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Air purification in elevators today

STRATEGIES AND IMPACT ON PASSENGER SAFETY AND HEALTH

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OTIS

The role of elevators in moving the world forward – and skyward – is undeniable. Efficient, safe, effective vertical transportation is key to streamlining the flow of people and goods throughout any building and enhancing the overall experience for occupants and visitors. On a larger scale, as global populations grow, elevators continue to enable the skyward growth of modern cities.

As the world navigates through a unique pandemic, new challenges emerge in balancing the needs of individual people and populations. And, disease transmission is a key concern for our customers.

At Otis, we created the elevator industry, and we continue to lead it today. The safety of our passengers and the riding public is always our highest priority. Now, we embrace today's challenges head-on by utilizing both technology and recommendations on behavior to create new ways of moving forward. In this brief, we'll discuss elevators and current known methods for air purification within elevators. Air purification is a complex topic and part of the broader air quality and healthy building conversation that has accelerated with the COVID-19 pandemic. We include one of our current solutions, the Otis Cab Air Purifier.

Vertical transportation

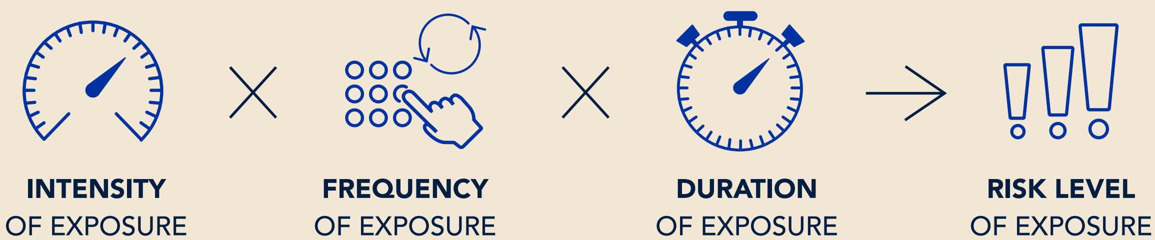
Otis is a company built on safety. Our company began with our founder's invention of the elevator safety brake in 1852, and while the systems and technologies employed today are significantly more advanced, safety remains at the heart of everything we do. With modern elevators equipped with multiple and redundant safety systems that work together, most passengers typically do not think twice before riding an elevator.

Ongoing concerns around the spread of COVID-19 have made today's circumstances anything but typical. We are responding to today's world, and offer a variety of new technologies to help ease passenger concerns. Building owners and operators can rely on us to constantly innovate new solutions. The overall approach is rooted in how Otis has always operated.

We are committed to safety, so you can feel confident while you are on the move.

A RISK-BASED APPROACH

A careful risk-based approach, rigorous testing, high levels of quality and other measures reflect our commitment to The Otis Absolutes of Safety, Ethics and Quality. In the face of a global pandemic, they become even more important. A risk-based approach, informed by science, is needed to recommend reasonable control measures for each situation as we phase forward (Defile, 2020). We recognize we can all learn together. Risk level is based on the intensity of exposure, frequency of contact and duration of contact. We also need to account for the dynamics of the elevator environment. Some additional considerations are driven by the vertical movement of the elevator, the opening and closing of doors, and the movement of people in and out of elevators, all within a reasonably small enclosure volume.



With a risk-based approach, it remains imperative to acknowledge and account for the fact that every building is different. When considering responses to the current pandemic, several factors and scenarios need to be balanced to achieve a range of positive outcomes and solutions for our customers and the riding public. These solutions primarily focus around four key areas:

- **People and elevator movement**
- **Guidance for safe riding**
- **Transmission risk mitigation**
- **Advanced technology solutions**

These focus areas underscore the need for a combination of technology and behavioral changes as different geographies and buildings phase forward and find varying and ever-evolving versions of a new normal.

Pandemic and airborne transmission

Responding to the new challenges requires a greater understanding of the risk itself. A July 9, 2020 update from the World Health Organization (WHO) and other experts indicated four main modes of transmission for the novel coronavirus, SARS-CoV-2:

DIRECT CONTACT
Refers to touching an infected individual.

