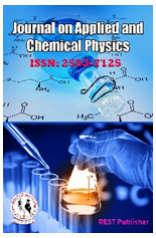
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Advancing Air Quality: Photo Thermal Purification through the GRA Approach

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ABSTRACT

Photo thermal air purifiers are advanced air cleaning systems that combine light and heat to remove airborne contaminants. These purifiers use photothermal materials, which absorb light and convert it into heat, effectively neutralizing pollutants like bacteria, viruses, volatile organic compounds (VOCs), and particulate matter. The heat generated helps to break down these harmful substances, rendering them harmless. Unlike conventional filters, photo thermal air purifiers don't rely on trapping particles but on destroying them at a molecular level. Photothermal air purifiers are significant as they offer a sustainable, efficient solution for air quality improvement by utilizing light energy to degrade pollutants. This technology is particularly effective in breaking down volatile organic compounds (VOCs) and pathogens, making it valuable for both residential and industrial applications. The methodology for developing photo thermal air purifiers involves selecting photo thermal materials, such as titanium dioxide or grapheme, that convert light into heat for pollutant degradation. These materials are then fabricated into purification units and exposed to controlled light sources to activate their photo thermal properties. Testing includes assessing the purifier's efficiency in breaking down pollutants like VOCs and pathogens under various light intensities and conditions. Performance is measured through pollutant concentration reductions and temperature variations. Finally, durability and energy consumption are evaluated to determine the purifier's practicality and scalability, ensuring it provides effective, sustainable air purification in real-world environments. Activated carbon filter, HEPA-Filters, UV-C Light Purifier, Ozone Generators, Ionizers purification efficiency, Energy consumption, Thermal management, Durability Maintenance HEPA-Filters is getting top of the table and UV-C Light Purifier is getting bottom of the table

1. INTRODUCTION

In recent years, air quality has emerged as a critical concern globally, primarily due to increasing levels of pollution from industrial activities, vehicular emissions, and indoor contaminants. The growing awareness of the health implications associated with poor air quality has led to the development of innovative technologies aimed at mitigating airborne pollutantsref1. Among these technologies, photothermal air purifiers have gained attention as an effective solution for enhancing indoor air quality. This introduction explores the principles, design, and advantages of photothermal air purifiers, as well as their potential applications in various environmentsref2. Photothermal air purifiers utilize light energy, typically from ultraviolet (UV) or visible light, to initiate chemical reactions that decompose or neutralize harmful airborne pollutants. The core principle behind photothermal purification involves the absorption of light by specific materials, which

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leads to an increase in temperatureref3. This thermal energy can either enhance the catalytic degradation of pollutants or directly facilitate their breakdown through photothermal effects. As a result, these purifiers can efficiently target various contaminants, including volatile organic compounds (VOCs), particulate matter, bacteria, and virusesref4. The purifier is equipped with light-emitting sources, such as UV lamps or LEDs. These sources emit light that is absorbed by a photocatalytic material, such as titanium dioxide (TiO_2), or a photothermal material, such as carbon-based nanomaterials. The absorption of light energy excites the electrons within these materials, generating reactive oxygen species (ROS) or increasing the temperature of the materialref5. The generated ROS play a crucial role in oxidizing and breaking down organic pollutants into less harmful substances, such as carbon dioxide (CO_2) and water (H_2O). In cases where thermal energy is employed, the elevated temperature can enhance the kinetic energy of molecules, facilitating the degradation of contaminantsref6. Many photothermal air purifiers are designed with filtration systems, such as high-efficiency particulate air (HEPA) filters or activated carbon, to capture particulate matter and larger pollutants before they reach the photocatalytic or photothermal unit. This multi-stage filtration approach ensures that the air is thoroughly cleaned of both particulate and gaseous pollutantsref7. After treatment, the purified air is released back into the environment, significantly reducing the concentration of airborne contaminants and improving overall air qualityref8. Photothermal air purifiers represent a promising innovation in the field of air quality management, leveraging light energy for effective pollutant degradation. Their ability to address a wide range of airborne contaminants makes them a valuable addition to traditional air purification technologiesref9. As advancements continue in materials science and energy efficiency, photothermal air purifiers are poised to play an increasingly important role in improving indoor air quality across various settings. The integration of these systems into homes, businesses, and public spaces can contribute significantly to healthier living environments, supporting global efforts to combat air pollution and its associated health risksref10.

