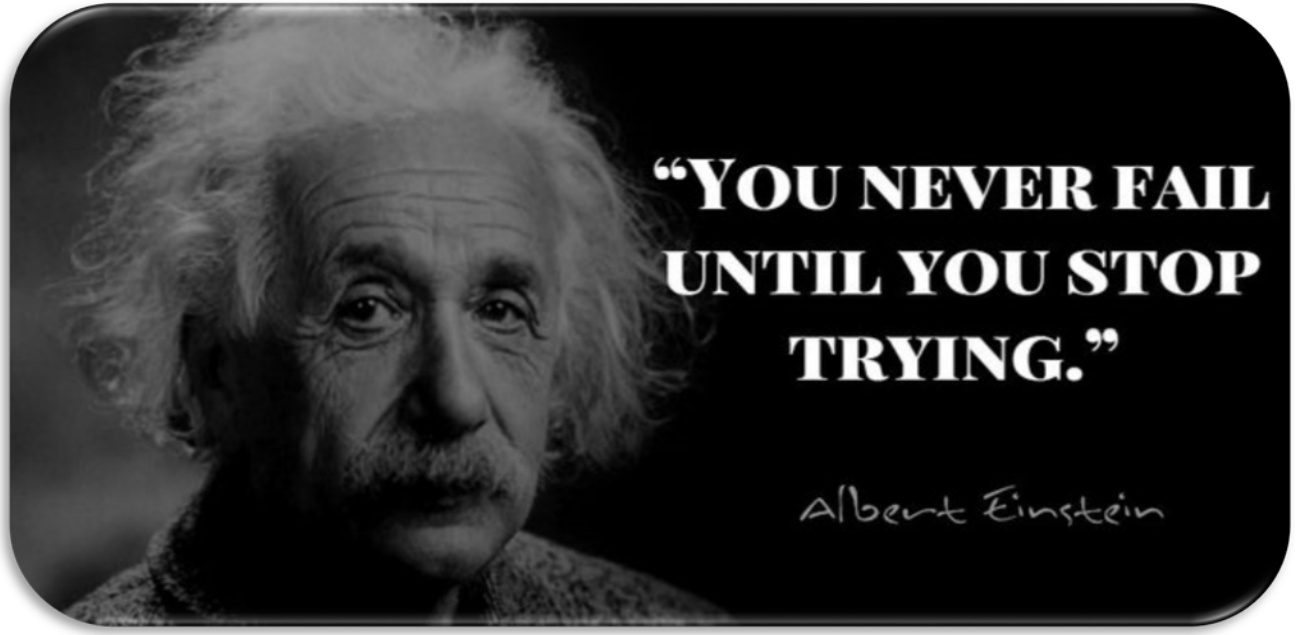
Practical & Adaptive approach towards HVAC systems with focus on COVID-19

Post COVID -19 operations preparedness – The progressive and evolving strategy.

Jointly presented by : Mr GC Modgil; Mr Pankaj Dharkar;Mr Tanmay Tathagat; Mr Rahul Deshpande; Mr Ashwani Kumar; & Mr Richie Mittal .

Presenter : Pramod Dhir (Dewpoint Services Consultants LLP) ; Dt. : 11th June 2020.

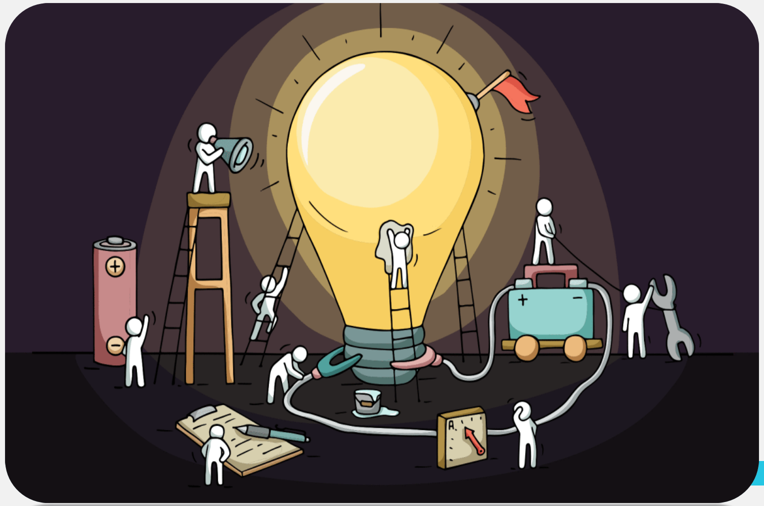
“When the enemy is invisible, and it changes its offense mechanism, the defense becomes vulnerable and life tries to discover different ways to tackle and overpower the enemy.”



You never fail until you stop trying !

Remember ,that CURRENTLY, this fight is progressive and evolving in nature.

SOLUTION GUIDELINE
: a simplistic approach !



STEP 1

Accepting the problem is a 50% solution in itself : HVAC systems reduce the risks of contracting COVID by virtue of filtration, dilution and treatment of air .

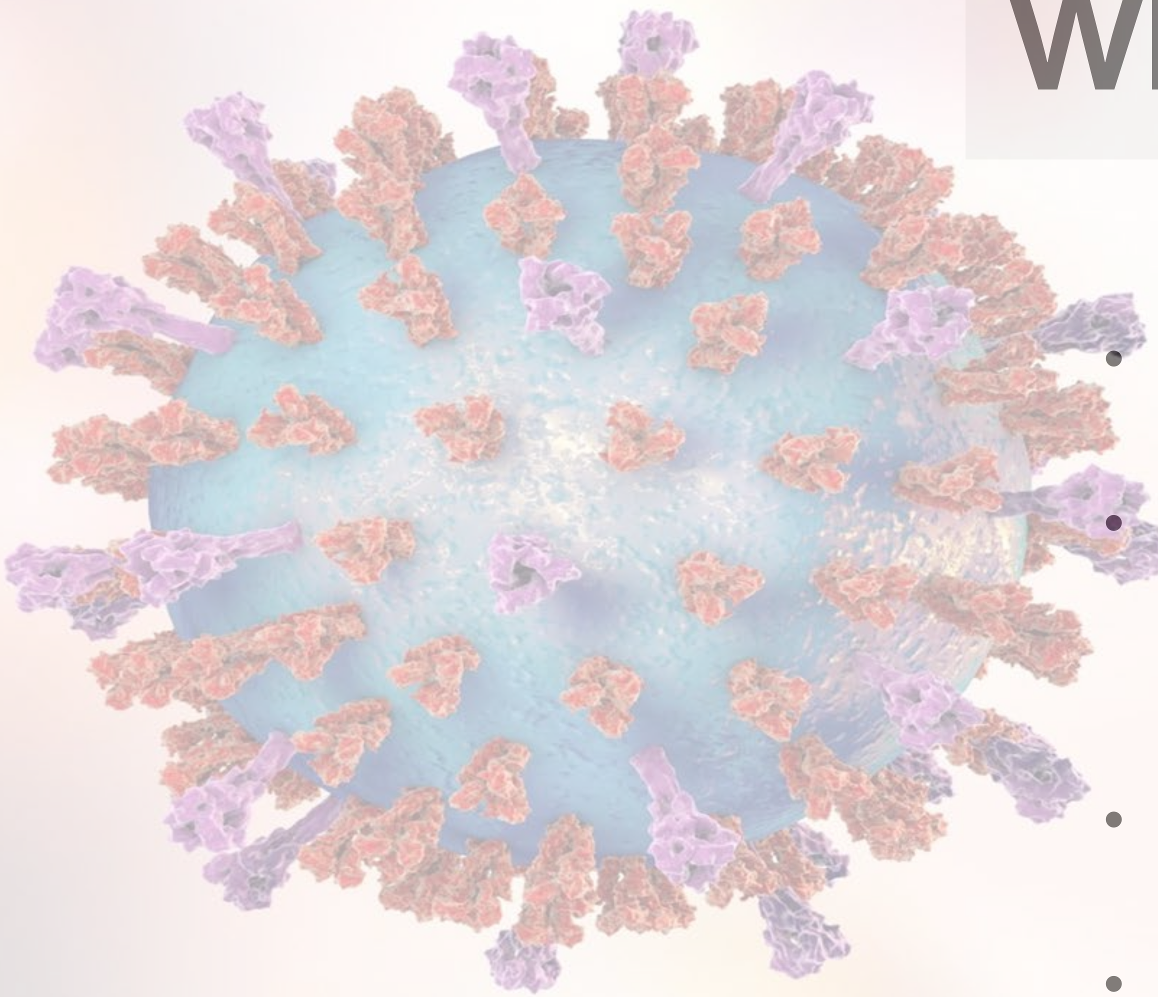
STEP 2

De-mystify the enemy; come around the enemy; build your defense ; adapt (don't sleep with the enemy!)

STEP 3

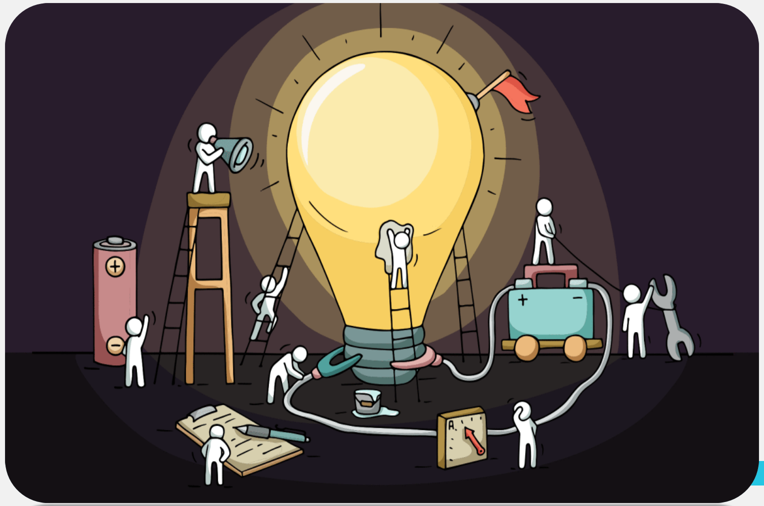
Implement, Improvise, Innovate, Improve, Repeat !
Identify the MUST DO, SHOULD DO & GOOD TO DO's

What is the problem ?



- COVID 19, a **constantly mutating virus**, that has stunned the medical researchers.
- So mush so that the newer cases are **asymptomatic** and its manifestations are not restricted to only respiratory compromises.
- The **particle size** is such that the conventional filtration systems fail to trap it.
- The human body does **not get auto-immune** after contracting this virus and recovering from it (as the research says of now, in the absence of a vaccine).

