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Comparative Analysis of Plant-Based and Electrostatic Precipitation Methods for Indoor Particulate

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Abstract
Particulate matter (PM2.5) plays a serious role in health risks both indoors and outdoors, especially in low-income households with limited access to traditional air purification systems. This study compares and evaluates the PM2.5 removal efficiency of two plants with air purifying capabilities- sunflower (Helianthus annuus) and peace lily (Spathiphyllum spp.) with a 3D printed electrostatic precipitator (ESP) having similar size and power demand. All experiments were executed in a controlled pollution chamber to provide a quantifiable time-dependent removal profile at a standardized PM2.5 load. Simultaneously the ESP was scrutinized each session for several performance aspects in energy consumption, noise, and maintenance in contrast to the passive and low-energy nature of plant use. Results concluded that plants indeed provided low-level efficacy at removals over sustained amounts of time, while the ESP proved to be more aiding in higher efficacy in shorter amounts of time, often requiring maintenance and periodic cleaning. Social-acceptance and sustainability were observed and discussed, favoring the cultural value of plants against the more technical efficacy of the ESP. Regarding relative performance, cost, and feasibility beginning with the recommendation of adoption of the plants for low maintenance and socially acceptable air quality, while the ESP could be used as a primary source for instant pm2.5 elimination. This integrated assessment offers a platform for developing access to a sustainable and affordable intervention on indoor air-quality issues faced by at-risk communities.

Keywords: *PM2.5, Indoor air purification, sunflower, ESP Precipitator, low-cost.*

1. Introduction:

Air quality has now become one of the biggest challenges facing the environment and public health in the 21st century. Fine particulate matter especially PM2.5 (particles having the aerodynamic diameter smaller than 2.5 µm) is especially important due to its ability to enter deep into the human respiratory tract, and cause cardiovascular, pulmonary, and neurologic diseases. The World Health Organization estimates that elevated air pollution specifically, PM2.5 results in millions of premature deaths per year, with populations belonging to lower income households being particularly affected due to lower access to effective air cleaning technology. Whereas conventional mechanical filters and commercially manufactured air cleaning systems are useful because they are effective, they are often costly, energy-intensive, and can require ongoing maintenance, making them impractical solutions for the economically disadvantaged. In recent years, two low budget solutions have been introduced: using indoor plants that may be capable of removing pollutants from the air, and at-home electrostatic precipitators (ESPs). Some indoor plant species such as sunflower (Helianthus annuus) and peace lily (Spathiphyllum spp.), have been shown to have the ability to remove airborne pollutants due to natural filtration mechanisms and are believed to be depositing pollutants, and ESPS capture fine particulates by using electrostatic charging and collection plates, providing efficient air cleaning while using minimal amounts of energy. This research aims to quantitatively compare the PM2.5 removal efficiency of sunflower and peace lily in contrast to a home-made ESP of similar footprint and energy use. In addition to removal efficiency, the research further examines time-dependent removal profiles, energy usage, noise, level of maintenance and social acceptability. The aim is to recommend a feasible sustainable indoor air-cleaning strategy tailored to low-income households.

2. Literature review:

Aya Elkamhawy et al. [3] looked at fine particulate pollution in South Korea, and in particular the problem that in many urban areas concentrations exceed WHO recommendations. This, in turn, leads to compromising public health. To address this problem, Aya Elkamhawy developed a hybrid air purification system that integrates vegetation soil filters with ESP technology, which goes beyond the passive plant-based methods by offering active air filtration in the soil. Based on the experimental assessments, the system has strong potential for practical applications. The vegetation soil filter at low air velocities removed 78.5% of PM2.5 and 47% of PM10, while at high air velocities the ESP filter removed 73.1% and 87.3% of PM2.5 and PM10, respectively. With this in mind, Aya Elkamhawy points out a gap in the literature, which is the limited use of passive vegetation systems in high-traffic outdoor areas, and this gap illustrates the usefulness of her active system for improving air quality in public urban areas.

In their study, Tzu-Ming Chen et al. [4] examined the problem of controlling and containing submicron and nanoparticulates that are discharged during the process of semiconductor (*SOI technology) manufacturing, as these particulates are considered highly corrosive as well as having a high tendency to adhere to surfaces, posing serious health and environmental hazards. Ordinary dry Electrostatic Precipitators (ESPs) must because of the accumulation of dust and the corresponding drop in efficiency, which makes the use of some sort of alternative solution necessary. To resolve these problems, Author Tzu-Ming Chen invented Single Stage Wire to Plate Wet Electrostatic Precipitators (WESPs) that are capable of collisional condensation and heterogeneous growth for enhancing particulates condensation and collection. The experimental results showed a 2.2 fold increase in collection efficiency of iron (Fe) nanoparticles from 67.9–92.9% without mist to 99.2–99.7% with mist. However, Author Tzu-Ming Chen mentioned that lack of scale, energy efficiency, and ability to apply on non SiO_2 particles are the main shortcomings.

