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REVIEW

Application of nanotechnology in air purifiers as a viable approach to protect against Corona virus

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Abstract
The outbreak of COVID-19 disease, the cause of severe acute respiratory syndrome, is considered a worldwide public health concern. Although studies indicated that the virus could spread through respiratory particles or droplets in close contact, current research have revealed that the virus stays viable in aerosols for several hours. Numerous investigations have highlighted the protective role of air purifiers in the management of COVID-19 transmission, however, there are still some doubts regarding the efficiency and safety of these technologies. According to those observations, using a proper ventilation system can extensively decrease the spread of COVID-19. However, most of those strategies are currently in the experimental stages. This review aimed at summarising the safety and effectiveness of the recent approaches in this field including using nanofibres that prevent the spread of airborne viruses like SARS-CoV-2. Here, the efficacy of controlling COVID-19 by means of combining multiple strategies is comprehensively discussed.

KEYWORDS
air contamination, COVID-19, filtration, nanobiotechnology, nanofibres

1 | INTRODUCTION

The COVID-19 disease is a newly discovered virus that spread in Wuhan, China at the end of 2019. Coronavirus is a virus family that introduced the cause of disease. The World Health Organisation (WHO) has declared COVID-19 as a pandemic on March 11, 2020. In the early 2000s, coronavirus has caused public health concerns that resulted in global epidemics, such as coronavirus disease 2019 (COVID-19), Middle East Respiratory Syndrome, and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This pathogen has been identified as a novel single-stranded RNA beta coronavirus that significantly impacted people's health and lives [1]. The virus is spreading rapidly throughout the world and there is a need to adopt some restrictions to control it.

The WHO has confirmed that COVID-19 is a public health emergency of international concern. Aerosol airborne viruses such as coronavirus have a wide variety of lengths and widths, extending from nanometres (e.g. virus particles) to micrometres (e.g. nonviable particles with viruses). Observations have shown that tiny particles contain viruses, which can stay airborne for a long time and are easy to transport to other places. Since smaller particles may carry respiratory viruses and stay in the air for longer, they may potentially be more hazardous. Subsequently, the exposed person would get severe diseases by inhaling particles into their lower lungs. This virus is primarily spread by respiratory droplets through sneezing and coughing of infected patients. These droplets are easy could spread through the air [2].

The basic data from different regions, such as Wuhan in China, Northern Italy, the Netherlands, and specific regions in the United States show that the severity of the pandemic is significantly correlated to SARS-CoV-2, COVID-19, and air pollution [3]. Several studies have evaluated the relationship between acute respiratory infections and hospitalised patients. They reported that the high rate of viruses is associated with a large proportion of acute respiratory infections [4, 5]. Recent evidence has shown that the mortality rate in people infected with viral respiratory infections in hospitals is higher than in people who have acquired the disease from infected people in the community [6]. Patients and healthy people generate the transmission of droplet aerosols. A recent study revealed that ventilation systems are more effective for coughing than for talking. They showed that the best performance was achieved when the patient sat and coughed, whereas the worst situation was lying and talking. Their study recommended that improving the air purifier could decrease the risk of cross-infection [7].

Heating, Ventilation, Air Conditioning (HVAC) filters, heating, and air cleaner models are specifically designed to filter impurities or pollution in the floating air. Air purification devices and purification may potentially reduce pollutants in the air, especially tiny particles containing viruses. Air purifiers can be useful in places where the level of outdoor air pollution is very high or where indoor humidity and temperature are not suitable. According to a report by the WHO, nearly 7 million people died from air pollution-related diseases in 2012, and approximately 4.3 million were caused by indoor air pollution [8]. Volatile Organic Compounds are the main factor that leads to indoor air pollution-related deaths. They are associated with Sick-Building Syndrome and Building-Related Illnesses (BRI). Volatile Organic Compounds are mainly found in products of offices, electrical appliances, cleaning, and maintenance agents. In recent decades, indoor air quality has become a major challenge. Therefore, several studies are devoted to the development of new technologies to improve air quality [9].

Air purification technology can remove air pollutants and improve indoor air quality. One of the best strategies to control COVID-19 can be to prevent its spread through the air. This requires a suitable cleaner that can trap virus particles from the air and prevent them from spreading. Various strategies have been developed for this purpose. Recently, several studies examined methods, such as cyclones, gelatin filers, and Polytetrafluoroethylene filters, for trapping MERS-CoV and SARS-Co viruses followed by Polymerase Chain Reaction analysis, and were reviewed. This article tried to discuss the newest technologies and applications of air ventilation and air purification systems that can help in this area.

2 | TRANSMISSION OF RESPIRATORY VIRUS IN AIR

The recent rapid spread of COVID-19 worldwide appears to be a real public health emergency. As the epidemic is developing, lack of evidence in the SARS-CoV-2 transmission pathways has classically led to a change in the infection prevention and control guidelines between weathering and airborne droplets [10]. The SARS-CoV-2 transmission pathways are through aerosols, droplets, and exposure to pollutants. Virus transmission to people is more comfortable in the indoor environment. Virus COVID-19 is primarily transmitted through droplets and aerosols produced by the mouth or nose (these organs make ACE2 receptors on their cell surfaces).

Second, the transmission of the virus is through contact with infected surfaces. The critical point is that the virus can infect people in indoor places, such as dentistry and healthcare clinics. Scientists could not find any evidence that COVID-19 can remain stable in airflow for a long time. Because of the lack of a suitable procedure for preventing the spread of air-born particles, SARS-CoV-2 is transmitted in aerosols produced by COVID-19 patients in hospital rooms. Several health implications are suggested for reducing the spread of COVID-19, such as social distancing, the obligation of wearing masks in crowded places, and regular hand washing. Since exposure to viruses increases indoors, a distance of 1.8 m (6 feet) does not guarantee immunity against infection. Recent findings suggest that the spread of SARS-CoV-2 in ferrets is indeed facilitated by direct contact with particles containing SARS-CoV-2 virus [11]. The mechanisms of attachment and shedding of viruses in ferrets by direct and indirect methods are similar to those of inoculated viruses. These researchers showed that in both methods the ferrets are practically infected. Another study was evaluating the impact of temperature on the transmission of disease. Results demonstrated that temperature could have a role in escalating transmission rates [12]. In another study, researchers used surface samples and air to measure viral shedding from 13 patients with COVID-19. They reported that viral contamination was detected in all samples, supporting the use of airborne isolation precautions when caring for COVID-19 patients [13]. In contrast, others reported that SARS-CoV-2 RNA was undetectable in air samplers [14]. A survey on SARS-CoV-2 environmental pollution in the air samples isolation at the ward and ICU have shown from the 218 ICUs only one sample contained SARS-CoV-2 RNA and of the 182 isolation ward samples, 9 samples contained SARS-CoV-2 RNA [15].

3 | AIR VENTILATION COULD REDUCE TRANSMISSION OF THE VIRUS

People usually spend most of their time in indoor places. Therefore, air quality is critical for public health [16]. Advanced air filters and HVAC systems could help decrease airborne pollutants, including viruses, in different places. Although air purification or filtration is not a perfect strategy for protecting people from the COVID-19 virus, filtration can be part of a strategy to reduce the possibility of COVID-19 spreading in indoor air. An effective air purifier should remove small particles (range 0.1–1 μm) in the air [17]. The size of SARS-CoV-2 is estimated around 0.1 μm in diameter [18] and a suitable air purifier could effectively trap the virus. The capability of an air purifier can be evaluated in a variety of ways.

Sometimes, manufacturers might indicate the efficiency of particle filtration for specific particle dimensions. Likewise, some other manufacturers use the Clean Air Delivery Rate system to rate the quality of air purification or filtration. In addition, High-Efficiency Particulate Air (HEPA) filters are frequently used. This filter can remove at least 99.95% of particles with diameter of less than 0.3 μm [19, 20].