INDIRECT (E.G., FOMITES)
Refers to transmission by touching a surface on which an infected individual has left the virus. For example, a cough or sneeze and a table or door handle.

AIRBORNE TRANSMISSION OF LARGE DROPLETS (NEAR FIELD OR CLOSE CONTACT)
Refers to close-range transmission by larger droplets that are sometimes visible. These droplets are coughed or sneezed by an infectious person directly onto the eyes, mouth or nose of a nearby person.

AIRBORNE TRANSMISSION OF AEROSOLS (FAR FIELD)
Refers to transmission of the virus in tiny, invisible droplets that are generated when an infectious person exhales, speaks, coughs, sneezes or sings, and that are then inhaled by another nearby person.

Emerging science and evidence seem to support that airborne transmission may be more critical than surface-to-surface transmission (WHO and Mandavilli, 2020). With the increasing emphasis on airborne transmission, the emphasis on indoor air quality continues to grow. Improved treatment of air may reduce not only the risk of SARS-CoV-2 transmission but have other ancillary benefits.

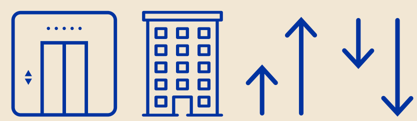
Improving indoor air quality has long been associated with broad health benefits and increased productivity (Allen, 2017 and 2020). In short, air purification is critical – both in terms of its potential for infection control during the current pandemic and moving well into the future.

Air in elevators

With an understanding of the importance of air quality in terms of pandemic response and beyond, it next makes sense to examine the air conditions specific to elevators as we explore ways to help make the spaces safer. Despite concerns around the relatively confined nature of the space, based on what we know today, the airborne transmission risk is lower compared with many other common spaces due to the high level of air exchange and the short duration of exposure.

In a July 16, 2020, Environmental Protection Agency (EPA) webinar, Dr. Richard Corsi, an indoor air quality expert, dean and professor at Portland State University, stated, "If nobody speaks on the elevator, you're looking at less than 1/1,000 [the risk compared with other scenarios evaluated, including restaurants, ride shares, choir practice and gyms]. ... I think that the risk is negligible." Dr. Corsi continued, "The focus probably should be on close contact and fomites, where you require people wear masks, have no-speaking etiquette, try to reduce the density if you can, and distance and face away."

Riding in an elevator benefits from the high turnover of air inside the cab and the short exposure time. Elevator cabs also have fans that can blow air into or out of the cab. These fans are typically sized to provide one air change per minute. For a 3,500-pound duty, one of the most common cab sizes in North America, this may mean a fan with a flow rate of 350 cfm or higher. In typical operating conditions, this provides a level of air exchange that may be much higher than in other parts of the building.



A SYSTEM WITHIN A SYSTEM

When considering an elevator ride, we consider the air and space the passenger encounters in the elevator cab itself, the hoistway or shaft in which the elevator travels, and the other parts of the building where people are moving. By elevator code, cabs must provide 3.5 percent of the platform area as ventilation openings for convection purposes (American Society of Mechanical Engineers, 2019). The opening for the fan and the opening around the doors may be included in the calculation. These openings provide inlets and outlets for convective transfer of passive airflow and aid when more active ventilation is present. Depending on the complexity of the building, additional factors including pressurization, fire considerations and more sophisticated HVAC systems should also be considered.

Elevator cabs are certainly not without risks. Behavioral changes will have a positive impact, but there is more we can do to improve elevator air. There is also more to be learned as increasingly better information becomes available within the context of SARS-CoV-2 and for complex situations in larger buildings where air is mixing and/or affected by other situations. However, when considering what we can do now, air purification devices are available and ready to help many buildings.

Air purification

There are multiple ways to clean air and improve air quality. Dozens of different technologies and variants of similar technologies exist today and have existed prior to the COVID-19 pandemic. Fundamentally, nearly all of these require air movement past or through an element that treats the air. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), NASA and several other organizations have different taxonomies of how to clarify filtration and air-cleaning devices and technologies (ASHRAE, 2015). Below are the most common available today.

