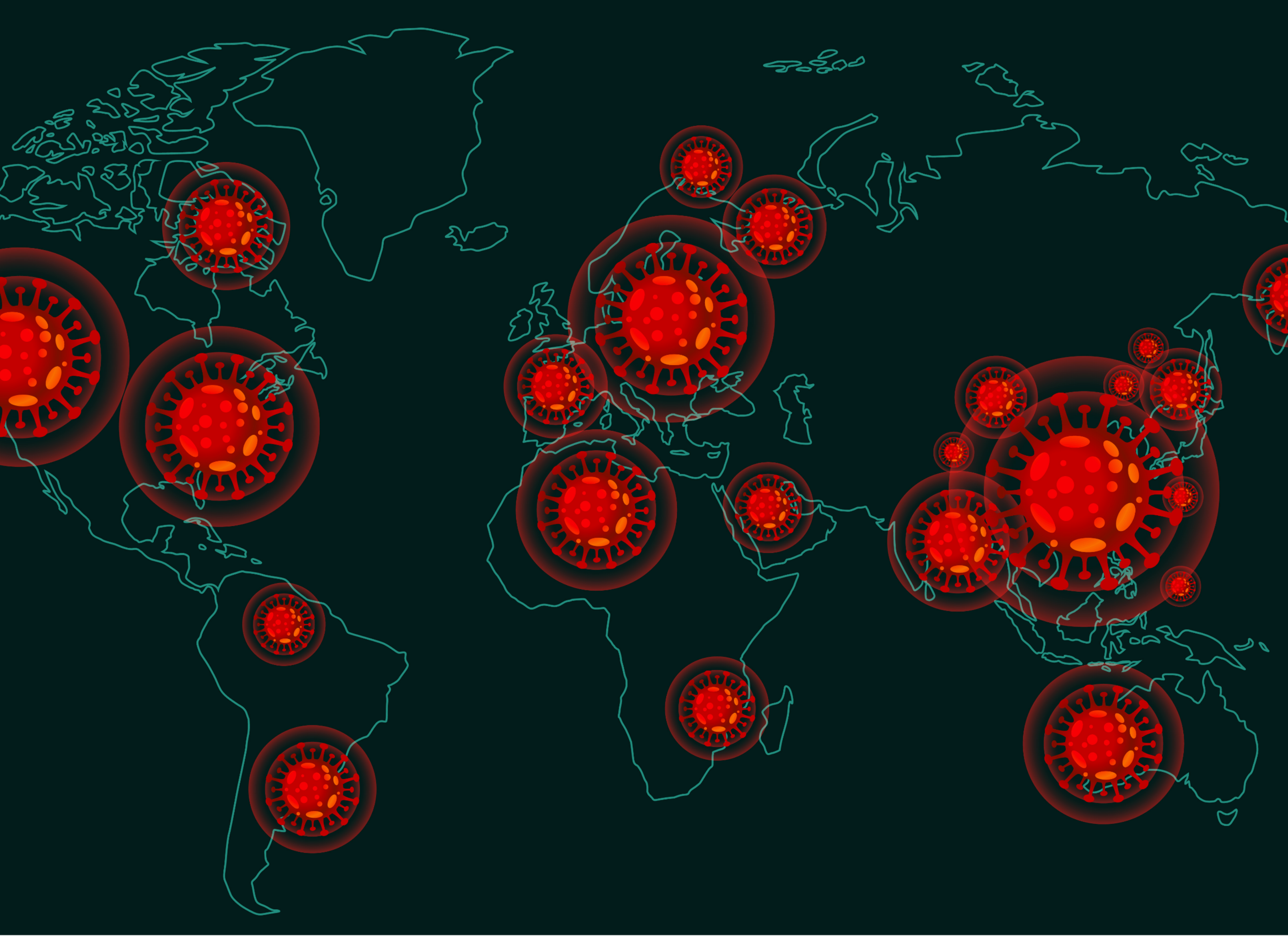


uHoo Business™

Understanding conditions for aerosol transmission of viruses:

Causes and control solutions in built environments

Monitoring indoor air quality provides proper real-time data that can be used to prevent and minimize the risk of communicable disease outbreaks such as COVID-19. This data allows you to learn about your environment and simultaneously understand its impacts on health and well-being; you can take proper action to reduce the risk of virus survival and virus transmission.

