



Research Article

## Thermodynamic performance analysis of an air conditioning system integrated with a solid desiccant dehumidifier wheel using solar reactivation

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### ARTICLE INFO

#### Article history

Received: 07 January 2025

Accepted: 31 May 2025

#### Keywords:

Air-conditioning System, Solid Desiccant Dehumidifier Wheel, Dehumidification Effectiveness, Regeneration Effectiveness, Adsorption Rate, Coefficient of Performance

### ABSTRACT

The present study investigates the thermodynamic performance of an air-conditioning system integrated with a solid desiccant dehumidifier wheel (SDDW) using a combined heating mode of electrical and solar heaters. The obtained results were compared with standard results. During the experimentation, the solid desiccant wheel with silica gel as an adsorption material was used along with a conventional vapour compression cycle. The effect of inlet air temperature in the range of 23.6 °C to 37.2 °C and air inlet velocity in the range of 1.5 m/s to 4.1 m/s on the thermodynamic performance of an air-conditioning system integrated with a solid desiccant dehumidifier wheel was experimentally investigated. A combined electrical and solar heater mode was used to supply regeneration air for the solid desiccant dehumidifier at a constant velocity of 4.5 m/s. Experimentation was performed in all three seasons, namely summer, rainy and winter, to find the effect of seasonal variation on the performance of the air-conditioning system. The dehumidification effectiveness and adsorption rate in all three seasons increased with a decrease in the air inlet temperature. A maximum experimental value of dehumidification effectiveness was obtained in the summer season. At 23.6 °C and 1.5 m/s air inlet velocity, the maximum value of dehumidification effectiveness was 0.19. While at the same temperature, the maximum value of the adsorption rate at 4.1 m/s air inlet velocity was 0.4 kg/hr. In all three seasons, regeneration effectiveness increased with an increase in the inlet air temperature. While the regeneration effectiveness was reduced due to an increase in the inlet air temperature. A maximum value of dehumidification effectiveness obtained in the summer season at 37.2 °C inlet air temperature and 1.5 m/s velocity was 0.298. The coefficient of Performance in all three seasons for the vapour compression cycle decreased with an increase in the inlet air temperature and ve-

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This paper was recommended for publication in revised form by  
Editor-in Chief Ahmet Selim Dalkilic



locity. A maximum experimentation value of the Coefficient of Performance obtained in the winter season for the vapour compression cycle at 23.6 °C inlet air temperature and 1.5 m/s air inlet velocity was 0.51. The combined use of these heating methods resulted in a 33% increase in effectiveness compared to the use of the electric heater alone.

**Cite this article as:** Chavali S, Nanwatkar R, Mutalikdesai S, Shinde T, Bagde A, Nitnaware P, Dikshit S, Kulkarni S. Thermodynamic performance analysis of an air conditioning system integrated with a solid desiccant dehumidifier wheel using solar reactivation. *J Ther Eng* 2026;12(2):665–683.

## INTRODUCTION

Air-conditioning plays a pivotal role in human life, serving as a cornerstone for achieving healthy and productive comfort conditions within buildings. The quality of indoor comfort conditions is defined by factors such as temperature, humidity, and the adequate supply of fresh air. Traditional cooling systems contribute significantly to global electricity demand and carbon emissions, especially in regions with high cooling needs. Energy-efficient air conditioning systems play a critical role in mitigating climate change by reducing energy consumption and lowering greenhouse gas emissions. By adopting advanced technologies such as solid desiccant dehumidifiers, variable speed compressors, and renewable energy integration, energy-efficient air conditioning minimises reliance on fossil fuels. These systems not only improve energy performance but also align with global sustainability goals, fostering cleaner energy practices and reducing the environmental footprint of cooling technologies. Jain et al. [1] examined that an air conditioning system with solid desiccant has higher performance due to the use of wet surface heat exchangers in the hot and humid climate conditions. G. W. Scherer [2] found that the modulus and viscosity of silica gel increase due to drying. Dai et al. [3] developed a mathematical model for parameter analysis of desiccant dehumidification for performance improvement. Mazzei et al. [4], through an extensive literature review, found that the use of hybrid systems with desiccant wheels saves the operating costs. Harshe et al. [5] found that the developed rotary desiccant wheels were useful for optimising energy recovery and dehumidification applications. Zhai et al. [6] developed equation-based model for desiccant wheels. It can be used to combine the simulation of heat and mass transfer of desiccant wheels. Ge et al. [7] developed a mathematical model that can be used to predict the performance of a compound desiccant wheel. Li et al. [8] found that an integration of a solar desiccant dehumidification system in a traditional air-conditioning system significantly improves the energy-saving potential for hot, wet weather. A. Christy [9] found that the heating process removes free and hydrogen-bonded silanol groups and alters the ratio between the two. Narayanan et al. [10] developed a numerical model for a non-adiabatic desiccant wheel. A prediction of the numerical model shows good agreement with experimental results. A. Yadav and L. Yadav [11] obtained better results for the effective regeneration sector desiccant wheel as

compared with the ordinary regeneration sector desiccant wheel through a developed mathematical model. Angrisani et al. [12] found that a solar desiccant cooling unit consisting of 16 m<sup>2</sup> of evacuated solar collectors was economically feasible. Giannetti et al. [13] perform a general analysis of heat and mass transfer entropy generation rate for desiccant wheels, aiming for design. Chan et al. [14] obtained a developed composite material for an air conditioning system by mixing silica gel, polyacrylic acid and sodium polyacrylate. An optimal composite material was obtained at a mixing ratio of 10:1:1. The absorption capacity of the composite material was 41 % greater than compared of silica gel at 25 °C air temperature and a relative humidity of 70%. Mandegari et al. [15] developed a two-dimensional unsteady-state numerical model for the simulation of heat and mass transfer. The results obtained from the model were validated through experimental data. It was observed that minimum exergy destruction occurs at lower process air velocity and rotational speed of 0.2 m/s and 4 r.p.h. respectively. In the country, higher regeneration air temperature and moderate regeneration air velocity, observed for minimum exergy destruction, are 140 °C and 1.7 m/s, respectively. Zouaoui et al. [16] observed that cool air at satisfactory conditions was generated only when a source of water at low temperature was available. Muthu et al. [17] obtained the regeneration section angle and regeneration air temperature for the optimum performance of the rotary desiccant wheel. Antonellis and Joppolo [18] studied correlations used to calculate desiccant wheel performance and found that these correlations can be easily used in energy simulation programs for comparing desiccant wheel-based air conditioning systems with conventional configurations. Shahzad et al. [19] observed that the CO<sub>2</sub> emission growth rate was higher. The efficiency improvement of water and power is the key to controlling CO<sub>2</sub> emissions. Rjibi et al. [20] found that the best performance of the desiccant evaporative cooling system was for a regeneration temperature of 60 °C. Goyal et al. [21] proposed a ternary simulation model to predict complete adsorption and desorption breakthrough of nitrogen, carbon dioxide and water vapour in an initially clean silica gel bed. Bilal et al. [24] observed that metal-organic frameworks (MOFs) 841 and 801 yielded maximum adsorption of 0.5 g/g and 0.3 g/g, respectively at 25 °C temperature. MOF-801 indicate excellent water production of 0.2-0.3 L/kg/day at 20 - 40 °C temperature and relative humidity 5% - 40%. From the simulation, Dezfouli et al. [25] found that



and latent heat loads, leading to degradation in their coefficient of performance. In response to this limitation, a rotary desiccant-assisted air conditioning system has been devised to maintain comfort parameters inside conditioned spaces by independently controlling temperature and humidity.

The novelty of this design lies in the regeneration of the rotary desiccant wheel is accomplished using solar energy as a non-conventional energy source, complemented by traditional heating coils. This innovative approach aims to address the limitations of conventional systems and explore the potential of solar reactivation in enhancing the efficiency and sustainability of air conditioning technologies. The innovative approach may result in a reduction in the size of the cooling coil due to the separation of sensible and latent load, contributing to space and energy efficiency. Furthermore, the separation of latent and sensible loads may lead to a decrease in the pressure ratio across the compressor, enhancing its efficiency.

The given diagram 1, represents a solar assisted desiccant based air conditioning system combined with a vapor compression cycle refrigeration (VCR) for high efficiency cooling and dehumidification. The system starts with the Air Inlet Blower that drags in moist surrounding air (T5) and precipitates it to the Solid Desiccant Wheel. This desiccant wheel dries incoming air, thus, doing dehumidification and the air is warm and dry at T6. This fails to provide adequate cooling effect on air since this dry air is passed through the Evaporator Coil of the VCR system where it

undergoes further cooling, hence, the output is dry and cool air (T7) which is blown to the conditioned space.

The VCR cycle begins with Compressor which compresses the low-pressure refrigerant that is in vapour state (at T1) to a high pressure and temperature state (at T2). This hot refrigerant is then passed through the Condenser Coil, where it gives the heat up to surroundings and turns to a high- pressure liquid (T3). The temperature and pressure (T4) of the Expansion Valve is then lowered, thus allowing it to absorb heat in the evaporator coil in the process of air cooling.

At the same time, Solar Flat Plate Collector harnesses solar energy and heats ambient air (T8). This hot air is driven through the desiccant wheel in an regeneration path, so that the desiccant can get rid of the absorbed moisture, and as such, regain the drying capability. After regeneration the exhaust air (T9) is discharged or reused as the return air (T10). The combination of solar thermal energy with desiccant dehumidification and conventional VCR cooling makes the system efficient, with a lowering of the electrical load and sustainable air conditioning.

