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Original scientific paper*

LIQUID DESICCANT SYSTEM; EVAPORATIVE COOLING SYSTEM; HEAT RECOVERY; AIR CONDITIONING; ROTARY DEHUMIDIFIER

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Abstract. *The rise in global temperatures caused by both natural and human factors—particularly the widespread use of fossil fuels—poses a serious threat to the environment and human health. Alongside environmental challenges, conventional air conditioning systems have proven inefficient due to high energy consumption and low performance in humidity control, especially in hot and humid regions. One innovative approach to reducing energy consumption and increasing efficiency is the use of absorption cooling systems, which absorb air moisture using liquid or solid sorbents and regenerate them using renewable heat sources such as solar energy. In this study, the performance and modeling of absorption cooling systems with different configurations of flat membrane and shell-and-tube heat exchangers were investigated. The main goal is to identify the best sorbent and system configuration to achieve maximum efficiency under similar climatic conditions. Predicted simulations show that the absorption cooling system provides an average total cooling capacity of 2.12 kW, with an overall coefficient of performance (COP) of 0.44 and a collector efficiency of 49% (based on absorber surface area).*

Key words: *liquid desiccant system, evaporative cooling system, heat recovery, air conditioning, rotary dehumidifier.*

1. INTRODUCTION

In recent years, reducing energy consumption and optimizing the performance of drying systems using evaporative and absorption cooling technologies have become a key priority in energy and environmental research. Evaporative cooling systems, especially in

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hot and dry regions, can consume 50 to 80 percent less energy compared to compression cooling systems without significantly compromising thermal performance. For example, Riangvilaikul and Kumar [1] designed a hybrid solar desiccant equipped with an indirect evaporative cooler, which lowered the air temperature entering the desiccant from 37.3°C to 30.2°C, while the desiccant temperature only decreased from 52.2°C to 49.1°C, demonstrating the positive impact of the indirect cooler in maintaining drying conditions. In a similar study, Parmar and Hindoliya [2] evaluated the system's performance in five Indian cities and found that the system's efficiency increased up to 51.4% under optimal conditions. Katejanekarn and Kumar [3] replaced the evaporative cooler with a heat exchanger, successfully reducing the dry air temperature entering the desiccant to about 27.9°C and creating optimal drying conditions. Kasza et al. [4] simulated and developed two different models of evaporative cooling drying systems operating in ventilation and circulation cycles in Miami. The results show that for regenerating the drying cycle, 95% of the energy can be obtained from solar energy using a 45-square-meter collector for the system based on the ventilation cycle. Uckan et al. [5] presented initial experimental results of a drying system based on evaporative cooling for hot and humid climatic conditions. The evaporative cooler used by Uckan and colleagues in their experiments was of the indirect type. Results showed that the ambient air temperature was reduced from 31°C to 19°C, and a continuous supply of air at 25°C could be maintained in the confined space. Furthermore, Bellemo [6] numerically investigated the cooling point of an evaporative refrigerator, also known as an indirect evaporative cooler, which is part of the drying cooling system. They studied its performance for various air mass flow rates, inlet air conditions, and rotation ratios. The results showed that increasing the ratio of primary to secondary airflow from 1.5 to 2.5 can boost cooling capacity by up to 20%. In another study, Pierrès et al. [7] implemented a solar drying system with evaporative cooling in the semi-humid climate of France, achieving up to a 60% reduction in the system's cooling energy demand. Ouazia et al. [8] examined the performance of a solar water absorption system in a residential building in Tunisia, finding that the sorbent water temperature reached about 75°C and provided effective cooling with minimal energy input. Alizadeh [9,10] proposed a liquid desiccant refrigeration system in connection with an indirect evaporative refrigeration system. It is a plate heat exchanger with a counterflow arrangement consisting of several air-water and desiccant plates separated by thin plastic sheets. These thin sheets provide the contact surface for heat and mass transfer between the air-water and the desiccant. The secondary air, which is cooled by direct evaporative refrigerant, is in contact with the water on the other side of the separating plate. The cooled secondary air removes heat from the primary air stream on the opposite side of the plate, thereby enabling the use of indirect evaporative refrigerant. The primary air is simultaneously dehumidified by the desiccant sprayed onto the cross-flow contact surface. The performance of the proposed model was observed theoretically and then experimentally under the climatic conditions of Brisbane, Australia. It was concluded that the efficiency of the evaporative refrigerant can reach up to 75% at a heat exchanger angle of 45 degrees. However, compared to conventional cooling systems, this technology has not developed on a production scale. This research aims to model and analyze the performance of moisture-removal drying systems powered by solar energy, using a combined approach of thermodynamic modeling, numerical analysis, and simulation of heat and mass transfer in various liquid and solid drying system configurations.

