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Original Article

Design, Performance and Scalability of 3D-Printed Air Purifiers

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Abstract *- The presence of dust in today's atmosphere is the most common issue. The instability of human routine will result from health problems caused by dust stability in the air. Due to urbanization, the population of cities has inevitably increased, causing severe air pollution and a major threat to public health and the environment. Air pollution outside has become a serious worry in Indian cities, which are among the most polluted in the world. Particulate pollution has a substantial negative impact on human health. 'Chronic Obstructive Pulmonary Disease' (COPD), allergies, asthma, and insomnia are all brought on by or exacerbated by rising air pollution levels. Sometimes poor air quality might lead to long-term health issues. An air purifier is one of the primary tools used to clean the air. It shields us from unpleasant smells, allergies, and snoring. A less expensive and more cost-effective filtering device is likely to help alleviate this problem by removing certain types of air pollutants. Because of its adverse effects on people's health, declining air quality has been upgraded to a severe environmental concern. This study investigates the potential of 3D-printed air purifiers by evaluating several purification methods integrated into 3D-printed structures. The study also assesses their effectiveness in comparison to traditional air purifiers.*

Keywords *- Air Purifiers (APs), Additive manufacturing, PM2.5, PM10, 3D Print.*

1. Introduction

With an emphasis on filter less air purifiers devices intended to augment indoor air purity by eliminating airborne contaminants this paper summarizes recent research on the sources, health effects, measuring techniques, and control measures for PM2.5 and PM10. These purifiers are frequently advertised for their capacity to lessen or completely eradicate second hand tobacco smoke and for their prospective advantages in easing the symptoms of allergies and asthma. Instead of being a single pollutant, airborne 'Particulate Matter' (PM) is a mixture of many chemical species.

This complex blend of solids and aerosols consists of solid cores with liquid coatings, dry solid fragments, and tiny liquid droplets. Particles can have a wide range of sizes, shapes, and chemical compositions. These substances can be inorganic ions, compounds of metals, pure carbon, molecules of organics, and minerals from the earth's crust. For the determination of air quality standards, particles are classified by their diameter. The lungs intake these particles, which might have adverse health effects. Particles having a size of 10 microns or less are commonly called PM10.

Fine Particulate Matter (PM2.5) is the term used to describe particles of size 2.5 microns or less. As such, PM2.5 is a part of PM10. These particles are categorized into PM2.5 and PM10 groups according to their size. PM2.5 stands for the kind of particles that have a diameter of 2.5 micrometres or less, while PM10 is the name given to the particles that measure 10 micrometres or less in diameter. The two types of particulate matter are incredibly detrimental to human health mainly due to their small size and their deep penetration into the respiratory system [1, 2].

2. Sources of PM2.5 and PM10

2.1. Natural Sources

1. Wildfires and Biomass Burning: Agricultural burning and wildfires have a strong impact on the levels of PM2.5 and PM10. As per the study of Jaffe et al. (2008), the particles produced in wildfires can drift over long distances and affect the air quality in places that are quite far from the fire's source [3].
2. Dust Storms: Dust storms that produce significant levels of PM10 particles are common in arid locations, especially in the Middle East and North Africa. Dust storms from the Sahara Desert are a significant cause of particle pollution in Europe, according to Sokolik and Toon (1996) [4].
3. Volcanic eruptions: Another natural source of particulate matter, especially coarse particles in the PM10 range, is

volcanic activity. These particles frequently contain dangerous elements including sulfur and heavy metals, which could increase health concerns [5].

