Scilight

Thermal Science and Applications
https://www.sciltp.com/journals/tsa

Article

Design and Testing of a Desiccant-Enhanced Evaporative Cooler

Nnamdi V. Ogueke [1,2,*], Ekene S. Mbonu [3], Victor A. Jumbo [1], Desmond O. Nwadike [1], Januarius C. Njoku [1] and Damaris A. Onyebuchulam [1]

[1] Mechanical Engineering Department, School of Engineering and Engineering Technology, Federal University of Technology Owerri, Owerri PMB 1526, Imo State, Nigeria
[2] Africa Centre of Excellence in Future Energies and Electrochemical Systems, Federal University of Technology Owerri, Owerri PMB 1526, Imo State, Nigeria
[3] Mechatronics Engineering Department, School of Electrical Systems Engineering, Federal University of Technology Owerri, Owerri PMB 1526, Imo State, Nigeria
* Correspondence: nvogueke@futo.edu.ng

How To Cite: Ogueke, N.V.; Mbonu, E.S.; Jumbo, V.A.; et al. Design and Testing of a Desiccant-Enhanced Evaporative Cooler. *Thermal Science and Applications* **2026**, *1*(3), 239–252. https://doi.org/10.53941/tsa.2026.100015

Received: 3 May 2026
Revised: 19 July 2026
Accepted: 28 July 2026
Published: 4 August 2026

Abstract: Evaporative cooling is one method that could help reduce post-harvest losses. However, its increased acceptability has been hindered by its poor performance in humid regions or during humid periods of the day or year, resulting in its inability to produce cooling during those periods. To address this challenge, an enhanced evaporative cooler for the preservation of fruits and vegetables was designed and tested. The system, an active direct evaporative cooler type, incorporated desiccant (activated carbon) and addressed the challenge of frequent desiccant saturation by using a sensor to control the regeneration process. Its major components are a desiccant wheel made of galvanised steel sheet, driven by a 12 V DC motor; a 220 V, 0.14 A-rated extractor fan; a 12 V DC, 70 W adsorbent regeneration heater-fan assembly; a humidification pad; and a water tank. Activated carbon was used as the desiccant. From the results obtained, when the system was tested during humid periods, the storage chamber temperature was maintained below the ambient value throughout the experimental periods, with an average difference of 4.14–5.13 °C. The average cooling power was 259–323 W, while the average COP was 2.95–3.67. Relative humidity within the storage chamber remained above 88% throughout the period. Thus, the designed system can produce cooling, even in a very humid region.

Keywords: desiccant; evaporative cooling; fruits and vegetables; post-harvest loss

1. Introduction

Agricultural products such as fruits, vegetables, meats, fish, etc., can be kept fresh for much longer periods if stored at low temperatures. Currently, in many developing countries like Nigeria, large quantities of these products are lost each year due to inadequate storage and processing facilities. Up to 45% of fruits and vegetables produced are lost post-harvest [1] annually. This problem is even more severe in remote rural areas where fresh food is produced. In these locations, the absence or irregular supply of grid-connected electricity to power refrigeration units for cold storage, alongside poor transport facilities to deliver produce to distant markets, pose serious obstacles to preventing spoilage. Consequently, there are stark differences in food availability and prices between harvest and off-harvest periods. The revenue lost due to high post-harvest spoilage and transportation damage discourages large-scale farming, ultimately leading to food shortages. Therefore, there is a pressing need for better methods of preserving agricultural produce, especially in rural areas and farming communities without reliable grid-connected electricity and during transport.

Currently, in Nigeria, agricultural produce like fruits and vegetables is mostly preserved using cooling systems powered by fossil fuel generators due to the challenge of accessing grid-connected electricity. This preservation method is costly, making it difficult for most farmers to afford. Farmers unable to access this method often resort to open-air storage or sell their produce quickly, even at a loss, to prevent spoilage. Evaporative cooling achieves cooling by causing air to flow over a wetted surface. It is a low-cost, environmentally friendly technology that can be effectively used, even in regions without grid-connected electricity. This method has been shown to provide effective cooling suitable for preserving fresh agricultural produce.

Ref. [2] reported that various types of evaporative cooler designs exist. For preserving agricultural produce, two major classifications exist: a passive direct evaporative cooling system and a non-passive (active) direct evaporative cooling system. A combination of these two forms is described as the hybrid type. These systems range from straw packing house types to more sophisticated designs. The key difference between the classes lies in how air moves through the moist area. The passive form relies on natural wind velocity for air movement, while the non-passive form uses a fan to facilitate air flow. Passive systems depend on natural air movement, lack moving parts, and do not require external energy input; therefore, they are generally easier to construct. Refs. [3–10] studied the passive type evaporative cooler and reported varying degrees of performance, ranging from 1–15 °C below the ambient temperature and relative humidity of 15–40% above the ambient condition. The extension in shelf life of the different products stored in them ranged from 2–15 days, depending on the product type. These performances were noted to depend on the period of the day or the season of the year. The best performances were recorded during afternoon periods, characterised by low relative humidity, or seasons of the year with low relative humidity. Hence, their performance depends largely on the ambient air relative humidity. Apart from the relative humidity, wind velocity influences the performance of evaporative coolers. Unfortunately, these two parameters cannot be artificially altered for passive evaporative coolers.

The active evaporative coolers use mechanical means to achieve air movement within the system; thus, air flow characteristics can be altered easily to achieve better performance. The active type could be direct or indirect. The cooled air is fed directly into the space requiring cooling in the direct type, while for the indirect type, a heat exchanger is employed to cool the space using the evaporatively cooled air. Thus, the direct type not only provides cooling but also increases the relative humidity of the storage space. According to [11], direct evaporative cooling utilises the latent heat of vaporisation, resulting in effective cooling, but it comes with the drawback of increasing humidity, unlike indirect evaporative cooling, which sacrifices some cooling efficiency in exchange for preventing humidity rise. Interestingly, an increase in humidity is required in agriculture for preservation since most agricultural products require low temperatures and high relative humidity for enhanced shelf life. Thus, the direct type of evaporative cooler is often employed in the preservation of agricultural products, as noted by [10]. Using the active type during low and moderate ambient relative humidity (RH) periods, cooling efficiencies >80% and shelf-life improvements exceeding 14 days have been achieved for different fruits and vegetables, depending on the design. While [12–14] reported cooling efficiencies of 85–87% with notable shelf-life improvements, [15,16] achieved 4–13 °C temperature drops, 95–97% RH, and quality preservation. Ref. [17] reported a 14-day shelf-life improvement, 16–26 °C cooling, and 33–88% RH rise. Ref. [18] observed shelf-life extension over 3 days for tomatoes, while [19] recorded 83% efficiency, reduced weight loss (7.5% to 3.9%), 76.8% RH, 7 °C cooling, and longer avocado shelf-life. Ref. [20] found temperature drops up to 10.94 °C when unloaded, and up to 9.88 °C when loaded, with an efficiency range of 3.62–96.42%.

Despite the noted better performance of the active systems over the passive ones, their performance during humid periods remains poor, thus making evaporative coolers unattractive [21,22]. The poor performance can be solved by introducing adsorbents, as reported by some researchers. Ref. [23] observed that successes achieved using desiccants have been in the order of magnitude of 1–5 °C below temperatures recorded without desiccant. Ref. [24] noted that some improvements were recorded when they used silica gel, but unfortunately, it became saturated between 15–17 min of operation. Thus, while improvements are possible using desiccants, sustaining the cooling by managing the desiccant saturation rate is required. While it has been established that incorporating desiccants can improve system performance, information on their application in a fully functional prototype of a simple type or non-complex direct evaporative cooler for fruits and vegetables preservation is scarce. Most of the reported works are for evaporative cooling for air conditioning applications [25–28] or the combined or multi-cycle types [29–31]. This work addresses the challenge of desiccant saturation rate on the performance of desiccant-enhanced evaporative coolers used in fruits and vegetables preservation by incorporating a means of ensuring adsorbent regeneration without breaking the cooling cycle, thus ensuring moisture adsorption from the ambient air is achieved continuously, thereby maintaining consistently lower inlet air relative humidity than that of the ambient air for enhanced cooler performance.

Novelty

This research introduces a desiccant-enhanced evaporative cooler that uniquely integrates a sensor-controlled desiccant wheel regeneration system, enabling continuous cooling even under high ambient humidity, a major limitation of conventional evaporative coolers. Unlike earlier designs, where desiccants quickly saturate and disrupt cooling, this system employs activated carbon with automated regeneration, ensuring sustained dehumidification without interrupting operation. The design achieves consistent average chamber temperatures 4–5 °C below ambient and relative humidity above 88%, demonstrating reliable preservation performance in tropical climates where traditional evaporative cooling fails. While detailed psychrometric modelling is beyond the intended scope, the emphasis here is on system-level innovation and practical applicability, showing how automated regeneration directly addresses the operational bottlenecks of conventional designs. Therefore, this innovation offers a practical, low-cost, and energy-efficient solution for reducing post-harvest losses in regions lacking reliable grid electricity.