2. RESEARCH METHODOLOGY

This research focuses on various designs of moisture absorption systems that can be regenerated using solar energy. The performance of the solar desiccant cycle depends on the solar collectors and the desiccant cycle. Mathematical modeling of the desiccant cycle is required to improve performance by using new designs at low regeneration temperatures, which can be easily achieved using solar energy. The analysis of these systems requires the application of thermodynamic and heat transfer concepts. The load and performance of air conditioning systems include both sensible and latent loads. The air conditioning unit must control the sensible and latent loads inside the building with the goal of providing comfort. These two components of the load are expressed by the sensible heat ratio, which is the ratio of the sensible load to the total load (sensible load+latent load). Lower values of the sensible heat ratio indicate a higher amount of latent cooling load.

$$\text{Sensible heat ratio} = \frac{\text{Sensible heat}}{\text{Sensible heat} + \text{Latent heat}} \tag{1}$$

In compressed vapor air conditioning systems, about 75% of the capacity is used to control the sensible load and 25% for the latent load, and comfort conditions are only achieved when the sensible heat ratio is above 0.75. Moisture control in these systems is done through condensation, which requires lowering the temperature and causes overcooling of the air followed by reheating, reducing the system’s performance. Desiccant cooling systems offer advantages such as significant energy cost reduction, the use of free energy sources like solar energy, no greenhouse gas emissions, and independent and effective control of sensible and latent loads. These systems can operate with either solid or liquid desiccants, with liquid types offering greater benefits due to their ability to regenerate at low temperatures, enabling more effective use of renewable energy sources. In this study, a rotary liquid desiccant dehumidifier and a desiccant cooling system based on the ventilation cycle are proposed, aiming to reduce the regeneration temperature and improve air conditioning performance. To evaluate the performance of different absorbents, the input parameters for each dehumidifier under identical climatic conditions are presented in Table 1.

Table 1 Geometric and operational parameters

Parameter	Value
Input operating air temperature (°C)	50
Regeneration input air temperature (°C)	75
Humidity ratio of the Regeneration input air (kg_v/kg_n)	0.025
Humidity ratio of the input operating air (kg_v/kg_n)	0.025
Flow rate of input operating air per unit area ($kg/(s.m^2)$)	3.5
Regeneration input air flow rate per unit area ($kg/(s.m^2)$)	1.2
Width of the dehumidifier (m)	0.12
Desiccant	Calcium Chloride Silica gel Lithium Bromide

	Lithium Chloride

In this study, the liquid moisture absorption system is examined in the form of a plate membrane exchanger and a shell-and-tube membrane exchanger. The shell-and-tube exchanger has a radius R and a width L, and its rotor includes narrow slots that are uniformly distributed across the cross-section (Fig. 1). These slots are covered with porous media impregnated with a drying solution. The flows of process air and regenerated air move in opposite directions in two separate sections of the system.

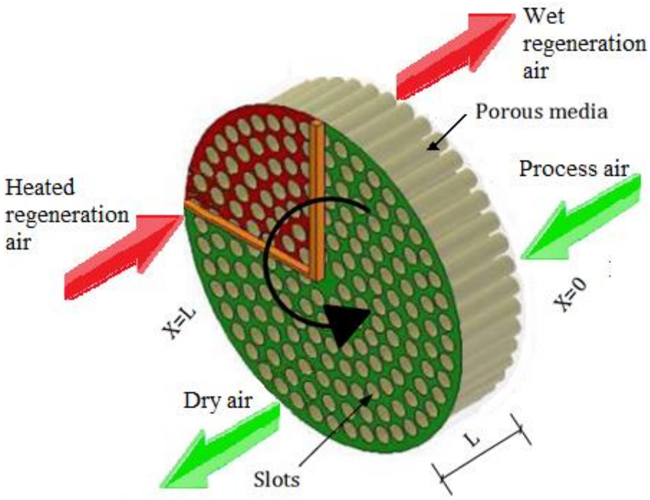

Fig. 1 A schematic diagram of the rotary liquid desiccant dehumidifier

For the target modeling, the slot is divided into nodes (Fig. 2), and mass and energy balance equations for the air flow and the desiccant surface have been developed to determine the air outlet conditions based on the following assumptions:

