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Guide to Creating Healthy Environments:
Building Systems & Technologies

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Optimizing building systems is a long-term effort to test and refine operational practices, technologies, and their effects. However, a collection of best practices for improving indoor environmental quality has been established by organizations such as ASHRAE and various building certification standards. A growing body of research is also emerging with recommendations for protecting occupant health as well as facilitating resilience and recovery. There are six primary areas related to building systems we can identify to ensure occupant health and safety:

VENTILATION AND AIR TREATMENT / AIR MONITORING / PLUMBING FIXTURES
INTERNAL TRANSPORTATION SYSTEMS / TOUCHLESS DEVICES / HEALTHY BUILDING PROGRAMS

The following pages provide some detailed information on each of these areas. This information intends to provide strategies that address conditions similar to the coronavirus (SARS-CoV-2) pandemic we are currently experiencing, as opposed to addressing factors related exclusively to this specific virus. As we look forward, healthy environmental design should address many factors, and the current pandemic is a learning experience for all of us that will inform how we design safe and healthy buildings in the future.

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VENTILATION AND AIR TREATMENT

In addition to eliminating proximity transmission, delivering outside air, and treating re-circulated air are the most effective systems-based interventions to protect indoor air quality and minimize the spread of pathogens. Modifications to existing building systems should not be made without the consultation of a qualified architect, engineer, or AE. **Strategies to consider for ventilation and air treatment include:**

Increasing the supply of outside air either at HVAC units or within individual spaces while reducing recirculated air.

- Increasing outside air dilutes pollutants and can help reduce the concentration of pathogens in recirculated air, thereby reducing the risk of infection.

- New buildings are likely to see changes in HVAC systems' design with a priority to maximize fresh air and reduce recirculation without reducing air changes. Radiant cooling with direct outside air is one of the most efficient options to maximize fresh air, but such strategies must overcome challenges of regional climate. Control of indoor dewpoint is critical when applying radiant cooling to prevent units from sweating.

- Existing facilities have a limit on the rate of outside air that can be introduced when the outside air is at peak design summer and winter conditions but can still maximize the amount of outdoor air as a fraction of total air. For all days below design day conditions, outside airflow can be increased while meeting heating and cooling loads. Importantly, this strategy can be implemented immediately and does not necessarily require an alteration of existing systems. However, there is also the possibility of retrofitting HVAC units to increase fresh air capacity or to introduce economizers. In some circumstances for existing buildings, more HVAC tonnage can be made available for cooling increased outdoor air requirements by reducing the building's internal loads (i.e., LED light retrofits, Energy Star appliances, automatic shading). By lowering the internal loads, the tonnage can be shifted to cool the increased outdoor air. Any change to an HVAC system should include proper re-balancing of the system.

- Owners and operators should be aware that increased ventilation can result in increased energy use required for the conditioning of outside air and maintenance costs through more frequent filter replacement (assuming longer running time). Owners and operators can weigh whether these costs are worthwhile to incur temporarily during periods of heightened concern about the presence of pathogens indoors.

- During the peak of a pandemic and in conjunction with other measures designed to maximize fresh air and manage the presence of pathogens, demand-controlled ventilation systems are recommended to be disabled temporarily. Outside air capacity should also be maximized on air handlers, until such time that viral infections cease to exist as an immediate threat.

- Energy Recovery units that utilize rotary air to air enthalpy wheels may also be bypassed temporarily, until such time that viral infections cease to exist as an immediate threat, or filtration increased to MERV 13 ahead of the recovery device. These actions would minimize cross-contamination (exhaust volumes must always be maintained, however - and potential humidity issues always addressed). Note that ASHRAE Technical Committee 5.5 has released Practical Guidance for Epidemic Operation of Energy Recovery Ventilation Systems that operators may refer to before modifying existing energy recovery units.

