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Solar Powered Air Purifier Integrated With Air Quality Monitoring

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Abstract: Air pollution is a major global environmental and health concern due to rising levels of particulate matter and harmful gases. These pollutants cause serious respiratory and cardiovascular diseases. Conventional air purifiers depend on grid electricity, increasing cost and indirect pollution. This project proposes a Solar Air Purifier with an AQI Monitoring System. A solar panel generates energy, stored in a battery via a charge controller. The system powers a DC fan and a multi-stage filtration unit. It includes a pre-filter, HEPA filter, and activated carbon filter. The HEPA filter removes fine particles with high efficiency, while the carbon filter removes gases and odors. An air quality sensor monitors pollution levels and displays real-time AQI on an LCD. The system is eco-friendly, cost-effective, and suitable for various environments. Experimental results show improved air quality, making it a sustainable solution for healthier living.

Keywords: Solar Air Purifier, Air Quality Index (AQI), Renewable Energy, HEPA Filtration, Activated Carbon Filter, Air Pollution Control and Environmental Monitoring

I. INTRODUCTION

Air quality has become a major concern due to rapid industrialization and urbanization. Harmful pollutants like PM2.5, PM10, CO, NOx, and VOCs degrade air quality. These pollutants cause respiratory, cardiovascular, and other health problems. Indoor air pollution is also significant as people spend most of their time indoors. Dust, smoke, and harmful gases accumulate due to poor ventilation. Air purifiers are commonly used to improve indoor air quality. However, conventional purifiers consume high electrical energy and increase costs. They also depend on non-renewable energy sources, contributing to pollution. This project proposes a solar-powered air purifier with AQI monitoring. It aims to provide an energy-efficient, eco-friendly, and sustainable solution for cleaner air.

Air Quality Index (AQI) Chart

AQI Range	Category	Color Code	Health Impact
0 – 50	Good	Green	Minimal impact on health
51 – 100	Moderate	Yellow	Acceptable; slight discomfort for sensitive individuals
101 – 150	Unhealthy	Orange	Breathing discomfort for sensitive people
151 – 200	Unhealthy	Red	Everyone may begin to experience health effects
201 - 300	Very Unhealthy	Purple	Health alert: serious effects possible
301 – 500	Hazardous	Maroon	Severe health effects; emergency conditions

PROBLEM IDENTIFICATION

Air pollution has emerged as a critical environmental and health issue due to increasing industrialization, urbanization, and the widespread use of fossil fuels. Harmful pollutants such as particulate matter (PM2.5 and PM10), carbon

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monoxide, nitrogen oxides, and volatile organic compounds significantly degrade both outdoor and indoor air quality. These pollutants pose serious health risks, including respiratory diseases, asthma, allergies, and cardiovascular problems. A major concern is indoor air pollution, where pollutants accumulate due to poor ventilation in homes, offices, and public spaces. Although air purifiers are used to address this issue, conventional systems depend on continuous electrical power, leading to high energy consumption and increased operational costs. Furthermore, reliance on non-renewable energy sources contributes to environmental pollution and is not sustainable in the long term.

There is a clear need for an energy-efficient, eco-friendly, and cost-effective air purification system that can operate independently of grid electricity. Additionally, existing systems often lack real-time monitoring of air quality, limiting user awareness of pollution levels.

Therefore, the problem identified is the lack of a sustainable air purification solution that integrates renewable energy with efficient filtration and real-time air quality monitoring to ensure a healthier living environment.

II. LITERATURE REVIEW

M. Reddy et al., 2019 [1] explored the development of a solar-powered ventilation and air purification system for rural and off-grid applications. The system utilized solar panels and battery storage to ensure continuous operation even during low sunlight conditions. Their experimental analysis showed that the system could operate effectively for 6–8 hours using stored energy. The research emphasized the feasibility of solar-based solutions in reducing dependency on conventional electricity sources.

R. Gupta et al., 2019 [2] analyzed the adsorption characteristics of activated carbon filters used in air purification systems. Their research showed that activated carbon can remove up to 70% of volatile organic compounds (VOCs) depending on operating conditions. The study emphasized that combining activated carbon filters with HEPA filters provides a comprehensive solution for both particulate and gaseous pollutant removal.

