Emerging technologies for air cleaning and their integration in HVAC systems: which role in the increasing quest for healthy and sustainable buildings?

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Abstract. The paper starts from the consideration of both the fundamental goals of getting healthier indoor environments and at the same time obtaining much higher building energy efficiencies. In this frame, it presents a review of the different electrically connected technologies for Air Cleaning that are proposed for integration in HVAC Systems and gives a brief description of the air-cleaning options, of the applied mechanism and of the target pollutants. Thereafter the functions attributed to the air-cleaning components (i.e. control of indoor pollutant sources and/or cleaning of outdoor fresh air) are classified in order to clarify the rationale behind the organizing principle of the HVAC system. The paper concludes by giving information on the status of standards regarding performance and safety requirements.

1 Introduction

Attention to Indoor Air Quality (IAQ) issues has sometimes been focused on the aspects of olfactory perception of air contaminants and therefore on the "impact on comfort" side rather than on the "impact on the healthiness" side of indoor environments and on the reduction of risks for people's health. The knowledge we now have on exposure to contaminants present in the air and on the transmission of infectious diseases through the air leads to considering in a new light the ventilation needs of buildings, the choices of plant systems and the prescriptive references still based mainly on indications of flow rates of fresh air.

We must make progress regarding the effectiveness of what we use in the control of contaminants that originate from different sources (indoor/outdoor) and that behave differently from each other (e.g. particulates vs. bioaerosols, bacteria vs. viruses).

On the other hand, we are increasingly attentive (and we must be even more so) to the use of energy in buildings and to the efficiency in the use of scarce and expensive resources.

In this context, of the need for better results and constraints regarding the use of energy for the ventilation and airing of buildings, we can certainly count on filtration techniques (typically: fibrous, adsorbent and electronic filters) that are well known and adequately regulated (e.g. UNI EN ISO 16890 - Air filters for general ventilation [1] and UNI 11254:2007 - Electrostatic air filters with active charge for general ventilation -
Determination of the filtration performance [2], whose applications are expanding and changing in the level of quality offered.

We now come to the ongoing development of technologies and the use of so called "active techniques for air cleaning and sanitization" (e.g. non-exhaustive: UV radiation, ionization, photocatalysis, etc.) based on different mechanisms of action and united by the need for electrical power alimentation. These solutions for cleaning the air of contaminants can also be integrated into building ventilation systems and evaluated in a "system" logic, broader and more promising than that of plug-and-play portable devices, whose performance can be highly influenced by the volume and the space in which they are collocated.

Many "active techniques for air cleaning and sanitization" and their inclusion in new and existing systems were highly proposed in the pandemic period COVID-19 due to the new needs and the new sensitivity to the topic of IAQ in general and to the control of bioaerosols in particular.

After the pandemic period of 2020, most of the attention to these "active techniques for air cleaning and sanitization" has decreased, but the need to develop the methods of their insertion into ventilation systems from a scientific and technological point of view has not, for the simple reason that coming NZEB (Nearly Zero Energy Buildings) and ZCB (Zero Carbon Buildings) are requiring more attention to the indoor ambient healthiness, due to a more hermetic condition of energy efficient building envelopes.

Even more relevant, in this field of the "active techniques for air cleaning and sanitization" is the urgent possibility to have regional or worldwide regulations (which establish terminology and classification of solutions), laboratories, test methods, reliable performance measures, evaluation and acceptance criteria, in order to give to these technologies a proper scheme of evaluations. A clearer evaluation possibility would be extremely important for: engineering consultants, users, maintenance people and all actors involved in the design and use of these new technologies, which are becoming relevant in front of the increasing quest for healthy and sustainable buildings.

2 The European Ventilation market context in which the "active techniques for air cleaning and sanitization" find their application field

Looking at the next 30 years, beyond the natural short and medium-term IAQ market trends, it is necessary to take into account the fact that the legislative action of the EU and of the Member States (MS) could have a decisive weight in influencing further development of ventilation, air renewal and air purification technologies and these in turn may require greater use of active disinfection and air sanitization techniques.

