Solar Powered Air Purification and Cooling

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Abstract - This paper presents a pioneering approach to address indoor air quality challenges in urban residential spaces through the integration of solar power and advanced technology. The developed system leverages dual-axis solar tracker technology for efficient energy harvesting and storage, ensuring continuous operation. Automation driven by energy-efficient algorithms orchestrates indoor air filtration using sensors and advanced filters to remove dust and toxic gases effectively. A key innovation is the integration of renewable energy with air purification, contributing to sustainable urban practices and healthier living environments. Central to this system is an intelligent air quality monitoring framework, based on the Arduino Uno microcontroller, facilitating real-time assessment of indoor air quality. Rigorous testing and residential experiments validated the system's capability in accurately monitoring air quality indicators. The findings highlight the potential impact of this system in mitigating the transmission of airborne viruses and pollutants, thereby enhancing indoor air quality significantly. This project represents a crucial step towards creating sustainable and healthier urban living environments.

Key Words: indoor air quality, solar power, air purification, intelligent monitoring, urban sustainability.

1.INTRODUCTION

The Indoor air quality (IAQ) is a critical concern in urban areas, necessitating sustainable and efficient air purification solutions. This project aims to develop an advanced solar-powered air purification and cooling system tailored for urban households. By integrating dual-axis solar tracker technology, the system efficiently harnesses solar energy to power air filtration and cooling processes. This renewable energy approach aligns with global sustainability goals and promotes healthier urban living environments.

Central to this system is an intelligent air quality monitoring system based on the Arduino Uno microcontroller. Rigorous testing and experiments in residential settings validate the system's ability to monitor and improve indoor air quality in real-time. Enhancing IAQ not only benefits overall well-being but also helps mitigate the transmission of airborne viruses and pollutants, contributing to better respiratory health and sustainable urban development.

2. LITERATURE REVIEW

The literature review for our project underscores recent advancements in indoor air quality (IAQ) monitoring and sustainable technologies relevant to solar-powered air purification and cooling systems.

Researchers have developed scalable IoT-based systems for comprehensive indoor pollutant assessment, emphasizing advanced sensor technologies. Cognitive wireless sensor networks have been explored for continuous indoor CO2 monitoring, contributing to health and comfort benefits. Studies have integrated IoT in CO2 monitoring to address health and comfort benefits. Bidirectional indoor monitoring systems have addressed EMI challenges, while a decision support algorithm has been proposed for air quality management. Discussions on indoor humidity's impact on air quality and health have provided valuable insights. Estimates of the global health burden of anthropogenic air pollutants have underscored the critical importance of air quality management for public health and environmental sustainability.

These studies inform our project's design by providing insights into effective sensor integration, IoT applications, and the importance of air quality management for sustainability and human well-being.

3. METHODOLOGY

The methodology for developing the solar-powered air purification and cooling system began with a comprehensive literature review to gather insights into indoor air quality monitoring and renewable energy applications. This review guided the definition of project objectives, emphasizing energy efficiency and addressing challenges related to urban air quality. In the design and development phase, a conceptual system design was formulated, integrating solar panels with air purification components. Virtual simulation using Tinkercad and programming of Arduino UNO facilitated real-time monitoring and validation of the system's functionality. Circuit design focused on integrating electronic systems for precise voltage regulation and sensor interfacing. During fabrication, materials were procured and assembled to ensure system functionality and reliability. Rigorous testing and validation were conducted to evaluate air purification and cooling performance across various conditions. This methodological approach aimed to deliver a sustainable and efficient solution for indoor air quality management using solar power, ultimately contributing to environmental conservation and public health enhancement.

4. MODELLING

The modelling phase of the solar-powered air purification and cooling system project plays a crucial role in designing and optimizing the system's performance. This chapter focuses on two critical aspects essential for designing a solar-powered air purification and cooling system: volume estimation for different room types and specifications for solar panels and batteries. Estimating room volumes helps in planning the layout and capacity of air quality improvement systems within various indoor environments like offices and bedrooms.

4.1. Volume Estimation for Different Room Types

Office spaces and bedrooms vary in size, impacting the volume of air that needs to be treated by the air purification and cooling system. For example, a 100-square-foot office room with an 8-foot ceiling has a volume of 800 cubic feet, while a 300-square-foot office room has a volume of 2400 cubic feet. Similarly, a standard 200-square-foot master bedroom has a volume of 960 cubic feet, and a smaller 100-square-foot bedroom has a volume of 800 cubic feet. Understanding these volumes is crucial for optimizing system placement and performance within indoor environments.