SOLUTION GUIDELINE
: a simplistic approach !



PURPOSE OF THIS PRESENTATION:

To interpret the guidelines and standards issued by various bodies , identify the challenges in implementing and provide a way forward to the building operators.

MYTH : HVAC systems promote the spread of COVID-19

Response : HVAC systems properly adapted to the current requirements (& based on the suggestive guidelines of ISHRAE / ASHRAE help in reducing the risk of propagating the said virus.

De-mystifying / Adaptation / Defense

INFECTION EQUATION:

$$\text{Infection} = \frac{(\text{Dose} * \text{Virulence} * \text{Time})}{\text{Level of host defence}}$$

Dose = Amount of virus particles in a space (**VARIABLE**)

Virulence = The severity or harmfulness of a disease (**FIXED**)

Time + Amount of time spent in an exposure (**FIXED** for an office)

Level of host defense = Immunity (**Fixed**)

what do we know, what have we learnt.

Dose of the pathogen is the ONLY VARIABLE

The analysis —

- Since **Dose is the only variable** in this equation, therefore, it is prudent in focusing onto it alone insofar as HVAC systems are concerned.
- Dose is a kind of load **generated inside** an office (or any space), or it **in-filters** into a space by human traffic, parcels, or any other form of carrier.

If infection has to be reduced, then the dose of pathogens needs to be handled by way of the following measures:

- **Filtration .**
- **Dilution strategy (Enhanced ventilation).**
- **Air flow patterns (**NOT COVERED IN THIS PRESENTATION**)**
- **Air Treatment.**
- OTHER ACTIVE / PASSIVE MEANS TO MINIMISE THE EXPOSURE OF INHABITANTS TO THE PATHOGENS IN THE BUILT FORMS.

The Ground reality —

- **Since this presentation is restricted to the challenges of adapting the existing buildings , the focus will remain on it.**
- **However, it will be prudent to also sensitize the audience friends about the elements that if our existing building had, how easy would it have been to implement the spirit / essence of the current proposals.**

KEY MISSING FACTORS THAT HAVE COMPROMISED THE "Modern" Buildings:

- Operable windows / Atrium roofs.
- Air Economisers to assist higher rates of outdoor air changes.
- Higher head rooms and adequately sized HVAC – AHU Rooms : (To enable the ease of incorporation of additional fans in the AHU rooms to assist incorporating HEPA / ULPA Filters)
- Improper selection of HVAC equipment
- Lack of scientific pressure relationship with outdoor air and mostly non-established air balance equation.

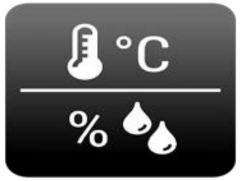
EXISTING (ON GROUND REALITY OF THE BUILDINGS & HVAC SYSTEMS) :

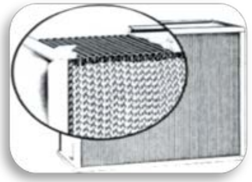
- Sealed Buildings (Generally a glass box)
- No operable windows.
- DOAS / TFAs of fixed / Variable speed (DCV) are installed. Exhaust : primarily fixed speed toilet / pantry extractors . Air balance not scientific in many cases
- Shafts within the building transfer the tempered outdoor air .
- Some buildings also have VRFs / Packaged / Split Air-conditioners.
- Some buildings have integrated fixed external louvers for drawing un-tempered outdoor air.

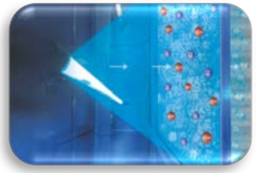
Current recommendations suggested as a mandate :

To minimize the "dose" of the pathogen, following are the measures that **MUST** be implemented.

- Maintain humidity and Temperature as prescribed by ASHRAE / ISHRAE.
- Increasing ventilation (and also Exhausting an equal (minus the pressurization air quantity) amount of outdoor air pushed into the space.
- Increasing Total number of air changes for better filtration.
- Installing high efficiency passive filters (HEPA)
- Install Engineered UVGI (with correct selection of intensity & dosage).







Practical Analysis of the mandate / suggestions:

Recommendations	Ease of doing	Does it ACTUALLY help ?	Remarks
Increase ventilation air	X	X*	x: In modern buildings (mostly glass façade) , ventilation air is through a TFA or drawn through the fixed ventilation louvers Increasing the ventilation air in multi-tenanted buildings is a practical problem.
			x* : Dilution does help , but, beyond a practical limit, it can bring in other pollutants from outdoor, thereby increase the load on the mechanical filters, and also sap on the energy.
Use of HEPA filters in AHUs.	X	?	Size of the corona virus is around 0.1 micron; while HEPA filters can trap particles upto 0.3 microns with highest efficiency.
			What about VRF systems and Packaged type / Mini Split Aircon systems?

Practical Analysis of the mandate / suggestions:

Recommendations	Ease of doing	Does it ACTUALLY help ?	Remarks
Enhance total ACPH.	x	√	What about VRF systems and Packaged type / Mini Split Aircon systems?
			Increasing TACPH involves the fan, fan motor and to an extent the air distribution design in an existing building.
Maintain temperatures around 26 Deg C.	√*	√*	Such elevated temperatures in modern (glass façade) may result in thermal discomfort .
Maintain Relative humidity 60%.	√*	√*	With increased ventilation, maintenance of the rH may be a challenge in coastal conditions.
Install UVGI	√	√	Challenge is to understand its basics and differentiate between surface and air application.

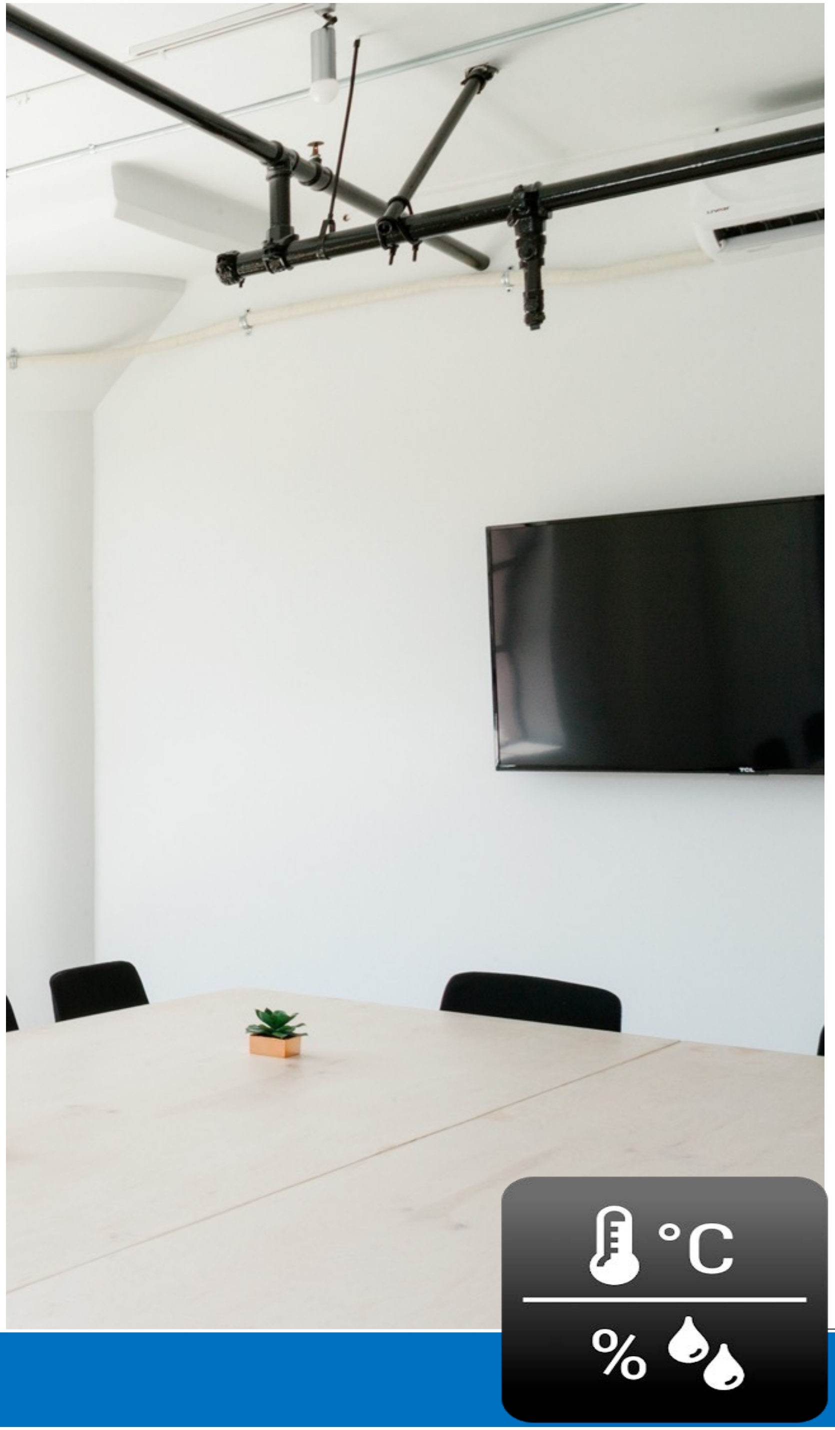
Challenges:

How does increasing ventilation in an existing building impact the design conditions:

After adjusting the fan speed and the intake / exhaust dampers, following will be the challenges:

TFA / DOAS : Since the cooling coil capacity is fixed, therefore, any increase in the outdoor air , will impact on the **off coil temperature and the dehumidification** process.

The duct carrying the tempered outdoor air will pose other limitation, and thereby pose **additional pressure drop on the fan**, which may not be able to deliver the desired air quantity.



Challenges:

Fixed size intake louvers in AHU rooms:

Most of the installations have a floor mounted Air handler with fixed louvers on the peripheral wall for outdoor intake, based on a theoretical air balance established by way of exhausting the equal amount of air through the toilets / pantries etc.

The only way to increase the ventilation air would be to install a fan that will provide the desired amount of air to the system. And, enhance the exhaust air outflow from the system.

Result:

Elevated off coil temperature.

De-humidification may get affected in tropical climates.

Challenges:
So, how do we adapt the existing HVAC system to our new requirements of :

- Enhanced ventilation

- Higher levels of filtration vis-à-vis the operating costs.

