# How to Safely Reoccupy our Buildings in a COVID-19 World

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## Executive Summary

Research consensus is that COVID-19 is primarily acquired through person to person contact and airborne transmission of respiratory droplets. It is also possible to become infected by touching a contaminated surface, then touching your eyes, nose or mouth. This virus is the greatest threat to us when we are in close proximity to others who are infected and/or in an enclosed environment with low levels of fresh air.  These conditions typically occur indoors and can result in clouds of viral particles remaining airborne for long periods of time, capable of infecting people who breathe while passing through the area.

To safely reoccupy our buildings, we need strategies to mitigate the risk presented by being inside our buildings.  In this document, we will outline strategies to detect the virus before it enters our buildings and protect building occupants from infectious levels of viral particles that do enter our buildings. No single solution is currently 100% effective at detecting and eliminating the threat, so we must adopt a layered approach for the protection of our occupants.

The safe building solutions we will discuss include highly-effective screening at building entry points, increased volumes of outside (fresh) air into our buildings, high-performance filtration systems at our HVAC air handling equipment, germicidal ultraviolet (UV) treatment of air in HVAC equipment, germicidal UV treatment within upper air volume of occupied spaces, hydrogen peroxide ($H_2O_2$) treatment of air to kill airborne and surface viral particles, control of flush valve toilet aerosols, and touchless entry hardware and fixtures. In addition, we will discuss the combination of these approaches into mobile “killer filters” to augment base building

HVAC capabilities in select areas. By layering these strategies, we can dramatically improve the safety of our buildings during and beyond the COVID-19 pandemic.

To evaluate potential solutions to the threat of COVID-19 we focused on solutions that have ample research data to support their effectiveness. This paper includes research on how we are most commonly infected by the COVID-19 virus and offers technologies for your consideration with focus on layering combinations of protection to achieve the highest practical levels of protection. We then share thoughts on the design implications of these strategies in various types of spaces in our buildings.

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# Method of Infection

The CDC stated that COVID-19 specifically spreads from person-to-person in the following ways[1]:

## Airborne Transmission

1. Between people who are in close contact with one another (within about 6 feet).
2. Through respiratory droplets produced when an infected person coughs, sneezes, or talks - these droplets can land in the mouths or noses of people who are nearby or possibly be inhaled into the lungs.
3. By people who are not showing any symptoms

In addition, on July 6, 2020 more than 200 scientists from 32 countries published an open letter to the World Health Organization urging them recognize the impact of the airborne spread of COVID-19.

> “Hand washing and social distancing are appropriate, but in our view, insufficient to provide protection from virus-carrying respiratory microdroplets released into the air by infected people. This problem is especially acute in indoor or enclosed environments, particularly those that are crowded and have inadequate ventilation”[2]

## Surface Transmission

As of July 2020, the CDC states that while it may be possible for a person to get COVID-19 by touching a virus-contaminated surface, **this is not thought to be the primary way the virus spreads**.[3] Rather, the virus “spreads easily between people” who are either in close contact with one another (within about 6 feet), or through respiratory droplets produced when an infected person coughs or sneezes. This change comes after German virologist Hendrik Streeck who was leading the response to the country’s worst-hit areas said that he had not found evidence that the virus could live on surfaces.[4] These findings are consequential: it is possible our past methods of cleaning surfaces to contain the spread of the virus have been ineffective.

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[1] Centers for Disease Control and Infection. How COVID-19 Spreads. (2020, June16). Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html

[2] Morawska, L., & Milton, D. K. (2020). It is Time to Address Airborne Transmission of COVID-19. Clinical Infectious Diseases. doi:10.1093/cid/ciaa939. Retrieved from https://academic.oup.com/cid/article/doi/10.1093/cid/ciaa939/5867798

[3] Centers for Disease Control and Infection. How COVID-19 Spreads. (2020, June 16). Retrieved from https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html

[4] Huggler, J., Tominey, C., & Dixon, H. (2020, April 03). No proof coronavirus can be spread while shopping, says leading German virologist. Retrieved July 23, 2020, from https://www.telegraph.co.uk/news/2020/04/02/no-proof-coronavirus-can-spread-shopping-says-leading-german/

## Asymptomatic Transmission

In June 2020, the [Annals of Internal Medicine] stated, "Asymptomatic persons seem to account for approximately 40% to 45% of SARS-CoV-2 infections, and they can transmit the virus to others for an extended period, perhaps longer than 14 days", according to the results of a Scripps Research analysis of public datasets on asymptomatic infections. Viral loads are similar in people with or without symptoms, but it remains unclear whether their infectiousness is of the same magnitude.

> "Our estimate of 40 to 45 percent asymptomatic means that, if you're unlucky enough to get infected, the probability is almost a flip of a coin on whether you're going to have symptoms." [5]

The CDC also says it estimates that 40% of coronavirus transmission is occurring before people feel sick.[6] The findings suggest that asymptomatic infections may have played a significant role in the early and ongoing spread of COVID-19.

> "The silent spread of the virus makes it all the more challenging to control," says Eric Topol, MD, founder and director of the Scripps Research Translational Institute and professor of Molecular Medicine at Scripps Research. "Our review really highlights the importance of testing. It's clear that with such a high asymptomatic rate, we need to cast a very wide net, otherwise the virus will continue to evade us."[5]

While more research is needed about COVID-19, there are clear signs this virus is transmitted through the air and over 40% of transmission is occurring by people who feel no symptoms.

## Risk Areas

Ventilation is important to clean air, and because of this, COVID-19 is largely an inside threat. In a study of 1,245 cases that occurred across China from January 4 to February 11, only two cases were traced to contact with an infected person out of doors. Both cases arose from a single outbreak.[7]

The fact that few have contracted COVID-19 outdoors, despite likely exposure to people with the virus on the street, is probably not an anomaly. Outdoor environments are inhospitable for the transmission of airborne viruses, simply because in order to infect a new host, a sufficient number of airborne particles must stay in place long enough for someone else to inhale them.[8]

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[5] Oran, D. P., & Topol, E. J. (2020). Prevalence of Asymptomatic SARS-CoV-2 Infection. Annals of Internal Medicine. doi:10.7326/m20-3012

[6] COVID-19 Pandemic Planning Scenarios. (2020). Retrieved July 23, 2020, from https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html

[7] Wilson, Kera. (2020). Chinese Study Finds Outdoor Activities Safe From COVID. Retrieved 27 July, 2020 from https://usa.streetsblog.org/2020/05/15/chinese-study-finds-outdoor-activities-safe-from-covid/

[8] Nishiura, H., Oshitani, H., Kobayashi, T., Saito, T., Sunagawa, T., Matsui, T., Wakita, T., & Suzuki, M. (2020). Closed environments facilitate secondary transmission of coronavirus disease 2019 (COVID-19). MedRxiv, 2020.02.28.20029272. https://doi.org/10.1101/2020.02.28.20029272

# Mitigating Risk in the Built Environment

We recommend a three-pronged strategy to combat COVID-19:

1) **Detect** people who may be sick before they enter, at the perimeter of facilities. By understanding the threat, there are many opportunities to improve detection rates.
2) **Protect** people inside building from infectious levels of viral particles that do enter the building. It is simply not possible to catch every single threat, so protection is very important.
3) **Treat** people who become infected. Treatment protocols are outside the scope of this paper.

## Layered Approach

As no current solution is 100% successful, a series of layered solutions could make it safe to reoccupy our buildings. An article by Peter Tippett, titled Saving Your Health, One Mask at a Time states the following:

> "If your nose reduces the risk by 80%, and a mask by another 80% and the six-foot distance by 80% more, then collectively, the failure rate would be (0.2*0.2*0.2 = .008) = 0.8%. In other words, the collection of countermeasures would be (1 minus the failure rate) = over 99% effective in reducing your chances of getting sick. In this example, any two together would be 96% effective and any one alone would be 80% effective."[9]

If you added a fourth layer of protection, the risk of infection would decrease to only 0.16%. By combining solutions with different failure modes we can effectively protect building occupants in a way that is also affordable.