Wen et al. [5] addressed re-entrainment of particles in electrostatic precipitators (ESPs) which, compared to fiber filters, are more efficient in HVAC applications but less effective for submicron particles due to poor particle retention. To Resolve: A new electrostatic precipitator (ESP) equipped with foam-covered collecting electrodes. The porous structure of foam, while remaining flame-retardant and low-conductive, trap particles while minimizing re-entrainment. Experiments confirmed 99% collection efficiency while varying corona voltages, repelling voltages, and airflow velocities. In the as optimized, ESP performance. However, Author Tsrong-Yi Wen lamented the absence of research in the optimization of foam materials. Additionally, the research was scaled for private household use.

The aerial dynamics of pollution and its harmful effects on people have been thoroughly assessed by Ioannis Manisalidis et al. [6] who also explained its significance in the domain of morbidity and mortality. Pollutants such as Particulate Matter and Ozone, nitrogen oxides, and heavy metal that could seriously endanger the rest of the populace and children particularly were exposed to in their findings to be the most devastating to the respiratory, cardiovascular and even neuro systems. Considering the climatic research along the epidemiological data and the pollution statistics of the world as developed and developing routed the industrial boom coupled with dilatory policies governance augment the exposure and the worsening of the outcomes for the outcomes for the the findings bodies of work of which could be characterized as astonishing understatement, were grievously emphasized, having studied the claimed rate of death were aimed to be 9 billion deaths attributed to air pollution, the most striking region being flagged for aggravation in further analyses.

Xi Xu et al. [7] analyzed the performance of electrodes in collecting particles in the context of high-temperature settings (300–900 K) in ESP (Electrostatic Precipitators) which tend to underperform at high temperatures. The electrodes used in the study included rods, saws, and screws of different diameters (3–8 mm) and different intervals (55–165 mm) which were tested along with ESP (Electrostatic Precipitators) to measure particle corona discharges and capture characteristics. The study results suggest that saw electrodes with 300 K temperatures electrostatically discharge currents which makes them more efficient to collect particles, while at 900 K temperatures the rod electrodes (5 mm diameter, 110 mm interval) electric fields make them more efficient at 87.4% collection. The study demonstrates that the spacing of electrodes needs to increase with an increase in temperature to reduce electric field disturbance. The study, however, showed efficiency problems in real life, and the necessity to change dynamic electrodes in order to increase the electrostatic collection efficiency for varying industrial systems.

The study conducted by Alireza Afshari et al. [8] focused on the need for air cleaning systems that can eliminate pollutants without harmful by-products. The data showed that modern ESPs made from anticorrosive materials, had a collection efficiency exceeding 95 for ultrafine particles, in addition to low power consumption and ozone generation. This shows that, contrary to existing air quality filtration systems, ESPs can improve indoor air quality without the disadvantages associated with traditional filtration systems. Still, Alireza Afshari pointed out a concerning research gap that addresses the discrepancy between the laboratory testing conditions and the real life use of the ESPs.

In his study focusing on particle collection in electrostatic precipitators Marek Kocik et al. [9] did some analysis on the influence of differing voltage polarities on the collection of particles. He used a wire-to-plate type ESP model with seven wire electrodes. A laser light reflection type particle size-meter was used to measure the size distribution of the precipitated seed particles. The collected data regarding polycharges and flow velocity indicated differences in collection efficiency. Yet the study also recognized a research gap in the analysis because the particle size-meter was restricted to the measurement of particles greater than 0.5 mm in diameter. This reinforces the conclusion that research is needed on electrostatic precipitators collecting smaller particles.

The objective that Nicole Britigan et al. [10] pursued was if the use of ionization and ozonolysis-type air purifiers emit O3 in quantities that exceed public health guidelines for indoor spaces. The goal involved field testing different kinds of air purifiers (ionization and ozonolysis) in various indoor type locations like offices, bathrooms and bedrooms. Their exposure assessments concluded that the devices in question produced O3 levels that measured more than the levels deemed safe by the public. A model that estimated O3 emissions based on the purifiers emit rate and the of the room O3 decay rate predicted and was later tested that the O3 meticulously verified to be emanating from stand alone generators was in fact, cumulatively formed. The research gap that needs to be closely studied was and is the impact of particulate matter on the operation of the ozonolysis air purifiers. Also, the changes in the model due to lack of in device humidity, decay rate trends, and air carrying stagnancy, could shed some light on it.

In this study, Sheng-Hsiu Huang et. al [11] focused on measuring the filtration capabilities of a miniature dual saw-like electrodes electrostatic precipitator (ESP), Literati as noted, addressing the growing demand for indoor air cleaning devices and the parameters of size, air flow rate, aerosol discharge voltage, and aerosol polarity on aerosol penetration. Their apparatus constructed an electrostatic precipitator (ESP) which was exposed to a polydisperse and monodisperse aerosol size of 30 nm to 10 µm, and measuring the aerosol concentration and size distribution assisted by spectrometers while monitoring the circuitry for ozone production. The researcher has concluded that a drop in voltage discharge increases airflow penetration and consequently aerosol concentration, as well as the airflow to voltage ratio of 0.25 and 0.5 electrovolts. The researcher has concluded that corona discharge, while achievable at lower economic costs, results in the production of ozone which exceeds that of positive corona. This study has revealed the absence of experimental data that could accommodate all previous designs and only then adapt to the requirements of electronically operated indoor air cleaning devices, modeled for miniature electrostatic precipitators without additional modifications.

