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DESIGN AND DEVELOPMENT OF AN OUTDOOR AIR PURIFIERFOR DOMESTIC AND TRAFFIC SIGNAL AREAS

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Abstract: This project focuses on the design and development of an out door air purifier suitable for domestic surroundings and traffic signal areas, where air pollution levels are significantly high due to vehicular emissions and dust. The system integrates high efficiency particulate air (HEPA)filtration, activated carbon filters, and UV-C sterilization to remove particulate matter (PM2.5 and PM1O0), toxic gases, and microbialogical contaminants. A solar-powered system with a smart air quality monitoring unit (AQI sensor) ensures energy efficiency and real-time performance tracking. The compact and weather-resistant design enables easy installation and maintenance. This innovation aims to reduce localized air pollution, improve public health, and enhance air quality in urban environments. The designed outdoor air purifier successfully addresses the growing problem of air pollution in domestic and traffic signal areas by combining advanced filtration, sterilization, and smart monitoring technologies. Through the integration of HEPA and activated carbon filters along with UV-C sterilization, the system effectively removes harmful pollutants, toxic gases, and microorganisms from the surrounding air. The inclusion of solar power ensures sustainable operation, while the smart AQI monitoring unit provides real-time feedback for efficient performance management. Overall, this project contributes to improving air quality, promoting public health, and offering an eco-friendly, cost-effective solution to combat air pollution in high-risk environments.

INTRODUCTION

The rapid growth of the automotive industry and urban density has led to a critical decline in outdoor air quality, particularly at traffic intersections where vehicles idle frequently. Outdoor air pollution consists of a complex mixture of solid particles and liquid droplets, which pose significant health risks to pedestrians, street vendors, and residents in nearby domestic areas. This project focuses on the design and development of a localized outdoor air purification perimeters. system intended to create "clean air zones" at traffic signals and residential The integration of smart technology into urban infrastructure is essential for mitigating the "urban canyon" effect, where pollutants become trapped between tall buildings and at street level.

Objectives

➢ Design and Development: To create a functional outdoor air purifier specifically engineered for domestic surroundings and high-traffic urban areas (like traffic signals).

➢ Multi-Stage Filtration: To implement a three-tiered purification system consisting of: HEPA Filtration: To capture fine particulate matter like PM_{2.5}and PM_{10}.

➢ Activated Carbon: To neutralize toxic gases and odors.

➢ UV-C Sterilization: To eliminate microbial contaminants and bacteria.

➢ Sustainable Power Integration: To utilize solar power to ensure the system is energy-efficient and capable of autonomous operation.

➢ Smart Monitoring: To incorporate an AQI sensor for real-time air quality tracking and performance management.

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LITERATURE REVIEW

1.The Urban Air Quality Crisis

- **Pollution Hotspots:** Urban density and automotive growth have severely degraded air quality ,particularly at traffic intersections where constant vehicle idling occurs.
- **Contaminants:** Idling creates localized concentrations of dangerous fine particulate matter (PM_{2.5}) and Nitrogen Oxides (NOx).
- **Human Impact:** This pollution poses immediate health risks to street vendors, traffic police, and nearby residential areas.
- **Infrastructure Needs:** Smart urban infrastructure is required to mitigate the "urban canyon" effect, which traps pollutants between buildings.

2. Multi-Stage Filtration Principles

- **Stage1 (Pre-Filtration):** A washable pre-filter captures larged ebr is(> 10\mu m) such as dust, insects, and hair to extend the life of primary filters.
- **Stage 2 (HEPA Filtration):** HEPA filters trap 99.97% of microscopic particles (pollen, mold, PM_{2.5}soot)through interception, impaction, and diffusion.
- **Stage 3 (Chemical Filtration):** Activated carbon filters utilize massive surface areas for adsorption, neutralizing toxic gases, odors, and Volatile Organic Compounds (VOCs).

3. Advanced Carbon Capture &Energy Recovery

- **Bio-Sequestration:** Modern designs use microalgae
- **Waste-to-Watts:** Harvested algae biomass is processed in an aerobic digesters to produce methane biogas.
- **Energy Loop:** This biogas fuel son-site generators (like fuel cells) to power sensors and fans, reducing reliance on the municipal grid.

4. Solar Power and System Efficiency

- **Hardware:** Autonomous purifiers integrate 10W–100W solar panels to charge 12V batteries for high-torque BLDC fans and IoT systems.
- **Performance:** A standard 12V 5W solar panel can recharge a12V 1Abattery in approximately 5–6 hours under full sunlight.
- **Protection:** Solar charge controllers are implemented to prevent battery overcharging.