[9] Tippett MD PhD, P. (2020, April 7). Saving Your Health, One Mask at a Time [Web log post]. Retrieved July 23, 2020, from https://www.linkedin.com/pulse/saving-your-health-one-mask-time-peter-tippett-md-phd/

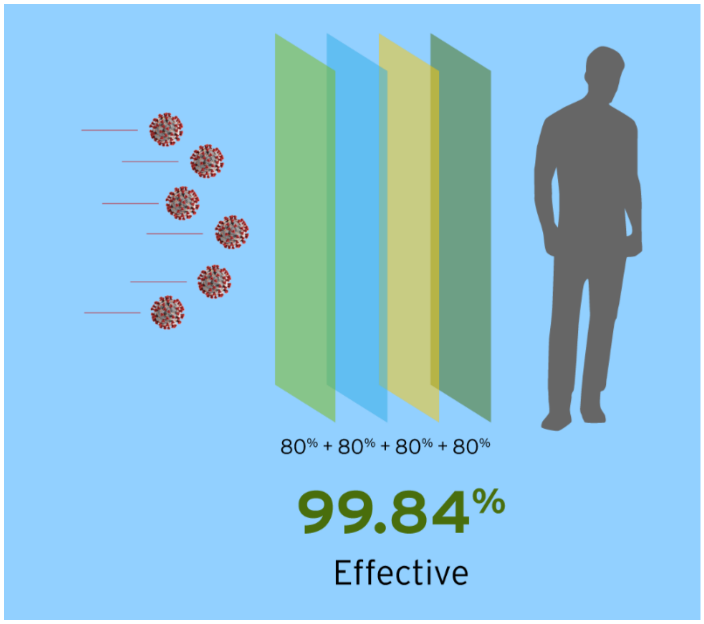


*Figure 1 Layering several partially effective solutions yields a highly effective defense.*

# Detect Infection Before Entry into Building

## Temperature Checks are Inadequate

Detection is important in stopping COVID-19 before it can threaten our building occupants. The key is detect infected persons when so many are asymptomatic. A screening process makes perfect sense for this, but what is the best way to screen and detect? In a study by Clinical Microbiology and Infection, patients with COVID-19 were screened. These patients had a variety of symptoms. Of these screenings, only 11% of patients were found to have a fever (>37.5 degrees celsius) [10]. So implementing temperature-check only screenings could miss over 88% of cases. In light of this, many government entities and employers are using questionnaires that ask about several possible symptoms as a screening tool[11]. Bringing together multiple variables of measurement improves the ability to identify potential cases.

[10] G.-u. Kim, M. -J Kim, S.H. Ra, J. Lee, S. Bae, J. Jung, S.-H Kim. (2020). Clinical characteristics of asymptomatic and symptomatic patients with mild COVID-19. Retrieved from https://www.clinicalmicrobiologyandinfection.com/article/S1198-743X(20)30268-8/fulltext

[11] Washington State Department of Health. (9 July 2020). Guidance for Daily COVID-19 Screening of Staff and Visitors. https://www.doh.wa.gov/Portals/1/Documents/1600/coronavirus/Employervisitorscreeningguidance.pdf

## Multifactor Testing

A device made by Symptom Sense tests four parameters without touching the individual inside in as little as 5 seconds. It measures pulse rate, respiratory rate, body temperature, and blood oxygen levels. Combining each of these variables results in a much higher rate of detection - up to 99% accuracy differentiating between an individual who is sick and not sick.[12] This unit is not designed to make a diagnosis, but to identify “sick” or “well”. This machine can be used at entry points for many high traffic areas. Multifactor screening methods will have value beyond the current pandemic by limiting exposure of the well population of a building to those who are sick.

*Figure 2 Photo of the Symptom Sense screening device made by Soter Technologies*

## Other Considerations for Detection Practices

Increasing screening before entering a building will create operational challenges for buildings with many occupants.

**Speed and Queuing**
Creating a plan for moving people through the screen queue in large buildings will be necessary. This may include single direction doors or scheduling entrance times to avoid congestion during screening.

**Implementing Procedures for Failed Screenings**
Organizations need train screening staff on handling employees and guests who do not pass the health screening. This could include providing resources like nearby healthcare providers.

**HR Policies**
Companies need to make sure their HR policies match screening protocols and address sick leave based on a failed screening.

# The Case for Clean Air

## The Human Biome

To best understand how to protect ourselves from COVID-19, we must understand our own human biome. Every human lives in a biome cloud of skin secretions, breath, perspiration, fecal residue, and various other bacteria and viral particles[13]. In health, this biome is small and non-threatening in our current world of frequent bathing, brushing teeth, deodorant and skin care.

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[12] Soter Technologies (2020). How It Works. Retrieved July 23, 2020, from https://www.symptomsense.com/how-it-works

[13] Meadow JF, Altrichter AE, Bateman AC, Stenson J, Brown G, Green JL, Bohannan BJM. 2015. Humans differ in their personal microbial cloud. *PeerJ* 3:e1258 https://doi.org/10.7717/peerj.1258

However, in sickness, this biome cloud can become infectious and may threaten those around it.

The size of the human biome is general placed at 2 meters. This is the distance contains exhaled air and any large droplets. The common suggestion for social distancing of six feet comes from research showing that large droplets from a cough will likely fall to the floor within 2 meters.[14] It was later discovered that this research had flaws. Further studies showed droplets, especially those that became aerosolized and hang in the air, carrying much further. COVID-19 can be carried in aerosol droplets from a cough or sneeze for 7 to 8 meters or roughly 25 feet.[15]

HYPERLINK "https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7293495/"

*Figure 3 Travel distance of large respiratory droplets and aerosols based on the type of explusion.*

The biggest problem is viral particles do not always dissipate quickly after being exhaled. Breathing, coughing and sneezing create aerosolized clouds of particles that can stay suspended in the air[16] waiting for the next person to walk by and breath in. In addition, HVAC systems without proper filtering can recirculate these aerosolized clouds, enabling the virus to travel from room to room. In a heavily traveled environment, these aerosol clouds from multiple infected persons could create a potentially dangerous cloud of pathogens that infect those passing by.

The risk these aerosolized clouds of infectious viral particles create means that addressing clean air in our buildings is imperative.

## Illustration: How Smoke Spreads

To further explain this concept, imagine a group of people smoking cigarettes, as Ed Yong suggested in the Atlantic.[17] If they are smoking inside and in a room of low ventilation, the smoke would quickly become dense and heavy. Whereas, if the group of smokers were outside, their cloud of smoke would more quickly dissipate and be less concentrated. The smell of the cloud would be less noticeable. This is the case for the viral cloud of coronavirus between an area of high ventilation versus low. The more of the coronavirus you inhale, the more likely you are to get sick. To decrease the amount of virus-contaminated loads in the air, the ventilation rate must be increased.[18]

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[14] Wells W.F. On air-borne infection: study II. Droplets and droplet nuclei. Am. J. Epidemiol. 1934;20:611–618. doi: 10.1093/oxfordjournals.aje.a118097

[15] Jayaweera, M., Perera, H., Gunawardana, B., & Manatunge, J. (2020). Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. *Environmental research*, *188*, 109819. Advance online publication. https://doi.org/10.1016/j.envres.2020.109819

[16] Kumar P., Morawska L. Could fighting airborne transmission be the next line of defence against COVID-19 spread? City Environ. Interact. 2019;4 doi: https://doi.org/10.1016/j.cacint.2020.100033.

[17] Weiss, H. (2020, May 28). What You Need to Know About the Coronavirus. Retrieved July 23, 2020, from https://www.theatlantic.com/health/archive/2020/03/coronavirus-covid-19-the-atlantics-most-crucial-coverage/607906/

[18] Beggs, Dr. Clive. (2000). The Use of Engineering Measures to Control Airborne Pathogens in Hospital Buildings. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.544.9303&rep=rep1&type=pdf.

The issue of clean air is not new. In 1912, Charles Chapin wrote:

> "Infection by air, if it does take place, as is commonly believed, is so difficult to avoid or guard against, and so universal in its action, that it discourages effort to avoid other sources of danger. If the sick room is filled with floating contagium, of what use is it to make much of an effort to guard against contact infection?" - The Sources and Modes of Infection.[19]

## Do the Math

According to the Swiss Centre for Occupational and Environmental Health[20], breathing and coughing are predicted to release large numbers of viruses, which can quickly lead to **billions** of virus copies in a poorly ventilated room where a coughing emitter is present. Only 100 viral particles of the seasonal flu are enough to infect a normal human. While it is unknown how many viral particles it takes to become sick with COVID-19, other coronaviruses like SARS have been measured. These studies have concluded about 1,000 particles in an hour of breathing is sufficient to become infected.[21]

If we assume these estimates for other corona viruses are reasonable estimates for COVID-19, consider the math for what this means for breathing:

- 2,000,000,000 viral particles per cubic meter
- 1,000,000 cubic centimeters (cc) a cubic meter
- 2000 viral particles per cubic centimeter
- The average human breath is about 500 cubic centimeters[22]
- Multiply 2,000 viral particles per cubic centimeter by 500 cubic centimeters per breath to get **1,000,000 viral particles per breath** from an aerosolized viral cloud.

