Ventilation, Filtration, & Equivalent Clean Airflow

Darryl DeAngelis
Director of Business Development
DarrylD@EBTRON.com

The Cost of Ventilation

Get’s More Expensive When Not Measured and Controlled

BSR/ASHRAE Addendum *a* to ANSI/ASHRAE Standard 169-2020, Climatic Data for Building Design Standards

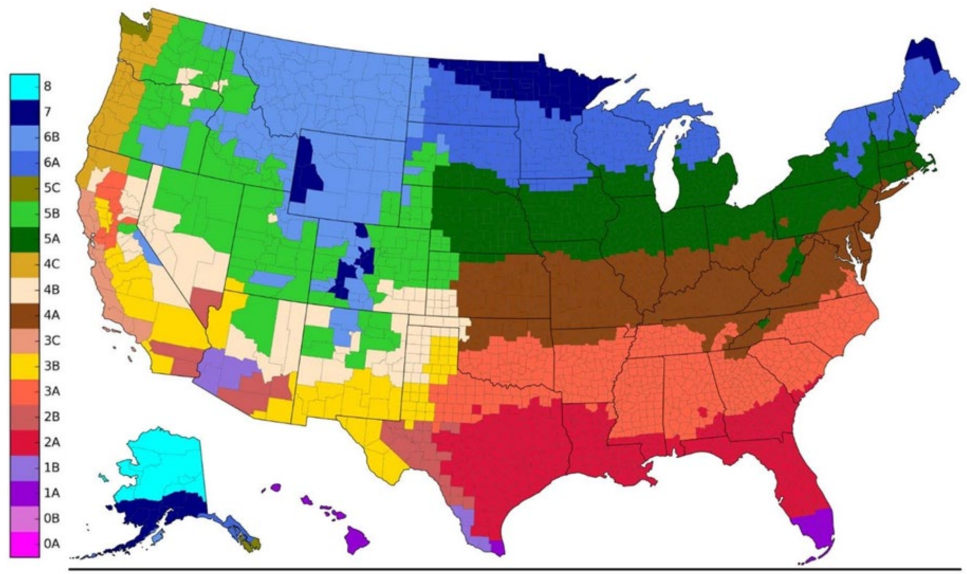


Figure A-2 Climate Zones for United States Counties

TABLE 2 Cost per cfm of outdoor air		
CLIMATE ZONE	$/cfm / yr OF OUTDOOR AIR	BLENDED UTILITY RATE $/kWh
1A	1.66	0.15
2A	1.55	0.14
2B	0.81	0.15
3A	0.65	0.14
3B	0.79	0.14
3C	0.16	0.28
4A	1.82	0.24
4B	0.84	0.15
4C	0.63	0.12
5A	3.25	0.28
5B	0.74	0.14
6A	2.63	0.16
6B	1.21	0.10
7A	2.98	0.16
8A	4.16	0.16

ASHRAE Journal, Vol. 65, No. 9, September 2023

	Per person L/s (cfm) per person
# of values	367
Mean	**49 (105)**
Std. Dev.	**54 (114)**
Minimum	0 (0)
10th percentile	6 (13)
25th percentile	13 (27)
Median	30 (63)
75th percentile	**66 (140)**
90th percentile	**116 (245)**
Maximum	**310 (657)**

NIST 7145 R, November 1, 2008
Analysis of Ventilation Data from EPA BASE Study

The Lack of Ventilation

What is the Impact of Low Ventilation?

Building and Environment 167 (2020) 106426

ELSEVIER

Contents lists available at ScienceDirect

Building and Environment

journal homepage: http://www.elsevier.com/locate/buildenv

Ventilation rates in California classrooms: Why many recent HVAC retrofits are not delivering sufficient ventilation

Check for updates

Wanyu R. Chan [a,*], Xiwang Li [a], Brett C. Singer [a], Theresa Pistochini [b], David Vernon [b], Sarah Outcault [b], Angela Sanguinetti [b], Mark Modera [b]

[a] Indoor Environment Group, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

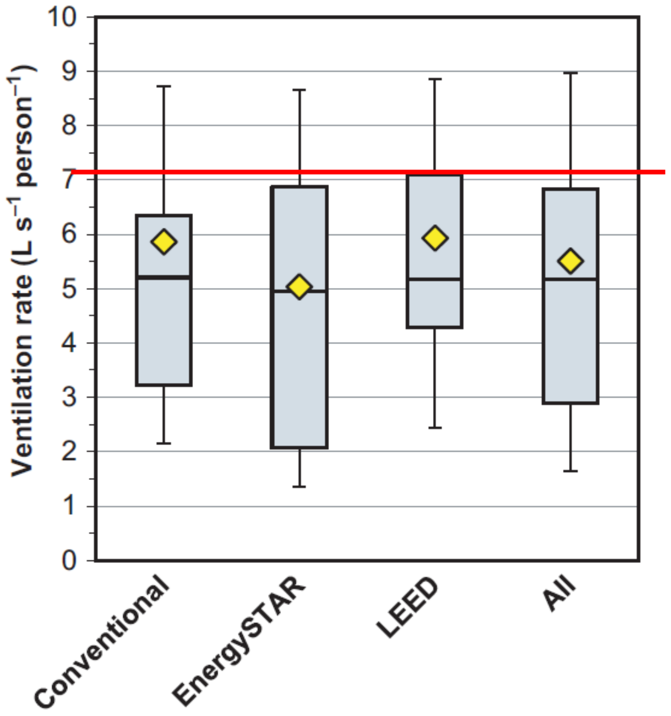
[b] Western Cooling Efficiency Center, University of California-Davis, Davis, CA, USA

