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Reducing the Risk of COVID-19 Using Engineering Controls

Guidance Document

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Early case reports and epidemiological studies of groups where SARS-CoV-2 has led to outbreaks of COVID-19 indicates that the primary means of disease transmission is the indoor spread of exhaled droplet aerosols. Armed with this knowledge, industrial hygiene professionals may limit SARS-CoV-2 transmission using the hierarchy of controls. Engineering controls that can keep infectious aerosols at very low levels indoors offer the greatest promise to protect non-healthcare workers and other vulnerable populations as we reopen our businesses and workplaces.

Relying upon individuals to maintain social distancing, perform perpetual hand washing, and, when available, wear the lowest form of personal protective equipment (PPE) on the market can only achieve so much in preventing the spread of COVID-19. And because infected people transmitting the disease can be asymptomatic or presymptomatic, it is impractical to "eliminate" all sources of infection. With this in mind, the industrial hygiene profession has long recognized that engineered solutions to reduce exposure to hazardous agents offer much greater protection than PPE or administrative controls in most workplace settings. (NIOSH) (See Figure 1)

Many employers and the public incorrectly assume that wearing face coverings or a respirator is the only way to reduce their risk of exposure. Invariably this is not the case—the reality is that wearing a respirator properly every day, all day, is uncomfortable and rarely done properly. Engineering controls have historically proven to be more reliable because they are less prone to human error.

