Evaluating Your HVAC Systems Readiness to Mitigate the Spread of SARS-CoV-2

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Learning Objectives

- Assess and document improvements for HVAC system(s) ability to respond to an infectious aerosol
- Understand how to create an effective Building Readiness Plan
- Explain potential engineering controls to implement in your HVAC systems to improve its virus transmission mitigation
- Explain different modes of operation for Epidemic Conditions In Place and Post-Epidemic Conditions in Place
- Discuss the future proofing of designs that may affect future HVAC design criteria

Agenda

- Introduction
- Transmission
- Building Readiness Intent and Plan
- Epidemic Conditions in Place (ECiP)
  - Evaluate Existing Systems
  - Mitigation Strategies
  - Steps to Re-occupy Your Building
- Considerations for Post-Epidemic Conditions in Place (P-ECiP)
- Future Design
- Conclusions
- Questions

Introduction of Speakers

Dennis Knight, PE
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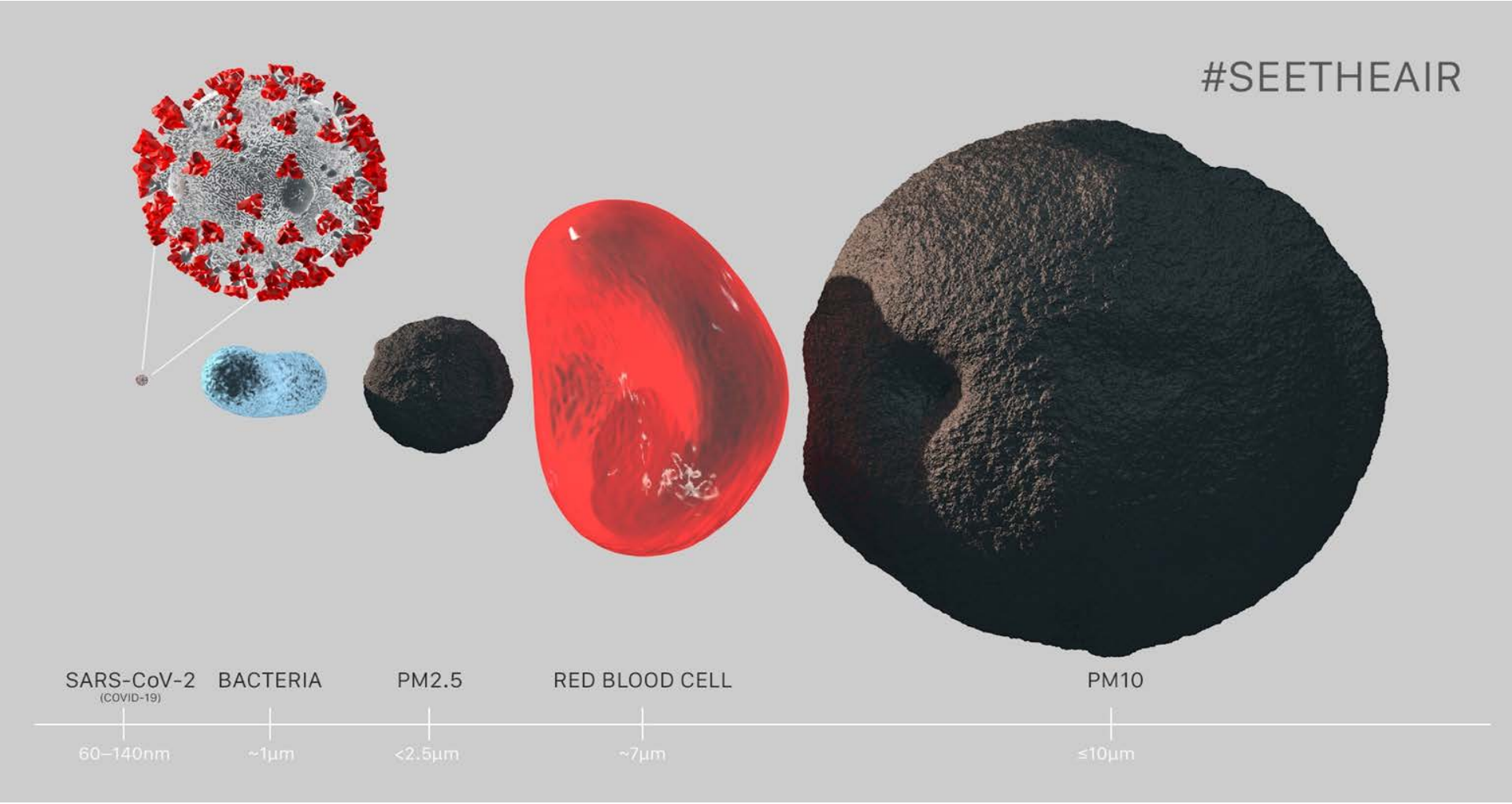
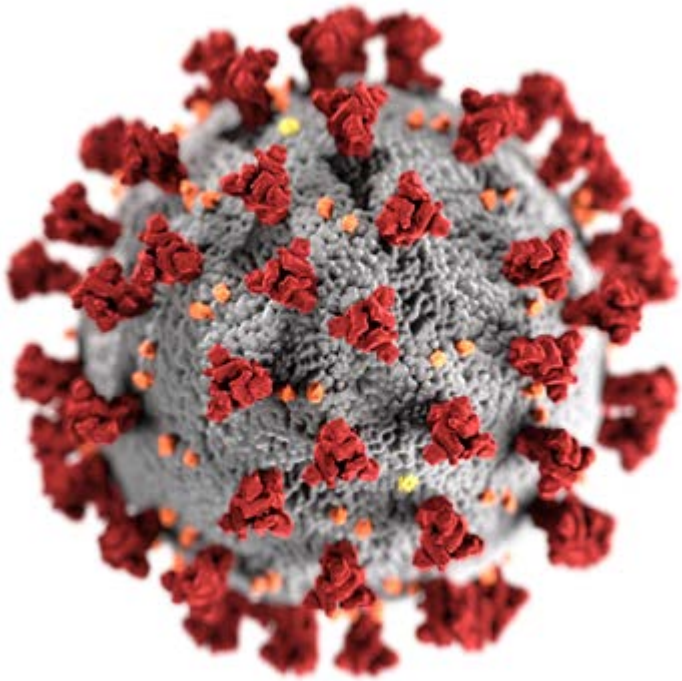
Transmission

What are we Mitigating?



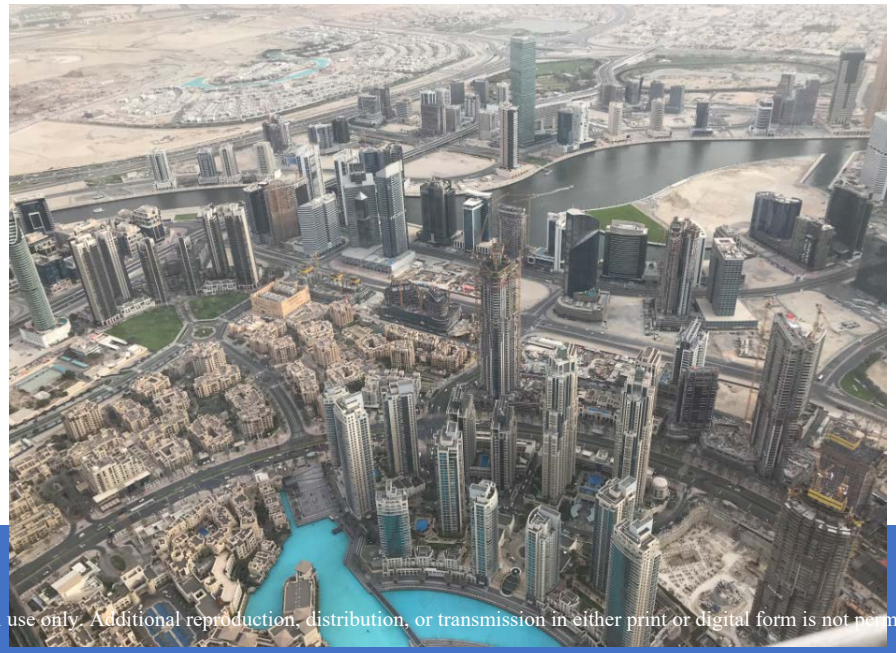
SARS-CoV-2



- RNA virus with lipid envelope
- Diameter ~ 120 nm (0.12 µm)
- Not determined
  - Shedding rate
  - Infectious dose
- Survival of hours in air, days on surfaces

The Importance of Indoor Air Quality
"Buildings are for People, not for Saving Energy"

- People are the most valuable/expensive part of a building
- 1:10:100:1000 rule (order of magnitude)
  - $ 1 of design cost
  - $ 10 of construction cost
  - $ 100 of operating cost (energy, water,…)
  - $1,000 of occupant cost (salary, benefits…)



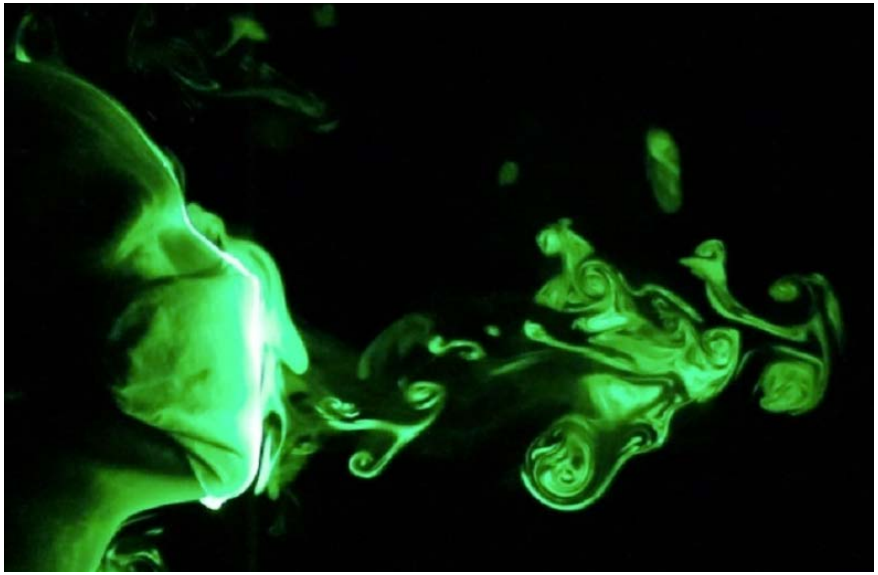
The Importance of Indoor Air Quality

- Indoor environmental quality (IEQ) affects
  - Safety (chronic and acute toxicity)
  - Comfort (odor perception)
  - Productivity/Learning
  - Health
    - Allergies and asthma
    - Cardiopulmonary disease
    - Infectious diseases

IAQ Control is Control of Contaminants

Transmission Modes

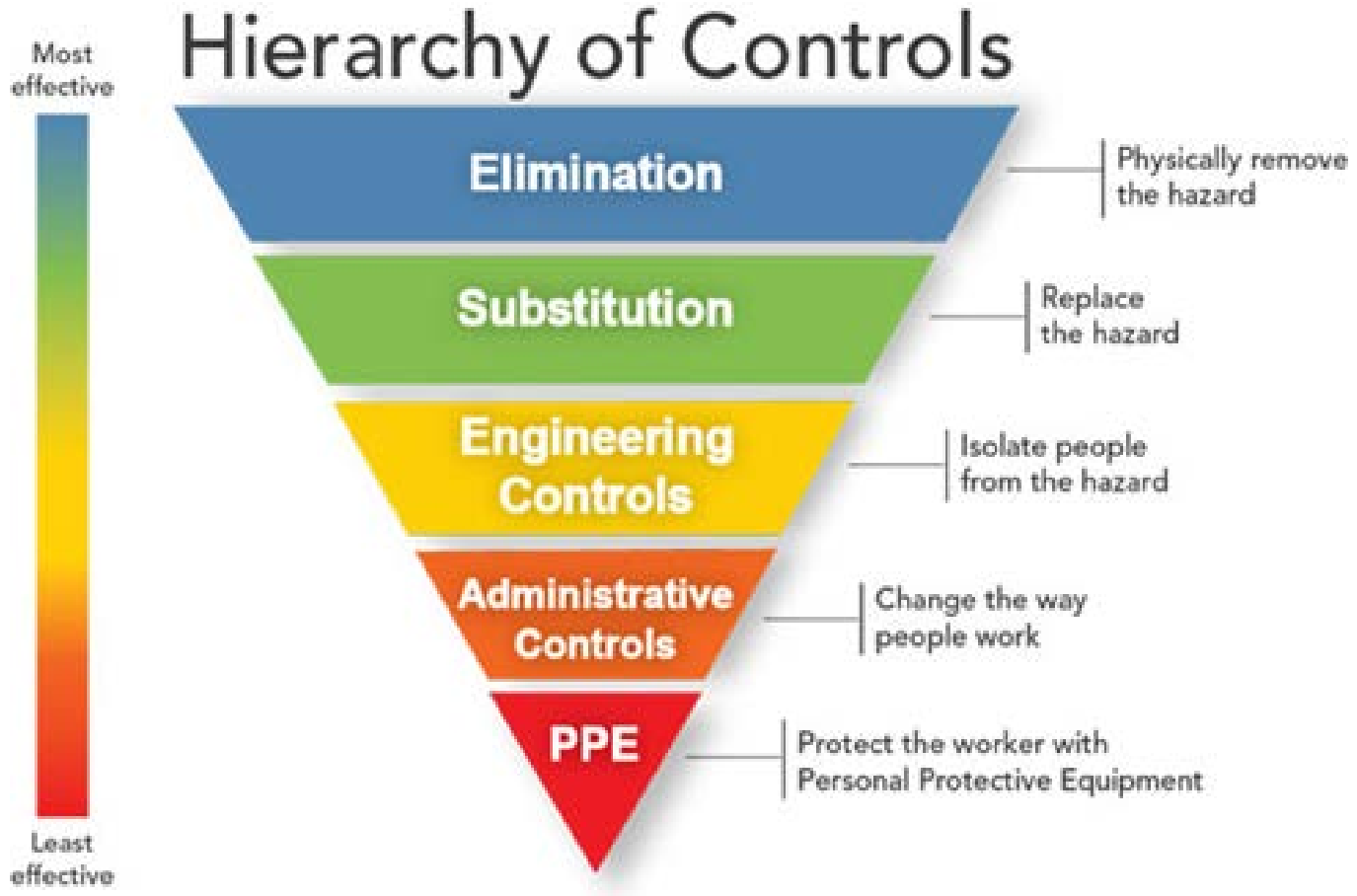
- Airborne
  - Large droplet/short range
  - Aerosol
- Fomite – intermediate surface
- Water/food
- Physical contact
- Insect/animal vector



FAU College of Engineering and Computer Science
Phys. Fluids 32, 061708 (2020); https://doi.org/10.1063/5.0016018

…HVAC mainly impacts aerosol and fomite transmission – only part of a solution

IAQ Control is Control of Contaminants



SARS-CoV-2 Transmission Debate

Health organizations (WHO)

- March 29th article “Modes of transmission of virus causing COVID-19” stated that it was predominantly large droplet transmission at short range and that airborne transmission was very unlikely
- July 4th petition by 239 experts to WHO that the virus is airborne[1]
- July 9th scientific brief indicates that airborne transmission outdoor of medical procedures requires more study

Health organizations (CDC)

- May 22nd media statement does not mention airborne transmission as a potential
- FAQ about SARS indicates “might be spread more broadly through the air (airborne spread) or by other ways that are not now known”
- SARS (original) also suggests possibility for COVID-19

1:Morawska et al (2020) https://doi.org/10.1093/cid/ciaa939

SARS-CoV-2 Transmission Debate

Unexplained COVID-19 “community spread” incidents cast doubt on claimed insignificance of airborne transmission, e.g.

Skagit Valley, WA choir rehearsal

- 53 of 61 participants infected
- 2.5 hours of rehearsal
- Multiple “arrangement” of people
- Chairs 6 to 10 inches apart
- Unknown ventilation
- MERV 11 filters in furnace

Miller et al (2020) https://doi.org/10.1101/2020.06.15.20132027

SARS-CoV-2 Transmission Debate

Unexplained COVID-19 “community spread” incidents cast doubt on claimed insignificance of airborne transmission, e.g.

Call Center, South Korea

- 94 of 216 employees
- Blue dots indicate “positive”
- HVAC system unknown

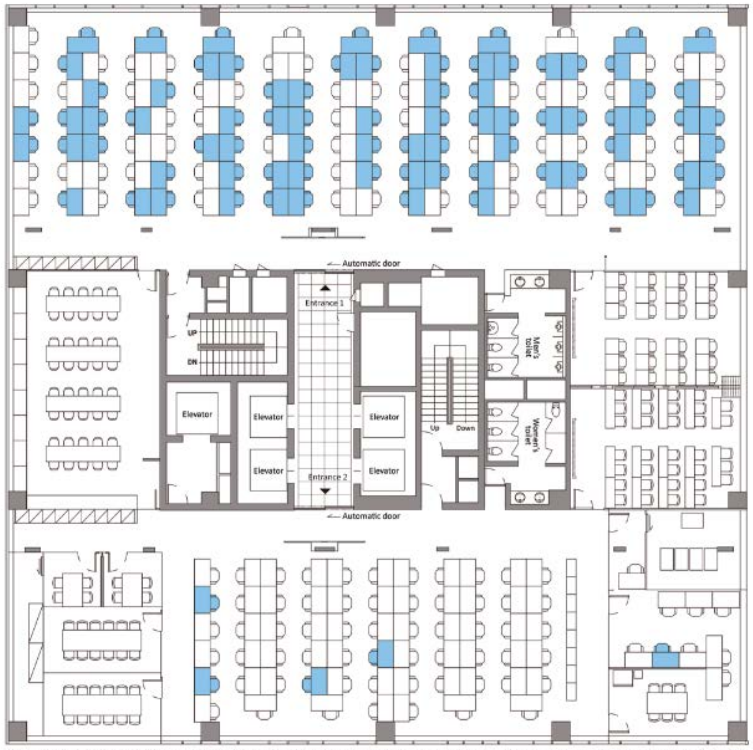


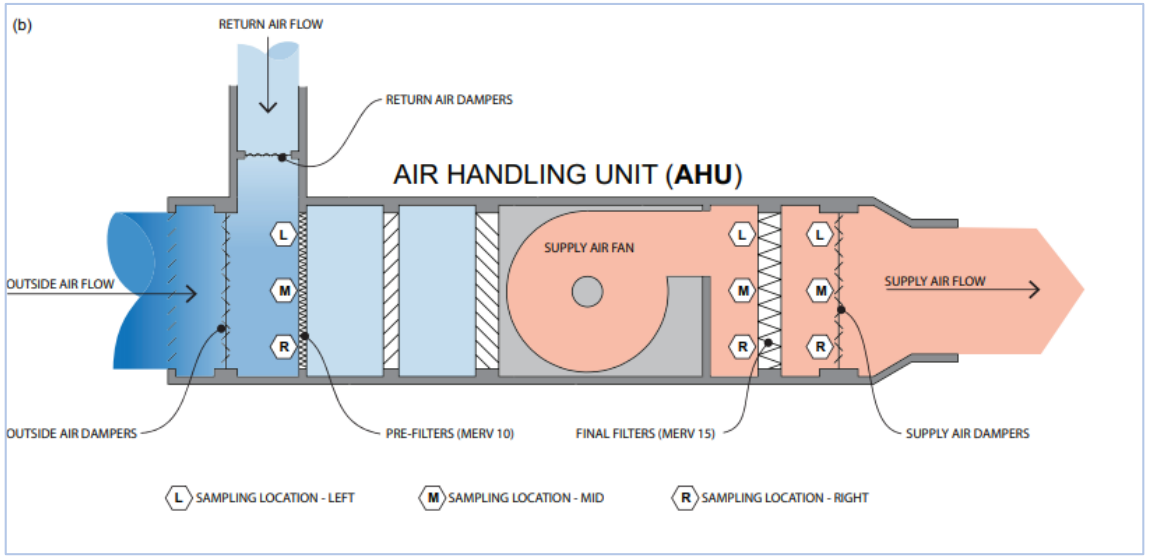
Figure 2. Floor plan of the 11th floor of building X, site of a coronavirus disease outbreak, Seoul, South Korea, 2020. Blue indicates the seating places of persons with confirmed cases.

