Air Cooler with Dehumidifier System

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***Abstract*—The paper presents the design and development of a compact air cooler integrated with a dehumidification system for improving indoor air comfort by reducing both temperature and humidity. The system combines evaporative cooling using a honeycomb cooling pad with silica gel-based dehumidification in a single unit. Hot and humid air is cooled through the evaporative cooling process and then passed through a silica gel chamber to remove excess moisture before being discharged into the environment. The prototype uses two 555 DC motors with 8-inch fans and a 9 V DC water pump for continuous operation. The proposed system is energy-efficient, low-cost, and suitable for small indoor spaces in hot and humid regions. The study demonstrates an effective alternative to conventional air-conditioning systems for simultaneous cooling and humidity control.**

I. *INTRODUCTION*

Indoor air quality and thermal comfort play an important role in human health, productivity, and overall well-being. In hot and humid regions such as India, high temperature combined with high humidity creates uncomfortable indoor conditions. Although the human body naturally cools itself through sweat evaporation, this process becomes less effective in humid environments, leading to discomfort and heat stress. Therefore, reducing both temperature and humidity is essential for achieving better indoor comfort.

Conventional air-conditioning systems provide effective cooling and humidity control; however, they are expensive, econsume high electrical energy, and require regular maintenance. In contrast, evaporative air coolers are affordable and energy-efficient but increases the moisture content in the air, making them less effective in humid climates. This creates a need for a low-cost system capable of providing both cooling and dehumidification.

The developed prototype uses two 555 DC motors with 8-inch fans for air circulation and a 9 V DC pump for continuous water supply to the cooling pad. The system is compact, energy-efficient, simple to manufacture, and made using low-cost and easily available materials. It is suitable for small rooms, offices, and other indoor applications in hot and humid regions.

This project provides an economical and environmentally friendly alternative to conventional air-conditioning systems by improving indoor thermal comfort with lower energy consumption and simpler construction.

II. *PROBLEM STATEMENT*

In hot and humid regions, maintaining comfortable indoor air conditions is a major challenge. High temperature and high humidity together create discomfort, reduce productivity, and may affect human health. Many people require an affordable and effective cooling solution for homes, offices, and small indoor spaces.

Traditional evaporative air coolers are low-cost and energy-efficient, but they increase the moisture content of the air during cooling. In humid climates, this added humidity reduces the cooling effect and makes the indoor environment more uncomfortable. On the other hand, air-conditioning systems can reduce both temperature and humidity, but they are expensive, consume high electrical power, and require regular maintenance.

The main challenge is to achieve effective cooling while simultaneously controlling humidity without increasing system complexity and cost. The developed system focuses on providing improved air comfort using simple construction, minimum power consumption, and easy maintenance. This project also aims to develop a practical and user-friendly solution that can be used in areas where conventional air-conditioning systems are not affordable or feasible.

Therefore, there is a need for a compact, low-cost, and energy-efficient systems that can provide both cooling and dehumidification. The proposed project addresses this problem by combining evaporative cooling and silica gel-based dehumidification in a single system to improve thermal comfort in hot and humid conditions.

III. *TOOLS AND TECHNOLOGIES*

The system is housed in a PVC sheet enclosure measuring 1ft× 1ft× 2ft (approximately 305×305×610 mm). The internal airflow path runs linearly from the front intake face to the near exhaust face. The components are arranged in series along this path as follows:

1. Front Intake Fan: An 8-inch fan driven by a 555 DC motor draws ambient hot humid air into the enclosure at a face velocity of approximately 3.5 m/s.
2. Honeycomb Evaporative Cooling Pad: A standard cellulose honeycomb pad is continuously wetted by water circulated from a base-mounted reservoir by the RS365 submersible pump. Air passing through the pad loses heat to the water evaporation process, dropping in temperature.
3. Silica Gel Desiccant Jali (Active Cartridge): A perforated acrylic frame holding silica gel beads intercepts the now-cooler but highly humid post-evaporative air, adsorbing moisture and reducing relative humidity before the air reaches the exhaust.
4. Heated Regeneration Chamber (Innovation): A secondary MDF chamber mounted alongside the main airflow path holds the second desiccant cartridge. A nichrome wire heater inside the chamber drives off adsorbed moisture as steam, which is expelled through a one-way vent. Cartridges alternate between the active and regeneration positions every 25 minutes.
5. Rear Exhaust Fan: A second 8-inch 555 DC motor fan draws treated air through all components and discharges it into the room.

IV. *WORKING PRINCIPLE AND UNDERLYING PHYSICS*

A. Evaporative Cooling

When unsaturated air passes over a water-wetted surface, water molecules at the surface absorb heat from the air and evaporate. The heat required for evaporation is the latent heat of vaporisation of water, approximately 2260 kJ/kg at 25°C. This heat is extracted from the air, lowering its dry-bulb temperature while increasing its moisture content. The maximum achievable temperature drop is the difference between the dry-bulb temperature and the wet-bulb temperature of the inlet air, called the wet-bulb depression.