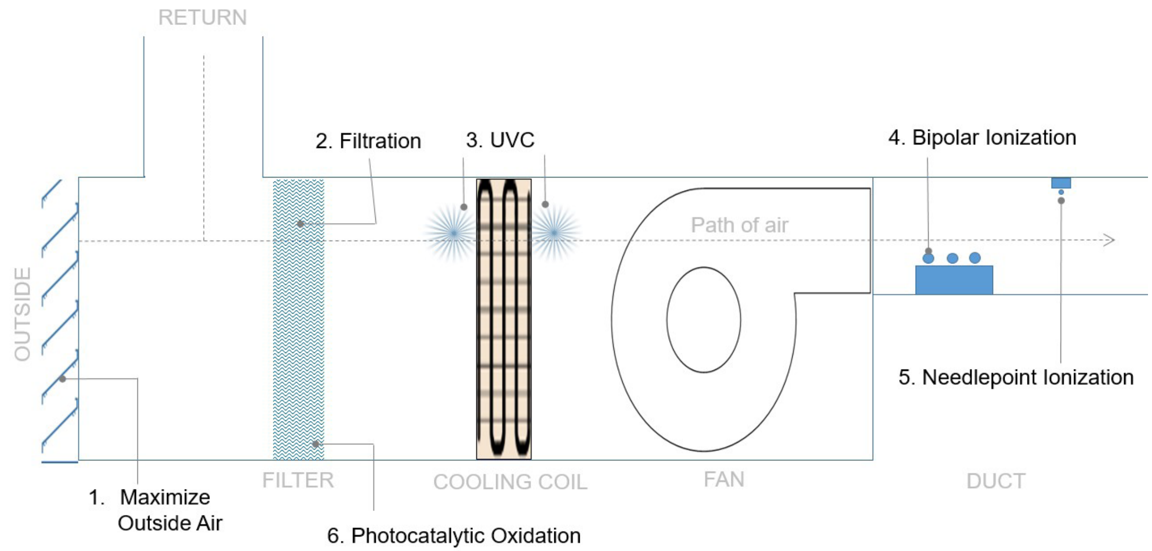
- Efforts to increase airflow concurrent with increasing the proportion of outside air in the space are likely beneficial. Strategies such as leaving conference room doors open can help protect the air quality of smaller enclosed rooms or densely occupied areas.

■ HVAC Compartmentalization: Instead of designing large HVAC air systems, one could compartmentalize the HVAC system into smaller air systems to prevent a virus from being spread to the entire building through large (building-wide) air systems. A floor-by-floor approach, instead of a full-building system approach, should not be an uncommon consideration.

■ Restroom exhausts should continuously run due to pathogens and the possibility of transmission through aerosolized droplets produced by the flushing of toilets. If any building exhaust is discharged to potentially occupied outdoor areas, additional filtration or sanitation might be necessary to protect people immediately outside the building.

■ If available, operable windows are the most effective means to deliver fresh air. They significantly increase the ratio of outside air to recirculated air and avoid increased demand on the mechanical ventilation systems. Considerations should be made as to whether opening windows is a security or functional concern. The strategy should be utilized when outside air conditions are favorable for temperature and humidity control inside the building. Retrofitting fixed windows with operable ones could come at a significant cost. This cost can be minimized by targeting windows in densely occupied and especially high-risk spaces where higher levels of outside air are especially important.

■ Caution should be used opening windows in restrooms since doing so can disrupt pressurization designed to contain and exhaust pollutants within restrooms. The use of operable windows can also potentially cause condensation issues depending upon weather conditions.



▲ **Treatment of Air at HVAC Units**

■ Additional protective measures to introduce more outside air include performing daily flush outs by increasing ventilation to 100% outside air (or maximum available building supply) for at least two hours prior to the introduction of occupants and continuing for two hours after building operations have ended. Ventilation can be maintained at lower levels through nights and weekends, even if the building is unoccupied. This might require extensive modifications to existing systems. Additionally, ASHRAE has suggested that running an HVAC system 24/7 is another strategy to dilute contaminants. It should be noted that while this protective measure increases the ability to provide a clean, healthy environment, current studies show SARS-CoV-2 does not last long in the air, and therefore this should not be a primary response specific to coronavirus.