Just thinking, for example, of the legislative package adopted by the European institutions between the end of 2018 and the first half of 2019 which establishes the regulatory framework of the Union's governance for energy and climate functional to the achievement of the new European objectives for 2030 on the subject and the decarbonization path by 2050 [3].

These decisions are part of a now consolidated efficient building framework for EU countries, which starting from the European Directive 2010/31/EU subsequently recast in the European Directive (EU) 2018/844 - EPBD (Energy Performance of Building Directive) [4] and currently being further revised, establishes requirements via progressively more stringent up to the highly efficient NZEB (Nearly Zero Energy Buildings) buildings and beyond.

In these very efficient buildings, with a very well-insulated building envelope, a considerable part of the winter energy needs can be met by free heat inputs which allow energy to be saved for air conditioning in the cold months. These free heat contributions can,
however, become disadvantageous in the summer season since the high insulation of the building envelope counteracts their dissipation towards the outside.

Substantial growth is expected in the world of intelligent shading (to limit the direct solar component in summer) and because these buildings (due to insulation needs) are increasingly quite hermetic, we are already seeing substantial upheavals in the ventilation needs of confined spaces (meeting rooms, offices, schools but also simply places of daily living such as private homes, etc.), since such quite hermetic buildings tend, by their nature, to trap air pollutants (both inside and outside the building) and encourage excessive humidity levels indoor which could lead in the most unlucky cases to unhealthy potential conditions for occupants.

![Diagram of air pollutants](image_url)

**Fig. 1.** Image by way of example and not exhaustive of Outdoor Air Sources of Contaminants. Source: US EPA (United States Environmental Protection Agency)

Confined environments are traditionally more polluted than the surrounding environment, because external pollutants are added to those emitted by the building inside and those generated directly and indirectly by its occupants. For example, it is known that high humidity values inside rooms have the potential to boost growth of harmful biological contaminants such as mold, bacteria and mites.

Inadequate management of the building, such as maintaining high humidity values inside for quite a long time, causes the development of harmful biological activities which in turn can cause allergies, asthma, irritation and in the most serious cases infections and respiratory diseases more serious. It is easily observed that the load of pollutants presents in confined spaces, due to direct and indirect causes, also greatly exceeds the values considered to be limit values for this category of substances.

Beyond the pollutants that can enter the confined spaces from the external environment (Fig.1), essentially two types of emissions occur in the building: those relating to the building and those caused by the occupants.
In general, as expressed by US EPA (United States Environmental Protection Agency) in its online publication "Introduction to indoor air quality" the following (non-exhaustive) substances, can be considered some of the most common indoor pollutants:

a) Asbestos  
b) Biological Pollutants  
c) Carbon Monoxide (CO)  
d) Formaldehyde/Pressed Wood Products  
e) Lead (Pb)  
f) Nitrogen Dioxide (NO2)  
g) Pesticides  
h) Radon (Rn)  
i) Indoor Particulate Matter  
j) Secondhand Smoke/ Environmental Tobacco Smoke  
k) Stoves and Heaters  
l) Fireplaces and Chimneys  
m) Volatile Organic Compounds (VOCs)  

![Indoor and outdoor air pollutants sources](Fig. 2).

The emissions of pollutants relating to the building are usually due to the release of substances that were used in the construction phase or possibly in subsequent renovation phases (Fig. 2). When a building or any other construction work is built, numerous products and materials are used which can contain various quantities of polluting substances.

Once the construction of the building is completed, many of these substances, which remain inside the materials and building components, tend to slowly release into the environment, passing from the porous supports to the air and accumulating in the rooms, especially if ventilation is not sufficient. The times necessary to completely evacuate pollutants from building materials are generally very long, in the order of years or decades.
Some polluting substances such as, for example, formaldehyde, are emitted by materials for very long times which are in the order of the useful life of the building. Everything that is new, especially if it derives from industrial production, can very often contain significant quantities of substances which are gradually acquired from the air of the internal environments of the building.