- Space constraints and other such limitations of an existing, rented, leased office spaces in modern buildings, which do not provide operable windows and or limited avenues of increasing the ventilation air.

Challenges:
How does installing HEPA filters affect the system:

Additional section required in the AHU body.

- Indeed the additional pressure drop encountered will pose a challenge to the fan and its motor.

- Increased operating cost and compromised air handling capacity of the Air handler.

- Elevated indoor temperature (in some cases might cause thermal discomfort, given the kind of "glass houses" the modern buildings are.

SUMMARY OF ADAPTABILITY , BASED ON SYSTEM LIMITATIONS :

Deployed (existing) HVAC systems in current buildings :

Re-circulatory systems:

Type-1 : Chilled water System (Air / Water Cooled)
Floor mounted Air handlers
Ceiling hung air handlers

Type-2 : VRF Systems / Packaged Units

Type-3 : Mini Split Aircon systems

Out door Air handling system :

Type-1 : Direct Outdoor Air Systems (DOAS)

Type-2 : Tempered Outdoor air systems (TFA ; without modulating dampers, electronic controls, No enthalpy recovery units, no re-heat systems etc.)

Type-3 : ERV (Simple small capacity Energy recovery Ventilators

Type-4 : Out door air inducted through permanent fixed louvers directly / indirectly into the space.

	TYPE OF SYSTEM	ADAPTABILITY TO INCREASED VENTILATION AIR	ADAPTABILITY TO ACCOMMODATE HEPA FILTERS
A	**Re-circulatory systems:**		
Type-1	Chilled water System (Air / Water Cooled)		
	Floor mounted Air handlers	Moderate for depth lesser than 2 Inches of HEPA	Moderate for depth lesser than 2 Inches of HEPA
	Ceiling hung air handlers	Low (chances of condensation,)	Nil
Type-2	VRF Systems / Packaged Units	Nil	Nil
Type-3	Mini Split Aircon systems	Nil	Nil
B	**Out door Air handling system :**		
Type-1	Direct Outdoor Air Systems (DOAS)	Moderate to High	Moderate
Type-2	Tempered Outdoor air systems (TFA ; without modulating dampers, electronic controls, No enthalpy recovery units, no re-heat systems etc.)	Moderate to Low	Moderate
Type-3	ERV (Simple small capacity Energy recovery Ventilators	Nil	Nil
Type-4	Out door air inducted through permanent fixed louvers.	Nil	Nil

PRACTICAL WAY TO ARM OUR DEFENCES AND STRENGTHEN OUR SYSTEMS:

Depending on the type of HVAC system in the building, below are some HVAC measures to implement.

- **Short-Term measures (MUST DO)**
- **Mid-Term measures (SHOULD DO)**
- **Long-Term Measures (GOOD TO DO)**

It is imperative to strategise the changes (volume & cost) associated with each type of building based on its own constraints.

"One size fits all" approach must NOT (and cannot) be adapted .

Implement the suggestions of ASHRAE / ISHRAE in the spirit of the same, and keep in mind the practicality aspects, which must then find a way to circumvent the challenges.

Drivers of the decision of retrofit and adaption :

Logistics (capital costs involved)

Ease of Availability of chosen remedial technologies.

Execution challenges.

Future emerging trends / directives based on the continued research .

PRACTICAL WAY TO ARM OUR DEFENCES AND STRENGTHEN OUR SYSTEMS:

Short-Term measures (MUST DO)

Pressurization - Implement pressurization control and/or enhance your current practices to properly pressurize your workspace, both internal zones with respect to adjacent areas.

Filtration – Change out standard filters with **antimicrobial coated filters.**

Increase Airflow - Both re-circulated and outside air to accommodate new sanitization procedures. (AS MUCH AS POSSIBLE---There is no recommendation for the set value)

Demand Control Systems - **RESET THE demand control systems** in order to assist the increased refrigeration demand due to enhanced ventilation.

Operating Hours - AIR SIDE ONLY to Operate for longer periods (unoccupied times) to ensure more filtration.

24/7 Systems - Since they have a higher risk of contamination, operate ventilation systems serving communal spaces such as toilet rooms continuously (24 hours/day).

PRACTICAL WAY TO ARM OUR DEFENCES AND STRENGTHEN OUR SYSTEMS:

Mid-Term measures (SHOULD DO)

Cleaning – Clean equipment exposed within workspace same as any other surface. Clean and disinfect duct systems. Initial deep cleaning followed by periodic disinfections.

Portable Air Treatment devices – These are devices that can help increase the total number of air changes in a space and can help in trapping the virus in a contained zone, and are ONLY working on a principle of the air passing through it. These combine antimicrobial, HEPA filtration / **Engineered UVC technologies** that will help the building operators bridge the time period between your immediate and long-term objectives, and at the same time achieve the mandated conditions.

PRACTICAL WAY TO ARM OUR DEFENCES AND STRENGTHEN OUR SYSTEMS:

Long-Term measures (GOOD TO DO)

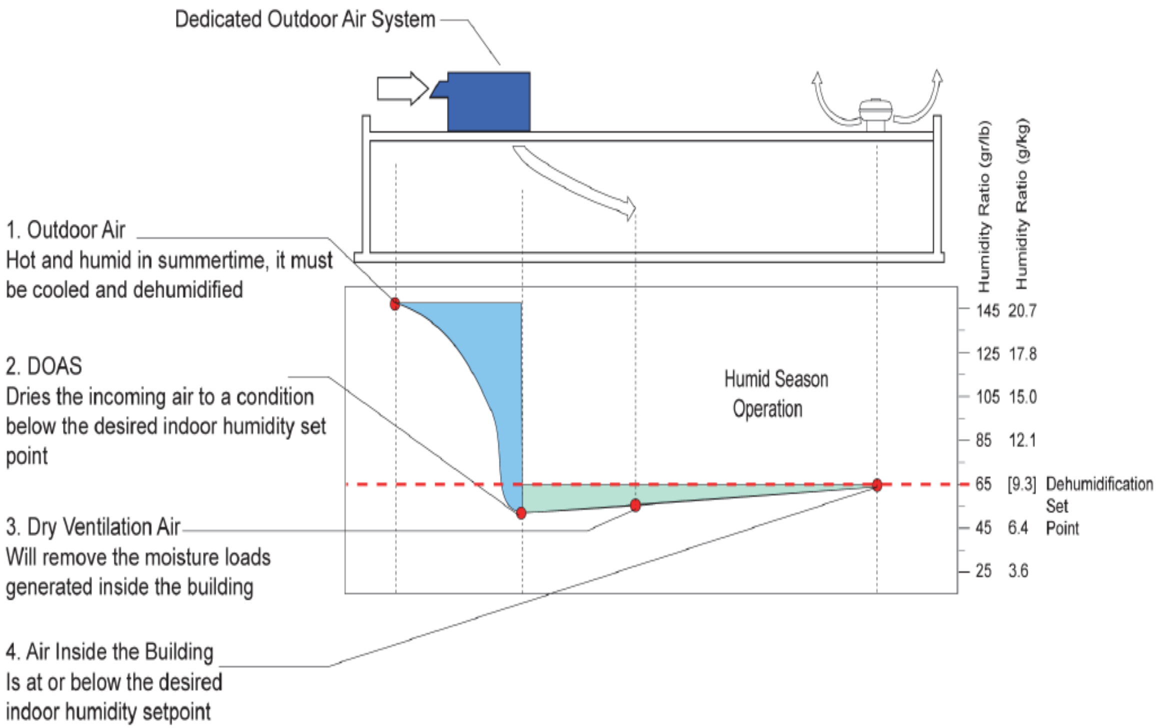
Enhanced Filtration – In addition to antimicrobial filters, the use of HEPA/MERV-13 filters may be considered but must be balanced against capabilities of existing systems and/or ability to augment them.

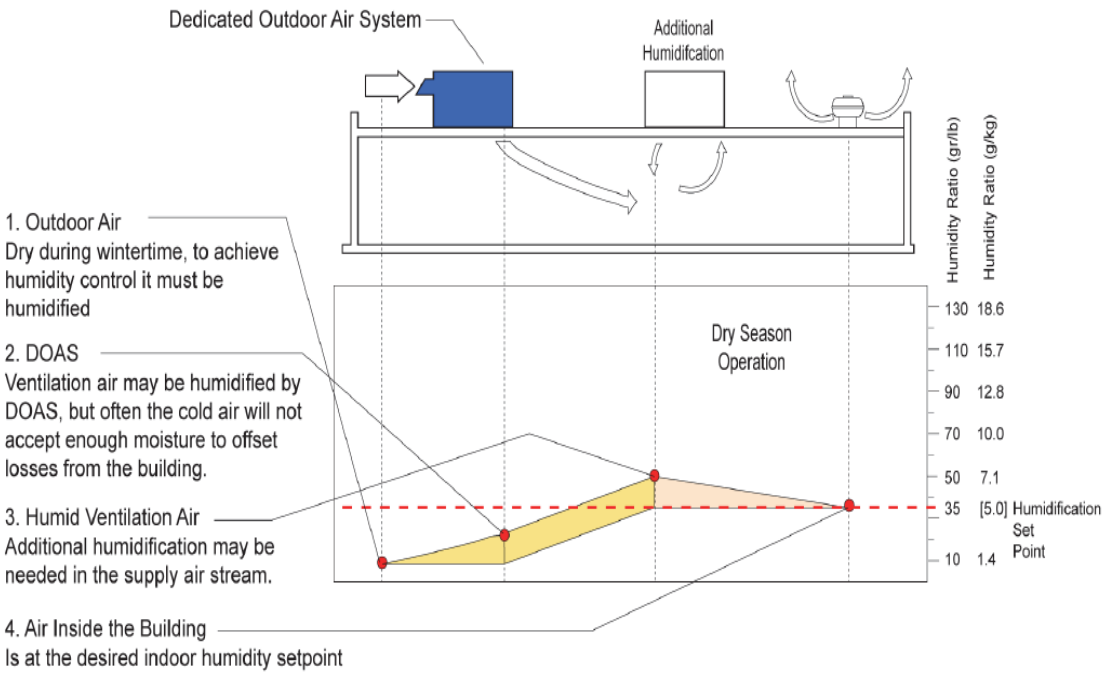
Bi-polar Ionization - Duct/AHU mounted units to provide **contamination control from dust** in the airstream. Based upon your system, these may need to be deployed at strategic locations.

