Schnackel University

THE COMPLETE GUIDE TO

ENHANCED HVAC INFECTION CONTROL

By Schnackel Engineers, Inc.

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About the Authors

Schnackel Engineers can assist you with a thorough evaluation of your building to ensure you are doing everything possible to prevent the spread of viruses within your facility. Please give us a call at 1-800-581-0963 or email us at info@schnackel.com for a consultation.

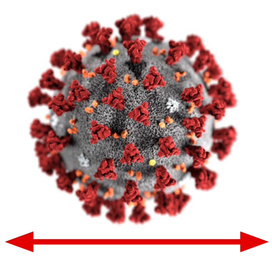
Introduction

The present world pandemic situation has brought up the question: *"What can we do to improve the air quality and reduce the possibility of disease spread in our facilities and buildings?"*

There are a vast array of available methods and technologies that can aid in the process of improving the air inside the occupied space and preventing infection. Air cleaning may be done as part of the HVAC system through enhanced filtration, fresh air regulation and sterilization, or by using in room devices, either permanent or temporary portable units.

Some of these technologies are time tested and proven in the medical and biotech fields. Some are promising new technologies that may prove to be effective in the long run, however, they have not been in use long enough to clearly identify their effectiveness. Some technologies are not proven to be effective at all at controlling infection agents. This series of white papers will try to separate the fact from the fiction and provide reliable guidance on how to effectively mitigate the spread of infection in buildings.

This first white paper will provide a very high level overview of the available technologies. Future white papers will go into greater detail on each of the topics herein.



0.12 microns

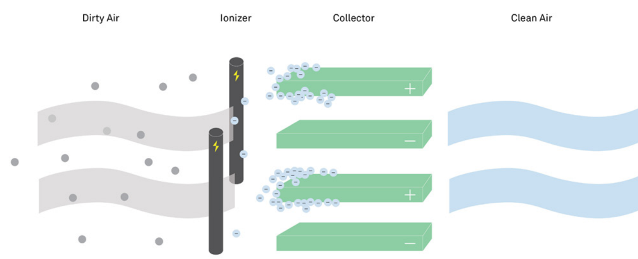
SARS -CoV-2

HVAC Systems:

Mechanical air filters, air filters, and Germicidal Ultraviolet (GUV) may be used individually or in combination to improve the air quality, however, mechanical filters have a very limited ability to effectively remove the very small particles associated with typical viruses. The particles are so small that most removal strategies have limited effectiveness. Therefore, a combined approach is necessary to make a meaningful difference.

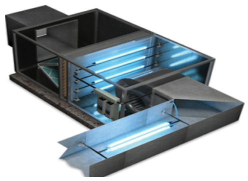
MERV 13 filter

<u>Mechanical Air Filtration:</u> Mechanical filtration should already be present in all HVAC systems. However, the efficiency of these filters can be increased to a rating greater than or equal to MERV 13 because filters of this rating are more efficient at capturing airborne particles of a smaller size (0.3 microns) than lower efficiency filters (3.0 microns). However, increased filter efficiency ratings come with increased pressure drop at the filter. This increased pressure drop must be watched carefully or significant performance degradation or damage could occur to the HVAC equipment. The existing HVAC unit may or may not be capable of overcoming the additional pressure drop of a higher efficiency filter.



Electrostatic Air Filter

<u>Electrostatic Air Filtration:</u> This method of filtration is used to remove very small particles from the air stream. The removal of the particles is achieved by electrically charging the air particles and then collecting them on charged plates. The removal efficiency is the fraction of the particles removed from the air passing through the filter. Unfortunately, electronic air filters are only effective if the collection plates are kept very clean. The efficiency drops off very rapidly as the plates become loaded. Also, electronic air cleaners generate ozone as a byproduct of their operation. Ozone can be harmful to health, however, there is no consensus regarding what level of ozone is considered safe.



UV Light Sterilization

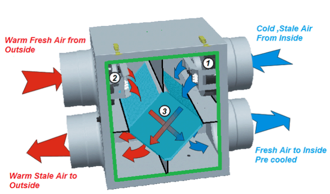
Germicidal Ultraviolet Sterilization: This method uses UV-C generating lamps installed within the supply air duct or within the unit itself. UV-C light kills bacteria and inactivates viruses. This technology has been in use in the medical and biotech fields for many years and is considered very effective at eliminating biological hazards, when properly applied.

Bipolar Ionization: This technology uses high voltage electrodes designed to create reactive ions in the air, which in turn are supposed to react with the airborne contaminants. Rigorous independent scientific studies on this method are not readily available. Ionization may also create ozone as a byproduct of its operation, similar to electrostatic filtration equipment.

Fresh Air:

The first step in any indoor air quality assessment is to verify that the existing fresh air ventilation rates meet the latest code requirements and industry recommendations, including ASHRAE 62.1-2019. Consider increasing the ventilation rates beyond current levels. Additional fresh air will improve the overall indoor air quality.

Increasing the ventilation rates decreases the amount of recirculated air to the space, thus diminishing the number of contaminants recirculated. However, the existing HVAC system may not be capable of maintaining the intended comfort levels in terms of temperature and relative humidity. In order to address this problem, energy recovery ventilators (ERV units) can ease the burden of increased ventilation air and save energy in the process.



Energy Recovery Ventilator

Implementing CO_2 monitoring and control lends a way to ensure adequate ventilation at all occupied times, while providing a good balance of energy consumption versus ventilation dilution.

In Room Devices:

There are many in room and portable devices that can reduce the spread of infectious particles in buildings. These include:

Upper Room Germicidal Ultraviolet: UV fixtures installed in the room at 7'-0" A.F.F. or higher.

Portable UV-C Decontamination: Fully automated robotic units. This method is used for surface decontamination. The room must not be occupied during decontamination using this equipment.

Portable Electronic Air Filter: These units use the same technology as the electronic air filters installed within the HVAC system, however, they are self-contained. HEPA filter versions are also common.

Room Ionization Units: These units use the same technology as Bipolar Ionization, with similar drawbacks.

Summary:

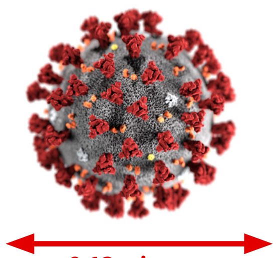
There are many options for improving the air quality of your facility. Depending upon your building, your existing HVAC system, and the function of your facility, you may choose one path or a combination of the options discussed in this white paper. Stay tuned for a more in depth look at each of these technologies in future white papers.

RESOURCES	
ASHRAE COVID-19 (CORONAVIRUS) PREPAREDNESS RESOURCES	https://www.ashrae.org/technical-resources/resources
Illuminating Engineering Society (IES)	IES Committee Report: Germicidal Ultraviolet (GUV) – Frequently Asked Questions
American Air Filter AAF	https://www.aafintl.com/
American Ultraviolet	https://www.americanultraviolet.com/

Introduction

In this white paper, we will discuss the various performance characteristics of HVAC filters with the goal, making an informed decision as to the right type of filter to use in a particular HVAC system application.

The removal of infectious particles from an airstream using filtration media is a difficult but, not necessarily impossible task. Many infectious particles are extremely small in size, with the SARS-CoV-2 particle itself measuring only 0.12 microns (µm) in size.



0.12 microns

SARS -CoV-2

However, individual infectious particles are not typically found floating in the air solo. They are usually attached to respiratory droplets, dust, water and other particles of varying size. The size of the particle carrying the virus greatly impacts the ability of the filtration media to remove the virus carrying particle and the virus with it. The larger the particle size, the easier it is to remove by filter media.

Very small particles can remain suspended in the air for long periods of time (up to 8 hours for a 1 µm particle) and travel for great distances in the space. They are also extremely difficult to remove with media filters. A 2015 study published by the National Institutes of Health examined the typical particle size associated with various types of respiratory viruses and found that these viruses were often found on particles as small as 0.3 to 0.7 µm.

HVAC Filter Media

Filter media comes in a wide variety of types, efficiency ratings, materials, and sizes. Since many infectious diseases are carried on particles as small as 0.3 µm, it requires a very high performance filter to be effective in removing the pathogens from an airstream once they reach the HVAC equipment. The typical disposable filters found in most HVAC equipment today do little to nothing to remove particles in the under 1 micron size range.

MERV Rating

Minimum Efficiency Reporting Value or MERV is a filter rating derived from ANSI/ASHRAE Standard 52.2 -- *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.* The MERV rating is on a scale of 1 to 16, MERV 1 being the lowest and MERV 16 the highest filter efficiency rating. The test measures the efficiency of the filter to capture particles of various sizes at established air flow rates. The particles sizes are grouped into three categories as seen in Table 1 below.

Standard 52.2 MERV	Composite Avg. Particle Size Efficiency % In Size Range, µm			Average Arrestance, %
	0.3 - 1.0	1.0 - 3.0	3.0 - 10.0	
1	n/a	n/a	<20	<65
2	n/a	n/a	<20	65 - 69
3	n/a	n/a	<20	70 - 74
4	n/a	n/a	<20	>74
5	n/a	n/a	≥20	n/a
6	n/a	n/a	≥35	n/a
7	n/a	n/a	≥50	n/a
8	n/a	≥20	≥70	n/a
9	n/a	≥35	≥75	n/a
10	n/a	≥50	≥80	n/a
11	≥20	≥65	≥85	n/a
12	≥35	≥80	≥90	n/a
13	≥50	≥85	≥90	n/a
14	≥75	≥90	≥95	n/a
15	≥85	≥90	≥95	n/a
16	≥95	≥95	≥95	n/a
17 (HEPA)	≥99.97	≥99	≥99	n/a
18 (HEPA)	≥99.997	≥99	≥99	n/a
19 (ULPA)	≥99.9997	≥99	≥99	n/a
20 (ULPA)	≥99.99997	≥99	≥99	n/a

Table 1
MERV ASHRAE Standard 52.2

A commercial air filter is tested under the ASHRAE Standard 52.2 at a face velocity of 492 fpm, unless noted otherwise on the manufacturer's test report. A filter will generally have a higher overall filtration performance level at a velocity lower than at 492 fpm. For example, a 24"x24"x1" filter would achieve very near a MERV 8 rating when installed in a 2,000 CFM system operating at 500 fpm, however it might perform at a higher than MERV 8 level when installed on a 1,200 cfm system operating at 300 fpm. Unfortunately, there is rarely any test data available to document the improved performance of a filter at lower velocities, however it is critical to maintain filter velocities below the ASHRAE test standard of 492 fpm to achieve the manufacturer's MERV rating and filter performance once installed in the system.

Historically Recommended Filter Standards

ASHRAE Standard 62.1-2019 Ventilation for Acceptable Indoor Air Quality requires MERV 8 as a minimum standard for all commercial buildings. The following table (Table 2) provides general guidance from ASHRAE for filter applications by MERV rating in a pre-COVID-19 world:

Standard 52.2 MERV	Particle Size Range (µm)	Typical Applications	Typical Filter Type
1 - 4	> 10.0	▪Pre-Filters to protect higher cost downstream air filters ▪Lint or other rough particle air filters ▪Typical Residential ▪Typical Non-Ducted Fan Coil Units	▪Throwaway: Disposable fiberglass or synthetic panel ▪Washable: Aluminum mesh ▪Electrostatic: Self-charging panel
5 - 8	3.0 - 10.0	▪Pre-Filters to protect higher cost downstream air filters ▪ Typical Commercial Buildings ▪Better Residential ▪Industrial Workplaces ▪Paint Booth Inlets and Outlets	▪Pleated Filters: Disposable extended surface area ▪Cartridge Filters: Synthetic media ▪Throwaway: Disposable synthetic panel
9 - 12	1.0 - 3.0	▪Pre-Filters to protect expensive downstream air filters ▪Hospital General Care and Public Areas ▪Better Commercial Buildings ▪Best Residential	▪Pleated Filters: Disposable extended surface area 4"-6" deep ▪Pocket or Bag Filter: 12"-36" deep ▪Rigid Cell Box Filter: 6"-12" deep ▪V-Cell Filter 12" d
13 - 16	0.30 - 1.0	▪Final Filters ▪General Surgery ▪Best Commercial ▪Hospital Inpatient Care, Laboratories, etc. ▪Smoking Lounges	▪Pocket or Bag Filter: 12"-36" deep ▪Rigid Cell Box Filter: 6"-12" deep ▪V-Cell Filter 12" deep

Table 2
Filter Applications and MERV Ratings

Current LEED guidelines (Version 4.0 and 4.1) require a minimum of a MERV 8 rating for all recirculating space conditioning systems, with one LEED IEQ Credit available for utilizing a minimum of a MERV 13 rating on all units supplying outdoor air to the building, along with the other necessary improvements to achieve this Credit.

However, based on the desire to capture COVID-19 carrier particles, a minimum of a MERV 13 rating would be required to achieve even a 50% capture of particles under 1 microns, and a MERV 16 filter rating is required to achieve a 95% capture rate.

Filter Efficiency vs. Average Arrestance Ratings

The ASHRAE 52.2 test standard measures filter performance in terms of the efficiency and the average arrestance capabilities of the filter. These two metrics are very distinct from each other, however, they can create considerable confusion regarding filter efficiencies and manufacturer's claims. Do not let the average arrestance rating of a filter fool you into believing that an inexpensive filter is capable of achieving high levels of efficiency in air cleaning, particularly of small particles. It is not. The average arrestance rating of a filter is used only to rate the performance of filters that are not able to meet the minimum threshold of 20% on the particle size based efficiency tests.

The definition of these two ratings is as follows:

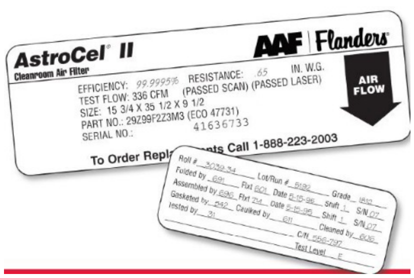
Arrestance: A measure of the ability of an air-cleaning device with efficiencies less than 20% in the size range of 3.0–10.0 µm to remove loading dust from test air. Measurements are made of the weight of loading dust fed and the weight of dust passing the device during each loading step. The difference between the weight of dust fed and the weight of dust passing the device is calculated as the dust captured by the device. Arrestance is then calculated as the percentage of the dust fed that was captured by the device.

A filter with an average arrestance rating of 74%, is simply removing 74% of the weight of the particles in the test air stream. It is not removing any measurable amount of particles smaller than 3.0 microns, let alone any particles in the COVID-19 carrier particle size range of 0.3 to 0.7 µm.

Efficiency: The ratio of the downstream-to-upstream particle count over a series of 6 test cycles utilizing 12 different particle sizes ranging from 0.3 µm to 10.0 µm (72 total tests). The lowest values over the 6 test cycles are then used to determine the Composite Minimum Efficiency Curve.

HEPA and ULPA Filters:

As we have seen from Table 2, the ASHRAE MERV rating system application tables stop at a rating of MERV 16, with a minimum filter efficiency of 95% rating over a particle size range of 0.3 to 10 µm. That is a very efficient filter; however, what if you want to go higher? HEPA or ULPA Filters can be the answer. In general, filters with a rating of MERV 16 or below are considered to be HVAC-system-grade filters for residential, commercial and general hospital use. MERV 17 through MERV 20 filters are typically used only in sensitive surgical operating rooms, clean rooms, pharmaceutical manufacturing, radioactive particle filtration and other contexts that require absolute cleanliness.



ULPA Filter Label

A High Efficiency Particulate Air (HEPA) filter is a filter that can remove at least 99.97% of dust, pollen, mold, bacteria, and any airborne particles with a size of 0.3 µm and smaller. An Ultra Low Particulate Air (ULPA) filter is a filter that can remove at least 99.999% of those same particulates. Some ULPA filters can reach test efficiencies of 99.9997%. The diameter specification of 0.3 µm for HEPA and ULPA filter testing corresponds to the worst case - the most penetrating particle size (MPPS). Particles that are larger or smaller than 0.3 µm are trapped with the same or higher efficiency. Using the worst case particle size results in the worst case efficiency rating, i.e. 99.97% or better for all particle sizes for a HEPA MERV 17 rated filter. ULPA filters have been proven nearly 100% effective on particles as small as 0.12 µm, which is the size of an individual COVID-19 virus capsid.

Static Pressure Concerns

As we have seen, a high filter efficiency (high MERV rating) is crucial to any attempt to reduce the spread of infection through the HVAC systems in buildings. However, it is not as simple as picking a filter with a high MERV rating. Due to their dense media and small passageways, high efficiency filters present a considerable amount of resistance to airflow that can quickly overwhelm the fans and motors in typical residential and commercial HVAC systems. This increased resistance, if not properly accounted for, can cause serious damage to the HVAC equipment including frozen cooling coils and potentially dangerous over-temperature conditions on heaters. In addition, the increased air resistance will increase energy cost of operating the system.

The following table (Table 3) provides the typical recommended initial and final resistance values for various types of filters along with the associated HVAC equipment that can typically accommodate the specified static pressure levels without damage. Actual filter pressure drops vary widely from these values, so the manufacturer of the specific filter used must be verified to ensure that the HVAC system can support the pressure loss.

Standard 52.2 MERV	Initial Resistance (inH_2O)	Final Resistance (inH_2O)	Remarks
4	0.10 @ 500 fpm	0.30	▪24x24x1Typical ▪Fan coils and other non-recirculating systems
8	0.33 @ 500 fpm	0.6	▪24x24x1Typical ▪Furnaces, rooftop AC
13	0.38 @ 500 fpm	1.0	▪24x24x2 Typical ▪Rooftop AC, modular air handlers
14	0.65 @ 500 fpm	1.4	▪24x24x6 Typical ▪Rooftop AC, modular air handling units, custom air handling units
16	0.80 @ 500 fpm	1.5	▪24x24x12 Typical ▪Custom air handling units
17 (HEPA)	1.4 @ 500 fpm	2.0	▪24x24x12 Typical ▪Highly customized air handling units
20 (ULPA)	1.4 @ 250 fpm	Up to 4.0	▪24x24x12 Typical ▪Highly customized air handling units

Table 3
Sample Filter Pressure Drop

Summary:

Filter efficiency standards are a complex subject that has been evolving for many years. ASHRAE Standard 52.2 provides a way, via the MERV ratings, to simplify the selection of the appropriate filter for any HVAC system. The particle size of the contaminant to be filtered, in conjunction with the static pressure capacity of the system, narrows the field to a manageable set of options.

Cost is a major consideration in the decision as to which filter to install. Filter costs vary from under $9 for a simple MERV 4 filter to upwards of $800 for a single HEPA or ULPA filter module, with a much lower CFM capacity, requiring multiple modules to achieve the same airflow capacity.

Filters in the most common MERV 8 and MERV 13 rating categories are typically priced at approximately $11.00 and $22.00 respectively for a 24"x24" face filter size. Moving up to a MERV 14 filter of the same size, which achieves a greater than 75% efficiency on 0.3 to 1.0 µm particles, will cost anywhere from $180 to $200. MERV 16 filters, which are the highest of the HVAC-system-grade filters, are approximately $300 each and achieve greater than 95% efficiency on 0.3 to 1.0 µm particles. (All prices are in 2020 dollars.)

Provided that the additional filtration efficiency is determined to be warranted, the only other constraining factor is the ability of the HVAC system to accommodate the additional static pressure presented by the higher efficiency filters. This should be carefully analyzed before the decision is made to go to a premium efficiency filter. A relatively simple engineering analysis is necessary to confirm the static pressure capability of the HVAC system and to determine what upgrades may be necessary to accommodate the increased static pressure and increased physical size of the higher efficiency models.

