How buildings can improve ventilation systems to reduce the transmission of COVID-19 and other airborne viruses

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Introduction

The Coronavirus, or COVID-19, pandemic is marking yet another historic event caused by a novel virus, urging organizations and government agencies to create guidelines for reducing the spread of the virus. In building environments, indoor air quality significantly affects the rate of transmission, as the virus can stay in the air for long periods of time. Measures can be taken to improve air quality by upgrading Heating, Ventilation, and Air Conditioning (HVAC) systems, installing ultraviolet (UV) lamps, installing bi-polar ionization devices, using higher Minimum Efficiency Reporting Values (MERV) filters or High Efficiency Particulate Air (HEPA) filters, increasing outdoor ventilation air of central systems, and increasing the use of operable windows in natural ventilation buildings.

As people head back to work from the quarantine, the need for additional ways to reduce the transmission of SARS-CoV-2 and future viruses will be paramount. While each method and system improvement have its advantages and drawbacks, all have the capability to improve air quality from current systems by implementing one or more of these measures. The level of success of the systems can vary based on the structural format of a building, therefore, each system should be considered carefully.

COVID-19

COVID-19 is a respiratory disease where the virus is transmitted by direct contact from surfaces, by large droplets (>20 μm), and aerosol (<20 μm) through people talking, coughing, and sneezing [1-3]. The main recommended precautions include frequent handwashing and maintaining a physical distance of 6 feet from others, in order to avoid contact with large respiratory droplets and aerosol [4]. However, aerosols, or small droplets, can stay in the air for a significant period of time, as well as travel large distances [5].

UV-C Light

Ultraviolet germicidal radiation (UVGI) using a UV-C wavelength bandwidth of 253.7 nm, has long been used as a disinfectant in laboratories and health care facilities for lab and medical equipment. UVGI works by damaging the DNA of microorganisms to inactivate molds, bacteria, viruses, and other pathogens [6]. This destructive effect of UVGI on DNA is proportional to the intensity of the light and the duration of the exposure [7]. Under ideal conditions, inactivation rates of 90% or higher can be achieved [8].

Based on the desired level of disinfection, the irradiance of UVC and exposure time must be carefully considered and designed. UVC lights can be installed in-duct in the supply side, or on cooling coils and drain pans, depending on the desired result, as both have advantages and disadvantages. In-duct systems are designed to provide aerosol disinfection and reduce the spread of airborne infectious diseases. Cooling and drain pan irradiation, which prevent the growth of bacteria, mold, and fungi in damp environments and surfaces, require less irradiance levels compared to in-duct systems, from a magnitude of 10-100, as the surface has essentially an infinite exposure time. This method has also been shown to increase the efficiency of Air Handling Units (AHU's); reducing the air-side pressure drop and increasing the air-side heat transfer coefficient by preventing cooling coil fouling by biofilms [7]. However, this system is not designed for airstream disinfection, and should be used with in-duct UVC lights to provide the greatest level of clean air.

Pros:

- In-duct system does not require AHU modification
- In-duct system can also maintain cleanliness of cooling coil surfaces when installed close to equipment, negating the need for additional UVC lights in the cooling coil [7].

Cons:

- While some studies have shown to achieve a high level of disinfection of moving airstreams, other studies are lacking. Further field studies are needed to benchmark system performance [8]
- Effectiveness is highly dependent on a variety of factors, including type of contaminant, UV-C intensity, exposure time, lamp distance and placement, air movement and patterns, temperature, relative humidity, and air mixing. [8]
- Material degradation from UVC light varies greatly with the material, materials must carefully be chosen or shielded [9]

Bi-Polar Ionization

Aerosols and other particulates can stay in the air for long periods of time due to their electrostatic charge. A relatively new method and technology to remove viruses, bacteria, and allergens from the air; bi-polar ionization systems use tubes with electrodes in ducts to create positive and negative charges (ions) in the air. As that air comes into the breathing space, the ions reduce the time that the aerosol remains charged and the droplets fall to the ground [10]. Some ions also react with oxygen and water vapor in the air to create free radicals, which create chemical changes and damage microorganisms, including viruses [11].

Pros:

- System requires no re-engineering of the HVAC system, and requires no continual adjustment or maintenance except a replacement of the bi-polar ion tube every 2 years [12]
- Air purification works in the habitable area, as opposed other systems which only work at the HVAC unit

Cons:

- While there is research that supports that bi-polar ionization showing contaminant reduction, the extent and effectiveness are still not well known, and further studies need to be done
- Surfaces must be cleaned often, as viruses that do not get killed from free radicals drop to the ground and surfaces, which can still be transmitted by direct contact.