Representatively and uniformly-deposited aerosol samples collected offline for particle analysis were a problem without an in-situ system, and J. Dixkens et al. [12] simply set out to solve this. Dixkens et al. used an elegantly simple design and evaluation framework for developing and optimizing a new class of electrostatic precipitators (ESPs) to enable charging and deposition of particles in separate, confined volumes, with subsequent numerical simulation and controlled experiments to optimize deposition of targeted particles. The electrostatic strategy enabled complete and uniformly distributed deposition of unipolarly charged particles of sizes between 0.03 and 10 microns, with predictive control over the deposition pattern. However, the research gap in this case relates to uncharged and less than 03 micron particles, and the underlying problem is insufficiently aggressive corona chargers targeting the collection system.

The problem of controlling fine particulate matter emissions from natural gas burning has significant negative impacts on both our environment and our health, and was addressed by L. Guan et al. [13] To mitigate these emissions, the researchers developed and tested a new type of dust flow separator, an electrostatic precipitator, and named it the dust flow separator electrostatic precipitator (DFS-ESP). The approach entailed measuring the exhaust gas composition within a closed chamber while varying the exhaust flow rates, gas temperatures, discharge voltages, and gas velocities to certain predetermined values, and later determining the specific particle characteristics by methods such as ESEM, CNPC, and OPC. The resulting data showed that the system of the DFS-ESP could remove as much as 95% of particles from the exhaust, and that the flow separator alone was able to concentrate and discharge 90% of the fine particles to the ESP. However, the study advanced the notion that the rest unexplored configuration of the DFS-ESP was capable of delivering much higher mass collection efficiency was, in every other way, lower than the collected dense particle dominator.

Kim et al. [14] approached the problem of ultrafine particulate matter in indoor subway stations in the most effective manner possible while simultaneously trying to reduce the emission of ozone and loss of pressure. Ozone emission and pressure loss are two prevalent negative effects of almost all filtration systems in today's world. To address this, they created and tested a 2-stage ESP for Air Handling Units in a real subway station. Then they tested it against today's MERV-10 and MERV-14 air filters. The findings showed that the novel ESP sustained over 80% PM collection in all size ranges spanning to PM1.0, which is greatly PM1.0 which is 11% higher than the MERV-14 filters, almost no ozone emission, and significantly lower pressure drop (15.5 Pa against 157 Pa for MERV-14). This study indicates more than one possible means of addressing air cleaning problems in today's world, focusing specifically on large indoor spaces such as subway stations. The novel ESP, with its ability to achieve high PM elimination with almost no ozone and low energy, is a best-fit solution.

Mainelis et al. [15] have tackled the critical problem of collecting airborne microorganisms—namely bioaerosols—efficiently and undamaged to their viability for environmental and health surveillance, as current inertial samplers tend to destroy microbial viability. Designing and calculating the performance of an Electrostatic Precipitator (ESP) was a great challenge for Mainelis. The ESP charges incoming particles to either collect or determine the charging efficiency on agar plates, via both biological (Bacillus subtilis var. niger spores and vegetative cells) and nonbiological (NaCl) particles, and under different charging and precipitation voltages and flow rates. The analyzed data suggest that the new ESP can effectively collect bioaerosols, with collection e?ciencies of about 80–90% for biological particles, even after charge neutralization, and that external charging is beneficial to collection of particles, particularly with optimal precipitation voltage settings. Particular emphasis is needed in future research to determine the polarity and net charge of other airborne microorganisms, and to study the biological efficiency of the sampler under diverse field conditions.

Regarding the need for unobtrusive, low-cost, and efficient bioaerosol collectors capable of collecting airborne microorganisms without damaging them, more specifically for the contextual framework of the bioterrorism threats and exposure assessment, Gediminas Mainelisa et al. [16] have focused on resolving these issues. They have tested an electostatic precipitator (ESP) which attempts to 'capture' airborne microorganisms by electrically charging them and precipitating them on the agar plates. The experiments conducted on the 'charge-neutralized' biological particles indicated that the ESP could at best 'remove' 80-90% of biological particles at a voltage of ±4000 V at the 'charge-neutralized' stage, and the viable counts of BG and P. brevicompactum specially classified as colony-forming units reached over 70% at 'capture' stage. More importantly, for the sensitive P. fluorescens cells the ESP counted twice as many cells compared to a Biosampler. An important gap in research was the need for more prototype ESP modifications to enable simultaneous counting of microorganisms of both polarities, which is critical for the effectiveness of the device for future applications to poorly studied and anonymous microorganisms.
The challenges associated with ultrafine particle collection in electrostatic precipitators (ESPs) have been studied by Akinori Zukeran et al. [17] in the 0.01 – 0.1µm range. They noted that in spite of the effectiveness of mass based collection ESPs, number densities were poorly measured. To investigate this, Zukeran and his colleagues employed a wire-plate-type ESP operating in the DC and non-bias pulse in simultaneous modes. Their experiments, performed during controlled incense combustion, included advanced counters in combination with microscopy based particle size measurement and variable dust loading simulation. Their results indicated that pulsed energization enhanced collection efficiency for ultrafine particles during higher dust load conditions, whereas coarse particles were not improved and larger DC operation dominated. The researchers proposed a hybrid two-stage ESP system where initial coarse particle capture is done with DC, while fine fraction capture is done with pulse mode, to better ESPs balanced performance span across wide range particle sizes. This work led to the need for further studies of re-entrainment phenomena with large particles and the pulsing particle behavior.