Figure 1 and 2 represents a schematic view and an actual photograph of the hybrid rotary desiccant air conditioning system using solar reactivation and traditional heating coils. It consists of a traditional vapour compression refrigeration system along with the rotary desiccant wheel consisting of silica gel as adsorbent material. The properties of silica gel are given in Table 1.

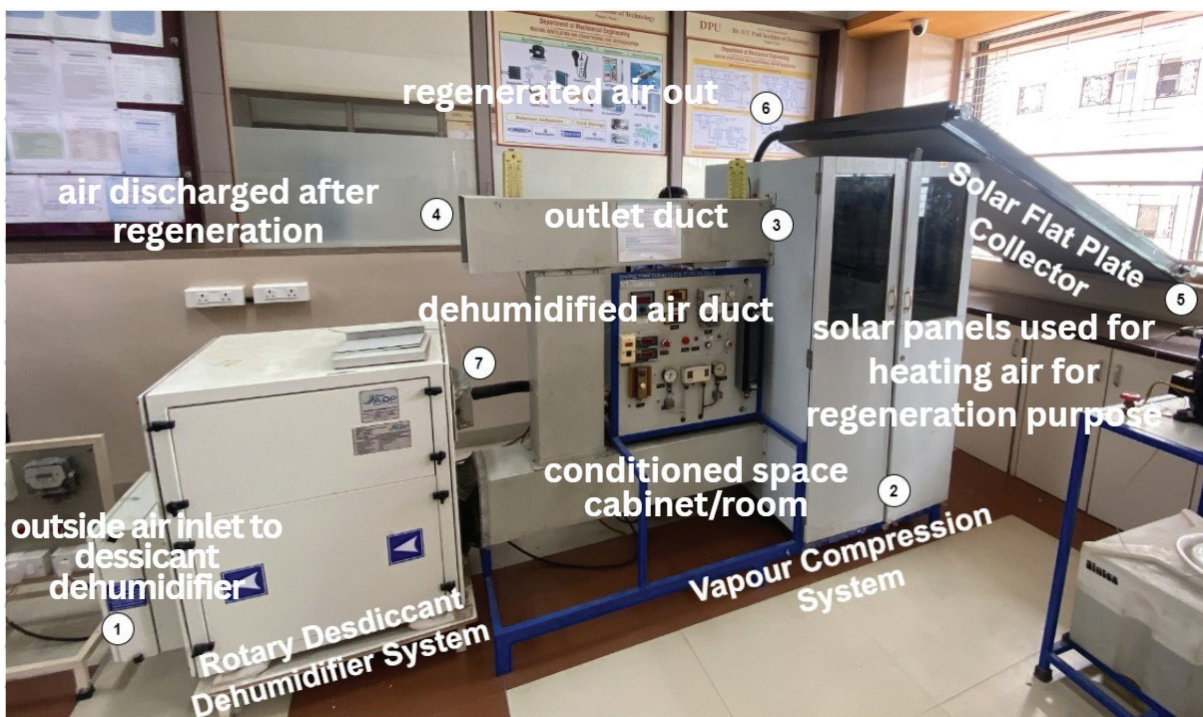


Figure 2. Actual photograph of a hybrid rotary desiccant air conditioning system.

**Table 1.** Properties of Silica gel. [22]

Features	Silica gel
Chemical composition	Sio2 Chemically inert
Chemical stability	Highly stable in $ph \leq 7$ and mild alkaline media
Mechanical stability	Narrow pore gel is unstable in aqueous media
Thermal conductivity	0.14–0.2 W/m/K and 0.08–1.2 BTU/ft/°F
The heat of adsorption for water	2512 kj/kg H <sub>2</sub> O and 1080 BTU/lb H <sub>2</sub> O

A flat plate solar collector, along with a conventional heater, is used to heat the atmospheric air known as regeneration air. During the experimentation mixture of normal atmospheric air and regeneration air is supplied to the rotary desiccant wheel, where silica gel absorbs moisture from the air. A blower present at the respective location draws the air. A dehumidified air is further supplied to the conventional vapour compression cycle, where it rejects the heat to the refrigerant present in the evaporator coils. A final conditioned air is then supplied to the control space. The selection and design of system components are contingent upon local meteorological conditions, the load to be managed, and the type of air conditioning cycle to be implemented. The temperature sensor is located at different positions to measure the temperature of the air and refrigerant. A location of temperature sensor and input experimental parameters are summarised in Tables 2 and 3, respectively. During the experimentation, the inlet air

temperature is varied in the range of 23.6 °C to 37.2 °C. The air inlet velocity is varied in the range of 1.5 m/s to 4.1 m/s. In the country, the regeneration air velocity is maintained constant, which is 4.5 m/s.

All experimental work is carried out in Pune City, Maharashtra, India. Pune city lies between 18° 32" North latitude and 73° 51" East longitude. Normal temperature of Pune city in the summer season lies between 22°C - 41°C. While the temperature in the winter season lies between 8°C - 25°C. The average relative humidity is around 69%, although it varies from around 51% during summer to 92% monsoon season. A general dehumidification process and regeneration process obtained from a hybrid rotary desiccant air conditioning system using solar reactivation and traditional heating coils is shown in Figure 3. Processes A, B, and C represent the dehumidification process using the desiccant wheel and sensible cooling. Process 7-8-D-E represents the regeneration process.

**Table 2.** Location of Temperature Sensor

Temperature Sensor	Location
T1	Temperature of refrigerant at the exit of the evaporator
T2	Temperature of refrigerant at the exit of the compressor
T3	Temperature of refrigerant at the exit of the condenser
T4	Temperature of refrigerant at the exit of the expansion valve
T5	Atmospheric air temperature
T6	Dehumidified air temperature
T7	Final conditioned air temperature
T8	Atmospheric air temperature for regeneration purposes,
T9	Regenerative (Heated) air inlet temperature
T10	Regenerative (Heated) air outlet temperature.

**Table 3.** Summary of Experimental Parameters

Season	Summary, Winter, Rainy
Air Inlet Temperature (°C)	23.6, 24.1, 27.6, 28.9, 33.4, 35.6 and 37.2
Air Inlet Velocity (m/s)	1.5, 2.6, 3.3 and 4.1
Regeneration Air Velocity (m/s)	4.5



$$VCCOP = \frac{h_1 - h_4}{h_2 - h_1} \quad (6)$$

Where  $h_1$  = Specific enthalpy of refrigerant at inlet of compressor (kj/kg).

$h_2$  = Specific enthalpy of refrigerant at outlet of compressor (kj/kg).

$h_4$  = Specific enthalpy of refrigerant at inlet of evaporator (kj/kg).

### RESULTS AND DISCUSSION

The testing conducted on the air conditioning system using solid desiccant provided valuable insights into its performance and efficiency under different conditions. The results indicate that the moisture removal capacity of the system depends on various design and operating

parameters. The energy conservation benefits of the desiccant system also studied. The effect of regeneration temperature, process air inlet temperature, regeneration air and process air velocity, mass flow rate of process air, climatic conditions and methods of regeneration on the desiccant wheel are studied with velocity of 4.5m/s.

### Variation of Dehumidification Effectiveness in the Summer Season

Figure 4 (a-d) indicates the variation of dehumidification effectiveness vs. inlet air temperature at different air velocities during the summer season with a 4.5 m/s regeneration velocity. Dehumidification effectiveness is a measure of how well a desiccant wheel removes moisture from the air. A considerable reduction in the dehumidification effectiveness is observed due to an increase in the inlet air temperature. At lower inlet air temperature, the relative humidity is higher, resulting

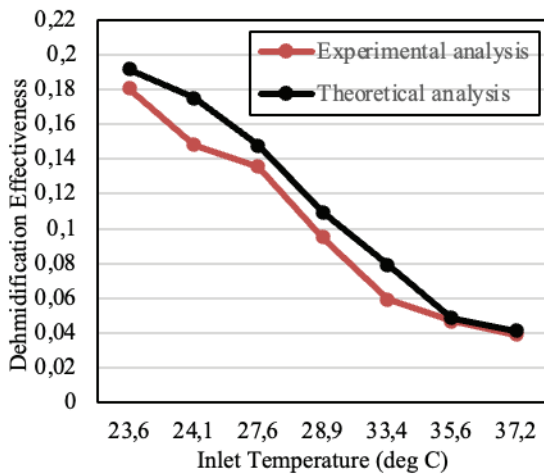


Figure (a)

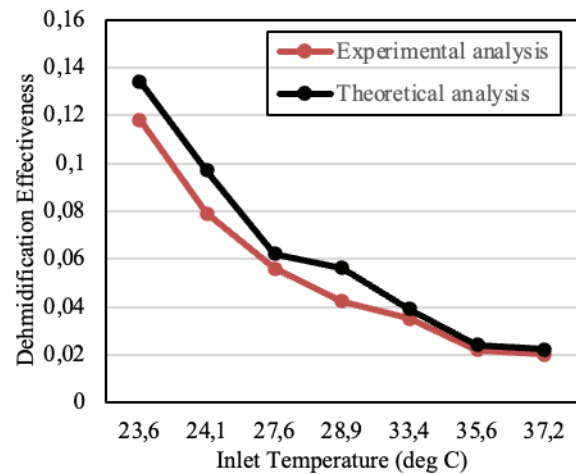


Figure (b)

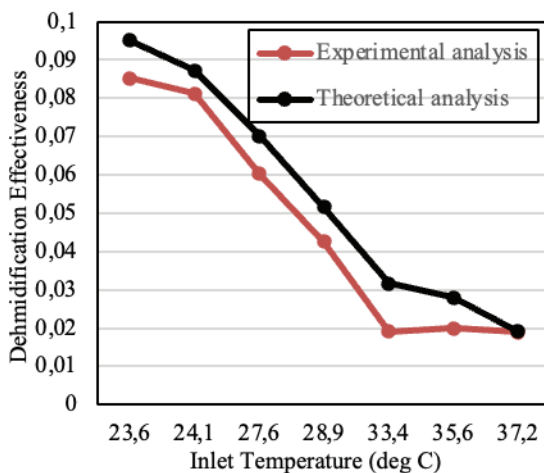


Figure (c)