ARTICLE INFO

Keywords:
Carbon dioxide
Schools
Field inspection
Air temperature
Indoor air quality

ABSTRACT

Previous research has shown that under-ventilation of classrooms is common and negatively impacts student health and learning. To advance understanding of contributing factors, this study visited 104 classrooms from 11 schools that had recently been retrofitted with new heating, ventilation, and air-conditioning (HVAC) units. CO_2 concentration, room and supply air temperature and relative humidity, and door opening were measured for four weeks in each classroom. Field inspections identified HVAC equipment, fan control, and/or filter maintenance problems in 51% of the studied classrooms. Across 94 classrooms with valid data, average CO_2 concentrations measured during school hours had a mean of 895 ppm and a standard deviation (SD) of 263 ppm. Ventilation rates (VRs), estimated using the daily maximum 15-min CO_2 in each classroom, had a mean of 5.2 L/s-person and a SD of 2.0 L/s-person across 94 classrooms. Classrooms with economizers, with or without demand control ventilation (DCV), tended to have lower mean CO_2. Improperly selected equipment, lack of commissioning, incorrect fan control settings and maintenance issues (heavily loaded filters) were all associated with under-ventilation in classrooms. Many classrooms in this sample were frequently too warm to support learning. There were 23 out of 103 classrooms that had indoor air temperature above 25.6 °C for more than 20% of the school hours. Better oversight on HVAC system installation and commissioning are needed to ensure adequate classroom ventilation. Periodic testing of ventilation systems and/or continuous real-time CO_2 monitoring (either as stand-alone monitors or incorporated into thermostats) is recommended to detect and correct ventilation problems.



Ventilation rates in recently constructed U.S. school classrooms
University of Michigan 2017

IAQ Benefits the Income Statement

Exceeding Minimum Ventilation Requirements Offsets Energy Cost

Change in Ventilation Rate (rates in cfm per person)	Estimated Increase in Performance (%)	Annual Economic Benefit per Worker @ $100K per Worker
15 to 20	0.6	$600
15 to 25	1.1	$1100
15 to 30	1.4	$1400

Cost Effectiveness of Improving Indoor Environments to Increase Productivity
Berkley Lab – IAQ Resource Bank

A statistical analysis of existing data has provided a central estimate of the average relationship between SBS symptom prevalence in office workers and building ventilation rate.

This analysis indicates a 15% increase in symptom prevalence as the ventilation rate drops from 17 to 10 cfm (8 to 5 L/s) per person and a 33% decrease in symptom prevalence rates as ventilation rate increases from 17 to 50 cfm (8 to 24 L/s) per person.

Ventilation Rates and Sick Building Syndrome Symptoms
Berkley Lab – IAQ Resource Bank

In the United States, most people's health costs are directly tied to their employers who contribute to their health insurance (a range from $14,000 to $20,000 per employee per year on average)

Research of 3,000 workers over 40 buildings, shows that 57% of all sick leave was due to poor ventilation