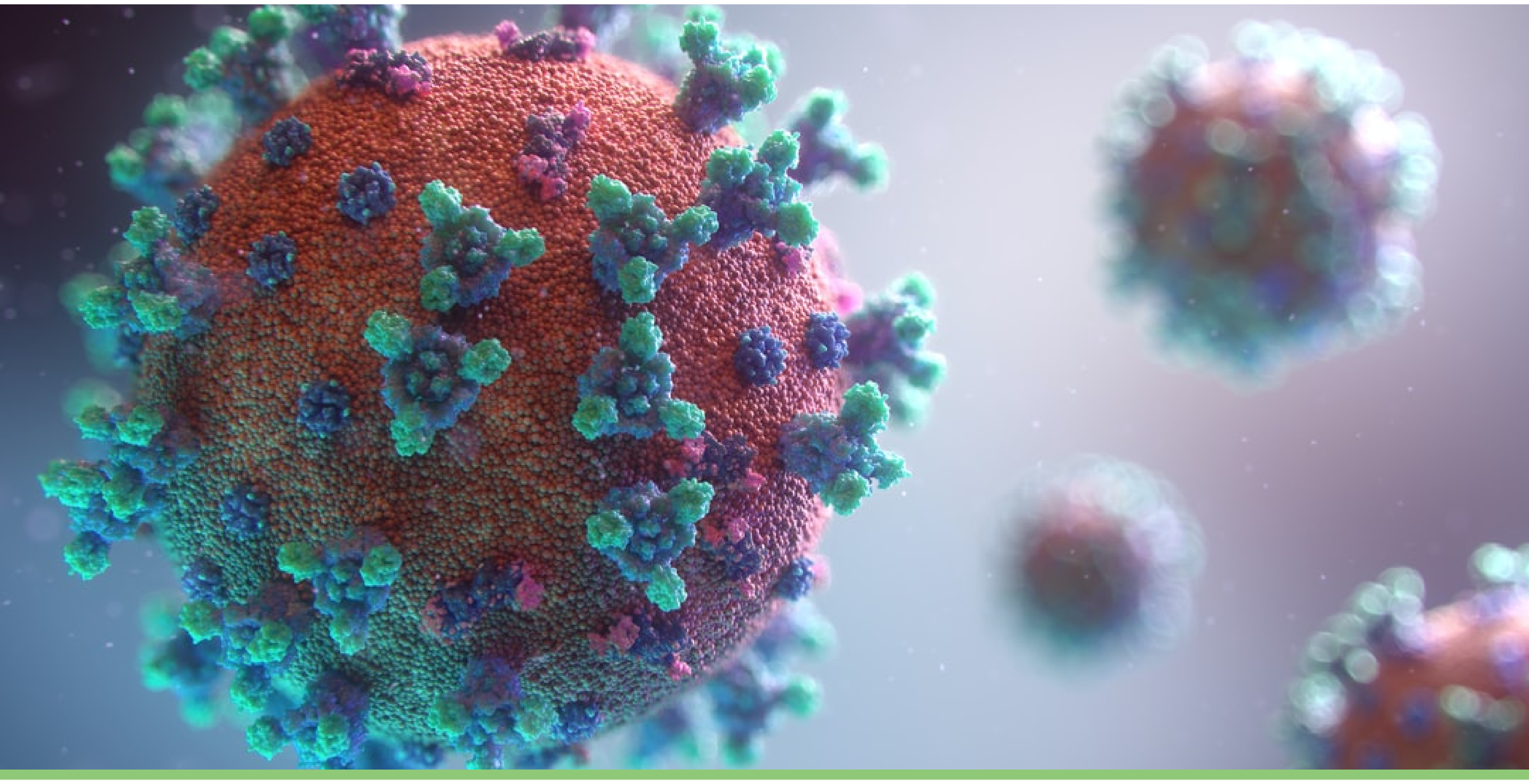
This paper is a continuation of our previous white paper regarding the impact of indoor air quality on virus survival and transmission. To read our first paper on "Using Indoor Air Quality to Create the uHoo Virus Index", go to https://getuhoo.com/virus-index.

Introduction

Fact: viruses and bacteria survive and spread in the air.

The COVID-19 outbreak of 2019 is not the first of its kind that has struck humanity in the 21st century. There was the severe acute respiratory syndrome (SARS-COV) in 2002-2003 and the Middle East respiratory syndrome (MERS-COV) in 2012. However, this novel coronavirus strain is by far the largest and most severe. It has claimed millions of lives and caused countries to close their borders and governments to impose nationwide lockdowns, resulting in adverse effects to businesses and economies. Scientists and medical researchers around the world scrambled to identify a cure, while organizations developed guidelines and measures to reduce anxiety over health concerns.

SARS-COV-2 - the coronavirus strain that is responsible for the pandemic - can be transmitted from person to person in tiny droplets called aerosols. They can linger and travel through the air especially in environments where there is poor ventilation. Mounting evidence of this transmission route made agencies such as the World Health Organization (WHO) and the United States' Centers for Disease Control and Prevention (CDC) consequently acknowledge it.[1]



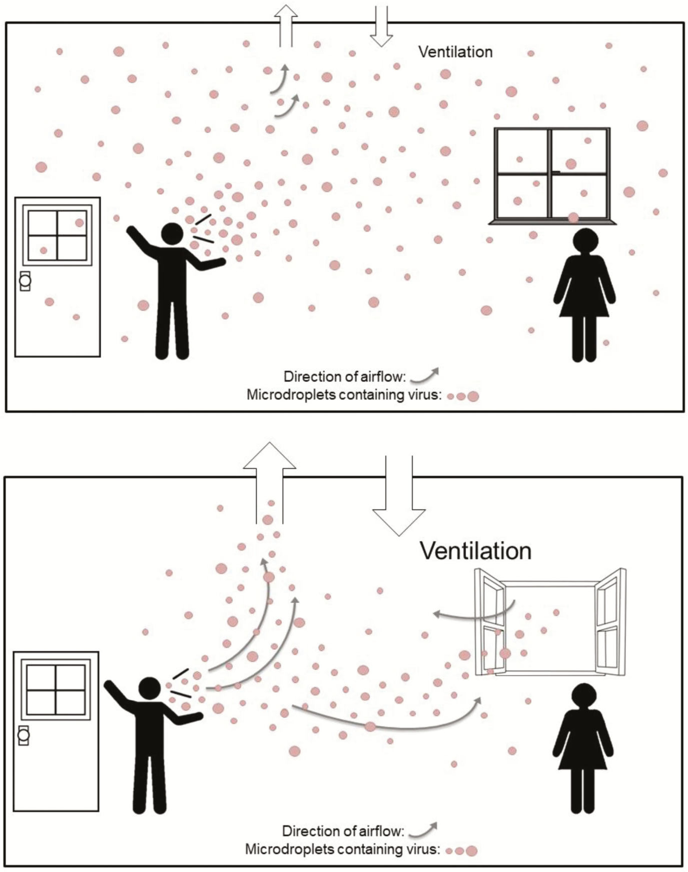
We looked at various studies on how poor indoor air quality affected transmission of the SARS-CoV-2 virus in the air and identified numerous causes.