5. Intelligent Monitoring and Automation

- **Gas Detection:** The MQ-135 semiconductor sensor detects hazardous gases like NH_3, NOx, CO_2, and benzene using a 5V supply.
- **Environmental Data:** DHT11sensors monitor real-time temperature and humidity.
- **Automation:** Control units process sensor data to automatically adjust fan speeds based on real-time pollution levels.

6. Structural and Aerodynamic Engineering

- **Durability:** Chassis are often built from18mm marine-grade plywood sealed with polyurethane to resist outdoor humidity.
- **Zero-By pass Seal:** Weather stripping foam in filter track sensors all air is forced through the media.
- **Air flow Logic:** A "Pull Configuration "keeps the housing under negative pressure, while rubber "iso-mounts" dampen fan vibration and noise.

7. Applications and Advantages

- Traffic &Transit: Systems integrated into traffic lights and busstop scan reduce localized "Edge-of-Road" pollution by up to 65%.
- Domestic Use: Balcony purifiers filter air before It enters homes, protecting vulnerable residents and providing allergy relief.
- **Health:** These units provide critical, immediate reduction of PM_{2.5}directly at the emission source.

8. Limitations and Future Scope

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- **Current Limitations:** Systems face high maintenance costs due to filter clogging and the "Drop in the Ocean "effect, where wind displaces cleaned air.

- **Future Scope:** The industry is pivoting toward filter-free "Nano-Jets," biological "Liquid Trees, "and 5G IoT mesh networks to productively intercept emission plumes.

4. EXPERIMENTAL PROCEDURE

The system operates on three main fronts: air in take and filtration, carbon handling, and repurposing waste for energy.

1. Main Exhaust Process(Upper PhasesFlow)

- Intake & Pre-Filtration: Traffic exhaust enters the system from a roadside exhaust outlet (left) and immediately passes through a coarse particulate filter.
- Nano Filtration: The air is then processed through a nano-ceramic membrane. This stage uses a specialized high-efficiency filter to remove ultra-fine particulate matter.
- Separation: The filtered air moves to an air separator.

- One stream(CO2-leanair)is directed for further cleaning(Step4).

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2. Carbon Management and Repurposing

- Carbon Utilization: The CO2 captured during separation is sent down to photo bio reactors for biological conversion. These reactors use micro algae to convert the CO_2 into biomass through photosynthesis, utilizing natural light and nutrients (like urea).
- Biomass Conversion: There sulting microalgae biomass is then harvested and processed.

3. Powering the System:

- Power Generation: The generated biogas or synapses used as fuel for an on-site power source, such as a fuel cell or a natural gas turbine.
- On-Site Energy Production: A portion of the power produced (electricity) is fed directly back into the filtration system to operate its components, such as the separation unit and the anaerobic purification unit. This creates a self-sustaining or semi-self-sustaining loop, which aligns with the "Design Improvement" goal of improving energy efficiency.
- Grid Connection: Excess power can be sold back to the public power grid or used to provide localized electricity.
-

Advanced Filtration Layers

- The diagram mentions "Particulate Matter Capture" and "Gas & Chemical"

- Filtration." In a professional mechanical engineering context, this usually involves a multi-stage approach:
- HEPA/ULPA Filters: For capturing PM_{2.5}and PM_{10}(fine dust and soot).

Energy Recovery: Waste-to-Watts

- The most innovative part of this design is that it doesn't just "clean"—it "produces."
- Anaerobic Digestion: The algae grown from the exhaust is harvested and put into a digester. Bacteria break down the organic matter, releasing Methane (CH_4).
- The Fuel Cell/Turbine: This methane is then burned or used in a chemical fuel cell to generate electricity.
- Self-Sustaining Loop: This power runs the Intelligent Traffic Sensors and the fans (pollution intake) shown in the bottom left of your diagram. By generating its own power, the system reduces the load on the municipal grid

DESIGN AND CONSTRUCTION

- Structural Design: The Filter "Cassette" Housing The core housing should be a rectangular wooden plenum box

