

MULTI- FUNCTIONAL AIR POLLUTION TREATMENT DEVICE

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Abstract:

This paper presents the design and development of a multifunctional air pollution treatment device capable of removing dust, odors, airborne pollutants, and bacteria, while also regulating air temperature seasonally—cooling in summer and heating in winter. The device integrates multiple air treatment technologies, including HEPA filtration for particulate removal, UV light for sterilization, activated carbon for pollutant removal, water mist for cooling, and air heating for winter. Experimental results show the system achieves a PM_{2.5} filtration efficiency of up to 99.97%, a bacterial sterilization efficiency of 95%, and a VOC removal efficiency of 90%, while effectively maintaining seasonal air temperature balance. With its versatile operation and high efficiency, this device has significant potential for real-world applications, particularly in households, offices, hospitals, and other enclosed environments.

Keywords: HEPA filtration; UV sterilization lamp; activated carbon; air treatment; water mist cooling; drying device.

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INTRODUCTION

As reported by the World Health Organization (WHO), air pollution and exposure to poor air quality are currently the biggest environmental threats to public health globally (González-Martín, Kraakman, Pérez, Lebrero, & Muñoz, 2021). Recent research on human exposure to indoor pollution suggests that indoor environments may be at least twice as contaminated as outdoor ones. In fact, the air in a living room may be more polluted than the air on an urban street with normal traffic. Historically, outdoor air pollution has received more attention, particularly in areas with heavy traffic or significant industrialization. However, with buildings becoming more sealed off from the outside world to save energy on heating and cooling, the dangers of prolonged exposure to indoor air pollution have become a growing concern in recent years (Guerreiro, 2013).

Indoor air contains both pollutants from outside sources and those specific to interior environments. Because indoor and outdoor pollution have different sources, compositions, and concentrations, it is difficult to generalize the effects of indoor air pollution based on studies of outdoor air pollution (Raju, Siddharthan, & McCormack, 2020). The majority of people on the planet live in cities and work in offices, and humans spend the majority of their time indoors (Al Horr *et al.*, 2016). Given that most people spend 90% (Tran, Park, & Lee, 2020) (Arif, Katafygiotou, Mazroei, Kaushik, & Elsarrag, 2016) (Frontczak & Wargocki, 2011) (Schweizer *et al.*, 2007) of their time indoors, in interior spaces, both public and private, including homes, gyms, schools, workplaces, and automobiles,...(Cincinelli & Martellini, 2017); mostly at home or at work—indoor environmental factors play a significant role in human well-being. Poor indoor air quality has recently been identified as a priority issue harming children's health, and it is considered one of the major national environmental hazards by the United States Environmental Protection Agency (González-Martín *et al.*, 2021). Because individuals spend so much time indoors, their exposure to different air contaminants is probably larger than their exposure to the outdoors (Colbeck & Nasir, 2010).

Particulate matter, biological pollutants (such as mold, fungi, spores, bacteria, and allergies), physical agents (such as temperature and electromagnetic fields), and more than 400 distinct chemical compounds—mostly volatile organic and inorganic compounds, or VOCs and VICs, respectively—are examples of indoor air pollutants. More recently, interior settings have been found to contain organic emergent compounds that are released from plastics, medications, or personal care items. Apart from the diverse range of indoor pollutants,

their prevalence and concentration are influenced by numerous elements, including outside air quality, the nation's socioeconomic progress, activity types, occupancy, environmental circumstances, time of year, etc. Furthermore, the sources and rates of pollution change quickly throughout time (Luengas *et al.*, 2015). NOx, volatile and semi-volatile organic compounds (VOCs), SO₂, O₃, CO, PM, radon, hazardous metals, and microbes are the main types of indoor air pollutants (Tran *et al.*, 2020). While the intrusion of outdoor pollutants is obviously dependent on human activities (road traffic, industry, etc.), endogenous sources include both permanent (building materials, adhesives, paints, varnishes, etc.) and occasional (furniture, cleaning and disinfection products, cooking, personal care products, human metabolism, etc.). Furthermore, indoor gas-phase interactions from other indoor airborne chemicals may result in secondary pollutants (Scher, 2007). One of the leading causes of death in our day and age is air pollution. 6.4 million fatalities worldwide were attributed to contaminated air in 2015 (Landrigan, 2017). The World Health Organization (WHO) estimates that indoor air pollution (IAP) kills 3.8 million people every year (Tran *et al.*, 2020).