This means all you have to do is enter a room and, within a few minutes of a cough or sneeze, you could have potentially received enough virus to establish an infection. These results explain the high rates of transmissions and implies the need for strict respiratory protection when people are in the same room with a COVID-19 case.

To protect our buildings, we need a major focus on protection from that cloud of viral particles.

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[19] Chapin, Charles. (1916).The Sources and Modes of Infection. New York, NY: J. Wiley & Sons. Retrieved from https://play.google.com/books/reader?id=8bJCAAAAIAAJ&hl=en&pg=GBS.PA1

[20] Riediker, M., & Tsai, D. (2020). Estimation of SARS-CoV-2 aerosol emissions from simulated patients with COVID-19 and no to moderate symptoms. *MedRxiv*. doi:10.1101/2020.04.27.20081398. Retrieved from https://www.medrxiv.org/content/10.1101/2020.04.27.20081398v1.full.pdf.

[21] Evans, M. (2020). Avoiding COVID-19: Aerosol Guidelines. MedRxiv, 2020.05.21.20108894. https://doi.org/10.1101/2020.05.21.20108894

[22] Hallett S, Toro F, Ashurst JV. Physiology, Tidal Volume. [Updated 2020 Jun 1]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2020 Jan-. Retrieved July 27, 2002 from https://www.ncbi.nlm.nih.gov/books/NBK482502/

## Hierarchy of Controls

The issue of containing the spread of COVID-19 is less of a medical issue and more an engineering issue. In fact, the top three Hierarchy of Controls, as outlined by the University of Nebraska and CDC NIOSH Task Force, are all engineering issues. The CDC states:

> "Controlling exposures to occupational hazards is the fundamental method of protecting workers. Traditionally, a hierarchy of controls has been used as a means of determining how to implement feasible and effective control solutions… Engineering controls are favored over administrative and personal protective equipment (PPE) for controlling existing worker exposures in the workplace because they are designed to remove the hazard at the source, before it comes in contact with the worker. Well-designed engineering controls can be highly effective in protecting workers and will typically be independent of worker interactions to provide this high level of protection. The initial cost of engineering controls can be higher than the cost of administrative controls or PPE, but over the longer term, operating costs are frequently lower, and in some instances, can provide a cost savings in other areas of the process." [23]

The Hierarchy of Controls is useful for understanding the benefit of various strategies for reducing risk in the workplace.

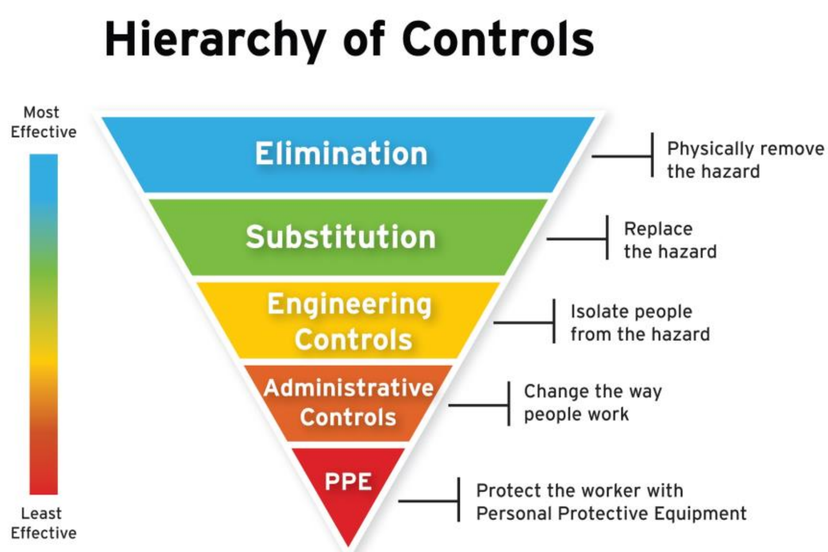


*Figure 4 Hierarchy of Controls is used to help assess risks in the workplace.* [23]

[23] National Institute for Occupational Safety and Health National Institute for Occupational Safety and Health. (2015, January 13). Hierarchy of Controls. Retrieved July 23, 2020, from https://www.cdc.gov/niosh/topics/hierarchy/default.html

Joseph G. Allen and John D. Macomber explored this issue in the April 2020 Harvard Business Review issue. They shared a similar version of the Hierarchy of Controls that focused on how company policies are reflected at each level.

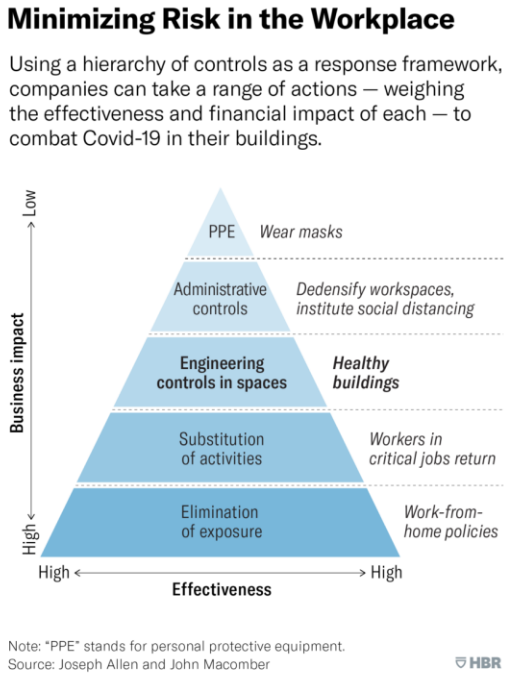


*Figure 5 Version of the Hierarchy of Controls focused on COVID-19.*[24]

Again, in this version engineering controls are key to allowing people to resume normal activities and for companies to effectively utilize their real estate investments.[24]

## Strategies for Defeating COVID-19 in Facilities

According to the American Society of Heating, Refrigerating, and Air Conditioning Engineering, "Mitigation of infectious aerosol dissemination should be a consideration in the design of all facilities."[25]

There are a wide variety of aspects for hazard elimination to keep air clean in buildings. These aspects include improvements of HVAC systems, HEPA Filters, Air Scrubbers, Use of Germicidal UV, chemicals in acceptable methods to mist the air, healthy buildings, humidity levels and other engineering innovations.

[24] Allen, Joseph and Macomber, John. (2020, April 29). What Makes an Office Building "Healthy". Harvard Business Review. Retrieved July 27, 2020 from https://hbr.org/2020/04/what-makes-an-office-building-healthy
[25] American Society of Heating, Refrigerating, and Air Conditioning Engineering. (2020, April14). ASHRAE Position Document on Infectious Aerosols. Retrieved from https://fliphtml5.com/krha/ghug/basic.

#### Ventilation Rate

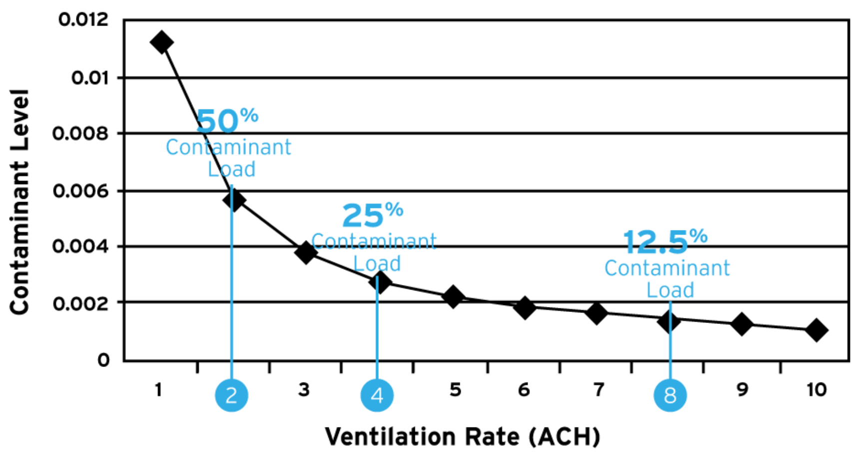


*Figure 6 Impact of Air Changes per Hour (ACH) on viral load [26]*

According to a study of airborne infection by CB Beggs, when you double the air changes per hour you half the contaminant load.[26] So, if you double the air changes from one to two, you cut the contaminant load by 50%. If you go from two to four, it is 25%. From 4 to 8, it is 12.5%. This study of airborne infection is from 2000, but more recent, NIOSH data reflects the same.