3. Methodology:

The initial stages of the methodology consisted of design and philosophy, which set the basic concepts and purpose of the project. The next step moving forward was the electronics and sensors phase, in which the components for the project were chosen and planned. Once completed, the prototype was setup to bring the design to a physical reality. The final three stages move to the evaluation phase, with each stage of development assessing the prototype's effectiveness. The first step is experimental design and setting up for testing, followed by the first round of testing to identify any quickly apparent problems, and finally, the last test iteration assesses that the prototype functions correctly and has been effective in evaluating the identified problem.

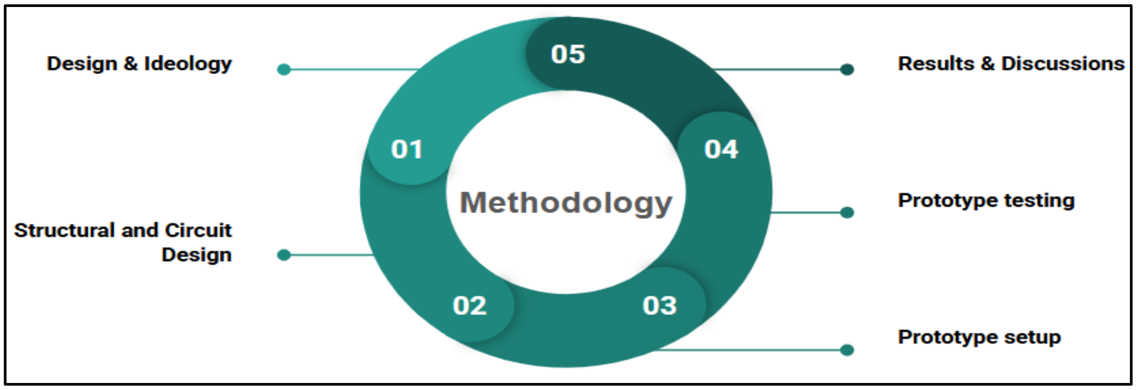

Fig 1: Methodology flowchart

Design and ideology

The electrostatic precipitator model was designed on solidworks. The principle of the mechanism was electrostatic energy and charge being able to separate out particles from the air around us. The model was a cylindrical shape with a long wire/beam electrode running through the center and a copper mesh all around the beam. The idea behind the design was that when air would pass through the device the particles would then stick to the copper mesh and let out clean air through the other side. Copper is a material which is able to carry electrostatic energy well and helps with the performance of the electrostatic precipitator. I drilled holes through the 1mm copper mesh to increase capture efficiency by making the copper more rugged and less smooth which helped with increasing the friction and particle collection from the copper mesh.

The model was then 3d printed in PLA in 2 different parts. This allowed for ease of cleaning and manufacturing. Moreover, splitting it into 2 detachable parts allowed for removal of the microplastics and other contaminants to be easily taken out and measured. PLA was chosen as it is a sustainable material which is biologically and environmentally safe. Furthermore, PLA is a rigid and strong material which fits the needs of my device. The vertical orientation of the device allows for gravity to help with the electrostatic capture mechanism as gravity makes it easier for heavy particles to settle down. Figure 2,3 and 4 show the CAD designs of the discussed idea.