UVC Lights – Recommended method by ASHRAE for in-duct installation to reduce the viral load with design, doses/fluence and kill rate. Also recommended for surface disinfection on cooling coils/drain pan etc.

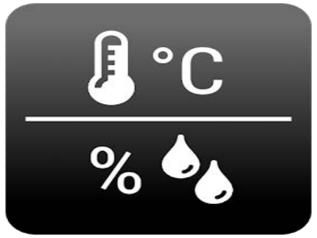
FAR-UV Lights – Primarily used in **hospital application** to interrupt the transmission of airborne infectious pathogens within indoor environment. UVC devices are designed and installed to irradiate only air in the upper part of the room. Efficiency depends a lot on the adequacy of air current. **System design is of very low intensity.(30-50 microwatt per cm sq.)**

ADAPTING THE DOAS FOR INCREASED LATENT LOAD DUE TO INCREASED VENTILATION OR TO ADD HUMIDITY IN COLD AND DRY SEASONS

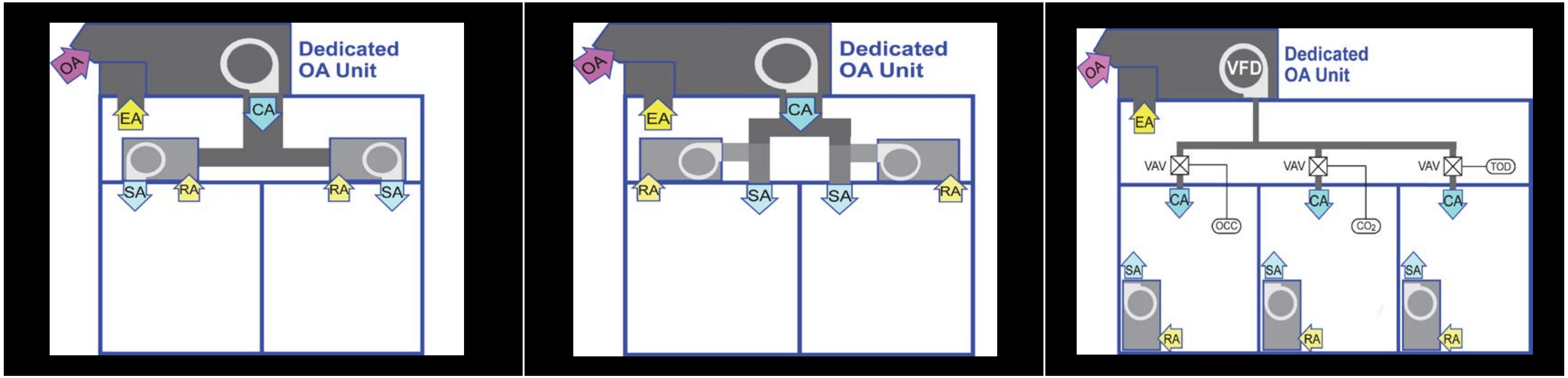




Re-defining the control strategies ; Re-adjusting the 3-dampers in the mixing box of the AHU can help offset the upset caused by the new demand of the system adaption. Re-visit the ventilation air requirement to validate it with respect to the new anticipated occupancy density.



ENHANCING VENTILATION WITH DEMAND CONTROLLED VENTILATION RESET AND RE_PROGRAMING BASED ON REAL TIME EQUIVALENT OCCUPANTS.

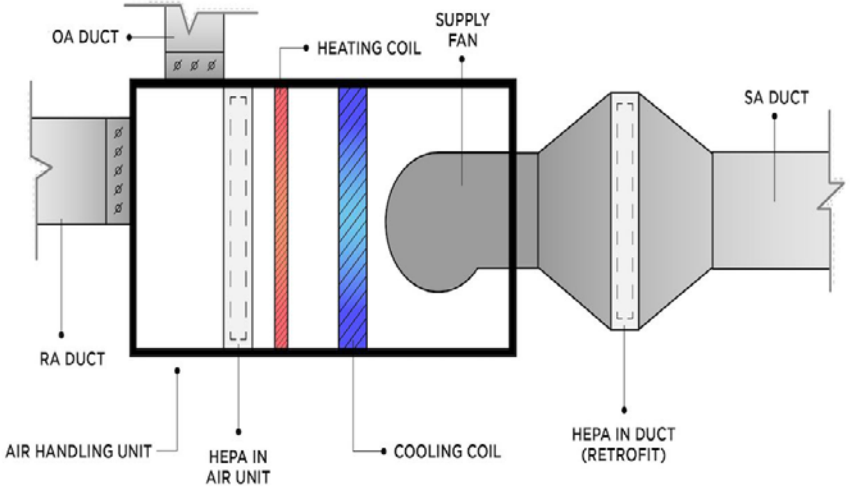


RECOGNISING THE DIFFERENCE BETWEEN SINGLE XONE AND MULTIPLE ZONE BUILDINGS AND HARNESSING THE POTENTIAL OF ENERGY SAVINGS FROM DEMAND CONTROLLED VENTILATION, WHILE STILL BEING COMPLIANT TO THE SUGGESTED GUIDELINES.

Disabling the Demand Controlled ventilation may be a prescriptive compliance to the guidelines mandated ; BUT, in buildings which have multiple zones, a prudent re-set of the DCV may help in off-setting the additional opex that could emerge due to enhanced ventilation.

ADAPTING THE AIR HANDLERS TO ACCOMMODATE THE ADDITIONAL MECHANICAL FILTERS OF HIGHER EFFICIENCY

HEPA FILTRATION



If in the Current design of buildings where the AHU rooms are compromised in terms of space and height, a FAN FILTER (HEPA) unit could be installed in series.

Additional pressure drop can be only handled with an additional fan and Filter section housing the HEPA / MERV-13 filters.

Advantages:

Proven technology, no moving parts, easily retrofitted
Effective at particle entrapment
Effective at protecting space-to-space contamination

Disadvantages:

Only captures particles from the ducted air – not within the space.

Increase in energy usage due to increase air pressure drop and motor work. Other restrictions / challenges due to physical constraints (case specifics).

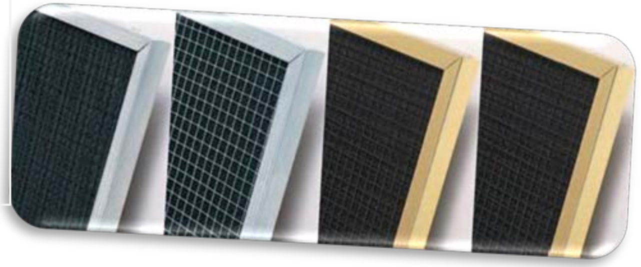
Increased maintenance due to filter replacement. EFFECTIVE AND SAFE DISPOSAL AND HANDLING MUST BE KEPT IN MIND.

Efficiency drastically falls below 0.3 Micron particles.

ALTERNATE MECHANICAL FILTERS AVAILABLE FOR ADAPTING THE AIR HANDLERS TO THE FILTRATION REQUIREMENTS.

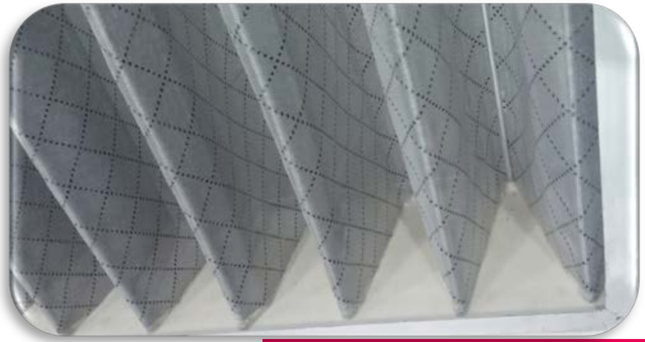
SELF CHARGING FILTERS

Self charging static air filter utilizes a patented configuration of alternate polarity, self-charging layers of polypropylene filtration media, to attract particles as small as 0.1 micron.



95% Peak Arrestance
93% Average Arrestance
4mm Initial Resistance at 1200 CFM
100 grams Dust Holding Capacity at .5" w.g.
130 grams Dust Holding Capacity at 1" w.g.
Lifetime Warranty
Anti-Microbial Media Core
Durable Aluminum Frame
Five Layers of Filtration Media

NANO FIBER FILTERS



- Award winning Filter technology
- Low pressure drop: 3-5mm
- Efficiency better than MERV 13 / HEPA
- Easy cleaning
- Efficient & Long life
- Cost effective
- Washable, reusable
- Available for AHU & FCU

The "novel" approach to the "novel corona"!

Due to multiple challenges on ground reality, its time to adopt newer / emerging technologies, while remaining within
the frame-work of ASHRAE / ISHRAE / Eq. guidelines / standards.

Effective measures include:

Approach : ASHRAE 62.1 standard demonstrative path of Ventilation Rate Procedure for Air Cleaning devices and Mechanical Filters.

Application : ASHRAE 62.1 VRP & Air cleaning Devices alongwith other measures as Air economisers (wherever possible)

The "novel" approach to the "novel corona"!

Installing filtration (antimicrobial filters, HEPA), bi-polar ionization and UVGI (Coils, and at components within the air system) . To minimize the pressure drop and the impact to an existing fan system, lower depth HEPA filters may be utilized.

To further enhance the effectiveness of filters, it is advisable to utilize filters with antimicrobial coatings. Filters may be treated with antimicrobial coatings to kill dangerous microbes on contact. Deactivating demand control systems that limit concentration of outside air / Using Ventilation Rate procedure of ASHRAE 62.1

The "novel" approach to the "novel corona"!

Operating systems longer and with higher outside air content to flush spaces due to increased use of cleaners.

Operating ventilation systems serving pantries & toilet rooms continuously (24 hours/day), since they have a higher risk of contamination.

Maintaining minimum relative humidity levels

Sanitizing ductwork with UV light.

Using portable air purifiers insofar as practical.

The "novel" approach to the "novel corona"!

The suggestions of emerging technologies have been well documented in the following articles :

- **Refer ASHRAE Position documents on Airborne Infectious diseases and on Filtration & Air cleaning.**

- https://www.ashrae.org/file%20library/technical%20resources/ashrae%20journal/2020journaldocuments/72-74_ieq_schoen.pdf
- **https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf**
- **https://www.ashrae.org/file%20library/about/position%20documents/filtration-and-air-cleaning-pd.pdf**
- **https://www.ashrae.org/file%20library/technical%20resources/covid-19/eiband-airbornetransmission.pdf**

Refer Item 2.7 of ASHRAE Position document on filtration and Air cleaning, which mentions as under :

The Indoor Air Quality (IAQ) Procedure of ASHRAE Standard 62.1 (2013b) allows that filtration and air cleaning, together with recirculation, can be used as a substitute for a portion of outdoor air ventilation.