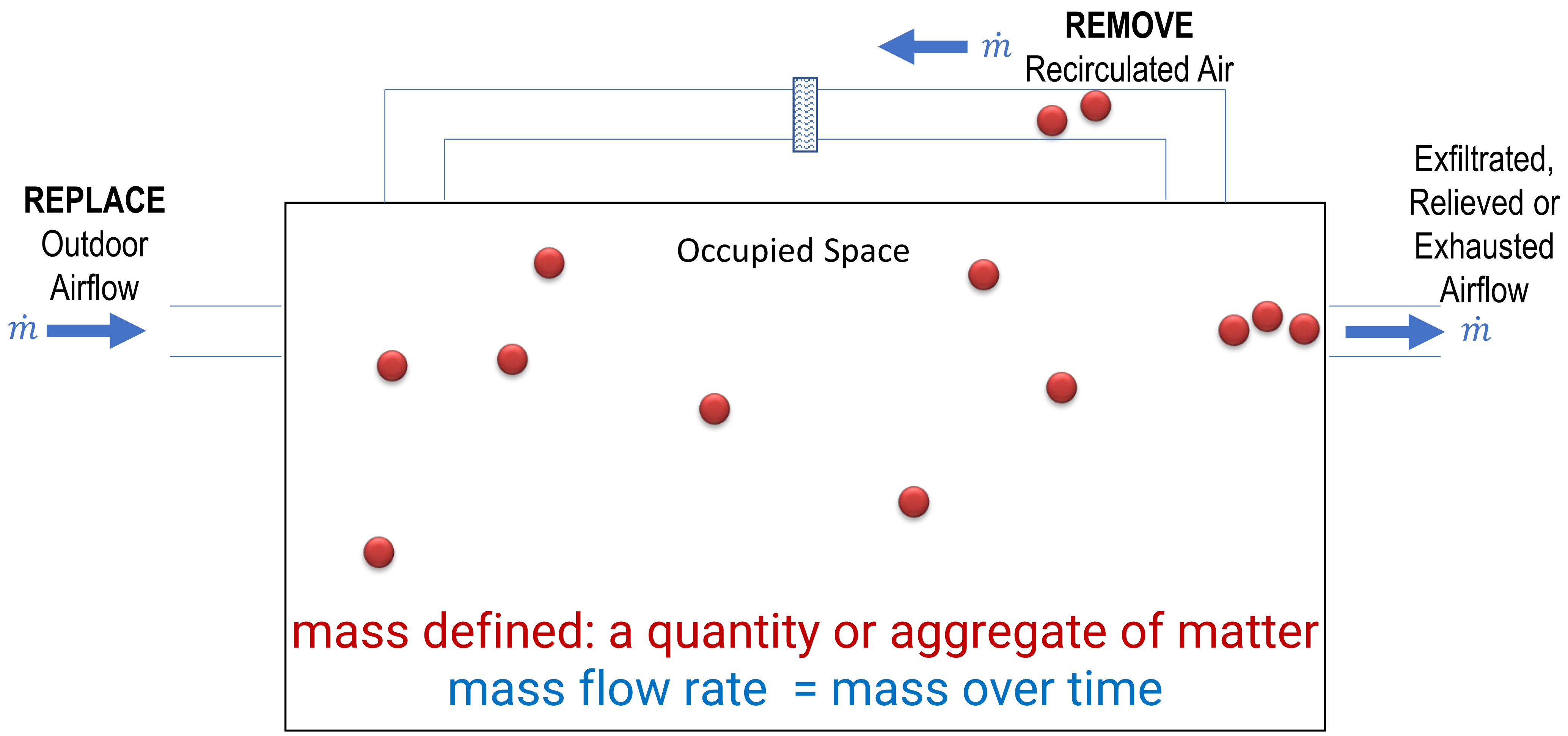
Benefits of higher ventilation rates estimated at $6,500 to $7,500 per person per year in employee productivity

Healthy building effective rents transact between 4.4 and 7.7% more per square foot than their nearby unhealthy neighbor peers

The Financial Impact of Healthy Buildings Dec. 1, 2020
MIT – The Real Estate Innovation Lab

