TIME

If We're Going to Live With COVID-19, It's Time to Clean Our Indoor Air Properly

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As the Omicron variant spreads rapidly across vaccinated and unvaccinated America, and a shocking number of Americans are still dying, many are wondering what the coming months will bring, how will they continue to protect themselves from COVID-19, and when, if ever, life will really return to something resembling the pre-pandemic normal. The good news is that this pandemic will eventually end due to effective vaccines, infection-induced herd immunity, and the further evolution of the virus. The bad news is that like seasonal influenza, COVID-variants may be with us for years to come, and this will certainly not be the last respiratory virus pandemic. We have long suffered from annual contagious respiratory infections, but exceptionally low rates of influenza and common colds during COVID-precautions have demonstrated that not all of this suffering need happen. So, we need to think clearly and scientifically about how better we can reduce the spread of viruses indoors especially when and where masks will no longer be in common use.

Are there effective engineering controls that can help make indoor environments truly safer?

Yes, the purpose of this piece is to emphasize the importance of focusing on air disinfection in the rooms where person to person aerosol transmission is occurring. Let me explain what each of these technologies are and how effectively they work.

It's All About the Air We Share

From the beginning of this pandemic, buildings managers, airport operators, restaurateurs, and the public have been being inundated with product promotions claiming to have the latest and greatest technology to protect workers, travelers, and customers from infection with SARS-CoV-2. Products are varied, including surface sanitizers, air filtration machines, ion generators, and a host of germicidal ultraviolet (GUV) devices, ranging from hand-held wands to whole-room irradiators and walk-through portals. An imaginative architectural firm in the Netherlands even planned to flood entire city squares and outdoor sports areas with safe, germicidal 222 nanometer ultraviolet light—their "Urban Sun" project. A Sharper Image gift catalogue listed no fewer than 14 air or surface disinfection gadgets, including a tiny ion generator meant to be worn around the neck.

Not all of these devices are likely to do what they're marketing claims. Others are almost certainly not effective at all. The challenge is to discern those from the products that could, in fact, play a significant role in our ongoing effort to limit the spread of airborne pathogens.

Marketers are quick to present in ads the results of industry-sponsored testing, typically claiming '99.9%" or greater reductions in particles or test bacteria or viruses. Often these reductions compare test organism concentrations in air before and after passing through a device but *not what happens in a room where the device would be used*, which is all that matters in the long run. The details of these company-sponsored tests are usually lacking—one common issue is the failure to mention the *rate* at which decontamination occurs in rooms, which is often far too slow to be of practical use. For example, a device may claim 99.9% air contamination, but only in the fine print indicate that the test was conducted over 24 hrs. That's not useful if you're sitting in a room with an infected person. What does matter to prevent person-to-person spread of infection is clearance in minutes. Testing is rarely controlled, unbiased, properly compared to other technologies, or conducted under real-world conditions. In fairness, it is extremely difficult and expensive to prove the efficacy of interventions to reduce infections, especially one like COVID-19 that is often asymptomatic and might go unnoticed (especially in a country, like the U.S., where testing capability has been sorely lacking), and where transmission can occur by several potential routes, or occur in any number of settings besides the site of the intervention (like on a school bus versus the classroom).

About 30 years ago, I wrote a commentary with a similar title for the *journal Infection Control and Hospital Epidemiology* about engineering approaches to prevent the spread of tuberculosis (TB)—the greatest single infectious killer of adults globally, in pre-COVID-19 times. While TB is an exclusively airborne infection, it hasn't always been as clear by what means SARS-CoV-2, other coronaviruses, influenza, smallpox, and even common colds can be transmitted. Early in the pandemic, aerosol spread of COVID-19 was considered less important than other transmission pathways. But it is now clear that vast majority of its spread is the result of inhaled aerosol, with a lesser amount attributable to direct contact with droplets.