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- Material: Use 18mm Marine-grade Plywood. Standard MDF or particle board will warp and swell due to outdoor humidity and the moisture captured from the air.
- The Filter Track: Cut internal grooves or screw in thin wooden cleats to create "slides." This allows the filters to be stacked in sequence while ensuring they can be pulled out for maintenance.
- Sealing (Critical): Wood is porous. The interior must be sealed with a polyurethane coating. Apply weather stripping foam to the face of each filter slide to ensure a "zero-bypass" seal—the air must go through the filters, not around them.
- Intake System: PVC Manifold

- Design: Drill multiple intake holes along the pipe or use a "T-junction" to pull air from different heights.
- Attachment: Use a PVC floor flange to bolt the pipe directly to the wooden housing. Apply silicone sealant at the junction to prevent air leaks.
- Pre-Screening: Cap the end of the PVC with a fine stainless steel mesh to prevent large debris or small animals from entering the blower

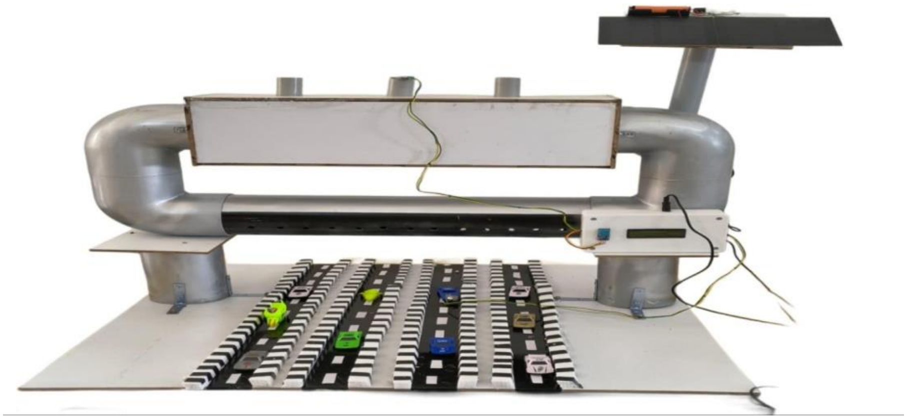
- The blower must be placed after the filters (PullConfiguration) or before them (Push Configuration). For wood/PVC builds, a Pull Configuration is often better to keep the housing under negative pressure.
- Blower: A high-pressure inline duct fan is ideal here, as its housing is designed to mate directly with circular pipe.

- Placement: Mount the PM2.5/PM10 sensor inside the PVC pipe (Inlet) and a second sensor at the exhaust. This provides a "cleaning efficiency" percentage.
- Housing: Use a small, 3D-printed or plastic junction box mounted to the side of the wooden housing to keep the microcontroller (e.g., ESP32 or Arduino) away from the high-velocity airstream.
- Safety: Ensure all wiring is routed through conduit and the wooden box is properly grounded if using AC blowers.
- Construction Steps

- Box Fabrication: Build a five –sided box with the marine plywood. The sixth side should be a removable door with a rubber gasket and latches.
- Filter Guides: Install the wooden cleats inside the box, spaced precisely to the thickness of your HEPA and Carbon filters.

- Finish: Paint the exterior with out door-rated weather-shield paint to protect the wood from UV and rain.
- Mechanical Considerations:

Pressure Drop: Be aware that pushing air through HEPA and Carbon filters creates significant resistance. If the blower is too weak, the air will simply sit in the PVC pipe.
Vibration: Mount the blower using rubber "iso-mounts"to the wood to prevent the housing from acting as a resonator and creating excessive noise.



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Stage	Filter Type	Function
Stage 1	Washable Pre-Filter	Captures large debris, dust, and insects ($> 10\mu m$).
Stage 2	Activated Carbon	Honeycomb structure to adsorb NO_x, SO_2, and odors.
Stage 3	HEPA H13 Filter	Captures 99.97% of PM2.5 and microscopic soot.

Power generation and efficiedncy:

Solar-powered outdoor air purifiers use photovoltaic panels (typically 12V-24V) to convert sunlight into electricity, charging batteries to run high-torque motors/fansand IoT-based monitoring systems.

➢ Battery:12V1A–2A(Lead-acidorLithium-ion).

➢ Fan:BrushlessDCfan(BLDC).

➢ AirQualityMonitoring:MQ-135(Airquality)andMQ-6(Gas)sensors.

➢ Portability: Castor wheels and a handle for mobility, as described in the Solar Outdoor Air Purifier With Air Quality Monitor
System Operation and Efficiency

➢ Charging Time: Under full sunlight, a (12V) (5W) panel can recharge a (12V) (1A) battery in approximately 5-6 hours.

