Luchtreinigers en binnenmilieu

Eindrapport

DEPARTEMENT
OMGEVING

omgevingvlaanderen.be

INHOUDSTAFEL

1 VRAAG IKV REFERENTIETAAK

<u>luchtreinigers en binnenmilieu</u>

Als gevolg van klimaatverandering wordt gesteld dat de gezondheidsimpact van allergenen (pollen, fijn stof,…) zal toenemen.
In het verleden heeft VITO al onderzoek uitgevoerd naar de werkzaamheid van mobiele en vaste luchtreinigers in het binnenmilieu. Ook komen nu steeds nieuwe toestellen/filters op de markt die beweren dat ze zorgen voor een gezond binnenmilieu. Of deze luchtreinigers effectief voldoende werkzaam zijn is niet zeker.
Graag hadden wij een overzicht van de mogelijke soorten van mobiele of vaste luchtreinigers en hun beschikbaarheid op de markt met een kritische evaluatie van hun werking. Ook voor het toepassen van filtermogelijkheden in mechanische ventilatiesystemen moet deze kritische evaluatie worden uitgevoerd. In deze evaluatie dienen minimaal volgende zaken te worden meegenomen: werkzaamheid, geschikt voor welke allergenen, prijs, onderhoudskosten en -voorwaarden, ...
Daarnaast moet een antwoord geformuleerd op volgende deelvragen:

- worden luchtreinigers al door andere overheden aangeraden? bv in buitenland?
- zijn er situaties waar gebruik wel aan te raden is en andere situaties waar ze helemaal niet nuttig zijn?
- Overzicht van de relevante wetgeving
- Relatie met ventilatie/verluchten?

2 INTRODUCTION

2.1 TYPES OF INDOOR AIR POLLUTANTS

There three main categories of indoor air pollutants that can have influence the quality of air in indoor environments: Particulate Matter, Gaseous pollutants and Biological Contaminations.

Particulate Matter (PM) can be composed of microscopic solids, liquid droplets, or a mixture of solids and liquid droplets suspended in the air. Typically, indoor PM can contain: dust, fumes, smoke, as well as particles from outdoors, which are complex mixture of solid and liquid particles.

Gaseous Pollutants (GP) include inorganic gases such as combustion gases (e.g. CO, NOx), ozone, as well as organic components that are not attached to the PM.

Biological Contaminations (BC) includes: viruses, bacteria, pollen, fungal spores and fragments, dust mite and cockroach body parts and droppings, and animal dander.

2.2 WAYS TO REDUCE THE INDOOR AIR POLLUTANTS

There are three major strategies to reduce pollutant concentrations in indoor air: Source Control, Ventilation, and Air Cleaning (US EPA, 2018)

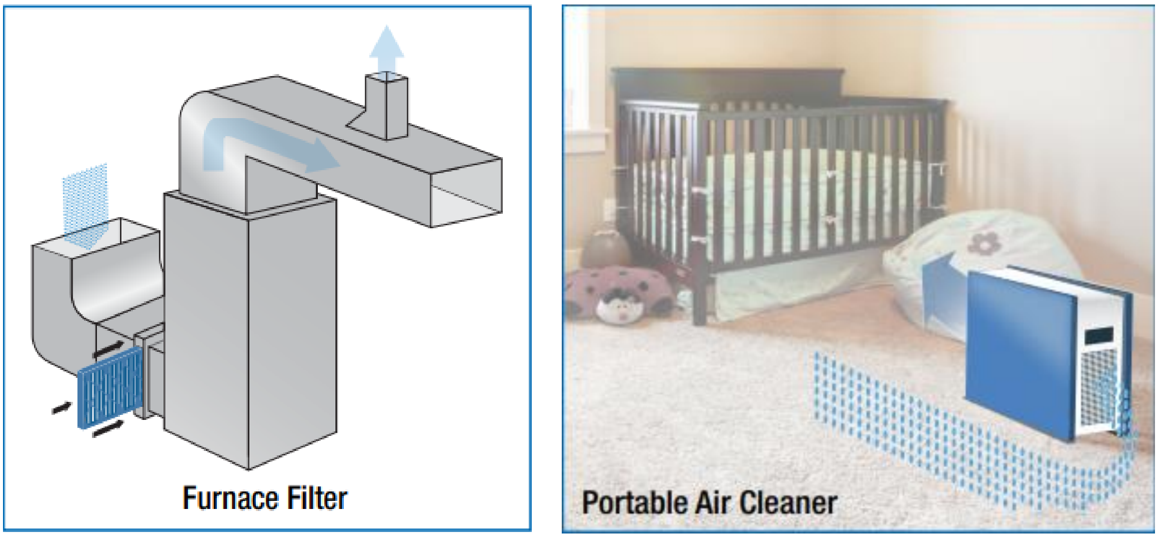
Source Control eliminates individual sources of pollutants or reduces their emissions. This represents the single most effective way to reduce the indoor pollutant concentrations and improve the indoor air quality.

Ventilation with outdoor air is a strategy to dilute the indoor air pollutant concentrations, considering that the outdoor air is relatively clean and dry or that it can be made so through air cleaning technologies (e.g. filtering).

Air Cleaning has been proven useful when used along with source control and ventilation, although it is not considered as a substitute of either method. When significant sources are present and/or exhaust and outdoor air ventilation are insufficient, the air cleaning alone cannot assure adequate indoor air quality.

2.3 TYPES OF AIR CLEANERS

There are two basic types of air cleaner/purifiers: HVAC duct-mounted air cleaners/purifiers (Figure 1A) and portable (standalone) (Figure 1B) devices. The HVAC duct mounted air cleaners are typically installed in the central HVAC system of building and can provide filtering/cleaning for many spaces in the building where and when the HVAC system is operating. The portable (standalone) air cleaners/purifiers on the other hand, are designed to provide cleaning/filtration of the air in the space where they are installed (US EPA, 2018).



A B

Figure 1 A graphical representation of HVAC duct mounted (A) and portable (standalone) (B) air cleaners/purifiers (US EPA, 2018)

The HVAC duct mounted air cleaning devices (Figure 1A) are typically installed either at the base of the air-handling unit or upstream in return grilles. Every HVAC system is equipped at least with a low-efficiency air filter to capture any particles in the airstream to protect the fan motor, heat exchanger, and ducts. These filters are not designed to improve indoor air quality. However, such a HVAC system can be relatively easily modified/upgraded to facilitate more efficient air filters to remove additional PM. Furthermore, other cleaning devices using various of cleaning technologies (e.g. electrostatic precipitation, adsorption, UV radiation and etc.) are typically installed in the HVAC system of residential and public building to improve the overall IAQ in their indoor spaces (US EPA, 2018).

The portable air cleaners/purifiers (Figure 1B) are typically standalone devices varying in size from tabletop devices to large console units. The difference of these portable air cleaning units from the induct HVAC devices is that they can be moved to whatever continuous and localized air cleaning is needed. These portable units are particularly useful in indoor spaces which are not equipped with forced air heating and/or air conditioning systems. The portable air cleaners usually include a filter or/and other air cleaning technology and a fan that propels air trough that filter/air cleaner. Some of the units marketed as having quiet operation may have no fan. However, units without a fan typically are much less effective that the units with a fan (US EPA, 2018).

3 AIR PURIFICATION TECHNIQUES

In general, the process of air purification includes removal of the unwanted materials, such as PM and gas/vapor compounds from an air stream. The most common techniques currently used for air purification in many municipalities and homes includes:

- Mechanical filtration
- Electric filtering
- Adsorption
- Ozonation
- Photocatalytic oxidation
- Plasma filtration
- Ultraviolet (UV) radiation

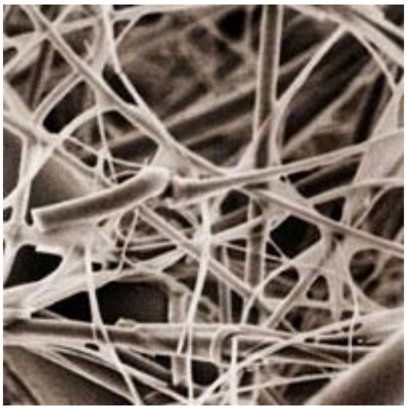
An overview of the effect of each air purification technology onto the main types of indoor pollutants is shown in Table 1.

