Improvements in Indoor Air Quality for Disease Mitigation

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Introduction

This report focuses on possible improvements to both new and, to a lesser extent, existing HVAC systems at airports to improve indoor air quality (IAQ). However, the approaches listed within this document may be applicable to any public building or HVAC system, including but not limited to schools, retail facilities, transportation hubs, and community centers. Even though this report has an emphasis on the approaches to consider for an airport, we would like to share our simplified list of possible approaches any facility could implement to improve their indoor air quality.

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We at Arora are not industrial hygienists but do rely on data compiled by them, and as applied by various product manufacturers confirmed through independent testing laboratories. Any evaluation or recommendations at this level should be considered general in nature to each type of system being discussed and not an endorsement of any product.

We also want it understood that the HVAC systems designed for airports in general are of a high-commercial/institutional quality but are not of a hospital/medical nature of design or construction. The degree and arrangement of filtration, total air volumes, specific pressure relationships, and expected energy use profiles do not lend themselves to medical applications. This paper is intended to outline methods and applications within the current HVAC systems and independent of or parallel to the HVAC systems, to maximize indoor air quality above what is normally provided.

Executive Summary

Of the various IAQ technologies available and discussed here, use of Bipolar Ionization applied within new or existing HVAC systems has merit, subject to further specific investigation. When incorporated into standard HVAC duct systems, the distribution of ions tends to be better than when deployed directly within the space.

In addition, ultra-violet spectrum C (UV-C) light has an application on return air filtration, but less-so in other parts of air handling units.

Local air cleaners for small rooms have at least an experimental application due to their low cost and apparent space requirements, but do not lend themselves to public passenger spaces due to their size and scale.

An air handling unit-based mitigation system would be less effective in removing pathogens during economizer cycle operation because space air would not be returned through the unit supply train for recirculation. Economizer operation provides more outside air to flush the space, but it does not clean the recirculated air.

Each technology has its own benefits which can make them a good fit for a specific application, and it is most likely a combination of the options mentioned below that will aid in improving the IAQ of the spaces they are meant to serve.

Electrostatic Air Filters

Electrostatic filters are reusable and washable. They can be installed in addition to an air handler's primary filtration system. They use electrical power, boosted to higher voltages, to charge airborne particles and help prevent them from entering the conditioned space. As dirty air enters the unit, the electrostatic filter creates an electric charge. The ionizers in the filter then emit charged ions. The ions attach themselves and add an electric charge to the particulates. The electrostatically charged particles are attracted to a collector, and a carbon filter removes the remaining odors, often including ozone. These filter arrays are deeper in airflow length than conventional filters and are known to produce ozone, but also tend to have relatively low air pressure drops, which saves fan energy. Due to their size, they must be designed-in when equipment is first installed. They are often impractical to retrofit into existing units, unless there is ample additional space available.

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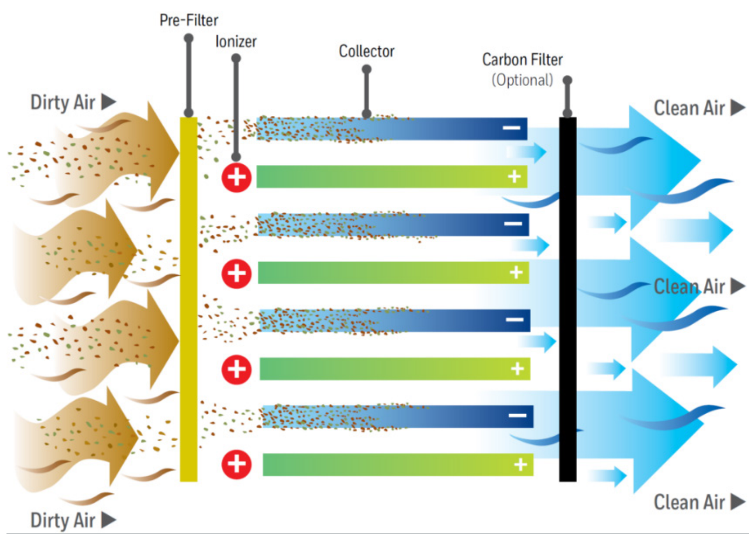
Electrostatic filters are best applied as early-stage filters and as their collectors load up with particulates, they become insulated and thus less-effective.



