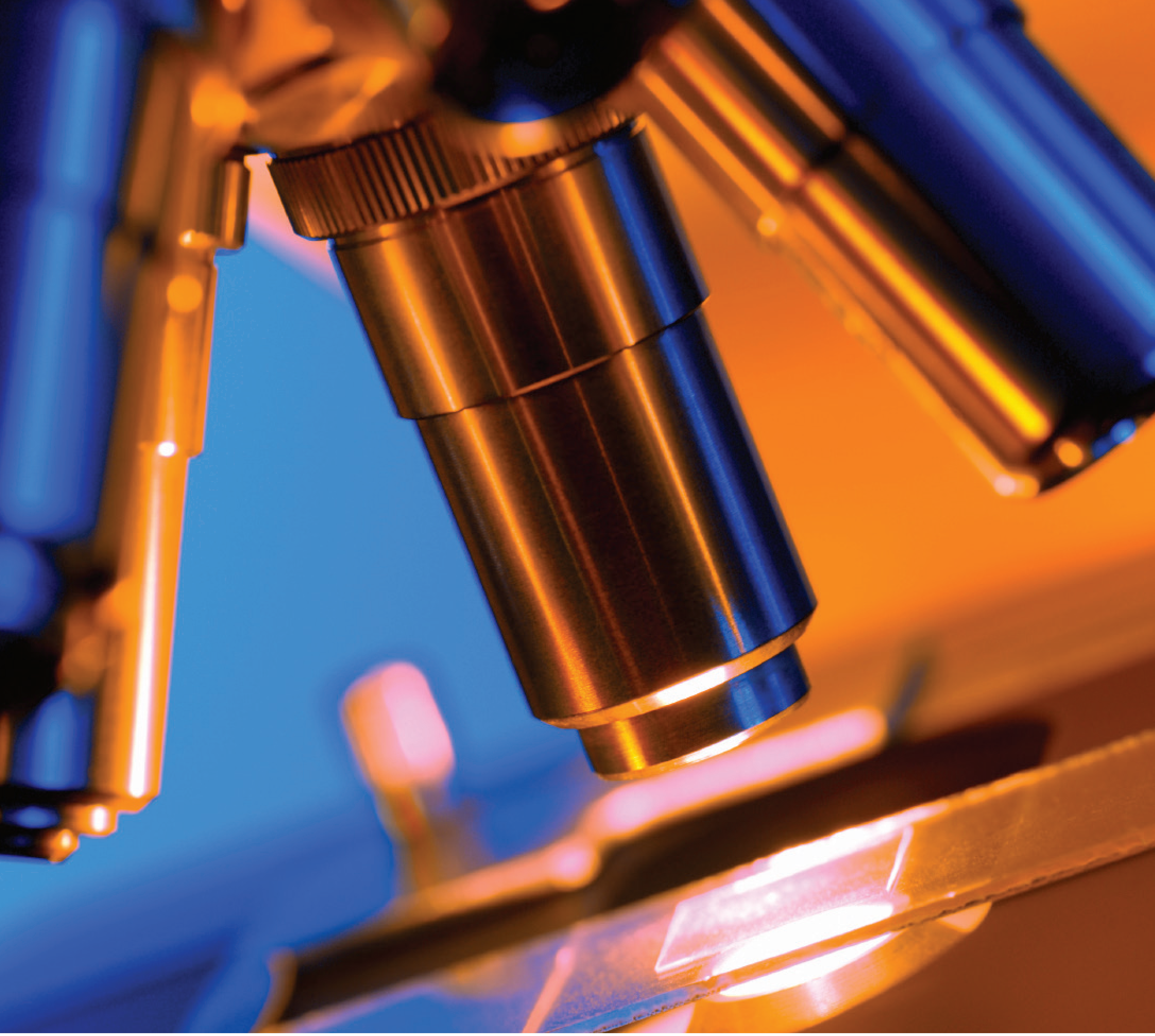

COVID-19 and IEQ in the Built Environment

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PARKHILLSMITH&COOPER

ABSTRACT

Buildings have had a measured impact on occupant health for several decades. Depending on the infrastructure systems and operation of the building, the impact can be positive or negative. One of the biggest factors affecting health is indoor air quality.

The World Health Organization (WHO) declared a health epidemic caused by the novel coronavirus (SARS-CoV-2), known to cause the disease COVID-19, on March 11, 2020. Research on commonly acquired viruses such as influenza, human coronavirus, and human respiratory syncytial virus (RSV) has shown that factors such as temperature and humidity can affect the transmission of the virus. Additional research has shown that ventilation systems can transfer contaminated particles within buildings.

This article reviews the research concerning how indoor environmental quality can limit the transmission of communicable diseases. Further discussion establishes strategies to control the indoor environment and protect occupants. By performing a risk assessment of a facility, potential concerns can be identified and counteracted with a strategy to mitigate the transmission of a virus.

EMERGENCE OF COVID-19

In December 2019, the first case of the novel coronavirus (SARS-CoV-2) was confirmed in Wuhan, Hubei Province, China. As of April 30, 2020, over three million cases have been confirmed globally with a death toll exceeding 230,000.[1] While many who become infected with the virus suffer mild symptoms like the common cold or influenza, a smaller population contract the respiratory disease COVID-19.