Outdoors, dilution of any aerosols is infinite—though the time it takes to dilute clouds of aerosol, depends on air movement. Think, for example, of how a cloud of cigarette smoke outdoors lingers or dissipates depending on whether there's a breeze or not. Indoors, however, aerosols almost always linger longer than outdoors—often long enough to be inhaled by someone sharing the same space. Put another way, if you breath in an indoor setting where other people are also breathing, you will almost surely breath in some amount of air that has been recently exhaled by someone else. That recycled air—the so-called *rebreathed air fraction*—estimated by room carbon dioxide measurements, is a good predictor of the risk of infection, given an infectious person generating infectious aerosol in the same room.

The point of this piece is not to promote a particular company or product. Most of my 40-year career in tuberculosis control focused on engineering and non-engineering control strategies, such as prompt, effective TB treatment, but there was little commercial interest in TB-related products because the market was primarily in poor countries. COVID-19 has changed that. Suddenly there is great commercial interest in airborne infection control, for schools, hospitals, and even restaurants, and a greater need to apply scientific principles and testing rigor to evaluating efficacy claims, and in making sound recommendations.

Think About Ventilation

Ventilation, natural or mechanical, is the main way that the risk of airborne infection indoors is reduced. For hospital airborne infection isolation and procedure rooms, the U.S. Centers for Disease Control and Prevention (CDC) recommends 6 to 12 room air changes per hour (ACH) with infection-free outdoor air, or air that has been filtered or otherwise decontaminated. One ACH occurs when a volume of air equal to that of the room enters and leaves over a period of one hour. As fresh air enters and mixes with contaminated room air, not all the contaminated air is removed by one air change. Under well-mixed conditions, one air change removes approximately 63% of room air contaminants, and a second air change removes about 63% of what remains, and so on. But under real world conditions, the protection achieved by ventilation also depends on the amount of contaminant (virus in this case) being added over time, i.e. by an infected person, and on the contagiousness of the infection. The greater the infectiousness of the virus, greater the infection-free ventilation needed to keep concentrations low. For Omicron, for example, 6-12 ACH ventilation, or equivalent air disinfection, may not be enough to prevent transmission. Unfortunately, not all transmission is preventable by air disinfection—for example, transmission at very close range where there is no time to remove or inactivate viruses generated by one person before they are inhaled by someone else.

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Many residential and older buildings without mechanical ventilation may have about one ACH or less due to air leakage around doors and windows—but when windows are open, depending on building design, orientation, and outside weather conditions, may enjoy significantly higher ACHs. For economical heating and cooling, however, windows are normally closed, especially in larger mechanically ventilated buildings, by design, or closed by occupants in response to outside temperatures. Automated mechanical ventilation systems often bring in a minimum amount of outside air under very cold or hot outside conditions, resulting in most air being recirculated within the building, thereby recirculating air contaminants rather than removing them.

The relationship of room ventilation to risk of infection isn't linear—that is, doubling of ventilation rate further reduces the concentration of air contaminants by only about half. This means that doubling poor ventilation from 1 ACH to 2 ACH provides relatively greater improvement in protection for room occupants than, for example, the increased protection from doubling ventilation from 6-12 ACH. This is because when air contaminants are low, much more air movement is required to dilute and remove them. Moreover, increases ventilation rates are costly, often requiring larger fans, blowers, ventilation ducts, and more electricity, as well as greater heating, cooling, and dehumidification capacity. At the same time, as noted, for the much more infectious Omicon variant, very high ventilation rates are needed to keep up with high viral concentrations and infectiousness . Therefore, because mechanical ventilation may not be sufficient to reduce the risk of infection, mechanical ventilation in public buildings should be supplemented by other methods of air disinfection. For current and future viral pathogens like SARS-CoV-19, relatively high levels of "equivalent" ventilation by supplemental air disinfection will be needed.

Installation of two different types of upper-room UVC luminaires at St Augustine of Canterbury Episcopal Church, Oklahoma City, OK.

