Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 11, November-2023

Enhancing Split Air Conditioner As Air Purifiers Through HEPA Filtration Integration

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Abstract— **As indoor air quality becomes an increasingly significant concern, the integration of High-Efficiency Particulate Air (HEPA) filtration within residential air conditioning systems presents a promising solution to mitigate airborne particulate matter, especially fine particulate matter (PM2.5 or PM1.0). This research paper explores the selection of HEPA filter specifications and evaluates the impact on particulate matter filtration efficiency after installing two HEPA filters in the air suction area of a residential air conditioner. Through comprehensive testing and data analysis, the paper demonstrates the effectiveness of the HEPA filter integration in reducing PM2.5 levels in indoor environments in air conditioner keeping the cooling comfort as required. The results reveal significant improvements in air quality, enhancing the health and well-being of residents. This research offers valuable insights into enhancing the usage of residential air conditioning systems and contributes to the broader discussion on improving indoor air quality in a world with increasing environmental challenges.**

Keywords: Air conditioner, HEPA Filter, Air Purification, Purification Efficiency, PM2.5 Measurement, Environment, Cooling Performance, Temperature, Particulate Matter

I. INTRODUCTION

The quality of indoor air has become a topic of growing concern in recent years, as mounting evidence highlights its significant impact on human health and well-being. The World Health Organization (WHO) estimates that 91% of the world's population resides in areas where air quality is unsafely high [1]. Among the various pollutants that can degrade indoor air quality, fine particulate matter, or PM2.5, stands out as a particularly insidious threat. PM2.5 refers to particles with a diameter of 2.5 micrometres or smaller, which can penetrate deep into the respiratory system, causing a range of adverse health effects, including respiratory problems, cardiovascular issues, and an increased risk of mortality.

One of the primary sources of indoor PM2.5 is the infiltration of outdoor air contaminated with pollutants such as industrial emissions, vehicle exhaust, and dust. To address this issue, a range of air purification technologies and strategies have been developed, among which High-Efficiency Particulate Air (HEPA) filtration is widely recognized for its effectiveness in capturing particles as small as PM2.5. HEPA filters are known for their high filtration efficiency, typically removing 99.97% of particles with a diameter of 0.3 micrometres or larger [2].
In the quest for cleaner indoor air, residential air conditioning systems can play a pivotal role. These systems not only regulate temperature but also have the potential to enhance indoor air quality through the integration of HEPA filtration. Air conditioning, as the name suggests conditioning of air i.e. treating air or altering its properties and bringing it to the required predefine composition for the comfort of the occupant is the primary purpose [3]. This research paper delves into the integration of HEPA filters in residential air conditioning units, with a focus on improving PM2.5 filtration and overall indoor air quality keeping the air-cooling properties of the air conditioner intact.

The paper seeks to address the right selection of grade of the HEPA filters to optimize filtration efficiency while minimizing the impact on the air conditioning system's performance and the evaluation of the real-world impact on indoor air quality by conducting PM2.5 filtration tests after installing the HEPA filters. Furthermore, this research extends the capability of the air conditioner by incorporating a digital display that provides real-time PM2.5 data, allowing residents to monitor and control their indoor air quality.
As the world grapples with environmental challenges and heightened awareness of the importance of healthy indoor environments, this research contributes to the ongoing discourse on enhancing residential air conditioning systems' performance and underscores the imperative of addressing PM2.5 pollution at its source. The following sections will delve into the methodology, results, and implications of integrating HEPA filtration in residential air conditioners, ultimately demonstrating its potential to significantly improve the quality of the air we breathe within our homes.

II. LITERATURE REVIEW

Indoor air quality is an increasingly significant concern, with links to various health issues. Poor air quality, especially concerning airborne particulate matter such as PM2.5, can lead to respiratory ailments, allergies, anxiety, irritation and other health problems [4,5,6,7]. This survey explores the use of residential air conditioners as air purifiers to address these concerns.