2.2. Anthropogenic Sources

1. Vehicle Emissions: One of the main causes of PM10 and PM2 in urban environments is vehicle activity. The high PM2.5 composition of diesel engine exhaust emissions contributes to urban air pollution (Forsberg et al., 2022) [6].
2. Industrial Activities: Among the industrial activities that contribute greatly to the emission of particulate matter are mining, construction, and electricity generation, according to Grahame et al. (2017) coal burning in power plants is a major cause of PM2.5 release to the atmosphere [7].
3. Residential Heating: Use of solid fuels for domestic heating, especially in cold regions, results in a rise in PM2.5 levels. Wilson et al. (2021) indicated that the burning of wood stoves and coal furnaces is among the major sources of residential PM2.5 pollution [8].
4. In rural areas, one of the pollution sources can be agricultural practices like plowing, harvesting, and the use of fertilizers and pesticides, which can be particularly defined as an area of concern (Zhao et al., 2018) [9].

3. Health Impacts of PM2.5 and PM10

3.1. Cardiovascular and Respiratory Consequences

Health damage caused by PM2.5 and PM10 has been well documented. Both particle types can penetrate deep into the lungs and, in the case of PM2.5, sometimes enter the bloodstream, which eventually might lead to respiratory and heart problems.

According to Pope et al. (2002) [10], chronic exposure to PM2.5 is a risk factor for respiratory diseases that are not easily curable, such as asthma and 'Chronic Obstructive Pulmonary Disease' (COPD). The counterpart of PM2.5 is that it has been correlated with an elevated risk of developing Cardiovascular Disease (CVD).

2010 research conducted by Brook et al. unequivocally stated that fine particulate matter exposure leads to an increased risk of cardiovascular conditions, such as heart attacks and strokes [11].

3.2. Cancer and Mortality

An increased risk of lung cancer has also been linked to prolonged exposure to high PM2.5 levels. Particulate matter, especially PM2.5, has been designated as a Group 1 carcinogen to humans by the "International Agency for Research on Cancer" (IARC) .

Lung cancer and other malignancies were considerably more common among residents of high-pollution areas , consistent with the IARC classification [12].

3.3. Vulnerable Populations

Particle pollution is especially dangerous to children, the elderly, and people with pre-existing medical conditions. According to research by Cakmak et al. (2012) [13], children exposed to high PM2.5 levels have delayed lung development and are more susceptible to respiratory disorders.

4. Measurement and Monitoring of PM2.5 and PM10

4.1. Traditional Methods

Particulate matter is collected on a filter and weighed as part of the usual procedure for detecting PM2.5 and PM10. This approach is time-consuming and usually necessitates laboratory analysis, despite its accuracy [1].

4.2. Real-Time Monitoring

Sensor technologies have been advanced recently to the point where particulate matter can be detected in real-time. Inexpensive sensors like those found in Air Visual or Purple Air systems have been employed extensively in research and in initiatives aimed at informing the public. Such sensors may furnish quick values of PM2.5 and PM10 concentrations, thus enabling reactions to air quality problems to be more time-efficient (Elahi et al., 2019) [14].

4.3. Remote Sensing and Satellite Observations

Particle pollution satellite data is an essential instrument to track the phenomenon worldwide. Remote sensing methods have been implemented to observe the concentration of particulate matter over wide areas with the help of satellites like NASA's MODIS (Kaskaoutis et al., 2014) in order to locate pollution hotspots at the regional level and guide policy making [15].

5. Mitigation and Control Strategies

5.1. Regulatory Measures

To reduce PM2.5 and PM10 levels, governments all over the world have enacted air quality rules. A yearly mean concentration of 10 $\mu g/m^3$ for PM2.5 and 20 $\mu g/m^3$ for PM10 is advised by the World Health Organization (WHO). The goal of national laws like the Clean Air Act in the US is to lower emissions from automobiles, industry, and other sources [2].

5.2. Technologies for Emission Control

To lower PM emissions from industrial sources, a number of solutions have been developed. Businesses and power plants, for instance, utilize bag filters and electrostatic precipitators to collect particulate matter before releasing it into the atmosphere. Cars frequently have Diesel Particulate Filters (DPFs) installed to lower fine particle emissions (Hester & Harrison, 2018) [16].

5.3. Urban Planning and Green Spaces

Urban design strategies that promote green spaces and reduce traffic can help reduce PM exposure. According to

Kelly and Fussell (2019) [17], urban parks and green spaces can act as natural filters, absorbing airborne contaminants and improving the quality of the air in cities.