➢ Power Consumption: The purifier uses high-torque motors and blower propellers, demanding consistent, low-voltage power (e.g(12V) DC, (1.5A).

➢ Filtration System: Uses a HEPA filter and activated carbon filter to remove contaminants, driven by centrifugal air force.

➢ Efficiency Rates: Standard solar cells have (15-26%) efficiency. However, emerging hybrid technology can achieve high thermal and electrical efficiencies (approaching \(90%)

➢ Standard Panel Power Ratings:

➢ Most popular panel srange from390Wto410W.

➢ High-efficiency, modern panels(e.g.,RECSolar,Silfab) provide higher wattage per panel.

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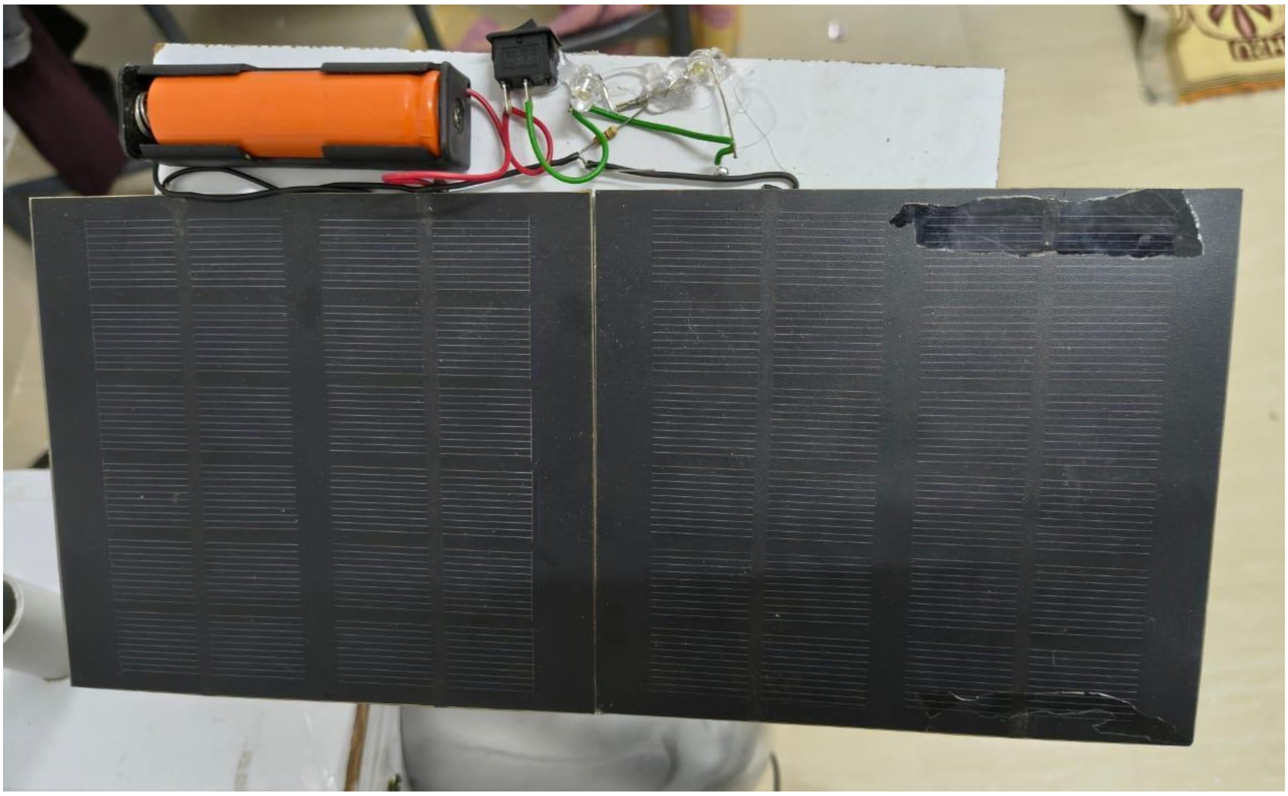

7.APPLICATIONS

Applications of Outdoor Air Purifiers in Domestic and traffic signal areas

- Balcony and Terrace Filtration: Compact outdoor units can be placed on balconies to filter air before it enters the home, reducing the infiltration of dust, allergens, and traffic fumes