2. Methodology

Figure 1 shows the enhanced evaporative cooler. It is constructed with plywood on the outside and an aluminium sheet on the inside. The space between the plywood and aluminium sheet is filled with polyurethane foam. The polyurethane foam and plywood act as insulation to minimise heat transfer from the ambient environment into the cooling chamber. The desiccant wheel is made of galvanised steel sheet, while the drive motor is a 12 V DC motor. A plywood housing encloses the desiccant wheel. Each desiccant bed contains 0.50 kg of activated carbon. The extractor is a 220 V, 0.14 A-rated fan. Adsorbent regeneration is achieved by a 12 V DC, 70 W heater-fan assembly. The humidification pad is of commercial quality, made from a blend of microfibre and synthetic fibre, capable of providing good humidification for evaporative cooling and filtration for impurity removal from the air. It measures 0.06 m, 0.47 m and 0.55 m, respectively, in thickness, width and height. The cooling chamber is 0.4 m × 0.5 m × 0.8 m (L × W × H), with three evenly spaced horizontal trays for storing the produce for preservation. The cooling chamber section is reinforced with an angle iron frame. The products for storage are evenly spread on the trays. Further details of the design are under consideration for a patent.

At the start of the process, Desiccant bed A is in Position (i), Desiccant bed B is in Position (ii), and Desiccant bed C is in Position (iii) (Figure 1b). Air is drawn in from Position (i) with the aid of an extractor fan installed at the back of the cooling chamber. The extractor fan is responsible for air movement in the entire system. Before passing through (i), the ambient air is dehumidified in Desiccant bed A. Then it comes into contact with the humidification pad contained inside, where moisture exchange occurs between the dehumidified air and the pad, resulting in cooling. The cooled air enters the storage chamber and maintains the temperature and humidity within the chamber at the desired product storage conditions. The desiccant wheel is mounted on a DC motor controlled by sensors. The humidity sensor monitors the exit air relative humidity from the desiccant bed. A relative humidity value higher than a set point value indicates a saturated adsorbent bed; the DC motor is then powered, rotating the desiccant wheel such that the desiccant bed, initially at position (i), moves to position (ii), where a heater fan forces heated ambient air at 78–82 °C through the bed to regenerate it for 13 min. The desiccant bed at position (iii), which is where the desiccant cools down after regeneration in (ii), moves to position (i) to become the active bed for the cooling process. The desiccant bed position change is accomplished in 10 s. This process continues as long as the evaporative cooler is operational. The humidification pad is kept moist by water that flows by gravity from the water tank through the water pipes. To ensure proper and even pad moistening, water is sprayed through small perforations on a horizontal section of the water pipe of the same width as the pad, from the upper end of the pad. Position (iii) is designed in such a way that the desiccant bed stays between two protective housings (Figure 1c), thus ensuring very minimal ambient air contact with the desiccant to avoid it getting saturated while in cool-down/stand-by mode.

The experimental rig is installed in an open section of the Energy Laboratory within the Mechanical Engineering Department building at the Federal University of Technology, Owerri, Nigeria. Owerri is situated in the South-Eastern part of Nigeria, with latitude and longitude coordinates of 5.48°N and 7.03°E, respectively. The region features a tropical climate characterised by substantial rainfall throughout the year and a relatively short dry season. The average daytime temperature ranges from 28 °C to 31 °C, while the average nighttime temperature spans from 22 °C to 24 °C. Relative humidity is generally high, averaging around 84% throughout the year, and can reach up to 90% during the rainy season. Data acquisition is conducted using an 8-channel Omega® temperature data logger, with a resolution of 0.1 °C and an accuracy of ±0.8 °C ±0.2% reading, and an Elitech® humidity logger of ±0.2% accuracy. Ambient temperature, ambient relative humidity, storage chamber temperature, and storage chamber relative humidity were recorded at 30-min intervals over the experiment period. The experiment began at 08:00 on each designated humid day and ended at 23:30. Selected days in July and

August, which fall within the rainy season and are characterised by high RH often in the range of 70–90%, were chosen as the test days to establish its performance during such periods, since the design improvement on the system was to always achieve cooling, even during humid periods, which has been a major challenge for evaporative cooling. In situ insolation on the experimental days was also recorded using a Frederiksen (SolData Instrument) hand-held pyranometer, produced in Silkeborg, Denmark, with a resolution of 1 W/m^2 and an accuracy of ±3% W/m^2.

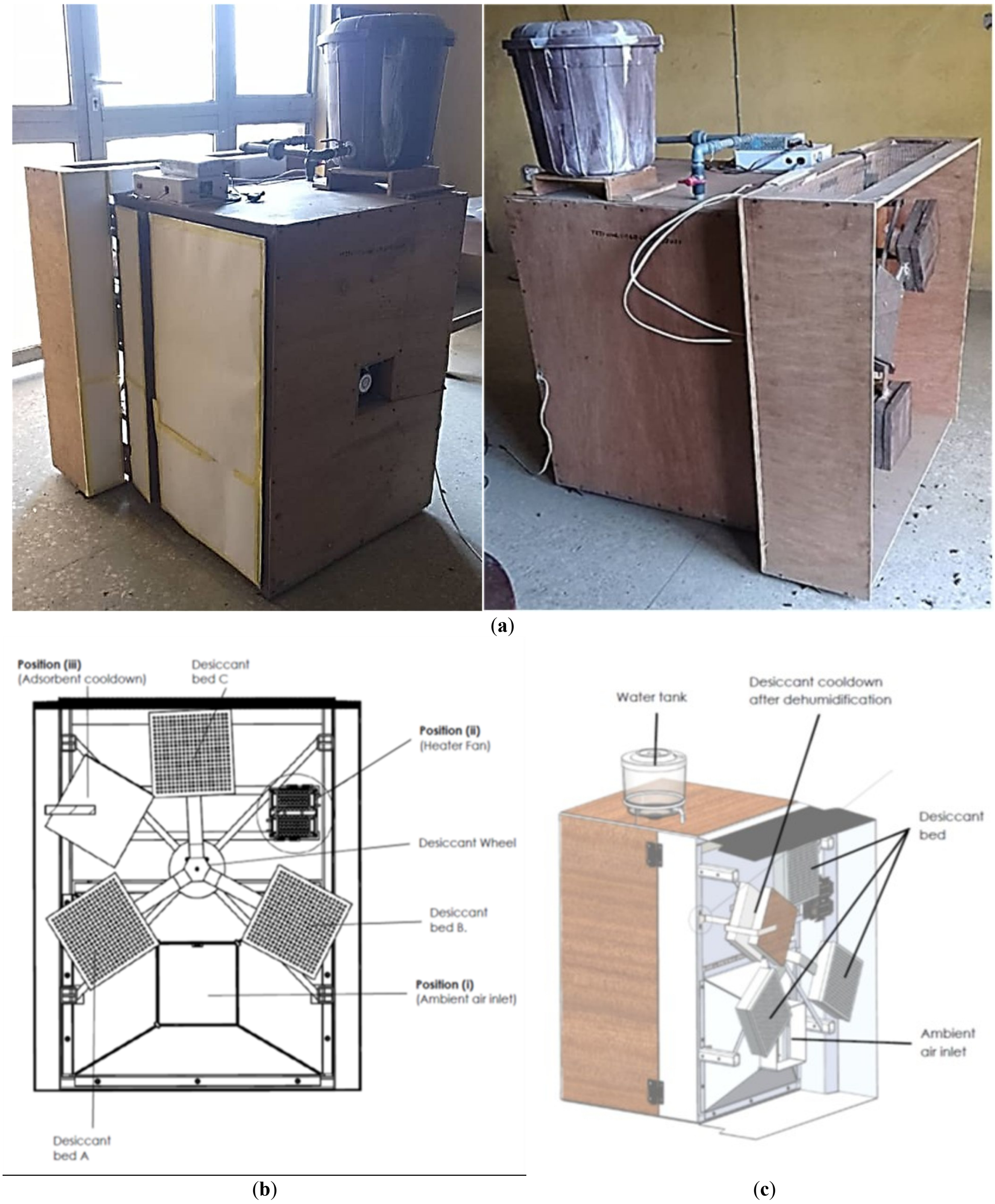

Figure 1. (**a**) Picture of the enhanced evaporative cooler. (**b**) Schematic drawing of the front side of the cooler showing the desiccant wheel. (**c**) CAD image of the cooler.