S. Kumar et al., 2020 [3] investigated the performance of HEPA filter-based air purification systems under various environmental conditions. Their findings revealed that HEPA filters are capable of removing up to 99.97% of airborne particles of size 0.3 microns. The study also analyzed airflow dynamics and pressure drop across the filter, concluding that proper system design and airflow optimization are critical for achieving maximum efficiency. The results confirmed that HEPA filtration remains one of the most reliable methods for particulate removal.

K. Patel et al., 2020 [4] designed and fabricated a low-cost air purifier using a multi-stage filtration approach. Their work focused on optimizing filter arrangement and airflow rate to enhance purification efficiency. Experimental results indicated a reduction of indoor air pollutants by approximately 50% within a short duration. The study concluded that cost-effective designs can still achieve significant air quality improvement.

N. Kumar et al., 2020 [5] have presented the design of an embedded system for real-time air quality monitoring using low-cost sensors. Their system utilized particulate matter sensors to measure PM2.5 and PM10 concentrations and displayed AQI values on an LCD interface. The study demonstrated that continuous monitoring improves user awareness and enables timely action for pollution control. The results indicated that integrating monitoring systems with purification units can enhance overall system efficiency.

A. Das and R. Sen, 2021 [6] conducted a performance evaluation of portable air purifiers in indoor environments. Their experimental study measured pollutant concentration before and after purifier operation under different airflow conditions. The results showed that PM2.5 levels were reduced by more than 50% within 30 minutes of operation. The research emphasized the importance of proper placement and airflow design in achieving maximum purification efficiency.

P. Singh et al., 2021 [7] developed a low-cost air quality monitoring system using embedded microcontrollers and particulate matter sensors. The system was capable of measuring PM2.5 and PM10 concentrations with an accuracy of ±10% compared to standard instruments. The study highlighted the importance of integrating monitoring systems with purification units to provide real-time feedback and improve system performance.

V. Ramesh et al., 2021 [8] investigated the development of an energy-efficient solar air purifier for sustainable applications. Their system demonstrated energy savings of up to 80% compared to conventional electric purifiers. The

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research highlighted the importance of integrating renewable energy with modern air purification technologies to achieve eco-friendly solutions.

D. Perumal et al. (2021) [9] designed an indoor-specific air purification system powered by solar energy. Their model includes an air quality monitor and a portable frame structure, making it suitable for mobility without compromising efficiency. This design improves usability in different indoor environments.

A. Verma and S. Mehta, 2021 [10] proposed a smart air purifier system using IoT-based monitoring and control mechanisms. The system incorporated low-cost air quality sensors to continuously monitor PM2.5 and PM10 concentrations and automatically adjust fan speed based on pollution levels. Their research highlighted that real-time monitoring and automated control improved purification efficiency by approximately 15% compared to conventional systems. The study also demonstrated the benefits of remote monitoring through mobile applications for user convenience and awareness.

III. SYSTEM DESIGN

The system design consists of four major sections: solar power supply unit, air purification unit, AQI monitoring system, and control/display unit.

The solar power supply unit includes a photovoltaic panel, charge controller, and battery. The solar panel converts sunlight into electrical energy, which is stored in the battery for continuous operation. The charge controller regulates voltage and prevents overcharging.

The air purification unit consists of a DC fan and multi-stage filters. The fan draws polluted air into the system, and the filters remove dust, smoke, and harmful gases. The HEPA filter captures fine particles, while the activated carbon filter removes odors and toxic gases.

The AQI monitoring system includes air quality sensors and a microcontroller. The sensor detects PM2.5 and PM10 levels, and the microcontroller processes this data to determine air quality.