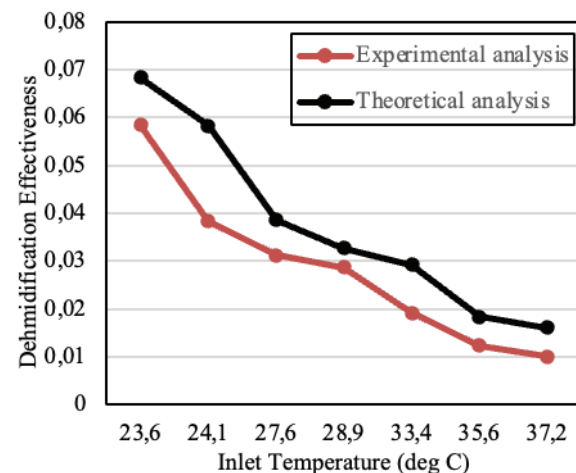


Figure (d)

**Figure 4.** Variation of dehumidification effectiveness in the summer season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m/s.

in the increased specific humidity of the desiccant wheel. Hence, a major difference in vapour partial pressure between the inlet air and the desiccant wheel leads to higher diffusion of the water vapour droplets inlet air to the desiccant material surface. Due to this, higher dehumidification effectiveness is obtained at lower inlet air temperature. Experimental investigation indicates that dehumidification effectiveness decreases from 0.19 to 0.032, with the increase in the inlet air temperature from 23.6 °C to 37.2 °C, at 1.5 m/s air inlet velocity. A similar nature is observed during theoretical and experimental studies. It is also found that dehumidification effectiveness reduces due to increases in the inlet air velocity. It is because the higher air inlet velocity minimises the contact time between the desiccant surface and the inlet air. Thus, the lower amount of water vapour is absorbed by the desiccant material due

to the lower contact time, which ultimately decreases the dehumidification effectiveness.

**Variation of Dehumidification Effectiveness in the Rainy Season**

A variation in the dehumidification effectiveness for the rainy season at different air inlet temperatures is shown in Figure 5 (a-d). Similar to the summer season, the dehumidification effectiveness at 4.5 m/s regeneration velocity decreases with increase in the inlet air temperature at different inlet air velocities. The relative humidity of air at a lower air inlet temperature results in better performance. Due to the higher environmental humidity level during the rainy season, the drop in the effectiveness of the dehumidifier is much lower than that of the summer season. Experimentation indicates that dehumidification effectiveness decreases from 0.130 to 0.067, with the increase in the

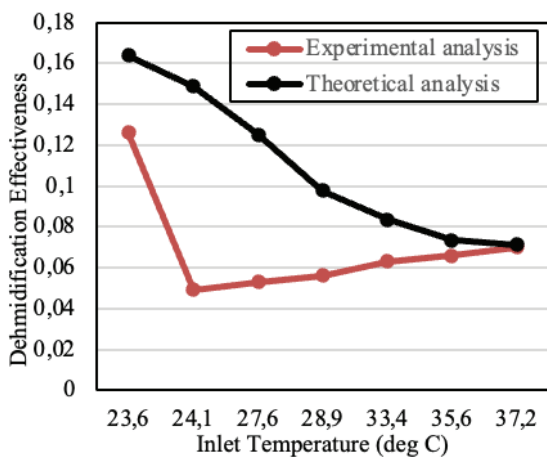


Figure (a)

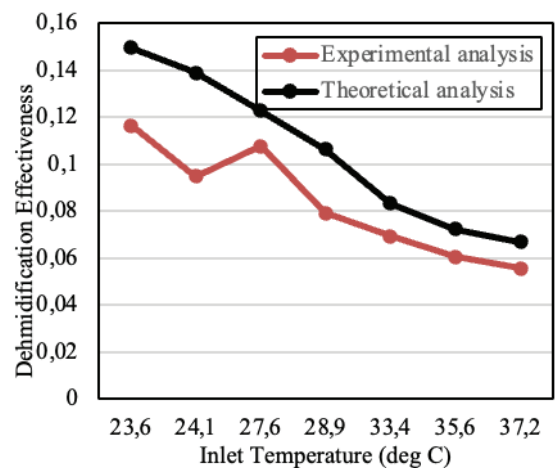


Figure (b)

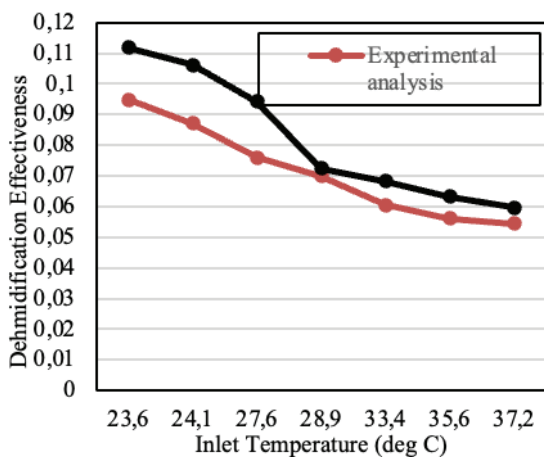


Figure (c)

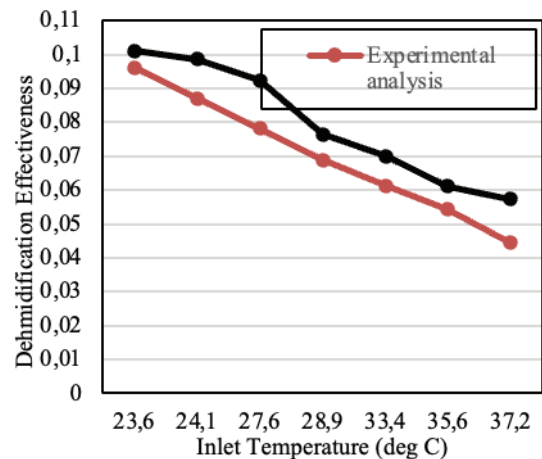


Figure (d)

**Figure 5.** Variation of dehumidification effectiveness in rainy season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m/s.

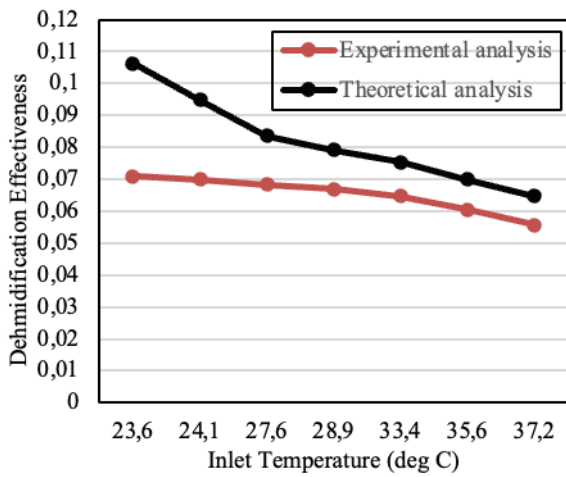


Figure (a)

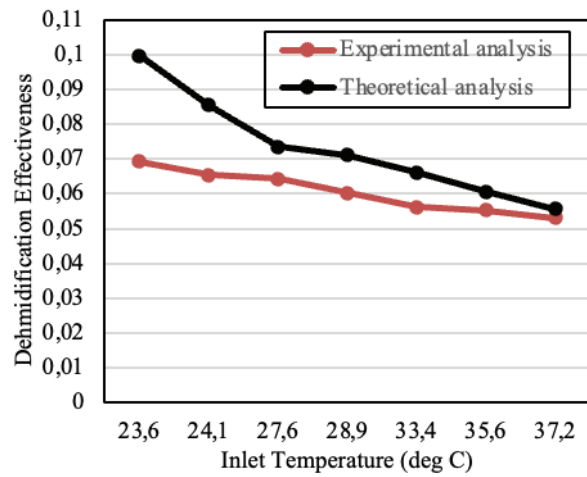


Figure (b)

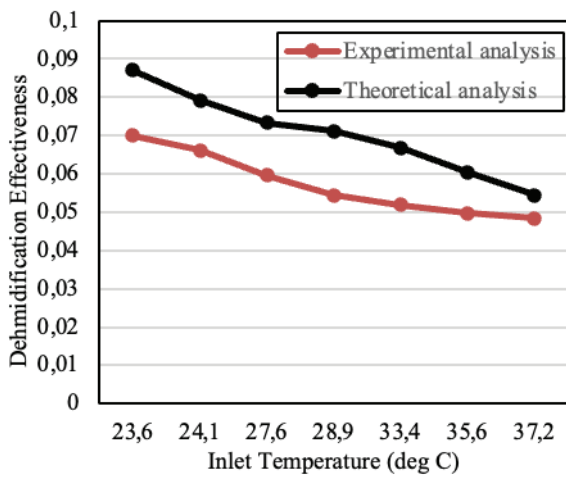


Figure (c)

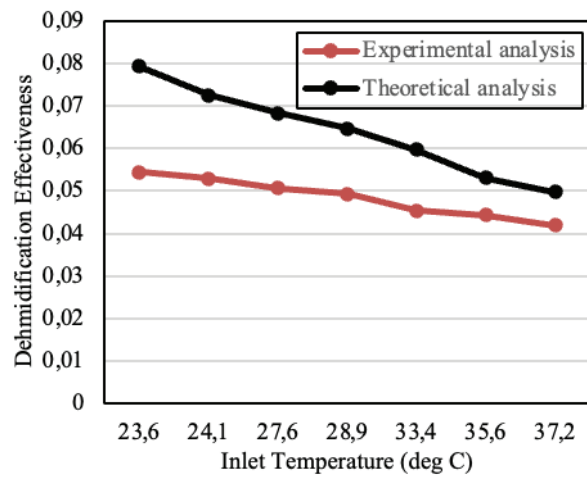


Figure (d)

**Figure 6.** Variation of dehumidification effectiveness in winter season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m/s.

inlet air temperature from 23.6 °C to 37.2 °C, at 1.5 m/s air inlet velocity. Better dehumidification effectiveness is obtained at lower air inlet velocity, because of a higher contact time of the inlet air with the desiccant wheel.

