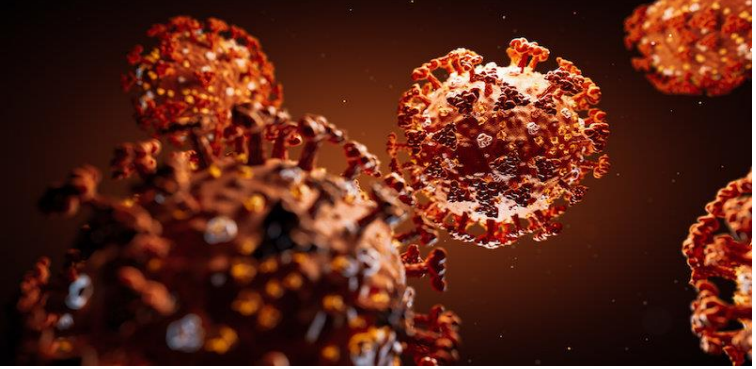
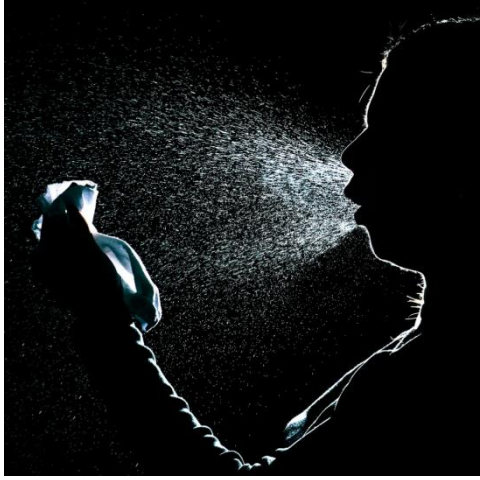




COVID IAQ & HVAC Best Practices for Forensic Engineers

Presented to

The National Academy of Forensic Engineers

July 31, 2021

Curt Freedman, PE & Bart Kemper, PE

Introduction

Indoor Air Quality (**I**.**A**.**Q**.) is fundamental to protect human health for any building occupancy and is an existing code requirement. Rooms of assembly are especially challenged with COVID to meet expected standards for air filtration, as well as temperature, humidity, air recirculation, treated outdoor air, and energy management.

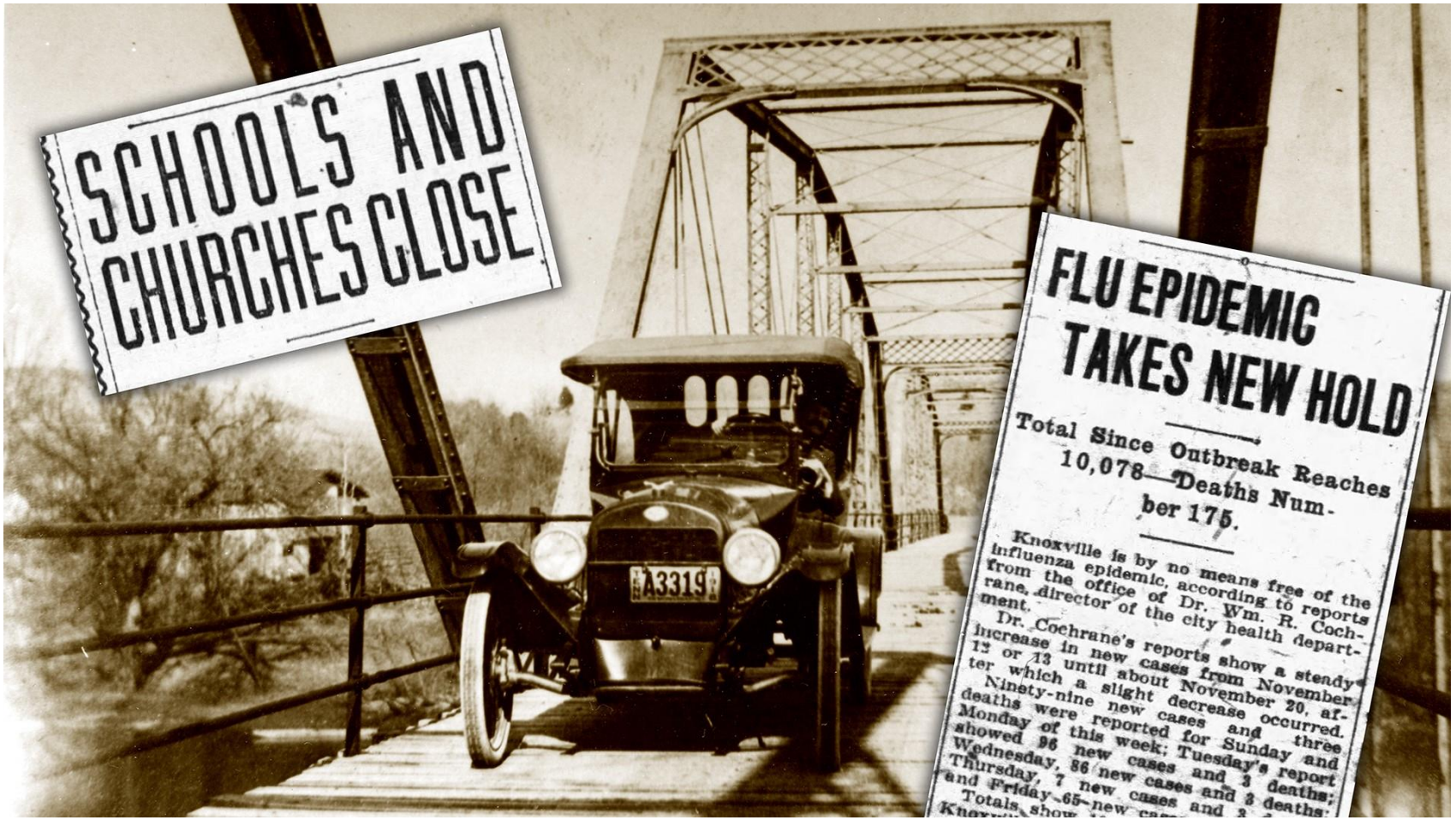
The recommendations and "Best Practices" that follow include HVAC technology upgrades, administration policy, and human actions to synergistically reduce the transmission of **COVID-19**, the **conventional flu**, and the **common cold**.

Presentation Outline

- Lessons Learned from our Past
- Virus Transmission
- The Role of the Engineer
- HVAC 101: Comfort & Air Balance
- Older HVAC v Modern HVAC
- Masks
- Planning for Entering & Exiting
- Ventilation Theory
- CDC Ventilation Guidelines
- Modeling
- Mitigation Technologies
- Hazard/Risk Assessment
- COVID Litigation
- Conclusions

Lessons Learned from our Past

Everything old is new again
[1918 Spanish Flu]



In 1918, face masks were mandatory some **12** years before any virus could even be seen with an electron microscope.

Seek **B**est **A**vailable **T**echnologies
"**B.A.T.S.**"

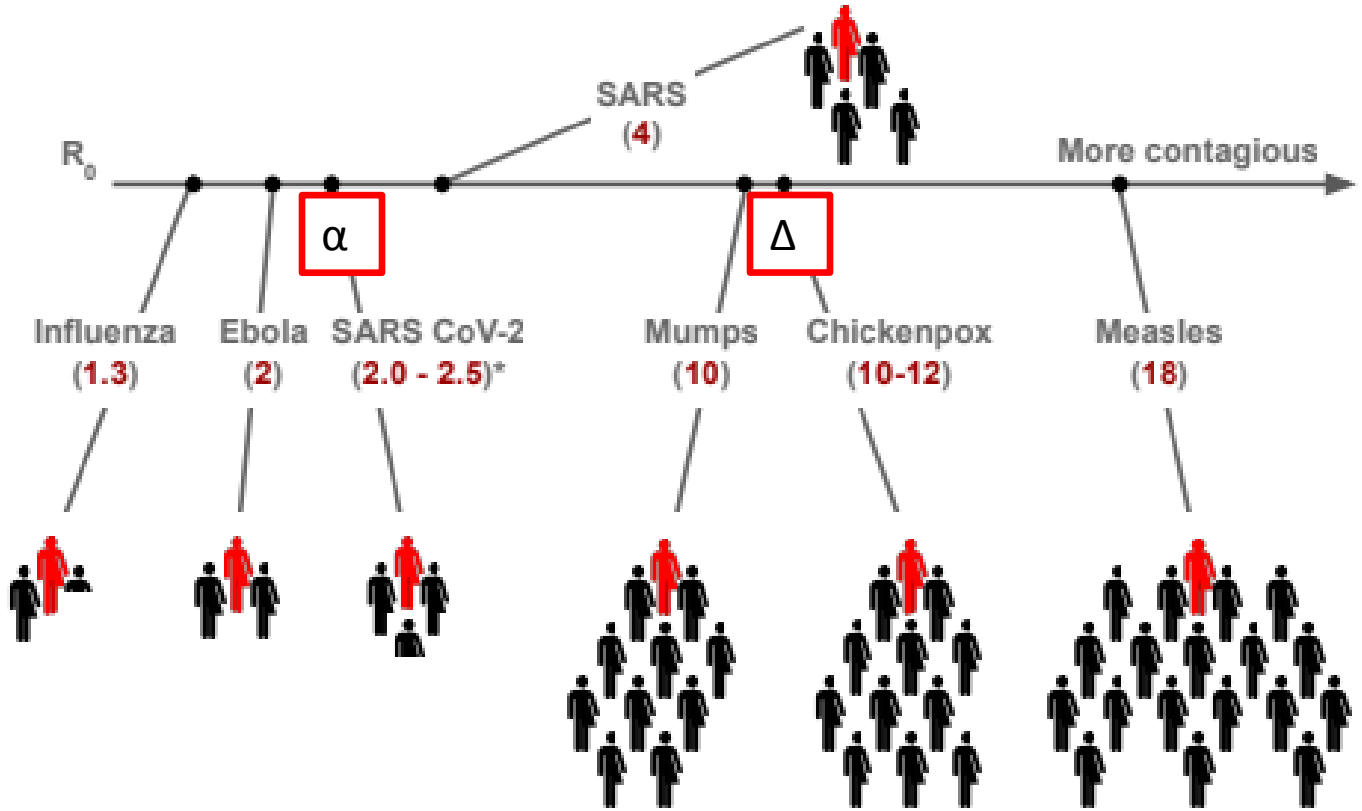
Ventilation ~ Ventilation ~ Ventilation

Virus Transmission

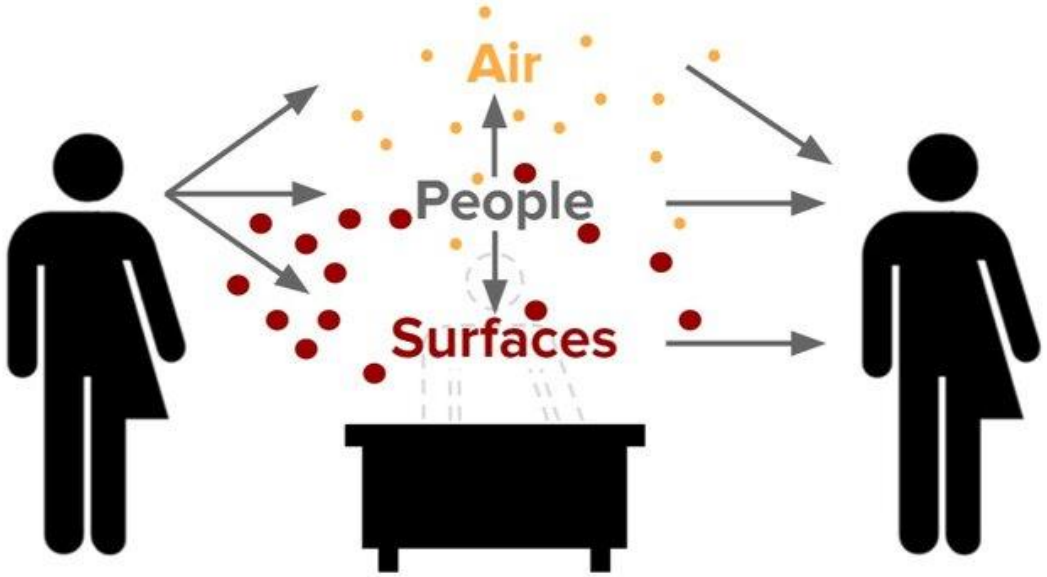
(Based on Established Science)