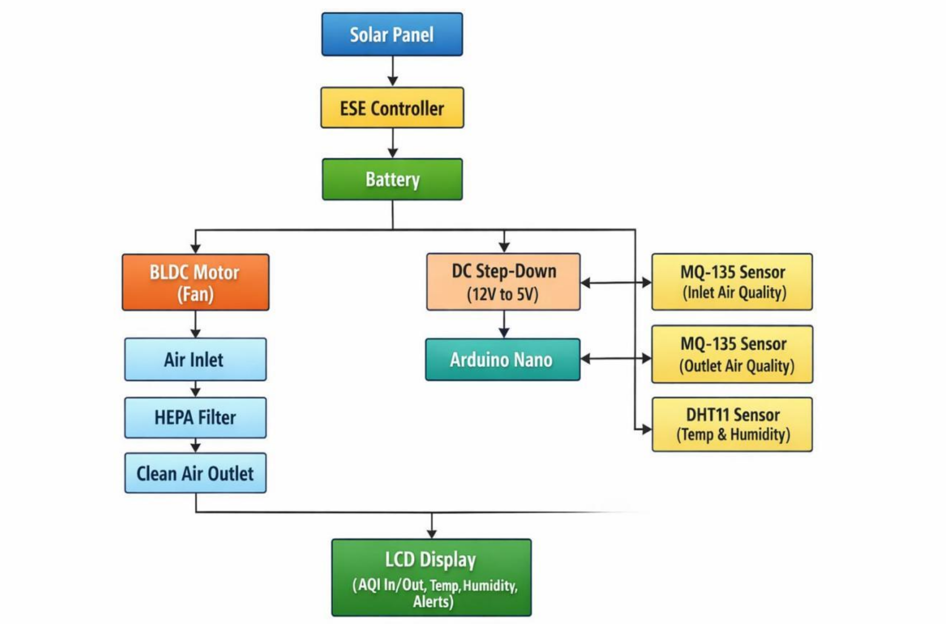

Fig.1: Block Diagram

IV. COMPONENTS DESCRIPTION

The solar panel is the primary power source of the system, converting solar energy into electrical energy using the Photovoltaic Effect. It consists of multiple photovoltaic (PV) cells made from semiconductor materials such as silicon.

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Fig.1 SOLAR PANEL+

4.2 Battery (12V)

The 12V battery is an essential component of the solar air purifier system, responsible for storing electrical energy generated by the solar panel and supplying power to the system when sunlight is not available. It ensures continuous and reliable operation during nighttime, cloudy weather, or fluctuations in solar input.

A battery works on the principle of electrochemical energy storage, where chemical energy is converted into electrical energy through chemical reactions. When the solar panel generates electricity, the battery stores this energy in chemical form. During system operation, the stored energy is converted back into electrical energy and supplied to components such as the microcontroller, sensors, and BLDC motor.

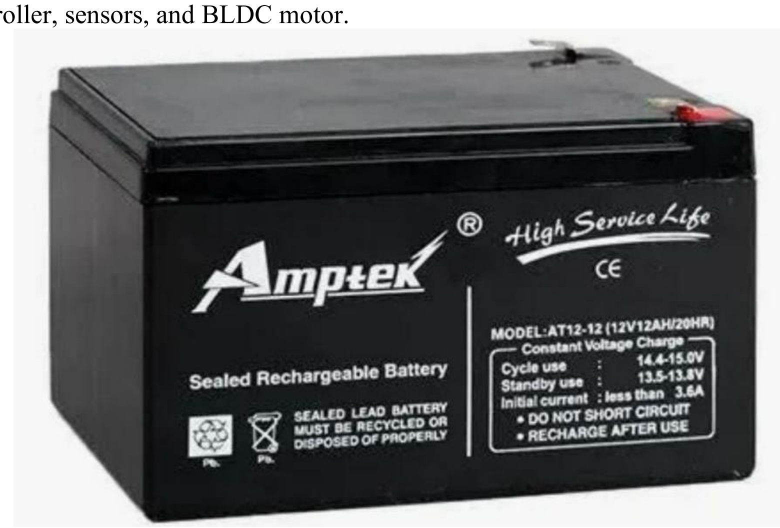

Fig.2: ESE (Energy Saving Equipment controller)

Is an intelligent electronic control unit used to optimize energy consumption and improve the efficiency of electrical systems. In your solar air purifier project, the ESE controller plays a key role in managing power and system performance.

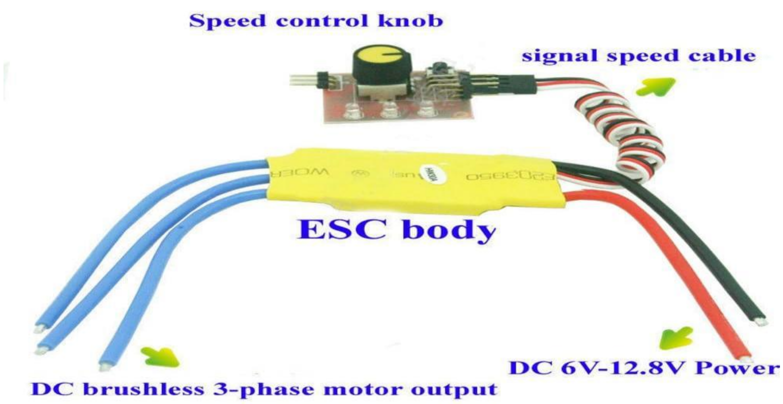

Fig- 4.3 ESE Controller

Fig.3: DC Step-down Converter (12V to 5V)

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A DC step-down 12V to 5V converter (also called a buck converter) is an essential component in your solar air purifier project used to reduce voltage from 12V to 5V safely and efficiently.