**Variation of Dehumidification Effectiveness in the Winter Season**

Figure 6 (a-d) represents the variation of dehumidification effectiveness vs. inlet air temperature during the winter session at different air velocities. Alike summer and rainy sessions, dehumidification effectiveness decreases with an increase in the air inlet temperature and velocity. A lower value of dehumidification effectiveness is observed in the winter session when compared with summer and rainy seasons. A specific humidity of atmospheric air in the winter session is lower than compared to summer and rainy seasons, resulting in a lower humidity adsorption rate, which

reduces dehumidification effectiveness. The findings reveal that fluctuations of dehumidification effectiveness depend on the air inlet temperature and velocity, since high air inlet temperature and velocity slow down the desiccant’s rate of moisture adsorption. Hence low air inlet temperature and velocity is recommended for better dehumidification effectiveness in all seasons.

**Variation of Regeneration Effectiveness in the Summer Season**

In an air conditioning system, regeneration effectiveness is known as the efficiency of a component called a regenerator in recovering heat from the exhausted air and transferring it to the incoming fresh air. A variation in regeneration effectiveness with inlet air temperature in the summer season at different air velocities, as shown in Figure 7 (a-d). Regeneration effectiveness at

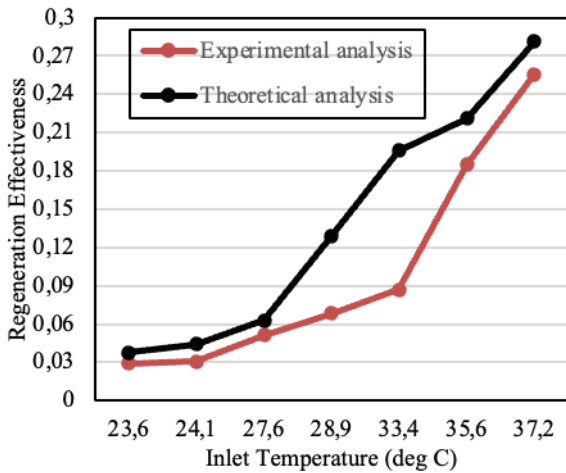


Figure (a)

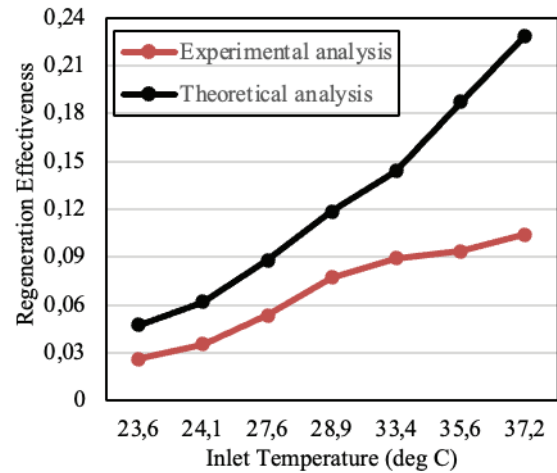


Figure (b)

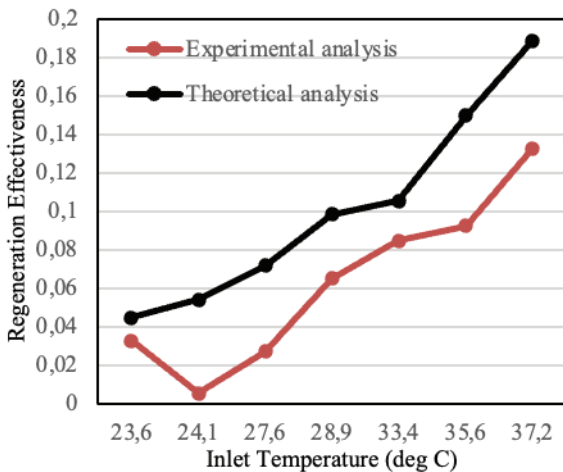


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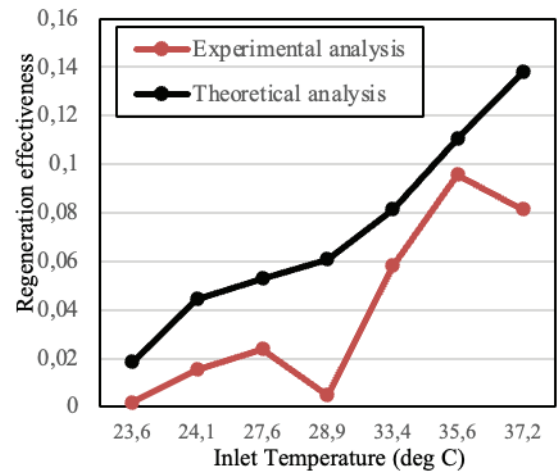


Figure (d)

**Figure 7.** Variation of regeneration effectiveness in the summer season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m/s.

4.5 m/s regeneration air inlet velocity increases with an increase in the air inlet temperature. As the ambient or air inlet temperature increases, the regeneration temperature also increases, which allows the desiccant wheel to regenerate. As the desiccant wheel is regenerated, it releases moisture into the incoming air. This moisture content is then transferred to the adsorption section, allowing the system to absorb more moisture from the incoming air. Thus, the regeneration effectiveness increases with air inlet temperature. A similar nature is observed for theoretical and experimental investigations at different inlet air velocities. For various air inlet temperatures the maximum value of regeneration effectiveness is obtained at 1.5 m/s air inlet velocity as compared with other velocities. As the inlet air velocity increases from 1.5 m/s, the air stays in contact with the desiccant wheel for a shorter duration of time,

hence, the regeneration effectiveness is less at the higher velocity. A maximum value of regeneration effectiveness obtained during experimentation at 37.2 °C air inlet temperature and 1.5 m/s air velocity is 0.298. While at the same temperature, at 4.1 m/s air velocity, the value of regeneration effectiveness is 0.08.

#### Variation of Regeneration Effectiveness in the Rainy Season

Figure 8 (a-d) represents the variation of regenerative effectiveness vs. inlet air temperature at different air velocities during the rainy season with a 4.5 m/s regeneration velocity. A regenerative effectiveness in the rainy session also increases with the increase in air inlet temperature as similar to the summer season. Moreover, reduced velocities of air at its inlet lead to higher effectiveness of regeneration in line with longer contact between the desiccant

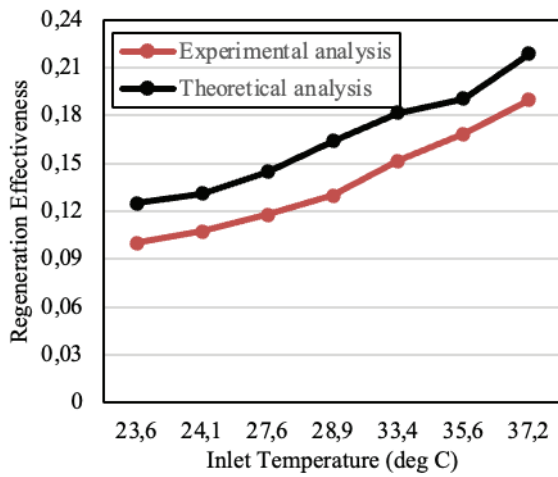


Figure (a)

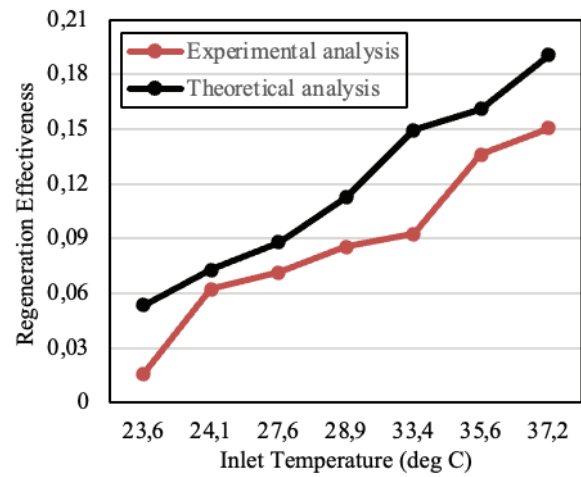


Figure (b)

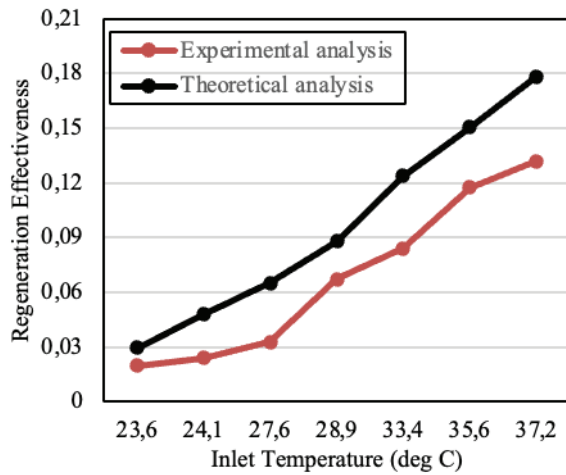


Figure (c)