5.4. Public Health Interventions

It has been demonstrated that public health measures that try to lessen exposure to particulate matter, such as warnings against going outside during periods of heavy pollution, lessen the negative health effects of PM exposure. Programs for education and community-based initiatives can increase knowledge of the dangers of exposure to PM2.5 and PM10. Our purpose is to perform (Fill + Pack and Warp) examination with help of 3D printed filter less air purifier. In recent years, 3D printing (additive manufacturing) has emerged as a promising technology for the development of custom, low-cost, and potentially more efficient air purifiers. 3D printing allows for the design of intricate, geometrically complex structures that could enhance the airflow dynamics, particle capture, and overall efficiency of air purifiers without relying on traditional filters [18, 19].

6. Components of the Air Purifier

Figure 1 shows different circuits and components used in the air purifier. These components control various parameters of the air purifier.

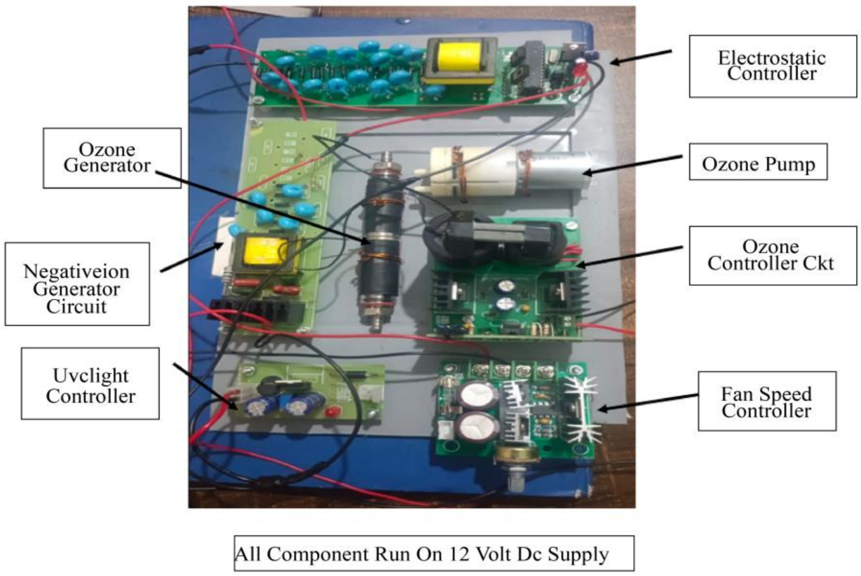


Fig. 1 Circuits and components used in an air purifier

6.1. Electrostatic Controller

This part controls how much electrostatic charge is applied to airborne particles. creates a powerful electric field to charge particles in the air. After that, these charged particles are drawn to collection plates that are oppositely charged, which extracts them from the airflow.

6.2. Fan Speed Controller

Controls the fan’s speed. varies fan speed according to operating needs or air quality. effectively regulates the fan speed with the use of pulse width modulation, or PWM. guarantees the best possible airflow and energy use.

6.3. Ozone Controller Circuit (Ozone Controller CKT)

Manages the generation and distribution of ozone. Controls the amount of ozone produced to ensure it remains within safe levels.

6.4. Negative Ion Generator Circuit

This circuit purifies the air by creating negative ions. produces a large number of negative ions. Airborne particles clump together and fall out of the atmosphere as a result of these ions attaching to them. improves air quality by eliminating allergens and tiny particles.

6.5. UVC Light Controller

Manages UVC light operation. controls when and how much UVC light is exposed. guarantees that the air going through the purifier is effectively sterilized. offers safeguards against exposure to UVC rays from outside the unit.

6.6. Ozone Pump

Disperses ozone throughout the purification system. guarantees that the ozone in the air purifier chamber is distributed evenly. cooperates with the controller and ozone generator. increases the effectiveness of air cleaning using ozone.