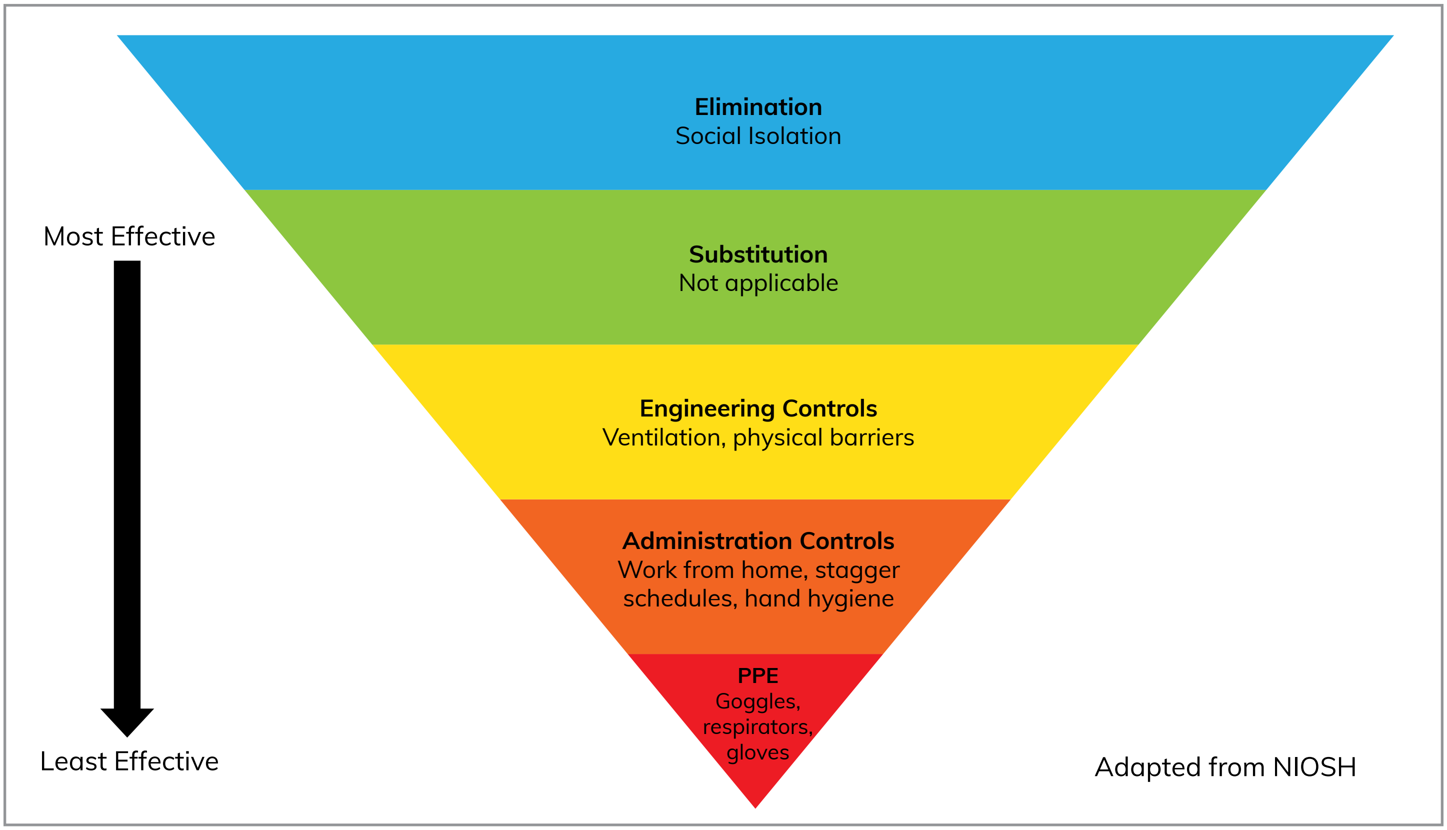


Figure 1: Applying the Hierarchy of Controls for COVID-19.

Accordingly, while federal and state OSHA plans require employers to ensure workers can use a selected respirator, OSHA also requires employers to consider feasible engineering and administrative options before resorting to their use or that of other PPE. Employers should select off-the-shelf, reliable, and effective engineering controls to reduce the risk of workplace disease spread.

The cost of PPE is also higher than most employers realize. Because OSHA requires medical evaluation, fit testing, and training, respiratory PPE is not a recommended long-term solution to prevent disease transmission outside of healthcare settings. Respiratory PPE is best used for short-term protection until engineering controls can be implemented. Costs to implement engineered solutions in a workplace can vary, depending upon the size of the facility and number of occupants, including employees and transient customers. Once engineering controls are installed, concerns of shortages and supply interruptions that have plagued PPE supplies are not likely to be an issue.

The American Industrial Hygiene Association (AIHA) and its volunteer committees of industrial hygienists recommend the use of engineering controls in all indoor workplaces, even those outside of the healthcare industry, to reduce the spread of COVID-19. The broad category of engineering controls that may be effective against the SARS-CoV-2 virus includes the following:

- Physical barriers, enclosures, and guards
- Automatic door openers and sensors
- Local exhaust ventilation
- Enhanced filtration to capture infectious aerosols
- Devices that inactivate or "kill" infectious organisms
- Dilution ventilation and increasing outside air delivery

Dilution Ventilation and COVID-19

Exemplifying one kind of engineered control, ASHRAE, a professional association of engineers, has issued position statements maintaining that changes to building and HVAC operation can reduce the airborne concentration of SARS-CoV-2 and the risk of it spreading through indoor air.

Increasing the number of effective air changes per hour—essentially, increasing the amount of "clean" or outdoor air delivered to the room—lowers the occupant's level of exposure to airborne viruses and therefore his or her relative risk of contracting the disease. Diluting indoor airborne virus concentrations can lower the risk of contracting the disease for the same reason that outdoor environments pose less risk of disease transmission.

This suggests that the risk of contracting COVID-19 can be significantly reduced by increasing indoor dilution ventilation rates and improving room air mixing—a principle recommended by the CDC and healthcare licensing bodies for hospitals and infectious disease wards. Indoor environments pose a much greater risk of exposure and spread of disease than outdoor environments. Outdoor environments offer "infinite dilution" of infectious aerosols, which strongly suggests that the risk of contracting COVID-19 can be significantly reduced by increasing dilution ventilation rates and improving room air mixing. To reduce the risk of disease transmission, maintain aerosol concentrations at very low levels, keep occupancy density low, and maintain physical distance. Accordingly, fundamental principles and equipment to capture and dilute aerosols can be applied to non-industrial workplaces to achieve more effective and reliable control of SARS-CoV-2 than face coverings and social distancing.

Effectively increasing the number of air changes in a room or building can be achieved by one or more of the following approaches. Using standalone "off-the-shelf" HEPA filtered air cleaners , installing enhanced filtration in central HVAC systems, and increasing the volume of outside air introduction are practical and immediate measures that can be implemented by building operators and employers.

Properly selected and installed, standalone single-space HEPA filtration units that are ceiling mounted or portable can effectively reduce infectious aerosol concentrations in a single space room or zone, such as a classroom, elevator, lobby, or office area. While in-room filtering units cannot eliminate all risk of disease transmission because many factors besides virus aerosol concentration contribute to the issue, the reduced concentration and residence time of infectious aerosols can substantially decrease an individual's likelihood of inhaling an infectious dose. (ASHRAE Position Statement on Infectious Aerosols, 2020)

Choosing and Implementing Engineered Controls

Compared to solutions relying mostly or exclusively on PPE, engineered solutions removes the onus from individuals and their personal habits or attentiveness. Machines do not get tired, sloppy, or distracted.