4.2. Solar Panel and Battery Specification

To power the air purification, cooling, and air quality monitoring systems, the required solar panel and battery specifications were calculated based on energy consumption:

- Total Daily Energy Consumption:

The combined power consumption of the systems (Air Purifier: 50W, Air Quality Monitoring: 5W, Air Cooling: 50W) amounts to 105W. With an average operating time of 8 hours, the daily energy consumption is 840 watt-hours (Wh).

- Sizing the Battery System:

A battery capacity of at least 1680 watt-hours (Wh) was determined to provide sufficient energy storage for one day, considering a 50% Depth of Discharge (DoD) for lead-acid batteries.

- Sizing the Solar Panel:

The solar panel, assuming 5 hours of effective sunlight per day, requires a wattage of approximately 168 watts (W) to fully recharge the battery.

These specifications ensure reliable and sustainable operation of the solar-powered system, optimizing energy usage for indoor air quality management and cooling. The modelling approach facilitates efficient system design tailored to specific room sizes and environmental conditions.

5. SYSTEM DESIGN AND WORKING

The primary objective of this project is to develop a sustainable solution for addressing poor indoor air quality in urban environments by integrating efficient air filtration, renewable energy utilization, and real-time air quality monitoring.

5.1. Dual-Axis Solar Tracker

The project incorporates a dual-axis solar tracker system designed to enhance solar panel efficiency by continuously orienting them for optimal sunlight exposure throughout the day. This system employs sensors and actuators to adjust solar panel positions along both horizontal and vertical axes, ensuring maximum energy capture.

5.1.1. Block Diagram

A detailed block diagram in Fig-1, illustrates the functioning of the dual-axis solar tracker system, highlighting key components such as solar panels, servomotors, Light Dependent Resistors (LDRs), Arduino UNO, battery, and step-down rectifier. The system optimizes solar panel positioning based on real-time sun tracking data to maximize solar energy absorption.

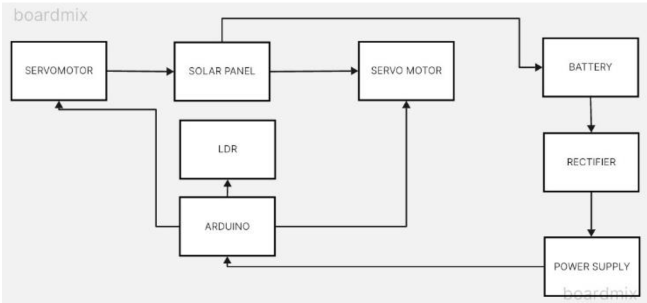

Fig-1: Dual – axis solar tracker block diagram

- Solar Panel: Converts sunlight into electricity.
- Servomotor: Controls solar panel positioning.
- LDR Sensor: Detects sunlight for sun tracking.
-Arduino UNO: Controls and optimizes solar panel orientation.
- Battery: Stores energy for system operation.
- Step-Down Rectifier: Converts higher DC input voltage to a lower DC output suitable for Arduino operation.

5.2. Air Purification and Cooling System

Another key aspect of the project is the integration of an air purification and cooling system to improve indoor air quality and regulate indoor temperatures.

5.2.1. Block Diagram

The block diagram in Fig.2 illustrates the functioning of the air purification and cooling system, highlighting components like Arduino UNO, sensors (LM 35, MQ 135, PM Sensor), relays, fans (cooler fan, exhaust fan), battery, and HC-05 Bluetooth module. This system continuously monitors environmental conditions and controls air quality parameters based on sensor data.

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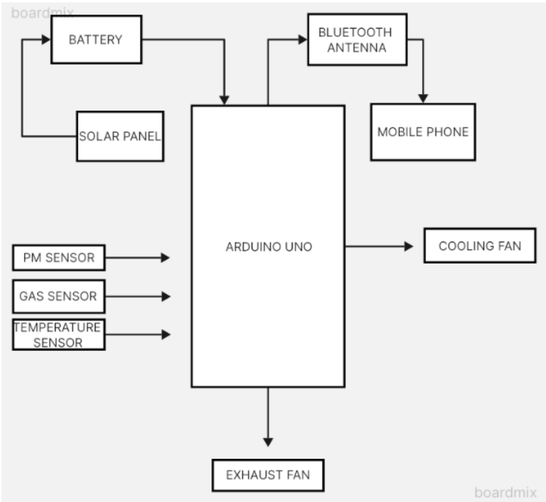

Fig-2: Air Purification and ooling block diagram

- Exhaust Fan: Removes unwanted air, moisture, and odors.
-LM 35 Temperature Sensor: Measures ambient temperature.
- MQ 135 Gas Sensor: Detects various gases for air quality monitoring.
-PM Sensor (GP2Y1010F4Z): Measures dust and particulate levels.
- 4-Channel Relay: Controls fan operation based on sensor data.
- Cooler Fan: Provides air circulation and cooling.
-HC-05 Bluetooth Module: Enables wireless communication for data monitoring and control.