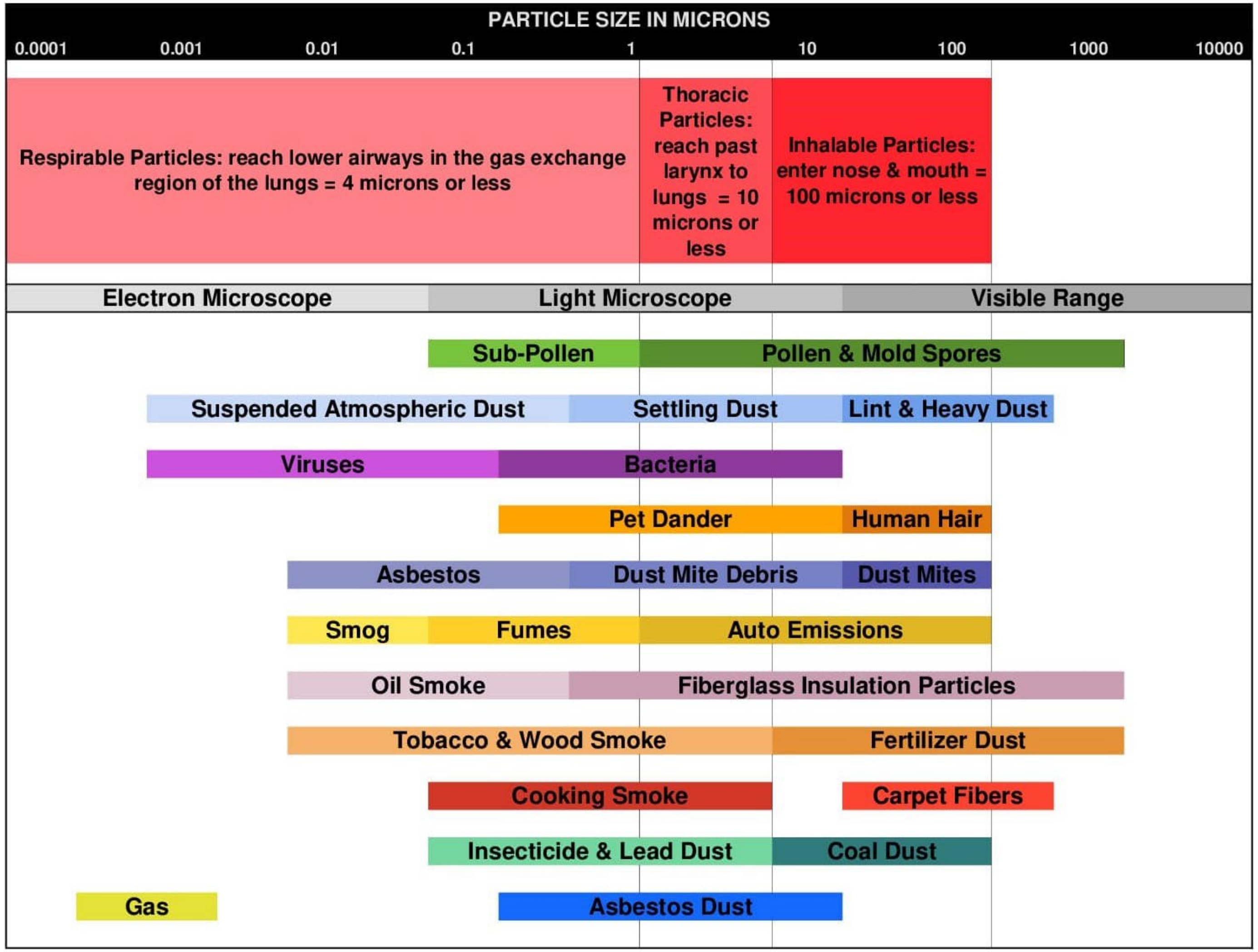
Purpose of Ventilation & Filtration

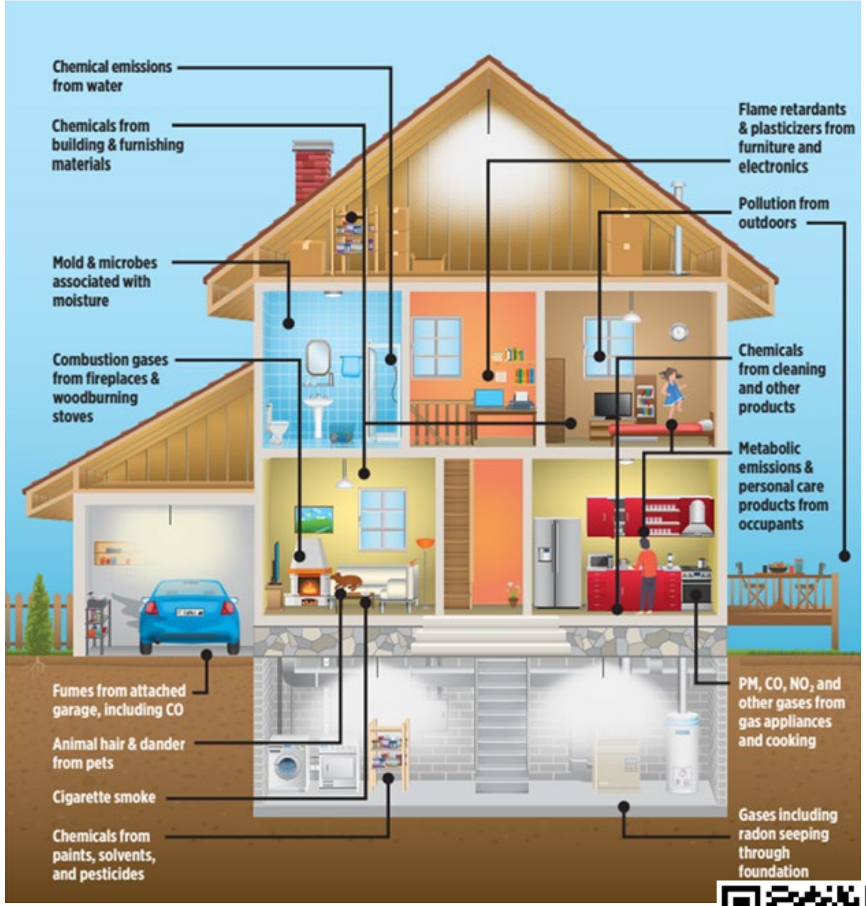
OA Dilution with Targeted High-Level Filtration