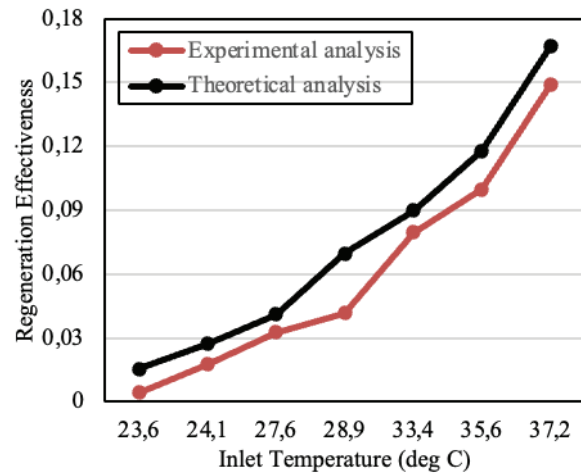


Figure (d)

**Figure 8.** Variation of regeneration effectiveness in rainy season for air inlet velocity of 1.5 m/s, b) 2.6 m/s, c) 3.3 m/s and d) 4.1 m/s.

surface and the inlet air. An experimental value of regeneration effectiveness at 37.2 °C air inlet temperature and 1.5 m/s inlet air velocity is 0.189. On the other hand, for the same air inlet temperature, at 4.1 m/s, the value of regeneration effectiveness reduced to 0.149. It is due to the lesser contact time between the incoming air and the desiccant wheel.

**Variation of Regeneration Effectiveness in the Winter Season**

A variation of regeneration effectiveness for different air inlet temperatures in the winter session at air inlet velocities in the range of 1.5 m/s to 4.1 m/s is shown in Figure 9 (a-d). In summer and rainy seasons, the regeneration effectiveness at 4.5 m/s regeneration velocity increases with an increase in the air inlet temperature. An experimental value of regeneration effectiveness in

the winter season at 37.2 °C air inlet temperature and 1.5 m/s inlet air velocity is 0.239. While for the same air inlet temperature and velocity, the value of regeneration effectiveness in the summer season is 0.298. It indicates that regeneration effectiveness in the winter session is lower as compared with the summer session. It may be due to the reduction in moisture-absorbing ability of the desiccant wheel, as the specific humidity of atmospheric air is low in the winter season as compared to summer. The regeneration effectiveness in the winter season also decreases with an increase in the air inlet velocities, similar to summer and rainy seasons.

**Variation of Adsorption Rate in the Summer Season**

Figure 10 (a-d) represents the variation of adsorption rate vs. inlet air temperature at different air velocities during the summer season with a 4.5 m/s regeneration velocity. In

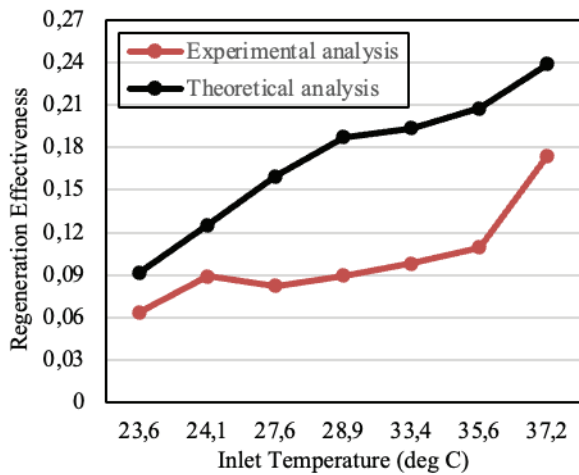


Figure (a)

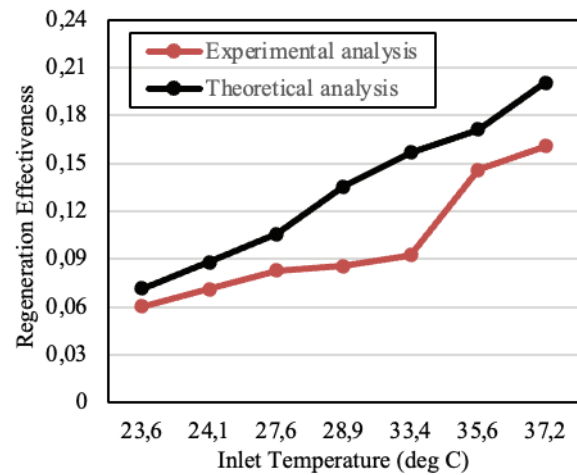


Figure (b)

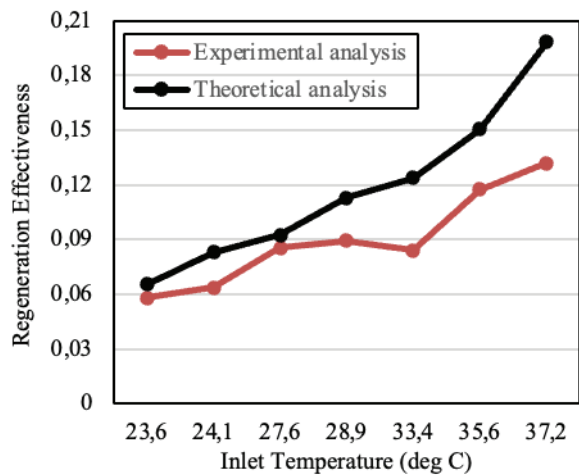


Figure (c)

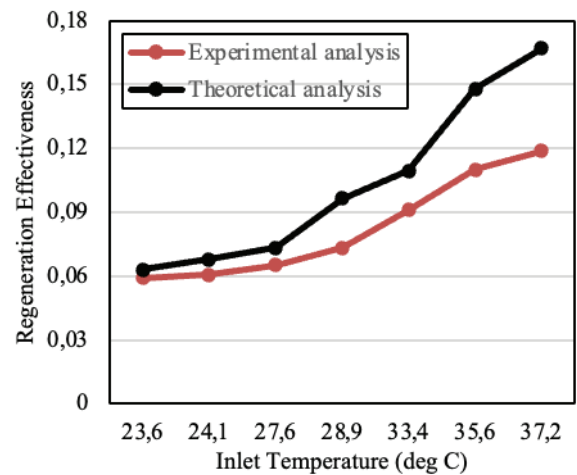


Figure (d)

**Figure 9.** Variation of regeneration effectiveness in winter season for air inlet velocity of a) 1.5 m/s, b) 2.6 m/s, c) 3.3 m/s and d) 4.1 m/s.

the air conditioner system adsorption rate is defined as the speed at which a solid adsorbent material absorbs water vapour from the air. The adsorption rate reduces due to an increase in the air inlet temperature at all velocities. High ambient temperatures characteristic of the summer season result in higher relative humidity of the air. Lower temperature provides higher presence of water vapour content in the air, hence a major difference of vapour partial pressure obtained between the inlet air and desiccant material surface, and this creates a higher diffusion of the water vapour droplets from the air to the surface. As, adsorption process is exothermic and has a preference for cooler air, a lower adsorption rate is obtained with an increase in the inlet temperature. On the other side, as the velocity of the inlet air increases, the adsorption rate also increases as a result of the increased mass properties flow rate of the humid air through the adsorber vessel. During the experimental

maximum adsorption rate obtained at 23.6 °C air inlet temperature and 4.1 m/s air velocity is 0.30 kg/hr, while for the same inlet air temperature adsorption rate obtained at 1.5 m/s air velocity is 0.20 kg/hr.

#### Variation of Adsorption Rate in the Rainy Season

A variation of adsorption rate for different air inlet temperatures in the rainy session at various air inlet velocities is shown in Figure 11 (a-d). Similar to the summer season, the adsorption rate in the rainy season also decreases due to an increase in the inlet air temperature. The atmospheric air has slightly higher specific humidity in the rainy season as compared with summer season, hence increase in the adsorption rate is observed in the rainy season as compared with summer season. An experimental value of adsorption rate in the summer season at 23.6 °C air inlet temperature and 1.5 m/s air velocity is 0.20 kg/hr. While at the same

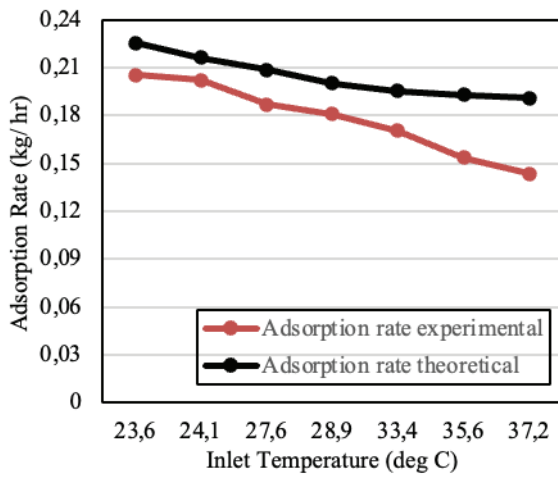


Figure (a)

