HVAC Systems and Methods of Abating Airborne Infection

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The current COVID-19 pandemic presents many challenges we have never faced during our lifetimes. Scientists are gaining knowledge about the virus every day, researching therapeutic interventions and how it spreads but much still remains unknown.

What We Know About Airborne Transmission

When an infected person emits respiratory aerosols (see figure 1), they can land on nearby persons, fall to the ground (or other surfaces) or remain suspended in the air for up to three (3) hours. While current evidence seems to suggest that the primary method of spread is by physical contact, an as-yet unknown portion of the aerosols gets mixed into room air and may eventually spread to other rooms within the building, representing another potential transmission route. Researchers at Lawrence Berkeley National Laboratory are currently studying the transport of droplets and aerosols to assess the risk of airborne transmission of the virus[1] .

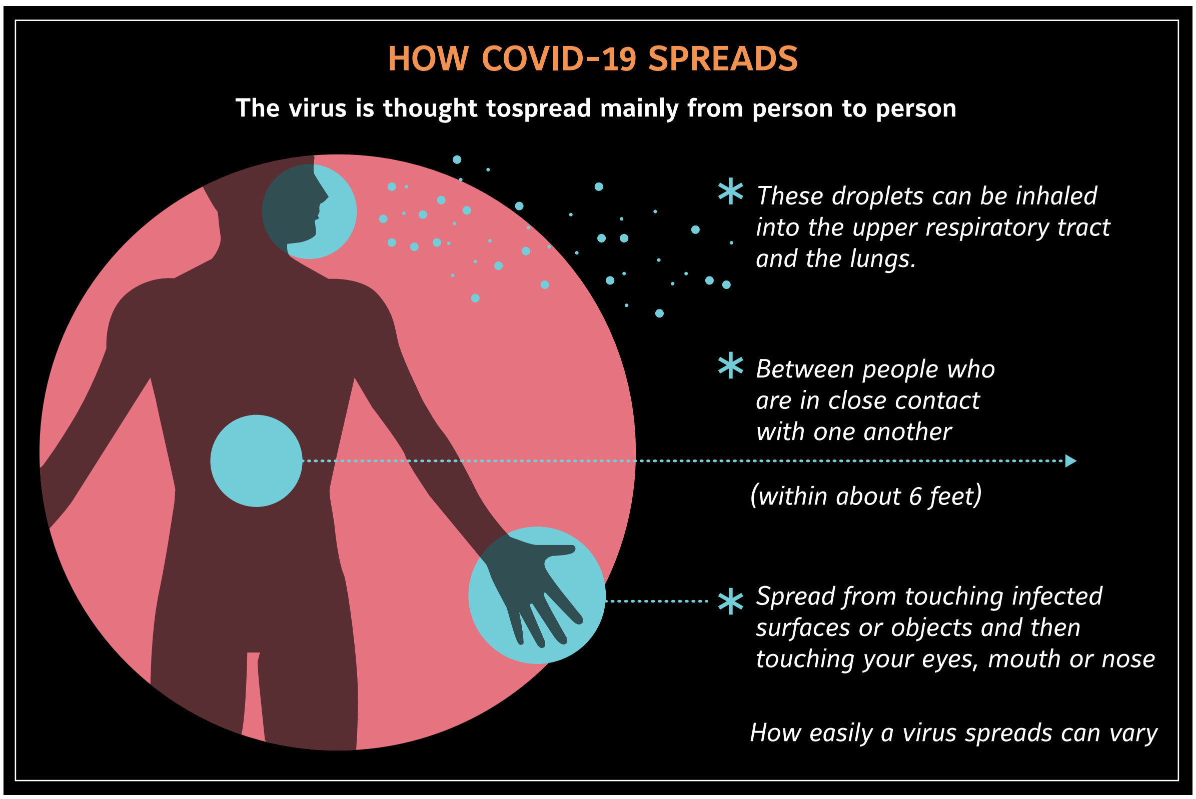

Figure 1. Methods of COVID-19 spread

Figure 2 relates the size of aerosols and the time it typically takes to drop five (5) feet from their point of discharge. According to the Centers for Disease Control and Prevention (CDC), droplet nuclei are typically in the 1 – 5 micron size range. The space relative humidity has also been shown to affect the transmission rate of viral nuclei. High relative humidity levels (above 60%) increase reproduction rates while levels below 40% tend to dehydrate the aerosol surrounding the nuclei, allowing it to remain suspended for longer periods.