Various air purification methods have been developed to combat indoor air pollution. These include mechanical filtration, electrostatic precipitators, ultraviolet germicidal irradiation, and chemical-based systems like activated carbon filters. Understanding these methods provides a foundation for the integration of HEPA filters into residential air conditioners.

HEPA Filtration and Its Effectiveness:

High-Efficiency Particulate Air (HEPA) filters are renowned for their ability to capture airborne particles, including PM2.5.

They are pleated mechanical air filters that have a considerable thickness to capture the particulates. The pleats create a mat of fibers that are randomly arranged. The random, dense arrangement of fibers in the HEPA filter helps to catch a range of particle sizes. As air particles pass through the air filter, they are caught by three mechanisms: diffusion, interception, and impaction. These fibers made from either glass or synthetic materials. HEPA air filters are the most important component of any air purifier. They are classified into different grades based on their filtration efficiency.

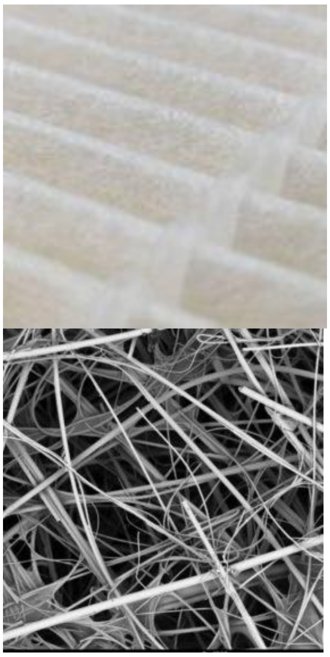

Figure 1: Closeup & microscopic View of HEPA Filters.

The most common HEPA filter grades are as follows:

- HEPA Grade H10 to H12: These filters can capture at least 85% to 99.5% of particles down to 0.3 micrometers in size.
- True HEPA Filters (H13 and H14): True HEPA filters capture at least 99.97% of particles down to 0.3 micrometers in size. They are considered the gold standard for HEPA filtration [8].

Split Air Conditioners: Functionality & Working

A split air conditioner, also known as a ductless air conditioner, is a type of air conditioning system commonly used for cooling individual rooms or small areas within a building. It consists of two main components: an indoor unit and an outdoor unit.

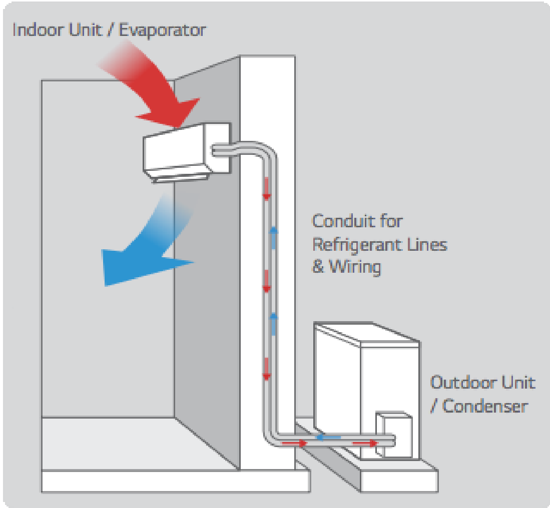

Figure 2: Representation of Residential Split Air Conditioner

- Indoor Unit: This component is typically mounted on a wall or ceiling inside the room you want to cool. It contains the evaporator coil, a fan, and the air filter. The indoor unit is responsible for cooling the indoor air.
- Outdoor Unit: The outdoor unit is usually installed outside the building, and it contains the condenser coil, a compressor, and a fan. This component is responsible for releasing the heat absorbed from the indoor air.

Here's how it Works:

1. Cooling Process: The split air conditioner cools the indoor space by circulating a refrigerant, such as R-410A, between the indoor and outdoor units. The refrigerant is a chemical compound that can easily change from a gas to a liquid and back again. This cycle of evaporation and condensation allows the system to absorb heat from the indoor air and release it outside.