Park et al (2020) https://wwwnc.cdc.gov/eid/article/26/8/20-1274_article#tnF1

SARS-CoV-2 Transmission Debate

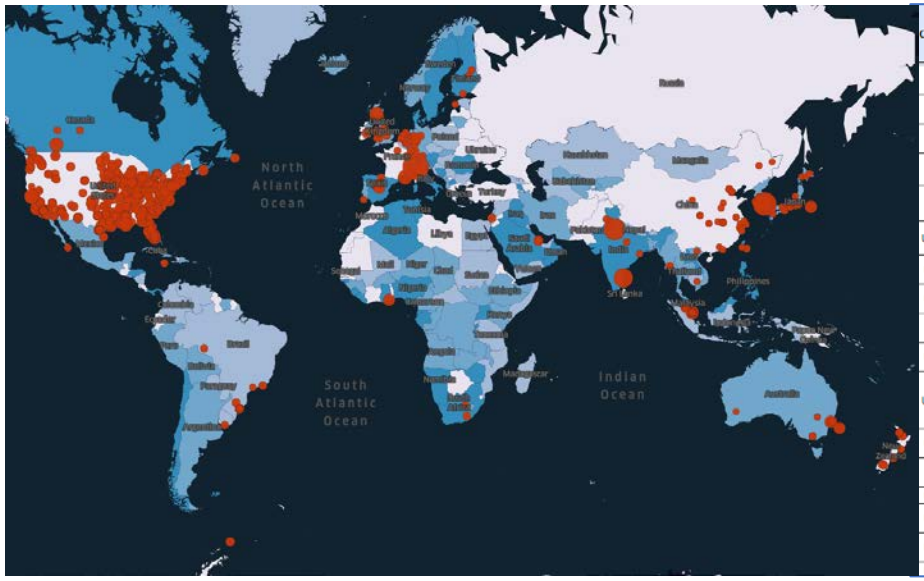
Identification of SARS-CoV-2 RNA in Healthcare Heating, Ventilation, and Air Conditioning Units

- ~ 25% of samples had RNA
- Virality not checked
- Working on next phase
- MERV-15 Filters
- Working Hospital



Horve, Dietz et al (2020) https://doi.org/10.1101/2020.06.26.20141085

Superspreading Event Tracking



https://superspreadingdatabase.github.io/bubble-map-timeline.html

Code	Country	City/Region	Lat	Long	Setting1	Description	Indoor / Outdoor	Cases	Index Date
ITA7	Italy	Milan, Italy	45.463194	9.174297	Sports: Audience	Soccer game attendance	Indoor / Outdoor	7000	19/02/2020
KOR8	South Korea	Daegu, South Korea	35.813435	128.646341	Religious	The Shincheonenji church cluster	Indoor	5016	12/02/2020
IND5	India	Delhi, India	28.598	77.196	Religious	Tablighi Jamaat events, multiple days + events	Indoor	4000	15/03/2020
IND4	India	Koyambedu Market East Road, Virrugambakkam, Koyambedu,	13.066	80.195	Market	Vegetable market	Indoor / Outdoor	2760	22/04/2020
FRA2	France	Mulhouse, France	49.230	7.324	Religious		Indoor	2500	18/02/2020
USA917	United States	Marion Correctional Institution — Marion, Ohio	40.616604	-83.069296	Prison		Indoor	2,439	15/03/2020
USA19	United States	Pickaway Correctional Institution — Scioto Township, Ohio	41.172402	-81.450184	Prison		Indoor	1,791	15/03/2020
USA20	United States	Trousdale Turner Correctional Center — Hartsville, Tenn.	39.26755	-85.69804	Prison		Indoor	1,315	15/03/2020
IDO	Indonesia	Bandung, West Java, Indonesia	-6.920	107.600	Army base	Indonesian Army Officer Candidate School	Indoor / Outdoor	1280	06/07/2020
USA21	United States	Lompoc Prison Complex — Lompoc, Calif.	34.629464	-120.336594	Prison		Indoor	1,114	15/03/2020
USA911	United States	San Quentin, California, United States	37.938	-122.4000	Prison	San Quentin State Prison	Indoor	1105	15/06/2020
USA22	United States	Smithfield Foods pork processing facility — Sioux Falls, S.D.	43.546358	-96.69063	Food processing		Indoor	1,098	15/03/2020
FRA5	France	Mediterranean Sea, France	42.920000	5.516572	Ship: Military	Navy ship	Indoor	1081	01/04/2020
USA23	United States	Cook County jail — Chicago, Ill.	41.88531	-87.62213	Prison		Indoor	1,057	15/03/2020
USA24	United States	Chuckawalla Valley State Prison — Blythe, Calif.	33.736458	-114.687973	Prison		Indoor	1,031	15/03/2020
USA25	United States	Tyson Foods meatpacking plant — Waterloo, Iowa	42.441117	-92.339209	Meat Processing		Indoor	1,031	15/03/2020
USA26	United States	Cummins Unit prison — Grady, Ark.	37.432335	-76.601616	Prison		Indoor	1,028	15/03/2020

Swinkels, K. (2020). COVID-19 Superspreading Events Around the World [Google Sheet]. Retrieved from https://docs.google.com/spreadsheets/d/1c9jwMyT1lw2P0d6SDTno6nHLGMtpheO9xJyGHgdBoco/edit?usp=sharing

Fundamental Assumptions

ASHRAE leadership has approved the following two statements regarding SARS-CoV-2.

AIRBORNE TRANSMISSION

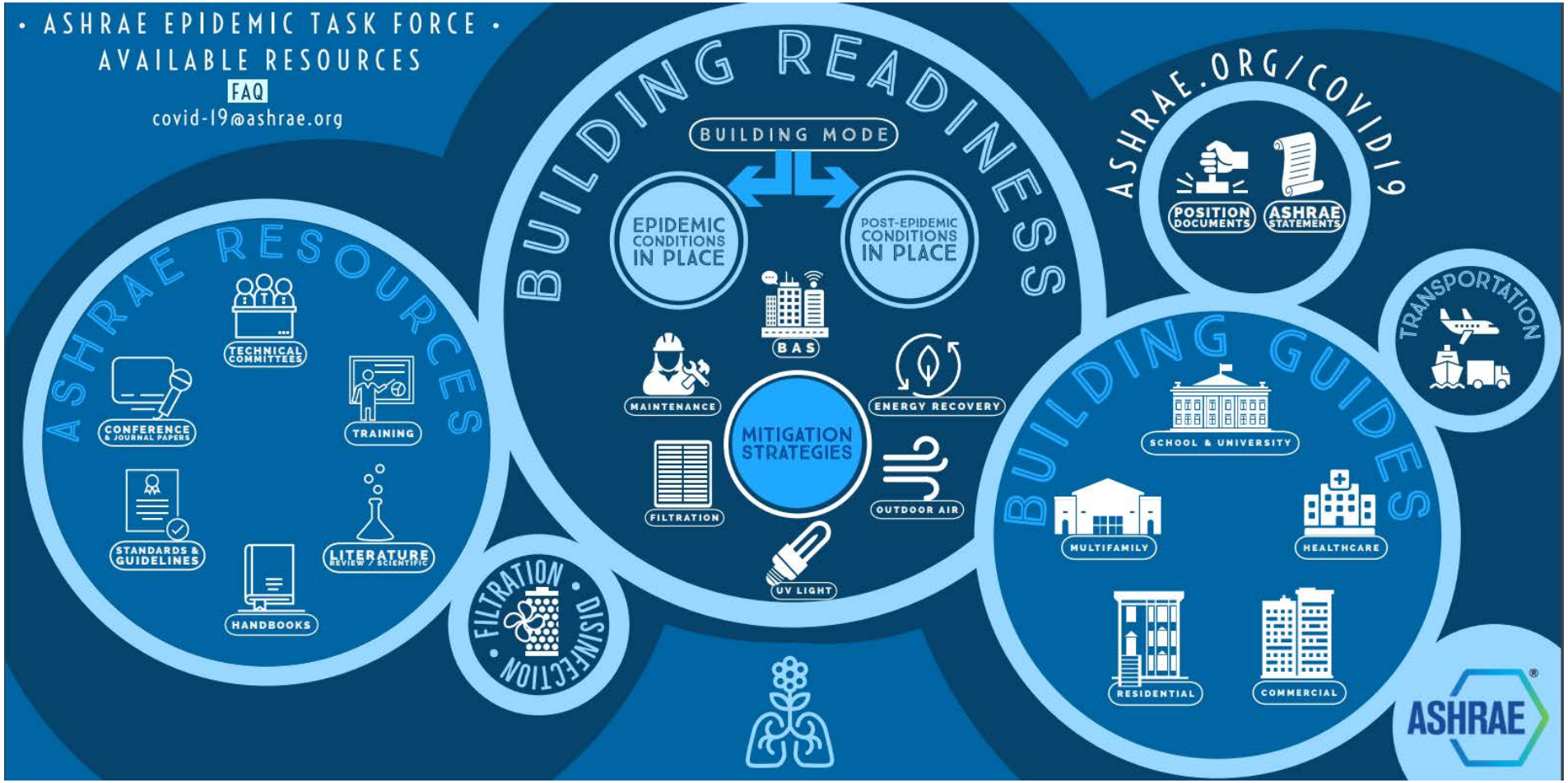
Transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.

OPERATION OF HVAC SYSTEMS

*Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. **In general**, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus.*

Building Readiness Intent

Roadmap to ASHRAE ETF Site



Building Readiness: Intent

Building Readiness is meant to create practical guidance for how your building is operating, should be operating and how to practically check its operation.

Building Readiness modes of operation for the building should include the following:

- Epidemic Conditions in Place (ECiP)
  - Occupied- at pre-epidemic capacity
  - Occupied- at reduced capacity
  - Unoccupied temporarily, and
  - Operation during building closure for indefinite periods

- Post-Epidemic Conditions in Place (P-ECiP)
  - Prior to Occupancy
  - Operational Considerations once Occupied

Building Readiness: Team

The Building Readiness Team could include professionals and licensed and certified individuals and companies that can perform the analysis, testing, design, construction, control programming, balancing, commissioning, maintenance and operation services required to make the adjustments and achieve the performance included in these recommendations.

The following are the typical service providers that may be required:

- Commissioning Provider (CxP)
- Test and Balance Company (TAB)
- Building Automation Systems (BAS) Company
- Contractors
- Architect and/or Engineer (AE)
- Owner's Facility Staff
- Building Operations

Building Readiness: Plan

- Document to record the mitigation strategies
  - MUST include non-HVAC strategies
  - Also include HVAC mitigation strategies
- Non-HVAC strategies could include, but not be limited to, the following items:
  - Building Occupancy Levels Allowed
  - Face mask requirement or recommendation
  - Social distancing between desks, breakrooms, conference rooms, elevator, etc.
  - Directional flow for office space
  - Personal hygiene
  - Cleaning requirements
- HVAC strategies could include, but not limited to, the following items:
  - Increased Ventilation
  - Improved Filtration
  - Air cleaning devices (such as UVGI and other newer technologies)
- Each HVAC system needs to be analyzed

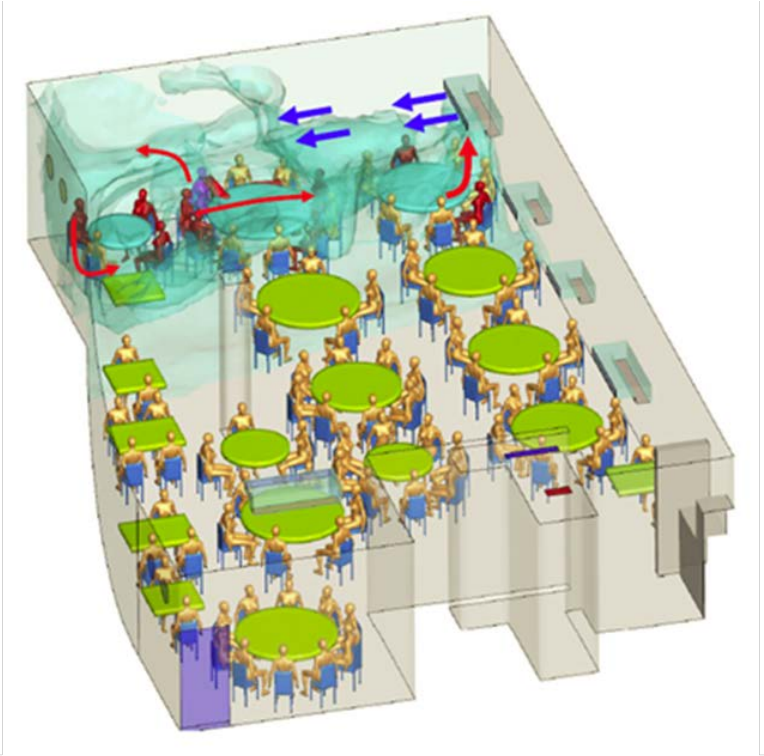
Building Readiness: Plan

- Building Readiness modes of operation for the building should include the following:
- Epidemic Operating Conditions in Place (ECiP)
  - Occupied- at pre-epidemic capacity
  - Occupied- at reduced capacity
  - Unoccupied temporarily, and
  - Operation during building closure for indefinite periods
- Post-Epidemic Conditions in Place (P-ECiP)
  - Prior to Occupying
  - Operational Considerations once Occupied

SARS-CoV-2 Transmission Evaluation

Guangzhou, CHN restaurant

- 10 of 21 diners at three tables
- Infected by 1 person
- Distance of up to 5m (16 feet)
- Poor ventilation and filtration



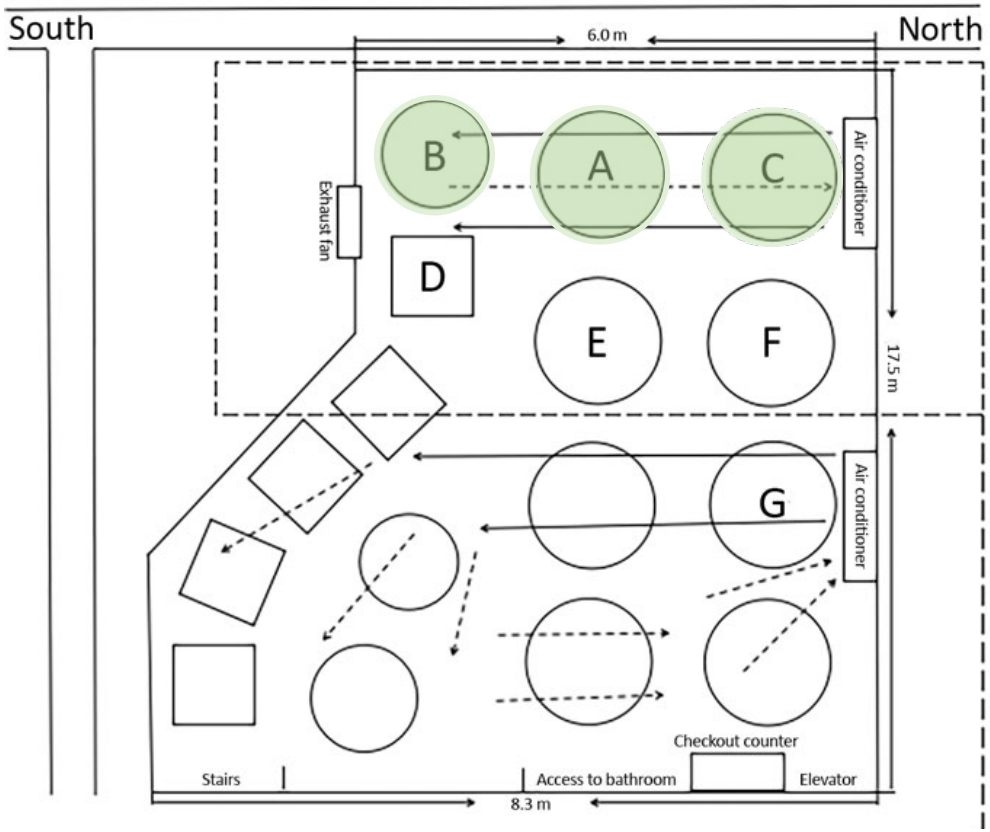
Li, et al. (2020) https://doi.org/10.1101/2020.04.16.20067728

SARS-CoV-2 Transmission Evaluation

Rule of thumb for indoor space:

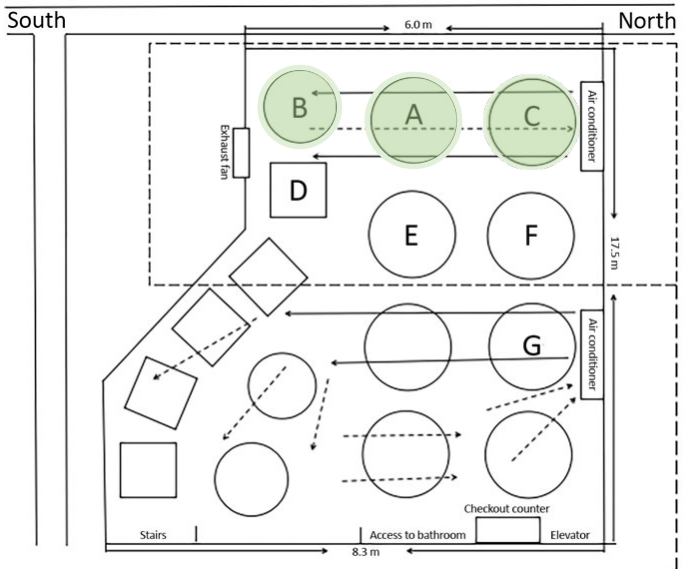
1. Outside Air? **Yes** (to code requirement and more)
2. MERV-13 filter? **Yes** (recirculation air)
3. Airflow direction? **Yes** (not blow from face of a person to others)