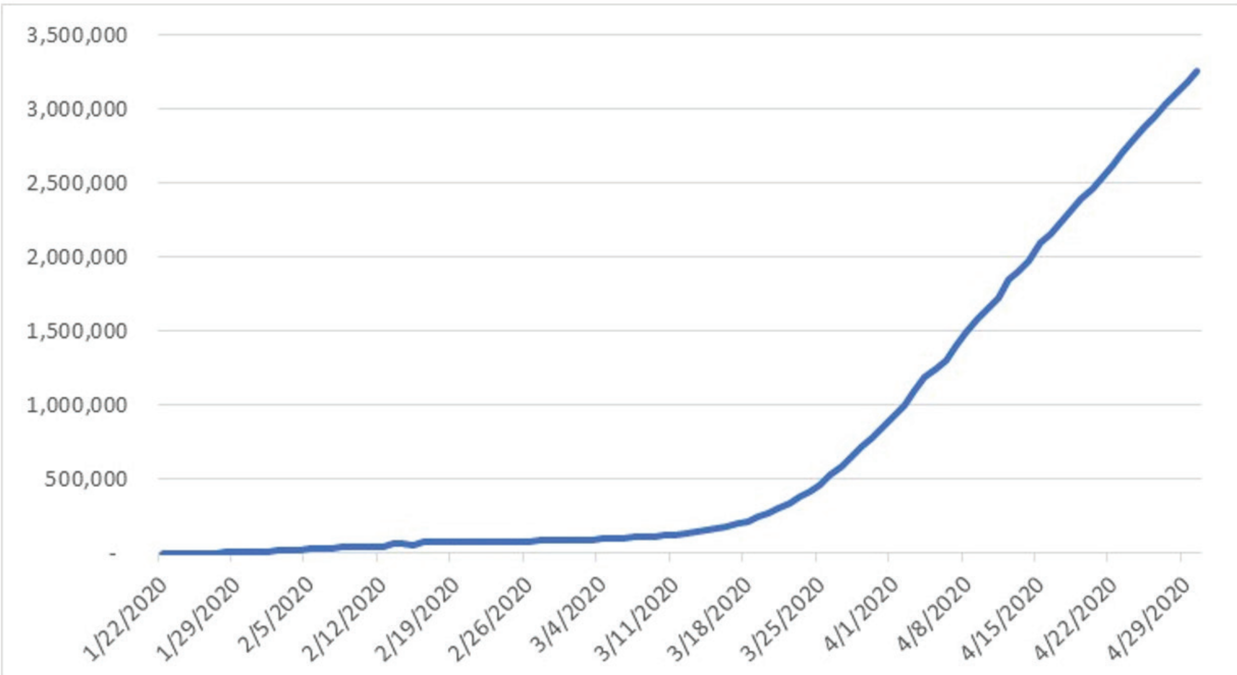

Figure 1 - Global Progression of COVID-19 Cases

A previous pandemic of coronavirus occurred in Asia during the 2003-2004 SARS (severe acute respiratory syndrome) outbreak. Classified as SARS-CoV-1, the virus affected 26 countries with 8,000 known confirmed cases.[2]

COVID-19 is referred to as the novel coronavirus because it is a new strain of the virus. Symptoms include fever, cough, fatigue, and difficulty breathing, which have the potential to develop into pneumonia in severe cases. Around one in five people who catch the virus require hospital treatment. Without a developed vaccine, daily life has been disrupted for countries in North America, Europe and Asia.

The most effective method to reduce transmission of the virus is isolation. School districts, community colleges, and universities have resorted to online distance learning. Several businesses have adapted to allow employees to work from home. Restaurants have transitioned to providing only take-out and delivery options while also directly selling their inventory.

COVID-19 is a communicable disease, meaning it can spread from person to person, as indicated in Figure 2. According to the World Health Organization (WHO), transmission occurs when someone who has COVID-19 coughs, sneezes, or exhales, which releases droplets of infected fluid.[3] Larger droplets attach to nearby surfaces such as walls, desks, chairs, or phones and can remain active for as long as three days. An uninfected person who touches infected surfaces and then touches their face, particularly their eyes, nose, or mouth, has a high risk of contracting the virus. Smaller particles that do not attach to hard surfaces remain airborne and can be active for up to three hours in indoor air.

After the SARS outbreak, Dr. Yuguo Li of the University of Hong Kong documented that airborne particles were transmitted through the building ventilation systems causing additional building occupants to become infected.[4] Although COVID-19 has not been documented to transmit in this manner, it is believed to be likely.