Purpose of Ventilation & Filtration

Remove Microscopic Particles and VOCs

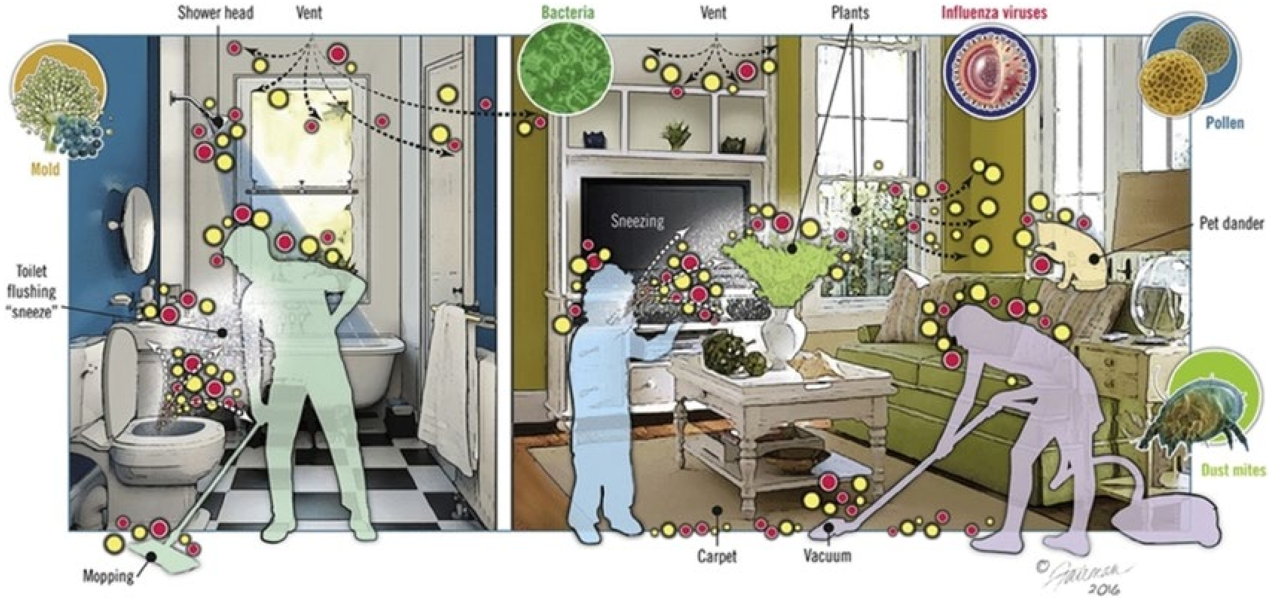




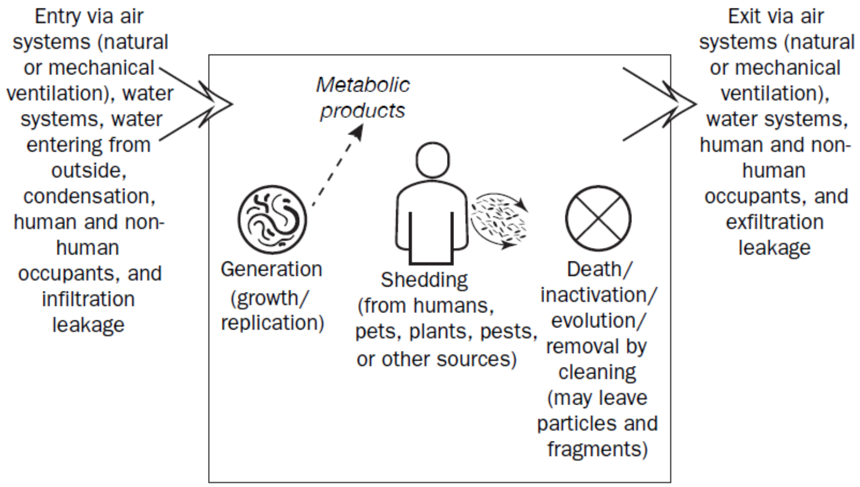
Source: National Academies – Why Indoor Chemistry Matters

Purpose of Ventilation & Filtration

We Live Among Millions of Microbes



Source: Chemistry - An Asian Journal – Sensors and Analytical Technologies for Air Quality



Ventilation and filtration have the potential to control the quality of airflow and indoor microbial conditions, but exercising this control requires sound maintenance practices and proper operation, especially the management of wet environments that may contribute to microbial growth.

Source: National Academies – Microbiomes of the Built Environment

Dilution Flow Rate

Density Impact

$$\rho = \frac{m}{V}$$

ρ is the density
m is the mass
V is the volume

Credit: Lisa Hickey

Air is a mixture of gasses, and its density is significantly impacted by pressure (altitude, weather) and temperature

Dilution flow rates are expressed in volumetric (actual) cfm (l/s) units standardized at specific density conditions 0.075 lbm/ft^3 (1.2 kg/m^2) at sea level 1 atm (14.69 psia), 70°F (21°C), 0% RH

When conditions are different than this standard condition, then actual flow rates need to be adjusted to have the same dilution effect, unless calculations and measurements are in standard flow rates scfm (sl/s)

