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Air purification in elevators today

A technical brief on elevator cab air purification strategies and their impact on passenger health and wellness

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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 continues to be a key concern for our customers.

At Otis, we created the elevator industry, and we continue to lead it today. Continuing to innovate and provide the best possible experience for our passengers and the riding public has always been among our highest priorities. 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 discussion of one of our current solutions, the Otis Cab Air Purifier.

Vertical transportation

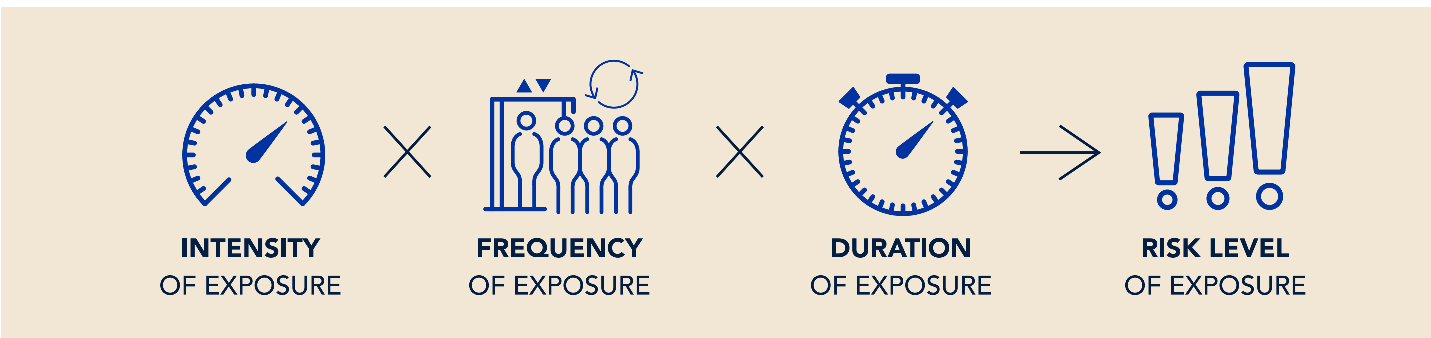
Otis began with our founder's invention of the elevator safety brake in 1852, and while the systems and technologies employed today are significantly more advanced, innovation remains at the heart of everything we do. With modern elevators equipped with multiple and redundant safety systems that work together, most passengers typically do not think twice before riding an elevator. We continue to strive to be the best at what we do and find new solutions to help people move in a taller, faster, smarter world.

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 providing science-based information, 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 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, frequency and duration of exposure. 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
- Exposure 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 continue 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 to lower the intensity of exposure 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 and share science-based information to help build confidence in riding elevators and beginning to gather again indoors. Despite concerns around the relatively confined nature of the space, the average elevator ride is short – less than one minute – limiting exposure time. In addition, elevator codes require openings for ventilation. By design, elevators have a high level of air exchange. Higher airflow reduces the number of airborne particles by removing them from the elevator.

Exposure time is minimal due to a short average elevator ride (<2 min)

By code, elevators are required to have openings for ventilation

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% 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 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.

While this knowledge and a simple analysis suggest that exposure in elevators is much lower compared with many other common spaces, every elevator riding scenario is different, with multiple variables that are important to the movement of people, air and elevators.

A recent study commissioned by Otis and led by Dr. Qingyan (Yan) Chen and his team of researchers at Purdue University examined these dynamics in an effort to better understand the relative risk of COVID-19 transmission in elevators. The study methods used state-of-the-art computational fluid dynamics (CFD) modeling to simulate airflow and replicate particle dispersion to study a matrix of configurations, occupancy patterns and operating conditions across several two-minute elevator rides.

Coupled with what we already know about elevator design and operation, the study findings support the idea that elevator travel with simple mitigation (such as proper mask usage and air purification) has a relatively lower exposure risk.* The high level of air exchange in an elevator lowers the risk. The higher the elevator ventilation rate, the lower the accumulated dose† a passenger is potentially exposed to – and, therefore, the lower the risk of COVID-19 exposure. The study also indicated that from an exposure perspective an elevator ride is comparable to a short time in an office or on a bus.

