Aerosols and HVAC

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Definitions:

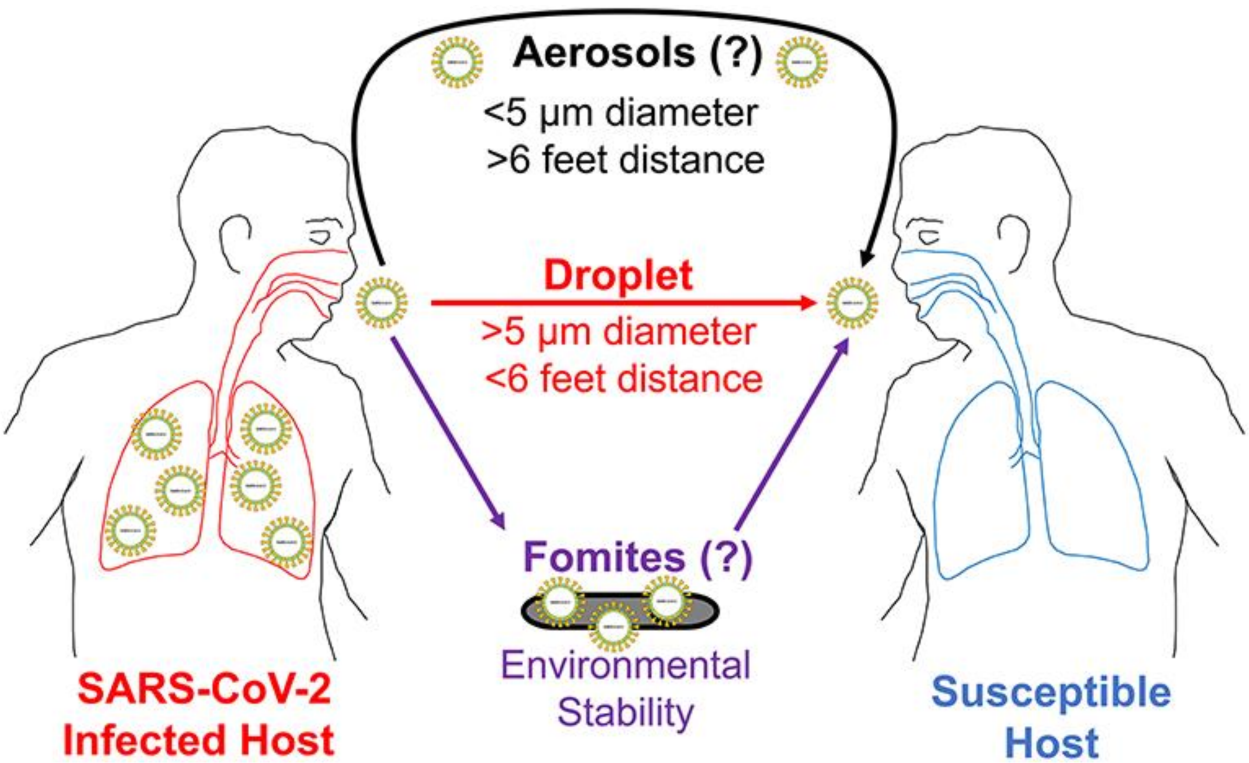
Airborne – Defined as the spread of an infectious agent caused by the dissemination of nuclei that remain infectious when suspended in air over long distances and time.

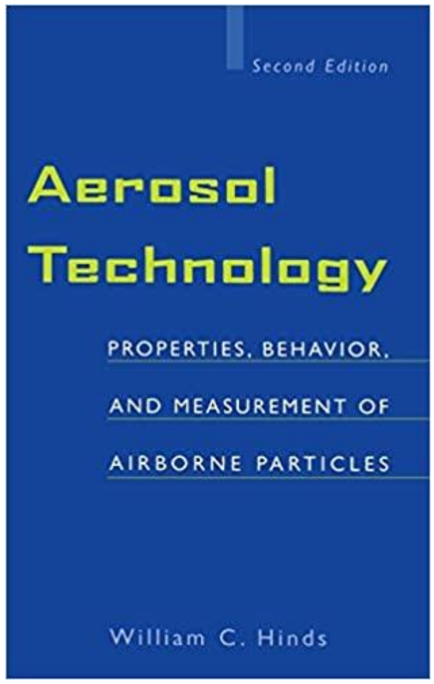
Aerosols – Defined by the CDC and the WHO as particles that remain in the air for minutes to hours and infect by inhalation. Particles smaller than ~ 5 µm do not settle very quickly to the ground, do not have enough inertia to reach others as droplets, and can be inhaled. These can only be defined as aerosols.

Droplets – Defined by the CDC and the WHO as projectiles that infect by impaction and fall quickly to the ground (often called “ballistic droplets”). Particles larger than ~5 µm have enough inertia to reach someone else 18 inches and 3 feet when talking, which is most relevant for SARS-CoV-2 where much transmission occurs for people with little or no symptoms who don’t cough.

Fomites – Inanimate objects whose surfaces can become contaminated when touched by the carrier of an infection and can then transmit the pathogens to those who next touch the surfaces: Doorknobs are often cited as the classic fomites.

Units: A micron is the same thing as a micrometer.





Written in 1982, it is still recognized as the text of choice among students and professionals who need to acquire a thorough working knowledge of modern aerosol theory and applications.

Please also note that aerosols are a binary system consisting of particles AND the gas in which they are suspended. Aerosol particles refers to the particle (liquid or solid) phase of aerosols. On page 1 an aerosol is defined as a "solid or liquid particles suspended in a gas" (obviously - in the case of indoor air that gas is air).

The term "aerosol" was coined 100 years ago (in 1920 - right after the 1918 flu) as the air analogy to hydrosol, a stable suspension of particles in a liquid. A key word in all of this is "suspended"

The air we breathe always contains solid particles or droplets and is therefore an aerosol. These aerosol particles can be from natural sources or man-made sources.

Our respiratory system is efficient at removing aerosols, but if they fall within particular size ranges, are highly concentrated, or toxic, they may cause adverse health effects.

Aerosol particles are dynamic. They can shrink by evaporation and grow by coagulation (particle collide and adhere) and condensation.

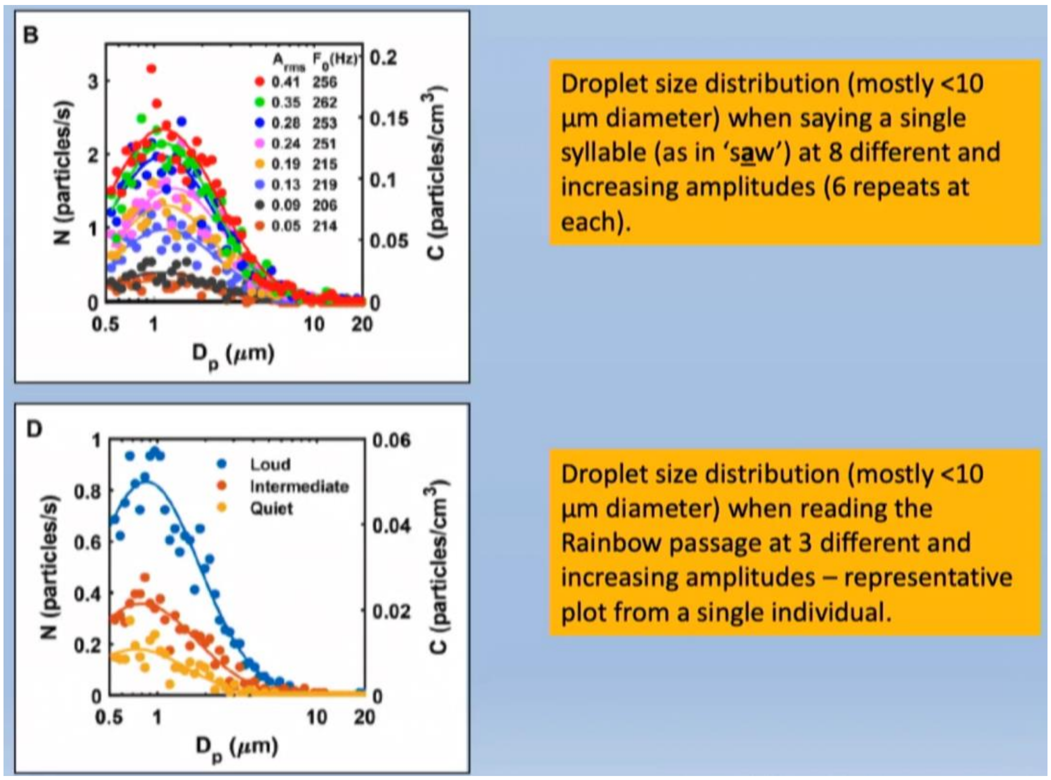
The chemical composition of aerosol particles also changes by adsorption and absorption of gases as well as condensation onto particle surfaces.

Aerosol particles do NOT stay suspended forever. While aerosol particles remain in air far longer than large droplets (what many are referring to as ballistic droplets), some fraction does deposit on indoor surfaces, often very far from the source.

Indoors, some fraction deposits onto surfaces by a combination of gravitational settling, inertial impaction, interception, Brownian motion (for very small particles), electrostatic attraction, and thermophoresis.

But how much deposits on indoor surfaces?

Using only aerosol particles of 0.5 to 4 microns, it is estimated that the fractional collective accumulation is between 3% and 20% of total particles depending on degree of ventilation, mixing conditions, and appropriate surface area adjustments.



The short-range airborne route is found to dominate at most distances studied during both talking and coughing. The large droplet route only dominates when the droplets are larger than 100 µm and when the subjects are within 0.2 m (8") while talking or 0.5 m (20") while coughing. The smaller the exhaled droplets, the more important the short-range airborne route. The large droplet route contributes less than 10% of exposure when the droplets are smaller than 50 µm and when the subjects are more than 0.3 m apart, even while coughing.

Rainbow passage is 330 words (~ 2 minutes of reading).

From CDC website (updated Oct. 5, 2020):

Scientific Brief: SARS-CoV-2 and Potential Airborne Transmission

Updated Oct. 5, 2020 Languages Print

The principal mode by which people are infected with SARS-CoV-2 (the virus that causes COVID-19) is through exposure to respiratory droplets carrying infectious virus.

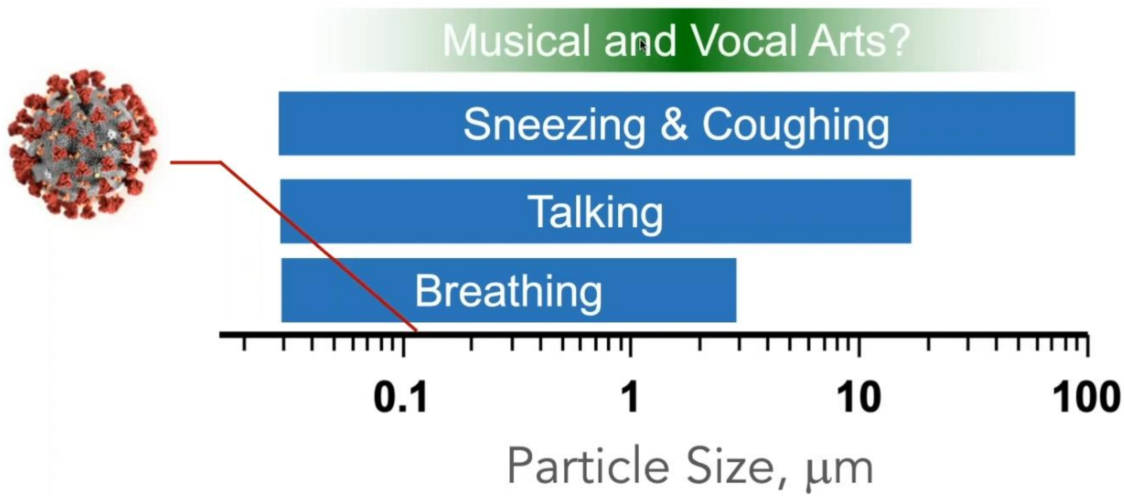
Respiratory droplets are produced during exhalation (e.g., breathing, speaking, singing, coughing, sneezing) and span a wide spectrum of sizes that may be divided into two basic categories based on how long they can remain suspended in the air:

- **Larger droplets** some of which are visible and that fall out of the air rapidly within seconds to minutes while close to the source.
- **Smaller droplets and particles** (formed when small droplets dry very quickly in the airstream) that can remain suspended for many minutes to hours and travel far from the source on air currents.