2. MATERIAL AND METHOD

Alternative

- **Activated Carbon Filter:** An activated carbon filter uses porous carbon to adsorb impurities from air or water, removing contaminants like odors, chemicals, and toxins. It's commonly used in air purifiers, water filters, and industrial applications.
- **HEPA Filters:** HEPA filters (High-Efficiency Particulate Air) capture 99.97% of particles as small as 0.3 microns, including dust, pollen, and bacteria. They're used in air purifiers, vacuums, and medical environments.
- **UV-C Light Purifier:** UV-C light purifiers use ultraviolet light to destroy airborne pathogens like bacteria, viruses, and mold by disrupting their DNA. They're commonly used in air purification systems and medical facilities for disinfection.
- **Ozone Generators:** Ozone generators produce ozone (O_3) to eliminate odors, bacteria, and mold by oxidizing pollutants. They are used in air purifiers and industrial cleaning; however, excessive ozone exposure can be harmful to humans and pets.
- **Ionizers:** Ionizers release negative ions that attach to airborne particles, like dust and allergens, causing them to clump together and fall out of the air. They help purify air but may produce small ozone amounts.

Evaluation Preference

- **Purification Efficiency:** Purification efficiency measures how effectively a filter or purifier removes contaminants from air or water. It's expressed as a percentage, with higher efficiency indicating better removal of particles, pollutants, or microorganisms.
- **Energy Consumption:** Energy consumption refers to the amount of power used by devices or systems. It's measured in kilowatt-hours (kWh) and influences operational costs and environmental impact, with efficiency being key to reducing usage.

- **Thermal Management**: Thermal management involves controlling heat generation and dissipation in devices to maintain optimal performance. It uses techniques like heat sinks, fans, and materials to prevent overheating and ensure energy efficiency and reliability.
- **Durability Maintenance:** Durability maintenance refers to actions taken to ensure a device or system lasts longer, such as regular cleaning, part replacement, and inspections. It enhances performance, reduces breakdowns, and extends product lifespan.

3. GREY RELATIONAL ANALYSIS (GRA) METHOD

Grey Relational Analysis (GRA) is a mathematical and statistical method used to analyze and evaluate relationships among various factors, particularly when dealing with systems that are uncertain or incomplete. Developed within the framework of Grey System Theory by Professor Deng Julong in the 1980s, GRA has gained prominence in fields such as decision-making, engineering, economics, and environmental management. [11]The method is particularly useful in situations where data is scarce or where systems are complex and nonlinear. The core principle of GRA is based on the concept of "grey" systems, which are characterized by uncertainty and incomplete information. Unlike black systems, which are fully known and white systems, which are completely unknown, grey systems fall in between, making GRA a suitable tool for their analysis.[12] GRA evaluates the degree of similarity or difference between sequences of data.[13] It does this by calculating a grey relational grade, which quantifies the relationship between the reference sequence (the ideal or desired outcome) and other comparative sequences (the alternative options).[15]. The grey relational grade is then determined by aggregating the grey relational coefficients. This grade provides a single value that indicates how closely each alternative aligns with the reference sequence. Higher grades suggest a stronger relationship to the ideal outcome. Finally, the alternatives are ranked based on their grey relational grades. This ranking helps decision-makers identify the most favorable options based on the analysis.[16] Grey Relational Analysis is a powerful tool for analyzing complex systems characterized by uncertainty and incomplete information. By focusing on the relationships among various factors, GRA provides valuable insights for decision-making across multiple disciplines. Its ability to handle ambiguity while offering a clear framework for evaluation makes it an indispensable method in today's data-driven world[17].

4. RESULT AND DISCUSSION

TABLE 1. Performance Comparison of Photo Thermal Air Purification Technologies

Air Purification Technology	Purification Efficiency	Energy Consumption	Thermal Management	Durability/Maintenance
Activated Carbon Filter	4.00	3.00	3.00	4.00
HEPA Filters	5.00	4.00	2.00	5.00
UV-C Light Purifier	3.00	3.00	4.00	3.00
Ozone Generators	2.00	5.00	5.00	2.00
Ionizers	3.00	4.00	3.00	4.00

Table 1 compares five air purifiers Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers based on four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA filters score highest in purification efficiency and durability but have lower thermal management. Ozone Generators excel in energy consumption and thermal management but score low in purification efficiency and durability. Activated Carbon Filters and Ionizers provide balanced performance across all parameters, though neither leads in any category. UV-C Light Purifiers perform well in thermal management but are moderate in other areas. This data highlights the strengths and weaknesses of each purifier type across the evaluated criteria.