1- The air flow in the dehumidification and regeneration zones is uniformly turbulent
2- Axial heat transfer and mass diffusion are neglected
3- It is assumed that no desiccant solution is present in the flow
4- Thermodynamic properties are assumed constant
5- Each slot is considered adiabatic

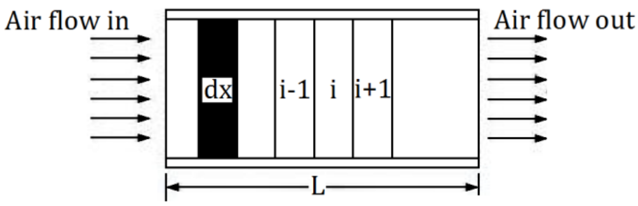

Fig. 2 Flow pattern in a slot

In this model, the process air is in direct contact with the desiccant surface, and due to the higher partial vapor pressure in the moist air compared to the desiccant surface, water vapor is absorbed from the air by the desiccant. This process releases heat, causing the desiccant temperature to rise, which increases the vapor pressure at the desiccant surface and reduces the dehumidification efficiency. The governing equations are given as follows [11]:

Mass balance equation for moist air

$$A_c \rho_a L\left(\frac{\partial \omega}{\partial t}+u\frac{\partial \omega_a}{\partial x}\right)=kA_h\left(\omega_s-\omega_a\right) \tag{2}$$

Mass balance at the desiccant surface

$$\rho_d A_c L\left(\frac{\partial \omega_s}{\partial t}+\frac{\partial \omega}{\partial t}\right)=kA_h\left(\omega_s-\omega_a\right) \tag{3}$$

Energy balance equation for air:

$$A_h C_{pa}\rho_a L\left(\frac{\partial T_a}{\partial t}+u\frac{\partial T_a}{\partial x}\right)=h_t A_c\left(T_s-T_a\right)+C_{pv}kA_c\left(\omega_s-\omega_a\right)\left(T_s-T_a\right) \tag{4}$$

Energy balance at the desiccant surface

$$A_h C_{pd} A_h \rho_d L\left(\frac{\partial T_s}{\partial t}\right)=h_t A_c\left(T_a-T_s\right)+kA_c\left(\omega_a-\omega_s\right)h_{fg}+C_{pv}A_c\left(\omega_a-\omega_s\right)\left(T_a-T_s\right) \tag{5}$$

Desiccant surface moisture

$$\omega_s=\frac{0.0622P_v}{1.0133\times 10^5-P_v} \tag{6}$$

Saturation vapor pressure at the desiccant surface

$$P_v=e^{\left(28.196-\frac{3816.44}{T_s-46.14}\right)} \tag{7}$$

Dehumidification capacity of the system

$$M=\dot{m}_p\times\left(\omega_{a,i}-\omega_{a,o}\right) \tag{8}$$

Coefficient of Performance (COP) of the system

$$DCOP=\frac{\dot{m}_p\times h_{fg}\times\left(\omega_{a,i}-\omega_{a,o}\right)}{\dot{m}_v\times\left(h_v-h_{amb}\right)} \tag{9}$$

Sensible Heat Ratio (SHR)

$$SER = \frac{\dot{m}_p \times (T_{a,o} - T_{a,i})}{\dot{m}_v \times (T_v - T_{amb})} \quad (10)$$

This study examines the performance of a refrigeration drying system based on a ventilation cycle (Fig, 3). In this system, the moisture in the air is first absorbed by the drying cycle (process 1-2). Then, the warm and dry air is cooled by a heat exchanger in the heat recovery unit using cold air (process 2-3). The air passes through an indirect refrigerant, where its temperature decreases to meet the room's cooling requirements (process 3-4). The dry and cooled air is then delivered to the room to provide comfort conditions (process 4-5). The return air from the room passes through a direct vapor refrigerant to lower its temperature and is used in the heat recovery cycle (process 5-6). Heat is exchanged between the cooled regenerated air and the hot air (process 6-7). Next, part of the operational air passes through a heater while the remainder is warmed by a solar collector (process 7-8). Finally, the dryer is regenerated using the hot air, and the absorbed moisture is expelled so the cycle can repeat (process 8-9).