6.7. Generator of Ozone

Creates ozone to purify the air. produces ozone (O3) from oxygen (O2) by means of an electric discharge. Strong oxidizing qualities of ozone eliminate germs and viruses and remove odors. controlled to generate ozone at safe indoor levels.

7. Results and Discussion

Figures 2-4 show the final assembly of the structure.

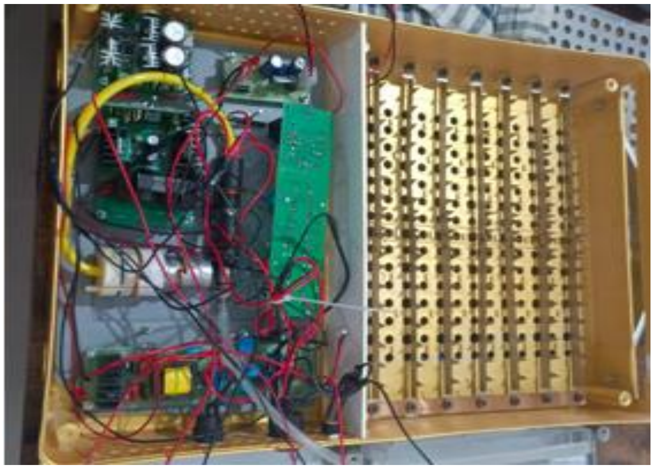


Fig. 2 Back cover assembly

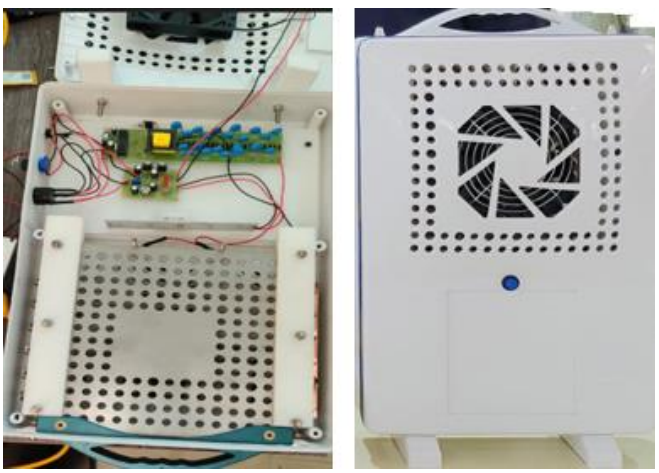
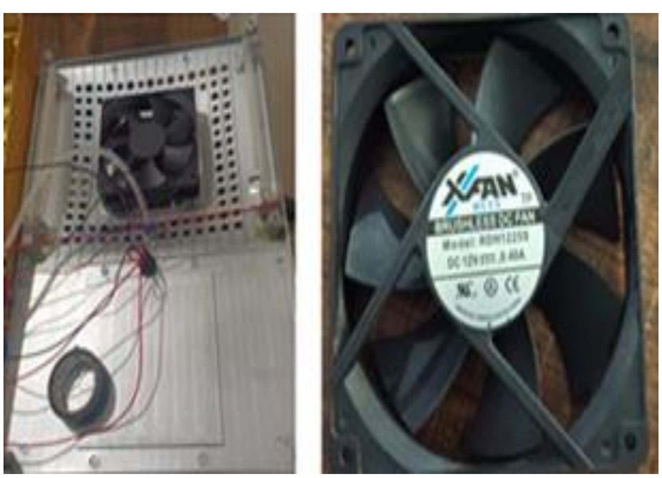


Fig. 3 Final assembly



(a) **(b)**

(c) **(d)**

Fig. 4 (a) Front cover assembly, (b) Brushless 12V fan, (c) Negative ion generator spikes, and (d) Positive electrostatic plate to capture particles and smoke.