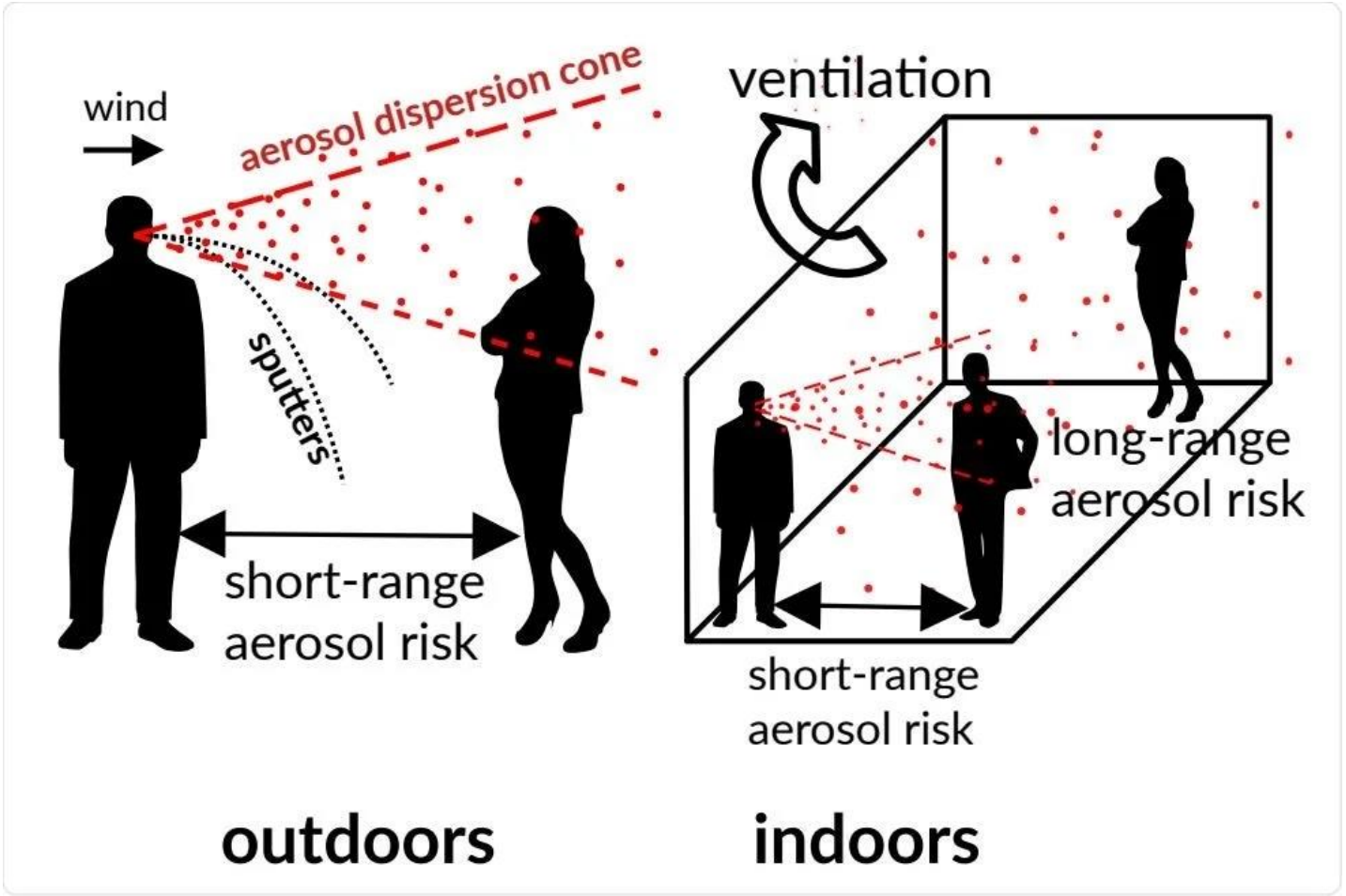
R_o, # Persons infected by one person

Alpha B.1.1.7, Beta B.1.351, Gamma P.1, **Delta** B.1.617.2

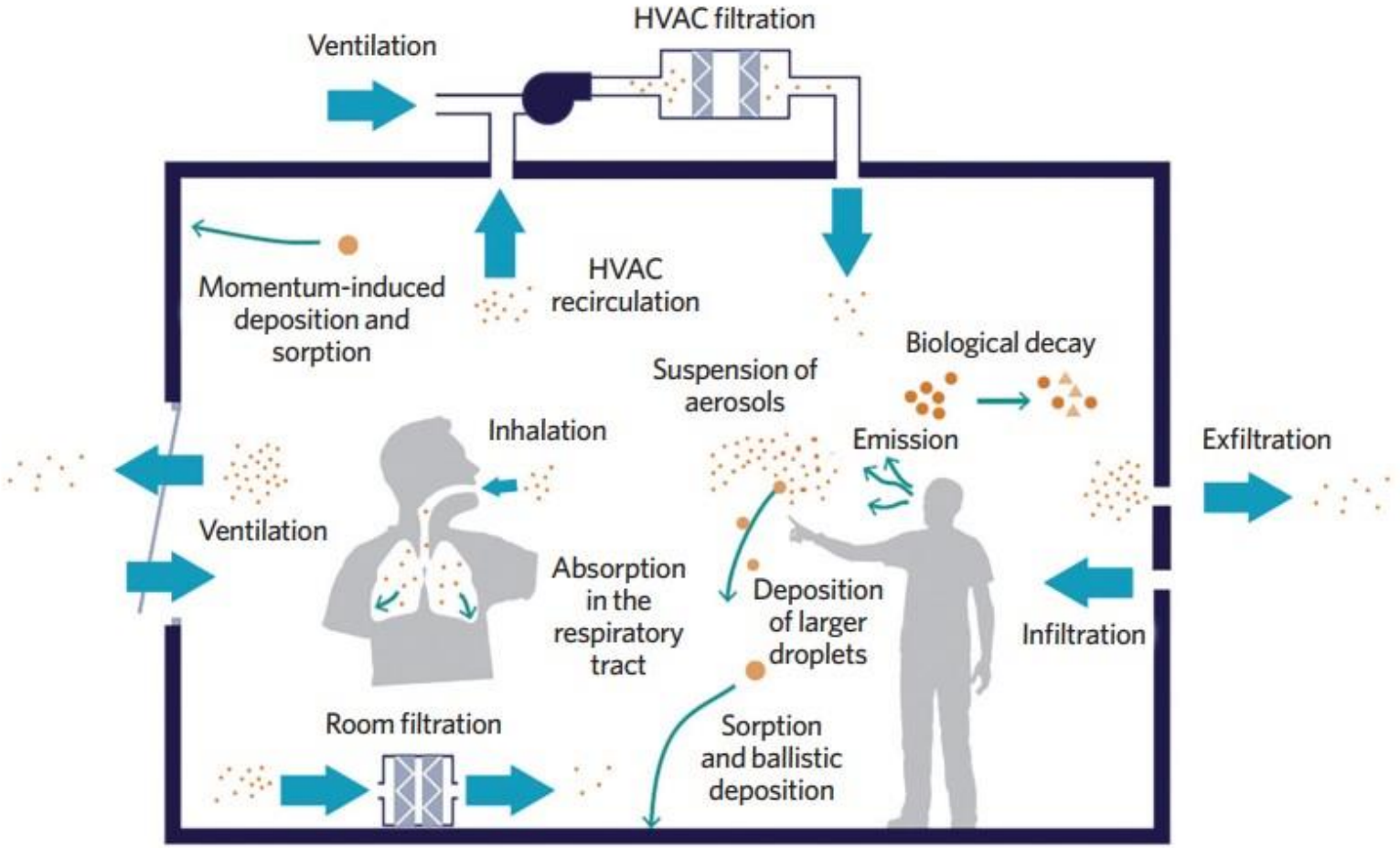


Infection happens somewhere between people, air and surfaces.




wind
aerosol dispersion cone
sputters
short-range
aerosol risk
ventilation
long-range
aerosol risk
short-range
aerosol risk
outdoors
indoors

HVAC: Single Zone Mass-Balance



The Role of the Engineer

The National Society of Professional Engineers
Fundamental Canons

Engineers, in the fulfillment of their professional duties, shall:

"Hold paramount the safety, health, and welfare of the public."

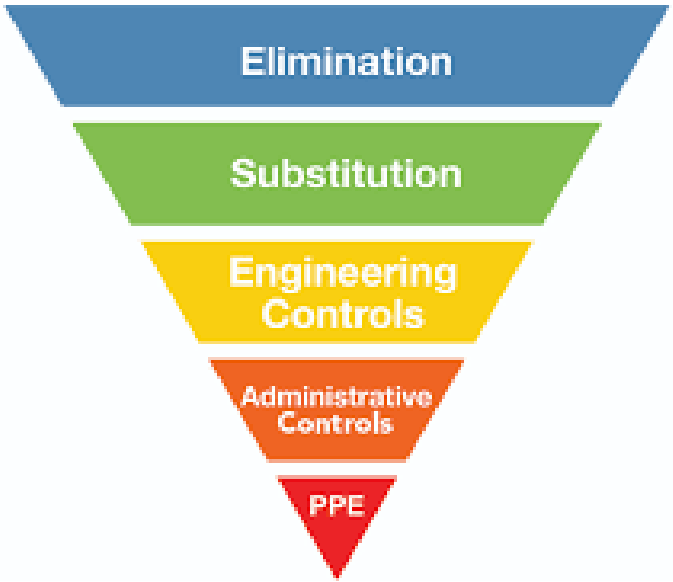
Paramount –

More important than anything else; supreme.

&
CDC Guidelines

In addition to ventilation improvements, the layered approach includes physical distancing, wearing face masks, hand hygiene, and vaccination.

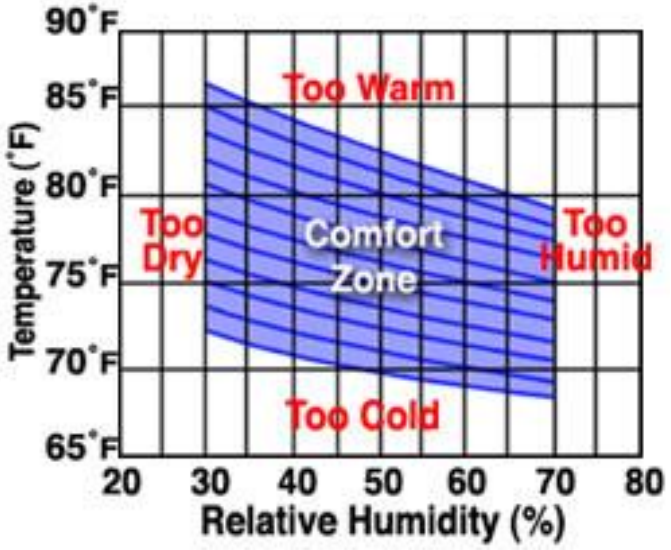
COVID Control Measures
The Role of the Engineer



- **Elimination – Lock down**
- **Substitution – Work from home**
- **Engineering Controls - Ventilation, filtration, UV light, cleaning, surface non-contact reengineering**
- **Administrative - PSAs, signage, scheduling, hygiene direction**
- **PPE – Masks, face shields, clothing**

HVAC 101
Comfort & Air Balance

HVAC Systems, Comfort & Air Balance Equipment



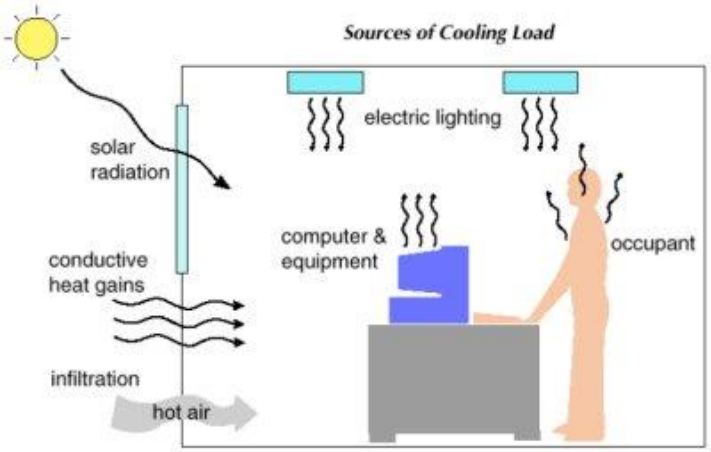
The purpose of HVAC systems is to add/remove heat, moisture, and air pollutants from a controlled space and provide conditions to promote human comfort/health.

Types of HVAC Systems

The purpose of HVAC systems is to add/remove heat, moisture and air pollutants from a controlled space and provide conditions to promote human comfort.

Types of heating systems:

- Direct Fired
- Furnaces, duct distribution
- Hydronic Baseboard
- Hydronic Fan-coil
- Hydronic Unit Heater
- Heat Pump
- Steam Radiator
- Unit Ventilator
- Variable Air Volume



Ventilation of an Assembly Space

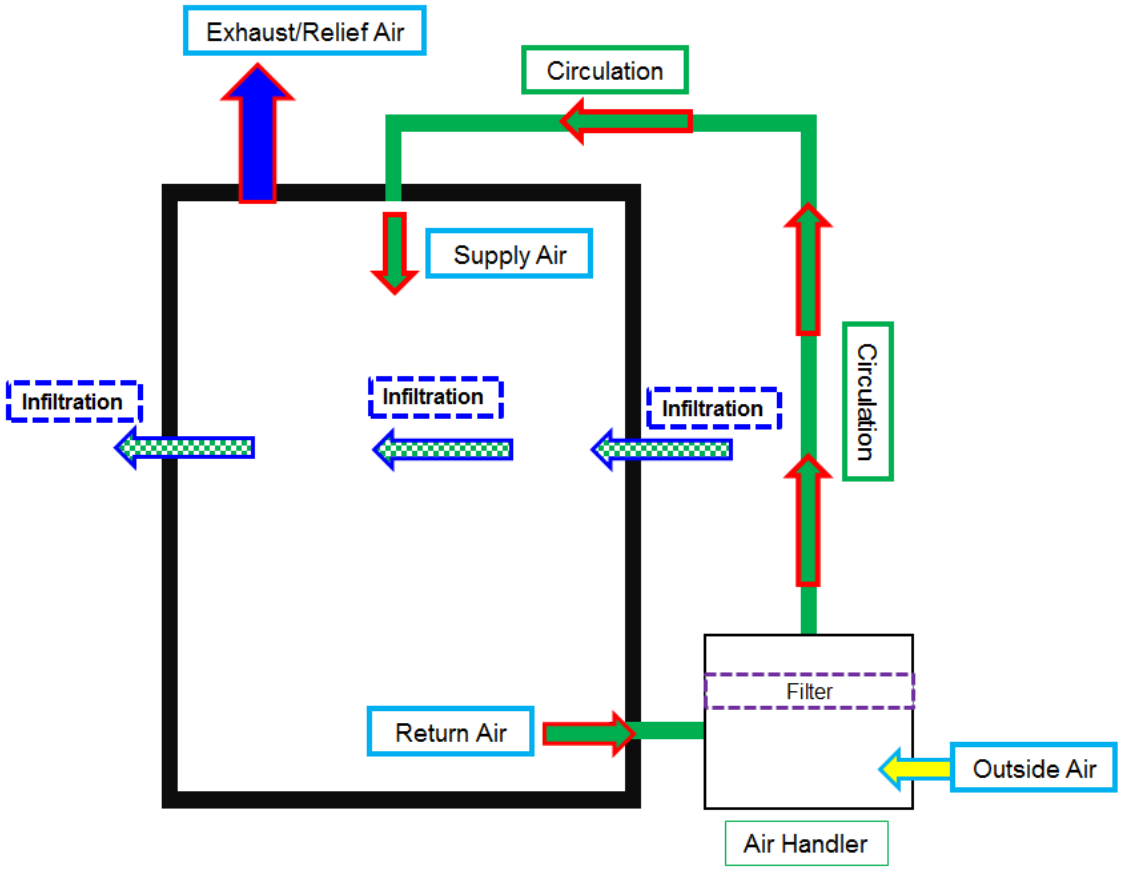
Circulation:

Rooms of Assembly require constant air circulation

Outside Air:

Activation of louvers, MUAU, or exhaust fan

Infiltration: Normally occurring air flow through walls/windows



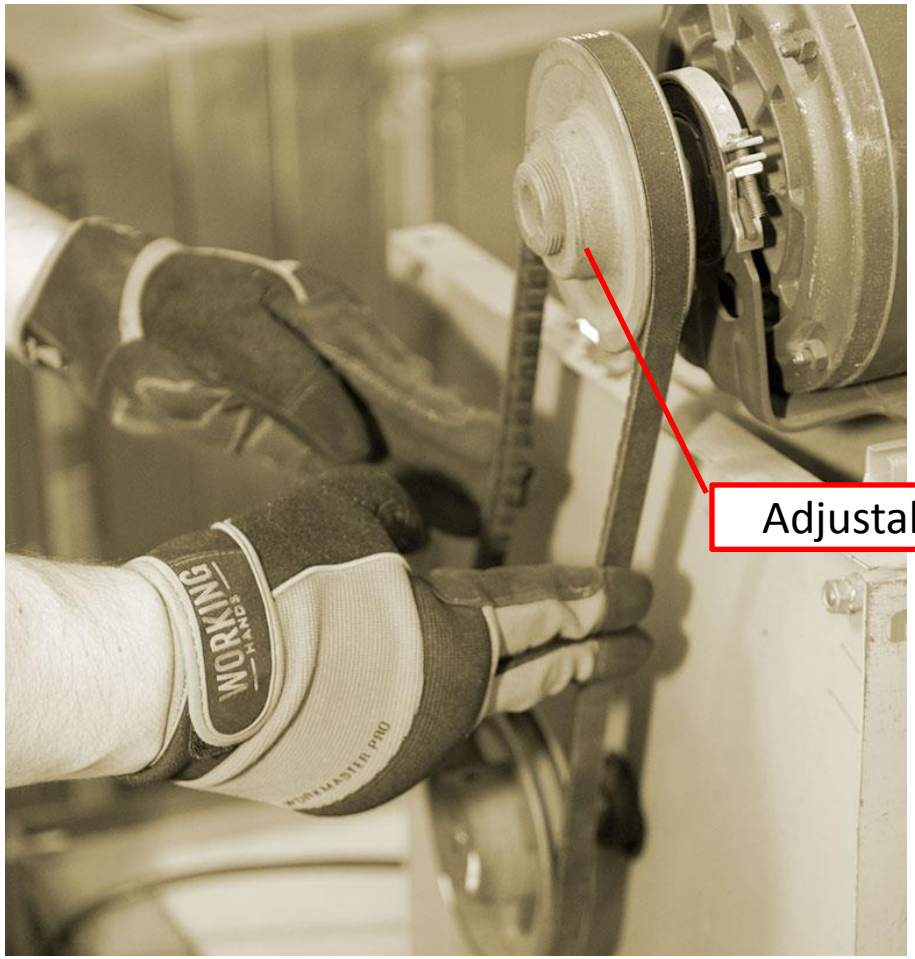
Air Balance Testing Equipment

Measures air velocity in ducts and building openings

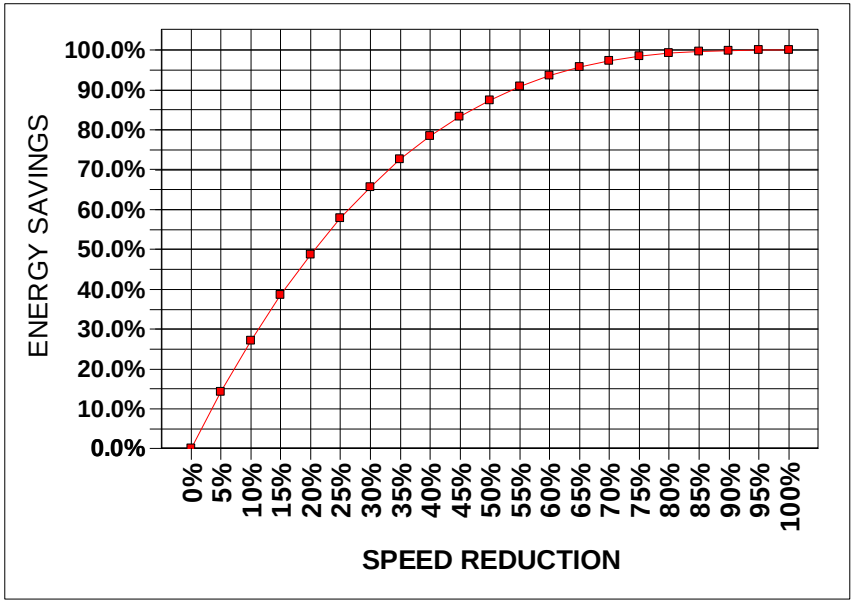
Anemometer

Flow Hood

Typical Cog V-belt with Adjustable Motor Sheave



Variable Frequency Drive (VFD) for control of blower/pump speeds



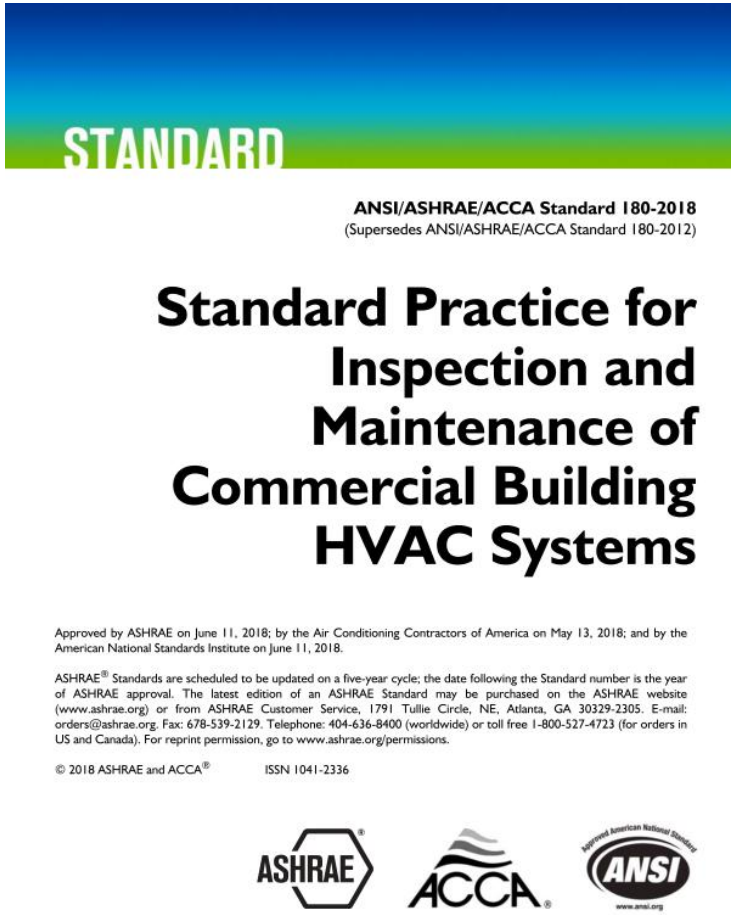
Mechanical Systems

Hydronic System

Rooftop Exhaust

HVAC Maintenance, Commissioning ASHRAE 180-2018

- HVAC Mechanical systems should be recommissioned at least once each year.
- Hydronic fan-coil systems that circulate boiler water must be protected with anti-freeze to prevent freezing in cold weather climates.



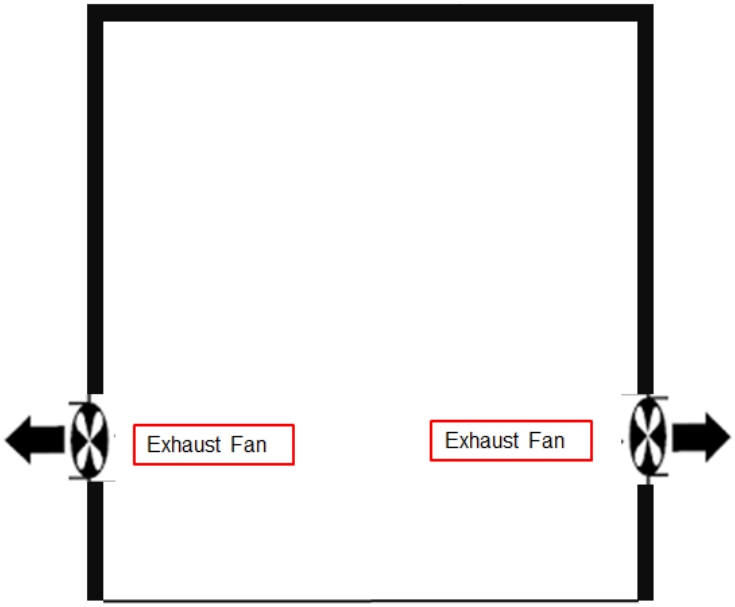
Older HVAC v Modern HVAC

COVID Preparation for Older Building HVAC
[No central HVAC duct distribution]

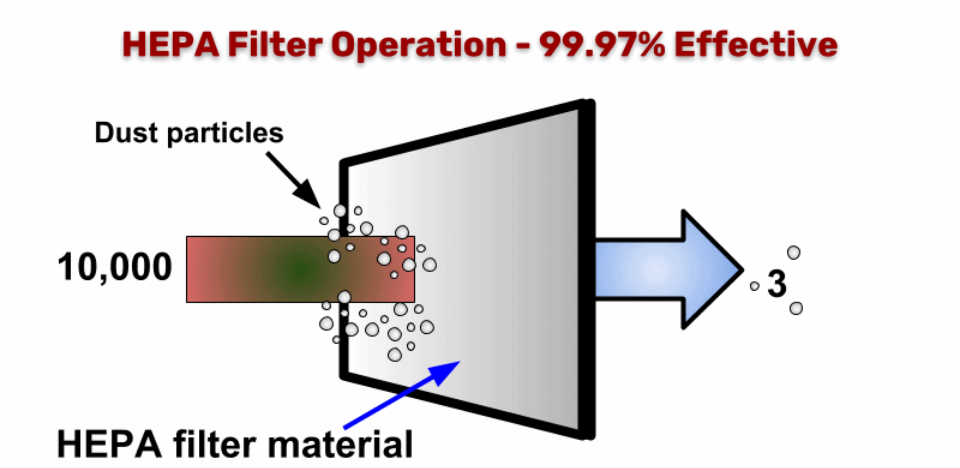
- Open Doors and Windows
- Utilize carbon dioxide monitors
- Window fans
- Ceiling fans
- Use of HEPA filters

Older Building
Steam Radiator Systems

Typical Window Fan
400 cfm, 20 persons/fan
Exhaust air out of space



Free-standing HEPA Filters

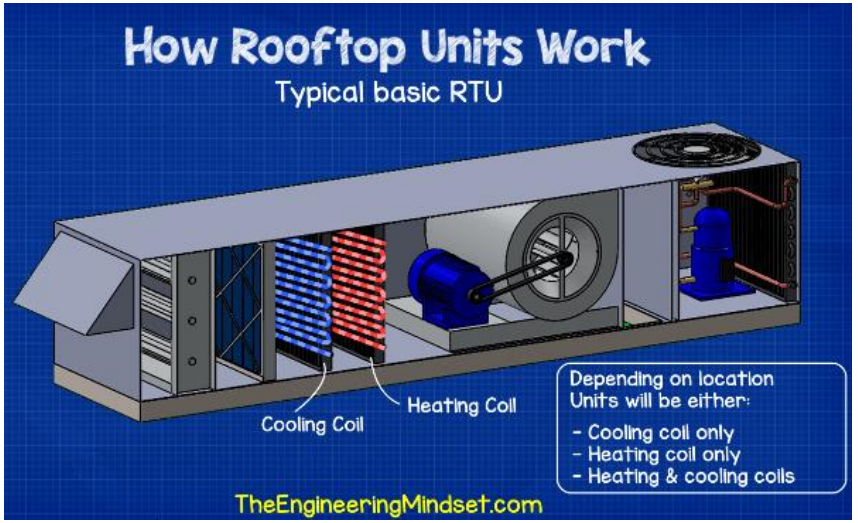


Carbon Dioxide Monitor/Controller

CO_2 Monitor

CO_2 Controller

Modern Building HVAC
Typical Heating/Cooling RTU



COVID Preparation for Modern Building HVAC

- Carbon dioxide controller
- Carbon dioxide monitor
- Exhaust fans
- Outside air louvers
- Ceiling fans
- Energy Recovery
- MERV-13 Filters

Carbon Dioxide Monitor/Controller

CO_2 Monitor

CO_2 Controller

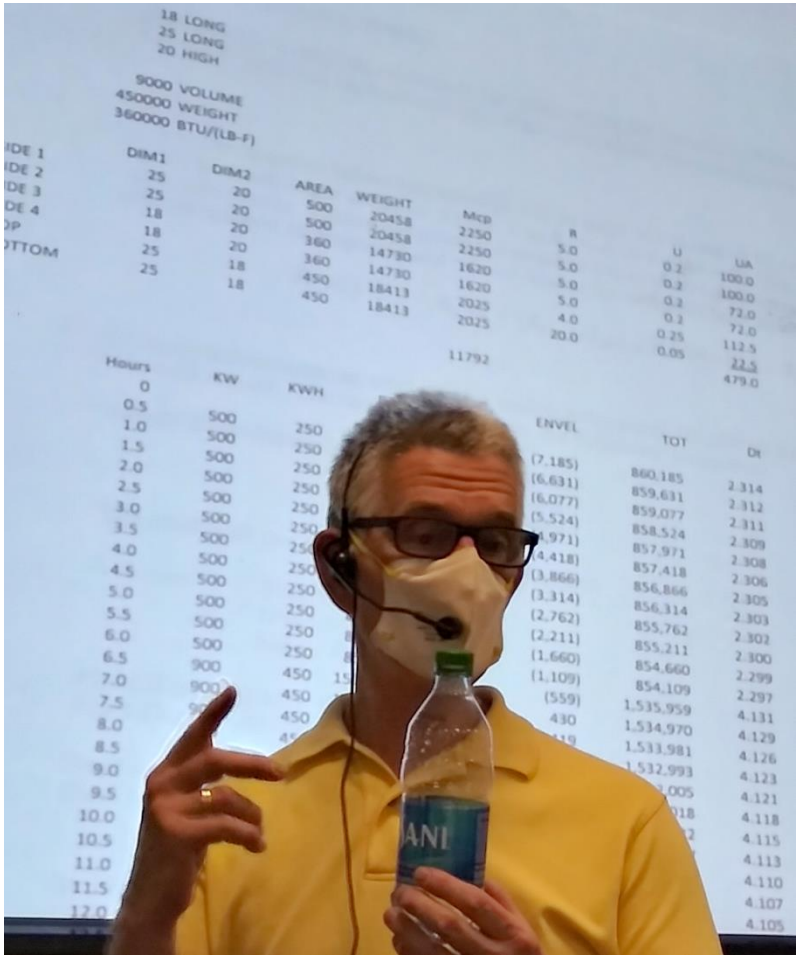
Masks
(Just Another Filter)

Engineering Comments on Masks
All participants mutually benefit by utilizing face masks

No, Bandanas & gators

Yes, N95 and surgical masks

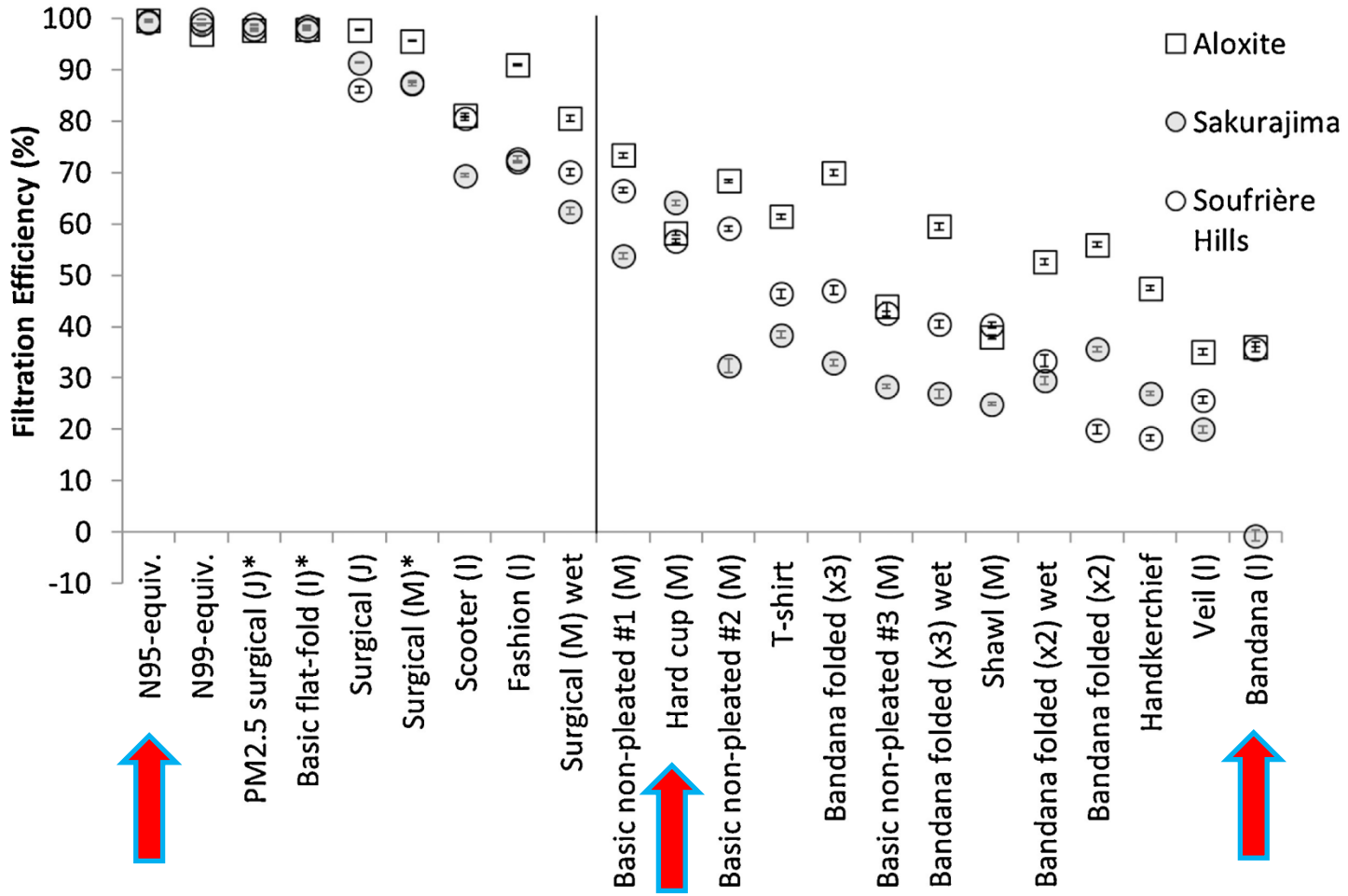
No, Face shields without masks



International Journal of Hygiene and Environmental Health, Volume 221, Issue 6, July 2018, Pages 967-976

The effectiveness of respiratory protection worn by communities to protect from volcanic ash inhalation.