RESOURCES	
ASHRAE	https://www.ashrae.org/
U.S. Dept. of Energy	https://www.energy.gov/
National Air Filtration Association	https://www.nafahq.org/
U.S. Environmental Protection Agency	https://www.epa.gov/
National Institutes of Health	www.nih.gov/

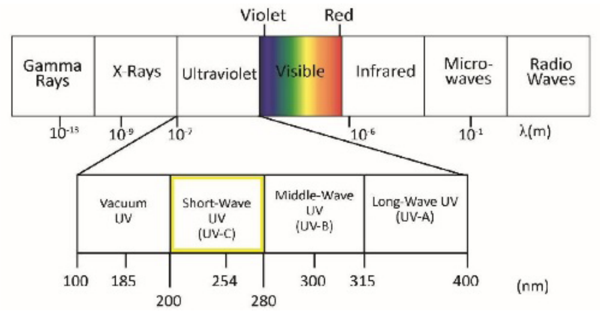
Introduction

In this white paper we discuss the different Germicidal UV (GUV) systems currently available for commercial, industrial and residential HVAC applications. GUV is a time-tested technology that has been used in hospital, pharmaceutical and clean room applications for decades. It is proven to be effective at killing viruses, bacteria and fungal organisms, as long as those agents can be directly exposed to UV rays of sufficient power and/or duration.

Ultraviolet Light

Ultraviolet is the region of the electromagnetic spectrum between 100 nm and 400 nm wavelengths, just below the visible light spectrum. The ultraviolet region is further divided into Vacuum UV (100 nm - 200 nm), Short-Wave UV known as UV-C (200 nm - 280 nm), Middle-Wave UV known as UV-B (280 nm - 315 nm), and Long-Wave UV known as UV-A (315 nm - 400 nm). The UV spectrum associated with disinfection is UV-C. Studies have shown that the peak germicidal wavelengths fall between 265 nm and 270 nm. Typical UV generating lamps produce 254 nm UV-C, which is very close to the peak. UV-C is very effective at inactivating viral, bacterial, and fungal organisms by destroying the molecular bonds that hold their DNA together.

Any UV spectrum can be detrimental to human skin and eyes, with UV-A and UV-B being most notorious for causing skin cancer. Even UV-C can cause skin and eye damage.



EM Spectrum UV

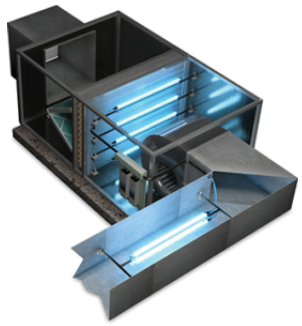
UV-C Use within HVAC Systems

The most common use of UV-C for air sterilization is within new and existing HVAC system equipment. There are two main applications of this technology in commercial HVAC systems:

Coil Surface and Drain Pan Irradiation: UV-C lamps are sometimes installed within the HVAC unit to inhibit the growth of bacteria and mold on the cooling coil and drain pan surfaces. Given the continuous exposure of the surfaces to the UV lamps, a low power level is enough to be effective in preventing growth. As a complement to system maintenance, this application has also been shown to benefit the overall system performance by reducing air pressure drop through the coil and increasing heat transfer efficiency.

In-Duct Air Disinfection: To achieve airstream disinfection, UV-C lamps are installed within the main supply air duct for the purpose of disinfecting the air as it passes through. In-duct air disinfection can be achieved by the same lamps used for the coil and drain pan irradiation, however the power intensity required is greater for the coil and pan irradiation process.

A typical target is an 85% inactivation rate, however, a greater rate is possible by increased lamp power level. Portable, self-contained recirculating units operate on this same technology.

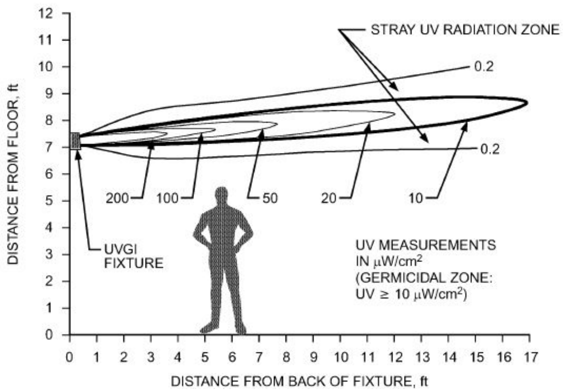


UV-C Sterilization in an HVAC System

In Room UV-C

Upper-Room GUV: A UV-C light device is installed on the wall a minimum of 7'-0" A.F.F. The fixture is designed to irradiate only the air above 7 feet, thus making the room safe for human occupation during irradiation. This approach relies on the normal mixing of the room air to bring infectious particles into the UV-C irradiated zone for deactivation. Upper-Room GUV can be used in areas without mechanical ventilation, however the presence of an HVAC system or even ceiling fans greatly improves the effectiveness of Upper-Room GUV. These fixtures have integral louvers to ensure the UV-C light energy is directed away from the room occupants at all times.

Upper-Room UV Fixture



Upper Room GUV Coverage Graph

UV-C Portable Room Decontamination: These types of devices are fully automatic and intended to be used for surface decontamination. These devices are to be used only when the room is not occupied. The "robot" moves around the room blasting it with UV-C radiation in all directions. Due to the high level of UV energy delivered by these devices, they are fully automated to include automatic shutoff in the event anyone accidentally enters the room while it is being irradiated.

Portable Automatic Device

Summary

The use of ultraviolet energy for disinfection has been around for over one hundred years. The technology has been evolving to meet the demands of an ever changing world. Well established methods (HVAC GUV and Upper-Room GUV have been joined by fully automated room decontaminators, as well as portable, self-contained air cleaners that incorporate GUV in their operation. These are all safe and proven anti-infectious agent technologies.

One very important safety reminder is that UV light, even UV-C light, is not safe for exposure to the skin or eyes for even a short period of time. Manufacturers of hand held and wand type systems may report that their far-UVC light (222 nm) is "safe" for human exposure, however if it is truly "safe" for humans, then it is likely doing very little to kill infectious particles.

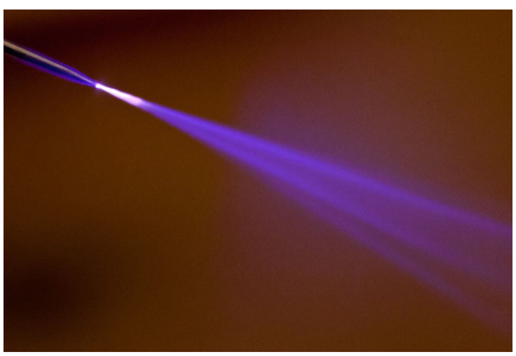
RESOURCES	
ASHRAE	https://www.ashrae.org/
U.S. Dept. of Energy	https://www.energy.gov/
Illuminating Engineering Society (IES)	https://www.ies.org/
American Ultraviolet	https://www.americanultraviolet.com/

Introduction

In addition to the mechanical filtration and UV-C disinfection methods discussed in our previous white papers, there are a number of other technologies commercially available that claim to disinfect the air or improve the overall air quality. In this white paper we look at one category of those technologies - ionization based air purification systems.

Background

Ionization air purification involves the use of a high voltage conductor (wire, plate, needle, etc.) to create air molecules with a negative (or positive) charge by adding (or removing) one electron to (or from) the air molecules, thereby creating $N2^-$ and $O2^-$ (or $N2^+$ and $O2^+$) molecules. These charged molecules (anions and cations respectively) attract impurities in the air by electrostatic attraction. Once they bond with the impurities in the air they are attracted to either positively charged surfaces (plates) in the device itself, or grounded surfaces in the nearby area like walls, floors and ducts.



Corona Discharge from a Needle

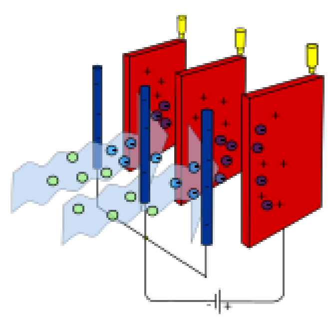
Ionization via corona discharge occurs when a conductor of sufficiently high voltage causes the fluid (air) around the wire to become conductive (ionized) without resulting in an electrical breakdown or arc to adjacent surfaces. This process creates a region of plasma (conductive gas) around the conductor. This plasma region generates the negatively or positively charged ions that are attracted to dust, bacteria and viruses in the airstream. With sufficiently high voltages, other products of corona discharge can include ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2) and nitric acid (HNO_3) if water vapor is present.

Electronic Precipitation Systems

Today there are many different technologies that rely on the ionization of air to promote air cleaning. The "electronic air cleaner" or "electrostatic precipitator" is one common type of ionization device that has been in commercial production since the mid-1950s. This device is a self-contained unit, typically installed in an air handling unit equipped with pre-filters and final filters to ensure longer life and reduced maintenance of the precipitator. Some freestanding room air purifiers also include electronic precipitators in their design.

These devices use thin corona wires charged to a very high voltage to create negatively charged ions that bond with airborne particles. These charged particles are immediately trapped by positively charged plates downstream of the corona wires.

These devices became fairly popular in the 1970s and 1980s however their popularity has waned as a result of two main factors. First, as the collector plates become dirty with captured particulate matter their effectiveness drops dramatically. Over time the surfaces of the collector plates corrode and the filter no longer performs as well as it did when it was new. Replacement cells are expensive, so they tend to be simply turned off. Second, it was soon discovered that these devices generate significant amounts of ozone ($O3$) as a byproduct of the ionization process, due to the operation of the corona wires.



Electronic Air Cleaner or Electrostatic Precipitator

Ozone Generators

Personal ozone generators became quite popular in the late 1990s and early 2000s with introduction of the Sharper Image "Ionic Breeze" product. The product was claimed to improve indoor air quality by reducing a multitude of airborne contaminants. The claims were found to be misleading. In addition, the early models of this product were designed to intentionally produce ozone as the primary "purification" method. Ozone has been determined to be a severe lung and eye irritant and, in significant concentrations, can be toxic.

The Occupational Safety and Health Administration's (OSHA) maximum Permissible Exposure Limit (PEL) for ozone in the workplace is 100 parts per billion (ppb) averaged over an 8-hour work period. The National Institute for Occupational Safety and Health (NIOSH) recommends exposures of no greater than 100 ppb over a 15-minute period and California Ambient Air Quality Standards' threshold is 70 ppb maximum over an 8-hour exposure period. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends no more than 10 ppb as a "safe" level and states that it should be maintained "as low as reasonably achievable."

Even the best ionization systems today can generate some trace amounts of ozone. Systems that generate as little as 2.2 mg/hr have been found to result in a 40 ppb concentration in a ventilated office space. Ozone, even at very low concentrations can be extremely detrimental to your health and should be avoided at any level.

Bipolar Ionization Systems

This technology also uses electrodes designed to create reactive ions in the air, however they are designed to create both positive and negative ions simultaenously by applying an alternating current (AC) to a tube with two electrodes in a process called cold plasma discharge. When voltage is applied to the electrodes, an ionization field is created around the tubes, creating both positive and negative ions (cations and anions) of oxygen.

Bipolar ionization systems differ significantly from previous ionic air cleaning technologies because rather than attempting to capture the particles on collection plates at the device itself, the ions are dispersed into the airstream to bond with air particles (dust, allergens, bacteria and viruses) agglomerating them into larger particles that fall to the ground or are more easily captured by the HVAC system's filtration systems. Since the cations and anions have a half-life of only about 30 seconds, their effective range in the air is fairly limited.

The positive and negative ions also react with water vapor and oxygen in the air to create free radicals, primarily OH. A free radical is a molecule, atom, or ion that has an unpaired valence electron, making them highly chemically reactive. They are inherently unstable and are "looking for" an H+ molecule to become chemically stable again. These free radicals can kill microorganisms, including viruses, by disrupting their ability to reproduce. They can bond to bacteria and viruses, robbing them of hydrogen molecules on their surface, thereby disrupting their ability to reproduce or infect. OH radicals, have a very short lifespan, less than 1 second, so any biological neutralization will occur at or near the unit equipment and not within the occupied space, as often claimed. The effectiveness of OH radicals as an airborne (gaseous) cleaner has not been proven conclusively in any peer-reviewed scientific study. The cations, anions and free radicals generated by bipolar ionizaiton units also react with VOC's in the air, breaking down the molecules into less harmful compounds like carbon dioxide and water, usually only in trace amounts. The ionizing tubes of a bipolar ionization system can be installed withing the discharge plenum of the air handler or into the main supply air duct. Bipolar Ionization in its current form has been available in the United States since the early 2000s. As a result, there is very little conclusive independent scientific research available.

Bipolar Ionization Module

Needle Point Bipolar Ionization Systems

One variant of bipolar ionization is Needle Point Bipolar Ionization (NBPI). In this case, instead of ionizing tubes, the systems use what the manufacturers call "needles" to do the ionization. The needle point electrode module is a fraction of the size of the tube type units, with a cross sectional area of only 0.50" x 3.25" compared to a 9" x 4.25" cross sectional area of the tube type module. These are compact modules that the manufacturer claims can be installed in ductless air conditioners. The manufacturers of both tube type and NBPI systems claim their process differs from corona discharge systems because the power output at the electrodes is low enough to not produce ozone as a byproduct.

Needlepoint Bipolar Ionization Module

Photocatalytic Oxidation Systems

This technology uses ultraviolet radiation combined with a catalyst, usually Titanium Dioxide (TiO_2), to generate free hydroxyl (OH) radicals, ionized hydro-peroxides and super-oxide ions (O_2-) that kill biological contaminants and VOCs. The UV radiation reacts with the Titanium Dioxide causing it to release electrons. The electrons react with water vapor in the air producing the OH radicals and with oxygen to produce the O_2- ions. These OH radicals then attack the microorganisms in much the same manner as the Bipolar Ionization technology discussed previously. There are significant drawbacks to this technology, including the production of small amounts of ozone during the Titanium Dioxide ionization process, as well as the potential for a byproduct of formaldehyde due to incomplete oxidation of airborne VOCs from paint, carpets, furniture, etc.

Due to the very short life of the OH radicals produced, the biological neutralization process occurs primarily on the surface of the catalyst, not in the airstream or in the occupied space, limiting the effectiveness of this process to the air that comes in direct contact with the catalyst. Therefore, they are typically only effective in relatively small systems and spaces.

Photocatalytic Oxidation Module

Summary

Unlike the previously addressed filtration and UV sterilization methods, there are very few independent, peer-reviewed scientific studies covering these ionization technologies in detail. Consequently, most of the available information comes from the manufacturers themselves or from studies sponsored by the manufacturers of this equipment. ASHRAE cautioned as recently as 2018 that: *"Convincing, scientifically rigorous, peer-reviewed studies do not currently exist on this emerging technology. Manufacturer data should be carefully considered."*

Before considering the installation of any of these products, check the available literature for any independent scientific test data regarding the generation of undesirable byproducts, such as ozone or formaldehyde. Ozone is considered hazardous to your health, even at concentrations as low as 10 ppb, so any device that generates even trace amounts of ozone should be avoided. Formaldehyde is a highly toxic systemic poison that should never be introduced into occupied spaces under any circumstances.

Electronic Precipitators carry a significant risk of ozone generation as well as degraded performance over time without continuous maintenance of the collection plates. For these reasons, they have fallen out of favor and should be avoided.

Ozone Generators are a definite no, since ozone is a known severe respiratory and eye irritant.

Bipolar Ionization appears to be a viable option for the overall improvement of air quality, however the manufacturers' advertising claims appear to be a bit overstated due to the short life span of the ions and free radicals produced by these systems. The claimed agglomeration and biological neutralization "throughout the occupied space" do not seem to be supported by the reaction times of the charged particles generated, ranging from well under 1 second to a maximum of about 30 seconds. In addition, any particles that are "dropped from the air" as claimed are subject to disturbance and reentry into the occupied zone if not cleaned up soon after they are precipitated.

Photocatalytic Oxidation may have specific limited applications, however these units tend to be only moderately effective in smaller rooms and carry with them the potential for the generation of small amounts of ozone during the ionization of the catalyst material by the UV lights. Incomplete oxidation of VOCs can also potentially lead to the formation of formaldehyde, depending on which VOCs are present in the airstream.

Final Considerations

When considering these relatively new technologies, we must be sure that in our quest to clean the air we do not end up introducing equally or potentially more dangerous agents than the ones we are trying to eliminate. Any technology that utilizes ozone as its primary method of sterilizing the air should be strictly avoided due to the known health risks of breathing ozone. Even the best ionization systems still generate trace amounts of ozone as a byproduct of the ionization process and should be carefully considered based on the amount of ozone generated. Depending on the size of the space served and the amount of outdoor air introduced for dilution, any ozone production above about 2.2 mg/hr is considered too high and should be avoided.

Lastly, these technologies should always be used in tandem with the appropriate mechanical filtration to physically remove the *potentially neutralized* contaminants from the air to avoid redistributing them, which could occur with systems that claim to drop them on surfaces within the occupied space.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Concordia University	http://www.concordia.ca/
AtmosAir Solutions	https://atmosair.com/
Global Plasma Solutions	https://globalplasmasolutions.com/
Universal UV Solutions	http://www.universaluvsolutions.com/
AirIsa	https://www.aerisa.com/
Centers for Disease Control	https://cdc.gov
US Department of Labor Occupational Safety and Health Administration	https://osha.gov
National Institute for Occupational Safety and Health	https://www.cdc.gov/niosh

Introduction

In our previous white papers on infection control through advanced HVAC strategies, we have focused on the removal of infectious particles from the airstream using various mechanical, photochemical or electronic means. This article will focus on the reduction of the concentration of infectious (and non-infectious) particles in the building through dilution ventilation.

The Ventilation Process

Ventilation is defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as *"the intentional introduction of air from the outdoors into a building"*. The purpose of introducing outdoor air is, and has always been, to reduce the concentration of indoor air pollutants by diluting them with "clean" outdoor air.

When introducing outdoor air into a building, the same amount of air has to be removed from the building or the pressure inside the building will increase. As our founder, Dale Schnackel, used to say: "How much air can you blow into a Coke bottle without letting any air out?"

The excess air that results from the forced introduction of outdoor air is removed via the building's exhaust systems, relieved by the HVAC system through dampers, or relieved via exfiltration through leaks and cracks in the building envelope, or by any other path available, such as open doors and windows.

Since it is assumed that the "clean" outdoor air mixes with the "dirty" air inside the building before it is relieved, some amount of the indoor pollutants are removed as part of the air removed from the building, diluting the indoor contaminants. Clean air in, polluted air out is the basic concept. However, in order for this approach to work, the outdoor air must be cleaner than the indoor air, and there must be a good level of air mixing within the spaces. Our next white paper on Ventilation Effectiveness will address the mixing of air within the occupied spaces and the HVAC systems' ability to remove airborne contaminants from the space.

"Clean" Outdoor Air

The entire premise of dilution through outdoor air ventilation is dependent on the cleanliness of the outdoor air surrounding the building and specifically, at the point of entry via louvers or fans. When designing or modifying ventilation systems it is important to consider the location of the outdoor air intake. Any locations that have a potential for high levels of contaminants should be avoided, such as docks, alleys, streets and parking lots.

Also, any sources of contaminants from within the building or other buildings must be avoided. Most codes regulate the required distance from potential contaminate sources, requiring anywhere from 10' to 25' of minimum separation. However, even when following these minimum code requirements, consideration should be given to prevailing winds, parapets and anything else that might impact the flow of outdoor contaminants into the building air intakes.

Even with the best attention to the intake air locations, some geographic locations are still subject to very poor outdoor air quality, which could actually be worse than the conditions inside the building. Refer to the section titled *Outdoor Air Quality Monitoring* later in this white paper for considerations in locations that may have less than ideal outdoor air quality conditions.

Positive vs. Negative Building Pressure

Depending on the amount of resistance to the flow of air through the relief pathways, a positive, neutral or negative pressure can be created in a building as a result of the ventilation process.