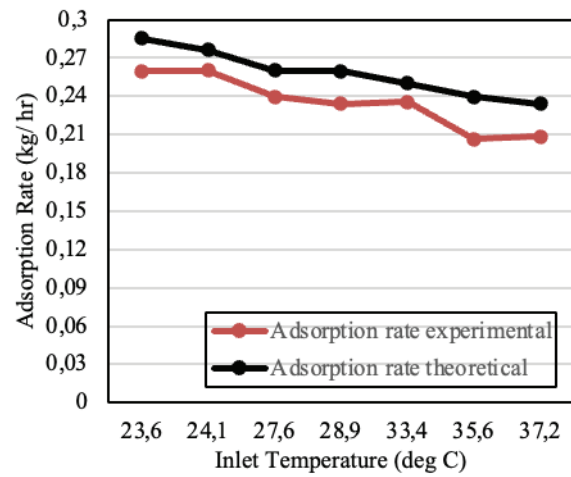


Figure (b)

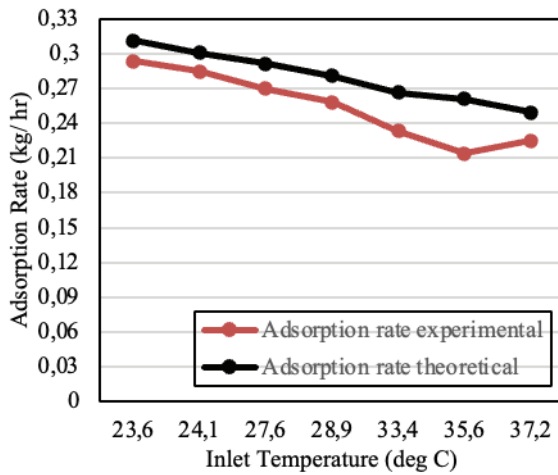


Figure (c)

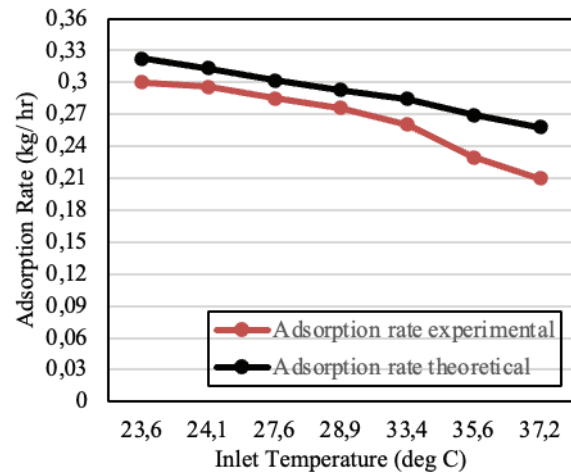


Figure (d)

**Figure 10.** Variation of adsorption rate in the summer season for air inlet velocity of a) 1.5 m/s, b) 2.6 m/s, c) 3.3 m/s and d) 4.1 m/s.

conditions, a value of adsorption rate in the rainy season is 0.252 kg/hr. Like summer season adsorption rate in the rainy season also increase with increase in the air inlet velocity.

**Variation of Adsorption Rate in the Winter Season**

Figure 12 (a-d) indicates the variation of adsorption rate with inlet air temperature at different air velocities in the range of 1.5 m/s to 4.1 m/s. In winter season also adsorption rate decreases with increase in the air inlet temperature. An adsorption rate, in the winter season is low as compared with summer and rainy season. In winter season temperature air is low as compared with other seasons. Cold air has a lower capacity to hold water vapour, results in the reduction of adsorption rate. An adsorption rate in the winter season also increases with increase in the air inlet velocity similar to summer and rainy season. A maximum experimentation

value of adsorption rate at 23.6 °C air inlet temperature and 4.1 m/s air inlet velocity in the summer, rainy and winter season is 0.30, 0.40, 0.25 kg/hr respectively.

**Comparison of Dehumidification Coefficient of Performance for Summer, Rainy and Winter Seasons**

A variation of dehumidification coefficient for summer, rainy and winter seasons with inlet air temperature at various air inlet velocities in the range of 1.5 m/s to 4.1 m/s is shown in the figure 13 (a-d). A dehumidification coefficient of performance (DCOP) for all the seasons decreases with increase in the air inlet temperature. A dehumidification coefficient for summer and rainy seasons closely matches with each other. While, in the winter season lower dehumidification coefficient was obtained as compared to summer and rainy seasons. This is because the adsorption process is exothermic, and the temperature

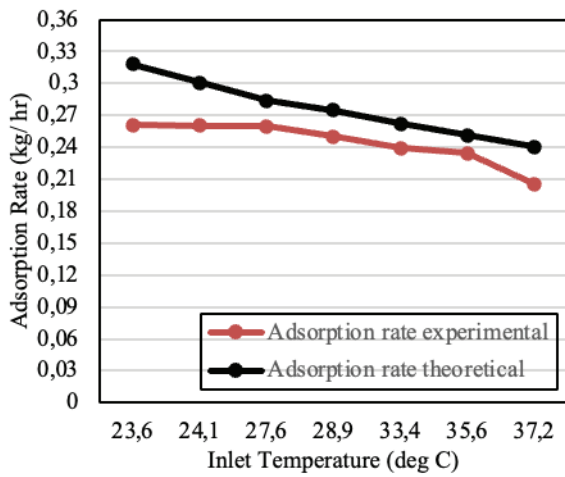


Figure (a)

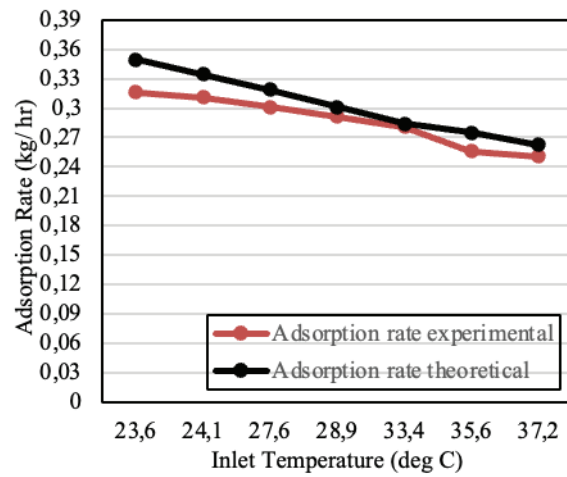


Figure (b)

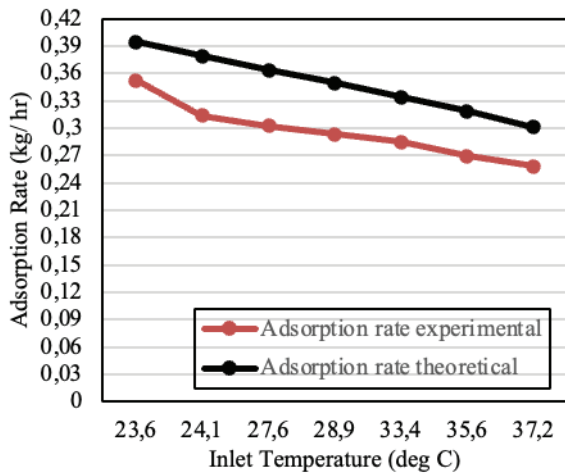


Figure (c)

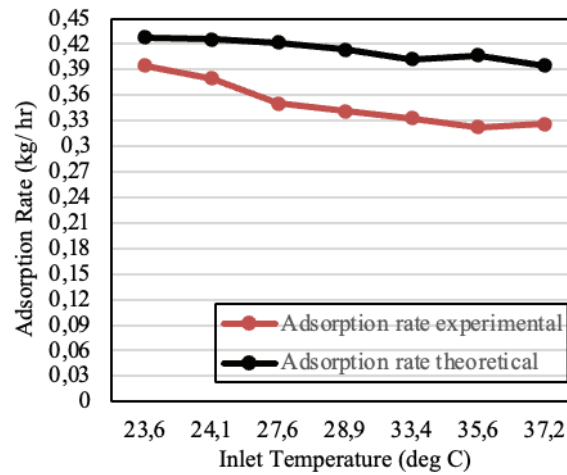


Figure (d)

**Figure 11.** Variation of adsorption rate in rainy season for air inlet velocity of a) 1.5 m/s, b) 2.6 m/s, c) 3.3 m/s and d) 4.1 m/s.

relationship that gives higher moisture content in the air enhances a higher vapor pressure difference between the inlet air and the desiccant material to promote diffusion of moisture. Also, increased regeneration temperature contributes to desiccant regeneration thereby enabling greater levels of moisture adsorption consequently leading to improved dehumidification coefficient of performance. Similar nature is observed for all the air inlet velocities. It is also clear that for in all the three seasons the value of dehumidification coefficient of performance increases with the increase in the air inlet velocities. As with increase in the inlet velocity there the air mass flow rate of air also increases. It provides desiccant wheel with more humid air of which moisture should be removed and thus ultimately increases Dehumidification Coefficient of Performance.