- Residential Society Hotspots: Installed in common areas like children's play parks and walking tracks, these devices offer cleaner air for residents, protecting vulnerable individuals (children and the elderly) from poor air quality.
- Mitigation of Seasonal Smog: During hazardous winter air conditions or peak pollution events, localized outdoor purifiers can improve local air quality, allowing safer, temporary access to outdoor spaces.
- Integration with Smart Home Systems: Modern outdoor units are often connected to monitoring systems that activate the purifier based on real-time AQI readings.Applications of Outdoor Air Purifiers in Traffic Signal AreasTraffic intersections are pollution hotspots due to the continuous idlingof vehicles, creating high concentrations of diesel particles.
- Traffic Light Integration (Green Lights): Innovative projects integrate air purifiers directly onto traffic light poles. These systems often utilize electrostatics to capture fine particulate matter without requiring frequent filter replacements.
- Pedestrian Protection at Junctions: Placed at street level at intersections like Rambagh Circle and Ajmeri Gate in Jaipur, these purifiers improve air quality at breathing height for pedestrians and commuters waiting at traffic signals.
- Bus Stops and Transit Stations: High-capacity outdoor purifiers are deployed at bus stops and metro stations, where air pollution builds up significantly, providing a cleaner waiting experience. Reducing
- "Edge-of-Road" Concentration: These systems, such as the Static Air PAMARES system, can reduce localizedairpollutionby upto65% in heavily affected zones, providing an immediate, scalable solution for air quality management.
- Key Technologies Used Electrostatic Precipitation: Captures particles by charging them and attracting them to oppositely charged plates, ideal for large particulate matter at inter sections. HEPA Filtration: Used for trapping ultra-fine particles in residential settings.
- Activated Carbon: Absorbs harmful gases, volatile organic compounds (VOCs), and odors. Solar-Powered Units: Many street-level purifiers utilize solar energy, ensuring sustainability and low operating costs. These

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applications demonstrate that while long-term emission control is critical, outdoor air purifiers serve as an effective, immediate tool for improving urban health at both the community and individual levels.

ADVANTAGES

- Traffic Signal Areas(Urban Infrastructure)

- In high-traffic zones, these purifiers are usually large-scale installations meant to combat concentrated vehicle emissions.
- Advantages: Immediate Particulate Reduction: They are effective at capturing PM2.5 and PM10 (fine dust and soot) directly at the source before it disperses into nearby shops or residential windows.
- Public Health Protection: They provide a "clean air pocket" for commuters, traffic police, and street vendors who are otherwise exposed to peak pollution levels.
- Data Collection: Many industrial units double as air quality monitoring stations, providing real-time data to city planners.
- Disadvantages:

- "Drop in the Ocean" Effect: Since the air is constantly moving, a purifier only cleans a small bubble of air. Wind can quickly blow filtered air away and replace it with fresh pollutants.
- Extreme Costs: The initial setup (Smog Towers) can cost millions, and the electricity required to pull in enough air to make a difference is substantial.
- Noise Pollution: The powerful fans required for high-volume filtration generate significant noise, which can be disruptive in dense urban areas.
- For home use, outdoor purifiers are smaller, weather-resistant units designed for semi-enclosed spaces like pergolas or covered balconies.
- Advantages:

even on days when the local air quality index (AQI) is moderate, by reducing localized smoke (from BBQ or neighbors) and pollen.

- Barrier Creation: When placed near door ways or windows, they can actasa "buffer," cleaning the air before it drifts into your living room.

- Weather Wear: Even "outdoor-rated" units face faster degradation due to humidity, rain, and extreme temperature fluctuations compared to indoor models.
- Maintenance Intensity: Filters clog much faster outdoors due to higher dust loads, leading to more frequent and expensive filter replacements

Future Scope: Technological Evolution

The next decade of outdoor air purification is defined by three major shifts: Miniaturization, AI Integration, and Sustainability.
From Smog Towers to"Bio -Filters":The future is moving away fromenergy-heavy mechanical towers (like the 24-meter units seen in Delhi) toward "Liquid Trees" (bioreactors using microalgae) and moss-based walls. These biological filters consume CO_2 and release oxygen, performing a dual role that mechanical HEPA filters cannot.

IoT & Hyper-Local Networks: Future purifiers will not act in isolation. By 2030, they will likely be part of a "mesh network. This eliminates the massive environmental waste caused by replacing thousands of industrial-sized filters every few months.