2.1. Desiccant Selection

Adsorbents act by reducing the moisture content in the ambient air, thereby increasing its moisture-uptake capacity and enhancing its evaporative cooling potential. Silica gel, Activated Carbon, and Liquid Desiccants have been used in evaporative cooling. Handling and the possibility of being entrained in the ambient air, resulting in the contamination of the agricultural product being preserved, are the disadvantages of liquid desiccant. Thus, interest has been more on silica gel and activated carbon when it comes to evaporative cooling for the preservation of agricultural products. Silica gel has a water adsorption capacity of 0.35–0.40 g/g and a regeneration temperature of ~70 °C [32]. It is synthetic and relies heavily on chemicals for production; thus, it has a high environmental footprint. Furthermore, its availability in the developing countries is restricted to the major cities, since they are often imported. Activated carbon regeneration temperature is higher than that of silica gel, but its adsorption capacity has been shown by [33] to be as high as 0.45 g/g when produced from biomass, with more variable performance, and it shows competitive or superior adsorption under high humidity conditions compared to silica gel. Production from renewable biomass reduces environmental impact compared to silica gel's synthetic sodium silicate route. Also, it is readily available in remote locations of developing countries. Thus, activated carbon was selected and used for this work.

2.2. Uncertainty Analysis

The error and uncertainty analysis of the experimental data was based on the reported accuracy of the measuring equipment. It is established using the expected uncertainty relation, which is considered more realistic than the maximum uncertainty [34]. It is given as Equation (1).

$$u_{R,RSs} = \sqrt{\sum_{i=1}^{i=N}\left(u_{x_i}\frac{\partial R}{\partial x_i}\right)^2} \tag{1}$$

where, $u_{R,RSs}$ is the expected uncertainty on variable R and u_{x_i} is the experimental uncertainty. Using equation 1, the expected uncertainties of the measurements of temperature and RH were established and presented in Table 1.

Table 1. Uncertainty analysis.

	Temperature Difference (°C)	Relative Humidity (%)	Solar Radiation (W/m^2)	Cooling Capacity (W)	Saturation Efficiency (%)	COP
Uncertainty	±2.2%	±2.1%	±7.9%	±2.7%	±5.1%	±2.7%

2.3. Performance Analysis

2.3.1. Cooling Capacity

The cooling capacity of the evaporative cooler was determined using the method described by [23]. Equation (2) enables its calculation.

$$Q = \dot{m}_a c_{pa}\left(T_{db,i} - T_{db,o}\right) \tag{2}$$

The specific heat capacity of air, c_{pa} (kJ/kgK), is calculated from Equation (3) [23,35]

$$c_{pa} = 0.0001296T_a + 1.009 \tag{3}$$

The air mass flow rate ($\dot{m}_a$) is linked to the air density (ρ_a) and volume flow rate ($\dot{V}$) by Equation (4).

$$\dot{m}_a = \dot{V} \times \rho_a \tag{4}$$

The air density is defined by Equation (5) [36]

$$\rho_a = -0.0043T_{db,i} + 1.2962 \tag{5}$$

2.3.2. Saturation Efficiency

The cooling effectiveness or saturation efficiency is established using Equation (6)

$$\varepsilon = \frac{T_{db,i} - T_{db,o}}{T_{db,i} - T_{wb,i}} \tag{6}$$

where $T_{db,i}$ is the inlet dry-bulb temperature, $T_{db,o}$ is the outlet dry-bulb temperature and $T_{wb,i}$ is the inlet wet-bulb temperature, determined using Equation (7) [37] with all the arctan functions evaluated in radians, $T_{db,i}$ and $T_{wb,i}$ are in °C and φ, the RH, in %.

$$T_{wb,i} = T_{db,i} \cdot \tan^{-1}\left(0.151977 \cdot \sqrt{\varphi + 8.313659}\right) + \tan^{-1}\left(T_{db,i} + \varphi\right) - \tan^{-1}(\varphi - 1.676331) + 0.00391838 \cdot \varphi^{3/2} \cdot \tan^{-1}(0.023101 \cdot \varphi) - 4.686035 \tag{7}$$

2.3.3. Coefficient of Performance

The coefficient of performance of the evaporative cooler is defined as the ratio of cooling capacity to the electric power consumption of the air fan and other auxiliary equipment used, like the air heater fan. Mathematically, it is given as

$$COP = \frac{Q}{P_f + P_{aux}} \quad (8)$$

3. Results and Discussion

Figures 2–5 show the recorded performance on the various days tested. These figures reveal a similar performance pattern, with the cooler maintaining a continuous storage chamber temperature below the ambient. Apart from that, the chamber temperature remained between 21–25 °C and the chamber RH between 88–94%. The temperature range, although higher than the storage temperature of most fruits and vegetables, should minimise temperature fluctuations and the resulting shock that stored products are subjected to, thereby reducing deterioration and damage rates.

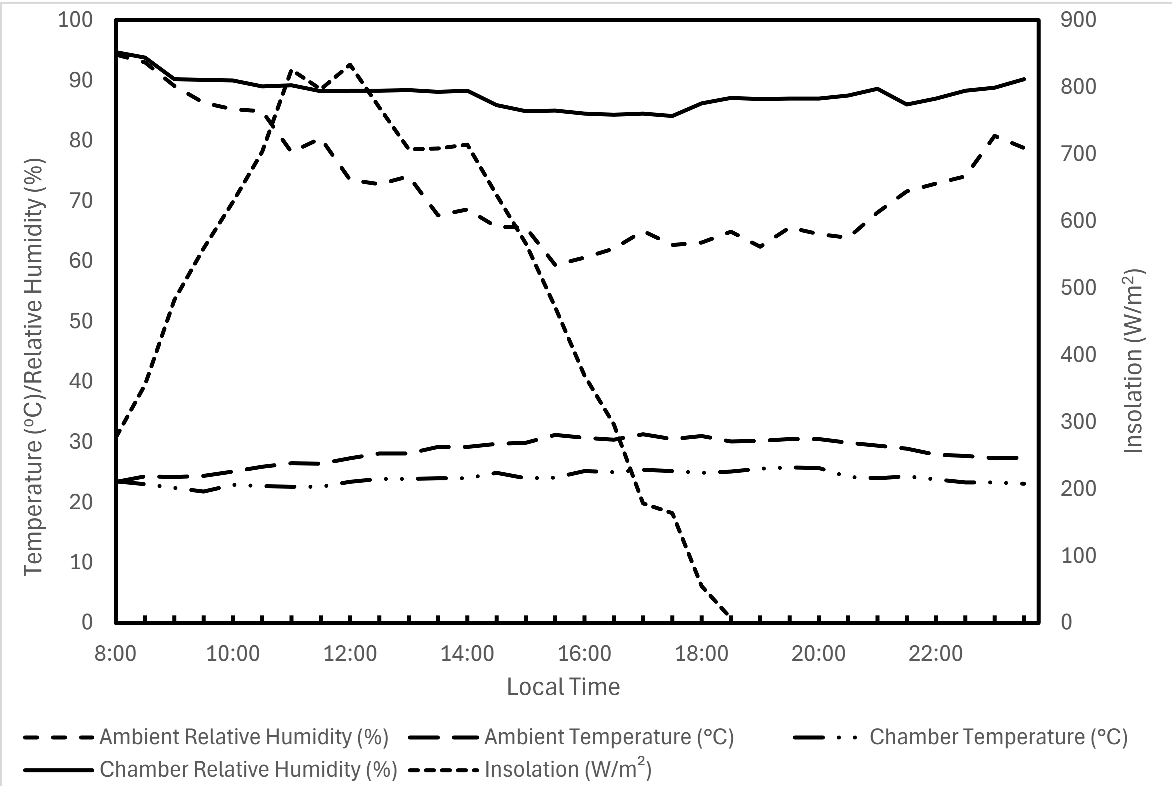

Figure 2. Performance on July 25.

Additionally, the relatively lower temperature achieved will lead to less heat-induced deterioration, and when combined with the generally high RH recorded in the chamber, should result in an improved shelf life for stored vegetables and fruits. Although the system did not reach the designed temperature of 15 °C, this can be attributed to minor construction errors and practical construction limitations during prototyping, including imperfect insulation, non-ideal sealing of the chamber, and variability in locally fabricated components, as well as the use of a fan with a lower flow rate than originally specified, due to the unavailability of the designated fan. Nonetheless, the recorded performance represents a significant improvement compared to prior reports of evaporative coolers in the same location during similar seasons, which did not achieve temperature depression, especially during nighttime and early morning hours. Importantly, the system consistently achieved cooling below ambient temperature and maintained high relative humidity, thereby fulfilling its intended preservation function under tropical conditions. Thus, the design principles employed remain valid, and the observed performance demonstrates the proof-of-concept feasibility. Also, the performance achieved with our system during this high RH period is comparable to the performance reported by [20] during a period of the year characterised by low RH and high ambient temperature.