Dilution Flow Rate

Density Impact – ASHRAE 62.1-2022 Addendum j

Elevation Atmospheric Pressure

Altitude (ft)	Pressure (psia)	Airflow (acfm)	World City	State / Country	Population (000,000)
Sea Level	14.696	100			
750	14.302	97	Charlotte	NC	872
1500	13.917	95	Munich	DE	1,475
2250	13.540	92	Edmonton	AB	981
3000	13.171	90	Billings	MT	110
3750	12.811	87	El Paso	TX	683
4500	12.458	85	Reno	NV	249
5250	12.114	82	Denver	CO	716
6000	11.777	80	Colo Sprgs	CO	465
6750	11.448	78	Loja	EC	180
7350	11.190	76	Mexico City	MX	8,851
8250	10.812	74	Addis Ababa	ET	4,793
8500	10.709	73	Bogota	CO	8,080
9350	10.364	71	Quinto	EC	2,239
10000	10.107	69	Huancayo	PE	425
11250	9.626	66	Cusco	PE	358
12000	9.346	64	La Paz	BO	845
13600	8.772	60	El Alto	BO	1,185

Cooling / Heating Design

Temp (°F)	Airflow (acfm)	World City
-30	123	Edmonton
-20	120	Quebec
-10	118	Billings
0	115	Denver
10	113	Reno
20	110	Charlotte
30	108	Cusco
40	106	Bogota
50	104	Huancayo
60	102	El Alto
70	100	Quinto
80	98	Addis Ababa
90	96	Colo Sprgs
100	95	El Paso
110	93	Phoenix
120	91	Mecca

Replacing Density with Airflow

Moisture Design

RH (%)	Airflow (acfm)
0	100.0
10	99.9
20	99.8
30	99.7
40	99.6
50	99.5
60	99.4
70	99.4
80	99.3
90	99.2
100	99.1

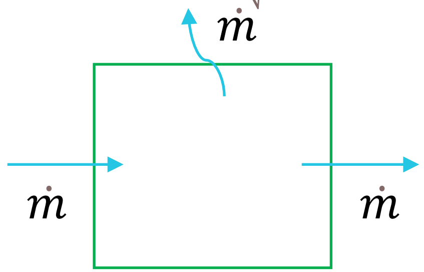
24% Under Min Ventilation

15% Above Min Ventilation

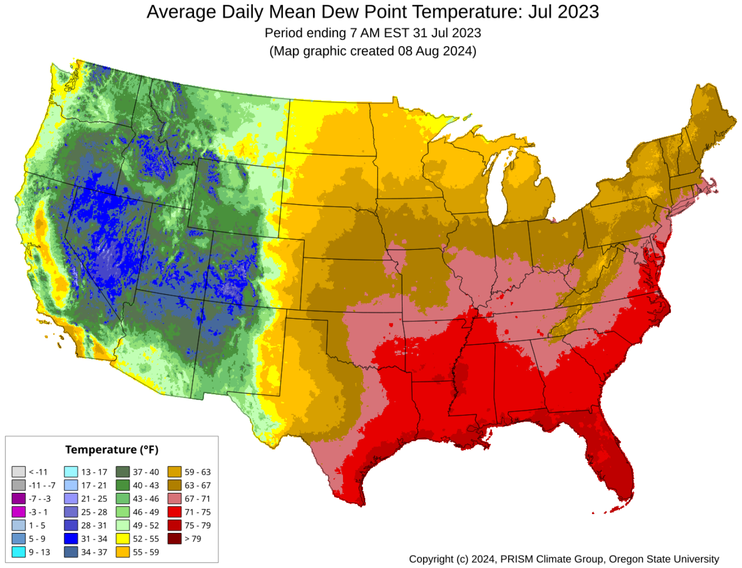
Controlling Airflow is More Than Ventilation

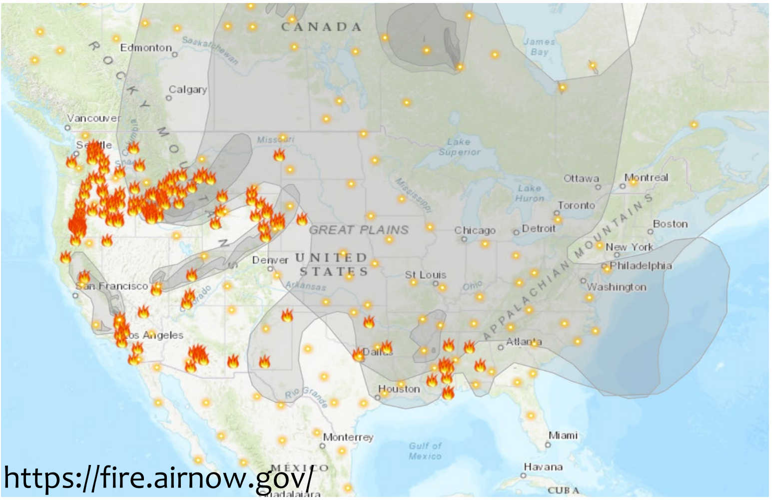
Building and Zone Pressurization are Key to IAQ and Energy