FILTRATION (MAY BE MECHANICAL OR ELECTRONIC PHYSICAL REMOVAL) – Mechanical filters use porous structures that contain fibers or stretched membrane material to remove particles from airstreams. Electronic filters include a wide variety of electrically connected air-cleaning devices that are designed to remove particles from airstreams.

SURFACE TECHNOLOGIES – With surface technologies, the material, makeup, texture or elements of a surface are adjusted to impact the air these surfaces encounter. This includes hydrophobics and photocatalytic material, metal ion migration, nano materials and other elements embedded, applied or textured into the surface, including antimicrobial peptides. Photocatalytic oxidation (PCO and PECO) is a subtype of this category, where the air cleaner initiates a chemical reaction to remove particles from the air when in contact with a surface.

CHEMICAL AND BIOLOGICAL EXCITATION – Mechanical filters use porous structures that contain fibers or stretched membrane material to remove particles from airstreams. Electronic filters include a wide variety of electrically connected air-cleaning devices that are designed to remove particles from airstreams.

COMBINATION – Any of these categories may be used in combination with each other. For example, a package may include a filter, ultraviolet germicidal irradiation (UVGI) lamp and an ionizing device surface.

OTHER PHYSICAL MEANS – This includes those that generate electrostatic, thermal, plasma, ultrasonic and/or ionic reactions. This category would include those that affect humidity or desiccation.

ELECTROMAGNETIC EXCITATION – Mechanical filters use porous structures that contain fibers or stretched membrane material to remove particles from airstreams. Electronic filters include a wide variety of electrically connected air-cleaning devices that are designed to remove particles from airstreams.

ADDITIONAL CONSIDERATIONS

While there are many options for improving air quality, it's important to consider the effectiveness of some of these solutions in the specific context of their potential use in elevators.

Filtration

Filtration systems have shown efficacy against many different microorganisms, but they require replacement. In an elevator setting, the filter may need to be installed on the car-top or in another tight setting, requiring special precautions and challenges related to changing or maintenance. In addition, care must be taken when designing forced air ventilation for an elevator cab; while the filtered air may be clean upon being introduced, it may disturb, distribute and recirculate contaminants around the cab.

UV technologies

There are a range of UVGI technologies that have shown some efficacy against viruses. As scientists and engineers continue to explore safe ways to use UV lighting away from people, careful consideration must be given before employing it within elevator air purification devices.

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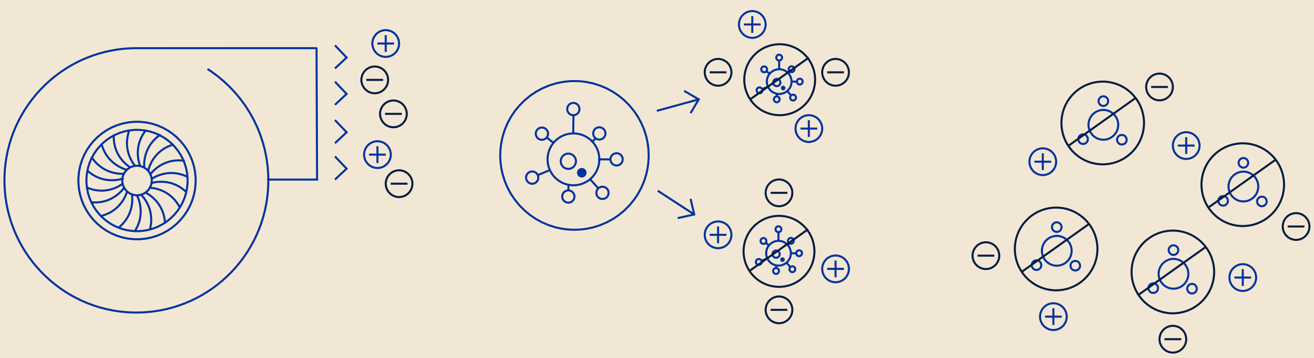
Bipolar ionization

One technology to improve air quality and control infection that has years of research and test results supporting its safety and efficacy is bipolar ionization. Bipolar ionization emits both positively and negatively charged particles that attach to and deactivate harmful substances like bacteria, allergens, mold and viruses (Essien, 2017 and Hagbom, 2015).