Various factors could significantly influence HVAC performance in preventing coronavirus diffusion. Several effective approaches to reducing virus transmission are included ventilation increasing, advanced filtration, humidification, and mechanical hygiene improving [21]. Animals and humans release large amounts of viral and bacterial pathogens into the air. It is necessary to install a filter to prevent particles from spreading to indoor locations. For this purpose, in a previous study, HVAC systems of the buildings are equipped and make the buildings maintain their fresh and healthy air. Then samples were collected from building ventilation filters to evaluate the types and concentrations of virus aerosols [22]. They emphasised that existing building HVAC filters might be a practical method to detect airborne viruses. Heating, Ventilation, Air Conditioning filters can serve as integrated long-term bioaerosol sampling devices to provide basic information on the aerobics and epidemiology of airborne viruses. These methods allow researchers to better investigate the spread of airborne viruses and identify potential agents of bioterrorism [22]. We could not deny the threat of the spread of common influenza viruses through small-particle aerosols. However, the link between the safety of the particle's ineffectuality and the risk of transmission at long distances through HVAC systems could be improbable. Implementing HVAC systems in buildings solves reduce the risk of influenza virus transmission [23]. In one study, the results showed that the position of an infected patient affects the risk of infection among health care workers and other residents of the same ward, and increasing the rate of air change in the ward minimises the risk of direct contamination. [24]. It was reported that the air change rate of 9 h per day can reduce the floating and deposition time of respiratory virus particles while increasing their energy efficiency [25]. This is a useful reference method for hospital administration, which can minimise the risk of airborne virus infection through better ventilation design methods [25]. A recent study investigated the effect of Air PurificationT on critical commercial and clinical outcomes compared to HEPA standard filtration. They found that patients admitted to areas with advanced air purification technology had statistically significant improvements in the length of stay, discharge time and costs. In addition, the rate of hospital infections in these areas showed a decreasing trend [26]. Since people spend almost 90% of their time Indoors, Air Quality inside the room is a global concern. Bio-aerosols (e.g. viruses, fungi, and bacteria) are the main pollutants that frequently contaminate the air [27].

A study on the results of Cultivated Bacterial Aerosol showed that once the APs are active, indoor air quality will increase by nearly 50% [28]. The researcher tested the capability of 4 filter prototypes (fibreglass filter (EU class F9), pre-filter (EU class G4), filter mat (EU class M6), and F8-9) to remove aerosol-containing Bovine Enterovirus 1, Equine arteritis Virus, *Actinobacillus pleuropneumoniae*, *Staphylococcus* (S.) aureus, and Porcine Reproductive and Respiratory Syndrome Virus from the air [29]. Depending on the type of filter used, the filter can block up to 99.9% of bacteria and 98% of viruses. Therefore, air filtration and other strict biosecurity measures can minimise the risk of transmitting airborne pathogens to animal facilities [29]. However, we should be cautious about using air purifiers to control the spread of COVID-19. The droplets may extend into the entire airflow of the air purifier when a person releases droplets near the air filtration system. In the following, a single infected person can become an infected group. The setting of the air purifier needs further research, because efforts to suppress infections through the air purifier may lead to new infections [30].

4 | USING OZONE AND RELATIVE HUMIDITY STRATEGY

Ozone is One of the best effective agents against the virus. It has been demonstrated that a combination of Relative humidity with low doses of ozone could be a powerful disinfectant for airborne microscopic pathogens such as φX174, MS2, and MNV-1 [31].

5 | USING ULTRAVIOLET RADIATION STRATEGY

COVID-19 has a high sensitivity to ultraviolet radiation, for this reason, UV-C radiation can effectively disrupt COVID-19 structures. Therefore, the technical parameters of UV-C fluorescent lamps are compatible with HVAC operating conditions. Observations have shown that it could inactivate more than 97% of the Influenza A virus, 90% of the SARS-CoV-2 virus, and 100% of *Legionella pneumophila.* UV-C emitters in HVAC systems enable simultaneous circulation, recuperation and disinfection of air pollution [32].

6 | HEAT STRATEGY

The survival of SARS-CoV-2 in the aerosol is around 4 hours. On the other hand was shown that above 60 °C air temperature, the virus becomes non-infectious. So, installing recovered heat of exhaust air in HVAC systems is a novel technology to eliminate SARS-Cov-2 activity. In this respect, at 60 °C, droplets containing the virus cannot exit from the exhaust duct. In a condenser, the heat is dissipated, which can heat the exhaust air [33]. The risk of airborne virus distribution in hospitals depends on airflow behaviour. This strategy also could change the direction of the air and exhaust conditions. One of the most efficient in removing contaminants is an improved isolation room ventilation procedure. In hospitals, the threat of airborne virus transmission is strongly influenced by the airflow and its change of direction due to the location of the air source and its outlet. Improved isolation room ventilation method is beneficial to the elimination of pollutants [34].

7 | ELECTRICAL NANOFIBRE FILTER STRATEGY

COVID-19 is about 60–140 nm in diameter with an average size of 100 nm (i.e. nanoparticles suspended in air). When this tiny germ is attached to human secretion, including droplets of saliva and nose, it could be easily transmitted through airborne. Polyvinylidene fluoride is a technology based on Nanofibres based filtration membranes that can effectively slow down the spread and deadly airborne coronavirus. The target of this technology is nanoparticles with sizes smaller than 100 nm. A sub-μm aerosol generator could generate sodium chloride-based aerosol. This type of aerosol has a diameter of 50–500 nm, which simulates viruses and attached aerosol. The suitability of Polyvinylidene fluoride Nanofibres for their morphology, uniformity, bead-free, and straightness has been approved. The range of dimensions of fibres is 84–349 nm [35]. Eventually, the corona discharge charged the fibres and achieved a virus filtration efficiency of 90%. However, interference between adjacent fibres and electricity leads to a rapid marginal increase in efficiency, but the pressure drop across the filter is much higher [36].

The aerosol concentration was assessed with a Condensation Particle Counter upstream of the aerosol. Then the concentration of the downstream was also calculated after the test filter. Therefore, filtration efficiency can be estimated using the following formula [36]:

$$\eta(\mathrm{Dp}) = 1 - \frac{\mathrm{Cd(Dp)}}{\mathrm{Cu(Dp)}} \quad (1)$$

where η is the class efficiency of the aerosol size Dp, Cu is the concentration upstream of the test filter, and Cd is the concentration downstream. The examination filter had a diameter of 7 cm. The pressure drop across the filter was likewise calculated. The quality factor can be described as [36]:

$$\mathrm{QF} = -\frac{\ln(1-\eta)}{\Delta \mathrm{p}} \quad (2)$$

In some modules with smaller fibre packing density, the fibres are redeployed in the filter and each module is divided by a permeable, electrical-insulator material, and the electrical intervention between adjacent charged fibres will be reduced [37]. Furthermore, reduced airflow resistance is achieved by introducing the scrim materials into the additional scrim material. A new way to diminish pressure drop is to distribute equal amounts of nanofibres to attain a particular efficiency in multiple layers. Each thin layer of nanofibres is supported by a spongy substrate with large transparent micropores [38] in between distributed in the filter stack. Multi-layers have actually been demonstrated to have slightly lower filtration efficiency than single layers. Nevertheless, the fibre density of each module compared to a single layer introduces larger pores and significantly decreases pressure loss [39]. From this perspective, the quality factor can be relatively maintained with increasing fibre quantity to reach high filtration efficiency [39, 40]. The diameter of the fibre determines the optimal amounts of fibre in each module. The diameter of the high-performance small fibre requires fine fibres per unit. Conversely, if there is no additional pressure drop, large-scale fibre length requires a larger amount of fibre per unit to compensate for the lower performance [41]. This method has led to the development of four brand-new optical fibres with different diameters (84, 191, 349, and 525 nm) in a single layer for the removal of 100 nm air-borne COVID-19 to achieve high efficiency at a pressure drop below 30 Pa. Although some ultra-low pressure drops can reach efficiencies of over 90%, other filters that meet close to 30 Pa have an efficiency of approximately 94% [36].

Hypothetical filter enhancements derived from Precision Engineering Attitude provide technology to protect people from deadly airborne viruses, including COVID-19 and air pollutants, that can cause unforeseen chronic diseases [35].

8 | AIR CIRCULATION BY NATURAL OR MECHANICAL VENTILATION

Wind and thermal energy are two critical factors that dramatically influence air circulation. Temperature variation is an agent that leads to airflow replacement. During natural air circulation, the room's air is returned with outdoor airflow. This phenomenon effectively regulates temperature and humidity and reduces indoor contaminants, such as virus-containing particles [42]. Auxiliary ventilation devices applicate advancement machines to enhance air exchange with the external environment, such as airflow, within a room. There are several forms of this ventilation, including fans, standalone air conditioners, portable units, or combined systems involving HVAC systems [43, 44].

9 | THE CURRENT AIR PURIFIER PURIFICATION TECHNOLOGY

The famous air cleaning technologies are derived from gas treatment technologies and industrial waste gas. We can categorise this technology into different classes: dust collectors, gas refining, and sterilisation technology [45] (Table 1). Different classes are available depending on European or American standards [17] (Figure 1).

TABLE 1 Air purifier technologies and their characteristics [46].