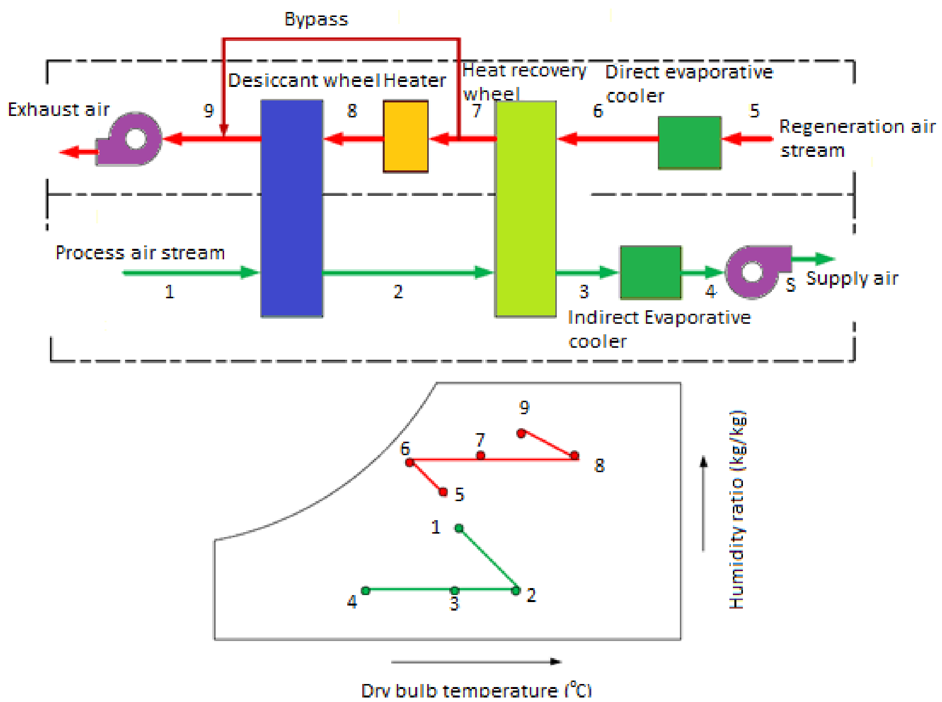

Fig. 3 Solid desiccant cooling systems and psychrometric processes

3. FINDINGS AND DISCUSSIONS

The results of the numerical simulation were compared with reference data [12]. The maximum deviation in the sensible heat ratio under various inlet air conditions was 1.9%, and up to 13.3% among different mass flow rate ratios (Fig. 4). This agreement indicates the accuracy and reliability of the developed numerical model in predicting the thermal behavior and performance of the absorption cooling system under real conditions.