Figure 1 compares five types of air purifiers Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers across four evaluation parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA filters and photo thermal purifiers score high in purification efficiency, with HEPA excelling in durability but lagging in thermal management. Ozone generators show high energy efficiency and thermal management but rank lower in purification efficiency and durability. Ionizers provide balanced performance across all

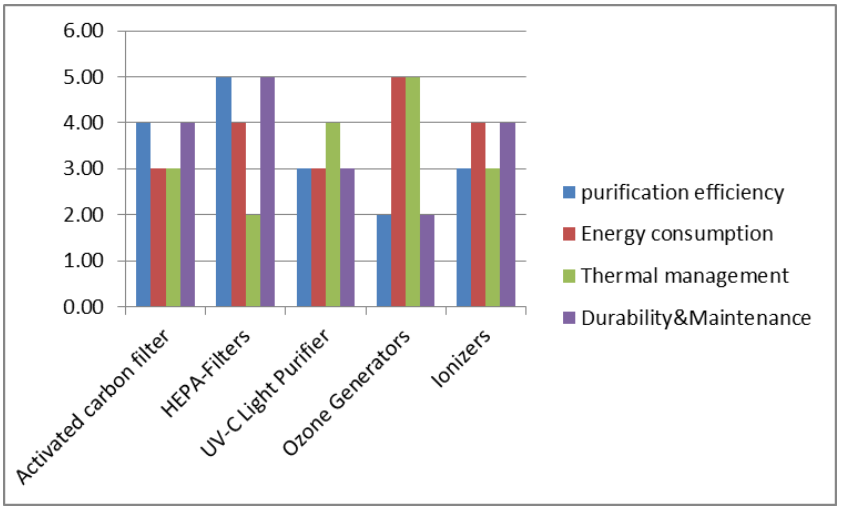


FIGURE 1. Photo Thermal Air Purifier

parameters, while UV-C Light Purifiers perform moderately well, except in durability. Overall, each purifier type has distinct strengths and weaknesses based on the evaluated criteria.

TABLE 2. Normalized Data

Air Purification Technology	Purification Efficiency	Energy Consumption	Thermal Management	Durability & Maintenance
Activated Carbon Filter	0.6667	0.0000	0.6667	0.3333
HEPA Filters	1.0000	0.5000	1.0000	0.0000
UV-C Light Purifier	0.3333	0.0000	0.3333	0.6667
Ozone Generators	0.0000	1.0000	0.0000	1.0000
Ionizers	0.3333	0.5000	0.6667	0.3333

Table 2 shows normalized data for five air purifiers (Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers) across four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA Filters have the highest normalized scores in purification efficiency and thermal management but score lowest in durability. Ozone Generators lead in energy consumption and durability but score the lowest in purification efficiency and thermal management. Activated Carbon Filters and Ionizers are balanced across most criteria, while UV-C Light Purifiers score moderately in durability. This normalization highlights relative strengths and weaknesses, illustrating how each purifier performs compared to the others on a 0-1 scale.