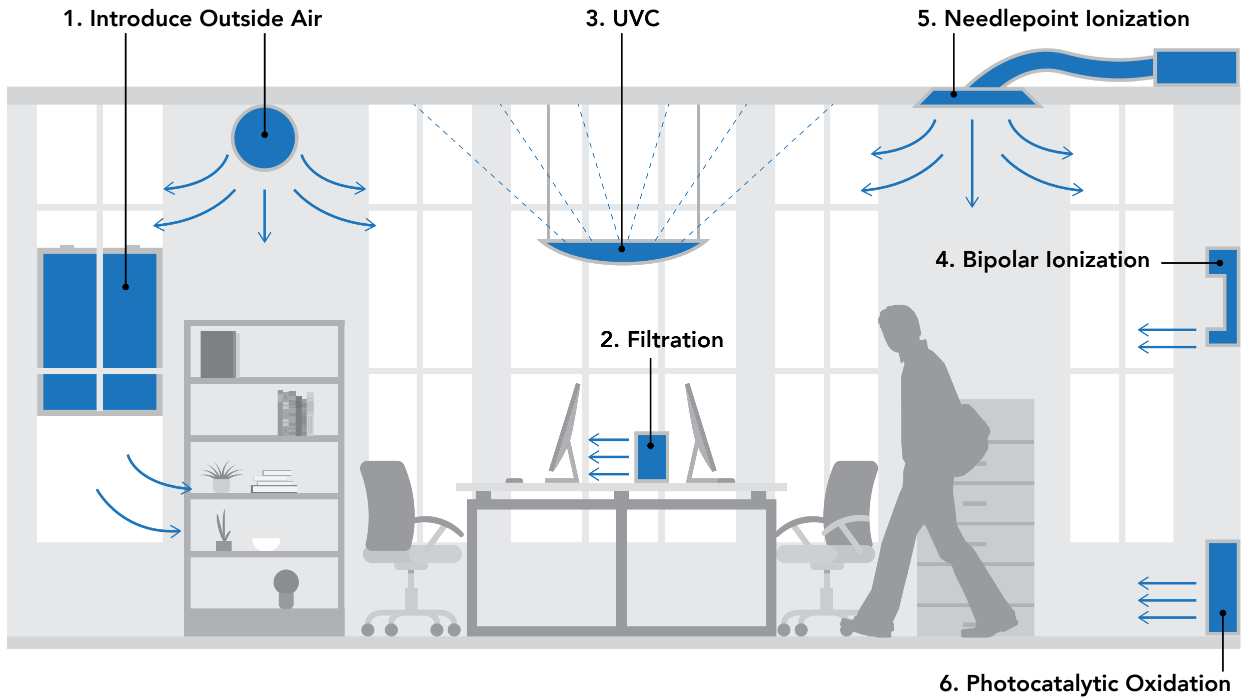
Filtration strategies such as HEPA and ULPA filters can also be installed at the HVAC unit or individual spaces.

■ Viral infection can take place through inhalation of virus particles present in respiratory droplets (>10 microns in diameter) or smaller droplet nuclei. Virus particles themselves can be significantly smaller (for reference, studies have shown coronavirus particles to be in the range of 0.08-0.16 microns). There is evidence that small virus particles can remain aerosol in indoor spaces for up to three hours and can be carried long distances by airflow within spaces and air ducts.

▪ Improving filtration is among the least intrusive and most straightforward methods to improve air quality in existing buildings. However, high performing air filters can effectively capture most, but not all, virus particles. HEPA filters have a 99.97% efficiency capturing particles with a diameter of 0.3 microns. Filters with a minimum efficiency of MERV 13 (or the ISO equivalent ePM1) are recommended. As MERV rating increases above MERV 13, some studies show a diminishing return on contaminants' removal. ULPA filters have the ability to filter particles as small as 0.1 microns with 99.999% efficiency.

▪ Caution should be used in upgrading HVAC filtration since it can cause excessive pressure drop and reduce airflow. Space to accommodate filtration media housing could also be an issue in existing facilities. Reducing peak demand by extending work hours or by minimizing occupancy can mitigate limitations in fan capacity. Regular changing of air filters is essential to ensure adequate ventilation and remove pathogens collected on the filter.

▪ In-room air filters with HEPA-level efficiency are available but only capable of treating a small floor area. Ideally, they are combined with ultraviolet sanitation and used strategically for certain areas, such as conference rooms, which are likely to be enclosed and used throughout the day. A potential drawback to in-room filtration is that the fan associated with the filter may become a source of noise within the space, and potentially blow particles from an infected person/area to an uninfected person/area.