Table 1 Effect of single purification technology to main types of indoor pollutants (Liu et al. 2017)

Purification technique	Suspended Particles	VOCs	Bacteria (0.2 – 10µm)	Viruses (0.01 – 0.3µm)
Mechanical filtration	Effective	Noneffective	Effective	Noneffective
Electric filtration	Effective	Not obvious	Partially effective	Partially effective
Adsorption	Partially effective	High efficiency	Partially effective	Noneffective
Ozonation	Not obvious	Effective	Effective	Effective
Photocatalytic oxidation	Not obvious	Effective	Effective	Effective
Plasma filtration	Not obvious	Effective	Effective	Effective
Ultraviolet (UV) radiation	Noneffective	Noneffective	High efficiency	High efficiency

3.1 MECHANICAL FILTRATION

Mechanical filtration is simple and one of the most common techniques for removing particulate impurities (e.g. pollen, inert particles, microorganisms). The mechanical filtration utilize media with porous structure (usually fibers or stretched membrane material) to capture the particulates from the air stream passing through the filter. Typically, the air is passed through the filter by means of a fan engine. The most commonly used type of mechanical filters is typically an assembly of fibers, usually made from cotton, polyester, polypropylene or other materials, that are randomly laid perpendicular to the air flow (Figure 1). The fibers may range in the size from less than 1µm to greater than 50µm in diameter. Filter packing density may also range in the interval between 1% and 30%.



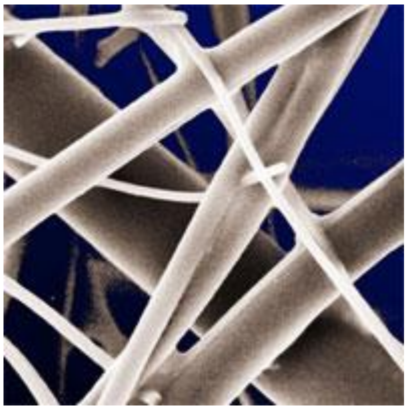


Figure 2 Electron microscope image of fibre media air filters

Overall, four different collection mechanisms govern particulate air collection: internal impaction, interception, diffusion and electrostatic attraction (Eurovent, 2017).

- *Internal impaction* – Due to particle inertia, a particle traveling in the air stream and passing around a fibre, deviates from the air stream and collides with a fibre. The importance of inertia for particle collection increases with increasing particle mass (i.e. particle diameter). In the case of typical air velocity in air filtration, the internal impaction becomes dominant from a particle diameter of > 1µm
- *Interception* – This mechanism occurs when a large particle, because of its size, collides with a fibre in the filter that the air stream is passing through. The probability of particle hitting a fibre due to interception increases with the particle size. Interception is dominated mechanism for particles with diameter between 0.5µm and 1µm.
- *Diffusion* – this mechanism occurs when the random (Brownian) motion of a particle causes that particle to contact a fibre. Diffusion-based particle collection increases with decreasing particle size and decreasing air velocity. Assuming there is no predominant electrostatic interaction, nanoparticles (i.e. particles with diameter <100nm) are deposited almost exclusively by diffusion.
- *Electrostatic attraction* – this mechanism occurs when particles are retained on the fibres by a weak electrostatic force. This mechanism plays a very minor role in mechanical filtration.

In general, the impaction and interception are the dominant collection mechanisms for particles greater than 0.2µm, and diffusion is dominant for particles less than 0.2µm. In practise the combined effect of these collection mechanisms occur simultaneously (Figure 3).

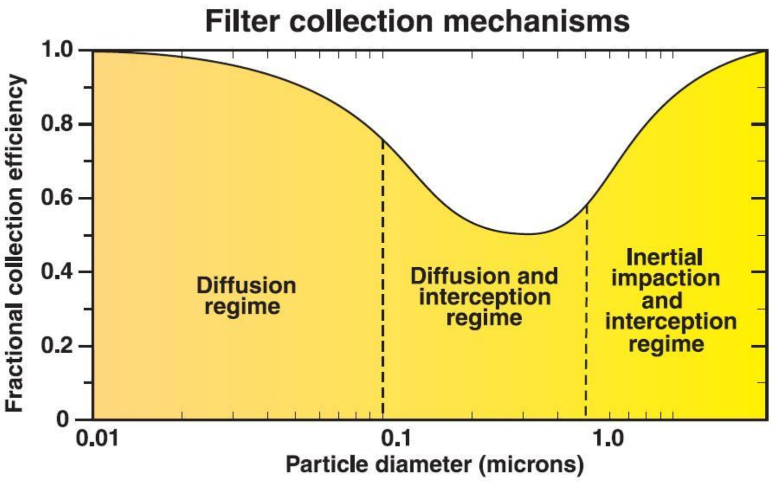


Figure 3 Fractional collection efficiency versus particle size for a mechanical filter

Very common modification of the fibre filters are the electrostatically enhanced filters which contain electrostatically enhanced fibres. These fibres attract the particles to the fibres in addition to retaining them, which increases significantly their collection efficiency especially for fine and ultra-fine particles (Stephens and Siegel, 2013). These types of filters are known to have lower initial pressure drop compared to filters using uncharged media of the same filter design and efficiency. However, because these filters generally rely on their charged fibres in order to provide high collection efficiency, the exposure of these filters to certain chemicals, aerosols, or high relative humidifies may decrease significantly their collection efficiency.

The main advantages and disadvantages of the mechanical filtration includes (US EPA, 2018):

Advantages:

+ High efficiency and removal capability for many particle sizes including microorganisms and allergens (e.g. pollen)
+ The efficiency of the mechanical filters is typically improved with loading

Disadvantages:

- Regular replacement is required to maintain the desired level of filtering efficiency
- Used particle filters can be source of sensory pollution/odors
- High pressure drops on some fibrous media filters (HEPA and ULPA) can negatively impact HVAC systems
- Electrostatically enhanced media filters suffer from reduced efficiency with loading

3.2 ELECTRIC FILTERING

Air filtration using an electrostatic precipitation (ESP) is also a commonly used technology for removing particles from the air stream in various industrial systems. However, due to its high efficiency in removing fine and ultra-fine particles and the low air flow resistance, this technology is also applied in HVAC systems and portable air cleaners.
The main principle of particle removal in ESP is based on electrically charging the particles, typically using corona wires or ion generation, followed by collecting these charged particles on oppositely charged deposition plates (precipitators) (Figure 4).

