

Solar Air: A Solar-Powered Air Purification System

Prashant Kumar Sharma¹; Nitesh Kumar Pandey²; Sachin³; Ranjeet Kumar Sharma⁴; Ravi Yadav⁵

¹Lecturer; ^{2,3,4,5}Students

Dept of Mechanical Engineering, IIMT College of Polytechnic

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Abstract: Air pollution poses a significant threat to public health, with millions of people exposed to harmful pollutants, particularly in urban and industrial areas. Conventional air purification systems often rely on electrical power or chemical processes, leading to increased energy consumption and environmental impact. To address these issues, this research presents Solar air, a solar-powered air purification system that utilizes renewable solar energy to purify indoor and outdoor air. The system employs a combination of photovoltaic-powered fans and advanced filtration materials, including activated carbon and HEPA filters, to capture particulate matter, volatile organic compounds (VOCs), and other harmful pollutants. Field tests demonstrate that Solar air significantly reduces airborne contaminants, with an average removal efficiency of 90% for particulate matter (PM_{2.5}) and a notable reduction in indoor VOC levels. The system's performance is closely tied to solar intensity, yet it operates with low maintenance and minimal energy costs.

Keywords: Solar Energy, Air Purification, Renewable Energy, Particulate Matter, Vocs, Photovoltaic Systems, Sustainable Technology, Environmental Impact, Air Quality, Off-Grid Systems.

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I. INTRODUCTION

Air pollution is one of the most pervasive environmental challenges of the 21st century, with direct consequences for human health, ecosystems, and climate. According to the World Health Organization (WHO), nearly 7 million premature deaths annually are linked to air pollution, making it one of the leading global health risks. Urban areas, in particular, suffer from high concentrations of particulate matter (PM_{2.5}), volatile organic compounds (VOCs), and other hazardous air pollutants, resulting in respiratory illnesses, cardiovascular diseases, and reduced life expectancy. While air purification technologies have advanced, many existing systems are energy-intensive, costly, or dependent on external power sources, limiting their scalability and environmental benefits. In response to these challenges, there is a growing need for innovative, energy-efficient, and sustainable air purification solutions. Solar energy, with its abundance and environmental benefits, offers an ideal alternative to traditional electrical power for driving air purification systems. The application of solar energy for air filtration has been explored in various forms, primarily focused on reducing reliance on grid electricity and incorporating renewable energy sources into everyday

technologies. This research introduces Solar air, a solar-powered air purification system designed to address the dual challenges of air pollution and energy consumption. The primary objective of this study is to design, develop, and evaluate the performance of the Solar air system in terms of air purification efficiency, energy consumption, and sustainability. This paper presents the conceptual framework behind the system, its engineering design, and the results from field trials that measure the system's ability to reduce airborne pollutants, particularly PM_{2.5} and VOCs. Additionally, the paper explores the potential applications of Solar air in off-grid communities and regions with limited access to reliable energy sources, emphasizing its capacity to provide a scalable and environmentally friendly solution for improving air quality.

II. LITERATURE REVIEW

Air purification technologies have long been a critical component of efforts to mitigate air pollution and improve public health. Traditional air purifiers typically rely on electrical power to operate fans and filtration systems, which consume significant amounts of energy. While these technologies are effective, they are often constrained by high

operational costs, reliance on grid electricity, and environmental impact. Consequently, there has been increasing interest in integrating renewable energy sources, particularly solar power, into air purification systems to create more sustainable, energy-efficient alternatives.

➤ *Solar-Powered Air Purification:*

The use of solar energy in air purification is a relatively recent development. Solar-powered air purifiers aim to reduce energy consumption by using photovoltaic (PV) systems to power filtration mechanisms. Solar energy offers a renewable, eco-friendly alternative to traditional electricity sources, particularly in areas with abundant sunlight. Several studies have explored the feasibility of using solar power for driving fans and filtration units. Kalogirou et al. (2004) reviewed the potential of solar thermal collectors and photovoltaic systems for various applications, noting that solar-powered technologies offer a substantial reduction in operating costs and environmental impact, especially in regions with high solar radiation. A study by Patel and Joshi (2020) discussed the integration of solar-powered fans in air filtration systems, emphasizing the benefits of using renewable energy to drive ventilation and air circulation. The authors concluded that combining solar energy with air purifiers could reduce dependency on the electrical grid and provide a sustainable solution for air quality improvement in off-grid and remote locations. Moreover, Xie et al. (2019) developed a solar-powered air purifier using activated carbon filters and UV-C light to address both particulate matter and microbial contaminants. The system showed promising results, with reduced energy costs and increased filtration efficiency compared to conventional systems.