Electrostatic Filter Diagram Source: https://www.simplythebestac.com/blog/wp-content/uploads/2017/02/Electronic-Air-Filtration-1-1024x725-1.png

For these filters to remain effective, regular cleaning and maintenance is required. Failure to do so will result in reduced indoor air quality. These filters rely on static electricity to capture airborne particles, so small particles like viruses and bacteria are more likely to be captured by the filter than mold particles or spores[1]. Replaceable filters with a MERV-13 or higher rating would be more effective in filtering out a greater range of airborne particles, particularly when agglomerated.

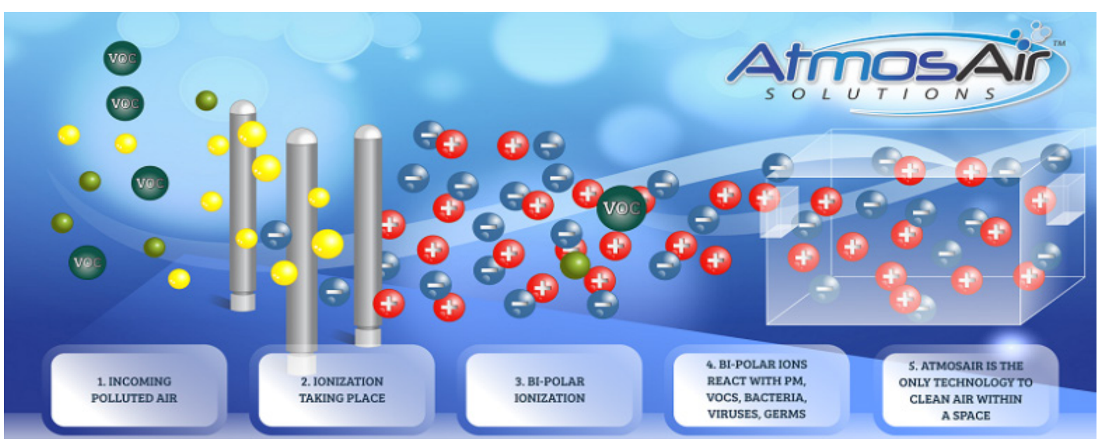
Ozone Generators

In the past, ozone generators were commonly used to remove odors as one facet of improving indoor air quality. The Environmental Protection Agency (EPA) has since conducted research into its effectiveness and safety, and they no longer recommend using it due to possible toxicity and harmful side effects on human tissue. There are other possible design strategies and equipment that can be added to HVAC systems to further mitigate the spread of pathogens.

Note: Bipolar Ionization is one method covered in more detail below; it is also a common principle used to generate ozone via electrical arcs, and a distinction must be made here. Any technology using Bipolar Ionization must comply with UL Standard 2998, Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners.

Bipolar Ionization Technology

Bipolar Ionization occurs when an alternating voltage source is introduced to a special ionization tube containing two electrodes. An ionization field produces positively and negatively charged ions. These ions attach to airborne particles in the space and cause oppositely charged particles to attract to other particles and become bigger and heavier, by a process called “agglomeration.” These larger particles can now be better trapped by HVAC system filters, so the filters operate more efficiently.