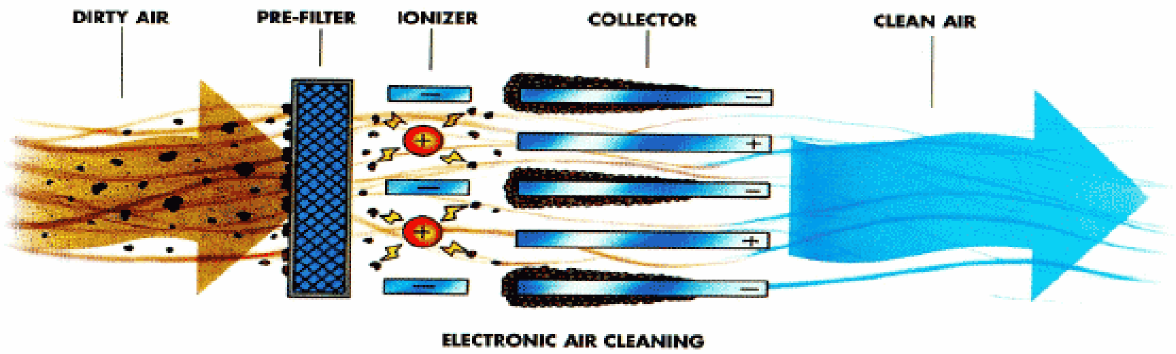


Figure 4 ESP operational diagram (source: http://www.airscrubbersinc.com)

The particle removal efficiency of an ESP filter is typically a function of particle size and several design parameters such as flow rate, voltage, collection cell area and strength and distribution of the electric field (Huang and Chen, 2002). A common method for classification of ESPs is the number of stages used to charge/remove particles from the air flow. ESP devices that use the same set of

electrodes to charge and collect the particles are called “single stage ESPs”. The “two stage ESP” devices utilize different set of electrodes to charge and collect the particles. A significant benefit of the two stage ESPs is the lower voltage used in these devices (12 – 13kV) in comparison with the single stage ESPs (50 – 70 kV), making them more attractive in energy consumption point of view (US EPA, 2018).
Another variation of the electric filters are the ionizers. Similar to the ESP, ionizers use high voltage wire or carbon fibre brush to electrically charge air molecules producing charged ions which then bond to airborne particles. The charged particles are then collected either on oppositely charged plates in the air cleaner or they adhere to various indoor surfaces such as walls, floors and furniture. Opposite charged particles can also bind to each other and form large particles that settle to surfaces (US EPA, 2018).

The main advantages and disadvantages of the electric filtering includes (US EPA, 2018):

Advantages:

+ Can have high removal efficiency for a wide range of particle sizes and specially for fine and ultrafine particles. In addition, these filters efficiently kill/inactivate various bacteria and viruses.
+ Low pressure drop and minimal impacts on the HVAC system
+ Low maintenance required
+ Low noise

Disadvantages:

– Possibility to emit ozone and nitrogen oxides in the indoor environment
– Efficiency typically decrease with loading and plates require cleaning
– Relatively high electric power draw requirements
– Ionizers: Typically, low effectiveness because of very low airflow rates and clean air delivery rates

3.3 ADSORPTION

To remove gaseous and vapor contaminants from the air stream gas-phase air filters are normally used. The most commonly used techniques for removing gases and odours from the air are based on sorption i.e. adsorption (electrostatic interaction between a molecule of gas or vapour and a surface of a solid material (adsorbent)) or chemisorption (chemical reaction between the gas and the sorption media). Unlike the particulate filters, sorbents cover a wide range of highly porous materials, varying from simple clays and carbons to complexly engineered polymers. Many sorbents – not including those that are chemically active – can be also regenerated by application of heat or other processes.
An important characteristic of the gas-phase air filters is that they typically are designed to remove one or more of the gaseous pollutants presented in the air stream that passes through them. They are not, however, designed to eliminate all gaseous pollutants.
Typically, a sorbent filter’s behaviour depends to several factors that can affect the removal of gaseous contaminants, such as:

- Airflow rate and the velocity through the sorbent
- Concentration of contaminants
- Presence of other gaseous contaminants
- Total available surface area of the sorbent

- Physical and chemical characteristics of the pollutant and the sorbent (such as weight, polarity, pore size, shape, column and the type and amount of chemical impregnation)
- Pressure drop
- Removal efficiency and removal capacity
- Temperature and relative humidity of the air stream

Some of the commonly used adsorption materials to remove gas contaminants and odours are activated carbon, activated aluminium oxide, natural or synthetic zeolites in granular form, oxides of silicon, molecular sieves and various polymers. Because of its simplicity, effectiveness and low cost activated carbon is one of the most frequently used adsorption materials in the HVAC systems and portable air cleaners. It has a potential to remove most hydrocarbons, many aldehydes, and organic acids (Huang et al., 2003; Kim et al., 2012, González-Martín et al., 2021). However, activated carbon is not especially effective in removing oxides of sulphur, hydrogen sulphide, low molecular weight aldehydes, ammonia and nitrogen oxide (US EPA, 2018)

The main advantages and disadvantages of the adsorption includes (US EPA, 2018):

Advantages:

+ Potential for high removal efficiency for various gaseous pollutants in air cleaning systems with a sufficient amount of media for the application
+ No by-product formation
+ For chemisorption: chemisorption is irreversible process i.e. pollutants are permanently captured
+ Can be easy integrated in interior surfaces to provide passive filtration

Disadvantages:

– Regular replacement is required due to their limited adsorption capacity. The removal efficiency decreases significantly in a year or even in a month if the air contains higher amount of pollutants.
– The physical adsorption is reversable process i.e. pollutants are not permanently captured and can be further released from the filter media to the indoor environment
– Effectiveness for many consumer-grade systems with small amounts of activated carbon is unknown
– High pressure drop of some sorbent media filters can negatively impact HVAC systems
– Different removal efficiency for different gases at different concentrations

3.4 OZONATION

Ozonation cleaning technology includes intentional ozone generation (via UV lamps, cold plasma and corona discharge techniques) typically for odor control. The principal of the ozonation cleaning technique uses the reaction between the ozone and its radicals with the indoor pollutants (chemical, particles and microorganisms) in air and surfaces, alternating their structure and properties. However, the reactions of ozone with the chemicals emitted from common indoor products (e.g. cleaners, air fresheners, deodorizers, paints, furniture and building materials) may also produce new and more harmful byproducts (Weschler, 2006; US EPA, 2014). Studies also showed that using ozone concentrations below the requirements of the public health standards, the ozonation has little potential to remove indoor air pollutants (Leppänen et al., 2017). Furthermore, ozone is also a potential lung irritant, therefore US EPA recommends that “*Ozone generators sold as air cleaners should not be used in occupied spaces.*” (US EPA, 2018).

The main advantages and disadvantages of the ozonation (US EPA, 2018):

Advantages:

- \+ Reacts with many indoor gases
- \+ Can be combined with less harmful technologies such as adsorbent media

Disadvantages:

- – High ozone generation rates
- – High amount of byproducts formation
- – Can cause degradation of indoor materials

3.5 PHOTOCATALYTIC OXIDATION

The photocatalytic oxidation (PCO) air cleaning technique typically utilize high-surface-area medium coated with titanium dioxide as a catalyst. The incoming gases are adsorbed onto the media and then irradiated with UV light which activates the catalyst (TiO2), which reacts with the adsorbed gases and chemically transforming them (US EPA, 2018; Luengas et al., 2015). A schematic overview of the PCO operation is shown in Figure 5.

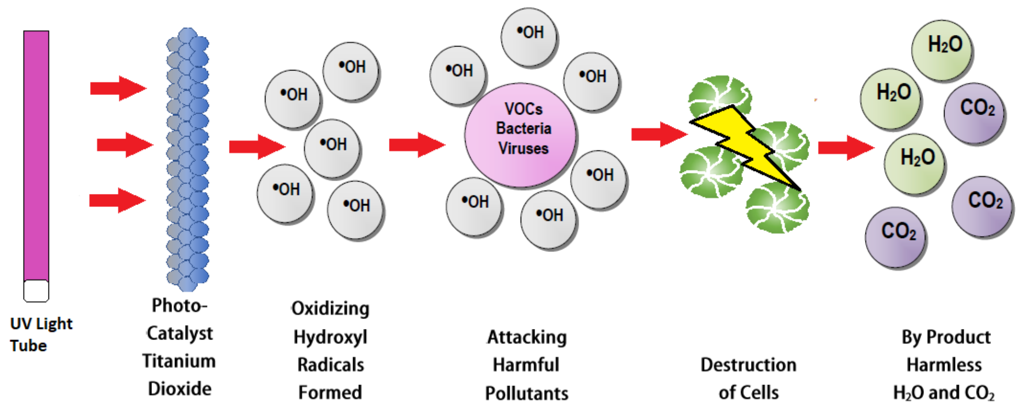


Figure 5 Photocatalytic oxidation operational diagram (source: https://www.whiteairsolutions.co.uk/)

Although the most widely used catalyst in the PCO systems is TiO_2, there are other catalysts such as: ZnO, ZnS, CdS, Fe_2O_3, SnO_2 (Mo et al., 2009). Although, the PCO technology can cope with wide range of pollutants, studies showed that PCO cleaners are often ineffective in completely transforming all gaseous pollutants in indoor air environments (Tompkins et al., 2005a,b). In a study reported by Chen et al. (2005), the VOC removal efficiency of 15 air cleaners using different technologies were compared. The authors reported much lower removal efficiency of the tested PCO cleaners for formaldehyde (1.6%), toluene (1.8%), and tetrachloroethylene (0.7%) that what was advertised for the tested devices.