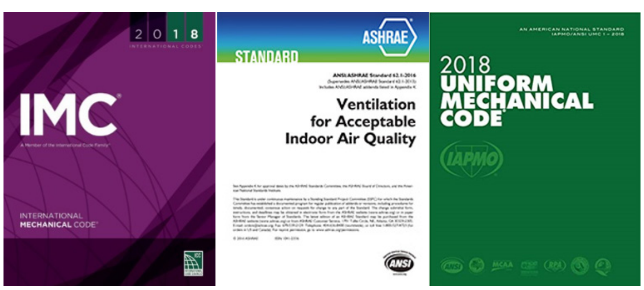
Negative building pressure occurs when there are more exhaust pathways (exhaust fans) than there are supply pathways (outside air units) for air exchange with the outdoors. Negative building pressures are generally undesirable because they result in the uncontrolled flow of unconditioned infiltration air into the building through windows, doors and cracks in the building envelope. This uncontrolled flow can cause a multitude of heating, cooling and humidity control problems, as well as indoor air quality issues if the outdoor air has undesirable qualities including pollution, dust or odors.

Neutral building pressure occurs when the intake and exhaust pathways are perfectly balanced, with the quantity of incoming air matching the quantity of outgoing air exactly. Neutral building pressure is a highly desirable condition, however in practice it is nearly impossible to achieve. Normal variations in wind direction and speed, as well as thermal buoyancy pressures (stack effect) disrupt the building pressure balance on a constantly changing basis. As a result, a neutral pressure building constantly swings back and forth between negative and positive pressure depending on the whims of Mother Nature.

By keeping the amount of outside air introduced slightly above the total amount of relief and exhaust air, a building can be maintained in a positive pressure condition. It is generally accepted that a slight positive pressure in a building is the most desirable ventilalancing condition. It reduces the flow of unconditioned infiltration air into the building, thereby maintaining control of where the outdoor air is drawn in, so that it can be monitored, filtered and conditioned appropriately at its source.

Regulations

National and local codes have minimum ventilation requirements based on the occupancy classification of the space and the number of occupants to be expected. In addition to the national and local codes, ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality provides recommended minimum ventilation rates for commercial buildings. Standard 62.1 excludes dwelling units in residential occupancies, laboratories that contain hazardous materials, smoking areas, and any patient care areas not specifically listed in the Standard. These specialty areas are covered in other codes and standards.



Sample Ventilation Codes and Standards

The ventilation rates specified in the applicable codes and standards should only be considered as minimum acceptable values - not what is necessary to maintain a clean, healthy environment within any particular space.

Indoor Air Quality Monitoring

Indoor air quality can be monitored by deploying sensors throughout the building. The most common method is the carbon dioxide (CO_2) sensor. Carbon dioxide level has been the traditional metric for maintaining indoor air quality for the last 20 years. This is because the occupant perceived quality of the indoor air has been linked to the number of people in the space and the amount of human respiration. By adjusting the outdoor air ventilation rate based on indoor CO_2 concentration, it has been the intent that the most offensive of the indoor contaminants, odorous bio-effluents (body odor), would be sufficiently removed by the introduction of the correct amount of "clean" outdoor air to keep CO_2 levels at acceptable values. ASHRAE has recommended indoor CO_2 concentrations be maintained at or below 1,000 ppm in schools and 800 ppm in offices, or no greater than 600 ppm higher than the outdoor ambient CO_2 level. (See chart below.)

Normal CO_2 Levels

The effects of CO_2 on adults at good health can be summarized to:

- normal outdoor level: 350 - 450 ppm
- acceptable levels: < 600 ppm
- complaints of stiffness and odors: 600 – 1,000 ppm
- ASHRAE and OSHA standards: 1,000 ppm
- general drowsiness: 1,000 – 2,500 ppm
- adverse health effects may be expected: 2,500 – 5,000 ppm
- maximum allowed concentration within a 8 hour working period: 5,000 – 10,000 ppm
- maximum allowed concentration within a 15 minute working period: 30,000 ppm

Extreme and Dangerous CO_2 Levels

- slightly intoxicating, breathing and pulse rate increase, nausea: 30,000 – 40,000 ppm
- above plus headaches and sight impairment: 50,000 ppm
- unconscious, further exposure death: 100,000 ppm

Engineering ToolBox, (2008).
Carbon Dioxide Concentration - Comfort Levels.

While CO_2 is still considered a good metric for maintaining minimum outdoor air quantities, it is not sufficient to address the overall issue of indoor air quality. Other contaminants must also be addressed including carbon monoxide, particulate matter, VOCs, biological contaminants, humidity, among others. True control of indoor air quality should include monitoring of a spectrum of contaminants that all impact the quality of the air we breathe. While there are no commercially viable monitors for biological contaminants like SARS-CoV-2 in the air, a robust monitoring strategy of the other factors contributing to indoor air quality will help minimize the concentration of these pathogens, while improving the overall quality of the air in our buildings.

Air quality monitoring systems can be stand-alone or a part of the building management and control system. The obvious advantage of tying air quality monitoring systems into a building management system is that the ventilation systems can be automatically adjusted to react to the indoor air quality conditions and either improve the quality of the air or conserve energy when the air quality conditions are within acceptable range.

Outdoor Air Quality Monitoring

Densely packed urban areas such as New York City, or locations known for stagnant outdoor air conditions, like Los Angeles, Phoenix and Houston, can often have such poor outdoor air quality that, during certain periods, ventilation rates should be kept to a minimum to prevent making the air inside the building more toxic rather than less toxic through outdoor air ventilation. In some cases, ozone or other contaminate levels outside may preclude any increase in ventilation rates above code minimum levels.

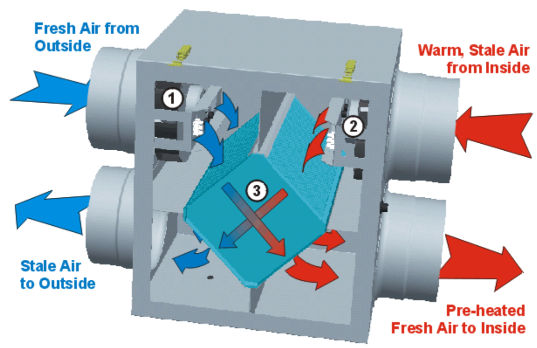
Under these conditions, outdoor air quality monitoring systems should be coupled with indoor air quality monitoring systems to compare the quality of the airstreams and optimize the blend to achieve the best possible conditions for the building occupants. In these difficult locations, other means of "cleaning" the air become even more essential.

Energy Recovery

Except under the mildest of outdoor conditions, the introduction of outside air significantly adds to the overall energy use of a building. To mitigate the added energy load, the implementation of an energy recovery scheme should be considered. Air-To-Air recovery solutions may be stand-alone ventilators (Dedicated Outdoor Air Units) or an accessory to the main HVAC unit.

Energy Recovery Devices

These units efficiently transfer the heating or cooling "energy" contained in the exhausted air stream into the new incoming airstream to reduce the burden of the outside air on the building's HVAC systems and energy consumption.



Energy Recovery Devices

Summary

The advent of the SARS-CoV-2 pandemic has increased the importance of dilution ventilation in the fight against disease spread through airborne contaminants. Dilution ventilation can be a very effective means of reducing the concentration of SARS-CoV-2 in the indoor air, however it has some drawbacks that must be controlled. A general rule of thumb is that a pollutant's concentration is reduced by approximately 50 percent for each doubling of the ventilation rate. This makes dilution ventilation very effective at reducing the concentration of contaminants, including viruses, suspended in the building's air. This benefit, however, comes at a cost in terms of the energy consumption and environmental impact of the building. Any ventilation strategy that includes dilution ventilation above minimum code levels should mitigate the impacts on the environment by implementing an efficient and cost effective energy recovery system. With increased ventilation rates, these systems pay back their initial costs very quickly in most locations.

The addition of both indoor and outdoor air quality monitoring systems should definitely be considered in areas where the outdoor air quality can, at times, be worse than the indoor air quality. This is particularly important in locales known for high outdoor ozone levels. The best intentions of a dilution ventilation strategy can be quickly dashed by poor outdoor air quality, creating a more toxic rather than less toxic indoor environment.

Therefore, the recommended ventilation rate for any space should be carefully determined based on many factors including the quality of the outdoor air, the overall filtration and air cleaning strategy for the building and the concern for energy consumption in the operation of the building. All of these factors must be balanced to determine the most appropriate ventilation strategy for any building.

Keep in mind that dilution ventilation only reduces the concentration of indoor contaminants once they are already suspended in the air, whereas removing the source of the contaminants is far more effective than any air dilution or air cleaning strategy. Our next white paper on Ventilation Effectiveness will address the overall effectiveness of the HVAC system in containing and removing airborne contaminants in buildings.

RESOURCES	
ASHRAE	https://www.ashrae.org/
U.S. Environmental Protection Agency	https://www.epa.gov/
RenewAire	https://www.renewaire.com/
Airxchange	https://www.airxchange.com/
Engineering Toolbox	https://www.engineeringtoolbox.com
The Weather Channel	https://www.weather.com/

Introduction

Next in our ongoing series of white papers on Enhanced HVAC Infection Control, we examine one of the most significant factors affecting the spread of disease within buildings - humidity.

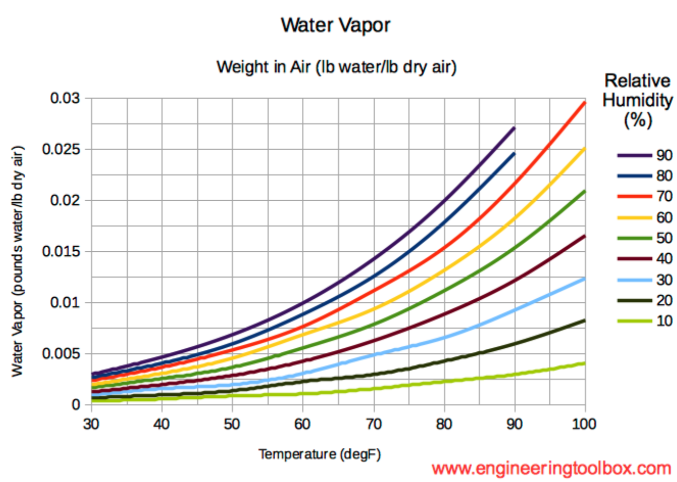
Humidity vs. Relative Humidity

The word "humidity" used on its own is a general term that does not define a specific measurable property of air. To be precise and measurable humidity must be classified as either Absolute, Specific or Relative.

Absolute Humidity is defined as the amount of water vapor (moisture) contained in the air, regardless of the temperature of the air. Absolute Humidity is typically measured in *lbs/ft3 or grains/ft3 (kg/m3 or g/m3).*

Specific Humidity is defined as the ratio of the mass of water vapor in air to the total mass of the mixture of air and water vapor being measured. Specific Humidity is typically measured in *grains/lb (g/kg).*

Relative Humidity is defined as the amount of water vapor contained in the air expressed as a percentage of the maximum amount of water vapor that the air can hold at the given temperature. The saturation level of air is the point at which water vapor will begin to condense out of the air and become liquid again (e.g. rain). The relative humidity at saturation is, by definition, 100%.



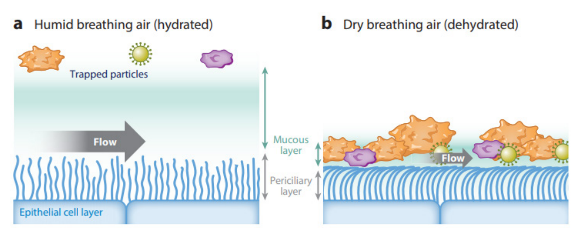
Relative Humidity vs. Temperature

When someone speaks of "humidity", without out any indication as to what type of humidity metric they are referring, it generally assumed to be Relative Humidity or RH, which is the most common and useful definition in terms of HVAC system design, human comfort and most environmental parameters.

In this white paper, we will be discussing how indoor air relative humidity affects human health and the spread of disease. Are there levels of indoor air RH that are beneficial to humans? Are there levels of RH that are detrimental to humans? What impact does RH have on potentially infectious agents? How do these levels compare? And finally, how can we use the building's HVAC systems to maintain humidity levels at their optimal levels?

RH Effect on Humans

Numerous studies have shown that human biological processes do not function well in environments with very low RH levels. A relative humidity level of less than 30% can cause dry skin, dry eyes, induce asthma, increase infections, and induce fatigue. Importantly, dry air weakens the body's mucociliary clearance mechanism, which is a biophysical process the body uses to rid the respiratory system of pathogens before they reach the lung tissue.



Mucociliary Clearance Mechanism

Many studies have shown that our natural respiratory defense mechanisms function optimally when the relative humidity level of the air is between 40% and 60%. Studies have also shown that infected subjects have more severe symptoms when the relative humidity is low, as opposed to when the relative humidity is in this desirable 40%-60% range.

Conversely, high humidity also adversely affects many functions of the human body, including its ability to reject heat. The body relies heavily on the heat of vaporization to cool the skin surface and keep the body cool. If indoor RH levels rise above about 60%, this evaporative process slows and requires the body to produce more sweat to maintain its appropriate internal temperature. The body also reacts to high RH levels by increasing the rate of respiration and increasing blood flow to the extremities, resulting in feelings of lethargy and sluggishness. High RH is also detrimental to those suffering from allergies, asthma and other respiratory illnesses. As the humidity levels rise, human respiration becomes more difficult, increasing the chances of an allergy/asthma attack or other forms of respiratory distress.

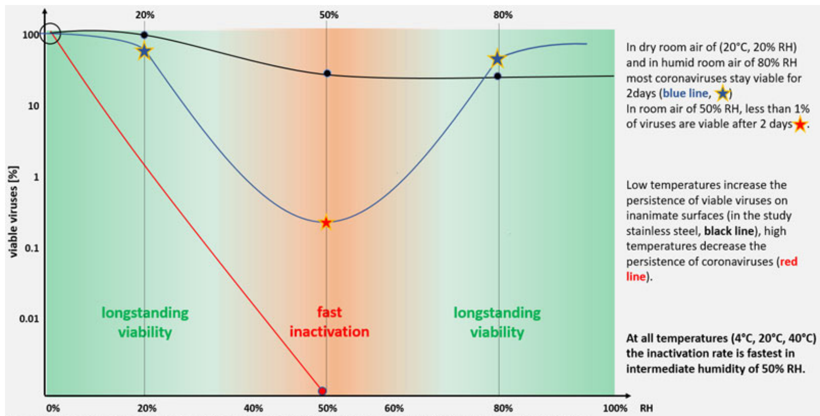
RH Effect on Pathogens

It has long been known that dry air coupled with cold temperature aids viral transmission. The annual patterns of the common cold and seasonal influenza viruses follows this phenomenon religiously. As temperate climates reach dry winter conditions, the incidence of colds and the flu inevitably increase until spring, when outdoor temperature and humidity levels rise and cases taper off. This fact has been known for centuries, but only recently have scientific studies conclusively identified the primary causes of these seasonal fluctuations in virus infections.

A comprehensive review of the most current research on the effects of seasonality on viral infections was recently pre-released by the *Annual of Virology* in an article authored by a team of doctors from Yale University and the University of Zurich (Moriyama, Hugentobler and Iwasaki) titled Seasonality of Respiratory Viral Infections. **[Click here](#)** for a link to the full review for an in-depth look at the mechanisms behind the seasonal virus phenomenon.

The current research repeatedly points to the impact that indoor relative humidity has on not only the human respiratory system's ability to fight off viral infections, but also the survivability and efficacy of the viruses' spread through airborne transmission. Low relative humidity has a very significant effect on airborne droplet transmission and the ability of the viruses to survive outside of a host carrier. This survivability applies to all droplet sizes, independent of their source, size or location. Even droplets located on contact surfaces (fomites) are impacted by the RH in the space, with conclusive evidence that midrange RH levels are the most effective at neutralizing the virus's ability to survive long enough to infect another host (person).

Nearly all recent studies have shown that a relative humidity range of 40% to 60% diminishes the ability of the virus to remain viable within a droplet, aerosol or fomite particle, minimizing the chances of a transmission dramatically. The impact of RH on aerosol particles is the most pronounced as shown in the graph below. Viability of the virus drops to 1% after 2 days in a 50% RH environment. This compares to over 80% virus viability at 20% or 80% RH. A number of animal studies have confirmed that aerosol viral infection rates decrease significantly at midrange RH levels, while infection rates are *enhanced* at both low and high RH levels.



Graph 2 Inactivation of SARS Coronavirus–Surrogate TGEV after 2 days, at different temperatures and humidities. Outdoor temp. 4°C, room temp. 20°C und desert temp. 40 °C. Fastest inactivation at all temperatures in intermediate humidity.

Casanova LM et al, Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces, APPLIED AND ENVIRONMENTAL MICROBIOLOGY, May 2010, p. 2712–2717

The research is conclusive: Relative humidity is one of the most influential variables in the fight against airborne and contact transmission of viruses, including the SARS-CoV-2 virus. This is particularly true for tight indoor environments. The current research also indicates similar humidity impacts on other microbiological organisms (primarily molds and bacteria), with even more pronounced results, particularly at high relative humidity levels.

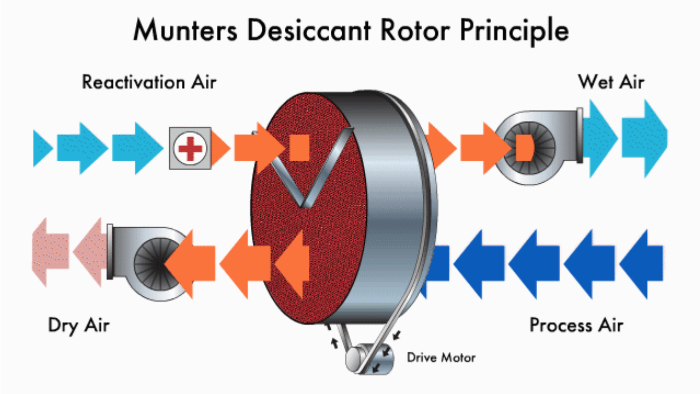
Summer Control of Humidity

A building's HVAC system can have a very dramatic impact on the relative humidity levels in the occupied spaces, provided the proper equipment and controls are implemented to monitor and control humidity levels directly. Unfortunately, most traditional HVAC systems are set up to only passively control humidity in the summer, through the natural condensation of humidity on cold cooling coils in the system.

Air conditioning systems are an extremely effective means of removing high summer humidity levels and most HVAC systems are *designed* to maintain indoor RH levels at or about 50-55% under summer design conditions. However, there is usually no active monitoring or direct control of the humidity levels, except in the most sophisticated buildings. Most often, summer humidity control only becomes a priority when excessively high humidity levels become apparent due to either light loading of the space, operational problems with the air conditioning equipment or defects in the design of the systems.

A thorough evaluation of the anticipated loading conditions, outdoor air ventilation rates, occupancy levels and the diversity of occupancy levels is essential to ensure that the air conditioning systems are properly designed and configured to address summer humidity levels independent of temperature control. With proper design, monitoring and control, a buildings' HVAC system provides the most economical and powerful means of keeping humidity levels within the desired 40% to 60% range that is ideal for infection control.

Under certain conditions, air conditioning systems alone may not be able to maintain acceptable indoor humidity levels during periods of high outdoor humidity. This can occur when the cooling equipment is oversized for the cooling load presented, or when outdoor air ventilation rates and outdoor air humidity conditions are too high for the air conditioning system to maintain acceptable RH levels. Under those conditions, other technologies can be applied, including reheat (hot gas, electric, hot water, etc.) or desiccant solutions to keep the indoor relative humidity levels below 60% at all times.



Winter Control of Humidity

Generally speaking, there is little to no control of winter humidity levels in most commercial and industrial buildings. Residential occupancies are more likely to include winter humidity controls, however these systems are usually aftermarket additions made by the occupants of the building as a result of the noticeable detrimental health effects of low humidity.