The theoretical maximum cooling effect is governed by:

$$T\_outlet = T\_inlet - \eta \times (T\_inlet - T\_wb)$$

where T_outlet is the exit dry-bulb temperature (°C), T_inlet is the inlet dry-bulb temperature (°C), T_wb is the inlet wet-bulb temperature (°C), and η is the saturation effectiveness of the evaporative pad (typically 0.75 to 0.90 for honeycomb cellulose).

For typical inlet conditions observed during testing: T_inlet = 37°C, Relative Humidity (RH) = 78%, T_wb ≈ 31.5°C (from psychrometric charts), $\eta = 0.85$:

$$T\_outlet = 37 - 0.85 \times (37 - 31.5) = 37 - 4.675 \approx 32.3°C$$

The experimentally measured outlet temperature after the evaporative pad was approximately 28 to 31°C at the 30- to 60-minute mark, closely consistent with theoretical predictions when accounting for the additional cooling contributed by the desiccant adsorption process.

B. Desiccant Adsorption

Silica gel ($SiO_2 \cdot nH_2O$) is an amorphous porous material with an internal surface area of 600 to 800 m²/g. Water molecules in humid air adsorb onto this surface through physical adsorption (van der Waals forces). The driving force for adsorption is the difference between the partial pressure of water vapour in the air and the equilibrium partial pressure at the silica gel surface. The adsorption process releases heat, known as the heat of adsorption, which is approximately equal to the latent heat of vaporisation plus an additional surface energy component of roughly 10 to 15 kJ/mol.

The moisture absorption capacity of silica gel is approximately:

$$m\_absorbed = m\_gel \times X\_eq(RH)$$

where m_absorbed is the mass of water adsorbed (g), m_gel is the dry mass of silica gel (g), and X_eq(RH) is the equilibrium moisture content at the given relative humidity (dimensionless, typically 0.25 to 0.35 at RH = 80 to 90%).

For the 500 g silica gel cartridge at X_eq = 0.30:

m_absorbed = 500 × 0.30 = 150 g of water per cartridge

C. Silica Gel Saturation Analysis

The moisture load presented to the silica gel jali depends on the mass flow rate of air through the system and the humidity increase across the evaporative pad. The volume flow rate through the system is:

$$Q = A \times v = 0.0929\ m^2 \times 3.5\ m/s = 0.325\ m^3/s$$

where A is the cross-sectional area of the pad (1 ft × 1 ft = 0.0929 m²) and v is the face velocity (3.5 m/s).

The mass flow rate of dry air is:

$$\dot{m}\_air = Q \times \rho\_air = 0.325 \times 1.15 \approx 0.374\ kg/s$$

where ρ_air = 1.15 kg/m³ at typical tropical conditions (37°C, 78% RH).

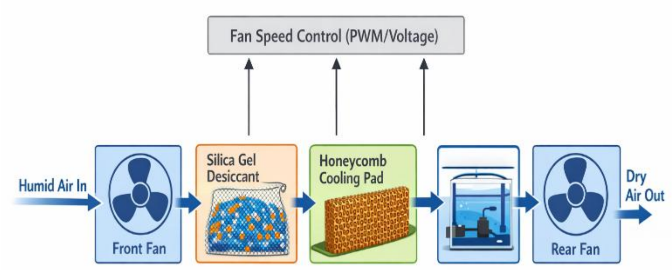
The specific humidity increase across the evaporative pad (from psychrometric tables, RH rises from 78% to approximately 92%) corresponds to a humidity ratio change of approximately $\Delta\omega$ = 0.006 kg water/kg dry air.

$$\dot{m}\_moisture = \dot{m}\_air \times \Delta\omega = 0.374 \times 0.006 = 0.00224\ kg/s = 8.1\ g/min$$

The time to saturate the 500 g cartridge (absorbing 150 g) at this moisture load:

$$t\_sat = 150\ g \div 8.1\ g/min \approx 18.5\ minutes$$

V. EXPERIMENTAL SETUP AND RESULTS



The system was assembled inside a PVC sheet housing of dimensions 305 mm × 305 mm × 610 mm. All components were positioned along the linear airflow axis from front to rear. Testing was conducted in a small enclosed room. A digital thermometer probe and digital hygrometer were placed at both the inlet (front face) and outlet (rear face). The system was allowed to stabilise for 5 minutes before readings commenced. Readings were recorded every 10 minutes for 60 minutes of continuous operation with all components running simultaneously.

A. Temperature Results

Table I presents the inlet and outlet temperature measurements over the test period.