**Comparison of Regeneration Rate for Summer, Rainy and Winter Seasons**

Figure 14 (a-d) represents a variation of regeneration rate for various inlet air temperature at different air inlet velocities. A regeneration rate is known as the speed at which a desiccant wheel is able to reabsorb moisture after it has been saturated by absorbing moisture from the air. The value of regeneration rate for all three seasons increases with increase in temperature. For various inlet air temperatures, value of regeneration rate in the summer season is considerably more as compared with rainy and winter seasons. In the summer season the ambient temperature is more. As the ambient temperature increases it also affects the regeneration temperature which also increase leads to increased removal of the moisture from desiccant wheel during regeneration phase. Thus, the regeneration rate also increases with increase in the ambient temperature. For all

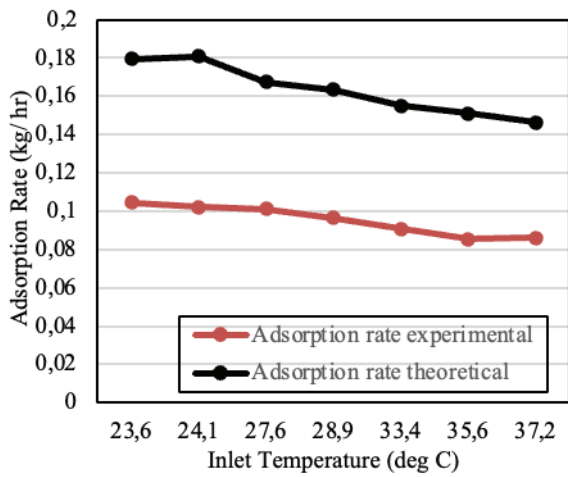


Figure (a)

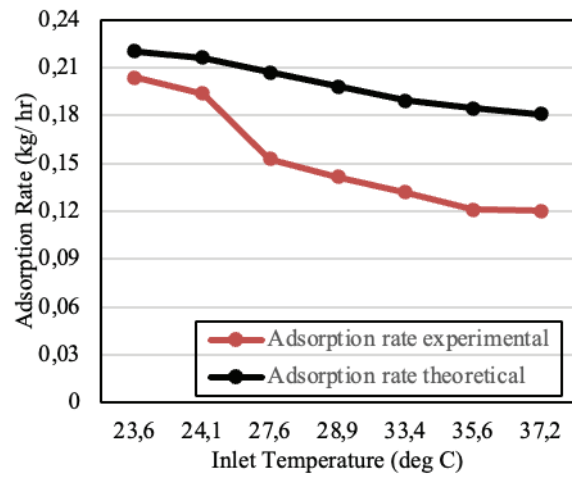


Figure (b)

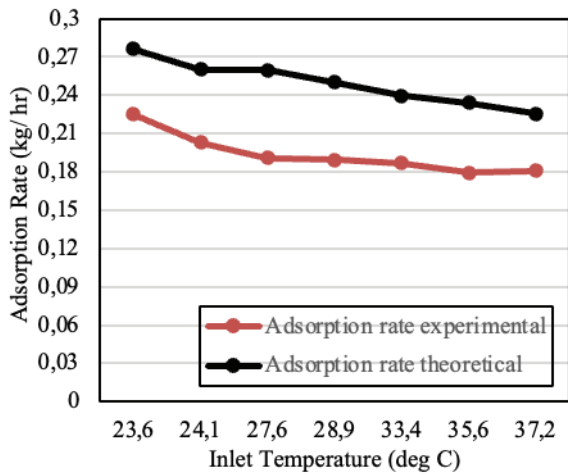


Figure (c)

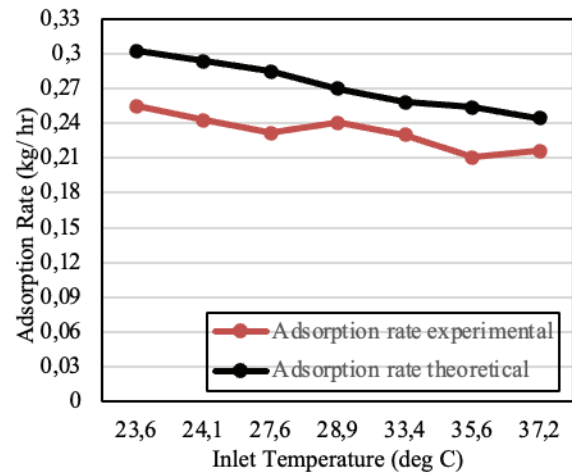


Figure (d)

**Figure 12.** Variation of adsorption rate in winter season for air inlet velocity of a) 1.5 m/s, b) 2.6 m/s, c) 3.3 m/s and d) 4.1 m/s.

the air inlet velocities similar nature is observed. Figure 14 (a)-(d) also indicate that for all the three seasons the value of regeneration rate increases with the decrease in the process air inlet velocities. It is because the lower process air inlet velocity maximizes the contact time between desiccant surface and incoming process air. Thus, then this rotary desiccant surface moves to regeneration sector where hot regenerated air takes the moisture from desiccant surface and hence regeneration rate increases.

**Comparison of Vapour Compression Cycle Coefficient of Performance (VCCOP) for Summer, Rainy and Winter Seasons**

A variation of vapour compression cycle coefficient of performance (VCCOP) for summer, rainy and winter seasons with inlet air temperature at various air inlet velocities in the range of 1.5 m/s to 4.1 m/s is shown in the

figure 15 (a-d). It shows that for all air inlet velocities, the value of coefficient of performance for vapour compression cycle in summer, rainy and winter season decreases with increase in the inlet air temperatures. It is because as the ambient temperature increases the rate of heat transfer from the condenser decreases. Hence cooling capacity of the air-cooled condenser reduces which increases the load of the vapour compression refrigeration system. Thus, less heat is absorbed by the refrigerant from the air at the evaporator section which ultimately decreases coefficient of performance. It is also observed that, in all three seasons coefficient of performance for vapour compression cycle decreases with the increase in the process air inlet velocities. A less contact time between the inlet air and cooling coil results in the reduced coefficient of performance due to increase in the air inlet velocity. The coefficient of performance for vapour compression cycle

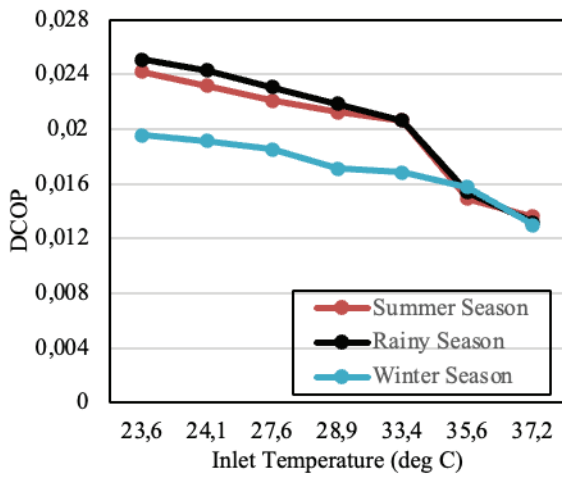


Figure (a)

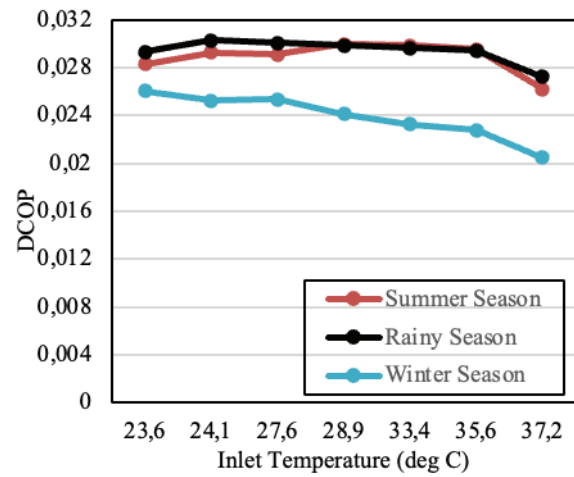


Figure (b)

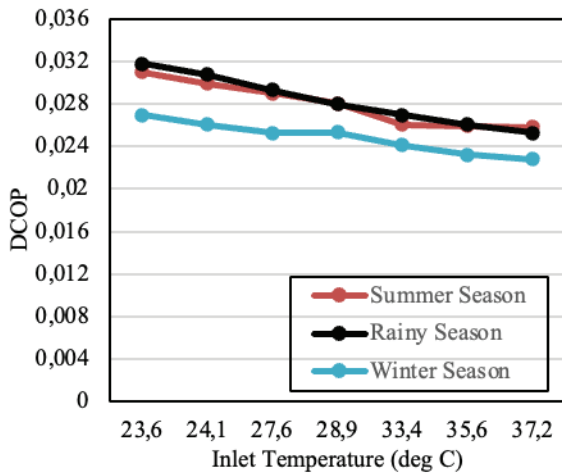


Figure (c)

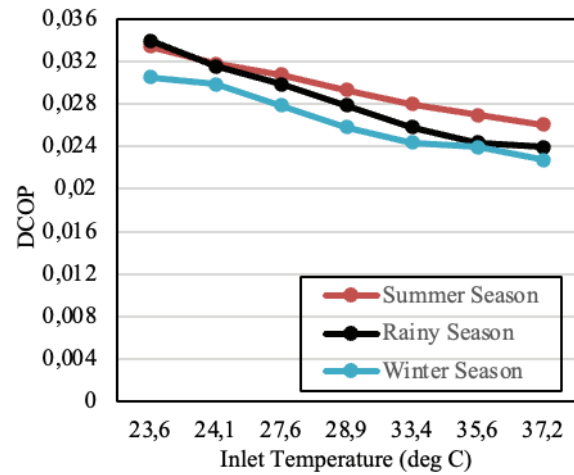


Figure (d)

**Figure 13.** Variation of dehumidification coefficient in summer, winter and rainy season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m/s.

is more in the winter season as compared to summer and rainy. A less power consumption in the winter season may results better coefficient of performance. A similar nature was observed for various parameters such as dehumidification and regeneration effectiveness, adsorption rate, dehumidification coefficient of performance and vapor compression cycle coefficient of performance by Hussain [23] when air conditioning system with solid desiccant dehumidifier wheel is powered by waste heat recovery system.

**CONCLUSION**

The experimental investigation of the air conditioning system with solid desiccant dehumidifier wheel and combined heating methods results in a 33% increase in effectiveness compared to the use of the electric heater alone.