Source: https://atmosair.com/technology/how-atmosair-works/

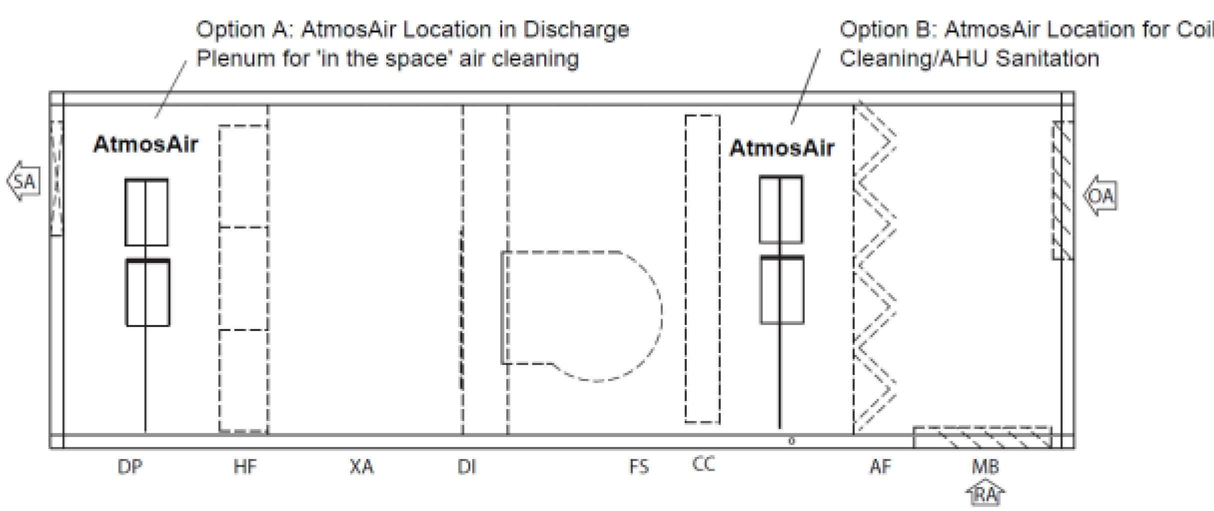
[1] *https://www.simplythebestac.com/blog/pros-cons-electrostatic-filters/*

As the particles agglomerate within the spaces, they are also more likely to become weighted down and fall to the floor and away from the breathing space. While this process does not kill the bacteria and viruses in the air, the negative ion-produced agglomeration, coupled with filter capture, disrupts the reproductive ability of viruses and bacteria, therefore lessening the chance of spreading and causing further infection[2]. The bipolar ionization tubes can be integrated into the supply ductwork or the air handling unit, or act as a standalone system. If the bipolar ionization tubes are installed within the supply air ductwork, it's more likely agglomerated particles would fall out of the air before the filters in an air handling unit would catch them.

As noted previously, any technology of this type must comply with UL Standard 2998, Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners.

Regarding Bipolar Ionization, if it meets no-ozone generation and is applied to open spaces, these can be effective in particle agglomeration to improve initial settlement of particulates gathered in normal housekeeping, with residual particulates more easily captured by HVAC system filters.

If applied to air handling systems specifically, placement within supply ductwork or in the AHU discharge supply path appears to be less invasive than "in-space" deployment. This by default would give the best distribution of ions within the space, with the same coverage as HVAC supply air would tend to do.



Example of Bipolar Ionization Tube installation in a generic air handling unit (for illustration only). Source: https://d3ciwvs59ifrt8.cloudfront.net/a02e5a7a-d7d4-4460-b933-6a0c761e7ef1/1d3eb8b6-9fda-498c-89fe-cd6e01c9dde2.pdf

[2] *http://atmosair.com/wp-content/uploads/2020/03/Cleaning-Indoor-Air-Using-Bi-Polar-Ionization-Technology_Dr.-PhilTierno_NYU-SchoolMedicine_2017.pdf*

HVAC Ultraviolet (UV-C) Light Purification Systems

A UV-C purifier emits a higher-frequency wavelength ultraviolet light that can kill mold, bacteria, viruses, and other pathogens[3].

UV light covers a wavelength spectrum from 100 to 380 nm and is subdivided into three regions by wavelength: UV-A (320 to 400 nm), UV-B (280 to 320 nm), and UV-C (200 to 280 nm), with UV-C having the higher frequency, shorter wavelengths, and higher biocidal effects[4].

Applications today would favor UV-C generated by light-emitting diodes (LED's), for lower energy consumption, avoidance of mercury in conventional UV lamps, cooler temperatures, and better moisture-resistance.

There is a common misperception that UV-C lights within the air handling unit and ductwork are effective at killing airborne contaminants.

A UV light system inside an air handling unit, within the cooling coil section of the unit, is designed to primarily keep the coils, drip pans, and interior surfaces of the condensing section clean from mold growth. Unkept units may grow mold in these sections due to condensation of humidity, which is then dispersed throughout the building by way of the ducted air. Though the primary role of the UV-C light is to keep the cooling coil section from growing mold, they are better-known for maintaining surfaces that are already clean.