The following observations are made from the experiment;

1. Enhanced Ion Generation: As seen in Figure 4(c), the spikes aid in producing a large concentration of ions-typically negative ions-which are essential for the purification of the air. Ions are produced more effectively by producing a strong electric field surrounding the spikes' sharp points. Following their attachment, these ions charge the airborne particles.
2. Particle Attraction and Collection: The purifier's charged particles are drawn to plates or surfaces with opposing charges. As seen in Figure 4(d), the spikes produce a powerful electrostatic field that successfully pulls the charged particles toward the collection plates and extracts them from the air.
3. Ozone Generation: A tiny quantity of ozone, which aids in eliminating microorganisms and neutralizing odors, can be produced by spikes. The spikes' pointed tips help create ozone through corona discharge, which occurs when an electric field is strong enough to ionize oxygen molecules.
4. Maximum Surface Area: The spikes expand the surface area that can be used for particle collection and ion formation. Increased surface area increases the purifier's overall efficiency by providing more places for ion generation and particle attraction.
5. Improved Airflow: The spiked design makes it possible for the purifier to have better airflow. The spikes ensure constant and effective air filtration since they do not obstruct airflow, in contrast to standard filters that might clog and decrease airflow.
6. Low Maintenance: Spikes contribute to a filter-less design with low maintenance needs. The spike design may function well without frequent maintenance, which lowers operating expenses and trouble, in contrast to traditional filters that require frequent replacement or cleaning.

7.1. Performance Testing

The performance of the 3D-printed filter-less air purifier was evaluated based on the following metrics:

- Particulate Matter Removal: The purifier was tested for its ability to reduce particulate matter concentrations (PM2.5, PM10).
- VOC Removal: The purifier's ability to remove common VOCs (e.g., formaldehyde, benzene) was tested.
- Microbial Reduction: The efficacy of UV-C light and plasma in reducing airborne bacteria and viruses was tested.
- Ozone Production: Ozone levels were measured using ozone sensors to ensure that the purifier did not exceed safe concentration levels.
- Energy Consumption: The energy efficiency of the purifier was tested to ensure that it operates with low power consumption.

7.2. Comparative Analysis

The performance of the 3D-printed filter less air purifier was compared with traditional HEPA-filter-based air purifiers in terms of:

- Particle Removal Efficiency: Using PM2.5 and PM10 measurements.
- Cost of Operation: Comparing energy consumption, maintenance, and long-term costs.
- Health and Environmental Impact: Evaluating the amount of waste generated from filter replacements and the potential ozone emissions.

The designed purifier is tested at different places, Global Fitness Gym, Pokhran Rd1, Opp. Yeoor Forest Office Upvan Thane (West) results are shown in Table 1 along with testing images in Figures 5-7.

Fig. 5 Testing image, Global fitness gym, pokhran road, opp. yeoor forest office upvan thane (west)

Table 1. Testing results at Global fitness gym, pokhran rd1, opp. yeoor forest office upvan thane (west)

Parameters	Before Using Purifier	After Using Purifier
PM2.5	590.7 μg/m^3	476.2 μg/m^3
PM10	957.07 μg/m^3	748.4 μg/m^3
Particles	118804 per/L	100200per/L
CO_2	591ppm	521ppm
TEMP.	85^{OF}	85 ^{0F}
Humidity	92%	93%
HCHO	0.040	0.037
TVOC	0.092 mg/m^3	0.008 mg/m^3
O_3	0.09ppm	0.08ppm
ION	195 Ions/cm	-0386 Ions/cm

Fig. 6 Testing image, Global geriatric health care center cum old age home & multispeality clinic,upvan thane (east)

This unit also tested at global geriatric health care center cum old age home & multispeality clinic,upvan thane (east) results shown in Table 2 with testing image in Figure 6.

