ASHRAE's New Standard 241
Control of Infectious Aerosols

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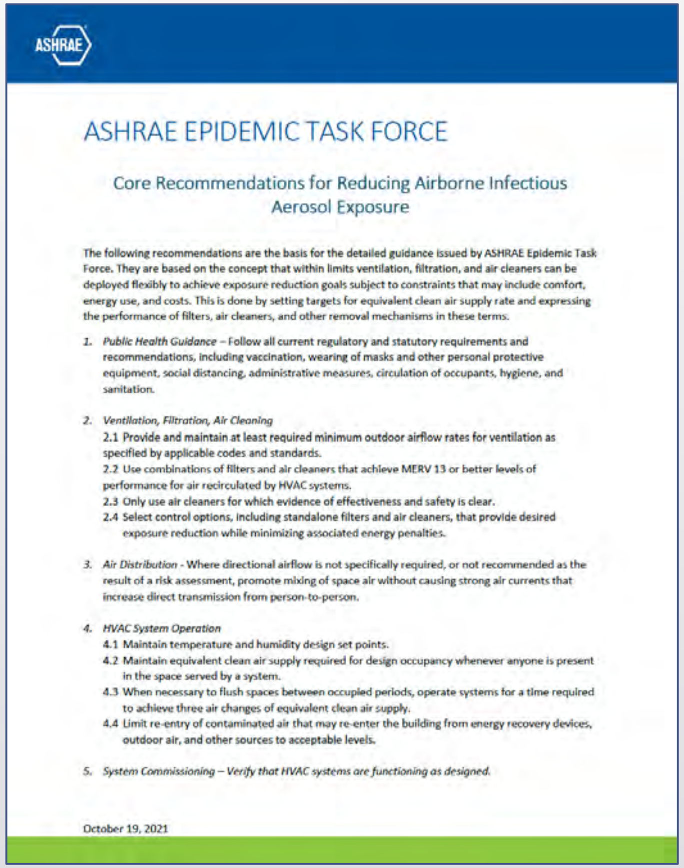
ASHRAE

Why develop a standard for airborne infection risk mitigation?

- Airborne transmission of infections can be important
- Indoor environment contributes to risk
- Current IAQ standards don't address it
- Complete and codify ASHRAE Epidemic Task Force guidance
- Not clear that 62.1/62.2 will change to incorporate it
- The White House asked for it…



ASHRAE EPIDEMIC TASK FORCE

Core Recommendations for Reducing Airborne Infectious Aerosol Exposure

The following recommendations are the basis for the detailed guidance issued by ASHRAE Epidemic Task Force. They are based on the concept that within limits ventilation, filtration, and air cleaners can be deployed flexibly to achieve exposure reduction goals subject to constraints that may include comfort, energy use, and costs. This is done by setting targets for equivalent clean air supply rate and expressing the performance of filters, air cleaners, and other removal mechanisms in these terms.

1. *Public Health Guidance* – Follow all current regulatory and statutory requirements and recommendations, including vaccination, wearing of masks and other personal protective equipment, social distancing, administrative measures, circulation of occupants, hygiene, and sanitation.

2. *Ventilation, Filtration, Air Cleaning*
   2.1 Provide and maintain at least required minimum outdoor airflow rates for ventilation as specified by applicable codes and standards.
   2.2 Use combinations of filters and air cleaners that achieve MERV 13 or better levels of performance for air recirculated by HVAC systems.
   2.3 Only use air cleaners for which evidence of effectiveness and safety is clear.
   2.4 Select control options, including standalone filters and air cleaners, that provide desired exposure reduction while minimizing associated energy penalties.

3. *Air Distribution* - Where directional airflow is not specifically required, or not recommended as the result of a risk assessment, promote mixing of space air without causing strong air currents that increase direct transmission from person-to-person.

4. *HVAC System Operation*
   4.1 Maintain temperature and humidity design set points.
   4.2 Maintain equivalent clean air supply required for design occupancy whenever anyone is present in the space served by a system.
   4.3 When necessary to flush spaces between occupied periods, operate systems for a time required to achieve three air changes of equivalent clean air supply.
   4.4 Limit re-entry of contaminated air that may re-enter the building from energy recovery devices, outdoor air, and other sources to acceptable levels.

5. *System Commissioning – Verify that HVAC systems are functioning as designed.*

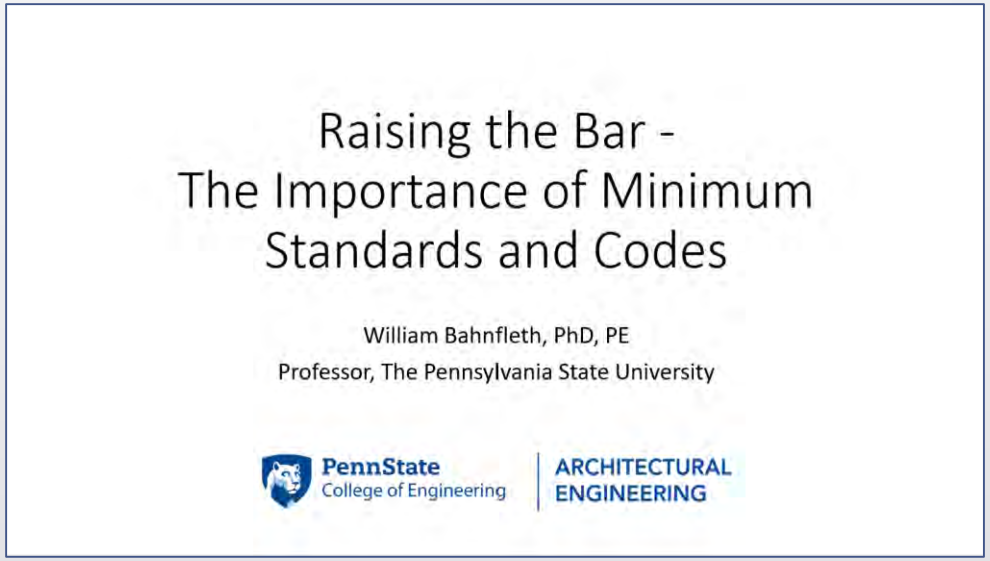
October 19, 2021

Chronology

- Late 2021 - White House Covid Response Team recognizes importance of buildings, begins interacting with ASHRAE and others
- Mar 2022 – White House "Clean Air in Buildings Challenge"
- Q2-Q4 2022 - Discussions about need for national model IAQ codes
- Sep 2022 – Johns Hopkins workshop "A National Strategy for Improving Indoor Air Quality"
- Oct 2022 – White House "Summit on Indoor Air Quality"