▲ **Treatment of Air at Room/Zone level**

▪ The CDC notes that very high air change rates are required to reasonably clear contaminants (>20 ACH) to be effective. No studies indicate that the required reduction in the virus is needed to reduce potential spread significantly.

Ultraviolet light sanitation is a time-tested solution for HVAC units, although limited solutions exist for treatment within individual spaces.

▪ Ultraviolet light within the spectrum of 100-280 nanometers (called UV-C) is most efficient at rendering viruses inactive. The optimal wavelength is 253.7 nm. The UV light's ability to kill viruses is directly related to the UV light intensity and exposure time to the virus. 222nm Far UV-C lamps are safe and effective but do not yet have FDA approval.

- Disinfection of cooling coils and drain pans can take place at lower UV-C levels. UV irradiance should be evenly distributed across the surface and operated continuously. This action does not inactivate viruses but keeps the biofilm off the coils.

- There are opinions that state in-duct sanitation of air can be achieved with an airstream of 500 fpm, a minimum irradiance zone of two feet, and 0.25 seconds of UV exposure time. However, the ASHRAE Position Document on Filtration Air Cleaning indicates that "Experience suggests that control of a moving air stream does not provide favorable killing rates because of the short dwell [exposure] time." Ideally, in-duct UV-C air disinfection should be combined with filtration, and retrofitting existing ductwork with UV-C may be difficult.

- UV fixtures can be mounted in densely occupied or high-risk areas at least seven feet above the finished floor. However, effectiveness depends on the air mixing within the space, and low UV-reflectivity walls and ceilings are required.

- The use of UV comes with potential health impacts for occupants. Direct exposure to UV light can be harmful. Most UV lamps used for sanitation are activated through a low-pressure gas, such as mercury vapor, which can be hazardous if contacted directly. LEDs are mercury-free, but those that produce the optimal range of UV light are rare and less efficient than lamps using low-pressure mercury vapor. Additionally, UV lights that are within occupied areas should be off when people are present. The lights can be controlled from afar for after-hours service or by motion detectors and occupancy sensors.

Ionization to clean the air is available in 'Bipolar' or 'Needlepoint' technologies.

- Bipolar ionization involves dielectric material generating positive and negative ions in the airstream that neutralize viruses. Needlepoint ionization uses carbon fiber needles to generate ions to react with airborne contaminants.

- Bipolar ionization can be used directly in rooms via wall units. Small units using Needlepoint ionization can be installed in ducts and VAV boxes.

- Bipolar ionizers produce ozone as a by-product of the sanitation process. Ozone is an indoor air pollutant with adverse human health impacts, so caution should be taken and spaces supplied by air that has undergone ionization should be monitored for the presence of ozone. Ionization systems should be specified to comply with UL 2998. Typically, the system should be shut off if ozone levels exceed 40 ppb to address the needs of asthmatic and respiratory impaired persons. Certain manufacturers such as AERUS, Global Plasma Solutions, and AIROCIDE have options that do not create ozone.

- The effectiveness of ionization is uncertain. At this point, inadequate peer-reviewed research exists on this technology.

- Caution when selecting a vendor for this technology is advised. There is a limited number of manufacturers with certified testing of these installed technologies.

Photocatalytic oxidation to clean the air is also a novel technology that may be installed with caution.