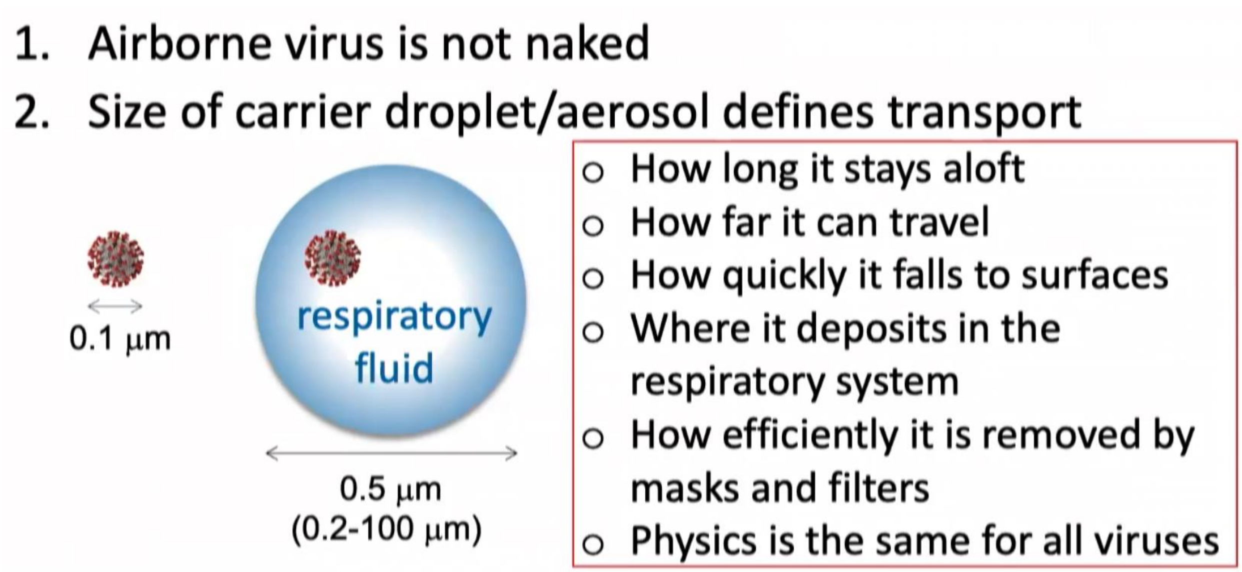
Once respiratory droplets are exhaled and as they move outward from the source, their concentration decreases through fallout from the air (largest droplets first, smaller later) combined with dilution of the remaining smaller droplets and particles into the growing volume of air they encounter.

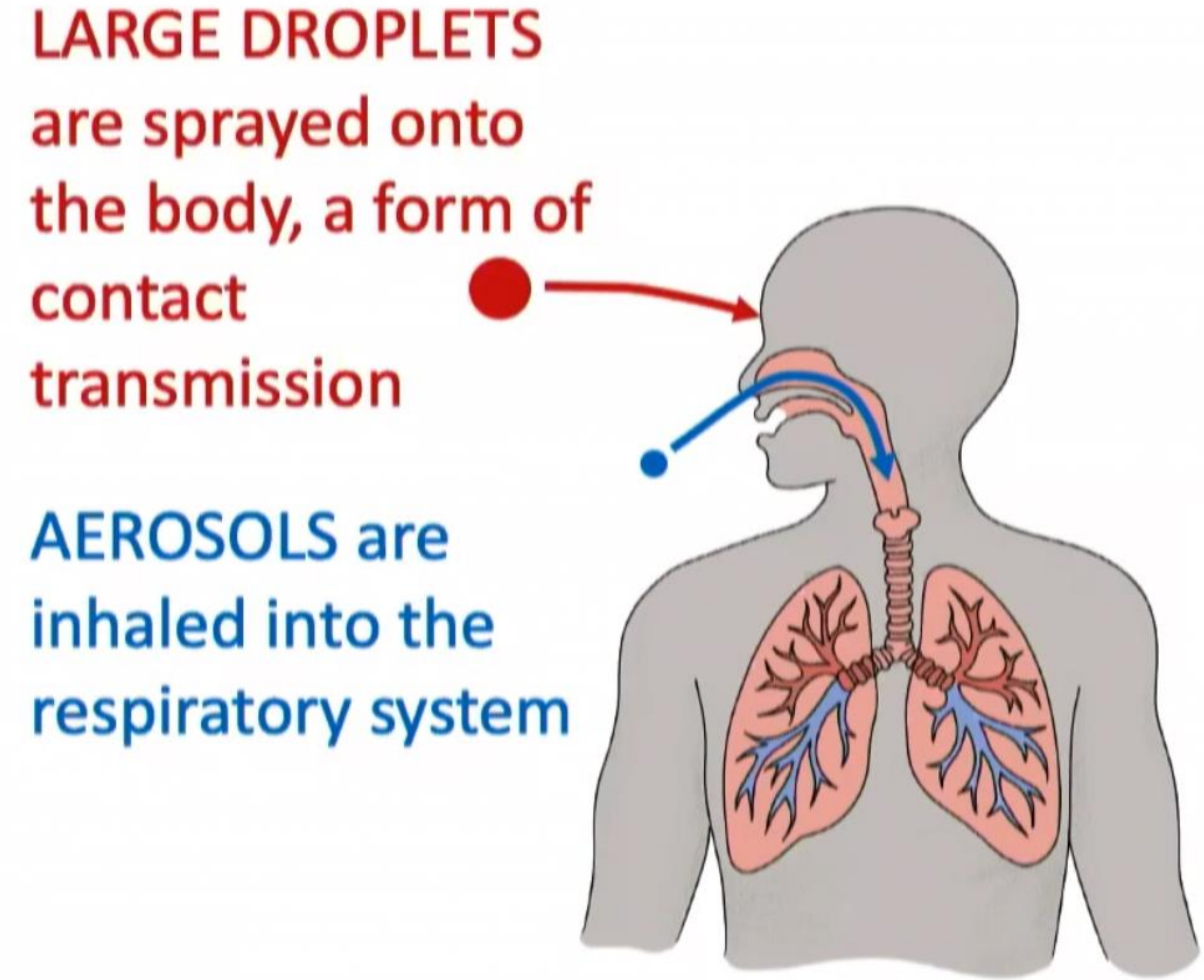
The case of airborne transmission

We do know that the SARS-CoV-2 virus is transported in particles emitted by an infected person. The virus cannot exist as a viable single particle with a diameter of 0.1 to 0.125 microns, it needs a carrier – usually other droplets that are typically 1.0 micron or larger. When we talk, shout, sing, cough, sneeze or simply breathe, we exhale small particles (“aerosols”) that are made of saliva or respiratory fluid (the liquid that wets the inside of your trachea, lungs etc.). These aerosols are the “carriers” of SARS-CoV-2 viruses, and can infect when they are inhaled. These aerosols can quickly decrease to approximately 40% of their original diameter, or smaller, due to evaporation.



Since they consist of both water and organic matter, potentially including the SARS-CoV-2 virus, they will never totally evaporate. The SARS-CoV-2 virus has been shown to be stable in airborne particles with a half-life of more than one hour, so it can potentially be inhaled by susceptible individuals causing infection and further spreading of the disease.




LARGE DROPLETS are sprayed onto the body, a form of contact transmission
AEROSOLS are inhaled into the respiratory system

The debate is whether these aerosols carry enough of the virus to infect another person. If the answer is yes, the implications for everyday life could be substantial.

Experts who study airborne viral transmission met in late August at a National Academies of Sciences, Engineering, and Medicine workshop and concluded that airborne transmission of SARS-CoV-2 is playing a role in the spread of the virus.

ASHRAE's Epidemic Task Force issued COVID-19 position statements, which indicate that transmission of SARS-CoV-2 through air is sufficiently likely that airborne exposure to the virus should be controlled.

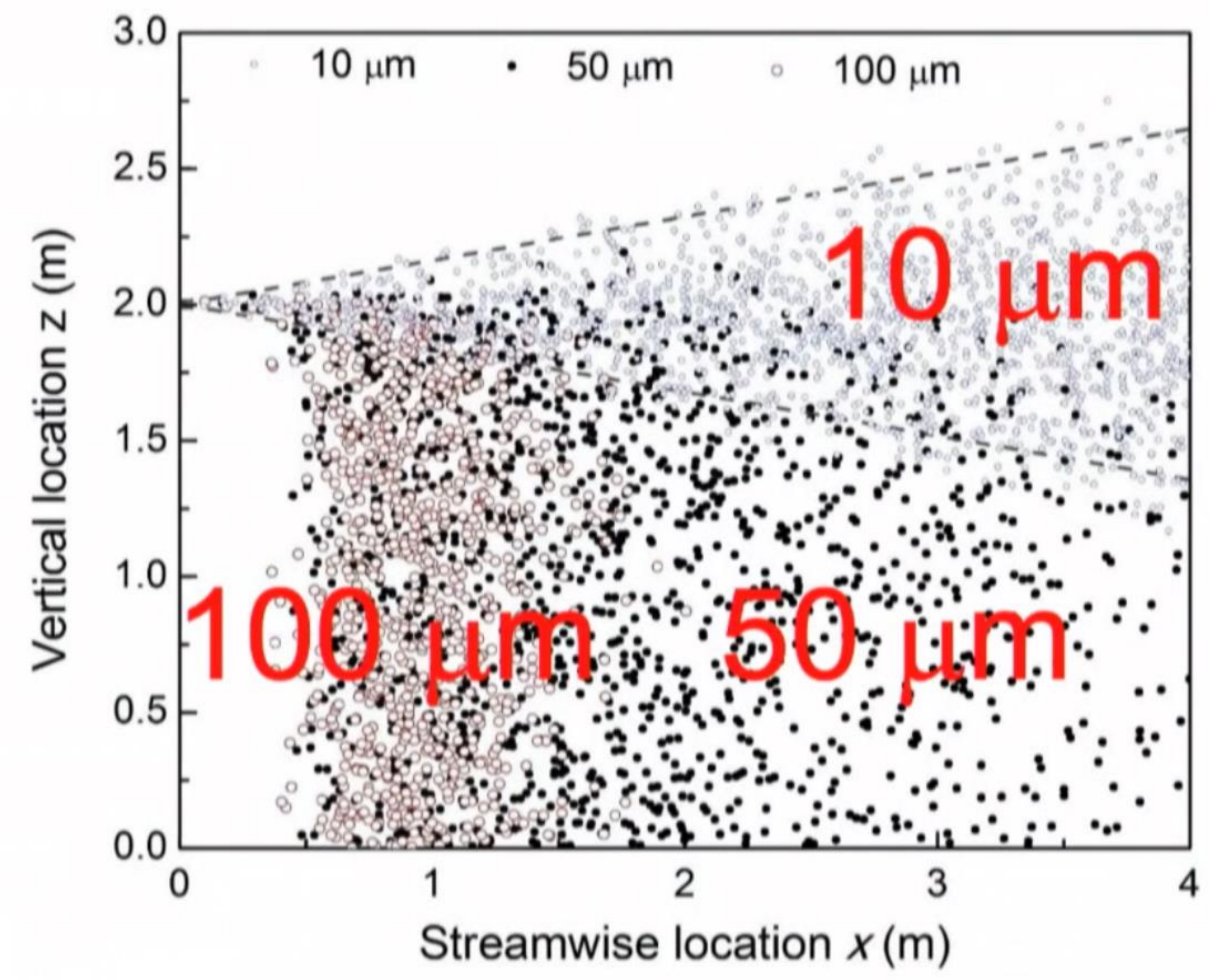
A study published in the Proceedings of the National Academy of Sciences reported that one minute of loud talking could produce "1,000 virus-containing droplet nuclei that could remain airborne for more than eight minutes."

While the evidence of airborne transmission may be deemed to be incomplete at present, more will arise as the COVID-19 pandemic continues. In contrast, the pathway to infection of the droplet and contact transmission routes has always been assumed to be via self-injection into mucous membranes (of the eyes, nose and mouth). Surprisingly, no direct positive evidence of this method of transmission has been reported. If the particles fall within 1-2 m of the person, then the only route of infection is by ballistic impact (hitting the mouth, nose or eyes). Cannot infect by inhalation. If they can be inhaled, they can travel farther than 1-2 m. They are less infective farther away due to much greater dilution (like smoke). These are aerosols.