As the ventilation rate is increased, so the number of new infections cases decrease. While this study reflects Beggs' research with tuberculosis, given the best available data, we believe it is also true of other viral activities such as COVID-19.

This provides the key metric for measuring our success in protecting against the aerosolized viral cloud, Effective Air Changes per Hour. By comparing a given solution's impact on the viral load of a space, we can compare it against a base increase in air changes.

# Protect from COVID-19 in the Air

Increasing the effective air changes per hour will lower the viral load in a space. To minimize the infectious levels of viral particals to building occupants we should have a goal of 20 effective air changes per hour. At this level we would anticipate 99% of viruses to be removed in 15 minutes[27].

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[26] Beggs, Dr. Clive. (2000). The Use of Engineering Measures to Control Airborne Pathogens in Hospital Buildings. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.544.9303&rep=rep1&type=pdf.
[27] Kim, Jin & Song, Joon & Yoon, Young & Choi, Seong-Ho (2015). Middle East Respiratory Syndrome Infection Control and Prevention Guideline for Healthcare Facilities. Infection & Chemotherapy. 47. 278. 10.3947/ic.2015.47.4.278. https://icjournal.org/DOIx.php?id=10.3947/ic.2015.47.4.278

| Air changes per hour | Minutes required for removal efficiency | |
|---|---|---|
| | 99% | 99.9% |
| 2 | 138 | 207 |
| 4 | 69 | 104 |
| 6 | 46 | 69 |
| 12 | 23 | 35 |
| 15 | 18 | 28 |
| 20 | 14 | 21 |
| 50 | 6 | 8 |
| 400 | <1 | 1 |

*Figure 7 Given a number of Air Changes per Hour we can determine the time required to remove a viral load from the space.[27]*

With this metric guiding our search for solutions, we have identified several solutions that we believe will allow organizations to reasonably reoccupy their buildings while having confidence in the data behind these efforts. There are other solutions we have not explored in this paper that may be able to generate additional effective air changes per hour.

# Clean the Air

Cleaning the air involves filtration of contaminants from the volume of air within the building and/or replacing the volume of air in the facility with fresh air from outside the building.

## Increase Properly Filtered Air Changes

The most fundamental solution to increase air changes per hour is to simply bring in a larger volume of outside air. This is expensive because it requires cooling and dehumidifying the additional outside air. Most general use spaces are designed for four ACH.[28] It is not practical to get more than 6 to 8 air changes per hour from this method with an existing HVAC system. It's important when using this method to have proper filtration as you circulate the air. Otherwise you risk spreading viral particles through the air conditioning system. HEPA filters are proven to stop viruses such as COVID-19 that are less than 100nm[29] However, COVID-19 viruses is thought to be carried on respiratory droplets that are between 1 µm and 10 µm which are at least 10 times bigger than the actual virus.[30] Whole building filtration is handled at the air

[28] Engineering ToolBox. (2005). Air Change Rates in typical Rooms and Buildings. [online] Retrieved July 27, 2020 from https://www.engineeringtoolbox.com/air-change-rate-room-d_867.html.

[29] Kumar, P., & Morawska, L. (2019). Could fighting airborne transmission be the next line of defence against COVID-19 spread? *City and Environment Interactions, 4*, 100033. doi:10.1016/j.cacint.2020.100033

[30] Bourouiba L. Turbulent Gas Clouds and Respiratory Pathogen Emissions: Potential Implications for Reducing Transmission of COVID-19. JAMA. 2020;323(18):1837–1838. doi:10.1001/jama.2020.4756

handling equipment and requires the air to make a full circuit through the occupied space and back through the return air system to be combined with fresh outside air and filtered again.

An important consideration when adding HEPA-level filtration to your building's HVAC system is the pressure differential across the HEPA filter. The dense HEPA filter typically requires a larger horsepower fan to achieve design airflow for any given system. Thus, adding HEPA filtration may become costly if your equipment is not designed to accommodate the pressure drop of a HEPA. For this circumstance, a low-pressure drop, high-efficiency HEPA technology is available which allows retrofit without replacing fan equipment. One such example of this technology is the Winged Fiber filter technology employed in the HEPA Corporation Winged Fiber HEPA filter product line[31].

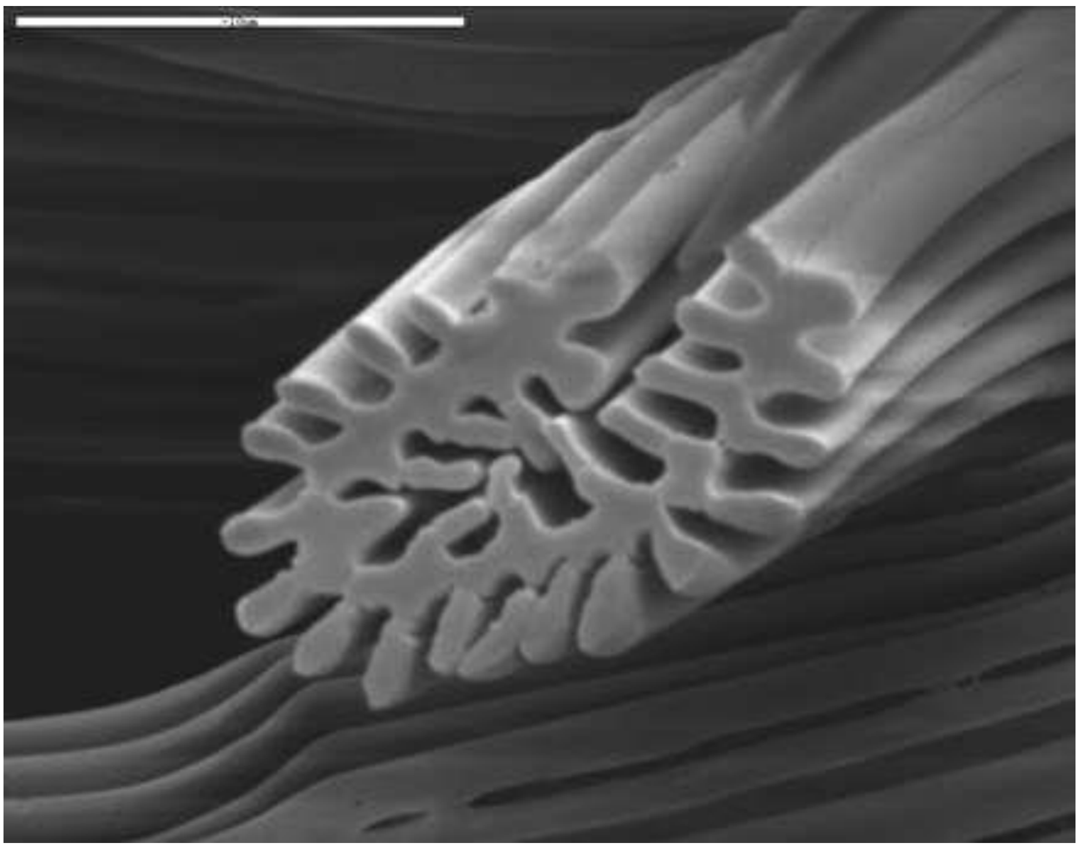

*Figure 8 Scanning Electron Microscope image of a Winged Fiber[32]*

[31] HEPA Corporation. (n.d.) Winged Fiber. Retrieved August 3, 2020, from http://www.hepa.com/standard-filters/winged-fiber
[32] Nano Filtration Technologies. (2010, August 13) Winged Fiber Media Presentation. https://www.slideshare.net/rdhurdle/3-2010-winged-fiber-presentation

