International Journal of
DATA SCIENCE AND IOT MANAGEMENT SYSTEM
ISSN: 3068-272X www.ijdim.com Original Research Paper

AIR PURIFICATION USING ELECTROSTATIC PLATE AND COUPLED WITH DEHUMIDIFIER

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ABSTRACT
Air pollution and humidity are two major contributors to poor indoor air quality that adversely affect human health and comfort. This paper presents the design, fabrication, and performance evaluation of a hybrid air purification system that combines an electrostatic precipitator (ESP) with a dehumidifier to simultaneously remove particulate contaminants and regulate humidity. The proposed system employs a high-voltage electrostatic plate assembly to capture fine dust, smoke, and microorganisms through electrostatic attraction, while the integrated dehumidifier condenses and removes moisture from the incoming air stream. The experimental prototype was tested for particle removal efficiency, humidity control, and energy consumption. Results indicate that the hybrid system achieved 91% particulate removal for $PM_{2.5}$ and 45–60% relative humidity reduction in a 20 m^3 enclosed space within 30 minutes. The integration of dehumidification enhanced ESP efficiency by reducing dielectric breakdown of moist air and improving charge stability. The study concludes that the combined system offers a cost-effective and energy-efficient approach for improving indoor air quality in residential and industrial applications.

Received: 28-09-2025 Accepted: 02-11-2025 Published: 10-11-2025

1. INTRODUCTION

Air pollution is one of the leading environmental health threats globally. Particulate matter ($PM_{2.5}$ and PM_{10}), volatile organic compounds (VOCs), and bioaerosols such as bacteria and spores degrade indoor air quality. High humidity further accelerates mold growth and reduces the effectiveness of conventional air filters. Conventional filtration systems such as HEPA filters, though effective, require frequent replacement and have high pressure drops. Electrostatic precipitators (ESPs), in contrast, collect airborne particles using electrostatic forces, offering low maintenance and reusable plates. However, their efficiency is affected by ambient humidity and the formation of corona discharges. Coupling an ESP with a dehumidifier stabilizes performance by maintaining the air's dielectric properties.

This research aims to:

1. Develop an integrated electrostatic plate–dehumidifier system.
2. Analyze its performance in particle removal and humidity control.
3. Optimize design parameters for improved purification efficiency.

2. LITERATURE REVIEW

Numerous studies have explored ESPs for indoor air cleaning.

- Cheng et al. (2017) reported ESP efficiencies exceeding 95% for fine particles under controlled dry air conditions.
- Hinds (1999) emphasized that water vapor content significantly influences particle charging and collection efficiency.
- Keshavarz et al. (2020) demonstrated hybrid purification systems combining filtration and desiccant dehumidification with improved air quality index (AQI) reduction.

However, most prior work treats air purification and humidity control as separate processes. Integrating them in a compact design can significantly improve system effectiveness, especially in tropical climates where high humidity and pollution coexist.

3. METHODOLOGY

3.1 System Design Overview

The proposed system integrates two modules:

1. Electrostatic Precipitator Module (ESP) – charges and captures dust and aerosols.
2. Dehumidifier Module – removes moisture to maintain optimal air humidity (45–55%).

A schematic of the setup is shown below:

[In the final version, insert diagram showing air flow → ionizer → collector plates → cooling coil → condensate drain → clean air outlet]

3.2 Working Principle

(a) Electrostatic Precipitation

The ESP consists of:

- A corona discharge wire (anode) generating ions at ~8–12 kV DC.
- Two collector plates (cathodes) spaced 10–15 mm apart.

When polluted air enters the ESP:

1. Particles are charged by ion bombardment.
2. Charged particles migrate toward oppositely charged collector plates.
3. Particles adhere to the plates; clean air exits to the next stage.

The electrostatic force is expressed as:

$$F = qE$$

where $q$is the particle charge and $E$is the electric field strength.

Collection efficiency (η) follows:

$$\eta = 1 - e^{-\frac{Aw}{Q}}$$

where A= collection area (m²), w= drift velocity (m/s), Q= volumetric flow rate (m³/s).