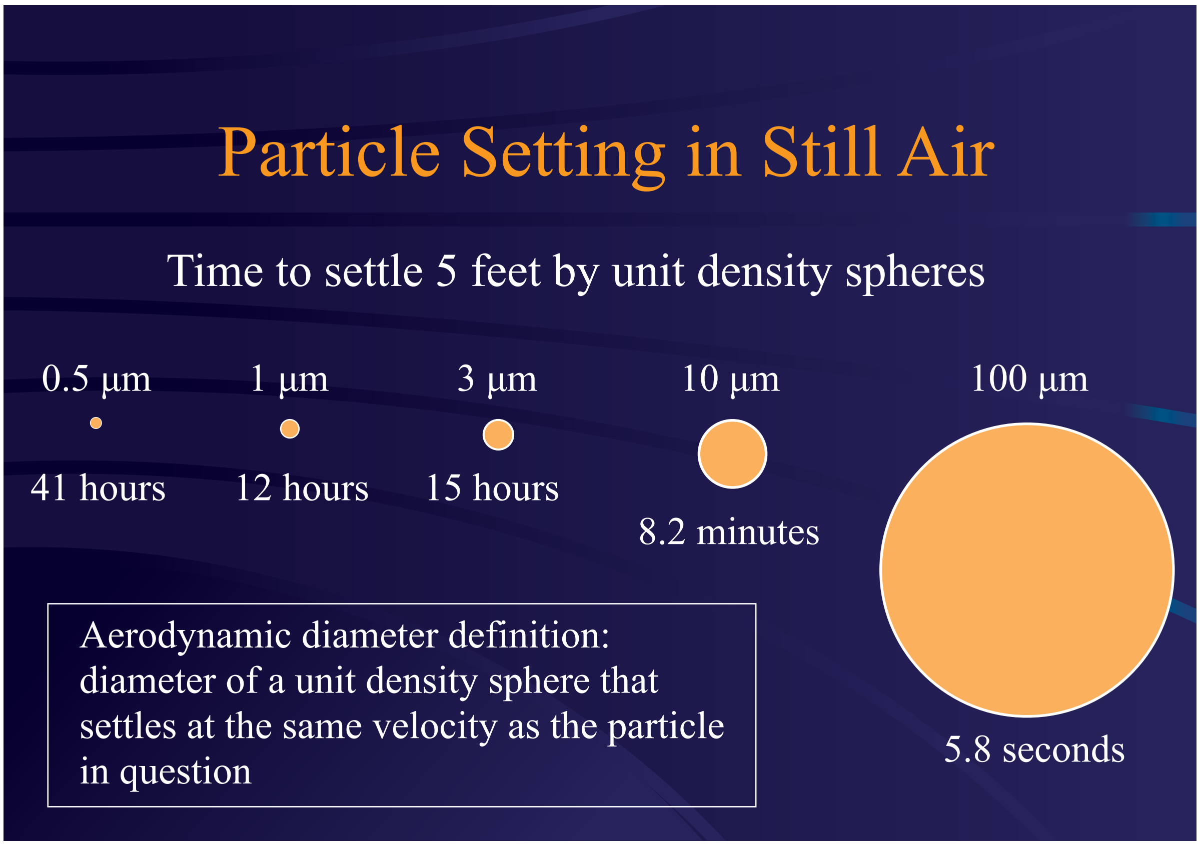

Figure 2. Comparative settling times by particle diameter in still air[2]

The purpose of this paper is to identify methods of abatement for airborne transmission that can be affected by HVAC systems. Transmission by surface contact is beyond the scope of the document.

HVAC System Abatement Strategies

Designers of mechanical systems should be aware that ventilation is not capable of addressing all aspects of infection control. HVAC systems, however, do impact the distribution and bioburden of infectious aerosols. Increased ventilation, as well as enhanced air filtration and cleaning (e.g. UVGI and bipolar ionization) technologies have been proven to reduce the risk of transmission of airborne aerosols.

Increased Ventilation

ASHRAE[3] recommends that during pandemic times "outside air for ventilation be increased to as much as the HVAC system can accommodate and still maintain acceptable indoor conditions during occupied hours". This statement underscores the fact that existing HVAC systems are often limited in their cooling capacity and can properly condition only a limited amount of outdoor during periods of near peak cooling or heating demand.

Building ventilation effectiveness[4] can be increased in two ways. The system ventilation effectiveness (E_{VS}) is elevated by increasing the outdoor air portion of the air mixture delivered to each space. In addition, the zone ventilation effectiveness can be enhanced by the room air distribution method that is employed.

Dedicated outdoor air systems (DOAS) that condition and supply 100% outside air to the space maximize system ventilation effectiveness. However, applying DOAS with all-air HVAC systems in humid and/or cold climates can result in severe energy penalties as outdoor air typically requires more energy to condition than recirculated return air. Decoupled space cooling devices such as chilled beams, radiant ceilings and fan coil units (including VRF types) and fan terminals with sensible cooling coils can complement the centralized air handling unit's sensible and/or latent cooling and enable its airflow requirements to be reduced, offsetting the energy penalty associated with centralized all-air DOAS.

Of course, the ultimate advantage of DOAS is that it does not recirculate return air and its airborne pathogens, instead exhausting all of it to the outdoors.