Figure 3: Representation of Particulate Matter (PM) Sensor

International Journal of Engineering Research & Technology (IJERT)
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2. Air Circulation**:** The indoor unit's fan circulates the warm indoor air over the evaporator coil. The refrigerant inside the coil evaporates, absorbing heat and moisture from the indoor air. This process cools the air, which is then blown back into the room. The heat absorbed by the refrigerant is carried to the outdoor unit.

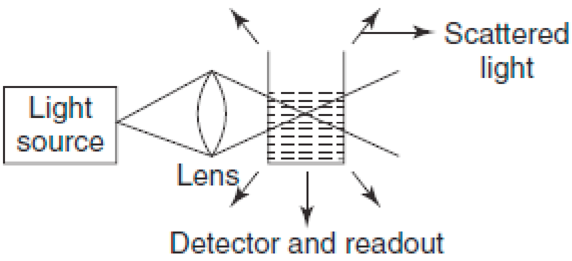

Figure 4: Working Principle of Particulate Matter (PM) Sensor

2. Heat Rejection: In the outdoor unit, the compressor pressurizes the refrigerant gas, causing it to release the heat it has absorbed. The fan in the outdoor unit helps dissipate this heat into the outside air.
3. Refrigerant Cycle: The refrigerant, now in a liquid state, is sent back to the indoor unit to repeat the cycle. This continuous process maintains a comfortable indoor temperature.

Air Quality Measurement: Particulate Matter

Air quality measurement is the process of quantifying and assessing the composition and concentration of various air pollutants and particulate matter in the atmosphere. Monitoring and measuring air quality is essential for understanding the impact of pollutants on human health, the environment, and climate. One of the most important parameters for measuring air quality is Particulate matter (PM). Particulate Matter (PM) sensors are vital tools in monitoring and assessing air quality. These sensors measure the concentration of tiny solid and liquid particles suspended in the air, which can have a significant impact on public health, the environment, and climate. PM sensors are categorized based on the size of particles they can detect, typically expressed as PM1, PM2.5, and PM10, which correspond to particles with diameters of 1 micrometer, 2.5 micrometers, and 10 micrometers or smaller, respectively.

PM sensors use various technologies to measure particulate matter concentrations. The most common sensing technology is Light Scattering. This method involves shining a light source through a sample of air. Particles in the air scatter the light, and the amount of scattered light is used to calculate particle concentration.

PM sensors are commonly used in urban areas to monitor air quality in real-time. Data from these sensors can be integrated into air quality indexes and shared with the public to provide health alerts and inform decision-making. PM sensors can also be employed indoors to evaluate air quality in homes, offices, and industrial settings. They help identify sources of indoor pollution and improve ventilation strategies. Scientists use PM sensors to conduct research on air quality, pollution sources, and the impact of PM on ecosystems and climate. They are valuable tools for studying long-term trends. PM sensors vary in accuracy and precision. Careful calibration and quality control are essential to ensure reliable data.

III. DESIGN & METHODOLOGY

To achieve the research objective of this study, various design considerations taken into account for the right selection of filter, Positioning of filter, Integration of filter in indoor unit and methodology to address the integration of digital display on the air conditioner, providing real time PM2.5 through a PM sensor enabling residents to monitor and control their indoor air quality effectively.

Selection of Filter specification

Selecting the appropriate HEPA filters for integration into a residential split air conditioner is a critical aspect of this study. The methodology for selecting the HEPA filters is based on various key parameters such as filtration efficiency, pressure drop, and filter size, aiming to optimize both air purification and system performance. It is essential to select the appropriate HEPA filter specification & size based on the specific air quality requirements, as higher efficiency filters may impose greater pressure drops on the system. The airflow rate or capacity of the HEPA filter must align with the air handling capacity of the indoor unit of the split air conditioner Though the integration of HEPA filters into air conditioning systems is a promising approach to enhance indoor air quality but it comes with various challenges & considerations.