HOW IT WORKS



1. Ionizers generate and disperse both negative and positive ions.
2. As bacteria, viruses or other cells divide, the ions attach to the cells, causing a chemical reaction.
3. These harmful viruses or other pathogens are neutralized – reducing the spread of airborne infection.

See page 11 for efficacy details regarding SARS-CoV-2

In the case of bacteria and viruses, this chemical reaction both depletes their ability to function, by causing oxidative stresses within the organism, and physical destruction of their outer layer, effectively inactivating them. Particulate matter can be removed as air ions attach to them, causing them to become ionized and in turn attract other charged particles, increasing the rate of settling via gravity (Kim, 2017).

ELECTRICAL METHODS OF IONIZATION

While there are numerous ways to ionize air, electric field methods are the most readily usable and cost-effective in most commercial and residential settings.

Electric field-based air ionization methods can generate ions either in a bipolar mode (both positively and negatively charged ions) or in a unipolar mode (usually just negative ions), depending on the design and the voltage pattern supplied to the electrodes. In either case, neither positive nor negative air ions have been observed in scientific studies to impart deleterious effects on the human body. Both negative and positive air ions are naturally occurring. That stated, even in the presence of positively charged ions, negatively charged air ions have been scientifically shown to have beneficial effects on human health, above and beyond the removal of pathogens and other particulates (Jiang, 2018 and Terman, 2006).

Needlepoint and brush-type bipolar ionizers are not high-voltage methods of ionization. This is important when you consider that ozone is generated from higher-voltage (>12.07 eV) electric field methods (most commonly corona discharge and dielectric barrier discharge) by either electrolysis of ambient water molecules at the anode or the splitting and recombination of diatomic oxygen. While it is a powerful and useful oxidant and corrosive agent, it is harmful to humans both in acute and chronic exposure. The Occupational Safety and Health Administration (OSHA) has set limits at 0.1 particles per million (ppm) for long-term exposure and 0.3 ppm for short-term exposure. In order to market products as "zero ozone," Underwriters Laboratories (UL) has set new certification standards for ozone production at less than 0.005 ppm (5 particles per billion).

Understanding the advantages of bipolar ionization as an air purification technology, and the importance of avoiding ozone generation, Otis has worked to offer the Otis Cab Air Purifier.

DIELECTRIC BARRIER DISCHARGEBIPOLAR IONIZERS – Remain relatively clean and can operate in either pulsed bipolar or unipolar mode, but they have low energy efficiency compared with other electric field methods and tend to generate undesirable byproducts.

NEEDLEPOINT AND BRUSH-TYPE BIPOLAR IONIZERS – Have fairly high efficiencies and very low generation of undesirable byproducts, but may accumulate dust in steady-state direct current operation.

GLIDING ARC DISCHARGE – Provides efficient ozone and nitrogen oxide (NOx) generation, and features open, easily shorted electrodes.

CORONA DISCHARGE IONIZERS – Have high efficiencies, but they tend to generate relatively high amounts of ozone.

ELECTROSTATIC PRECIPITATORS – Operate via a similar principle to the corona discharge method, but they do not generally disperse ions, instead operating as a filter by ionizing contaminants within an airstream and collecting them immediately on downstream plates within the unit.

Introducing the Otis Cab Air Purifier

The Otis Cab Air Purifier works to remove impurities and contaminants from the air, or otherwise neutralize them via needlepoint bipolar ionization (NP-BPI). In this device, a voltage is established across a series of needles on two brush-like strips in the shape of antennae. This voltage differential between the needles within each brush generates both positive and negative ions within the surrounding air, mostly from oxygen, nitrogen and water vapor. A ventilation fan drives the ions into the elevator cab, and they are distributed via normal air circulation.

Contaminants become electrostatically charged and, in some cases, chemically altered due to their interaction with the positive and negative ions. For living microorganisms such as bacteria and fungi, the exposure to the ions induces oxidative stress and reduces cellular survival. For viruses, exposure to the ions destroys their external components and renders them effectively inert. These effects occur whether the germs may be residing in droplets in the air or on surfaces.