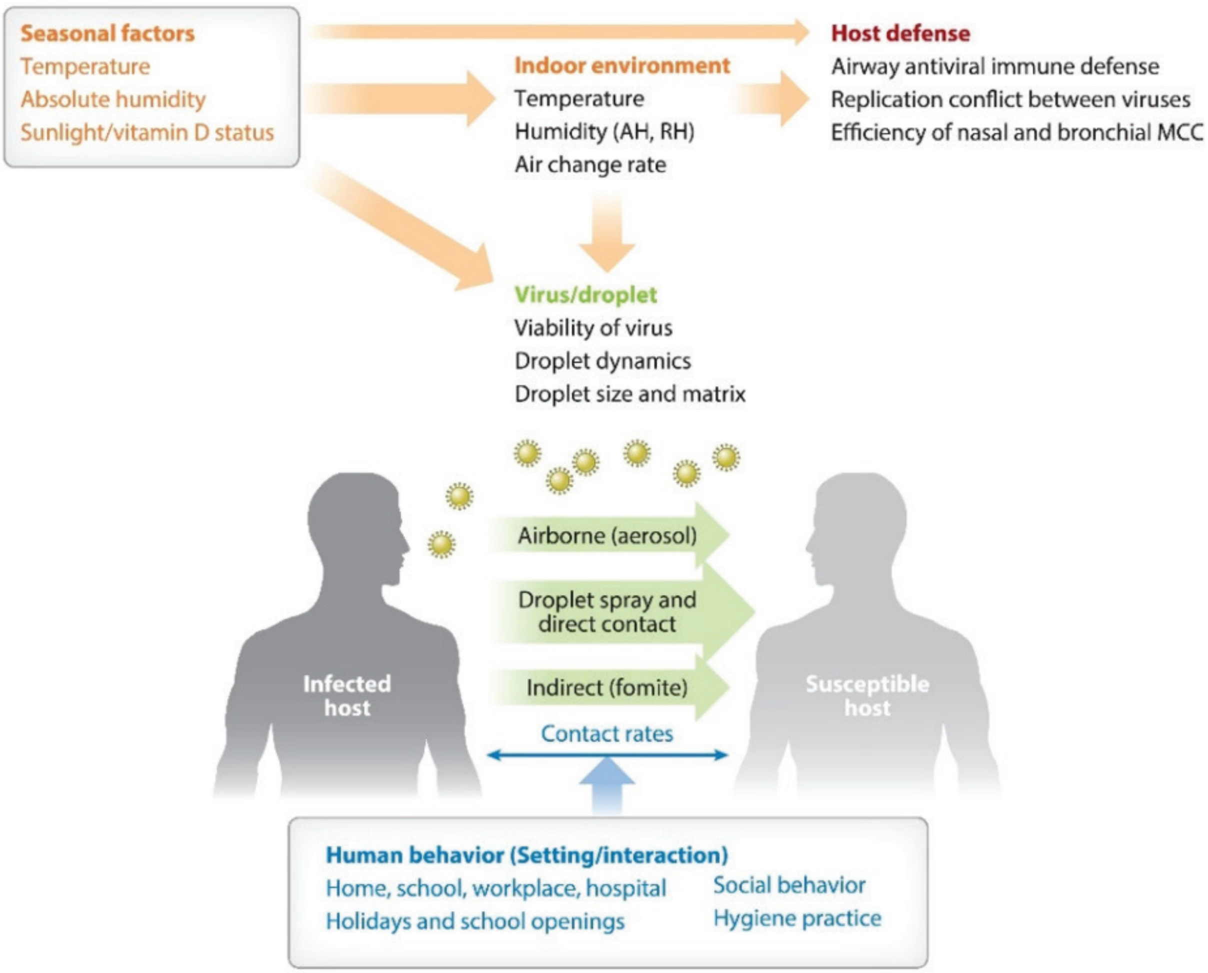

Figure 2 - Factors that Affect Virus Transmission [5]

GUIDING PRINCIPLES FOR WORKPLACES

In March 2020, the Occupational Safety and Health Act (OSHA) developed guiding principles for businesses to prepare workplaces in response to COVID-19. [6] Types of facilities are classified based on occupant exposure to the virus as described in Figure 3.

Figure 3 - OSHA Occupational Risk Pyramid

- ***Very High Exposure Risk:*** Healthcare workers (doctors, nurses, dentists, paramedics, and emergency medical technicians), healthcare or laboratory personnel, and morgue workers performing autopsies.
- ***High Exposure Risk:*** Healthcare delivery and support staff (doctors, nurses, and hospital staff) who must enter patient rooms, medical transport workers (ambulance operators), and mortuary support staff.
- ***Medium Exposure Risk:*** Jobs that require frequent and/or close contact with the public in areas where there is ongoing community transmission, including schools, high population density work environments, and high-volume retail settings.
- ***Lower Exposure Risk:*** Workers who have minimal contact with the general public and other coworkers.

OSHA further describes implementing workplace controls for each risk category by using a "hierarchy of controls" framework. OSHA indicates the best way to control a hazard is to remove it. If it is not possible to remove the hazard, the hierarchy suggests methods to control the hazard, starting with the most effective means to the least effective means. Typically, a combination of control measures is necessary to prevent workers from exposure. This hierarchy for workplace controls is described below:

1. ***Engineering Controls:*** Installing high-efficiency air filters, increasing ventilation rates in the work environment, installing physical barriers, and specialized negative pressure ventilation.

2. ***Administrative Controls:*** Encouraging sick workers to stay home, minimizing human contract, establishing alternating shifts, discontinuing nonessential travel, etc.
3. ***Safe Work Practices:*** Providing resources and a work environment that promotes personal hygiene and requires regular hand washing.
4. ***Personal Protective Equipment (PPE):*** Gloves, goggles, face shields, face masks, and respiratory protection.

Depending on the category of risk exposure, the recommended workplace controls vary. The lower risk exposure category does not recommend that any engineering controls be put in place. Most buildings and occupants fall into the medium exposure risk category. OSHA only recommends installing physical barriers such as plastic sneeze guards to protect cashiers and customer service individuals or installing drive-thru lanes for customer service if feasible. Even though increased filtration and increased ventilation is primarily focused on the high and very high-risk exposure categories, these measures should still be considered for the buildings in the medium-risk category.

VIRUS RELATIONSHIP BETWEEN TEMPERATURE AND HUMIDITY

Due to the relatively short span that COVID-19 has been in existence, experts still do not fully understand how the virus interacts with its environment. Additionally, the virus has only been observed in the winter months. Spring months are just beginning, and no one knows how summer temperatures might affect virus transmission. Research performed as of April 2020 has shown COVID19 to have similar transmission factors as seasonal mannerisms like the influenza (H1N1) virus.