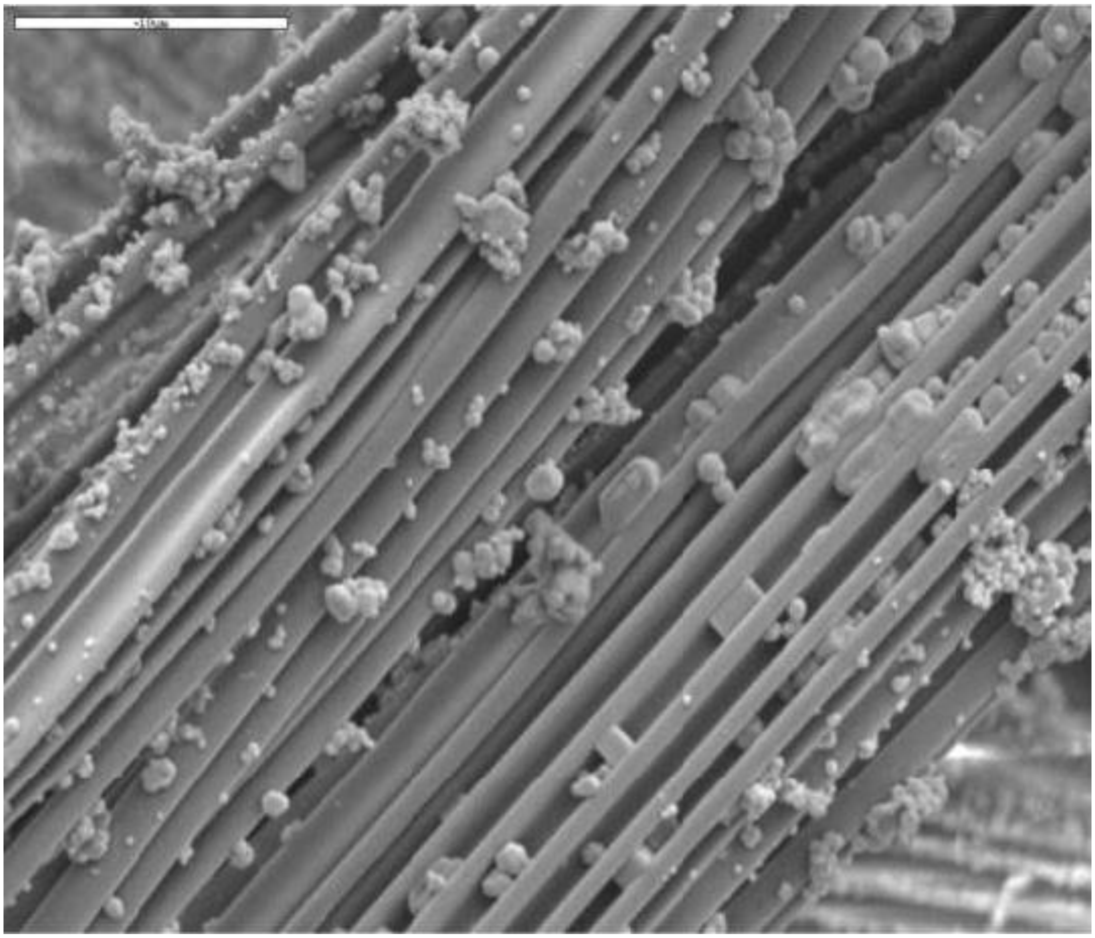

*Figure 9 Scanning Electron Microscope image of Winged Fibers loaded with particles* [32]

## Air Scrubbing Unit

Placing an air scrubber within the occupied space to augment the building's HVAC system in heavy traffic areas can reduce viral and contaminant load. An air scrubbing unit increases the room air exchange equivalent to prevent infection of the occupants. By being so close to the source of viral particles it is able to remove them from the air more quickly than a filter in the central air handler. These could be placed in rooms during period of increased risk and then removed when the threat is gone. Air scrubbing equipment may be as simple as a HEPA filtration system to remove contaminants from the air, or more sophisticated to include germicidal ultraviolet light to kill pathogens inside the filter chamber.  This type of packaged "killer filter" system may also be configured to include air treatment on the supply side, such as $H_2O_2$ treatment.

Killer Filter Diagram

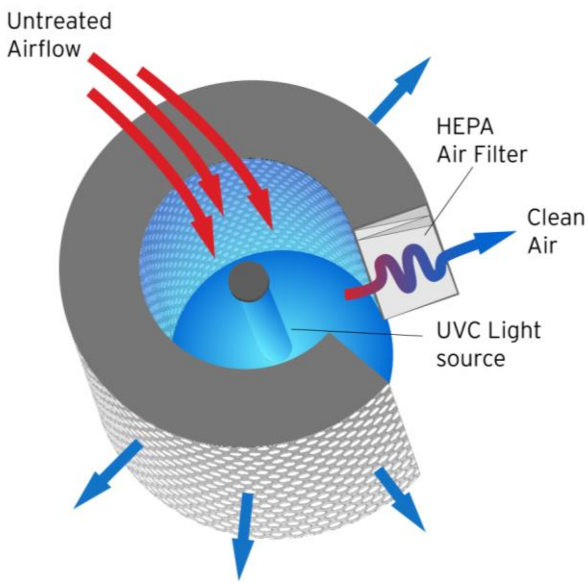


*Figure 10 This "Killer Filter" combines germicidal UV-C with a HEPA filter to kill viruses, fungi and bacteria. Then the inactivated particles are filtered out of the air by the HEPA filter.*

The germicidal UV and HEPA filter pulls air into the central cavity where it passes through a germicidal UV light before passing through a HEPA filter.

# Treat the Air

Solutions to treat the air, work by killing the virus in an occupied room. The air doesn't have to pass through a filter, instead these solutions permeate the in-place air.

## Dry Hydrogen Peroxide Gas Air Treatment

Another important air treatment option is a device that generates safe levels of $H_2O_2$, hydrogen peroxide gas, using the oxygen and water vapor from the air. This technology has been available for 20 years and proven to kill mold, bacteria and viruses in the air and on surfaces. It has been proven as a safe and effective tool for mold remediation in water damaged buildings. It produces the equivalent of a high number of air changes per hour by quickly dissipating contaminants and eliminating viral load from the air. Small versions of the hydrogen peroxide units simply plug into a wall and produce hydrogen peroxide gas to protect the occupants of rooms. Other larger variants of this unit, like the one pictured below, are designed to install on the supply side of the building's HVAC system and disinfect all areas of a building, including the entire HVAC system.

*Figure 11 CIMR 414 is a hydrogen peroxide gas generating unit from CIMR Technology that is placed on the supply side of the air handler.*

This product is called CIMR, Continuous Infectious Microbial Reduction. The unit generates 0.02 parts per million (ppm) $H_2O_2$ from oxygen and water vapor in the air. The system is self-regulating, as the $H_2O_2$ molecules interact when the density increases beyond 0.02 PPM and dissipate back to oxygen and water vapor, maintaining a 0.02 level that permeates all areas of the building. The $H_2O_2$ molecules are electrically charged and attracted to bacteria and virus particles, exploding the cellular wall upon contact.


*Figure 12 The CIMR 414 from CIMR Technology being measured for hydrogen peroxide in the room. The reading is 0.02 parts per million.*

Test data provided by CIMR Technology manufacturer

CIMR® Infection Control Technology systems have been in the field for years. They have been used in catastrophic events such as Hurricanes Rita, Ike, and Katrina. In all cases, our systems were successful in the Stabilization and Remediation cleanup of the buildings.

Kansas State University and Sandia Labs found that hydrogen peroxide gas technology disinfected 99% of the H5N8 Virus on surfaces within two hours.

Dr.Muto and S.Silvestri of the University of Pittsburgh Medical Center presented results from the use of CIMR® Infection ControlTechnology systems at the Fifth Decennial International Conference of Healthcare-Associated Infections, March 18-22,2010.

They concluded:

- CT11 HAI rate was reduced by 48% (8.8 vs 4.6) and the VRE A rate reduced by 56% (9.3 vs 4.1) during the post period, MRSA A rate was unchanged (1.5 vs 1.9).
- VRE A rates were significantly lower in the T vs C unit in the post period and the HAI rate trended towards significance. MRSA A was low in both time periods and in both units.

**Effective at Reducing Microbial Populations on Surfaces**

| | |
|---|---|
| Staphylococcus aureus: | 98.5% reduction |
| MRSA - Staphylococcus aureus (Methycillin Resistant): | 99.8% reduction |
| Escherichia coli: | 98.1% reduction |
| Bacillus spp.: | 99.38% reduction |
| Streptococcus spp.: | 96.4% reduction |
| Pseudomonas aureuginosa: | 99.0% reduction |
| Listeria monocytogenes: | 99.75% reduction |
| Candida albicans: | 99.92% reduction |
| Stachybotrys chartarum: | 99.93% reduction |
| Norovirus: | 99.9% reduction |

*Figure 13 Hydrogen Peroxide gas' effectiveness and reducing microbial populations at a concentration of 0.02 ppm*

## Germicidal Ultraviolet Light

Germicidal Ultraviolet light, or UV-C, has been used effectively for many years to eliminate viruses, bacteria and other contaminants from air and surfaces. GUV systems are used in hospitals at high-intensity to sterilize rooms and equipment. The same technology has been used successfully for many years to kill molds, viruses and other contaminants on HVAC coils and condensate drain pans by placing UV-C lamps adjacent to the coil. The UV-C kills all contaminants in line of sight of the lamps. GUV systems have also been used effectively at high-intensity to disinfect air on the fly in HVAC systems.