However, when selecting engineering controls, such as increasing the number of air changes per hour (ACH), the minimum level of protection offered by the new control should exceed the protection offered by PPE alone. In Figure 2, the expected relative risk reduction offered by an N95 respirator is 90 percent, therefore only engineering controls that offer greater than 90 percent relative risk reduction should be considered. In this instance, engineering controls that offer fewer than 4.5 effective air changes per hour are no better than commercially available respiratory protection.

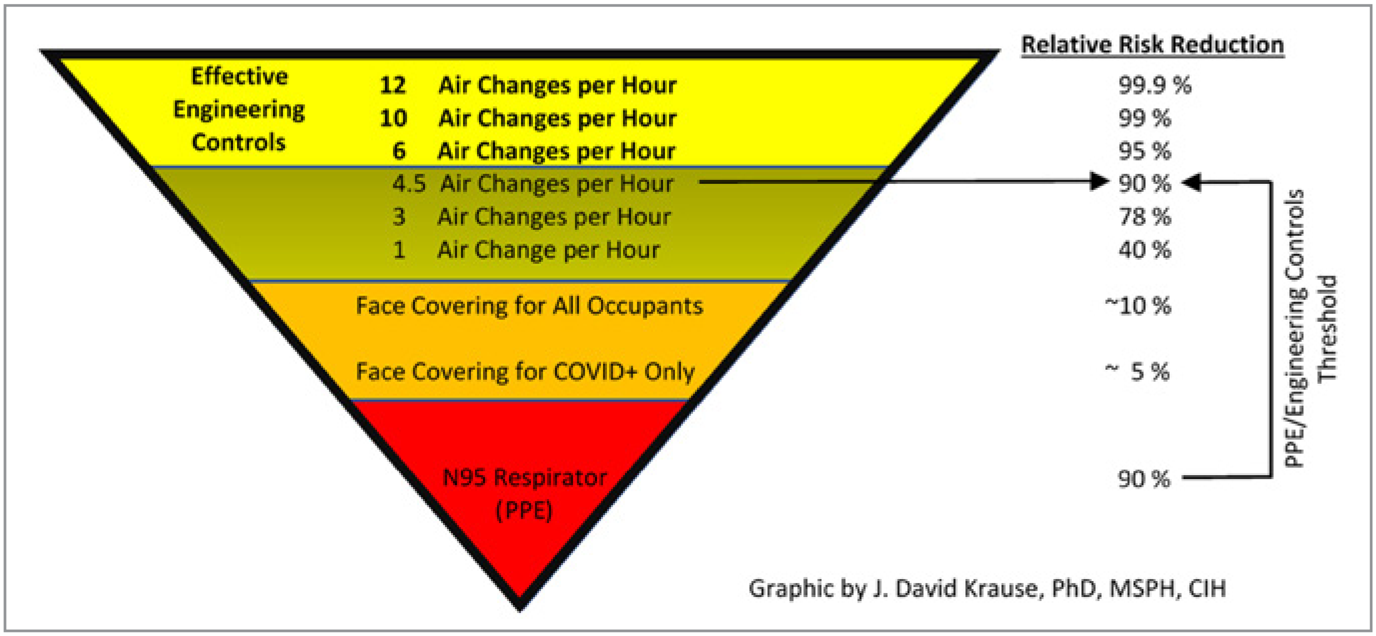


Figure 2*

**To learn how the relative risk reduction estimates were derived for Figure 2, download the [SUPPLEMENT for Reducing the Risk of COVID-19 using Engineering Controls](#).*

In hospitals and other indoor environments where infectious people are likely present, delivering between 6 and 12 air changes per hour of outside or clean air significantly reduces the spread of infectious airborne diseases. (See Figure 3) In non-healthcare facilities where occupant density cannot be limited to fewer than 1 person per ~30 ft^2 (i.e. 6-foot radius), or there is likelihood that infected persons are present, delivering higher air change rates than 6 ACH may be necessary.

Additional factors must be considered for site-specific engineering controls, such as in-room air mixing, the number of occupants per square foot of office space, and the air flow dynamics already in place. A knowledgeable mechanical engineer and industrial hygienist familiar with ventilation controls and infection prevention should be consulted when selecting, installing, and evaluating engineering controls for a workplace.