A recent study conducted by Beihang University and Tsinghua University in Beijing, China, recorded ambient temperature and absolute humidity at locations in 100 Chinese cities containing more than 40 cases of COVID-19 that experienced new cases between January 21 and 23, 2020.[7] The purpose of the study was to explore how temperature and humidity might affect transmission of the virus. During the study, researchers were able to calculate a daily effective reproductive number, R, for each of the study cities.

The evaluation determined that a subtle 1.8°F (1°C) rise in temperature and one percent increase in relative humidity could lower the effective reproductive number. The research team took the same relationship between temperature and relative humidity examined in China and applied it to cities outside of the country to develop a worldwide model based on the recorded average temperature and relative humidity documented in March 2019 to forecast the reproductive rate for March 2020. The results are shown in Figure 4 below.

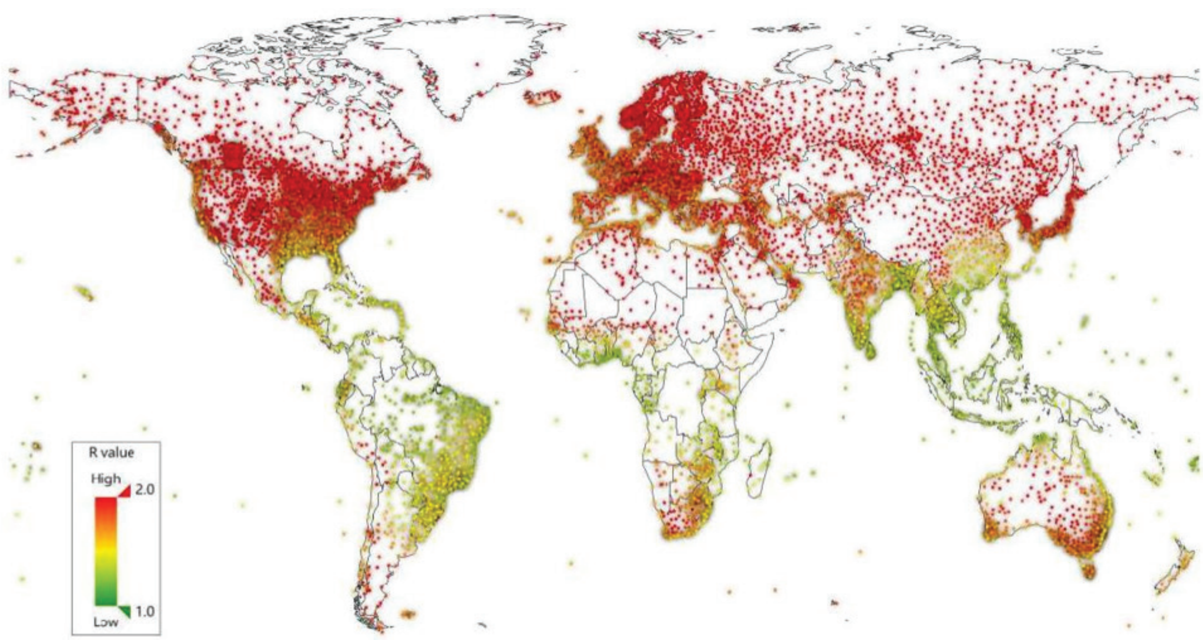

Figure 4 - March 2020 Effective Reproductive Value Forecast Model

The research team further applied the same principles described above to forecast the effective reproductive number in July 2020 as shown in Figure 5 below.