Challenges and Considerations:

When integrating HEPA filters into air conditioners, certain challenges and considerations need to be addressed, such as the impact on the system's airflow and energy consumption. HEPA filters have the property of dropping the air flow passing though it to trap the particles to clean the air. The design and selection of filters must balance the need for improved air quality with system efficiency.

In order to get the highest level of air purification through air conditioner, H14 Grade of HEPA filters can be used but using H14 grade means lots of pressure drop in terms of air flow. The higher the grade or the efficiency of the filter means higher will be the pressure drop. This higher-pressure drop will result in reduced air flow discharge from the indoor unit (IDU). Air conditioner testing in a psychometric lab shows that if air flow discharge from the indoor unit is less than the cooling capacity of the complete air conditioning system decreases. Eventually it will result in lower efficiency of the air conditioner in terms of cooling capacity.

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Parameter	Filtration Efficiency	IDU Air Flow	Cooling Capacity
Without HEPA Filter	NA	950 CMH	5350W
With HEPA H11	~ 95%	860 CMH	5270W
With HEPA H14	~ 99.97%	730 CMH	4900W

Table 1: Experimental Result with different HEPA Grade

From testing data, it is observed that there is huge drop in the airflow and cooling capacity of the air conditioner with higher grade of the HEPA filter. Also, it is inferred that reduction in air flow of indoor unit is directly proportional to the reduction in the cooling capacity delivered by the air conditioner. So, the need to choose the optimized grade of the HEPA filter is extremely imperative to safeguard the primary objective of an air conditioner i.e., Cooling comfort to the user. For residential & office buildings, application of H11 grade HEPA can be taken into consideration to get the desired air purification & Cooling comfort. To compensate for the reduction in the air flow due to HEPA filter, indoor unit fan blower can be operated to higher Rotation Per Minute.

Integration of Filter in Air Conditioners

After finalizing the grade of the filter, defining the position & size of HEPA filters in accordance with design of the indoor unit is also critical. HEPA filters come in various sizes and shapes. The dimensions of the filters must be aligned with the dimensions of the air suction path within the air conditioner. Ensure that the chosen filters can cover only a significant portion of the suction area (e.g., 40% to 50%) without causing any big restrictions on airflow. Filters should not cover the entire suction area because when air conditioning unit will be running for a long time in a poor air quality environment then HEPA filter will soon get chocked which will result in very less air passing through them. When there is a small amount of air entering the indoor unit then less heat transfer will occur. It will eventually result in a drastic decrease in the cooling capacity of the air conditioner system. Also, it will shorten the life of the HEPA filters.

Considering the ease of filter replacement and maintenance, filters should be readily accessible and easy to change to maintain system performance. One of the ways to install the filters is mentioned in Figure 5. HEPA filters are installed just below the regular mesh filters and on the top side of the indoor unit frame. Putting HEPA filters below Mesh filter will result in longer life & cost effectiveness of the HEPA filter as the bigger size particles will be filtered out by a washable mesh filter itself.

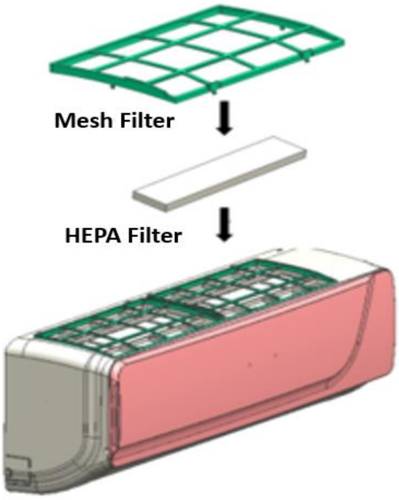

Figure 5: Installation of HEPA Filter in Indoor Unit

Real-Time Air Quality Monitoring:

In recent years, the importance of real-time air quality monitoring has gained recognition. A real-time PM 2.5 sensor was integrated into the air conditioning system to continuously monitor the level of fine particulate matter in the indoor air. Real time PM2.5 data generated by the PM sensor in milliseconds periodically, It is then sent to the main controller of the Indoor Unit. This main control board has the microcontroller inbuilt in it. The microcontroller will filter this data based on the predefined moving average algorithm. Stable values are then sent to the display controller of the indoor unit where these values can be shown by the 3-digit display ranging from 000 to 999.