When we enter a new car, for example, we immediately smell "the so-called new smell" which is nothing more than a varied mixture of volatile substances (VOCs), including pollutants, contained in the plastics and fabrics which can be, if in high concentrations, harmful to the human body. The evacuation of pollutants can advantageously be promoted by means of adequate ventilation, preferably of a continuous and automatic type.

Mechanical ventilation can represent a very effective solution for the correct evacuation of pollutants from buildings. Through the entry of appropriately filtered and purified external air, richer in oxygen and with a lower concentration of pollutants than the internal one, the pollutants present inside the building will consequently be diluted and removed from the building, preventing their accumulation and concentration.

For all these reasons, ventilation and related solutions for the purification, sanitation, disinfection and sanitization of air is a market which (with different percentages depending on the different segments and technologies) is expected to grow strongly in the years to come in Europe and also in many countries all over the world.

2.1 Non-Residential Buildings

![Fig. 3. Estimation of the evolution of mechanical ventilation systems in non-residential buildings [5].](image)

In the European Community's estimates, in order to understand how the evolution of efficient buildings according to the EPBD (Energy Performance of Building Directive), impacts the expected growth of ventilation systems by 2050, ventilation could reach a rate of coverage (for example for the non-residential sector) of 90% of buildings: that is to say that according to estimates made by the European Community, it is expected that only 10% of buildings could be without ventilation in the year 2050 (Fig. 3).
2.2 Residential Buildings

As regards the residential sector, the considerations may be similar, with the difference that the number of systems will be orders of magnitude greater than in the non-residential sector and that the air flow rates involved and therefore the dimensions of the ventilation units will be larger modest.

In the residential field, it is predicted that ventilation could have a coverage rate of 58% of buildings in 2050 (in 2020 this value was estimated at 25%) and therefore it is expected that only 42% of residential buildings in 2050 could be without ventilation (Fig. 4).

![Share of EU27 permanently occupied dwelling area using type of Ventilation](image)

**Fig. 4.** Estimation of the evolution of mechanical ventilation systems in residential buildings [5]

With a similar expected growth in the adoption of ventilation systems in both the residential and non-residential sectors, it is therefore relevant to understand how much the indispensable traditional filtration techniques (typically mechanical and electronic) can find in active air cleaning, disinfection and sanitization devices a valid “allied” tool for achieving complete air purification even in the field of pathogenic microbes that can be suspended in the air.

It is for this reason that alongside the so-called passive techniques (typically fibrous and adsorbent filters) it is good to start paying more attention to the so-called "active techniques for air cleaning and sanitization" (by way of example but not limited to: Photocatalytic oxidation (PCO), Ultraviolet light (UV-C), Plasma, Ionization, etc.), since they can offer a completely new and useful scenario for the healthiness of internal environments, even in the presence of airborne pathogenic charges.

3 Overview of the main "active techniques for air cleaning and sanitization”

If we exclude for a moment ozone, which from a regulatory point of view, currently in Italy can be marketed and used exclusively as a sanitizer but with precise requirements regarding maximum concentrations and its use in the absence of human presence, we can narrow the
field of active air disinfection and sanitization devices in 4 large categories, namely (Table I):
• Ultraviolet (UV-C)
• Photocatalytic Oxidation (PCO)
• Ionization
• Cold Plasma

Table I - Exemplification and not exhaustive resume of some advantages and disadvantages linked to the most common "active techniques for air cleaning and sanitization.”