Photo by PA Jensen, FAI

The Importance of Air Filtration

Presented with particulate air contamination, a standard engineering response is to filter the air. High-efficiency air filters can be used in building ventilation systems to assure that fewer than 99.9% of respirable-size particles are recirculated back into rooms, essentially converting recirculated air into the equivalent of infection-free outdoor air. While some filter manufacturers boast of inactivating virus with UV, bipolar ions, cold plasma, or other technologies as advantageous over simple retention, there is no practical difference for risk in rooms. Importantly, while environmentally adapted TB bacteria and fungal spores readily spread through ventilation ducts, and this is theoretically possible for SARS-CoV-2 virus, there are few if any convincing reports of COVID-19 spread from room-to-room or floor-to-floor exclusively through ventilation systems – a relevant exception being a single report of spread of waste-water contaminated air not through ventilation ducts, but through faulty plumbing stacks in a high-rise apartment building in China.

While it is often difficult to discern among several airborne infection transmission pathways, the apparent paucity of reports of transmission through ventilation ducts likely reflects the well-known fragility of envelope viruses, such as SARS-CoV-2, although dilution in rooms and ventilation ducts to concentrations below infectious dose could also be playing a role. Importantly, if air recirculation in ventilation ducts is not contributing importantly to COVID-19 transmission in buildings, the value of high-efficiency filters or germicidal UV in recirculating ventilation ducts for preventing spread is speculative and limited at best. Moreover, to a person sharing air in a room with someone with infectious COVID-19, there is little comfort in knowing that the air will be decontaminated only *after* it leaves the room. A more effective air disinfection strategy is to rapidly decontaminate the air *within the room* where person-to-person transmission occurs.

“In the room where it happened” is a song from the Hamilton musical, but it could also be a guide to the application of air-disinfection technology. The evidence-based options for enhanced in-room air decontamination include increased ventilation, portable room-air cleaners, upper-room germicidal UV, and newer whole-room Far UV. Ion generators can also be used in rooms, but the evidence for efficacy is far less than for other approaches.

Below I will explain and compare each of these interventions for increasing ventilation or supplementing with in-room air disinfection

Natural ventilation

Natural ventilation is by far the most common form of room decontamination worldwide that can be highly effective with proper building design and favorable outdoor conditions. However, windows are often closed in inclement weather, and wind currents are not always conducive to good air exchange within buildings. With global warming, moreover, increasing use of efficient ductless air conditioners is resulting in windows being closed, reducing natural ventilation, and greatly increasing the risk of airborne infections. Extreme air pollution is another factor limiting the use of outdoor air for air disinfection in some parts of the world. Many mechanically ventilated commercial buildings don’t have operable windows, and deep interior spaces often make natural ventilation ineffective.

Portable room-air cleaners

These comprise a wide range of devices in price and performance. They usually consist of a box with a fan or blower and air filters, with or without UV or more sophisticated technologies for trapping particles or inactivating pathogens. The major determinants of room-air cleaner efficacy are: 1) the flow rate of air processed (clean-air delivery rate) relative to room volume, 2) the flow patterns produced in the room—which determines the ability of the device to process most of the air in the room rather than reprocess the same air near the device over and over again. In many applications, room air cleaners are undersized for the room volume, producing very few equivalent ACH. But, when properly sized they can be intrusively large, and when run at an effective fan speed, many room air cleaners are noisy and produce drafts. They may be acceptable in a gym, but generate too much noise for a classroom or house of worship. Nevertheless, when they are sized to produce at least 6 equivalent ACH, room air cleaners can be an effective intervention to reduce in-room transmission of airborne infections.