Individual zone ventilation effectiveness (E_{VZ}) is determined by the method by which air is supplied to and returned from the space. It is largely dependent on the relative buoyancy of the supply air and the supply/return air locations. Stratified systems such as thermal displacement ventilation (TDV) and some underfloor air distribution (UFAD) systems, utilize low level supply air outlets coupled with overhead returns to provide enhanced ventilation effectiveness during cooling operation. These systems also provide unidirectional (vertical) air motion around the occupants that enhances the conveyance of exhaled aerosols to the upper levels of the space where they can be removed with the return air.

Enhanced Filtration

Commercial HVAC air handling units typically contain two filter sections[5]. The final filter, located downstream of its other components, has an efficiency requirement that is dependent on its application. This may range from a MERV-8 (for general commercial building applications) up to a MERV-20 (for certain clean room applications). Most air handling units are also furnished with a pre-filter installed ahead of the coils and fan section. This filter is primarily intended to limit the passage of particulates that might compromise the performance of the air handler components and extend the service life of the higher efficiency final filters.

Fibrous filters capture particulates in four distinct ways (see figure 3). Larger particles may be "strained" by the filter surface as their diameter exceeds the fiber spacing. Smaller particles may also be captured by inertial "impaction" with the fibers on the filter face. Other smaller particles may penetrate the face of the filter only to be "intercepted" by fibers within the filter's depth. Finally, very small particles exhibit Brownian motion and randomly "diffuse" through the filter media where they often attach to a fiber.

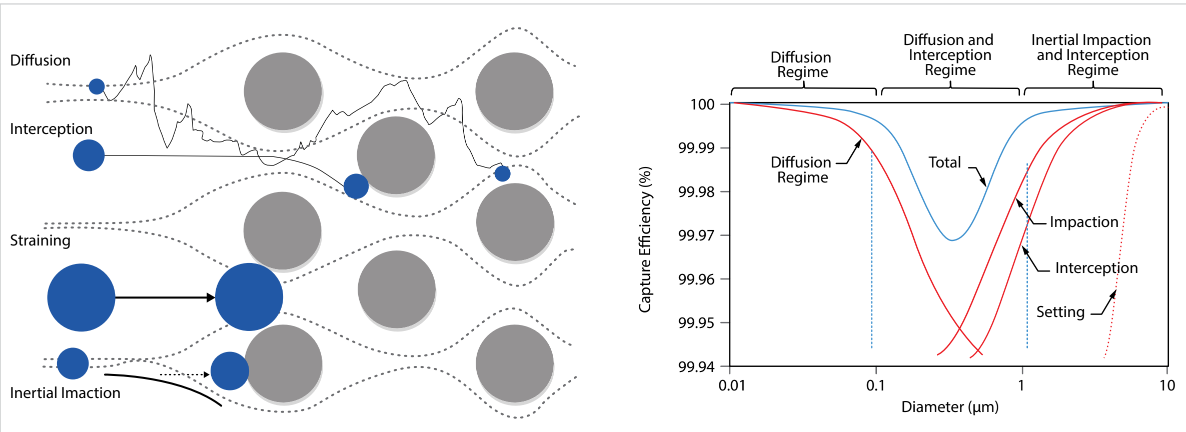

Figure 3. Methods of particulate capture by filtration media[6]

The Minimum Efficiency Reporting Value (MERV) rating system (see table 1) relates a filter's efficiency at capturing particle of specific sizes. Although coronavirus nuclei are only 0.1 micron in diameter, the aerosol droplets that transports them are typically in the 1 to 5-micron range.

MERV Rating	Air filter will trap Air Particle size 0.3 to 1.0 microns	Air filter will trap Air Particle size 1.0 to 3.0 microns	Air filter will trap Air Particle size 3 to 10 microns	Filter Type ~ Remove These Particles
MERV 1	< 20%	< 20%	< 20%	Fiberglass & Aluminum Mesh ~ Pollen, Dust Mites, Spray Paint, Carpet Fibres
MERV 2	< 20%	< 20%	< 20%	
MERV 3	< 20%	< 20%	< 20%	
MERV 4	< 20%	< 20%	< 20%	
MERV 5	< 20%	< 20%	20% to 34%	Cheap Disposable Filters ~ Mold Spores, Cooking Dusts, Hair Spray, Furniture Polish
MERV 6	< 20%	< 20%	35% to 49%	
MERV 7	< 20%	< 20%	50% to 69%	
MERV 8	< 20%	< 20%	70% to 85%	
MERV 9	< 20%	Less than 50%	85% or Better	Better Home Box Filters ~ Lead Dust, Flour, Auto Fumes, Welding Fumes
MERV 10	< 20%	50% to 64%	85% or Better	
MERV 11	< 20%	65% - 79%	85% or Better	
MERV 12	< 20%	80% - 90%	90% or Better	
MERV 13	Less than 75%	90% or Better	90% or Better	Superior Commercial Filters ~ Bacteria, Smoke, Sneezes
MERV 14	75% - 84%	90% or Better	90% or Better	
MERV 15	85% - 94%	95% or Better	90% or Better	
MERV 16	95 % or Better	95% or Better	90% or Better	
MERV 17	99.97%	99% or Better	99% or Better	HEPA & ULPA ~ Viruses, Carbon Dust, <.30 pm
MERV 18	99.997%	99% or Better	99% or Better	
MERV 19	99.9997%	99% or Better	99% or Better	
MERV 20	99.99997%	99% or Better	99% or Better	