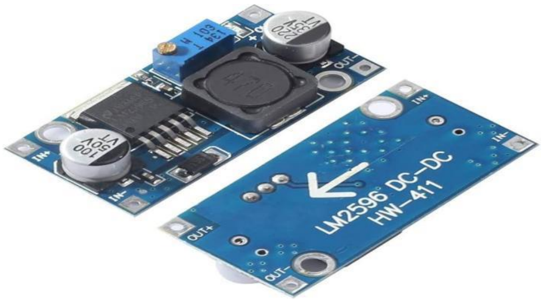

Fig.4; DC Step Down Converter

A HEPA (High Efficiency Particulate Air) filter is a highly efficient air filtration device used to remove very fine particulate matter from air. It plays a critical role in improving indoor air quality by trapping harmful particles such as dust, pollen, smoke, and microorganisms. In modern air purification systems, HEPA filters are considered the core filtration component due to their superior efficiency.

Fig.5: HEPA Filter

The Arduino Nano is the central processing unit (brain) of the solar air purifier system. It is a compact, efficient, and easy-to-use microcontroller board based on the ATmega328 microcontroller. It is widely used in embedded systems and automation projects due to its small size and versatility.

In this project, the Arduino Nano is responsible for receiving input data from various sensors such as the AQI sensor (PM2.5/PM10), MQ-135 gas sensor, and DHT11 temperature and humidity sensor. It processes this data and controls the output devices such as the display unit and, if required, the motor control system.

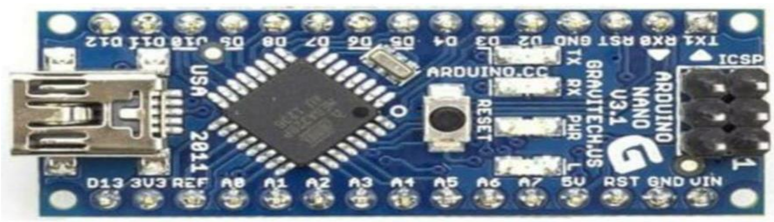

Fig.6: Arduino nano

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The MQ-135 gas sensor is widely used for monitoring air quality by detecting harmful gases present in the environment. It is an important component in the solar air purifier system as it helps measure the concentration of gaseous pollutants that are not captured by particulate sensors like PM2.5/PM10.

Fig.7: Gas Sensor MQ135

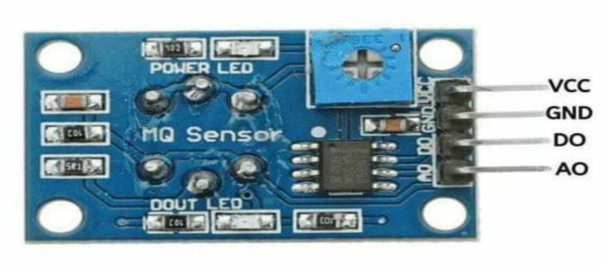

Fig.8: MQ 135 Pin Out

The DHT11 sensor is a low-cost digital sensor used to measure temperature and relative humidity of the surrounding environment. It plays an important role in the solar air purifier system by providing environmental data that affects air quality and system performance.

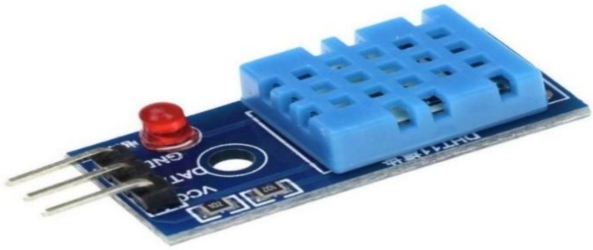

Fig.9: DHT 11 Temperature And Humidity Sensor

4.9 BLDC Motor (1400 kV)

The BLDC (Brushless DC) motor is an important component used in the solar air purifier system to drive the fan for air circulation. It converts electrical energy into mechanical energy, enabling the movement of air through different filtration stages such as pre-filter, HEPA filter, and activated carbon filter.