TESTS OF THE OTIS CAB AIR PURIFIER INDICATE SIGNIFICANT REDUCTION OF:

- Germs, such as bacteria, fungi, viruses and other potentially harmful microbes
- Various odors
- Smoke
- Dust or allergens such as pollen and dander

The Otis Cab Air Purifier works to remove impurities and contaminants from the air, or otherwise neutralize them via needlepoint bipolar ionization (NP-BPI).

COVID-19 EFFECTIVENESS

Although not tested directly against SARS-CoV-2, the virus causing COVID-19, the Otis Cab Air Purifier has demonstrated effectiveness against viruses similar to the novel coronavirus, both in air and on hard surfaces. This device was effective in disinfecting MS2 bacteriophage, an EPA-approved surrogate for SARS-CoV-2, in a government-approved lab, as well as Influenza A (H1N1) in separate studies.

For the MS2 bacteriophage virus, the tested efficacy is listed as 97.5 percent for airborne virus and 81 percent for virus present on surfaces after 10 minutes. The EPA-suggested statement concerning efficacy against the emerging pathogen SARS-CoV-2 is as follows:

COVID-19 is caused by the SARS-CoV-2 virus. The Otis Cab Air Purifier has demonstrated effectiveness against viruses similar to SARS-CoV-2 both in air and on hard, porous, and non-porous surfaces. Therefore, the Otis Cab Air Purifier can likely be effective against SARS-CoV-2 when used in accordance with the directions for use against MS2-bacteriophage and Influenza A (H1N1) in air and on hard, porous, and non-porous surfaces. Refer to the CDC and EPA websites for additional information.

ADVANTAGES OF THE OTIS CAB AIR PURIFIER

There are various technologies on the market today, including ionic particle generation (similar to the Otis Cab Air Purifier), UVC or UVA ultraviolet light, blue-violet (405 nm) visible light, air filtration and chlorine dioxide. The Otis Cab Air Purifier device has the following advantages.

- **It can be installed outside of the cab with no effect on appearance or performance**
- **There are no additional passenger safety concerns due to the usage of this device**
- **It can be used continuously with no need to recharge or refill it, and it does not need to be cleaned outside of normal elevator maintenance**
- **It has been proven effective against viruses, bacteria and fungi**
- **It is electrically certified in the majority of all jurisdictions**

Of particular note, the Otis solution uses NP-BPI rather than corona discharge ionization. Corona discharge ionization tends to generate ozone, whereas NP-BPI does not generate a significant amount (Shahin, 1969; Skalny, 2007 and 2008). In fact, the Otis Cab Air Purifier device is specifically designed to generate a very low concentration of ozone that is far below the upper limits described by OSHA standards.

This product has been tested against and shown to meet the requirements for UL 2998 certification, which is the most stringent certification around ozone-generating products. UL 2998 certifies the product creates <0.005 ppm. The Food and Drug Administration (FDA)-defined limit is a maximum of 0.05 ppm, so this product is well below the FDA guidelines. It has two brushes that produce 110 V DC. There are two antennae operating at 110 V DC that are located within or just outside the fan housing unit, but not in the normal work area exposed to an elevator mechanic and/or AHJ inspector. By mounting the device in or near the fan, close to the air supply for the existing ventilation, the device extends the benefits of the good ventilation while adding effective air purification.

Keep the world moving

The world continues to look different every day as we collectively look for the best ways to navigate a global pandemic and enhance the health and safety of people everywhere. The safety of riding in an elevator benefits significantly from the high turnover of air inside the cab and the short exposure time, but there is always more to consider.

As our understanding of COVID-19 and its transmission continues to grow, so too does the Otis portfolio of offerings to help protect passenger safety and improve air quality. We continue to invest in research and development to improve passenger safety and air purification in elevators even further. By employing a risk-based approach, we can help customers implement new behaviors and technologies to address direct, indirect and airborne modes of disease transmission and create safer air in elevators. These include solutions, like our Otis Cab Air Purifier, designed to significantly reduce airborne bacteria and viruses in today's elevator. We encourage you to connect with an Otis expert to learn more about the Otis Cab Air Purifier, along with a full line of solutions that help to keep people and populations safe at a time it matters most.