<table>
<thead>
<tr>
<th>Technology</th>
<th>Principle of work</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>UV light kills or inactivates several pathogens</td>
<td>- Can be effective if intensity is high and contact time is sufficient - Can be used to inactivate pathogens on cooling coils or other surfaces</td>
<td>- Can generate ozone - May cause eye damage - high electrical absorption requirements - Inactive but does not remove microbes - effective on surfaces but there is no data attesting to its action on airborne bioaerosol - does not act on particulates</td>
</tr>
<tr>
<td>Photocatalytic oxidation (PCO)</td>
<td>(Photo) catalytic oxidation (PCO) uses a catalyst with maximized surface area, usually coated with titanium dioxide; The gases are transformed when they come into contact with the catalyst, previously activated by a UV source</td>
<td>- Can degrade a wide range of pathogenic pollutants, oxidizing them - Can be combined with adsorbent media to improve effectiveness</td>
<td>- May generate harmful by-products if not properly engineered - no standardized testing methods - Removal efficiency also depends on the surface of the catalyst - catalyst has a finite life - not effective on particulates</td>
</tr>
<tr>
<td>Plasma</td>
<td>An electric arc is generated by the passage of electric current; the gases involved are ionized and chemically transformed thanks to the breaking of intramolecular bonds</td>
<td>- Can be effective on gas phase contaminants, oxidizing them - Can be combined with other air cleaning technologies to improve performance</td>
<td>- the wide variety of plasma generation types has created confusion about how the product actually works - harmful subproducts Can form - does not act on particulates</td>
</tr>
<tr>
<td>Ionization</td>
<td>One or more electrodes electrostatically charge the particles or VOCs via a high voltage</td>
<td>- Silent - Low maintenance - Low pressure drop</td>
<td>- Can generate ozone - does not remove particulates</td>
</tr>
</tbody>
</table>

Before entering into detail on the description of the four active techniques mentioned above and to conclude the overview of ozone, it should be noted that it is classified as a toxic substance for humans. Scientific studies have shown that even at concentrations lower than 0.2 ppm it can cause symptoms especially affecting the respiratory tract: alteration of the permeability of the epithelia with consequent reduction in lung function (up to edema), cough, dyspnea, worsening of respiratory pathologies (for example asthma) and inflammatory reactions (Krishna et al., 1995; Krishna et al., 1998). Ozone also causes other ailments such as burning eyes, headaches and weakness. A possible genotoxicity of the molecule is also suspected (Victorin, 1992). Finally, ozone, due to its high oxidative potential, could react with other chemical components present in the room where it is introduced, and potentially release volatile compounds dangerous for health (Weschler et al., 1992a, 1992b, 1996; Zhang and Lioy, 1994).
For these reasons, various international bodies have expressed severe provisions regarding exposure to ozone. For example, the Food and Drug Administration (FDA) requires that ozone output for medical instruments must not exceed 0.05 ppm. The Occupational Safety and Health Administration (OSHA) requires that workers should not be exposed to an average of 0.10 ppm ozone for 8 hours. The National Institute of Occupational Safety and Health (NIOSH) recommends a maximum exposure limit of 0.10 ppm, which should not be exceeded under any circumstances.

Environmental Protection Agency (EPA) national air quality standards impose a maximum exposure limit of 0.08 ppm over an 8-hour average.

3.1 Ultraviolet light (UV-C) and Photocatalytic Oxidation (PCO)

Already towards the end of the 19th century, using solar radiation as a source of ultraviolet radiation (UVR which stands for Ultraviolet Radiation), studies were started to understand the molecular changes in living organisms produced by the absorption of UVR rays. In the twentieth century, with the invention of mercury vapor electric arc lamps, a controllable and economical source of short-wavelength, 253.7 nm, germicidal UVR became available. Thus began the systematic study of the impacts of UVR on biological systems in different disciplines, using germicidal UVR lamps.

The impacts of UV radiation on biological systems have been studied to provide an understanding of the protection of humans from hazardous exposure and the ability of UV radiation to stem the spread of infectious diseases by inactivating microorganisms in food, water and air.

In the twenty-first century, the mitigation of pathogenic threats, mainly due to bacteria and viruses, in environments frequented by people inside buildings has taken on further importance for the disinfection and sanitization of air and surfaces.

Bacteria are actually single-celled organisms that can be found naturally throughout our bodies and in our environment. Viruses, on the other hand, are smaller than bacteria and attach themselves to another living cell and use that cell’s genetic material to reproduce. Most viruses cause diseases such as COVID-19, which has become very relevant in recent years, influenza, the common cold, chickenpox and many others. Well-known dangerous bacteria are Salmonella, Staphylococcus Aureus (MRSA), E. coli and many others. While bacteria and viruses are clearly different, they both have one common attribute, they have genetic material (DNA and RNA).

