
EXPERIMENTAL ASSESSMENT OF ACTIVATED CHARCOAL GRANULES AS WET PAD FOR EVAPORATIVE COOLING IN POSTHARVEST STORAGE SYSTEMS DESIGN

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ABSTRACT

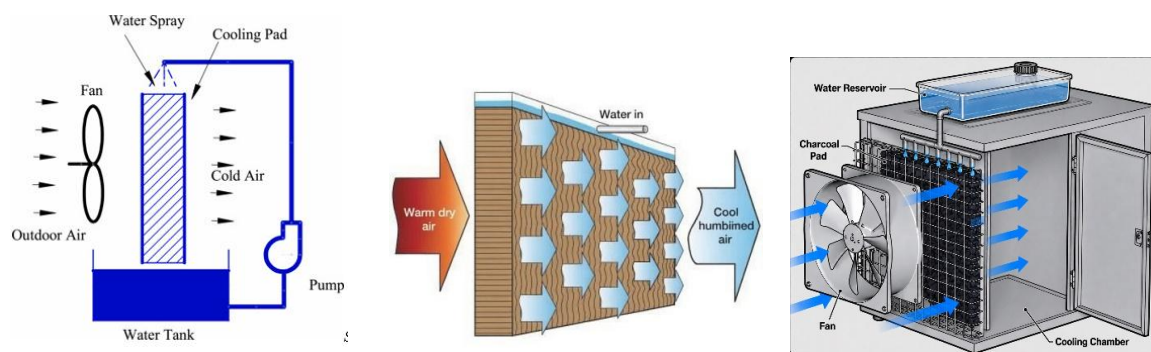
Evaporative cooling serves as an energy-efficient alternative to conventional vapor-compression air conditioning. It is a cooling method that uses water to lower air temperature. The conventional cellulose or plastic pads that are mostly used are costly, non-renewable, and require frequent replacement. This experimental study was carried out to assess the suitability of charcoal granules as alternative material for evaporative cooling pad used in postharvest storage systems. A test setup is designed to evaluate the performance of charcoal granules. Water absorption and retention characteristics (retention capacity) are critical parameter in evaporative cooling systems, as it directly influences evaporation rate, cooling effectiveness, operational stability, and overall water consumption. The water retention capacity of the charcoal (internal micro-porosity) was determined to be 0.62 (g/g), with a porosity (bulk void fraction) of 52%. The temperature gradients and relative humidity difference were evaluated. The ambient temperature was lowered from an average of 30 – 42°C to 19 – 30°C (ΔT of 10–12°C). Relative Humidity rises from an average of 32%–60% ambient to 75 – 97% inside the chamber. The chamber demonstrates reliable and statistically significant cooling performance, with an average of 24.8% efficiency (8.8°C reduction) across varying ambient conditions. The system delivers consistent temperature drop with substantial moisture addition, reducing sensible heat while slightly lowering (or maintaining) total enthalpy. Performance is consistent across the three days. It is highly effective in humidification, achieving an average relative humidity of 89.48% with 97% efficiency (nearly doubling ambient RH).

Keywords: Evaporative cooling; charcoal granules; cooling pad; cooling Efficiency; relative humidity efficiency; water retention capacity

INTRODUCTION

An evaporative system is a cooling method that uses water to lower air temperature (Bodile et al., 2025). It works by passing warm air through a wet cooling pad, where the water absorbs heat and evaporates, making the air cooler before it is circulated. It is an adiabatic exchange of sensible heat to latent heat (Kumarasinghe et al., 2026). The cooling pad is the most important part of this system because its performance directly affects how well the cooling works. Water is continuously supplied to the pad manually or using a pump, keeping it wet. A fan pushes warm air through the wet pad, and as the air passes through, the water absorbs heat and turns into vapor, cooling the air. This cool air is then spread into the room or space. The process continues as long as water is supplied and air flows through the pad. The cooling pad's efficiency depends on its material, thickness, water-holding capacity, and airflow, making it a key part of the system (Ogumo et al., 2017).

The trend of using fan-pad evaporative cooling systems in agricultural systems is increasing. The air from outside the facility is forced to enter through a constantly wet porous medium (pad). Sensible and latent heat transfer occurs when the air is in contact with the water surface. Air loses sensible heat, decreasing its temperature, while water evaporates from the surface of the pad, increasing the humidity of the air. The air at the outlet of the pad has a lower temperature and a higher relative humidity than the inlet one (Vega et al., 2022).



Illustrative diagrams of how the cooling pad works

Cooling through evaporation is an ancient and effective method of lowering temperature. Both plants and animals use this method to lower their temperatures. Trees, through the method of Evapotranspiration, for example, remain cooler than their environment (Bodile et al., 2025)..

The operational effectiveness of an evaporative cooling is made up of a porous material that is fed with water. Hot dry air is drawn over the material. The water evaporates into the air raising the humidity and at the same time reducing the temperature of the air. The system is dependent on the conditions of the air and it is necessary to determine the weather conditions that may be encountered to properly evaluate the possible effectiveness of evaporative cooling (Warke & Deshmukh, 2017).

The tendency to use fan-pad evaporative cooling systems in agricultural buildings is increasing, but the rate of this increase is inhibited because of the high cost of the commercial pad materials example; CELdek which costs between Twenty Thousands to Seventy Thousands per square meter. Therefore, there is a need to evaluate the locally available cheap materials using as pads (Shitanda et al., 2015).

Evaporative cooling serves as an energy-efficient alternative to conventional vapor-compression air conditioning, particularly in arid and semi-arid climates where low humidity allows for significant thermal reduction through water evaporation (Franco-salas, 2021). Despite its advantages, the performance of traditional cooling media—such as cellulose or plastic—is often constrained by material costs, limited sustainability, and the necessity for frequent replacement (Kumarasinghe et al., 2026).