In most office buildings and small retail settings, using a computational fluid dynamics (CFD) model is not necessary to achieve intended effects. However, in complex buildings with existing mechanical and exhaust systems, CFD modeling may be needed to design and implement a robust and reliable system.

Standalone high efficiency particulate arrestance (HEPA) air filtering devices (AFDs) can be used to supplement outdoor air ventilation supplied through HVAC systems in order to achieve equivalent air exchange rates (AERs) capable of significantly reducing infectious aerosol concentrations in workplaces and offices. The CDC's *Guidelines for Environmental Infection Control in Health-Care Facilities*, published in 2003 recommends using recirculation HEPA filters to "increase the equivalent room air exchanges." The guidelines further suggest that "recirculating devices with HEPA filters may have potential uses in existing facilities as interim, supplemental environmen-

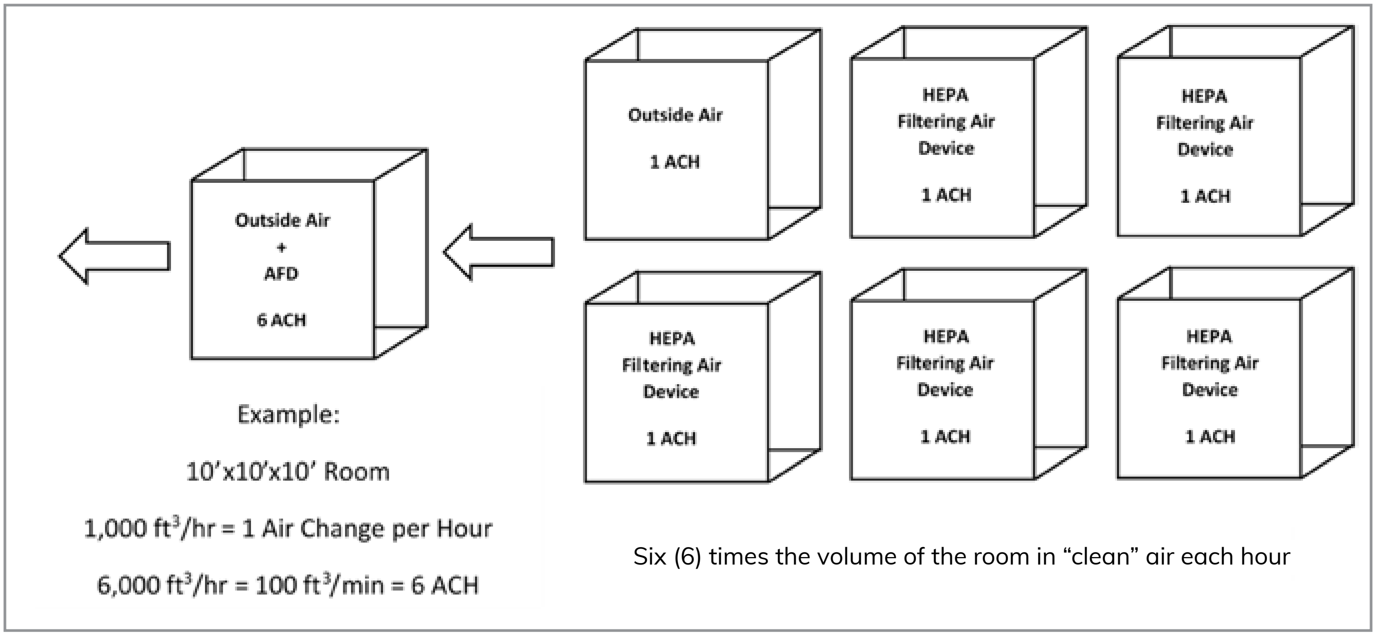


Figure 3

tal controls to meet requirements for the control of airborne infectious agents." (https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#tableb1)

But HEPA rated filters are not necessary to achieve meaningful reductions in airborne concentrations. Enhanced filtration using filters with MERV (minimum efficiency reporting value) ratings between 13 and 15 can also be used, but higher flow rates may be necessary to achieve similar effects. Installing improved filtration (MERV 13 or higher) in central HVAC systems can serve to supplement air change rates by further reducing infectious aerosol concentrations in recirculated air. Increasing filtration of an HVAC system should be evaluated by a mechanical engineer to ensure the fan can handle the increased pressure load and that air does not bypass the filters. Increased maintenance and filter changes will likely be needed.