illustration Provided by LakeAir / www.lakeair.com

Table 1. Filter particulate capture efficiencies and MERV ratings

Filters rated MERV 17 or greater are referred to as high efficiency particulate air (HEPA) or ultra-low particulate air (ULPA) filters. These filters offer a very high rate of capture for small particles like the coronavirus nuclei. Although MERV 13 filters are technically not rated to catch small dehydrated viral particulates, they are quite effective at capturing aerosol droplets containing viral nuclei caused by cough/sneezing. It is obvious that the thickness of the filter media significantly increases the capture by means of interception and diffusion. Filters rated below MERV-13 are commonly employed for dust particle removal and not generally viable for capturing the virus.

HEPA filters may be applied within the HVAC system or in recirculation units positioned within the occupied space. The employment of these filters within the HVAC system poses certain challenges. The pressure drop of the filters is very high, so they must be sized for relatively low face velocities (typically 100 FPM or less). This might be accommodated in new HVAC system designs but would be difficult to achieve in the retrofit of existing air systems. In any case, a significant energy penalty will result from the addition of these filters.

Finally, these high efficiency filters must be accessible for "bag in, bag out" replacement to avoid exposure of maintenance personnel to the virus.

Enhanced Air Cleaning

Ultraviolet germicidal irradiation (UVGI) and bipolar ionization (BPI) are other technologies that show promise for the abatement of airborne transmission of the virus.

UVGI usually refers to UV-C light distributed at a wavelength of 254 nm. It is a cost-effective method of inactivating airborne viruses and can also be used to inactivate droplets containing the virus on surfaces. The UV-C light's efficacy rate is exponentially dependent on the susceptibility of the pathogen, and its irradiation dosage which is equal to its effective irradiance flux multiplied by the pathogen's exposure time. Coronavirus has a very high susceptibility constant and is thus very susceptible to deactivation by UVGI means.

There are two basic UVGI abatement strategies. The most widely used application is in the form of passive upper room fixtures containing UVGI lamps that provide a horizontal layer of UV-C energy field above the occupied zone (see figure 4 below). These fixtures are designed to inactivate bacteria that enter the upper irradiated zone, and their efficacy is highly reliant on, among other factors, the airflow field conditions in the room[7]. In order to maximize the UVGI deactivation rate, the room air distribution system must efficiently deliver the aerosol to the irradiated zone. Upper room UVGI is often seen as a cost-effective measure to supplement the general ventilation system in a room. The use of thermal displacement ventilation or high induction, low throw ceiling supply outlets (e.g. swirl diffusers) can enhance the deactivation rate of the upper room UVGI system.

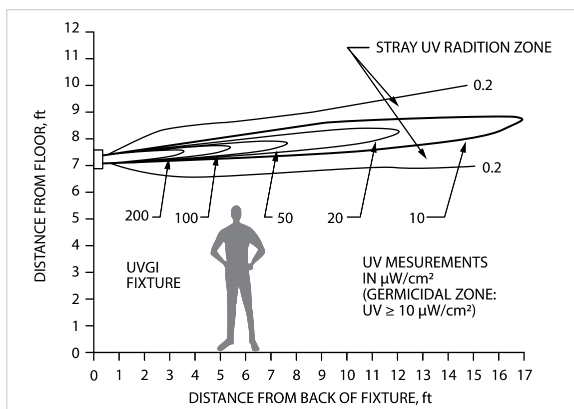

Figure 4. Upper room ultraviolet germicidal irradiation (UVGI)

In-duct UVGI utilizes UV-C lamps installed inside the supply air stream to inactivate bacteria, fungus and virus on the surfaces of the air handling unit cooling coils. This technique can also be applied within other components of the HVAC system. Effective deactivation of the virus requires high levels or irradiation due to their short exposure time that results from typical design air velocities of around 500 FPM. These systems should be complemented by a pre-filter with the maximum MERV rating that can be economically accommodated, but at minimum MERV 8.

According to an American Biological Safety Association position paper, biological effects in humans from overexposure to UV-C radiation vary with wavelength, photon energy, and duration of exposure[8].

UV-C light in the range of 207 to 222 nm, known as far-UVC, has been shown to effectively deactivate viruses without penetrating (and damaging) human skin or eyes. Nonetheless, upper room fixtures are designed and located to shield the occupants from direct UV-C light exposure.

As with filtration devices, portable UV-C devices are also commercially available but are primarily used for UVGI disinfection of room surfaces while the room remains unoccupied.