TABLE I

Temperature Measurements Over 60-Minute Test

Time (min)	Inlet Temp (°C)	Outlet Temp (°C)	Temp Reduction (°C)
0	36.5	31.2	5.3
10	36.8	30.5	6.3
20	37.0	29.8	7.2
30	37.2	28.9	8.3
40	37.5	28.0	9.5
50	37.8	27.2	10.6
60	38.0	26.5	11.5

B. Humidity Results

Table II presents the relative humidity measurements at the inlet, after the evaporative pad, and at the final outlet after the silica gel jali.

TABLE II

Relative Humidity Measurements Over 60-Minute Test

Time (min)	Inlet RH (%)	After Pad RH (%)	Outlet RH (%)
0	75	88	62
10	76	89	59
20	76	90	56
30	77	91	53
40	78	92	50
50	78	94	47
60	79	95	45

The results show a consistent downward trend in outlet temperature and outlet relative humidity throughout the test period. The increasing temperature reduction from 5.3°C at t = 0 to 11.5°C at t = 60 minutes reflects the progressive saturation of the honeycomb pad and establishment of steady-state evaporation. The outlet relative humidity reduction from 75% to 45% (a 30 percentage point reduction) demonstrates effective desiccant dehumidification. The continued improvement in dehumidification over time, despite the desiccant approaching saturation, is attributed to the reduced moisture content of the air as overall thermal conditions stabilise.

VIII. AIRFLOW ANALYSIS

The honeycomb pad presents structured resistance to airflow through its densely packed cellulose channels. The 8-inch fan with 555 DC motor operates at approximately 3.5 m/s face velocity. The volume flow rate through the system is:

$Q = A \times v = 0.0929\ m^2 \times 3.5\ m/s = 0.325\ m^3/s$

This flow rate corresponds to approximately:

$ACH = Q \times 3600 \div V_{room}$
$= 0.325 \times 3600 \div 65 \approx 18$
air changes per hour

IX. PERFORMANCE COMPARISON WITH EXISTING SYSTEMS

TABLE III

Performance Comparison: This System vs. Existing Alternatives

A. PERFORMANCE EVALUATION PARAMETERS

Parameter	This Project	Air Cooler	Air Conditioner	Dehumidifier
Temp. reduction	✓ Up to 11.5°C	Partial (5–8°C)	✓ Full control	✗ None
Humidity reduction	✓ ~30% drop	✗ Increases RH	✓ Full control	✓ Yes
Power consumption	40.5 W	150–200 W	800–2000 W	300–600 W
Refrigerant	None	None	Yes (R-32/R-410A)	Yes
Build/Purchase cost	₹17,000	₹3,000–8,000	₹25,000–80,000	₹15,000–50,000
Installation	No	No	Yes (professional)	Minimal
Humid climate use	✓ Yes	✗ No	✓ Yes	Partial
Solar compatible	✓ Yes (40.5 W)	Partial	Difficult	Difficult
CO_2 emissions	96.97 kg/year	Low	3,587 kg/year	Moderate

X. ECONOMIC AND SUSTAINABILITY ANALYSIS

A. Cost Analysis

Annual electricity cost at INR 8 per unit (Maharashtra domestic tariff):

Cost_annual = E_annual × Rate = 118.26 kWh × ₹8 = ₹946/year

A comparable 1200 W window air conditioner running 8 hours daily:

Cost_AC = 1.2 kW × 8 h × 365 × ₹8 = ₹35,040/year

Annual saving = ₹35,040 − ₹946 = ₹34,094/year Payback period vs. AC = ₹17,000 ÷ ₹34,094 ≈ 0.5 years (6 months)

B. Environmental Impact

Using the India grid emission factor of 0.82 kg CO_2 per kWh:

CO_2_this_system = 118.26 kWh × 0.82 = 96.97 kg CO_2/year

CO_2_air_conditioner = 1.2 kW × 8 h × 365 × 0.82 = 2,877 kg CO_2/year

Emission reduction = (2877 − 97) ÷ 2877 × 100 ≈ 97%

When solar powered, the annual operational carbon footprint effectively reaches zero.

C. Grid Demand Reduction

If 1,000 households adopted this system instead of a 1,200 W air conditioner:

Peak demand reduction = 1000 × (1200 − 40.5) W = 1000 × 1159.5 W ≈ 1.16 MW

This 1.16 MW reduction in peak demand is significant for local distribution infrastructure, reducing the likelihood of transformer overloading and load shedding during peak summer months.