This is conditional upon detailed analysis of contaminant sources, rates of contaminant removal by air-cleaning systems, contaminant concentration targets, and perceived acceptability targets (Burroughs 2006; Lamping and Stanley 2008; Grimsrud et al. 1999, 2011; Stanley et al. 2007; Dutton et al. 2013).

There is, however, only limited scientific evidence showing that outdoor air ventilation intake flow can be partially or completely replaced by filtration and air cleaning.

One consideration that warrants discussion is that the overlap between contaminants with indoor sources versus those with external (outdoor) sources is relatively small and the use of increased ventilation air without filtration and air cleaning can result in substituting one set of contaminants (internally generated) with a different set (externally generated) with any associated health effects. This is especially important in regions that do not meet national or regional air quality standards for one or more criteria pollutants (i.e., ozone, PM10, PM2.5) or where there may be local sources of air pollution. In these instances outdoor ventilation air should be cleaned before being introduced into the building.

UVC: Intensity, Dosage, Time & Application fundamentals

- UVGI inactivates microorganisms by damaging the structure of nucleic acids and proteins at the molecular level, making them incapable of reproducing. Absorbed UV photons can damage DNA in a variety of ways.

- **UVGI effectiveness depends primarily on the UV dose (D_{UV}, *µJ/cm2) delivered to the microorganisms: Note that this equation refers to* time *(1Joule = 1 WSec)***

$$D_{UV} = It$$

where *I is the average irradiance in µW/cm2, and t is the exposure time in seconds (note that 1 J = 1 W/s). Although Equation appears quite simple, its application can be complex (e.g., when calculating the dose received by a microorganism following a tortuous path through a device with spatial variability in irradiance). The dose is generally interpreted as that occurring on a* ***single pass through the device or system.***

- **The survival fraction *S of a microbial population exposed to UVC energy is an exponential function of dose:***

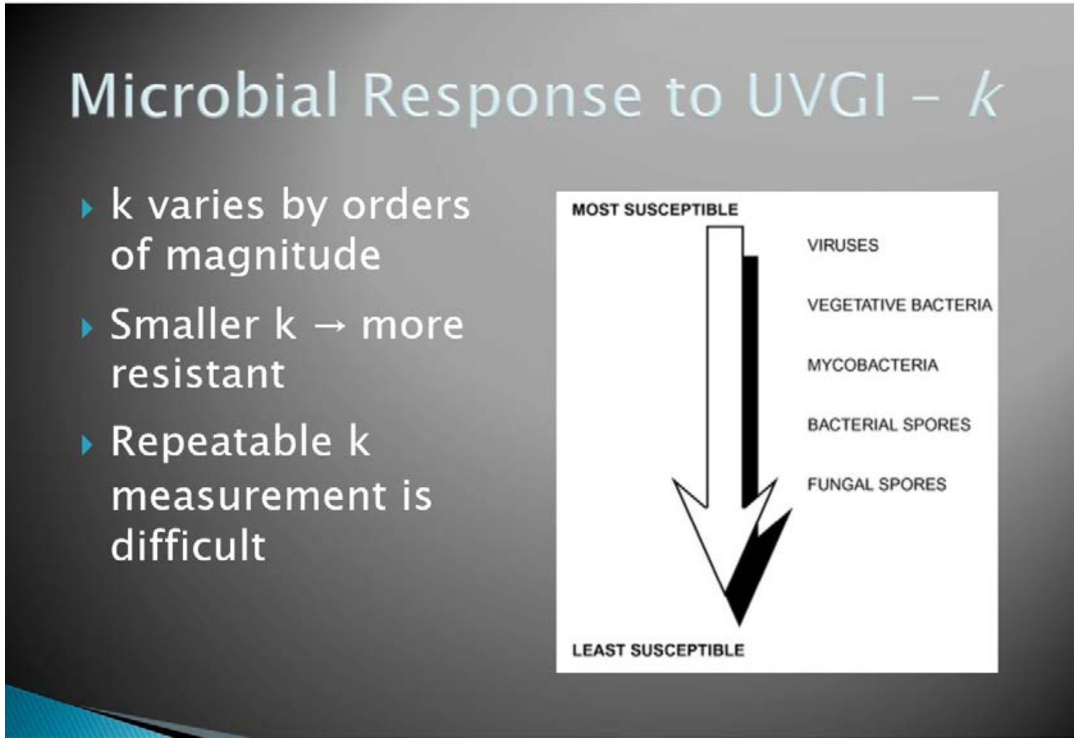
$$S = e^{-kDUV}$$

where *k is a species-dependent inactivation rate constant, in cm2/µJ. The resulting single-pass inactivation rate η is the complement of S:*

$$\eta = 1 - S$$

- **Inactivation rate constant (k-values) are species dependent and relate the susceptibility of the given microorganism population to UV radiation. Measured K values for various bacteria/virus including corona are given in different scientific journals.**

UVC: Dosage, Time & Application fundamentals



Representative Values ($cm^2/\mu W\text{-}s$)

- Bacillus anthracis (bacterial spore)
  - Water: 0.000056
  - Surface: 0.0002702
- Mycobacterium tuberculosis (vegetative bacteria)
  - Water: 0.0004773
  - Air: 0.0047210
- Influenza A (RNA virus)
  - 0.0010103 (water)
  - 0.0011900 (air)
- Measles: 0.0010510 (RNA virus, water)
- MHV coronavirus: 0.00377 (RNA virus, air)

Sources: Kowalski, Wladyslaw. 2009. *Ultraviolet Germicidal Irradiation Handbook*. Berlin: Springer-Verlag Berlin Heidelberg.
. Walker, C. and G. Ko. 2007. Environ. Sci. Technol. 41:5460-5465. (Coronavirus)

Reference:

- https://www.ashrae.org/file%20library/technical%20resources/covid-19/i-p_a19_ch62_uvairandsurfacetreatment.pdf

Environ. Sci. Technol. **2007,** *41,* 5460–5465

Effect of Ultraviolet Germicidal Irradiation on Viral Aerosols

CHRISTOPHER M. WALKER† AND GWANGPYO KO*,‡

University of Texas Health Science Center at Houston, Houston, TX, and Department of Environmental Health, Institute of Health and Environment, Seoul National University, Seoul, Korea

Ultraviolet (UV) germicidal air disinfection is an engineering method used to control the airborne transmission of pathogenic microorganisms in high-risk settings. Despite the recent emergence of respiratory viral pathogens such as SARS and avian influenza viruses, UV disinfection of pathogenic viral aerosols has not been examined. Hence, we characterized the UV disinfection of viral aerosols using the bacteriophage MS2, adenovirus, and coronavirus. Our objectives were to characterize the effect of nebulization and air sampling on the survival of important viral pathogens, quantitatively characterize and estimate the UV susceptibility of pathogenic viral aerosols, and evaluate the effect of relative humidity (RH) on the susceptibility of viral aerosols, to 254 nm UV–C. The viruses were aerosolized into an experimental chamber using a six-jet Collison nebulizer, exposed to 254 nm UV, and sampled using an AGI-30 liquid impinger. Both the MS2 and adenovirus aerosols were very resistant to UV air disinfection, with a reduction of less than 1 logarithm in viable viral aerosols at a UV dose of 2608 μW s/cm². The susceptibility of coronavirus aerosols was 7–10 times that of the MS2 and adenovirus aerosols. Unlike bacterial aerosols, there was no significant protective effect of high RH on UV susceptibility of the tested viral aerosols. We confirmed that the UV disinfection rate differs greatly between viral aerosols and viruses suspended in liquid.

Introduction

Bioterrorism threats and the potential airborne spread of new pathogens such as severe acute respiratory syndrome (SARS) coronavirus and influenza virus (*1–4*) have stimulated engineering control measures to prevent airborne transmission of infectious microorganisms indoors. One currently recommended engineering control method for high-risk settings is the use of 254 nm ultraviolet germicidal irradiation (UVGI) (*5–7*). UVGI is effective for inactivating infectious microorganisms in various settings (*5, 8, 9*). UV air disinfection is applied as either duct irradiation or upper room UVGI (UV irradiation above people's heads in a room) to inactivate airborne infectious agents and microbial toxins. Until recently, air disinfection by UVGI was mainly focused on preventing the transmission of tuberculosis (TB) in high-risk settings such as hospitals (*10, 11*). The Centers for Disease Control and Prevention (CDC) has recommended UVGI as a supplemental control for TB transmission in hospital isolation rooms (*11*). A number of previous studies have indicated that UV air disinfection protects humans from adverse health effects caused by airborne microorganisms indoors (*12–14*).

The efficacy of UV air disinfection depends on the UV susceptibility of the airborne microorganism, the level of UV irradiance, and the UV-irradiated air volume (*15*). Characterization of the UV susceptibility of viral aerosols is the first step in determining the potential usefulness of UV irradiation for preventing the transmission of airborne infectious viruses in the indoor environment. UV inactivation rates of bacteria suspended in liquid (*16*) and in air (*17–20*) vary greatly among species.

Most studies of viral UV inactivation have examined UV disinfection on surfaces or in water (*12, 21–23*). Although UVGI has potential as an effective infection control measure for bacterial aerosols, limited data exist regarding UVGI inactivation of viral aerosols (*9, 16, 24*). There are currently no data that evaluate the usefulness of UV air disinfection in preventing the airborne transmission of respiratory animal viral aerosols such as the SARS coronavirus.

Relative humidity (RH) is an important parameter determining the UV inactivation rate of bacterial aerosols (*20, 25, 26*). Various bacteria such as *Serratia marcescens*, mycobacteria, and *Escherichia coli* display increased UV resistance with increased RH. The mechanism underlying the effect of RH on the UV inactivation rate of airborne microorganisms is not well characterized. Increased UV resistance is most likely associated with hygroscopic characteristics of bioaerosols because increased particle size is obser… differ… betw… the inactivation rate of bacterial aerosols by sunlight increases with increases in RH (*28*). The effect of RH on the UV susceptibility of pathogenic viral aerosols is unknown.