In practice, today's IAQ-founded design standards include positive-pitch stainless-steel drain pans, stainless steel cooling coil frames, and positive drainage of cooling coil condensate, such that normal maintenance reduces the build-up of biological growth. (Note that existing units may not have all these features.)

Further, the current practices for the marine environment include phenolic-coated coils, which more readily shed cooling coil condensate, moving it through the coil to the drain pans. These coatings can be damaged over time by exposure to UV light.

There is a common misperception that UV-C lights within the air handling unit and ductwork are effective at killing airborne contaminants. Though the primary role of a UV-C light is to keep the cooling coil section from growing mold, these systems also have a limited effect on killing pathogens that are airborne as the air passes through a UV-C lights section. Three of the most important factors to how effective a UV-C light scrubs the air of contaminants are time, distance from the UV-C light, and UV-C light intensity. For example, if a lamp has an output of approximately 800 ma, the average bacterium will be killed in ten seconds at a distance of 6 inches[5]. Most airborne contaminants within a ductwork system will not experience the required amount of contact time in order to completely destroy the pathogen. For example, assuming a standard internal air velocity of 500 FPM and a cooling coil section 18" deep, the travel time through the UV-C light's area of influence will be approximately 0.18 seconds.

[3] https://www.light-sources.com/blog/killing-bacteria-with-uv-light/
[4] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4702654/
[5] https://www.americanultraviolet.com/uv-germicidal-solutions/faq-germicidal.cfml

Installing the UV-C light within the ductwork itself also affects the air passing through. However, duct air velocities are often in the range of 1000-2000 FPM, further reducing UV light/pathogen contact time. Many manufacturers claim that their UV-C lights have reduction rates up to 99.9% depending upon the specific microbe, but this is only true if proper care is given to the placement and intensity of the UV-C light selection and enough light/pathogen contact time. These claims should be understood to refer to stationary pathogens on fixed surfaces, not necessarily airborne pathogens in motion. UV-C lights can be effective against pathogens whose motion has been arrested by filters. Activated carbon filters should be considered to capture any ozone generated by the UV-C lamps. Operation at lower temperatures, normal within most air handling systems, further reduces their efficacy. This is a relatively low-cost solution, and many air handler manufacturers offer this as an accessory option to the units. However, due to minimal radiation/pathogen contact time, reduced effectiveness at lower temperatures, degradation of coil coatings, and limited benefits given positive drainage of condensate, we do not recommend UV-C lights in coil sections of air handling units.

There is, however, an application on the return-side of air handling units, if the air is also filtered. Application of UV-C on the upstream face of return air filters would help maintain filter surface sepsis control on captured particulates, where residence times are indefinite until filters are changed.

In medical applications, use of UV-C is often applied in emergency room waiting areas, up near ceilings to wash the corners with UV-C radiation. These ER's, where "unknown arrivals" sit for sometimes extended periods, are also usually sequestered from the larger volume. The studies on the effectiveness of UV-C for in-space sepsis control have been based on multi-drug resistant tuberculosis (MDRTB) in homeless shelters. Such studies date back to the 1980's and 1990's. (E. Nardell, et. al.)[6]

Only recently, studies are underway and results are preliminary regarding UV-C effectiveness on Coronaviruses, COVID-19 included. This is stated to illustrate that this medical approach in an airport or other large, open public spaces may be premature, but may have an application to be explored as studies show efficacy. This also is an opportunity to deploy upper-level UV-C on an experimental basis in the field, if stakeholders agree. Also, where UV emitters are exposed to view in public spaces, there is a possibility of eye damage over time and discomfort in the short term. This would be mitigated by louvers or shielding to reduce or eliminate direct line-of-sight exposure to occupants. (E. Nardell, et. al.)[7]

Only recently, studies are underway and results are preliminary regarding UV-C effectiveness on Coronaviruses, COVID-19 included.

[6] *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2099326/*
[7] *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2099326/*

In summary on UV-C, Arora does not recommend its use in open spaces without further evaluation. However, it is our opinion that UV-C with return air filtration can be effective on captive particulates on the filter surfaces, especially in conjunction with Bipolar Ionization to enhance particulate capture.