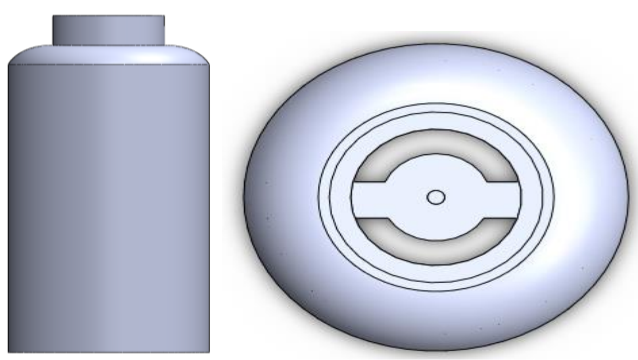

Fig 2: ESP CAD Design outside view

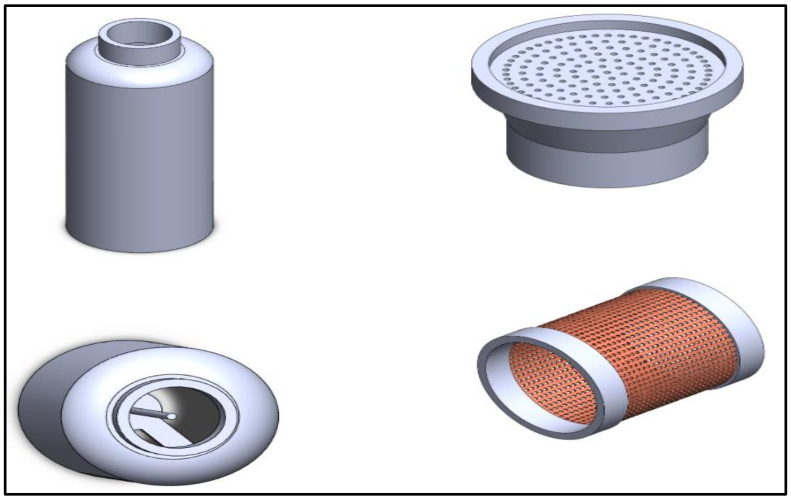

Fig 3: Inner components CAD Design

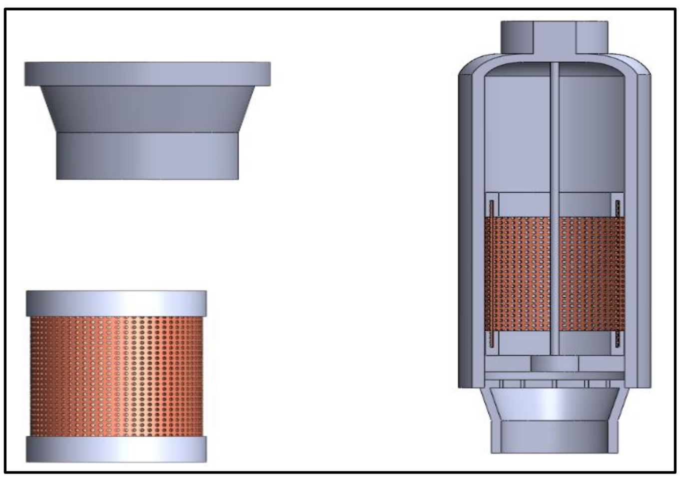

Fig 4: ESP CAD Design Sectional view

Electronic components and sensors :

1) **Van de Graaff:** Van de Graaff generator is a scientific device that produces a buildup of high-voltage static electricity using a moving belt that transfers electric charge to a large, hollow metal sphere atop an insulated column. It was used to generate high voltage electricity which was then used to ionize the particles in the air. These ionized particles were now attracted to the copper mesh which then let clean air through as the particles stuck to the copper inside the chamber itself. The ground wire of the van de graaff was connected to the copper electrode and the positive wire was connected to the beam in the middle. These 2 opposite charges created an electric field inside the chamber. This is why particles were able to get ionized and separated from the air/gas.

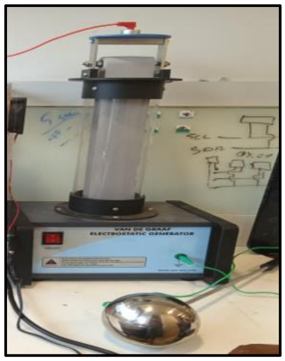

Fig 5: Vann De Graff

2) **ESP32 Microcontroller:** Fig 6 shows an ESP33 board [1]. An ESP32 is a versatile, low-cost microcontroller used in Internet of Things (IoT) devices, home automation, robotics, and other embedded systems due to its built-in Wi-Fi and Bluetooth capabilities, dual-core processor, and various I/O interfaces. ESP32 Dev Module was connected to the dust sensor for data collection and analysis.

Fig 6: ESP32 Microcontroller

3) **Dust sensors:** Fig 7 shows an optical dust sensor [2]. An optical dust sensor was used to measure the particulate matter of 2.5 mm. It detects scattered or reflected infrared light from dust particles in the air using a LED and a photodetector. This allowed the measurement of dust particles in particles per minute. Detection of amount of dust helped detect the efficiency of the prototype.

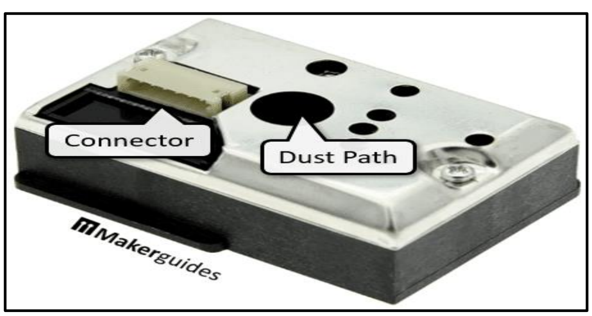

Fig 7: Dust Sensor GP2Y1010AU0F

4) **Exhaust fans:** These fans will be used to push the air and the contaminants inside of the closed setup/environment. This is what will allow for the readings to be taken as well as the device' usability and performance to be determined. They act as ventilation and as a start point for the contaminants to enter the room and then diffuse within it.

Fig 8: Exhaust fan

Test environment and setup :

Testing was conducted by creating 2 enclosed environments for the sunflowers and the ESP respectively with clear acrylic sheets. Each room was equipped with their own exhaust fan which was used to push air and spread contaminants in the environment. Readings were taken with the help of dust sensors which were connected to the microcontroller which calculated and displayed the readings on any device connected. This thorough method of testing and obtaining data with a highly controlled and accurate environment enabled maximum reliability in the readings we got.