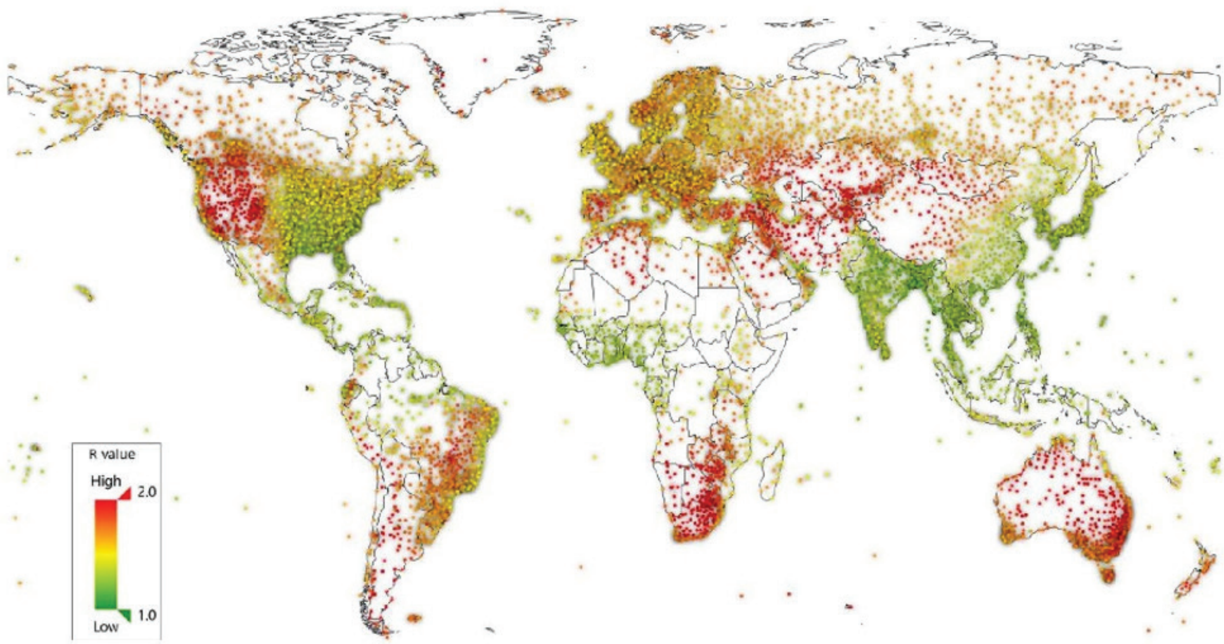

Figure 5 - July 2020 Effective Reproductive Value Forecast Model

The forecast model depicted in Figure 4 indicates areas that would see a higher transmission rate due to northern hemisphere winter temperatures. The forecast model was consistent with the rapid increase in cases identified in the United States and European countries documented at the Johns Hopkins University of Medicine Coronavirus Resource Center.[1] The forecast model shown in Figure 5 indicates that the transmission of cases should slow as warmer weather becomes more prevalent in the northern hemisphere. However, the model also shows areas with arid climates will still be at risk of continuing a steady transmission of the virus.

The research team concluded that there were two likely reasons for this finding. First, colder air temperatures have been known to allow viruses to be more stable, as is consistent with the influenza virus. Respiratory droplets, which contain the virus, can remain airborne longer in dry air. Secondly, a host's immune system can be weakened by colder, dry air to make an individual more susceptible to a virus. If the effective reproductive number behaves as indicated in Figure 5 during the summer months, it is likely the COVID-19 virus will also be seasonal.

Unfortunately, the weather and external elements cannot be controlled. Indoor environmental parameters can be controlled. As previously indicated, the transmission pattern for COVID-19 behaves like the influenza virus. While not a member of the coronavirus family, influenza is also a respiratory virus with similar symptoms. The influenza virus first emerged in 1918 in military personnel during World War I and has caused multiple pandemics, most recently in 2009.

With the continued seasonal transmission of the influenza virus, numerous studies have endeavored to understand its transmission better. A 2015 study by the Centers for Disease Control (CDC) on various animals under laboratory conditions concluded that 50% indoor relative humidity is ideal to limit the transmission of the influenza virus. Studies on ferrets and guinea pigs showed that the influenza virus transmission was much higher below 30% relative humidity and above 65% relative humidity.[5] At temperatures lower than 40°F (5°C), the transmission rate remained high regardless of the increase in humidity. The ideal conditions for reducing transmission of the virus were at 68°F (20°C) and 50% percent indoor relative humidity.

The above conditions are observed to be ideal for a host airway antiviral defense, including mucus production and airway integrity. These findings appear to be consistent with the Sterling Chart, indicating optimum relative humidity ranges for health, in Figure 6 below.