For efficient ballistic impact on conversation partner, droplets need to travel horizontally ~0.5-1 m (3-6 ft). For this, they need enough momentum to overcome air drag. So they need to be > 300 um. Otherwise, friction of the air stops them along the way. Bottom line: When talking, there are very few particles 300 um and larger, which are visible with the naked eye (a human hair is 80 um). And those very few particles have to hit very small targets: eyes, nostrils, mouth.

Aerosols stay in the air minutes to hours indoors, finely divided, many chances for inhalation. For this combination of reasons, physics greatly favors aerosols and greatly disfavors droplets for infection under close proximity. When talking, it is aerosols. It is well-known that only particles smaller than ~100 um can be inhaled. Larger particles cannot.

The infectious agents of several other diseases (tuberculosis, measles, chickenpox) are recognized to be transmissible via the airborne route. For other respiratory viruses, including SARS-CoV, MERS-CoV (Middle-East Respiratory Syndrome coronavirus), respiratory syncytial virus (RSV – a common cause of bronchiolitis in infants) and influenza, both short-range and longer-range airborne transmission are possible.



Larger Particles equate to less virus as the originate from the mouth. Smaller particles originate from deeper parts of the respiratory tract (location of the virus) and therefore contain higher virus concentration. So breathing and speaking is the main source of small, virus-laden particles, not coughing or sneezing.

Yet despite this, international health organizations, like the WHO (World Health Organization), continue to place insufficient emphasis on protection from small, virus laden, airborne droplets. Other organizations that deal with building environmental control systems, such as REHVA (the Federation of European Heating, Ventilation and Air Conditioning Associations) and ASHRAE have acknowledged the potential airborne hazard indoors and recommended ventilation control measures accordingly.

Given uncertainties in human exposure and dose estimates, as well as source and particle size distributions, mixing conditions, etc., it is slightly conservative, but reasonable to neglect such deposition losses.

Researchers don't yet know how many individual pieces of SARS-CoV-2 an aerosol produced by an infected person's cough might hold. But in one study researchers used a model to estimate that a person standing and speaking in a room could release up to 114 infectious doses per hour.

Another thing to consider is how easy these particles are to inhale. In a recent computer model study, researchers found that people would most likely inhale aerosols from another person that is talking and coughing while sitting less than 6 feet away.

From CDC website (updated Oct. 5, 2020):

Airborne transmission of SARS-CoV-2 can occur under special circumstances

Pathogens that are mainly transmitted through close contact (i.e., contact transmission and droplet transmission) can sometimes also be spread via airborne transmission under special circumstances. There are several well-documented examples in which SARS-CoV-2 appears to have been transmitted over long distances or times. These transmission events appear uncommon and have typically involved the presence of an infectious person producing respiratory droplets for an extended time (>30 minutes to multiple hours) in an enclosed space. Enough virus was present in the space to cause infections in people who were more than 6 feet away or who passed through that space soon after the infectious person had left. Circumstances under which airborne transmission of SARS-CoV-2 appears to have occurred include:

- **Enclosed spaces** within which an infectious person either exposed susceptible people at the same time or to which susceptible people were exposed shortly after the infectious person had left the space.
- **Prolonged exposure to respiratory particles**, often generated with expiratory exertion (e.g., shouting, singing, exercising) that increased the concentration of suspended respiratory droplets in the air space.
- **Inadequate ventilation or air handling** that allowed a build-up of suspended small respiratory droplets and particles.

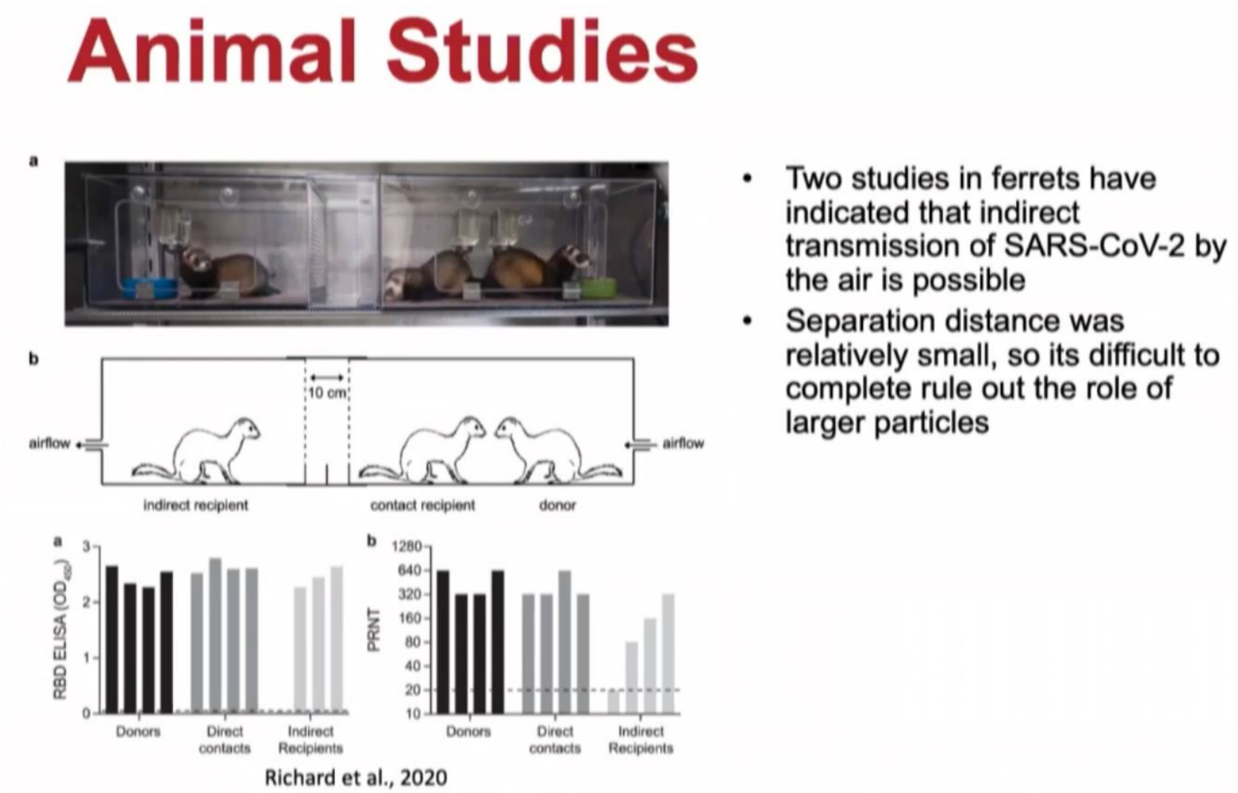
By now many people have heard about R0—the basic reproductive number of a pathogen, a measure of its contagiousness on average. But unless you've been reading scientific journals, you're less likely to have encountered k, the measure of its dispersion. A simple definition of k is that it's a way of asking whether a virus spreads in a steady manner or in big bursts, whereby one person infects many, all at once. After nine months of collecting epidemiological data, we know that this is an overdispersed pathogen, meaning that it tends to spread in clusters, but this knowledge has not yet fully entered our way of thinking about the pandemic—or our preventive practices.

There are COVID-19 incidents in which a single person likely infected 80 percent or more of the people in the room in just a few hours. But, at other times, COVID-19 can be surprisingly much less contagious. Overdispersion and super-spreading of this virus are found in research across the globe. A growing number of studies estimate that a majority of infected people may not infect a single other person.

In study after study, we see that super-spreading clusters of COVID-19 almost overwhelmingly occur in poorly ventilated, indoor environments where many people congregate over time—weddings, churches, choirs, gyms, funerals, restaurants, and such—especially when there is loud talking or singing without masks. For super-spreading events to occur, multiple things have to be happening at the same time, and the risk is not equal in every setting and activity. Muge Cevik is a clinical lecturer in infectious diseases and medical virology at the University of St. Andrews and a co-author of a recent extensive review of transmission conditions for COVID-19.

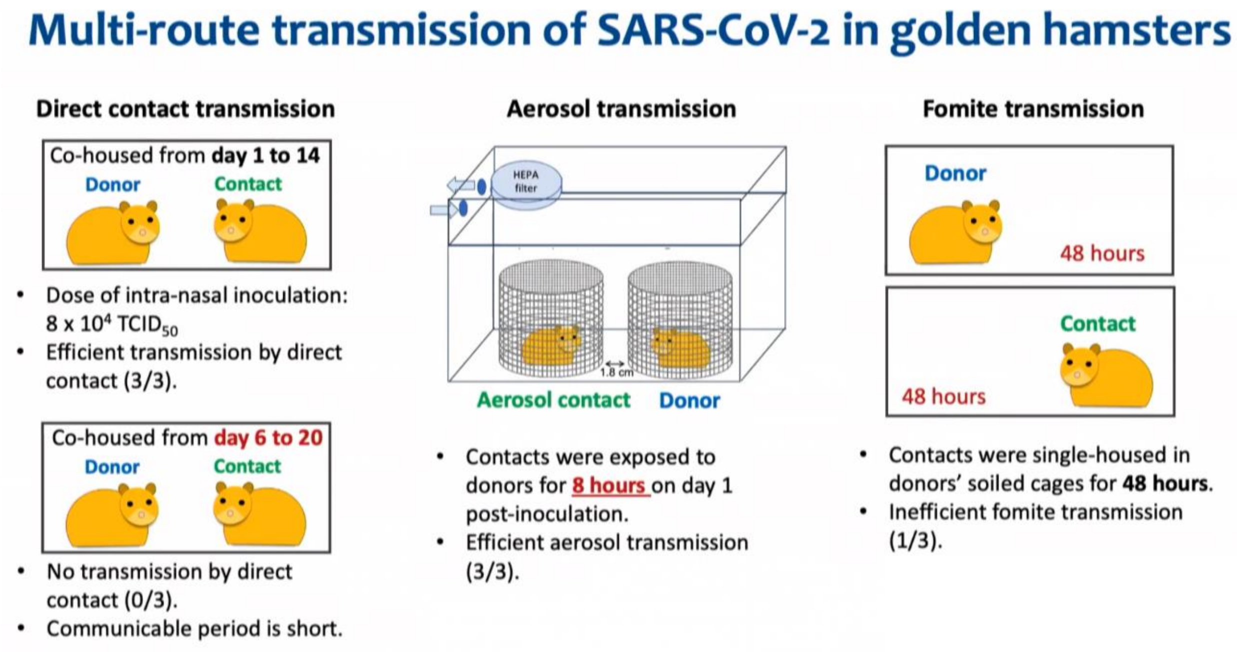
Cevik identifies “prolonged contact, poor ventilation, a highly infectious person, and crowding” as the key elements for a super-spreader event. Super-spreading can also occur indoors beyond the six-feet guideline, because SARS-CoV-2, the pathogen causing COVID-19, can travel through the air and accumulate, especially if ventilation is poor. Given that some people infect others before they show symptoms, or when they have very mild or even no symptoms, it’s not always possible to know if we are highly infectious ourselves. We don’t even know if there are more factors yet to be discovered that influence super-spreading. But we don’t need to know all the sufficient factors that go into a super-spreading event to avoid what seems to be a necessary condition most of the time: many people, especially in a poorly ventilated indoor setting, and especially not wearing masks. Natalie Dean, a biostatistician at the University of Florida, indicates that given the huge numbers associated with these clusters, targeting them would be very effective in getting our transmission numbers down.

Animal studies have conformed transmission through air.



One donor ferret is housed in a cage (right-hand side of the picture). Six hours later, a direct contact ferret is added to the same cage as the donor ferret. The next day, an indirect recipient ferret is placed in an opposite cage (left-hand side of the picture) separated by two steel grids, 10 cm apart, to avoid contact transmission. The direction of the air flow (3.5 cfm) is indicated by the arrows.

Conclusion was that SARS-CoV-2 can be transmitted efficiently via the air between ferrets, resulting in a productive infection and the detection of infectious virus in indirect recipients, as a model for human-to-human transmission.