Water retention capacity and porosity are the major properties expected of a material that can be used as cooling pad (Deoraj et al., 2015). Most pad media for the evaporative cooling system are made from agricultural residue, although there are some commercially created pad media for sale in the market. Among materials that have been used for cooling pad manufacturing include jute, cellulose, aspen, PVC, hessian, wood shaven, rice straw, cotton fleece, latex, foam and luffa fiber (Udo et al., 2025).

A pad material should be porous enough to allow free flow of air. It should be able to absorb water and allow evaporation. It should have maximum amount of wetted surface area for an adequate period of air water contact time to achieve near saturation. The material should be locally available and inexpensive. Moreover, it should allow easy construction into required shape and size (Awafo et al., 2020).

Charcoal granules present a compelling, low-cost alternative, offering a porous structure that facilitates high water-air contact and effective heat exchange within sustainable cooling systems (Kouchakzadeh & Brati, 2013). The inherent microporosity of carbonized biomass promotes superior water retention through capillary action, which is essential for maximizing mass transfer during the evaporative process (Yeneneh, 2023).

Furthermore, utilizing this carbon-based medium aligns with broader efforts to integrate sustainable, waste-derived materials into HVAC design, potentially mitigating the environmental impact associated with traditional synthetic padding (Kumarasinghe et al., 2026). Beyond these structural benefits, charcoal granules exhibit potential for long-term operational durability, as their resistance to biological degradation may offer a more robust lifecycle compared to conventional cellulose pads susceptible to rapid salt and dust accumulation (Franco-salas, 2021).

Commercially available cooling pads are expensive and accordingly, there is an urgent need to evaluate the performance of suitable locally available materials when used as cooling pads, particularly for rural agricultural systems (Perez, 2022). Previous researches showed a cooling capacity of some materials used as wet pad coir fibre (89.6–92.8%), fine fabric (47.22–85.51%), coarse fabric (63.88–86.32%), polyvinyl chloride (PVC), sponge (38.9%), jute (62.1%) and luffa (55.1%) (Vega et al., 2022).

Charcoal is a local waste derived from pyrolysis of biomass (Berihun, 2023). Activated charcoal undergoes two-steps heating process. It serves as an excellent wet pad material due to their microporous structure, which facilitates high water absorption and slow release for sustained evaporation. Unlike commercial cellulose pads, charcoal is locally sourced, durable, and less prone to microbial growth. This study assesses its performance as a granular wet pad in post-harvest storage systems, focusing on microclimate control and produce quality preservation.

Charcoal is an ideal material for refrigeration because it has pores, which absorb and store water. This reduces heat from outside. And because wet charcoal does not allow easy passage of heat, it results in low temperatures inside the cubicle. Due to its pore structure, charcoal can absorb a lot of water quickly (Defraeye et al., 2024).

MATERIALS AND METHODS

The construction and experiment were carried out in Birnin Kebbi, (12.4318°N, 4.1956°E) north western Nigeria, and is only limited to this location and carried out only for three days due to some constraints. Conducted in the month of April/May when the annual temperature was at its peak in the region, and lowest relative humidity due to hot dried air.

3.1 Experimental Setup

To measure the cooling performance of the charcoal, a special cooling chamber is designed and constructed. A direct evaporative cooling test apparatus typically consists of a fan, ducting, and a pad of 13cm x 13cm with 5cm thickness was filled with charcoal granules (particle size 35–45 mm). This particle sizes are necessary for optimal airflow. If the particles are too small there might be unbreathable sludge that prevent water distribution. Water is distributed via drip at a rate of 0.0125 liter per minute to keep the pad saturated. The fan (SUNON KDE1212PMV1) has an Air Flow Rate of 0.060m³/s. The chamber comprises a hollow rectangular duct (24cmx18cm with 2cm thickness) made of Polyurethane (PU) Foam and lagged with aluminum sheet. (Fig1) Airflow is forced by a fan through the pad into the chamber where thermo-hygrometer is attached directly inside to measure modified temperature and humidity. Temperature and relative humidity were measured using HTC-1 digital thermo-hygrometers. The instruments were used according to the manufacturer's operating instructions. Formal laboratory calibration against a traceable reference standard was not performed before the experiment due to lack of resources which represents a limitation of the study. The reported temperature and relative-humidity values are interpreted within the measurement accuracy specified for the instruments.



Figure 1: Some Pictures from the experiment

3.2 Experimental Procedure

- Activated charcoal is used as a cooling medium. Charcoal has a high surface area, which allows it to absorb and release heat efficiently.
- Water is poured over the charcoal, causing it to evaporate and cool the air around it pores.
- Fan is used to force the surrounding air in to the wetted pad and pass through it as cooled air
- Cooling Chamber: The cooled air is then circulated through a chamber, where the temperature and relative humidity are being measured using a thermo-hygrometer

3.3 Charcoal Preparation

Charcoal granules are washed to remove dust, sieved for uniformity, and packed into cuboid wire mesh to make a pad of granules. Bulk density, porosity, and water holding capacity are major factors in determine the efficiency of the system

4.0 RESULTS AND DISCUSSION

4.1 Microclimate Performance

The ambient temperature and humidity are monitored and measured in the experiments, and compared with the cooling chamber. The experimental data for the reduction of temperature across the time is summarized in Table 1. The experimental data for the increase in humidity with respect to time is summarized in Table 2

Table 1: Chamber temperature and Ambient temperature (°C)