V. RESULTS AND DISCUSSION

The developed system was tested under indoor environmental conditions using a solar-powered air purifier integrated with air quality monitoring sensors. Two MQ-135 sensors were placed at:

- **Inlet (before filtration)** – to measure polluted air
- **Outlet (after filtration)** – to measure purified air

TIME (min)	Inlet AQI	Outlet AQI	Air Quality Improvement
0	210	210	No purification
5	200	140	Moderate improvement
10	170	110	Good improvement
15	150	60	Clean air achieved

The system continuously displayed:

- Inlet Air Quality Index (AQI)
- Outlet Air Quality Index (AQI)

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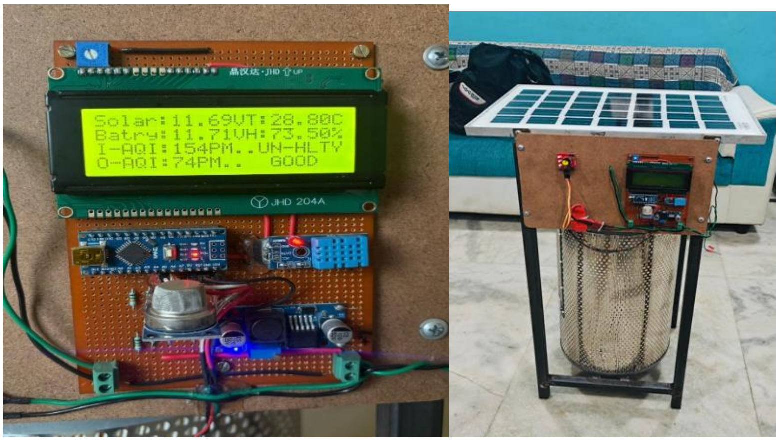
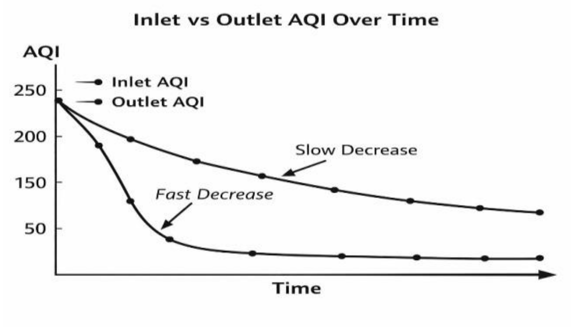


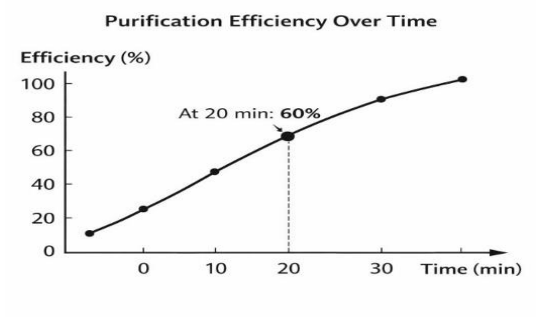
Fig.:10 PROTOTYPE OUTPUT LCD Display showing Air Quality Readings

Graphical Representation

1. Inlet vs Outlet AQI Graph



2. Efficiency Graph



The results clearly show that the system effectively reduces air pollution levels. Initially, both inlet and outlet AQI values were the same, indicating no purification. As the system started operating, the outlet AQI decreased significantly compared to the inlet AQI.

The HEPA filter successfully removed particulate matter, while the continuous airflow ensured steady purification. The reduction in AQI from Hazardous/Unhealthy levels to Moderate/Good levels demonstrates the effectiveness of the system.

VI. CONCLUSION

The project "Solar Powered Air Purifier Integrated with Air Quality Monitoring" successfully demonstrates an eco-friendly, energy-efficient, and intelligent solution for improving indoor air quality. By utilizing solar energy, the system reduces dependency on conventional power sources while ensuring sustainable operation.

A key feature of this system is its ability to monitor both inlet and outlet air quality, allowing for a clear evaluation of purification efficiency. The integration of sensors such as MQ-135 and DHT11 with a microcontroller enables real-time data acquisition and display. The system continuously compares air quality levels and provides instant alerts on the display when pollution levels are high, enhancing user awareness and safety.

The multi-stage filtration process effectively removes dust, smoke, and harmful gases, resulting in a significant improvement in Air Quality Index (AQI). The inclusion of a battery backup ensures uninterrupted performance even during low solar conditions

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