The setup was done according to the following process :

1) The ESP was centrally placed to ensure uniform circulation of the contaminants and it was connected to a van de graaff generator which supplied almost 200V of electrostatic ionization.

2) The monitoring sensor(optical dust sensor) was placed at the inlet and outlet to measure air quality and particle presence.

Testing environments:

1) **Sunflower Testing Environment:** The sunflower was placed inside one half of the acrylic chamber, with controlled PM2.5-laden air introduced using exhaust fans. The chamber ensured a closed environment, limiting external airflow and maintaining consistent pollutant exposure. Real-time PM2.5 sensors recorded concentration changes over time to evaluate removal efficiency. The sunflower's broad leaves provided surface area for dust deposition and microplastic adherence. Conditions such as light, humidity, and airflow were kept constant throughout the test to ensure reproducibility.

Fig 9: Sunflower Testing Environment

2) **Peace Lily Testing Environment:** The peace lily was tested in the same acrylic chamber section under identical conditions to the sunflower to allow direct comparison. PM2.5-rich air was evenly distributed by the fans, and sensors tracked particulate concentration decay. The peace lily's glossy leaves and natural stomatal activity offered potential for particle trapping and limited pollutant absorption. Environmental parameters such as airflow rate, chamber volume, and pollutant type were controlled. Observations also included practical aspects like plant health, leaf dust accumulation, and ease of cleaning after the experiment.

Fig 10: Peace Lily environment test

3) **Electrostatic Precipitator (ESP) Testing Environment:** The ESP was placed in the other half of the acrylic chamber, aligned vertically to maximize particle capture efficiency. The system was powered by a Van de

Graaff generator, charging particulates as they passed through and depositing them on the copper mesh. Fans were used to circulate PM2.5-rich air through the device, while sensors measured inlet and outlet concentrations. The detachable PLA body allowed easy collection of deposited materials after testing. Noise, energy consumption, and ease of cleaning were also recorded as part of the evaluation.

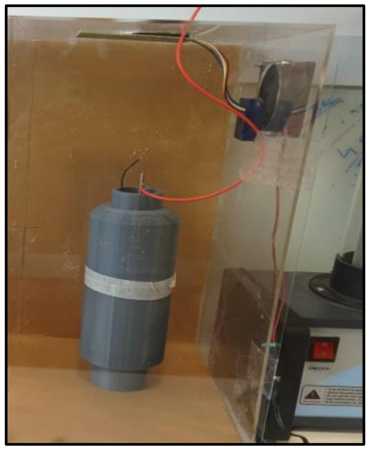

Fig 11: ESP Test setup

Materials used for testing

1) **PETE micro plastics:** PETE is a common synthetic polymer. When mechanically abraded or fragmented it produces a size spectrum from visible flakes down to micrometer and sub-micrometer particles. Particle density ≈ 1.38 g/cm³; hydrophobic surface chemistry. PETE microplastics are commonly found in the real world in places such as water bottles and soil. They contaminate drinking water and have profound impacts on our health if ingested in large quantities. For example, PETE microplastics cause inflammation and lung issues. For this testing procedure, PETE plastic sheets were made using a dremel tool to grind it into fine microplastic matter which was fit for testing.

Fig 12: PETE Particles

2) **ESP(expanded polystyrene):** Low-density polymeric foam (EPS) that fragments into low-mass, often angular flakes and micro-beads. Bulk density is very low and fragments can be highly electrostatically

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responsive. ESP thermocol slabs were bought and then rubbed against a rough surface. Due to the friction, the ESP converted into fine pieces which were perfect for testing the device.

Fig 13: Thermocol particles

3) **Dry Soil:** Soil particles have dimensions similar to the PM2.5mm particles. Hence this helped assess the results precisely. Dry soil dust consisting of silicates, clays and organic detritus was used, typically irregular, dense particles with a broad size distribution (from tens of micrometers down into sub-micron).

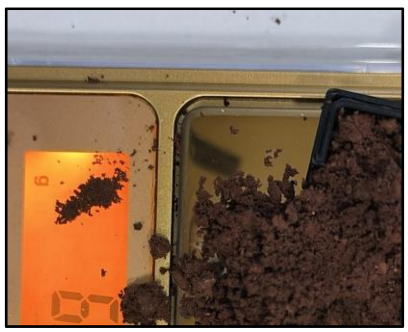

Fig 14: Soil Particles

Hence Fig 18 shows the final prototype setup which was used for testing purposes. The acrylic box with 2 sections can be seen where one section shows the plant test and section 2 shows the 3D Printed ESP. There are 2 DC fans on the sides of the both sections for driving in the air and exhaustion of the air. The dust sensors are placed near the fans to test the amount of dust. Section 2 has the input from Van De Graaff for generating the electrostatic fields.