Mueller, Horwell, Apsley, Steinle, McPherson, Cherrie, Galea



"*Does That Face Mask Really Protect You*"

Larry E. Bowen, 2010

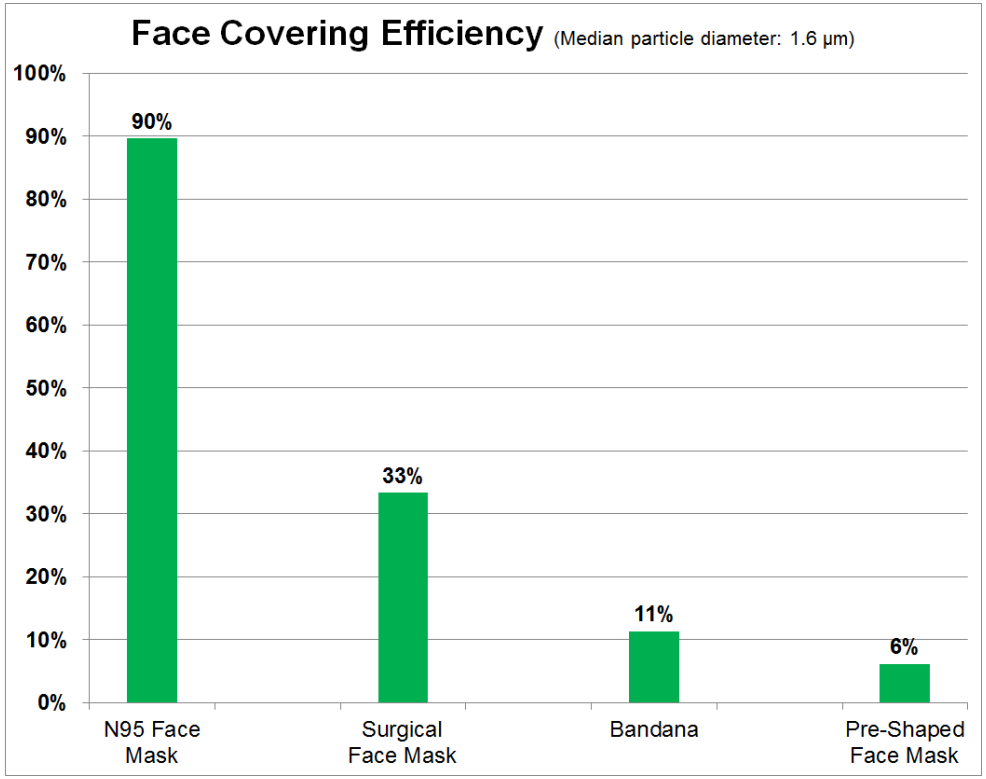
Southern Research Institute, Birmingham, Alabama

Figure 2
Surgical Face Mask

Figure 3
Pre-Shaped Face Mask

Figure 4
Bandana Face Mask

Figure 5
N95 Face Mask



Planning for Entering & Exiting

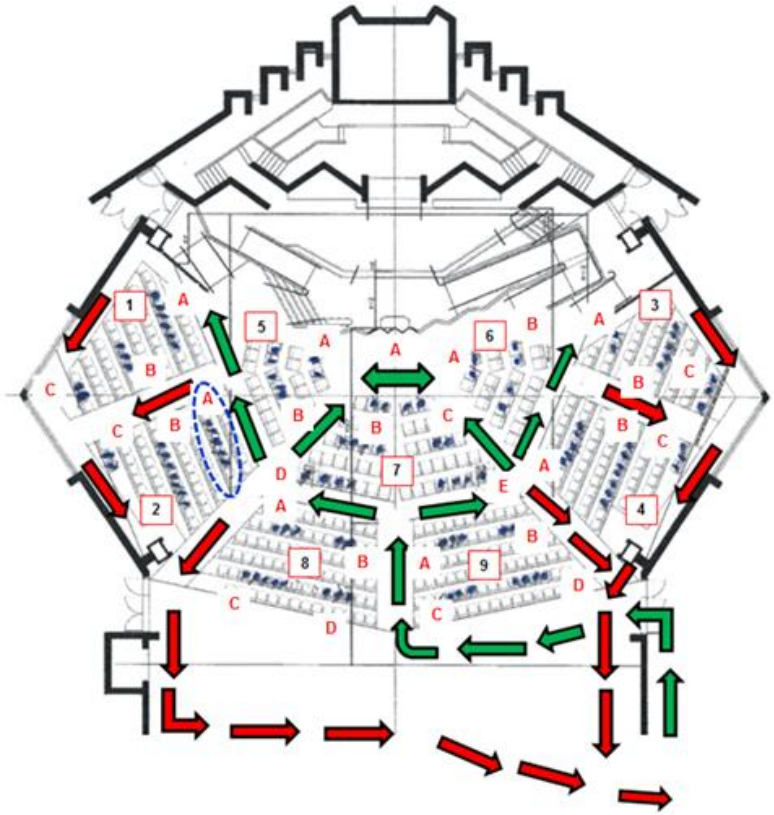
Guidelines: Entering & Exiting

Places of assembly are encouraged to take steps to encourage orderly entering and exiting in a manner that encourages social distancing.

- Signage or floor markings, to be posted to have one-way aisles or otherwise direct attendees to follow certain pathways for entering and exiting the service
- Maintain social distancing with tape or other markings
- Row-by-row exiting

Both Free-standing and fixed Seating (less than 36” between rows)

Seating & Entrance/Egress Plan

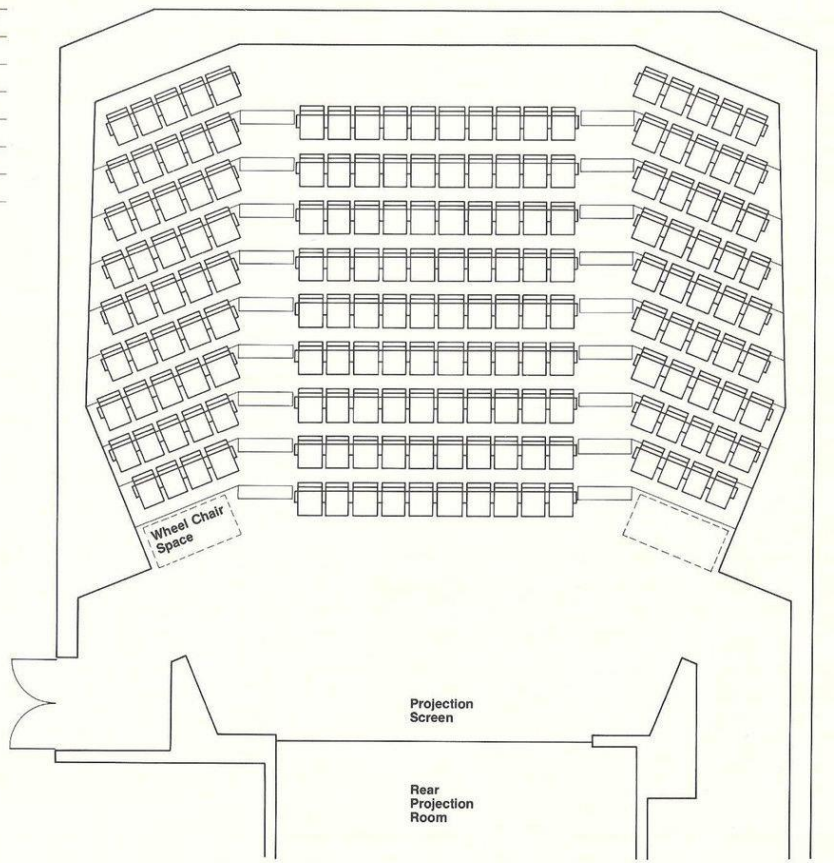


Section	Family Units		Maximum Family Unit Capacity					Maximum Seating
			A	B	C	D	E	
1	3		6	3	2			11
2	3		5	7	2			14
3	3		2	3	5			10
4	3		5	7	3			15
5	2		6	2				8
6	3		2	2	2			6
7	5		4	4	2	4	4	18
8	4		3	2	5	3		13
9	4		3	2	4	4		13
Totals:	30							108

Modern Theater Seating

[New – 7.3 sf/seat, Old – 5.0 sf/seat] [36” between rows]

Basic Theater Form	End Stage
Quantity of Seats	178
Seating Area	1304 Sq. Ft.
Space per Seat	7.3 Sq. Ft.
Row Spacing	3′-0″
Most Distant Seat	45′-0″
Stage Elevation	None
Floor Design	Risers 12″



ASHRAE Standard 62.1

ASHRAE Standard 62.1

["Ventilation for Acceptable Indoor Air Quality“]

- CO_2 at the concentrations commonly found in buildings is not a direct health risk, but CO_2 concentrations can be used as an indicator of occupant odors (odorous bio-effluents) and occupant acceptance of these odors.

- At the activity levels found in typical office buildings, steady-state CO_2 concentrations of about 700 ppm above outdoor air levels (**400 + 700 = 1,100 ppm**) indicate an outdoor air ventilation rate of about **15 cfm**/person.

ASHRAE 62.1 (2019)
Places of Assembly, Offices, Worship, Courtrooms

- 5 cfm/person + 0.06 cfm/sf

- Example: 100 persons, 2,000 sf (20 sf/person)

- 100 persons x 5 cfm/person = 500 cfm
- 2,000 sf x 0.06 cfm/sf = 120 cfm

- Total: 620 cfm or **6.2** cfm per person (Outdoor air)

Comment: ASHRAE 62.1 is not adequate.

ASHRAE 62.1 (2019)
Classrooms

- 10 cfm/person + 0.12 cfm/sf

- Example: 30 persons @ 35 sf/student, 700 sf

- 30 persons x 10 cfm/person = 300 cfm
- 700 sf x 0.12 cfm/sf = 84 cfm

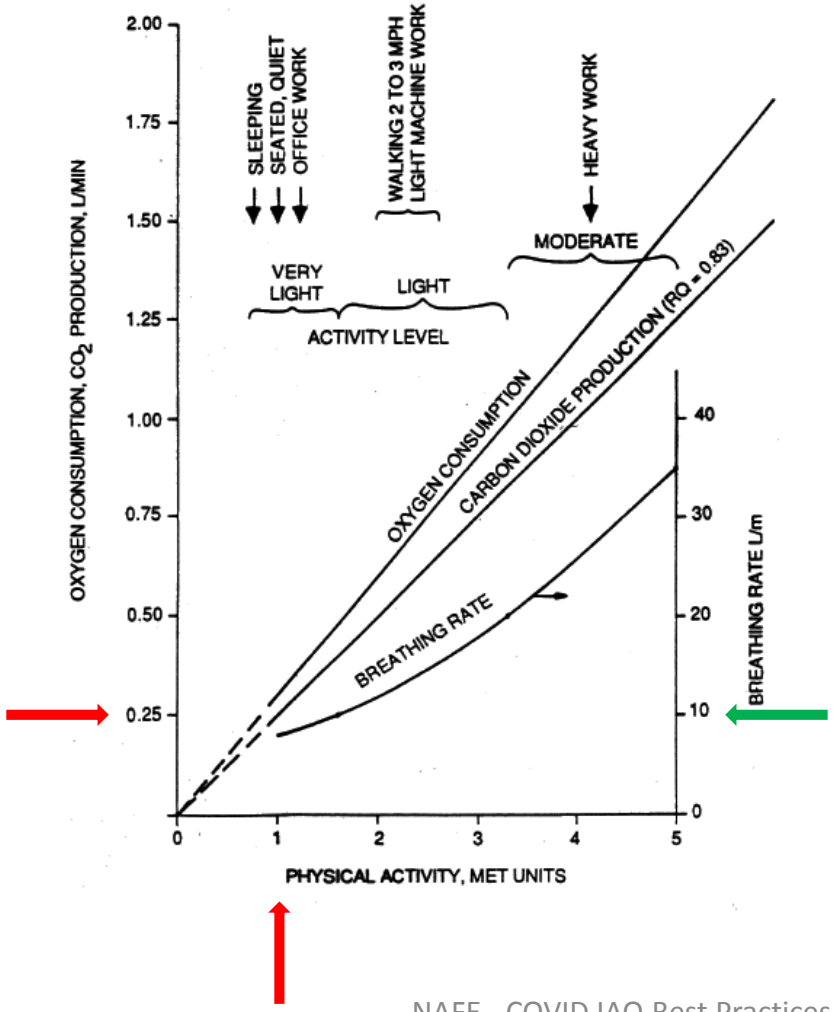
- Total: 384 cfm or **12.8** cfm per person (Outdoor air)

Comment: ASHRAE 62.1 is not adequate.