Bipolar air ionization (BPI) systems utilize high voltage electrodes to create reactive ions in the supply air passing through the air handling unit that react with airborne contaminants, including viruses, changing them into highly reactive hydroxyl radicals. As a result, the virus cannot cause infection, even if it enters the body.

Convincing scientifically rigorous, peer-reviewed studies do not currently exist on this emerging technology; manufacturer data should be carefully considered. BPI systems may also emit ozone, some at high levels. Manufacturers are likely to have ozone generation test data.

General System Guidance

While some misleading statements published online suggest that HVAC systems are a source of disease spread across a building, there is overwhelming evidence that the HVAC systems can actually play an important role in reducing disease transmission. Systems that maintain the prescribed volume delivery of clean outdoor ventilation air to all areas of the building during every load scenario are more likely to prevent airborne disease transmission than systems that don't.

While an HVAC system's ability to condition occupied spaces is determined by its zonal supply airflow rate and temperature, its ability to reduce airborne pathogens in the space is a function of the amount of return air leaving the space and the ability of the system to remove any pathogens from the air before it is recirculated by the air handling unit.

Most modern office buildings in North America are designed with "all air" variable volume (VAV) systems. The primary area for discussion with VAV is the fact that the system centrally mixes large portions of air returned from the building with outdoor ventilation air, potentially re-distributing airborne contaminants across the building. What should not be overlooked is that the system is at the same time removing airborne contaminants from the occupied space, so these systems should not be disabled during a pandemic situation.

ASHRAE recommends that the ratio of outdoor to recirculated return air be increased as much as possible to increase the VAV system's dilution rate and contaminant removal efficiency. During high demand operation, this places an increased burden on the air handling unit coils (leading to increased energy consumption). Still, it is recommended that the outside air dampers (see figure 5) be opened as far as possible while maintaining an acceptable (although possibly compromised) level of comfort within the building.

Figure 5. Rooftop air handling unit with economizer provisions

Where possible, ASHRAE also recommends increasing the final filtration level within the air handling unit to MERV 13 in order to capture airborne aerosol droplets before they can be recirculated. However, increasing the final filtration level will often affect the air handling unit's airflow capacity, limiting its ability to provide adequate cooling to the space. An alternative method of reducing the recirculation of pathogens is the use of in-duct UVGI or bipolar ionization within the air handling unit, but the limitations of implementing those technologies, especially in existing systems are discussed in the abatement strategies section of this document.

Dedicated outdoor air systems (DOAS)

The ideal solution for contaminant removal from the indoor environment is the employment of a 100% outdoor air system (DOAS) which exhausts all of the air removed from the space, virtually eliminating the possibility of pathogen recirculation. This, however, is rarely possible to implement on existing systems as they are typically designed to perform with a low ratio (20 to 30%) of outdoor to recirculated air. Designing new HVAC systems with DOAS can also result in high energy penalties during peak heating and cooling seasons as the outdoor air becomes much more expensive to cool and dehumidify than recirculated return air.

When centralized "all-air" cooling strategies are applied, supply airflow rates are almost always driven by the zone sensible cooling or heating requirements which can be 2.5 to 3 times those required for zone humidity control. As the air handling unit's latent cooling remains proportional to its sensible cooling, a significant amount of excess latent cooling is accomplished with a corresponding energy penalty.

The employment of zone level de-coupled cooling systems can reduce the energy burden associated with DOAS systems and will be discussed in subsequent sections of this document.

Application of Technologies to Specific Facility Types

Commercial Office and Government Buildings

The pandemic has forced many office based workers to temporarily work out of their homes and while technology has made this transition relatively easy for most, not all work can be performed remotely especially that of first responder call center and government employees working in high security buildings. Employers have had to react swiftly to the crisis, implementing several measures to reduce the chances of infection spread through social distancing, disinfecting and erecting physical barriers. But what about the risk posed by airborne aerosols?

Decoupled Sensible Cooling Systems

Systems that do not centrally recirculate return air (i.e. those based on DOAS air handling units), offer a viable alternative to VAV if higher indoor air quality is a top priority for a new HVAC system design. As all of the air returned from the space is exhausted, high levels of final filtration are not required as the return air is not recirculated. These systems have seen greater adoption in North America in the last decade or so.

Decoupled sensible cooling systems, such as chilled beams or series fan-powered sensible cooling terminals, not only provide the correct ventilation rates at all times but also allow ventilation air to be delivered at a neutral temperature (i.e. around 62-65°F during cooling season) which can reduce energy consumption by reducing overcooling and reheat.

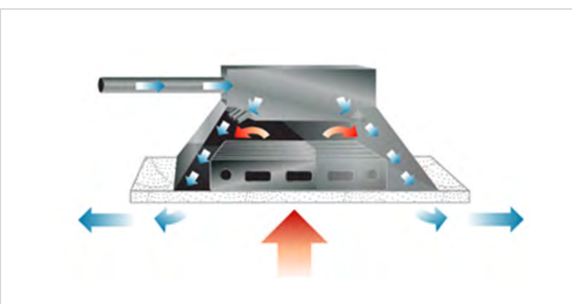

Figure 6. Active chilled beam

Active chilled beams (see figure 6) are one of the most common DOAS-decoupled HVAC systems used in North America with the first systems being installed in educational buildings around 2004.