Indoor environmental quality (IEQ) has a major effect on productivity, well-being, and human health (Deng, Dong, Guo, & Zhang, 2024). Currently, various indoor air purification devices are available on the market, but most of them focus on addressing a single pollutant type, such as dust filtration, odor removal, or disinfection. However, in real-world environments, indoor air pollution is caused by multiple factors simultaneously, necessitating a more comprehensive solution. This issue is particularly severe in factories, restaurants, offices, public restrooms, and enclosed spaces, where pollution levels can be significantly high, yet no existing devices provide an all-in-one solution for air treatment.

In response to this challenge, this study shows the design of a multi-functional air treatment device, capable of simultaneously eliminating dust, odors, bacteria, and toxic gases, while also integrating seasonal air temperature regulation functions (cooling in summer and heating in winter). The system is equipped with remote monitoring features, enhancing operational efficiency and air quality management. Initially, the device is intended for use in residential and small commercial spaces, with future expansion into industrial applications for performance evaluation in larger-scale environments.

This research aims not only to improve indoor air quality in residential and occupational settings but also to contribute to sustainable development goals, public health protection, and the reduction of respiratory and

cardiovascular diseases, ultimately enhancing the overall quality of the living environment.

RESEARCH SUBJECT AND METHODOLOGY

Research subject

The present study shows a multi-functional air treatment device, which integrates various air purification and thermal control technologies to regulate indoor air quality effectively. The system combines multiple air treatment methods, including dust filtration, odor removal, bacterial disinfection, toxic gas absorption, cooling, and heating, to create a comprehensive air management solution. Integrating seasonal air temperature regulation, including cooling during summer and heating during winter. Enhancing operational efficiency and adaptability for various applications, including residential, commercial, and industrial environments.

Research methodology

To achieve the research objectives, the following methodologies are employed:

- Experimental Methods: Conducting laboratory and real-world tests to assess the performance of individual components (HEPA filter, UV sterilization, activated carbon adsorption, mist cooling, and heating).
 - Observational Methods: Monitoring indoor air quality before and after deploying the air treatment system in different environments.
 - Simulation and Modeling: Using computational fluid dynamics (CFD) and air quality modeling software to optimize system performance.
 - Analytical Calculations: Evaluating energy consumption, filtration efficiency, and pollutant removal effectiveness based on empirical data.
 - Verification and Validation: Comparing test results with environmental standards and previous studies to ensure accuracy and reliability.
- This research aims to develop an efficient and adaptable air purification system that meets modern air quality standards while being energy-efficient and cost-effective for widespread use.

Device structure

Overview of the device

This study introduces a multi-functional air treatment device that integrates various air purification and conditioning technologies (Fig. 1). The system is designed to eliminate multiple air pollutants present in indoor environments, ensuring cleaner, healthier air for human habitation.

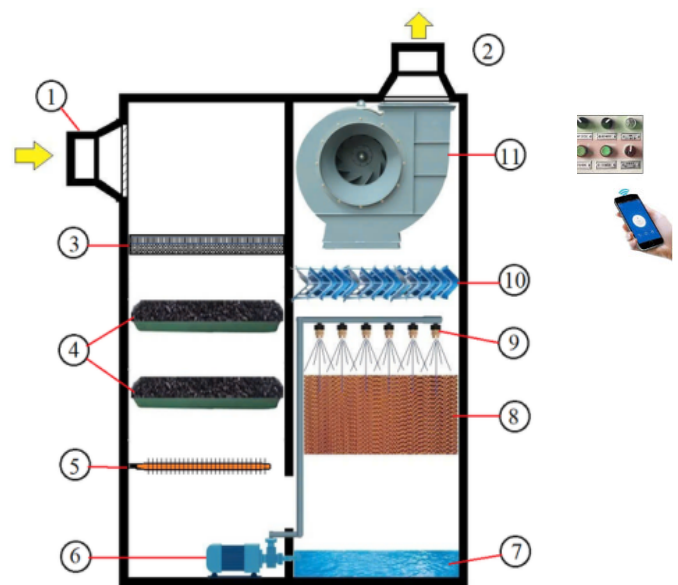
The device is engineered to handle a broad spectrum of air contaminants, including particulate matter (PM2.5, PM10), odors, bacteria, volatile organic compounds (VOCs), and harmful gases. Additionally, it incorporates temperature regulation functions, providing cooling in summer and heating in winter.