5.3. User Interface

The project incorporates a user-friendly mobile application, "Serial Bluetooth Terminal," for monitoring indoor air quality in real-time. This app allows users to visualize indoor temperature, gas and dust levels, and external air toxicity metrics, empowering them to take proactive measures for maintaining healthy indoor environments.

6. SIMULATION

Simulation plays a critical role in the development of a dual-axis solar tracker, allowing for thorough evaluation and optimization of system performance under diverse environmental conditions. By utilizing simulation tools like Tinkercad, we can refine the tracker's design and control algorithms without the need for expensive physical prototypes.

6.1. Dual – Axis Solar tracker

Key observations from the simulation include the accurate detection of the sun's position using Light Dependent Resistors (LDRs), precise tracking along both azimuth and elevation axes for optimal solar panel orientation, integration of Arduino UNO for sensor data processing and tracker control, and continuous adjustment of solar panel angles to maximize exposure to sunlight throughout the day. Fig.3 shows the simulation of dual – axis solar tracker. These insights obtained through simulation guide the refinement and validation of the dual-axis solar tracker system, enhancing its performance and reliability in real-world applications.

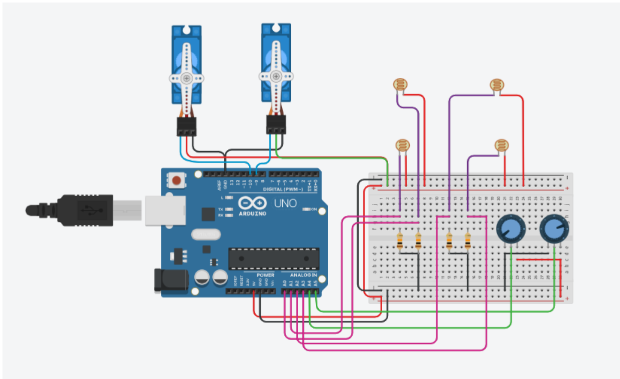

Fig-3: Dual – axis solar tracker simulation diagram

6.2. Air Purification and Cooling System

Simulation is essential for optimizing air purification and cooling systems for indoor comfort and health. It enables modelling of different system configurations and performance parameters before implementation, aiding in energy efficiency assessment and control strategy testing. Fig.4 shows the simulation of air purification and cooling system. The simulation observations show specific system responses based on indoor conditions: at 25°C-30°C, the green LED lights up with F2 and F4 active; above 30°C, the red LED illuminates with F1 and F3 active. High indoor gas or particulate levels trigger the red LED and buzzer, activating F1 and F3. Elevated indoor and outdoor gas levels lead to similar activations. Normal gas and particulate levels activate F2 and F4.

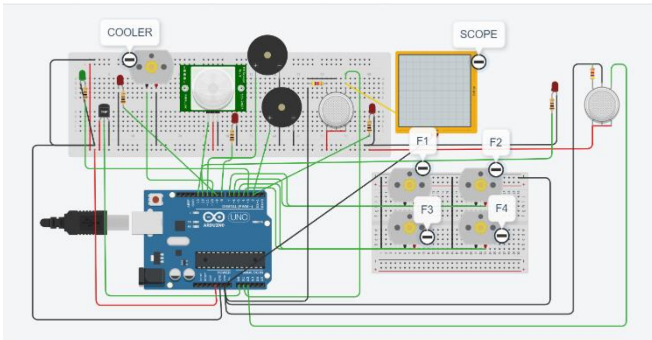

Fig-4: Air purification and cooling simulation diagram

7. IMPLEMENTATION

This focuses on the practical implementation of two core components within the project: the solar tracking system and the air purification system. The solar tracking system was designed to optimize the orientation of a 12V 5W solar panel using Light Dependent Resistors (LDRs) and servo motors controlled by an Arduino board. Simultaneously, the air purification system integrates sensors for pollutant detection, particulate matter measurement, and temperature monitoring, along with a fan control system for air circulation regulation.

7.1. Solar tracking system

The solar tracking system was implemented to optimize the orientation of a 12V 5W solar panel for maximum sunlight exposure. A 200 by 100mm plywood base securely held the solar panel, equipped with four strategically placed Light Dependent Resistors (LDRs) to measure sunlight intensity.

Each LDR was connected to specific analog pins on an Arduino board for accurate readings. Servomotors controlled by the Arduino adjusted the solar panel's azimuth and elevation based on LDR data. A custom solar tracking algorithm calculated optimal panel angles throughout the day, fine-tuned through calibration tests. Solar energy harvested was used to charge a battery, ensuring continuous system operation and autonomous functionality. This comprehensive setup enabled efficient solar energy utilization and sustainable performance of the tracking system.