Active chilled beams are suitable for many office applications and are well matched to the heating/cooling loads of both existing and modern office buildings. While it is true that a chilled beam is in itself a recirculation unit, recirculation only occurs locally so contaminants drawn through the beam's induced air path air are confined within the space and not redistributed across the entire building when used with a DOAS.

These systems remove the majority of the zone sensible heat gains locally, thereby reducing the airflow rate of the centralized air handling unit to that required for zone latent cooling (humidity control), which is typically 30 to 40% that required for its sensible cooling. The reduced ducted airflow rate combined with the local room air recirculation still results in consistent upper room air circulation rates that are at least 30% higher than those associated with a VAV mixed air system, making them an ideal compliment for upper room UVGI systems.

Their primary advantage of active beams over other DOAS-decoupled systems is life cycle cost. Active chilled beams are virtually maintenance free, requiring only infrequent (measured in years) coil cleaning. Dirt will not adhere to the coil surface as it operates dry and filters are not required. Unlike refrigerant-based systems (e.g. VRF) active beam systems have very few moving parts and what is often overlooked is the long life expectancy of this system which can be decades more than most systems.

Reduced maintenance make ACB's an ideal solution for high security government buildings where service personnel must be put through rigorous security screening before being granted access to the building. This is the primary reason that an active beam system has been employed for buildings like the National Geospatial Intelligence Agency headquarters in Fort Belvoir, VA.

Fan Coils Units (FCU's) and Series Fan Terminals with Sensible Cooling (SFSC's) allow decoupled zone temperature control although one important distinguishing factor between these two systems is that FCU's are typically designed with low temperature chilled water, condensing coils and condensate drains. SFSC's (see figure 7) on the other hand are designed to be used with medium temperature chilled water (55-60°F), benefitting the owner with lower maintenance costs as dry coils stay clean longer and do not require condensate removal provisions.

Figure 7. Series fan terminal with sensible cooling

One distinct advantage FCU's and SFSC's have over active beams is the option of installing high efficiency filters up to a MERV 13 in their recirculation air path. Although technically speaking, a MERV 13 filter is not rated to catch particles as small as virus, they will capture respiratory droplets caused by cough/sneezing. According to the CDC, droplet nuclei typically fall in the 1 – 5 micron size. Note that 1 micron droplets can remain airborne for up to 12 hours[4]. The installation of such filters will capture aerosol droplets and prevent them from being passed from one space to another by recirculated air. Terminals equipped with EC motors are generally capable of overcoming the higher filter resistance while maintaining their established airflow rate and cooling/heating capacities. These terminals can also be added to an existing system to overcome performance limitations that may be associated with increased outdoor air delivery. Like all systems, FCU's and SFSC systems have some drawbacks including additional maintenance and increased interstitial ceiling space as compared to active beams.

Educational Facilities

Many experts have noted that one of the most worrying aspects of the COVID-19 pandemic, is the spread of the virus by asymptomatic people which can be as much as 50% of all those infected[13]. While asymptomatic carriers may not shed much virus into the air by coughing or sneezing, the virus is still shed through respiration. Children seem to experience milder symptoms than adults and this combined with asymptomatic carriers, could result in classrooms being a hub of transmission to the wider community. Along with social distancing policies in classrooms, displacement ventilation (especially when paired with DOAS) can be an effective measure for combating airborne transmission.

High occupancy densities characteristic of educational buildings require greater ventilation airflow rates and thus classrooms are ideal candidates for DOAS-based HVAC systems. Studies have shown that up to 85% of recently installed HVAC systems in K-12 classrooms are not adequately ventilated[9]. Maximizing classroom ventilation rates is important for two reasons, firstly a reduction in respiratory CO_2 levels has been shown to reduce acute respiratory illness (ARI) rates throughout a building[10], and secondly, there is growing evidence that high CO_2 concentrations can affect cognitive performance[11].

Thermal Displacement Ventilation

Thermal displacement ventilation (TDV) systems (see figure 8) supply cool conditioned air at or near the floor level. Unlike mixed air delivery systems, the air is introduced at a low velocity and affects minimal mixing with the ambient room air. As such, the conditioned air falls due to natural buoyancy forces and forms a reservoir of cool fresh air at the floor level throughout the classroom. Space occupants produce convective heat plumes that draw the conditioned air from the reservoir and transport it in a uni-directional manner, depositing it into the upper regions of the space. These convection currents also transport respiratory bi-products (including pathogens) and related odors to the overhead return where they can be efficiently removed from the space. It also makes them an ideal compliment for upper room UVGI systems.