Time of the Day	TEMPERATURE DAY 1		TEMPERATURE DAY 2		TEMPERATURE DAY 3	
	Chamber	Ambient	Chamber	Ambient	Chamber	Ambient
05:00	27.5	34.0	26.0	33.0	27.0	34.0
06:00	26.0	33.5	26.0	34.0	26.5	33.0
07:00	23.5	36.5	25.5	34.5	24.0	35.5
08:00	20.5	35.5	23.0	35.0	22.5	35.0
09:00	19.0	32.5	21.5	33.5	22.5	31.5
10:00	22.5	34.5	22.0	34.5	23.0	31.5
11:00	23.0	35.0	22.0	36.0	24.5	33.0
12:00	26.5	35.5	26.0	36.5	25.0	34.5
13:00	28.0	37.0	27.5	36.5	27.0	36.0
14:00	30.5	40.0	30.0	38.0	29.5	39.5
15:00	32.5	41.5	31.5	39.5	30.5	40.0
16:00	31.5	39.0	31.5	38.5	31.0	38.0
17:00	30.0	38.5	29.0	37.5	30.5	36.0
18:00	30.5	38.0	29.5	37.5	29.0	36.0
19:00	29.0	38.0	29.5	37.0	29.0	35.5
20:00	28.5	36.5	28.0	34.5	28.0	35.0
21:00	28.5	36.0	28.5	34.0	27.0	34.5
22:00	28.0	33.5	27.5	32.0	27.0	33.0

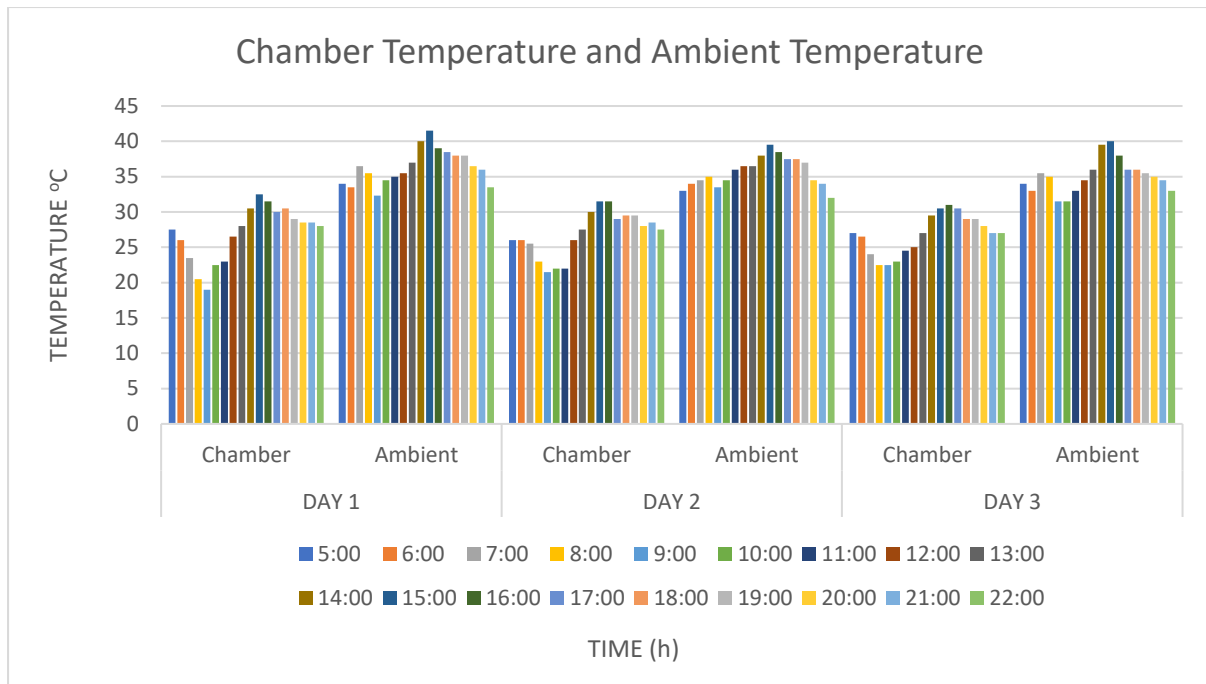


Figure 2: Comparison of chamber temperature and ambient temperatures. The colour bars correspond to time range