![The Spectrum of Light](image)

**Fig. 5.** Image by way of example and not exhaustive of the light spectrum and the wavelength range of UV-A, UV-B and UV-C rays [3]
When we're exposed to the sun, it's important to protect ourselves from sunburn and from DNA and RNA damages that could be induced by UV radiation. This is exactly how UV radiation can inactivate viruses and bacteria, ultimately damaging their DNA. A DNA molecule is made of two strands linked together by four bases: adenine (A), cytosine (C), guanine (G), and thymine (T). These bases are like an alphabet, and their sequence forms the instructions for cell reproduction. UV radiation can cause thymine bases to fuse together, disrupting the DNA sequence and essentially disabling the replication machinery. Because the DNA sequence is no longer correct, it can no longer replicate correctly. UV radiation therefore destroys the ability of viruses and bacteria to reproduce, inactivating them.

Ultraviolet (UV) is a portion of the electromagnetic spectrum with a wavelength immediately shorter than the light visible to the human eye and immediately longer than that of X-rays. The International Commission on Illumination (CIE) [4] divides the spectrum of ultraviolet in four regions, as illustrated in Figure 5:
- UV-A, 315 nm - 400 nm;
- UV-B, 280 nm - 315 nm;
- UV-C, 200 nm - 280 nm.

The use of germicidal UV radiation (GUV) within the UV-C range (from 200 nm to 280 nm), against airborne transmission of infectious agents (bacteria and viruses) has been successful and safe for over 70 years, by means of compact devices designed to treat indoor air. The UV-C part of the UV spectrum has the highest energy. Whilst it is possible to damage some microorganisms and viruses with most of the ultraviolet radiation spectrum, UV-C is the most effective and hence UV-C is commonly used as GUV.

Among the various active technologies that use UV-C, an emerging solution proven to be effective in inactivating viruses and bacteria in the air and on surfaces, with significant advantages in overall terms in the fight against airborne pathogenic loads, has proven to be Photocatalytic Oxidation, commonly called PCO (English acronym: Photocatalytic Oxidation). The integration of this technology into HVAC systems generally does not involve modifications to them and does not increase pressure drops, as instead happens for example with the possible addition of high-efficiency filter banks (Figure 6).

Fig. 6. Purely illustrative and non-exhaustive image of the application of photocatalytic technology for air duct application.
At a scientific level, it has been demonstrated that semiconductor (SC) photocatalysis effectively degrades a wide range of pollutants, including pathogens. Although the detailed mechanism of photocatalysis varies depending on different airborne pollutants and viral elements, it is commonly accepted that the primary reactions responsible for the photocatalytic effect are interfacial electron-hole oxidation-reduction reactions that are generated when the catalyst is exposed to sunlight, sufficient energy and well-defined characteristics.

Compared with other photocatalyst elements, titanium dioxide (TiO$_2$) appears to be the most promising material due to its behaviour, stability with high photoactivity and relatively low cost. For these reasons, the photocatalytic inactivation, using TiO$_2$, of a large number of organic contaminants, including bacteria and viruses, has been widely studied even very recently [7].

It must be taken into consideration that there are often devices on the market that combine one or more technologies, therefore, in the absence of specific standards, it is very important that at least these devices have been tested by independent and accredited third-party bodies, in order to understand what may be the effectiveness and efficiency in reducing airborne pathogenic loads.

By way of example and not exhaustively, various experiments were carried out in 2020 to test the effectiveness of some devices; one interesting could the one created by the "Luigi Sacco" Department of Biomedical and Clinical Sciences [8].

Referring to a test environment, it highlights that the device that uses two combined technologies (PCO and UV-C) has shown the ability to reduce the viral load against the SARS-CoV-2 virus inoculated in the liquid phase both on a surface and on a fabric.