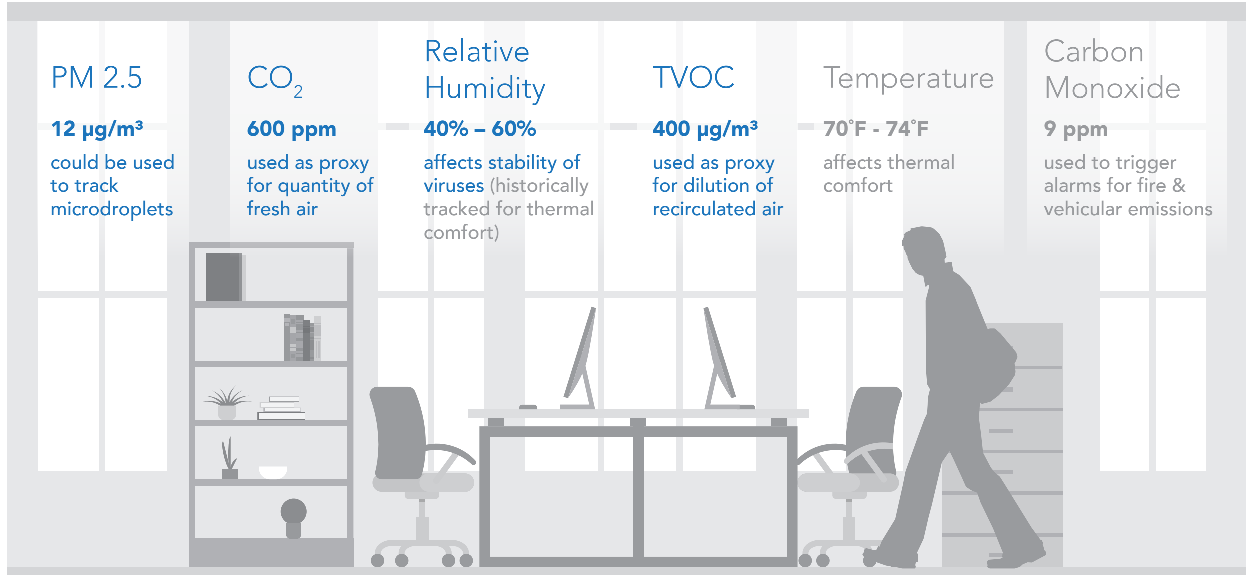
- Photocatalytic oxidation involves the use of UVC radiation on Titanium Dioxide to generate ions and neutralize viruses in the air stream. This process can take place as part of HVAC systems or via portable units installed within individual spaces.

- Photocatalytic oxidation has questionable effectiveness to remove contaminants at levels necessary for human health and has the potential to generate harmful byproducts, such as ozone and formaldehyde.

- As with Ionization, inadequate peer-reviewed research exists on this technology.

SUMMARY OF AIR TREATMENT STRATEGIES DISCUSSED IN THIS DOCUMENT

AHU & RTU TREATMENT	1 MAXIMIZE OUTSIDE AIR	2 FILTRATION	3 UVC TREATMENT	4 BIPOLAR IONIZATON	5 NEEDLEPOINT IONIZATION	6 PHOTOCATALYTIC OXIDATION
Description	Increasing outside air dilutes pollutants in recirculating air and reduces risk of contagion.	HEPA filters can remove particles up to 0.3 microns and are applicable for viral aerosols. ULPA filters can remove particles up to 0.1 microns and are applicable for viral pathogens	UVC is used to degrade organic material with low-pressure mercury vapor lamps which emit 253.7 nm wavelenghts	Dielectirc material generates positive and negative ions that are introduced in air stream to neutralize virus	Carbon fiber needles generate positive and negative ions that neutralize virus in air stream	UVC radiation on Titanium Dioxide generates ions that neutralize virus in air stream
Risk 1	Existing HVAC systems have a limit to the volume of fresh air that can be introduced.	High pressure drop would lead to reduced airflow rates	UV lamps typically use mercury vapor, which can be hazardous if contacted	Potential for ozone generation	Novel technology which produces ions for a short duration	Novel technology which may generate formaldehyde
Mitgation 1	Retrofit HVAC units to increase fresh air capacity or introduce economizers. If using existing units, override settings to maximize fresh air for all hours.	To overcome fan capacity, reduce peak demand by extending work hours & minimizing occupancy	Ensure careful handling to avoid breakage, and periodically check lamps.	Ozone monitors installed in spaces can switch-off Bipolar Ionization unit above 75ppb	Air handler treatment can be supplemented with in-duct compact units	-
Risk 2	Increased energy use in hot/humid climates.	Recirculation of air would still leave occupants exposed to pathogens in rooms/spaces.	-	Inadequate peer review research exists on this technology	Inadequate peer review research exists on this technology	Inadequate peer review research exists on this technology
Mitigation 2	Temporarily absorb increased cost during periods of heightened concern.	Supplement air treatment at room/zone with appropriate technology	-	-	-	-
Other considerations	Radiant cooling with direct fresh air is one of the most efficient methods to maximize fresh air when designing new buildings while reducing recirculation.	Improving filtration standards is the least intrusive and most straightforward method to improve air quality in existing buildings.	UVC is a proven technology that can result in energy savings if outside air is reduced. In addition, it can lead to lower maintenance by reduced biofouling on cooling coils.	It can result in energy savings if outside air is reduced.	It can result in energy savings if outside air is reduced.	It can result in energy savings if outside air is reduced. In addition, it can lead to lower maintenance by reduced biofouling on cooling coils.
SUPPLEMENTAL SPACE TREATMENT	**1 INTRODUCE OUTSIDE AIR**	**2 FILTRATION**	**3 UVC TREATMENT**	**4 BIPOLAR IONIZATON**	**5 NEEDLEPOINT IONIZATION**	**6 PHOTOCATALYTIC OXIDATION**
Description	Retrofit fixed windows with operable ones and open when possible. In new buildings, introduce fresh air directly in rooms instead of mixing it at air handler.	Portable units are available to install in rooms	Ceiling fixtures and movable fixtures are available to install in rooms.	Wall units can be installed directly in rooms.	Small units can be installed in ducts and VAV boxes	Portable units are available to install in rooms
Risk 1	Operable windows could pose condensation issues depending upon weather conditions.	Fan may become a source of noise for certain types of spaces.	Although UVC fixtures come with shielded protections, a broken fixture may expose occupants and room-finishes to harmful UVC radiation.	Potential for ozone generation	Inadequate peer review research exists on this technology	Inadequate peer review research exists on this technology
Mitgation 1	Establish operational protocols for different weather conditions.	Identify other supplemental treatments for noise-sensitive spaces	Place fixtures strategically to avoid accidental breakage and routinely test fixtures	Ozone monitors installed in spaces can switch-off unit above peak threshold	-	-