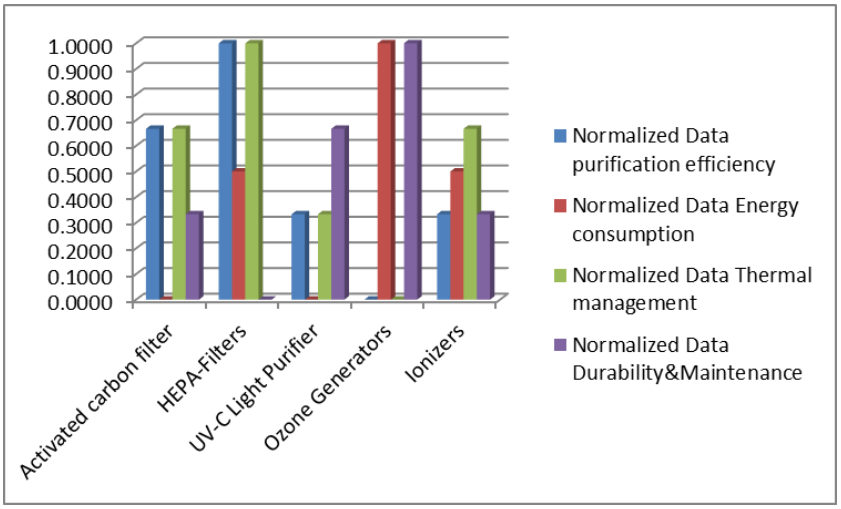


FIGURE 2. Normalized Data

Figure 2 presents normalized data for five air purifier types (Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers) based on four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA filters show high scores in purification efficiency and durability but moderate scores in thermal management. Ozone generators excel in energy consumption and thermal management but score low in purification efficiency. UV-C Light Purifiers have balanced but generally lower normalized scores across parameters. Ionizers show moderate to high scores in thermal management and durability, while Activated Carbon Filters are relatively balanced across all criteria. The normalization helps highlight each purifier's relative strengths.

TABLE 3. Deviation Sequence

Air Purification Technology	Purification Efficiency	Energy Consumption	Thermal Management	Durability & Maintenance
Activated Carbon Filter	0.3333	1.0000	0.3333	0.6667
HEPA Filters	0.0000	0.5000	0.0000	1.0000
UV-C Light Purifier	0.6667	1.0000	0.6667	0.3333
Ozone Generators	1.0000	0.0000	1.0000	0.0000
Ionizers	0.6667	0.5000	0.3333	0.6667

Table 3 presents deviation sequences for five air purifiers Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers across four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA Filters exhibit the smallest deviations in purification efficiency and thermal management, indicating superior performance in these areas. Ozone Generators have the lowest deviation in energy consumption and durability, showing strengths in these parameters. Activated Carbon Filters and Ionizers have balanced deviations, with moderate strengths and weaknesses. UV-C Light Purifiers have higher deviations in most areas, suggesting less optimal performance compared to other purifiers. These deviations highlight how each purifier deviates from ideal performance in each parameter.

TABLE 4. Grey Relation Coefficient

Air Purification Technology	Purification Efficiency	Energy Consumption	Thermal Management	Durability & Maintenance
Activated Carbon Filter	0.6000	0.3333	0.6000	0.4286
HEPA Filters	1.0000	0.5000	1.0000	0.3333
UV-C Light Purifier	0.4286	0.3333	0.4286	0.6000
Ozone Generators	0.3333	1.0000	0.3333	1.0000
Ionizers	0.4286	0.5000	0.6000	0.4286

Table 4 displays the Grey Relation Coefficient (GRC) values for five air purifiers Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers across four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA Filters achieve the highest GRC values for purification efficiency and thermal management, indicating strong performance in these areas. Ozone Generators excel in energy consumption and durability with the highest GRC values, suggesting a close relationship to ideal performance in these aspects. Activated Carbon Filters and Ionizers show moderate performance with balanced GRC values, while UV-C Light Purifiers perform relatively lower in most categories. These GRC values reveal each purifier's relative closeness to optimal performance across all parameters.

TABLE 5. Grey Relational Grade (GRG)

Air Purification Technology	GRG
Activated Carbon Filter	0.4905
HEPA Filters	0.7083
UV-C Light Purifier	0.4476
Ozone Generators	0.6667
Ionizers	0.4893

Table 5 shows the Grey Relational Grade (GRG) for five air purifiers Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers. The GRG represents each purifier's overall performance across four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA Filters have the highest GRG at 0.7083, indicating the best overall performance. Ozone Generators also score well at 0.6667, reflecting strong energy efficiency and durability. Activated Carbon Filters and Ionizers have similar GRG scores, showing balanced performance across parameters.

TABLE 6. Rank of Air Purification Technologies

Air Purification Technology	Rank
Activated Carbon Filter	3
HEPA Filters	1
UV-C Light Purifier	5
Ozone Generators	2
Ionizers	4

Table 6 ranks five air purifiers Activated Carbon Filters, HEPA Filters, UV-C Light Purifiers, Ozone Generators, and Ionizers based on their overall performance across four parameters: purification efficiency, energy consumption, thermal management, and durability & maintenance. HEPA Filters rank first, indicating the best overall performance, followed by Ozone Generators in second place, mainly due to their strong energy efficiency and durability. Activated Carbon Filters are ranked third, showing balanced performance, while Ionizers are fourth, with moderate effectiveness across the parameters. UV-C Light Purifiers rank last, reflecting lower overall performance compared to the other purifiers. This ranking highlights the most effective purifier type.