While ultraviolet germicidal irradiation (UVGI) and other technologies to inactivate, but not capture, viruses may be capable of reducing airborne concentrations of infectious aerosols, many factors can reduce their effectiveness without being readily recognized by users. Such technologies and equipment can often require significant modification to existing mechanical equipment and ongoing service.

Engineering Precautions

When increasing outside air delivery through HVAC systems, engineers must take precautions to avoid exceeding the mechanical system's design and operational capabilities. Too much outdoor air can introduce high levels of humidity, causing mold and bacterial growth within the HVAC system, its ducts, and the occupied areas of the building. When outdoor air pollution from wildfires, nearby excavation, or demolition activities threatens the area, outside air dampers may have to be temporarily closed.

When installing AFDs it is important to avoid air flows that interfere with existing HVAC systems, or that directs potentially contaminated air into a clean area. This often requires the expertise of an engineer, industrial hygienist, or experienced contractor to properly site each device.

Ongoing maintenance and cleaning of AFDs, including changing pre-filters and HEPA filters, is necessary to ensure effective operation. Precautions must be taken to prevent worker exposures to accumulated infectious viruses on the filters or the AFD exterior during filter changes and maintenance. PPE recommended for maintenance activities such as filter changes and periodic cleaning include goggles, gloves, apron, and N95 respirator. This should be performed when unprotected individuals are not nearby.

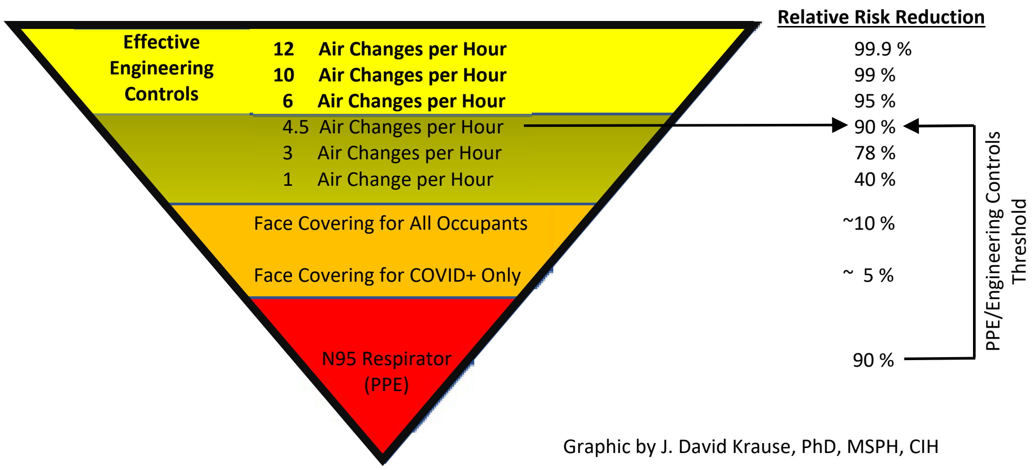
Any modifications made to central HVAC systems, either to accommodate a new use of the space, changes in occupant density, or to improve filtration should be specified and reviewed by a mechanical engineer.

Conclusions

As the nation moves to restart the economy and in-person education, we must seriously consider and adopt effective engineering controls in public buildings in order to protect the health of employees and occupant. Using "off-the-shelf" technologies, equipment, and time-tested methods to control infectious aerosols is the most reliable way to reduce the risk of disease spread. Relying upon control measures that only offer marginal protection against the spread of disease could extend this pandemic until a vaccine is developed, produced, and distributed. Scientifically proven methods to control the spread of airborne diseases that include enhanced ventilation with outdoor air, and high efficiency filtration, have not been widely implemented outside of healthcare facilities.

Industrial hygienists and mechanical engineers can design, install, and evaluate engineering controls that are capable of keeping infectious aerosols at very low levels indoors and offer more reliable protection. Together, we can help reduce the risk of disease transmission among workers and members of the community in properly designed and maintained buildings through the use of engineering controls.

Appendix



Derivation of estimated relative risk reduction offered by different control measures described in Figure 2

This supplement is provided to explain how estimates of relative risk reduction were derived for face coverings and engineering controls in Figure 2 of the AIHA guidance document *Reducing the Risk of COVID-19 using Engineering Controls*, Version 1, August 11, 2020. Citations of published studies and available CDC guidance are provided by reference and the considerations made by authors and contributors to the guideline are discussed.