The lack of winter humidification in commercial and industrial buildings is primarily due to the fact that, until recently, the impact of low humidity levels on biological and viral efficacy was not well understood. Recent concerns over the rapid spread of the SARS-CoV-2 virus, particularly in the "super-spreader" events that have been widely publicized, along with the concern for reopening plans in the face of no proven vaccine therapy, has brought these concerns to the forefront.

Fortunately, there are a large number of time-tested, proven technologies that can be readily applied to both existing and new build situations without breaking the bank due to a high cost of implementation. Air humidification equipment has been around for over a century and is very effective and safe if properly designed, maintained and operated.

The best method of uniformly distributing humidity throughout the occupied spaces is with add-on systems for the central heating and ventilating systems that are already provided in the building. These systems generally rely on the generation of "clean" steam, which is injected into the airstream in the supply air ducts or HVAC equipment through in duct distributor units.

In Duct Steam Distributor

Steam-to-Steam Humidifier

The "clean" steam can be generated by a number of methods including small electric steam generators (electrodes), gas fired steam generators for larger systems or steam-to-steam humidifiers in large buildings that have available steam used for the building heating systems. The most common central humidifiers, particularly for retrofit applications, are electrode steam humidifiers, due to their versatility and ease of installation.

The selection of the best central humidification strategy should be the result of a through engineering study of the options available for a specific building in order to optimize the initial cost vs. the long term operating and maintenance cost of the system selected.

Humidifiers can also be stand-alone units, where the application of "clean" steam is not possible or practical at the heating and ventilating units. The stand-alone units are typically applied in a room by room basis and can be residential or commercial rated. The technologies are similar to the HVAC equipment based systems, however the steam is injected directly into the space rather than into the duct for distribution with the air ventilation system.

There is one type of humidifier system that should be avoided due to its potential to generate additional biological hazards at the source of the humidity being introduced into the airstream. Humidifiers relying on evaporation or evaporative pads tend to be very attractive due to their low initial cost, however unless they are meticulously maintained and periodically disinfected, they can become a significant potential source of hazards including Legionella, mold and other airborne biological contaminates.

Summary

It seems that nature has laid out a relative humidity range in which humans are best able to defend themselves against viruses and that same range appears to be the range in which viruses are at their weakest. That optimal range is 40% to 60% RH. In the fight against SARS-CoV-2, as well as other biological hazards, it is important to maintain the indoor relative humidity within that ideal range, regardless of the season.

Indoor relative humidity plays a very important role in preventing the spread of respiratory infections. Pathogens literally thrive in air with less than 40% RH, however more importantly, they are not nearly as infectious in the 40% to 60% RH range. HVAC systems can be effectively used to maintain the indoor relative humidity levels in the desired range with the addition of the appropriate sensors and controls and, in temperate climates, the addition of humidification equipment.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Occupant Health, Building Energy Performance and Humidity - Stephanie Taylor, M.D., M. Arch.	https://www.ashrae.org/professional-development/tech-hour-videos
Low ambient humidity impairs barrier function and innate resistance against influenza infection	https://www.pnas.org/content/pnas/116/22/10905.full.pdf
Annual of Virology, Seasonality of Respiratory Viral Infections	https://www.annualreviews.org/doi/pdf/10.1146/annurev-virology-012420-022445
Influenza Virus Transmission Is Dependent on Relative Humidity and Temperature, National Institutes of Health	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2034399/#:~:text=The%20stability%20of%20influenza%20virions,60%25%E2%80%9380%25).
Engineering Toolbox	https://www.engineeringtoolbox.com
ASHRAE Journal	https://www.ashraejournal.org/
Condair Group, Inc.	https://www.condair.com/
Munters Corporation	https://munters.com/

Introduction

Our previous white paper on Dilution Ventilation examined how the concentration of contaminants in the air can be significantly reduced by introducing "cleaner" outdoor air into the occupied space. In this paper we will discuss how well we can expect the outdoor air to mix with the air in the rooms and the likelihood that any airborne contaminants in the rooms will be captured and returned to the HVAC equipment for treatment or removal.

Ventilation – More Than Just Outdoor Air

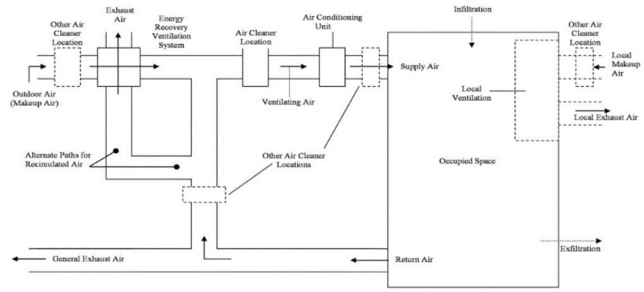
Proper ventilation of the occupied spaces is critical to maintaining acceptable indoor air quality (IAQ) and thereby the overall health and wellbeing of the inhabitants of the building. Ventilation design has been a topic of debate among engineers for decades, with ever changing theories on the best methodologies, air exchange rates and distribution strategies necessary to achieve acceptable indoor air quality. With the advent of improved digital monitoring and control technologies, these debates have been quelled by the empirical data gathered regarding the required ventilation rates necessary to achieve acceptably low concentrations of known airborne contaminants.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has developed the de facto standard for designing for and monitoring indoor air quality in its *ANSI/ASHRAE Standard 62.1 – Ventilation for Acceptable Indoor Air Quality.* Nearly all codes today refer exclusively to this Standard.

ASHRAE defines "Ventilation" as:

The process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space.

It is important to note that ventilation involves not only outdoor air ventilation, but also the recirculation of air within the building. Very few buildings are configured for a 100% outdoor air ventilation rate, therefore, it is important to consider both recirculated room air and the outdoor air that is introduced at the HVAC equipment, along with other components including infiltration and localized exhaust systems. The diagram below, reprinted from ANSI/ASHRAE Standard 62.1-2019, illustrates the various components that potentially contribute to the overall ventilation of any occupied space.



ANSI/ASHRAE 62.1 Ventilation System Diagram

Room Air Mixing Efficiency

Nearly all HVAC systems deliver primarily recirculated air, along with a percentage of fresh air from the outdoors, as part of the supply air delivered to the occupied spaces. It is a given that the supply air delivered to the spaces by the HVAC unit is well mixed due to the turbulence of the air in the ductwork system, however how well does the supply air delivered to the room mix with the rest of the air in the room?

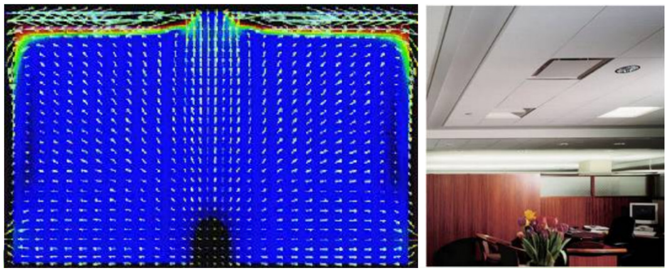
The goal of diluting the contaminants in the room air depends on the efficiency of the mixing of the air in the room. If portions of the room or rooms have little or no air movement, the dilution of contaminants will be inconsistent and will not be as effective in the stagnate areas.

A number of factors affect the mixing of air in a room. They include, in no particular order:

- Quantity, type, and location of the diffusers.
- The temperature and volume of air delivered.
- The supply air discharge velocity.
- The supply air discharge patterns.
- The location of the return air grilles with respect to the occupied zone and with respect to the supply air diffuser(s).
- The location of the exhaust air grilles with respect to the sources of contaminants and with respect to the supply air diffuser(s).
- The overall layout and physical configuration of the room itself.
- The air exchange rate.

The preceding factors are just a few of the many variables influencing the mixing of air in the occupied spaces. However, these are the factors that are most likely to be influenced by the system designer. The end goal of any air distribution system design is to achieve a well-mixed distribution of air throughout the space. Perfect air mixing everywhere is not easily attainable, however using proper discharge device selection and location the system designer can aid in the thorough mixing of the air in the room.

High Induction Supply Air Diffuser Design



The key to good air mixing in the space (effectiveness) is having a relatively high velocity of air discharged from the supply air diffusers so that room air movement is induced by the high velocity stream of supply air. The temperature of the air delivered to the space has a very significant impact on the mixing of air, particularly if the air volume is varied based on the load in the room, as occurs in a Variable Air Volume (VAV) system.

Air change effectiveness (ACE) is a calculation of an air distribution system's ability to effectively deliver ventilation air to a building, zone or space. ACE is defined by ASHRAE as the age of air that would occur throughout the building if the indoor air was perfectly mixed divided by the average age of the air where the occupants breathe. The "age of the air" in the ACE calculation refers to the average time elapsed since molecules of air in a given volume of air entered the building from outside.

Studies have consistently shown that during the cooling mode (supply air discharge temperatures of approximately 55ºF), air mixing is generally very good, approaching (or exceeding) a 1.00 ACE rating. However, during the heating mode ACE often drops dramatically, particularly in Variable Air Volume (VAV) systems operating at or near their minimum total circulation rate. ACE in the heating mode, for systems with ceiling level supply diffusers, can range from as low as 0.69 to a high of 0.91, with a mean value of 0.72. This reduced air mixing in the heating mode, combined with the many other seasonal influences on the spread of viral contaminants (humidity, activity level, etc.), helps explain why viral infections typically spread more rapidly in cold northern climates during the winter months.

The ACE values described herein are based on the assumption of a well-designed approach to air delivery to the space. Poorly designed systems that result in short circuiting of the air from the supply diffusers to the return/exhaust grilles, or an insufficient amount of total air delivered to the space will see markedly lower ACE values. Good air distribution design is essential to the effective mixing of fresh air and room air in the occupied spaces.

ANSI/ASHRAE Standard 62.1 provides some generalized zone level effectiveness values (Ez) for use in the calculation of the minimum required rate of outdoor air introduction necessary to achieve acceptable indoor air quality. From the table on the following page, it is clearly evident that the selection of the supply diffuser and return/exhaust grille locations is very important to proper room air mixing and therefore the amount of outdoor air ventilation required to maintain the air quality within the defined acceptable range.

Table 6-4 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Well-Mixed Air Distribution Systems	
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is less than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above average space temperature where the supply air-jet velocity is equal to or greater than 150 fpm (0.8 m/s) within 4.5 ft (1.4 m) of the floor and ceiling return	1.0
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply outlet located more than half the length of the space from the exhaust, return, or both	0.8
Makeup supply outlet located less than half the length of the space from the exhaust, return, or both	0.5

ANSI/ASHRAE 62.1 2019 Ventilation Effectiveness

The better the supply air mixes with the air in the occupied space, the better the chances are that any airborne contaminants will be carried back to the HVAC unit, where they can either be trapped or rendered inactive by any of the air cleaning methods installed in the unit. Short circuiting of the air in the space should be avoided under any circumstances.

Droplets vs. Aerosols

A "droplet" is defined by Merriam-Webster *as a tiny drop (as of a liquid)*. Droplets produced by exhalation, coughing, sneezing or speaking are referred to as respiratory droplets. Respiratory droplets consist of mucus and other matter from the respiratory tract surfaces, containing various microbes, viruses and other contaminants that can be spread to other humans. Respiratory droplets are typically larger in size and usually fall to the ground or nearby surfaces relatively quickly to become "fomites" - objects or materials which are likely to carry infection.

An "aerosol" is defined by Merriam-Webster as *a suspension of fine solid or liquid particles in a gas.* Respiratory aerosols, which are also produced by exhalation, coughing, sneezing or speaking, are small enough in size to have significant buoyancy and can remain airborne for much longer periods of time before succumbing to gravity.

A 2008 study by Chao, Wan, Morawska, Johnson, Ristovski and Hargreaves, in combination with a 1987 study by Fairchild and Stamper found that the respiratory droplet and aerosol particulate size range for coughs, sneezes and speaking range anywhere from 0.3 µm to 1500 µm, with the highest particle concentrations in the 6-14 µm range, whether based on total particle count (6 µm) or the mean diameter of the particles expelled (12.3-14.0 µm).

Respiratory droplets are commonly divided into two size groups, large droplets (>5 µm in diameter) and small droplets (≤5 µm in diameter).

Large droplets fall rapidly to the ground or onto other surfaces, where they can remain viable for anywhere from a few hours to a few days depending on the surface material and room conditions. Based on various research studies, these larger particles rarely travel more than six feet from their source. This is the basis of the six foot social distancing recommendations coming from public health officials. These larger particles are not transported back to the building's air handling equipment for discharge or removal by filtration, exhaust or sterilization devices. Therefore, HVAC systems are completely ineffective at stopping the spread of SARS-CoV-2 between building occupants due to large droplet transmission.

Facial coverings (masks) are by far the most effective means of stopping these larger particle sizes at their source, reducing the risk of infection of others in the area or others that will come in contact with the surrounding surfaces in the near future.

Smaller droplets (≤5 µm) remain airborne much longer and can evaporate into droplet nuclei, which can remain suspended in the air for up to 3 hours, according to several studies. These droplet nuclei and associated aerosols are the types of infectious particles that HVAC systems can be very effective at removing or neutralizing, provided the ventilation effectiveness of the room is good, the particles are captured at the return/exhaust air grilles and they are transported to the air handling equipment by the return air or exhaust air ductwork. There, they can either be removed by filtration/exhaust or neutralized by the various sterilization methods discussed in our previous white papers.

Summary

At present time, it is not believed that the primary transmission method of the SARS-CoV-2 virus is through airborne droplet nuclei or aerosols. However, recent reports have suggested that the virus may indeed be capable of significant airborne transmission, particularly in poorly ventilated buildings or rooms. Many of the "super-spreader" events appear to be the result of airborne transmission to large groups of people in sub-standard indoor locations. This has prompted the World Health Organization and the Centers for Disease Control to acknowledge that the possibility of significant airborne transmission exists.

As a result, ventilation effectiveness, coupled with proper ventilation rates and increased filtration efficiency, is an area of concern that must be addressed in order to safely reopen our buildings. Ventilation effectiveness is largely dependent upon how well the HVAC system has been designed to ensure adequate mixing of the air in the occupied space, so that the smaller infectious particles can be quickly transported to the HVAC equipment, where the other measures of infection control covered in this series of white papers can have a meaningful impact on the spread of the virus. Even in existing facilities, relatively minor revisions can be made to improve the ventilation effectiveness of a system, without requiring complete renovations.

According to all known studies of modern air distribution design, ventilation effectiveness is quite high when the system is in the cooling mode, approaching 100%. However, it can drop significantly in the heating mode, due to reduced airflows and stratification of the air in the space. With some relatively minor adjustments to the control systems, particularly in Variable Air Volume (VAV) systems, ventilation effectiveness can be significantly improved using higher heating airflow rates and adjustments to the recirculation rates at the air handling equipment.

RESOURCES	
ASHRAE	https://www.ashrae.org/
National Center for Biotechnology Information	https://www.ncbi.nlm.nih.gov/
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
National Institutes of Health	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7293495/
eLife	https://elifesciences.org/articles/57309
National Environmental Balancing Bureau	https://www.nebb.org
Air Change Effectiveness and Pollutant Removal Efficiency During Adverse Mixing Conditions, Fisk, Faulkner, Sullivan and Bauman, Indoor Air, 1997 Lawrence Berkeley Laboratory and the Center for Environmental Design Research, UC Berkeley	https://www.osti.gov/servlets/purl/803749
Characterization of Expiration Air Jets and Droplet Size Distributions Immediately at the Mouth Opening. Chao, Wan, Morawska, Johnson, Ristovski, Hargreaves, et al., J Aerosol Sci, 40 (2) (2009), pp. 122-133	https://reader.elsevier.com/reader/sd/pii/S0021850208001882?token=A5CFDD9AFD3063EC8054DFAC8ABCE22BE4F544AD7A539F9C0A6152E030452474DCEFBB6E78E92C0898A9E8C048074051
Fairchild and Stamper, Particle Concentration in Exhaled Breath. Am. Ind. Hyg. Assoc. J. 48 (1987), 948–949.	https://www.tandfonline.com/doi/abs/10.1080/15298668791385868
World Health Organization	https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public
Centers for Disease Control	https://cdc.gov

CHAPTER 2:

OCCUPANCY SPECIFIC BUILDINGS

Introduction

As we wrap up our white paper series on Enhanced HVAC Infection Control, we will be addressing specific building types and occupancy classifications in an effort to identify the most useful strategies that can be applied to each type of building or occupancy in order to improve the air quality and safety of the indoor environment.

Our primary objective will be to answer the question: *What should I do to my building to improve the safety and comfort of the occupants?*

In this white paper we will discuss the unique characteristics of the HVAC systems in covered mall buildings to see how well they can be adapted to the best recommendations and guidelines regarding indoor air quality and infection control.

Design Criteria

According to the International Code Council (ICC), a Covered Mall Building is defined as:

> *A single building enclosing a number of tenants and occupants, such as retail stores, drinking and dining establishments, entertainment and amusement facilities, passenger transportation terminals, offices and other similar uses wherein two or more tenants have a main entrance into one or more malls.*

The ICC definition goes on to include Open Mall Buildings defined as:

> *Several structures housing a number of tenants, such as retail stores, drinking and dining establishments, entertainment and amusement facilities, offices, and other similar uses, wherein two or more tenants have a main entrance into one or more open malls. Anchor buildings are not considered as a part of the open mall building.*

In this article, we are focused on the enclosed, covered mall building, which is provided with mechanical heating, ventilation and air conditioning systems. A covered mall building is typically divided into the "common mall area" and the individual tenant bays, consisting of the retailers, restauranteurs and other occupants of the overall building. A future white paper will address the individual needs of the individual tenants based on their specific occupancy categories and the unique aspects of their HVAC systems design.

The design and construction of any covered mall building is a very long and involved process, engaging a myriad of consultants and contractors to achieve the final objective of a safe, comfortable and attractive environment for the life of the building. The design team must anticipate and take into account the different types of tenants, the various activities that might take place at the mall, and any seasonal variations the facility might experience. In addition, the code and regulatory requirements for covered malls are some of the most extensive and stringent of any building type.

These projects are designed and constructed by only the largest and most experienced firms, with great attention to detail to make sure that all requirements are met. Jurisdictional oversight of covered malls is very strict, due to their size and potential impact on the local community. Because of these stringent conditions, the HVAC systems in covered malls are some of the largest and most robust systems, which can operate under a wide variety of indoor and outdoor conditions and still maintain the desired comfort levels. The quality of the design and construction, coupled with the stringent regulatory requirements make covered mall buildings potentially some of the safest indoor environments available.

Ventilation Systems

The HVAC systems for covered mall common areas are designed to provide ventilation for peak occupancy loads and still maintain the desired comfort level at all design conditions. The outdoor air ventilation requirements are prescribed by the applicable codes and standards, which typically include both a high occupancy rate (25 SF/person) and a high ventilation rate (7.5 CFM/person + 0.06 CFM/square foot). Based on these requirements, a typical covered mall concourse area of 50,000 square feet, for example, would be required to provide up to 18,000 CFM of outdoor air ventilation depending on the occupancy load. This ventilation rate would support a peak occupancy of over 2,000 people in the 50,000 square foot space at one time, while maintaining air quality levels within acceptable standards.

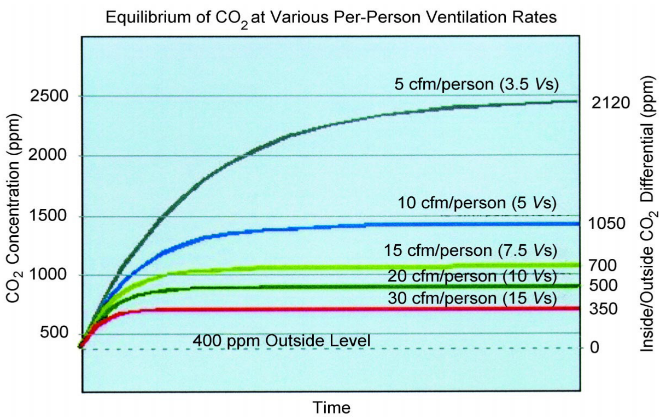
This high peak ventilation rate in the covered mall provides the opportunity for much higher than normal ventilation rates at any time the covered mall building is not operating at peak occupancy.