▲ **Common Air Monitoring Sensors**

***Highlighted sensors are relevant to air monitoring for pollutant containment & mitigation.**

AIR MONITORING

Air monitoring is critical to ensure that pollutant containment and mitigation strategies are operating properly. Air monitoring does not prevent a virus or particulates from circulating in an environment, but it can help ensure a high safety level of indoor air.

▪ Continuous monitoring can be integrated with a Building Management System through sampling the chemical makeup of the air for CO2, particulate matter, and TVOCs, which are significant pollutants tracked to determine overall air quality. Hand-held tools are also commercially available to sample these and other pollutants such as ozone and formaldehyde within individual spaces.

▪ Air quality monitoring is especially critical in densely occupied areas. It can also be used to ensure that air sanitation solutions like ionization and photocatalytic oxidation are performing as designed and are not creating byproducts that are potentially harmful to occupant health.

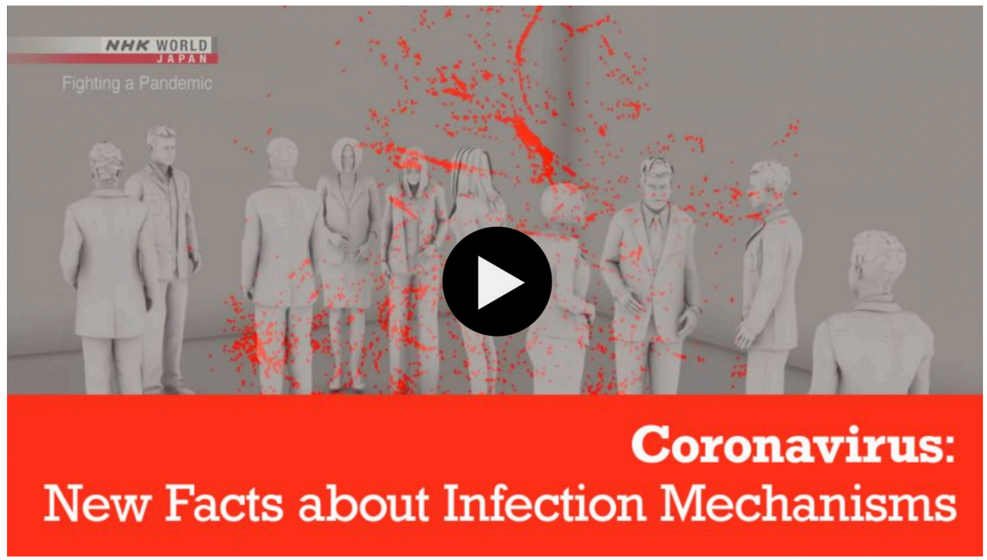
▪ Relative humidity is usually a secondary consideration in thermal comfort controls and ends up being indirectly controlled by thermostats. But research over the years has proven that stability of winter viruses reduces above 40% relative humidity and that of summer viruses reduces below 60% relative humidity. (Source) Humidistats can be introduced and monitored by Building Management Systems to control humidity levels between 40% & 60% thereby adding an additional level of viral mitigation and avoiding the aggravation of mucus membranes that can take place at very low humidity levels (less than 30%). Buildings in cold climates may integrate humidifiers in conjunction with humidistats for a stringent control of relative humidity.