Relating to airflow/HVAC

Cigarette smoke is a good way to visualize how ventilation, environment and velocity can affect how quickly a particle of any size behaves -- if anyone remembers restaurants having smoking and non-smoking sections – you know that smoke aerosols travel around indoors easily.

A 1988 study found that the cigarettes smoke particle size of six different brands all had an average diameter of 0.1 microns. As we know, COVID-19 has a diameter of 0.1 to 0.125 microns, and just like cigarette smoke, it usually travels with a carrier.

Research done in May of 2018 found that 29% of the cigarette smoke aerosols traveled through the HVAC system from a room with smokers to a room with non-smokers.

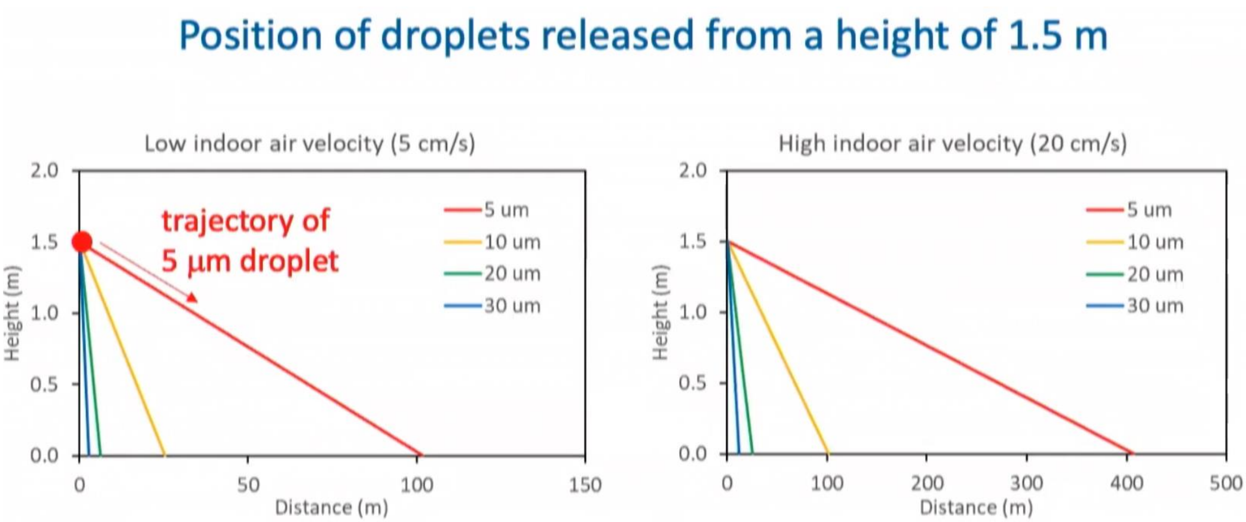
Both the World Health Organization and U.S. Centers for Disease Control and Prevention say that poor ventilation increases the risk of transmitting the coronavirus.

Existing evidence is sufficiently strong to warrant engineering controls targeting airborne transmission as part of an overall strategy to limit infection risk indoors.

Typical indoor air speed is between 0.1 m/s and 0.25 m/s (20-50 ft/min). So a droplet needs to fall within 10-20 seconds to land within 1-2 m. This air movement, along with minimal currents from human bodies, lighting and office equipment often prevents the aerosols from settling quickly.

An ASHRAE Journal article in July of 2020 stated that the air handling system serving the infected space can transfer agent through the ductwork to other spaces in dangerous doses. The system becomes a secondary source of infection agent in the building (first is aerosols ejected by an infected person).

The horizonal and vertical air velocity vectors created by the air handling system are greater than the settling velocity of the aerosol. Therefore, the air movement entrains the aerosol and transfers it through the ductwork from the infected space to the other spaces. Swabs taken from exhaust air outlets in a hospital room with SARS-CoV-2 infected patients tested positive, supporting this conclusion.

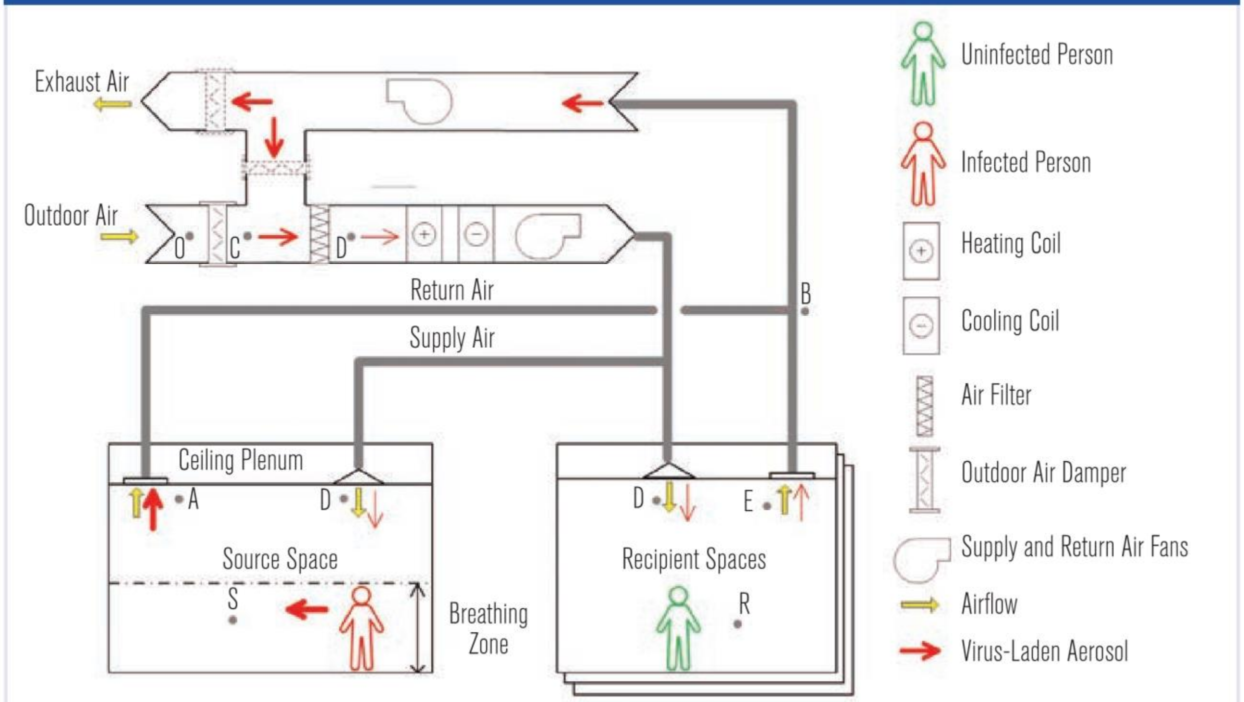


5 cm/s = 2 inches/sec

20 cm/s = 8 inches/sec

Typical indoor air speed is 4 inches – 10 inches/sec (20-50 ft/min)

FIGURE 2 Diagram of the virus-laden aerosol travel through air-handling system.



The July ASHRAE Journal article

Figure 2 shows a typical air handling system. The infected person emits the viral contamination with a consistent over time rate into the breathing zone of one of the spaces. The return airflow in the source space entrains the contamination and distributes it with a reduced concentration to the Recipient spaces. Typical space occupancy (exposure to contamination) varies from 4 hours to 24 hours. Typical hourly air changes rates of 8 to 20 mean that the time required for the contamination to travel from the source to recipient spaces is 8 minutes to 3 minutes, respectively. The potential travel time is incomparably lower than the exposure period.

The July ASHRAE Journal article comes up with an equation to solve for the overall ability of the system to suppress potential spread of the contamination. They call this the CCT (Contamination Containment Efficiency). It factors in contamination concentration in the space, at the return grille, outdoor air percentage, filter efficiency and airflow values.

Most HVAC systems can reduce aerosol concentrations via two methods, increased ventilation (outdoor air) and filtration. Some mechanical systems are designed to bring in a minimum amount of outdoor air based on building codes and design standards. The ability to increase the flow of outdoor air above these minimum values is usually limited by the ability to control temperature and humidity and the duct system used to distribute the air. For aerosol removal, filtration (rated above MERV 13) can supplement outdoor air ventilation.

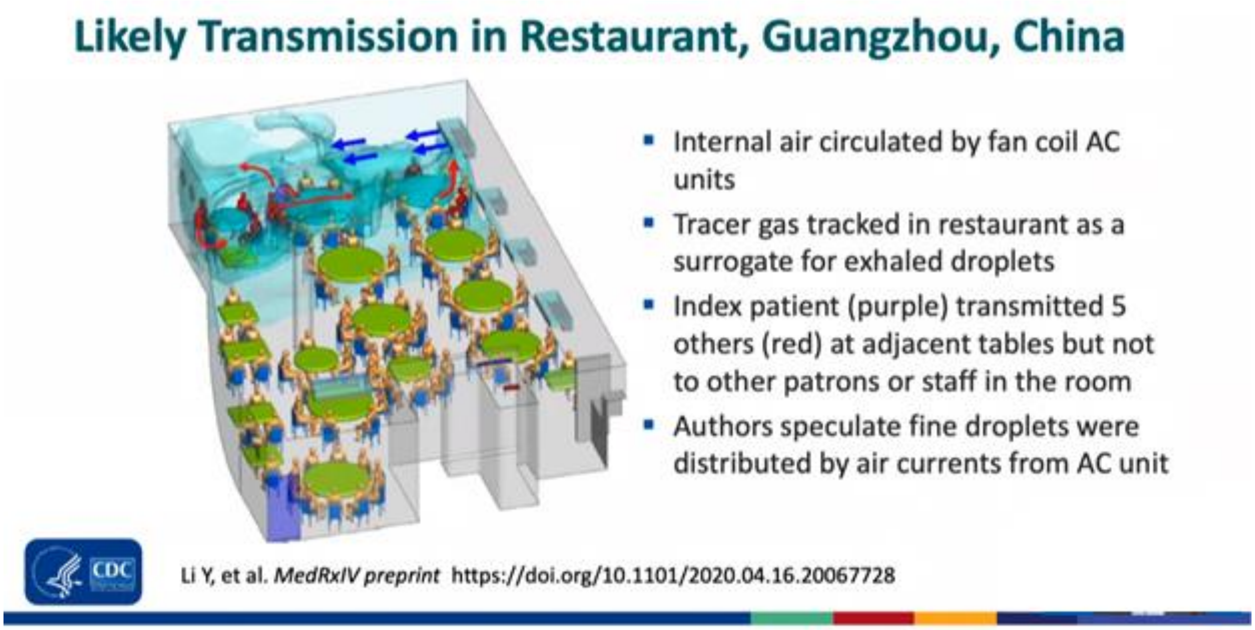
Although the physical distance required to avoid transmission through direct contact dictates the requirements for the floor area per person, the rate of ventilation provided and the efficiency of ventilation are the parameters that control the concentration of virus-laden microdroplets in the air exhaled by the occupants, and will guide decisions on safe occupancy numbers. In a school or a supermarket, for example, if the number of infected students or shoppers is low, and the ventilation rate is high, the risk of airborne transmission can be low.

According to the ASHRAE Position Document on Infectious Aerosols, the use of highly efficient particle filtration in centralized HVAC systems reduces the airborne load of infectious particles. This strategy reduces the transport of infectious agents from one area to another when these areas share the same central HVAC system through supply of recirculated air. The document also states that filtration will not eliminate all risk of transmission of airborne particulates because many other factors besides infectious aerosol concentration contribute to disease transmission.

The ”ASHRAE Position Document on Airborne Infectious Diseases” has general recommendations to increase outdoor air volume and install UVC germicidal lights to better protect the indoor environment from airborne virus diseases. This publication recognizes that virus spread by air-handling systems is a valid concept.

The ASHRAE Position Document on Infectious Aerosols does not make a definitive recommendation on indoor temperature and humidity set points for the purpose of controlling infectious aerosol transmission. However, it does that that scientific literature generally reflects the most unfavorable survival for microorganisms when the RH is between 40% and 60%.

A study from a restaurant outbreak in China concluded that droplet transmission was prompted by air-conditioned ventilation. The key factor for infection was the direction of the airflow. To prevent spread of COVID-19 in restaurants, they recommended strengthening temperature-monitoring surveillance, increasing the distance between tables, and improving ventilation.