From the Johns Hopkins workshop, Sept. 2022

- Incentives have their place, but standards and codes do the heavy lifting
- Support for energy conservation provides a model for improving IAQ
- Energy conservation will probably remain the higher priority, but must not be allowed to drive bad decisions about IAQ
- Standards have limited impact if not adopted into code
- National model IAQ standards can promote both standard evolution and changes to codes



Chronology (cont'd)

- Nov 2022 – White House asks ASHRAE to develop a "national pathogen control" standard ASAP, preferably by end of US Covid restrictions on May 11
- Dec. 6, 2022 – ASHRAE Board commits to developing a consensus, non-ANSI standard in six months (by June 2023)
- Dec 2022 – call for members
- Jan 2023 - roster and title/purpose/scope approved at winter meeting
- Feb 28, 2023 – first meeting of project committee (start the clock…)
- May 11, 2023 – public review draft approved by project committee (73 days)
- June 15, 2023 – recommendation to publish by project committee (108 days)
- June 24, 2023 – ASHRAE approves Standard 241for publication at annual meeting (116 days)

Dr. Ashish Jha – former Coordinator, White House COVID-19 Response Team

"(T)his effort to try to improve indoor air quality, reduce the burden of respiratory pathogens – yes, it's been something we have been talking about at the White House – yes, a lot of experts have been talking about it. Talking is good. Talking is important, but what ASHRAE did over the last six months in building out the standards, the 241 standards, that just got approved on Saturday, fundamentally changes the game.

It is one of the most important public health interventions I have seen in years, if not decades."

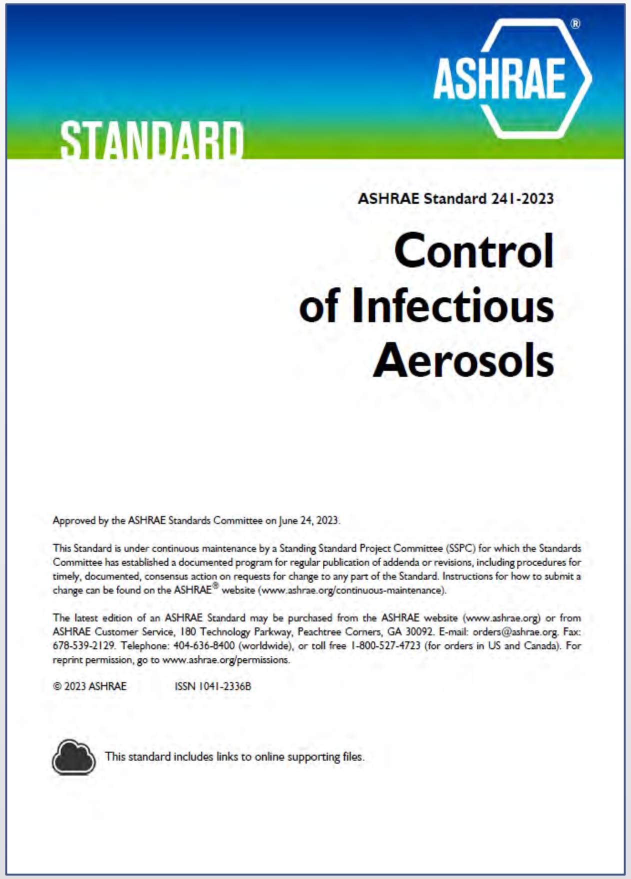
Purpose and scope

Purpose

- Establish minimum requirements for control of *infectious aerosols* to reduce risk of disease transmission in occupiable space of new and existing buildings and major renovations (non-residential, residential, health care)
- Outdoor air systems, *air cleaning* systems
  - Design
  - Installation
  - Commissioning
  - Operation
  - Maintenance
- Specify *equivalent clean airflow* to be provided in *infection risk management mode*

Scope

- Does NOT establish overall requirements for acceptable indoor air quality
- Addresses *long range transmission*, i.e., outside close proximity to an infector



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STANDARD

ASHRAE Standard 241-2023

Control of Infectious Aerosols

Approved by the ASHRAE Standards Committee on June 24, 2023.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. Instructions for how to submit a change can be found on the ASHRAE® website (www.ashrae.org/continuous-maintenance).

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This standard includes links to online supporting files.

Main topics

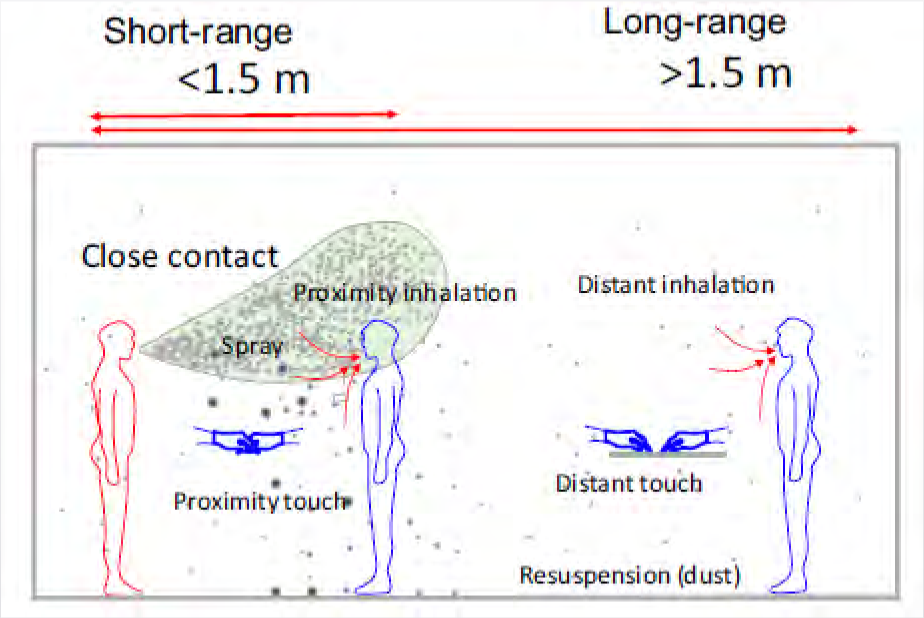
- Definitions
- Prerequisites
- Equivalent clean airflow for infection risk mitigation
- Air distribution and natural ventilation
- Air cleaning
- Assessment, planning , implementation
- Operations and maintenance
- Additional requirements for dwelling units
- Normative and informative appendices

Key definitions

- Infectious aerosol
- Air cleaning
- Long-range transmission
- Infection risk management mode (IRMM)
- Building readiness plan (BRP)
- Equivalent clean airflow (ECA)