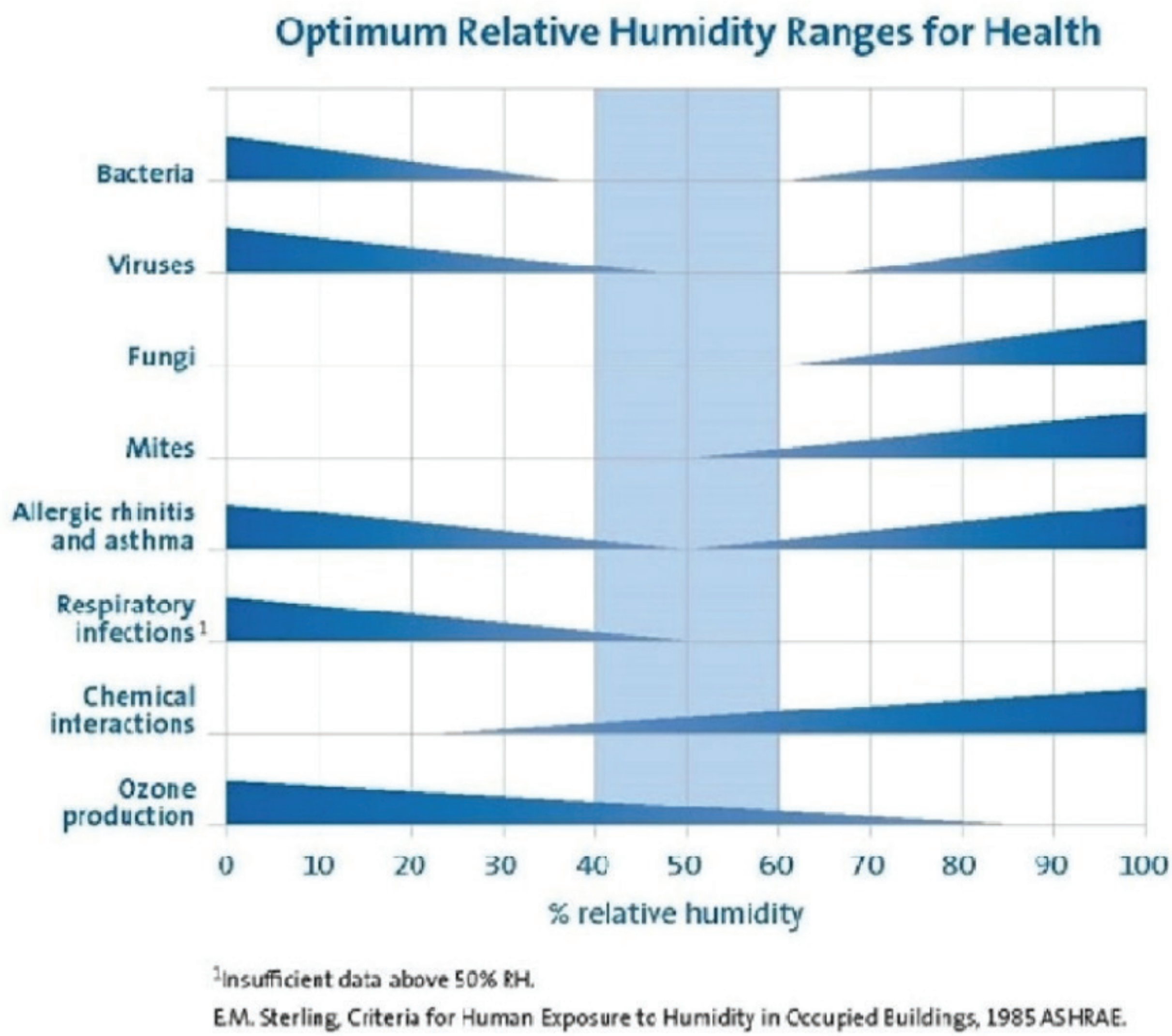

Figure 6 - The Sterling Chart – Optimum Relative Humidity for Health

BUILDING VENTILATION

In 1974, a young girl attending school in Upstate New York began showing measles symptoms. She was only in her classroom for a few hours, and even though 97% of the students in the school were vaccinated, 28 students spread across 14 classrooms contracted the disease.[8] Why? The ventilation system recirculated air throughout the school, introducing minimal outside air into the building.

Based on the knowledge that COVID-19 respiratory droplets have been confirmed to survive in the air for at least three hours and that the droplet size is capable of being transferred by air moving equipment, special attention needs to be placed on proper building ventilation. Studies have shown that poorly ventilated areas can be responsible for transmitting a virus, especially when the air temperature is dry. A recent study by Hokkaido University in Sapporo, Japan, analyzed superspreading events that showed how closed environments with minimal ventilation contributed to a characteristically high number of secondary infections.[9]

Most people interact, work, sleep, commute, and spend 90% of their lifetime in enclosed spaces.[10] This implies that most person-to-person transmission events happen indoors. Both the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the Federation of European Heating, Ventilation and Air Conditioning Association (REHVA) have suggested that increasing ventilation in buildings is necessary to help combat the virus within a building. In buildings without a ventilation system, these entities recommend using operable windows to increase the amount of fresh air for occupants. REHVA even recommends using operable windows in buildings with ventilation systems when possible.[11]

REHVA further recommends that recirculating air systems not be used during a pandemic. This includes closing return air dampers and introducing only outside air into buildings. While this might work in some situations, many heating and air conditions systems are designed so only a minimal amount of fresh air is introduced and are not sized to handle 100% fresh air. This could lead to occupant comfort problems but is recommended to protect public health.

ASHRAE is currently reviewing the amount of optimal outside air per occupant and is expected to release guidance later this year. One approach for ventilation is extending the period of ventilation. Building management systems typically do not allow outside air to be introduced into the building until the time it is occupied and continues to allow outside air until the time the building is no longer occupied. By introducing outside air two hours before the building is occupied and two hours after it is unoccupied, the ventilation system can be flushed to help eliminate contaminants that may have appeared during occupation.

AVAILABLE STRATEGIES

Based on the conclusion that indoor temperature, relative humidity, and outdoor air ventilation can reduce virus transmission, there are several technologies available to optimize indoor environments. However, be cautious since technology is rarely a simple plug-and-play configuration.

Building Humidification

Research implies that maintaining indoor relative humidity close to 50% can limit transmission of viruses. Although there is no evidence to suggest that this weakens COVID-19 stability, there is evidence that it indirectly supports antiviral defense.

Many areas of the United States do not suffer from a lack of high outdoor relative humidity during most of the year. Several mechanical systems are designed to remove humidity from the indoor environment rather than introduce it. However, this is not typically the case during the winter months when respiratory viruses seem to be more prevalent. Additionally, as shown by Figure 5 above, locations with arid outdoor conditions during the summer months have the potential to have a higher effective reproductive number.

The introduction of humidification directly into spaces or indirectly through the building ventilation system might reduce the transmission of the virus. However, be advised that humidifiers will cause an increase in energy costs as well as maintenance and operational costs. A water quality analysis should be performed to determine if any treatment should be provided to the water used by the humidifier to extend the life of the equipment. Additionally, inhabitants living in arid, dry climates may have become normalized to the environmental conditions. Introducing moisture into interior spaces to achieve the optimum range of 40-60% relative humidity may cause residents to feel uncomfortable.

Ultraviolet Germicidal Irradiation (UVGI)

Many people are familiar with the effects of ultraviolet (UV) radiation; prolonged exposure to the sun causes a sunburn or potentially skin cancer without protection. Exposure to UV lights destroy cells by causing thymine bases in the cell's DNA to interact and form a dimer, a form of intermolecular bond, which is then removed by the DNA's own correction mechanisms.[12] By continued exposure to the UV light, the chance that these mechanisms incorrectly replace or do not replace the dimer, increase. This can eventually lead to the death of the cell.

Viruses are not able to reproduce on their own, but they do contain genetic material such as DNA and RNA, allowing the virus to reproduce by attaching to host cells and injecting their DNA. A team at Columbia University explored the possibility of UV lights preventing microbial diseases.[13] A UV light emitting a C wave of 222 nanometers was used to effectively kill an airborne H1N1 influenza virus in an aerosol UV irradiation chamber, which emitted droplets in the air similar to those produced by humans from coughing and breathing. The study concluded that small quantities of UV-C light in indoor public spaces would be a safe and economical tool to target airborne microbial viruses.