Hence this system may be effectively used in the higher humidity industries such as food processing, pharmaceuticals, and electronics manufacturing. Following are the major conclusion drawn from the experimentation investigation of air conditioning system with solid desiccant dehumidifier wheel at 4.5 m/s constant regeneration air velocity.

- 1) Dehumidification effectiveness in all three seasons increases with decrease in the air inlet temperatures and velocity. A lower value of dehumidification effectiveness is observed in the winter session when compared with summer and rainy seasons. A maximum experimentation value of dehumidification effectiveness obtained in the summer season at 23.6 °C inlet air temperature and 1.5 m/s air inlet velocity is 0.19.
- 2) In all the three seasons, regeneration effectiveness increases with increase in the inlet air temperature.

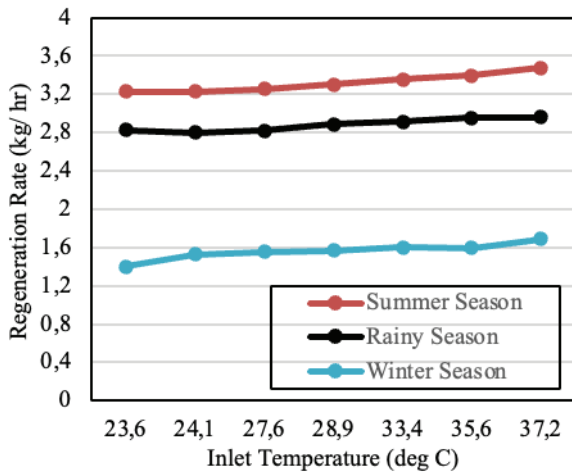


Figure (a)

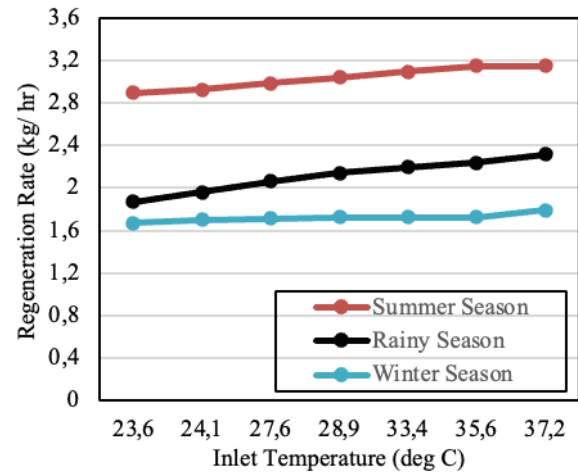


Figure (b)

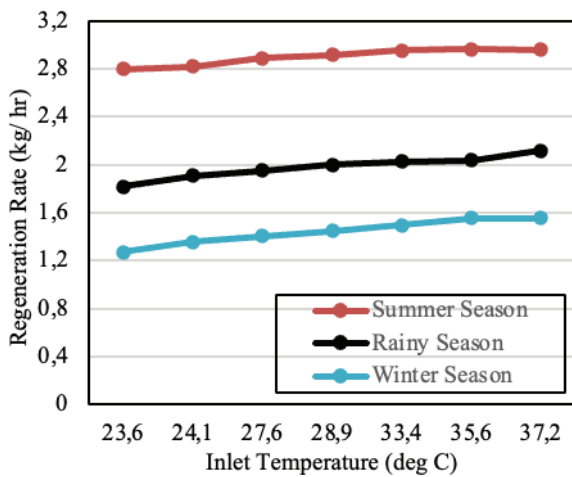


Figure (c)

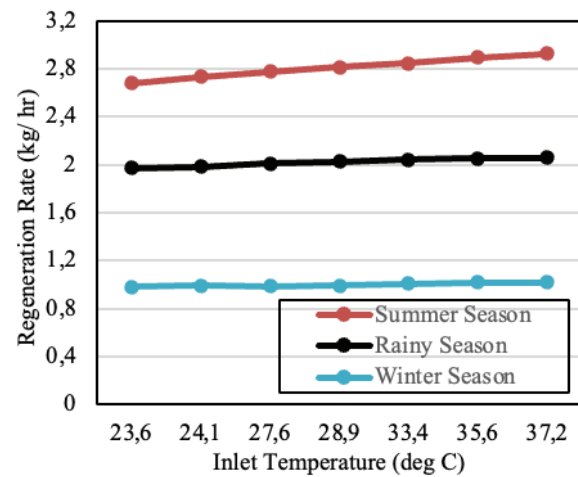


Figure (d)

**Figure 14.** Variation of regeneration rate in summer, winter and rainy season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m/s.

While it reduces due to the increase in air let velocity. A better regeneration effectiveness is obtained in the summer season as compared to rainy and winter season. A maximum experimentation value of dehumidification effectiveness obtained in the summer season at 37.2 °C inlet air temperature and 1.5 m/s air inlet velocity is 0.298.

3) Adsorption rate in the summer, rainy and winter season increases with decrease in the inlet air temperature. On the other side, adsorption rate increases with increase in the air inlet velocity. A rainy season has better adsorption rate as compared to summer and winter season. A maximum experimentation value of adsorption rate obtained in the rainy season at 23.6 °C inlet air temperature and 4.1 m/s air inlet velocity is 0.4 kg/hr.

4) In all the three seasons, dehumidification coefficient of performance increases with decrease in the inlet air temperatures. While it reduces due to the reduction in the air let velocity. A dehumidification coefficient of performance is low in the winter season as compared to summer and rainy season.

5) Coefficient of Performance in all the three seasons for vapour compression cycle decreases with increase in the inlet air temperature and velocity. A higher Coefficient of Performance is obtained in the winter season as compared with summer and rainy season. A maximum experimentation value of the Coefficient of Performance obtained in the winter season for vapour compression cycle at 23.6 °C inlet air temperature and 1.5 m/s air inlet velocity is 0.51.

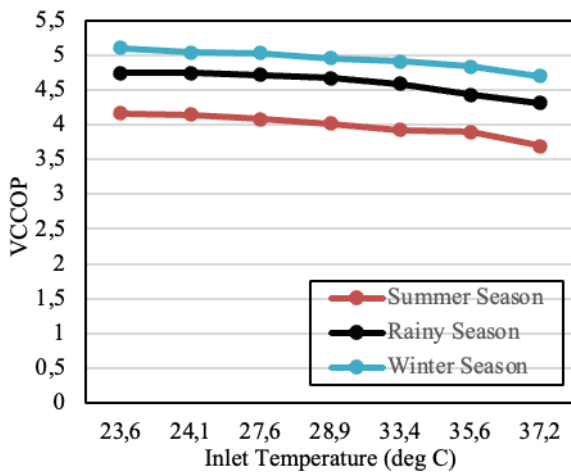


Figure (a)

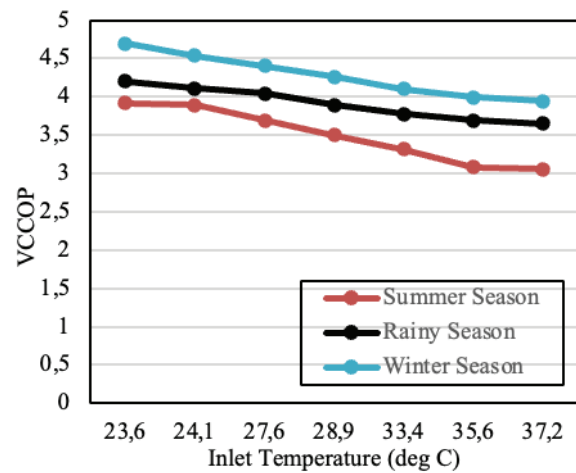


Figure (b)

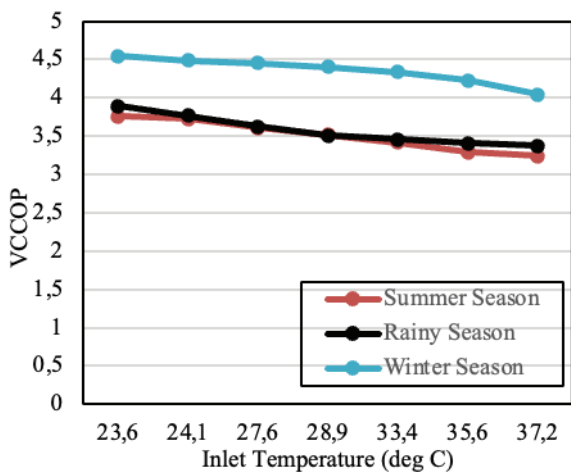


Figure (c)

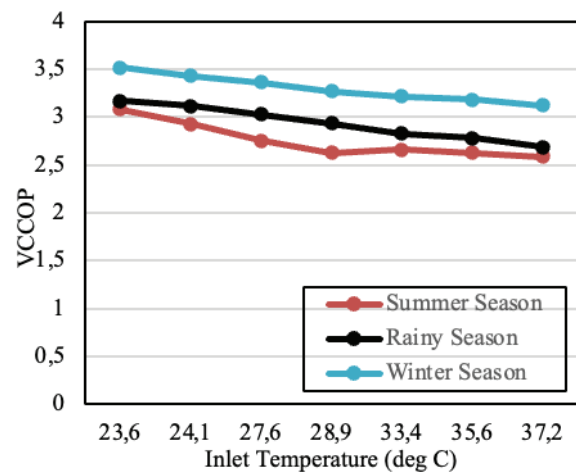


Figure (d)

**Figure 15.** Vapour compression cycle coefficient of performance in summer, winter and rainy season for air inlet velocity of a) 1.5m/s, b) 2.6m/s, c) 3.3m/s and d) 4.1m

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## ETHICS

There are no ethical issues with the publication of this manuscript.

## STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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