Germicidal UV lamps and fixtures

Upper-room germicidal UV (GUV) fixtures are a more than 80-year-old technology, well-proven, safe, and underused technology for airborne infection control. Upper room GUV works by flooding the "upper room" (above the heads of occupants) with sufficient germ-killing ultraviolet light to rapidly inactivate airborne pathogens. All known pathogenic microbes contain either DNA or RNA and are susceptible to GUV. Air mixing between the upper and lower room results in high rates of air disinfection in the lower, occupied room. In the 1930s upper room GUV fixtures were installed in school classrooms in two Philadelphia suburbs and were convincingly shown, compared to classrooms without fixtures, to markedly reduce the spread of measles—the most infectious of airborne respiratory viruses. It was widely used in U.S. health care settings before the discovery of antibiotics for tuberculosis, and vaccines for the childhood viral infections, measles, mumps, and rubella. Renewed interest in GUV in health care settings, homeless shelters, prisons, jails and other congregate settings followed the 1985-92 resurgence of TB in the U.S. and Europe. Since then, GUV has found its greatest application in countries endemic for TB, but it has remained an extremely useful but underdeveloped technology for any airborne infection. COVID-19 has again renewed interest in GUV, upper room as well as a newly developed shorter wavelength, called Far UV. As for visible lighting, more efficient LED sources for GUV are rapidly being developed and may be the predominant technology for upper room use in the near future.

Far UV refers to 222 nm UV that has the remarkable properties of being equally or more effective against airborne viruses and bacteria, but unable to penetrate even the thin liquid layer covering the surface of the eye, or the outermost layers of skin. While conventional upper room UV has long been safely used to disinfect air in occupied rooms, Far UV appears safer yet with little potential for even mild eye or skin irritation when used within established exposure guidelines. It does not reach the deeper layer of skin cells where solar UV can cause skin cancer. Far UV sources require effective filters to prevent exposure to unwanted longer-wavelength UV that can be damaging. Applications of current Far UV fixtures might include treating air and counters between workers and clients, such as bars, salons, restaurant tables, elevators, other high contact settings. Far UV is currently being used, for example, in a Boston homeless shelter, a Boston nightclub and piano bar, and for some critical U.S. military applications.

Shows the application of an upper room UV fixture in a classroom. The fixture is the black box on the upper, left side of the front wall, with blue light visible. Another fixture on the rear wall would contribute to an effective upper room air disinfection zone.

Compared to mechanical ventilation and room-air cleaners, GUV is cheaper and much more effective. Upper-room GUV decontaminates a large volume of air at once, typically the upper two feet (20%) of a room with a 9 ft ceiling, for example. Air mixing between the lower and upper room, assisted by rising warm air produced by occupants, ventilation outlets, or fans, results in high rates of air disinfection in the lower, occupied room. In a controlled study in a hospital in South Africa, we showed that GUV inactivation of airborne TB bacteria was equivalent to 24 ACH—well beyond the capacity of most mechanical ventilation systems and room-air cleaners. Independent investigators aerosolized test bacteria into an unoccupied hospital room in Russia and compared mechanical ventilation, upper room GUV, and three commercial room air cleaners. They found that upper-room GUV was about 9.4 times more cost-effective than mechanical ventilation for the same amount of air disinfection. Based on the potential energy savings over ventilation, the U.S. Dept. of Energy is supporting the commercial development and deployment of LED UV technology for air and surface disinfection.

There have been several barriers to the broader acceptance and application of GUV including unfamiliarity with the technology, and especially safety concerns. GUV raises safety concerns primarily because of a public perception that it is the same as the UV in sunlight. But not all UV is the same. It is skin exposure to the more tissue-penetrating longer wavelength UV in sunlight (UV-A and UV-B radiation) that is associated with skin cancer, and eye exposure to sunlight with cataracts, whereas shorter wavelength GUV penetrates eyes and skin surfaces far less, not reaching the lens of the eye to cause cataracts, or the deep layers of skin where it could induce cancer within well-established exposure limits. As mentioned, Far UV is far less penetrating and safe for direct exposure of room occupants. Acceptance and wider deployment of safe and highly effective UV systems will require education—of professional engineers, architects, and safety personnel, as well as the general public.