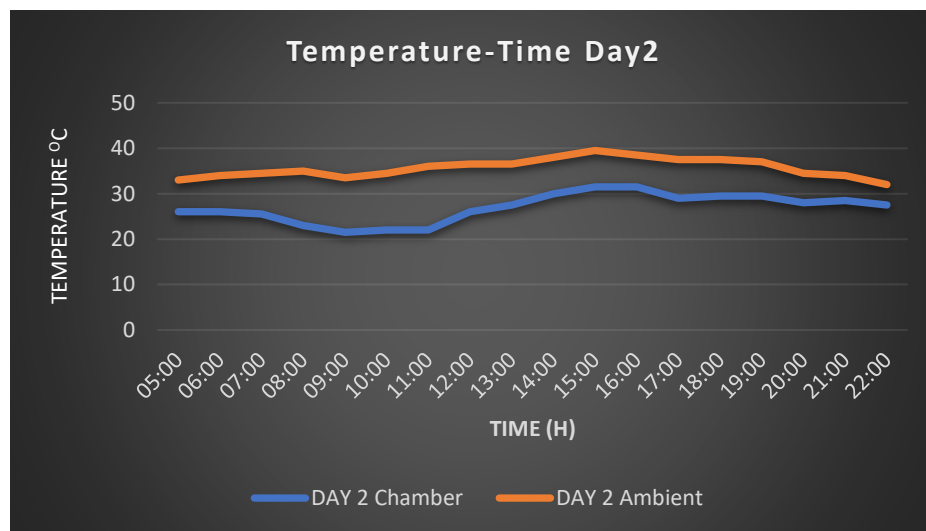


Figure 4: Temperature Behavior Day2

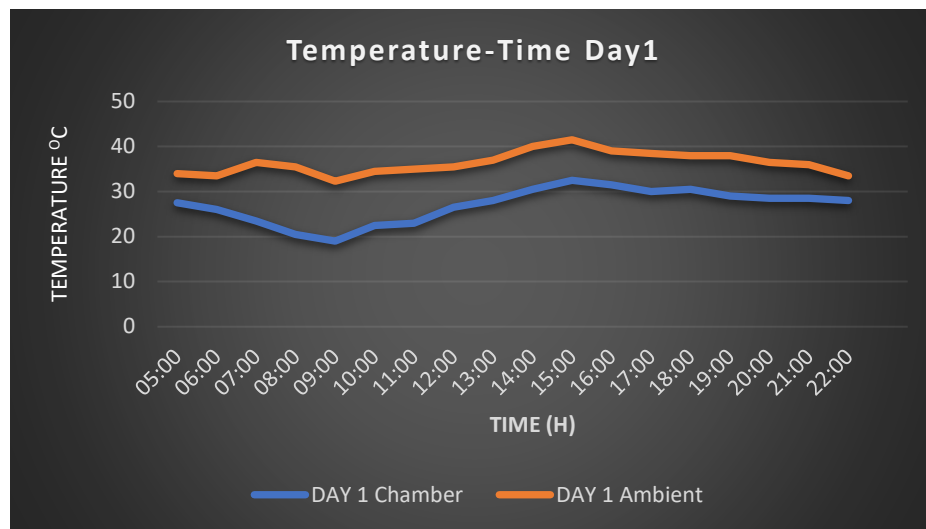


Figure 3: Temperature

Behavior Day1

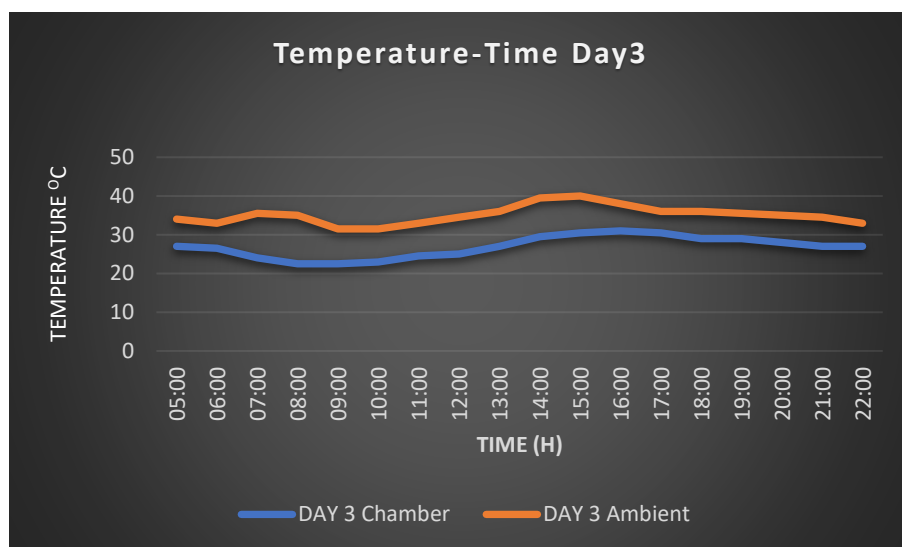


Figure 5: Temperature

Behavior Day3

Table 2: Chamber humidity and ambient humidity (%)

Time of the Day	RELATIVE HUMIDITY DAY 1		RELATIVE HUMIDITY DAY 2		RELATIVE HUMIDITY DAY 3	
	Chamber	Ambient	Chamber	Ambient	Chamber	Ambient
05:00	65	54	92	61	94	58
06:00	84	56	94	59	99	58
07:00	87	65	99	59	99	60
08:00	99	64	99	57	99	62
09:00	99	60	99	55	99	55
10:00	99	55	99	55	97	52
11:00	92	50	99	52	98	50
12:00	91	45	95	49	92	47
13:00	88	42	89	47	90	45
14:00	80	40	85	41	86	42
15:00	81	38	85	41	84	39
16:00	86	35	82	37	85	35
17:00	82	35	82	35	85	35
18:00	80	33	86	37	90	34
19:00	75	40	88	41	92	30
20:00	81	42	88	44	95	33
21:00	77	45	90	48	95	32
22:00	86	51	90	55	97	32