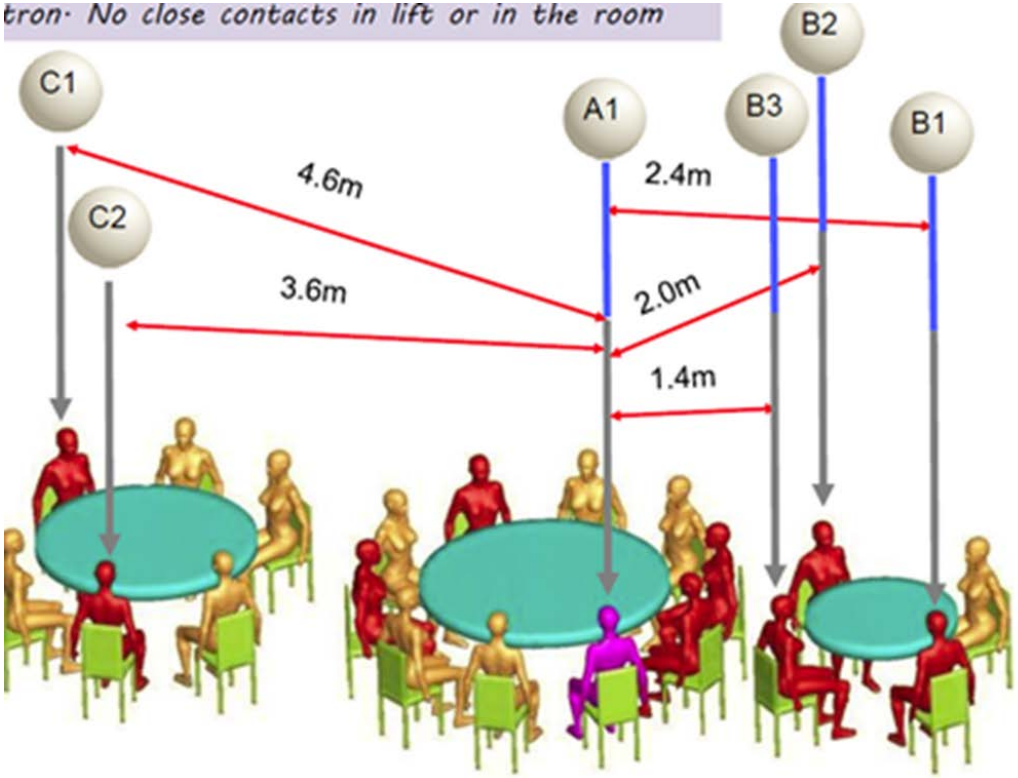
Guangzhou, CHN Restaurant Evaluation



- Outside Air? NO
- Filter > MERV-13? NO
- Airflow Direction? NO

Guangzhou, CHN Restaurant Evaluation





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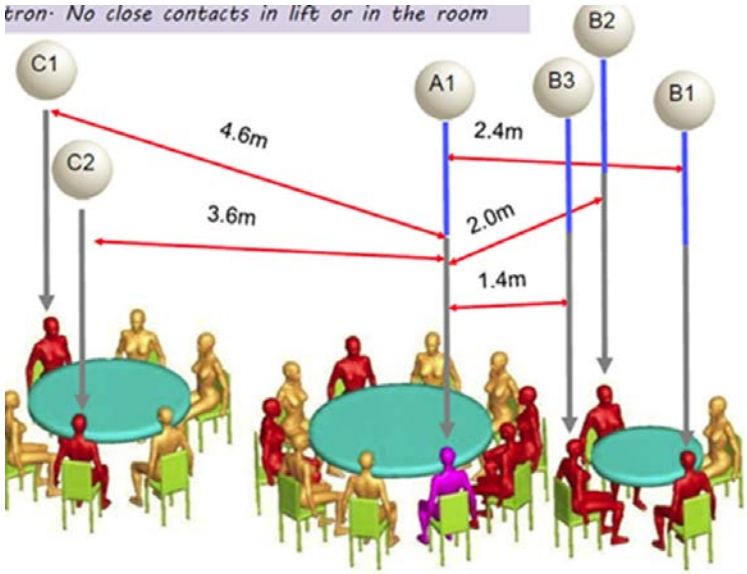
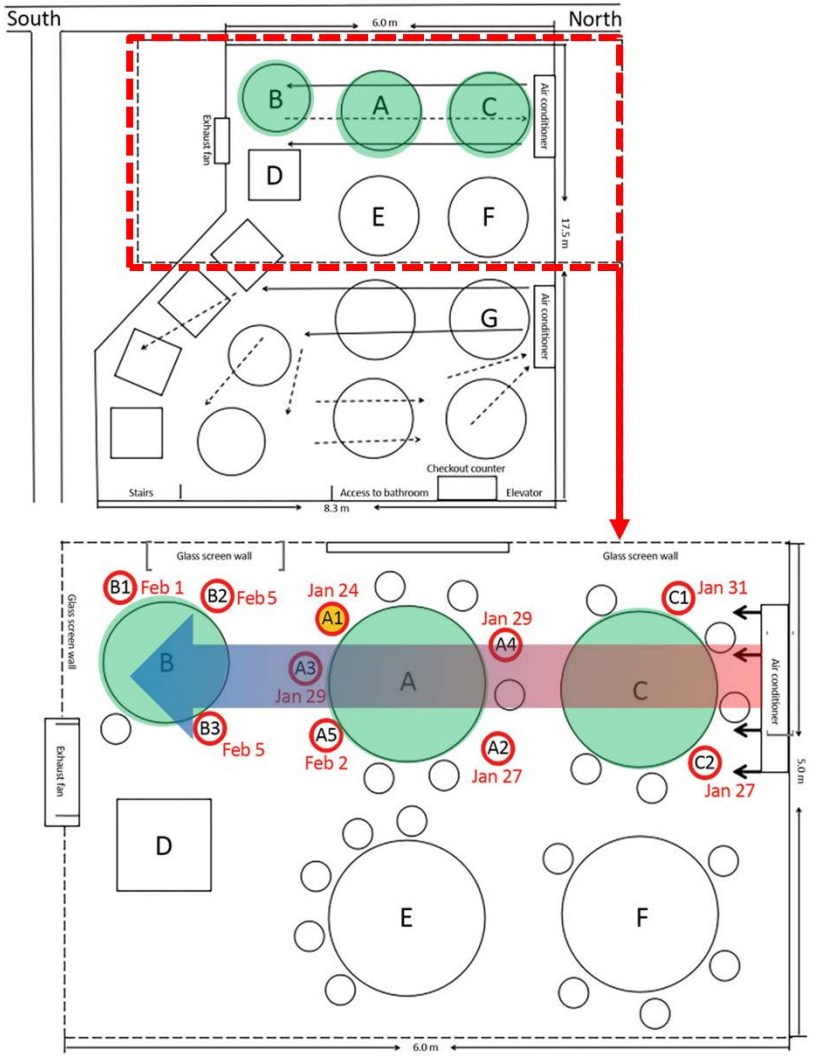
Guangzhou, CHN Restaurant Evaluation





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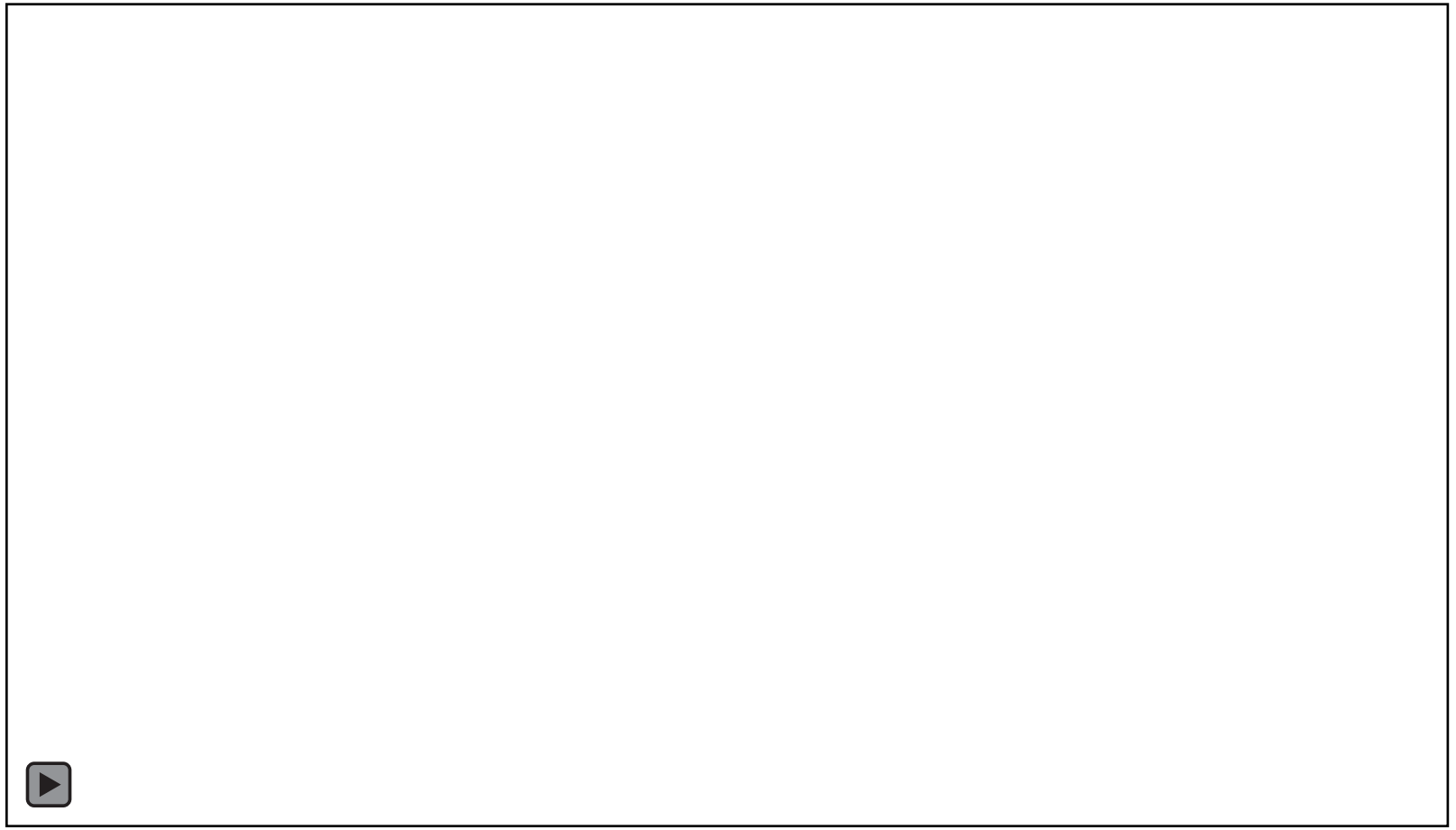
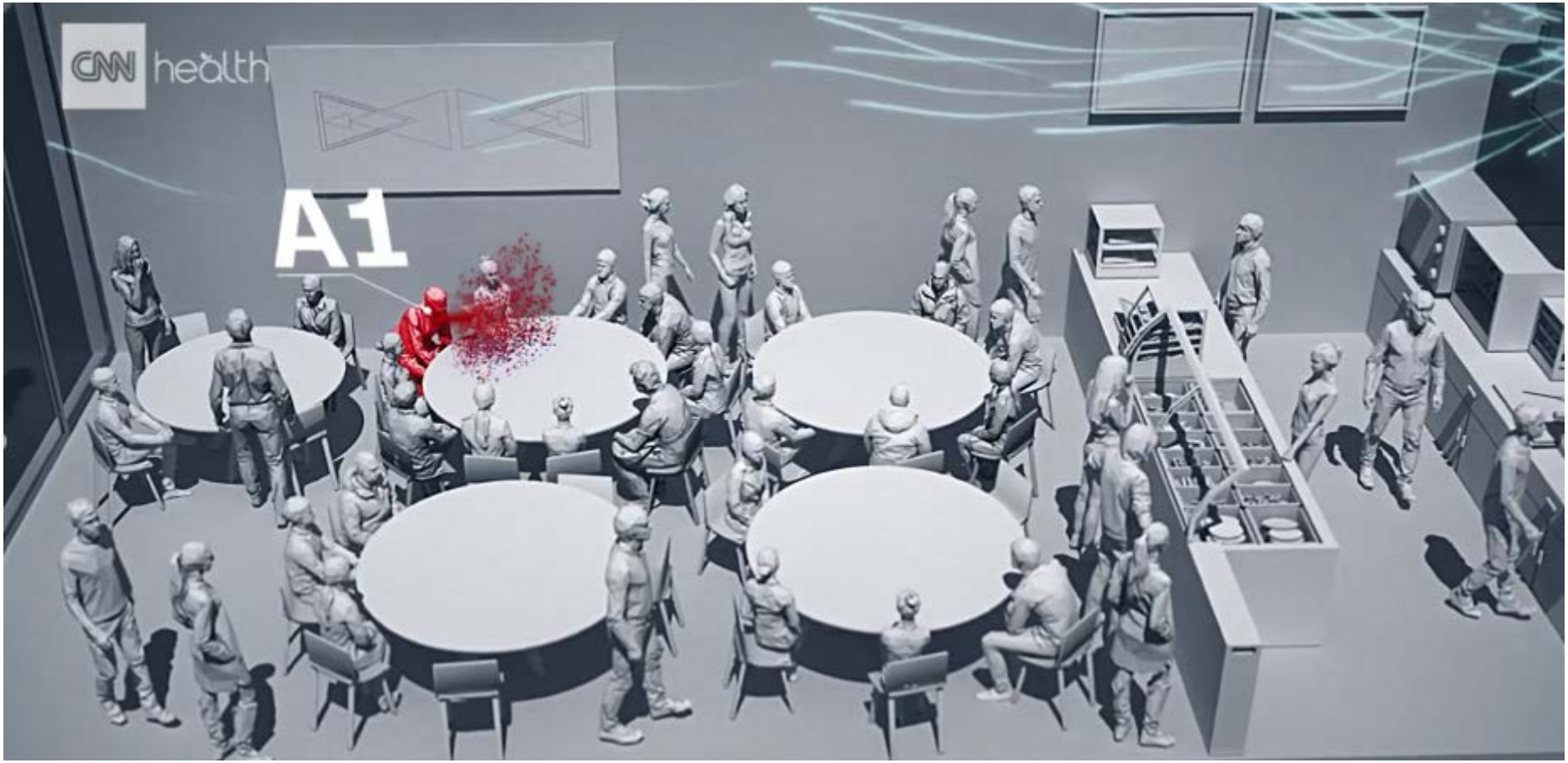
- Airflow Direction? NO

Guangzhou, CHN Restaurant Evaluation



Guangzhou, CHN Restaurant Evaluation



Guangzhou, CHN Restaurant Evaluation

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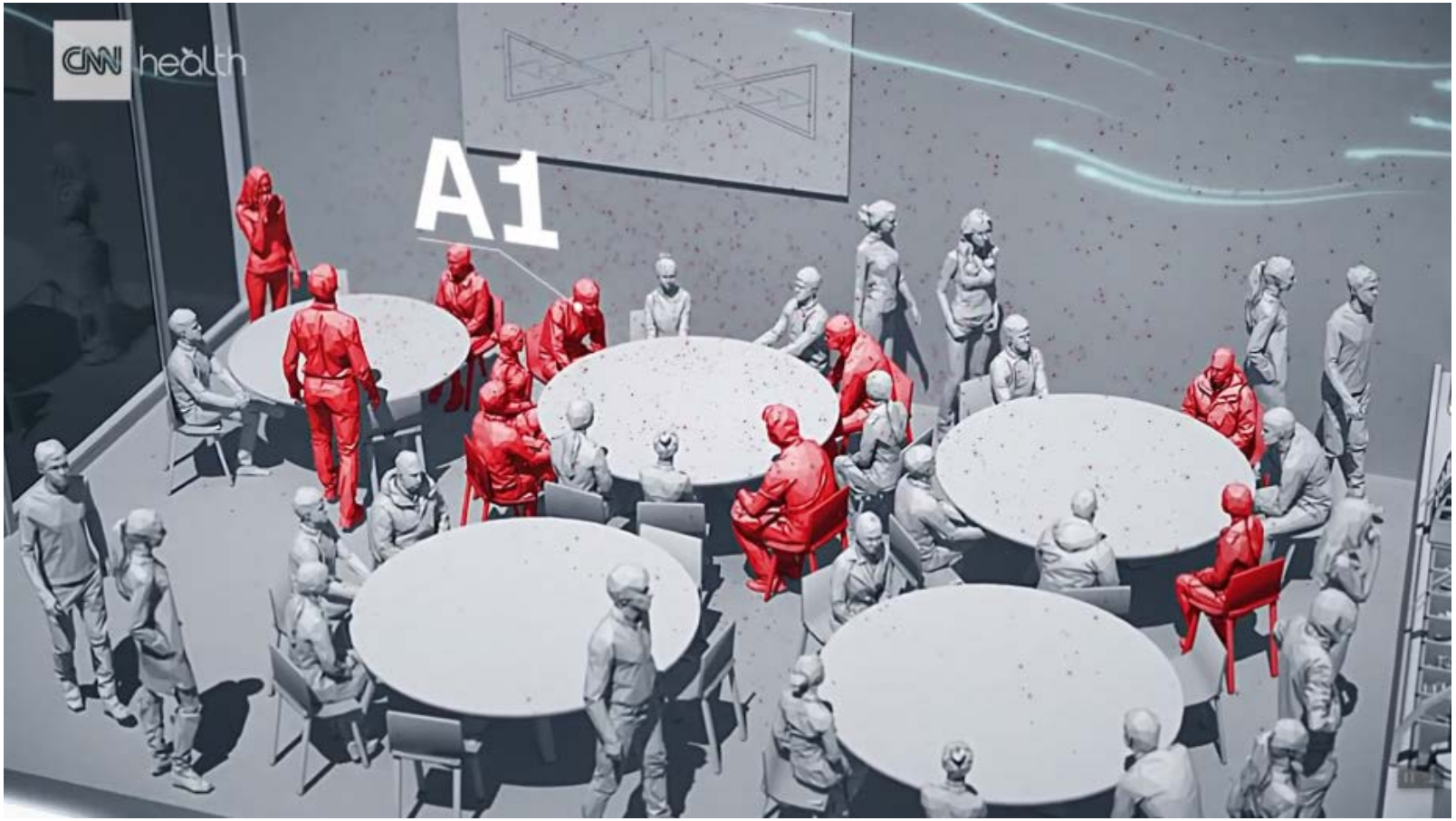
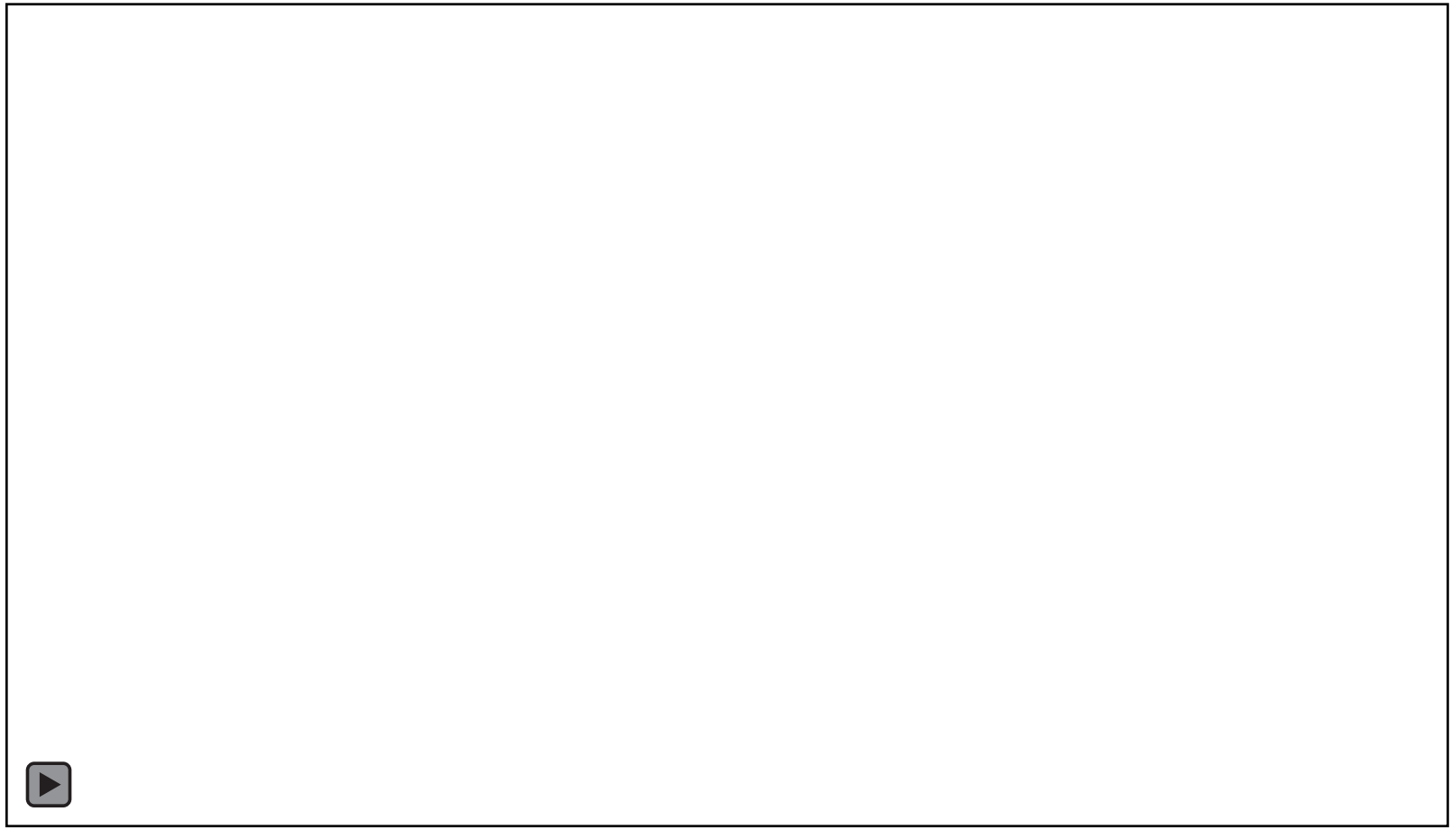