Ventilation Theory

Air Changes per Hour (ACH) v. CFM per person

MET, (Metabolic Equivalent of Task)



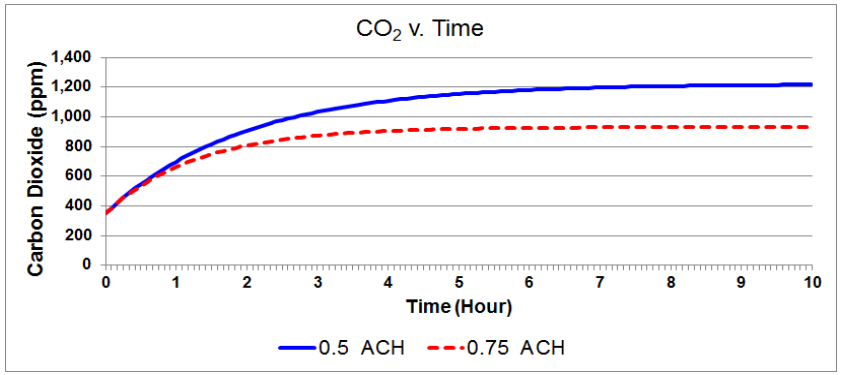
MET	Description
0.9	Sleeping
1	**Listening to Lecture**
1-2	Office Work
2-3	Golf
4-9	Tennis
7-8	Chopping Wood
10	Lap Swimming
16	6-Minute Mile

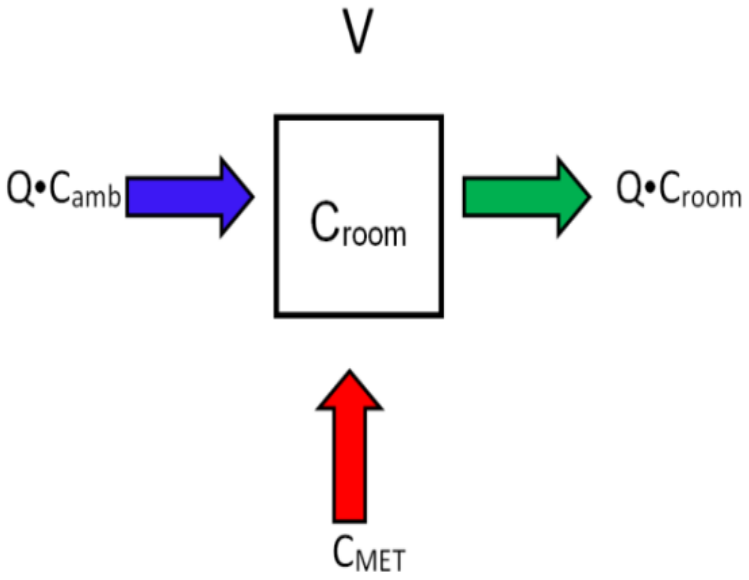
Note: 10 liter/min = 0.353 cfm

1 MET = 0.00733 cfm of CO_2

1 MET = 0.207 liter/min of CO_2

Steady State Model





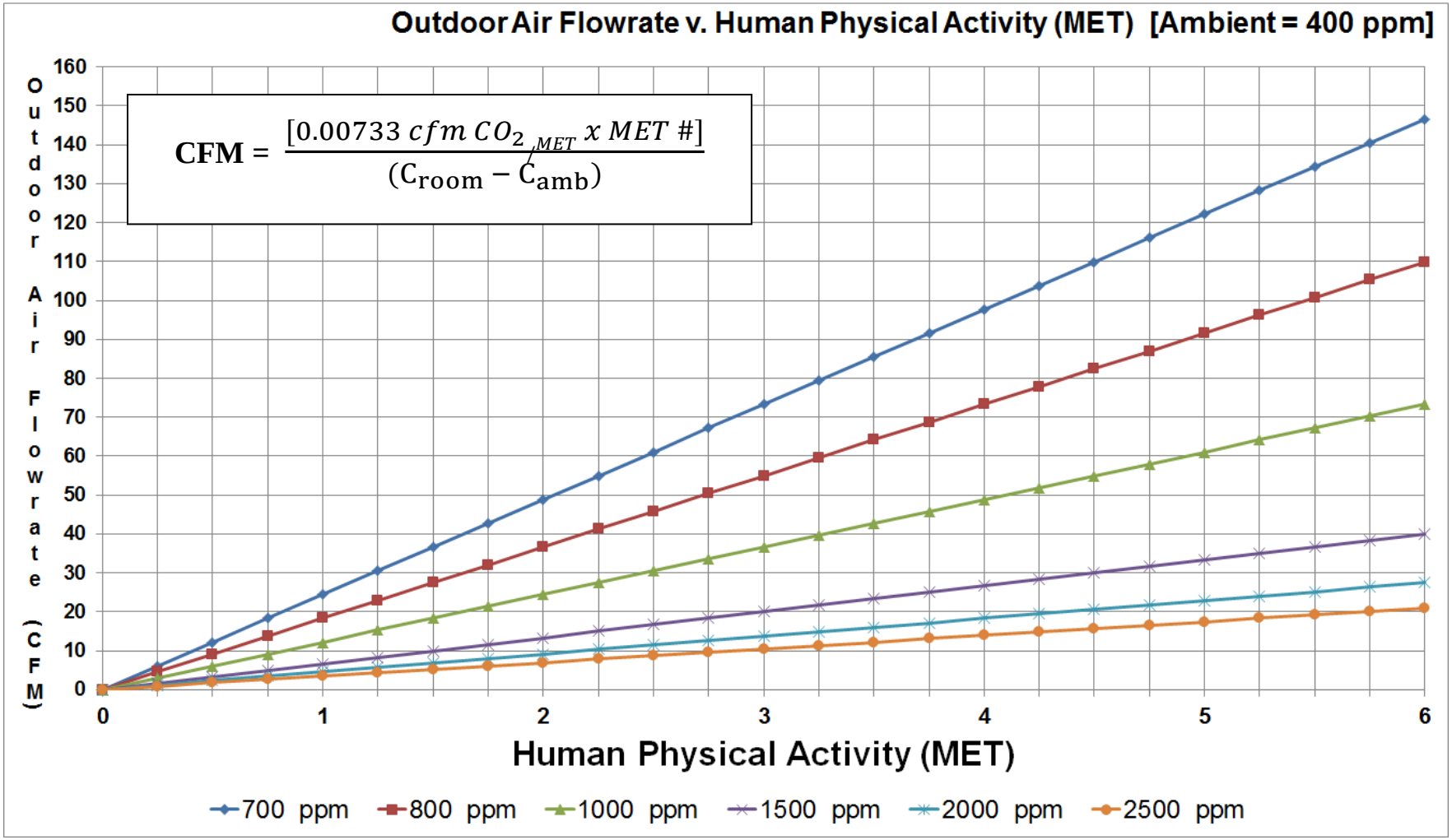
$$\Sigma CO_2 = Q \bullet C_{amb} + C_{MET} = Q \bullet C_{room}$$

$$C_{MET} = Q \bullet (C_{room} - C_{amb})$$

$$Q = C_{MET} / (C_{room} - C_{amb})$$

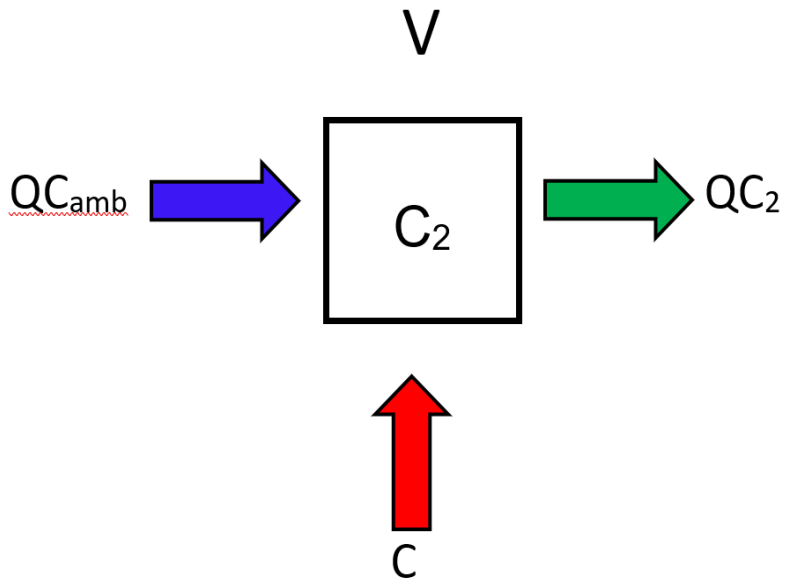
- $\mathbf{Q}\ (\text{CFM}) = \dfrac{[0.00733\ cfm\ CO_{2\ MET}\ x\ MET\ \#]}{(C_{room} - C_{amb})}$

Steady State



Carbon Balance

$$\Sigma CO_2 = Q \bullet C_{amb} + C + V \bullet C_2 - Q \bullet C_2 \quad [\text{cf of } CO_2]$$

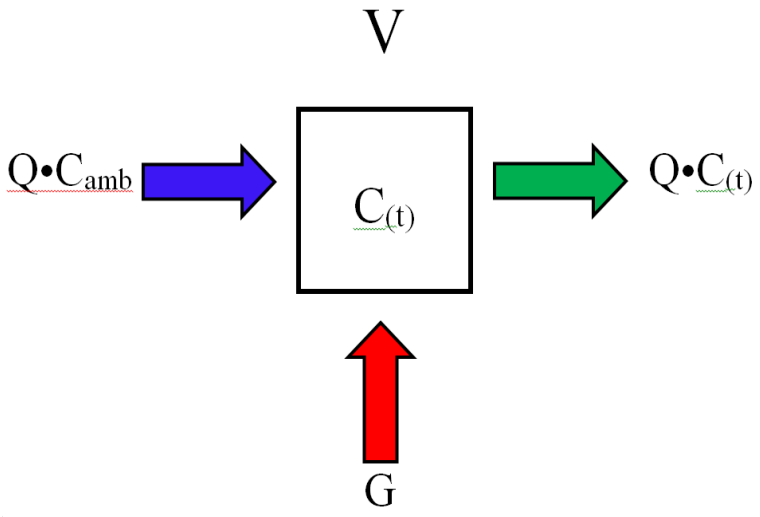


Exponential Growth/Decay Analysis

$$\mathbf{C(t) = C_{amb} + G/Q + (C_{(i)} - C_{amb} - G/Q)e^{-(Q/V)t}}$$

- $C_{(t)}$ = Indoor CO_2 concentration at time t
- $C_{(i)}$ = Initial CO_2 concentration
- C_{amb} = Ambient/Outdoor CO_2 concentration
- G = CO_2 generation (volume of CO_2 per time interval)
- I = Q/V
- Q = Infiltration volume per time interval
- V = Room volume

Iterative Analysis Utilizing Discrete Equations



$$\Sigma CO_2 = Q \bullet C_{amb} + G + V \bullet C_{(t)} - Q \bullet C_{(t)}$$

CO_2 = Concentration: 1 ppm =1 cf of CO_2 per 1,000,000 cf of air

G – cf of CO_2 per time interval; 1 MET = 0.00733 cf CO_2 per minute

1 MET = Metabolic human activity level for a typical 70 kg person
(t) = present interval iteration

Iterative Analysis Utilizing Discrete Equations (cont.)

- $\frac{\Sigma CO_2}{V} = C_{t+1} = C_t + G/V + Q \cdot (C_{amb} - C_t)/V$

CO_2 = Concentration; 1 ppm = 1 cf of CO_2 per 1,000,000 cf of air

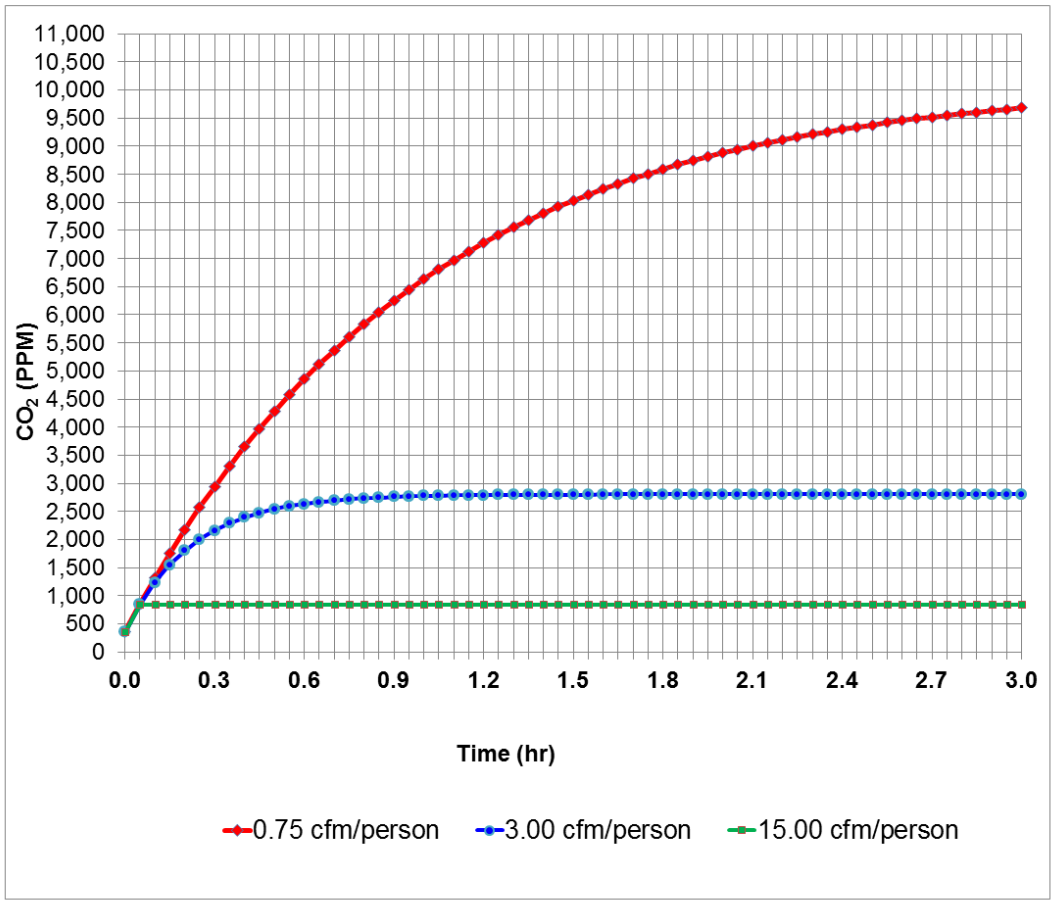
$C_{(t)}$ = CO_2 concentration at time interval (t)

G – cf of CO_2 per time interval; i.e.: 1 MET = 0.00733 cf CO_2 per min.