The PCO cleaners are also known to generate various harmful by-products such as ozone, carbon monoxide, formaldehyde and nitrogen oxides (Hodgson et al., 2007). To mitigate the emissions of harmful by-products to the indoor environments, various PCO systems include adsorbent media placed downstream (US EPA, 2018). In addition, the higher cost of catalyst media replacement, limit the widespread use of this technology (Guieysse et al., 2008).

The main advantages and disadvantages of the photocatalytic oxidation (US EPA, 2018):

Advantages:

+ Can degrade a wide array of gaseous pollutants (e.g. aldehydes, aromatics, halogenated hydrocarbons and etc.)
+ Can be combined with adsorption media to improve effectiveness

Disadvantages:

- Can generate harmful by-products such as formaldehyde and ozone
- Often relatively low removal efficiency for many of the typical indoor gaseous pollutants
- Lack of field studies to validate performance
- Catalyst often has a limited lifespan

3.6 PLASMA FILTRATION

Plasma filtration technology utilizes high voltage current to ionize the air and create plasma (mixture of electrons, positive ions and neutral particles (atoms and molecules). The type of plasma that is most commonly used in air purification is so called "cold plasma" or "non-thermal plasma". This is a plasma that is not in thermodynamic equilibrium with regards of its thermodynamic properties. Cold plasma bind particles by electrostatic phenomena and also produces UV radiation and is therefore effective method to kill/inactivate also microorganisms (US EPA, 2018). The generated free radicals and oxidants in the plasma can further brake chemical bonds and promote transformation of VOC into carbon dioxide and water (Luengas et al., 2015). Plasma filtration is often combined with other cleaning technologies (e.g. PCO) to improve effectiveness and minimize by-product emissions (Figure 6).

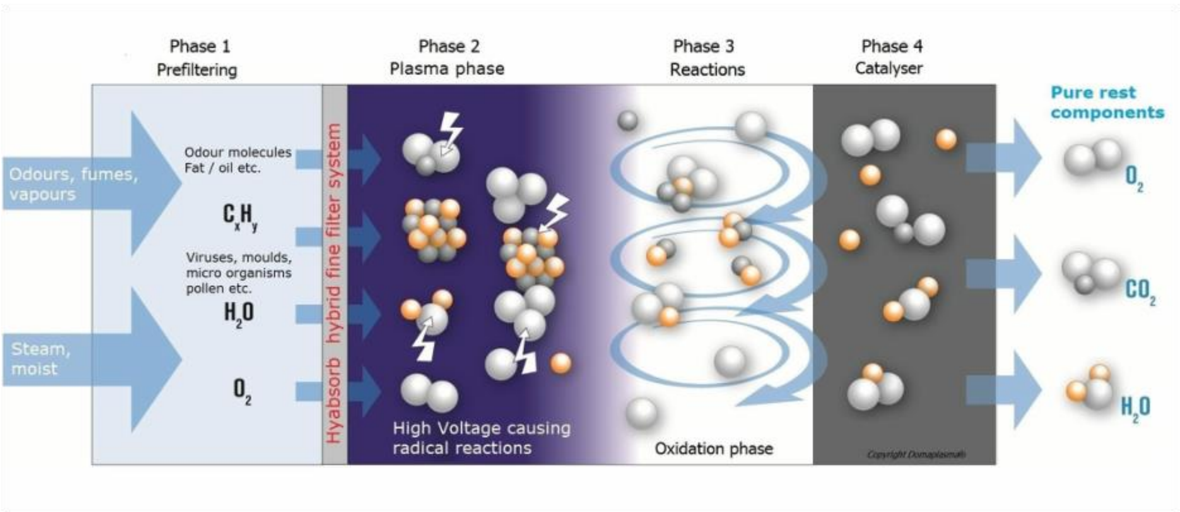


Figure 6 Plasma air filtering combined with PCO (source: http://www.domaplasma.com)

The main advantages and disadvantages of the plasma filtration (US EPA, 2018):

Advantages:

+ Potential for high removal efficiency for various gaseous pollutants
+ Can kill/inactivate various microorganisms (e.g. bacteria, viruses)

- + Can be combined with other air cleaning technologies (e.g. photocatalytic oxidation) to improve performance and minimize by-products emissions

Disadvantages:

- – Formation of various by-products including ozone, particles, formaldehyde, carbon monoxide, chloroform, nitrogen oxides, and a large number of other inorganic gases
- – Most studies investigated gaseous removal while fewer have evaluated PM removal

3.7 ULTRAVIOLET (UV) RADIATION

Ultraviolet radiation and specially the short-wave UV (UV-C: 100 – 280 nm) can effectively penetrate the outer structure of the microorganism’s cell(s) and alter its DNA, preventing replication and causing cell death (US EPA, 2018). The UV disinfection on surfaces and air is most effective at wavelength at 264 nm (Figure 7) (Luengas et al., 2015).

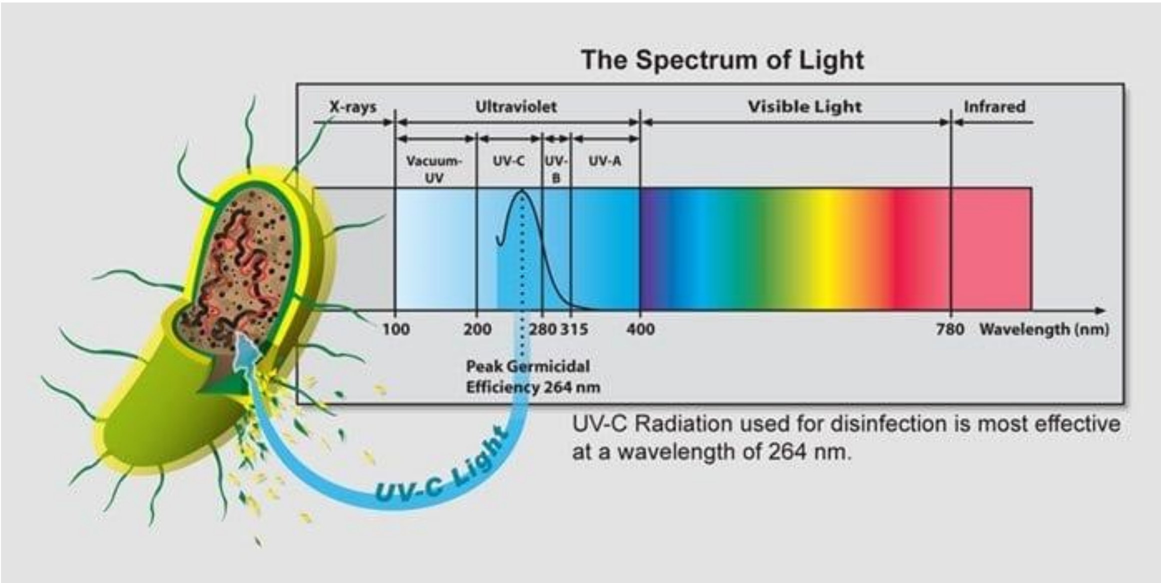


Figure 7 UV germicidal radiation spectrum (source: https://www.european-hygiene-group.se/)

There are two primary applications of disinfection with UV radiation: air stream disinfection (system designed to reduce the viability of microorganisms as they flow through the HVAC systems of portable air cleaners) and surface cleaners (designed for surface disinfection that are most commonly used to prevent microorganism’s growth on various surfaces inside the HVAC systems). Typically, the UV lamps for airstream and surface disinfection are installed downstream of the filter and upstream of the cooling coils inside the duct of the HVAC systems. In the portable air cleaners, they are typically installed downstream to the filter (US EPA, 2018).