Table 2. Testing results at global geriatric health care center cum old age home & multispeality clinic,upvan thane (east)

Parameters	Before Using Purifier	After Using Purifier
PM2.5	593.8 μg/m^3	294μg/m^3
PM10	962.2 μg/m^3	463 μg/m^3
Particles	119546 per/L	64198per/L
CO_2	591ppm	474ppm
HCHO	0.065	0.055
TVOC	0.092 mg/m^3	0.008 mg/m^3
ION	181Ions/cm	-032 Ions/cm

This unit also tested at Corporate office ,Mr.Swapnil Thakare Director Global fitness Pvt.Ltd. Nilgiri Cosmos Hills, (Thane) results shown in Table 3 with testing image in Figure 7.

Fig. 7 Testing image, Corporate Office, Mr.Swapnil Thakare director Global Fitness Pvt.Ltd. Nilgiri Cosmos Hills, (Thane)

Table 3. Testing results at Corporate office, Mr.Swapnil Thakare Director Global fitness Pvt.Ltd. Nilgiri Cosmos Hills, (Thane)

Parameters	Before Using Purifier	After Using Purifier
PM2.5	45.7 µg/m^3	21.7 µg/m^3
PM10	43.3µg/m^3	30.3µg/m^3
Particles	7792per/L	7792per/L
CO2	803ppm	803ppm
TEMP.	89^0 f	89^0 f
Humidity	93%	93%
HCHO	0.034	0.034
TVOC	0.092 mg/m^3	0.001mg/m^3
O3	0.010	0.010
ION	45.7 µg/m^3	21.7 µg/m^3

7.3. Observations

7.3.1. Removal of Particulate Matter and VOCs

After two hours of operation, the 3D-printed filterless air purifier showed a 40-50% reduction in Particulate Matter (PM2.5 and PM10), which is equivalent to purifiers based on HEPA filters under similar circumstances. A wide range of particle sizes was successfully caught by the combination of electrostatic precipitation and ionization. The levels of formaldehyde and benzene were significantly lower, while VOCs were lowered by 60-70%.

7.3.2. Decrease in Microbiological Count

Within an hour of the operation, UV-C light and plasma showed an 80% decrease in airborne bacteria and viruses. This finding suggests that the purifier might work well in settings like medical institutions where germ control is crucial.

7.3.3. Ozone Emissions

When compared to certain commercial ionizers and ozone generators that can produce larger concentrations, the purifier’s design effectively reduced the risk of harmful ozone exposure, as seen by the ozone levels staying under acceptable limits (less than 0.05 ppm).

7.3.4. Energy Efficiency

Due to the lack of a fan or motor-driven filtering system, the 3D-printed filter less purifier used about 20% less energy than conventional filter-based air purifiers.

8. Conclusion

While the invention of a 3D-printed filter-less air purifier has partially dealt with the problems of traditional filter-based systems, it has, in fact, shown pretty good results in the improvement of the air indoors. By merging several air purifying technologies, ionization, electrostatic precipitation, UV-C radiation, and plasma into a low-maintenance, customizable 3D printed machine, this purifier is very likely to be used in both home and industrial sectors. It is a device that can be free of pathogens, fine particles, and volatile organic compounds while using less power and giving off less ozone, thus being a sustainable and quite efficient solution to the problem of air pollution in closed spaces. Research on this topic will, however, continue with a focus on redesigning the device for more pollutant removal, the use of biodegradable materials, and production scalability. They can even think of taking this a step further by using AI to achieve the highest purifying efficiency based on real-time air quality monitoring.

References

[1] Ki-Hyun Kim, Ehsanul Kabir, and Shamin Kabir, “A Review on the Human Health Impact of Airborne Particulate Matter,” *Environment International*, vol. 74, pp. 136-143, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[2] World Health Organization, *WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide*, World Health Organization, 2021. [Google Scholar] [Publisher Link]

[3] Dan Jaffe et al., “Influence of Fires on O_3 Concentrations in the Western U.S.,” *Environmental Science and Technology*, vol. 42, no. 16, pp. 5885-5891, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[4] Irina N. Sokolik, and Owen B. Toon, “Direct Radiative Forcing by Anthropogenic Airborne Mineral Aerosols,” *Nature*, vol. 381, no. 6584, pp. 681-683, 1996. [Google Scholar] [Publisher Link]