Peak occupancy levels in covered malls rarely occur, and usually only during the holiday shopping season. As a result, during the vast majority of the year, the ventilation systems are operated at a reduced rate by means of CO_2 sensor controlled dampers. The CO_2 sensor controlled dampers regulate the amount of outdoor air introduced in order to control energy costs during non-peak periods.

Since covered mall HVAC units are usually large, high capacity units, they are equipped with outdoor air economizer dampers and powered exhaust systems, as required by nearly all energy codes. This means the units are capable of bringing in up to 100% of the total circulated air from the outdoors.

By simply adjusting the CO_2 ventilation control set point, it is possible to dramatically increase the amount of fresh air ventilation provided to the space. Per our previous white paper on Dilution Ventilation, a doubling of the ventilation rate will roughly cut the concentration of contaminates in the air by approximately one-half, including airborne or aerosol viruses. By simply reducing the CO_2 ventilation control set point from 1,200 ppm to 600 ppm, the ventilation rate will be doubled and the concentration of contaminates will be halved, without any adverse impacts on the HVAC systems, which are designed for these high ventilation rates.

Most modern CO_2 ventilation controls are set up to maintain a fixed differential (700 ppm) above outdoor ambient CO_2 levels, which are typically 300 to 500 ppm ambient depending on the geographic location. Cut the set point differential value by one-half and the ventilation rate will approximately double. The following graph illustrates the correlation between indoor equilibrium CO_2 concentration and ventilation rates.



The only caveat to this strategy is an increase in energy consumption at any time the outdoor conditions are unfavorable relative to the desired indoor temperature and humidity conditions. Therefore, dilution ventilation is an easily accomplished strategy for covered mall buildings, as long as the cost of the energy consumed is recognized as the tradeoff. In some cases, even this caveat can be partially mitigated by installing energy recovery units on the units, where such systems can be reasonably applied. This will reduce energy costs, especially during periods of increased ventilation rates.

The recommendation for increased outdoor air ventilation should be readily achievable by covered mall HVAC systems, without any need for expensive or time consuming system modifications.

Filtration Upgrades

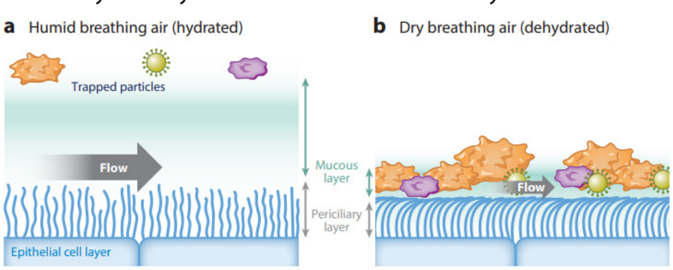
Due to the size of covered mall buildings and their high occupancy requirements, the HVAC units serving them consist of large, high capacity commercial equipment. These units are specified to have large fans capable of overcoming high static pressures (resistance to airflow). In our previous white paper on Filtration, we found that MERV Ratings of 13 and up provide a very effective means of stopping the spread of infectious particles, such as the SARS-CoV-2 virus.

The additional static pressure that comes with replacing existing filters with a higher MERV rating (typically 1.0" for MERV 13 to 1.5" for MERV 16) should be relatively easy to accomplish in a covered mall setting. If the HVAC units are belt-driven, the sheaves (pulleys) may need to be adjusted or even replaced. If the units are equipped with the direct-drive type motors, these are also relatively easy to adjust to account for the increased static pressure of higher efficiency filters. None of these modifications would be difficult or expensive to achieve in practice.

Again, the recommendation for increased filter efficiency to MERV 11 to 13 should be readily achievable by covered mall HVAC systems, without any need for expensive or time consuming system modifications. Anything above MERV 13 becomes more challenging due to the 6”-12” filter depth and increased static pressure drops at these higher efficiencies.

Humidity Control

Numerous medical studies over many years have shown that the cilia in the body’s airways do not function as efficiently in low humidity conditions as they do in higher humidity conditions. Cilia are the hair-like organelles lining the body’s airways that expel viral and other particles. If the air gets too dry, they simply are not able to move foreign particles away from the respiratory system as effectively as they can under normal humidity conditions.



According to ASHRAE Standard 62.1 Ventilation for Acceptable Indoor Air Quality, indoor relative humidity (RH) levels should be maintained at or below 65% to prevent microbial growth. ASHRAE Standard 62.1 does not provide a minimum recommended humidity level, however other ASHRAE guidelines recommend that humidity levels be maintained between 30% and 60% RH. The United States Environmental Protection Agency also recommends maintaining indoor relative humidity between 30 and 60% RH [EPA 2012]. Relative humidity levels lower than 30% have also been found to cause eye irritation, nasal congestion and, for some individuals, aggravated allergies. The ideal indoor relative humidity for human respiratory function and good health is generally accepted to be between 30% and 60% RH.

Low relative humidity can also lead to increased survival of airborne viruses, thereby increasing the spread of viral infections. A recent technical review (Seasonality of Respiratory Viral Infections, Annual Review of Virology, March 2020) completed by a group of doctors and researchers from Yale University and the University of Zurich, Miyu Moriyama, Walter J. Hugentobler and Akiko Iwasaki, confirmed that the airborne stability and viability of a virus in heavily influenced by the relative humidity, particularly inside of buildings, where the air is shared by multiple occupants. This very thorough compilation and review of the available research on the link between environmental parameters and disease spread found that viruses are able to remain viable and airborne for much longer periods of time at humidity levels below 30%. The virus’s increased viability at low humidity, coupled with a reduced effectiveness of the cilia at low humidity results in a significant increase in the infection transmission rate inside buildings.

Enclosed malls, with their rigorous design requirements and increased capacity to handle high occupancy periods, allow for better dehumidification control in the summer months. The large covered mall HVAC units are capable of running efficiently under part-load conditions and thus are able to maintain constant humidity levels within the ideal range of 30-60% RH, without cycling of the air conditioning systems that is required with smaller commercial and residential equipment.

Covered malls typically do not include winter humidification capabilities, instead relying on respiration and food service to provide baseline levels of humidity. Some mall HVAC systems have the ability to add humidity centrally, with the addition of steam humidification units at key locations throughout the mall, in those geographic locations with low outdoor humidity levels during the winter months. Milder climates are not as susceptible to low humidity levels and should be able to maintain humidity levels without supplementation.

Building Management Systems

Covered mall buildings are typically controlled by a Building Management System (BMS). The BMS allows for the mall conditions, including temperature, humidity, equipment status and outdoor conditions to be closely monitored and controlled automatically as conditions change. Any deviation from the set point conditions can be set to trigger alarms, warning the facility personnel and off-site maintenance organizations so that the appropriate intervention can take place in a timely manner.

Summary

Covered mall buildings, by the nature of their large, well designed HVAC systems and controls, are well positioned to be easily adapted to the latest recommendations and guidelines with regard to indoor air quality and infection control. The advanced ventilation, filtration and humidity control strategies discussed in our previous white papers can be easily implemented in a covered mall environment to provide one of the safest, healthiest, anti-viral indoor environments.

Our specific recommendations for covered mall buildings include the following:

- ✔ Increase Ventilation Rates: Lower demand controlled ventilation (DCV) CO_2 sensor settings to 700 ppm total or 350 ppm differential to drive up outdoor air ventilation rates. If there are no demand controlled ventilation systems present (older malls), install DCV immediately to reap the energy benefits and gain control of the indoor pollutant concentration levels.

- ✔ Increase Filtration System Rating: Install minimum MERV 11 and preferably MERV 13 (or higher) filters to improve the system's efficiency at removing airborne particles containing infectious materials. MERV ratings lower than 11 have almost zero impact on particulates smaller than 1.0 micron and will not stop most infectious particles, including viruses.

- ✔ Relative Humidity Range: Monitor and maintain humidity levels between 30% and 60% RH. Summer dehumidification will usually be controlled within thi range using the existing multi-stage equipment. Winter humidification may require the addition of steam generating humidifiers in key areas of the concourse to raise the humidity level above 30% in colder winter climate locations.

RESOURCES	
ASHRAE	https://www.ashrae.org/
U.S. Environmental Protection Agency	https://www.epa.gov/
Centers for Disease Control and Prevention	https://www.cdc.gov/
Annual of Virology, Seasonality of Respiratory Viral Infections, March 2020	https://www.annualreviews.org/doi/pdf/10.1146/annurev-virology-012420-022445
ASHRAE Journal	https://www.ashraejournal.org/

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in office buildings.

Our primary objective will be to answer the question: *What should I do to my office building to improve the safety and comfort of its occupants?*

We will review the common systems types found in office buildings and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
  - Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:

- Increase ventilation rates or percentage of outdoor air.
- Disable demand-controlled ventilation (DCV).
- Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical Office HVAC System Types

Commercial office buildings may be served by a wide variety of system types including, but not limited to, the following:

- Central air handlers with terminal VAV boxes.
- Central air handlers with zone dampers.
- Terminal units: Fan coil, WSHP, GSHP, VRF, split-systems
- Commercial packaged roof top units

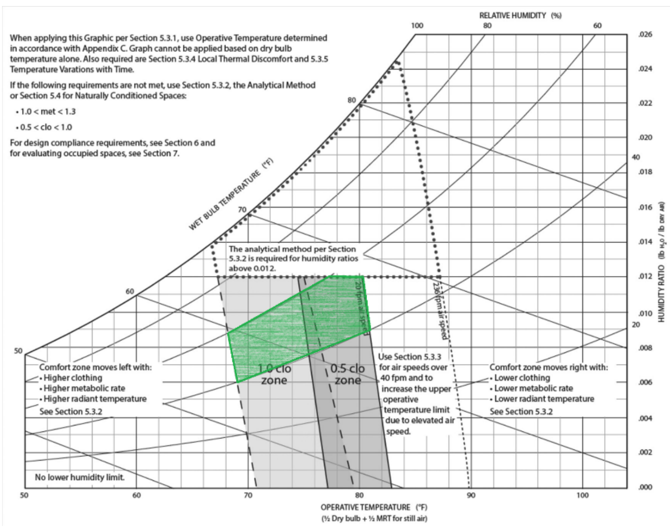
The central air handling systems (indoor modular, indoor self-contained and outdoor packaged types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods. The terminal unit systems are usually paired with a dedicated outside air system. These systems are typically equipped with the appropriate temperature controls and filtration equipment to meet the minimum code requirements and basic comfort needs of the building occupants.

Nearly all of the system types associated with office buildings offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". In addition, the perceived comfort level is impacted by a multitude of factors including the metabolic rate of the activities in the space, the air temperature, the radiant temperature, the relative humidity, the clothing insulation levels of the occupants and the average airspeed in the occupied zone. According to ASHRAE Standard 55, an acceptable level of occupant comfort means that less than 10% of the occupants polled would rate their experience in the space as "thermally dissatisfied". ASHRAE calls this metric the predicted percentage of dissatisfied or PPD. Basically, you will never please everyone, so as long as you please at least 90% of the occupants, it is considered satisfactory performance.

Instead of indicating a specific temperature range for each occupancy, ASHRAE 55 recommends that spaces be maintained within a band of coincident temperature and humidity levels, taking into account the velocity of air movement in the occupied zone, as indicated by the grey shaded area on the graph below.



ASHRAE 55: Acceptable Range of Operative Temperature and Humidity for Spaces

The green shaded area superimposes the recommended anti-viral humidity range of 40%-60% RH on the ASHRAE 55 comfort zone chart to achieve a PPD of <10% in a highly effective, anti-viral office environment. As is evident from the graph, there is a fairly narrow range of coincident temperatures and humidity levels that are considered acceptable for both human comfort and for infection control. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still lands within the green bounded area of human comfort and effective infection control.

Facilities personnel or qualified service contractors should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems

ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 5 cfm per person plus 0.06 cfm per square foot of floor area of outdoor air for office spaces. Assuming a typical office occupant density of 200 square foot per person and an 8'-6" ceiling height, this translates into approximately 0.6 air changes per hour of outdoor air. While it meets minimum code requirements, a 0.6 air change rate is not considered sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution. See our white paper on Dilution Ventilation for further details.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical office systems may or may not be able to achieve a 2 to 4 air change rate, while still maintaining acceptable indoor temperatures and humidity. Therefore, the goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air.

Many modern office buildings are equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space or return air stream. These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO2 concentration or <600 ppm above the outdoor ambient CO2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system.

During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

Terminal unit systems which rely on Dedicated Outdoor Air Systems (DOAS) may be more challenging when it comes to increasing the ventilation rate. DOAS units are typically designed to within a fairly narrow band of the code prescribed minimum outdoor air ventilation rates and therefore would require significant modifications or even unit replacement to achieve the higher ventilation rates necessary to achieve effective airborne pathogen dilution.

<u>All</u> HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Central air handling units and commercial package roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions. Most office buildings have a reasonable capacity to dehumidify the air in the building using the central air conditioning systems, however very few office buildings are equipped with any type of humidification equipment to keep viral spread low during the winter months.

Humidification Mode

Central air handling units and commercial package roof top units should be fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur. Zone level humidity control is generally not necessary since the overall humidity within the building will equalize relatively quickly in most office arrangements.

Facilities served by terminal units will need to be evaluated on a case-by-case basis. Individual humidifiers featuring in-duct steam distribution might work in some instances. However, in most cases a different approach is warranted. Humidifiers with wall-mounted distributors, floor type single room humidifiers and countertop personal humidifiers are some of the options available when central systems are not present to handle the humidification needs. The DOAS, if so equipped, may be the best method of providing facility wide humidification in buildings equipped with terminal unit systems.

Dehumidification Mode

Most office HVAC systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. In addition, some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. This should be a relatively rare condition in most modern office buildings.

Additional Prevention Measures

In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold.

- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source.

- High exposure risk areas like bathrooms, cafeterias, gyms and elevators can be fitted with ionization purification systems, either bi-polar or photocatalytic oxidation type, as additional measures to control potential viral spread in these critical locations.

- In-room or personal filtration, sterilization and humidification units can be utilized where the central system strategies presented herein are either not practical or not possible due to the existing HVAC system configuration. These systems are particularly useful for buildings utilizing terminal unit type HVAC systems. When selecting these systems, it is very important to look for independent testing and research regarding their effectiveness to make sure they perform the stated functions reliably and do not produce any harmful byproducts such as ozone or formaldehyde, which can result from some of the ionization processes.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in retail stores.

Our primary objective will be to answer the question: *What should I do to my store to improve the safety and comfort of my employees and customers?*

We will review the common systems types found in retail stores and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:

- Increase ventilation rates or percentage of outdoor air.
- Disable demand-controlled ventilation (DCV).
- Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community resuming-business-toolkit.html)

Typical Retail Store HVAC System Types

Retail stores may be served by a wide variety of system types including, but not limited to, the following:

- Commercial packaged roof top units
- Terminal units: Fan coil, WSHP, split-systems
- Central air handlers with terminal VAV boxes (large systems)

The central air handling systems (commercial packaged roof top and central air handler types) address the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods. In retail applications, the terminal unit systems typically get their outside air directly from the outdoors via louvers or gravity intake vents if the space has access to exterior walls or roofs.

Some terminal unit systems are paired with a dedicated outside air system, often controlled by the Landlord. These systems are typically equipped with the appropriate temperature controls and filtration equipment to meet the minimum code requirements and basic comfort needs of the building occupants.

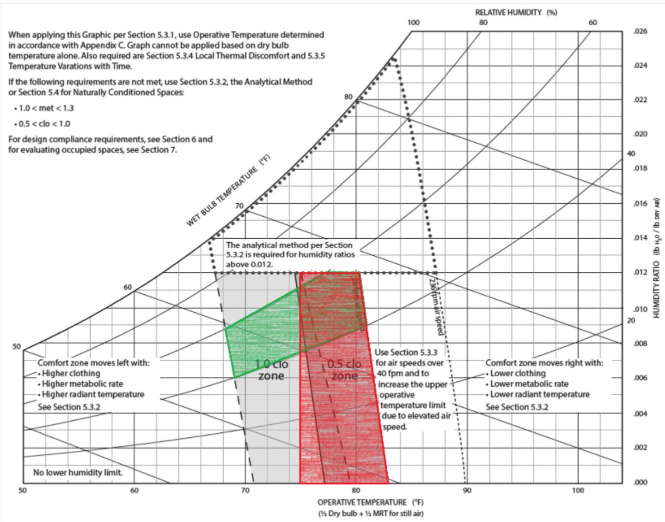
Nearly all of the system types associated with retail stores offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". In addition, the perceived comfort level is impacted by a multitude of factors including the metabolic rate of the activities in the space, the air temperature, the radiant temperature, the relative humidity, the clothing insulation levels of the occupants and the average airspeed in the occupied zone, not to mention basic personal preferences.

According to ASHRAE Standard 55, an acceptable level of occupant comfort means that less than 10% of the occupants polled would rate their experience in the space as "thermally dissatisfied". ASHRAE calls this metric the predicted percentage of dissatisfied or PPD. Basically, you will never please everyone, so as long as you please at least 90% of the occupants, it is considered satisfactory performance per ASHRAE. In retail occupancies, these levels are usually lower than in most occupancies, especially with regard to temperature expectations.

Instead of indicating a specific temperature range for each occupancy, ASHRAE 55 recommends that spaces be maintained within a band of coincident temperature and humidity levels, taking into account the velocity of air movement in the occupied zone, as indicated by the grey shaded area on the graph below.



1ASHRAE 55: Acceptable Range of Operative Temperature and Humidity for Spaces

The green shaded area superimposes the recommended anti-viral humidity range of 40%-60% RH on the ASHRAE 55 comfort zone chart to achieve a PPD of <10% in a highly effective, anti-viral indoor environment. The red shaded area indicates a region of unacceptable dry bulb temperatures for a retail store. As is evident from the graph, there is a fairly narrow range of coincident temperatures and humidity levels that are considered acceptable for both human comfort and for infection control. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still lands within the green bounded area of human comfort and effective infection control, while avoiding unacceptably high dry bulb temperatures in the red zone.

Qualified service technicians should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve HVAC infection control.

Ventilation Systems

ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 7.5 cfm per person plus 0.12 cfm per square foot of floor area of outdoor air for sales areas. Based upon a sales area occupant density of 15 people per 1000 ft2 and a 10'-0" ceiling height, this translates into approximately 1.4 air changes per hour of outdoor air. While it meets minimum code requirements, a 1.4 air change rate is not considered sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution. See our white paper on Dilution Ventilation for further details.

Air changes per hour	Minutes required for removal efficiency 99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical retail store systems may or may not be able to achieve a 2 to 4 air change rate, while still maintaining acceptable indoor temperatures and humidity. Therefore, the goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air to meet minimum acceptable comfort standards.

Many retail stores are already equipped with Demand Controlled Ventilation systems, or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space or return air stream. These systems are designed to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient

CO_2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivered to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system. The addition of a pre- and post-occupancy purge cycle will provide an even further reduction in the space contaminant levels.

During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and contaminant control improvement reasons.

Terminal unit systems which rely on Dedicated Outdoor Air Systems (DOAS) may be more challenging when it comes to increasing the ventilation rate. DOAS units are typically designed to within a fairly narrow band of the code prescribed minimum outdoor air ventilation rates and therefore would require significant modifications or even unit replacement to achieve the higher ventilation rates necessary to achieve effective airborne pathogen dilution. In addition, most DOAS units in a retail setting are controlled by the Landlord, requiring a coordinated, facility-wide approach to infection control.