Machineries	Advantages	Disadvantages
Electrostatic filters	- Able to remove airborne particles, viruses, and odours	- Maybe is not as useful as traditional filters
	- Relatively longer lifespan	
HEPA filters	- Powerful in removing 99.97% of 0.3-μm particles	- Short perdurability
	- No ozone production or other harmful byproducts	- Ineffective in removing viruses, harmful gases, and odours
Photo-catalytic oxidation	- Viruses and gases are effectively removed	- Ineffective in removing airborne particles
		- Ozone production
Ultraviolet light	- Effective in sterilising air that passes UV lamps via forced air	- Airborne particles could not be removed

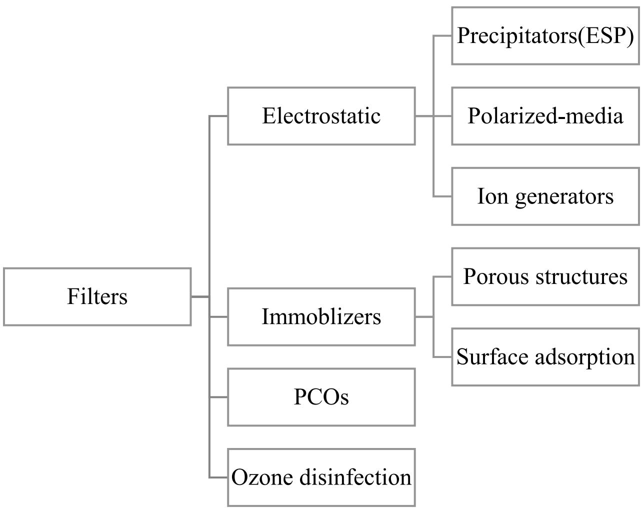

FIGURE 1 Different types of filters.

10 | POLARISATION AND IONISATION ELECTRONIC FILTERS

A highly coherent electronic air cleaner is introduced first in 1996 by Constantine's J. Joanna. In this technology, pads of dielectric fibres are inserted between grounded screens and ionising elements.

The ionising elements polarise the fibrous pads and, along with that, dust-transitory particles were charged via the filter. In this method, negative or positive dust particles are collected and attracted to the fibrous pads, and the efficiency is improved [47, 48].

10.1 | Polarised-media electronic air cleaners

The electronically polarised medium air cleaner was created by Engineering Dynamics LTD. It is also known as the Dynamic Medium Air Cleaning System which is associated with the physical processes of impingement, polarisation, and agglomeration to reach a very high multi-pass efficiency with very low-pressure drop [49].

These types of equipment expand the mechanical standard of removal mechanisms linked to fibrous filters by charging the fibres [50].

The agglomeration process provides effective captures of small particles [49]. In a novel filter media, a unique fibrous material with permanent electrostatic charges called "electret" is used. These types of filters are popular among manufacturers of air-cleaning devices [50]; The composite technique includes air filtrating (composed of metal screens for applying an electric field surrounded by two polarized fibreglass media), mixing turbulence, and electrostatic deposition was reported that could reduce the concentration of 22Rn progeny [51]. A study showed that the filtration of electrically charged Continual Filament Melt-spun (CFM) media is combined with a static structure and charge [52]. Several field studies examined structures of electrically charged and non-charged CFM media and explained their potential mechanical filtration properties. Research results showed that the synergistic relationship between the web structure and charge distribution is the key to electret HVAC media's performance characteristics [17].

Moreover, these studies recommended that non-charged and charged (CFM) media provide better long-term and efficient filtration than polyester/cotton media of the basis weight [53]. They distinguished the triboelectrically-charged nonwoven electrets, which engaged wool, adopted needle-punched nonwoven technology, and polypropylene fibres. They undervalue that this electret media's filtration efficiency was exceptionally higher than that of neutral media and is considered a perfect material for fibre filtration. Also, they proposed that the duration and area of electrical charge might decline with the rise of fibre diameter. Other studies tested the primary parameters of electret filter media including filter thickness, fibre charge density, packing density, face velocity, and fibre diameter through theoretical experimental methods and models [54]. This study reported that face velocity and fibre charge density are larger for filtration efficiency than other parameters. Likewise, filtering efficiency increased with decreasing face velocity and rising fibre charge density.

Furthermore, several parameters would be increasing aerosol perforation through the electret filter media such as filter thickness, width of filter, packing density, raising the amount of electric charge, decreasing fibre charge density, and packing density. In contrast, aerosol perforation has a positive proportion with face velocity and fibre diameter [55]. Different types of polarized-media filters because of electrostatic force are shown in Figure 2.

10.1.1 | Mechanism of action of polarised electret in air cleaners

Airborne particles will be polarized and flooded on the fibres when proximate to charged fibres.

Charged media filters based on a high power of voltage supply mainly use a filter medium-size assembled from an insulating material medium, such as glass, ethers, or esters of cellulose.

A non-uniform and enormous electrostatic field was generated from a grid composed of alternatively charged and grounded members close to the media. The ionisation stage is designed in the charged media filter devices; so that particles are first charged in a corona discharge ioniser, then accumulated on a charged media filter mat. This configuration delivers higher efficaciousness than without using the prior ionisation stage [50]. In Table 2, the mechanism of filtration in various electret approaches is revealed.

10.2 | Ioniser purifiers

Air ions naturally are produced by several normal phenomena, including lightning, wind, snow, waterfalls, combustion, and the rolling of ocean waves. Another source of production of air ions is the direct-current electric transmission line. Although the intermittent transmission line emits air ions, the distance from the ground conductor is not great because most of the air ions are absorbed into the conductor and neutralised with each alternating cycle [56].

Negative Air ions are generated by the light of a specific wavelength through the direct ionisation of air molecules. For instance, UltraViolet (UV), is a certain wavelength of light, which is used directly to ionise air atoms to generate Negative Air ions [57]. The key point for evaluating air quality is negative ions. They could effectively eliminate fog, dust, and some pathogens. They react with positive ions and activate air. It is essential to improve the quality of life.

By activating immune cells and affecting sleep patterns, negative ions positively could impact health maintenance. Generating negative ions discharge is an ideal method to improve the way to improve indoor air quality. However, during this process, ozone is generated. Corona wire heating is a suitable method to suppress the production of ozone [58]. Different types of ion generation were shown in Figure 3.

10.2.1 | Mechanism of action of ioniser air purifiers

Public ionisers use ionisation to decay molecules in the air. This technique creates robustly negative ions and causes adjoining molecules like ozone, positive ions, and others. Nature spontaneously produces negative ions and can create a sense of well-being. Positive ions are considered to have deteriorating effects on the human body. Conversely, negative ions have been understood that they have a significant positive impact on health conditions. Therefore, there are a few applications that use negative ions.

In Negative ionisers, the Polymer Fusion Technology is implemented to fusion the C60 series of carbon materials with other materials (such as oxygen or carbon) alternate chemical, electric, and physical attributes of ionised particulate matter. Most notably, eco-friendly material (excluding eight heavy metal pollutants) can be decomposed at a high temperature. This confirms compliance with global environmental security standards. Synthesis of high or super-high-molecular-weight fullerene gives it the privileged to have extraordinary chemical and physical properties. With their reduced operative static,

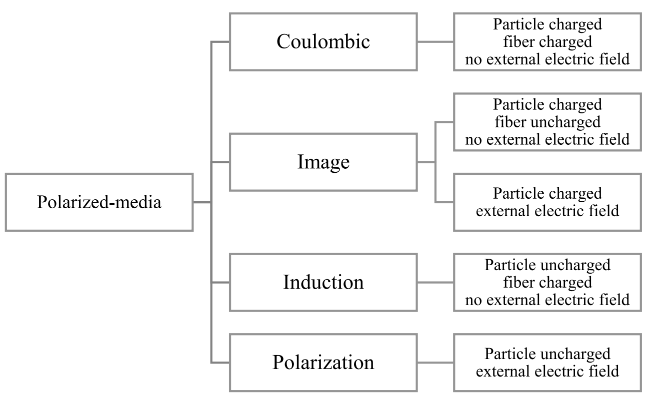

FIGURE 2 Different types of polarised-media filters caused by electrostatic force.

TABLE 2 Filtration mechanisms of different electret filtration processes [17].