Excerpt from ASHRAE Position Document on Filtration and Air Cleaning, January 13, 2018 relating to UV-C:

> Ultraviolet (UV-C) disinfection (also called ultraviolet germicidal irradiation [UVGI]) is used to degrade organic material and inactivate microorganisms. The system is not a filter; thus, inactive particles remain in the airstream, which, in the case of dead fungal spores, may still cause a negative human response to their integral mycotoxins. The most effective wavelength range for inactivation of microorganisms is between 220 and 300 nm, with peak effectiveness near 265 nm. The typical source of UV-C in commercial

and residential air and water systems is low-pressure mercury vapor lamps, which emit mainly near optimal 253.7 nm. UV-C systems may be installed inside HVAC systems, irradiate air near the ceiling, or be incorporated in a stand-alone (portable) air cleaner. The effectiveness of a UV-C system to inactivate microorganisms in the air and/or on surfaces has been amply demonstrated; the best results were obtained for the long-term irradiation of downstream coil surfaces to avoid fungal amplification on wet surfaces. Experience suggests that control of a moving airstream does not provide favorable killing rates because of the short dwell time. Under ideal conditions, inactivation and/or killing rates of 90% or higher can be achieved but depend on the following: the type of microbial contaminant; specific species; physical or mechanical factors such as UV-C intensity, exposure/dwell time, lamp distance and placement, and lamp life cycle and cleanliness; air movement and patterns; temperature; relative humidity; and air mixing. Airborne removal is best applied in conjunction with filtration of particles with prefiltration in order to protect lamps and mechanical filtration downstream for microbial particles. Proposed ASHRAE Standard 185.1 provides a method for testing UV-C lights for use in air handling units or air ducts to inactivate airborne microorganisms, and ASHRAE Standard 185.2-2014 provides a method of testing ultraviolet lamps for use in HVAC units or air ducts to inactivate microorganisms on irradiated surfaces.[33]

According to the Illuminating Engineering Society, upper-room germicidal ultraviolet light (GUV) is a safe means of air disinfection that is possible in rooms with high ceilings.[34] The Illuminating Engineering Society notes,

> "In this method, specially designed and installed UV-C fixtures that irradiate only the air above 2.1 meters (seven feet) constantly disinfect the upper air volume. This is most effective when there is constantly mixed air by fans and HVAC ventilation, but even without strong ventilation or fans, air constantly mixes by movements and normal convective currents."

One question about GUV light is whether or not it is safe to implement into workplaces. The Illuminating Society says,

> "UVGI lamp emissions can pose a workplace safety and health hazard to the eyes and skin if the lamps are improperly used or installed. However, these lamps can be used safely if workers are informed regarding the hazards and follow appropriate precautions. Upper-room GUV has been safely used for preventing airborne transmission for at least 70 years."

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[33] American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2018). Position Document on Filtration and Air Cleaning. https://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd.pdf

[34] IES Photobiology Committee. (2020). IES Committee Report: Germicidal Ultraviolet (GUV) – Frequently Asked Questions. (IES CR-2-20-V1). Illuminating Engineering Society. https://media.ies.org/docs/standards/IES%20CR-2-20-V1a-20200507.pdf

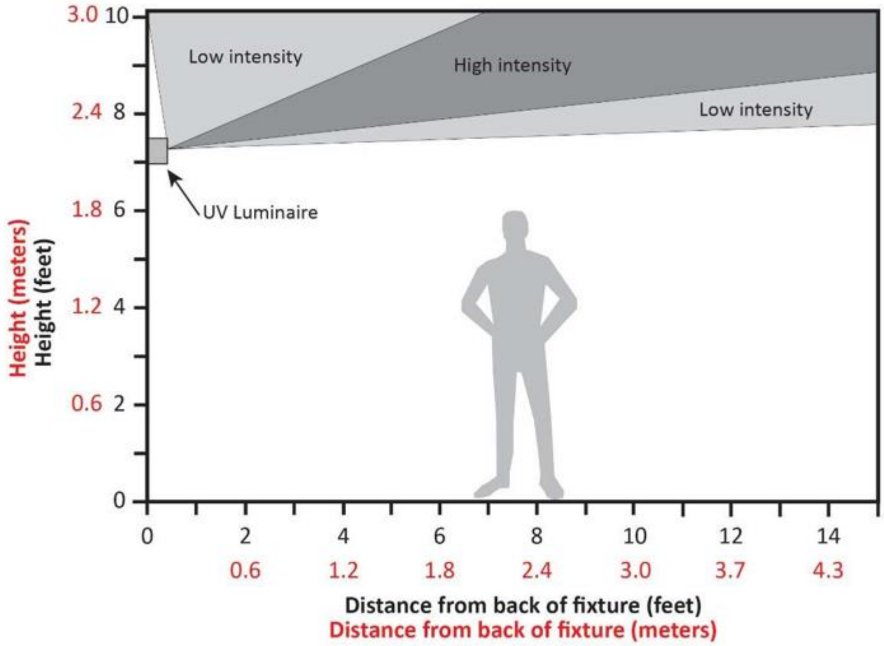


*Figure 14 Use of UV-C in the upper space of a room avoids exposing to people in the room.*

While some eye injuries have been reported, mostly from maintenance workers who are working in the upper room without turning off fixtures, there are no known long-term consequences from an accidental UV-C overexposure[34]. For safety purposes, only trained maintenance workers should be responsible for any cleaning or installation in the upper room.

A recent study from the Massachusetts Institute of Technology has similar findings:

> Illumination of the air-space in patient rooms with ultraviolet light has been shown to dramatically reduce viral longevity in aerosol form, and thereby prevent infection. This could be used to decrease Aerosol Decay Time in spaces where increasing air circulation (i.e., reducing Room Air-Cycle Time) is impractical.[35]

UV-C has been widely studied and proven effective, however without a pressing threat, it has yet to be widely adopted.

"We have struggled in the past to see this highly effective, very safe technology fully implemented for airborne infections," said Dr. Edward A. Nardell, a professor of global health and social medicine at Harvard Medical School. "We've done the studies. We know it works."[36]

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[35] Evans, M. (2020). Avoiding COVID-19: Aerosol Guidelines. MedRxiv, 2020.05.21.20108894. https://doi.org/10.1101/2020.05.21.20108894

[36] Chang, K. (2020, May 07). Scientists Consider Indoor Ultraviolet Light to Zap Coronavirus in the Air. Retrieved July 27, 2020, from https://www.nytimes.com/2020/05/07/science/ultraviolet-light-coronavirus.html

## Other Air Purification Technologies – Bipolar Ionization

Another important technology that is implemented to treat the air and kill contaminants is Bi-Polar Ionization. The following is a description by ASHRAE[33]:

- High voltage electrodes create reactive ions in air that react with airborne contaminants, including viruses.
- The design of the corona discharge system can be modified to create mixtures of reactive oxygen species (ROS), ozone, hydroxyl radicals and superoxide anions.
- Systems are reported to range from ineffective to very effective in reducing airborne particulates and acute health symptoms.
- Convincing scientifically-rigorous, peer-reviewed studies do not currently exist on this emerging technology; manufacturer data should be carefully considered.
- Systems may emit ozone, some at high levels. Manufacturers are likely to have ozone generation test data.

# Protect: Special Considerations

## Toilet Control

Toilet control can begin by simply putting lids on flush valve toilets we have now.

Studies in Hong Kong and at the United States' NIOSH indicate that the forced water toilet flushing system aerosolizes whatever is in the bowl and contributes to contamination of the space[37]. Without a lid to close, a single flush may release up to 80,000 droplets into the air.[38] In fact, it would take up to 15-20 flushes to stop putting those particles into the air.