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Central air handling units and commercial package roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

High MERV Pleated Filters

Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions. Most retail store systems have a reasonable capacity to dehumidify the air in the store using the air conditioning system, however very few retail stores are equipped with any type of humidification equipment to keep viral spread low during the winter months.

Humidification Mode

Central air handling units and commercial package roof top units should be fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur. Stores served by terminal units will need to be evaluated on a case-by-case basis. Individual humidifiers featuring in-duct steam distribution might work in some instances. However, in most cases a different approach may be warranted. Humidifiers with wall-mounted distributors, or floor type humidifiers are available options.

Dehumidification Mode

Most retail store HVAC systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. In addition, some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. This should be a relatively rare condition in most instances in a retail store environment.

Additional Prevention Measures

In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential.

These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold.
- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the space.
- Ionization Systems will be largely ineffective in larger retail sales environments due to the high volumes of air and difficulty in accessing the systems within the tenant spaces. These systems are better suited to smaller areas with high total air exchange rates and more concentrated exposure risks.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types, this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in restaurants.

Our primary objective will be to answer the question: *What should I do to my restaurant to improve the safety and comfort of its patrons and employees?*

We will review the common systems types found in restaurants and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per ANSI/ASHRAE Standard 62.1 are maintained.
- Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:
Increase ventilation rates or percentage of outdoor air.
Disable demand-controlled ventilation (DCV).
Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical Restaurant HVAC System Types

Restaurants may be served by a wide variety of system types including, but not limited to, the following:

- Commercial packaged roof top units
- Terminal units: Fan coil, WSHP, VRF, split-systems
- Central air handlers (rare)

The central air handling systems (commercial packaged roof top and central air handler types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods.

The terminal unit systems usually get fresh outside air via wall louvers or via gravity intake vents on the roof.

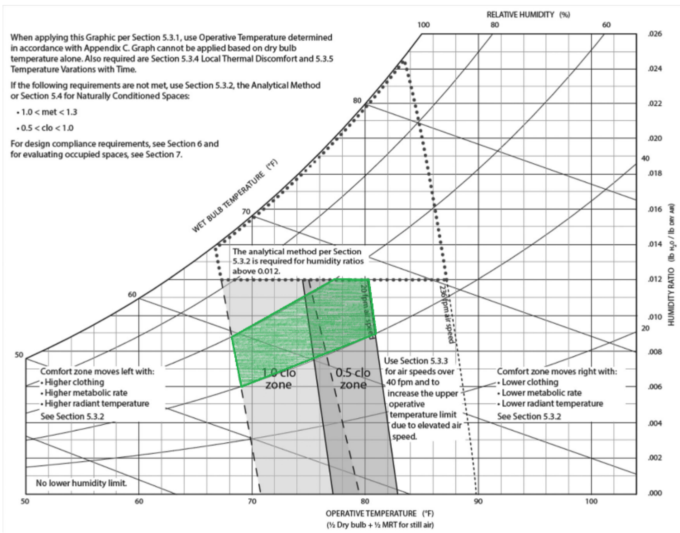
Nearly all of the system types associated with restaurants offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". In addition, the perceived comfort level is impacted by a multitude of factors including the metabolic rate of the activities in the space, the air temperature, the radiant temperature, the relative humidity, the clothing insulation levels of the occupants and the average airspeed in the occupied zone, not to mention basic personal preferences.

According to ANSI/ASHRAE Standard 55, an acceptable level of occupant comfort means that less than 10% of the occupants polled would rate their experience in the space as "thermally dissatisfied". ASHRAE calls this metric the *predicted percentage of dissatisfied or PPD*. Basically, you will never please everyone, so as long as you please at least 90% of the occupants, it is considered satisfactory performance per the ASHRAE Standard.

Instead of indicating a specific temperature range for each occupancy, ASHRAE 55 recommends that spaces be maintained within a band of coincident temperature and humidity levels, taking into account the velocity of air movement in the occupied zone, as indicated by the relatively large grey shaded area on the graph below.



ASHRAE 55: Acceptable Range of Operative Temperature and Humidity for Spaces

The green shaded area superimposes the recommended anti-viral humidity range of 40%-60% RH on the ASHRAE 55 comfort zone chart to achieve a PPD of <10% in a highly effective, anti-viral indoor environment. As is evident from the graph, there is a fairly narrow range of coincident temperatures and humidity levels that are considered acceptable for both human comfort and for infection control. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result lands within the green bounded area of human comfort and effective infection control.

Qualified service technicians should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems

ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 7.5 cfm per person plus 0.18 cfm per square foot of floor area of outdoor air for restaurant dining rooms. Based upon a dining area occupant density of 70 people per 1000 ft2 and a 10'-0" ceiling height, this translates into approximately 4.3 air changes per hour of outdoor air. Because of the high people density, this air change rate is sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution. See our white paper on Dilution Ventilation for further details.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical restaurant systems may already be able to achieve a higher air change rate than the recommended 2 to 4 minimum range. The goal is be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air. If properly balanced to meet the minimum code values stated above, many restaurant HVAC systems are already providing a good level of dilution ventilation for infection control. However, without a proper technical assessment, the performance is unknown.

During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high as 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

Most commercial kitchens are already extremely well ventilated due to the large amounts of air exhausted by the grease hoods and vapor hoods throughout the kitchen and dish wash areas. These areas are often experiencing upwards of 10 air changes per hour due to the large quantity of exhaust required for the cooking equipment.

There are some smaller kitchen formats that do not involve grease laden vapors, which may not have as much ventilation as is necessary to keep the concentration of infectious particles in the ambient kitchen air low enough. In these cases (sandwich shops, coffee shops, etc.) the same principles discussed above for dining rooms would apply to the kitchens also. An evaluation of each kitchen facility should be performed to determine the baseline air exchange rate provided by the existing exhaust systems to ensure adequate ventilation to keep the staff safe and to maintain outstanding food safety.

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates currently delivered to the occupied spaces are as high possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of improving filtration performance with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Central air handling units and commercial package roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions. Cooking, food and diner respiration all provide some level of humidity improvement in the winter, however these factors alone are unlikely to achieve the recommended minimum 40% RH necessary to reduce the spread of viruses and other pathogens in colder climates. Most restaurants systems have a reasonable capacity to dehumidify the air in the building using the air conditioning system, however very few restaurants are equipped with any type of supplemental humidification equipment to keep viral spread low during the winter months.

Humidification Mode

Commercial package roof top units and central air handling units should be fitted with central "clean-steam" humidification systems and in-duct steam distributors for each unit serving the dining areas, where the typical sources of moisture are not able to maintain adequate humidity levels in the winter. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur.

Restaurants served by terminal units will need to be evaluated on a case-by-case basis. Individual humidifiers featuring in-duct steam distribution might work in some instances. However, in most cases a different approach is warranted. "Clean-steam" humidifiers with wall-mounted distributors are a viable option where in duct units are not possible.

Humidification of the kitchen and back of house areas is probably not necessary due to the large amount of humidity generated by the cooking, food preparation and ware washing activities taking place in these areas.

Dehumidification Mode

Most restaurant HVAC systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. In rare cases, these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary to remain below 60% RH in the summer, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions without over-cooling the space. This should be a relatively rare condition in most restaurant settings.

Additional Prevention Measures

In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold.
- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source.

Summary

Well-designed restaurants are already very well ventilated and have a reasonably good ability to control humidity. Increasing filtration levels and verifying that all systems are operating at their peak performance levels may be all that is necessary to bring your restaurant into good standing with respect to infection control. Older restaurants will likely require some updates, however those updates are probably warranted regardless of the consideration of their infection control performance.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types, this paper examines the unique challenges of mitigating the spread of airborne diseases in health clubs.

Our primary objective will be to answer the question: *What should I do to my health club facility to improve the safety and comfort of its patrons and employees?*

We will review the common systems types found in health clubs and fitness centers and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:
Increase ventilation rates or percentage of outdoor air.
Disable demand-controlled ventilation (DCV).
Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical Health Club HVAC System Types

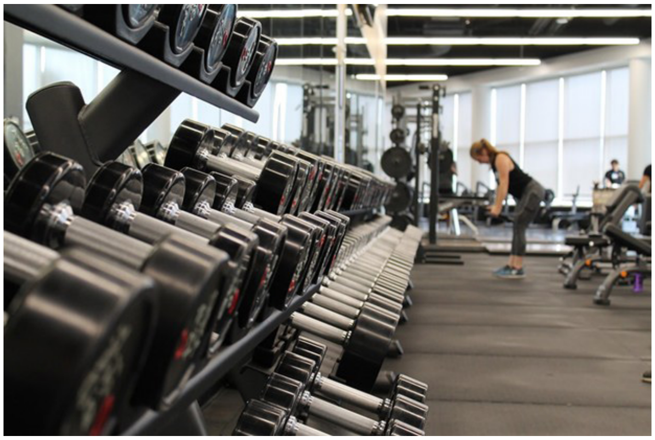
Health Club Facilities may be served by a wide variety of system types including, but not limited to, the following:

- Commercial packaged roof top units.
- Commercial split-systems.
- Central air handlers.
- Fan coil units or water source heat pump terminal units.

The central air handling systems (indoor modular, indoor self-contained and outdoor packaged types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods.

The smaller commercial split systems and fan coil/WHSP units usually obtain fresh outside air via wall louvers or gravity intake vents on the roof.

Nearly all of the system types associated with health club facilities offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system type, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.



Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. According to ASHRAE Standard 55, an acceptable level of occupant comfort means that less than 10% of the occupants polled would rate their experience in the space as "thermally dissatisfied". ASHRAE calls this metric the *predicted percentage of dissatisfied or PPD*. Basically, you will never please everyone, so as long as you please at least 90% of the occupants, it is considered satisfactory performance per the ASHRAE Standard.

In health clubs, temperatures in the 70ºF to 75ºF maximum are necessary to be considered "comfortable" by the patrons, unless there is a specific objective in mind like Bikram Yoga or other unusually warm environment.

Qualified service technicians should verify that temperature and humidity sensors are present in all areas and that they are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems

ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 20 cfm per person plus 0.06 cfm per square foot of floor area of outdoor air for health clubs. The occupant density for health clubs is divided into two classes: 40 people per 1,000 ft^2 for aerobics rooms and 10 people per 1,000 ft^2 for weight rooms and other general exercise areas. Assuming a 10'-0" ceiling height, this translates into approximately 5 air changes per hour of outdoor air for aerobics rooms and 3 air changes per hour for weight rooms. If the ceiling heights are higher, the air exchange rate will be proportionally lower.

Because of the relatively high rate of outdoor air per person, the baseline air change rates may be sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a <u>minimum</u> of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution. See the table below and our white paper on Dilution Ventilation for further details.

Air changes per hour	Minutes required for removal efficiency 99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

The goal is be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air. If properly balanced to meet the minimum code values stated above, many health club HVAC systems are already providing a good level of dilution ventilation for infection control. However, without a proper technical assessment, the performance is unknown.

Some health club facilities may be equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space or return air stream. These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient CO_2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended *disabling* DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system.

High ventilation rate purge cycles up to two hours before club opening are also recommended to ensure that the air in the club is as clean as possible when patrons begin to arrive. Purge cycles prior to opening will often coincide with moderate outdoor air conditions, resulting in large volumes of clean fresh air being introduced without too much impact on indoor space conditions. Purge cycles must be carefully applied, however, to ensure that coil temperatures and room temperatures/humidity levels remain in check during extreme weather conditions, particularly in the winter months.

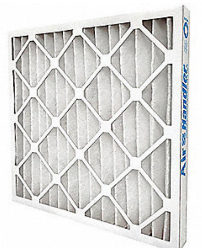
Most health club systems of the central fan types (rooftops and central air handlers) are equipped with outdoor air economizers. During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

It is critically important that all HVAC systems, regardless of type, be checked to ensure that the ventilation rates delivered to the occupied spaces are as high possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Central air handling units and commercial package roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture.



Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Fan coil unit and water source heat pump type systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-11 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions. Elevated people activity levels in health clubs provide some level of humidity improvement in the winter, however these factors alone are unlikely to achieve the recommended minimum 40% RH necessary to reduce the spread of viruses and other pathogens in colder climates.

Most health club facilities, regardless of type, have the ability to dehumidify the air in the club using the air conditioning systems, however very few health club facilities are equipped with any type of humidification equipment to keep viral spread low during the winter months. This is perhaps the most valuable enhancement you can make to keep your clubs safe during the colder winter months.

Humidification Mode

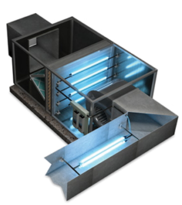
Central air handling units and commercial package roof top units should be fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur. Health clubs served by commercial split systems, fan coil units and water source heat pumps will need to be evaluated on a case-by-case basis. Individual humidifiers featuring in-duct steam distribution should work in most instances. However, in some cases a different approach is warranted. "Clean-steam" humidifiers with wall-mounted distributors are a viable option where in duct units are not possible and, properly applied, they provide just as effective a result as the in duct system.

Dehumidification Mode

Most health club HVAC systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. In addition, some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. This should be a relatively rare condition in most health club facilities.

Additional Prevention Measures

In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:



- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold. These systems are strongly recommended for all health club facilities, not only due to the current COVID-19 pandemic, but also for general cleanliness and sterilization of the air and equipment in a health club setting. Fresher, cleaner, disinfected air is always a welcome feature of any health and fitness club.

- In large areas with high ceilings Upper Room GUV can be installed for additional protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source and are preferred to the in-duct solutions wherever ceiling heights permit its use.

- Portable UV disinfection units can also be considered for off-hours, unoccupied sterilization of the equipment and room surfaces. However, staff must be thoroughly trained in the use of these powerful systems to avoid any possibility of human exposure to the damaging rays of the UV sterilization equipment.

Summary

Health clubs are well suited to provide a high level of infection control capability due to the strict code requirements surrounding outdoor air ventilation rates. However, many older clubs may not be in compliance with these newer standards and regulations.
Even in modern clubs, many of the HVAC systems may have been compromised since they were originally constructed, either intentionally to save energy or through normal wear and tear. Therefore, they should be verified to ensure they are performing in accordance with their original design specifications.

One improvement that all health and fitness clubs should definitely consider is the addition of humidification equipment to ensure that winter humidity levels stay above at least 30%, or preferably above 40% at all times.

It is critically important that any existing club is thoroughly evaluated by a qualified professional to ensure that the existing systems are adequate to promote a safe and healthy environment for exercise. Due to the high respiratory and metabolic rate of the patrons of these clubs, it is important to make sure the systems are performing to their peak capabilities and are meeting basic infection control requirements and standards.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control.	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in hotel facilities.

Our primary objective will be to answer the question: *What should I do to my hotel facility to improve the safety and comfort of my guests and employees?*

We will review the common systems types found in hotels and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.
  (https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:
Increase ventilation rates or percentage of outdoor air.
Disable demand-controlled ventilation (DCV).
Improve filtration to MERV-13.
(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical Hotel HVAC System Types

Hotel facilities may be served by a wide variety of system types including, but not limited to, the following:

- Terminal units: Fan coil, WSHP, GSHP, VRF, PTACS.
- Commercial packaged roof top units.
- Central air handlers.

The central air handling systems (indoor modular, indoor self-contained and outdoor packaged roof top types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods. The terminal unit systems are usually paired with a dedicated outside air system or are provided with through wall louvers to obtain fresh air directly.

The system types associated with hotel facilities offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system type, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". This is particularly true when considering individual hotel rooms.

Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still provides acceptable human comfort, effective infection control and satisfied customers.

Facilities personnel or qualified service contractors should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems

ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 5 cfm per person plus 0.06 cfm per square foot of floor area of outdoor air for guestrooms, 7.5 cfm per person plus 0.06 cfm per square foot of floor area for lobbies, and 5 cfm per person plus 0.06 cfm per square foot of floor area for multi-purpose rooms. These requirements translate into approximately 0.86 air changes per hour of outdoor air for the guestrooms, 1.43 air changes per hour of outdoor air for the lobby, and 3.30 air changes per hour of outdoor air for the multi-purpose areas.

While these rates would meet minimum code requirements, the air change rates of the guestrooms and lobby are not considered sufficient for the purpose of an effective dilution ventilation strategy for virus control. The multi-purpose areas required air change rate is considered sufficient, however many of these spaces are likely not performing to these levels due to energy conservation efforts and/or deferred maintenance. Therefore, even the multipurpose spaces should be tested and balanced prior to any reopening of the facilities for use.

Most recent viral control studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution. See our white paper on Dilution Ventilation for further details.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

CDC Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical hotel common area systems may or may not be able to achieve a 2 to 4 air change rate, while still maintaining acceptable indoor temperatures and humidity. Therefore, the goal for the common area systems should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air.

Guest room systems are less critical since they are typically occupied by members of the same traveling unit and are therefore not concerned about inter-person spread while inside the guest room. See the section later in this white paper about guest room disinfection systems.

Demand Controlled Ventilation Systems

Many common area systems, particularly in newer facilities, are equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space or return air stream. These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the space at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient CO_2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system.

During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

Dedicated Outdoor Air Systems

Terminal unit systems which rely on Dedicated Outdoor Air Systems (DOAS) may be more challenging when it comes to increasing the ventilation rate. DOAS units are typically designed to within a fairly narrow band of the code prescribed minimum outdoor air ventilation rates and therefore would require significant modifications or even unit replacement to achieve the higher ventilation rates necessary to achieve effective airborne pathogen dilution. Such modifications may or may not be possible without significant investment in replacement systems and ductwork.

Ventilation System Maintenance

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and are meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Central air handling units and commercial package roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread. Each system should be evaluated by an HVAC design professional to determine the optimum replacement filter efficiency.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions. Most hotel facilities have a reasonable capacity to dehumidify the air in the building using the air conditioning systems, however very few hotels are equipped with any type of humidification equipment to keep viral spread low during the winter months.

Humidification Mode

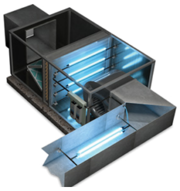
Central air handling units and commercial package roof top units should be fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur. Common areas served by terminal units will need to be evaluated on a case-by-case basis. Individual humidifiers featuring in-duct steam distribution might work in some instances. However, in most cases a different approach is warranted. Humidifiers with wall-mounted distributors can be used in common areas. Countertop personal humidifiers could be provided in guestrooms, if desired.

Dehumidification Mode
Areas served by central air handlers or packaged roof top air conditioners systems should be able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. In addition, some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions.

Additional Prevention Measures

In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

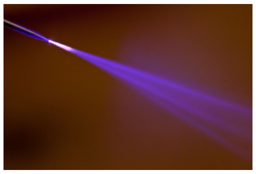
- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold. In-duct UV disinfection is generally only applicable to common area systems due to the restricted space and lack of ductwork in the guest room systems.



- In large areas with high ceilings Upper Room GUV can be installed for additional protection, killing the airborne viruses as they circulate within the room. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source. They can only be installed in areas where there is no possibility of human exposure to the UV radiation, generally above 7'-0" above the floor.

- High exposure risk areas like bathrooms, dining areas, gyms and elevators can be fitted with ionization purification systems, either bi-polar or photocatalytic oxidation type, as additional measures to control potential viral spread in these locations.

- Guestroom units that are not capable of handling the added static pressure of increased filtration could be fitted with Needle Point Bipolar ionization technology to enhance the viral protection in these rooms.



- Portable UV-C decontamination units can also be used to sterilize guest room surfaces between guest stays. However, careful use and staff training is essential to ensure that there is no human exposure during their operation.

RESOURCES	
ASHRAE	https://www.ashrae.org/
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Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in senior living facilities.