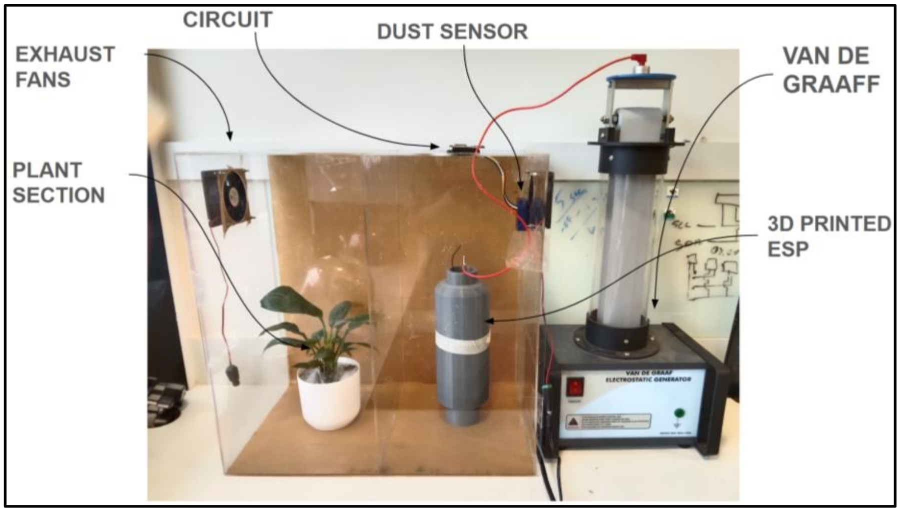

Fig 18: Prototype setup

Results:

Collection efficiency calculation : Post testing of the different cycles both the collector plate and the chamber floor were inspected and measured. The microplastic particulate matter was thoroughly collected and made using a high precision weighing scale. The formula for calculating the collection efficiency is

$$n\% = \frac{Initial\ Mass - Removed\ Mass}{Initial\ mass} \times 100$$

$$Removed\ Mass = Initial\ Mass - Residual\ Mass$$

1) **ESP Testing**

Material Tested	Initial Material Mass	Residual After ESP	Mass Removed by ESP	Efficiency Percentage
Thermocol particles	2.08 g	0.16 g	1.92 g	92.30%
Soil particles	3.00 g	0.16 g	2.84 g	94.66%
PVC Pipe particles	3.14 g	0.11 g	3.03 g	96.49%

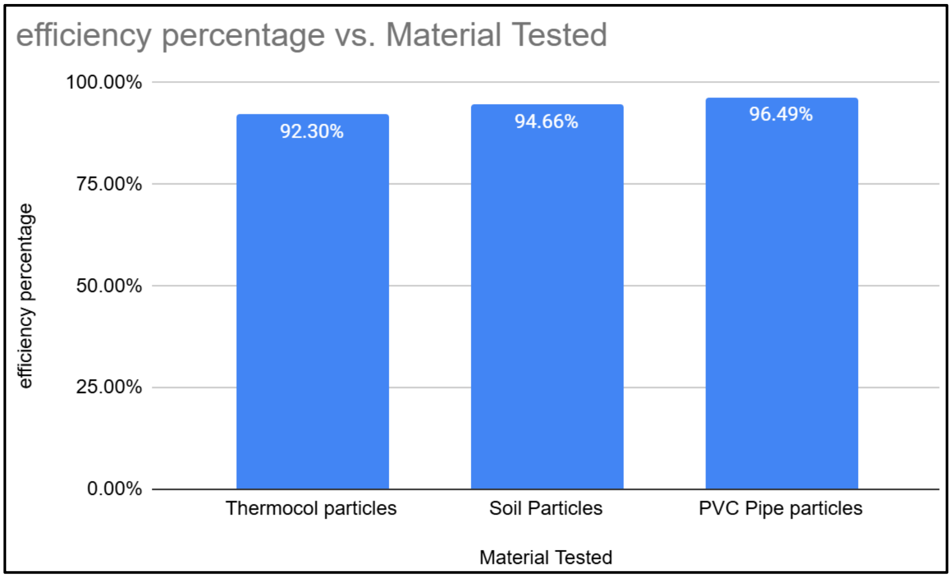

Fig 15: ESP Precipitator Analysis

2) Sunflower Testing

Material Tested	**Initial Material Mass**	**Residual After ESP**	**Mass Removed by ESP**	**Efficiency Percentage**
Thermocol particles	3.05 g	2.20 g	0.85 g	72%
Soil particles	3.50 g	2.80 g	0.70 g	80%
PVC Pipe particles	3.0 g	2.34 g	0.66 g	78%