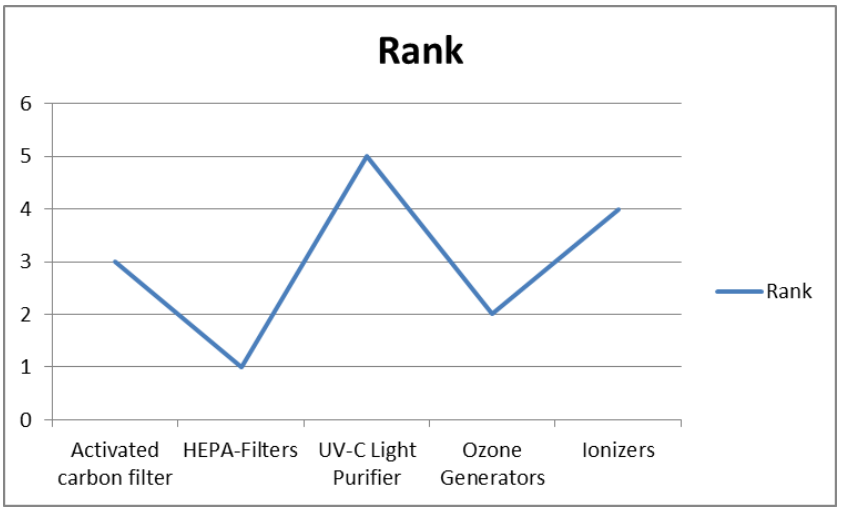


FIGURE 3. Rank

Figure 3 presents a ranking of various air purification technologies based on effectiveness. It plots five methods: Activated Carbon Filter, HEPA Filters, UV-C Light Purifier, Ozone Generators, and Ionizers against their respective ranks. HEPA Filters received the highest rank of 5, indicating strong effectiveness, while Activated Carbon Filter and Ionizers ranked lower, around 2. The UV-C Light Purifier had a peak rank of 4, while Ozone Generators fluctuated but settled at a rank of 3. This visualization highlights the relative performance of each air purification method in improving air quality.

5. CONCLUSION

Photo thermal air purifiers are a cutting-edge solution in the field of air quality management, utilizing light-activated materials to break down pollutants in the air. This technology leverages the principles of photo thermal conversion, where light energy, primarily from sunlight or artificial sources, is absorbed by specific materials and converted into heat. This

heat generation can then be used to catalyze reactions that degrade harmful substances and microbial contaminants. This makes photo thermal purifiers both versatile and efficient, as they can operate under various light conditions, including visible light, without requiring additional chemical agents. The primary advantage of photo thermal air purifiers is their ability to harness energy from light, providing a renewable and potentially self-sustaining means of air purification. This energy efficiency translates to lower operational costs over time, especially in environments where they can utilize ambient sunlight. Additionally, the mechanism by which they break down pollutants is environmentally friendly. Unlike some air purification systems that rely on filters or chemical treatments, photo thermal air purifiers do not generate secondary pollutants. Instead, they use heat and catalysis to decompose harmful substances into benign by-products such as carbon dioxide and water. Moreover, photo thermal air purifiers are particularly effective against a range of pollutants. Volatile organic compounds (VOCs), which are commonly found indoors due to emissions from household products, furniture, and paints, can be effectively broken down by these systems. VOCs contribute to poor indoor air quality and are associated with a range of health issues, including respiratory problems and headaches. By breaking down VOCs, photo thermal purifiers can contribute to healthier indoor environments. Furthermore, photo thermal air purifiers can deactivate pathogens, including bacteria and viruses, by disrupting their cell membranes through heat, making them useful in healthcare settings and public spaces. The effectiveness of photo thermal air purifiers depends largely on the materials used in their construction. Typically, these systems employ semiconductors, metal oxides, or other materials capable of photo thermal conversion. Titanium dioxide (TiO_2) is a commonly used material due to its strong photocatalytic properties, high stability, and non-toxicity. However, to enhance its photo thermal capabilities, it is often combined with other materials, such as graphene or carbon nanomaterials, which help improve light absorption and heat generation. Research in materials science is continually advancing the capabilities of photo thermal air purifiers. For instance, the development of black phosphorus and other two-dimensional materials has opened new possibilities for enhancing the efficiency and scope of these systems.

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