Guangzhou, CHN Restaurant Evaluation



Epidemic Conditions in Place (ECiP)

- Evaluate Existing Systems
- Mitigation Strategies
- Steps to Re-occupy Your Building

Epidemic Conditions in Place (ECiP)

"Houston, we have a problem"

(Erroneous quote attributed to Jack Swigert, Apollo 13)

Epidemic, Pandemic or Disaster Conditions Have Been Declared or Recognized to Exist

ECiP - Building Readiness Plan Systems Evaluation

- Gather Information
- Evaluate the Systems in Person
- Identify Deferred Maintenance
- Identify Mitigation Strategies
- Create a Work Plan
- Review with Stakeholders
- Implement

ECiP - Building Readiness Plan Systems Evaluation

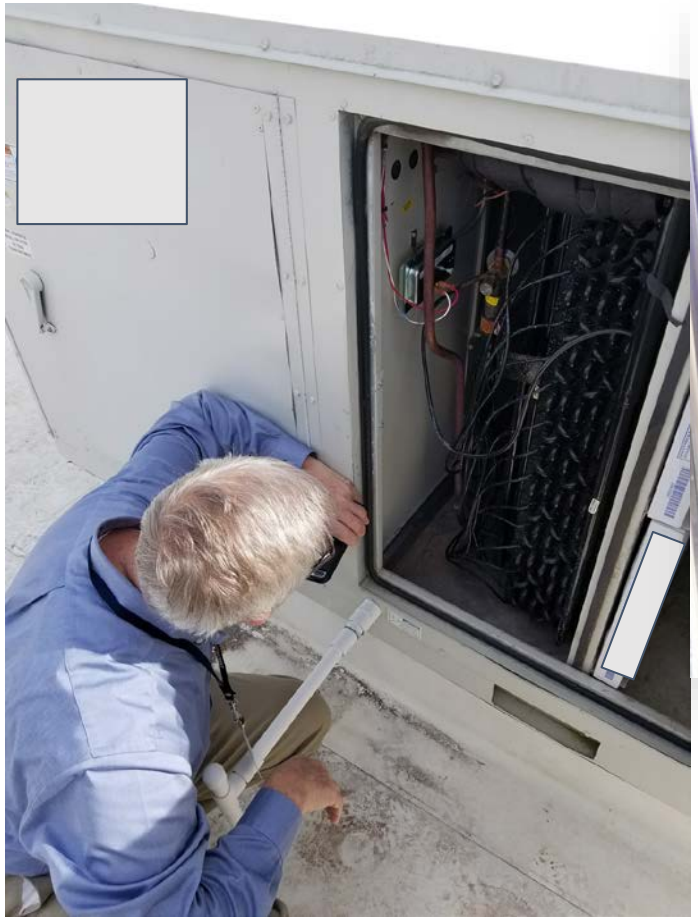
Gather as much documentation on the building as possible, such as:

- Most recent design documents, specifically HVAC and Plumbing systems
- Record documents, such as as-builts and specifications
- Equipment submittals
- Building Automation System (BAS) reports
- Recent TAB or Commissioning reports

ECiP - Building Readiness Plan Workflow

- Walk the facility with stakeholders
- Consult insurers, legal counsel as necessary
- Consult local, state and federal regulators, as necessary

ECiP - Building Readiness Plan Inspect Components & Systems

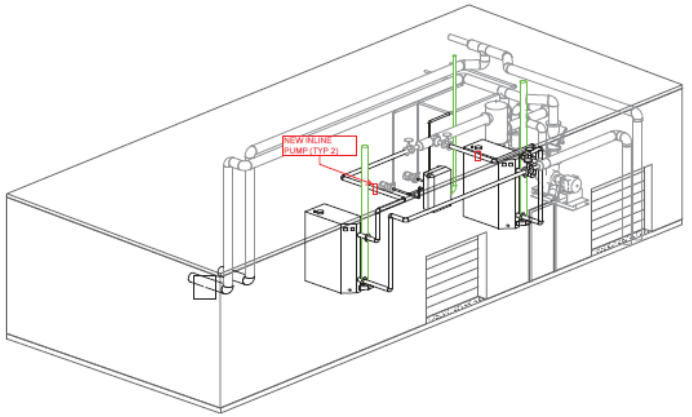


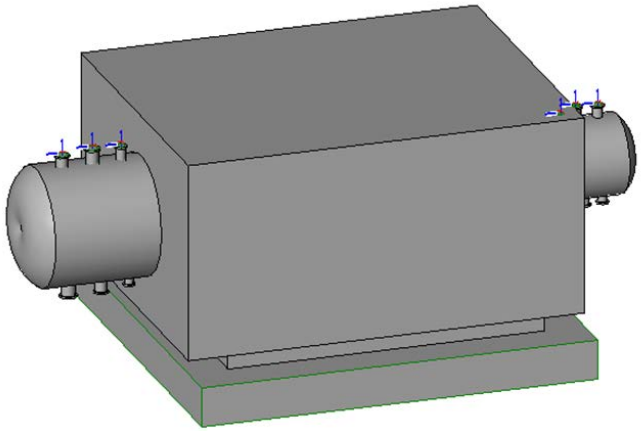
ECiP - Building Readiness Plan Inspect Components & Systems

- Air Handling Equipment
  - Coils
  - Filters
  - Air cleaning devices
  - Dampers
- Dedicated Outdoor Air Systems
  - Energy Recovery

ECiP - Building Readiness Plan HVAC System Types

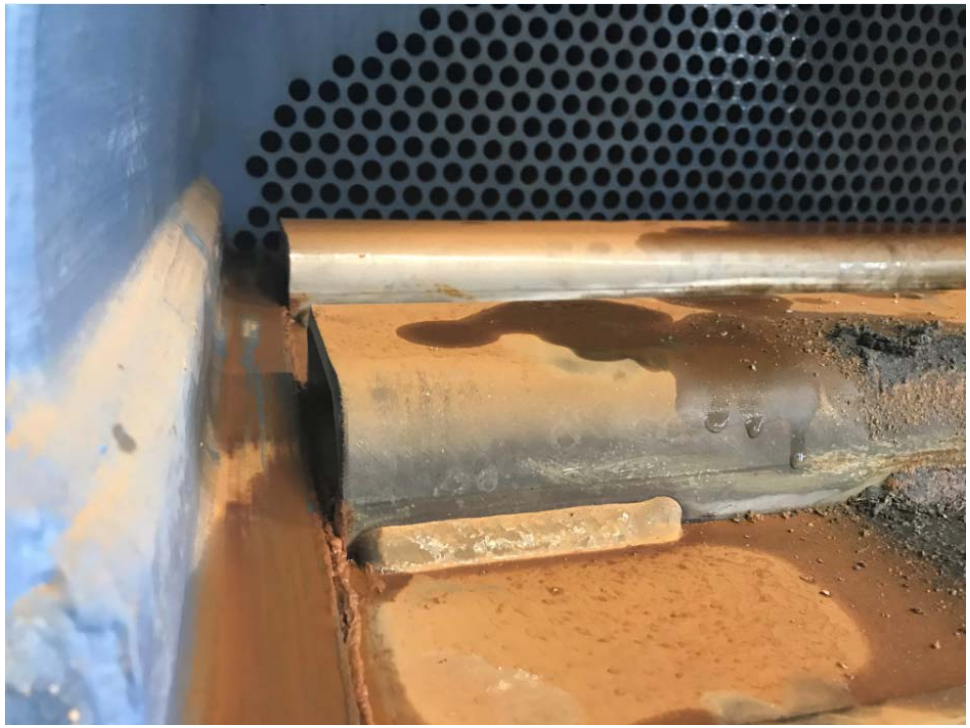
- Single Zone
  - Split Systems
  - Packaged Rooftop
- Multizone
  - Variable Air Volume (VAV)
  - Variable Refrigerant Flow (VRF)
  - Fan Coil Units
- All Air
- Air Distribution Devices



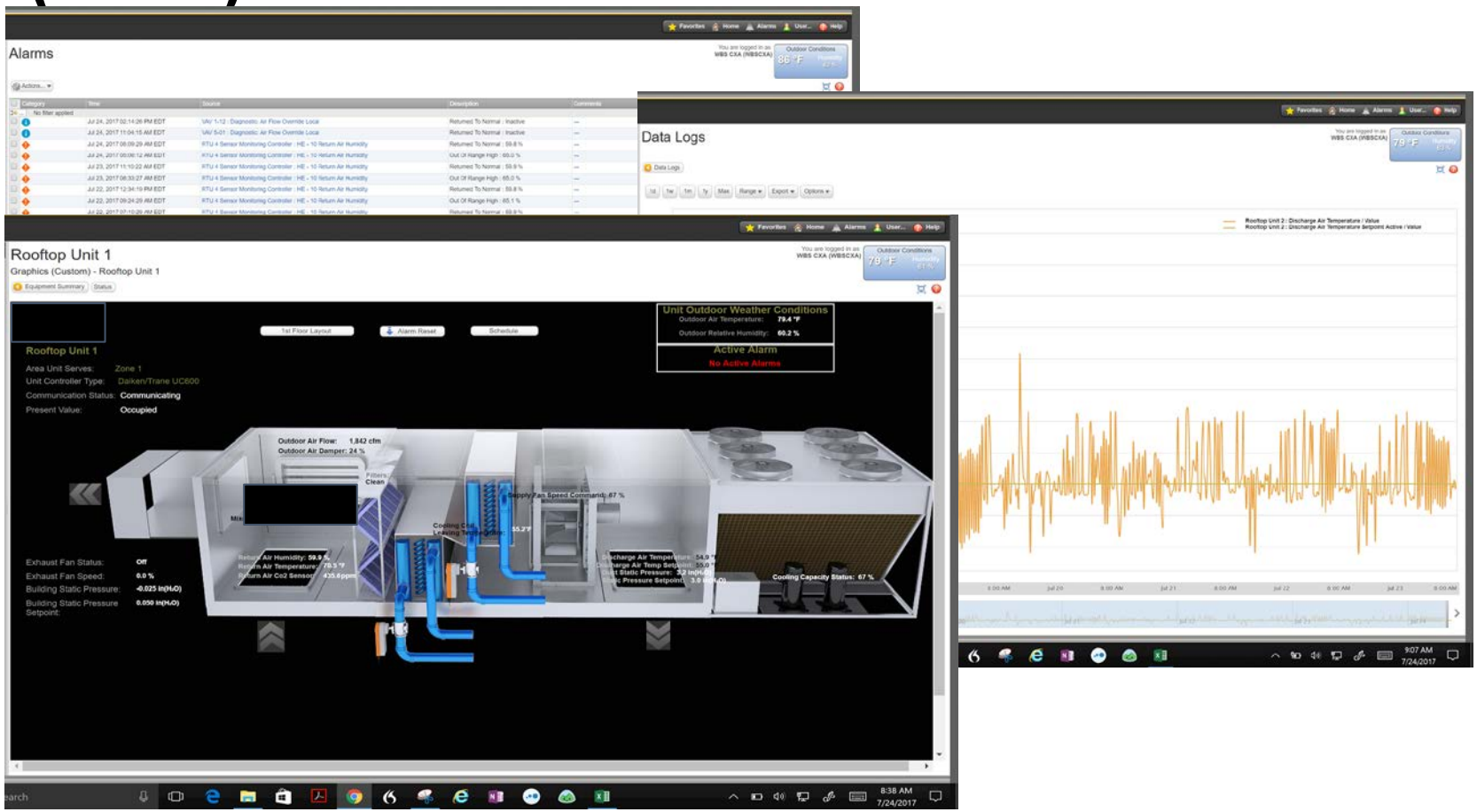


ECiP - Building Readiness Plan HVAC System Types

- Water Distribution Systems
  - Chilled Water
    - Chillers
    - Cooling Towers
    - Pumps
    - Water Treatment
  - Heating Hot Water
    - Boilers
    - Pumps
    - Water Treatment
- Steam
  - Boilers
  - Water Treatment



ECiP - Building Readiness Plan Building Automation Systems (BAS)



ECiP - Building Readiness Plan BAS (cont'd)

- Print out current values set points and adjustable values from BAS (hard copy and PDF) prior to changes
- Perform complete backup of BAS and equipment controller settings and history prior to changes
- Store backups offsite and in secure Cloud Storage
- Setup and verify remote access to BAS is working and secure (work with IT, if appropriate)

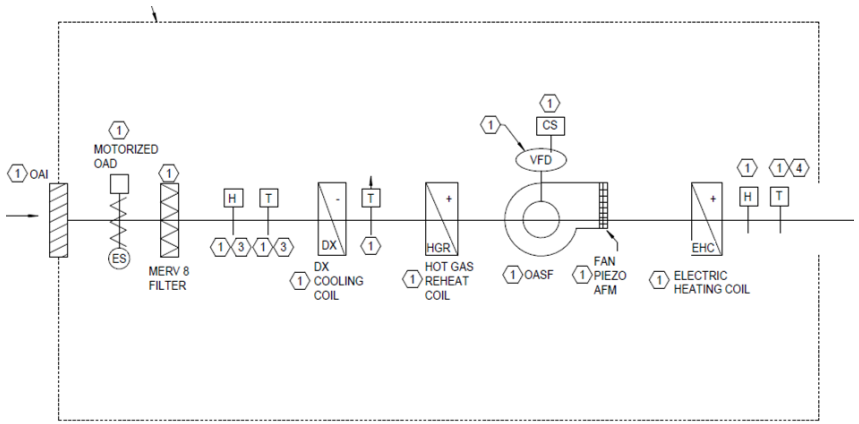
ECiP - Document the Work Plan Log All Deficiencies

Issue Log	
Tag	Issue
RTU-1	Broken Condensate Drain Line
RTU-1	OA Damper Frozen Closed
Nurses Office	Pressurization appears to be positive

ECiP- Mitigation Strategy Evaluation

- Ventilation
- Filtration
- Temperature and humidity control
- Air distribution
- Disinfection

ECiP - Building Readiness Plan
BAS- Sequences of Operation



INPUT/OUTPUT SUMMARY
VAU-1 THROUGH VAU-4

	INPUTS									OUTPUTS				FEATURES									
	DIGITAL			ANALOG						DIGITAL			ANALOG	ALARM			ENERGY MGMT						
	UNIT GRAPHIC DISPLAY	STATUS (PERCENT SPEED)	END SWITCH	CURRENT SENSING RELAY	TEMPERATURE	RELATIVE HUMIDITY	AIR FLOW	RUN TIME	SUPPLY FAN VFD FEEDBACK	START/STOP	OPEN/CLOSE	BAS CONTROL	DAMPER POSITION	FAN SPEED	STATUS/INTERLOCK	HIGH/LOW LIMIT	RUN TIME TOTALIZATION	FAULT (VFD)	OPTIMUM START/STOP	DAY/NIGHT SETBACK	OCCUPIED/UNOCCUPIED	BAS TREND	FAILURE MODE (SEE NOTES 1 AND 2)	NOTES
OUTSIDE AIR DAMPER	X		X							X		X										C	2
OUTDOOR AIR SUPPLY FAN START/STOP	X									X								X	X	X	X	O	
OUTDOOR AIR SUPPLY FAN STATUS	X	X		X				X					X	X								X		
OUTDOOR AIR SUPPLY FAN VFD	X								X			X						X				X	C	2
FAN PIEZO AFM AIRFLOW	X						X															X		
OUTSIDE AIR TEMPERATURE	X				X																	X		
OUTSIDE AIR RELATIVE HUMIDITY	X					X																X		
COOLING COIL LEAVING AIR TEMPERATURE	X				X										X							X		
UNIT DISCHARGE RELATIVE HUMIDITY	X					X									X							X		
UNIT DISCHARGE AIR TEMPERATURE	X				X										X							X		
UNIT DISCHARGE AIR DEW POINT TEMP (CALCULATED)	X														X							X		
GLOBAL CO2 LEVEL/OA TEMP/RH	X																					X		
COMPRESSOR UTILIZATION	X	X										X				X			X	X		X	C	2