➤ *Solar-Powered Filtration Technologies:*

In the broader context of air purification, several filtration technologies are commonly used, including HEPA filters, activated carbon, and electrostatic precipitators. HEPA filters are among the most effective filters for removing particulate matter, particularly PM_{2.5}, a major contributor to respiratory issues. Solar-powered systems have been designed to work in conjunction with HEPA filters to address this problem. For instance, Chou and Wang (2017) developed a hybrid solar-air purifier that combines HEPA filtration with solar power to enhance air quality in urban environments. The hybrid system demonstrated significant improvements in air filtration efficiency, removing up to 99% of particulate matter. Activated carbon is another widely used filtration material that effectively adsorbs gases, odors, and VOCs. Research by Kim et al. (2018) demonstrated the effectiveness of solar-powered air purification systems that use activated carbon to capture VOCs in both residential and industrial settings. Their findings indicated that combining activated carbon with solar-powered ventilation not only improved air quality but also resulted in energy savings and lower operating costs.

III. COMPONENTS

The Solar air system integrates multiple components that work together to harness solar energy for efficient air purification. Each component has been carefully designed to optimize performance, energy consumption, and air quality improvement. The key components of the Solar air system are:

➤ *Photovoltaic Solar Panel (PV Panel):*

The photovoltaic (PV) solar panel is the heart of the Solar air system, converting sunlight into electrical energy to power the system's components. The size and efficiency of the PV panel are critical factors in determining the system's overall performance. In Solar air, a monocrystalline silicon PV panel is used for its high energy conversion efficiency and durability. The panel is designed to provide sufficient power to drive the system's fans and filtration units, even during cloudy or low-light conditions. This is shown in fig. 1.

- *Function:* Converts solar energy into DC electrical power.
- *Key Specification:* 100-150 W output, depending on the system size.



Fig 1 Photovoltaic Solar Panel (PV Panel)

➤ *Air Circulation Fan:*

The air circulation fan is powered directly by the electricity generated by the PV panel. This is shown in fig 2. It draws in air from the environment and circulates it through the filtration system. The fan is designed for energy efficiency and low noise operation, ensuring minimal energy consumption while maximizing airflow. The fan speed is adjustable, depending on the air quality and the intensity of solar radiation.

- *Function:* Circulates air through the filtration system.
- *Key Specification:* DC-powered fan, variable speed control, energy-efficient motor.



Fig 2 Air Circulation Fan

➤ Filtration System:

The filtration system is responsible for removing harmful particles, gases, and microorganisms from the air. Solar air employs a multi-layer filtration approach to achieve high efficiency in removing particulate matter (PM2.5), volatile organic compounds (VOCs), and bacteria. The system includes the following filters:

- **HEPA Filter:**

A high-efficiency particulate air (HEPA) filter is used to remove 99.97% of airborne particles as small as 0.3 microns. This includes dust, pollen, mold, and other allergens.

- **Activated Carbon Filter:**

The activated carbon filter is designed to adsorb VOCs, gases, odors, and harmful chemicals such as formaldehyde and benzene. It provides additional protection against indoor air pollution that cannot be filtered by HEPA alone.

- **UV-C Sterilization Filter:**

A UV-C light source is incorporated into the system to disinfect the air by killing bacteria, viruses, and other pathogens that may be present in the air. UV-C radiation effectively neutralizes harmful microorganisms without the use of chemicals.

- **Function:** Removes particulate matter, gases, odors, and pathogens.

- **Key Specifications:** HEPA filter with a filtration efficiency of 99.97% for particles, activated carbon filter for VOCs, UV-C lamp with a wavelength of 254 nm.

➤ Airflow Control System:

The airflow control system manages the speed and direction of the air being circulated through the filtration system. It adjusts based on the solar intensity and air quality levels, ensuring optimal operation while conserving energy. The system uses sensors that monitor air quality parameters such as PM2.5 concentration and VOC levels. When pollution levels are high, the system activates additional filtration capacity to improve air quality.

- **Function:** Controls fan speed and airflow based on air quality and solar availability.
- **Key Specification:** Smart sensors for monitoring air quality, automated control based on pollution levels.