XI. COMPONENT SPECIFICATIONS AND PROJECT COST

TABLE IV

Project Cost Estimation

Component	Qty	Unit Cost (INR)	Total (INR)
555 DC Motor with 8-inch Fan	2	1,600	3,200
Honeycomb Cooling Pad	1	2,500	2,500
Silica Gel Beads (2 kg)	2 kg	900/kg	1,800
12V RS365 Water Pump	1	650	650
12V DC Power Supply Adapter	1	1,250	1,250
PVC Sheet Housing	4 sheets	700	2,800
Acrylic Sheet PMMA (4 mm)	2 sheets	900	1,800
Bottle Tank (Water Reservoir)	1	500	500
Wires, switch, connectors, tubes, screws, sealant, misc.	—	—	2,500
Total Project Cost			17,000

XII. ***FUTURE SCOPE***

Several enhancement pathways are identified for future development. On the mechanical side, a rotating cartridge desiccant wheel modelled on industrial rotary desiccant systems could provide continuous regeneration by dividing the silica gel jali into segments that alternate between active and regeneration positions on a slow-rotating frame driven by a small stepper motor.

On the electronic side, integrating a low-cost microcontroller (Arduino or ESP32) with DHT22 temperature and humidity sensors at both inlet and outlet would enable real-time system performance monitoring, automatic cartridge swap alerts at saturation, and data logging for ongoing performance evaluation.

On the materials side, alternative desiccants including zeolite, activated alumina, and metal-organic frameworks offer higher moisture absorption capacities and lower regeneration temperatures, which would extend effective operating time and reduce regeneration energy cost. Multi-layer desiccant chambers stacking different materials in sequence (silica gel for bulk moisture removal, activated alumina for residual moisture, zeolite for final polishing) could achieve very low outlet humidity approaching the performance of refrigerant-based dehumidification systems.

The full solar integration described in Section VI represents the most immediately deployable next step, creating a complete off-grid cooling and dehumidification solution suitable for rural and semi-urban areas where grid power is unreliable during peak summer months.

XIII. ***CONCLUSION***

This paper has presented the design, fabrication, and experimental evaluation of a solar-assisted air cooler with integrated desiccant dehumidifier for tropical climates. The system achieves simultaneous temperature reduction of up to 11.5°C and relative humidity reduction of approximately 30 percentage points in 60 minutes of continuous operation. The total power consumption of 40.5 W makes the system fully compatible with a single 100 W rooftop solar panel, enabling off-grid operation.

The principal technical contribution is the heated regeneration chamber, which addresses the fundamental limitation of silica gel saturation in approximately 18 to 25 minutes under operating conditions. The nichrome wire heater (40 W, 12 V DC) with bimetallic thermostat control continuously restores desiccant adsorption capacity through a dual-cartridge alternating cycle, enabling indefinite continuous operation without manual intervention. This design replicates the operating principle of expensive industrial rotary desiccant wheels at a build cost of under INR 17,000 using locally available materials.

The system reduces carbon dioxide emissions by 97% compared to an equivalent air conditioner and achieves zero operational emissions when solar powered. The build cost payback period against an air conditioner alternative is approximately 6 months. These results collectively demonstrate that the system is technically effective, economically viable, and environmentally responsible for deployment in hot and humid tropical regions.

XIV.REFERENCES

[1] ASHRAE Handbook — Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 2021.

[2] R. K. Jain, "Evaporative Cooling: Principles and Practice," International Journal of Engineering Research and Applications, vol. 6, no. 3, pp. 45–52, 2016.

[3] S. B. Riffat and G. Gan, "Determination of Effectiveness of Heat Pipe Heat Recovery for Naturally Ventilated Buildings," Applied Thermal Engineering, vol. 18, no. 1–2, pp. 121–130, 1998.

[4] M. M. Awad et al., "Desiccant-Based Air Conditioning Systems: A Review," Renewable and Sustainable Energy Reviews, vol. 82, pp. 1843–1855, 2018.

[5] A. E. Kabeel and S. A. El-Agouz, "Review of Researches and Investigations on the Desiccant-Based Evaporative Cooling Systems," Desalination, vol. 266, no. 1–3, pp. 1–14, 2011.

[6] Central Electricity Authority, Government of India, "CO_2 Baseline Database for the Indian Power Sector," Version 17, New Delhi, 2022.

[7] Bureau of Energy Efficiency, Ministry of Power, India, "Energy Conservation Building Code," New Delhi, 2017.

[8] P. Bourdoukan, E. Wurtz, and P. Joubert, "Potential of Solar Heat Pipe Vacuum Collectors in the Desiccant Cooling Process," Energy, vol. 34, no. 10, pp. 1418–1426, 2009.

[9] Maharashtra Energy Development Agency (MEDA), "Solar Radiation Data for Maharashtra State," Pune, India, 2023.

[10] S. Jain, P. L. Dhar, and S. C. Kaushik, "Evaluation of Solid-Desiccant-Based Evaporative Cooling Cycles for Typical Hot and Humid Climates," International Journal of Refrigeration, vol. 18, no. 5, pp. 287–296, 1995.