We examined the effects of nebulization and sampling on respiratory viral aerosols. We also determined the UV susceptibility of three viral aerosols, i.e., respiratory adenovirus, coronavirus (a surrogate for the SARS coronavirus), and the bacteriophage MS2, as well as the effect of RH on their UV susceptibility. Finally, the UV inactivation rates for the viral aerosols were compared with those for viruses suspended in liquid to determine the usefulness of extrapolating from previous studies of the UV susceptibility of bioaerosols.

Materials and Methods

Cultivation and Assay of Tested Viruses. *Bacteriophage MS2.* Both the MS2 (ATCC 15597-B1) bacteriophage and *E. coli* C3000 host strain (ATCC 15597) were obtained from the American Type Culture Collection (ATCC). MS2 was assayed using the single agar overlay method (EPA Method 1601). The preparation of coliphage stocks was performed by inoculating 100 mL of TSB (50 mM $MgCl_2$) with 100 μL of stock coliphage and 300 μL of log-phase *E. coli* C3000. The culture was incubated overnight at 37 °C with shaking. Chloroform was added to the culture (0.4 volume), which vortexed for 1 min and centrifuged for 20 min at 4000g. The supernatant was decanted and stored at −70 °C until use. For the MS2 assay, log-phase *E. coli* C3000 was prepared by adding 300 μL of overnight culture to 30 mL of TSB and incubating for 4 h at 37 °C. The optical density (OD) of the culture was determined as the absorbance at 520 nm, using

* Corresponding author phone: 822-3668-7881; fax: 822-762-9105; e-mail: gko@snu.ac.kr.
† University of Texas Health Science Center.
‡ Seoul National University.

10.1021/es070056u CCC: $37.00 Published on Web 06/21/2007

Dosage required (Scientific journal) : Choice of kill rate should be evaluated with respect to feasibility and the cost involved. However, its worthwhile to note that no design can guarantee a COVID free environment even if 7 Log (99.99999%) kill tare is adopted.
A prudent design (suggestive) should be anywhere between Log 1 to Log3); however, if a higher kill rate is desirous, and the capital expenditure permits, then 4Log – 7Log could be attempted.

of viral aerosols, to 254 nm UV–C. The viruses were aerosolized into an experimental chamber using a six-jet Collison nebulizer, exposed to 254 nm UV, and sampled using an AGI-30 liquid impinger. Both the MS2 and adenovirus aerosols were very resistant to UV air disinfection, with a reduction of less than 1 logarithm in viable viral aerosols at a UV dose of 2608 μW s/cm². The susceptibility of coronavirus aerosols was 7–10 times that of the MS2 and adenovirus aerosols. Unlike bacterial aerosols, there was no significant protective effect of high RH on UV susceptibility of the tested viral aerosols. We confirmed that the UV disinfection rate differs greatly between viral aerosols and viruses suspended in liquid.

It is pertinent to understand the difference between power, intensity and energy.

POWER	INTENSITY/IRRADIANCE	ENERGY/DOSE/FLUENCE
Power is the inherent ability or capacity available in an equipment to perform certain tasks. This is expressed in unit µw or micro watt **(1µw = 10^{-6} W) or µJ/Sec.**	Intensity is the application of power on a unit surface area. This is expressed in **µw/cm² or µJ/sec.cm².**	Energy is the work performed when power (or intensity of power) is applied to perform a task for a period of time. This is expressed in units µwsec/cm² or J/cm². This is the product of intensity of power (µw/cm²) multiplied by the duration of time (in seconds) the object is exposed to this intensity **µw/cm² x sec = µw Sec/cm² .**
This is the ABSOLUTE POWER OF THE LAMP.	**Applicability : Surface Disinfection.**	**Applicability : Air Disinfection. And has a function of time.**

Interpreting DULBECCO modified eagle medium for SARS

Chemical disinfection of the exhaust air from COVID-19 patient room can be done by bubbling the exhaust air through a "Diffused air aerator tank" (preferably of non-metallic material) holding a 1% sodium hypochlorite solution [13, 14, 15]. The concentration shall be checked on a regular basis and dosing undertaken based on need. The aeration tank shall be placed in an unpopulated outdoor area and not inside enclosed space. Suitable PPE shall be used while handling the hypochlorite solution and direct contact with skin and eyes shall be avoided. The above chemical inactivation procedure for treatment of exhaust air is suggested based on the available information at this time.

The other two options available for exhaust air treatment being UV irradiation and heating. MER Darnell et al. [16] observed that, an exposure time of 45min at a temperature of 75 °C resulted in complete inactivation of SARS-CoV. ***Similarly, an UVC (254 nm wavelength) irradiation with an exposure time of 15 minutes at irradiation intensity of 4016 µW/Cm2 resulted in complete inactivation of SARS-CoV.***

This refers to a study which suggests that an UVC (254 nm wavelength) irradiation with an exposure time of 15 minutes at irradiation intensity of 4016 µW/Cm2 resulted in complete inactivation of SARS-CoV.

The correct interpretation is as under, keeping in mind the difference between intensity and dosage:

This refers to an intensity of 4016 microwatt / SqCm (Dosage of approx.4000 microwatt second per SqCm) with density correction of liquid medium vis-à-vis that of air.

It is important to also be aware of the target kill rate (1 log : 90% to 7 log values : 99.99999%)

Interpreting DULBECCO modified eagle medium for SARS : UVC INTENSITY/ENERGY for COVID-19

The document refers to studies done on SARS-CoV, commonly known as SARS. While SARS is within the Coronavirus family, it is not CoVid-19 specifically and some variation is to be expected.-

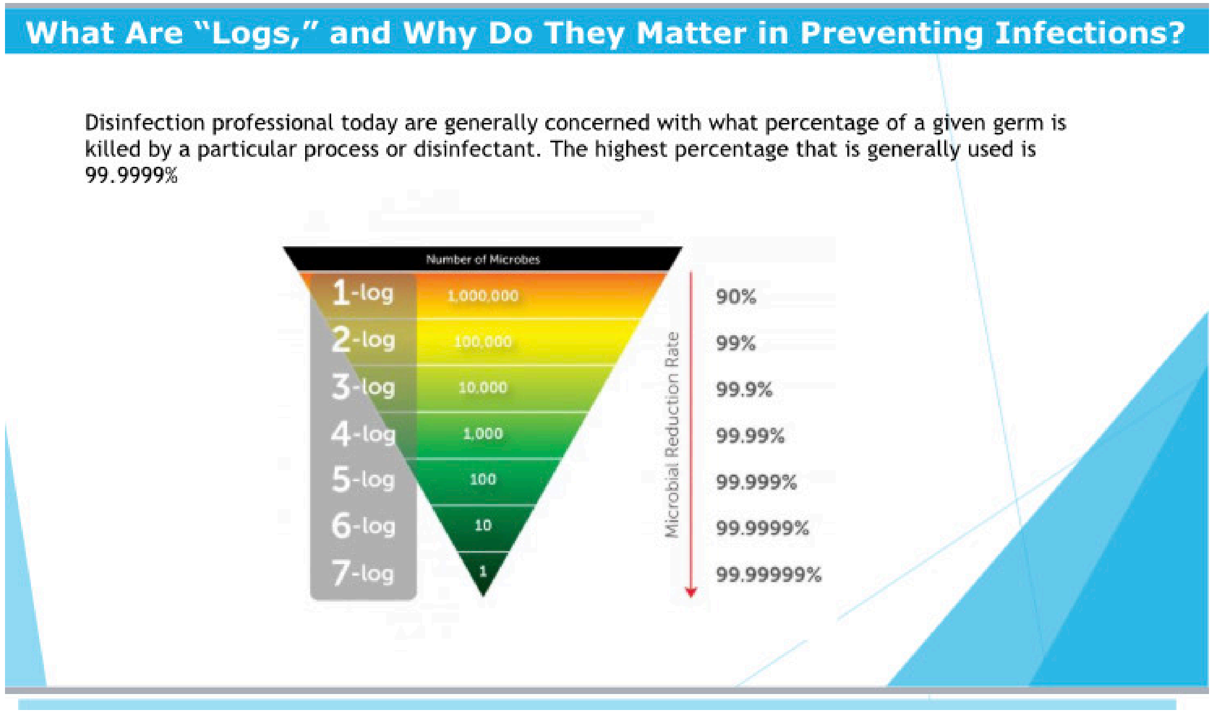
- Dosage of 4016 µW/cm2 of 254 nm wavelength UVC suggested.
- This study titled 'Inactivation of the coronavirus that induces severe acute respiratory syndrome, SARS-CoV', conducted tests done on the **virus in liquid not in air.**
- Under the methods section of the study it notes that the virus was placed in a volume of Dulbecco's modified Eagle's medium. Dulbecco's modified Eagle's medium is a liquid.
- It can be seen here https://www.sigmaaldrich.com/life-science/cell-culture/classical-media-salts/dmem.html .
- **Required UV intensity is higher in liquid as the liquid itself will absorb some of the intensity of UVGI.**
- The penetration of UV rays is inversely proportional to the density of the medium.

- As liquid is significantly denser than air, the rate of penetration in air is much higher than liquid. Intensity of 4016 µW/cm2 with exposure time of 900 Secs (15 mins x 60 = 900 Secs) results in energy of 3,414,400 µW Sec/cm2. Density of Dulbecco's modified Eagle's medium is higher than density of water depending of the percentage of contents in this medium.
- When applied in the medium of pure or distilled water (density 62 Lbs/Cft) and extrapolating it to when applied to air (density 0.075 Lbs/Cft), the above level of energy reduces to 3,414,400 ÷ (62/0.075) **= 4130 µW Sec/cm2** to achieve the same result (at approx. log 7 kill rate).

UVC INTENSITY/ENERGY

The intent of the previous slide is to differentiate the usage between scavenging the exhaust air using Air aerator chamber on hospital exhaust air AND filtration and air cleaning of INTAKE air for the HVAC systems through the air handlers.