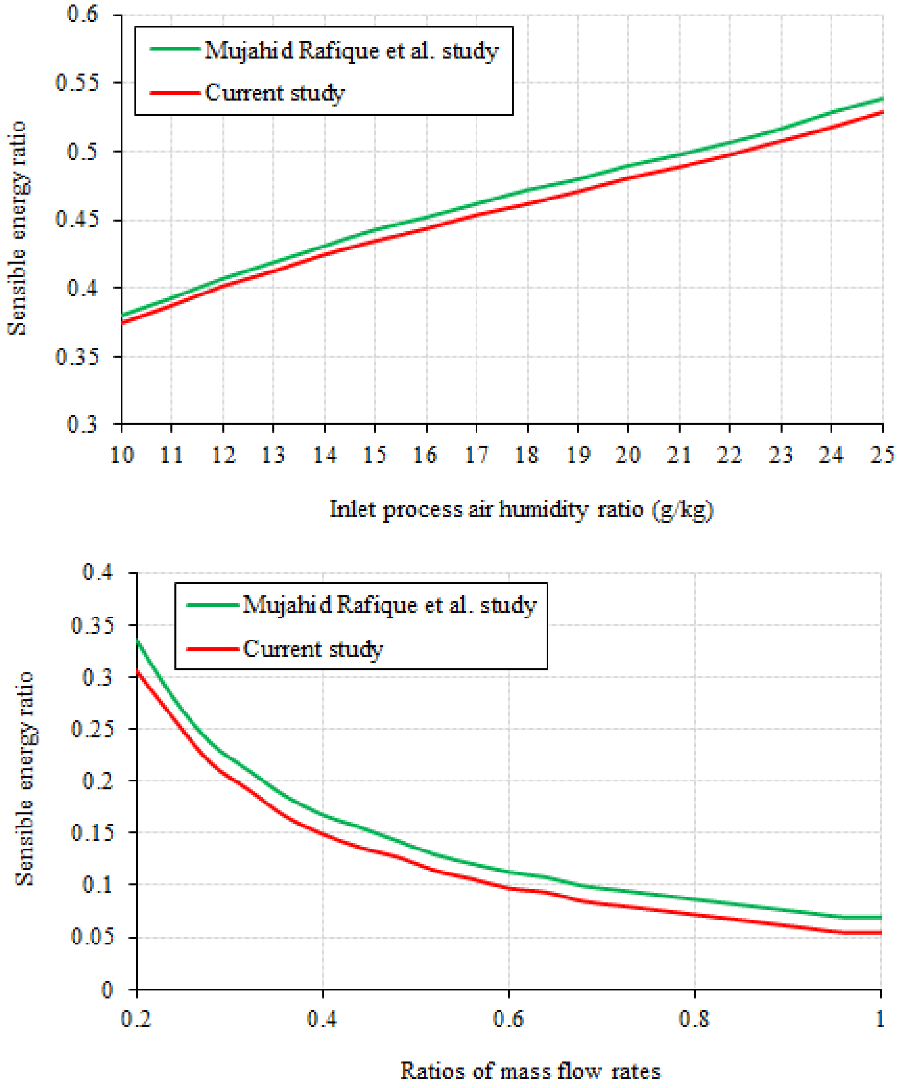

Fig. 4 Change in the sensible heat ratio for different inlet air conditions and various mass flow rate ratios in the model by Mojahed Rafigh et al. [12] and the recent study

The heating and cooling equipment sizes were initially estimated for both solar and non-solar systems. Monthly cooling and heating energy demands for these systems are shown in Fig. 5 and the results indicate that solar systems require less cooling and heating energy. This is due to the reduced humidity and temperature of the conditioned air, which leads to lower energy demand in the drying process. A comparison among three cities shows that the required capacity for solar systems is lower than that of non-solar systems, highlighting the significant energy savings achievable through the use of solar energy in thermal systems.

