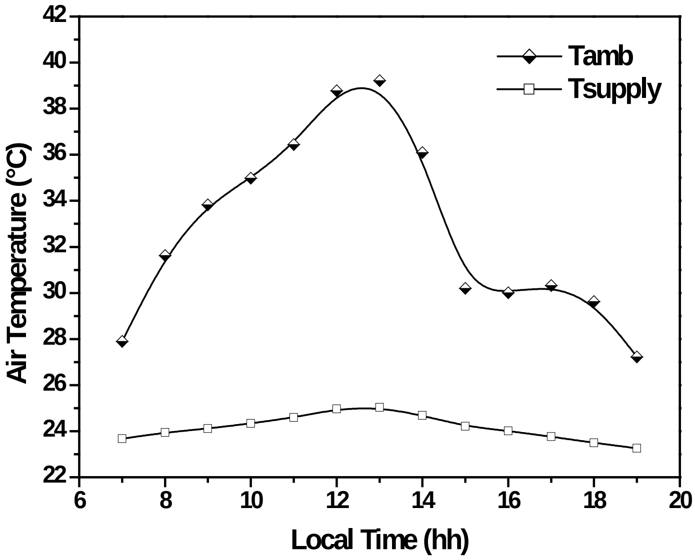

Figure 6. Air temperature at the inlet and outlet of the cooling system.

5. Conclusion

The objective of this study is to present a comparison between a theoretical simulation and experimental results of a desiccant cooling system which is efficient and can be very useful in the hot and humid climatic

Journal of Physics: Conference Series **596** (2015) 012016 doi:10.1088/1742-6596/596/1/012016

conditions. This comparison is to validate the simulation results of the proposed system. The simulation results show the influence of the climatic parameters (Fresh air temperature and Fresh air humidity) in the cooling capacity (CC) with acceptable percentage deference between the experimental and theoretical results. We test the system under a typical summer day of a hot and humid place (Tunis, Tunisia) and we conclude that the system can be a sustainable solution to operate in the Tunisian climate and the theoretical simulation should be followed by an experimental work under real conditions to prove the theoretical results and to improve the economic side of system in terms of energy efficiency.

References

[1] Ma Q, Wang R Z, Dai Y J, Zhai X Q 2006 *Energ. Build.* **38** 447-453
[2] Hellmann H M and Grossman G 1995 *Int. J. Refrig* **18** 177-189
[3] Mei L, Dai Y J 2008 *Renew.and Sust. Ener. Rev.* **12** 662-689
[4] Shuli Liu 2008 Thesis "A Novel Heat Recovery/Desiccant Cooling System" University of Nottingham.
[5] Gommed K and Grossman G 2012 *Int. J. of Refrig.* **35** 676-684
[6] Gommed K and Grossman G 2007 *Sol. Ener.* **81** 131-138
[7] Mavroudaki P, Beggs CB, Sleigh P A and Halliday S P 2002 *Appl. Ther. Eng.* **22** 1129-1140
[8] National Agency for Energy Conservation Tunisia (NAEC), http://www.anme.nat.tn.
[9] United Nations (UN), Office for Africa of north, the renewable energy sector for North Africa situation current and perspective Economic commission on Africa (ECA). p32, September2012.