While the study did not look for live virus, it is clear that infected people are releasing, at a minimum, viral RNA, in bowel movements. Also, if a person who used the restroom before you is infected, you have a chance of contracting the virus via breathing the air in the bathroom. If you must use a public restroom with a toilet that does not have a lids, wait a few minutes before entering so gravity can bring the droplets to the floor. Replacing flush-valve toilets with tank style toilets in commercial buildings would be expensive and present janitorial and maintenance considerations. A cost-effective and immediate answer is to put lids on the toilets in our buildings with signs "Please close lid before flushing".

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[37] Wilson, G., Jackson, V., Boyken, L., Schweizer, M., Diekema, D., Petersen, C., . . . Perencevich, E. (2020). Bioaerosols generated from toilet flushing in rooms of patients with Clostridioides difficile infection. *Infection Control & Hospital Epidemiology, 41*(5), 517-521. https://doi.org/10.1017/ice.2020.11

[38] Potential spread of pathogens via aerosol droplets produced by toilet flushing. (2020, February 14). Retrieved July 27, 2020, from https://www.cityu.edu.hk/research/stories/2020/02/14/potential-spread-pathogens-aerosol-droplets-produced-toilet-flushing

## Personal Protective Equipment (PPE) and Best Practices

Personal protective equipment (PPE) serves as a good temporary step to prevent the spread of COVID-19. Researchers emphasize there are two main reasons to wear a mask: protection for the wearer and to protect others from becoming infected from the person wearing the mask.[39]

A study published in Nature Medicine in April[40] looked at people infected with the flu and seasonal coronaviruses. It found that even loose-fitting surgical masks blocked almost all the contagious droplets the wearers breathed out — and even some infectious aerosols, too — tiny particles that can linger in the air.

Other recent studies offer indirect evidence for universal mask use, even if worn by people who are feeling healthy. One study, published in late May in BMJ Journals[41], looked at people in households in Beijing where one person was confirmed to have COVID-19. At the time, explains study co-author Raina MacIntyre, “research was already showing that the majority of transmission of the virus was happening inside households”, and China already had a culture of mask wearing. The study found that in households where everyone was wearing a face masks indoors as a precaution before they knew anyone who lived there was sick, the risk of transmission was cut by 79%. "The more people that were wearing a mask, the more protective it was," says MacIntyre, head of the biosecurity program at the Kirby Institute at University of New South Wales in Australia. In other words, when everyone wore a mask, it protected the whole household.

Another study, published in the Journal Cell[42], suggests that the coronavirus may first establish itself in the nasal cavity, before sometimes moving down to the lungs to cause more serious damage. If that is the case, the findings "argue for the widespread use of masks" to prevent the virus from exiting an infected nose, or entering an uninfected one.

Finally, in a modeling study, published last week in the Proceedings of the Royal Society A[43], concluded that, if the majority of a population wore face masks in public, even just homemade ones, the act could dramatically reduce transmission of the virus and help prevent future waves of the pandemic.

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[39] Hendrix MJ, Walde C, Findley K, Trotman R. Absence of Apparent Transmission of SARS-CoV-2 from Two Stylists After Exposure at a Hair Salon with a Universal Face Covering Policy — Springfield, Missouri, May 2020. MMWR Morb Mortal Wkly Rep 2020;69:930-932. DOI: http://dx.doi.org/10.15585/mmwr.mm6928e2

[40] Leung, N.H.L., Chu, D.K.W., Shiu, E.Y.C. *et al.* Respiratory virus shedding in exhaled breath and efficacy of face masks. *Nat Med* 26, 676–680 (2020). https://doi.org/10.1038/s41591-020-0843-2medRxiv 2020.02.28.20029272; doi: https://doi.org/10.1101/2020.02.28.20029272

[41] Wang Y, Tian H, Zhang L*, et al.* Reduction of secondary transmission of SARS-CoV-2 in households by face mask use, disinfection and social distancing: a cohort study in Beijing, China. *BMJ Global Health* 2020;**5:**e002794.

[42] Hou, Y. J., Okuda, K., Edwards, C. E., Martinez, D. R., Asakura, T., Dinnon, K. H., . . . Baric, R. S. (2020). SARS-CoV-2 Reverse Genetics Reveals a Variable Infection Gradient in the Respiratory Tract. Cell, 182(2). doi:10.1016/j.cell.2020.05.042

[43] Stutt, R. O., Retkute, R., Bradley, M., Gilligan, C. A., & Colvin, J. (2020). A modelling framework to assess the likely effectiveness of facemasks in combination with ‘lock-down’ in managing the COVID-19 pandemic. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*. doi:10.1098/rspa.2020.0376

These studies display the importance of wearing a face mask as a temporary safety precaution.

One warning about solely relying on masks to the exclusion of air ventilation comes from Matthew Evans from MIT:

> Mask use may help to prevent direct exposure when a minimum of 2 m interpersonal distance cannot be maintained, but is not sufficient to prevent infection in an enclosed space regardless of the distance between occupants.[44]

# Design Implications

COVID-19 is going to change how we design our buildings. REES has considered how this research will impact our current buildings and the design of facilities in the future.

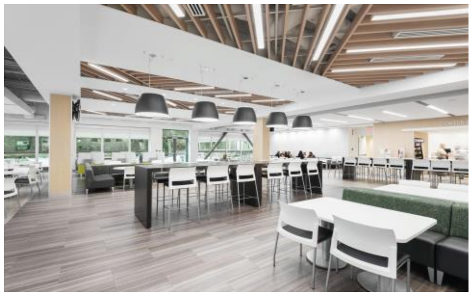
**Entry and Lobby**

Entrances and lobbies have become screening points to prevent COVID-19 from entering the building. At entry points, designers will need to allow additional space for screening. Consideration must be made for the flow of people through that entry and of the timing of how we schedule people to enter the building.

**Site Amenities**
Building amenities are important spaces to carefully evaluate since people pass through these spaces continually and congregate, often more closely than in the work areas:

[44] Evans, M. (2020). Avoiding COVID-19: Aerosol Guidelines. MedRxiv0.05.21.20108894. https://doi.org/10.1101/2020.05.21.20108894

**Cafes**



Touchless entries and devices, high numbers of air changes per hour, Germicidal Ultraviolet light at the air handler as well as possible Germicidal Ultraviolet light in the upper zone of the occupied space if the space has high ceilings, should all be considered. We may also want to consider hydrogen peroxide air treatment, which will clean the air and surfaces continually.

**Large Conference Centers**

Large Conference Centers may be a good place to use Germicidal Ultraviolet light in the upper zone of the occupied space.

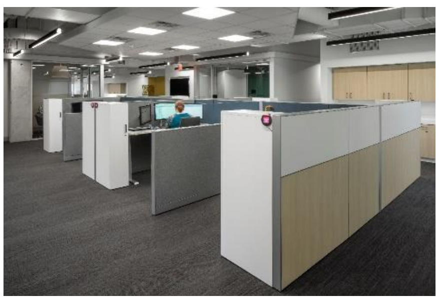
**Fitness Centers**

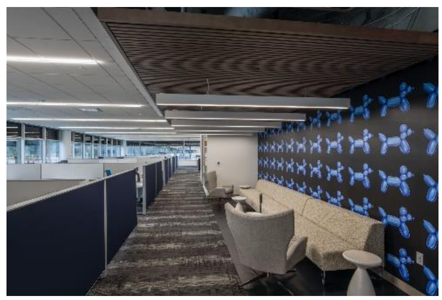
Fitness centers are another place where people are working out hard and breathing hard, so you're going to see more virus particles in that space. Consider a killer filter in the occupied space in addition to the GUV at the air handler.

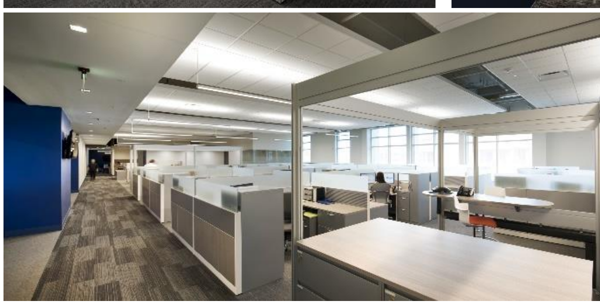
## Elevators

Elevators are another challenging area for COVID-19. These are small spaces with people in close proximity. Hydrogen Peroxide units with circulating fans placed on the top of the elevator car may be a good solution. When possible, healthy stair use should be encouraged.