Particle	Fibre	E-field	Electrostatic force	Equation
Charged	Charged	None	Electrostatic force	$N_E = \frac{qQ}{2\pi\varepsilon_0 r}$
Charged	Neutral	None	Image force	$N_E = \frac{1}{16\pi\varepsilon_0}\left(\frac{\varepsilon_f - 1}{\varepsilon_f + 1}\right)\frac{q^2}{(r - r_f)^2}$
Neutral	Charged	None	Induction force	$N_E = \frac{d_p^3}{8\pi\varepsilon_0}\left(\frac{\varepsilon_p - 1}{\varepsilon_p + 2}\right)\frac{Q^2}{r^2}$
Neutral	–	External electric field	Polarisation force	$N_E = \frac{\pi\varepsilon_0 d_p^3}{4}\left(\frac{\varepsilon_p - 1}{\varepsilon_p + 2}\right)\nabla \lvert E\rvert^2$
Charged	–	External electric field	Image force	$N_E = qE$

Note: ε_0 = permittivity of free space; ε_p = dielectric constant of the particle; ε_f = dielectric constant of fibre; d_p = particle diameter; d_f = fibre diameter; r_f = fibre radius; q = net charge on particle; Q = net charge on a unit length of fibre; E = externally applied electric field; E = electric field with components; θ = polar angular coordinate; and r = radial distance from fibre axis.

these materials can produce many pure OH- electrons This feature reduces machine performance and operator static, and results in the rapid movement of particles, dust and airborne droplets down to a height of 10 cm above the ground.

Consequently, the floating, storage, and attachment of airborne particles are significantly prevented. As large amounts of airborne particles are disinterested, the construction defect rate can be reduced meaningfully [59]. Several possible beneficial effects of the negative ion strategy are indicated in Figure 4.

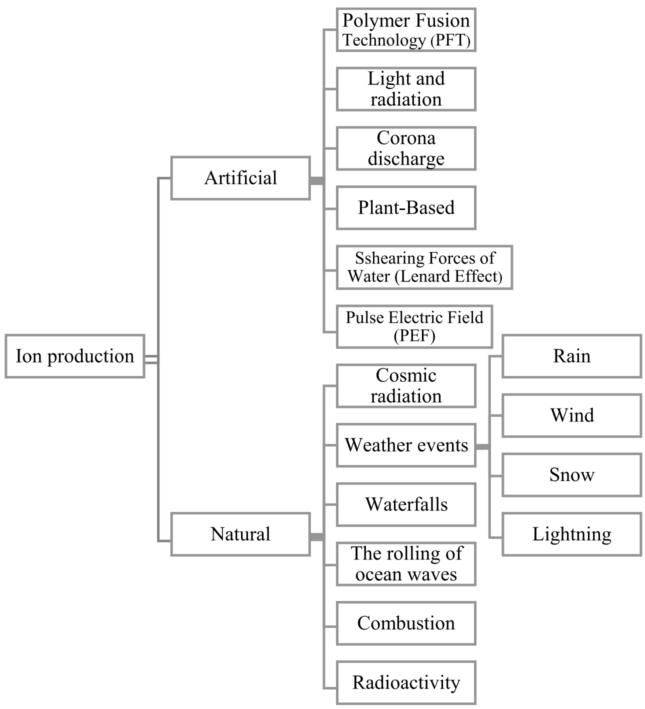

FIGURE 3 Ion generation classification [57, 59].

11 | PHOTO-CATALYTIC OXIDATION

A new technology called Photo-catalytic Oxidation (PCO) employs Titanium Dioxide (TiO_2) and visible or near-UV light source to remove air stream pollutants [60]. Present procedures are used to eliminate virus contaminants. Photo catalysis for air treatment is a feasible, economical green process. Besides, conventional air purifiers spend significant energy and release tremendous greenhouse gases, while this technology is more eco-friendly and requires less disposal of used materials [61]. Since photo catalysis for air treatment could excrete dangerous organic molecules, it potentially eliminates SARS-CoV-2 viruses [62]. Another approach of PCO technology is using antiviral Copper oxide/Titanium dioxide (CoO/TiO2) which works with diverse mechanisms. The CoO nanoparticles comprise valence states such as Cu (I) and Cu (II). Cu (I) species disrupt the protein structures of the virus, thus causing significant antiviral properties even if a source of light is not available [63, 64]. In the PCO reaction, semiconductors of a doped or pure metal oxide including Zno, CdS, TiO_2, and Fe (III)-doped TiO_2 are frequently used as the photo-catalysts TiO_2 which can destroy the bacteria and viruses, at the same time. Consequently, it can reduce the air contaminants, such as formaldehyde, sulphur dioxide, and nitrogen dioxide [65].

In Table 3, Figure 5, several recent approaches and classifications in PCO technology were brought.

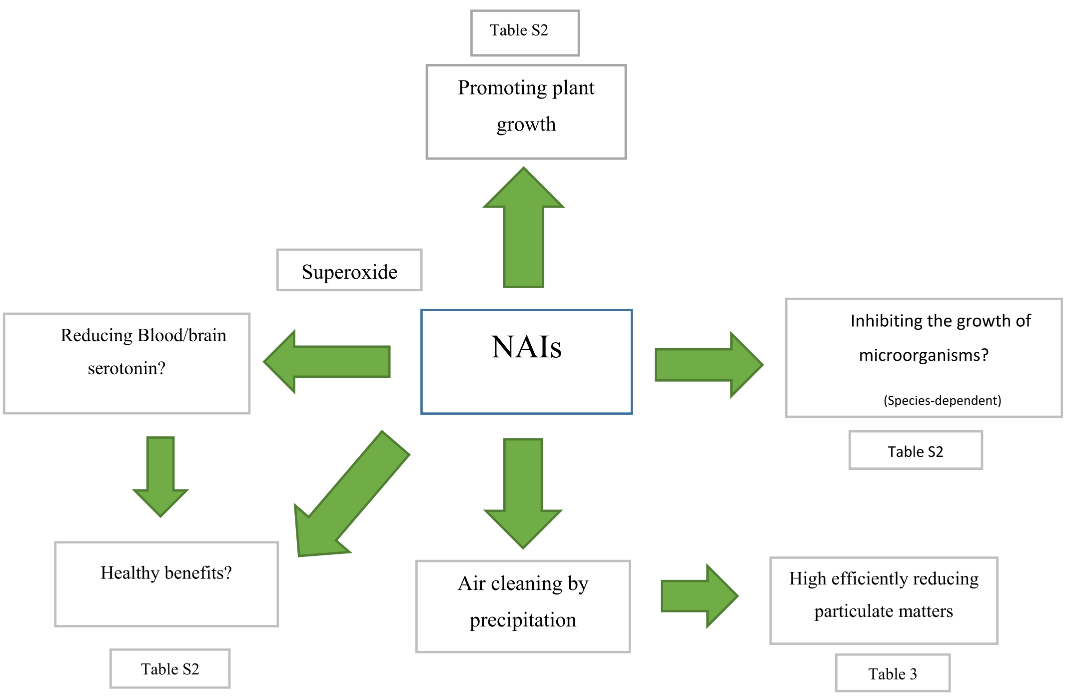

FIGURE 4 The positive effects of Negative Air ion (NAI) [57].

11.1 | Mechanism of action of photo-catalytic oxidation in air pathogen cleaning

In a study conducted in 2020, an in situ solvothermal method was employed to arrange several diverse photo-catalysts, including N-doped TiO_2, Ag-doped TiO_2, TiO_2, TiO_2, and N/Ag co-doped TiO_2. This was resulted in more successful photo-catalytic degradation of gaseous ammonia (NH3) under visible-Light-Emitting Diode (LED) irradiation.

Likewise, Yang et al. (2010) provided a series of N-doped anatine TiO_2 photo-catalysts active under the visible spectrum [83]. Besides, porous Polyurethane is used to immobilise a V-dopant precursor by establishing chemical bonds. The porous substrate could raise adsorption in photo-catalyst and enhance the dismissal of the toluene from aerosols. This approach is efficient for the photo-catalytic elimination and mineralisation of toluene under visible spectrum and room temperature [84]. In another research, based on the sol-gel and wet impregnation approaches, NH_4VO_3 was used as a doped precursor to prepare a new V2O5/S-TiO_2 (x) photo-catalyst. This novel material displayed significantly greater photocatalytic activity and visible-light absorption [85]. Furthermore, under the availability of the light source, CoO Nanocluster possesses Cu(II) species attends as an electron acceptor over photo-induced

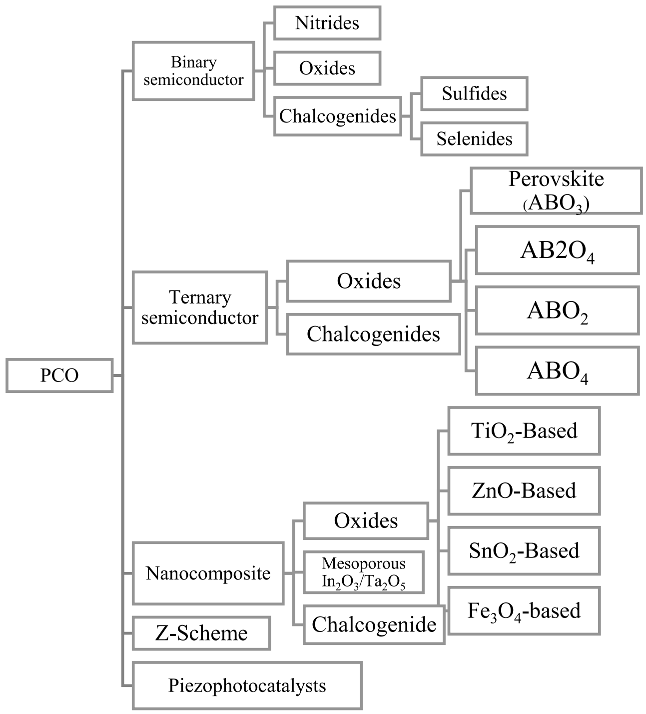

FIGURE 5 Photo-catalyst classifications [82].