Key technical specifications include: (1) Maximum airflow capacity: 520 m³/h, ensuring efficient air circulation. (2) Static pressure: 328 Pa, allowing effective air filtration and pollutant removal. (3) Adjustable operation settings, enabling users to customize air treatment levels based on environmental conditions and specific air quality requirements.

The system combines multiple treatment technologies into a single compact unit, designed to be energy-efficient, easy to maintain, and highly adaptable for residential, commercial, and industrial applications.

The device is equipped with an automatic monitoring system and can be remotely controlled via a mobile application. This integration allows users to track real-time air quality parameters and adjust operating modes as needed.

With smart sensors, the system can detect air pollutants, humidity levels, and temperature fluctuations, enabling automatic adjustments to optimize performance. The remote control function ensures convenient operation, allowing users to switch between different air treatment modes from anywhere, enhancing user experience and energy efficiency.



- | | |
|----------------------|---------------------------|
| 1 - Air inlet | 7 - Water tray |
| 2 - Air outlet | 8 - Contact equipment |
| 3 - HEPA equipment | 9 - Water nozzle |
| 4 - Activated carbon | 10 - Water barrier device |
| 5 - Drying equipment | 11 - Air fan |
| 6 - Water pump | |

Fig. 1. Structure of the air treatment device

HEPA Filtration System

The HEPA (High-Efficiency Particulate Air) (Fig. 2) filter operates based on three primary mechanisms:

- Inertial Impaction: Larger particles tend to continue moving due to inertia and collide with the filter fibers.
- Diffusion: Smaller particles are affected by Brownian motion, increasing their probability of coming into contact with and being captured by the fibers.

- Interception: When a particle moves close to a fiber, it gets trapped due to Van der Waals forces.

Irving Langmuir, a Nobel Prize-winning chemist, claims that the hardest particles to filter are those with a diameter of about 0.3µm. For particles of this size, HEPA filters are therefore made to have a minimum efficiency of 99.97% (Sharma, Munawar, & Kozman, 2013).

In this multi-functional air treatment device, the HEPA filter used has dimensions 310 × 285 × 25 mm, specifically tested for PM2.5 and PM10 particle removal efficiency. This ensures optimal filtration of fine dust and airborne pollutants, significantly improving indoor air quality.



Fig. 2. HEPA filtration device

Activated Carbon Pellets

The device utilizes two trays of SPAC-tablet activated carbon pellets, which are cylindrical in shape, with a length ranging from 2 to 4 mm and a diameter between 3 and 3.36 mm (Fig. 3). The primary function of activated carbon in this system is to:

- Adsorb toxic gases, such as carbon monoxide (CO), sulfur dioxide (SO₂), nitrogen oxides (NO_x), and ozone (O₃).
- Eliminate unpleasant odors, including those from cooking, smoke, and industrial emissions.
- Remove volatile organic compounds (VOCs), commonly emitted from paints, solvents, cleaning agents, and building materials.

Activated carbon is widely used due to its high surface area and strong adsorption capacity, effectively trapping and neutralizing pollutants. The SPAC-tablet



Fig. 3. SPAC-Tablets Activated Carbon

format enhances gas absorption efficiency, ensuring cleaner and fresher air in enclosed environments.