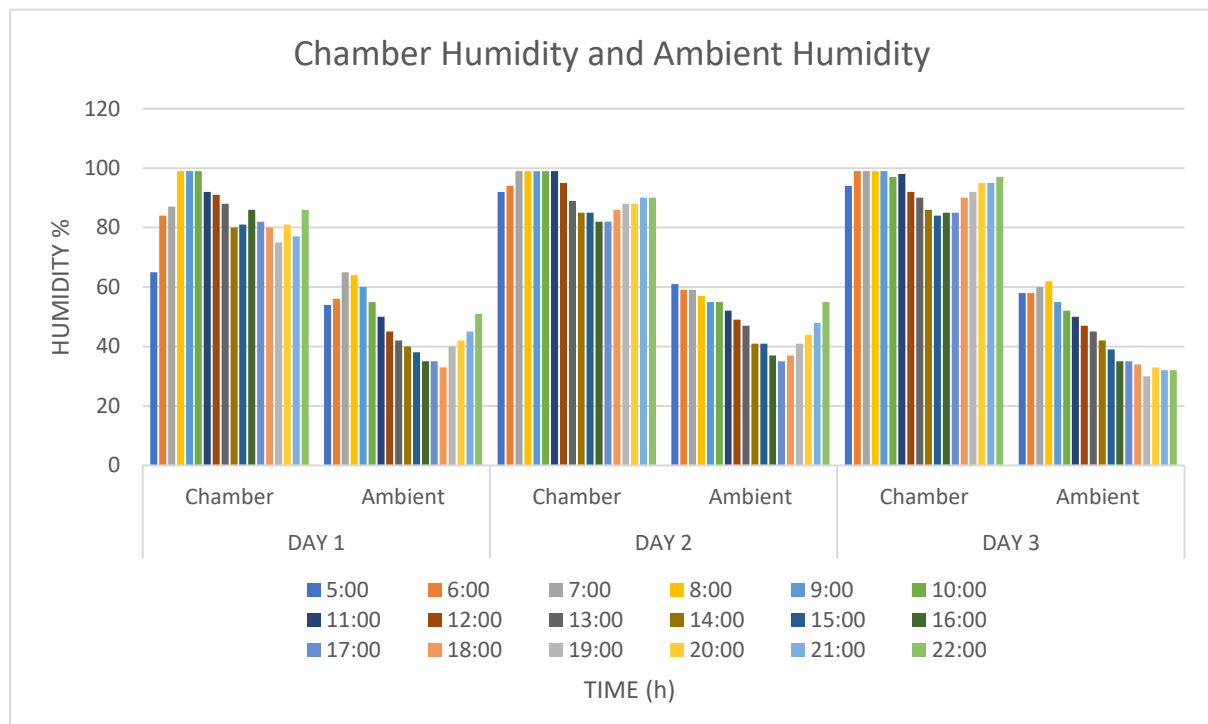


Figure 6: Comparison of chamber humidity and ambient humidities. The colour bars correspond to time range

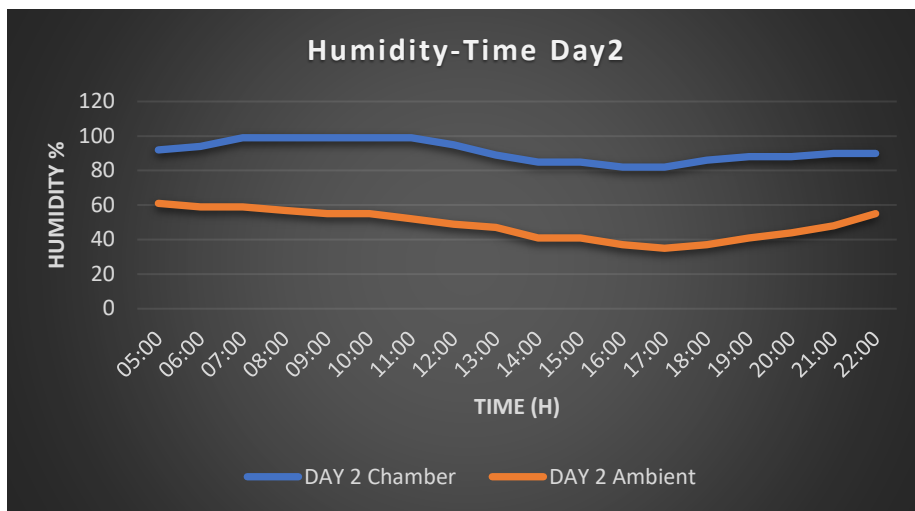


Figure 8: Humidity

Behavior Day2

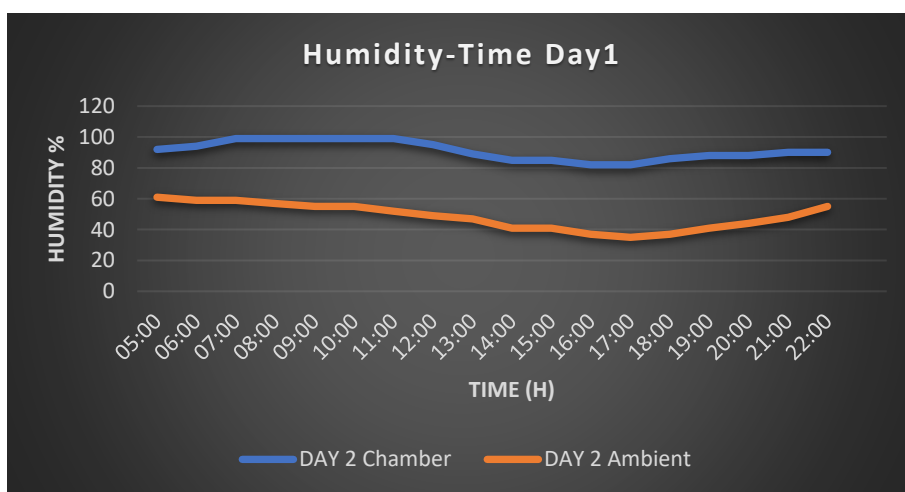


Figure 7: Humidity

Behavior Day1

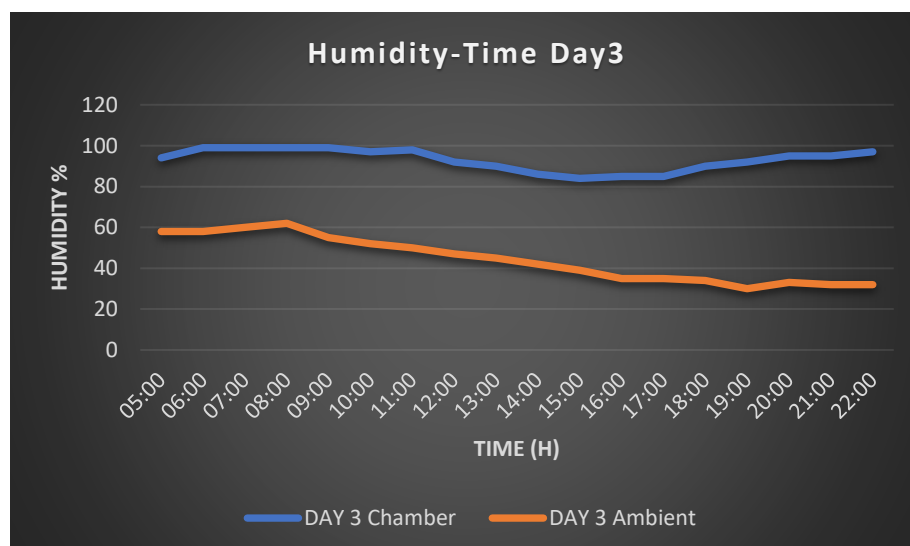


Figure 9: Humidity

Behavior Day3

4.2 Performance Analysis

The performance in the system was assessed by considering two factors;

- i. The response to decrease ambient temperature
- ii. The response to increase ambient relative humidity