Long-range transmission

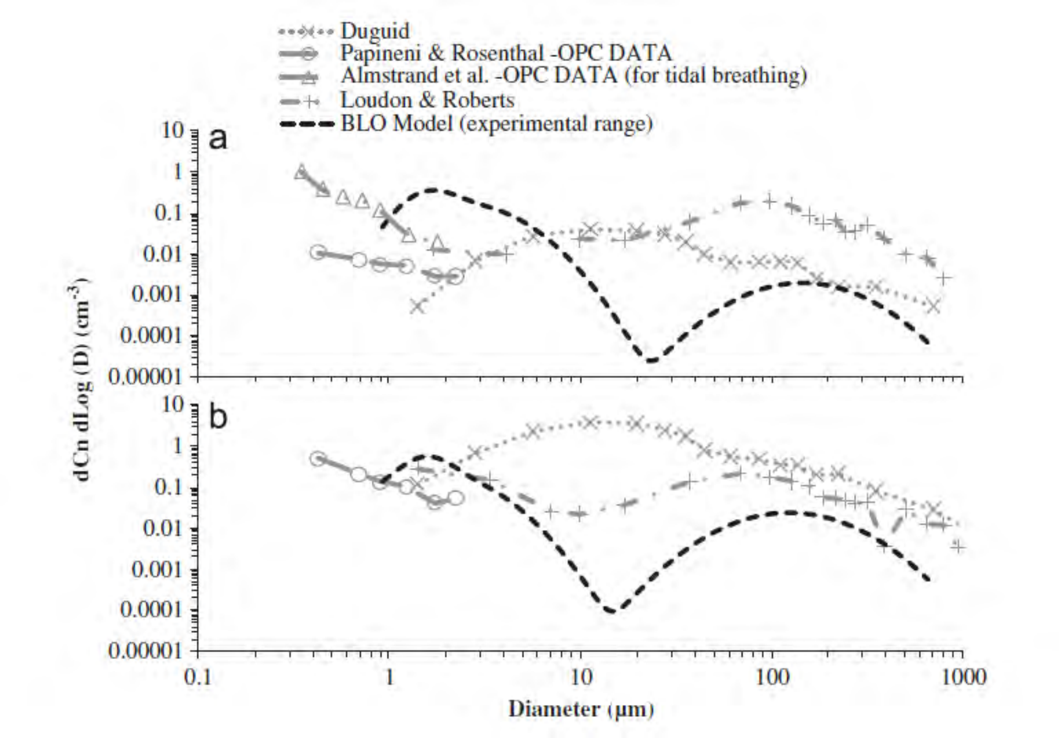
- Transmission by exposure to infectious aerosol not in close proximity to an infector
- Basis for risk assessment
- Focus on long-range does not mean there is no effect on short-range



Li, Y. 2020. *Indoor Air.* DOI: 10.1111/ina.12786

Infectious aerosol

- Airborne particles containing active pathogens capable of causing infection
- Size, emission rate determined by respiratory activity, not pathogen size



Johnson, et al. 2011. Modality of human expired aerosol size distributions. Journal of Aerosol Science 42:839-851.

Air Cleaning

- Reducing infectious aerosol concentration through capture and removal or inactivation
- Air cleaning technologies
    - Mechanical filters (including electret media)
    - Germicidal ultraviolet light
    - Reactive species – ionizers, photocatalytic oxidation, other oxidants
- *Mention of specific technologies in the standard is not endorsement!*

Infection Risk Management Mode (IRMM)

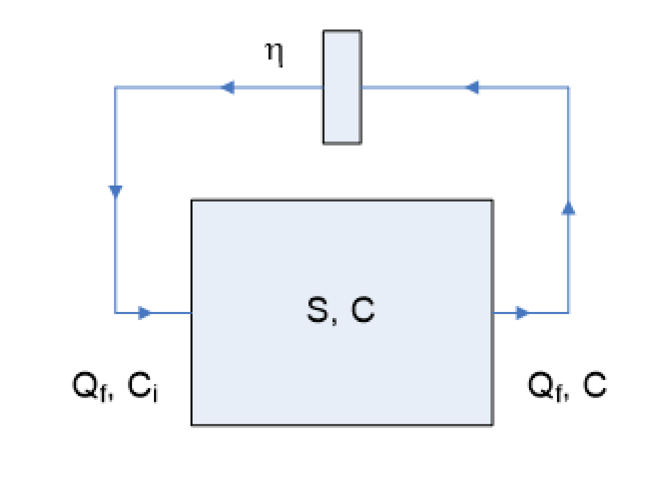
- *The mode of operation in which measures to reduce infectious aerosol exposure documented in a building readiness plan are active*
- Someone must decide when IRMM is needed
  - Public health official
  - Owner
  - Occupant
- Why not all the time?
  - Additional energy use and cost may be incurred during IRMM
  - Infection risk and consequences of infection vary over a wide range
- An example – maybe the first – of resilience applied to IAQ

Building Readiness Plan (BRP)

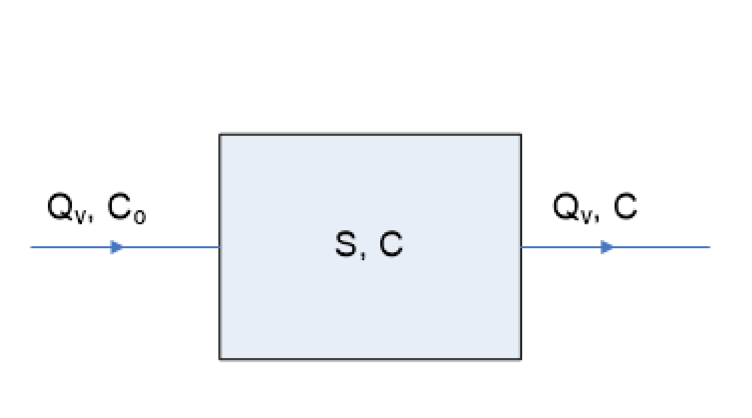
- *A plan that documents the engineering and non-engineering controls that facility systems will use for the facility to achieve its goals*
- Summarizes results of assessment and planning exercises and documents measures to be implemented in IRMM
- Direct descendant of ASHRAE Epidemic Task Force guidance

Equivalent Clean Airflow (ECA)

- *The flow rate of pathogen-free air that, if distributed uniformly within the breathing zone, would have the same effect on infectious aerosol concentration as the sum of actual outdoor airflow, filtered airflow, and inactivation of infectious aerosols*
- Concept on which the entire standard depends
  - Determine ECA for infection risk mitigation (ECAi)
  - Determine total flow rate for spaces, systems (V_{ECAi})
  - Figure out how to achieve it during IRMM



Filtration of recirculated air with efficiency “η” at flow rate “Q_f” controlling source “S” to achieve concentration “C”



For an equivalent dilution process with uncontaminated air: $Q_v = \eta\ Q_f$

Multiple sources of ECA can be added to determine the total for a space or system

Prerequisites

- Standard 241 is only addresses infection risk – does not replace exisiting standards for acceptable indoor air quality
- A facility must comply with the applicable version of standard (ASHRAE 62.1, 62.2, 170 or other approved by the authority having jurisdiction) as determined by its occupancy and date of construction or major renovation
- Prerequisite standards set minimum requirements of outdoor air and filtration for normal operation

ECA requirements are based on risk assessment

- Many decisions to make
  - Absolute or relative risk
  - Acceptable risk level
  - Infector number and emission rate, infectious dose
  - Exposure time
  - Susceptible number and activity level
  - Removal/inactivation mechanisms
    - Engineering controls
    - Personal protective equipment
    - Natural loss – decay, deposition
- Probabilistic approach is needed
  - Most factors are distributed (not single valued)
  - Some factors vary over orders of magnitude
- What is the most appropriate unit?
  - ECA per person?
  - ECA per infector?
  - ACH of ECA?
  - ???