Hydrogen Peroxide Disinfection Technology

Recently, an airport in the New York City area was the first to implement a hydrogen peroxide disinfection system within their terminals. This technology is inserted into a supply ductwork system. UV lights react with H_2O and O_2 in the air to create hydrogen peroxide molecules (H_2O_2). Those molecules are supplied into the spaces to coat and disinfect all stationary surfaces, and then the hydrogen peroxide eventually decomposes in oxygen and water. Manufacturers claim this type of system continuously disinfects over 99.9% of microbes on surfaces[8]. This technology has been widely adapted in hospital and medical settings. Since this is the first time a continuous hydrogen peroxide disinfection system has been implemented in an airport, it will be interesting to see the effectiveness of this technology in a non-medical setting. Arora is interested to see the effect in an airport setting but is hesitant to recommend this approach outside its intended medical application. More time is required in order to determine if this is an appropriate solution for all commercial facilities, although it does appear to be a promising technology.

Standalone Air Purification Systems

Air purification systems are commonly available as portable units, but they are also available as permanent wall/ceiling mounted systems. These units address specific rooms or areas directly. It would operate independently of the HVAC system to provide continuous air purification. The unit itself typically consists of a high efficiency MERV 14 filter and a fan for continuous circulation. Aside from serving individual rooms, multiple units can be used to serve larger areas as well. This design approach decreases the amount of time particulates remain in the air in the immediate area being served. This is often deployed in the design of hospitals. Lastly, since these systems operate independently of the HVAC system, they are not dependent on whether the air handling unit is operating in economizer mode, so they can serve a space year-round.

In summary on stand-alone air purification systems, they would be most effective on smaller, isolated spaces such as offices and workrooms, but not public spaces. The cost is relatively low, such that the effectiveness can be gauged on an experimental basis before deciding on a wider deployment.

[8] *https://uvsolutionsmag.com/articles/2020/evolving-technologies-for-decontaminating-healthcare-environments/*

Conclusion

While all the options discussed above would assist in maintaining cleaner, healthier supply air to an airport, not all are practical in application.

An electrostatic filter would be effective at filtering small airborne particles but becomes less efficient as the load increases, requiring regular cleaning, so it is not recommended unless the owner makes the necessary maintenance investment.

> Any option mentioned is not 100% effective in capturing all airborne particulates, but each system has its benefits for cleaning specific elements.

Bipolar Ionization allows for airborne particles to be captured more easily by the filters and removed from the breathing zone; applied appropriately with zero ozone generation, this approach will amplify the standard HVAC filters' ability to capture otherwise smaller particles. Applying bipolar ionization within an AHU system provides the best distribution of ions, borne by the supply air distributed throughout the space. If applied in the spaces served, it would mean less modifications to the HVAC equipment but will require fan systems to distribute ions throughout the space. Most HVAC systems serving public spaces tend to operate constantly, at least at low levels when less occupied, but this ensures a constant distribution of ions.

UV-C lights installed within an air handling unit can prevent the growth of mold and bacteria on the inside surfaces of the unit (condensate covered coils and drip pans) and on filters themselves. This aids in preventing the growth of legionella, the cause of Legionnaires' disease, as another example.

However, UV-C lights are not effective in treating pathogens/viruses within the air flowing through a unit, nor are they as effective in the colder areas of the unit, such as at the cooling coil.

UV-C does have an application in treating return air filters where particulates would be held for significantly longer periods, enough to be effective in killing the pathogens stationary on surfaces.

Like UV-C, Hydrogen Peroxide Disinfection technology also appears to be most effective at killing pathogens on surfaces. As a newer technology in non-medical applications, more time is necessary to determine its effectiveness and therefore we cannot currently recommend this application.

Unlike the other options, in-space standalone air purifiers can clean the air at person-level in an enclosed room, compared to relying on the primary air conditioning system where that system may supply air overhead. Back of house spaces are more practical to apply these, versus public passenger spaces due to the relatively small space volumes these standalone systems are designed to serve.

These systems are small enough and lower in cost, such that they can be tried on an experimental level to gauge their effectiveness in actual use, before being used more widely.

An air handling unit-based mitigation system would see its utility in eliminating pathogens reduced during economizer cycle operation as no space air would be returned through the unit supply train for recirculation. The benefit during economizer operation is a higher throughput of outside air to flush the space, but not clean the recirculated air.