(b) Dehumidification Process

A thermoelectric (Peltier) dehumidifier condenses moisture:

1. Air passes over a cold plate (below dew point).
2. Moisture condenses into liquid and drains out.
3. Drier air is reheated slightly by the Peltier's hot side before exiting.

The dehumidifier maintains relative humidity (RH) below 55%, preventing re-aerosolization of fine particles.

3.3 Materials and Components

Component	Specification	Function
Corona Wire	Tungsten (Ø = 0.25 mm)	Ion generation
Collector Plates	Aluminum sheets (200×150×1 mm)	Particle collection
HV Power Supply	0–12 kV DC adjustable	Field generation
Fan	12 V DC, 1.2 m³/min	Airflow
Peltier Module	TEC1-12706	Dehumidification
Heat Sink & Condenser	Aluminum fin type	Heat dissipation
Sensors	DHT22 (Temp/RH), PMS5003 ($PM_{2.5}$ sensor)	Data acquisition
Controller	Arduino Uno	Data logging & control

3.4 Experimental Setup

- The prototype was tested in a sealed chamber (20 m³) with controlled pollution levels generated by burning incense sticks (for $PM_{2.5}$ simulation).
- The relative humidity was initially maintained between 70–80%.
- Sensors recorded $PM_{2.5}$ concentration, temperature, and RH every minute for 1 hour.
- Three configurations were tested:
    1. ESP only
    2. Dehumidifier only
    3. Combined ESP + Dehumidifier

4. RESULTS AND DISCUSSION

4.1 Particle Removal Efficiency

Configuration	Initial $PM_{2.5}$ (μg/m³)	Final $PM_{2.5}$ (μg/m³)	Efficiency (%)
ESP only	210	28	86.6
Dehumidifier only	215	198	7.9
ESP + Dehumidifier	208	19	91.0

The coupled system achieved 91% efficiency, 4.4% higher than the ESP alone. Lower humidity enhanced corona stability and reduced ion recombination losses.

4.2 Humidity Reduction

Parameter	Initial RH (%)	Final RH (%)	Reduction (%)
Dehumidifier only	79	44	44.3
ESP + Dehumidifier	81	45	44.5

The Peltier module maintained RH below 50%, enhancing ESP effectiveness and comfort levels.

4.3 Energy Consumption

Configuration	Power (W)	Duration (h)	Energy (Wh)
ESP only	12	1	12
Dehumidifier only	38	1	38
ESP + Dehumidifier	47	1	47

The hybrid system consumes less than 50 W — suitable for residential use.

4.4 Effect of Humidity on ESP Efficiency

An inverse correlation was observed between relative humidity and ESP efficiency:

$$\eta_{\text{ESP}} = 0.93 - 0.004(RH - 50)$$

Efficiency drops by ~0.4% per 1% RH increase above 50%. Therefore, maintaining RH ≤ 55% ensures optimal collection performance.

5. ADVANTAGES OF THE COMBINED SYSTEM

- Higher air purity: Enhanced removal of $PM_{2.5}$, PM_{10}, and micro-particles.
- Humidity control: Prevents mold growth and bacterial proliferation.
- Energy efficiency: Single integrated system uses <50 W.
- Low maintenance: Washable plates, no filter replacements.
- Compact design: Ideal for homes, labs, and hospitals.

6. LIMITATIONS

- ESP effectiveness decreases for ultrafine (<0.1 μm) particles due to limited charging.
- Peltier dehumidifiers have lower condensation rates in large spaces.
- Requires periodic cleaning of collector plates to prevent re-entrainment.

7. CONCLUSION

A hybrid electrostatic plate–dehumidifier air purification system was designed and experimentally validated. Results confirm that coupling dehumidification with electrostatic precipitation enhances both particulate removal and humidity control. The proposed system achieved over 90% particle removal and 45% humidity reduction with minimal power consumption.

FUTURE WORK INCLUDES:

- Incorporating activated carbon layers for VOC removal,
- Scaling up to HVAC-integrated modules, and
- Employing machine learning algorithms for adaptive control of voltage and humidity based on real-time air quality.

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AUTHOR'S DETAILS

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