1. Poor Ventilation and Air Exchange in Closed Spaces

One of the earliest recorded massive outbreaks was in a meat processing facility in Westphalia[2], Germany. More than 1,400 tested positive for the COVID-19 virus within 1 month from initial contact.

Inadequate ventilation was identified as the biggest contributor to the infection. The initial transmission occured in a confined area of the processing plant. Temperature was kept at 10 degrees Celsius with minimal to no fresh air exchange. Workers in the area were also constantly close together. This environment made it very conducive for the virus to survive and be transmitted.

This kind of aerosol transmission, as opposed to droplets, can travel further than 2 meters and can stay in the air for longer periods of time; thus, it has a much higher risk of transmission. Physical distancing does not always guarantee non-transmission. In instances of enclosed spaces, other measures are needed such as improved ventilation and airflow, and installation of filtering devices. It also helps to be able to monitor whether there is sufficient ventilation and air filtration so that proper action can be promptly taken.

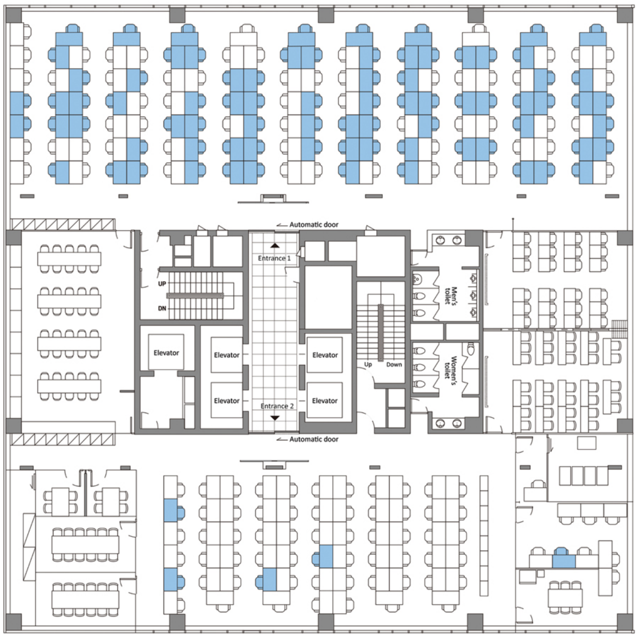


Distribution of respiratory microdroplets in an indoor environment with (A) inadequate ventilation and (B) adequate ventilation.

Source:
academic.oup.com/cid/article/71/9/2311/5867798

2. High Density Environments

There was an outbreak in a mixed-use building in one of the busy districts of Seoul, Korea[3]. This incident recorded a total of 94 people being infected out of the 216 employees working on that floor. This 43% attack rate became more alarming when it was discovered that the transmission was concentrated on the same side of the building on the 11th floor (see image on the right).



An illustration of the floor plan of the site of the 2020 COVID-19 outbreak in a call center in Seoul, South Korea. The blue seats represent the locations of people who became infected. Published in the CDC medical journal, Emerging Infectious Diseases.

Source:
wwwnc.cdc.gov/eid/article/26/8/20-1274-f2

Similarly, a 5-day prayer meeting at a church in Mulhouse France which saw an attendance of 2,500 people has been identified as one of the worst superspreader events in Europe[4]. At the time that the event was happening, there were only 12 reported cases in the country, and all of them were confined in small provinces. After the event, about 2,500 cases of infection and 21 deaths across multiple countries have been traced back to the attendees.

The risk of virus transmission increases in high density environments. It is important to keep in mind that aerosolized transmission in enclosed spaces can surpass physical distancing measures. Applying these measures without getting to know what's in the air is similar to shooting in the dark.

3. Droplet Transmission From Strong Indoor Airflow

Enclosed spaces that rely on strong air conditioning to recycle indoor air are also hotspots for viral transmission. Such was the case in a restaurant in Guangzhou, China[5], where 10 people from 3 different families were infected by the COVID-19 virus.