Our primary objective will be to answer the question: *What should I do to my facility to improve the safety and comfort of its occupants?*

We will review the common systems types found in senior living facilities and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:
Increase ventilation rates or percentage of outdoor air.
Disable demand-controlled ventilation (DCV).
Improve filtration to MERV-13.
(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical HVAC System Types at Senior Living Facilities

Senior living facilities may be served by a wide variety of system types including, but not limited to, the following:

- Terminal units: Fan coil, WSHP, GSHP, VRF, PTACS, split systems.
- Commercial packaged roof top units – Common areas.
- Central air handlers – Common areas.

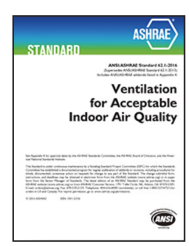
The central air handling systems (indoor modular, indoor self-contained and outdoor packaged types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods. The terminal unit systems are usually provided with through wall louvers to obtain fresh air directly from the outdoors. The system types associated with senior living facilities offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". This is particularly true with seniors, who often prefer higher indoor temperatures throughout the year.
Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still provides acceptable human comfort, effective infection control and satisfied seniors.

Facilities personnel or qualified service contractors should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems



Ventilation requirements for the living quarters are dictated by ANSI/ASHRAE Standard 62.2. The living quarters, regardless of configuration, will likely have an air change rate of outdoor air of less 1 air change per hour.

The common areas ventilation requirements are dictated by ANSI/ASHRAE Standard 62.1. The typical air change rate of outdoor air can range from as high as 5.5 air changes per hour in cafeterias to as low as 0.4 air changes per hour in the corridors.

While these rates would meet minimum code requirements, the air change rates of the living quarters and corridors, for example, are not considered sufficient for the purpose of an effective dilution ventilation strategy for virus control. The cafeteria and dining areas required air change rate is considered sufficient, however many of these spaces are likely not performing to these levels due to energy conservation efforts and/or deferred maintenance. Therefore, even the cafeteria and dining areas should be tested and balanced as part of any upgrade plans.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Infectious Agent Dilution Ventilation Performance
The goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air. See our white paper on Dilution Ventilation for further details and energy conservation recommendations.

Demand Controlled Ventilation Systems

Demand controlled ventilation (DCV) systems are rare in senior living facilities due to the need for constant ventilation of the facility. The CDC has recommended disabling DCV systems, and it is Schnackel Engineers' recommendation to do so in any senior living facility. DCV is not appropriate in a senior living facility where infection control is tantamount to maintaining a safe and healthy living environment for seniors.

Ventilation System Maintenance

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Central air handling units and commercial package roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture.

Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread. Each system should be evaluated by an HVAC design professional to determine the optimum replacement filter efficiency. In room filtration systems may be an option for areas where reasonable filtration cannot be achieved with the HVAC systems installed.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions. Most senior living facilities have a reasonable capacity to dehumidify the air in the building using the air conditioning systems, however not all senior living facilities may be equipped with any type of humidification equipment to keep viral spread low during the winter months.

Central air handling units and commercial package roof top units lacking a humidification system should be *immediately* fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur.

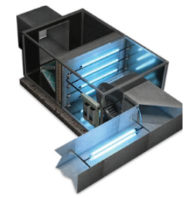
Facilities served entirely by terminal units that are not equipped with a humidification system will need to be evaluated on a case-by-case basis. Individual "clean-steam" humidifiers featuring in-duct steam distribution might work in some instances. However, in most cases a different approach is warranted. Steam humidifiers with wall-mounted distributors, floor type single room humidifiers and countertop personal humidifiers are some of the options available.

All existing humidification systems should be checked to ensure they are working properly and are capable of maintaining the humidity level within the desired range. It is not possible to overemphasize the importance of maintaining humidity levels in the 40% - 60% range to reduce the possible spread of viral contaminants.

Additional Prevention Measures

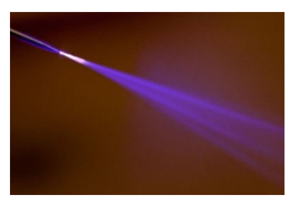
In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold. However, sufficiently high lamp power and quantities are necessary to effectively kill any airborne viruses.



- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source. They can only be installed in areas where there is no possibility of human exposure to the UV radiation, generally above 7'-0" above the floor.

- High exposure risk areas like public bathrooms, dining rooms, fitness/therapy rooms and elevators can be fitted with ionization purification systems, either bi-polar or photocatalytic oxidation type, as additional measures to control potential viral spread in these critical locations.
- Small HVAC systems that are not capable of handling the added static pressure of increased filtration could be fitted with Needle Point Bipolar Ionization technology to enhance the viral protection of the area served, although these systems require routine cleaning and maintenance to maintain their effectiveness.



RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in medical clinics and medical offices.

Our primary objective will be to answer the question: *What should I do to my facility to improve the safety and comfort of its occupants?*

We will review the common systems types found in these facilities and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:

- Increase ventilation rates or percentage of outdoor air.
- Disable demand-controlled ventilation (DCV).
- Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical Medical Clinics and Medical Offices HVAC System Types

Medical clinics and medical office facilities may be served by a wide variety of system types including, but not limited to, the following:

- Commercial packaged roof top units.
- Terminal units: Fan coil, WSHP, GSHP, VRF, split-systems.
- Central air handlers.

The central air handling systems (indoor modular, indoor self-contained and outdoor packaged types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods. The terminal unit systems are usually paired with a dedicated outside air system or, in older facilities, are fitted with through wall louvers to obtain fresh air directly.

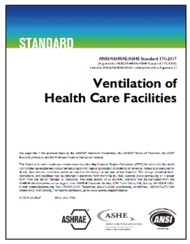
Nearly all of the system types associated with medical clinics and medical office facilities offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

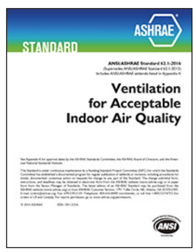
ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies, however ANSI/ASHRAE Standard 170-2017, Ventilation of Health Care Facilities, does address the temperature and humidity requirements for health care facilities. This standard specifies a temperature range of 70°F to 75°F and maximum of 60% RH for general exam rooms, which provides an appropriate guideline for these types of outpatient facilities. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still lands within this recommended range. Facilities personnel or qualified service contractors should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems

ANSI/ASHRAE/ASHE Standard 170-2017, Ventilation of Health Care Facilities, requires 2 air changes per hour of outdoor air minimum and 4 total air changes per hour minimum for general exam rooms and clinical areas.



ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 5 cfm per person plus 0.06 cfm per square foot of floor area of outdoor air for office spaces and waiting areas. Assuming a 9'-0" ceiling height and a typical occupant density, this translates into approximately 1 to 1 ½ air changes per hour of outdoor air.



While the recommendations contained in these Standards will meet *minimum* code requirements, the air change rates are not considered sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of *outdoor* air to achieve a reasonable level of infectious agent dilution.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical medical clinic and medical office systems may or may not be able to achieve an increase to 2 to 4 air change rate, while still maintaining acceptable indoor temperatures and humidity. Therefore, the goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air. See our white paper on Dilution Ventilation for further details.

Demand Controlled Ventilation Systems

Some newer medical clinics and medical offices may be equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO2 levels in the space or return air stream. These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient CO_2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system, albeit to higher levels of ventilation that were previously recommended.

During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

Dedicated Outdoor Air Systems

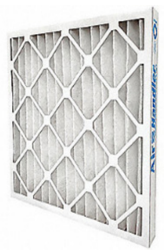
Terminal unit systems which rely on Dedicated Outdoor Air Systems (DOAS) may be more challenging when it comes to increasing the ventilation rate. DOAS units are typically designed to within a fairly narrow band of the code prescribed minimum outdoor air ventilation rates and therefore would require significant modifications or even unit replacement to achieve the higher ventilation rates necessary to achieve effective airborne pathogen dilution. Such modifications may or may not be possible without significant investment in replacement systems and ductwork.

Ventilation System Maintenance

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high as possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

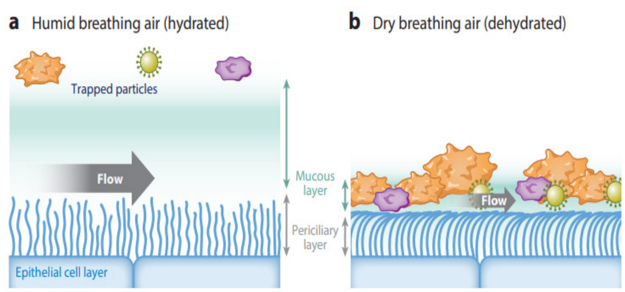


Central air handling units and commercial packaged roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread. Each system should be evaluated by an HVAC design professional to determine the optimum replacement filter efficiency.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions.



Mucociliary Clearance Mechanism

All types of medical facilities should control humidity directly to maintain the highest level of infection control, due to the likelihood of infectious patients entering the building and to maintain a healthy indoor environment for the benefit of the staff and patients. This is critically important even in a post-Covid world, since the impacts of many types of infectious agents, including viruses, bacteria and mold, are exacerbated by either low humidity or high humidity or both.

Most medical clinics and medical office facilities have the ability to dehumidify the air in the building using the air conditioning systems, however most older facilities are not presently equipped with any type of humidification equipment to keep viral spread low during the winter months.

Humidification Mode
Central air handling units and commercial packaged roof top units should be immediately fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur.

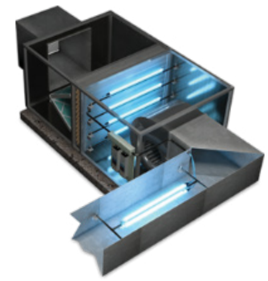
Facilities served by terminal units will need to be evaluated on a case-by-case basis. Humidifiers featuring in-duct steam distribution might work in some instances, however, in most cases a different approach is warranted. Humidifiers with wall-mounted distributors or self-contained single room humidifiers are some of the options available for facilities without a viable means of installing central humidification.

Dehumidification Mode
Most medical clinics and medical office systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. Some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. Dehumidification is as important as humidification to prevent the growth of mold and the propagation of viruses and bacteria in any facility.

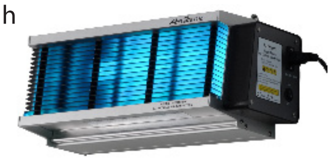
Germicidal Ultra Violet Sterilization

In addition to the recommendations discussed above, Germicidal UV Sterilization (GUV) is strongly recommended in medical facilities to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold.



- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source. They can only be installed in areas where there is no possibility of human exposure to the UV radiation, generally above 7'-0" above the floor.



RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in schools.

Our primary objective will be to answer the question: *What should I do to my school's HVAC systems to improve the safety and comfort of its occupants?*

We will review the common systems types found in schools and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:

- Increase ventilation rates or percentage of outdoor air.
- Disable demand-controlled ventilation (DCV).
- Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical School HVAC System Types

School facilities may be served by a wide variety of system types including, but not limited to, the following:

- Terminal units: Fan coil, WSHP, GSHP, VRF, split-systems.
- Central air handlers with terminal VAV boxes
- Commercial packaged roof top units.

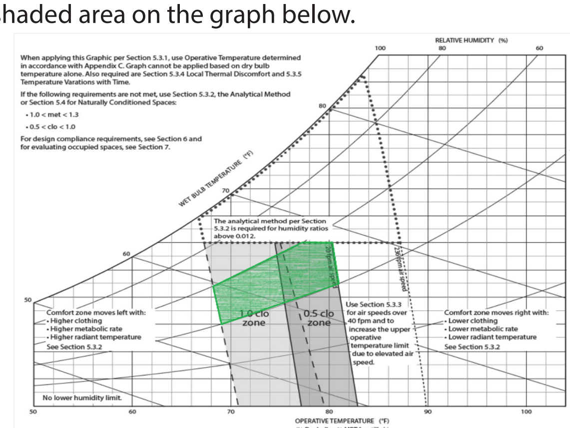
The central air handling systems (indoor modular, indoor self-contained and outdoor packaged types) handle the introduction of fresh outside air in the equipment itself, through various forms of dampers and intake hoods. The terminal unit systems are usually paired with a dedicated outside air system or are fitted with through wall louvers or gravity intake hoods to obtain fresh air directly.

Nearly all of the system types associated with school facilities offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". In addition, the perceived comfort level is impacted by a multitude of factors including the metabolic rate of the activities in the space, the air temperature, the radiant temperature, the relative humidity, the clothing insulation levels of the occupants and the average airspeed in the occupied zone.

Instead of indicating a specific temperature range for each occupancy, ASHRAE 55 recommends that spaces be maintained within a band of coincident temperature and humidity levels, taking into account the velocity of air movement in the occupied zone, as indicated by the grey shaded area on the graph below.



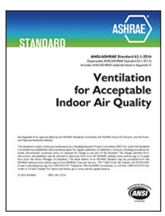
ASHRAE 55: Acceptable Range of Operative Temperature and Humidity for Spaces

The green shaded area superimposes the recommended anti-viral humidity range of 40%-60% RH on the ASHRAE 55 comfort zone chart to achieve a PPD of <10% in a highly effective, anti-viral environment. As is evident from the graph, there is a fairly narrow range of coincident temperatures and humidity levels that are considered acceptable for both human comfort and for infection control. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still lands within the green bounded area of human comfort and effective infection control.

Facilities personnel or qualified service contractors should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems

Based on the requirements of ANSI/ASHRAE Standard 62.1-2019, typical school occupancies should be receiving anywhere from 1.5 air changes to 3.0 air changes of outdoor air. Older facilities may be significantly higher or lower than these rates depending on the type of system, the level of maintenance, past energy conservation efforts and the tightness of the building.



While the ASHRAE 62.1 Standard meets minimum code requirements, some areas may not achieve the air change rate that is considered sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution. See our white paper on Dilution Ventilation for further details.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical school systems may or may not be able to achieve a 2 to 4 air change rate, while still maintaining acceptable indoor temperatures and humidity. Therefore, the goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air.

Demand Controlled Ventilation Systems

Some newer school buildings may be equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space or return air stream. These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient CO2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system.

Economizer Operation

During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

Dedicated Outdoor Air Systems

Terminal unit systems which rely on Dedicated Outdoor Air Systems (DOAS) may be more challenging when it comes to increasing the ventilation rate. DOAS units are typically designed to within a fairly narrow band of the code prescribed minimum outdoor air ventilation rates and therefore would require significant modifications or even unit replacement to achieve the higher ventilation rates necessary to achieve effective airborne pathogen dilution. Such modifications may or may not be possible without significant investment in replacement systems and ductwork.

Ventilation System Maintenance

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high as possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher. This is particularly important for older facilities that may not be operating properly due to maintenance issues or overly aggressive energy conservation efforts.

Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system.

Centralized Air Handling Equipment

Central air handling units and commercial packaged roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Terminal Unit Equipment

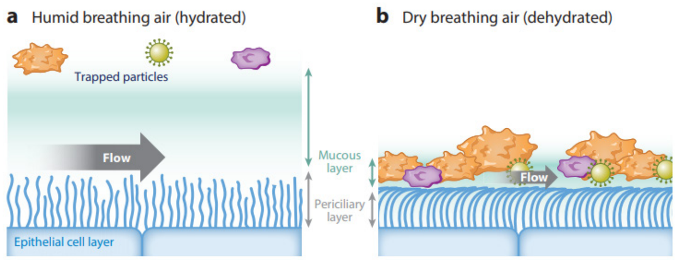
Terminal Unit systems can be more challenging when it comes to filtration. Since terminal units are relatively small in size and therefore have smaller fans and motors, most will not be capable of handling an upgrade to a MERV-13 rating. However, the filters should still be upgraded the highest MERV rating that each unit can safely handle. Even an upgrade to MERV-8 or MERV-10 can provide a meaningful reduction in the concentration of airborne infectious particles, particularly the larger droplets that are associated with SARS-CoV-2 spread. Each system should be evaluated by an HVAC design professional to determine the optimum replacement filter efficiency.

In-Room Filtration Equipment

In-room filtration systems may provide a viable option in older facilities equipped with small terminal units that are incapable of achieving the recommended filtration levels. These units should incorporate minimum MERV-13 or higher filters and preferably HEPA filters. In-room units should be sized to provide at least 6 air changes per hour (by volume) to significantly reduce the airborne contaminants levels. This means that in a space with well mixed air, the entire volume of air will be filtered once every 10 minutes. Using a HEPA filter (99.97% efficient on particles from 0.3 to 1.0 μm) in the in-room unit, this would reduce the number of particles initially in the air by 99% in 50 minutes.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions.



Mucociliary Clearance Mechanism

Most air conditioned school buildings have a reasonable capacity to dehumidify the air in the building using the air conditioning systems, however very few facilities are equipped with any type of humidification equipment to keep viral spread low during the critical winter months.

Humidification Mode

Central air handling units and commercial packaged roof top units should be fitted with central “clean-steam” humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur. Facilities served by terminal units will need to be evaluated on a case-by-case basis. Individual humidifiers featuring in-duct steam distribution might work in some instances. However, in most cases a different approach is warranted. Humidifiers with wall-mounted distributors or self-contained single room humidifiers are some of the options available for facilities without a viable means of installing central humidification.

Dehumidification Mode

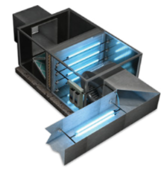
Schools whose operating schedule is primarily during the winter months, or do not have any air conditioning systems installed, can be less concerned about dehumidification, since the spread of respiratory viruses is typically reduced during the warmer months.

Most air conditioned school systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. Some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. Dehumidification is as important as humidification to prevent the growth of mold and the propagation of viruses and bacteria in any facility.

Additional Prevention Measures

In addition to the recommendations discussed above, there are several other options available to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold.



- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source. They can only be installed in areas where there is no possibility of human exposure to the UV radiation, generally above 7’-0” above the floor.

- Portable Decontamination Units can be used to powerfully disinfect classrooms and other areas in the event of a known infection case, or as a routine preventive measure on nights or weekends. These powerful remotely controlled units should only be used when the spaces are completely unoccupied and it is certain that no human exposure can occur, either from inside the building or through exterior windows that are not equipped with sufficient window coverings.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in theaters and places of assembly.

Our primary objective will be to answer the question: *What should I do to my facility to improve the safety and comfort of its occupants?*

We will review the common systems types found in these facilities and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations.

Theaters and places of assembly (churches, concert venues, night clubs, etc.) are perhaps the hardest hit occupancies by the Covid-19 pandemic shutdowns due to their high occupant density and the very social nature of the events that take place in these facilities. They are also among the most difficult facilities to effectively control viral and biological disease spread through the HVAC systems, although there are many tested and emerging technologies that can be implemented to hasten their return to full occupancy and care-free operation.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss. (https://www.ashrae.org/technical-resources/resources)

The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:
Increase ventilation rates or percentage of outdoor air.
Disable demand-controlled ventilation (DCV).
Improve filtration to MERV-13.
(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical HVAC System Types

Theaters and public assembly facilities may be served by a variety of primarily forced air system types including, but not limited to, the following:

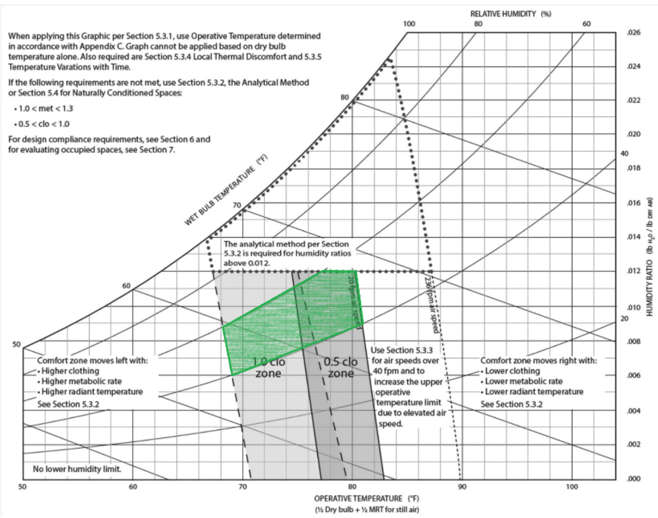
- Commercial Packaged Roof Top Units.
- Constant Volume Central Air Handlers.
- Variable Air Volume Systems

These systems handle the introduction of fresh outdoor air in the equipment itself, through various forms of dampers and intake hoods or louvers. Nearly all of these system types offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. Different individuals have different expectations with respect to temperature and humidity in order to determine if a space is considered "comfortable". In addition, the perceived comfort level is impacted by a multitude of factors including the metabolic rate of the activities in the space, the air temperature, the radiant temperature, the relative humidity, the clothing insulation levels of the occupants and the average airspeed in the occupied zone.