The neutralization of SARS-CoV-2 on the inoculated petri dish, exposed to treated air for 20 minutes in a volume of 2.13 m$^3$, showed a reduction of 1.0 log (90.0%) greater than the natural decay of the virus verified in the test control performed under equal conditions, but without technology. The reduction on the cloth made up of 45% polyether and 55% cellulose, inoculated with SARS-CoV-2, exposed to treated air for 20 minutes in a volume of 2.13 m$^3$, showed a reduction of 2.5 log (99.7%) higher than the natural decay of the virus verified in the control test, carried out under equal conditions, but without technology.

### 3.2 Ionization

The basic technology of ionizers consists of one or more polarizing electrodes made in various shapes (tips, metal nets or meshes, tufts, etc.) powered with high positive and/or negative direct voltage or alternating for some special applications and with values of completely negligible power.

This technology was born in the years of the Cold War and in the creation and construction of anti-atomic bunkers. In fact, it was seen that although the air treated in these rooms was purified and clean in the best possible way, life inside was difficult for both humans, animals and plants.

The studies and research carried out on the matter led to the belief that it was a lack of ionic balance (number of negative and positive ions) that exists in a natural external environment, as it is mainly caused by atmospheric events and natural phenomena that occur in the troposphere (e.g. wind, storms, lightning, sea movements, waterfalls, etc.).

The continuous movement and thermal treatment of the air in these particular indoor environments led to an unnatural destruction of negative ions in favor of the creation of positive ones.

The balance considered favorable was quantified as approximately 2000 negative ions and 1500 positive ions per cm$^3$. 
The alteration of this balance was and is believed to lead to poor absorption of oxygen present in the air by the blood circulating in the lungs of human beings.

The "cleaning" effect of the air occurs through the generation of an electric field that produces (emission) positive and/or negative ions from the molecules of the air present (plasma) which, by binding to the airborne particles present, cause them to aggregate (clusters) between them and, once these have reached a sufficient mass, they fall to the ground due to gravity or adhere electrostatically to the nearest surfaces having an opposite or neutral charge.

The micro-bacteriological removal performance of these systems, however, is normally declared only by private institutes or laboratories according to their investigation methods which normally are neither unique nor comparable to each other. The efficacy tests reported describe experiments and illustrate experiences conducted in still air, in static boundary conditions on surfaces or cultural terrain for long exposure times which, as can easily be understood, are never comparable to real conditions of use.

3.3 Cold plasma

Cold plasma is formed when the electrons are provided with enough energy to "move away" from the molecules, remaining free, without however altering these molecules. In this situation of thermodynamic imbalance, only the electrons acquire energy, causing a moderate overall increase in temperature which therefore remains overall close to the ambient temperature. The pressure is also environmental, thus allowing the technology to be applied in numerous contexts without particular difficulty.

Non-Thermal Plasma is today an emerging technology whose applications range from uses in the food and medical industries, where its sanitizing capabilities are exploited for delicate surfaces, to uses in agriculture where it inhibits mold and allows us to reduce the use of pesticides and so on. However, each application requires a specific type of reactor for the formation of cold plasma, as well as different application systems. It is therefore an advanced technology with high potential but, on the flip side, complex to apply.

In the majority of air sanitizers currently on the market, the generation of cold plasma occurs through the principle of electron acceleration, which is obtained by applying high voltage alternating current to a generally cylindrical DBD (Dielectric Barrier Discharge) reactor: the potential gradient exceeds a certain value causing the ionization of the fluid (air in this case). In this process, molecular dissociation reactions and the formation of radical species occur. It is necessary to underline the difference with ionization via an electrostatic field, aimed at removing only solid particulates, in which only a minimal quantity of reactive chemical species is formed.

The reactivity of the species produced by cold plasma allows the reduction of various types of chemical and biological pollutants: VOCs (volatile organic compounds) [9], [10] (therefore also odors), viruses [11], bacteria [12] and mold.

However, it is known that harmful by-products can form, including ozone or formaldehyde, and therefore they must be appropriately evaluated as a whole considering the advantages and possible disadvantages (which cannot be excluded a priori) deriving from their use. “Plasma” air purifiers are sometimes combined with other air purification technologies, such as PCO or adsorbent media, but very little information exists on the performance of these systems in real indoor environments.