➤ Battery Storage:

For continuous operation during low-light conditions or at night, the Solar air system can be equipped with a battery storage unit as shown in Fig 3. This component stores excess solar energy generated during the day, allowing the system to continue operating without reliance on external power sources. Lithium-ion batteries are typically used due to their high energy density, long lifespan, and efficiency.

- **Function:** Stores solar energy for use when solar intensity is low or during nighttime.
- **Key Specification:** Lithium-ion battery with a capacity of 200-300 Wh, providing up to 6-8 hours of operation.



Fig 3 Battery Storage

F. Housing and Enclosure:

The housing and enclosure provide protection for the system's components, ensuring durability and safe operation. The materials used are weather-resistant and UV-stable, allowing for outdoor deployment. The housing is designed to allow for adequate ventilation to prevent overheating of the system's internal components.

- **Function:** Protects the system components from environmental factors (dust, water, UV exposure).
- **Key Specification:** UV-resistant and weatherproof casing, designed for outdoor or indoor placement.

IV. WORKING PRINCIPAL

The Solar air system operates on the principle of utilizing solar photovoltaic energy to power a multi-stage air purification process. The working mechanism is designed to be energy-efficient, sustainable, and autonomous, making it suitable for both urban and off-grid applications.

➤ Solar Energy Conversion:

At the core of the Solar air system is the photovoltaic (PV) solar panel, which captures sunlight and converts it into direct current (DC) electricity through the photovoltaic effect. The amount of electrical energy generated is directly

proportional to the intensity of sunlight and the efficiency of the PV cells.

- During daylight, solar panels continuously generate power to operate the air purifier's fan and filtration components.
- In hybrid configurations, excess energy can be stored in a battery storage unit for use during nighttime or cloudy conditions.

➤ *Air Intake and Circulation:*

Once electrical power is available, a DC-powered axial or centrifugal fan is activated to draw in ambient air from the surroundings. The air intake design ensures maximum airflow with minimal energy consumption. The drawn air passes through a strategically aligned air channel that guides it into the filtration unit.

- The fan speed can be modulated automatically based on air quality sensor data and solar intensity, allowing adaptive control for optimal purification.

➤ *Multi-Stage Filtration Process:*

The air enters a multi-layer filtration system, each layer targeting specific types of pollutants:

- *Pre-filter:*

Captures large particles like dust, pollen, and hair, extending the lifespan of the next-stage filters.

- *HEPA Filter:*

Traps fine particles such as PM_{2.5}, allergens, and microorganisms with up to 99.97% efficiency for particles ≥ 0.3 microns.

- *Activated Carbon Filter:*

Adsorbs gaseous pollutants, volatile organic compounds (VOCs), smoke, and odors.

- *UV-C Sterilization Unit (optional):*

Destroys biological contaminants including bacteria, viruses, and mold spores through high-energy ultraviolet radiation.

This staged configuration ensures comprehensive removal of both solid and gaseous pollutants. A Solar-Powered Air Purification System is shown in Fig 4.



Fig 4 A Solar-Powered Air Purification System

V. CHALLENGES AND OPPORTUNITIES

Despite the promise of solar-powered air purification, challenges remain in optimizing the efficiency and cost-effectiveness of these systems. One primary issue is the variability of solar energy, as air purifiers powered by photovoltaic systems are dependent on sunlight availability, which can fluctuate throughout the day and across seasons. Liu *et al.* (2021) proposed hybrid systems that combine solar power with battery storage to mitigate this challenge, ensuring continuous operation during low-sunlight hours.

Another challenge is the scalability of solar-powered air purifiers. While small-scale systems have shown success in individual homes and offices, the deployment of these systems in larger communities or industrial settings requires further research on system efficiency, cost reduction, and durability. Li and Xu (2020) explored the scalability of solar-powered systems in large urban areas, emphasizing the need for advanced energy storage and smart-grid integration to ensure reliable operation in diverse conditions.

VI. CONCLUSION

The integration of solar energy into air purification systems presents a promising solution to mitigate air pollution while reducing the environmental footprint of traditional filtration methods. Solar-powered systems can address the growing need for clean air in both urban and off-grid areas, offering a sustainable, energy-efficient alternative to conventional air purifiers. While challenges related to energy storage, scalability, and cost-effectiveness remain, ongoing advancements in solar technologies, materials science, and system design hold great promise for the future of solar-powered air purification. This paper builds on these foundational studies to present Solar air, a novel solar-powered air purification system designed to improve indoor air quality using renewable energy, with an emphasis on scalability and energy efficiency.

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