Kill rate on absolute terms of Log mean rate needs to be understood and accordingly applied. 1-log implies 90% while 7-log is 99.99999% kill rate



UVC: Dosage, Time & Application fundamentals

62.2 2019 ASHRAE Handbook—HVAC Applications

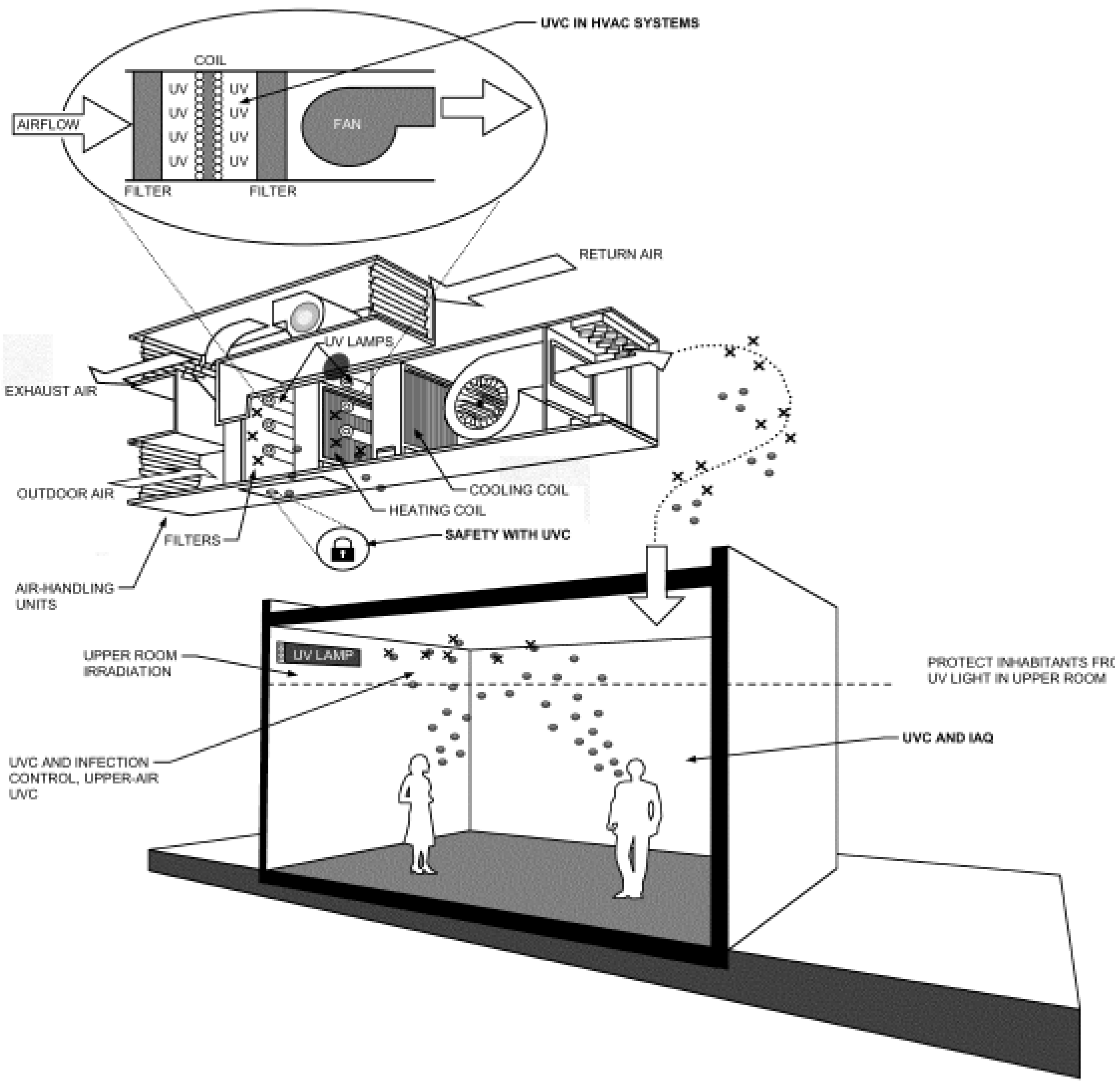


Fig. 1 Potential Applications of UVC to Control Microorganisms in Air and on Surfaces

Upper-Air UVC Devices (Fixtures)

The primary objective of upper-air UVC placement and use is to interrupt the transmission of airborne infectious pathogens within the indoor environment.

Various upper-air UVC devices are designed to generate a controlled UVC field above the heads of occupants and to minimize UVC in the lower, occupied area of the room.

In-Duct UVC Systems: Airstream Disinfection

The principal design objective for an in-duct UVC air disinfection system is to distribute UV energy or fluence uniformly in all directions throughout the length of the duct or air-handling unit (AHU) to deliver the appropriate UV dose to air moving through the irradiated zone with minimum system power. Enhancing the overall reflectivity of the inside of the air handler can improve UVC system performance by reflecting UVC energy back into the irradiated zone, thus increasing the effective UV dose.

UVC: Dosage, Time & Application fundamentals

62.2 2019 ASHRAE Handbook—HVAC Applications

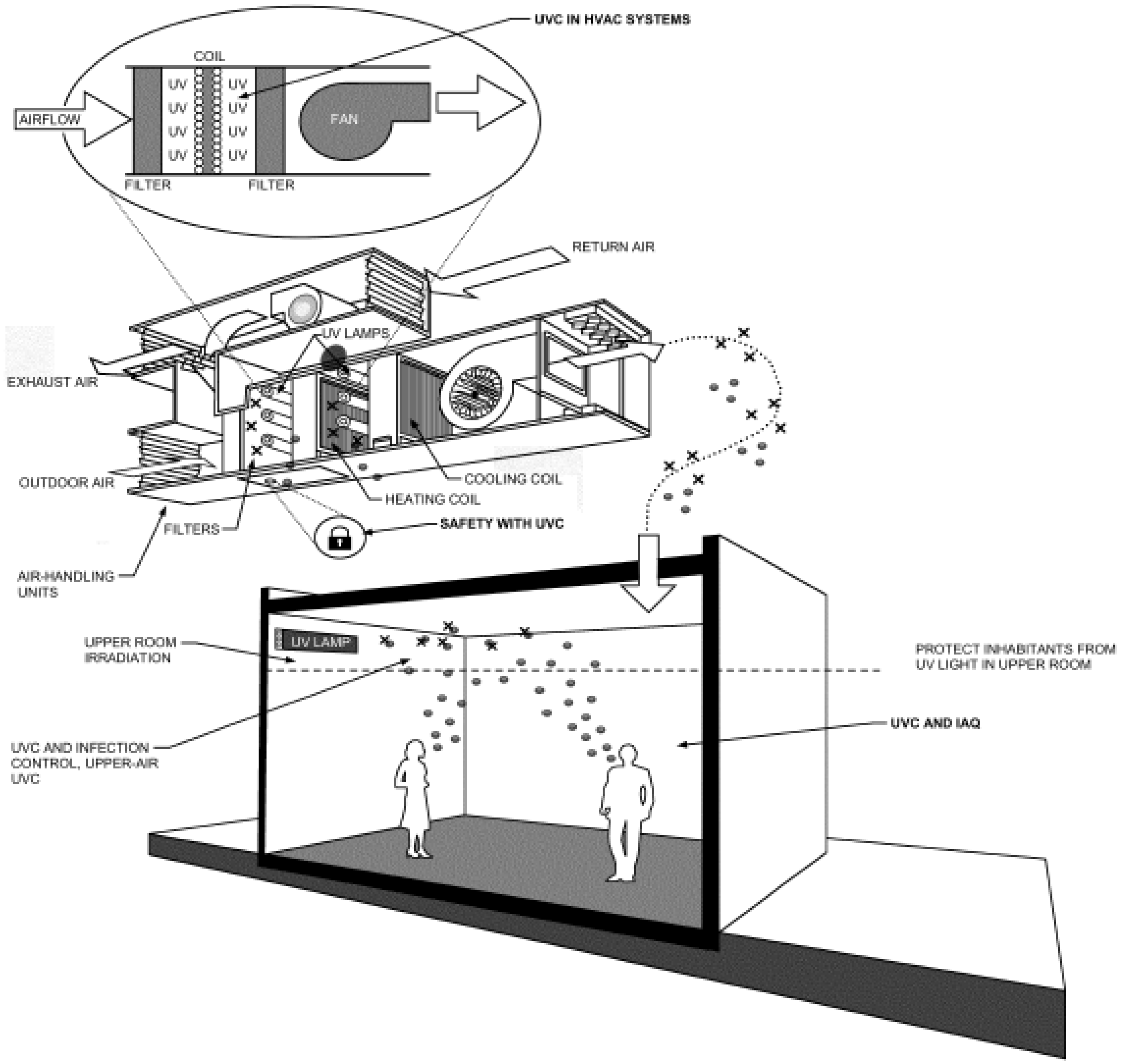


Fig. 1 Potential Applications of UVC to Control Microorganisms in Air and on Surfaces

Upper-Air Versus In-Duct UVGI approach:

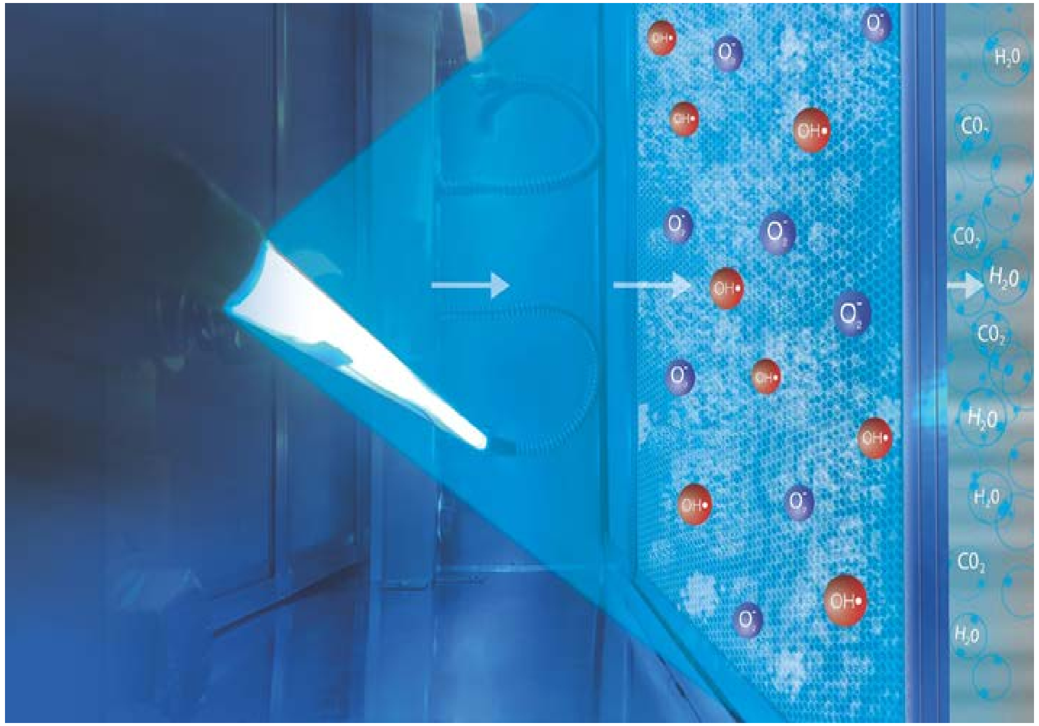
The study (Lee et al. 2009) **conducted** seems to strongly favor in-duct systems where they are applicable.