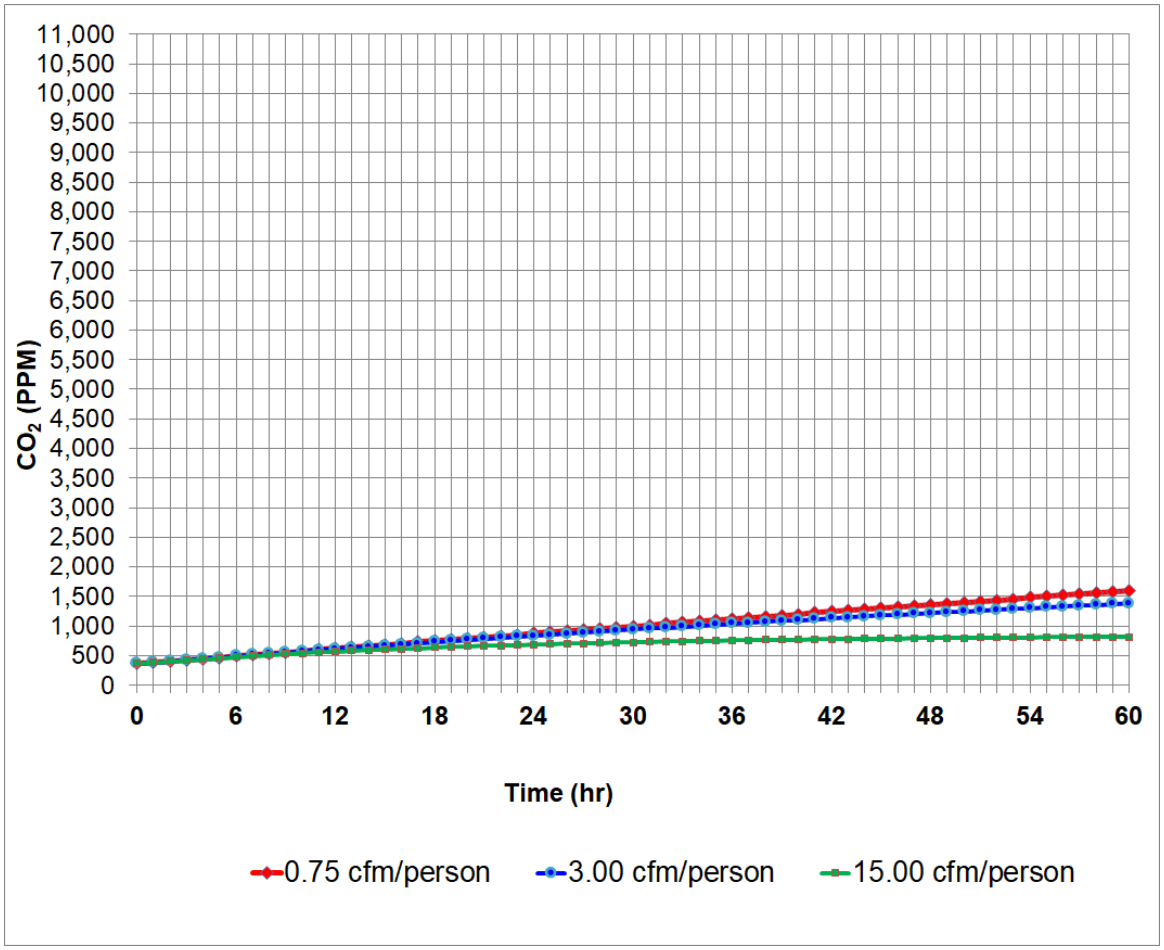
1 MET = Metabolic human activity level for typical 70 kg person

(t) = present interval iteration; (t+1) = next interval iteration

Example: Small Enclosure (Real time)
[3’ W x 3’ L x 5’ H = 45 cf]



Example: Large Room Living Space (Real time)
[25’ W x 40’ L x 20’ H = 20,000 cf]



CDC Ventilation Guidelines Engineering Reasoning

CDC:

"***Ensure that ventilation systems operate properly and increase circulation of outdoor air as much as possible by opening windows and doors, using fans, etc.***"

CDC – June 2, 2021

https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html

"***One potential target benchmark for good ventilation is CO_2 readings below 800 ppm.”***

- ***800 ppm = 20 cfm/person of fresh air (@ MET 1)***

❖***ASHRAE standard of only 7 cfm/person is not adequate.***

-Maximize existing O.A. capacity

3x 7 cfm/person O.A ventilation; 33% occupancy

Basis of Proposed Ventilation Rates

a) At 33% occupancy, outdoor air flowrates can be increased to provide more fresh air per person. If systems were designed for 7 cfm per person, the systems should be able to provide approximately three-times the outdoor air at 33% occupancy

b) Determine maximum COVID Occupancy

c) Determine maximum cooling capacity

d) Determine maximum heating capacity

e) If system meets energy capacity requirements, set outside air flowrates based on the following criteria:

Recommended Ventilation Rates

Air circulation:

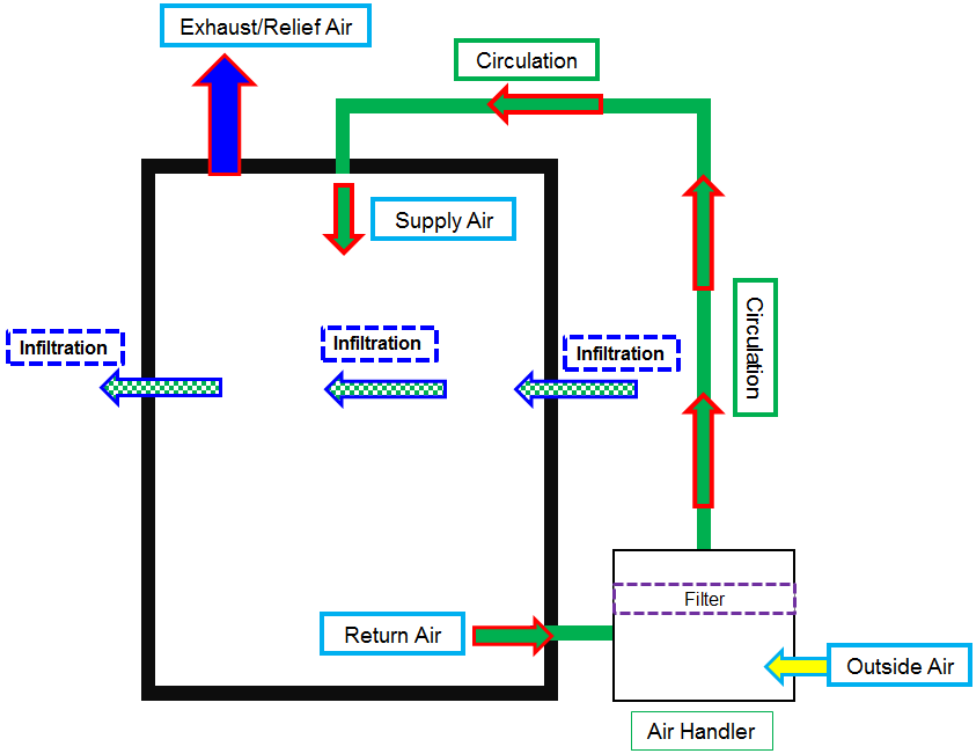
0.75 cfm per sf (1 ton/500 sf)

+ 25 cfm/person

Air circulation to be enabled **2** hours before event and **2** hours after event.

Exhaust or Outside Air:

20 cfm/person and as maintained by a carbon dioxide controller.



Modeling

Wells-Riley, Rudnick, Milton

[Require medical/biology evaluations]

How to stay within the rails of a Mechanical Engineer?

$$P = 1 - e^{\frac{-Ipqt}{Q}}$$

$P = Probability\ of\ infection$

$I = Number\ of\ infector\ individuals\ in\ the\ space$

$p = Average\ breathing\ rate\ of\ individuals\ in\ the\ space$

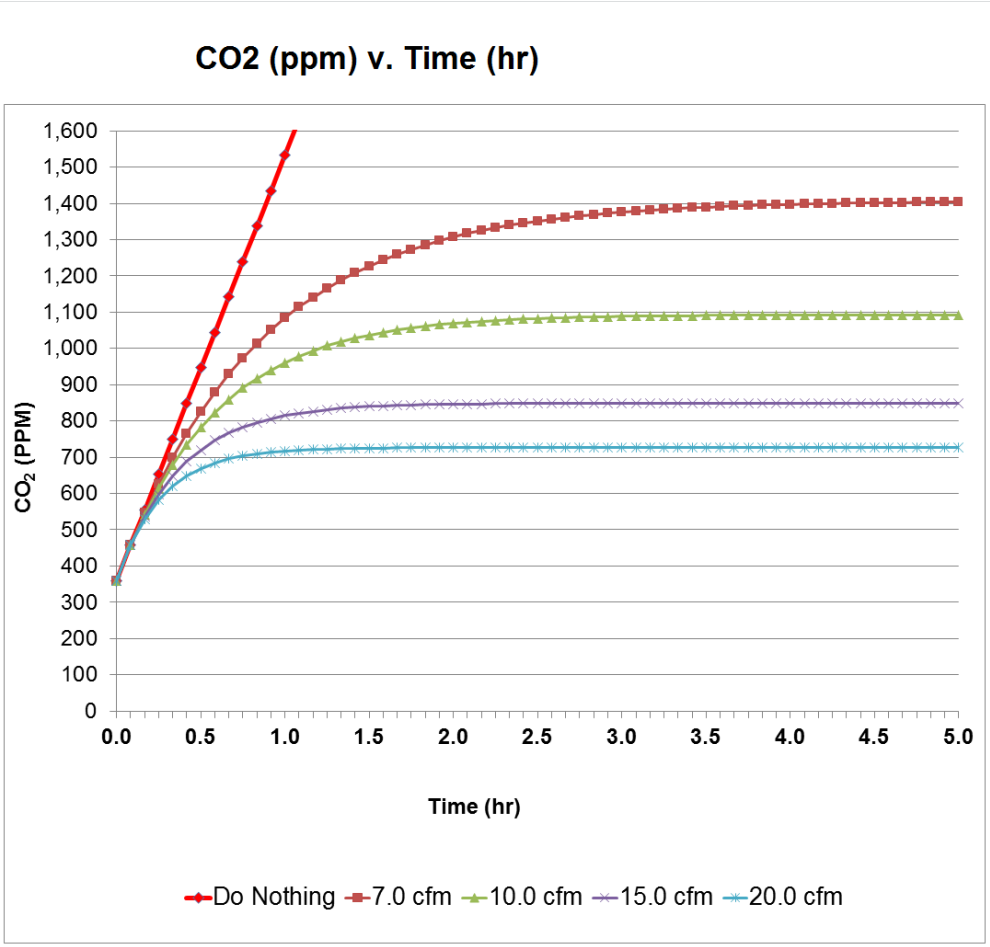
$q = Quanta\ generation\ rate$

$t = Exposure\ time$

$Q = Air\ flow\ rate\ from\ HVAC\ system$

Example: Sanctuary Seating

[3’ x 5’ x 25’ high seating area (15 sf/person), 0– 20 cfm/person]



Example: Sanctuary Seating
[3’ x 5’ x 25’ high seating area (15 sf/person), 0–20 cfm/person]

CFD STUDY
50 people

3’x5’x50 = 750 SF
750SFx25’ = 18750 CF

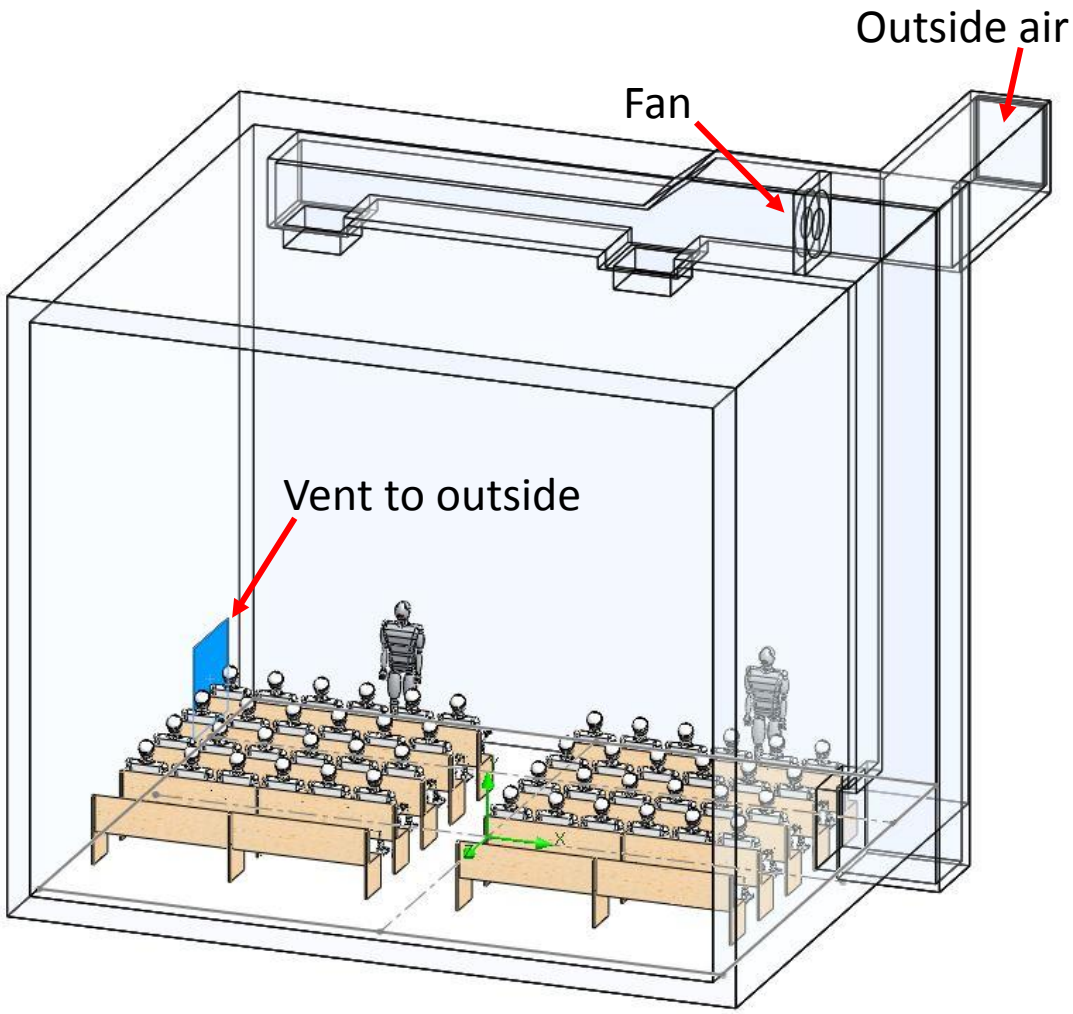
10 air exchanges
= Volume*Exch/60min
=3125 CFM flow