▪ Historically, PM2.5 has been related to dust pollution, by-products of combustion, and other outdoor particles and was not tracked indoors until very recently. PM2.5 sensors use laser scattering to estimate the number of particles in the air. There is ongoing research that potentially identifies the role of 'microdroplets' in viral propagation through the air. (Source) Microdroplets are droplets less than 10 micrometers in diameter and released through breathing, coughing, or sneezing. If research conclusively proves that microdroplets are indeed a potential source of viral propagation, PM2.5 sensors could be used to determine the presence of microdroplets in rooms. Local ventilation may respond to this sensor to either dilute or exhaust ambient air, thereby reducing the risk of infection. Alternatively, we can envision that this sensor may trigger some alarm or notification that an occupant would utilize to make a decision, such as whether to wear a mask, evacuate, or take other precautions.

▪ Beyond air sampling, one can monitor other components of a building's air ventilation system to ensure that pressurization differentials and humidification ranges are maintained properly. For example, public restroom facilities should be maintained at negative pressure compared to adjacent spaces.

▪ If an HVAC system is not capable of accurately monitoring humidity levels or CO_2, which can serve as a proxy for other air quality metrics, localized data loggers can be installed.

▪ While completely unknown at this point, and speculative on our part, we anticipate future code changes addressing the need to monitor (and appropriately respond) to air quality in some aspect. We also speculate the development of biosensors in the future that may detect specific viruses in ambient air.



▲ **This video may be helpful in understanding the propagation of microdroplets within an enclosed space.**

PLUMBING FIXTURES

Plumbing fixtures represent high-touch point components of a building's interior as well as a source for the potential spread of pathogens.

■ There is some evidence that virus particles might be spread through building plumbing systems or aerosols produced by toilet flushing. Toilets should be flushed with lids down, if possible. Retrofitting toilets with lids is a way to minimize the spread of contaminants. However, the manipulation of lids presents another touchpoint, so this needs to be carefully considered.

■ P-traps need to be sealed and installed correctly to ensure that seals are functioning properly and that pathogens cannot be spread through plumbing systems.

■ Operating restroom exhaust fans continuously will help remove pollutants and introduce fresh air.

■ Touchless fixtures can potentially remove a route of the spread of pathogens.

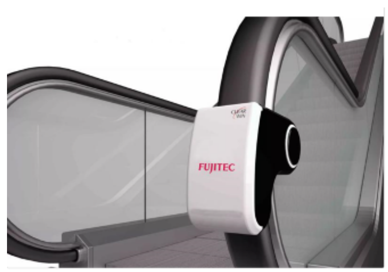
■ It is recommended to temporarily disable forced-air driven hand dryers during a pandemic to reduce air turbulence. Paper towels may be used instead for drying hands.

INTERNAL TRANSPORTATION SYSTEMS

People-based transportation systems such as elevators and escalators involve two major considerations: 1) these are high-touch point areas and 2) it's typical for these to be densely occupied. These issues can be addressed as follows:

■ Materials used for cab finishes and escalator cladding should be impervious and easily cleanable.

■ Frequently touched surfaces like buttons and handrails should be cleaned and sanitized regularly. Products that constantly clean escalator handrails, for example, are already being developed and should be considered either in retrofit or new installations.



■ Consider ways to maintain physical distancing by marking elevator corners and limiting the occupancy of elevator cabs. Occupancy sensor-based 'people-counting' may be included within these systems or lobbies to ensure compliance. This will impact travel times for occupants using high-use elevators, so appropriate queuing and pre-function areas should be provided. Increased air circulation within cabs might also be considered.