Using UV-C lights in air handling unit systems has gained popularity in the healthcare industry. Schools have also begun to adopt the technology to enhance indoor air quality. While retrofit kits are available for air handling unit systems, it is optimal to size equipment to house the UV lights to maintain the proper distance between components and meet the electrical requirements. It is also recommended to include a safety switch so exposure to the UV-C light does not occur when equipment panels are removed. Additionally, if humidifiers are used as described in the section above, the integrity of the UV-C light can be compromised.

Air Filtration

HVAC systems of commercial buildings are not typically engineered to remove biological contaminants such as airborne bacteria or viruses effectively. Air filters are rated by the Minimum Efficiency Reporting Value (MERV). MERV ratings are assigned to filters based on testing criteria listed in ASHRAE Standard 52.2.[14] The system ranges in scale from one to twenty. The higher the MERV number, the more efficient the filter. The standard for commercial buildings is a MERV 8 filter, which is 30-35% efficient.

To capture droplet nuclei, such as discharge from a sneeze, a MERV 13 filter (90% efficient) is the minimum accommodation necessary. Increases in efficiency are available but not necessary for commercial buildings. Hospital inpatient care recommends MERV 15, general surgery recommends MERV 16, and cleanrooms recommend MERV 20 to manage higher risk environments.

Unfortunately, switching out filters is not as simple as it sounds. The media of a more efficient filter is denser, which allows it to capture smaller contaminants. This creates an increase in air pressure drop across the filter, which the fan system must work to overcome. If the fan is not properly sized for the higher static pressure, a loss of airflow could occur, which could produce additional problems in the system.

Standard 52.5 Minimum Efficiency Reporting Value	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
20	n/a	n/a	< 0.30 pm particle size	Cleanrooms	>99.999% eff. On .10-.20 pm Particles
19	n/a	n/a	Virus (unattached)	Radioactive Materials	Particles
18	n/a	n/a	Carbon Dust	Pharmaceutical Man.	Particulates
17	n/a	n/a	All Combustion smoke	Carcinogenetic Materials	>99.97% eff. On .30 pm Particles
16	n/a	n/a	.30-1.0 pm Particle Size	General Surgery	**Bag Filter**- Nonsupported microfine fiberglass or synthetic media, 12-36 in. deep, 6-12 pockets **Box Filter**- Rigid Style Cartridge Filters 6 to 12" deep m ay use lofted or paper media.
15	>95%	n/a	All Bacteria	Hospital Inpatient Care	
14	90-95%	>98%	Most Tobacco Smoke	Smoking Lounges	
13	89-90%	>98%	Proplet Nuceli (Sneeze)	Superior Commercial Buildings	
12	70-75%	>95%	1.0-3.0 pm Particle Size	Superior Residential	**Bag Filter**- Nonsupported microfine fiberglass or synthetic media, 12-36 in. deep, 6-12 pockets **Box Filter**- Rigid Style Cartridge Filters 6 to 12" deep m ay use lofted or paper media.
			Legionella		
11	60-65%	>95%	Humidifier Dust	Better Commercial Buildings	
			Lead Dust		
10	50-55%	>95%	Milled Flour		
			Auto Emissions	Hospital Laboratories	
9	40-45%	>90%	Welding Fumes		
8	30-35%	>90%	3.0-10.0 pm Particle Size	Commercial Buildings	**Pleated Filters**- Disposable, extended surface area, thick with cotton-polyester blend media, cardboard frame
			Mold Spores		
7	25-30%	>90%	Hair Spray	Better Residential	**Cartridge Filters**- Graded density viscous coated cube or pocket filters, synthetic media
			Fabric Protector		
6	<20%	85-90%	Dusting Aids	Industrial Workplace	**Throwaway**- Disposable synthetic panel filter.
			Cement Dust		
5	<20%	80-85%	Pudding Mix	Paint Booth Inlet	
4	<20%	75-80%	>10.0 pm Particle Size	Minimal Filtration	**Throwaway**- Disposable fiberglass or synthetic panel filter.
			Pollen		
3	<20%	70-75%	Dust Mites	Residential	**Washable**- Aluminum Mesh
			Sanding Dust		
2	<20%	65-70%	Spray Paint Dust		
			Textile Fibers	Window A/C Units	**Electrostatic**- Self charging woven panel filter.
1	<20%	<65%	Carpet Fibers		

Figure 7 - ASHRAE Standard 52.2 Filter Ratings

Air Purification Systems

Air purification systems have been increasing in popularity, particularly in buildings that have a lower rate of fresh air in the ventilation system. These systems can collect particles much smaller than standard filers and are used to mitigate high levels of mold spores, pollen, virus, bacteria, volatile organic compounds (VOCs), and smoke. There are two methods that these systems use.

The first method is through bipolar ionization. A series of tubes are used to provide a charge to particles passing through the air, which creates a bipolar (both positive and negative) charged particle. This causes the particle to attach to larger, heavier particles to increase its weight, so the particles either fall to a surface or are captured in the ventilation system air filters.

The second method uses air scrubbers equipped with UVGI lights and coated media pads to oxidize the particles into hydrogen and oxygen.

The benefit to these systems is that they can be retrofitted into existing ventilation systems or can be purchased as portable units with the flexibility to be located in different areas of a building.

Chilled Beams

Due to the impact that air recirculation can have on transmitting particles between spaces in a facility, passive chilled beam systems have become a seriously considered option for building cooling systems. Passive chilled beam systems use induction to draw warm air across a coil using gravity and air buoyancy. This system does not supply primary air to the building, does not have a ductwork system, and is not supplied with a fan.