## Workplaces

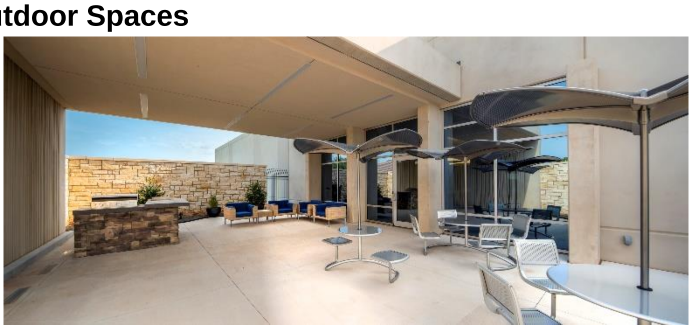


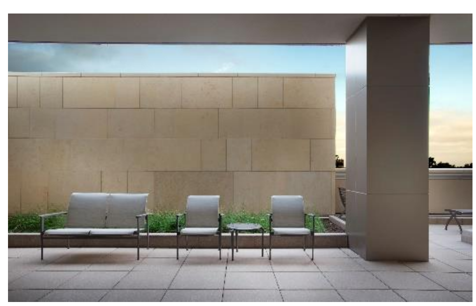




Our workplaces have been trending toward smaller, greater density areas with many shared spaces. Since people spend long hours in this area, special attention should be paid to the air here. Layering multiple solutions is key.

## Outdoor Spaces





Wherever possible, employers should encourage employees to use outside spaces more, since we know it’s an area where COVID is unlikely to be transmitted. Providing strong Wi-Fi, electrical outlets and comfortable seating areas so people can work productively is extremely important.

**Restrooms**

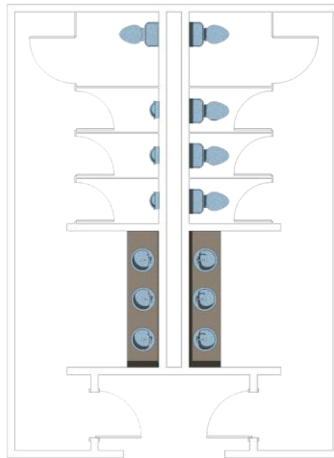


*Figure 15 Typical bathroom design*

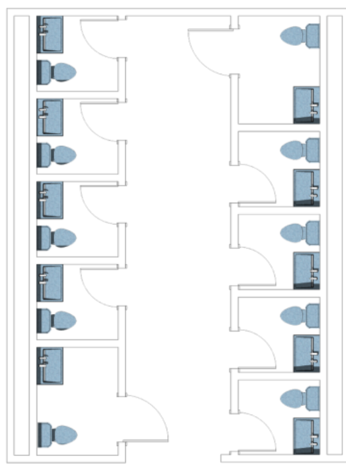


*Figure 16 Bathroom design with individual washrooms to limit exposure to a single area.*

In addition to the technology to clean the air, we may want to consider separate washrooms for user, including a toilet and lavatory, so any viral cloud is confined to a single area. Lids on toilets and signage to encourage closed lids when flushing are important. We also recommend using touchless fixtures.

# Solutions Matrix

The Solutions Matrix below displays suggestions for how you can use some of the solutions discussed in specific areas of your building.

| | Multi-Factor Screening | No Touch | GUV at Air Handler | Upper GUV | Killer Filter | Hydrogen Peroxide | Toilet Control | Increase Fresh Air |
|---|---|---|---|---|---|---|---|---|
| Entry / Lobby | ● | ● | ● | ● | ○ | ● | | ● |
| Café | | ● | ● | ● | ● | ● | | ● |
| Conference Center | | ● | ● | ○ | ● | ● | | ● |
| Fitness Center | | ● | ● | ● | ● | ● | ● | ● |
| Restrooms | | ● | ● | ○ | ○ | ● | ● | ● |
| Elevators | | ● | ● | | ○ | ● | | ● |
| Work Areas | | ● | ● | ● | ● | ● | | ● |
| Outdoor Spaces | | | | | | | | |

● Primary Consideration
○ Secondary Consideration

*Figure 17 Solutions matrix developed by REES to identify which specific changes are best suited for specific types of spaces.*

# Summary

To conclude, COVID-19 and the case for reducing widespread disease is not a short-term issue. There is no single answer to making our buildings healthy. However, these steps for effective health screening, increased fresh air (outside air), high performance filtration, air treatment, toilet controls, touchless fixtures used in combination will significantly reduce the risk of infection transmission. By taking the necessary actions to make our buildings safe, we can begin to return to a more normal work environment and transition beyond the COVID-19 pandemic.

# About the Authors

**General PK Carlton, Jr. MD, FACS**
General PK Carlton, Jr. MD, FACS is the former Surgeon General for the United States Air Force. He served in this capacity from 1999 until 2002. After serving for 37 years in the US Air Force he retired and then served as Director of Homeland Security for the Texas A&M Health Science Center. He has completed extensive research on COVID-19 and SARS. General Carlton has no financial interest in any of the products or solutions described in this report. He has served for more than 10 years on the Board of Directors of REES and is a key advisor to our practice.

**Allan Parr AIA, LEED AP**
Allan Parr is the President and Chief Executive Officer of REES. He has experience in virtually all aspects of real estate and facility management operations. His experience spans the areas of architectural design, interior design, engineering management, workplace standards development, real estate strategy, space management, ADA compliance and facility management. A registered Architect and member of the American Institute of Architects, Parr has nearly 25 years of experience delivering successful projects and developing new business. Allan is also a proud Texas A&M alum.

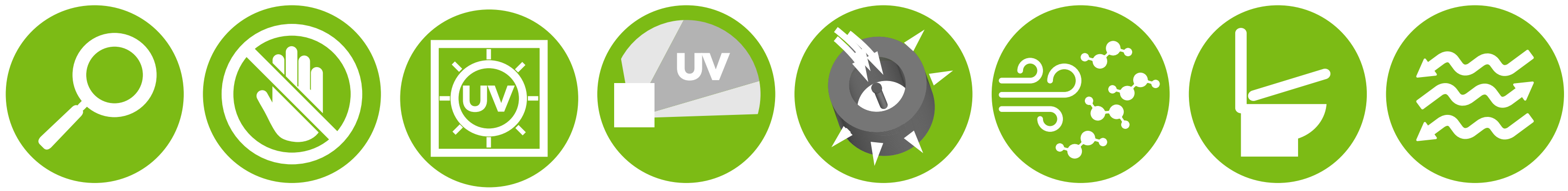
**Farooq Karim AIA, RID, LEED AP**
Farooq is a Vice President and serves as REES' Director of Design. He has a passion for working collaboratively with clients to develop creative solutions for their projects. As both an architect and interior designer, Farooq works with our clients to develop holistic and integrated design solutions. Farooq is involved in his community and participates in organizations such as Leadership Oklahoma, Leadership Oklahoma City, the Oklahoma City Arts Council, Boy Scouts of America, Big Brothers Big Sisters, Oklahoma Foundation for Excellence and many others. Farooq has been with REES for more than 23 years. He also holds the distinction of being the most committed college football fan in the office, having not missed a home football game for his favorite team since 1975.

# About REES

REES was founded in 1975 as a healthcare architecture and planning practice. Since the very beginning, we have been dedicated to delivering exceptional design solutions to our clients. Today, REES is a thriving mid–sized architecture, planning and interior design firm, focusing on healthcare, corporate commercial, media, education, senior living projects and other project types. REES collaborates with our clients to design solutions that enrich lives and help their organizations thrive.

# DESIGN SOLUTIONS MATRIX

This matrix can provide a starting point for your organization to build a strategy to safely reoccupy your buildings and maintain a healthy indoor environment for the future. To learn more about these strategies and how to safely reoccupy our buildings in a COVID-19 world, visit: **rees.com/covid** or call (214) 522-7337.




| | Multi-Factor Screening | No Touch | GUV at Air Handler | Upper GUV | Killer Filter | Hydrogen Peroxide | Toilet Control | Increase Fresh Air |
|---|---|---|---|---|---|---|---|---|
| Entry / Lobby | ✓ | ✓ | ✓ | ✓ | ☑ | ✓ | | ✓ |
| Café | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Conference Center | | ✓ | ✓ | ☑ | ✓ | ✓ | | ✓ |
| Fitness Center | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Restrooms | | ✓ | ✓ | ☑ | ☑ | ✓ | ✓ | ✓ |
| Elevators | | ✓ | ✓ | | ☑ | ✓ | | ✓ |
| Work Areas | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |

✓ Primary Consideration ☑ Secondary Consideration

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