The main advantages and disadvantages of the UV radiation (US EPA, 2018):

Advantages:

- + Can be effective at high intensity with sufficient contact time
- + Can be used to inactivate microbes in the HVAC systems and other surfaces

Disadvantages:

- – Can generate ozone

- Potential for eye injury
- Effectiveness increases with lamp intensity which is typically low in residential air cleaners
- High electrical power draw requirements
- Inactivates but does not remove microorganisms

4 EFFECT OF AIR CLEANING TECHNOLOGIES ON THE MAIN GROUPS OF INDOOR AIR POLLUTANTS

4.1 EFFECT OF AIR CLEANING TECHNOLOGIES ON PARTICLES

One of the major and also the most studied impact of air cleaning to the indoor air quality is the removal of particulate matter (PM). Studies showed that the PM concentrations in indoor air can be effectively reduced using air cleaning based on mechanical filtration (Quang et al., 2013; Azimi et al., 2014; Sadiktsis et al., 2016; Kim et al., 2016; Alavy et al., 2019, Blondeau et al., 2021). The particle collection efficiency of different filter classes has been reported to be >50% for F7 (Sadiktsis et al., 2016; Kim et al., 2016, Blondeau et al., 2021) and >80% for F9 (Sadiktsis et al., 2016; Azimi et al., 2014) tested with 0.4µm particles. Typical characteristic for the mechanical filters is that their particles removal efficiency is not affected by air velocity, temperature and humidity making them preferable air cleaning technology in various HVAC and portable air cleaning systems (Blondeau et al., 2021). A review published by Cheek et al. (2020), the authors showed that using air cleaners (utilizing various air cleaning technologies) indoors reduce the PM2.5 concentrations by 22.6% to 92.0% in homes and 49% in schools. The large variation of the removal efficiency between the analysed studies, the authors attributed to various factors including study design, intervention duration, cleaning technology and user compliance.
Although the higher efficiency filters i.e. Efficiency Particulate Air (EPA) and High-Efficiency Particulate Air (HEPA) filters have much higher removal efficiency i.e. between 99.5% and 99.995% of removing fine and ultra-fine particles, these filters are usually not installed in residential HVAC systems. A typical residential air handling unit and the associated ductwork would not be able to accommodate such filter size and increased airflow resistance. Only specially built high performance homes may occasionally be equipped with HEPA filters installed in properly designed HVAC systems. However, those types of filters are widely used in standalone portable air purification units, where the devices are designed to work with the increased air flow resistant of HEPA filters. The particle removal efficiency of such portable air purification units has been reported in the range of 40% - 90% for particle size range of 0.1 – 2 µm (Sultan et al., 2011; Wheeler et al., 2014; Barn et al., 2018). However, the studies showed that the overall relative effectiveness of these units with respect of reducing indoor particle counts is a function of particle diameter. In a study published by Ward et al. (2005) the authors found that the overall relative efficiency of these units decreases as the diameter of particles increases above 0.25µm.

Although the theory of Electrostatic precipitation (ESP) air cleaning technology has been extensively studied, only few studies have investigated removal during the operation of in-duct ESP within a residential building. Howard-Reed et al. (2003) reported removal efficiency of an in-duct ESP system of 55% - 85% for particles between 0.3µm and 10µm. In another study conducted by Wallace et al (2004) the performance of ESP technology for removing particles smaller than 0.1µm was assessed. The authors reported that ESP operation reduced the concentration of particles greater than 18 nm by more than 50%. According to Bliss et al. (2005), the efficiency of electronic filters is more than 90% for 0.3 – 6 µm particle sizes. Similar results were reported also from Blondeau et al. (2021), where the authors observed nearly 100% PM removal efficiency from a commercial in-duct ESP air cleaner tested with Di-Ethyl-Hexyl-Sebacate particles with size range of 0.2 – 5.0 µm at airflow rate of 1200 m^3/h. During the same study, the authors also observed decrease in the efficiency to 55%

and 71% for particles of 0.2 – 0.3 µm and 0.7 – 1.0 µm, respectively, when the airflow rates were increased to 3600 m^3/h. However, the efficiency of the ESP system for the bigger particles (> 1.0 µm) remained higher than 93%. The authors attributed this decrease of the collection efficiency for ultrafine particles to the less ionization efficiency of these particles during the charging stage of the process, caused by the increased air velocities.

Despite their limited use, the other type of electric air cleaning systems i.e. ionizers and ion generation also showed relatively high removal efficiency (>70%) for particles in indoor environments (Lee et al., 2004; Pushpawela et al., 2017). In addition, the removal efficiency of the ionizers based cleaners shows not to be affected by the size of the particles: Lee et al. (2004) reported removal efficiency of an ionizer based system at 97% and 95% for PM0.1 and PM1, respectively, tested in lab conditions. In another study however, Warning and Siegel (2011) studied the impact of ion generation in the indoor air in a real indoor environmental condition using a 27 m^3 residential room. The authors reported overall decrease of 10 – 46% in the measured concentrations of fine (0.1 – 2.5µm) particles during the operation of the ion generator. Pushpawela et al. (2017) compared the PM removal efficiency of two portable air cleaner devices equipped with an ionizer and a high-flow air filter fitted with mechanical high efficiency HEPA filter, respectively, at different room sizes and ventilation conditions. The study showed about 45% PM removal efficiency of the ionizer versus 60% PM removal efficiency of the HEPA filter in 20 m^3 room without any ventilation. When tested in ventilated rooms however, the estimated PM removal efficiency of both devices were lower. The study reported 40%, 30, and 22% PM removal efficiency of the ionizer in ventilated room with volume of 32 m^3, 45 m^3, and 132 m^3, respectively, while the PM removal efficiency of the air cleaner with HEPA filter measured in the same ventilated rooms were 25% (at 32m^3), 10% (at 45m^3), and 6% (at 132 m^3). The study showed that while the air cleaner using mechanical filtration was more effective than the ionizer in smaller size rooms, the ionizer was evidently more effective in larger rooms. The authors conclude that air ionizers are more suited than high-flow air filters in removing ultrafine particles from rooms larger than about 25 m^3. Moreover, the study also showed also that small ions produced by the ionizer, placed in one room, were carried through the air conditioning system into other rooms, effectively removing particles from the air in these rooms in the process.

A clear advantage of the electronic filtering technology that makes it very attractive to HVAC systems is its low air resistance. Lower air resistance allows using less powerful motors for the blowing fans resulting less power consumption of the system. However, the electronic air filtering technology it is still not widely used in the residential HVAC systems due to possibilities of ozone generation caused by corona discharge (Boelter et al., 1997). Warning and Siegel (2011) reported increased ultra-fine (<0.1 µm) particles, ozone and to a less extend formaldehyde and nonanal concentrations during the operation of the ion generator in a residential room. Poppendieck et al. (2014) measured up to six times higher indoor ozone concentrations than outdoors in environments where ESP system was continuously operated.

The PM removal efficiency for the air cleaners using activated carbon filters is typically dependant to the fibre order of the filter: for instance, filters with more homogeneous order of the fibres showed better PM removal efficiency. Studies also showed that the number of fibre layers (i.e. filter thickness) plays significant role in the removal efficiency. Lormier et al. (2008) reported PM removal efficiency of activated carbon filter of 52 – 86% for fine (0.1 – 2.5 µm) and ultra-fine (< 0.1 µm) particle sizes. The variation in the removal efficiency was attributed to the different thickness of the tested filters. In a more recent study, Kim et al. (2020) investigated the PM removal efficiency of activated carbon fibre filters and its dependency to the filter thickness and air velocities in laboratory scale. The authors reported average removal efficiency of 5.9% (0.7 – 10.5%) for PM10 and 10.6%

(8.8 – 12.8%) for PM2.5 using 200 mm filter; 41.1% (28.6 – 50.5%) for PM10 and 29.6% (19.2 – 36.6%) for PM2.5 using 400 mm filter; 44.3% (28.2 – 65.9%) for PM10 and 36.3% (23.0 – 51.9%) for PM2.5 using 600 mm filter. The authors also reported that high PM removal efficiency for tested filter thicknesses was observed at flow rates of 2.0 – 3.0 m/s.