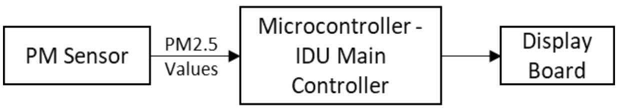

Figure 6: Representation of PM2.5 measurement and display

Certain precautions to be considered while choosing the location of the PM sensor installation in the indoor unit frame. It should not come in direct contact with the discharge air path.

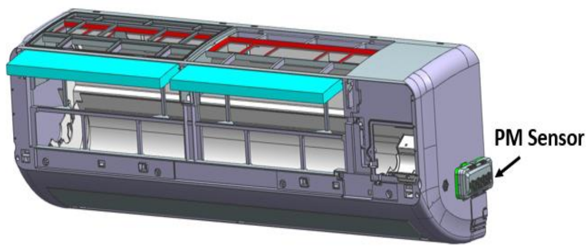

Figure 6: Position of PM Sensor & HEPA Filter in Indoor Unit

Otherwise, the sensor will take filtered air as its input and measure its PM2,5 level. Main controller will then display the PM2.5 values which will be lesser than the actual PM2.5 values of the room. One of the ways to fix the sensor on the IDU is mentioned in figure 6.

IV. OBSERVATIONS AND DISCUSSIONS

Once the HEPA filter specification, its size, its location is selected and it is integrated into the Indoor unit along with PM sensor for the real time PM2.5 data, we can now validate this enhanced air conditioning unit to check its air purification capability.

Experimental setup consists of the following components:

1. Testing Room: A dedicated testing room has been designated for this experiment. The room is fully enclosed to eliminate external air ventilation, ensuring that the air quality can be controlled and monitored accurately.
2. Pollution Generator: To introduce controlled levels of air pollution into the testing room, a pollution generator is employed. In this study, cigarette smoke is used as a source of air pollution due to its fine particulate matter emissions and its ability to produce consistent and measurable pollution levels.
3. Enhanced Air Conditioner: The enhanced air conditioner, which has been equipped with HEPA filters and a real-time PM 2.5 sensor, is installed in the testing room. This air conditioner will be subjected to the pollution generated within the room, allowing for the assessment of its air purification capability.

Experimental procedure involves a baseline air quality measurement using the integrated PM 2.5 sensor. This establishes the initial PM 2.5 levels in the enclosed testing room when no active air purification is taking place. Then the pollution generator is activated to introduce controlled levels of air pollution into the testing room. Cigarette smoke is generated to simulate real-world air pollution scenarios. This phase aims to create a polluted indoor environment for assessment.

Now the enhanced air conditioner is turned on and allowed to operate in the pollution-filled environment. During this phase, the HEPA filters within the air conditioner begin the process of filtering and purifying the indoor air. The real-time PM 2.5 sensor continuously monitors and records PM 2.5 levels within the testing room. The sensor data is logged at regular intervals for analysis. Data collected during the experiment include PM 2.5 levels at different time points, which allow for the assessment of how effectively the HEPA filtration system reduces PM 2.5 levels in real-time. The data collected is analyzed to determine the effectiveness of the enhanced air conditioner in reducing PM 2.5 levels and improving indoor air quality in the presence of pollution.