A standalone air purification system adds an additional first cost and a cost to maintain a separate system.

Please note that any option mentioned is not 100% effective in capturing all airborne particulates, but each system has its benefits for cleaning specific elements. They can be used independently or simultaneously with each other. Arora recommends a combination of these approaches to maintain higher air quality.

Appendix

A Word on Filters

Filters for years have been known in the industry by “percentage efficiency”, e.g. 30-35%, 65%, 85%, 95% and the HEPA-ULPA range, 99.999 etc.%. These have been replaced by the Minimum Efficiency Reporting Value, or MERV system.

The historic “percentage” system could be misleading and understate the range of particles they did capture. The percentages were weighted, a “dust-spot” metric and aggregate efficiencies based on capture of a range of particle sizes, from “DOP Smoke” at 0.30 microns, on-up to visible particles.

In order to be effective, the airflow turnover to a space, even when occupants are gowned and gloved, is dozens of times higher than general HVAC use.

For example, a 30-35% pre-filter, (MERV-8 today) the first in-line in most applications, did not just capture 30 to 35% of what went through them. They did and do capture (have “arrestance” of) over 70 percent of particulates larger than five (5) microns, which includes pollen and some spores. But they capture fewer of the smaller particles, 30% of those at 0.1 microns, for example.

Not all MERV ratings directly correspond to the “percentage” system, but there are some general correlations. For example, MERV-13 corresponds to an 85% filter, which is the least filter used in most medical applications. MERV-13 filters capture over 90% of particles larger than three (3) microns. This is the typical second-stage type used by clients.

Lastly on this topic, one will see the terms “HEPA” or “ULPA” (High Efficiency Particulate Air and Ultra-Low Particulate Air filters, respectively). These correspond to 99.997% and 99.999% efficiency.

The use of these filters for general HVAC purposes is capital, energy, and effectiveness-wasteful in our opinion.

These filters are designed for use in cleanrooms, bone marrow transplant rooms, and other low-particle tolerance applications where occupants are gowned and encapsulated in protective gear. They require much larger airflow areas and impose significantly higher pressure drops and energy penalties to move air across them.

In order to be effective, the airflow turnover to a space, even when occupants are gowned and gloved, is dozens of times higher than general HVAC use. There is no practical way to meet these filters’ particulate-removal potential with hundreds or thousands of occupants in street clothes with luggage in-tow. The standard filters currently used by clients achieve well over 95 percent of the desired particulate effects in this regard. We do not recommend HEPA/ULPA filtration in these applications. We are similarly skeptical of their use in small portable air cleaners for the same reasons.

An exception would be HEPA vacuums and air cleaners used for contained abatement applications, but not general HVAC.

ILLUSTRATIVE MERV FILTER CHART NOTING EFFICIENCY BY PARTICLE SIZE. NOTE THAT CLIENTS USE MERV-8 FOLLOWED BY MERV-13 FOR GENERAL HVAC USE, NOT COUNTING DOWNSTREAM CARBON FILTERS AND DUSTING FILTERS.

MERV (Minimum Efficiency Reporting Value)	Composite Average Particle Size Efficiency, % in size, µm			Average Arrestance, %	Size of Contaminant that can be captured
	0.3-1.0	1.0-3.0	3.0-10.0		
1	-	-	20% or better	65% or Less	Lint Pollen Bugs Sanding Dust
2	-	-	20% or better	65% - 69%	
3	-	-	20% or better	70% - 74%	
4	-	-	20% or better	75% or Greater	
5	-	-	20% - 34%	-	Cement Dust Mold Spores Gelatin Powder
6	-	-	35% - 49%	-	
7	-	-	50% - 69%	-	
8	-	20% or better	70% or better	-	
9	-	35% or better	75% or better	-	Milled Flour Auto Emissions Welding Fumes
10	-	50% - 64%	80% or better	-	
11	20% or better	65% - 79%	85% or better	-	
12	35% or better	80% or better	90% or better	-	
13	50% or better	85% or better	90% or better	-	Bacteria Tobacco Smoke Talcum Dust
14	75% - 84%	90% or better	95% or better	-	
15	85% - 94%	90% or better	95% or better	-	
16	95% or better	95% or better	95% or better	-	