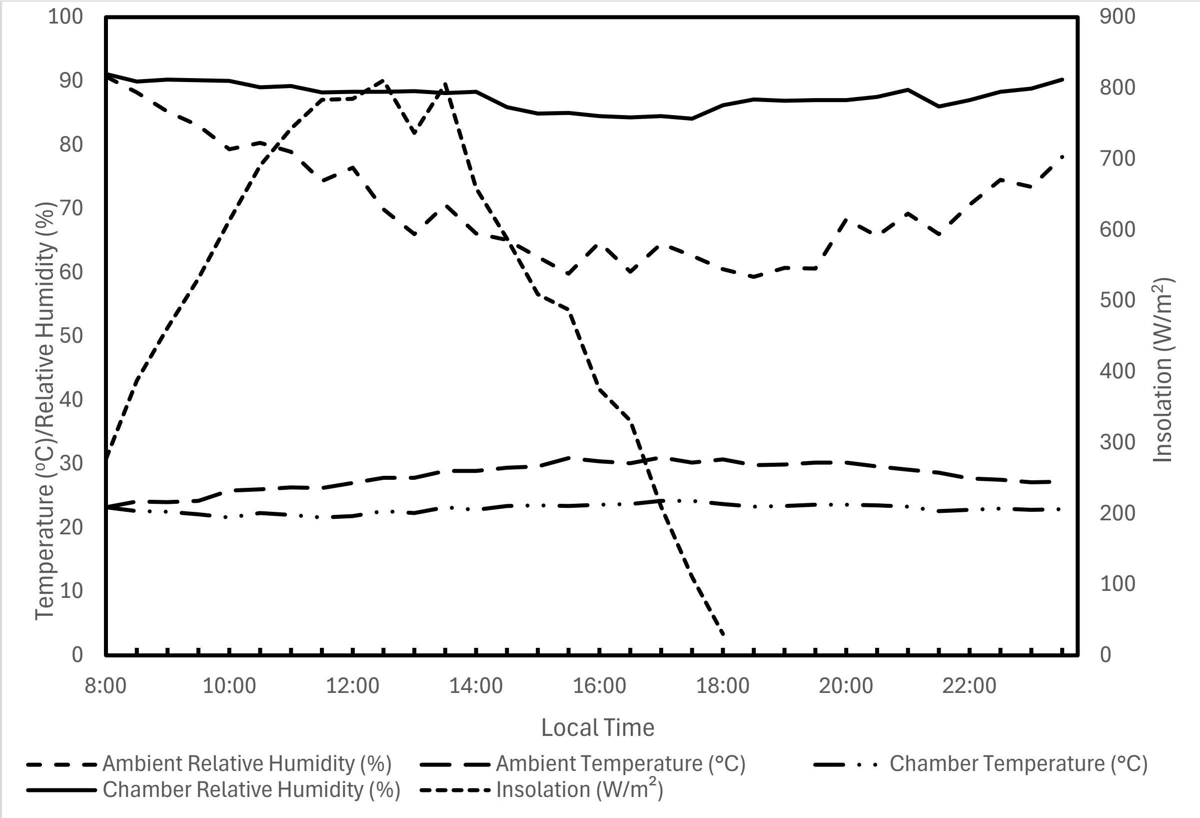

Figure 3. Performance on July 30.

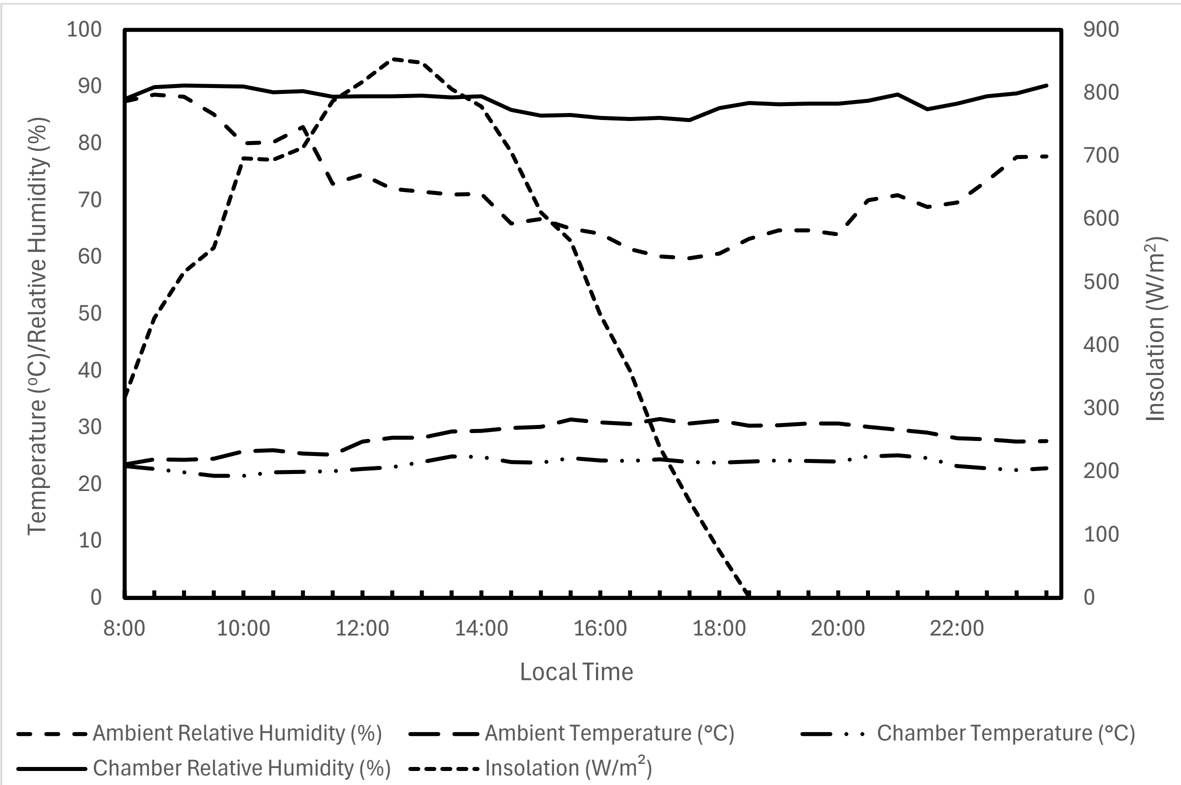

Figure 4. Performance on July 31.

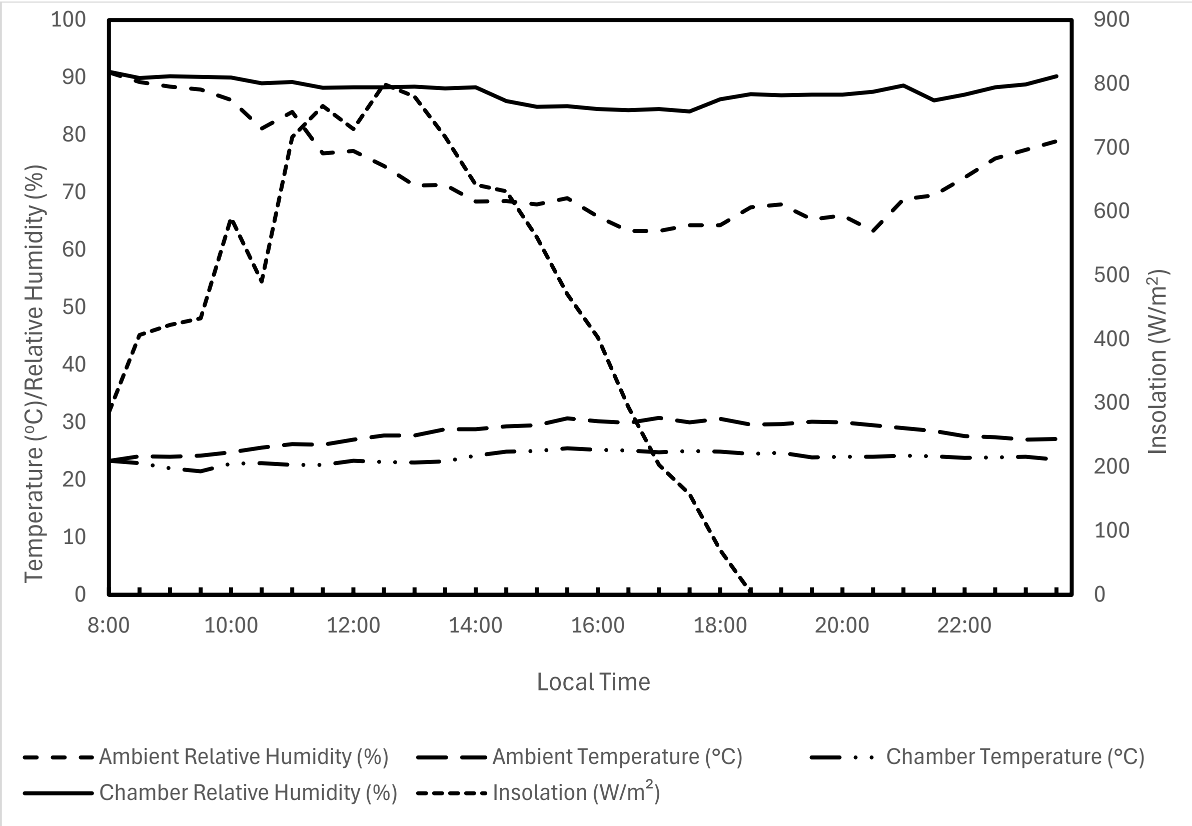

Figure 5. Performance on August 11.