4.2 EFFECT OF AIR PURIFIERS ON CHEMICAL COMPOUNDS

Adsorption and more specifically physical adsorption using activated carbon is one of the most widely used air cleaning technology to remove various inorganic and organic gaseous compounds from indoor air (Sidheswaran et al., 2012), although alumina, silica gel or various polymer materials are also commonly used (González-Martín et al., 2021). In a study published by Chen et al. (2005) the authors investigated the efficiency of 12 portable and 4 in-duct air cleaners utilizing five different air cleaning technologies (including adsorption, photocatalytic oxidation, ozonation, plasma, and green filtration) for removing multiple VOCs from indoor air. The study found that among others the adsorption was the most efficient (up to more than 90%) method of removing 16 of the most common VOCs present indoors. The authors also observed that the VOC removal efficiency in the tested adsorption devices were very heterogenous and mainly dependent on pollutant hydrophobicity. Furthermore, Jo and Yang (2009) showed that high relative humidity and the inherent variability of pollutant levels in indoor environments might also have negative impact onto the efficiency of adsorption filters. Nevertheless, removal rates of 90% - 100% have been reported for BTEX using activated carbon (Jo and Yang, 2009) and carbon nanocomposites (Srivastava et al., 2019) as adsorbent materials. Removal capacities of up to 140 µg/m²h (Zuraimi et al., 2018) or 8.11 mg/g (Xu et al., 2013) have been reported for formaldehyde using various adsorption based air cleaning technologies. In a study conducted by Srivastava et al. (2019) the authors reported retention capacities of 1821mg/g, 946 mg/g and 1076 mg/g for the removal of benzene, toluene and xylene, respectively for alkaline-treated carbon nanotubes and carbon monospheres. In a recent review published by González-Martín et al. (2021) regarding state-of-the-art in indoor air pollution control strategy the authors concluded that adsorption technologies are the best current physical/chemical technology for remove various organic and inorganic pollutants from indoor air (González-Martín et al., 2021).

Although, not as efficient as the physical/chemical adsorption technologies, the other popular air cleaning technology can also affect the concentrations of the gaseous chemical compounds in indoor environments. For instance, the strong oxidizing O_3 molecules generated from the ozone generators can react with various organic and inorganic volatile compounds present in the indoor environments. While the concentrations of some VOCs may be reduced, studies showed that the efficiency of the ozonation in reducing the indoor concentrations of the most common VOC is significantly lower than the physical/chemical adsorption technology (Luengas et al., 2015). A significant drawback of this technology is the high levels of ozone produced during ozonation. Furthermore, the secondary pollutants produced during the reaction of O_3 with various VOCs are additional health concern (Chen et al., 2005, Luengas et al., 2015). Therefore, this technology is very often not recommended for use in occupied spaces (US EPA, 2018).

Even though, the PCO cleaning technology affects wide range of indoor air pollutants, the overall removal efficiency of this technology is very much pollutant and catalyst specific (González-Martín et al., 2021). Table 2 shows a summary of adsorption and photocatalytic degradation of VOCs by various typical carbon-based nanocomposites published by Zou et al. (2019). Nevertheless, recent studies reported up to 60% removal efficiency (removal capacity: 1989 µg/m² h) of formaldehyde (Feng et al., 2017), and more that 75% for TVOCs (Zeng et al., 2020) for PCO based air cleaners. Quicy et al. (2010) reported 20 – 90% removing efficiency of tested PCO air cleaners with typical indoor toluene concentrations (10 – 500 ppbv). 100% removal efficiency of 2-propanol and toluene (80 - 400 ppbv) from PCO based cleaners at 0% relative humidity have been reported by Vildozo et al. (2011). The study also reported lower toluene removal efficiency (around 60%) of the same PCO air cleaner when the relative humidity was increased to 60%. These findings suggested that humidity plays a significant role in the removal efficiency of VOCs by PCO. Moreover, the areal elimination capacity of the PCO based air cleaning systems is an important design parameter for optimizing the pollutant removal efficiency of this technology. One of the major drawbacks of this air cleaning technology is the formation of potentially toxic by-products such as formaldehyde and acetaldehyde (Zhong et al., 2013). However, a combining the PCO cleaning technology with chemisorbed scrubber might reduce the generated by-product concentrations and reduce the potential health risks. Nevertheless, the generation of harmful radicals and secondary organic aerosols (e.g. formaldehyde, acetaldehyde), along with the higher cost of catalyst media replacement, limit the widespread use of this technology despite its relatively higher removal efficiency for specific pollutants of the modern PCO based systems (Guieysse et al., 2008; Lyulyukin et al., 2018; Vikrant et al., 2019).

Table 2 Summary of adsorption and photocatalytic degradation of VOCs by typical carbon-based nanocomposites (Zou et al., 2019)

Carbon based Nanocomposites	Initial concentration VOC	Adsorption Efficiency	Photocatalytic Efficiency
TiO_2 – ACFs	Toluene: 115 ppm, 460 ppm, 877 ppm, 1150 ppm	 99.4% 97% 99% 99%	 100% 81%[1] 62%[1] 57%[1]
TiO_2 – ACFs	Formaldehyde: 0.8 ppm	14.6%	83.6%[2]
Au/TiO_2 – ACFs	Styrene: 25 ± 1.5 ppm	-	91%[2]
CNTs/TiO_2 nanofiber	Limonene: 0.1 ppm, 0.7 ppm 1.6 ppm	-	92%[2] 69%[2] 42%[2]
MnO_2/MWCNT	Formaldehyde: 10 ppm	-	43%[2]
CNTs/TiO_2	Benzene: 250 ppm Styrene: 25 ± 1.5 ppm	- 95%	64.6%[1] 55.4%[2]
MWCNT/TiO_2	Acetone: 300 ± 20 ppm	-	50%[2]
Graphene/Fe^{3+}- TiO_2	formaldehyde	-	58%[2]
ZnO - TiO_2	Acetaldehyde: 200 ppm	-	3.08 mg/g catalyst[1]
N-doped graphene – Fe_2O_3	Acetaldehyde: 810 ppm	-	55%[2]
rGO - TiO_2	Formaldehyde: 0.5 ppm Methanol: 4000 ± 200 ppm	- -	88.3%[2] 80 mg/g catalyst[2]

Table 2 (continued)

Carbon based Nanocomposites	Initial concentration VOC	Adsorption Efficiency	Photocatalytic Efficiency
Ce - GO - TiO_2	Formaldehyde: 10 ppm	-	83.8%[2]
P25/graphene	Benzene: 156 ppm	8%	76.2%
GO - TiO_2	2-ethyl-1-hexanol: 0.8 ppm	-	55.1%[1]
Graphene hydrogel – AgBr@rGO	Bisphenol A: 20 ppm	87.2%	91.4%[2]
TiO_2/AC	Formaldehyde: 1 ppm Methanol: 22.4 ppm Aromatics: 0.1 ppm Propene: 100 ppm 2-Propanol: 2000 ppm Acetone: 175 ppm Cyclohexane: 600 ppm	33.9% - 95% - 93 – 94% 71% 35%	79.4%[2] 53%[2] 90%[2] 60%[2] 98%[2] 85%[1] -
TiO_2/biochar	Bisphenol A: 20 ppm	46.01%	22.41%[2]
g-C_3N_4/biochar	2-Mercaptobenzothiazole: 10 ppm p-nitrophenol: 32 ppm	- 90%	90.5%[2] 70%[2]
Biochar/Fe_3O_4	Carbamazepine: 30 ppm	-	50%[2]