Water Mist Cooling System

The water mist cooling system is designed to reduce air temperature during hot seasons by utilizing a fine mist spray to absorb heat from the surrounding air. The system operates similarly to an absorption device (Fig. 4), allowing for flexibility in using different cooling liquids. Key Functions:

- Air Cooling: The fine mist evaporates quickly, drawing heat from the air and effectively lowering the temperature.
- Pollutant Absorption: The water mist captures and dissolves air pollutants such as dust, particulate matter (PM), and certain gases (SO₂, NO_x, VOCs).
- Humidity Control: Helps increase humidity in dry conditions, improving air quality and comfort.

The system includes a cooling pad to enhance heat exchange efficiency and is powered by a DC 12V pump with a flow rate of 8 L/min and a pressure range of 4-5 meters. Users can adjust operational parameters to optimize cooling performance based on environmental conditions.

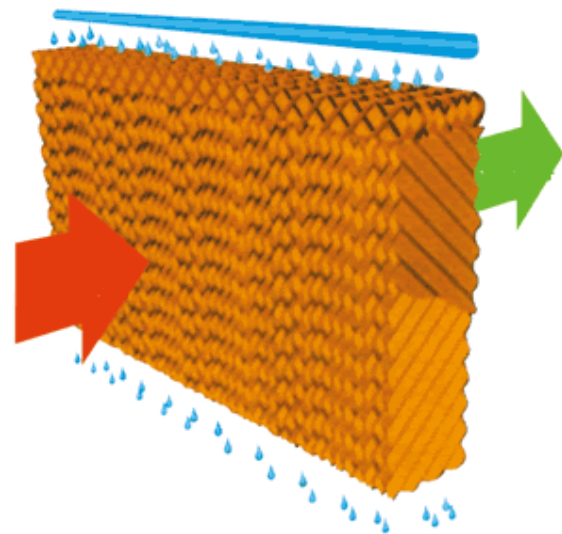


Fig. 4. Absorption - cooling device

The device includes a cooling pad to enhance heat exchange between water and air. Water is supplied by a 12V DC pump with a flow rate of 8 L/min and a pressure of 4–5 meters. The operating parameters can be adjusted during operation.

Air sterilization using UV light

The UVC device (Fig. 5) is a germicidal technology that emits UVC radiation onto surfaces or directly into the air. Airflow exposed to UVC rays undergoes sterilization due to the ability of UVC to eliminate harmful substances, bacteria, and viruses. The device not only disinfects incoming air before it enters the room but also eliminates microbial accumulation within the system. It operates at a power of 34W with a wavelength of 185 nm.



Fig. 5 UVC Sterilization device

Air Heating Device

The heating device utilizes a 220V U-shaped electric (Fig. 6) resistance element with a power rating of 1500W, equipped with heat dissipation fins. It is designed to warm the air during winter.



Fig. 6 U-Shaped heating element

Automatic air quality monitoring device

The automatic air quality monitoring device (Fig. 7) displays nine key indoor parameters, including HCHO, TVOC, PM2.5, PM10, CO, CO2, temperature, and humidity. The results are connected via Wi-Fi and displayed on a smartphone for real-time monitoring.



Fig. 7. Automatic gas monitoring device

Operation via mobile device

The device can be remotely controlled via a smartphone, allowing users to monitor operating modes and set appropriate operation schedules (Fig. 8). This ensures optimal environmental treatment efficiency while maximizing energy savings.



Fig. 8 Device control via mobile phone

Experimental Procedure

The air treatment device model was placed in a sealed room with an area of 12m², a height of 3.3m, and a total volume of approximately 40m³. Before the device was activated, the concentrations of air pollutants were measured and recorded as a baseline for evaluation. The device was then switched on and operated continuously throughout the experiment. Air quality data, including fine particulate matter (PM2.5, PM10), formaldehyde (HCHO), total volatile organic compounds (TVOC), carbon monoxide (CO), and carbon dioxide (CO₂), were recorded at 3-minute intervals. This process allowed for continuous monitoring of pollutant concentration variations over time, enabling an accurate assessment of the device’s air purification efficiency.