In a health care setting, controlling transmission of airborne pathogens at their source would suggest an upper-room approach.

However, in the context of our practical reality in hospitals (over crowded, maintenance challenges and ignorance of in-depth knowledge of its application) situation suggests that this may be applied only in-duct and AHUs or surfaces treatment.

UVC: Application : Bio-flim on cooling coils (wet side) and the drain pans.

Bio-film has no relevance to COVID-19, and is simply a mould and fungus which should be removed in any case for a better IAQ. Therefore the application purpose here must be keeping in mind the dosage, Intensity and contact time (there-of) , which will automatically treat the bio-film issues as well. However, the challenges of degradation of the Air handler inside components (rubber gaskets / filters / Electrical wire insulation), which in turn indicates that the higher intensity should be imparted in the ducts, keeping in mind the over-all system longevity.

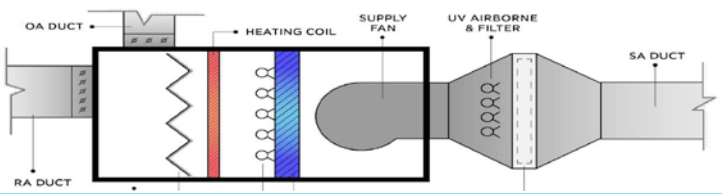


If the aim is to kill the bacteria, fungus, and prevent mold growth on **coil and drain pan** by virtue of biofilm phenomenon, then the **surface decontamination** approach is suitable, and it is advisable to install UVGI (with reflector) on cooling coil, for surface de-contamination.

A large dose can be delivered to a stationary surface with **a low UVC irradiance** because of the essentially infinite exposure time, making it relatively easy to cost-effectively prevent the growth of bacteria and mold on system components.

UVC: Application : Surface or Air ?

UV LIGHT

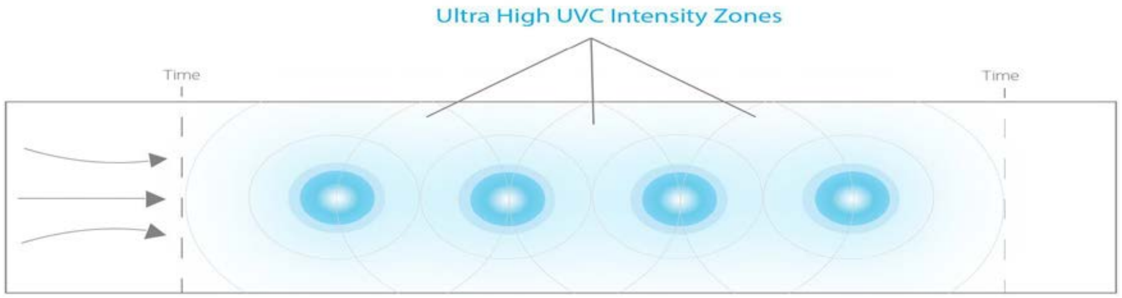


Advantages:

Can destroy microorganisms like mold, bacteria, and germs
Applicable in a room-based or in-duct application.

Disadvantages:

Does not filter contaminants from the space



UVGI can be used for air contaminants but the intensity, length of the lamp, velocity of the air (contact time) must be the main consideration for the same.

In-duct air disinfection systems should be designed to have the desired single-pass inactivation level under worst-case conditions of air temperature and velocity in the irradiated zone. The worst-case performance reflects the combined effect of the number/power of UVC fixtures; air residence time, which is inversely proportional to air velocity; and lamp/ballast characteristics, including wind chill effect and depreciation (as discussed in Chapter 17 of the 2016 *ASHRAE Handbook—HVAC Systems and Equipment*).

As a rule of thumb, in-duct systems should be installed in a location that can provide a minimum of 0.25 s of UV exposure; otherwise, system cost and power consumption will be excessive.

ALL ENGINEERING CALCULATIONS OF UV DOSAGE AND ITS TARGETED INTENSITIES SHOULD BE A PART OF MANUFACTURER'S SUBMISSION.

UVC: Application : Surface or Air ?

SURFACE (Intensity : (Micro watt/ Sq Cm)	AIR (Time & Intensity) : Micro watt second/ SqCm
Successful solution supported by many research papers	Adequate contact time is required with respect to the air flow rate
Hitting stationary target	Targeting air passing through ducts at high flow
Lesser intensity required (Adequate engineered intensity in micro w/cm2) at a an optimal distance with reflector plate. Refer ASHRAE chapter 62 (Application).	Intensity as per CDC/ASHRAE guidelines. 1,000 - 10,000Micro watt seconds/ Sqcm.
Very effective in AHU coils for removing mould, bacteria, fungal growth on the heat exchanger coils	Even microorganisms of small size are inactivated, unlike in filtration technology.
Initial and running costs are low	Highly cost effective for assured and validated kill rate. Operating cost is low.
Can be installed to cover the COIL / Engineered products for surfaces . **STANDARD LAMP CONFIG. : 425 mA (QUARTZ SLEEVE RECOMMENDED, for increased lamp life)**	Installed in ducts, larger the duct, more cost effective is the system. **HIGH OUTPUT LAMP CONFIG. : 800 mA (min.) (QUARTZ SLEEVE RECOMMENDED, for increase lamp life); This, if installed in the AHU will automatically handle the bio-film issues. But will adversely impact air handler internals like filter/Rubber component etc. Over a period of time.**

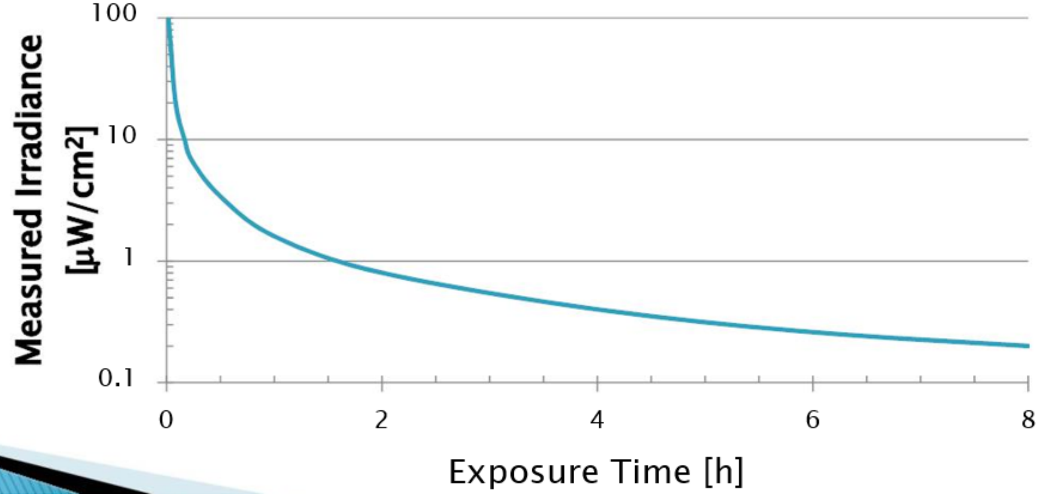
ASHRAE recommended : Safety Aspects that must be followed.

- UVGI system used MUST have adequate safety validation
- Coil and any duct mounted system MUST have safety validation by for Fire and smoke.
- Accepted safety validations are
  - Operational safety **UL** 1995
  - Safety against Fire and Smoke for duct mounted equipment **UL** 2043

ASHRAE recommended : Safety Aspects that must be followed.

Exposure Limits

- NIOSH Limits for 253.7 nm UVC
  - 1 s: 600 μW/cm²
  - 1 min: 100 μW/cm²
  - 1 hour: 1.7 μW/cm²
  - 8 hours: 0.2 μW/cm² (standard for upper-air)
- In-duct systems may produce 1000-10,000 μW/cm²
- Safe exposure for in-duct range is ~10 s or less



Protective Measures

- Use full protective clothing when servicing or inspecting operating equipment
- Upper-air
  - Warning signs
  - On/off switches and disconnects
- In-duct
  - Warning labels—doors/access panels
  - Lamp disconnects outside lamp chamber
    - Positive disconnects preferred
    - If switched, locate away from room lighting
  - UV-absorbing view ports

Conclusion on UVC technology:

Disinfection of air and surfaces with germicidal light (UVGI) is a well established technology with demonstrated effectiveness against many pathogens.

254 nm UVC is the predominant wavelength today due to its high effectiveness and the availability of Hg vapor lamps. **Lamps with quartz sleeve are more reliable and effective**.

UVGI can be applied to air streams and surfaces in HVAC systems & to air and surfaces in spaces.

In application, care must be taken to limit the human exposure and exposure of materials subject to photo-degradation.

UVGI is an adjunct to ventilation and filtration of particulate matter, and NOT a replacement.

Conclusion on HEPA FILTRATION:

Existing Buildings :

Installing HEPA Filters is a challenge and if they have to be installed, then the AHU has to be replaced.

Its NOT only HEPA, the correct way is to install MERV 8 / MERV 13 & HEPA (3 Stage filtration) to minimise the load on HEPA filters.

Conclusion on ENHANCED VENTILATION & Total number of ACPH:

Existing buildings :

It maybe NOT possible to enhance the same, without major retrofits.

Therefore , Air filtration devices may be used in accordance with ASHRAE standard 62.1

Wherever possible, in case of DOAS / TFA systems, Ventilation air must be enhanced with adequate air cleaning devices and a reset / adjustments of the demand controlled ventilation.

HVAC systems DO NOT PROMOTE THE SPREAD OF COVID -19.

All is required that we understand the defence against the virus, and implement the strategies with an engineered & a progressive approach, rather than adopting the "one size fits all" approach.

Yes, staying outdoor is the BEST. BUT, given the fact that we spend 80% of our time indoors, and our habitats / work places are environmental controlled, it becomes in-evitable that the systems be adapted to this unprecedented requirement, and that the new built-forms be sensitive to these features, going forward.

THANK YOU

Stay safe, stay healthy!

Lets fight corona together!