The temperature difference between the ambient and the chamber varied between 1.5–7.5 °C, depending on the time of day. It is highest during the afternoon hours when RH is between 55–65% and lowest during the commencement of the experiment when RH is generally >88%, and that delayed the chamber pull-down time. However, as the experiment progressed, more cooling became possible, leading to an increase in the temperature difference between the ambient and chamber air, even with a relative humidity still >84%. In general, a temperature difference of 3–4 °C was achieved at 9:30–10:30 am. The cooling performance recorded, even during high RH periods, can be attributed to the adsorption properties of the activated carbon incorporated in the air inlet channel of the system while the temperature depression recorded may have been affected by the heat of adsorption which increased the inlet air temperature slightly after dehumidification by the desiccant, with the result that temperature of air approaching the humidification pad is slightly higher than the ambient temperature. The chamber RH was generally higher than the ambient RH, except at the commencement of the experiment, when they were quite close.

The lowest average temperature depression between the ambient and the cooling chamber of 4.14 °C was recorded on August 11. This day had the highest average ambient RH of 73.32%. Similarly, July 30, which had the lowest ambient RH of 70.47%, presented the highest average ambient air–cooling chamber temperature depression of 5.13 °C.

Although on an hourly basis, the ambient RH values are quite close (Figure 6), their average values (Figure 7) show a clear difference between the days considered. The same applies to the chamber temperature. Notably, the chamber temperature remains relatively constant, regardless of whether the ambient RH and temperature are high or low, and it is always lower than the ambient temperature. This indicates the dehumidifying function of the adsorbent. In fact, during periods of high ambient RH and for the temperature depression achieved, it would be expected that the chamber RH would be much higher than recorded, probably approaching 100%. However, the recorded values suggest that the high RH ambient air passing through the adsorbent experienced a substantial reduction in its RH, which then increased after evaporative cooling. Additionally, the temperature depression values could have been higher, but for the exothermic process associated with moisture adsorption. Hence, air cooling after adsorption is important to improve chamber cooling further.

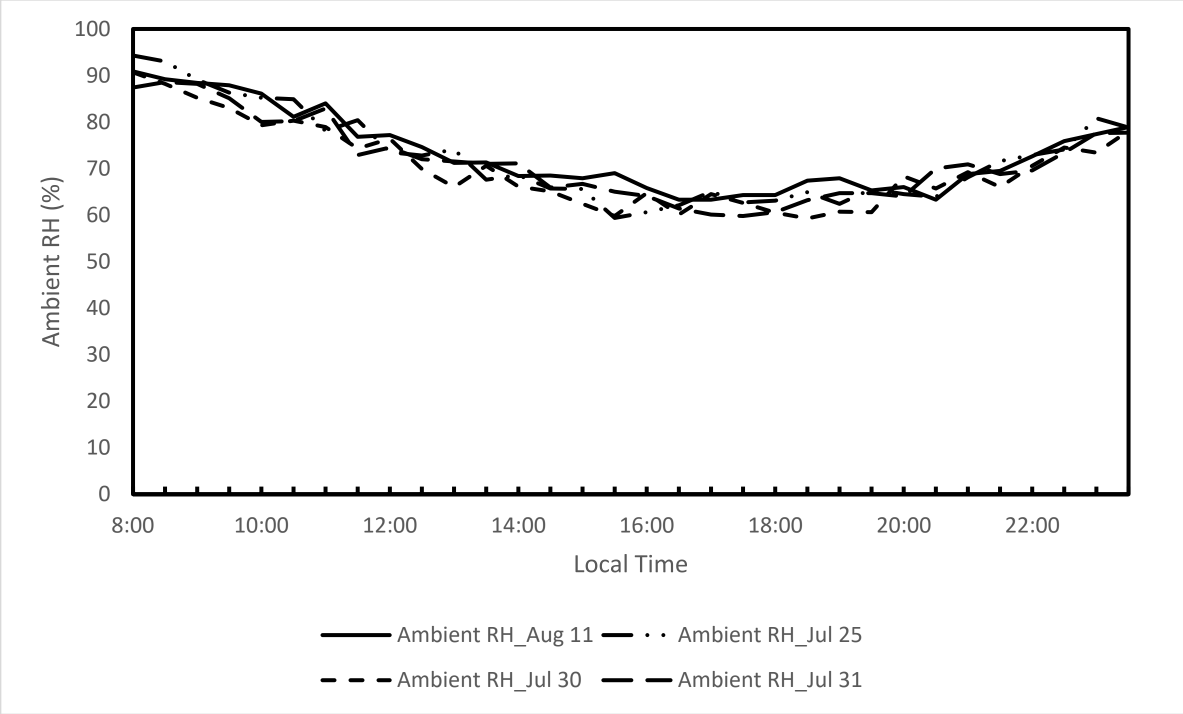

Figure 6. Comparison of the ambient RH values for the considered days.

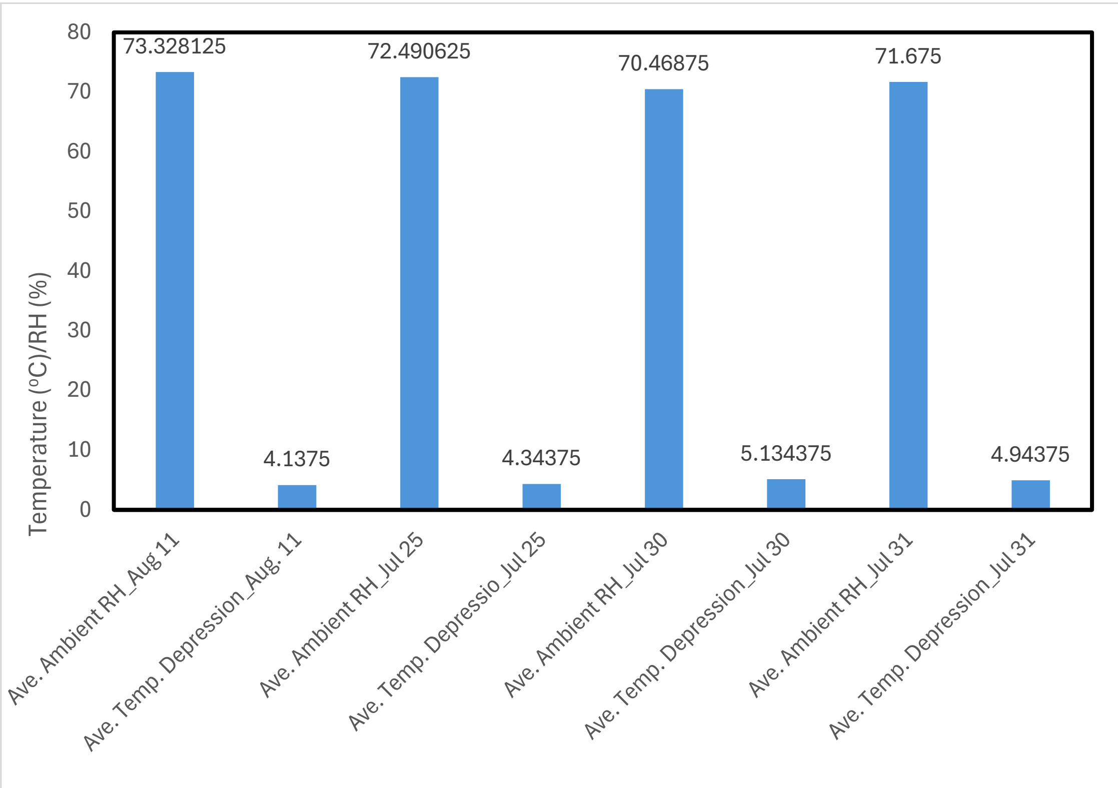

Figure 7. Average ambient temperature and RH on the considered days.