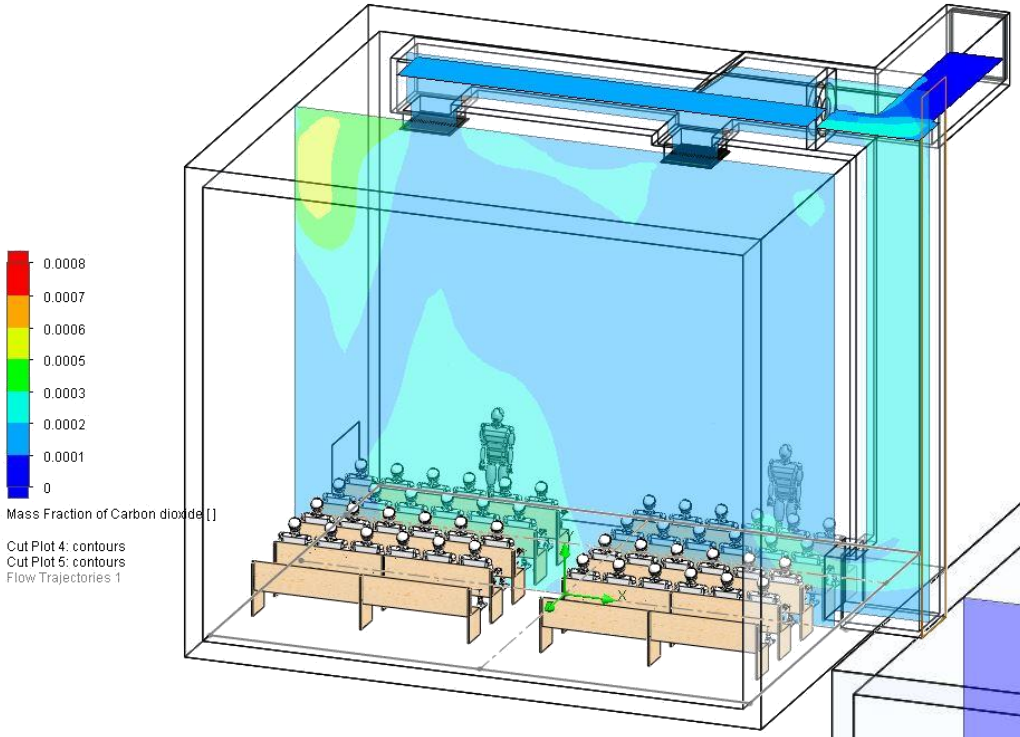
Fresh air
7 CFM/person=350 CFM

➔*Social distancing*:
350 CFM/17 = 20.6 CFM

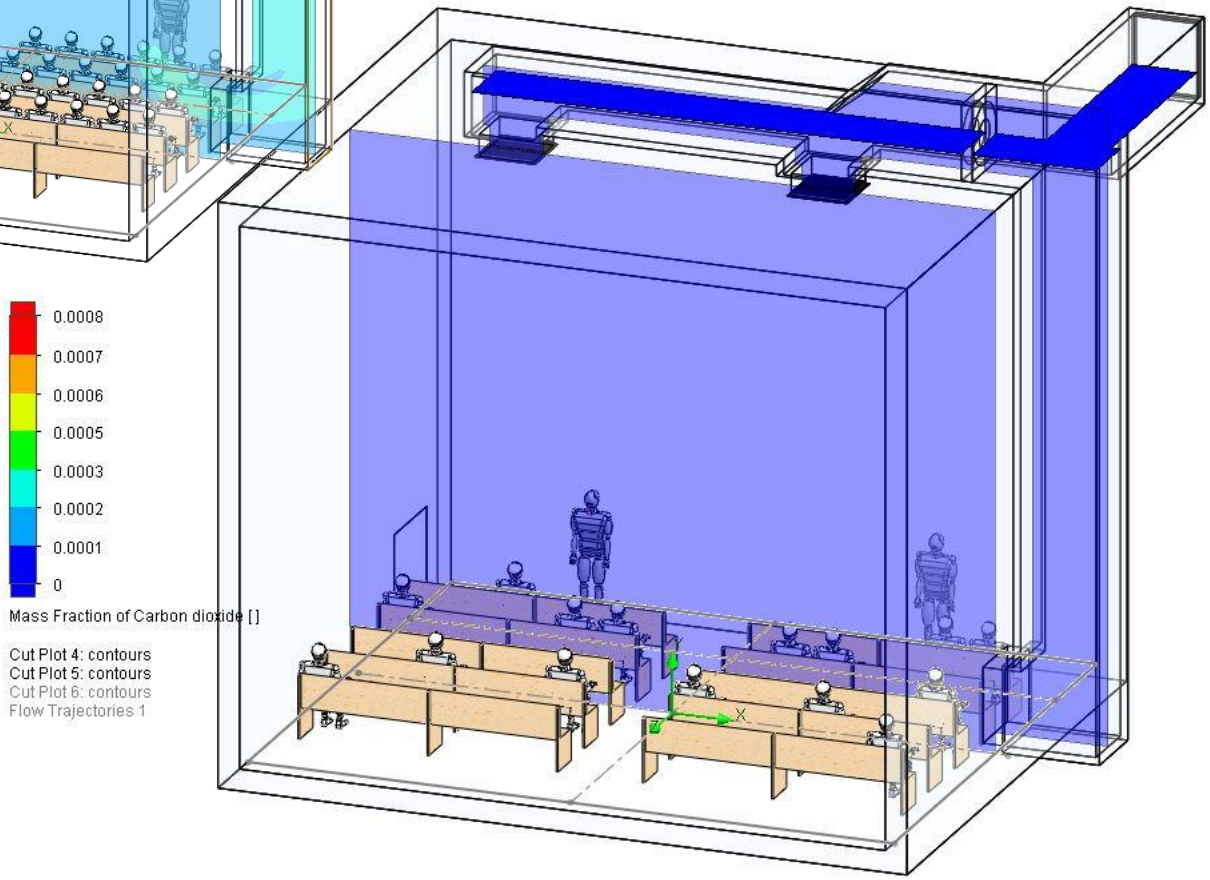
Diffusers not shown

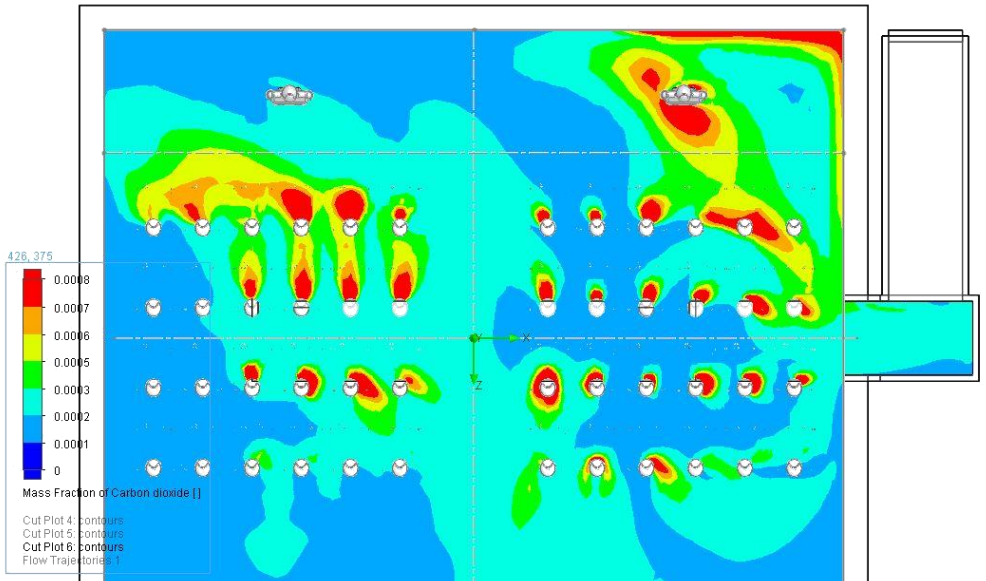
Neglects use of filters,
UVC, masks





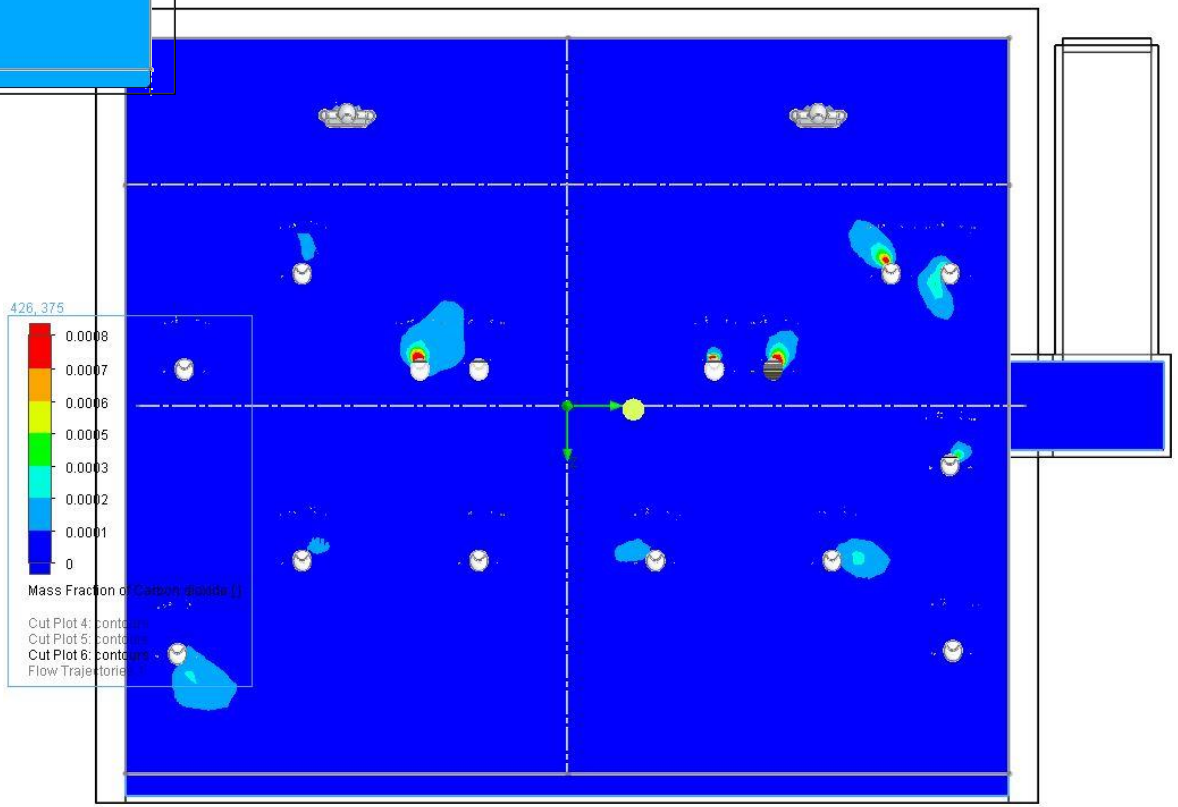
CO2 (Volumetric Fraction)
Max = 800 PPM (0.0008)
1200 PPM absolute

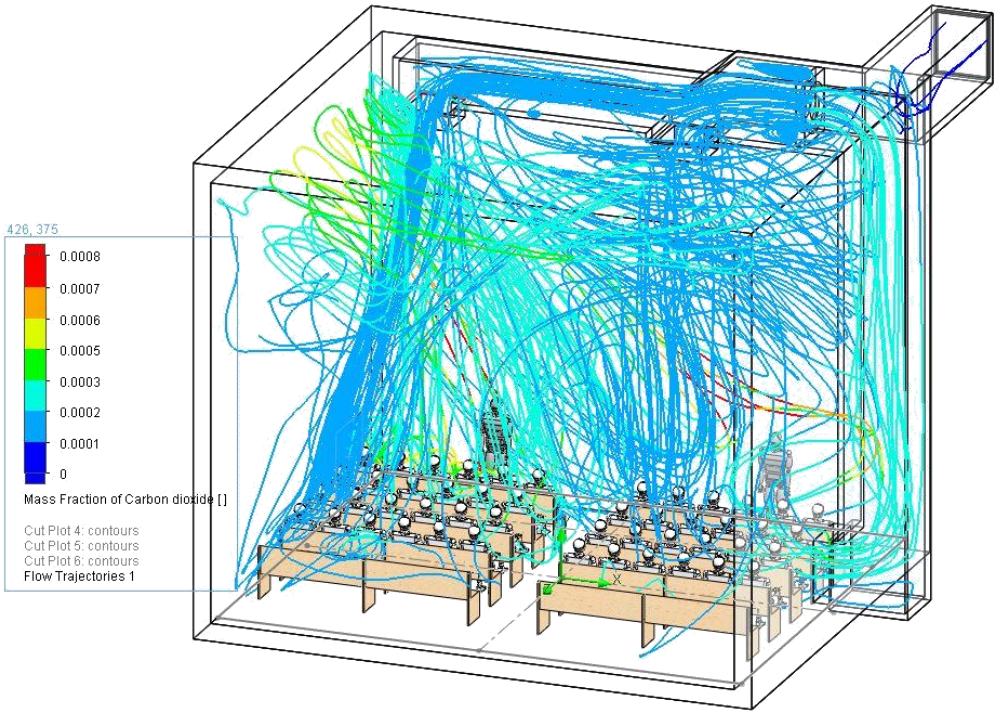




CO2 (Mass Fraction)
Max = 800 PPM (0.0008)

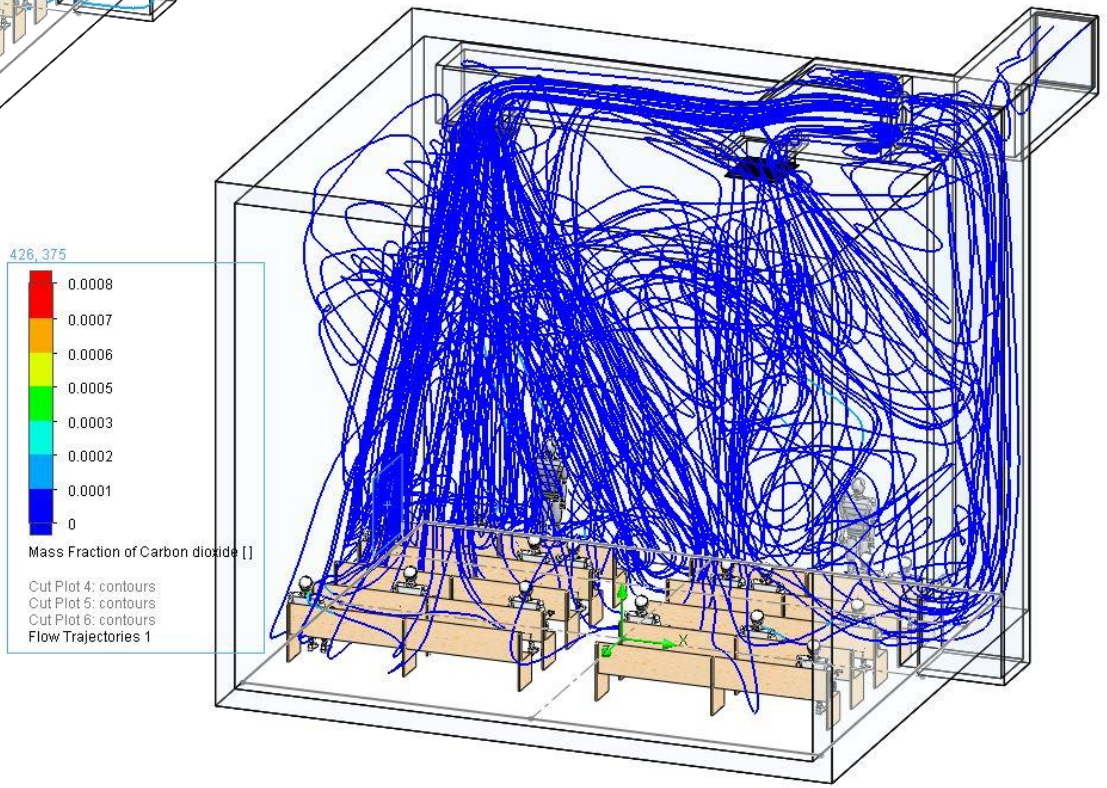
Plan view @ 3.5 feet elev.