RESULTS AND DISCUSSION

Evaluation of Processing Speed and Treatment Efficiency

Pollutant concentrations were measured over time to determine the reduction in contaminant levels within the sealed room. The recorded results are presented as follows (Fig. 9):

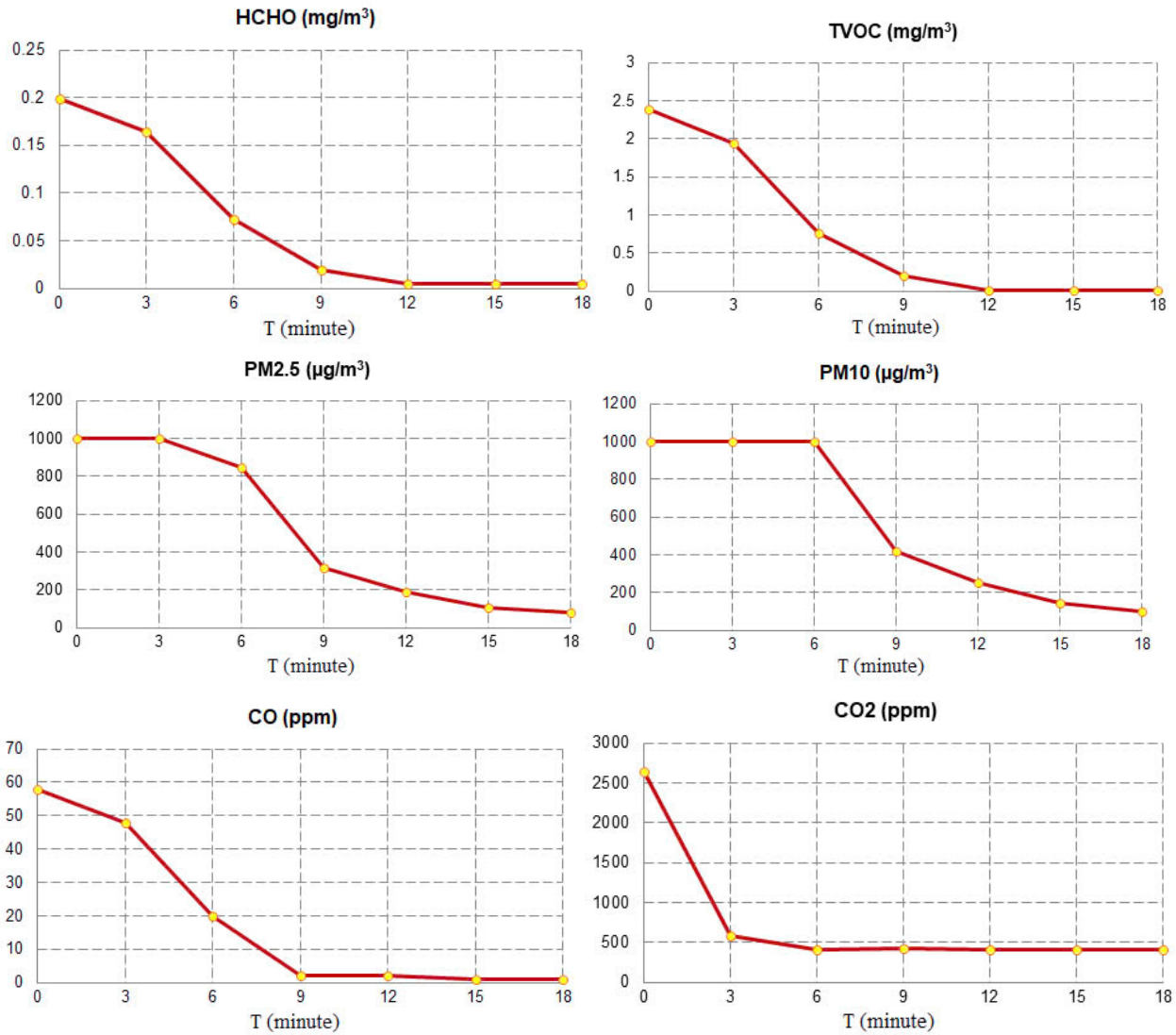


Fig. 9 Measured treatment efficiency over time.