Wells-Riley model of infection risk

$$P = \frac{N_I}{N_S} = 1 - \exp\left(-\frac{Iqpt}{Q}\right)$$

$$P \approx \frac{Iqpt}{Q} \ \textit{for small} \ \frac{Iqpt}{Q}$$

$$P \approx \frac{(N_S R_C)qpt}{Q} \propto \frac{1}{Q/N_S}$$

P = probability of a susceptible person becoming infected [ ]

N_I = number of new infections

N_S = number of susceptible persons

R_C = community infection rate [ ]

I = number of infectors

q = quanta (infectious dose) emission rate [1/hr]

p = pulmonary ventilation rate per susceptible [m^3/h]

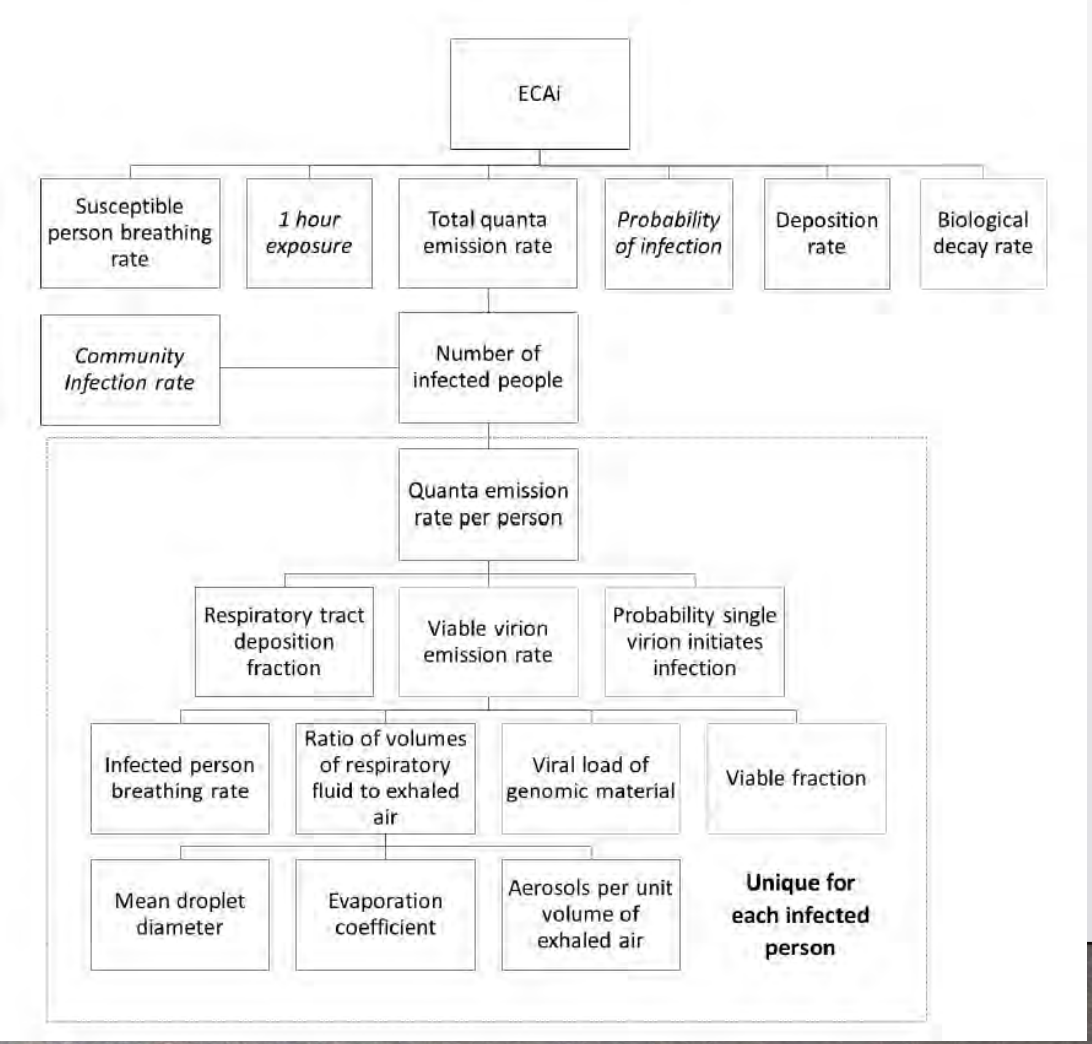
t = exposure time [hr]

Q = equivalent clean airflow [m^3/h]

- If rate of infection in the population is considered, personal risk depends on the equivalent clean air flow rate per person
- Air change rate is not directly relevant!

Risk assumptions in Standard 241

- Wells-Riley model
- Number of infectors a function of community infection rate
- Roughly equal risk, low per hour regardless of space type
- Natural loss factors considered
- Probabilistic analysis using distributed variables
- Requirements given in ECA per person for infection risk mitigation (ECAi)



Calculation of required ECA (V_{ECAi}) or maximum IRMM occupancy

- ECAi and number of occupants, $P_{Z,\ IRMM}$ determine requirement for a given zone, V_{ECAi}

$$V_{ECAi} = ECAi \times P_{Z,IRMM}$$

- $P_{Z,\ IRMM}$ can be different from design occupancy
- Available V_{ECAi} and ECAi can determine maximum number of occupants in IRMM

$$P_{Z,IRMM} = V_{ECAi} / ECAi$$

- Current coverage includes 25 space types in 7 occupancy categories, 20-90 cfm/pers