- Develop Sequences of Operation for
  - Normal Occupied Mode
  - Normal Unoccupied Mode
  - Emergency shutdown
  - Partial shutdown
  - Starting back up after an event – re-occupancy
  - Alarms

ECiP- Document the Work Plan

- Identify issues between existing systems' operation and design intent
- Identify the deferred maintenance to be done
- Identify the mitigation strategies to implement
- Detail any design modifications or component additions needed
- List all changes being proposed to BAS
- Identify existing alarm settings to be adjusted for the "epidemic" normal

ECiP- Building Readiness Plan

- Identify the mitigation strategies to be used
  - HVAC
  - Non-HVAC
- Identify the mode of operation for the system and building
  - Include people loading percentage
  - Pre- and post-flush calculation or approach
  - How DCV will be disabled
- Identify maintenance concerns and issues
- Identify emergency mode of operations for people

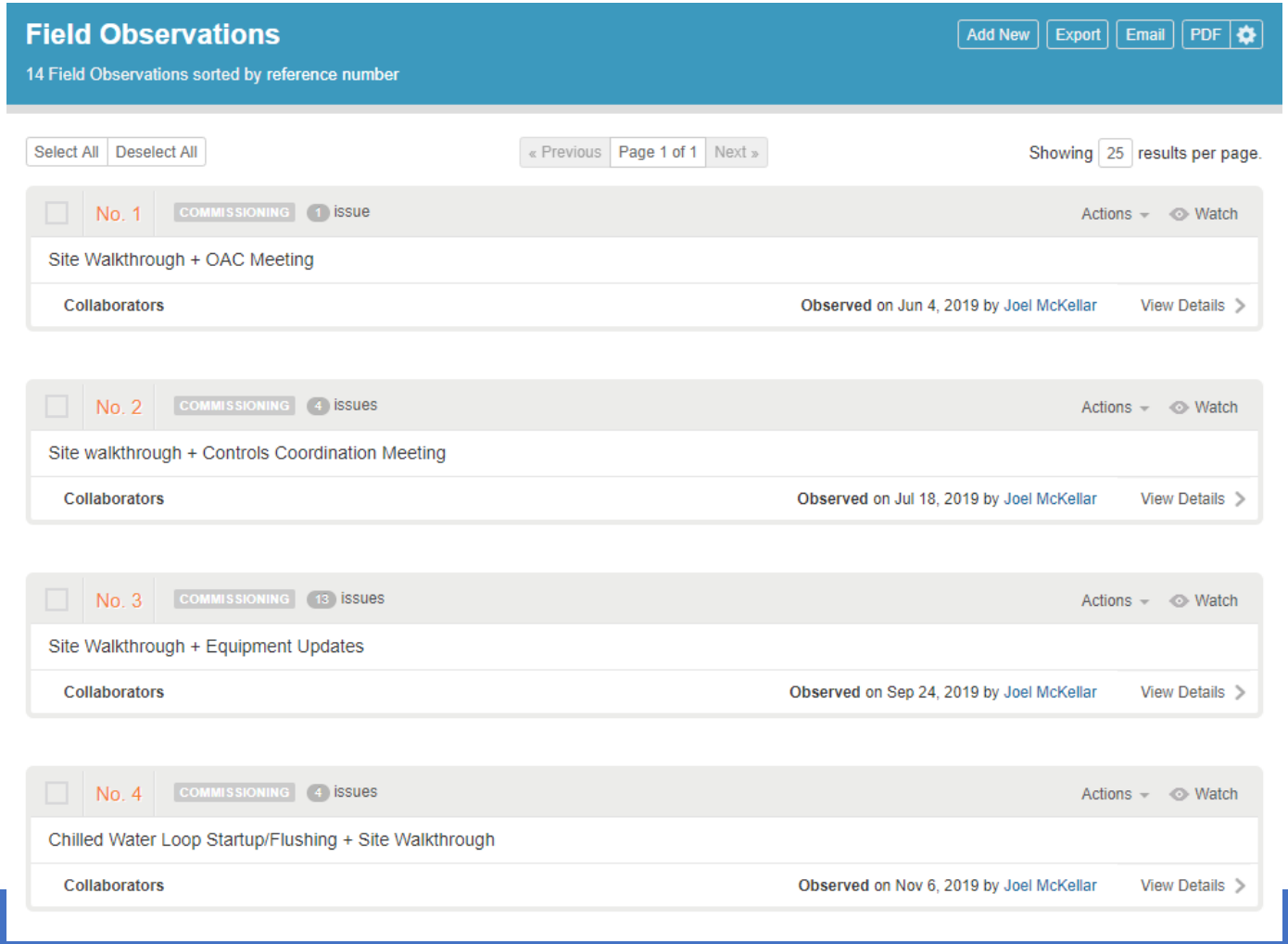
ECiP - Execute the Plan

Plan		
Tag	Issue	Priority
RTU-1	Repair Condensate Drain Line	3
RTU-1	Repair Frozen OA Damper	1
AHU-1	Upgrade Filters to MERV 13	2
Nurses Office	Balance to a negative pressure	1

ECiP - Document the Work Plan Work Orders

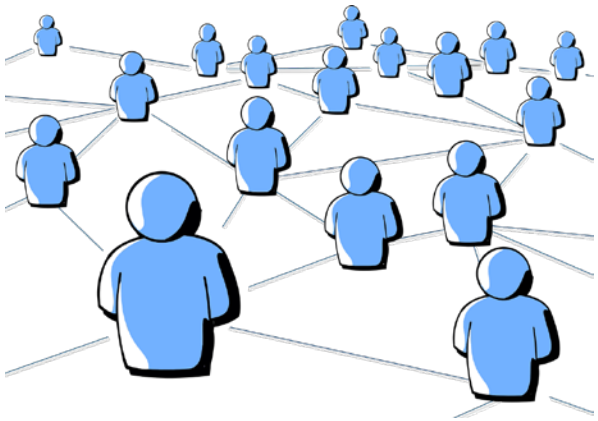
- Collaborate with stakeholders to plan for modifications to operations
- Make small changes at a time
- Continue routine and scheduled maintenance

ECiP - Communicate the Plan Keep Good Records



ECiP - Communicate the Plan!

- Communicate
  - Clear, concise, correct and complete
  - Prefer written- email or text
  - Phone (follow-up email)
  - Meetings
- Document
  - If It's Important - Write it down!
- Follow Up
  - Don’t set yourself up for failure

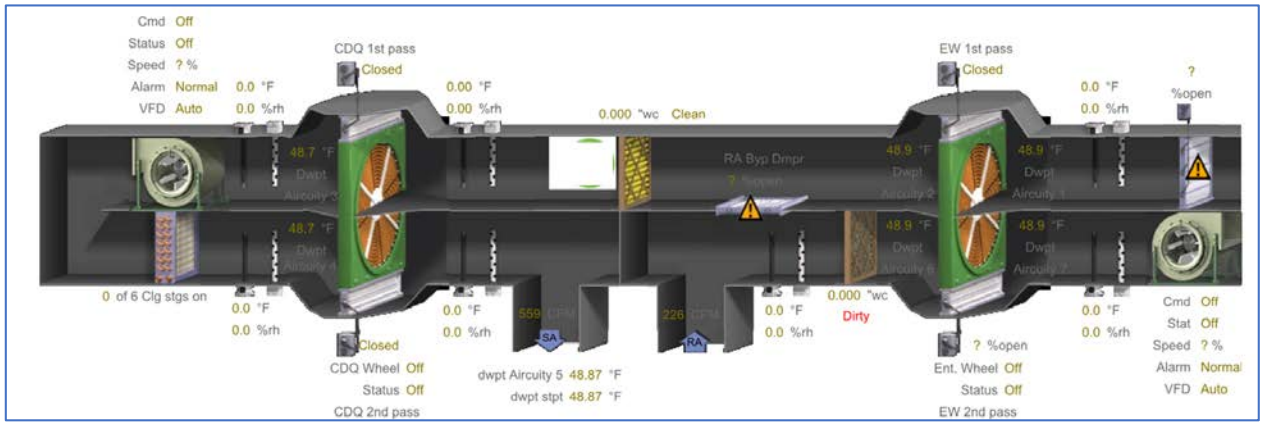


Epidemic Conditions in Place (ECiP)

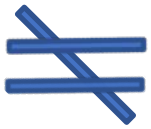
- Evaluate Existing Systems
- Mitigation Strategies
- Steps to Re-occupy Your Building

ECiP- Engineering Controls

- Ventilation
- Filtration
- Temperature and humidity control
- Air distribution
- Disinfection



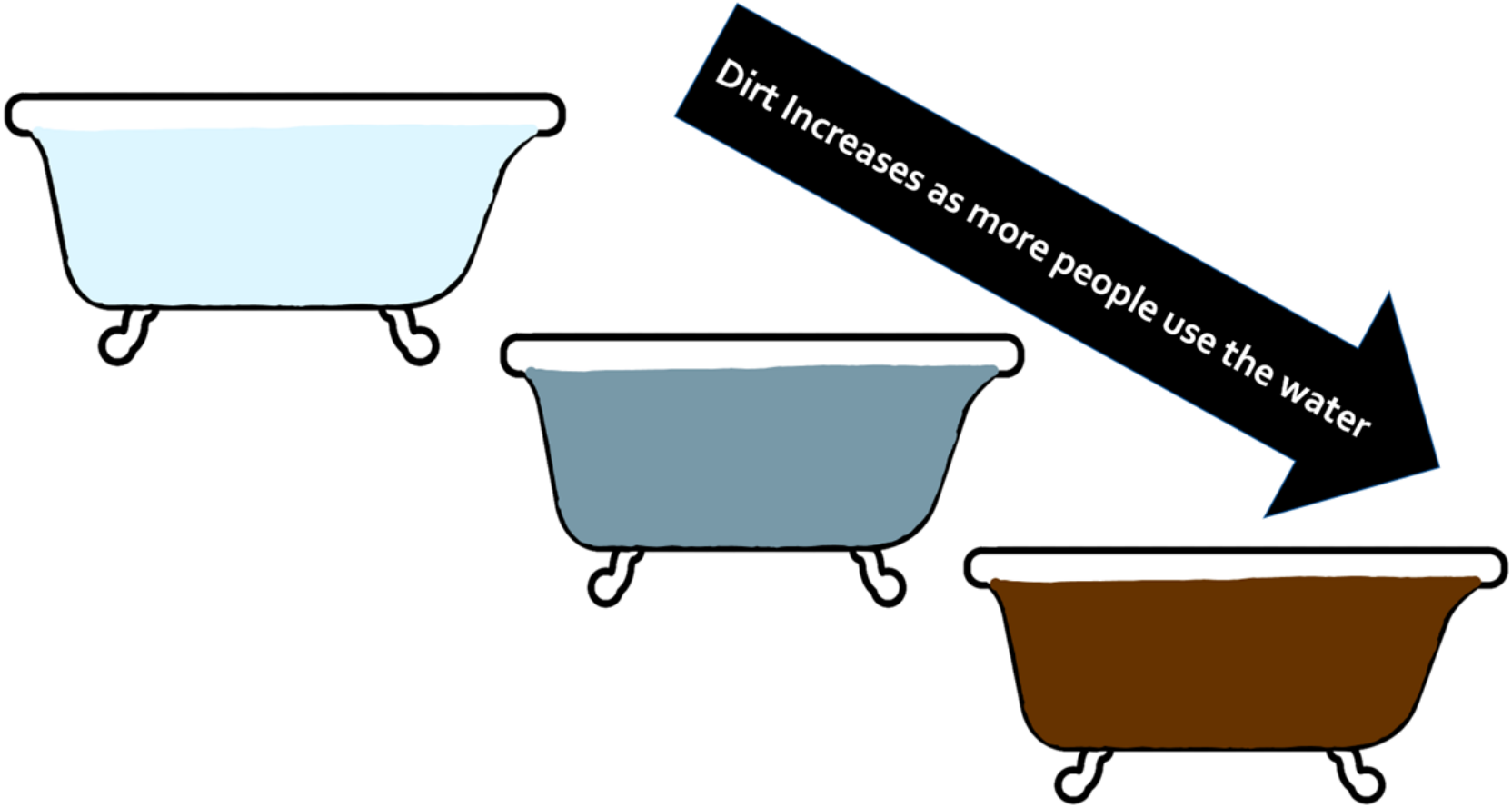
ECiP- Engineering Controls

Mitigate  Eliminate

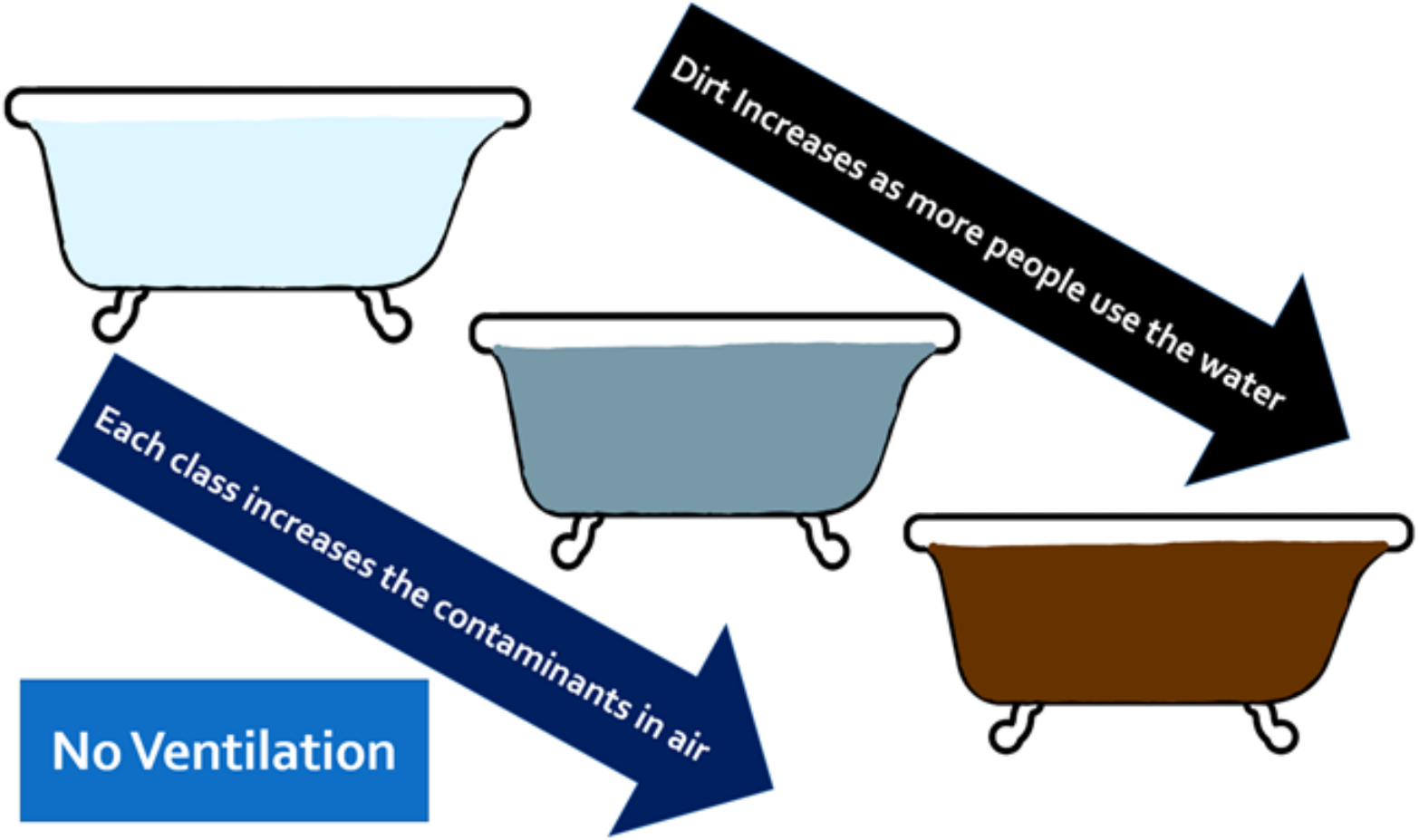
ECiP- Engineering Controls Can We Increase Ventilation?

- Encourage building owners/ operators to increase ventilation air
  - without causing new issues
- Possibly let room design temperature setpoint slide a little
  - More outside air can be distributed into the space
- Check coil cleanliness
- Evaluate additional capacity available
- Can add control programming at BAS
- Disable Demand Controlled Ventilation*

ECiP- Engineering Controls Ventilation per Design / Code



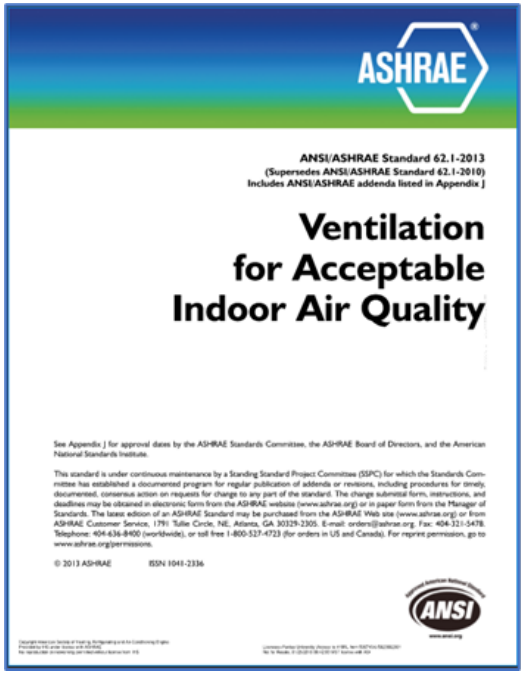
ECiP- Engineering Controls Ventilation per Design / Code

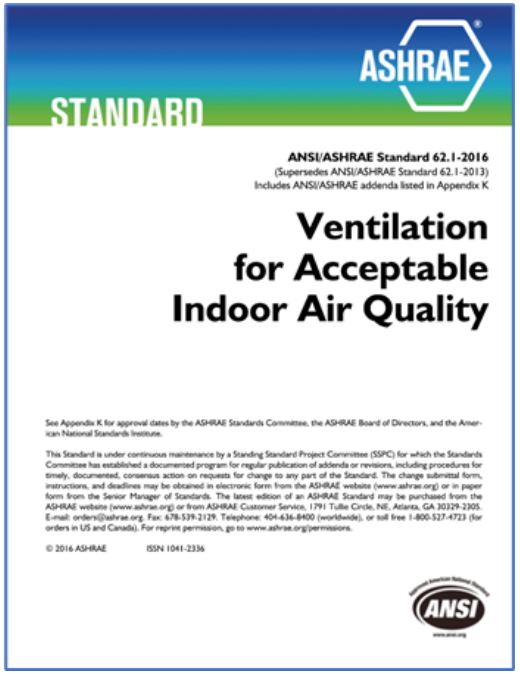


ECiP- Engineering Controls Ventilation per Design / Code

ECiP- Engineering Controls Ventilation per Design / Code

- ASHRAE Standard 62.1 – Ventilation for Acceptable Indoor Air Quality





ECiP- Engineering Controls Can We Increase Ventilation?