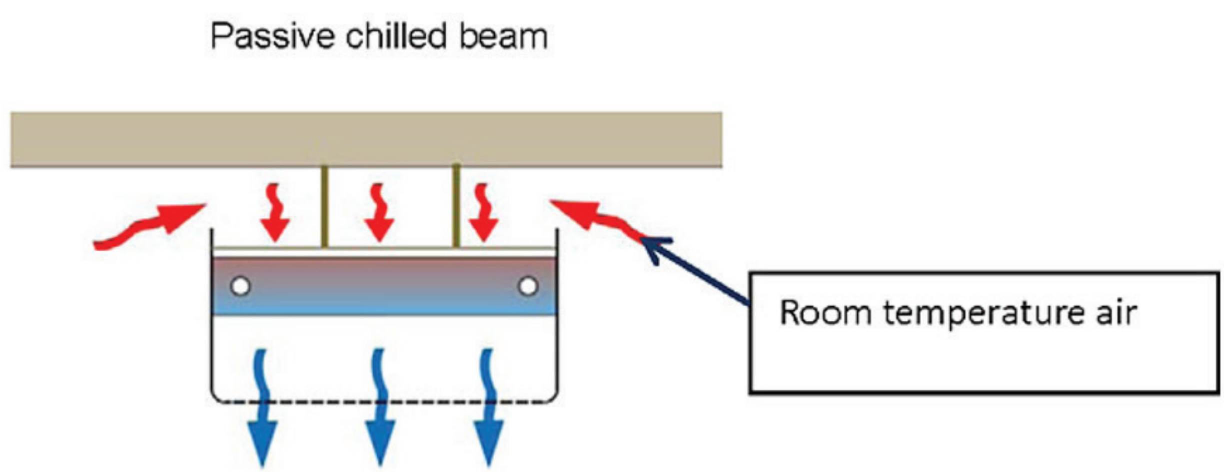

Figure 8 - Passive Chilled Beam Diagram

A separately operated heating system and a dedicated outside air system is important to be provide with this approach. This system requires a controlled temperature environment to ensure that the dew point temperature in the space does not reach the temperature of the coil, which would cause condensation to occur. It is also beneficial that air movement within the space is only provided through the outside air ventilation system, which will assist in removing contaminants.

CONCLUSION

As the world begins to ease restrictions for working from home and large crowds are allowed to gather, increased importance will be placed on indoor environmental quality. The future is unknown as to how COVID-19 will react throughout the summer months or if a rebound effect will occur when cooler temperatures return, as is common with viruses such as influenza. Nor is it known when a new virus will emerge with equal or more devastating ramifications.

While several strategies can optimize indoor environmental conditions to reduce virus transmission, it can be a daunting task to determine the best path forward. A proactive first step is to have a risk assessment performed. This includes a holistic assessment of the building ventilation system, outside air delivery, filtration effectiveness, indoor temperature/humidity conditions, and potential cross-contamination concerns. This exercise generates strategies to help mitigate future risks and create healthier indoor environments.

REFERENCES

1. Johns Hopkins University of Medicine Coronavirus Resource Center. Retrieved April 30, 2020. https://www.coronavirus.jhu.edu/map.html
2. World Health Organization. SARS (Severe Acute Respiratory Syndrome). https://www.who.int/ith/diseases/sars/en/
3. World Health Organization. (2020) Getting your workplace ready for COVID-19. https://www.who.int/docs/default-source/coronaviruse/getting-workplace-ready-for-covid-19.pdf?sfvrsn=359a81e7_6
4. Li, Dr. Yuguo, et al. (2007) Role of ventilation in airborne transmission of infectious agents in the built environment – a multidisciplinary systematic review. Blackwell Munksgaard Journal Compilation.
5. Iwasaki, Dr. Akiko, et al. (2020) Seasonality of Respiratory Viral Infections. Annual Review of Virology, 17(1), 2-18.
6. OSHA. (2020) Guidance on Preparing Workplaces for COVID-19. OSHA 399003 2020.
7. Wang, Jingyuan. (2020) High Temperature and High Humidity Reduce the Transmission of COVID-19. Beihang University.
8. Allen, Dr. Joseph G. (2020) Your Building Can Make You Sick of Keep You Well. New York Times. Retrieved April 12, 2020. https://www.nytimes.com/2020/03/04/opinion/coronavirus-buildings.html
9. Nishiura, Dr. Hiroshi, et al. (2020) Closed Environments Facilitate Secondary Transmission of Coronavirus Disease 2019. National Institute of Public Health.
10. SHRAE. (2020) ASHRAE Position Document on Airborne Infectious Diseases. Retrieved April 12, 2020. https://www.ashrae.org/file%20library/about/position%20documents/airborne-infectious-diseases.pdf
11. REHVA. (2020) REHVA COVID-19 Guidance Document.
12. Saffern, Devorah. (2018) UV Light: A New Tool for Disease Prevention. Princeton Public Health Review. Retrieved May 12, 2020. https://pphr.princeton.edu/2018/01/28/uv-light-a-new-tool-for-disease-prevention/
13. Welch, David, et al. (2017) UVC Light: A new tool to control the spread of airborne-mediated microbial diseases. Center for Radiological Research. Columbia University. https://www.biorxiv.org/content/biorxiv/early/2017/12/28/240408.full.pdf
14. ASHRAE (2017) ASHRAE Standard 52.2 Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size

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