Figures 8–10 show the cooling capacity, saturation efficiency, and COP of the system during the test days. Figure 8 reveals a maximum cooling power of 381–471 W and an average value of 259–323 W, depending on the day, obtained using a fan delivering 0.052 m^3/s of air. Generally, higher cooling capacities were obtained on July 30th, which recorded the lowest average RH. Considering the generally high RH during the test period (Figure 6) and the low fan flow rate and air velocity, the cooling capacity values obtained are a good indication of the cooling enhancement achieved with the desiccant. The trend shows that maximum values occurred between 16–20 h. The saturation efficiency (Figure 9) showed values exceeding 100% during some periods of the day, an indication of the dehumidifying effect of the desiccant. The highest values were recorded during the early morning hours and late-night hours, when RH was highest. The average Saturation Efficiency was between 108–120%. These values are in line with previously reported studies [38–40] that applied different enhancement procedures. Ref. [41] reported achieving a saturation efficiency of 100% by the proper selection of pad material without any other form of performance enhancement. Saturation efficiency above 100% is possible in desiccant-enhanced systems since adsorption renders the air drier and lowers the inlet wet-bulb temperature. This enhances the air capacity for moisture removal, thereby providing better cooling and lowering the saturation temperature. This is possible since evaporative cooling is basically an adiabatic saturation process. Thus, lowering the wet-bulb temperature will alter the original adiabatic saturation path.

The average COP was determined as 2.95–3.67. The highest COP values of 4.2–5.2 were obtained from 16:00–18:00 h, while the lowest COP values were recorded in the morning hours of 8:00–10:00 h, when RH was highest, usually >88%. Compared to similar studies [23,29,42,43], with or without desiccant enhancement, previously reported, the COP obtained in this study, for the fan size and air velocity, is considered good. Ref. [42] reported that the evaporation rate and COP increase with an increase in air velocity. They recorded COP values of 1.14, 2.55, and 3.55, respectively, at air velocities of 0.1, 0.3, and 0.6 m/s. Also, considering the review by [44], the comparable temperature depression achieved here, despite higher ambient RH, demonstrates strong potential for shelf-life extension. Table 2 presents a comparison with similar non-complex or simple-cycle systems in which desiccants were used to enhance cooling. The Table reveals that, apart from [23], which, given the reported air velocity, is a much larger system, the performance of the present work is very good, especially considering that it operated at a much higher ambient RH. Interestingly, at present, few studies have applied desiccant enhancement to simple evaporative coolers for fruit and vegetable storage, and none have evaluated all key performance metrics (COP, cooling capacity, saturation efficiency, and temperature depression). Most available work focuses on comfort cooling, combined cycles or moisture removal by adsorbents.

The climate in Nigeria is generally grouped into two: the dry season, characterised by an ambient temperature of 28–35 °C and RH of 20–60%, and the rainy season, characterised by an ambient temperature of 26–30 °C and RH 70–90%. The good performance of evaporative coolers in environments with low RH, such as in Nigeria during the dry season, has been established. Thus, with the performance recorded by this system during the very humid periods, the authors believe the system can function effectively all year round in the Nigerian climate. Thus, future work will focus on the extended performance testing of the system to ascertain its shelf-life extension potential and the quality of the preserved products.

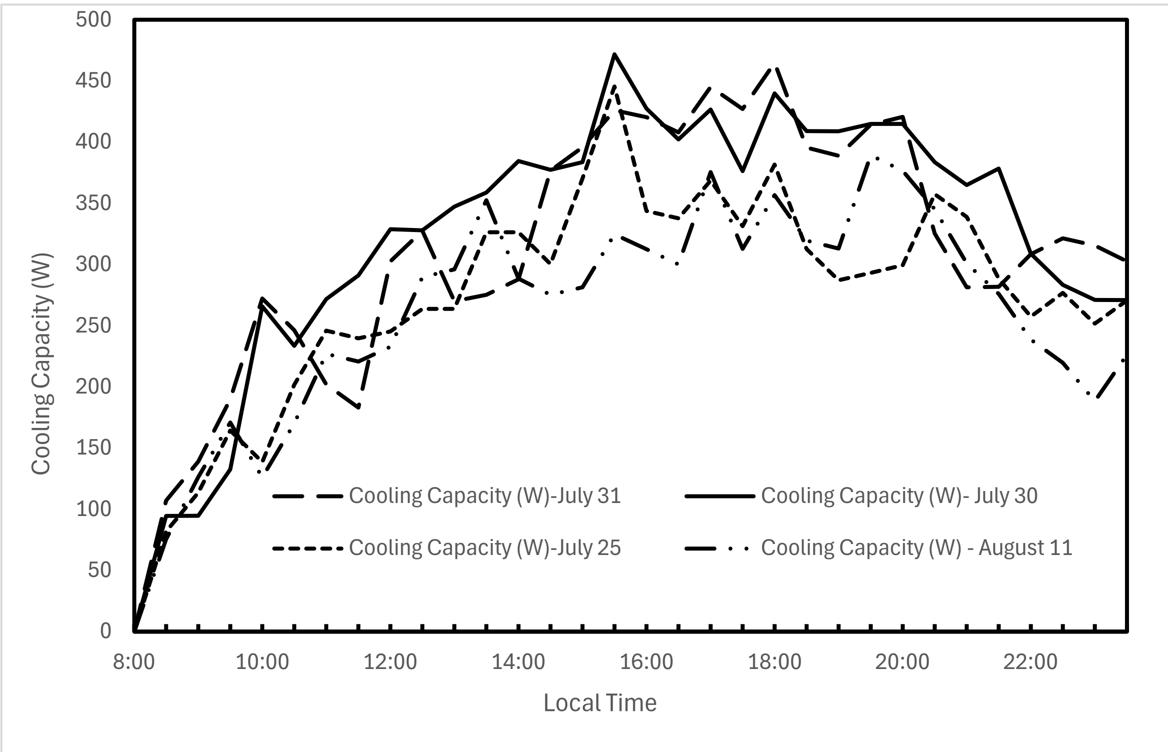

Figure 8. Cooling capacity of the evaporative cooler during the test days.

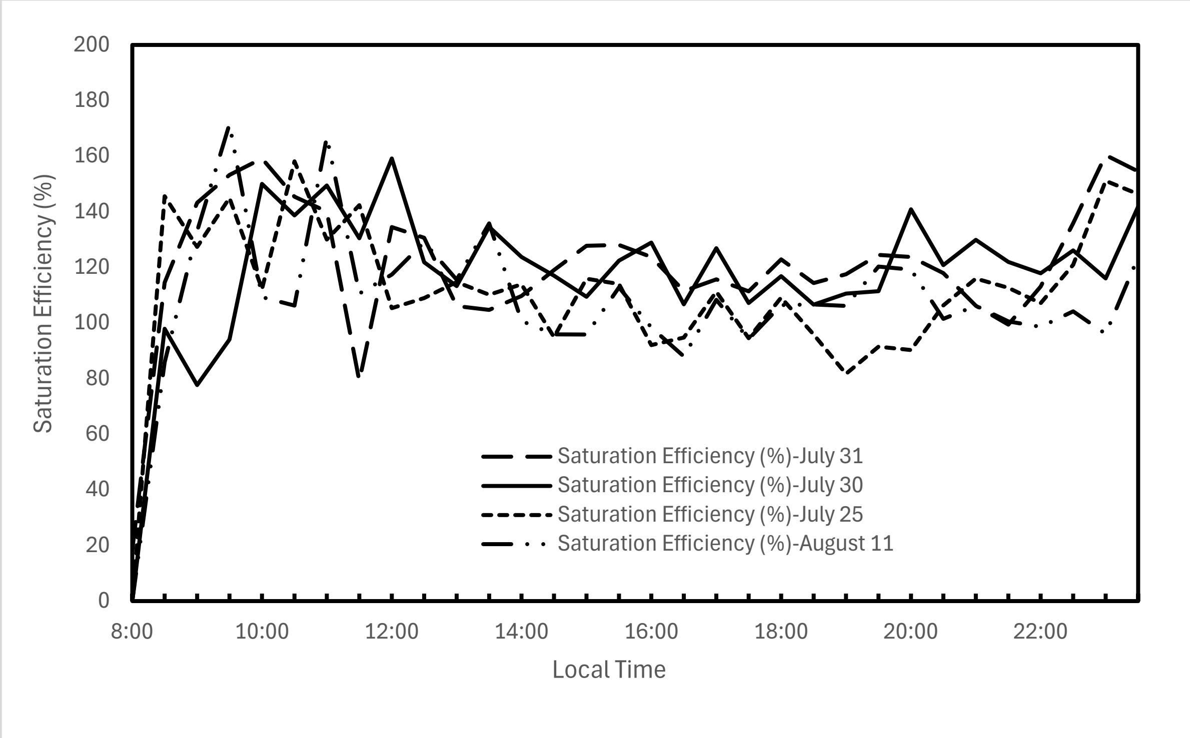

Figure 9. Saturation efficiency of the evaporative cooler during the test days.