The cooling efficiency and relative humidity efficiency were determined using the following equations; (Leonard & Msacky, 2023).

$$\text{Cooling Efficiency} = \frac{(\text{Ambient Temp} - \text{Chamber Temp})}{\text{Ambient Temp}} \times 100 \dots\dots\dots 1$$

$$\text{RH Efficiency} = \frac{(\text{Chamber RH} - \text{Ambient RH})}{\text{Ambient RH}} \times 100 \dots\dots\dots 2$$

4.2.1 Statistical Analysis of Temperature

For all monitoring days, results showed that average daily ambient temperature was 35.76°C as measured over three consecutive days. The inside Chamber temperature was 26.94°C. The inside Chamber temperature was ranged from 19.0°C to 31.5°C while the ambient was 31.5°C to 41.5°C with an average temperature difference of 8.83°C (Chamber cooler). Table 1. At the highest efficiency, the Chamber had inside temperature of 19.0°C which is 13.5°C lower than the ambient temperature.

Table 3: Per-day averages (Temperature)

Day	Chamber (°C)	Ambient (°C)	Difference (°C)	Efficiency (%)
Day 1	26.97	36.38	9.41	26.04
Day 2	26.94	35.67	8.72	24.49
Day 3	26.89	35.25	8.36	23.78
Overall	26.94	35.76	8.83	24.77

ANOVA Single factor results (Comparing all chamber versus all ambient temperatures) showed that the chamber temperatures differed statistically from the ambient temperature at $p \leq 0.05$. A p-value: < 0.0001 (extremely significant) was obtained, with F-statistic: 266.99 which signifies a significant reduction of ambient temperature. This shows a highly statistically significant difference between Chamber and Ambient temperatures. The chamber consistently maintains lower temperatures.

Two-way ANOVA (factors: Day + Type + Interaction) test indicates the cooling effect is consistent across days (no significant day-to-day variation in the difference). Table 4.

Table 4: Two-way ANOVA (factors: Day + Type + Interaction) – Temperature

Source	Sum Sq	df	F-stat	p-value	Significance
Day	6.71	2	0.42	0.661	Not significant
Type (Chamber/Ambient)	2104.98	1	260.58	< 0.0001	Highly significant
Day × Type	5.06	2	0.31	0.732	Not significant
Residual	823.95	102	-	-	-

The Overall average cooling efficiency is 24.77% ranging from 14.1%-42.3%. The hourly trends indicate strongest cooling in early morning (higher % efficiency when ambient is rising).

Efficiency generally stable but slightly lower in late afternoon/evening. Chamber temperature tracks ambient but stays ~8–9°C cooler on average.

Correlation between Chamber and Ambient is 0.685 (moderate positive), that is Chamber responds to ambient changes but maintains a consistent offset. Minimum Chamber temp is 19.0°C (09:00 Day 1) and maximum difference is 15.0°C

4.2.2 Statistical Analysis of Relative Humidity

The average daily ambient humidity is 46.74% as measured over three consecutive days. The inside chamber humidity is 89.48%. The inside Chamber humidity was ranged from 65% to 99% while the ambient was 32% to 64% with an average humidity difference of 42.74% (Chamber much more humid). Table 3. At the highest efficiency, the Chamber had inside humidity of 99% which is 40% higher than the ambient. Table 5.

Table 5: Per-day averages (Humidity)

Day	Chamber RH (%)	Ambient RH (%)	Difference (%)	RH Enhancement Ratio (%)
Day 1	84.56	47.33	37.22	84.95
Day 2	90.78	48.50	42.28	91.12
Day 3	93.11	44.39	48.72	121.16
Overall	89.48	46.74	42.74	99.08

ANOVA Single factor results (Comparing all chamber versus all ambient humidities) showed that the chamber humidity differed statistically from the ambient humidity at $p \leq 0.05$. A p-value: < 0.0001 (extremely significant) was obtained, with F-statistic: 646.27.

Two-way ANOVA (factors: Day + Type + Interaction) test indicates the chamber maintains higher relative humidity than ambient air (highly significant difference). There is a slight but significant interaction with days, efficiency improved over the three days. Table 6.

Table 6: Two-way ANOVA (Day + Type + Interaction) – Relative Humidity

Source	Sum Sq	df	F-stat	p-value	Significance
Day	267.72	2	1.89	0.1563	Not significant
Type (Chamber/Ambient)	49,322.81	1	696.41	<0.0001	Highly significant
Day $\times$ Type	598.02	2	4.22	0.0173	Significant
Residual	7,224.11	102	-	-	-

The overall average Relative Humidity efficiency is 99.08% (the chamber roughly doubles the ambient humidity on average). Ranging from 44% – 147%. Efficiency is lower in the early morning (when ambient RH is relatively higher) and peaks strongly in the afternoon and evening. Correlation between Chamber and Ambient RH: 0.72 (strong positive) — Chamber follows ambient patterns but consistently adds substantial moisture. Chamber RH is very stable (often near 99% saturation), while ambient varies more.

4.3 Combined Temperature and Humidity (Psychrometric) Analysis

This experiment is a direct evaporative cooling + humidification system. It cools the air by evaporating water (sensible cooling) while adding moisture (latent heat gain), ideally following a near-constant wet-bulb temperature / enthalpy line on the psychrometric chart. Table 7. Shows psychrometric analysis of the system. Table 6. Shows performance per day of the system

Table 7: Psychrometric Analysis

Parameter	Ambient	Chamber	Difference
Dry Bulb Temp (°C)	35.83	26.94	-8.89°C
Relative Humidity (%)	46.7	89.6	+42.9%
Humidity Ratio (W, kg/kg)	0.0172	0.0203	+0.0031 (+18%)
Enthalpy (h, kJ/kg)	80.27	78.83	-1.44
Wet Bulb Temp (approx °C)	~25.5	~25.8	~+0.3 (near constant)