Figure 8. Thermal displacement ventilation

TDV systems have been proven to provide generally improved classroom ventilation. ASHRAE Standard 62.1[4] awards these systems a zone ventilation effectiveness factor (E_Z) of 1.2 as opposed to the 1.0 awarded to mixed air systems. Additional information about thermal displacement, including engineering guides and educational webinars can be found on the Titus website (www.titus-hvac.com).

Active Chilled Beams

This system, described in the previous section of this document, has proven to be quiet (suitable for ANSI/ASA S12.60 design standard[12]), comfortable, energy efficient and is also one of the lowest cost DOAS-decoupled systems available. Active beams remove 50 to 75% of the space sensible heat gains by means of their integral cooling coil. As such, they are capable of satisfying the space design cooling requirement with a ducted (primary) airflow rate that is typically much lower than that required by all-air systems. Consistent and increased upper room air circulation also compliments the use of upper room UVGI fixtures.

Induction Displacement Units

Induction Displacement Units (IDU's) combine an active chilled beam, displacement diffuser and convective heating into a single floor mounted unit. IDU's (illustrated in figure 9) are quiet in operation and are suitable for ANSI/ASA S12.60 standard designs. Displacement ventilation relies on convective forces to move airborne contaminants upwards and out of the breathing zone, reducing the chance of airborne pathogens being transmitted to other room occupants.

Figure 9. Induction displacement terminal

Pairing IDU's with a DOAS ventilation system offers several advantages over conventional displacement ventilation systems. Like with all active chilled beams, a significant portion of the classroom sensible heat gains are removed by the units' integral cooling coil, significantly reducing the classroom's ducted (primary) airflow rate. This minimizes the air handling unit's airflow rate and thus required cooling capacity to enable the use of 100% outdoor air delivery with minimal energy impact.

Healthcare Facilities

Standard Patient Rooms

ASHRAE Standard 170-2013 "Ventilation of Healthcare Facilities" included a small but major change that allows recirculated air from terminal units (such as active chilled beams or fan coil units) to count towards that total space air changes. In other words, of the total 4 ACH recommended for a patient room, 2 ACH can be drawn through a local recirculating unit instead of being made up at the central air handler. This change has encouraged the use of DOAS in the less critical areas of healthcare buildings (where recirculation units are permitted) such as patient rooms. Several states have now updated their local codes to be in line with the latest FGI Guidelines/ASHRAE Standard 170, so DOAS-decoupled system designs are becoming more common. Figure 10 illustrates the use of active chilled beams for such an application.

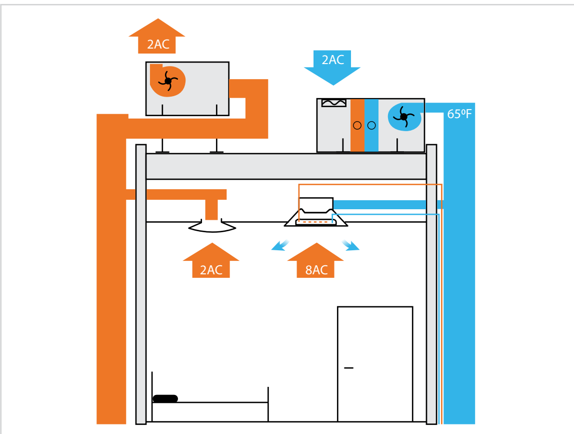

Figure 10. Active beams serving a standard hospital patient room

Fan coil units, series fan boxes with sensible cooling and active chilled beams can be used in these applications, although note that a single unit cannot be shared across more than one room and the recirculated room air must be drawn directly into the terminal unit from the room and not through a shared ceiling interstitial. In this respect, active chilled beams have an advantage over fan terminals as they have a lower installed cost due to the fact they do not require power wiring or separate supply or return ductwork/grilles. They are also much quieter than fan terminals. Active beams have one notable disadvantage in that they cannot be fitted with high efficiency filters to filter the recirculated room air unlike fan-powered units.

A DOAS-decoupled system has several advantages over a conventional "all air" design for patient rooms and other non-critical areas of a hospital where air recirculation is allowed:

- The DOAS provides 100% outdoor air to the building so the ductwork does not need to be sized to carry any recirculated air. This significantly reduces the size of the distribution ductwork across the building.
- Centralized recirculation of return air is eliminated, reducing the potential for cross contamination.
- Terminal reheat is virtually eliminated as the as the supply air to the room is halved (2 versus 4 ACH) and DOAS primary air can be sent to the patient room at a warmer temperature (typically 65°F) in the cooling season as the chilled beams or fan coils satisfy most of the room cooling load.
- Water, which is more efficient than air, is the primary medium to transport heat around the building.
- Active chilled beams provide higher total air change rates than a typical "all air" system. Commercially available beams typically provide at least three recirculating air changes for every primary air change.