- Cooling:
  - Inadequate Capacity for Sensible Cooling
  - Inadequate Capacity for Latent Cooling (dehumidification)
- Heating:
  - Inadequate Capacity for Heating
    - Potential for frozen coils or other system damage
  - Increased humidification loads in humidified buildings

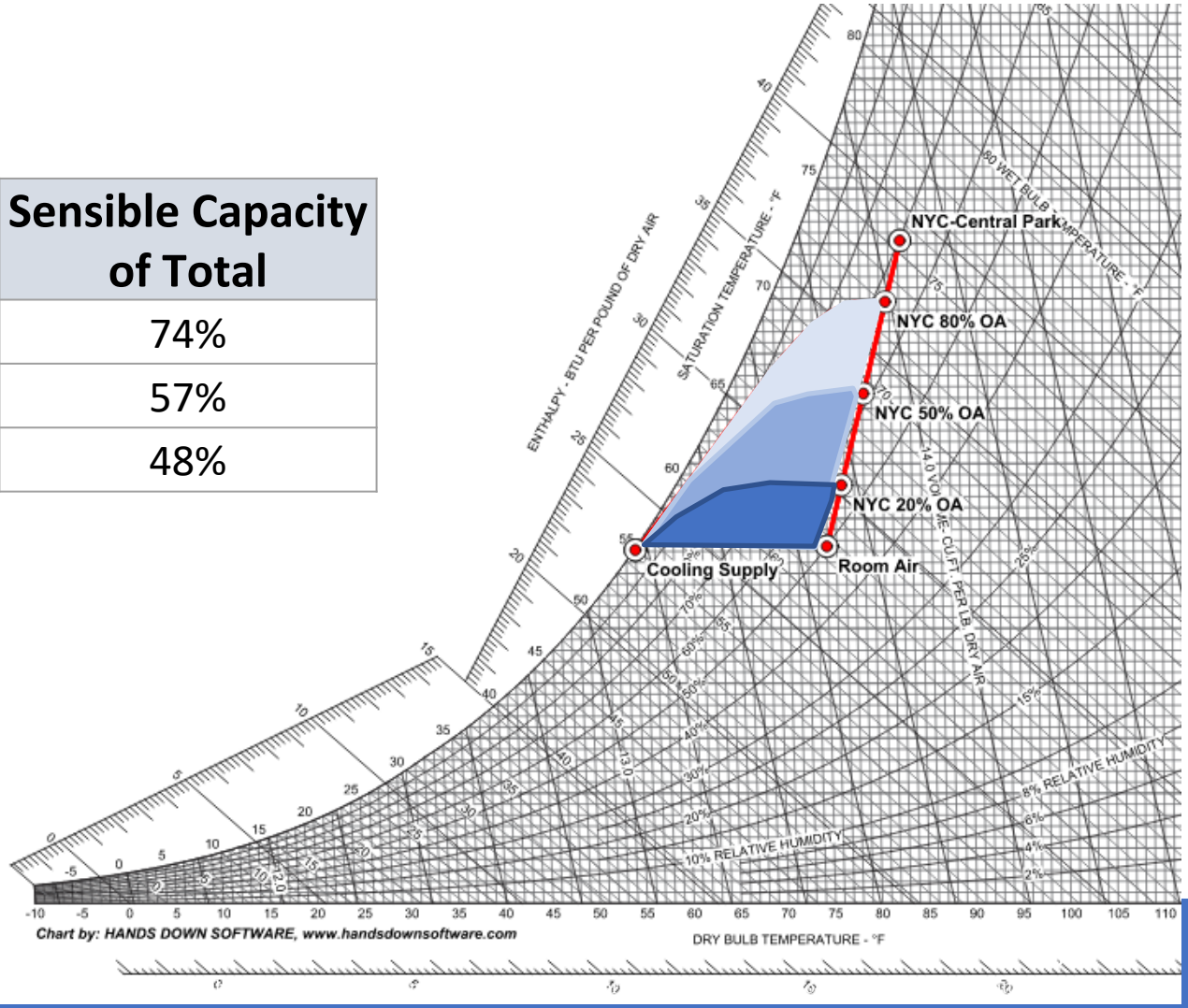
ECiP- Engineering Controls Impact on Coil

- 10,000 CFM unit
- 44F CHW
- 12F delta
- 52F SA
- 78F RA
- 60% RA
- 88F MCDB
- 80F WB
- 8 row
- 126 FPI

Percent OA	EAT DB / WB	CHW GPM	Coil Pressure Drop (Ft H2O)	Total Capacity (MBH)	Sensible Capacity (MBH)
20	78.43 / 69.31	88.64	7.06	541.29	292.45
30	79.64 / 70.80	95.82	8.14	596.98	306.33
40	80.84 / 72.64	107.15	9.99	671.74	320.33
50	82.04 / 73.64	113.49	11.10	712.95	333.99
60	83.24 / 75.00	121.01	12.49	768.22	347.89
70	84.44 / 76.30	131.79	14.61	826.98	361.82
80	85.63 / 77.57	139.60	16.24	881.63	375.69
90	86.81 / 78.80	151.96	18.99	941.36	389.49

ECiP- Engineering Controls Impact on Coil

OA%	Load Increase %	Sensible Capacity of Total
20%	N/A	74%
50%	45%	57%
80%	90%	48%



ECiP- Engineering Controls
Can We Increase Ventilation?

- Use Increased OA instead of Supply Temperature Reset
  - Requires BAS
  - Monitor RH or Dewpoint
  - Requires programming update
- Twist on Economizer Mode

ECiP- Engineering Controls Flushing Calculations

- One air change = $c / C_0 = exp^{-1} = 0.368$
- Three air changes = $c / C_0 = exp^{-3} = 0.050$
- Therefore, three air changes result in the removal of 95% of the contaminants in the space for a well mixed system
- Assumptions:
  - V = Volume
  - Q_t = Total air flow
  - c = space concentration
  - C (t=0) = C_0
  - $C_{OA} = 0$
  - N = number of air changes
  - ACH is outdoor airflow rate in air changes per hour
  - t[h] = hours for pre- and post-flush

https://www.ashrae.org/technicalng-readiness#prepostflush

ECiP- Engineering Controls Flushing Calculations

$$VdC = \left(QC_O - QC\right)dt$$

Outdoor air concentration is zero so

$$VdC = -QCdt$$

$$\frac{dC}{C} = -\frac{Q}{V}dt$$

$$\int_{C_0}^{C}\frac{dC}{C} = -\int_{0}^{t}\frac{Q}{V}dt$$

$$\ln\left(C\right) - \ln\left(C_O\right) = -\frac{Qt}{V}$$

$$\frac{C}{C_O} = \exp\left(-\frac{Qt}{V}\right) = \exp\left(-N\right)$$

Where N = number of air changes

Time for N air changes:

$$N = \frac{Qt}{V}$$

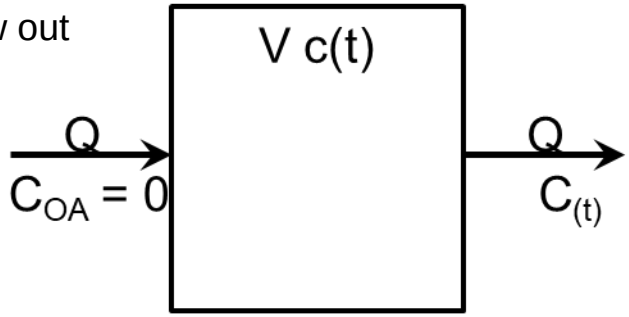
$$t = \frac{N}{Q/V}$$

$$t\left[h\right] = \frac{N}{ACH}$$

Where ACH is the outdoor air flow rate in air changes per hour (ACH)

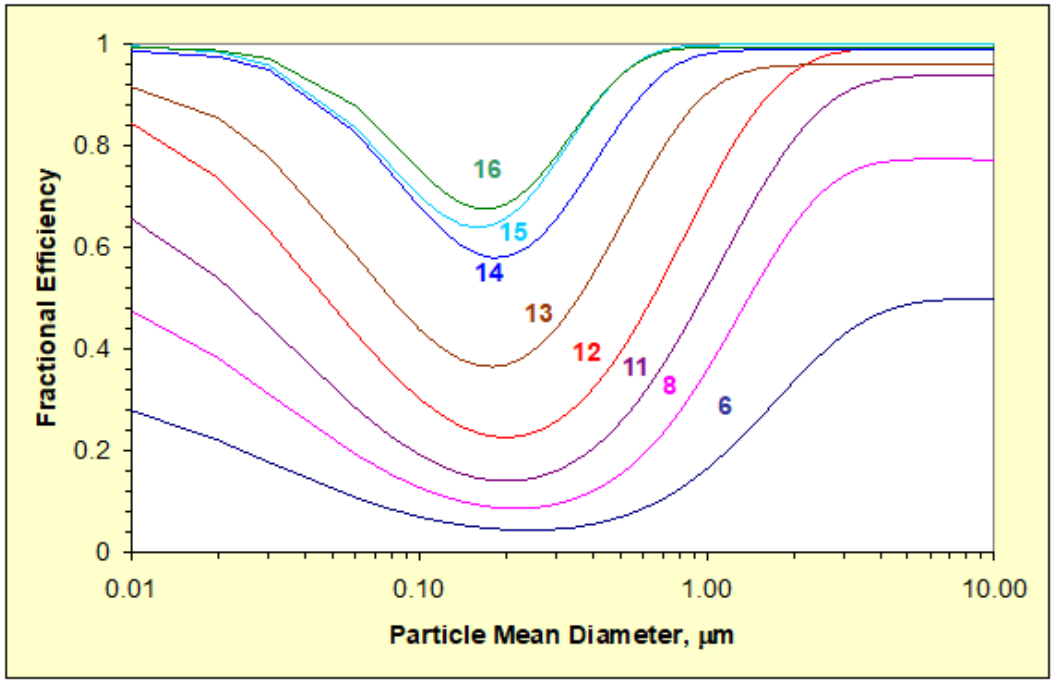
Change of contaminant in space is equal to flow of contaminant in minus flow of contaminant out during a time interval dt

Flow in – Flow out



ECiP- Design Consideration
Can We Increase Filtration?

- Most buildings have MERV 6 or MERV 8 filters
- ASHRAE recommends using filters that are MERV 13 or MERV 14



Approximate Equivalent Ratings for Filters Tested Under ASHRAE Standard 52.2 (MERV) and ISO 16890	
ASHRAE MERV * (Standard 52.2)	ISO 16890 Rating
1-6	ISO Course
7-8	ISO Course >95%
9-10	ePM_{10}
11-12	$ePM_{2.5}$
13-16	ePM_1

Representative MERV rated filter performance. (Kowalski and Bahnfleth 2002)

ECiP- Design Consideration MERV or MERV-A

Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm			
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0	Average Arrestance, %
1	N/A	N/A	$E_3 < 20$	$A_{avg} < 65$
2	N/A	N/A	$E_3 < 20$	$65 \le A_{avg}$
3	N/A	N/A	$E_3 < 20$	$70 \le A_{avg}$
4	N/A	N/A	$E_3 < 20$	$75 \le A_{avg}$
5	N/A	N/A	$20 \le E_3$	N/A
6	N/A	N/A	$35 \le E_3$	N/A
7	N/A	N/A	$50 \le E_3$	N/A
8	N/A	$20 \le E_2$	$70 \le E_3$	N/A
9	N/A	$35 \le E_2$	$75 \le E_3$	N/A
10	N/A	$50 \le E_2$	$80 \le E_3$	N/A
11	$20 \le E_1$	$65 \le E_2$	$85 \le E_3$	N/A
12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$	N/A
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$	N/A
14	$75 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
15	$85 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	N/A

Table J-2 KCl Conditioned Per Appendix J Minimum Efficiency Reporting Value (MERV-A) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV-A)	Composite Average Particle Size Efficiency, % in Size Range, µm			
	Range 1 (0.30 to 1.0 µm)	Range 2 (1.0 to 3.0 µm)	Range 3 (3.0 to 10.0 µm)	Average Arrestance, %
1-A	N/A	N/A	E_3-A < 20	$A_{avg} < 65$
2-A	N/A	N/A	E_3-A < 20	$65 \le A_{avg}$
3-A	N/A	N/A	E_3-A < 20	$70 \le A_{avg}$
4-A	N/A	N/A	E_3-A < 20	$75 \le A_{avg}$
5-A	N/A	N/A	$20 \le E_3$-A	N/A
6-A	N/A	N/A	$35 \le E_3$-A	N/A
7-A	N/A	N/A	$50 \le E_3$-A	N/A
8-A	N/A	$20 \le E_2$-A	$70 \le E_3$-A	N/A
9-A	N/A	$35 \le E_2$-A	$75 \le E_3$-A	N/A
10-A	N/A	$50 \le E_2$-A	$80 \le E_3$-A	N/A
11-A	$20 \le E_1$-A	$65 \le E_2$-A	$85 \le E_3$-A	N/A
12-A	$35 \le E_1$-A	$80 \le E_2$-A	$90 \le E_3$-A	N/A
13-A	$50 \le E_1$-A	$85 \le E_2$-A	$90 \le E_3$-A	N/A
14-A	$75 \le E_1$-A	$90 \le E_2$-A	$95 \le E_3$-A	N/A
15-A	$85 \le E_1$-A	$90 \le E_2$-A	$95 \le E_3$-A	N/A
16-A	$95 \le E_1$-A	$95 \le E_2$-A	$95 \le E_3$-A	N/A

ECiP- Design Consideration Can We Increase Filtration?

- Concerns over the change in filter
  - Filter rack depth
  - Leakage of the frame
  - Impact on Fan Capacity
  - Additional Energy Use

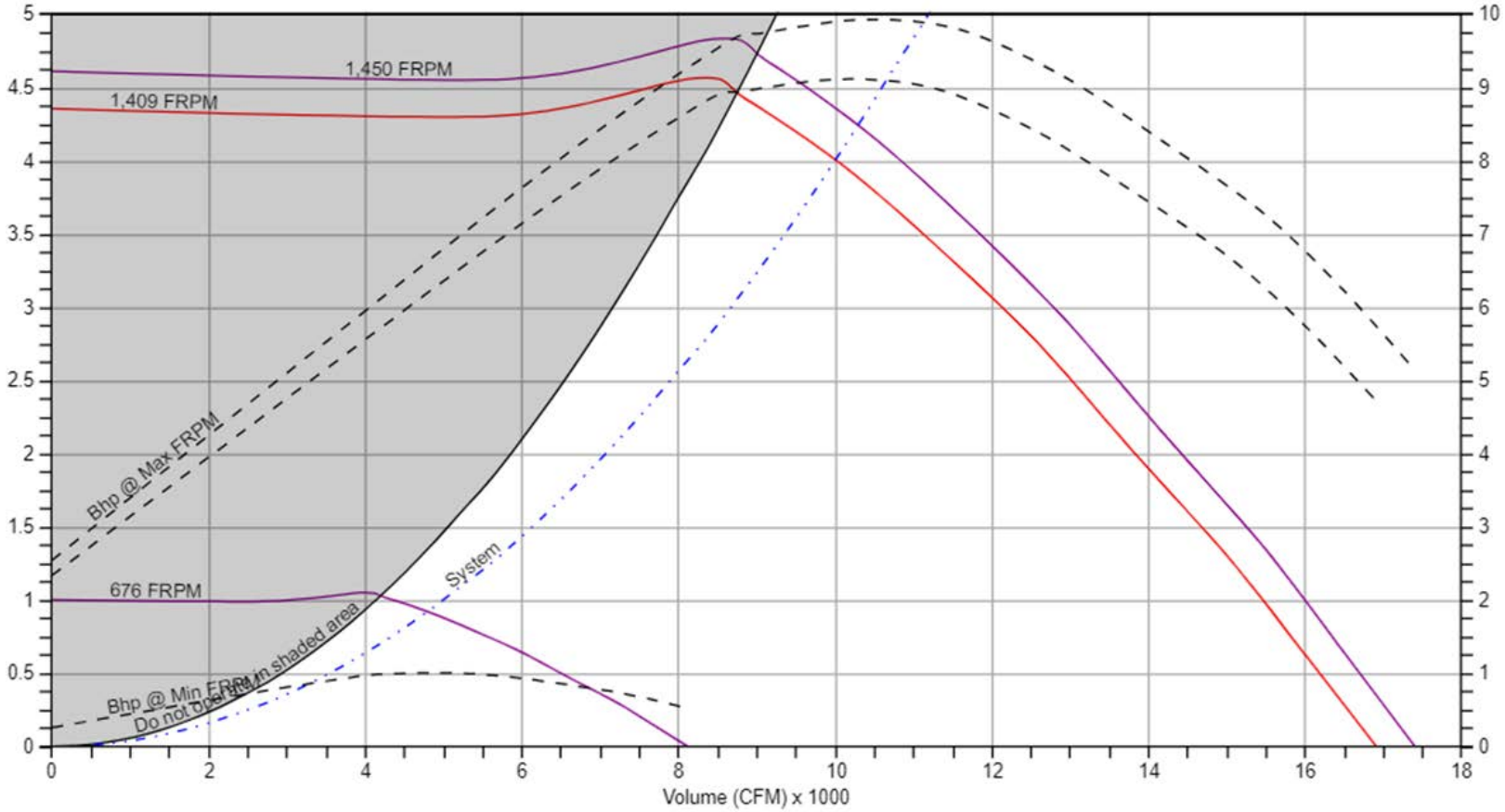
Frame Leakage Impact

Table 5: Effective MERV ratings with bypass included

Filter	1 mm gap, 2 bends	1 mm gap, 0 bends	10 mm gap, 2 bends	10 mm gap, 0 bends
MERV 6	6	6	5	<5
MERV 11	11	11	8	8
MERV 15	14	14	8	8

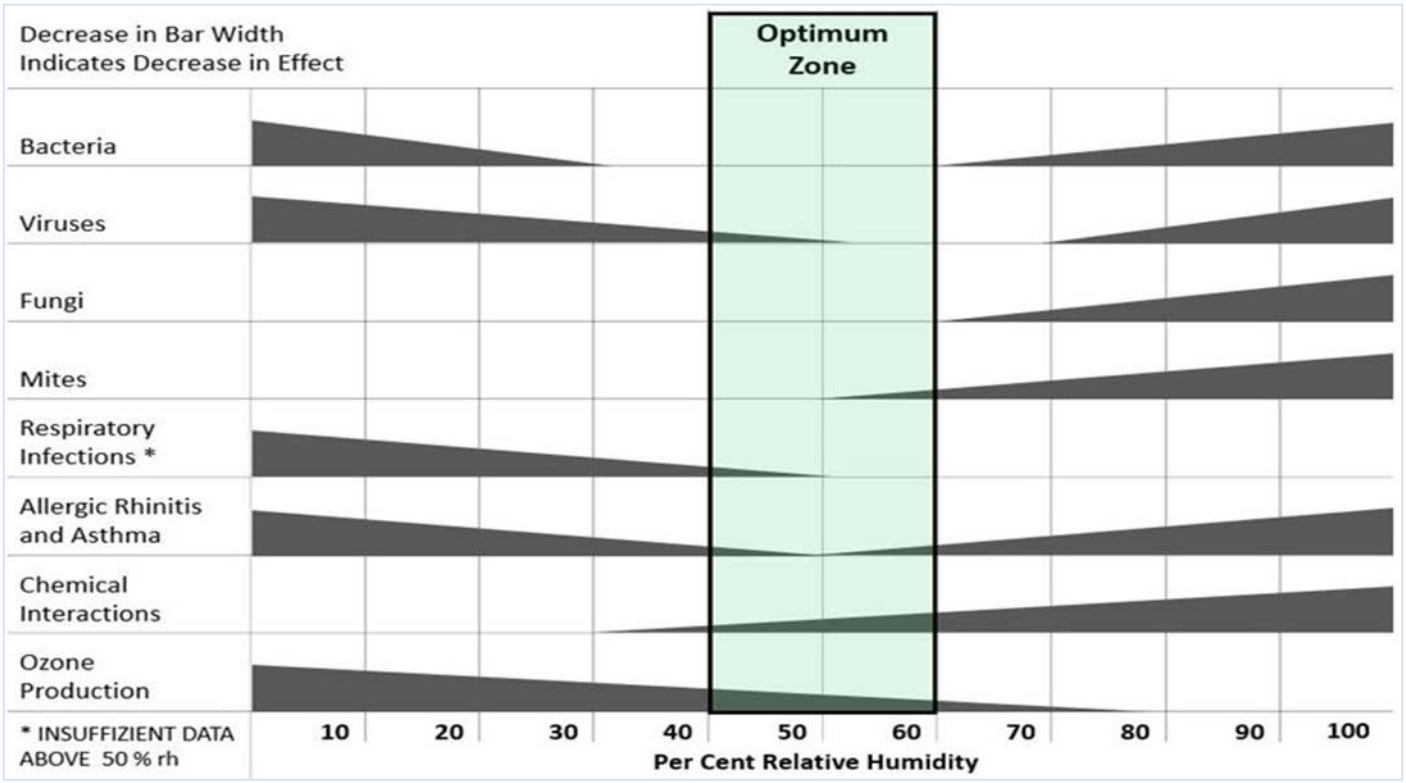
Ward, Matthew & Siegel, Jeffrey. (2005). Modeling Filter Bypass: Impact on Filter Efficiency. ASHRAE Transactions. 111.