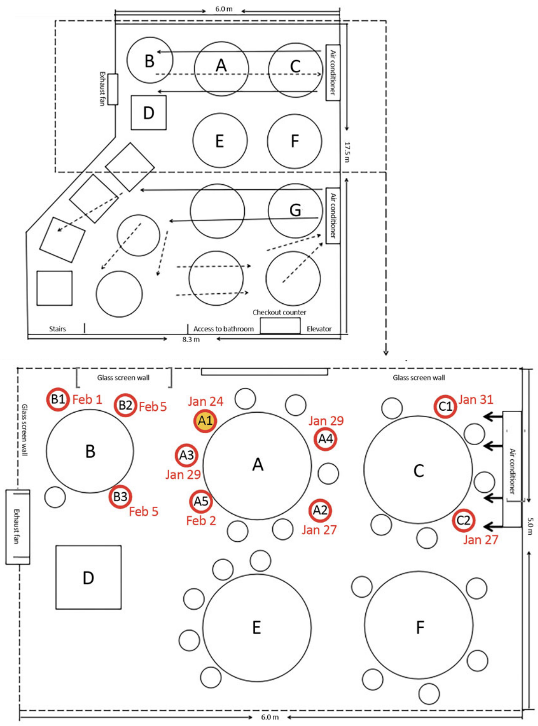
In the same way that the office workers in Korea got infected, there is a high probability that poor indoor air quality caused the transmission of the virus. This is a particularly important example for 2 reasons:

1. Initial transmission did not happen within the same table; the people who were infected were tables apart. This means that the most likely cause was through droplet transmission prompted by air conditioning.

2. Another important point to highlight in this case is the airflow pressure that is likely to have caused the propagation of droplets within the restaurant. Strong airflow from the air conditioning unit could have likely carried the droplets to the other tables. Simply following the minimum physical distancing guidelines is not enough.

Sources were inconclusive but it can be deduced that if there was no physical contact and the only connection they had was the air conditioning, which circulated the air in the premises, then transmission may have occurred by air.

In this case, it was clear what had to be done. Ventilation had to be improved, particulates in the space controlled, filtered and reduced, and temperature and humidity had to be effectively monitored and managed.



The dates indicate when the individuals were tested positive. On January 23, 2020, family A traveled from Wuhan and arrived in Guangzhou. On January 24, the index case-patient (patient A1) ate lunch with 4 other family members (A2–A5) at restaurant X. Two other families, B and C, sat at neighboring tables at the same restaurant. Later that day, patient A1 experienced onset of fever and cough and went to the hospital. By February 5, a total of 9 others (4 members of family A, 3 members of family B, and 2 members of family C) had become ill with COVID-19.

Source:
wwwnc.cdc.gov/eid/article/26/7/20-0764-f1

4. Aerosolized Virus Transmission in Everyday Environments

Daily encounters and regular routines tend to be taken for granted. These are the times when we usually let our guards down. These are the events when we need to raise awareness and be cautious with our surroundings, most especially indoors.

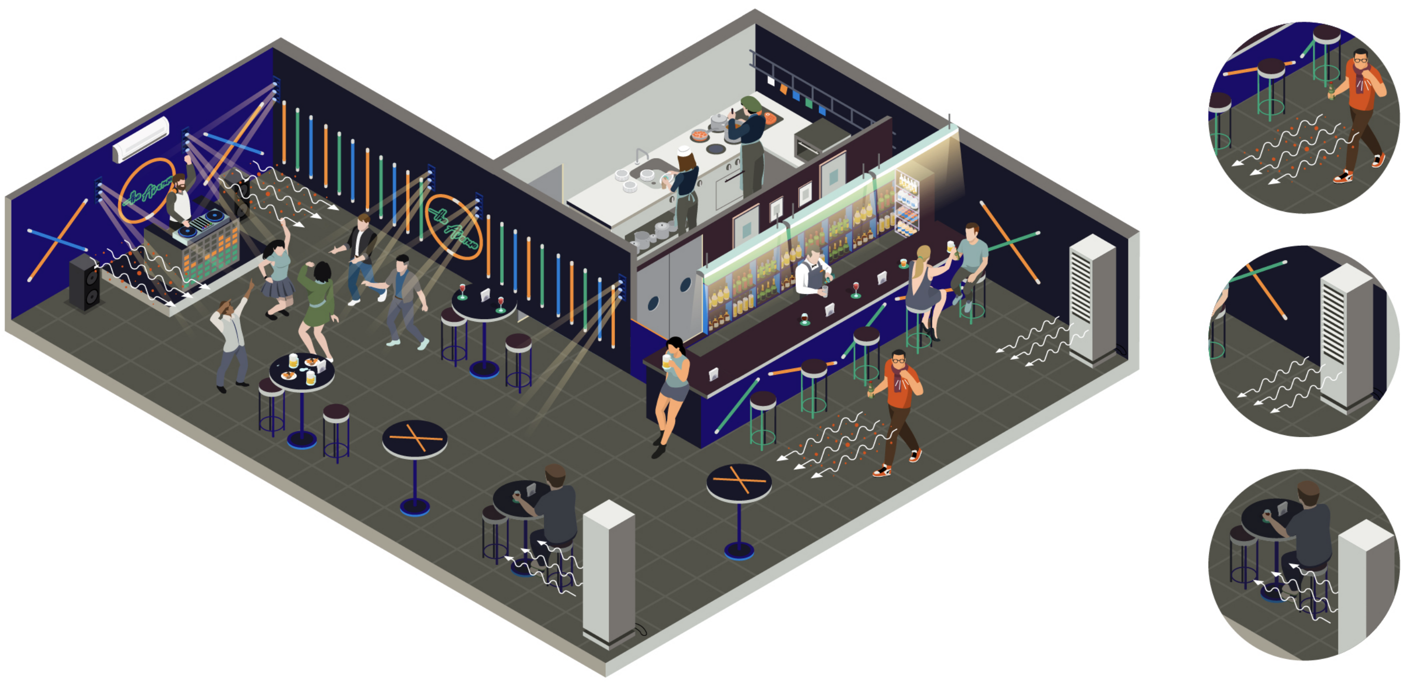
A compilation of cases[6] in Spain evaluated coronavirus transmission in a number of environments. Different factors were considered as to how it contributed to the rate of infection.