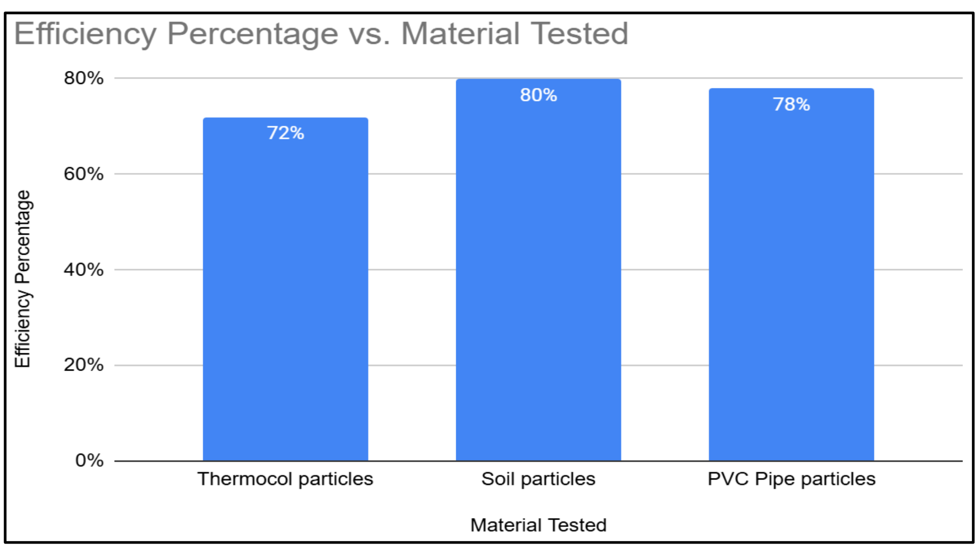

Fig 16: Sunflower Test Analysis

3) Peace Lily Testing

Material Tested	Initial Material Mass	Residual After ESP	Mass Removed by ESP	Efficiency Percentage
Thermocol particles	4.21 g	2.03 g	2.18 g	51%
Soil particles	3.61 g	1.21 g	2.40 g	66%
PVC Pipe particles	3.04 g	1.50 g	1.54 g	50%

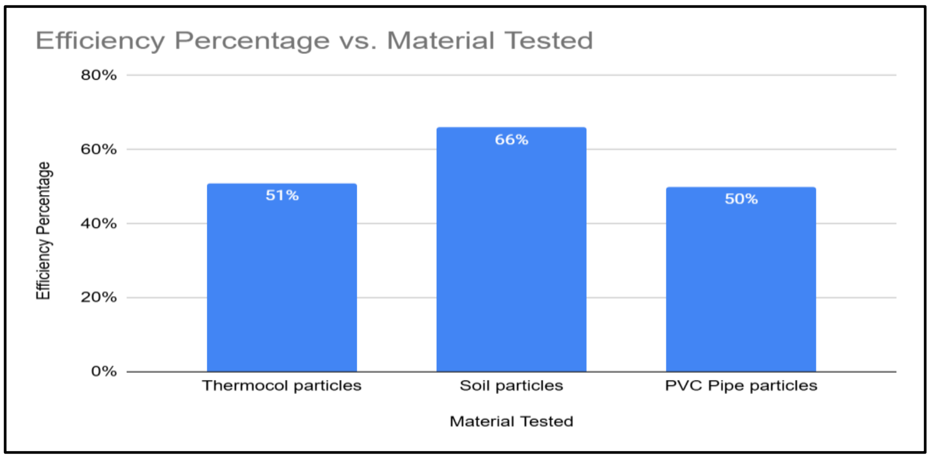

Fig 17: Peace Lily Test Analysis

Conclusion

The comparative testing of the self-built electrostatic precipitator (ESP), sunflower (Helianthus annuus), and peace lily (Spathiphyllum spp.) under controlled pollution events highlights clear differences in PM2.5 removal efficiency across technologies and biological systems. The ESP consistently demonstrated the highest efficiency, removing 92.30% of thermocol particles, 94.66% of soil particles, and 96.49% of PVC fragments. Its performance is attributed to the strong electrostatic field generated by the central electrode and copper mesh, which effectively charges and captures fine particulates regardless of material type. The near-uniform efficiency across particle categories suggests that the ESP is relatively insensitive to particle density and surface chemistry, making it a reliable, high-performance solution. In comparison, the sunflower exhibited moderate to high removal efficiencies, ranging from 72% for thermocol to 80% for soil particles. Its broad leaves with textured surfaces promoted effective deposition and adhesion of particulate matter. Notably, sunflower achieved its highest efficiency for soil particles, likely due to their greater density and irregular morphology, which enhanced impaction and retention on leaf surfaces. The results indicate that sunflower plants can serve as a biologically sustainable supplement for PM2.5 reduction, particularly in environments where continuous power supply for ESPs may not be feasible. The peace lily performed least effectively, with efficiencies between 50% and 66%. Removal was highest for soil particles (66%), while thermocol and PVC fragments showed lower efficiencies of 51% and 50%, respectively. Despite its popularity as a household plant, the peace lily's relatively smooth and smaller leaf area appears less effective in trapping airborne particulates compared to sunflower. Nonetheless, its ornamental appeal and minimal maintenance requirements make it socially acceptable as a low-cost intervention, though its contribution to PM2.5 mitigation is limited. Overall, the findings confirm that the ESP provides the most robust and rapid particulate removal, but at the cost of requiring energy input, maintenance, and noise control. Sunflower plants present a promising natural alternative with substantial efficiency, while peace lily, though less effective, offers ease of use and cultural acceptability. For low-income households, an integrated approach using plants for passive, continuous filtration and ESPs for rapid pollutant reduction may provide a balanced, sustainable strategy for improving indoor air quality.

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