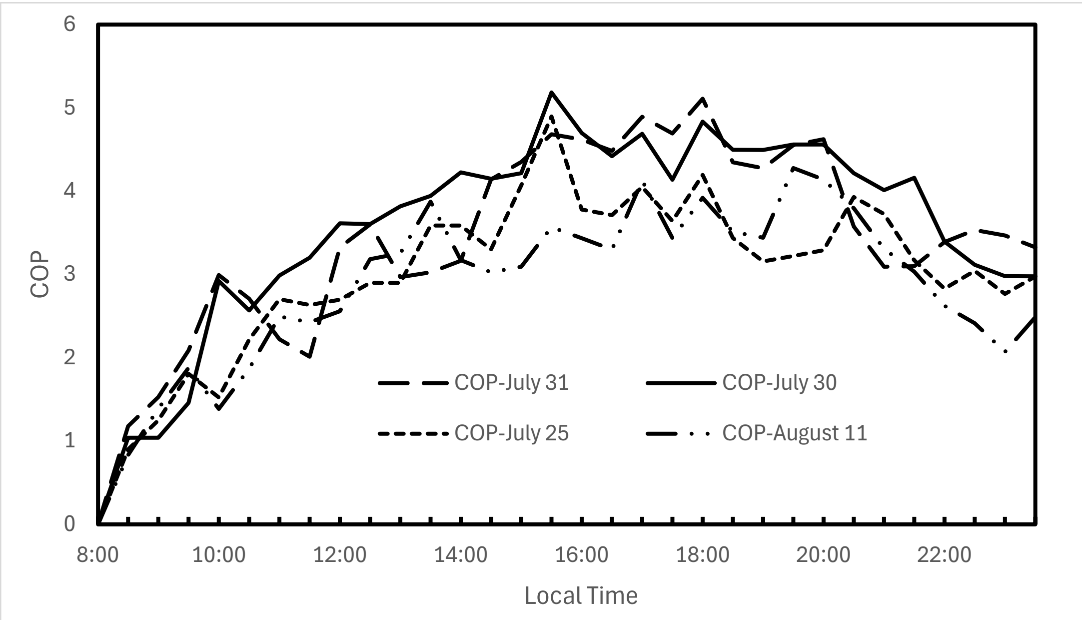

Figure 10. COP of the evaporative cooler.

Table 2. Comparison of the COP obtained in this study with previously reported ones.

Wet Media	Ambient Temperature (°C)/Ambient RH (%)	Air Velocity (m/s)	COP	Temp. Depression (°C)	Cooling Capacity (W)	Desiccant Type	
Blend of microfibre and synthetic fibre	23–32/60–95	0.2	2.95–3.67 (Average)	4–5	259–323	Activated Carbon	Present study
Cotton fiber pad	25–32/30–60	2	52.2	10.83–14.28	3653	Activated Carbon	[23]
Wetted fabric	30/55–60	-	-	3.7	Not Reported (Efficiency of 87.2%)	Silica-Gel	[45]
Wetted fabric	30/55–60	-	-	3.2	Not Reported (Efficiency of 79.3%)	Activated Carbon	[45]
corrugated cellulose paper	21.0–36.1/12.5–47.5	0.98 m/s	0.022–1.29	3–12	7000	Triethylene glycol (TEG)	[43]

4. Conclusions

A desiccant-enhanced evaporative cooler has been designed, built and tested. The design was aimed at creating a system that could provide cooling continuously at all times of the day and periods of the year, and in all locations, including predominantly high RH periods or locations. Thus, it factored in moisture removal from ambient air using desiccants and the management of saturated desiccant to ensure continuous cooling operation. The prototype was tested in Owerri, a southeastern Nigerian town, during the wet season, known to be highly humid, with an average RH > 88%. Based on the test results, the following conclusions can be drawn.

(i) Introduction of the desiccant and a system to ensure desiccant regeneration resulted in an average cooling of 4.14–5.13 °C below ambient temperature. Throughout the experiment, the cooling chamber temperature was maintained at a value below that of the ambient.
(ii) Saturation efficiency was generally above 100%, indicating the enhancement in cooling due to the desiccant. The average values were 108–120%.
(iii) A maximum cooling power of 381–471 W and an average value of 259–323 W, depending on the day, were recorded, while the average COP was 2.95–3.67.

These results are a good indication that the designed system can produce cooling, even in very humid regions.

Author Contributions

V.A.J., J.C.N. and D.A.O.: investigation, methodology; D.O.N.: investigation, methodology, writing—original draft; E.S.M.: software, methodology, visualisation; N.V.O.: conceptualization, writing—review & editing, funding acquisition, supervision. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Tertiary Education Trust Fund (TETFund) grant number NRF2021/SETI/ASF/00199.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data used in this article are available and can be accessed on request from the authors.

Acknowledgments

The authors wish to acknowledge the contribution of Engr. N. Emukah, who handled the construction of the experimental rig.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

References

1. Food and Agricultural Organization of the United Nations [FAO]. FAOSTAT Statistical Database. 2022. Available online: https://www.fao.org/faostat/en/#data (accessed on 26 January 2025).
2. Kapilan, N.; Isloor, A.M.; Karinka, S. A comprehensive review on evaporative cooling systems. *Results Eng.* **2023**, *18*, 101059. https://doi.org/10.1016/j.rineng.2023.101059.
3. Anyanwu, E.E. Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables. *Energy Convers. Manag.* **2004**, *45*, 2187–2195. https://doi.org/10.1016/j.enconman.2003.10.020.