For instance:

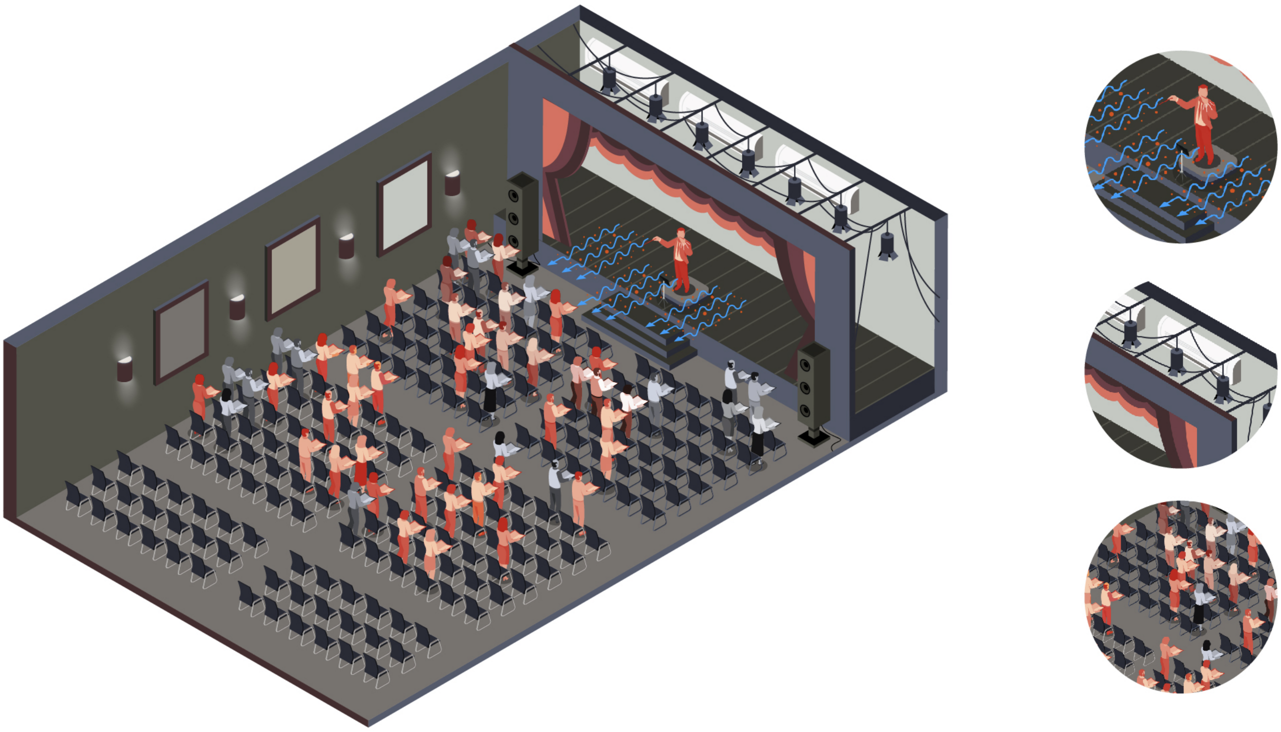
A small gathering of 6 in a living room without masks and proper ventilation has a probable transmission rate of 5 out of 6.

A closed classroom where students stay for 2 hours, assuming that the teacher is infected, risks 12 students being infected irrespective of distance from the teacher.

A night club or a bar, even at 50% reduced capacity, still risks infection of 14 out of 15 people.



A choir rehearsal in the United States, where 61 out of 120 members attended, even with distancing measures, still managed to have transmitted the virus to 53 members. Some of those who contracted the virus were even 14 meters away.



These situations showed that, in certain conditions, the primary channel for virus spread is the air. Even with common preventive measures such as physical distancing and maintaining proper hygiene, infection risk is still high. We need to understand that aerosols are distributed randomly and the way to manage infection in these situations is to have the proper tools to monitor and prevent transmission.

Addressing the Airborne Transmission Threat: Understanding the Components of Air Quality

A number of steps and simulations were taken to test the transmission rate in the cases. Most of them involved reducing time of exposure, wearing protective gear, and physical distancing. The results were progressive, but still had room for improvement. This leads to air quality. In all of the researched cases, one prominent factor was ventilation, a key air quality consideration. Without proper ventilation and fresh air exchange, transmission is bound to happen.

A deeper understanding of the air that people are breathing helps in developing measures that can prevent situations like this from happening. The more you know about the air, the more you can take control in preventing infections from viruses and other pathogens.

Temperature

This is an important factor for two reasons. First is thermal comfort, which refers to providing a comfortable environment. Second is how temperature directly affects virus survival, and mold and bacterial growth. In addition, inconsistencies with temperature can trap air contaminants that will allow them to linger in the air longer.[7]

Humidity

Improper management of humidity creates skin problems, mold growth and even dust mites. Humidity is a critical factor in affecting virus survival in any indoor environment.