Mr. Lu is deputy chief of the Department of Control and Prevention for Infectious Disease at the Guangzhou Center for Disease Control and Prevention. His research interests are the surveillance, control, and prevention of respiratory infectious diseases, including influenza, avian influenza, and scarlet fever.

Using an influenza virus, an article in the October 2020 ASHRAE Journal predicted the airborne virus concentrations in eight settings to determine the inhalation dose for possible exposure times.

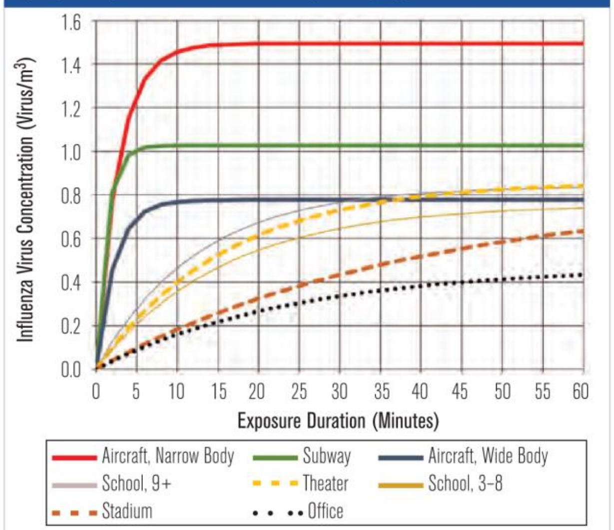


FIGURE 2 Infectious aerosol concentration versus time predictions in the air in the eight settings for a group of 20 persons with one ill person within the group and assuming uniform mixing for the group. It shows how infectious aerosol concentration reaches its equilibrium concentration more quickly the higher the occupancy density, which in turn makes for a potentially higher viral inhalation dose.[14]

Lisa Brosseau, a retired professor of public health states that though masks can limit the spread of larger particles, they are less helpful for smaller ones, especially if they fit only loosely. “I wish we would stop relying on the idea that face coverings are going to solve everything and help flatten the curve,” she says. “It’s magical thinking—it’s not going to happen.”

Brosseau does believe the evidence is trending toward the conclusion that airborne transmission is “the primary and possibly most important mode of transmission for SARS-CoV-2.” She says, “I think the amount of time and effort devoted to sanitizing every single surface over and over and over again has been a huge waste of time. We don’t need to worry so much about cleaning every single surface we touch.” Instead, the focus should be on other factors, like where we spend our time.

Brosseau, now retired, was a professor at the University of Illinois at Chicago (UIC) School of Public Health from 2015 to 2018, where she was director of the Illinois Education and Research Center.

Possible Solutions

Once the virus escapes into the air inside a building, you have two options: bring in fresh air from outside or remove the virus from the air inside the building.

The benefits of an effective ventilation system, possibly enhanced by particle filtration and air disinfection, for contributing to an overall reduction in the indoor airborne infection risk, are obvious.

It is important to recognize that as long as an infected individual is in an indoor space, virus-laden aerosol particles will accumulate to higher concentrations in that space until (in a well-mixed space) an approximate steady-state concentration occurs.

The steady-state condition is reached when the rate of emissions from the source is equal to the rate of removal by ventilation, deposition onto surfaces, & filtration. At this point the rate of change of concentration with time is zero.

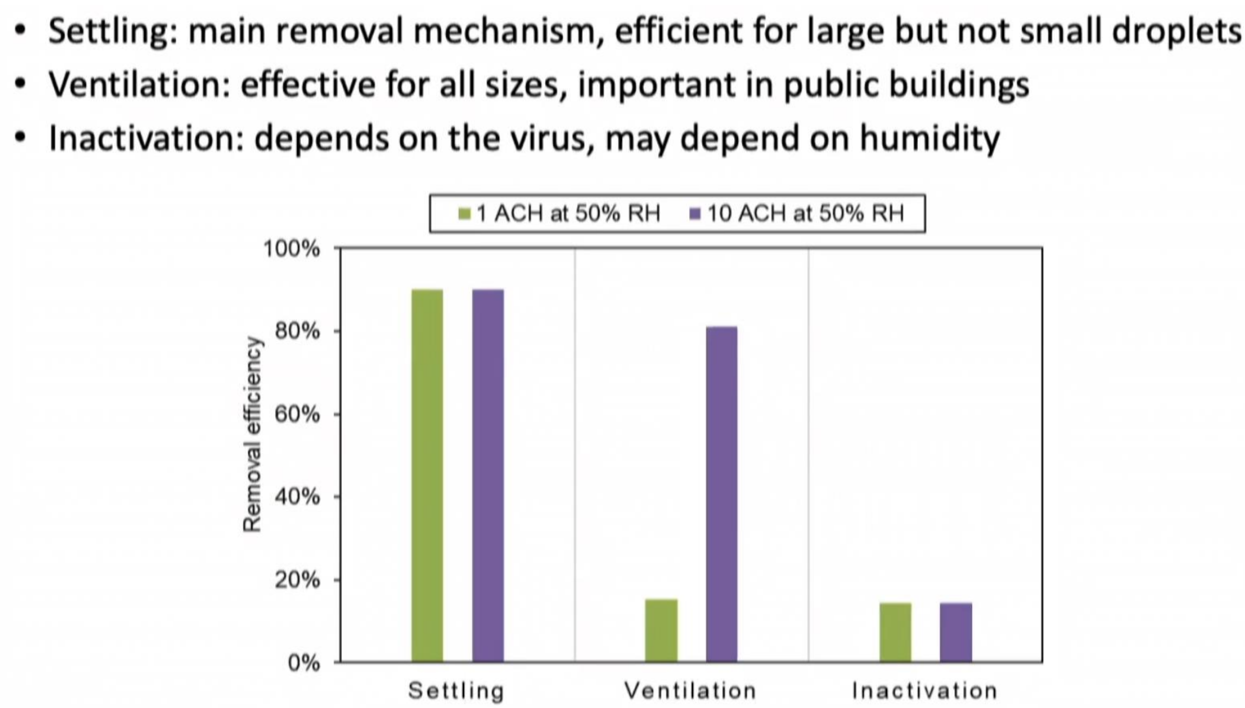
The time to achieve 95% of steady-state is 3/B (where B is the sum of removal mechanisms, each w/ units of inverse hours). K-12 classrooms may have outdoor air change rates as low as 0.5/hr. w/o filtration and little deposition this = 6 hrs to steady-state.

Appropriate building engineering controls include sufficient and effective ventilation, possibly enhanced by particle filtration and air disinfection, avoiding air recirculation and avoiding overcrowding.

Ventilation is going to be a big problem for older buildings that usually have worse ventilation systems, and areas with a lot of those might need to remain closed for much longer. The impact of asymptomatic spread (transmission by people who don't feel ill) and superspreaders only compounds the problem even further.

Many buildings in the U.S., especially schools, do not meet recommended ventilation rates. Thankfully, it can be pretty easy to get more outside air into a building. Keeping windows and doors open is a good start. Putting a box fan in a window blowing out can greatly increase air exchange too. ASHRAE recommends 6.7 L/s (14 cfm) per person of OA.

Ventilation rates below 5 L/s (10.6 cfm) per person have a negative impact on acute respiratory infections. Outdoor Air rates less than 25 L/s (53 cfm) per person increase the risk of sick building symptoms.



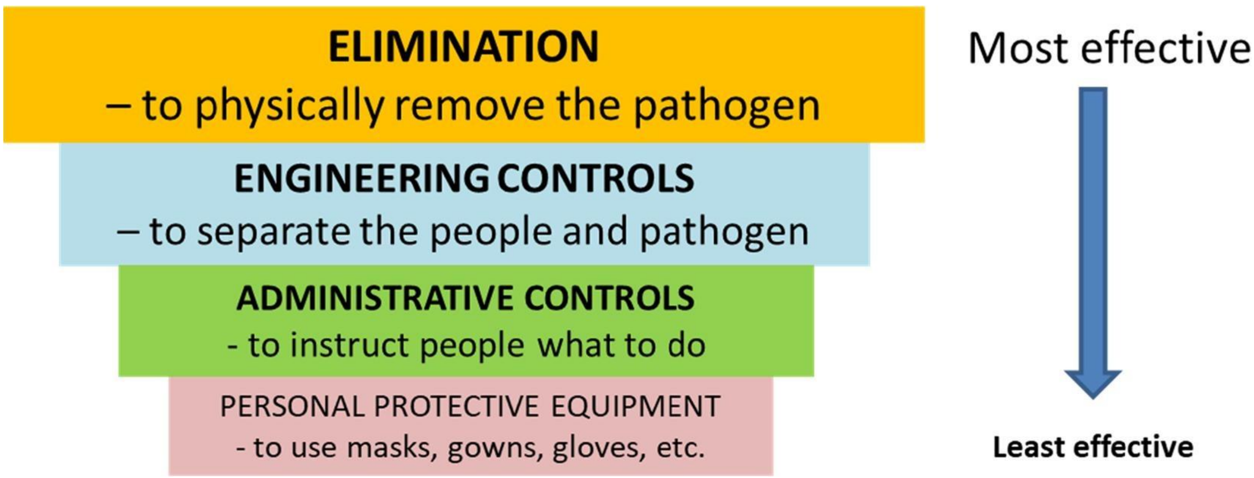
Ventilation airborne protection measures which already exist can be easily enhanced at a relatively low cost to reduce the number of infections and consequently to save lives. The options discussed should always be implemented in combination with other existing measures (like hand-washing and use of PPE) to reduce infection via other important routes of transmission, as none of them can be completely excluded in any exposure event.

In environments such as public buildings and other shared spaces, like shops, offices, schools, kindergartens, libraries, restaurants, cruise ships, elevators, conference rooms or public transport - lower ventilation rates exist and are intended primarily to control indoor air quality. The likelihood of infected persons sharing air with susceptible occupants is high, posing an infection risk contributing to the spread of the infectious disease.

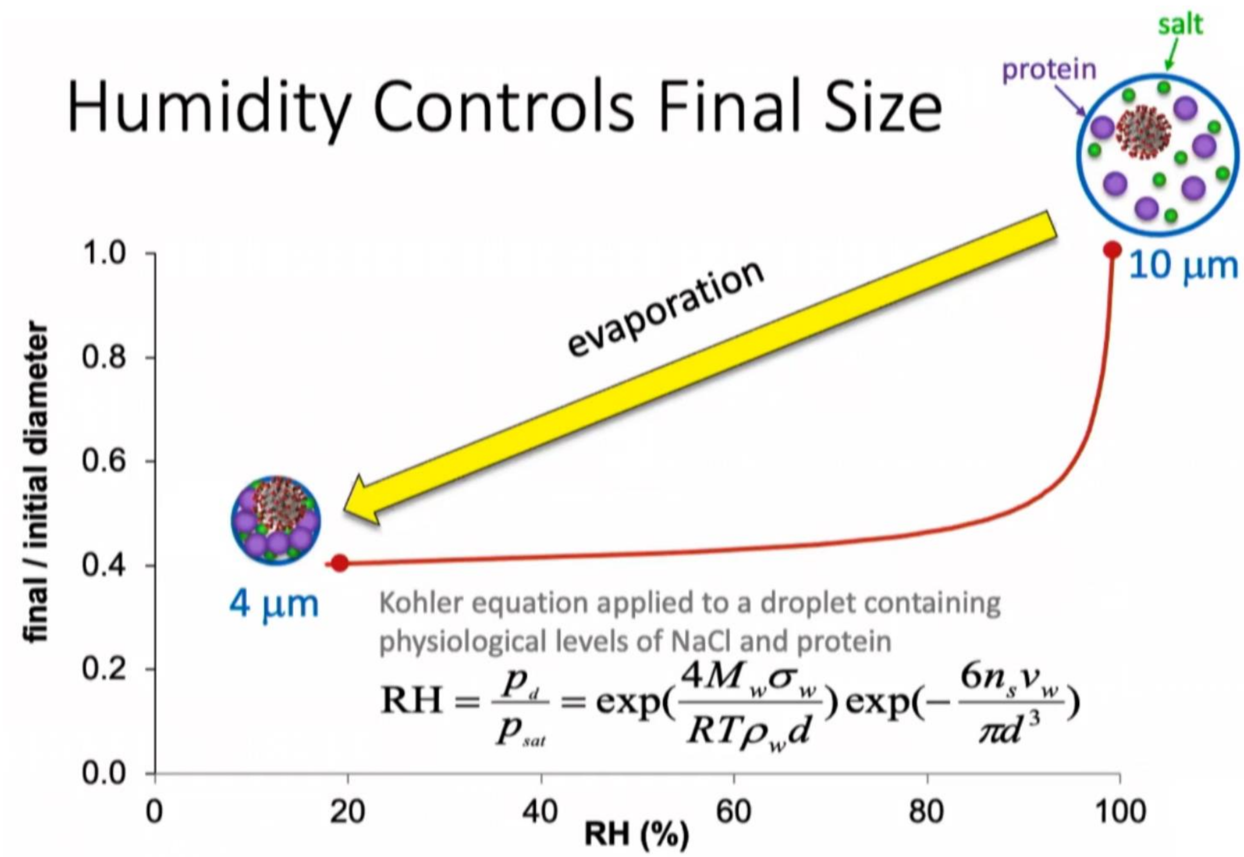
Ventilation plays a critical role in removing exhaled virus-laden air, thus lowering the overall concentration and therefore any subsequent dose inhaled by the occupants. Appropriate distribution of ventilation (e.g. placement of supply and exhaust vents) ensures that adequate dilution is achieved where and when needed, avoiding the build-up of viral contamination. The central guiding principle is to replace contaminated air with clean air, but sometimes local barriers to this process may occur, e.g. where partitions are used or curtains drawn for privacy or medical procedures. If these barriers are in use, secondary or auxiliary measures may be needed to achieve requisite ventilation effectiveness.