■ Consider staggering operation hours so that the use of elevators is spread throughout the day. Escalators and horizontal people-movers (moving sidewalks) should be marked to accommodate individuals' proper spacing to maintain physical distancing.

■ Control systems can minimize contact with some high-touch surfaces. For elevators specifically, a call-less system that can be actuated by an employee or visitor's proximity key card or mobile phone can prevent touching of a common controller or elevator call button.

■ In multi-floor office buildings served by vertical transportation, equal pressure should be maintained between floors.

TOUCHLESS DEVICES

Touch-less devices, when employed successfully, can replace high-touch devices.

▪ Ideally, any button, switch, actuator, or other similar devices that require human touch should be evaluated for proper functioning with a touchless device.

▪ “Wave to open” sensors, proximity sensor with an auto operator, RF devices, occupancy sensor similar to what is commonly used to control lighting, or other sensor controlling a component or device are effective ways to avoid contact with surfaces.

▪ Densely occupied or highly used (and touched) components – such as the front door to a facility -- should be prioritized for the design or retrofitting of touchless devices.

▪ When appropriate, touchless devices may be integrated with thermal sensors for detecting elevated body temperature.

HEALTHY BUILDING PROGRAMS

Health-focused certification programs, while not a “building system” itself, are a set of prescriptions and metrics derived from leading industry organizations and advisory groups. Complying with programs such as the USGBC’s LEED program, the IWBI’s WELL Building Standard, GIGA’s Reset Air Standard, and CfAD’s Fitwel Standard will inherently provide building systems and design parameters that emphasize the health and wellness of building occupants.

▪ The LEED rating system includes a category focused on Indoor Environmental Quality that includes credits like Increased Ventilation and Enhanced Indoor Air Quality Strategies that are consistent with the introduction of additional outside air and increased filtration referenced above.

▪ In May 2020, the USGBC released multiple pilot credits with best practices for re-entering workspaces and for cleaning and disinfection.

▪ The WELL Building Standard is a specialized rating system focusing on occupant health and wellness. Sections of the standard reward best practices for air quality monitoring, air filtration and sanitation, and design considerations like easily cleanable surfaces and adequate hand-washing facilities.

▪ The WELL Building Standard has issued a guide highlighting features from the standard that are most valuable to promote resilience and recovery.

▪ FITWEL Standard was created by a joint partnership between the Center for Disease Control, General Services Administration, and Center for Active Design to benchmark the design and operation of buildings that promote occupant health. On May 6th , 2020 Center for Active Design released a guideline for building professionals titled “Research to Action: Building Health for All® in the Face of COVID-19” as a supplement to Fitwel Standard.

▪ Unlike other standards, the RESET Air Standard certifies an occupied building’s indoor air quality through measured IAQ data. The following IAQ parameters must meet threshold values that are continuously monitored daily: PM2.5, TVOC, CO2, CO, Temperature, and Humidity.

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Practical Guidance for Epidemic Operation of Energy Recovery Ventilation Systems, Authored by ASHRAE TC 5.5

We would like to thank the following MEP Engineering partners who have provided peer review and/or supporting expertise and information in the creation of this summary document: Affiliated Engineers, Inc. (AEI), Arup, CFI Companies Consulting Engineers, CMTA, Inc., DBR Engineering Consultants, Inc., E&C Engineers & Consultants Inc., IA Naman + Associates, Inc., Infinity MEP Consultants, Synergeer Engineering, Vanderweil Engineers, and Wylie Consulting Engineers

Contact the following Kirksey leaders for more information on designing healthy, forward-thinking environments for your specific needs:

Workplace - Randall Walker / Brian Malarkey

Healthcare - Necia Bonner / David McLemore

Community/Religious - Janis Brackett

Government – Benito Guerrier

Collegiate - Steve Durham

pK-12 - Nicola Springer

Hospitality/Hotels/Multifamily - Doug Hammel

Science & Technology (Labs, Mission Critical, & Industrial) - Brian Richard

Commercial Buildings - Paul Newsoroff / Scott Wilkinson

Sustainability & Building Programs - Colley Hodges

Building Physics/Systems - Kapil Upadhyaya

Brand Integration/Graphics + Signage - Melissa Schmitz

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