ECiP- Design Consideration
Can We Increase Filtration?



ECiP – Relative Humidity Levels

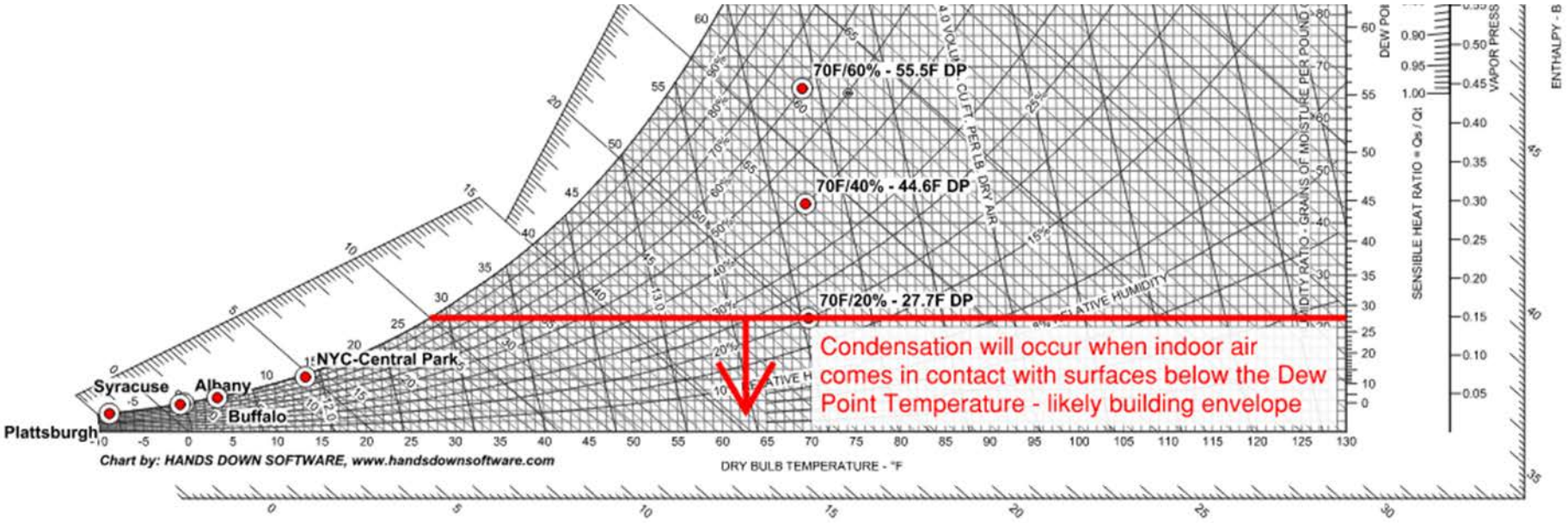
- ASHRAE Guidance is to maintain 40% to 60%



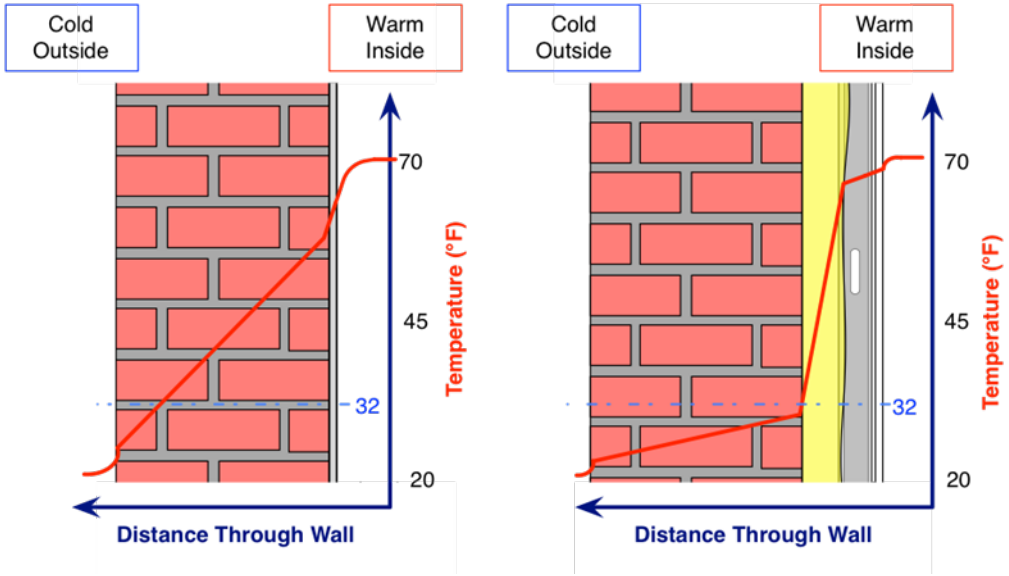
ECiP – Relative Humidity Levels

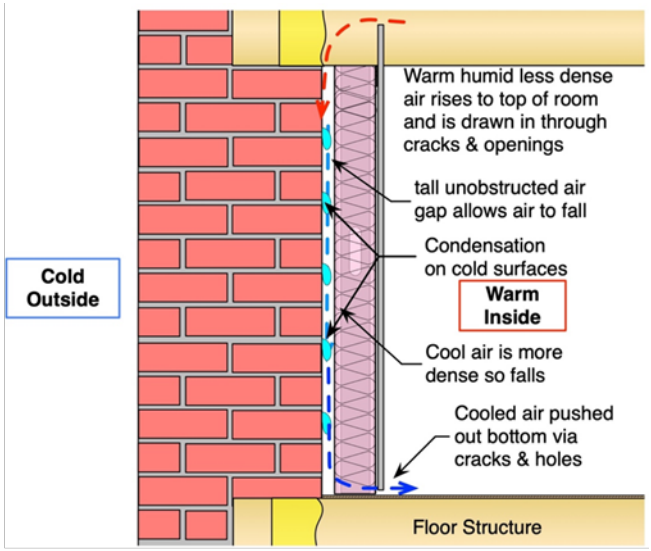
- Humidifier Application Considerations
  - Will increased humidity cause issues for building and/or occupants?
  - Can desired humidity rate be achieved with central system distribution?
  - Is appropriate water treatment feasible?
  - Can equipment be maintained properly?

ECiP – Relative Humidity Levels



ECiP – Relative Humidity Levels

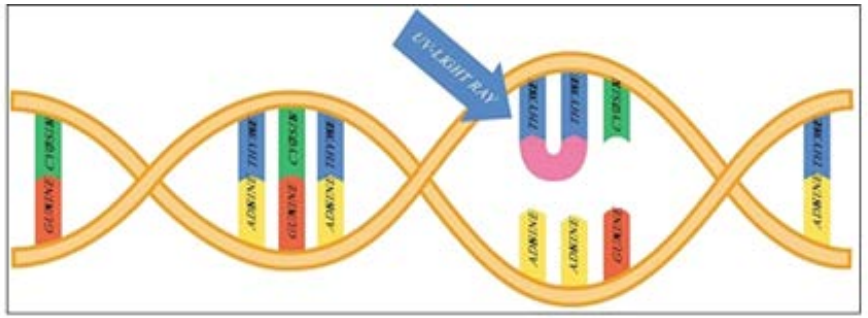


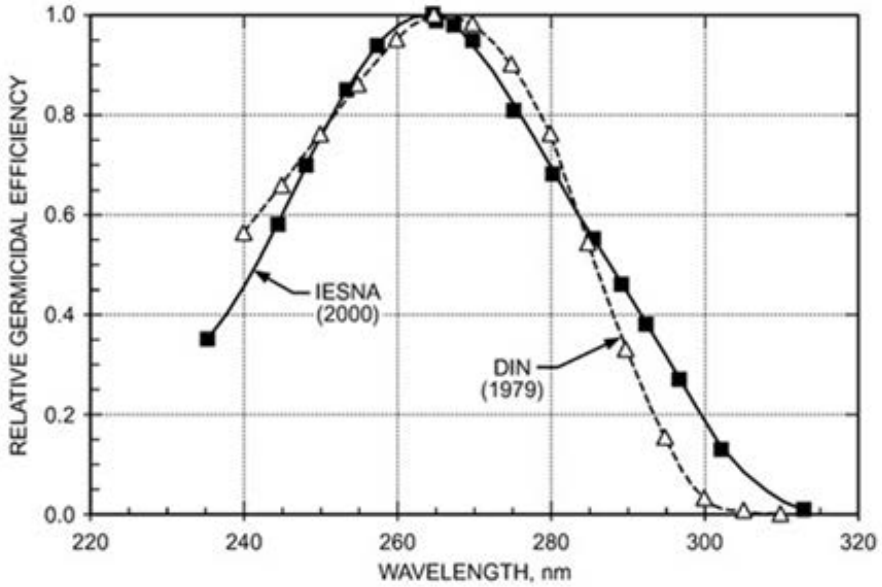


Images used with permission from Building Science Corporation

ECiP- Design Consideration UVGI/ Air Cleaning

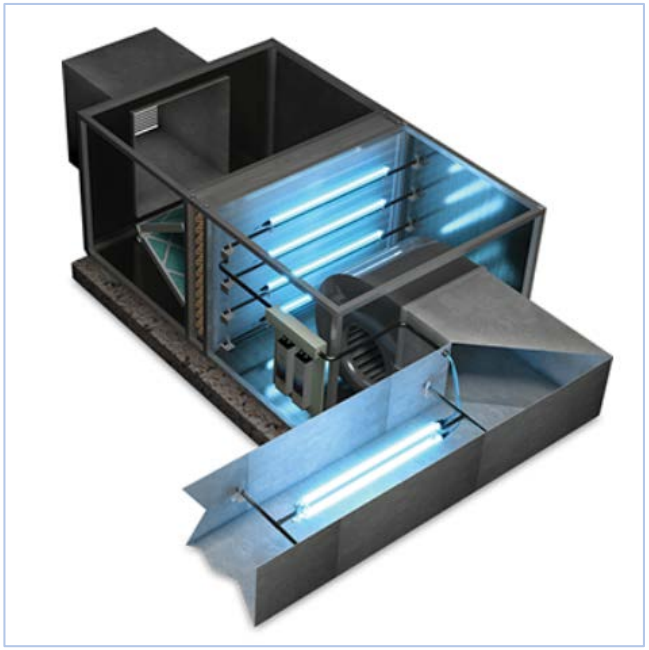
- Ultraviolet light in UVC band
- 265 nm ideal, 254 nm produced by low pressure Hg vapor lamps is standard
- Disrupts microbial DNA/RNA, prevents reproduction
- Exponential dose response
- Coronavirus susceptibility is good
- Long record of application, CDC approved for tuberculosis control as adjunct to filtration





ECiP- Design Consideration UVGI/ Air Cleaning

- Banks of UV-Lamps installed inside HVAC systems or associated ductwork
- Requires high UV doses to inactivate microorganisms on-the-fly as they pass through the irradiated zone due to limited exposure time
  - Minimum target UV dose of 1,500 $mW \cdot s/cm^2$ (1,500 mJ/cm^2)
  - Systems typically designed for 500 fpm moving airstream
  - Minimum irradiance zone of two feet
  - Minimum UV exposure time of 0.25 second



Images from Fresh-Aire UV https://www.freshaireuv.com/wp-content/uploads/2019/08/trs-ads-shadow-big.png

Bipolar Ionization and other Emerging Technologies

ASHRAE consulted with CDC regarding the use of Bipolar Ionization and other emerging technologies and received the following guidance:

"CDC does not provide recommendations for, or against, any manufacturer or manufacturer's product.

While bi-polar ionization has been around for decades, the technology has matured and many of the earlier potential safety concerns are reportedly now resolved. If you are considering the acquisition of bi-polar ionization equipment, you will want to be sure that the equipment meets UL 2998 standard certification (Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners) which is intended to validate that no harmful levels of ozone are produced.

Relative to many other air cleaning or disinfection technologies, needlepoint bi-polar ionization has a less-documented track record in regards to cleaning/disinfecting large and fast volumes of moving air within heating, ventilation, and air conditioning (HVAC) systems. This is not to imply that the technology doesn't work as advertised, only that in the absence of an established body of evidence reflecting proven efficacy under as-used conditions, the technology is still considered by many to be an "emerging technology".

As with all emerging technologies, consumers are encouraged to exercise caution and to do their homework. Consumers should research the technology, attempting to match any specific claims against the consumer's intended use. Consumers should request efficacy performance data that quantitively demonstrates a clear protective benefit under conditions consistent with those for which the consumer is intending to apply the technology. Preferably, the documented performance data under as-used conditions should be available from multiple sources, some of which should be independent, third party sources."

ECiP - Special Considerations Reentrainment

- It is important to note that this is not a major concern for buildings that are not intentionally having COVID-19 positive people in the building or spaces.
- For re-entrainment of the virus to be an issue, there must be someone present in the building shedding, have it captured by the HVAC system, and be exhausted and then re-entrained through the outside air and re-introduced elsewhere.
- There is a very low percentage of being the transmission route for a building, but warrants being checked.

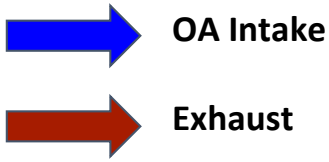
ECiP - Special Considerations Reentrainment

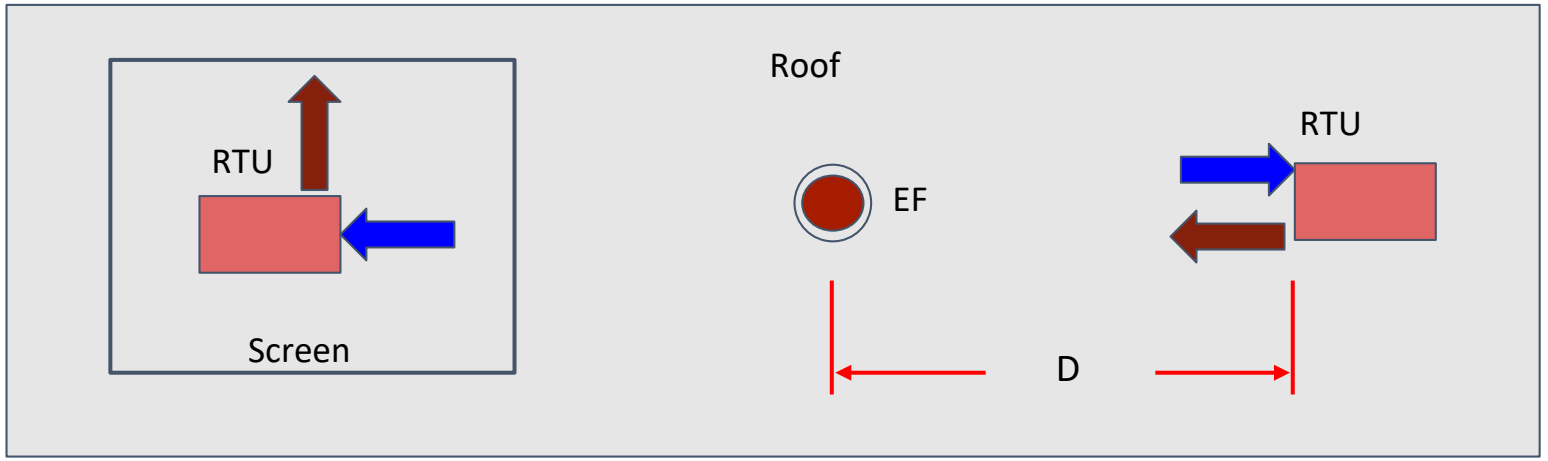
- Re-entrainment of contaminants from exhaust air can occur in all buildings.
- Re-entrainment can occur at any receptor (outside air intake, operable window, doors, etc.).
- Please refer to the Exhaust Re-entrainment Guide for information on the different field investigations:
  - Level 0 - Observation for Re-entrainment Risk Assessment
  - Level 1 - Semi-Qualitative Re-entrainment Risk Assessment
  - Level 2 - Experimental Re-entrainment Risk Assessment
  - Level 3 - Qualitative based on known emissions Re-entrainment Risk Assessment
  - Level 4 - Expert Re-entrainment Risk Assessment