However, it is now well established that Non-Thermal Plasma presents aspects of undoubted interest, especially with regards to its ability to kill microorganisms through a whole series of non-specific and different mechanisms which cannot therefore generate the onset of resistant microbial phenotypes (as is always possible in the case of chemical biocides). The most important mechanisms of action are (Figure 7):
- damage to nucleic acids by UV radiation which always accompanies the generation of NTP.
- lipoperoxidation mainly affecting the fatty acids of the external cell surface carried out by reactive oxygen species (ROS);
- alteration of the protein chemical structure with their functional damage and inactivation by hydroxyl radicals.
- Electroporation of the cell membrane due to the charged particles that accumulate outside [13].

**Fig. 7.** Illustrative picture of the mechanisms of microbial inactivation of non-thermal plasma [14]

The recent COVID-19 epidemic has highlighted the potential of sanitization also in relation to this virus. According to a study by the University of Padua, there is an effective antiviral activity against SARS-CoV-2 with a reduction in the viral load equal to 99.99999% after only 30 minutes of exposure.

From the point of view of critical issues, the main discriminating factor in the use of NTP sanitization systems is the quantity of electrical charges generated in relation to the position in space and the volume to be treated. In fact, given the high reactivity of the ionized molecules produced, this results in a very short "life" time, so their range of action is mainly in the vicinity of production and therefore their number and their location are priority aspects for the purposes of their effectiveness.

In a well-determined volume for performance purposes, in real conditions of use and in relation to their generation source, these technologies must be correctly and uniformly sized and distributed in the environment considered.

### 4 Conclusions

The renewed attention to indoor air quality, following the Covid 19 pandemic, is destined to also have a strong impact on the design and management of air conditioning and ventilation systems which will increasingly have to balance the need for energy saving, which has had a predominant role until now, with the healthiness of the environments and the protection of the health of the occupants. The role of the "active techniques for air cleaning and sanitization" in the increasing quest for healthy and sustainable buildings is expected to be relevant in cooperation with traditional ventilation techniques and traditional fibrous, adsorbent and electronic air filters, normally used in HVAC systems. It will probably be necessary to rethink the minimum ventilation standards or privilege system solutions that allow for more flexible management, capable of adapting to emergencies, using a triple level of activation and use of, non-exhaustive:
intelligent ventilation;
— traditional mechanical fibrous, adsorbent and electronic air filters;
— active techniques for air cleaning and sanitization
— as a triple combined approach that can be applied in the same system design.

In this context, as the characteristics and performances of mechanical filtration systems and electrostatic filters have been well regulated, it is necessary at a regulatory and academic level to provide for the "active techniques for air cleaning and sanitization" systems, which are increasingly adopted in aeraulic systems in all buildings, an adequate level of knowledge of performance and safety, with specific adequate standards, in order to deliver to future generations buildings that are not only efficient but also healthy and with high quality of the built environment.

**Special thanks**

Special thanks go to the whole CTI (Comitato Termotecnico Italiano) Technical Commission CT 242, Working Group 1, dedicated to the creation of a standard to classify active sanitization, disinfection and air sanitization devices, with reference to the technology used, identifying the performance parameters and test methods. The objective of the working group is to produce a regulatory document that helps operators in the sector to choose the active techniques that can be usefully combined with traditional filtration systems, thus ensuring the effectiveness of the system also with regard to the inactivation of any airborne pathogenic charges. In particular, in order of exposure in present document:

— Luca Gatti, Managing Director of Air Control Srl (Italy) for the contribution related to the Photocatalytic Oxidation (PCO) chapter 3.1;
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— Luigi Bontempi, Independent Consultant at Tecnica Bontempi snc (Italy) for the contribution related to the Ionization chapter 3.2;
— Fabrizio Cervelli, researcher at Archa srl for the contribution related to the Cold Plasma chapter 3.3.

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