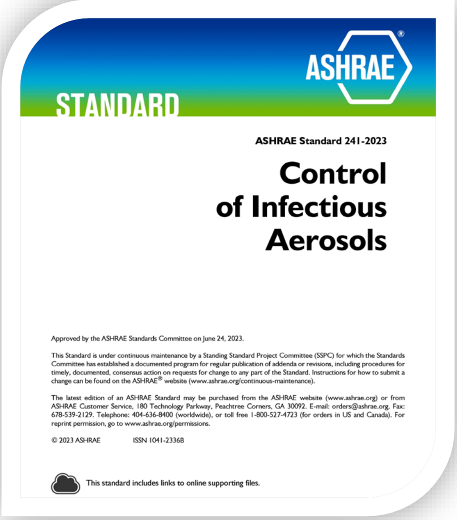
$$Q = 776CA\sqrt{\frac{2\Delta p}{\rho}}$$



$$Q = OA - EA$$
$$= SA - (RA + EA)$$
$$Q = Pressurization\ Flow$$







STANDARD

ASHRAE

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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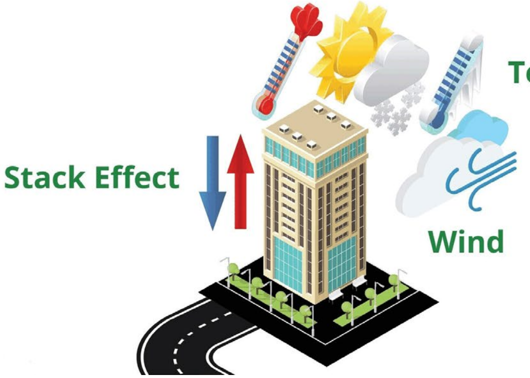


Internal Factors

- Variable Occupancy
- Variable Load
- Operational Changes
- System Degradation
- Deferred maintenance

ASHRAE Introduces Ventilation Standard

Clean Air for Occupants

62-1973
Standard for Natural and Mechanical Ventilation

SECTION 1.0 PURPOSE AND SCOPE
This standard defines ventilation requirements for spaces intended for human occupancy and specifies minimum and recommended ventilation air quantities for the preservation of the occupants' health, safety, and well-being.

Good ventilation practice exists when clean ventilation air is provided in sufficient quantities to maintain the required oxygen, carbon dioxide, and other air quality levels in the space under consideration.


Florence Nightingale

"Founder of Modern Nursing"

Authored "Notes on Nursing"

I. VENTILATION AND WARMING.

First rule of nursing, to keep the air within as pure as the air without.

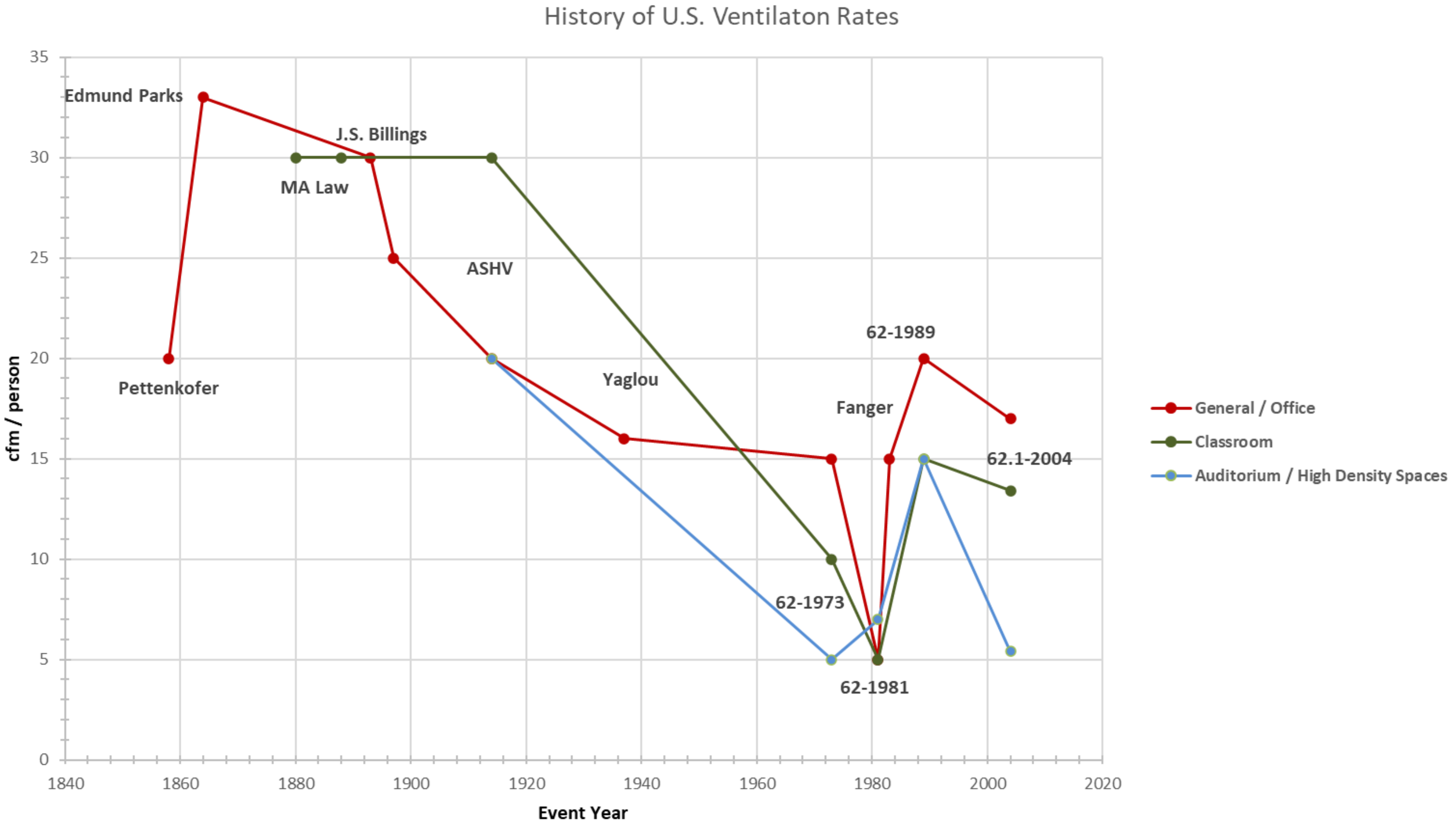
The very first canon of nursing, the first and the last thing upon which a nurse's attention must be fixed, the first essential to the patient, without which all the rest you can do for him is as nothing, with which I had almost said you may leave all the rest alone, is this: TO KEEP THE AIR HE BREATHES AS PURE AS THE EXTERNAL AIR, WITHOUT CHILLING HIM. Yet what is so little attended to? Even