TABLE 3 Recent photo-catalytic oxidation (PCO) articles.

Materials	Target(s)	Mechanism	Ref.
F, Cu-doped TiO_2	Methicillin-resistant *Staphylococcus aurous* (MRSA)	Visible-light activated (VLA) photo catalysis and copper ion toxicity	[66]
Pd-TiO_2	Airborne MS2 viruses	VUV photolysis reaction in the gas phase due to vacuum UV higher photon energy (6.70 eV) and VUV photo catalysis	[67]
Cu-TiO_2 nanofibres	Bacteriophage f2 and its hosted. coil285	VLA photo catalysis	[68]
Graphitic carbon nitride (g-C_3N_4) with low-density porous expanded perlite (EP) mineral (g-C3N4/EP-520 composite)	*E. coli* and MS2	VLA water-surface-floating photo catalysis	[69]
TiO_2 coating	Aspergillums Niger spores, *E coli*, *Micrococcus luteus*, *Bacillus* subtitles (cells and spores),	UV light-activated (UVLA)photo catalysis	[70]
TiO_2 and ZnO	*S. Aurous*, *P. aeruginosa*, *C. freundii*, S. saprophytic us, *E. coli*, MRSA, A. fumigatus, Penicillium	UV light-activated (UVLA) photo catalysis	[71]
Nano-sized TiO_2 which coated porous ceramic	Influenza virus H1N1	UVLA photo catalysis	[72]
TiO_2-coated Pyrex	*Escherichia coli*	UVLA photo catalysis	[73]
TiO_2-coated glass fibre filter	*Escherichia coli*	UVLA photo catalysis	[74]
Polysiloxane coating polyurethane foam and anchoring the active TiO_2 particles	*Legionella pneumophila*	UVLA photo catalysis	[75]
TiO_2 thin films/glass fibre	*Escherichia coli*	UVLA photo catalysis	[76]
TiO_2-coated cellulose/polyester fibre	*Escherichia coli*	UVLA photo catalysis	[77]
Cu-doped TiO_2/PU	*C. fermata*	VLA photo catalysis	[78]
TiO_2-coatedmechanical filter	*Escherichia coli*, *Candida famata*, λ vir phage	UVLA photo catalysis + negative air ions	[79]
Ag–TiO_2/PU	*Escherichia coli*	VLA photo catalysis + adsorption	[80]
Silver-doped TiO_2/activated carbon felt (ACF)	Penicillium expansum Spores	Photoelectron and UV light activated catalysis	[81]

Abbreviation: VUV, Vacuum-ultraviolet.

interfacial charge transfer. As a result, these nanoparticles could establish a type of anti-virus Cu(I). They create numerous holes with robust oxidation power in the valence band of TiO_2 under visible-light irradiation [64]. The table below describes the efficacy of PCO technology in the reduction of various pathogens (Table 4).

12 | USE OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN THE HEATING, VENTILATION, AIR CONDITIONING

Artificial intelligence (AI) and machine learning (ML) is a new area of research that is a promising technology used by many healthcare providers. It can lead to increased speed and improved processing power and perform health care tasks with better quality and higher reliability than humans [87]. Thus, healthcare clinicians and industries worldwide operated diverse AI and ML technology to manage the COVID-19 pandemic, along with challenges during the outbreak. However, AI in the medical industry is not dedicated to substituting human interactions, but provides decision support for healthcare based on what it is modelled for [88]. Contact tracing is an exciting strategy for applying AI and ML in confrontation with SARS-Cov-2. The contact-tracking is for recognising and controlling people that are infected with COVID-19. For this purpose, diverse countries could use digital contact-tracing procedures with phone software, using various techniques such as Global Positioning System, Bluetooth, contact details, Social graph, mobile tracking data, network-based API (Application Programing Interface), system physical address, and card transaction data. All these apps are created to collect personal data which is intercepted through AI and ML technology to track someone who has recently been infected with SARS-Cov-2 [89]. We suggested equipping air purifiers like HVAC with this technology for quickly identifying infected people and automatically turning on and speedily cleaning the environment. In a recent study, a group of researchers introduced a demand-driven deep learning-based framework with aid of a deep learning algorithm and the artificial intelligence-powered camera that could be integrated with a management system of building energy and deliver precise predictions of occupancy conditioning and optimising the HVAC systems [90].

TABLE 4 Photo-catalytic oxidation (PCO) proven pathogen reduction [86].

Pathogen	Results
Norwalk virus (nor virus)	99.6% reduction
Methicillin-resistant Staphylococcus aurous (MRSA)	99.9% reduction
Staphylococcus aurous (S.aureus)	99.8% reduction
Clostridium difficile	99.8% reduction
Listeria monocytogenes (Listeria)	97.3% reduction
Group A streptococci (GAS)	97.4% reduction
Pseudomonas aeruginosa	99.9% reduction
Streptococcus pneumonia	99.9% reduction
Bacillus anthracis (Anthrax)	97.6% reduction
H1N1 (Swine flu)	99.9% reduction
H5N1 (Bird flu)	99.9% reduction
Stachybotrys chartarum (Fungus and spores)	99.4% reduction
Candida albicans (Mould and spores)	99.5% reduction
Volatile organic compounds (over 60 VOCs)	91% average reduction
Volatile organic compounds (ammonia/Nox/H_2S/O_3)	89% average reduction
Odours (Alkanes, Acetone, Alcohols, Ketones)	87% average reduction
Basidiospores (Allergens, Fungus, Ringworm)	99.4% reduction
Allergens (pet dander, dust mite antigens)	91% reduction

13 | PORTABLE AIR PURIFIERS IN CURBING COVID-19

The Centres for disease Control and Prevention presented a guideline for airborne transmission emphasising Portable HEPA filters. Portable HEPA filters integrated with a powered fan system are an excellent choice for extra air cleaning. A recent research reported that installing a portable HEPA could effectively elevate the ventilation rate. They demonstrated that infections airborne by 75% would be decreased in a room [91]. American Society of Heating, Refrigerating, and Air-Conditioning Engineers also suggested that using portable air cleaners in confined areas (where difficult to hold social distancing, such as small public spaces, fitness centres, employee locker rooms or employee break rooms where the ventilation is inadequate) could be extremely practical [92]. The U.S. Environmental Protection Agency advises “Considering the use of portable air cleaners to improve ventilation, filtration and heating especially in areas where adequate ventilation is difficult to obtain”. It is possible to limit the spread of droplets that can carry infectious viruses by guiding the airflow so that it does not blow directly from person to person [93]. A few studies have also investigated the usage of air purifiers in particular rooms to decrease the risk of illness. For instance, Zhao et al. [94] conducted research and recommended the use of air purifiers in dentistry clinics as an additional protection approach during the COVID-19 epidemic Action must be taken quickly to improve indoor air quality and protect households from respiratory disease in the event of future pandemics [95]. To investigate the qualitative and quantitative efficiency of the portable filtration systems in controlling the spreading of COVID-19, validated Computational Flow Dynamics models were developed and equipped in two common public spaces ballroom and a restaurant. The results of the study showed that the majority of the particles emitted by the mouth of the infector are dispersed indoors before settling on people, equipment, tables, walls and the floor, while only a small fraction of these particles are evacuated by the central air conditioning system. [96]. An observation study in clinical spaces of a hospital with patients with COVID-19 indicated that aerosols quickly crossed from the patient room into other parts of the hospital. They reported that portable air purifiers effectively cleared aerosols and decreased their spread to other sites. They demonstrated two small portal air purifiers in a single patient room approximately 99% of aerosols emptied within 5.5 min [97]. Overall, we can conclude that using portable air purifiers might assist as to control COVID-19 in closed places where air flowing is low.