Opening windows is another method that can be used to increase ventilation. Installing fans to move more air is preferred to ensure a more constant and continuous ventilation rate and can assist with moving aerosols out of the breathing zone where they will linger in a stagnant environment.

The recirculation of air is a measure for saving energy, but care must be taken, as it can transport airborne contaminants (including infectious viruses) from one space and distribute them to other spaces connected to the same system, potentially increasing the risk of airborne infection in areas that otherwise would not have been contaminated.



OSHA Hierarchy of Controls

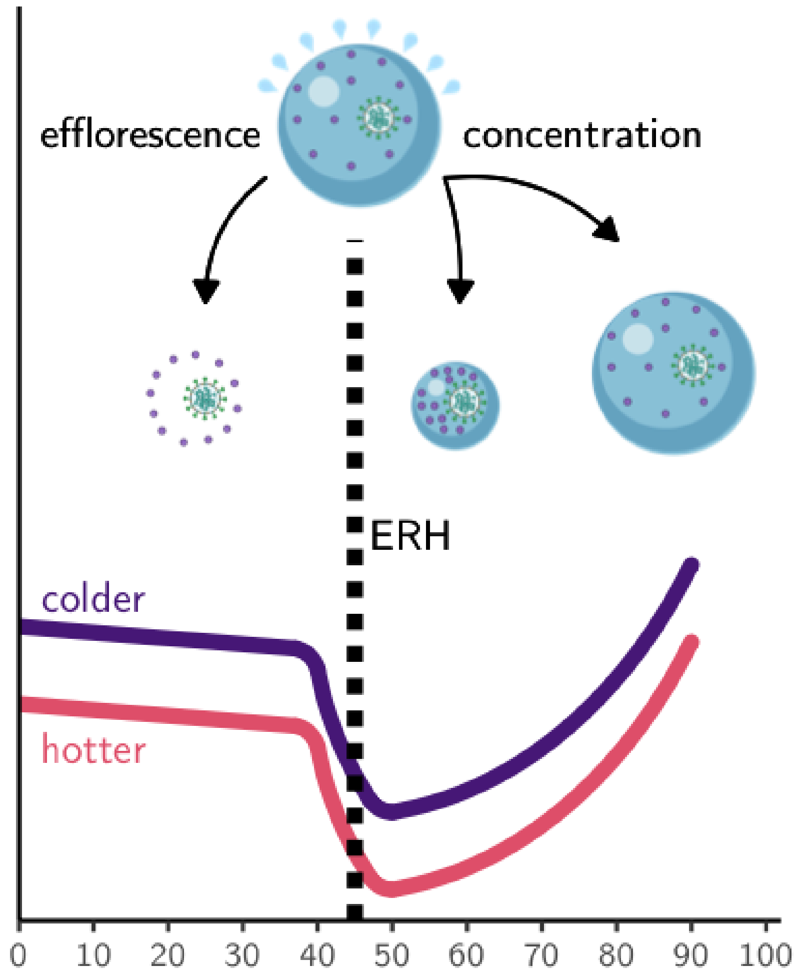


Ambient relative humidity sets the concentration level of the aerosols. Water evaporates from the solution until an equilibrium with the ambient environment is reached.

Lower RH equates to more evaporation. But below a certain threshold relative humidity, the efflorescence (the migration of a salt to the surface of a porous material) relative humidity (ERH), the human respiratory fluid can crystalize. Concentrated solutions are favorable for reactions.

So we expect this U-shaped pattern. Above the ERH, more humidity, you get better virus survival. Below the ERH, virus survival should rise again. And that is exactly what we see!

Epi takeaways: outdoors, you've got sunlight and ventilation to help you, even if it's cold.



Humidity levels must be maintained between 40% and 60% RH. If lower than 40%, the droplet will evaporate, making it more difficult to capture and increasing its travel distance. Even at 60% RH, the majority of the liquid has already evaporated. Levels above 60% RH are not going to result in better control of the virus-laden particles, but you start to sacrifice comfort and have to worry about growth of bacteria, fungi, mold, etc.

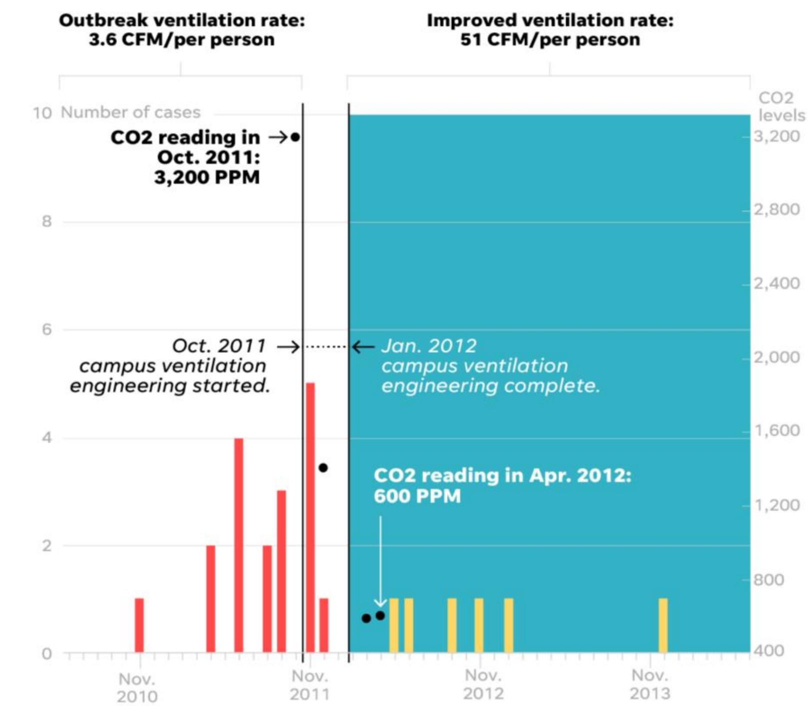
According to a study released on October 13, 2020 by research giant Riken and Kobe University, simulations showed that air humidity of lower than 30% RH resulted in more than double the amount of aerosolised particles compared to levels of 60% or higher. The finding suggests that the use of humidifiers may help limit infections.

While the exact air exchange rate (ACH) depends on the number of people and size of the room, most experts consider roughly six air changes an hour to be good for a 10-foot-by-10-foot room with three to four people in it.

So how do you know if the room you're in has enough air changes? Aside from measuring the supply air coming into the space, you can use CO2 as a proxy. Every time you exhale, you release CO2 into the air. Since the coronavirus is most often spread by breathing, coughing or talking, you can use CO2 levels to see if the room is filling up with potentially infectious exhalations. The CO2 level lets you estimate if enough fresh outside air is getting in.

Outdoors, CO2 levels are just above 400 parts per million (ppm). A well ventilated room will have around 800 ppm of CO2. Any higher than that and it is a sign the room might need more ventilation.

In a study of an outbreak of tuberculosis at Taipei University in Taiwan, rooms were under-ventilated with a rate of 3.6 CFM/per person and carbon dioxide levels were found to be in a range of 1,200 parts per million to 3,000 PPM. Tuberculosis, like COVID-19, is an airborne disease. The university increased the ventilation rate to 51 CFM/per person, resulting in carbon dioxide levels dropping to 600 PPM, and the outbreak ended.



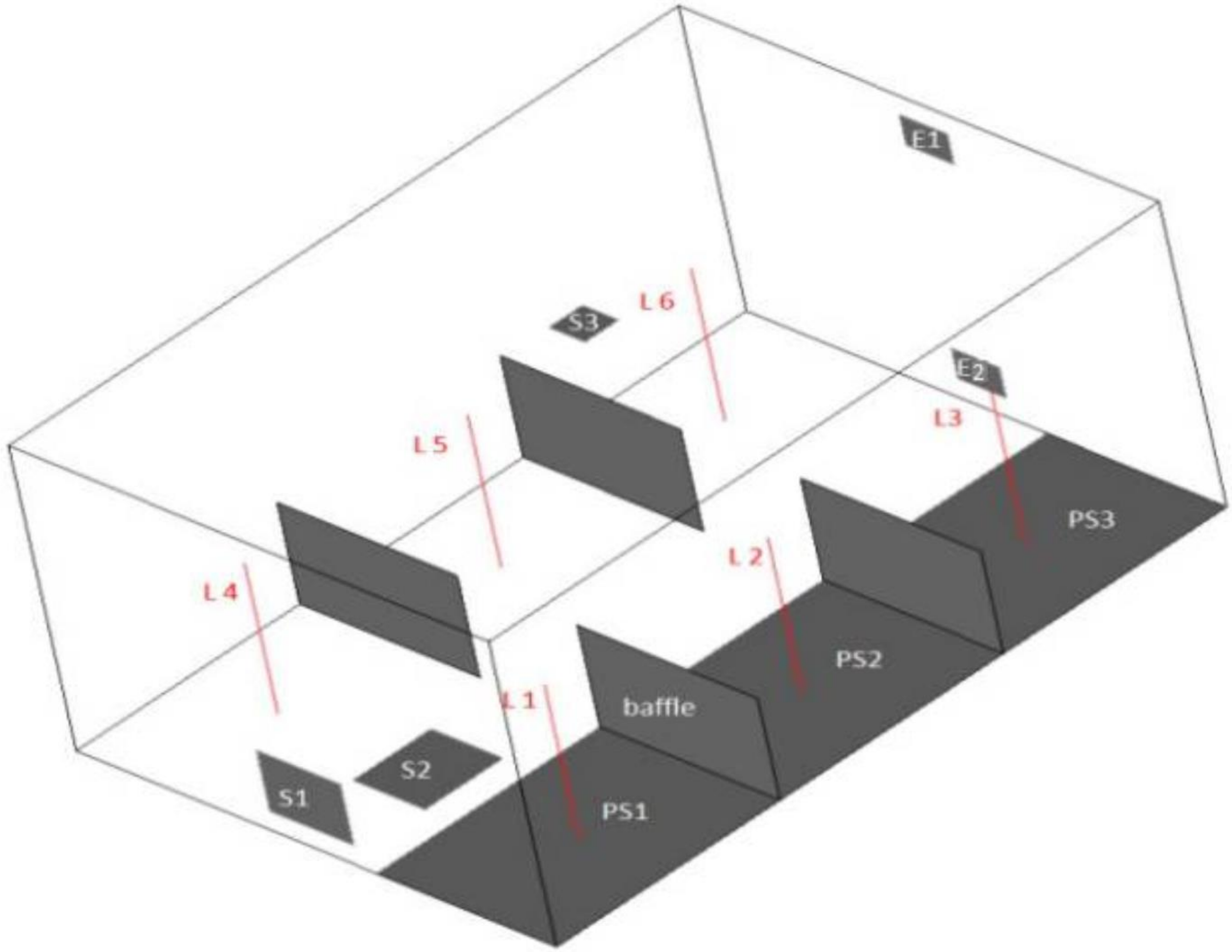
SOURCE Du C-R, Wang S-C, Yu M-C, et al. 'Indoor Air'