Table 5-1 Minimum Equivalent Clean Airflow per Person in Breathing Zone in IRMM

	ECAi	
Occupancy Category	**cfm/person**	**L/s/person**
Correctional Facilities		
Cell	30	15
Dayroom	40	20
Commercial/Retail		
Food and beverage facilities	60	30
Gym	80	40
Office	30	15
Retail	40	20
Transportation waiting	60	30
Educational Facilities		
Classroom	40	20
Lecture hall	50	25
Industrial		
Manufacturing	50	25
Sorting, packing, light assembly	20	10
Warehouse	20	10
Health Care		
Exam room	40	20
Group treatment area	70	35
Patient room	70	35

Values doubled for loud vocalization

Comparing standard 62.1 outdoor air and ECAi

- ECAi rates are much higher than 62.1 rates
- Constant risk ECAi values give very different ACH values for different space types

	ASHRAE 62.1 Default [cfm/pers]	ASHRAE 241 ECAi [cfm/pers]	ASHRAE 241 ACH **with 8'** ceiling
Office	17	30	1.1
Classroom	13	40	10.5
Restaurant	10	60	31.5

ANSI/ASHRAE Standard 62.1 VRP inputs

	R_P [cfm/pers]	R_A [cfm/ft^2]	Occupant Density [#/1000 ft^2]
Office	5	0.06	5
Classroom	10	0.12	35
Restaurant	7.5	0.18	70

Meeting the equivalent clean air target

- V_{ECAi} requirement can be met by
  - Outdoor airflow – mechanical/natural
  - ECA from multizone air cleaning systems
  - ECA from in-room air cleaning systems
- Approach allows maximum flexibility to user
- Limitations on compliance
  - Must have prerequisite minimum outdoor air
  - To receive credit toward meeting requirements, mechanical filters must be MERV-A 11 or higher (MERV 11 acceptable until 1/1/2025) or equivalent

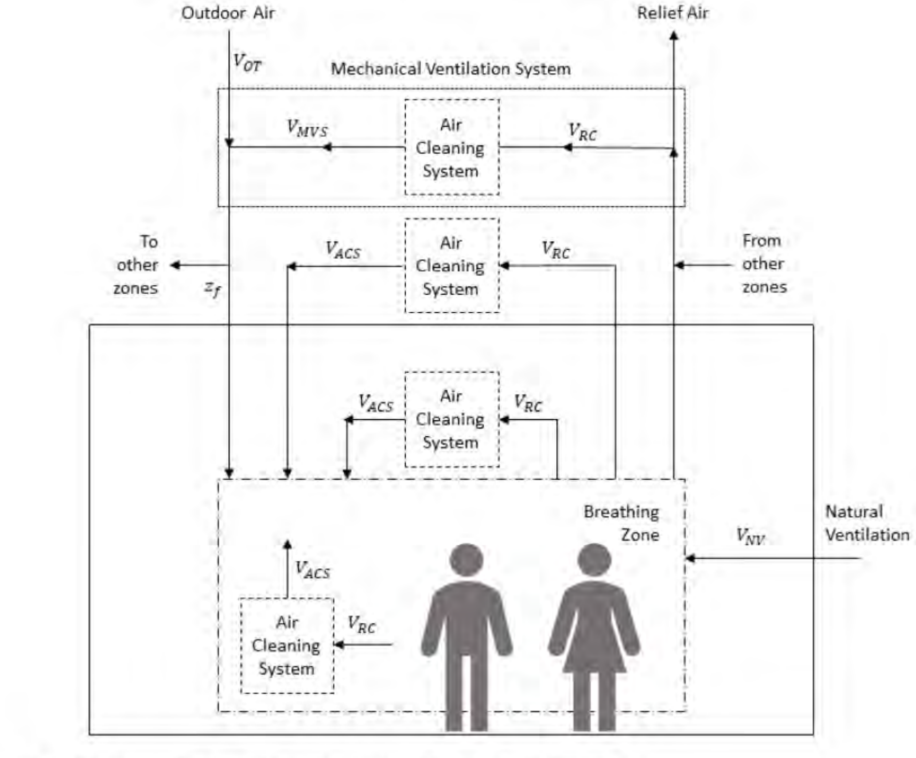


Figure 6-1 Sources of outdoor and clean air (for V_{RC}, see Section 7).

Air distribution and natural ventilation

- Important but difficult topic, mostly for future development
- Classifies air cleaning system location (floor, wall, ceiling) and air discharge (up, down, horizontal, none) and limits some combinations based on room air distribution type (e.g., downflow air cleaner discharge with upflow air distribution)
- Mainly references ASHRAE Standard 62.1 for natural and mixed-mode ventilation requirements
- Does not yet address ventilation/contaminant removal effectiveness

Air cleaning system effectiveness and safety

- Lack of information and standards related to air cleaning systems was a major problem during the Covid pandemic
- Effectiveness – ability to remove or inactivate infectious aerosols
- Safety – adverse effects direct exposure (UV-C, oxidants), secondary contaminants (particles, ozone)
- Standard 241 establishes minimum requirements for effectiveness and safety testing

Air cleaning system testing

- Standard 241 does not recommend or rank technologies
- Goal is to establish a level playing field to enable use of effective, safe technologies
- Existing methods of test are referenced when available (ASHRAE 52.2, ASHRAE 185.1, AHAM AC-1, AHAM AC-5)
- Normative Appendix A provides procedures when a standard is not available

Air cleaning systems are classified generically

- In-Duct Air Cleaning Systems that Clean Air in the Air-Handling Unit, Ductwork, or Plenum
- In-Duct Air Cleaning Systems that Clean Air in the Occupied Zone
- In-Room Air Cleaning Systems
- Mechanical Fibrous Air Cleaning Systems.
- Air Cleaning Systems that Inactivate Infectious Aerosols (additional requirements)

Estimated efficiencies are provided for mechanical filters rated by ASHRAE Standard 52.2

Table 7-1 Infectious Aerosol Removal Efficiency (ε_{PR}) for Mechanical Fibrous Filters

ANSI/ASHRAE Standard 52.2 MERV (Prior to 1/1/2025) MERV-A (After 1/1/2025)	ISO 16890 ePM	Weighted ε_{PR}
<11		0%
11	ePM2.5 50%	60%
12	ePM2.5 65%	71%
13	ePM1 50%	77%
14	ePM1 70%	88%
15	ePM1 85%	91%
16	ePM1 95%	95%
HEPA [a]	ISO 20E [b]	99%

a. High-efficiency particulate air (HEPA) filters are not tested under ANSI/ASHRAE Standard 52.2 [5] or ISO 16890-1 [6]. However, HEPA filters are included here for completeness.
b. Tested in accordance with ISO 29463 [7].