CO2 (Volumetric Fraction)
Max = 800 PPM (0.0008)

Trace from exit
Note: UV-C would change recirculation



Mitigation Technology Modeling Summary

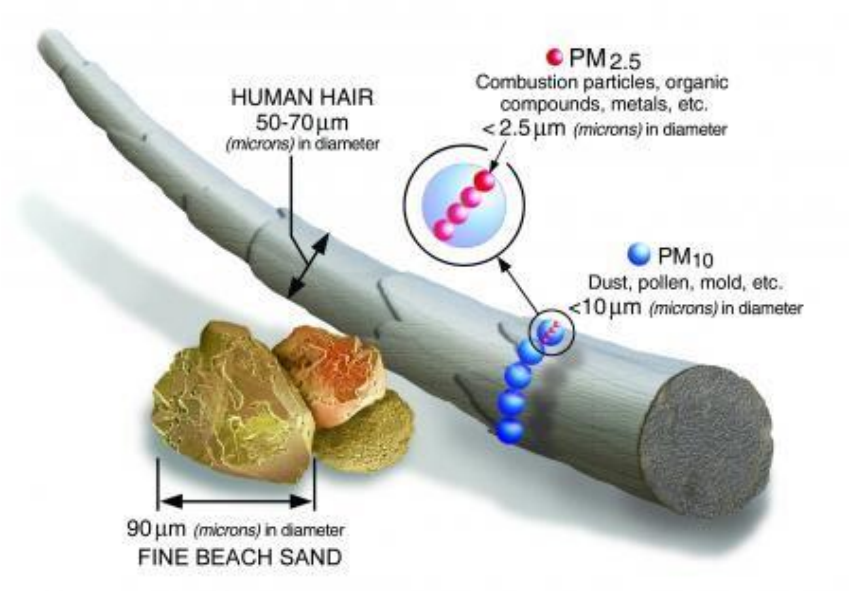
Pittsburgh International Airport

Touchless Passenger Journey:

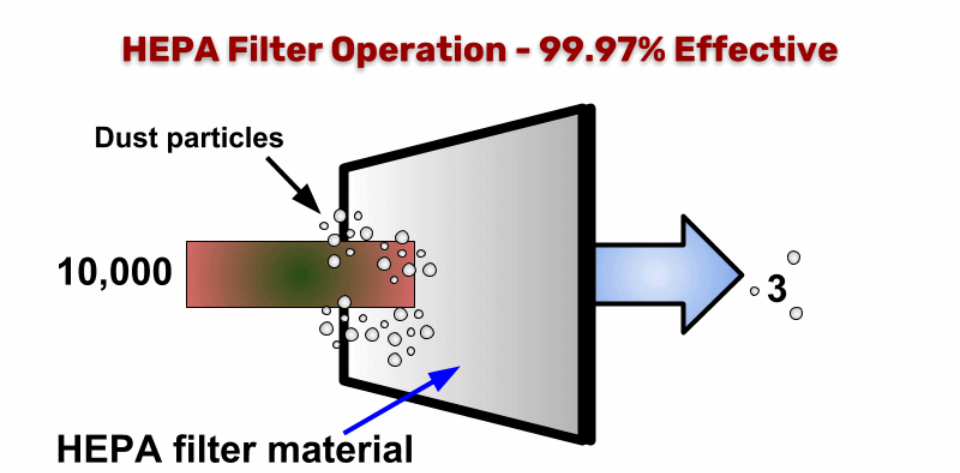
- Wave to call elevators
- Foot pedal door operation
- Antimicrobial copper film on select surfaces
- Real time indoor air quality reporting and rest room cleaning status

MERV 13 Filters

[**M**inimum **E**fficiency **R**eporting **V**alue]



HEPA Filters



Bipolar Air Ionization

(**Concern for ozone production and respiratory irritation**)

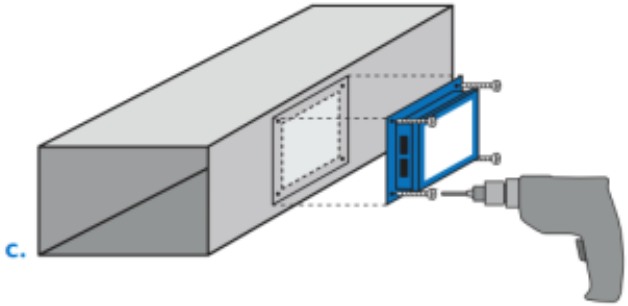
PlasmaAir

INSTALLATION, OPERATION
& MAINTENANCE MANUAL

Plasma Air
7000 SERIES
(MODELS 7100, 7200, 7300, 7400)

REV 11/2019

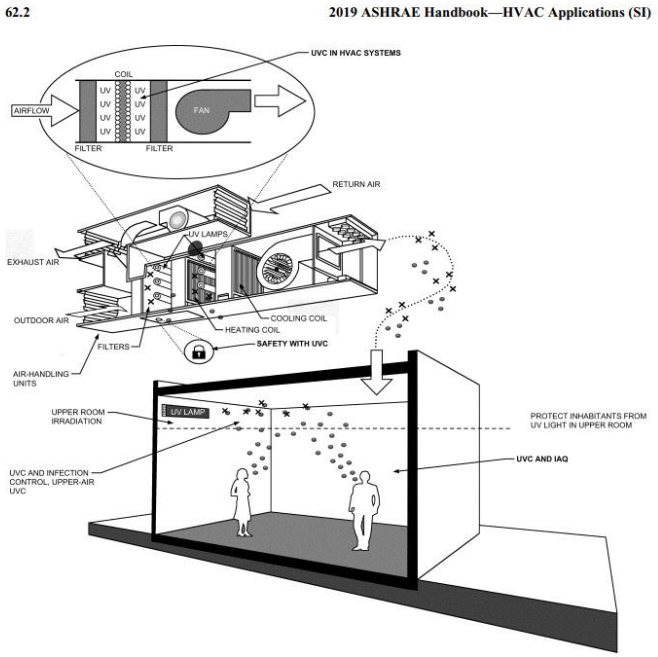
www.plasma-air.com

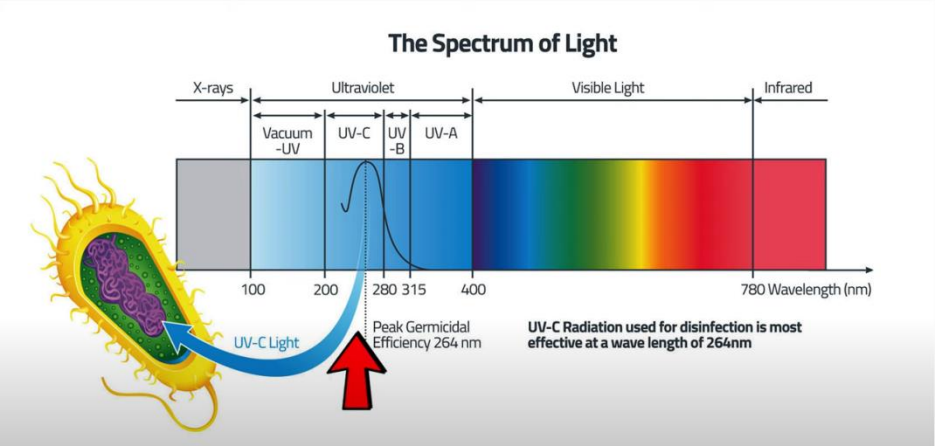


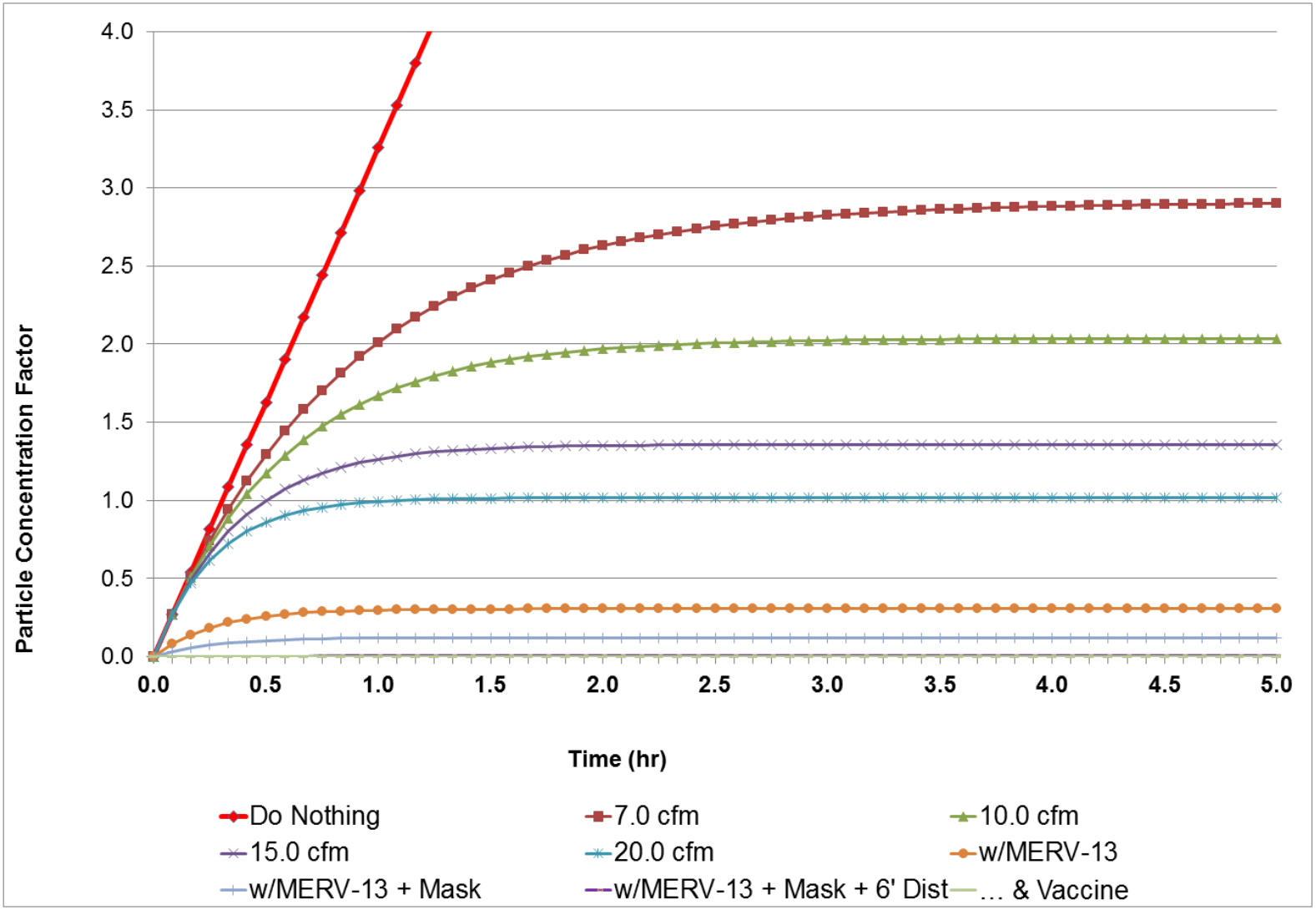
Ionizers give air particles an electrical charge, which pulls them toward collector plates with an opposing electrical charge.

Ultraviolet Light

[Local benefit. Partial effectiveness on airstream.]






Potential COVID Particle Concentration v. Time (hr)
Particle Concentration Factor
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Time (hr)
Do Nothing
7.0 cfm
10.0 cfm
15.0 cfm
20.0 cfm
w/MERV-13
w/MERV-13 + Mask
w/MERV-13 + Mask + 6' Dist
… & Vaccine

COVID HVAC Conclusions

The use of **carbon dioxide controllers** can be utilized to provide the maximum outside air ventilation based HVAC capabilities at design weather conditions and occupancies of **33**% or less.

Additional mitigation steps include the following:

a) Installation of MERV-13 filters or HEPA units;
b) Use face masks;
c) 6’ Distancing;
d) Vaccine;
e) Ultraviolet light for cooling coils;
f) Energy recovery for make-up air.

Hazard/Risk Assessment

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

OSHA **PART 1910 -- OCCUPATIONAL SAFETY AND HEALTH STANDARDS**

Even in cases where hazards for which OSHA does not have a specific standard, such situations are governed by Section 5(a)(1) of the Occupational Safety and Health Act.

The Occupational Safety and Health Act requires that a place of employment be free from recognized and foreseen hazards that are causing or are likely to cause death or serious physical harm.

Risk assessment is the process where you:

- identify hazards;
- evaluate the risk associated with that hazard;
- determine ways to eliminate/control the hazard.

Four components of the General Duty Clause

- The four components are:

1) The employer failed to keep the workplace free of a "hazard";
2) The hazard was "recognized" either by the cited employer individually or by the employer's industry generally;
3) The recognized hazard was causing or was likely to cause death or serious physical harm;
4) There was a feasible means available that would eliminate or materially reduce the hazard.

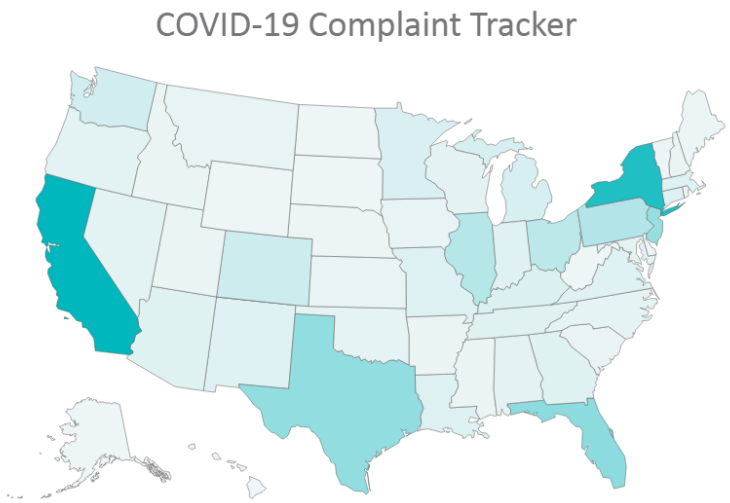
Section 5(a)(2) requires employers to "***comply with occupational safety and health standards promulgated under this Act***".

COVID LITIGATION

COVID Litigation

https://www.huntonak.com/en/covid-19-tracker.html

Many Complaints filed



- IAQ
- HVAC deficiencies
- Commercial offices
- Breach of contract
- Business interruption due to mechanical system deficiencies

Main Conclusions

The use of carbon dioxide controllers can be utilized to provide optimum outside air ventilation-based HVAC capabilities at design weather conditions and occupancies of **33%** or less.

Additional mitigation steps include the following:

a) Use of N95 face masks for all participants;
b) Installation of MERV-13 filters;
c) Ultraviolet light (Surfaces, only partial effect on airstream);
d) Bipolar Air Ionization (not recommended due to ozone concerns).

Q1) What are the COVID Mitigation Measures

a) Masks
b) Surface sanitizing/cleaning
c) MERV-13 Air Filter
d) Maintain HVAC in good operating condition
e) Social distancing
f) Ultraviolet lighting
g) Planned exiting and entrances
h) Hand sanitizer
i) PPE
j) All of the above

Q2) How to minimize litigation exposure in the workplace?

a) Implement Best Engineering Practices and BATs
b) Practice social distancing
c) Follow/exceed ASHRAE standards
d) Utilize face masks
e) Call for vaccine passports
f) Utilize HVAC registered professional engineers
g) All of the above

Discussion/Questions

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