ECiP - Special Considerations Reentrainment

Conditions of Interest

- OA Intake Locations
- Exhaust Locations

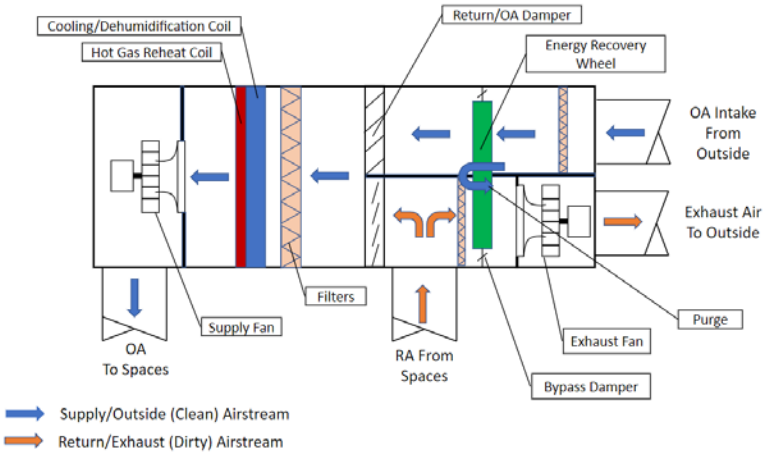


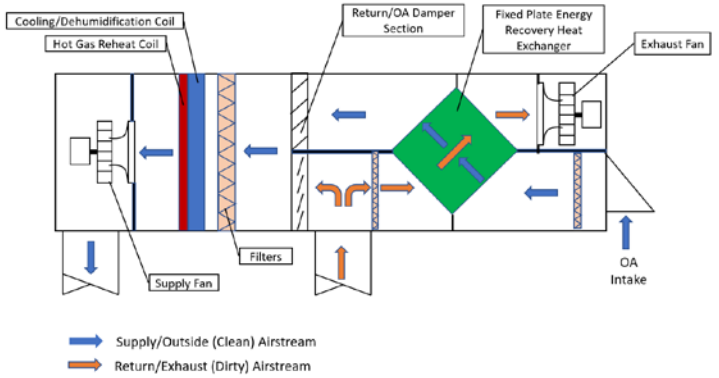


ECiP - Special Considerations DOAS & ERVs

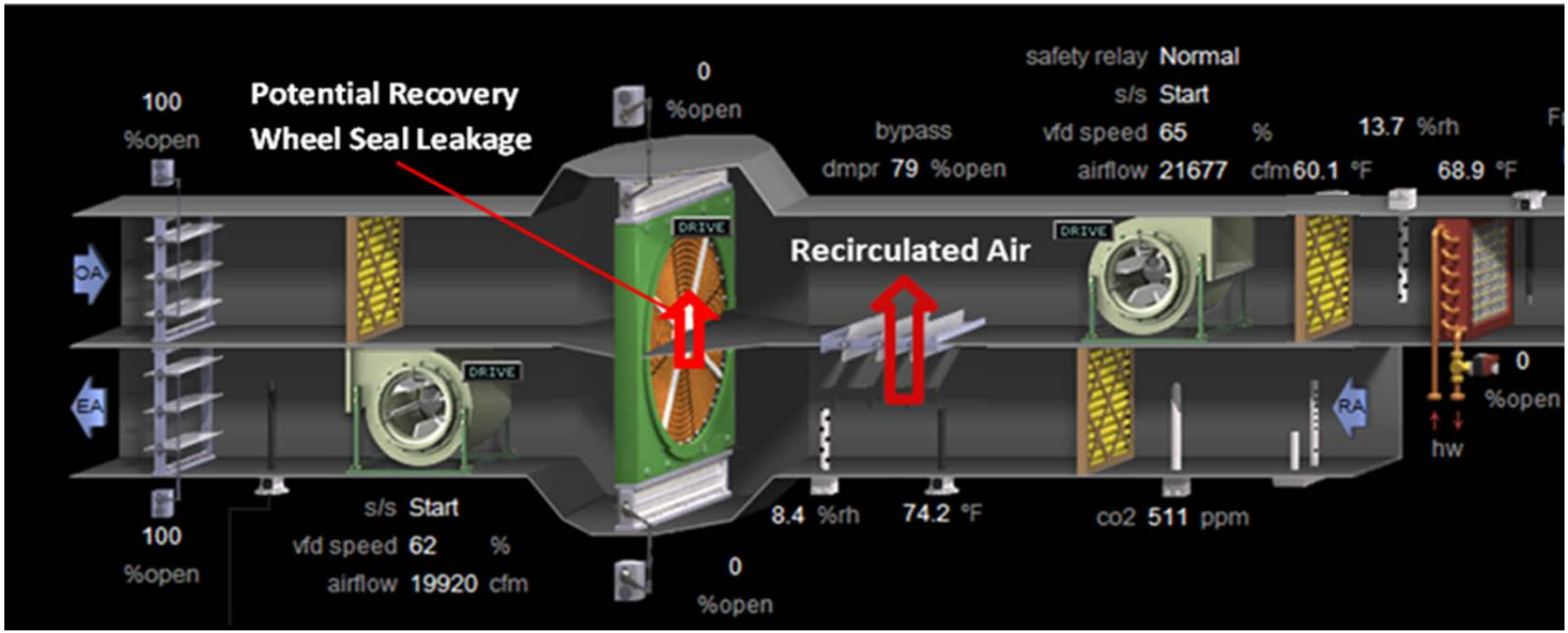
Conditions of Interest

- Wheel/Plate Condition
- Filters
- Bypass Capability
- Cross Contamination Control
  - Fan Arrangement
  - Pressure Differential
  - Seals
  - Purge

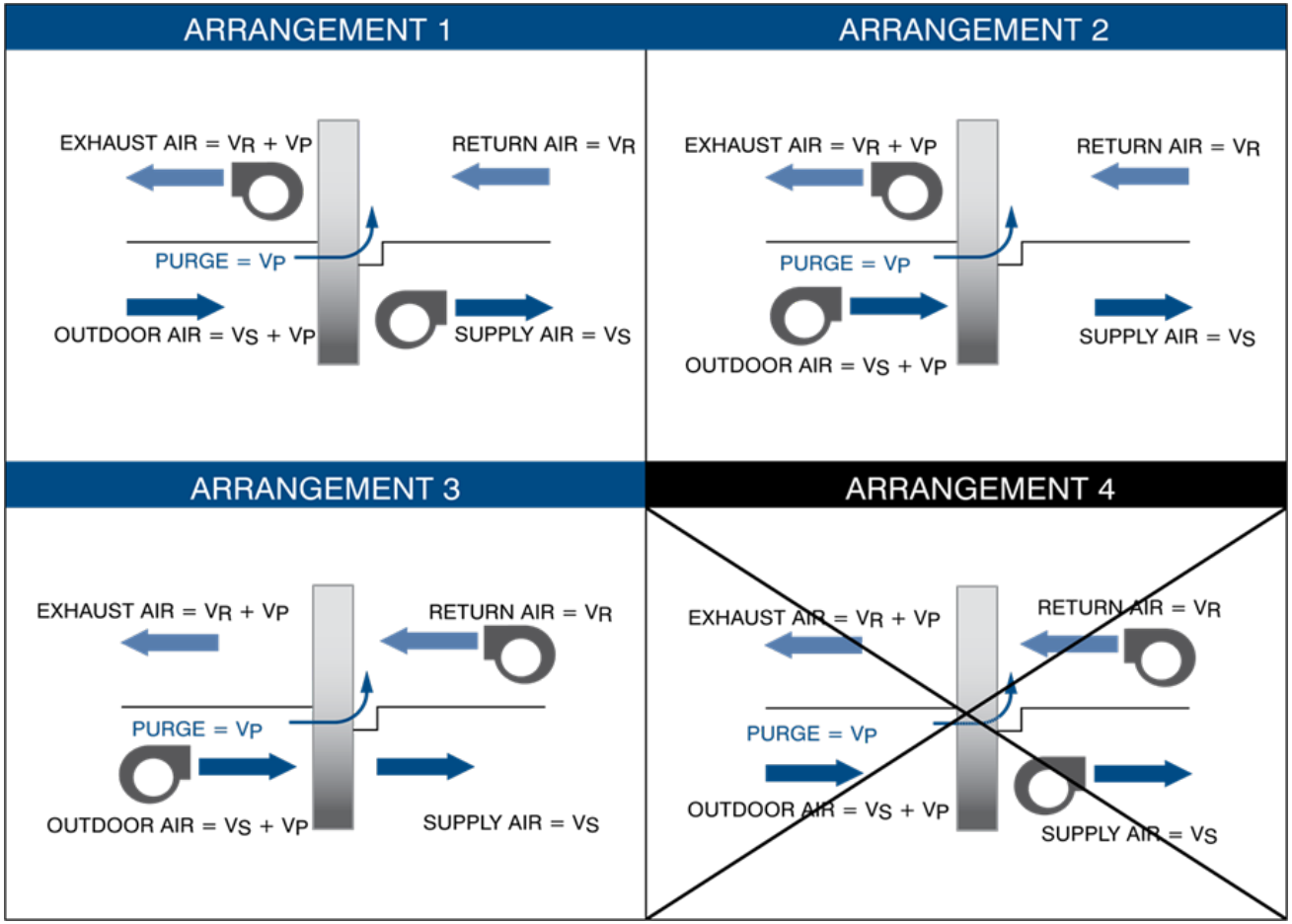




ECiP - Special Considerations DOAS & ERVs

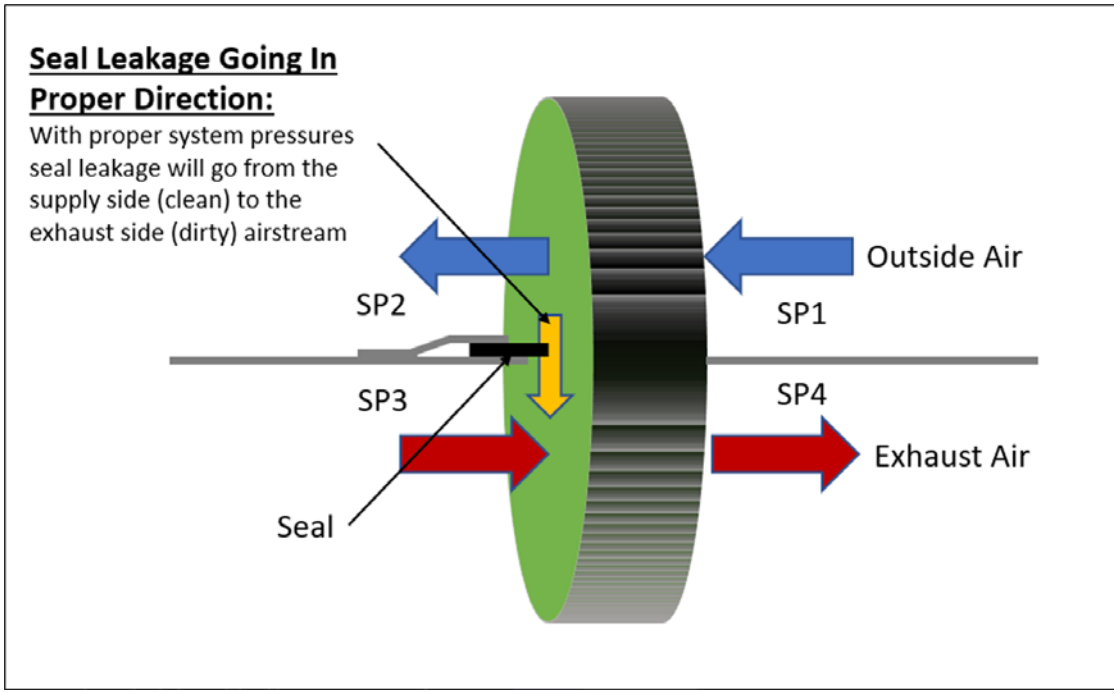


ECiP - Special Considerations DOAS & ERVs



ECiP - Special Considerations DOAS & ERVs

Arrangement 1 or 3 require measurements



ECiP - Special Considerations DOAS & ERVs

ERV Wheel Exchanger Measurements

Date:	
Jobsite:	
Location	
Unit #	

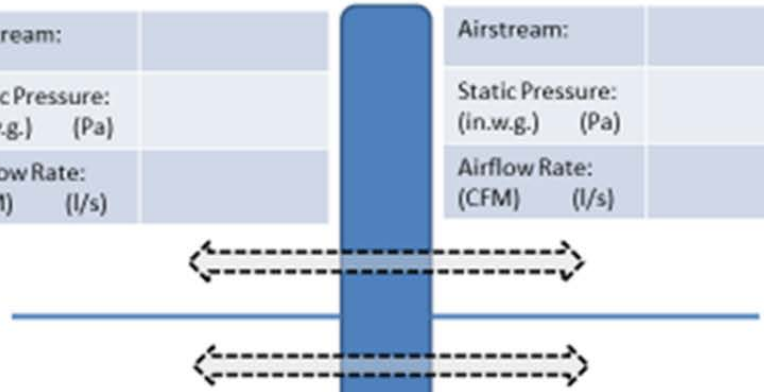
Record at a minimum:
SP2
SP3
Leaving Supply Airflow
Rotation Speed
Purge Angle

Rotation Speed:	
Purge Angle:	

Draw in Blowers Locations and Airflow Directions

Airstream:	
Static Pressure: (in.w.g.) (Pa)	
Airflow Rate: (CFM) (l/s)	

Airstream:	
Static Pressure: (in.w.g.) (Pa)	
Airflow Rate: (CFM) (l/s)	



Airstream:	
Static Pressure: (in.w.g.) (Pa)	
Airflow Rate: (CFM) (l/s)	

Airstream:	
Static Pressure: (in.w.g.) (Pa)	
Airflow Rate: (CFM) (l/s)	

SP1	static pressure measured at Entering Supply Airflow Compartment 1
SP2	static pressure measured at Leaving Supply Airflow Compartment 2
SP3	static pressure measured at Entering Exhaust Airflow Compartment 3
SP4	static pressure measured at Leaving Exhaust Air Airflow Compartment 4

Supply-side Pressure Drop		(in. w.g.) (Pa)
Exhaust-side Pressure Drop		(in. w.g.) (Pa)

ECiP - Special Considerations DOAS & ERVs

- Evaluation for Leakage
  - Leaving Supply static pressure (P2) should be at least 0.5 in. w.g. greater than the entering return airstream static pressure (P3) measured near the wheel surfaces. This means there is a positive static pressure differential.
  - Positive pressure differential means the pressure at the supply outlet (P1) of the wheel is higher than the exhaust inlet of the wheel.
    - This causes seal leakage in the desired direction: from supply air to return to be exhausted.
  - Pressure differential as-installed is frequently different from the original pressure differential calculated during design, refer to the original commissioning report, if available, that identified the as-installed initial pressure differential.

ECiP- Combining Engineering Controls

- Combinations of controls can be synergistic
  - MERV rated filter + UV can approach HEPA performance
- Some combinations of controls are mutually exclusive
  - DOAS + central filtration for indoor contaminants
- Some are additive but trade off
  - Ventilation + air cleaning

- Air cleaner effectiveness – describes incremental effect of a control

$$\varepsilon = \frac{C_{uncontrolled} - C_{controlled}}{C_{uncontrolled}}$$

Nazaroff, W. 2000. Effectiveness of Air Cleaning Technologies. *Proc. of Healthy Buildings 2000*.

Epidemic Conditions in Place (ECiP)

- Evaluate Existing Systems
- Mitigation Strategies
- Steps to Re-occupy Your Building

Re-Occupying: Know Limitations

- Cannot make any claim or guarantee that compliance with our standards and guidance will provide health, comfort or occupant acceptability, but shall strive for those objectives, consistent with ASHRAE policy.
- Many infectious diseases (including SARS-CoV-2) are primarily transmitted through direct person-to-person contact or through large aerosol droplets exchanged at close range. Ensure those measures are being enforced by building owners.

Re-Occupying: General Recommendations

- Use your Building Readiness Plan
- Notify relevant people of the opening
- Follow local, state, and federal orders/regulations/guidelines
- Follow CDC and OSHA for PPE
- Perform Systems Analysis (if not done previously)

P-ECiP: Prior to Re-Occupying

- Flush Building with as much fresh air as possible for 4 hours (or achieve 3 air changes)
- Flush your water systems and check water treatment
- Update BAS for any modifications that you are going to change (Schedule, DCV on, etc…)
- Operate the systems for 24 hours and monitor
- Review trends and check for issues
- Utilize the Building Readiness Guide for Post Epidemic Conditions in Place (P-ECiP) guide

Considerations for Post-Epidemic Conditions in Place (P-ECiP)

P-ECiP: Post Event Activities

- Update your Systems Manual
- Evaluate your systems and think:
  - Did your maintenance program have any scheduled preventive maintenance periods missed because the building was unoccupied?
  - Did you have issues acquiring maintenance materials during the pandemic?
  - Were you able to continue daily or weekly rounds at the building?
  - Were there systems that were not able to be put into a setback mode?
  - Do the building mechanical systems have reset and ventilation control strategies to increase outside air back to normal?
  - Are there other lessons learned that need to be addressed within the building from this experience?

Future Design

Considerations for Future Design

- AHU capacity for increased ventilation
  - Fan, Coil, Chilled Water, Ductwork
- Filter Capabilities
  - “dirty” target in static pressure calculation
- Space air distribution effectiveness
- BAS Modes of Operation to include:
  - Occupied, Unoccupied, Extended Unoccupied, Epidemic / Pandemic
- Air disinfection strategies
- Water systems ability to drain
- Document the mitigation features for facilities

Conclusion

- Assess and document improvements for HVAC system(s) ability to respond to an infectious aerosol
- Understand how to create an effective Building Readiness Plan
- Explain potential engineering controls to implement in your HVAC systems to improve its virus transmission mitigation
- Explain different modes of operation for Epidemic Conditions In Place and Post-Epidemic Conditions in Place
- Discuss the future proofing of designs that may affect future HVAC design criteria

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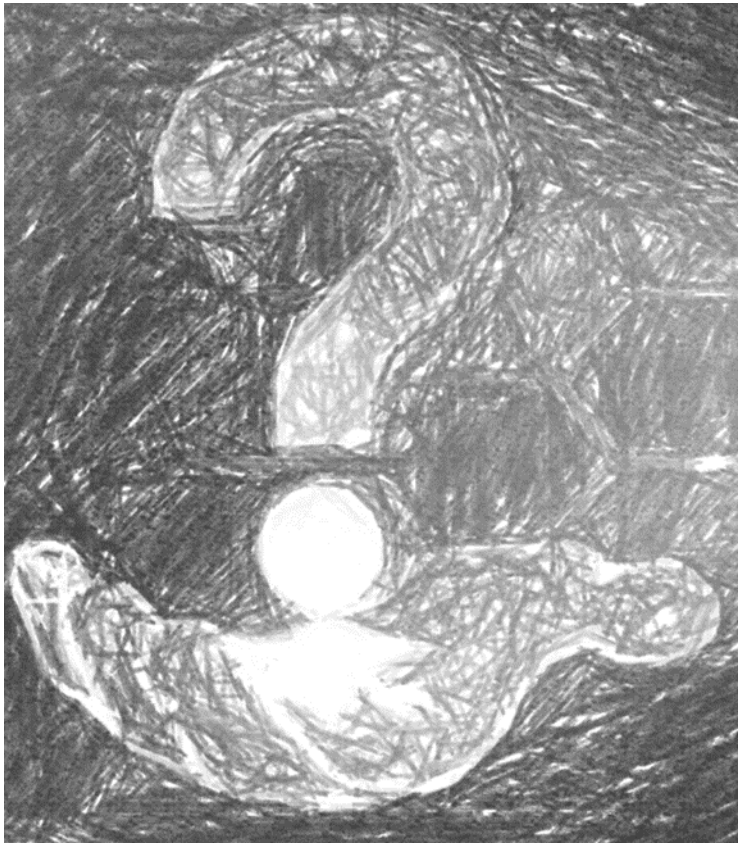

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