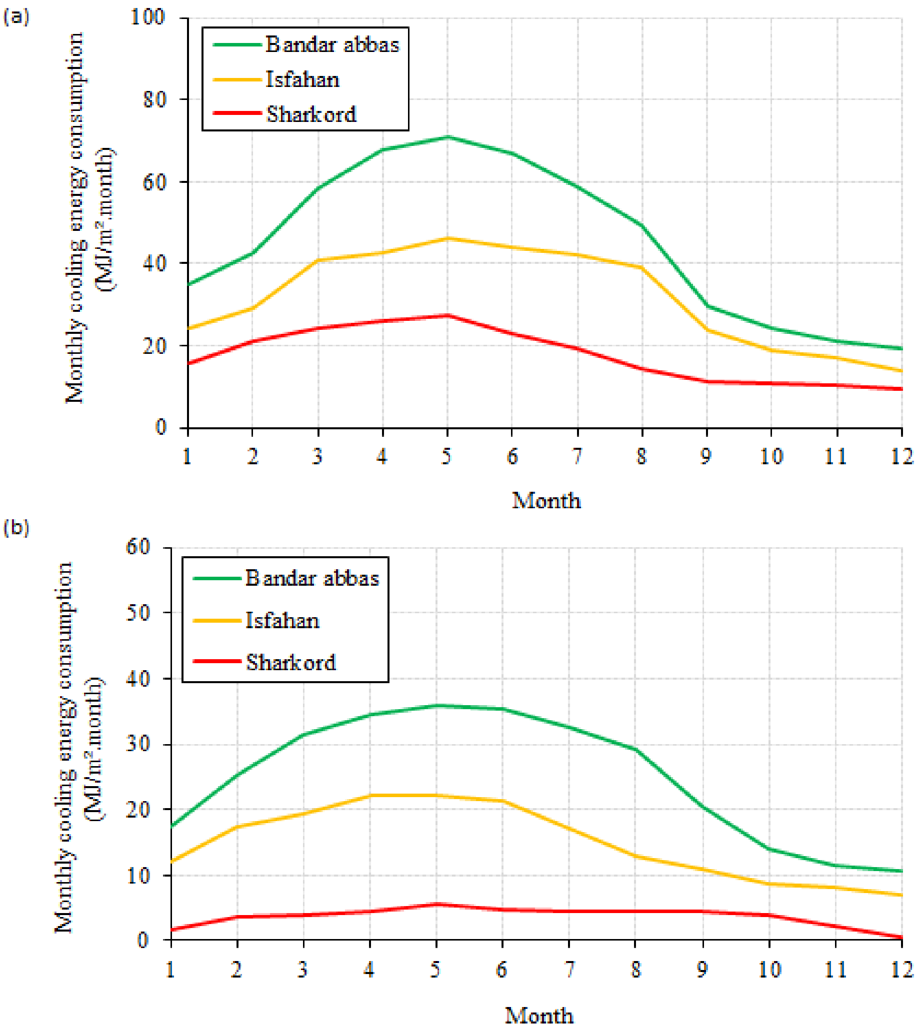

Fig. 5 The annual cooling energy requirements for (a) non-solar and (b) solar systems

Figure 6 shows that dilution enthalpy depends more on salt concentration than on temperature. The saturation limit of salt concentration is 36.9%, and exceeding this value leads to salt crystallization and system performance issues. In the numerical model, the concentration is limited to this value, and crystallization is not considered. Additionally, the absorption and desorption enthalpy of the salt solution is greater than the latent heat of pure water, and as the salt concentration decreases, the solution enthalpy also decreases. Cooling and heating water play a key role in transferring this energy.

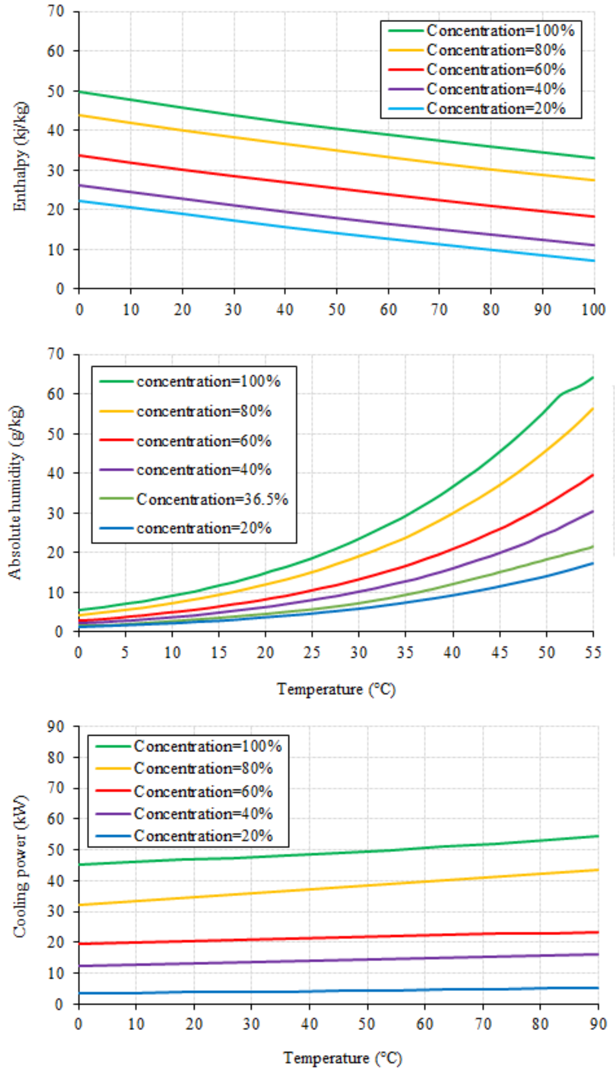

Fig. 6 Enthalpy changes, relative humidity, and cooling capacity as a function of temperature for different solution concentrations

