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"Design, Development, and Analysis of a Solar Thermal Powered Automatic Air Purification System''

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Abstract: Air pollution in urban and industrial regions remains a significant threat to public health, often exacerbated by the high energy consumption and carbon emissions of conventional grid-powered purification systems (Sharma et al., 2025; Sharyani et al., 2025). This study presents the design and analysis of an automatic air purification system powered by solar thermal and photovoltaic energy (Sharyani et al., 2025; Suri et al., 2025). The proposed system utilizes a multi-stage filtration process, incorporating activated carbon and HEPA filters to effectively eliminate airborne contaminants (Sharma et al., 2025; Suri et al., 2025).

Field tests of the solar-powered prototype demonstrate an average removal efficiency of 90% for particulate matter (PM2.5) and a substantial reduction in indoor volatile organic compounds (Sharma et al., 2025). The integration of intelligent sensor technology and microcontrollers allows the system to monitor air quality in real-time and adjust its purification settings dynamically to optimize energy use (Sharyani et al., 2025; Suri et al., 2025). Furthermore, performance evaluations of hybrid solar collectors indicate that a total efficiency of 44.68% to 58.59% is achievable under varied conditions (Thinsurat et al., 2018). This research highlights a sustainable, low-maintenance solution for air quality management in environments such as dental clinics and healthcare facilities, where maintaining sterile air is critical (Sharyani et al., 2025).

Keywords

- Solar Thermal Energy
- Air Purification
- HEPA Filtration
- PM2.5 Removal Efficiency
- Photovoltaic-Thermal
- Automated Air Quality Monitoring
- Sustainable Healthcare
- Volatile Organic Compounds
- Renewable Energy Systems
- Urban Air Remediation

INTRODUCTION

Air pollution represents a critical global health crisis, particularly in industrial and densely populated urban areas where harmful pollutants like PM2.5 and volatile organic compounds are prevalent (Kachare et al., 2026; Sharma et al., 2025). While traditional air purification systems are effective, they often depend on grid electricity, contributing to high operational costs and carbon emissions (Abhishek & Khushavant, 2026; Sharma et al., 2025). This project focuses on the development of an automatic air purification system powered by solar thermal and photovoltaic energy (Ojha et al., 2023; Sharyani et al., 2025). By integrating renewable energy sources with advanced filtration technologies like HEPA and activated carbon, the system aims to provide a self-sustaining, eco-friendly solution for improving indoor and outdoor air quality (Al-Talib et al., 2023; S et al., 2025).

LITERATURE REVIEW

Recent research highlights the effectiveness of combining solar energy with multi-stage filtration. Studies have demonstrated that systems using HEPA and activated carbon filters can achieve purification efficiencies as high as 96%

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while operating for up to 14 hours a day on solar power (Kachare et al., 2026). Innovations in this field include the integration of IoT-enabled monitoring, which uses microcontrollers like Arduino or Raspberry Pi to adjust fan speeds dynamically based on real-time pollutant levels (Abhishek & Khushavant, 2026; Sharyani et al., 2025; Vakharia & Chavan, 2025). Furthermore, some designs utilize solar air heaters or thermal collectors to pre-process air and enhance system efficiency in industrial settings (Ojha et al., 2023; Sharyani et al., 2025). Comparative analyses of filtration materials show that while HEPA filters offer superior particulate capture, materials like polypropylene can serve as cost-effective alternatives for resource-constrained environments (Vakharia & Chavan, 2025).

METHODOLOGY

The development of the system involves several key hardware and software components:

- **Energy Harvesting & Storage:** The system utilizes solar thermal collectors or photovoltaic panels to capture energy, which is stored in sealed lead-acid batteries to ensure continuous operation (Abhishek & Khushavant, 2026; Sharyani et al., 2025).
- **Sensing & Control:** An Arduino or NodeMCU microcontroller serves as the central hub, processing data from MQ series sensors (e.g., MQ135 for air quality, MQ-2 for gas) and DHT11 sensors for temperature and humidity (Abhishek & Khushavant, 2026; S et al., 2025; V et al., 2025).
- **Filtration Stages:** The air is pulled through a three-stage process:
    1. **Pre-filter:** Captures large dust and dirt particles (Kachare et al., 2026).
    2. **HEPA Filter:** Removes 99.97% of fine particulate matter (PM2.5) (Kachare et al., 2026).
    3. **Activated Carbon Filter:** Neutralizes odors and absorbs volatile organic compounds (Kachare et al., 2026; Sharma et al., 2025).
- **Automation:** The system is programmed to activate automatically when pollutant levels exceed a specific threshold, optimizing energy consumption (S et al., 2025; Sharyani et al., 2025).

RESULTS

Experimental evaluations of similar solar-powered prototypes show a high removal efficiency of 90% for PM2.5 and significant reductions in VOC levels (Sharma et al., 2025). Research indicates that solar panel efficiency in such systems can reach approximately 67.37% (Al-Talib et al., 2023). Testing of different filter materials revealed that while three-layer polypropylene fabrics can reach an efficiency of 87.50%, standard HEPA filters consistently provide higher-grade filtration for medical and sensitive environments (Vakharia & Chavan, 2025). The autonomous system successfully maintains purified air levels for extended periods without requiring external power (Kachare et al., 2026).

DISCUSSION

The integration of solar thermal power offers a dual advantage: reducing energy dependency on the grid while promoting environmental sustainability (Sharma et al., 2025; V et al., 2025). Unlike conventional purifiers, this system operates with minimal maintenance and zero operational carbon emissions (Ojha et al., 2023; Sharma et al., 2025). The use of IoT features allows facility managers to monitor air quality remotely via mobile dashboards, making the system ideal for healthcare facilities, dental clinics, and smart homes (Sharyani et al., 2025; V et al., 2025). However, the performance remains tied to solar intensity, suggesting that future iterations could benefit from hybrid power sources or more efficient thermal storage (Sharma et al., 2025; Sharyani et al., 2025).

CONCLUSION

The design and analysis of the solar thermal powered automatic air purification system demonstrate that renewable energy can effectively support high-efficiency air filtration (Joseph, 2024). This project bridges the gap between urban sustainability and public health by providing a scalable solution for air quality management (Sharyani et al., 2025). Future developments will focus on enhancing filtration performance with proprietary filter materials and expanding the IoT framework for larger-scale industrial applications (Sharyani et al., 2025; V et al., 2025).

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