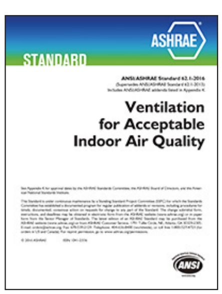
Instead of indicating a specific temperature range for each occupancy, ASHRAE 55 recommends that spaces be maintained within a band of coincident temperature and humidity levels, taking into account the velocity of air movement in the occupied zone, as indicated by the grey shaded area on the graph below:



ASHRAE 55: Acceptable Range of Operative Temperature and Humidity for Spaces

The green shaded area superimposes the recommended anti-viral humidity range of 40%-60% RH on the ASHRAE 55 comfort zone chart to achieve a predicted percentage of dissatisfied (PPD) rating of <10% in a highly effective, anti-viral environment. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still lands within the green bounded area of human comfort and effective infection control. Facilities personnel or qualified service contractors should verify that the temperature and humidity sensors in all areas are calibrated and operating properly, prior to embarking on an upgrade program to improve infection control.

Ventilation Systems



ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 5 cfm per person plus 0.06 cfm per square foot of floor area of outdoor air for auditoriums and lobbies. Assuming a 25'-0" ceiling height and a typical occupant density, this translates into approximately 1.9 air changes per hour of outdoor air.

While these rates meet the minimum code requirements, the air change rates are not considered sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution.

Air changes per hour	Minutes required for removal efficiency	
	99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical theater systems may or may not be able to achieve an increase in the ventilation rate to 2 to 4 air changes, while still maintaining acceptable indoor temperatures and humidity. Therefore, the goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air. See our white paper on Dilution Ventilation for further details.

Demand Controlled Ventilation Systems

Some newer facilities may be equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space or return air stream. These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient CO_2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2 .)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained, and even installed if they are not already present, to help ensure that the maximum amount of outdoor air is being introduced during periods of high occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system, albeit to higher levels of ventilation that were previously recommended.

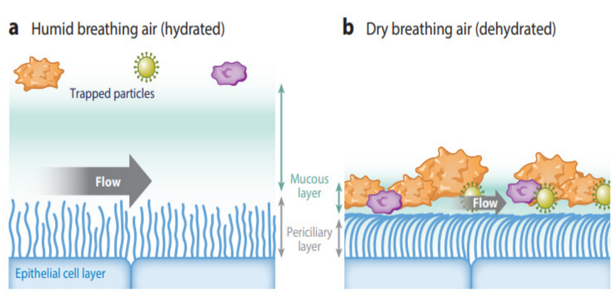
During periods of economizer operation (mild weather conditions), outdoor air rates rise to as high 100% of the supply air quantity, providing excellent air change rates (>10 AC/hr), better indoor air quality and lower energy costs. Any system that is not already equipped with an air side economizer, should be analyzed to determine if it can be retrofitted for both energy conservation and viral control improvement reasons.

Ventilation System Maintenance
All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high as possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

Filtration
Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system. Central air handling units and commercial packaged roof top units, whether constant volume or VAV design, should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. Sometimes increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Humidity Control
As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions.

Most facilities have the ability to dehumidify the air in the building using the air conditioning systems, however few facilities are equipped with any type of humidification equipment to keep viral spread low during the winter months.



Mucociliary Clearance Mechanism

Humidification Mode
Central air handling units and commercial packaged roof top units should be <u>immediately</u> fitted with central "clean-steam" humidification systems with in-duct steam distributors for each unit. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur.

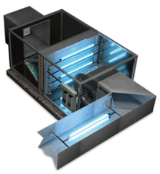
Dehumidification Mode

Most theater systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. Some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric/hot water reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. Dehumidification is as important as humidification to prevent the growth of mold and the propagation of viruses and bacteria in any facility.

Germicidal Ultra Violet Sterilization

In addition to the recommendations discussed above, Germicidal UV Sterilization (GUV) is strongly recommended to provide additional layers of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In-Duct UV disinfection systems can be installed to disinfect the air as it passes through the HVAC unit and to keep the coils and drain pans free of any type of pathogen, including viruses, bacteria and mold.



- In public areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source. They can only be installed in areas where there is no possibility of human exposure to the UV radiation, generally above 7'-0" above the floor and are not recommended in dark viewing rooms, like movie theaters and performance halls.

- Portable UV Decontamination Units can be used to powerfully disinfect auditoriums and other areas as a routine preventive measure during off hours. These powerful remotely controlled units should only be used when the spaces are completely unoccupied and it is certain that no human exposure can occur.

Ionization

Air ionization systems are a promising new technology that have been effectively applied to several large public assembly facilities like the Staples Center in Los Angeles, California, for example. These systems operate on the principal of the ionization of the moving air molecules, usually at the HVAC equipment or in the ductwork, to both neutralize viral and biological contaminates and to agglomerate these and other particles so that they can be more easily removed by conventional filtration devices. The larger agglomerated particles are heavier and often precipitate out of the airstream, preventing further circulation to the facility.

Ionization air purification involves the use of a high voltage conductor (wire, plate, needle, etc.) to create air molecules with a negative (or positive) charge by adding (or removing) one electron to (or from) the air molecules, thereby creating N_2^- and O_2^- (or N_2^+ and O_2^+) molecules. These charged molecules (anions and cations respectively) attract impurities in the air by electrostatic attraction. Once they bond with the impurities in the air they are attracted to either positively charged surfaces (plates) in the device itself, or grounded surfaces in the nearby area like walls, floors and ducts.

Ionization equipment comes in two primary types: Bipolar ionization units, which incorporate large tubes of encapsulated ionization chambers and needlepoint ionization units, which utilize tiny fibers or "needles" that emit the corona discharge directly into the air stream. The selection of the appropriate type of system is dependent on many factors including the availability of space in the HVAC equipment and the volume of air being treated.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

Introduction

Continuing our look into occupancy specific building types this paper examines the unique characteristics and challenges of mitigating the spread of airborne diseases in warehouses and industrial facilities.

Our primary objective will be to answer the question: *What should I do to my facility to improve the safety and comfort of its occupants?*

We will review the common systems types found in these facilities and make recommendations for improving the infection control potential of these systems. We will also examine how well these systems can be adapted to meet the latest infection control standards and recommendations. This white paper focuses only on the large volume storage and production areas of these facilities. Please refer to our Offices White Paper for our recommendations for the administrative areas of these facilities.

Agency Recommendations

The latest recommendations from the ASHRAE Epidemic Task Force for Commercial Buildings (updated 08/17/2020) include the following improvements related to any building's HVAC system:

- Maintain temperatures in accordance with ANSI/ASHRAE Standard 55-2017.
- Maintain relative humidity between 40% and 60%.
- Verify minimum ventilation requirements per Standard 62.1 are maintained. Increase ventilation rate as allowed per installed equipment and still maintain comfort levels.
- Operate systems at maximum outside air mode for two hours before and two hours after occupied times.
- Increase filter rating to MERV-13 if equipment can handle the additional pressure loss.

(https://www.ashrae.org/technical-resources/resources)

- The Centers for Disease Control and Prevention's Resuming Business TOOLKIT includes the following general recommendations for all ventilation systems:
- Increase ventilation rates or percentage of outdoor air.
- Disable demand-controlled ventilation (DCV).
- Improve filtration to MERV-13.

(https://www.cdc.gov/coronavirus/2019-ncov/community/resuming-business-toolkit.html)

Typical Warehouse/Industrial System Types

Warehouses and industrial facilities may be served by a wide variety of system types including, but not limited to, the following:

- Commercial Packaged Roof Top Units
- Central Air Handlers
- Heating & Ventilating Units
- Unit Heater and Exhaust Systems

HVAC system types associated with these facilities offer many options for improving indoor air quality and reducing the risk of the spread of contaminants and pathogens. The key is selecting the right combination of measures to achieve the optimum result for each system, within the budget constraints of the project, while maintaining acceptable comfort levels for the occupants.

Temperature Control

ANSI/ASHRAE Standard 55-2017 does not directly specify temperature requirements for various occupancies. This is due to the fact that occupant comfort is a very subjective matter. In addition, warehouses and industrial facilities have very wide ranging requirements with respect to what is considered acceptable temperatures. Any modifications to the HVAC systems should be carefully coordinated to ensure that the end result still lands within the established acceptable range of temperatures to ensure human comfort, proper facility operation and effective infection control.

Ventilation Systems

ANSI/ASHRAE Standard 62.1-2019 requires a minimum of 0.06 cfm per square foot of floor area of outdoor air for warehouses. Assuming a 40'-0" ceiling height, this translates into less than 0.1 air changes per hour of outdoor air.

While this rate meets minimum code requirements, it is not considered sufficient for the purpose of an effective dilution ventilation strategy for viral control. Most recent studies and the current CDC guidelines recommend a minimum of 2 to 4 air changes per hour of outdoor air to achieve a reasonable level of infectious agent dilution.

Air changes per hour	Minutes required for removal efficiency 99%	99.9%
2	138	207
4	69	104
6	46	69
12	23	35
15	18	28
20	14	21
50	6	8
400	<1	1

Time required for infectious agent removal based on the number of air changes per hour (adapted from CDC guideline [28])

Infectious Agent Dilution Ventilation Performance

Depending on the HVAC system installed and the outdoor temperature/humidity conditions, typical warehouse systems are unlikely to be able to achieve an increase to 2 to 4 air change rate without requiring major renovations and/or additions to the existing HVAC systems. Plus, the energy consumption impacts of doing so make these air change rates impractical for most of these occupancies. Therefore, the goal should be to achieve the maximum outdoor air ventilation rate possible at any given time without overloading the HVAC's system ability to properly condition the air and retain reasonable energy efficiency. Generally speaking, achieving true dilution ventilation of these large volume spaces is simply impractical, except in the smallest of these facilities with low ceiling heights.

Demand Controlled Ventilation Systems

Some warehouses and industrial facilities may be equipped with Demand Controlled Ventilation systems or DCV, which vary the amount of outdoor air introduced based on the measured CO_2 levels in the space (or return air stream). These systems are design to adjust the outdoor air intake system to reflect the actual occupancy of the building at any given time, rather than simply bringing in a fixed amount of outdoor air to meet minimum code requirements. DCV systems were introduced primarily as an energy conservation measure to ensure that the central HVAC system was not bringing in any more outdoor air than was necessary to maintain acceptable indoor air quality levels, generally defined to be indicated by <1,000 ppm total CO_2 concentration or <600 ppm above the outdoor ambient CO_2 concentration level. (Outdoor air typically contains between 350 and 450 ppm CO_2.)

While the CDC has recommended disabling DCV systems, it is Schnackel Engineers' recommendation that they be maintained to help ensure that the maximum amount of outdoor air is being introduced during periods of higher occupancy. However, in lieu of a typical pre-COVID-19 set point of 1,000 to 1,200 ppm total CO_2, these systems should be lowered to a 600 ppm maximum set point to effectively double the amount of fresh air delivery to the space when the building is heavily occupied. As a general rule of thumb, a doubling of the ventilation rate will cut the concentration of contaminants in the air by approximately 50%. The system can then scale back the fresh air delivery somewhat during periods of lower occupancy or high outdoor ambient conditions, without requiring any manual intervention in the control of the system, albeit to higher levels of ventilation that were previously recommended.

Ventilation System Maintenance

All HVAC systems, regardless of type, should be checked to ensure that the ventilation rates delivered to the occupied spaces are as high as possible without compromising comfort levels or causing undue loading on the system equipment. All dampers, motors, controls and accessories associated with the ventilation systems should be checked to ensure they are working properly, and meeting at least the minimum code requirements, if not higher.

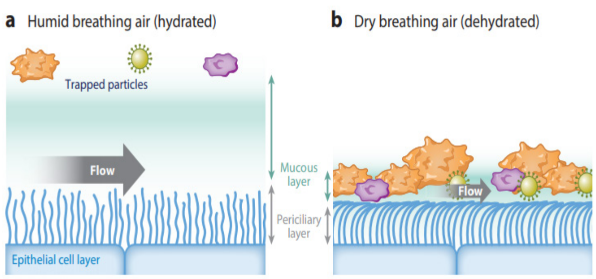
Filtration

Our Filtration White Paper took an in-depth look at the available filtration technologies that can be applied to almost any HVAC system. Please refer to that white paper for more specific information about MERV ratings, filter efficiencies and the associated pressure drop considerations. The primary objective of increasing filtration with respect to infection control, is to install as high-efficiency of filters as is possible, subject to the static pressure limitations of the HVAC system. However, in warehouses and industrial facilities, systems are often designed using 100 percent exhaust ventilation, which eliminates the need for filtration of the return/exhaust air. In facilities with recirculating air systems, those systems should be equipped with as high efficiency of filters as can be accommodated by the existing equipment.

Central air handling units and commercial packaged roof top units should be capable of overcoming the additional static pressure associated with the higher MERV ratings recommended for infection control. Whenever possible, install filters of a MERV-13 rating, or higher, to achieve maximum viral droplet capture. In some cases, increasing the MERV rating of the filters will require either no modifications to the HVAC equipment or minor changes to the belts, pulleys and possibly the supply fan motor, all of which can be accomplished at a relatively minor cost.

Humidity Control

As we learned in our Humidity Control White Paper, maintaining the optimum humidity level of 40%-60% RH may be the single most effective way to mitigate the spread of viruses in buildings. This is due to both the human body's adverse reaction to low humidity and the viruses' ability to thrive and spread under low and high humidity conditions.



Mucociliary Clearance Mechanism

Humidification Mode

Warehouses and industrial facilities should be immediately fitted with central "clean-steam" humidification systems with large, in-room steam distributors for each area. If central plant steam is available, it can be utilized in a steam-to-steam converter arrangement to ensure the moisture delivered to the space is free of any boiler water treatment chemicals. Never directly inject boiler plant steam into the air as treatment chemicals present potential health hazards. Evaporative type humidifiers should be avoided unless they are coupled with UV light sterilization systems to ensure no mold or bacterial growth can occur. Generally speaking, evaporative pad humidifiers will be relatively ineffective in large volume space due to their inability to release sufficient moisture to materially change the humidity in the space.

Dehumidification Mode

If a facility is provided with an air conditioning system, most of these systems are able to operate efficiently under part-load conditions and maintain humidity levels within the target range during the summer months. Some of these systems may already be equipped with a dehumidification cycle option, utilizing either hot refrigerant gas or electric reheat to prevent over-cooling. If additional dehumidification is necessary, reheat coils can be added to the existing equipment to allow for drying of the air during light loading conditions. Dehumidification is as important as humidification to prevent the growth of mold and the propagation of viruses and bacteria in any facility.

Germicidal Ultra Violet Sterilization

In addition to the recommendations discussed above, Germicidal UV Sterilization (GUV) is can be provided to provide an additional layer of infection control and prevention. Often a multi-layered approach is the best strategy to bring a building up to its maximum infection control potential. These measures can include the following:

- In large areas with high ceilings Upper Room GUV can be installed for added protection, killing the airborne viruses as they circulate within the rooms. These systems are extremely effective at killing airborne virus droplets and aerosols very near to their source. They can only be installed in areas where there is no possibility of human exposure to the UV radiation.

RESOURCES	
ASHRAE	https://www.ashrae.org/
Centers for Disease Control	https://www.cdc.gov/coronavirus/2019-nCoV/index.html
ASHRAE Journal	https://www.ashrae.org/technical-resources/ashrae-journal
Schnackel Engineers White Paper Series – Enhanced HVAC Infection Control	http://www.schnackel.com/firm/white-papers/enhanced-hvac-infection-control-white-papers

ABOUT THE AUTHORS

PEDRO FERRER, P.E.
DIRECTOR OF HVAC
Schnackel Engineers, Inc.

ABOUT PEDRO

Pedro has been involved in the supervision, design and drafting of mechanical systems for 25 years. He will oversee the design teams assigned to the project to ensure complete integration and coherence of the mechanical, plumbing and electrical designs. Duties include selection of efficient, cost effective mechanical and plumbing systems, performing mechanical, electrical and envelope operational cost analysis calculations, and providing technical assistance and site observations during construction as required to ensure satisfactory and timely project completion.

EDUCATION

B.S. Engineering Technology
University of Nebraska
Omaha, NE

Broad Mechanical and Electrical Engineering curriculum

EXPERIENCE

2008 to Present:
Schnackel Engineers, Inc.
Omaha, NE

2007 to 2008:
Schnackel Engineers, Inc.
New York, NY

2005 to 2006:
The Schemmer Associates
Omaha, NE

1993 to 2005:
Schnackel Engineers, Inc.
Omaha, NE

AREAS OF EXPERTISE

- Mechanical Engineering Design
- Specification Writing
- Field Survey
- Heating and Cooling Calculations
- Operational Cost Analysis Studies
- Plumbing Design
- Hydronic Design
- Construction Administration

PROJECTS COMPLETED

Over 3,000 individual projects successfully completed with Schnackel Engineers, Inc.

REGISTRATION

Licensed in Nebraska

"Sensible, responsible, common sense design to meet the client needs."

GREGORY R. SCHNACKEL, P.E., LEED AP

PRESIDENT
PRINCIPAL MECHANICAL, ELECTRICAL AND PLUMBING ENGINEER

ABOUT GREG

Greg, as Principal-in-Charge and Engineer-of-Record, will be responsible for all mechanical, electrical, plumbing, fire protection and information technology aspects of the Project.

Greg has been involved in all phases of supervision, design and drafting of mechanical and electrical systems for the past 45 years and brings a lifetime of experience to the project team. Greg's extensive involvement as the Chief Architect of the company's proprietary AEA Integration software has further enhanced Greg's ability to apply cost effective, value-based solutions to building systems design in a manner unmatched in the industry.

EDUCATION

B.S. Electrical Engineering
University of Nebraska
Lincoln, NE

Broad Electrical Engineering curriculum with emphasis on Mechanical Engineering and Computer Science.

EXPERIENCE

1976 to present:
Schnackel Engineers, Inc.
Omaha, NE

AREAS OF EXPERTISE

- Mechanical, Electrical, Plumbing and Fire Protection Engineering and Information Technology Design
- Specification Writing
- Field survey
- Contract Administration
- Technology Integration
- Corporate Management
- Optimization of MEP Systems Design through Advanced Technological Innovation

PROJECTS COMPLETED

Over 20,000 individual projects successfully completed with Schnackel Engineers, Inc.

REGISTRATION

Licensed Professional Engineer, Mechanical and Electrical Disciplines – 50 States, Puerto Rico, the District of Columbia, and the Canadian provinces of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Prince Edward Island, and Nova Scotia.

- Certified GreenPoint Rated, New Home Rater
- NCEES Model Law Engineer #10950
- LEED Accredited Professional

"Schnackel Engineers is the world leader in MEP/FP/IT engineering. Our revolutionary AEA Integration software combined with our exceptional customer service and the quality of our work is unmatched in the industry. Schnackel Engineers offers complete peace of mind that your project will be done right, done on time and at the lowest possible initial cost and long-term life-cycle cost."