[1] mineralization efficiencies calculated based on the amount of CO_2 produced
[2] conversion efficiencies calculated from the amount of VOC reduced

Plasma air cleaning systems has been reported to achieve relatively high removal efficiency (up to 90%) for various VOCs (Van Durme et al., 2009, González-Martín et al., 2021). However, different removal efficiencies have been reported for different VOCs. For instance, Zadi et al. (2020) reported removal efficiency of 29 -52% (benzene) and 10.3 – 34.7% (propionic acid) from dielectric barrier discharge non-thermal plasma based air cleaning system. Lee at al. (2021) on the other hand, reported only 5% removal efficiency of acetone from in-duct non-thermal plasma air cleaner. However, most of these efficiency assessments have been performed under lab conditions using relatively high concentrations of the VOC pollutants and low humidity. Blondeau et al. (2021) reported removal efficiency close to zero for an in-duct plasma based air purifier tested with mixture of VOCs at typical indoor concentrations (with max of 100 µg/m^3 for each individual VOC in the mix). The assessments were performed at temperature and relative humidity representing typical wintertime (19°C/45% RH) and summertime (24°C/70% RH) conditions in airconditioned office buildings in Europe. In another study, Van Durne et al. (2009) reported decrease of the toluene removal efficiency of non-thermal plasma air cleaner from >90% (tested at 0% RH) to 39 – 61% (at

30% - 72% RH). These outcomes showed that the efficiency of the non-thermal plasma based air cleaning system can be largely influenced by the humidity of the air and the VOC removal efficiency of the plasma based air cleaners could be lower in real indoor environmental conditions advertised.

4.3 EFFECT OF AIR CLEANERS ON MICROORGANISMS

The typical mechanical filtration technology used in the HVAC systems have been found to have excellent filter efficiency for larger particles such as pollen, house dust, and animal dandruff. In term of microorganisms however, filters show to be more effective in removing bacteria with large diameter (e.g. 0.2 – 10 µm) from the air stream, while they are not that effective in removing much small microorganisms such as viruses (diameter 0.01 – 0.3 µm). In the study published by Blondeau et al. (2021), the minimum efficiency of around 50% was reported for particles around 0.3 µm from an in-duct air purifier that combines mechanical filter and an activated-carbon filter. The results from the performed experiments also showed that the efficiency of the filtration from these filtering media was not affected by air velocity, temperature and relative humidity. The more effective for smaller particles, HEPA filters on the other hand are typically not installed into the residential HVAC systems due to the relatively high airflow resistance created by the small pores. Such systems require more powerful engines and specially designed ductwork to cope with the resulted higher air pressures. However, HEPA filters are widely used in standalone portable air purification units, where the devices are designed to work with the increased air flow resistance of HEPA filters. In a study published by Wen et al. (2014) the authors reported >99% removal efficiency of airborne *Serratia marcescens* bacteria by using HEPA filter based air purification device. Cheong et al. (2004) evaluated the influence of a portable HEPA filtration unit on the indoor fungal spore levels of in residential indoor environments. The authors reported up to 35% decrease of the indoor fungal spore levels in air filtered homes. Despite the relatively high microbial removal efficiency, the mechanical filtration technology does not inactivate the collected microorganisms. Therefore, often the mechanical filtration-based air purifiers are often combined with UV radiation technique for killing/inactivating the collected microorganisms.

Air purification systems based on ESP filtration showed relatively high microbial removal efficiency. Blondeau et al. (2021) reported nearly 100% bacteria removal efficiency of an in-duct ESP filter system at 1200 m^3/h, using *S. epidermidis* and *A. brasilienis*. However, the removal efficiency was reported to drop to 55%, when the airflow rate was increased to 3600 m^3/h. Chen et al. (2020) conducted a study were an electrostatic precipitator was evaluated to reduce nanometric and micron-sized particles (e.g. bacteria, viruses) in indoor air environments. Under optimal conditions of operation, the findings reveal removal efficiency of 94% and 99% for particles sizes of 10 – 20 nm and 30 – 300 nm, respectively. Moreover, the performed experiments showed that the collection conditions (collection time and voltage) of the tested ESP system had no influence on the efficiency of particle sizes between 10 – 300 nm.

UV radiation is commonly used to kill/inactivate microorganisms (e.g. bacteria, viruses, fungi) in laboratories, food industry and operation theatres. This technology constitutes an effective method for sterilization in ambient temperatures and pressure (De Robles et al., 2017). Under laboratory conditions germicidal UV radiation (GUV) has been shown to be effective against various microorganisms including vaccinia (McDevitt et al., 2007), *Mycobacteria* (Xu et al., 2003), influenza (McDevitt et al., 2012), and coronaviruses (Walker and Ko, 2007; Heilingloh et al., 2020). However, studies showed that the inactivation of the microorganisms exposed to UVG decreases with the increase of the humidity (Xu et al., 2005; McDevitt et al., 2012).

Photocatalytic systems showed high efficiency in eliminating fungi, viruses and bacteria. Typical use of this technology is the deep coating of HEPA or glass filters with a photocatalyst such as TiO_2 , which further decontaminates the airborne bacteria in a photocatalytic reaction (Ahmadi et al., 2021). Studies reported nearly 100% bacteria removal efficiency (Blondeau et al., 2021), 72 – 98% removal efficiency for viruses (Zhao et al., 2014; Ishiguro et al., 2013), and > 90% fungicidal efficiency (Rodrigues-Silva et al., 2017). Chuaybamroong et al. (2010) conducted a study where the microbial removal efficiency of HEPA filters combined with photocatalysis was assessed using various bacteria. The study reported that when the filtering system is used the microbial concentrations can be reduced by 60 – 100%, depending of the microbial species.

5 INITIAL AND MAINTENANCE COST OF AIR PURIFICATION DEVICES

Proper maintenance, including monitoring of the filter efficiency and the system integrity is critical to ensure proper operation of the air cleaners/purifiers. Not properly maintained air cleaner/purifier devices might deteriorate their air cleaning efficiency or even become a secondary source of pollutions. Therefore, to ensure better performance of their devices, the manufacturers often give detailed information regarding the cleaning or replacement frequency of each particular filter type. Many of the products on the market also integrate filter efficiency monitoring and warning system in order to prompt the customer when filters need to be replaced.

Although, the high removal efficiency of the HEPA filters widely used in consumer grade standalone air cleaning devices, these filters have relatively high cost and need to be changed frequently. Following the information presented in in **Fout! Verwijzingsbron niet gevonden.** the service life of these filters is limited to 2 - 6 months up to 1 year at normal conditions, adding significant amount of maintenance cost per year (**Fout! Verwijzingsbron niet gevonden.**). Only one manufacturer (Philips) from the listed in the **Fout! Verwijzingsbron niet gevonden.** devices, reports longer filter service life (up to 3 years). However, the manufacturer stipulated that "*the recommended life of the filters is based on a theoretical calculation of the average annual regional values of harmful outdoor air particles and daily use of the air purifier for 16 hours in automatic mode*" (www.philips.be). The manufacturer also recommend following the information of the integrated into the device filter efficiency monitoring system for replacing the filters. It is very likely in real conditions the service life of these filters to be significantly shorter that suggested by the manufacturer.

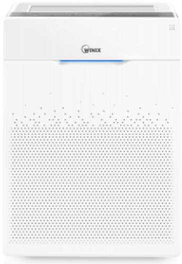
With regards to the cost ESPs has a higher initial setup cost than the mechanical filters, but do not need to be replaced yearly. The ESPs operational cost is expected to be less than the mechanical filters because of the much lower pressure drop that they impose to the system (i.e. do not need very powerful fans). Although, the installation cost of the cold plasma air filtration is rather high, the devices based on this technology only need regular cleaning of the filters than completely replacement. In addition the pressure drop of these filter systems is negligible, which further reduce the overall operational and maintenance costs of these devices in a long term.