Table 1. Device processing speed in the room

Pollutant Factor	First concentration	Last concentration	Time (minute)
CHCO	200	100	5
TVOC	2391	500	7
PM2.5	>999	50	19
PM10	>999	100	19
CO	58	9	9
CO2	2648	1000	3

Due to the measurement device's limitation in detecting extremely high particulate concentrations, it consistently displays the maximum value when pollutant levels exceed its detection range. However, the concentrations of other pollutants are accurately recorded.

The summarized results, which determine the processing time required to reduce pollutant concentrations from their peak levels to the permissible limits (as specified in TCVN 13521:2022 – Residential

and public buildings – Indoor air quality parameters), are presented in **Table 1**.

These results indicate that the highest treatment speed was observed for gaseous pollutants, with a processing time of approximately 9 minutes. For particulate matter, the treatment time was around 19 minutes. The processing duration depends on the initial concentration of pollutants in the room. However, the findings demonstrate that the device effectively reduces pollutant levels to acceptable thresholds for human occupancy within a relatively short period.

Evaluation of Device Treatment Efficiency

The pollutant concentrations at the device's inlet and outlet were measured under the same conditions in the 12m² room. The results are presented in the following **Table 2**. The results indicate that the overall efficiency of the device is remarkably high, with particulate matter removal reaching approximately 99.7% and other gaseous pollutants exceeding 90%. This efficiency is

Table 2. Device Treatment Efficiency

Pollutant Factor	First concentration	Last concentration	η (%)
CHCO	200	6	97.0%
TVOC	2391	14	99.4%
PM2.5	5000	15	99.7%
PM10	5000	19	99.6%
CO	58	6	89.7%
CO2	2648	407	84.6%

dependent on the initial concentration of pollutants, which is determined by the emission source.

Evaluation of air environment regulation capability

Experiments were conducted by operating the cooling system during the hottest midday period and the heating system on the coldest day of the test period to assess the effectiveness of the air regulation devices.

Measurement results showed that the water mist cooling system reduced the air temperature from 31°C to 26.5°C after 10 minutes of operation, while increasing humidity from 58% to 90%. Meanwhile, the heating device raised the room temperature from 23°C to 27°C within 7 minutes, effectively warming the space during winter conditions.

Practical applications of the device

+ Applicability in various environments

Implementation in diverse living and working spaces. The air treatment device can be widely deployed in various environments, including households, office spaces, hospitals, and manufacturing facilities. In residential and office settings, the device helps maintain stable air quality, minimizing the risks of air pollution caused by fine dust (PM2.5, PM10), bacteria, viruses, and volatile organic compounds (VOCs), thereby creating a cleaner and healthier indoor environment. For hospitals and medical facilities, where sterile conditions are crucial, the device can reduce the risk of cross-contamination through its high-efficiency UV sterilization and particulate filtration technologies. In industrial and manufacturing environments, the device enhances working conditions by effectively removing dust, exhaust gases, and harmful pollutants, contributing to compliance with occupational safety standards and improving workers' health and well-being.

The device is commonly used to treat polluted air in enclosed spaces. Polluted air, when processed through the device, returns as clean air to the room. Therefore, this device can be applied in various functional spaces such as kitchens, manufacturing areas, and laboratories (Fig. 10). It is also effective in odor removal from restrooms, especially public restrooms where odors are

generated continuously and in large amounts (Fig. 11). Additionally, the device is suitable for cleaning the air in smoking rooms, ensuring that cigarette smoke pollution does not spread outside while providing a healthier environment for those smoking inside (Fig. 12). Furthermore, the device can be used to filter outdoor air to supply fresh air to rooms, ensuring proper ventilation and maintaining the desired room temperature (Fig. 13).