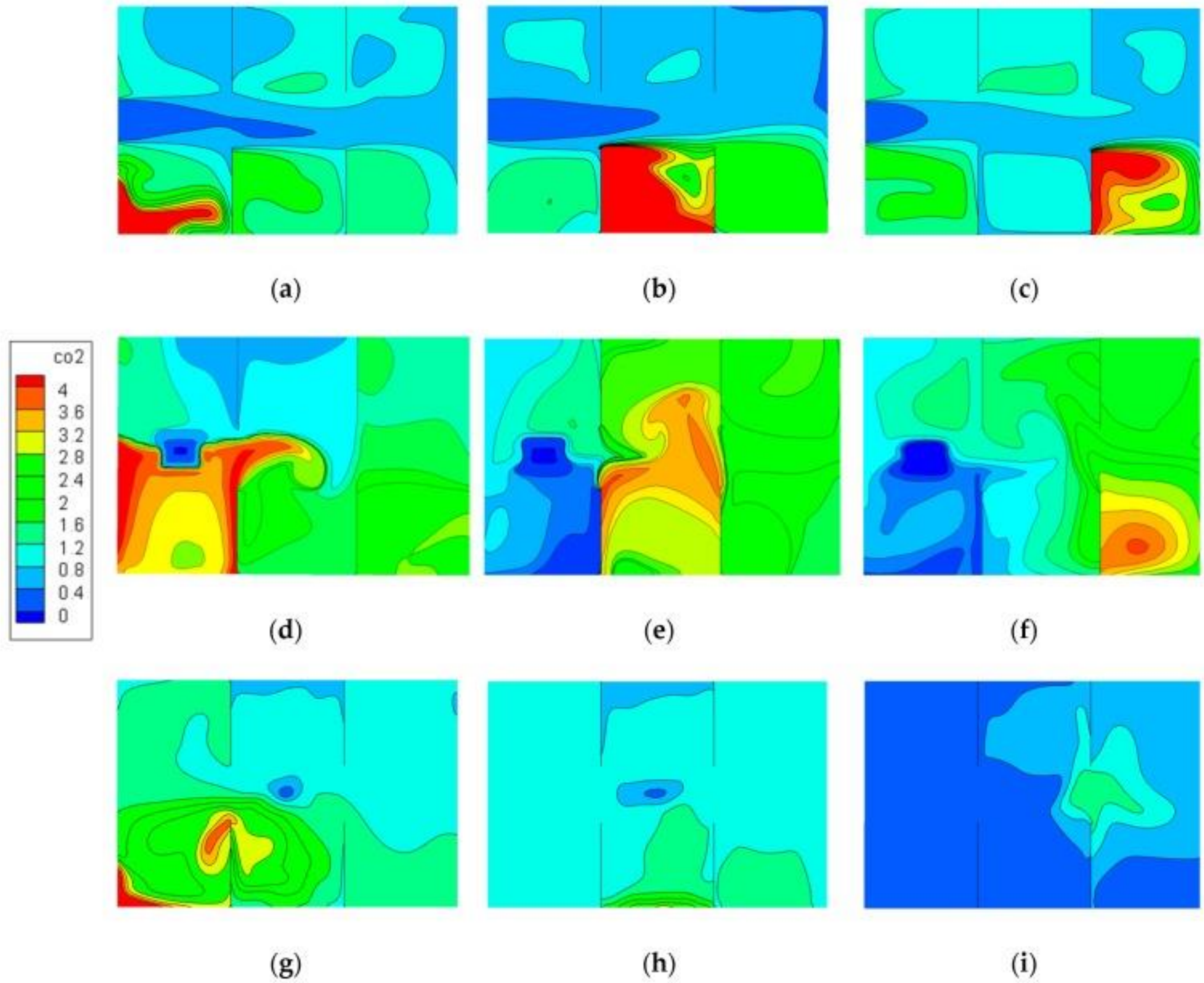
HVAC system control strategies can usually be modified to increase ventilation to a certain extent in the occupied zones, with relatively little additional cost, to reduce the risks of airborne transmission between occupants. However, this is not via a simple ‘flick of a switch’, as HVAC systems are complex and usually designed for individual buildings within standard specific operating parameters. Many requirements need to be considered apart from the ventilation rate, including control of temperature, relative humidity, air flow distribution and direction.

During an epidemic, including the current COVID-19 pandemic, air should not be recirculated as far as practically possible, to avoid the dissemination of virus-laden particles throughout the indoor environment For central air handling units at a building level or serving multiple zones, recirculation should be avoided, and the system operated on 100% outdoor air (OA) if possible. Disabling recirculation can be achieved by closing the recirculation dampers and opening outdoor air dampers.

Airflow patterns make a difference as well. The ASHRAE Position Document on Infectious Aerosols states that advanced techniques such as computational fluid dynamics (CFD) analysis, if performed properly with adequate expertise, can predict airflow patterns and probable flow paths of airborne contaminants in a space. Such analyses can be employed as a guiding tool during the early stages of a design cycle.

In a 2018 study called “Effects of Internal Partitions on Flow Field and Air Contaminant Distribution under Different Ventilation Modes”, the researchers found that different ventilation modes have great influence on indoor airflow distribution, and the top-supply, down-return ventilation mode is better at providing a desirable airflow pattern. For layouts using baffles to separate different zones, the baffles will significantly affect the indoor airflow distribution. It is suggested that the baffles’ locations should be carefully designed in order to avoid blocking the airflow. The partitions (baffles) used in the study were 1.5m wide x 1m tall (5’ x 3.3’). While these might seem short, they tested various heights (up to 5’ tall) and the results show that the effect of the baffle height is not significant with regard to the pollutant removal efficiency under the same ventilation mode and pollutant source location. The ventilation mode and pollutant source location play dominant roles. Tracer gas was CO_2, with a release rate of 4.25 m2·h. The frequency of air change was set at 10 times per hour.


E1
S3
L6
E2
L3
L5
PS3
L2
L4
PS2
L1
baffle
S2
S1
PS1



This figure shows the pollutant concentration distributions on a horizontal plane under different ventilation modes and pollutant source locations. This plane represents the breathing zone while occupants sit quietly. CO2 concentration is in dimensionless form. As shown in the figures, cases in the same row adopted the same ventilation pattern, and the pollution source was located in the same position for cases in the same column.

> a–c illustrates three cases of the **down-supply (low on the wall) /up-return (high on the wall)** ventilation pattern (S1 & E1)
>
> d–f illustrates three cases of the **floor-supply /up-return (high on the wall)** ventilation pattern (S2 & E1)
>
> g–i illustrates three cases of the **top-supply (ceiling) /down-return (low on the wall)** ventilation pattern (S3 & E2)

When indoor pollution sources exist, the top-supply down-return ventilation mode shows better performance in removing pollutants. It should be noted that both down-supply and floor-supply ventilation modes are commonly used under the condition of temperature stratification in an indoor environment, and the effect of temperature plays a key role when assessing indoor airflow and dispersion problems.

Both nanometer-sized aerosol particles and micrometer-sized droplets can be captured by a filter. The Filter Efficiency is a function of Dm, Df, fiber packing density, and flow rate. Freshly generated particles may be highly charged but immediately start to neutralize after emission. Ambient aerosols are expected to have a net neutral average charge that follows a Boltzmann distribution after <100 min aloft (note, lifetimes of nanoparticles span hours to days over this size range). Differences in the charge state or distribution of charges of the aerosol may impact the measured Filter Efficiency with E_B typically enhancing FE.

A test on Air Filters and their ability to capture airborne virus particles was described in the August 2020 edition of the ASHRAE Journal. The test consisted of a single-pass ducted system using an aerosolized MS2 virus, which has approximately the same aerosol characteristics as a human virus and can serve as a surrogate for viruses of similar and larger size and shape. The test was performed on electrostatically charged MERV 12, 13 & 14 filters with a MERV 5 used as a comparative filter.

TABLE 4 Descriptive statistics of viral filtration efficiency data.

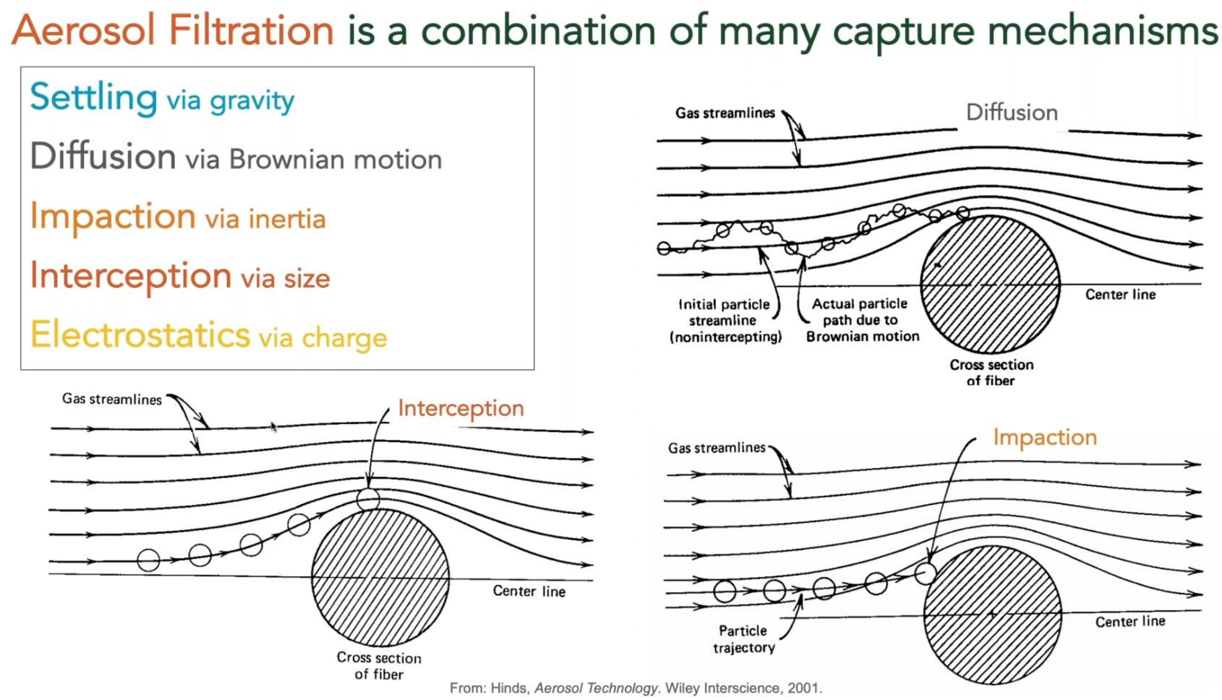
FILTER	N	MEAN	STD DEV	COEF VAR	MEDIAN	MINIMUM	MAXIMUM
MERV 5	6	32%	10.5%	32.8	36%	12%	40%
MERV 12	6	78%	8.8%	11.3	77%	70%	93%
MERV 13	6	89%	8.2%	9.3	91%	79%	98%
MERV 14	6	97%	1.4%	1.5	96%	95%	99%

The following conclusions can be drawing from this study:

- High-Efficiency HVAC filters were found to be effective at capturing airborne virus particles.
- Filter viral filtration efficiency (VFE) was found to be generally correlated to its MERV rating, i.e., the higher the MERV rating, the higher the viral filtration efficiency.
- In comparison to commonly used E1, E2 & E3 particle size efficiencies (used in ASHRAE 52.2) of clean filters, VFE was found to be higher than initial E1 efficiency, but lower than initial E2 and E3 efficiencies.
    - The 52.2 procedure calls for efficiency measurements to be taken on twelve (12) particle size ranges. For reporting and rating purposes, these twelve (12) ranges are grouped into three (3) wider ranges:
        - E1 - 0.3 - 1.0 Microns
        - E2 - 1.0 - 3.0 Microns
        - E3 - 3.0 - 10.0 Microns

Standard 52.2-2017 -- Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size

Performed better at capturing smaller microns



It seems counterintuitive, but smaller microns are easier to capture through filters than larger ones.

The root of the problem is our intuition to think of filters like a net. If a particle is smaller than the holes in the net, it gets through. So the smaller the particle, the harder it is to capture. That logic works for big objects.