Based on filter efficiency curve and distribution of infections aerosol by particle size

Efficiency is calculated if an air cleaner is rated using AHAM AC-1

- AHAM AC-1 determines Clean Air Delivery Rate (CADR) for smoke ($CADR_s$), dust($CADR_d$), pollen($CADR_p$)
- Standard 241 ECA is a weighted average – 30% smoke, 30% dust, 40% pollen

$$V_{ACS} = 0.3 \cdot CADR_s + 0.3 \cdot CADR_d + 0.4 \cdot CADR_p$$

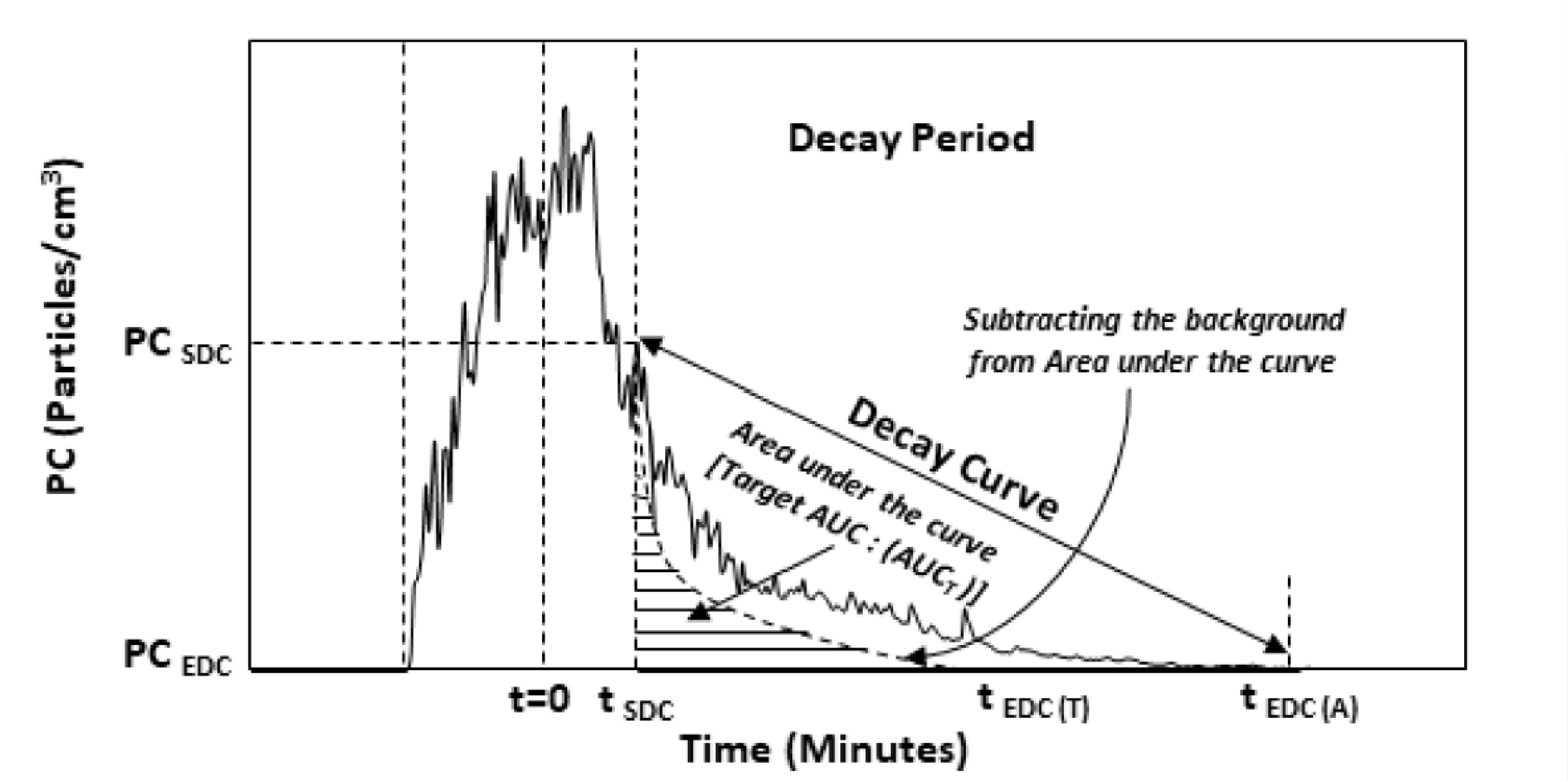
Air cleaning system safety

- Chemicals emitted by air cleaning systems or created by chemical reactions in air
  - Ozone
  - Formaldehyde
  - Particles
- Fan noise (reported only)
- UV-C in occupied space

Assessment, Planning, and Implementation

- Builds on ASHRAE Epidemic Task Force Building Readiness guidance
- Applies commissioning practices to infection risk mitigation systems
- Requirements for developing the Building Readiness Plan
- Assessment of existing V_{ECAi} to determine need for additional controls
- Supporting information
  - Tracer particle test procedure for determining V_{ECAi} in-place
  - Checklists for assessment and commissioning (appendix)
  - Building Readiness Plan template (appendix)
  - Equivalent outdoor air calculator (downloadable at ashrae.org/241-2023)
  - Guidance on assessing energy recovery ventilators (downloadable)
  - Guidance on preventing re-entry of contaminated air

Tracer particle test to determine in-place V_{ECAi}



Building Readiness Plan Template

BUILDING READINESS ASSESSMENT				Office Building
Date Conducted				City, State

This is a sample Building Readiness Assessment worksheet prepared in September 2020 based on initial ASHRAE Epidemic Task Force Guidance. A similar worksheet, aligned with the requirements of Standard 241 Section 8.2.1 Existing Building Assessment, will be created by the Standard Project Committee.
The requirements and recommendations listed below are **NOT** for compliance with Standard 241.

Building Readiness Tasks	Level	Status	Details	Ref.
Ventilation				
Provide as much outside air as the HVAC system can accommodate while maintaining acceptable indoor conditions.	Baseline	In Place	Ventilation system provides outdoor air at its maximum capacity of 27 cfm/person (based on ASHRAE default occupant density), greater than 62.1 minimum standard.	1, 2
Disable demand-controlled ventilation.	Baseline	In Place	OA VAV boxes are providing maximum airflow; return air CO2 sensors are not being used to reduce airflow.	1
Limit occupancy in areas with inadequate ventilation.	Baseline	N/A		1
Assess Energy Recovery Ventilation systems for cross-contamination and adjust airflows as necessary.	Baseline	TBD	OAHU heat wheel seals have been inspected for wear; unit does not have a purge section. Confirm pressures higher on supply side relative to exhaust side.	2, 3
Ensure outdoor air intake has sufficient separation distance from contaminant sources (cooling tower, exhaust fan, pedestrian walkway, etc.).	Baseline	In Place		1
Filtration				
Use at least MERV-13 filters in all recirculating systems.	Baseline	In Place	Filters upgraded from MERV-13 to MERV-15.	1, 2, 4
Ensure good seal on filters (tape, gasket, sizing, etc.).	Baseline	In Place	Filters are taped at seams to minimize bypass of unfiltered air.	1, 2, 4
Use in-room HEPA filters in areas with limited system filtration capabilities.	Enhanced	Consider	Consider installing in-room HEPA filters in densely occupied spaces or spaces with higher risk activities; devices should produce no ozone.	1, 2, 4
Pressurization and Exhaust				
Resolve any significant building pressurization issues.	Baseline	N/A		[illegible]