Table 8: Per-Day Performance of the system

Day	ΔT (°C)	Cooling Eff. (%)	ΔRH (%)	RH Enhc. Ratio (%)	ΔW (kg/kg)	Δh (kJ/kg)
1	-9.41	25.9%	+37.8	80.0	+0.0014	-6.15
2	-8.86	24.7%	+42.2	87.1	+0.0027	-2.35
3	-8.42	23.8%	+48.7	109.8	+0.0050	+4.17
Avg	-8.89	24.8%	+42.9	99.1%	+0.0031	-1.44

The positive Day 3 value is associated with the substantially higher moisture content of the chamber air ($\Delta W = +0.0050$ kg/kg), which increased the latent component of moist-air enthalpy despite the reduction in dry-bulb temperature

4.3 Water Retention Capacity of the Charcoal

Water retention capacity is a critical parameter in evaporative cooling systems, as it directly influences evaporation rate, cooling effectiveness, operational stability, and overall water consumption. Accordingly, the water absorption and retention characteristics of the charcoal cooling pads were experimentally evaluated. The charcoal sample was completely dried under natural sunlight to remove residual moisture and achieve a constant dry mass. The dry weight of the sample (W_{dry}) was recorded using a precision balance. The sample was then submerged in water for 30 minutes to achieve full saturation after which they were removed and allowed to drain freely for a short period to eliminate excess surface water. The saturated weight (W_{wet}) was subsequently measured. The water retention capacity was calculated using the following Equation; (Kumarasinghe et al., 2026)

$$\text{Water retention capacity (g/g)} = \frac{W_{wet} - W_{dry}}{W_{dry}} \dots\dots\dots 3$$

Table 9: Water retention capacity charcoal cooling pad samples based on dry and wet weight measurement.

Parameter	Charcoal Sample 1	Charcoal Sample 2	Charcoal Sample 3	Mean ± SD
Dry weight (g)	190	195	185	190.00 ± 5.00
Wet weight (g)	310	308	303	307.00 ± 3.61
Water retained (g)	120	113	118	117.00 ± 3.61
Water Retention Capacity (g/g)	0.632	0.579	0.638	0.616 ± 0.032

4.4 The porosity of the charcoal

A porous medium such as the cooling pad is also characterized by its porosity and permeability. Porosity or void fraction (ϵ) is a measure of the empty spaces between material particles. To determine the porosity of the material, a container of known volume was filled with the material and then water was added to the top of the container. The porosity was then computed using Equation (4) (Vega et al., 2022). A porosity of 52% was determined.

$$\text{Porosity } (\epsilon) = \frac{\text{Water added}}{\text{Container volume}} \dots\dots\dots 4$$

5.0 DISCUSSION

The pad cooling efficiency is one of the main parameters that had been used to characterize the effectiveness of an evaporative cooling system. The drop in temperature and the increase in relative humidity in the air leaving the pad provides a clearer idea of the improvement in the thermal condition of the air.

The chamber demonstrates reliable and statistically significant cooling performance, with an average of 24.8% cooling efficiency (8.8°C reduction) across varying ambient conditions, and an average relative humidity of 89.48%. The pad represented similar result to those of other alternative materials (Leonard & Msacky, 2023), designed and tested a charcoal cooler for postharvest storage and reported an average cooling efficiency of 25.92% compared to sand cooler in the same experiment with a cooling efficiency of 22.15%. and an average relative humidity of 52.2% (Elmsaad & Omran, 2015), in their experiment found that a luffa pad yielded an average relative humidity of 73.67%, straw fiber pads 71.87%, CELdek 70.33% and sackcloth 69% (Korese & Hensel, 2016) evaluated a bulk charcoal as cooling pad under different pad configuration and reported a cooling efficiency vary from 56.71% - 96.10% to 45.41% - 90.06%, depending on the pad configuration, air velocity and the water flow rate. (Kulkarni et al., 2014) tested a jute fiber pad and reported a temperature range between 25.8°C and 26.2°C. The saturation efficiencies range from 69 % to 59 %. (T.D et al., 2023) reported a clay based cooling pad of 65% cooling efficiency and 68% from the cellulose pad. Though there was no side-by-side experiment to compare the charcoal with other commercial pads because of their unavailability in the market at the time of conducting this experiment, but existing literature shows the charcoal granules performed excellently compared to other cooling pad materials.

6.0 CONCLUSION AND RECOMMENDATIONS

Charcoal granules are a viable, sustainable wet pad medium for evaporative cooling in post-harvest systems, delivering effective cooling and significant humidity rise. It is less expensive compared

to other cooling pad materials. It cost less than Ten Thousand Naira (N10,000) to produce a charcoal pad of one meter square compared to other cooling pad material like CELdek which costs between Twenty Thousand to Seventy Thousand per square meter depending on thickness. Experimental data support its use in resource-limited settings. The chamber demonstrates reliable and statistically significant cooling performance, with an average of 24.8% efficiency (8.8°C reduction) across varying ambient conditions. Performance is consistent across the three days. It is highly effective at humidifying the environment, achieving an average 97% efficiency (nearly doubling ambient RH). The system delivers consistent temperature drop with substantial moisture addition along a near-constant wet-bulb line, reducing sensible heat while slightly varying enthalpy. The positive Day 3 value of the enthalpy is associated with the substantially higher moisture content of the chamber air ($\Delta W = +0.0050$ kg/kg), which increased the latent component of moist-air enthalpy despite the reduction in dry-bulb temperature.

Future work should optimize granule size/distribution, fan speeds variance, and conduct long-term experiments across geographical zones. It also recommends incorporating calibration against traceable reference instruments before and after the experiment to improve measurement confidence.