And it's basically how HEPA filters work for particles bigger than 0.3 microns. These particles either can't fit through or their inertia causes them to hit the filter fibers (processes called impaction and interception).

But when we get to really small particles – like particles under 0.3 microns, things start getting weird.

Particles that small have so little mass that they actually get bounced around like a pinball when they hit gas molecules (known as Brownian Motion). So they move in random zigzag patterns.

These tiny particles are small enough to fit through HEPA filters if they flew straight. But because they fly in zigzag patterns, they end up hitting the fibers and getting stuck.

Research conducted by the US Department of Homeland Security has shown that in the presence of UV light, aerosolized particles would disappear in less than a minute. Germicidal ultraviolet (GUV) 'in-duct' application within air-conditioning systems and ventilation ducts may also be a practical approach for disinfecting contaminated extracts or in cases where it is not possible to stop recirculation of ventilation flows. However, these systems are of little benefit against person-to-person transmission when installed in the supply air of once-through systems that do not recirculate air within the space or building.

The University of Colorado did a study a few years back for the CDC using fungi and mycobacteria found that at 2.2 m/s (433 fpm), the in-duct UV worked very well, but at 5.1 m/s (1004 fpm) there was no reduction. Exposure time is critical. The same study showed improvement in the UV light being installed in the mixed air duct versus the supply air duct. Lamp intensity and exposure time are critical.

The US Centers for Disease Control has approved both upper-room and in-duct systems for use in controlling tuberculosis transmission as an adjunct to HEPA filtration. Upper room UVC fixtures utilize the natural rise and fall of convection or mechanical air currents to circulate airborne infectious agents to the ceiling (or upper wall), where they are exposed to UVC radiation and killed. An increase in Upper Room UV irradiance has a linear correlation in effective air change rates. Fans can be added to improve circulation.

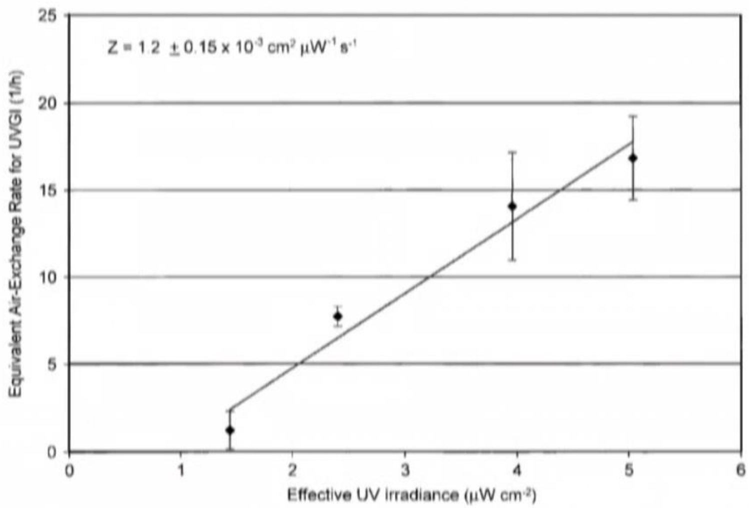


Fig. 7. UVGI inactivation rate as a function of effective UVGI spherical irradiance for *M. parafortuitum*. Effective UVGI spherical irradiance is the irradiance measured by actinometry in the upper-room zone only normalized to the fraction of room volume irradiated by UV (0.3/2.5 m).

You can make your own filter/fan setup if the HVAC does not allow for modification or you do not have a method of increasing ventilation. Simply taping a filter on the inlet side of a box fan and putting it in the middle of the room can have benefits. Room air gets sucked into the filter first, and the fan blows clean air out. That's "pull-through" instead of "blow-through," the way residential AC works. This configuration lets the pressure pull the filter tight against the fan. You'll still probably need tape to try and eliminate gaps.

In room air cleaners – look at "Clean Air Delivery Rate". This value should match or exceeds the square footage of the room you are trying to clean. They should be certified by Association for Home Appliance Manufacturers. Still not sure of best place to locate the in room cleaners. Will depend on air flows in the space.

Air ionization works through the reaction of negatively and positively charged ions. The ions attach to airborne pathogens, such as viruses causing a chemical reaction on the cell membrane's surface. This deactivates the viruses, rendering them harmless, so they can no longer spread or cause infection.

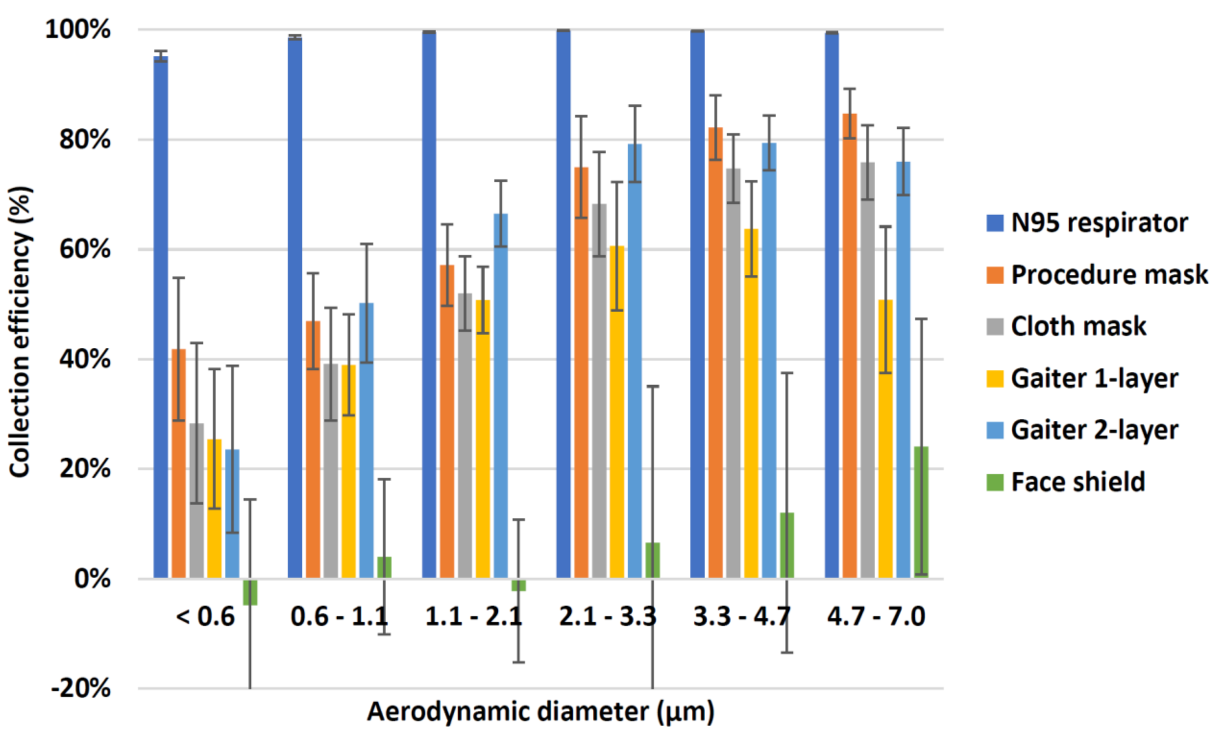
Testing carried out by Tayra and backed by the Spanish Ministry of Defense Biological Laboratory in Spain on the BiPolar Ionization technology showed a reduction of MS2 Bacteriophage, a surrogate for SARS-CoV-2 (COVID-19), in indoor environments.

There is mounting research to suggest that clean, disinfected air plays a vital role in preventing the spread of SARS-CoV-2, the virus causing COVID-19.

The research tests were conducted in a Madrid hotel converted into a residence and confinement center for medical staff during the pandemic. The experiments took place in simulated ICU hospital rooms within the hotel. This environment was explicitly designed to test air ionization on small aerosolized viral particles.

The ionizer was installed in the fan coil unit supply air duct that delivered air to the test space. The bacteriophage MS2 was then nebulized into the test space. During the first phase of the test, the supply air into the room was untreated. During the second phase, the supply air entering the test room was ionized using the bipolar ionization system. A reduction of approximately 2 log units of the bacteriophage was obtained in the air that was ionized by the Plasma Air system. This corresponds to a 99% reduction after exposure to ionization.

We need to increase ventilation where we can and start making as widespread as possible use of air sanitation with germicidal UV and maybe BiPoalr Ionization and humidity control in those places that must be open. We need to stagger hours of starting work and keep density low, or open windows. And we need to wear masks. Masks will still stop the forward-momentum of the small aerosols when we breath, talk, sneeze or cough.

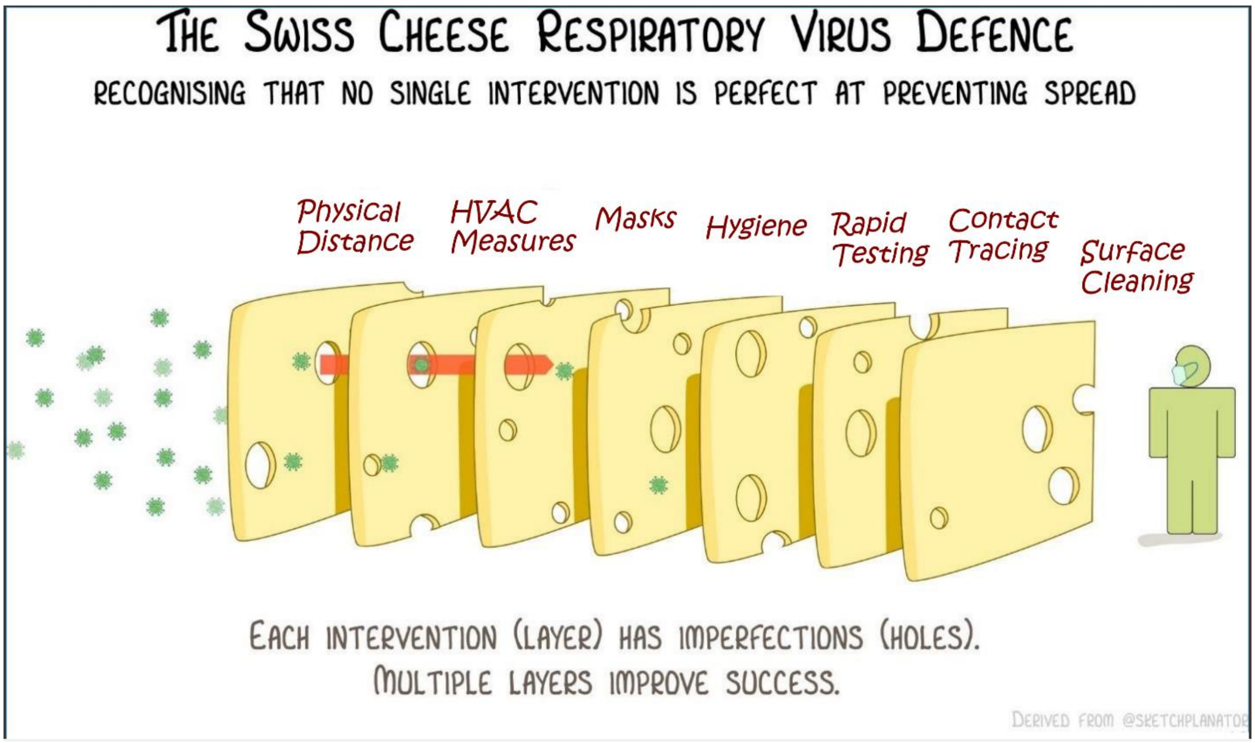


In this study released on October 7th, they used a cough aerosol simulator with a headform to propel small aerosol particles (0 to 7 µm) into different face coverings.

N95 blocked 99% of aerosols (< 5µm), surgical mask 59%, 3-ply cloth mask 51%, neck gaiter 47% (1 layer) and 60% (2 layer), face shield 2%.

When you breath in, the negative pressure you create will draw in aerosols through the openings on the sides or bottom of your mask.

A study at Mass General Hospital Brigham during March and April showed that universal masking at was associated with a significantly lower rate of SARS-CoV-2 positivity among 9850 Healthcare workers. Despite local and statewide measures, the case number continued to increase in Massachusetts throughout the study period, suggesting that the decrease in the SARS-CoV-2 positivity rate in MGB HCWs took place before the decrease in the general public.



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