Equivalent Clean Air Calculator

	B	C	D	E	F	G	H
1		Assessment	Planning	Planning	Planning	Planning	Implement
2	Units	EXISTING	Option 1	Option 2	Option 3	Option 4	FINAL SYSTEM
3		AHU with X,Y,Z	Description	Description	Description	Description	Description
4	Type	Office	Office	Office	Office	Office	Office
5	CFM / Person	30	30	30	30	30	40.0
6	Sq Ft	2,000	2,000	2,000	2,000	2,000	2,400
7	Ft	9	9	9	9	9	9
8	Cu Ft	18,000	18,000	18,000	18,000	18,000	21600
9	CFM	1,800	1,800	1,800	1,800	1,800	1800
10	CFM	240	240	240	240	240	272
11	Quantity	12	12	12	12	12	12
12	Quantity	8	8	8	8	8	12
13	CFM	360	360	360	360	360	480
14	CFM	240	240	240	240	240	480
15	MERV	12	13	13	13	13	13
16	241 or DNFE	241	241	DNFE	241	241	241
17	εPR	71.0%	77.0%	67.0%	77.0%	77.0%	77.0%
18	%	0.0%	35.00%	50.00%	0.00%	0.00%	0.00%
19	CFM	400	100	0	0	0	0
20	CADR	0	4	0	0	0	0
21	Quantity	0	1	0	0	0	0
22	CFM	0	150	0	200	0	200
23	Quantity	0	2	0	1	0	1
24	CADR	0	300	0	0	0	0
25	Quantity	0	3	0	0	0	0
26							
27	CFM	240.0	240.0	240.0	240.0	240.0	272.0
28	CFM	1107.6	1201.2	1045.2	1201.2	1201.2	1176.6
29	CFM	0	126	257	0	0	0
30	CFM	400	100	0	0	0	0
31	CFM	0	4.0	0.0	0.0	0.0	0.0
32	CFM	0	300.0	0.0	200.0	0.0	200.0
33	CFM	0	900.0	0.0	0.0	0.0	0.0
34	CFM	1748	2871	1543	1641	1441	1649
35	Method	IRMM	IRMM	IRMM	IRMM	IRMM	IRMM
36	**CFM / person**	**218.5**	**358.8**	**192.8**	**205.2**	**180.2**	**137.4**
37	Pass / Fail	PASS	PASS	PASS	PASS	PASS	PASS
41							

Operations

- BRP on site, accessible, current
- Essential supplies stocked
- Operating modes defined:
  - Normal – occupied/unoccupied
  - IRMM – occupied/unoccupied
  - Temporary shutdown
- Temperature and humidity – maintain design set points when occupied
- Operating schedules
  - On for all occupied hours
  - No on-off control of HVAC fans
- Flushing not required between occupancy periods
- Operator training
- Occupant communication

Maintenance

- Adapted from requirements in ASHRAE/ACCA Standard 180
- Frequency of some activities is increased during IRMM, e.g., check air handler outdoor air flow annually in IRMM vs. every 5 years per 62.1
- Items specific to infection controls have been added

Table 9-2 Minimum Maintenance Activity and Frequency for Additional Engineering Controls and Associated Components While in Use

Engineering Control	Inspection/Maintenance Task	Frequency
In-room air cleaners	Verify unit is in appropriate location and operating as intended per the *BRP*. Confirm that the air cleaner is operating at the speed or setting assumed in the V_{ECAi} calculation. Maintain systems and equipment and verify performance per manufacturer's instructions. Visually inspect intake for debris and clean as necessary.	Monthly
Ultraviolet (UV) germicidal irradiation	Maintain systems and verify performance and safety per manufacturer's instructions and in accordance with ANSI/IES RP-44-21 [11] and ANSI/IES RP-27.1.22 [20] or equivalent. Adjust, clean, and replace equipment as needed.	Assess quarterly or per manufacturer's recommended interval
All air cleaning systems and equipment (including in-room, in-duct, and UV air cleaners)	Maintain systems and equipment and verify performance per manufacturer's instructions. Adjust, clean, and replace equipment as needed. If equipment cannot be repaired, remove equipment from service and use a substitute engineering control to maintain V_{ECAi} in occupied space.	Assess quarterly or per manufacturer's recommended interval
Separation space	The designated temporary separation areas shall be tested for negative pressure whenever an infected individual is present.	As used

Additional requirements for dwelling units

- Lids on toilets
- Water in plumbing traps
- HVAC systems serving multiple units – block flow to units with vulnerable or infected occupants
- Fully enclosed separation area for infected occupants, health-care patient room V_{ECAi} (70 cfm/pers)
- Health-care patient room V_{ECAi} in dwelling unit with vulnerable occupants

Future

- Communication – publications, presentations, web page
- Pilot testing
- ANSI certification
- Referencing in ASHRAE 62.1/62.2
- Adoption in code

- Continuous maintenance
  - Performance path
  - Energy use requirements
  - Add more space types
  - Expand air distribution content
  - Update air cleaner testing requirements to reference new standards

Applying ASHRAE Standard 241-2023 to the Westford Regency Ballroom

Data and assumptions - space

- Floor area: 6,380 ft^2 (110’ x 58’)
- Volume: 80,004 ft^3
- Design occupancy: 464 (per owner)
- ASHRAE 62.1
  - R_p = 5 cfm/pers
  - R_a = 0.06 cfm/ ft^2
  - V_{bz} = 2,702 cfm

Data and assumptions - HVAC

- Three rooftop units
- MERV 13 filters (77% efficient)
- Total airflows
  - Supply air: 14,400 cfm (estimate)
  - Outdoor air: 2,880 cfm (complies with ASHRAE 62.1)
  - Recirculated air: 11,520 cfm