While elevators are certainly not without risks, the study also revealed the positive impact of both behavioral changes and air purification. Simple mitigation, like proper mask usage, cuts relative exposure risk in half. Air purification technologies, which are discussed in greater detail in the pages that follow, were shown to reduce exposure risk even further.

*See page 12 for more information and the Otis air study white paper available at otis.com for more details.
†Accumulated dose is the amount of virus a person is exposed to and depends on intensity, frequency and duration of exposure.

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.

ELECTROMAGNETIC EXCITATION – Excitation by electromagnetic waves either in the ultraviolet (UV), visible, radio or even microwave frequencies can also be used to affect particulates in air. In UV germicidal irradiation (UVGI), for example, wavelengths of light in the UV spectrum degrade organic material and inactivate microorganisms and some viruses.

CHEMICAL AND BIOLOGICAL AGENTS – Excitation by chemical and biological means includes sorbent air cleaners and other air cleaners where a chemical or biological reagent interacts with the contaminant to remove it. Sorbent air cleaners specifically involve physical adsorption (physisorption) and chemisorption to remove gaseous contaminants from airstreams.

SURFACE TECHNOLOGIES – Directly affecting the material, makeup, texture or elements of a surface can also have an impact on the air the surface encounters. 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.

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

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

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 often require replacing filters, recirculation and/or ducting. 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.

Unlike many other spaces in a building, elevators typically do not have recirculated air and are designed for the air to pass through the cab. Filtration only adds benefit if the air supplied passes through the filter and there are other ways to clean the air that is introduced into an elevator cab.

UV technologies

There are a range of ultraviolet germicidal irradiation (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 the elevator or air purification devices.

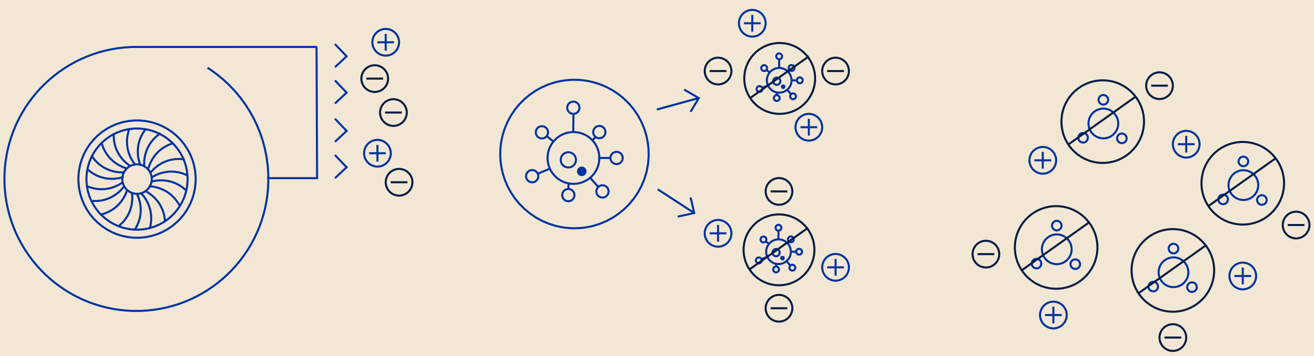
UVGI can be applied inside of a building system away from contact with people. Examples include the use of UVGI to clean escalator handrails or UVGI applied within the ducts of a large air-handling system. In some cases, there are novel, emerging antiviral/antimicrobial UV solutions and other lighting technologies that can be applied with intensities and other parameters that are safe for exposure in spaces shared by people.

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 systems.

Bipolar ionization

One technology to improve air quality and lower the intensity of exposure 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 or otherwise remove harmful substances like bacteria, allergens, mold, viruses, volatile organic compounds (VOCs) and other particulates (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 potential spread of airborne particles.