Read More: *Let's Not Be Fatalistic. We Know How to Fight Omicron*

But not all GUV devices on the market pass the test in terms of plausible benefit, and these detract from the credibility of the proven applications. There are numerous examples of GUV devices targeting both commercial and home applications that are not evidence-based and are unlikely to be effective in reducing COVID-19 transmission. For instance, a small GUV air disinfecting device designed to be worn around the neck cannot possibly move enough air to reduce aerosol transmission. Or, another example, small boxes with UV sources designed to decontaminate cell phones are likely no better than an occasional wipe down with alcohol. Equally irrational are GUV wands because delivering an effective germicidal dose is unpredictable when waving a wand over a surface, and they must be low power to avoid accidental direct over-exposure of eyes or skin. At an even larger scale, GUV portals have been marketed and used in building entrances or exits to "disinfect" people walking through them. This makes no sense not only because no significant decontamination of skin or clothing is possible, but respiratory virus resides in the human respiratory tract, and cannot be eliminated from the outside. Finally, the Urban Sun project for disinfecting large outdoor spaces likewise makes no sense since dilution and upward convection air currents already render the outside far safer than indoors. Under crowded indoor or indoor conditions, very close-range person to person aerosol transmission may be difficult to interrupt by air disinfection of any kind—requiring other proven interventions like vaccines, distancing, and masks.

Ionization

A variety of ionizers (bipolar, unipolar, and cold plasma) are marketed to generate positive and negative ions, deployed directly into occupied rooms or within filtration systems, to cause infectious particles to be attracted to filters or stick to each other and then settle out of the air and onto surfaces where they can no longer be inhaled. The mechanisms of action of ion generators is not fully understood and might include direct chemical inactivation of viruses and bacteria. Ion generators have been incorporated into a variety of products, with marketing claims based on industry-funded performance testing, there are very few published independent studies. In an older study conducted in Lima, Peru, a crude ionization system was directly compared to upper room UV and shown to be about 50% effective in decontaminating infectious hospital air of TB organisms. UV was 73% effective. But, in that study room air ionization had a serious practical limitation: the walls of the rooms in which the study was were blackened with black soot that became ionized and settled out onto surfaces. Other studies have shown that ionization can produce ozone from oxygen, as well as other dangerous ions and gases. These can lead to unanticipated, potentially toxic chemical reactions with other room air contaminants. Both the safety and effectiveness of ion generators require greater study to be compared to the established interventions of ventilation, room air cleaners, and GUV.

Nearly two years into the COVID-19 pandemic, the post-pandemic world is becoming clearer. While vaccines remain the mainstay of controlling person to person aerosol transmission, the efficacy of social distancing and mask wearing has been proven scientifically, albeit not fully accepted or implemented. Since the vast majority of COVID-19 likely spreads indoors, air disinfection is an underutilized role making indoor living safer. Building ventilation, natural and mechanical, is vitally important for the health and comfort of occupants. At its best, natural ventilation can be highly effective in reducing the risk of aerosol born infection, but it is not feasible or reliable in many climates and buildings. Mechanical ventilation is designed for comfort, not infection control, and generally in most buildings cannot achieve the air change rates needed to protect against a highly infectious viral aerosol like the current COVID-19 variants.

It's clear that for indoor spaces air disinfection is a safe and efficient way to reduce transmission. Although they are not equivalent, the three established and proven air disinfection technologies are mechanical ventilation, upper room GUV, and portable room air cleaners. Of these, upper room UV is the most cost-effective and is demonstrably safe and readily available to deploy today to reduce COVID-19 and other respiratory virus transmission. Far UV is available, even safer, and may be a more effective air disinfection technology because it works around room occupants and does not depend on room air mixing. Although limited by the ability to quietly move sufficient air in many rooms, room air cleaners also have a role for in-room air disinfection, especially in small rooms where at least 6 equivalent air changes per hour can be achieved. Implementation of effective air disinfection, while driven by the COVID-19 pandemic, should find its way into building codes and practices so that we are not as unprepared for seasonal respiratory viruses, ongoing epidemics like TB, and the next pandemic.