Carbon Dioxide

Excessive carbon dioxide in indoor air is an indicator of lack of ventilation and fresh air. High levels of carbon dioxide can also cause headaches, nausea and fatigue.[8]

TVOCs

Volatile organic compounds are your regular garden mix of emissions from chemicals found in furniture, equipment, skincare products, and cleaning products, among others. Depending on volume and toxicity of the chemical, its effects can vary from short term headaches, dizziness, eye, nose and throat irritation, to more serious illnesses such as kidney damage and even cancer.[9]

Dust Particles

(various sizes include 1, 2.5, 4 and 10 microns)

This refers to fine particulate matter that is suspended in the air. These particulates come from various sources such as heaters and tobacco smoke and are fatal to people with heart and lung problems when exposed for a long time. High levels of dust particles staying suspended in the air can also act as a medium for the virus to stay suspended in the air and travel in the air.[10]

Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a toxic gas that can be emitted from defective and unvented combustion appliances, tobacco smoke and kerosene heaters. Prolonged exposure to this chemical can contribute to the forming of chronic bronchitis. This is especially dangerous for people with pulmonary diseases as well as young children who will be at risk of respiratory infections.[11]

Carbon Monoxide

Carbon monoxide (CO) is an odorless and toxic gas. This is the silent killer. People need to be aware if there are abnormal levels of this gas in their indoor air. This is usually found in leaking furnaces, unvented heaters, tobacco smoke and emissions from truck or bus exhausts. This is responsible for fatigue, impaired vision, and even reduced brain function. Exposure to excessive levels can lead to fatal results.[12]

Ozone

Ozone is dangerous when inhaled continuously and in high amounts. This is produced when emissions of VOCs and nitrogen oxide are exposed to heat and sunlight, this can also come from cleaning products. Exposure to Ozone can impair lung function, which will make it difficult to breathe. It is especially dangerous for people who have asthma, bronchitis and emphysema.[13]

Formaldehyde

Formaldehyde is a colorless, strong-smelling gas typically used in various building items such as plywood, paper product coatings and disinfectants. Long term exposure to low-levels in the air or on the skin can cause skin and respiratory problems. Acute exposure causes severe irritations to the eyes, nose and throat. Studies have also shown that formaldehyde exposure can cause cancer.[14]

Air Pressure

Air pressure is especially important in mixed-use buildings that have special use areas. Pressure is used to normalize air change between rooms and areas inside a building, which will prevent the infiltration of bad air that introduces particulate matter such as dust.

uHoo Virus Index™: Simplifying Virus Survival and Aerosol Transmission Risk Assessment

Reducing virus risk is top priority to reduce susceptibility to the coronavirus. The uHoo Virus Index™ is the world's first and patented technology that utilizes AI-powered insights based on scientific research to provide a real-time risk assessment of the coronavirus surviving and being airborne. With this information, you would know specifically which actions to take to reduce coronavirus risk.

The uHoo Virus Index is based on a comprehensive analysis of multiple air quality factors - temperature, relative humidity, particulate matter of varying sizes, nitrogen dioxide, and carbon dioxide. The safety thresholds are based on scientific research conducted by organizations such as the World Health Organization (WHO) and the Occupational Safety and Health Administration (OSHA) and published research work conducted by various scientists and universities.[15]

The uHoo Virus Index ranges from 1-10, and sub-categorized into four levels:

1 to 3 (Good)
Virus survival is low and airborne virus spread is unlikely.

4 to 6 (Mild)
Virus survival is moderate and airborne virus spread is possible but air quality poses little to almost no direct health risk for people who are usually not sensitive to air pollution. Sensitive people may experience health effects. More attention to air quality should be given and actions to improve air quality is recommended.

7 to 8 (Bad)
Virus survival is prolonged and airborne virus spread is likely. Air quality poses some health risk. Critical assessment of your air quality is necessary and actions to improve air quality is required.

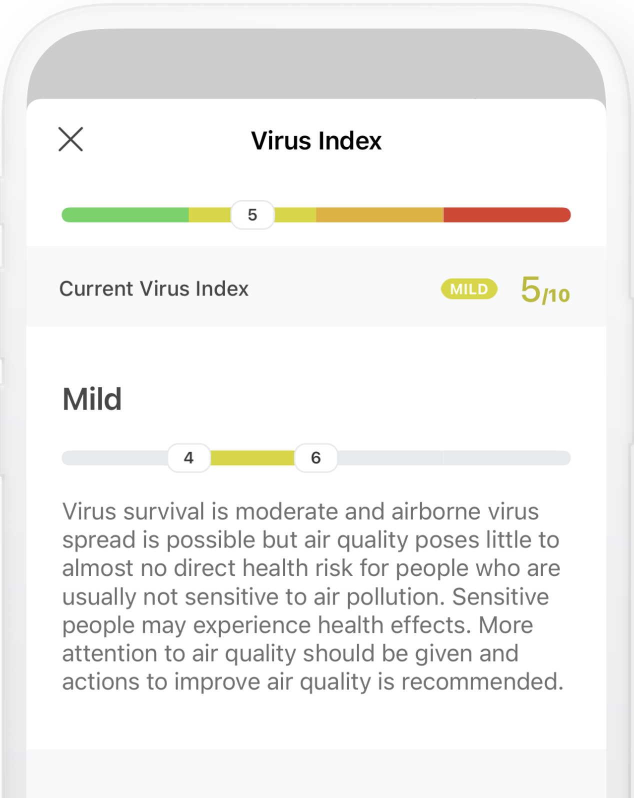
9 to 10 (Severe)
Virus survival is high and airborne virus spread is likely. Air quality would affect most people and actions to improve air quality is necessary.