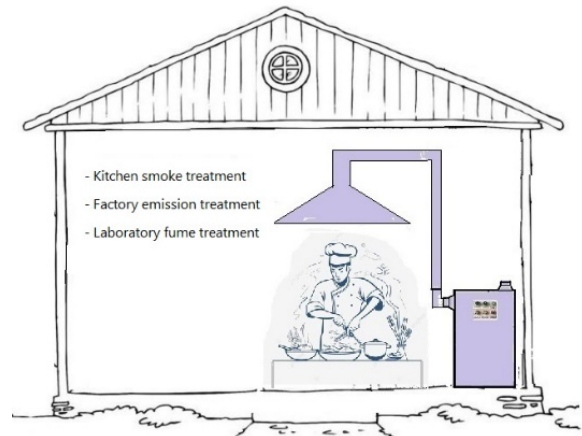


Fig. 10. Kitchens, manufacturing facilities, and laboratories

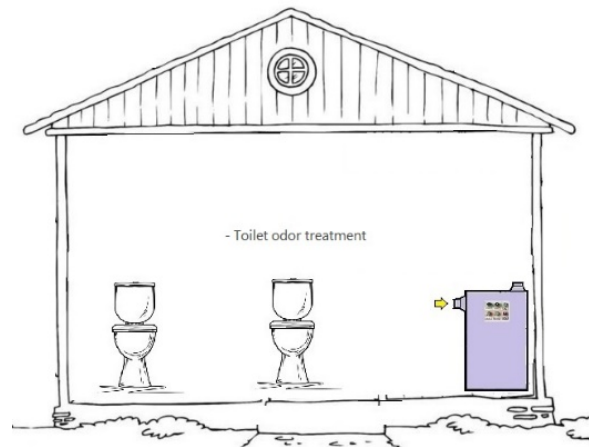


Fig 11. Restroom odor control

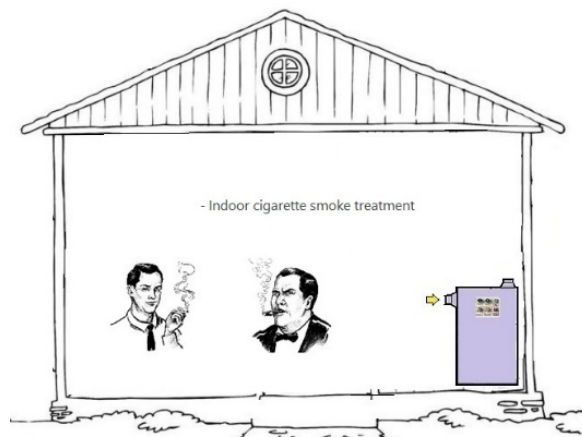


Fig 12. Smoking room air purification

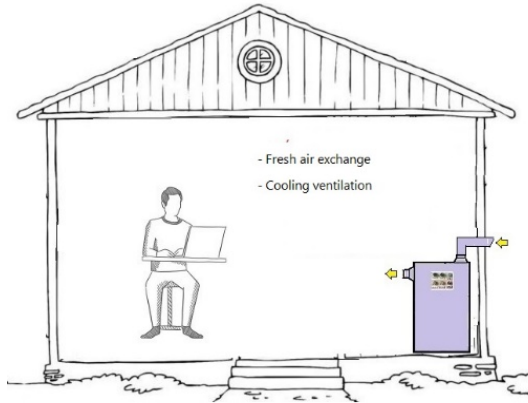


Fig 13. Outdoor air filtration for fresh air supply

High Efficiency in Enclosed Spaces. One of the key advantages of the device is its ability to operate efficiently in enclosed environments where natural ventilation is limited. In spaces such as sealed rooms, basements, storage areas, laboratories, or small spaces with few windows, concentrations of fine dust, bacteria, and harmful gases can quickly increase due to poor air circulation. By integrating multiple air treatment technologies, including HEPA filtration, activated carbon adsorption, and UV sterilization, the device effectively removes airborne pollutants. Additionally, its water mist cooling system in summer and air heating function in winter enhance user comfort, creating a more pleasant living and working environment, especially in areas without air conditioning or a complete HVAC system.