Rengasamy et al reported that fabric materials commonly used to construct face coverings may only provide marginal protection against particles in the size range of virus-containing particles in exhaled breath. Average penetration levels for the three different cloth masks were between 74% and 90% (meaning they captured between 10% and 26% of aerosols), while N95 filter media controls showed penetration of only 0.12% at 5.5 cm/sec face velocity.[1]

The average penetration levels for three different models of towels and scarves ranged from 60–66% and 73–89% respectively. "The results obtained in the study showed that cloth masks and other fabric materials had 40–90% instantaneous penetration levels when challenged with polydisperse NaCl aerosols. Similarly, varying levels of penetration (9–98%) were obtained for different size monodisperse NaCl aerosol particles in the 20–1000 nm range." Two of the five surgical masks that were evaluated demonstrated 51–89% penetration levels against polydisperse aerosols.[1]

While not evaluated in this study, face seal leakage is known to further decrease the respiratory protection offered by fabric materials. Aerosol penetration for face masks made with loosely held fabric materials occurs in both directions (inhaled and exhaled). Due to their lose fitting nature and the leakage that occurs even when a face mask is properly worn, a modifying factor of 25% was applied.

Finally, compliance with the proper wearing of face coverings when people generate the most aerosols (i.e. speaking, exercising, etc.) significantly impacts the anticipated risk reduction they can offer. Due to observed lapses in proper wearing of cloth face coverings (i.e. covering only the mouth or wearing them below the chin) and when people pull the mask down when speaking to someone, a modifying factor of 50% was applied. A face covering only worn half the time or covering only the mouth offers less risk reduction.

MacIntyre et al reported that laboratory tests showed the penetration of particles through cloth masks to be very high (97%) when compared to medical masks (44%) that were tested, and when compared to N95 3M model 9320 (<0.01%), and the 3M Vflex 9105 N95 (0.1%). In other words, the cloth masks tested in this study only captured 3% of the exhaled aerosols.[(2)]

This study also evaluated compliance of healthcare workers wearing cloth masks and medical masks. They found that healthcare workers complied only 56.5% of the time for cloth masks and 56.8% of the time for medical masks.[(2)]

The high levels of initial penetration reported in the studies cited above, ranging from 40-97% equates to capture efficiencies of 3-60%. The impact of typical leakage and frequent non-compliance with proper use and wear, is the basis for a generous estimate of 5-10% relative risk reduction for face masks and cloth face coverings. Studies do suggest that surgical and medical masks, when worn properly and with full compliance could offer greater protection, for both the wearer and for those nearby. However, their availability and proper use is not currently required and was not the basis for the relative risk reduction estimated for reusable facial coverings and masks.

This supplement is not intended to suggest that face coverings and masks not be used, but rather to objectively examine and recognize their contribution to risk reduction. In light of the limited level of relative risk reduction offered by face coverings and masks the AIHA has recommended engineering controls be used to reduce the risk of exposure in indoor environments, which is anticipated to reduce the transmission of disease, even in nonhealthcare settings.

Estimates of relative risk reduction presented in the figure above that can be offered by outside air ventilation and/or enhanced filtration (i.e. HEPA or MERV 17) were derived using the model presented below. Initial and ending concentrations of respirable aerosols were modeled at various air change rates in a room over a 30-minute period. Similarly, the steady state concentration of aerosols given equal source strength (i.e. virus-containing aerosols exhaled by a person) can be estimated using this model. The formula and its applicability to infectious disease control are described in detail in the CDC Guidelines for Environmental Infection Control in Health-Care Facilities (2003).[(3)]

$$t2 - t1 = -[\ln(C2 / C1) / (Q / V)] \times 60, \text{ with } t1 = 0$$

where

t1 = initial timepoint in minutes

t2 = final timepoint in minutes

C1 = initial concentration of contaminant

C2 = final concentration of contaminant

C2 / C1 = 1 – (removal efficiency / 100)

Q = air flow rate in cubic feet/hour

V = room volume in cubic feet

Q / V = ACH

1. Rengasamy, S., Eimer, B., and Shaffer, R. E. Simple Respiratory Protection—Evaluation of the Filtration Performance of Cloth Masks and Common Fabric Materials Against 20–1000 nm Size Particles. Ann. Occup. Hyg., Vol. 54, No. 7, pp. 789–798, 2010
2. MacIntyre CR, Seale, H., Dung, , TC, et al. A cluster randomised trial of cloth masks compared with medical masks in healthcare workers. BMJ Open 2015;5:e006577. doi:10.1136/bmjopen-2014-006577
3. CDC Guidelines for Environmental Infection Control in Health-Care Facilities (2003) https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#tableb1

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