14 | FUTURE PERSPECTIVES

Due to the high capacity of the COVID-19 airborne epidemic, many people are exposed to the disease in most places, including schools, hospitals, stores, and other public places. Indoor air ventilation systems with proper functioning are essential to prevent indoor pollution in building a healthy environment. On the other hand, since micro particles in airborne such as dust and smoke can promote the transmission of the virus, to combat this virus, these air ventilation systems are beneficial in different approaches. Moreover, it can be a relatively suitable strategy with more excellent knowledge of the virus, including its structure, mechanism, unique characteristics, and sensitivity to factors that play a role in its persistence and transmission. However, using this knowledge also need further studies on air purification and ventilation and combining that knowledge for designing an appropriate system to minimise virus transmission.

Heating, Ventilation, Air Conditioning systems conventionally operate at very prescribed ventilation rates and temperature settings [98] without focussing on energy efficiency. Therefore, to attain optimal energy and a healthy indoor environment, efficiency would be the chief challenge for HVAC systems inventors. Novel and developed building ventilation technologies could provide solutions to save energy and achieve building energy efficiency through different aspects such as adjusted system sensing, progressive ventilation systems [99], adjusted system sensing [100], monitoring [101], regulatory technologies, and data analytics. Fluid mechanics modelling also has widely been applied to form a scheme and use in advanced ventilation systems.

Nevertheless, there is an extensive way to online control different ventilation systems by CFD57. A CFD-based ML approach using artificial intelligence (AI) technology can be a prospective technique to run high-speed and accurate airflow expectations to comprehend online ventilation control. Another approach includes using recovered heat from exhaust air in HVAC [33], Electrical Nanofiber filter strategy for capturing COVID-19 [35], or other strategies by using ultraviolet radiation, and UV-C radiation can disrupt COVID-19 structures [32]. These approaches are currently in the experimental stage. More comprehensive research is needed to achieve a proper approach to controlling the virus.

15 | CONCLUSION

The spread of the SAR-COV-2 virus through the air has been proven in most studies. In numerous studies, to prevent the spread of the disease, one of the common strategies is to prevent its spread by air. These days, various studies are underway in the field of air purifiers. Numerous studies show that air purifiers and ventilation systems play an important role in controlling the spread of infectious agents, especially in indoor spaces. Some studies have suggested using advanced HVAC systems. Others have suggested the use of temperatures above 60 degrees Celsius, UV-C fluorescent lamps, and the use of ozone to disinfect the virus. Furthermore, using an electrical nanofibre filter indicated could efficiently discharge the virus and decrease the infection with SAR-COV-2. However, by considering the widespread problem of the SAR-COV-2 virus and its variants created for the economy and normal life of human society, there is still a need to introduce a suitable and comprehensive ventilation system to control such problems. It seems that the use of an integrated HVAC system that uses a combination of different strategies such as heat and UV-C fluorescent lamps can effectively prevent spread of infectious agents.

AUTHOR CONTRIBUTIONS

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CONFLICT OF INTEREST STATEMENT

No authors have any financial or other conflict of interest.

PERMISSION TO REPRODUCE MATERIALS FROM OTHER SOURCES

None.

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No original data was produced for the writing of this review.

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REFERENCES

1. Wang, H.J., et al.: Review and prospect of pathological features of corona virus disease. Fa Yi Xue Za Zhi. 36(1), 16–20 (2020)
2. Manoj, M.G., et al.: Potential link between compromised air quality and transmission of the novel corona virus (SARS-CoV-2) in affected areas. Environ. Res. 190, 110001 (2020). https://doi.org/10.1016/j.envres.2020.110001

3. In't Veen, J., Kappen, J.H., van Schayck, O.C.P. (eds.) Air Pollution: A Determinant for COVID-19? pp. 164. Ned Tijdschr Geneeskd (2020)
4. Kouni, S., et al.: Evaluation of viral co-infections in hospitalized and non-hospitalized children with respiratory infections using microarrays. Clin. Microbiol. Infection: the official publication of the European Society of Clinical Microbiology and Infectious Diseases 19(8), 772–777 (2013). https://doi.org/10.1111/1469-0691.12015
5. Shi, T., et al.: Aetiological role of common respiratory viruses in acute lower respiratory infections in children under five years: a systematic review and meta-analysis. Journal of global health 5(1), 010408 (2015). https://doi.org/10.7189/jogh.05.010408
6. Spaeder, M.C., Fackler, J.C.: Hospital-acquired viral infection increases mortality in children with severe viral respiratory infection. Pediatric Critical Care Medicine | Society of Critical Care Medicine 12(6), e317–e321 (2011). https://doi.org/10.1097/pcc.0b013e3182230f6e
7. Zhou, Y., Ji, S.: Experimental and numerical study on the transport of droplet aerosols generated by occupants in a fever clinic. Build. Environ. 187, 107402 (2020). https://doi.org/10.1016/j.buildenv.2020.107402
8. Mannucci, P.M., Franchini, M.: Health effects of ambient air pollution in developing countries. Int. J. Environ. Res. Publ. Health 14(9), 1048 (2017). https://doi.org/10.3390/ijerph14091048
9. Taranto, J., Frochot, D., Pichat, P.: Combining cold plasma and TiO2 photocatalysis to purify gaseous effluents: a preliminary study using methanol-contaminated air. Ind. Eng. Chem. Res. 46(23), 7611–7614 (2007). https://doi.org/10.1021/ie0700967
10. Santarpia, J.L., et al.: Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care. Sci. Rep. 10(1), 12732 (2020). https://doi.org/10.1038/s41598-020-69286-3
11. Kim, Y.-I., et al.: Infection and rapid transmission of SARS-CoV-2 in ferrets. Cell Host Microbe 27(5), 704–709.e2 (2020). https://doi.org/10.1016/j.chom.2020.03.023
12. Riddell, S., et al.: The effect of temperature on persistence of SARS-CoV-2 on common surfaces. Virol. J. 17(1), 145 (2020). https://doi.org/10.1186/s12985-020-01418-7
13. Santarpia, J.L., et al.: Transmission potential of SARS-CoV-2 in viral shedding observed at the university of Nebraska medical center. medRxiv, 2020.03.23.20039446 (2020)
14. Chan, V.W.M., et al.: Air and environmental sampling for SARS-CoV-2 around hospitalized patients with coronavirus disease 2019 (COVID-19). Infect. Control Hosp. Epidemiol. 41(11), 1258–1265 (2020). https://doi.org/10.1017/ice.2020.282
15. Lei, H., et al.: SARS-CoV-2 environmental contamination associated with persistently infected COVID-19 patients. Influenza and other Respiratory Viruses 14(6), 688–699 (2020). https://doi.org/10.1111/irv.12783
16. Cao, P., Xia, W.: Effect of Indoor Air Pollution on Human Hazard and Prevention & Control (2004)
17. Liu, G., et al.: A review of air filtration technologies for sustainable and healthy building ventilation. Sustain. Cities Soc. 32, 375–396 (2017). https://doi.org/10.1016/j.scs.2017.04.011
18. Bar-On, Y.M., et al.: SARS-CoV-2 (COVID-19) by the numbers. Elife 9, e57309 (2020). https://doi.org/10.7554/elife.57309
19. Zhang, J., et al.: Study of viral filtration performance of residential HVAC filters. ASHRAE J. 62(8), 26–32 (2020)
20. Ding, J., Yu, C.W., Cao, S.-J.: HVAC systems for environmental control to minimize the COVID-19 infection. Indoor Built Environ. 29(9), 1195–1201 (2020). https://doi.org/10.1177/1420326x20951968
21. Light, E., et al.: HVAC and COVID-19. ASHRAE J. 62(9), 20–28 (2020)
22. Goyal, S.M., et al.: Detection of viruses in used ventilation filters from two large public buildings. American Journal of Infection Control 39(7), e30–e38 (2011). https://doi.org/10.1016/j.ajic.2010.10.036
23. Ezratty, V., Squinazi, F.: Pandemic influenza virus inside buildings: is there a risk of transmission by ventilation or air conditioning systems? Environnement, Risques & Santé 7(4), 255–263 (2008)
24. Bolashikov, Z.D., et al.: Exposure of health care workers and occupants to coughed airborne pathogens in a double-bed hospital patient room with overhead mixing ventilation. HVAC R Res. 18(4), 602–615 (2012)
25. Yu, H.C., et al.: Ventilation of general hospital wards for mitigating infection risks of three kinds of viruses including Middle East respiratory syndrome coronavirus. Indoor Built Environ. 26(4), 514–527 (2017). https://doi.org/10.1177/1420326x16631596
26. Stawicki, S.P., et al.: The impact of comprehensive air purification on patient duration of stay, discharge outcomes, and health care economics: a retrospective cohort study. Surgery 168(5), 968–974 (2020). https://doi.org/10.1016/j.surg.2020.07.021
27. Ghosh, B., Lal, H., Srivastava, A.: Review of bioaerosols in indoor environment with special reference to sampling, analysis and control mechanisms. Environ. Int. 85, 254–272 (2015). https://doi.org/10.1016/j.envint.2015.09.018
28. Bragoszewska, E., Bogacka, M., Pikoń, K.: Efficiency and eco-costs of air purifiers in terms of improving microbiological indoor air quality in dwellings-A case study. Atmosphere 10(12), 742 (2019). https://doi.org/10.3390/atmos10120742
29. Wenke, C., et al.: Efficiency of different air filter types for pig facilities at laboratory scale. PLoS One 12(10), e0186558 (2017). https://doi.org/10.1371/journal.pone.0186558
30. Ham, S.: Prevention of exposure to and spread of COVID-19 using air purifiers: challenges and concerns. Epidemiology and health 42, e2020027 (2020)
31. Dubuis, M.E., et al.: Ozone efficacy for the control of airborne viruses: bacteriophage and norovirus models. PLoS One 15(4), e0231164 (2020). https://doi.org/10.1371/journal.pone.0231164
32. Vranay, F., et al.: Adaptation of hvac systems to reduce the spread of covid-19 in buildings. Sustainability 12(23), 1–20 (2020). https://doi.org/10.3390/su12239992
33. Rezaei, N., et al.: A novel methodology and new concept of SARS-CoV-2 elimination in heating and ventilating air conditioning systems using waste heat recovery. AIP Adv. 10(8), 085308 (2020). https://doi.org/10.1063/5.0021575
34. Cho, J., Woo, K., Kim, B.S.: Removal of airborne contamination in airborne infectious isolation rooms. ASHRAE J. 61(2), 8–21 (2019)
35. Leung, W.W.F., Sun, Q.: Electrostatic charged nanofiber filter for filtering airborne novel coronavirus (COVID-19) and nano-aerosols. Separ. Purif. Technol. 250, 116886 (2020). https://doi.org/10.1016/j.seppur.2020.116886
36. Leung, W.W.F., Sun, Q.: Electrostatic charged nanofiber filter for filtering airborne novel coronavirus (COVID-19) and nano-aerosols. Sep. Purif. Technol. 250, 116886 (2020). https://doi.org/10.1016/j.seppur.2020.116886
37. Comunian, S., et al.: Air pollution and covid-19: the role of particulate matter in the spread and increase of covid-19's morbidity and mortality. Int. J. Environ. Res. Publ. Health 17(12), 4487 (2020). https://doi.org/10.3390/ijerph17124487
38. Leung, W.W.-F., Sun, Q.: Charged PVDF multilayer nanofiber filter in filtering simulated airborne novel coronavirus (COVID-19) using ambient nano-aerosols. Separ. Purif. Technol. 245, 116887 (2020). https://doi.org/10.1016/j.seppur.2020.116887
39. Leung, W.W.-F., Hung, C.-H., Yuen, P.-T.: Effect of face velocity, nanofiber packing density and thickness on filtration performance of filters with nanofibers coated on a substrate. Separ. Purif. Technol. 71(1), 30–37 (2010). https://doi.org/10.1016/j.seppur.2009.10.017
40. Mao, N.: Nonwoven fabric filters. In: Fibrous Filter Media, pp. 133–171. Elsevier (2017)
41. Sadrmanesh, V., Chen, Y.: Bast fibres: structure, processing, properties, and applications. Int. Mater. Rev. 64(7), 381–406 (2019). https://doi.org/10.1080/09506608.2018.1501171
42. Chartier, Y., Pessoa-Silva, C.: Natural Ventilation for Infection Control in Health-Care Settings. World Health Organization (2009)
43. Janssen, J.: Ventilation for acceptable indoor air quality. ASHRAE J. 31(10), 40–48 (1989)
44. Bharathi, V.P., et al.: Design of HVAC for a Corporate Building Using AHU (2015)
45. Wu, M., Liu, K.: Air Purification in Confined Spaces. Institute of Physics Publishing (2020)