4. Khatun, A.; Singh, R.P.; Kumar, A. Development of a low-cost evaporative cooling storage structure for perishable commodities. *Food Sci. Res. J.* **2019**, *10*, 221–231. https://doi.org/10.15740/HAS/FSRJ/10.2/221-231.
5. Islam, M.P.; Morimoto, T. Zero energy cool chamber for extending the shelf-life of tomato and eggplant. *Jpn. Agric. Res. Q.* **2012**, *46*, 257–267. https://doi.org/10.6090/jarq.46.257.
6. Prabha, A.; Sharma, H.R.; Goel, A.K.; et al. Changes in Ascorbic Acid Content of Lemon Fruit Stored in Zero Energy Cool Chamber and under Ambient Atmosphere. *J. Dairy. Foods Home Sci.* **2006**, *25*, 73–75.
7. Ronoh, E.K.; Kanali, C.L.; Ndirangu, S.N.; et al. Performance Evaluation of an Evaporative Charcoal Cooler and Its Effects on Quality of Leafy Vegetables. *J. Postharvest Technol.* **2018**, *8*, 60–69.
8. Ronoh, E.K.; Kanali, C.L.; Ndirangu, S.N. Effectiveness of an evaporative charcoal cooler for the postharvest preservation of tomatoes and kales. *Res. Agr. Eng.* **2020**, *66*, 66–71. https://doi.org/10.17221/52/2019-RAE.
9. Ohagwu, C.J.; Nwakaire, J.N.; Ugwu, S.N.; et al. Evaluation of Fresh and Fleshy Cucumber Quality and Shelf-Life Using Charcoal Cooler Bin in the Tropics. *Agric. Eng. Int. CIGR J.* **2023**, *25*, 285–295.
10. Defraeye, T.; Schudel, S.; Shrivastava, C.; et al. The charcoal cooling blanket: A scalable, simple, self-supporting evaporative cooling device for preserving fresh foods. *Biosyst. Eng.* **2024**, *238*, 128–142. https://doi.org/10.1016/j.biosystemseng.2023.12.001.
11. Güzelel, Y.E.; Olmuş, U.; Büyükalaca, O. Performance evaluation of different types of indirect evaporative coolers: A CFD-based comparative study. *J. Build. Eng.* **2024**, *96*, 110399. https://doi.org/10.1016/j.jobe.2024.110399.
12. Muñoz, R.C.; Diuco II, L.T.; Martinez, S.M.S.; et al. Automated Electronic Evaporative Cooler for Fruits and Vegetables Preservation. *Int. J. Eng. Sci. Res. Technol.* **2017**, *6*, 352–364. https://doi.org/10.5281/zenodo.814406.
13. Awafo, E.A.; Nketsiah, S.; Alhassan, M.; et al. Design, Construction, and Performance Evaluation of an Evaporative Cooling System for Tomatoes Storage. *Agric. Eng.* **2020**, *24*, 1–12. https://doi.org/10.1515/agriceng-2020-0031.
14. Babaremu, K.O.; Adekanye, T.A.; Okokpujie, I.P.; et al. The Significance of Active Evaporative Cooling System in the Shelf Life Enhancement of Vegetables (Red and Green Tomatoes) for Minimizing Post-Harvest Losses. *Procedia Manuf.* **2019**, *35*, 1256–1261. https://doi.org/10.1016/j.promfg.2019.06.084.
15. Ndukwu, M.C.; Manuwa, S.I.; Olukunle, O.J.; et al. Development of an Active Evaporative Cooling System for Short-Term Storage of Fruits and Vegetable in a Tropical Climate. *Agric. Eng. Int. CIGR J.* **2013**, *15*, 307–313.
16. Adekanye, T.; Babaremu, K.; Okunola, A. Evaluation of an Active Evaporative Cooling Device for Storage of Fruits and Vegetables. *Agric. Eng. Int. CIGR J.* **2019**, *21*, 203–208.
17. Mogaji, T.S.; Fapetu, O.P. Development of an Evaporative Cooling System for the Preservation of Fresh Vegetables. *Afr. J. Food Sci.* **2011**, *5*, 255–266.
18. Zakari, M.D.; Abubakar, Y.S.; Muhammad, Y.B.; et al. Design and Construction of an Evaporative Cooling System for the Storage of Fresh Tomato. *ARPN J. Eng. Appl. Sci.* **2016**, *11*, 2340–2348.
19. Langat, V.K.; Kanali, C.L.; Ronoh, E.K.; et al. Performance evaluation of an evaporative charcoal cooler utilizing thin-film photovoltaic system for preservation of avocado. *Int. J. Agric. Environ. Res.* **2022**, *8*, 290–302. https://doi.org/10.51193/IJAER.2022.8206.
20. Ndukwu, M.C.; Usoh, G.; Akpan, G.; et al. Development of a Small Dual-Chamber Solar PV-Powered Evaporative Cooling System for Fruit and Vegetable Cooling with Techno-Economic Assessment. *Agri. Eng.* **2024**, *6*, 2553–2576. https://doi.org/10.3390/agriengineering6030149.
21. Amer, O.; Boukhanouf, R.; Ibrahim, H.G. A Review of evaporative cooling technologies. *Int. J. Environ. Sci. Dev.* **2015**, *6*, 111–117. https://doi.org/10.7763/IJESD.2015.V6.571.
22. Obura, J.M.; Banadda, N.; Wanyama, J.; et al. A Critical Review of Selected Appropriate Traditional Evaporative Cooling as Postharvest Technologies in Eastern Africa. *Agric. Eng. Int. CIGR J.* **2015**, *17*, 345–354.
23. Mekonen, T.N.; Delele, M.A.; Molla, S.W. Development and Testing of Solar Powered Evaporative Air-Cooling System with an Improved Performance. *Cogent Eng.* **2023**, *10*, 2178115. https://doi.org/10.1080/23311916.2023.2178115.
24. Samer, M.; Abdelsalam, E.; Abd Elhay, Y.B. Enhancing the Efficiency of Evaporative Cooling Pads for Livestock Barns and Greenhouses by Moisture Adsorption. *Agric. Eng. Int. CIGR J.* **2016**, *17*, 36–63.
25. Lee, Y.; Park, S.; Kang, S. Performance analysis of a solid desiccant cooling system for a residential air conditioning system. *Appl. Therm. Eng.* **2021**, *182*, 116091. https://doi.org/10.1016/j.applthermaleng.2020.116091.
26. Chen, L.; Deng, W.; Chu, Y. Experimental study on desiccant evaporative combined chilled air/chilled water air conditioning systems. *Appl. Therm. Eng.* **2021**, *199*, 117534. https://doi.org/10.1016/j.applthermaleng.2021.117534.
27. Kashif, M.; Niaz, H.; Sultan, M.; et al. Study on Desiccant and Evaporative Cooling Systems for Livestock Thermal Comfort: Theory and Experiments. *Energies* **2020**, *13*, 2675. https://doi.org/10.3390/en13112675.
28. Zhang, Y.; Chen, Y.; Yang, H.; et al. Experimental performance investigation on a desiccant-assisted two-stage evaporative cooling system in hot and humid areas. *Appl. Energy* **2025**, *377*, 124704. https://doi.org/10.1016/j.apenergy.2024.124704.
29. Hussain, G.; Aleem, M.; Sultan, M.; et al. Evaluating Evaporative Cooling Assisted Solid Desiccant Dehumidification System for Agricultural Storage Application. *Sustainability* **2022**, *14*, 1479. https://doi.org/10.3390/su14031479.

30. Raza, H.M.U.; Sultan, M.; Aleem, M.; et al. Experimental study on advanced indirect evaporative cooling and desiccant dehumidification systems for agricultural greenhouses. *Int. Commun. Heat. Mass. Transf.* **2026**, *172*, 110321. https://doi.org/10.1016/j.icheatmasstransfer.2025.110321.
31. Mahmood, M.H.; Sultan, M.; Miyazaki, T. Solid desiccant dehumidification-based air-conditioning system for agricultural storage application: Theory and experiments. *Proc. Inst. Mech. Eng. Part. A J. Power Energy* **2019**, *234*, 534–547. https://doi.org/10.1177/0957650919869503.
32. Hraiech, I.; Zallama, B.; Belkhiria, S.Z.G.; et al. Experimental characterization of silica gel adsorption and desorption isotherms under varying temperature and relative humidity in a fixed bed reactor. *Sci. Rep.* **2025**, *15*, 29041. https://doi.org/10.1038/s41598-025-14677-7.
33. Chairunnisa; Miksik, F.; Miyazaki, T.; et al. Development of biomass based-activated carbon for adsorption dehumidification. *Energy Rep.* **2021**, *7*, 5871–5884. https://doi.org/10.1016/j.egyr.2021.09.003.
34. Cimbala, J.M. Experimental Uncertainty Analysis. 2013. Available online: https://www.me.psu.edu/cimbala/me345/Lectures/Exper_Uncertainty_Analysis.pdf (accessed on 11 October 2025).
35. Liao, C.M.; Singh, S.; Sen, T. Part A: Toxic/ Hazardous Substances and Environmental Engineering Characterizing the performance of alternative evaporative cooling pad media in thermal environmental control applications. *J. Environ. Sci. Health* **1998**, *33*, 1391–1417. https://doi.org/10.1080/10934529809376795.
36. Delele, M.A.; Ngcobo, M.E.K.; Getahun, S.T. et al. Studying airflow and heat transfer characteristics of a horticultural produce packaging system using a 3-D CFD model. Part I: Model development and validation. *Postharvest Biol. Technol*, **2013**, *86*, 536–545. https://doi.org/10.1016/j.postharvbio.2013.08.014.
37. Stull, R. Wet-Bulb Temperature from Relative Humidity and Air Temperature. *J. Appl. Meteorol. Climatol.* **2011**, *50*, 2267–2269. https://doi.org/10.1175/JAMC-D-11-0143.1.
38. Eldessouky, H. Performance Analysis of Two-Stage Evaporative Coolers. *Chem. Eng. J.* **2004**, *102*, 255–266. https://doi.org/10.1016/j.cej.2004.01.036.
39. Jain, D. Development and testing of two stage evaporative cooler. *Build. Environ.* **2007**, *42*, 2549–2554. https://doi.org/10.1016/j.buildenv.2006.07.034.
40. Heidarinejad, G.; Bozorgmehr, M.; Delfani, S.; et al. Experimental investigation of two-stage indirect/direct evaporative cooling system in various climatic conditions. *Build. Environ.* **2009**, *44*, 2073–2079. https://doi.org/10.1016/j.buildenv.2009.02.017.
41. Velasco-Gómez, E.; Tejero-González, A.; Jorge-Rico, J.; et al. Experimental investigation of the potential of a new fabric-based evaporative cooling pad. *Sustainability* **2020**, *12*, 7070. https://doi.org/10.3390/su12177070.
42. Doğramaci, P.A.; Riffat, S.; Gan, G.; et al. Experimental study of the potential of eucalyptus fibres for evaporative cooling. *Renew. Energy* **2019**, *131*, 250–260. https://doi.org/10.1016/j.renene.2018.07.005.
43. Awafo, E.; Addo, A.; Bart-Plange, A. Performance analysis of a desiccant evaporative cooling system for mango fruit storage in the savannah and transitional zones of Ghana. *Agric. Eng.* **2019**, *23*, 1–14. https://doi.org/10.1515/agriceng-2019-0021.
44. Ogueke, N.V.; Jumbo, V.A.; Njoku, J.C.; et al. Evaporative Cooling for Agricultural Preservation: Technologies, Challenges, and Future Prospects. *Therm. Sci. Appl.* **2026**, *1*, 122–137. https://doi.org/10.53941/tsa.2026.100009.
45. Mugwaneza, E.; Nyaanga, D.; Wafula, N. Performance evaluation of experimental solar evaporative cooling systems. *J. Eng. Agric. Environ.* **2024**, *10*, 1–10. https://doi.org/10.37017/jeae-volume10-no2.2024-2.