7.2. Air purification and cooling system

The implementation of the air purification and air-cooling systems involved systematic setup and integration for enhanced indoor air quality and temperature regulation.

For the air purification system, sensors including gas, dust, and temperature sensors were installed and connected to an Arduino board for monitoring indoor air quality. The prototype room was divided into filtered (Chambers 1 and 3) and non-filtered (Chambers 2 and 4) areas with corresponding air intake and exhaust fans controlled by the Arduino. Indicator LEDs and a buzzer provided real-time alerts based on sensor thresholds, ensuring effective air quality management.

Simultaneously, the air-cooling system utilized strategically placed fans within the chambers to manage airflow and maintain comfortable indoor conditions. Arduino programming monitored temperature data to activate the cooling fan as needed, optimizing indoor temperature regulation based on sensor readings.

Extensive testing validated system performance and integration, ensuring comprehensive indoor air quality management and user comfort enhancement within the project setup.

7.3. *User interface*

Following individual component implementations, our project advanced to system integration and testing to assess overall performance. We implemented real-time data monitoring using the HC-05 Bluetooth module for continuous sensor data transmission to a mobile app. Comprehensive testing evaluated responsiveness, energy efficiency, and indoor air quality improvement. We also prioritized developing a user-friendly interface for intuitive system control and monitoring, enhancing user experience and accessibility. This phase was crucial for refining our solution and ensuring its effectiveness.

8. RESULT

A solar-powered air purification and cooling system achieved significant milestones across its key components. Integration of a dual-axis solar tracker optimized solar panel orientation, maximizing energy capture throughout the day. This enhancement led to increased energy efficiency and overall system performance by ensuring maximum exposure to sunlight. For air purification, the system utilized sensors including the LM35 for temperature, MQ135 for gas detection, and PM Sensor for particulate matter assessment. Real-time data processing enabled dynamic control of fans to maintain optimal air quality levels, effectively removing pollutants and contaminants from indoor environments. Additionally, the cooling system regulated indoor temperatures using cooler and exhaust fans, ensuring comfortable conditions during fluctuating climates. The Arduino UNO served as the central control unit, processing sensor data and executing control algorithms to optimize air quality and energy utilization based on real-time inputs. Extensive testing validated the system's reliability and responsiveness under various environmental scenarios, highlighting its potential as a sustainable solution for indoor air quality management and energy-efficient cooling.

9. CONCLUSION

The solar-powered air purification and cooling system designed for urban households offers a cutting-edge solution to enhance indoor air quality. By integrating dual-axis solar tracker technology, energy-efficient automation, and intelligent air quality monitoring with the Arduino Uno microcontroller, this system addresses the urgent need for cleaner, sustainable living environments in urban areas. Real-time filtration of indoor air from dust and toxic gases not only improves resident well-being but also supports the global transition to renewable energy sources. Extensive testing confirms the system's reliability in monitoring air quality indicators across diverse residential settings. This research is poised to significantly impact public health by reducing airborne virus transmission and pollutants, promoting a healthier urban living experience. Through sustainable innovation, this system exemplifies how technology can contribute to a cleaner, safer, and more environmentally conscious future for urban households.

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Appendix 1: Datasheet of Arduino UNO R3

Microcontroller:
- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Input Voltage (limits): 6-20V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- Analog Input Pins: 6
- DC Current per I/O Pin: 40 mA
- DC Current for 3.3V Pin: 50 mA
- Flash Memory: 32 KB (0.5 KB used by bootloader)
- SRAM: 2 KB
- EEPROM: 1 KB
- Clock Speed: 16 MHz

Power:
- The board can be powered via the USB connection or with an external power supply.
- The power source is selected automatically.
- The external power supply can be 7-12V (recommended) or 6-20V (limits).

Other Features:
Reset Button: Used to reset the microcontroller.
Operating Temperature: 0°C to 85°C
Dimensions: 68.6mm x 53.4mm

Appendix 2: Datasheet of HC-05 Bluetooth Antenna

Key Features:

- Bluetooth v2.0+EDR (Enhanced Data Rate) compliant.

- Frequency: 2.4GHz ISM band.

- Modulation: GFSK (Gaussian Frequency Shift Keying).

- Profiles: Bluetooth Serial Port Profile (SPP).

- Default baud rate: 9600 bps (adjustable).

- Operating Voltage: 3.3V DC.

- Range: Typically, up to 10 meters.

Pin Configuration:

The HC-05 module typically has 6 pins:

- VCC: 3.3V power supply.

- GND: Ground.

- TXD: Transmit Data (from module).

- RXD: Receive Data (to module).

- STATE: Status indicator (connected/not connected).

- EN (or KEY): Enable pin for switching between AT mode and communication mode.