About the authors

Stephen R. Nichols is a systems engineer with cross-functional interest in product development, architecture, innovation and strategy. Stephen is interested in finding simplicity in complex systems as well as the intersection of human experiences and people-centered design with vertical transportation technology, building ecosystems and urban environments. He is based at Otis's engineering center and world headquarters in Farmington, Connecticut. He is a two-time National Academy of Engineering Frontiers of Engineering alumni and received the 2019 Gilbreth lectureship. He has earned degrees in mechanical engineering from Tufts University and RPI and a professional certificate in systems engineering from MIT. Since March 2020 he has been the research, development and integration lead on the cross-functional global task force at Otis focused on pandemic response.

James T. Auxier, Ph.D. leads global technology development at Otis focused on emerging technology trends, business needs, and strategic areas of technology development in partnership with Otis Global Engineering and other cross-functional teams. He is a dynamic leader with previous experience in the building systems, aerospace and medical device industries and extensive university partnership and research experience, including 15 years focused on aerothermal technology development. He has earned degrees in biomedical engineering from Yale University, a master's in mechanical engineering from Stanford University and his Ph.D. in biomedical engineering from the University of Kentucky. Since March 2020 he has been the science and technology lead on the cross-functional global task force at Otis focused on pandemic response.

References

Alexander D D, Bailey W H, Perez V, Mitchell M E, Su, S. "Air Ions and Respiratory Function Outcomes: A Comprehensive Review." Journal of Negative Results in BioMedicine, September 9, 2013; 12, 14. See: https://doi.org/10.1186/1477-5751-12-14

Allen J G, Macomber J D. "What Makes an Office Building 'Healthy.'" Harvard Business Review, April 29, 2020. See: https://hbr.org/2020/04/what-makes-an-office-building-healthy

Allen J G. "Research: Stale Office Air is Making You Less Productive." Harvard Business Review, March 21, 2017. See: https://hbr.org/2017/03/research-stale-office-air-is-making-you-less-productive

ASME A17.1/CSA B44 Handbook on Safety Code for Elevators and Escalators. ASHRAE Position Document on Filtration and Air Cleaning reaffirmed by Technology Council on January 13, 2018, after initial publication on January 29, 2015. See: https://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd.pdf

Bailey W H, Williams A L, Leonhard M J. "Exposure of Laboratory Animals to Small Air Ions: A Systematic Review of Biological and Behavioral Studies." BioMedical Engineering Online, June 5, 2018; 17, 72. See: https://doi.org/10.1186/s12938-018-0499-z

Centers for Disease Control and Prevention. Coronavirus Disease 2019 (COVID-19) Frequently Asked Questions, specifically, "How Does the Virus Spread?" See: https://www.cdc.gov/coronavirus/2019-ncov/faq.html#Spread

Charry J M, Kavet R. 1987. Air Ions: Physical and Biological Aspects. Boca Raton, Florida, USA: CRC Press.

Defile N C, Allen J G, Scheepers P, Levy J. "The COVID-19 Pandemic: A Moment for Exposure Science." Journal of Exposure Science & Environmental Epidemiology, April 29, 2020. See: https://www.nature.com/articles/s41370-020-0225-3

Derwinski T. "Safety Chain: A Look at Safety Systems in a Modern High-Rise Elevator in Light of 2018 Chicago Incident." Elevator World, June 2019. See: www.elevatorworld.com

Essien D, Coombs K, Levin D, Zhang Q. "Effectiveness of Negative Air Ionization for Removing Viral Bioaerosols in an Enclosed Space." Conference Proceedings from CSBE/SCGAB 2017 Annual Conference, The Canadian Society for Bioengineering, August 6-10, 2017.

Hagbom M, Nordgren J, Nybom R, Hedlund K O, Wigzell H, Svensson L. "Ionizing Air Affects Influenza Virus Infectivity and Prevents Airborne-Transmission." Scientific Reports, June 23, 2015. See: https://www.nature.com/articles/srep11431

Jiang S Y, Ma A, Ramachandran S. "Negative Air Ions and Their Effects on Human Health and Air Quality Improvement." International Journal of Molecular Sciences, September 28, 2018. https://doi.org/10.3390/ijms19102966 and references therein.