46. Mills, A., Lee, S.-K.: A web-based overview of semiconductor photochemistry-based current commercial applications. J. Photochem. Photobiol. Chem. 152(1), 233–247 (2002). https://doi.org/10.1016/s1010-6030(02)00243-5
47. Kilic, A., et al.: 4 - the charging and stability of electret filters. In: Brown, P.J., Cox, C.L. (eds.) Fibrous Filter Media, pp. 95–121. Woodhead Publishing (2017)
48. Joannou, C.J.: Ionizing and Polarizing Electronic Air Filter. Google Patents (1996)
49. Lohmann, E., Vaculik, F.: Dynamic Medium Air Cleaning System (Electronically Polarized Medium Air Cleaner). Air & Waste Management Assoc, Pittsburgh (1997)
50. Fisk, W.J., Park Ridge, N.J.: Indoor Air Quality Control Techniques: Radon, Formaldehyde, Combustion Products. Noyes Data Corp (1987)
51. Bigu, J.: Radon progeny reduction by means of an air cleaner of the polarized media type. Ann. Occup. Hyg. 37(5), 481–496 (1993)
52. Myers, B.A.: Cooling issues for automotive electronics. Electronics Cooling 9(3), 24–27 (2003)
53. Das, D., Waychal, A.: On the triboelectrically charged nonwoven electrets for air filtration. J. Electrost. 83, 73–77 (2016). https://doi.org/10.1016/j.elstat.2016.08.004
54. Huang, S.-H., et al.: Factors affecting filter penetration and quality factor of particulate respirators. Aerosol Air Qual. Res. 13(1), 162–171 (2013). https://doi.org/10.4209/aaqr.2012.07.0179
55. Wang, C.-S.: Electrostatic forces in fibrous filters—a review. Powder Technol. 118(1), 166–170 (2001). https://doi.org/10.1016/s0032-5910(01)00307-2
56. Bailey, W.H., Williams, A.L., Leonhard, M.J.: Exposure of laboratory animals to small air ions: a systematic review of biological and behavioral studies. Biomed. Eng. Online 17(1), 72 (2018). https://doi.org/10.1186/s12938-018-0499-z
57. Jiang, S.-Y.M., Ma, A., Ramachandran, S.: Negative air ions and their effects on human health and air quality improvement. nternational Journal of Molecular Sciences 19(10), 2966 (2018). https://doi.org/10.3390/ijms19102966
58. Ping, L., et al.: Experimental study on optimum of low-ozone negative ion generator. In: Keping, S., Gefei, Y. (eds.) Recent Developments in Applied Electrostatics, pp. 203–206. Elsevier Science Ltd, Oxford (2004)
59. Shiue, A., Hu, S.-C., Tu, M.-L.: Particles removal by negative ionic air purifier in cleanroom. Aerosol Air Qual. Res. 11(2), 179–186 (2011). https://doi.org/10.4209/aaqr.2010.06.0048
60. Mamaghani, A.H., Haghighat, F., Lee, C.-S.: Photocatalytic oxidation technology for indoor environment air purification: the state-of-the-art. Appl. Catal. B Environ. 203, 247–269 (2017). https://doi.org/10.1016/j.apcatb.2016.10.037
61. Escobedo, S., de Lasa, H.: Photocatalysis for air treatment processes: current technologies and future applications for the removal of organic pollutants and viruses. Catalysts 10(9), 966 (2020). https://doi.org/10.3390/catal10090966
62. Escobedo, S., Lasa, H.: Photocatalysis for air treatment processes: current technologies and future applications for the removal of organic pollutants and viruses. Catalysts 10(9), 1–38 (2020)
63. Zhao, J., Yang, X.: Photocatalytic oxidation for indoor air purification: a literature review. Build. Environ. 38(5), 645–654 (2003). https://doi.org/10.1016/s0360-1323(02)00212-3
64. Miyauchi, M., Sunada, K., Hashimoto, K.: Antiviral effect of visible light-sensitive cuxo/tio2 photocatalyst. Catalysts 10(9), 1–19 (2020). https://doi.org/10.3390/catal10091093
65. Lu, Y.W., et al.: Research on photocatalytic technology of sterilization and air purification. Kung Cheng Je Wu Li Hsueh Pao/Journal of Engineering Thermophysics 25(2), 311–313 (2004)
66. Leyland, N.S., et al.: Highly Efficient F, Cu doped TiO2 anti-bacterial visible light active photocatalytic coatings to combat hospital-acquired infections. Sci. Rep. 6(1), 24770 (2016). https://doi.org/10.1038/srep24770
67. Kim, J., Jang, J.: Inactivation of airborne viruses using vacuum ultraviolet photocatalysis for a flow-through indoor air purifier with short irradiation time. Aerosol. Sci. Technol. 52(5), 557–566 (2018). https://doi.org/10.1080/02786826.2018.1431386
68. Zheng, X., et al.: Photocatalytic disinfection performance in virus and virus/bacteria system by Cu-TiO2 nanofibers under visible light. Environ. Pollut. 237, 452–459 (2018). https://doi.org/10.1016/j.envpol.2018.02.074
69. Zhang, C., et al.: Visible-light-driven, water-surface-floating antimicrobials developed from graphitic carbon nitride and expanded perlite for water disinfection. Chemosphere 208, 84–92 (2018). https://doi.org/10.1016/j.chemosphere.2018.05.163
70. Wolfrum, E.J., et al.: Photocatalytic oxidation of bacteria, bacterial and fungal spores, and model biofilm components to carbon dioxide on Titanium dioxide-coated surfaces. Environ. Sci. Technol. 36(15), 3412–3419 (2002). https://doi.org/10.1021/es011423j
71. Rodrigues-Silva, C., et al.: Bacteria and fungi inactivation by photocatalysis under UVA irradiation: liquid and gas phase. Environ. Sci. Pollut. Control Ser. 24(7), 6372–6381 (2017). https://doi.org/10.1007/s11356-016-7137-8
72. Daikoku, T., et al.: Decomposition of organic chemicals in the air and inactivation of aerosol-associated influenza infectivity by photocatalysis. Aerosol Air Qual. Res. 15(4), 1469–1484 (2015). https://doi.org/10.4209/aaqr.2014.10.0256
73. Keller, V., et al.: Biological agent inactivation in a flowing air stream by photocatalysis. Chem. Commun.(23), 2918–2920 (2005). https://doi.org/10.1039/b503638k
74. Pal, A., et al.: Photocatalytic inactivation of airborne bacteria in a continuous-flow reactor. Ind. Eng. Chem. Res. 47(20), 7580–7585 (2008). https://doi.org/10.1021/ie701739g
75. Josset, S., et al.: UV-A photocatalytic treatment of Legionella pneumophila bacteria contaminated airflows through three-dimensional solid foam structured photocatalytic reactors. J. Hazard Mater. 175(1), 372–381 (2010). https://doi.org/10.1016/j.jhazmat.2009.10.013
76. Lin, C.-H., et al.: Novel TiO2 thin films/glass fiber photocatalytic reactors in the removal of bioaerosols. Surf. Coating. Technol. 205, S341–S344 (2010). https://doi.org/10.1016/j.surfcoat.2010.08.009
77. Pigeot-Remy, S., et al.: Survival of bioaerosols in HVAC system photocatalytic filters. Appl. Catal. B Environ. 144, 654–664 (2014). https://doi.org/10.1016/j.apcatb.2013.07.036
78. Pham, T.-D., Lee, B.-K.: Advanced removal of C. famata in bioaerosols by simultaneous adsorption and photocatalytic oxidation of Cu-doped TiO2/PU under visible irradiation. Chem. Eng. J. 286, 377–386 (2016). https://doi.org/10.1016/j.cej.2015.10.100
79. Yu, K.-P., et al.: Removal of bioaerosols by the combination of a photocatalytic filter and negative air ions. J. Aerosol Sci. 39(5), 377–392 (2008). https://doi.org/10.1016/j.jaerosci.2007.12.005
80. Pham, T.-D., Lee, B.-K.: Novel integrated approach of adsorption and photo-oxidation using Ag–TiO2/PU for bioaerosol removal under visible light. Chem. Eng. J. 275, 357–365 (2015). https://doi.org/10.1016/j.cej.2015.04.055
81. Ye, S.-y., et al.: Enhanced photocatalytic disinfection of P. expansum in cold storage using a TiO2/ACF film. Int. J. Food Microbiol. 136(3), 332–339 (2010). https://doi.org/10.1016/j.ijfoodmicro.2009.09.028
82. Xu, C., et al.: Nanostructured materials for photocatalysis. Chem. Soc. Rev. 48(14), 3868–3902 (2019). https://doi.org/10.1039/c9cs00102f
83. Yang, G., et al.: Preparation of highly visible-light active N-doped TiO 2 photocatalyst. J. Mater. Chem. 20(25), 5301–5309 (2010). https://doi.org/10.1039/c0jm00376j
84. Pham, T.-D., Lee, B.-K.: Novel adsorption and photocatalytic oxidation for removal of gaseous toluene by V-doped TiO2/PU under visible light. J. Hazard Mater. 300, 493–503 (2015). https://doi.org/10.1016/j.jhazmat.2015.07.048
85. Gurulakshmi, M., et al.: Enhanced visible-light photocatalytic activity of V2O5/S-TiO2 nanocomposites. Appl. Catal. Gen. 449, 31–46 (2012). https://doi.org/10.1016/j.apcata.2012.09.039
86. Nanocoat, U.: PCO Filter (2020). https://www.usananocoat.com
87. Davenport, T., Kalakota, R.: The potential for artificial intelligence in healthcare. Future healthcare journal 6(2), 94–98 (2019). https://doi.org/10.7861/futurehosp.6-2-94