Low level displacement diffusion has been shown to reduce airborne contaminant concentrations for most of the patient room and offer the same contaminant removal performance with 4 ACH as a conventional overhead mixing operating at 6 ACH[14]. Displacement ventilation diffusers can be used with SFSC terminals as the supply air temperature from which is typically around 60-62°F which is warm enough to be delivered at floor level. Active chilled beams are also available in floor mounted "Induction Displacement Units", which are also designed to be coupled with DOAS.

Conversion of Standard Patient Room for ARI Patients

An influx of ARI patients into a hospital may well exceed the number of available airborne infectious isolation (A.I.I.) rooms during a pandemic crisis. Recommendations for A.I.I. rooms have not been revised since the outbreak of the current pandemic. In summary, the current FGI guidelines/ASHRAE Standard 170 recommends a total of 12 ACH, of which 2 ACH must be outdoor air. Since all 100% must be exhausted, the 10 ACH of makeup air is usually drawn from corridors via door transfer grilles and also keeps the A.I.I. room under negative pressure which is a critical requirement.

The use of recirculation units such as fan coils or active chilled beams are not permitted under the FGI guidelines, so only conventional "all air" HVAC systems can be used in these rooms.

Standard patient rooms can be converted for patients infected with a respiratory disease by installing mobile or ceiling mounted fan filter units (see figure 11).

Figure 11. Mobile fan filter unit

Fan filter units are fitted with HEPA filters and can be used to negatively pressurize the patient rooms relative to the main corridors and while achieving the required 12 exhaust air changes. They can be installed relatively quickly using the following ASHRAE recommended[15] approaches in order of preference:

1. HEPA to outside – the HEPA fan unit discharge is ducted through an outside window. The window is removed and the opening covered, exhaust air is ducted through a sealed hole in the covering. Patient return grille should be sealed.
2. HEPA to return – the HEPA fan unit discharge is ducted to the ceiling return air grille in the patient room. The exhaust duct is attached to the return grille with the remaining part of the return grille being sealed off. With this approach, dampers for return airflow paths should be shut to ensure 100% of the air is exhausted from the building.

Careful location of the supply and exhaust grilles (see figure 12) is important to attain the maximum dispersion of infectious agents within the space.

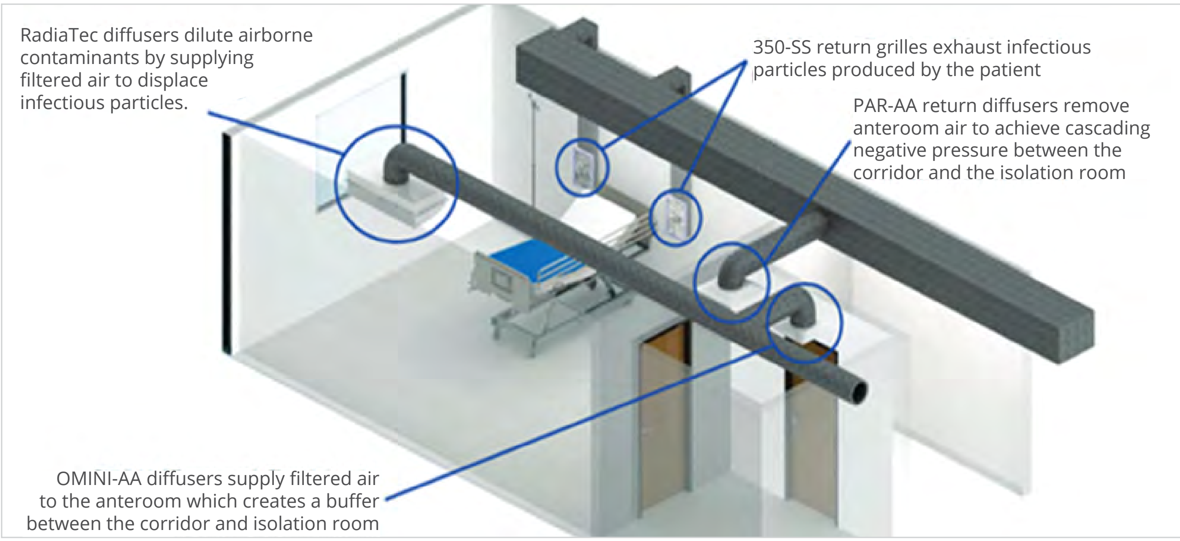

Figure 12. Location of supply and return outlets in an AII isolation room

Installing 1-way throw radial diffusers at the wall/ceiling opposite the end of the patient bed dilutes airborne infectious contaminants and help disperse them towards the exhaust grilles which should be located in the ceiling above the bed headboard.

As the current COVID-19 pandemic unfolds, scientists and researchers will continue to learn more about the virus and make recommendations about how best to control its spread. It is also critical that everyone involved in the design, operation, and maintenance of buildings follows the latest recommendations. HVAC systems and air cleaning technologies can be applied in ways to help abate the airborne transmission of the virus, but they represent only a partial solution.

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