Equivalent clean airflow analysis

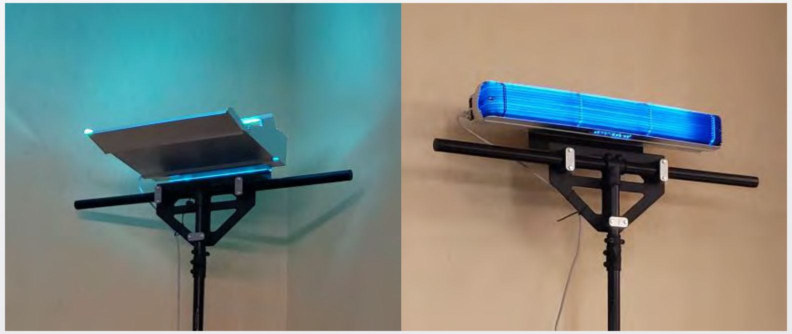
- ASHRAE Standard 241 requirement, design occupancy
  - Auditorium ECAi: 50 cfm/pers
  - Total required, 464 occupants: 23,200 cfm
- Existing V_{ECAi}
  - Outdoor air: 2,880 cfm
  - Filtered recirculated air: 8,870 cfm (11,520 cfm × 0.77)
  - Total: 11,750 cfm
- Additional V_{ECAi} needed for full occupancy: 23,200 – 11,750 = 11,450 cfm
- Maximum occupancy without modifications: 11,750/50 = 235

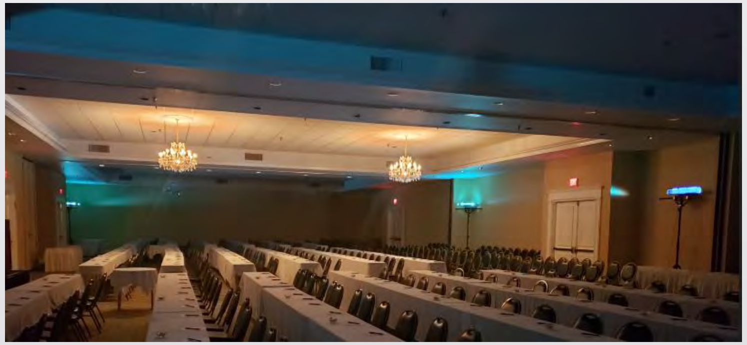
Options for getting an additional 11,450 cfm of equivalent clean airflow

- 100% outdoor air (14,400 cfm)
  - Not enough, and it eliminates filtration of recirculated air
  - Eliminates effect of filtration (no recirculation)
- Increase filter efficiency further
  - HEPA only adds 2,650 cfm, also brings total to 14,400 cfm
- In room air cleaners – large, or lots of them, ~0.1 W/cfm, so >1 kW fan power at full occupancy
- Upper room germicidal UV(254 nm)

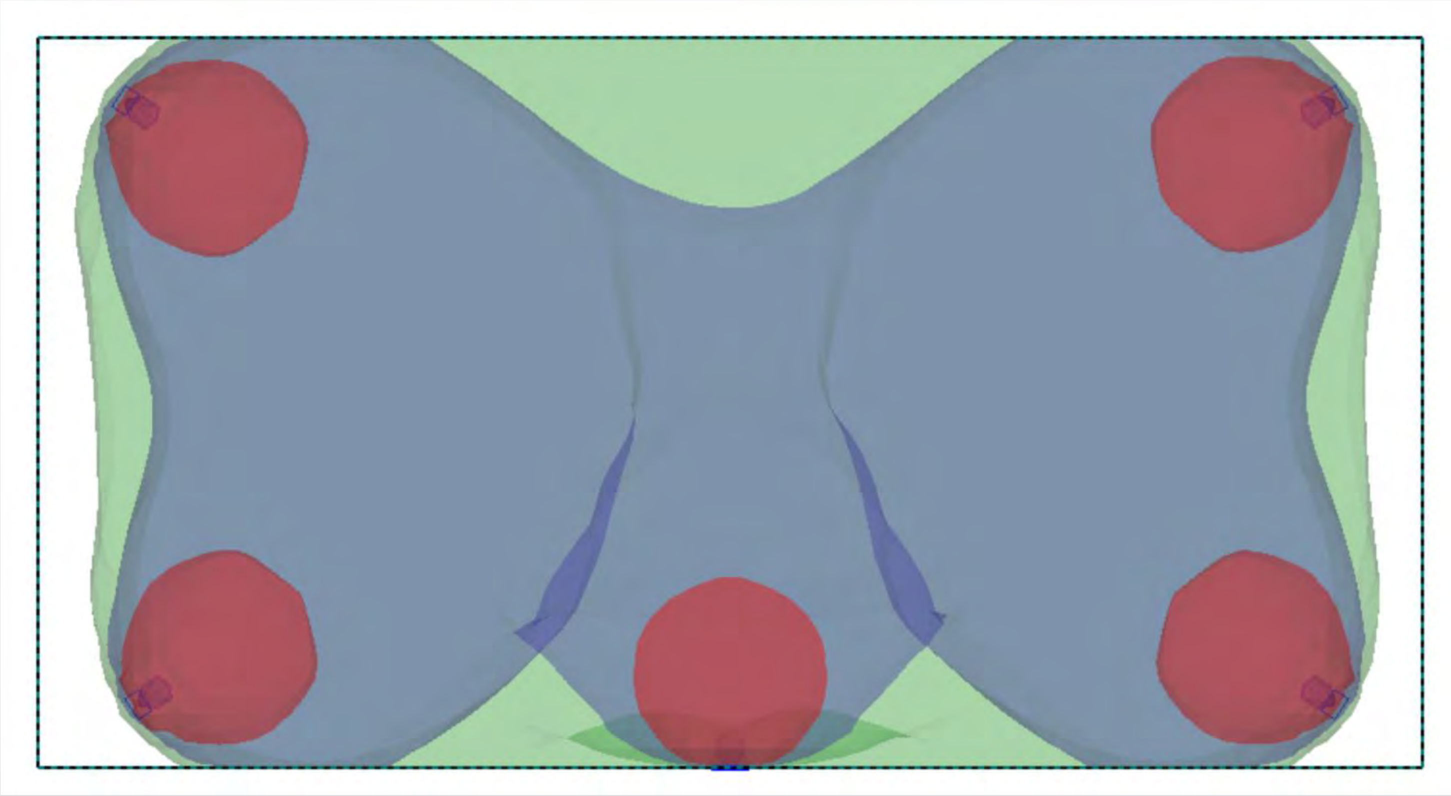
Typical sizing for upper room germicidal UV

- ASHRAE Guideline 37 (under development)
  - 0.012 W/m^3 UV power for 20 ACH ECA against tuberculosis (1/10th susceptibility of SARS-CoV-2)
- Dosing volume: 63,800 ft^3 = 1,807 m^3
- Total UV output power: 21.7 W
- Input power to fixtures: 24 W with three open fixtures
- $V_{ECAi,\ GUV} \cong$ 25,000 cfm, > 2X what's needed – could downsize significantly





The 5 temporary fixtures in use here greatly exceed the ASHRAE 241 requirement



Thank you!

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