Let's look at how these factors affect your uHoo Virus Index.

Temperature

Ideal Range: 19°C to 24°C (66°F to 75°F)

A research paper published in 2011 by Chan KH, et al. discussed the critical role of temperature in the survival of viruses. The study showed that lower temperatures and lower humidity can be conducive for prolonged survival of the virus while higher temperatures can reduce virus survival rate. This was supported by a peer-reviewed research paper on a systematic review of the effects of temperature and humidity on COVID-19.[16] Warmer temperatures reduce the viability of the viruses such as influenza and the SARS coronavirus. In cold temperatures (4°C or lower), the virus is more stable and respiratory droplets - as containers of viruses - remain in suspension longer in the air. Maintaining temperature at the ideal level therefore helps to reduce the survival rate of the virus and keeps you comfortable indoors.



Relative Humidity

Ideal Range: 40 to 60%

In environments with lower than 40% Relative Humidity (RH), droplets from a cough or a sneeze lose their moisture quickly. This results in droplets becoming 'dry aerosols' and capable of staying in the air for longer periods. Viral particles remain infectious much longer below 40% and above 80%.

Virus particles are most inactive at 50% humidity, and retain their infectiousness the further from that median value, plateauing at 20% and 80%, respectively.[17] Staying within 40% to 60% relative humidity is ideal from a comfort perspective but 50% is the most ideal in terms of fast virus inactivation.

Keeping the humidity at the ideal range not only helps you stay comfortable but also keeps you healthy. Low humidity (less than 30%) may promote dry nasal passage which makes people more susceptible to cold viruses while high humidity (more than 70%) may promote mold growth which can be harmful to people with weakened immune systems.[18]

$PM_{2.5}$

Ideal Range: Below 15µg/m³

Particulate Matter also known as "Particle Pollution" is a complex mixture of extremely small particles and liquid droplets. Particulate Matter at 2.5 microns in size or smaller can be inhaled deep into the lungs and cause irritation and corrosion of the alveolar wall, which impairs lung function. They are also known to carry microbiomes.[19]

These particles are small enough to stay suspended in the air. A study conducted by Feng, Cindy et al published in the Journal of Environmental Health[13] showed an increased vulnerability to influenza-like illnesses when levels of $PM_{2.5}$ were above the ideal range. The data suggests that $PM_{2.5}$ stays airborne longer, creating a "condensation nuclei" which virus droplets attach to. These are then inhaled by people, resulting in infection.

Thus, it is best to keep your $PM_{2.5}$ levels low to minimize risk of infection.

PM_1

Ideal Range: Below 15µg/m³

PM_1 are ultra-fine particles that are smaller than 1 micron in size which may contain higher concentrations of toxic and harmful chemicals and pollutants such as carbon and heavy metals.[20] When a significant amount of these particles penetrate into the bloodstream, they can cause damage to the arteries and potentially spread to the cardiovascular tissues and other organs.

Similar to $PM_{2.5}$, PM_1 also stays suspended in the air and allow virus droplets to attach themselves onto it to travel further in the air. PM_1 is also closer to the size of virus particles; thus, readings above safe levels indicate a higher risk of viruses being present.

At worst, PM_1 also contributes to deadly diseases such as heart attacks, lung cancer, dementia, emphysema, and edema that can lead to premature death.

Carbon Dioxide (CO_2)

Ideal Range: Below 800ppm

Carbon Dioxide has long been used as an indicator of good indoor air quality primarily because of its association with ventilation. When carbon dioxide levels are high, it may indicate that your space is not well ventilated. Lack of ventilation restricts air flow and allows particles to stay suspended in the air much longer; thereby increasing your risks of inhaling these particles. Having adequate ventilation also means that you're able to properly circulate air, flush out particles in the air and bring in fresh air.

The ideal level of CO_2 is also needed to reduce the risk of lung inflammation.[21] Chronic inflammation caused by persistent high CO_2 levels is not ideal for your health. Moreover, longer exposure to high CO_2 can cause fatigue, headaches, and dizziness. It is also possible to develop hypercapnic acidosis[22], characterized by increased levels of carbon dioxide in the blood. This suppresses immune function and can make one more susceptible to disease and viruses.

Nitrogen Dioxide (NO_2)

Ideal Range: Below 53ppb

Nitrogen dioxide concentrations come from indoor sources such as stove fuel as well as outdoor sources such as emissions from cars and buses. A number of studies draw a strong correlation between nitrogen dioxide exposure and serious health effects - from respiratory infections to cardiovascular diseases. A study published in the National Library of Medicine showed that exposure to NO2 increases the susceptibility of adults to respiratory virus infections.[24]

How do these Parameters Differ from Standards

When it comes to dealing with viruses, the lower the risk the better. The thresholds set in uHoo's Virus Index are different from the default air quality safety thresholds set inside the uHoo platform, which is based on US EPA, the World Health Organization (WHO) and the Occupational Safety and Health Administration (OSHA) standards, among others. The uHoo Virus Index thresholds are based on specific environments, derived from scientific research conducted by governments, scientists, and universities, suitable for viruses to survive. It has stricter guidelines compared to the air quality safety thresholds set by the above mentioned organizations.

Virus Control and Mitigation Measures

2020 is the year that everyone in the world was drastically reminded of how critical indoor air quality is. As businesses start to open up, they need to ensure that they are operating in the best interests of their employees, customers, and the general public.