Kim K-H, Szulejko J E, et al. "Air Ionization as a Control Technology for Off-gas Emissions of Volatile Organic Compounds." Environmental Pollution, June 2017; 225, 729-743. Accessed August 17, 2020. See: http://dx.doi.org/10.1016/j.envpol.2017.03.026

Lazzerini F T, Orlando M T, De Prá W. "Progress of Negative Air Ions in Health Tourism Environments Applications." Boletín de la Sociedad Española de Hidrología Médica, 2018; 33. See: http://hidromed.org/hm/images/pdf/BSEHM%202018_33(1)27-46_Lazzerini-F.pdf

Lin H F, Lin J M. "Generation and Determination of Negative Air Ions." Journal of Analysis and Training, February 8, 2017; 1:6. https://doi.org/10.1007/s41664-017-0007-7

Mandavilli A. "239 Experts With One Big Claim: The Coronavirus Is Airborne." The New York Times, July 4, 2020. See: https://www.nytimes.com/2020/07/04/health/239-experts-with-one-big-claim-the-coronavirus-is-airborne.html

Marr L, Corsi R. "SARS-CoV-2 in Indoor Air: Principles and Scenarios." Indoor Air Quality Science and Technology webinar presented by the United States Environmental Protection Agency, July 16, 2020. See: https://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-science-and-technology

National Academies of Sciences, Engineering and Medicine. "Does Ultraviolet (UV) Light Kill the Coronavirus?" Based on Science, Published on April 22, 2020. See: https://sites.nationalacademies.org/BasedOnScience/covid-19-does-ultraviolet-light-kill-the-coronavirus/index.htm

Public Health Agency of Canada. "Prevention and Control for Health Care Settings: Canadian Pandemic Influenza Preparedness: Planning Guidance for the Health Sector." See: https://www.canada.ca/en/public-health/services/flu-influenza/canadian-pandemic-influenza-preparedness-planning-guidance-health-sector/prevention-and-control-of-influenza-during-a-pandemic-for-all-healthcare-settings.html

Schurk D. "Test Study Results Needle Point Bi-Polar Air Ionization for VOC Remediation." Houston Methodist Hospital, 2014.

Shahin M M. "Nature of Charge Carriers in Negative Coronas." Applied Optics, 1969; 8, 106-110.

Skalny J D, Horvath G, Mason N J. "Mass Spectrometric Analysis of Small Negative Ions (e/m < 100) Produced by Trichel Pulse Negative Corona Discharge Fed by Ozonised Air." Journal of Optoelectronics and Advanced Materials, April 2007; 9, 887-893.

Skalny J D, Orszagh J, Mason N J, Rees J, Aranda-Gonzalvo Y, Whitmore T D. "Mass Spectrometric Study of Negative Ions Extracted from Point to Plane Negative Corona Discharge in Ambient Air at Atmospheric Pressure." International Journal of Mass Spectrometry, April 15, 2008; 272, 12-21. See: https://doi.org/10.1016/j.ijms.2007.12.012

Terman M, Terman J S. "Controlled Trial of Naturalistic Dawn Simulation and Negative Air Ionization for Seasonal Affective Disorder." American Journal of Psychiatry, December 1, 2006, 163(12), 2126-2133.

United States Environmental Protection Agency. "Coronavirus Cases Trigger EPA Rapid Response." Released January 29, 2020. See: https://www.epa.gov/pesticides/coronavirus-cases-trigger-epa-rapid-response

World Health Organization. Scientific brief: "Transmission of SARS-CoV-2: Implications for Infection Prevention Precautions." July 9, 2020. See: https://www.who.int/news-room/commentaries/detail/transmission-of-sars-cov-2-implications-for-infection-prevention-precautions

Wu C C, Lee G W M, Cheng P, Yang S, Yu K P. "Effect of Wall Surface Materials on Deposition of Particles with the Aid of Negative Air Ions." Journal of Aerosol Science, May 2006, 37, 616-630. https://doi.org/10.1016/j.jaerosci.2005.05.018

Zhou P, Yang Y, Huang G, Lai, A. "Numerical and Experimental Study on Airborne Disinfection by Negative Ions in Air Duct Flow." Building and Environment, January 2018, 127, 204-210. https://doi.org/10.1016/j.buildenv.2017.11.006