In this study, the performance of a solar absorption cooling system was simulated over a 20-day period during the summer of 2020, from 8 a.m. to 6 p.m., in three cities: Isfahan, Bandar Abbas, and Shahrekord (Fig. 7).

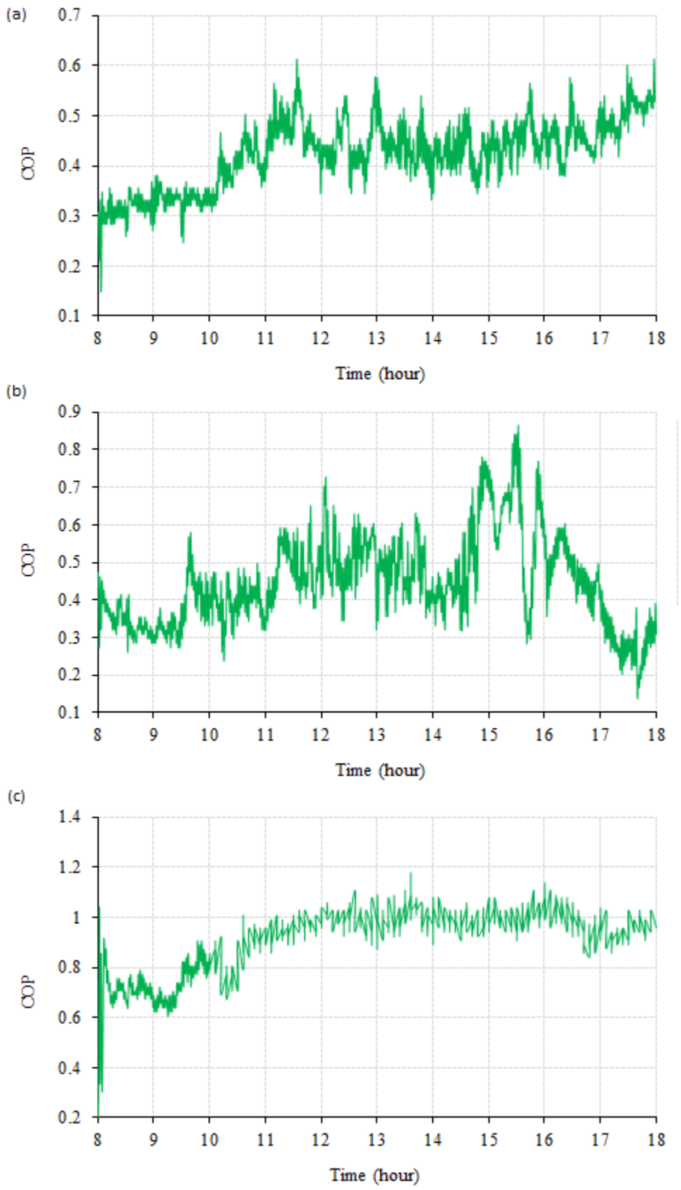

Fig. 7 Variation of the coefficient of performance for the time range from 8 a.m. to 6 p.m. in (a) Bandar Abbas, (b) Isfahan, and (c) Shahrekord

The results showed that under the hot and humid conditions of Bandar Abbas, the system's average cooling capacity was 2.31 kW, with a thermal coefficient of performance (COP) of 0.53. In Isfahan, which has a dry and moderate climate, the thermal COP reached 0.6, and in Shahrekord where cooling is only needed in summer — the electrical COP recorded was 1.0. A relative humidity above 66.9% required the regenerator to remain active for most hours of the day, slightly increasing the hot water load. During midday hours, solar energy provided the majority of the cooling demand, and collector efficiency reached up to 53%. However, the overall system efficiency was only 1.40%, primarily due to heat losses in piping and storage tanks.