To minimize infection risk, control measures can be classified into three categories[25]:

Administrative

Detection, triage, information sharing, education and training, providing resources for proper indoor air quality management

Personal Protection

Wearing of masks or any protective device to prevent the inhalation and spread

Engineering & Environmental

Intervention measures such as improving air exchange rates, upgrading HVAC systems, and IAQ monitoring

Having a proactive and comprehensive IAQ management plan is particularly helpful, where an administrative officer or an IAQ officer can identify key performance indicators based on the needs and purpose of a building. **A good plan always starts with having baseline information to work on. You can only manage what you can measure. With an IAQ monitoring tool that measures your air quality continuously, you get real time data to proactively address potential threats to indoor air that may be harmful to the health and well-being of the people inside the building. This also ensures that the IAQ strategies that will be employed are specifically suited to the identified issues.**

Indoor air quality monitoring devices that can measure factors such as temperature, relative humidity, carbon dioxide, particulate matter the size of 1 micron and 2.5 microns, and nitrogen dioxide levels can help determine if your environment has a risk of virus survival and transmission. Being able to integrate into the HVAC system also helps your facility team easily manage and control without always relying on manual checking and third party assessments, which either take long or do not provide relevant data. Moreover, this makes it easier to institutionalize control measures as a normal part of building operations.

uHoo Business Solutions Help You Take Control and Ensure Safety

uHoo provides businesses with solutions that provide reliable data, insights and actions on air quality parameters that matter.

1. Provide hope

by detecting the risk of the coronavirus so that appropriate action can be taken to reduce risk, improve the environment, and create peace of mind.

2. Reduce anxiety

by making air quality measurements visible to stakeholders so that they can be empowered to participate and make informed decisions about where they work, live or play.

3. Enhance wellness

by monitoring and managing air quality to help create a healthy, safe, and comfortable environment.

4. Simplify Management

by providing a consolidated view of all your locations on one screen so that you can easily identify and address any air quality issues.

5. Reduce risk

by providing a real-time assessment of coronavirus and air quality risk so you can immediately take action to reduce any risk.

6. Integrate

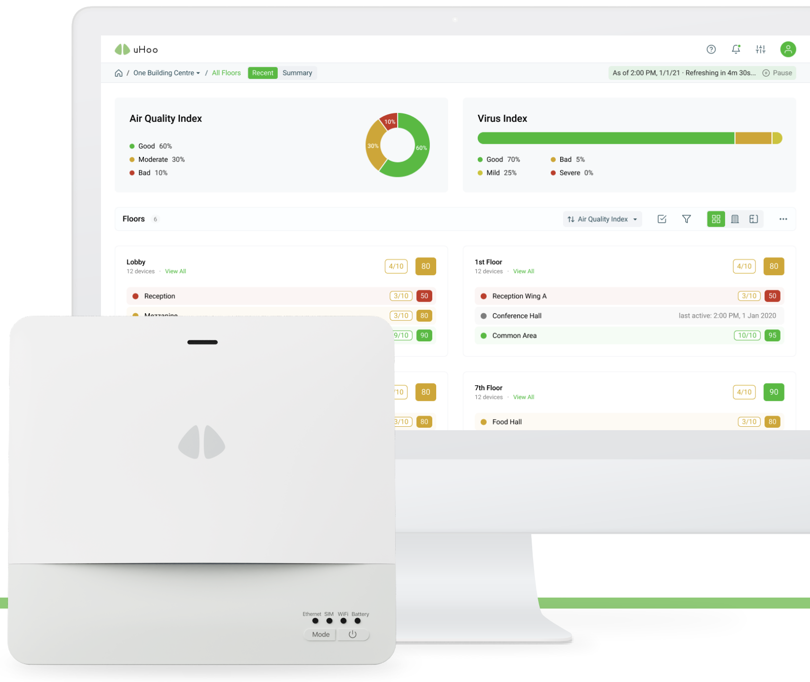
by easily connecting with your building's HVAC systems to automatically control and manage your heating, cooling, ventilation, and fresh air.

7. Reduce cost

by identifying and addressing air quality issues immediately to reduce absenteeism and sick days, and prevent wear and tear of your equipment.

8. Be informed

by having real-time access to all your air quality data, tips on how to improve your workplace, and case studies on how other customers have benefited.



Conclusion

Drawing on the above discussion, we find that there are many studies on viruses such as SARS-CoV-2 that could deepen our understanding of their nature in terms of survival and transmission in indoor environments. In the fight for health and safety, we believe that knowledge is a critical weapon. It is our aim to contribute to this end and to encourage everyone to keep abreast with developments. Diseases can spread wherever people have direct or indirect contact so it is always prudent to follow general recommendations on hygiene procedures, the use of personal protective equipment, and physical distancing. Building code requirements - as well as enforcement - can also be significantly improved to include more stringent health and well-being standards.

Taking care of your air quality and making sure it is at optimal levels increases virus inactivation and helps to keep your immune system healthy. Knowing how to fight an invisible enemy using uHoo allows you to make educated decisions about health and measure the impact of your actions.

The uHoo Virus Index and all parameters that uHoo measures give you the ability to know what action to take to maintain a healthy indoor environment. Taking care of the space where we work and live, by keeping air quality healthy, is more than just for our own benefit, it's also about saving lives.

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