REFERENCES

- Awafo, E. A., Nketsiah, S., Alhassan, M., & Kubi, E. A. (2020). DESIGN , CONSTRUCTION , AND PERFORMANCE EVALUATION OF AN EVAPORATIVE COOLING SYSTEM FOR TOMATOES. *Scienco*, 24(4), 1–12. <https://doi.org/10.1515/agriceng-2020-0031>
- Berihun, B. (2023). Development and performance evaluation of the evaporative cooler technology for the preservation of fresh fruits and vegetables in North-west Ethiopia.
- Bodile, D., Garghate, V., Khode, R., Yedkar, A., Wankhade, A., & Bhagat, S. (2025). Cooling Pad in Evaporative System : A Review. *International Research Journal of Scientific Studies*, 2(3), 1–6. <https://doi.org/https://doi.org/10.64383/irjss.20250335>
- Defraeye, T., Schudel, S., Shrivastava, C., Motmans, T., Umani, K., Crenna, E., Shoji, K., & Onwude, D. (2024). Biosystems Engineering The charcoal cooling blanket : A scalable , simple , self-supporting evaporative cooling device for preserving fresh foods. *Biosystems Engineering*, 238(December 2023), 128–142. <https://doi.org/10.1016/j.biosystemseng.2023.12.001>
- Deoraj, S., Ekwue, E. I., & Birch, R. (2015). An Evaporative Cooler for the Storage of Fresh Fruits and Vegetables. *The West Indian Journal of Engineering*, 38(1), 86–95.
- Elmsaad, E., & Omran, A. (2015). Evaluating the Effect of New Local Materials of Evaporative Cooling Pads Department of Agricultural Engineering , Faculty of Agricultural Sciences , School of Economics , Finance and Banking , College of Business ., *American-Eurasian J. Agric. & Environ. Sci.*, 15(1), 78–84. <https://doi.org/10.5829/idosi.aejaes.2015.15.1.12494>
- Franco-salas, A. (2021). Optimal operation of evaporative cooling pads : A review. *Renewable and Sustainable Energy Reviews*, 151(September), 1–14. <https://doi.org/10.1016/j.rser.2021.111632>
- Korese, J. K., & Hensel, O. (2016). Experimental evaluation of bulk charcoal pad configuration on evaporative cooling effectiveness. *AgricEngInt: CIGR Journal Open Access*, 18(4), 11–21. <https://doi.org/http://www.cigrjournal.org>
- Kouchakzadeh, A., & Brati, A. (2013). The evaluation of bulk charcoal as greenhouse evaporative cooling pad. *Agric Eng Int: CIGR Journal*, 15(2), 188–193. <https://doi.org/http://www.cigrjournal.org>
- Kulkarni, R. K., Rajput, S. P. S., Gutte, S. A., & Patil, D. M. (2014). Laboratory Performance Of Evaporative Cooler Using Jute Fiber Ropes As Cooling Media. *Int. Journal of Engineering Research and Applications*, 4(12), 60–66. <https://doi.org/www.ijera.com>
- Kumarasinghe, S., Thilakarathna, R., & Welivitiyage, Y. (2026). Experimental Performance Evaluation of Clay- Based Cooling Pads with Optimized Geometry for Direct Evaporative Cooling Systems Experimental Performance Evaluation of Clay-Based Cooling Pads with Optimized Geometry for Direct Evaporative Cooling Systems. *Research Square*, 1(4), 0–18.

- <https://doi.org/https://doi.org/10.21203/rs.3.rs-8666200/v1>
- Leonard, L. S., & Msacky, N. J. (2023). PERFORMANCE EVALUATION OF EVAPORATIVE COOLING SYSTEMS AS. *INTERNATIONAL JOURNAL OF ENVIRONMENT*, 12(2), 17–40.
- Ogumo, E. O., Kunyanga, C. N., Okoth, M. W., & Kimenju, J. (2017). Current knowledge and performance of existing charcoal coolers in improving the overall quality and shelf-life of French beans. *African Journal of Agricultural Research*, 12(49), 3399–3409. <https://doi.org/10.5897/AJAR2017.12749>
- Perez, G. A. (2022). *Optimizing Forced-Air Evaporative Cooling Chambers for Vegetable Preservation by*.
- Shitanda, D., Oluoch, O. K., & Pascall, A. M. (2015). Performance evaluation of a medium size charcoal cooler installed in the field for temporary storage of horticultural produce. *Agricultural Engineering International: CIGR Journal*., 13(1596), 1–12.
- T.D, K., C.P, R., & M.D.S., S. (2023). Potential of a Charcoal Evaporative Cooling Chamber for Extending the Shelf Life of Vegetables. *Environmental Engineering and Green Technology*, 3(36), 2023.
- Udo, M. O., Oyedepo, S. O., Afolalu, S. A., Ongbali, S. O., Kilanko, O., Leramo, R. O., Saleh, B., Dirisu, J. O., Omoleye, J. A., Odewole, G., Babalola, P. O., Fasogbon, S. K., Solomon, E. C., Bolarinwa-odunayo, B., & Uchechukwu, I. O. (2025). Experimental performance evaluation of a solar powered evaporative cooling system for preservation of agricultural produce in tropical region. *Journal of Thermal Engineering*, 11(3), 858–879. <https://doi.org/10.14744/thermal.0000951>
- Vega, F. A. O., Rios, A. P. M., Saraz, J. A. O., Damasceno, F. A., & Barbari, M. (2022). Comparative Analysis of the Cooling Efficiency in Tropical Climate of Three Alternative Materials for Evaporative Cooling Pads. *Applied Sciences*, 12(77), 1–29. <https://doi.org/https://doi.org/10.3390/app12010077>
- Warke, D. A., & Deshmukh, S. J. (2017). Experimental Analysis of Cellulose Cooling Pads Used in Evaporative Coolers. *International Journal of Energy Science and Engineering*, 3(4), 37–43.
- Yeneneh, K. (2023). Design , Fabrication and Evaluation of Evaporative Cooling System for the Storage of Fruits and Vegetables. *International Journal of Applied and Structural Mechanics*, 03(04), 9–22. <https://doi.org/https://doi.org/10.55529/ijasm.34.9.22>