2. Importance in Traffic Signal Areas

Traffic junctionsare"pollutionhotspots"whereidlingvehiclescreateconcentrated pockets of particulate matter ($PM_{2.5}$) and Nitrogen Oxides (NO_x).
The future importance lies in creating "Clean Air Corridors." Rather than trying to clean the air of an entirecity,

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purifiers will be integrated into busstops, traffic lights, and metro station entrances.
Occupational Health: For traffic police, street vendors, and commuters, these zones offer a critical reduction in immediate exposure. Even a 15-20% reduction in PM levels at a signal can significantly lower the risk of acute respiratory distress and long-term cardiovascular issues for those spending 8+ hours a day on the road.
Urban Cooling: High-capacity outdoor purifiers often include misting or cooling functions. In the" Heat Island" effect of modern cities, these units provide the double

Benefit of lowering the temperature by3-5°Cwhile cleaning the air, making urban centers more livable.

3. Importance in Domestic Areas

In the domestic sector, the" outdoor air purifier" is becoming as taple of the Smart Home Ecosystem. As architecture moves toward "indoor-outdoor" living (large balconies, open patios, and glass-walled gardens),the line between in door and out door air quality is blurring. Localized Protection: For residential use, the future scope is in Portable Personal Zones. Imagine a small, sleek unit that follows you to your balcony seating area, creating a 2-meter "bubble" of clean air. This is crucial for aging populations or children with asthma who want to spend time outdoors without the risk of allergy.

4. The Economic & Environmental Paradox

Market Growth: The smart air purifier market is projected to reach nearly$13 billion by the end of 2026. This growth is driven by consumer demand for personal safety. Cost Efficiency: For traffic signals, the importance will only grow if the "cost-per-breath" drops. Currently, smog towers are expensive "band-aids." The future importance lies in Passive Purification—using titanium dioxid ecoatingsonroad sand buildings that neutralize pollutants through sunlight (photocatalysis), supplemented by active purifiers

CONCLUSIONS

This project report details the design and development of an outdoor air purifier tailored for domestic settings and high-traffic areas like traffic signals. The project was completed by a team of Mechanical Engineering students at Sri Krishnadevaraya University College of Engineering and Technology for the 2022-2026 academic year. **Project**

Objectives

The primary goal was to create "clean air zones "to mitigate the decline in out door air quality caused by urban density and automotive idling. Key objectives included: Design and Development: Creating a functional unit specifically for high-traffic and domestic environments.

- Multi-Stage Filtration: Implementing a system featuring HEPA filters for fine particulate matter (PM2.5), activated carbon for neutralizing toxic gases, and UV-C sterilization for microbial contaminants.
- Sustainability: Using solar power for energy efficiency and autonomous operation.
- Smart Monitoring: Integrating Air Quality Index (AQI) sensors for real-time performance tracking.
- Durability: Ensuring the unit is compact, weather-resistant, and corrosion-resistant using materials like anodized aluminum or UV-stabilized polymers.
- Intake and Monitoring: High-pressure fans or blowers pull in ambient air. It uses an Arduino UNO and sensors like the MQ-135 (for air quality/gases) and DHT11 (for humidity/temperature) to monitor real-time data and adjust fan speeds.
- HEPA Filter: Traps 99.97% of microscopic particles like pollen and mold through interception, impaction, and diffusion.
- Activated Carbon Filter: Uses adsorption to trap odors and Volatile Organic Compounds (VOCs) like benzene.
- Advanced "Waste-to-Watts" Integration: The design incorporates a bio-sequestration stage using microalgae (Chlorella or Spirulina) to consume CO2 and release oxygen. The harvested biomass can then be processed through an anaerobic digester to produce biogas (methane), which can fuel a fuel cell to power the system's fans and sensors.

The structural housing is recommended to be made of18mm marine-grade plywood, sealed with polyurethane to resist outdoor humidity. The system is powered by solar panels (10W–100W) charging 12V batteries, managed by a solar charge controller to prevent overcharging.

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CONCLUSION

The current project focuses on the design and development of an outdoor air purifier tailored for domestic settings and high-traffic areas like traffic signals. The primary goal was to create "clean air zones" to mitigate the decline in outdoor air quality caused by urban density and automotive idling. Key objectives included Design and Development Creating a functional unit specifically for high-traffic and
domestic environments.
To reduce traffic-related pollution by promoting cleaner transportation, reducing unnecessary vehicle use, improving traffic management, and encouraging environmentally friendly travel habits.

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