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

In the case of bacteria and viruses, a chemical reaction both depletes their ability to function, by causing oxidative stresses within the organism, and physically destroys 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 and cluster with 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).

DIELECTRIC BARRIER DISCHARGE BIPOLAR 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

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 (UL 2998) 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.

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 (NPBI). 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 moves the ions into the elevator cab, and they are distributed via normal air movement.

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 (NPBI).

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.

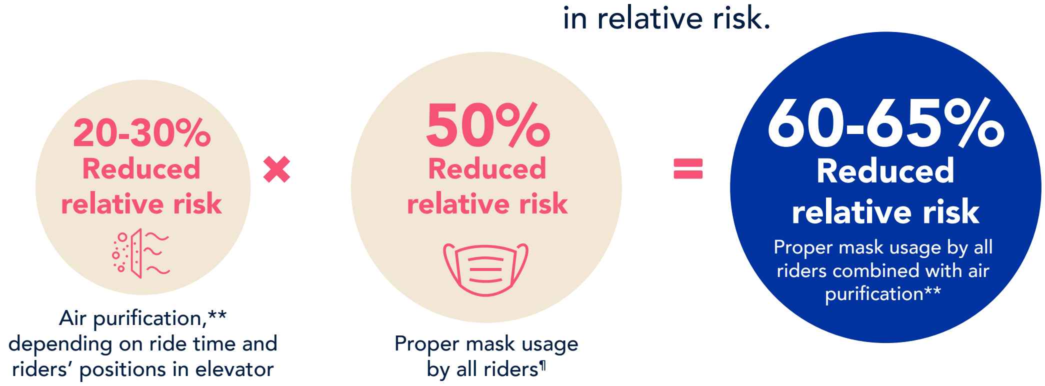
For the MS2 bacteriophage virus, the tested efficacy is listed as 97.5% for airborne virus and 81% for virus present on surfaces after 10 minutes. The EPA-suggested statement concerning efficacy against the emerging pathogen SARS-CoV-2 is as follows:

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.

The efficacy of the air purification effect is related to the concentration of the ions in the air.

For a space the size of a typical elevator cab, the target is >1000 ions/cc for negative air ions. In a bipolar ionizer, both negative and positive ions are generated and measurable, but the targets are based on a minimum concentration of negative ions that was characterized for efficacy against various microbes, VOCs and particulate matter. Tests on cabs in operation show that ion concentrations of at least 4x the above target are typical, so an ample margin is provided. Ion concentration levels will vary momentarily with traffic level as the doors open and close, along with environmental factors such as temperature, humidity and weather. Ongoing monitoring shows that the ion levels are sustained with proper installation and maintenance.

Efficacy of the air purification effect in combination with the high level of air exchange and airflow in many elevators was studied with Dr. Chen. The modeling results indicated that the use of NPBI reduced risk exposure 20 to 30%, depending on the ride time and riders' positions within the elevator. Furthermore, the use of NPBI combined with proper mask usage by all passengers yielded a 60 to 65% reduction in relative risk.



**Needlepoint bipolar ionization (NPBI). Additional details on the study, including the full white paper, can be found at otis.com.
¶Proper mask usage compared with no masks. Assumes proper mask wearing of typical cloth or surgical style mask per WHO and CDC guidelines.

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 identified passenger 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 NPBI rather than corona discharge ionization. Older-style corona discharge ionization tends to generate ozone, whereas newer NPBI technology 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 good ventilation while adding effective air purification.

Made to move you™

The world continues to look different every day as we collectively look for the best ways to navigate a global pandemic and enhance the lives of people everywhere. Riding in an elevator benefits significantly from the high turnover of air inside the cab and the short exposure time, and the research shows that behaviors including proper wearing of masks and air purification technologies such as needlepoint bipolar ionization can further reduce risks.

As our understanding of COVID-19 continues to grow, so too does the Otis portfolio of offerings to help passengers and improve air quality.

We continue to invest in research and development to improve passenger experience 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 exposure 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 moving 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 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.

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