+ Energy Efficiency and Environmental Benefits

Energy Savings Compared to Air Conditioners. One of the significant advantages of the device is its substantially lower energy consumption compared to conventional air conditioning systems, achieving a reduction of 50% to 70% in energy use. This efficiency is made possible by integrating advanced air treatment technologies, such as water mist cooling, which replaces energy-intensive air conditioning. Additionally, the device contributes to sustainable development goals by reducing greenhouse gas emissions and aligning with energy-saving and environmental protection standards.

Enhancing Indoor Air Quality and Workplace Productivity. The device not only improves air quality but also has a positive impact on human health and work efficiency. In enclosed environments, poor air quality can lead to respiratory irritation, allergies, reduced concentration, and lower productivity. By removing fine dust, bacteria, viruses, and airborne pollutants, the device helps minimize health risks associated with indoor air pollution. Moreover, its seasonal air regulation capability, including cooling in

summer and heating in winter, creates a more comfortable working and living environment, ultimately enhancing work performance and overall quality of life for users.

Limitations and Solutions

Humidity Control to Prevent Mold Growth and Protect Indoor Air Quality. The water mist cooling system is an effective solution for reducing air temperature while consuming minimal energy. However, to ensure optimal performance and avoid humidity-related issues, the system must be tightly controlled to maintain an appropriate humidity level. Excessive humidity, especially in enclosed or poorly ventilated spaces, can create favorable conditions for mold and bacteria growth, negatively affecting air quality and human health. Therefore, it is essential to integrate smart control mechanisms or humidity sensors to optimize the misting process, ensuring that the air remains both cool and dry, maintaining a balanced and comfortable indoor environment.

Regular Maintenance of HEPA and Activated Carbon Filters to Maintain Performance. The filters in the device, including HEPA filters and activated carbon, play a crucial role in removing fine dust (PM2.5, PM10), bacteria, and harmful gases. However, over time, these filters can become saturated with contaminants, reducing their efficiency. To ensure optimal performance, regular cleaning and replacement are essential. The HEPA filter should be replaced according to the manufacturer’s recommendations to maintain maximum PM2.5 removal efficiency. Similarly, activated carbon needs to be regenerated or replaced periodically to sustain its adsorption capacity for VOCs and toxic gases. Without proper maintenance, the device may become less effective, compromising indoor air quality.

Upgrading the Device with Smart Air Sensors for Automatic Operation. An important development direction for the device is the integration of smart air sensor technology, allowing for automatic adjustments based on real-time air quality conditions. These sensors can monitor key parameters such as PM2.5 concentration, VOC levels, temperature, and humidity, optimizing operational efficiency in a flexible and energy-efficient manner. When poor air quality is detected, the system can automatically activate air filtration, sterilization, or temperature regulation mechanisms without user intervention. This enhancement not only improves user experience but also ensures that the device operates at peak efficiency at all times. Additionally, IoT connectivity and mobile applications can provide remote monitoring and control

capabilities, creating a modern and intelligent air purification system.

CONCLUSION

The integrated air treatment device has been successfully designed and tested, demonstrating high efficiency in improving indoor air quality. The system incorporates multiple air purification technologies, including HEPA filtration for dust removal, UV sterilization for eliminating bacteria and viruses, activated carbon adsorption for gaseous pollutants and volatile organic compounds (VOCs), as well as seasonal air cooling and heating functions. With its multi-functional design, the device is capable of meeting the demands of various environments, ranging from households, offices, and hospitals to industrial production facilities.

In the future, the device can be further upgraded with smart features to optimize operational efficiency. The integration of an IoT-based control system will enable real-time air quality monitoring and automatic operation. Utilizing intelligent sensors and adaptive control mechanisms, the device will be able to adjust its operation dynamically, ensuring maximum efficiency while maintaining energy savings. Additionally, users will have the capability to remotely control the device via a mobile application, receiving air quality alerts, adjusting operational settings, and receiving maintenance reminders. These advancements will not only enhance user convenience but also contribute to creating a healthier, safer, and more sustainable living and working environment.

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