The experimental phase of this study yielded a remarkable outcome, underscoring the efficiency of the integrated HEPA filtration system in reducing PM2.5 levels within a confined environment. After 60 minutes of operation, the enhanced air conditioner, equipped with HEPA filters and real-time PM2.5 monitoring, successfully reduced the initial PM2.5 concentration from approximately 620 µg/m³ to a significantly improved level of 55 µg/m³. This represents a PM2.5 reduction of more than 90% within a closed room with an approximate volume of 1300 cubic feet.

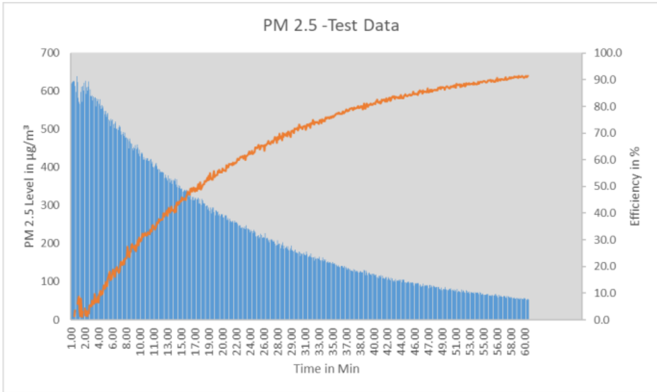

Figure 7: Graph of PM2.5 Reduction vs Time

This result attests to the substantial air purification capability of the system, achieving an impressive level of filtration efficiency. The ability to reduce PM2.5 pollution to such low levels within a relatively short timeframe underscores the potential of this technology to contribute to healthier indoor environments and improved indoor air quality for residential settings. However, it is essential to recognize that this experiment was conducted in a controlled setting, and real-world applications may present different challenges and outcomes.

V. CONCLUSION

In an era where air quality is of paramount concern, this research has delved into the integration of HEPA filtration and real-time PM 2.5 monitoring within residential split air conditioning systems, with the aim of enhancing indoor air quality without compromising much on the cooling capacity of the system. By selecting the right specification, size and installation location of HEPA filter, Cooling capacity of the enhanced air conditioner can be maintained. A real-time PM 2.5 sensor was integrated into the air conditioning system to continuously monitor the level of fine particulate matter in the indoor air. The sensor was placed strategically within the system to provide accurate readings. The findings of this study have illuminated the potential of this integrated system to significantly improve the air quality within confined indoor spaces. This study offers a pathway to healthier and cleaner indoor environments with cooling comfort. It underscores the potential of the integrated system to improve indoor air quality and enhance the well-being of occupants. As we move forward, it is our hope that this research contributes to the continued advancement of technologies aimed at creating safer and more comfortable living spaces for individuals and families worldwide.

VI. FUTURE SCOPE

The promising results of this research open the door to various future research opportunities and applications in the field of indoor air quality and residential HVAC systems.

1. Long-Term Performance and Durability Studies: Extensive, long-term studies should be conducted to assess the durability and sustained performance of HEPA filters within residential air conditioning systems. Understanding how these filters perform over extended periods and under various conditions is essential for practical applications.
2. Energy Efficiency Optimization: Investigate ways to optimize the energy efficiency of residential HVAC systems integrated with HEPA filtration. This includes assessing the impact on energy consumption, exploring energy-efficient air conditioning system designs, and implementing smart HVAC controls.
3. Adaptation to Diverse Climates: Explore how the performance and efficiency of HEPA filters may vary in different climate regions. The adaptability of the system to diverse weather conditions and air quality challenges should be investigated.
4. Advanced Filtration Technologies: Explore emerging filtration technologies, such as electrostatic, nanofiber, or activated carbon filters, and their potential to complement or enhance HEPA filtration in residential air conditioning systems
5. Indoor Air Quality Sensor Integration: Explore the integration of additional sensors to monitor and control other indoor air quality parameters, such as volatile organic compounds (VOCs) and carbon dioxide (CO_2).

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