MERV and HEPA Filters

MERV is a standardized rating system that classifies filters for their efficiency of particle filtration between .3 and 10 µm. All building HVAC units have filters with a MERV rating that specifies what size and percentage of particulates can be captured. This rating is derived from a test method developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE). The filters are rated from 1 to 16, per the table below [13]

MERV Rating	Average Particle Size Efficiency (PSE) .3 to 1 µm	Average Particle Size Efficiency (PSE) 1 to 3 µm	Average Particle Size Efficiency (PSE) 3 to 10 µm	Typical Controlled Contaminant	Typical Applications
MERV 1	-	-	<20%	Pollen, dust mites, sanding dust, textile fibers	Minimum filtration Residential, window air conditioners
MERV 2	-	-	<20%		
MERV 3	-	-	<20%		
MERV 4	-	-	<20%		
MERV 5	-	-	20 – 34.9%	Mold, spores, hair spray, dusting aids, cement dust	Commercial buildings, better residential, industrial workplaces
MERV 6	-	-	35 – 49.9%		
MERV 7	-	-	50 – 69.9%		
MERV 8	-	-	70 – 84.9%		
MERV 9	-	<50%	>85%	Legionella, lead dust, auto emissions	Better commercial, superior residential
MERV 10	-	50 – 64.9%	>85%		
MERV 11	-	65 – 79.9%	>85%		
MERV 12	-	80 – 89.9%	>90%		
MERV 13	<75%	>90%	>90%		

MERV 14	75 – 84.9%	>90%	>90%	All bacteria, droplet nuclei (sneeze), most smoke	Superior commercial, hospital inpatient care, smoking lounges
MERV 15	85 – 94.9%	>90%	>90%		
MERV 16	>95%	>95%	>95%		

For effective filtration of bacteria and viruses, MERV 13-16 is recommended and MERV 16 performs best for capturing small particles, including droplets.

HEPA filters are primarily used in hospitals and laboratories, where filtration of either biological matter such as bacterium, fungi, pollen, and viruses or filtration of industrial particles from automobiles and industrial facilities is of utmost importance. The filters are composed of a mat of randomly arranged fine glass threads, or fiberglass. They remove 99.97% of airborne particles .3 µm in diameter [14]. In comparison, N95 respirators, used as personal protective equipment for medical personnel encountering infected patients, are effective in removing 95% of airborne particles .3 µm in diameter. HEPA filters are the most effective in consistently removing airborne particles. While necessary for hospitals and labs, it is not required for commercial office or residential buildings, but can be implemented for cleaner and safer air to further prevent the spread of viruses like SARS-CoV-2 and Influenza A and B.

Adapting higher MERV rating and or HEPA filters in commercial or residential buildings requires careful design and selection of fans, as pressure drops would increase. Energy usage would also increase as a higher horsepower fan is required if the available power is insufficient. When selecting any filter with a different MERV rating or HEPA, the available fan power must be evaluated.

Pros:

- Most effective and proven method in capturing airborne particles
- Passive filtration, does not require much maintenance other than replacement
- Most MERV filters generally fit in the existing filter modules and sections.

Cons:

- Will cause an increase in static pressure, existing AHU fans must be able to handle increased load
- HEPA filters are 12-inches wide; AHU's need additional space for filter frames.

Outdoor Ventilation

Utilizing HVAC systems to increase the percentage of outdoor air has the potential of greatly reducing the concentration of aerosol droplets with viruses. In most buildings, outdoor air is generally 15-20% of the circulated air. This can be increased to address COVID-19. Generally, most central HVAC systems have excess capacity due to overdesign and a factor of safety built in by designers. This can be used to increase the ventilation by 5-10%. Additionally, the design day load, where HVAC systems are sized to operate during the hottest and coldest days, are encountered for a very limited time on peak loads. Careful analysis must be done to make sure not to overload the HVAC system, and a variety of factors must be considered to determine the acceptable outdoor ventilation percentage. Added methods include disabling demand-control ventilation controls that reduce air supply based on occupancy, [15] and running the HVAC system for an extended period of time. Systems with airside economizers have the advantage of adequate outside air ventilation during moderate climatic conditions, however at peak loads they still need to be analyzed to consider increasing the percentage of outside air.

In natural ventilated buildings, where operable windows are used for ventilation, the fresh air in occupied spaces is increased by opening the windows. Window trickle vent mechanisms can be installed to provide a minimal opening setting on windows. Building occupants that are not familiar with trickle vents can be informed on how to use them to increase ventilation.

Pros:

- Minimum upgrades required, can be done at a relatively low upfront cost.

Cons:

- HVAC system will use a greater amount of energy cooling/heating the outdoor air
- Effectiveness is based on the percentage of outdoor air and limited to system capabilities

Conclusion

Using HVAC equipment such as UV lamps, bi-polar ionization devices, and higher rated MERV or HEPA filters, the circulation of airborne viruses can be mitigated. Correspondingly, air quality can be improved by increasing outdoor air intake of central systems and increasing the use of operable windows in natural ventilation buildings.

The health of a building's occupants can be protected by reducing the transmission of SARS-CoV-2 through these improvements. While each method and system improvement has its advantages in varying building classifications and indoor environments, all have the capability to improve air quality from current systems. The selection of one or more of these systems must follow careful examination based on a building's layout and current HVAC setup.

Disclaimer: These methods to improve air quality do not provide any form of guarantee from the COVID-19 infection or transmission through HVAC systems. These improvements have the capability to reduce particulates, which are carriers of viruses and bacteria in the air stream, but may not entirely eliminate the contaminants.

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