88. Gloria Phillips-Wren, N.I., Jain, L.C.: Intelligent Decision Making: An AI-Based Approach. H: Springer (2008)
89. Lalmuanawma, S., Hussain, J., Chhakchhuak, L.: Applications of machine learning and artificial intelligence for Covid-19 (SARS-CoV-2) pandemic: a review. Chaos, Solit. Fractals 139, 110059 (2020). https://doi.org/10.1016/j.chaos.2020.110059
90. Tien, P.W., et al.: A deep learning framework for energy management and optimisation of HVAC systems. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing (2020)
91. Ventilation in Buildings. June 2, 2021 June 2, (2021) [cited 2021 June 2, 2021]; https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html
92. ASHRAE: ASHRAE Position Document on Filtration and Air Cleaning (2015)
93. Rodríguez Pérez, M., et al.: Are the Portable Air Cleaners (PAC) Really Effective to Terminate Airborne SARS-CoV-2? (2021)
94. Zhao, B., An, N., Chen, C.: Using an air purifier as a supplementary protective measure in dental clinics during the coronavirus disease 2019 (COVID-19) pandemic. Infect. Control Hosp. Epidemiol. 42(4), 493 (2020). https://doi.org/10.1017/ice.2020.292
95. Domínguez-Amarillo, S., et al.: Bad air can also kill: residential indoor air quality and pollutant exposure risk during the COVID-19 crisis. Int. J. Environ. Res. Publ. Health 17(19), 7183 (2020). https://doi.org/10.3390/ijerph17197183
96. Zhai, Z., et al.: Application of portable air purifiers for mitigating COVID-19 in large public spaces. Buildings 11(8), 329 (2021). https://doi.org/10.3390/buildings11080329
97. Buising, K.L., et al.: Use of portable air cleaners to reduce aerosol transmission on a hospital coronavirus disease 2019 (COVID-19) ward. Infect. Control Hosp. Epidemiol. 43(8), 987–992 (2021). https://doi.org/10.1017/ice.2021.284
98. Li, X., Shen, C., Yu, C.W.: Building Energy Efficiency: Passive Technology or Active Technology? SAGE Publications Sage UK, London (2017)
99. Ren, C., Cao, S.-J.: Implementation and visualization of artificial intelligent ventilation control system using fast prediction models and limited monitoring data. Sustain. Cities Soc. 52, 101860 (2020). https://doi.org/10.1016/j.scs.2019.101860
100. Cao, S.-J., Ding, J., Ren, C.: Sensor Deployment Strategy Using Cluster Analysis of Fuzzy C-Means Algorithm: Towards Online Control of Indoor Environment's Safety and Health. Sustainable Cities and Society (2020).102190
101. Shao, X., Wang, K., Li, X.: Rapid prediction of the transient effect of the initial contaminant condition using a limited number of sensors. Indoor Built Environ. 28(3), 322–334 (2019). https://doi.org/10.1177/1420326x17753709

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