4. CONLUSIONS

This study investigated the performance of a solar absorption cooling system, focusing on the concentration of the absorbent material and the climatic conditions of three cities in Iran: Bandar Abbas, Isfahan, and Shahrekord. The results showed that installing a solution-to-solution heat exchanger can reduce cooling and heating loads by up to 26%. Increasing the solution temperature entering the regenerator or decreasing it at the dehumidifier improves moisture removal. Economically, the proposed solar absorption cooling system consumes 19% less primary energy and has a 12% lower life cycle cost compared to conventional air conditioning systems; with the addition of an energy recovery ventilator, these figures improve to 32% and 21%, respectively. Utilizing solar heating for solution regeneration alongside a natural gas boiler as backup was identified as the most technically and economically optimal configuration. In simulations conducted over a 20-day period under various climatic conditions, system performance was evaluated. In Bandar Abbas, the average cooling capacity was 14.4 kW with a thermal COP (coefficient of performance) of 0.48, while Isfahan showed a COP of 0.58. In Shahrekord, the system performed effectively only during the summer months. The daily cooling capacity ranged from 2.9 to 2.17 kW, and the overall system COP was approximately 0.6. The results indicated that the solution inlet temperature to the regenerator and dehumidifier were the most critical parameters for matching capacity, improving efficiency, and enhancing dehumidification. Additionally, using a solar heat source with a minimum temperature of 70°C can result in significant energy savings, although an effective storage system is required to compensate for the intermittent nature of solar energy.

REFERENCES

1. Riangvilaikul, B., Kumar, S. 2010, *An experimental study of a novel dew points evaporative cooling system*, Energy and Buildings 42(5), pp 637-644.
2. Dhananjay, P., Soni, N. 2017, *Review on study of waste heat utilization techniques in vapour compression refrigeration system,* International Research Journal of Engineering and Technology 4(7), pp 2033-2039.
3. Thosapon, K., Chirarattananon, S., Kumar, S. 2009, *An experimental study of a solar-regenerated liquid desiccant ventilation pre-conditioning system,* Solar Energy, 83(6), pp 920-933.

4. Kasza, I., Adler, D., Nelson, D.W., Yen, C.L.E., Dumas, S., Ntambi, J.M., Alexander, C.M. 2019, *Evaporative cooling provides a major metabolic energy sink,* Molecular metabolism, 27, pp 47-61.
5. Uçkan, İ., Yılmaz, T., Hürdoğan, E., Büyükalaca, O. 2014, "*Exergy analysis of a novel configuration of desiccant based evaporative air conditioning system*, Energy Conversion and Management, 84, pp 524-532.
6. Bellemo, L. 2017, *Analysis of a solid desiccant cooling system with indirect evaporative cooling*. Technical University of Denmark.
7. Le Pierrès, N., Leroux, G., Wurtz, E. 2021, *Eco-efficient evaporative and ground-coupled system with terra-cotta evaporative walls,* In Eco-efficient Materials for Reducing Cooling Needs in Buildings and Construction, pp. 117-138.
8. Ouazia, B., Barhoun, H., Haddad, K., Armstrong, M., Marchand, R. G., Szadkowski, F. 2009, *Desiccant-evaporative cooling system for residential buildings*. In 12th Canadian Conference on Building Science and Technology, pp. 1-12.
9. Alizadeh, H.R., Mortezapour, H., Akhavan, H.R., Balvardi, M. 2021, *Physicochemical changes of barberry juice concentrated by liquid desiccant-assisted solar system and conventional methods during the evaporation process*. Journal of Food Science and Technology, 58(11), pp 4370-4381.
10. Alizadeh, H., Ghasempour, R., Shafii, M. B., Ahmadi, M. H., Yan, W. M., Nazari, M. A. 2018, *Numerical simulation of PV cooling by using single turn pulsating heat pipe,* International Journal of Heat and Mass Transfer, 127, pp 203-208.
11. Abdel-Salam, A. 2015, *A novel liquid desiccant air conditioning system with membrane exchangers and various heat sources*, University of Saskatchewan.
12. Rafique, M.M. 2020, *Evaluation of metal–organic frameworks as potential adsorbents for solar cooling applications,* Applied System Innovation, 3(2), pp 26.