The UV-PCO air cleaning technology has typically high initial as well as operational costs. The initial costs are usually associated with the configuration of the reactor, the intensity of the UV light, selection of appropriate catalyst and etc.

An overview of various in-duct mounted and standalone (portable) air cleaners available on the market with information about their initial and maintenance prices is shown in Table 3 and **Fout! Verwijzingsbron niet gevonden.**.

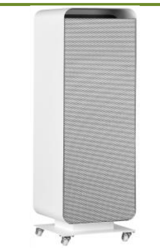
Table 3 An overview of standalone air purification devices available on the Belgian market

#	Product		Capacity	Technology	Price, EUR	Maintenance (average service life/cost)	Maintenance Cost (€/year)
1	Philips 800 Series		190 m³/h (for rooms up to 49 m²)	Mechanical Filter (HEPA)	160	Mechanical Filter (HEPA) – (12m/40€)[a]	40€
2	Winix ZERO N Luchtreiniger		168 m³/h (for rooms up to 45 m²)	Mechanical Filter (HEPA)	179	HEPA Filter – (2m/49€)	294€
3	Refresh Luchtreiniger /Airbi/		200 m³/h (for rooms up to 30 m²)	Mechanical Filter (HEPA) Active Carbon Filter Plasma Wave ionization	189	Mechanical Filter (HEPA) + Active Carbon Filter – (2m/39€) Prefilter – (2m/19€)	348€
4	Spring Luchtreiniger /Airbi/		320 m³/h (for rooms up to 50 m²)	Mechanical Filter (HEPA) Active Carbon Filter Plasma Wave ionization Cold Catalyst Filter UV irradiation	279	Mechanical Filter (HEPA) – (2m/39€) Active Carbon Filter – (2m/39€) Cold Catalyst Filter – (2m/39€) UV lamp – (2y/25€)	714€

5	Winix ZERO Luchtreiniger		462 m³/h (for rooms up to 92 m²)	Mechanical Filter (HEPA) Active Carbon Filter Plasma Wave ionization	299	Mechanical Filter (HEPA) – (2m/59€) Active Carbon Filter – (2m/27€)	516€
6	Philips 1000 Series		260 m³/h (for rooms up to 63 m²)	Mechanical Filter (HEPA) Active Carbon Filter	300	Mechanical Filter (HEPA) – (24m/43€)[a] Active Carbon Filter – (12m/35€[a])	56€
7	Winix ZERO Pro PlasmaWave luchtreiniger		480 m³/h (for rooms up to 96 m²)	Mechanical Filter (HEPA) Active Carbon Filter Plasma ionization	329	Mechanical Filter (HEPA) – (2m/69€) Active Carbon Filter – (2m/27€)	576
8	KC-D40EUW /SHARP/		190 m³/h (for rooms up to 22 m²)	Mechanical Filter (HEPA) Active Carbon Filter Ion Generator	334	Mechanical Filter – (1y /79€) Active Carbon Filter – (10y/59€) Humidifier filter – (1y/39€)	123.9
9	Blaupunkt UVirus Killer		370 m³/h (for rooms up to 74 m²)	Mechanical Filter (HEPA) Active Carbon Filter Plasma Wave ionization Cold Catalyst Filter	369	Mechanical Filter (HEPA) – (2m/39€) Active Carbon/Photocatalytic Filter – (2m/28€)	402

				UV irradiation			
10	Philips 2000 Series		333 m^3/h (for rooms up to 79 m^2)	Mechanical Filter (HEPA) Active Carbon Filter	430	Mechanical Filter (HEPA) – (24m/43€)[a] Active Carbon Filter – (12m/35€)[a]	56€
11	Philips 3000 Series		520 m^3/h (for rooms up to 135 m^2)	Mechanical Filter (HEPA) Active Carbon Filter	500	Mechanical Filter (HEPA)+ Active carbon – (3y/68€)[a]	23€
12	Airbi Maximum luchtwasser/bevochtiger		-	Mechanical Filter (HEPA)	519	Mechanical Filter (HEPA) – (2m/39€)	234
13	Philips 4000 Series		610 m^3/h (for rooms up to 158 m^2)	Mechanical Filter (HEPA) Active Carbon Filter	580	Mechanical Filter (HEPA)+ Active carbon – (3y/100€)[a]	33.3€
14	Airbi Space Luchtreiniger		800 m^3/h (for rooms up to 160 m^2)	Mechanical Filter (HEPA) Active Carbon Filter Plasma Wave ionization	649	Prefilter – (2m/19€) HEPA + Active Carbon Filter – (2m/139€)	948

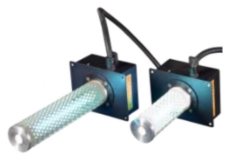
15	SNE RAS-60 Photocatalytic Air Purifier		for rooms up to 80 m²	UV/photocatalytic technology	906	UV/Photocatalytic Cell – (1y/205€)	205
16	agronLab UVGI-80 - Sterilizer : UV air purifier		800 m³/h (for rooms up to 32 m²)	UV Radiation (UVC)	999	UV lamp – (6m/100€)	200
17	AirExchange 600-T luchtreiniger		600 m³/h (for rooms up to 100 m²)	Mechanical Filter (HEPA) Active Carbon Filter UV/photocatalytic technology	1199	Mechanical Filter (HEPA) + Active Carbon Filter + UV/photocatalytic technology – (2m/168€)	1008
18	PureAirPro 1200 air purifier		1245 m³/h (for rooms up to 600 m²)	Mechanical Filter (HEPA) Active Carbon Filter	1440	Mechanical Filter (HEPA) + Active Carbon Filter – (2m/180€)	1080

19	LENA UV-C Sterilon HEPA air purifier		10 - 200 m³/h (for rooms from 20m² to 100 m²)	Mechanical Filter (HEPA) Active Carbon Filter UV lamp	1814	Mechanical Filter (HEPA) – (2m/- €) Active Carbon Filter – (2m/ - €) UV lamp – (1y/ - €)	-
20	CC 6000		6000 m³/h (for rooms up to 1000 m²)	Mechanical Filter (HEPA) Active Carbon Filter	9395	Mechanical Filter (HEPA) Active Carbon Filter	-
21	GENANO 5250M		500 m³/h (for rooms up to 100 m²)	Electric Filtering (Corona discharge) Active Carbon Filter	12588	Active Carbon Filter	-

- No information available

[a] The recommended life of the device is based on a theoretical calculation of the average annual regional values of harmful outdoor air particles and daily use of the air purifier for 16 hours in automatic mode. (www.philips.be)

Table 4 An overview of HVAC duct mounted air purification devices available on the Belgian market

#	Product		Capacity	Technology	Price, EUR	Maintenance (average service life/cost)	Maintenance Cost (€/year)
1	Elixair® E1250		1000 m³/h	Electric Filtering (ESP) Active Carbon Filter	2200	Active Carbon Filter - 40 EUR – (12m/40€)	40€
2	Brink Pure induct - WTW ionisatie filterbox		600 m³/h	Plasma Wave ionization	1150	-	-
3	SNE CAP H		400 - 4000 m³/h	UV Photocatalytic	499 - 619 EUR	UV / photocatalytic cel – (1.5y/156€)	104
4	SNE FAP DF		3500 - 25000 m³/h	UV Photocatalytic	995 - 1445 EUR	UV / photocatalytic cel – (1.5y/180€)	120
5	CC 400 Concealed		83 - 471 m³/h	Mechanical filter (possible upgrade with adsorption filters)	1995 - 2645 EUR	Mechanical filter – (-y/-€) Adsorption Filter – (-y/-€)	-

6	Genano® Tube		max 400 m³/h	Electric Filtering (Corona discharge) Active Carbon Filter		Active Carbon Filter (-y/-€)	-
	- No information available						

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