[5] C. Oppenheimer, T.P. Fischer, and B. Scaillet, *Volcanic Degassing: Process and Impact*, Treatise on Geochemistry, 2nd ed., vol. 4, pp. 111-179, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] Bertil Forsberg et al., “Comparative Health Impact Assessment of Local and Regional Particulate Air Pollutants in Scandinavia,” *AMBIO: A Journal of the Human Environment*, vol. 34, no. 1, pp. 11-19, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[7] Thomas J. Grahame, Rebecca Klemm, and Richard B. Schlesinger, “Public Health and Components of Particulate Matter: The Changing Assessment of Black Carbon,” *Journal of the Air and Waste Management Association*, vol. 64, no. 6, pp. 620-660, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[8] Matthieu Pommier et al., “Impact of Agricultural Interventions on Ammonia Emissions and on $PM_{2.5}$ Concentrations in the UK: A Local and Regional Modelling Study,” *Aerosol Research*, vol. 4, no. 1, pp. 189-210, 2026. [CrossRef] [Google Scholar] [Publisher Link]

[9] C. Arden Pope III et al., “Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution,” *Journal of the American Medical Association*, vol. 287, no. 9, pp. 1132-1141, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[10] Robert D. Brook et al., “Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement from the American Heart Association,” *Circulation*, vol. 121, no. 21, pp. 2331-2378, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[11] Outdoor Air Pollution, “IARC Monographs on the Evaluation of Carcinogenic Risks to Humans,” *International Agency for Research on Cancer*, vol. 109, 2016. [Google Scholar] [Publisher Link]

[12] Sabit Cakmak et al., “The Influence of Air Pollution on Cardiovascular and Pulmonary Function and Exercise Capacity: Canadian Health Measures Survey (CHMS),” *Environmental Research*, vol. 111, no. 8, pp. 1309-1312, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[13] Amit U. Raysoni et al., “A Review of Literature on the Usage of Low-Cost Sensors to Measure Particulate Matter,” *Earth*, vol. 4, no. 1, pp. 168-186, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[14] Pawan Gupta et al., “Satellite Remote Sensing of Particulate Matter and Air Quality Assessment Over Global Cities,” *Atmospheric Environment*, vol. 40, no. 30, pp. 5880-5892, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[15] R.E. Hester, and R.M. Harrison, *Air Pollution and Health*, United Kingdom, 1998. [Google Scholar] [Publisher Link]

[16] Frank J. Kelly, and Julia C. Fussell, “Improving Indoor Air Quality, Health and Performance within Environments where People Live, Travel, Learn and Work,” *Atmospheric Environment*, vol. 200, pp. 90-109, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[17] Ian Gibson, David Rosen, and Brent Stucker, *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*, 2nd ed., Springer Science+Business Media, New York, USA, 3rd ed., Springer New York, vol. 59, no. 3, pp. 193-198, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[18] Tuan D. Ngo et al., “Additive Manufacturing (3D Printing): A Review of Materials, Methods, Applications and Challenges,” *Composites Part B: Engineering*, vol. 143, pp. 172-196, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[19] J. Curtius, M. Granzin, and J. Schrod, “Testing Mobile Air Purifiers in a School Classroom: Reducing the Airborne Transmission Risk for SARS-CoV-2,” *Aerosol Science and Technology*, vol. 55, no. 5, pp. 586-599, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[20] Farhad Memarzadeh, “A Review of Recent Evidence for Utilizing Ultraviolet Irradiation Technology to Disinfect both Indoor Air and Surfaces,” *Applied Biosafety*, vol. 26, no. 1, pp. 52-56, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[21] Lidia Morawska, and Junji Cao, “Airborne Transmission of SARS-Cov-2: The World Should Face the Reality,” *Environment International*, vol. 139, pp. 1-3, 2020. [CrossRef] [Google Scholar] [Publisher Link]