Without cleanliness, you cannot have all the effect of ventilation; without ventilation, you can have no thorough cleanliness.

Very few people, be they of what class they may, have any idea of the exquisite cleanliness required in the sick-room. For much of

Decline of Ventilation Rates

Are We Repeating Past Mistakes



Sick Building Syndrome or Building Related Illness

Used Interchangeable but are Different

Indicators	Description	
	SBS	BRI
Symptomatology	Building occupants complain of symptoms associated with acute discomfort, e.g., headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odours	Building occupants complain of symptoms, such as cough; chest tightness; fever, chills; and muscle aches
Diagnosis	Non-diagnosable illness	Diagnosable illness
Aetiology (cause)	The cause of the symptoms is not known	The symptoms can be clinically defined and have clearly identifiable causes
Duration	Most complainants report relief soon after leaving the building	Complainants may require prolonged recovery times after leaving the building

Source: Creating Healthy and Sustainable Buildings: An Assessment of Health Risk Factors

Airborne Infectious Microorganisms

Bioaerosols that can Remain in the Air, can be Inhaled, and can Cause Illness

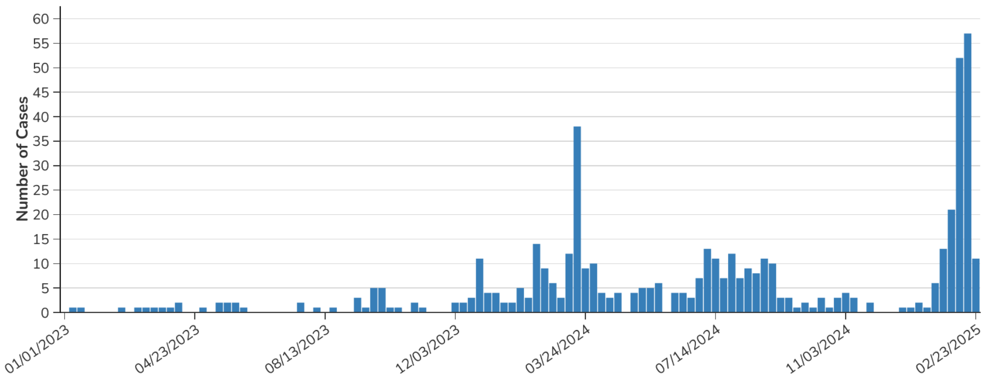
- **Aspergillosis Disease:** Fungal infection caused by the inhalation of Aspergillus *[airborne via mold spores]*
- **Chickenpox Disease:** Highly Contagious virus (infects unvaccinated) *[airborne via infected host]*
- **Enteric viruses:** Group of viruses related with the digestive system of hosts, including the genera Adenovirus, Calicivirus, Enterovirus, Rotavirus, etc. *[airborne via infected host, toilet flushing]*
- **HPS:** “Hantavirus Pulmonary Syndrome” respiratory virus *[Rodents and their droppings]*
- **Influenza A:** “Bird Flu” avian respiratory virus (from infected bird to human) *[airborne via infected host]*
- **Influenza B:** Respiratory virus *[airborne via infected host]*
- **Legionnaires’ disease and Pontiac fever:** Bacterial infection causing pneumonia *[airborne via stagnant water]*
- **Measles:** Highly contagious viral infection (infects unvaccinated) *[airborne via infected host]*
- **MERS:** Middle East Respiratory Syndrome zoonotic respiratory virus *[airborne via infected host]*
- **Norovirus**: “Stomach Flu” gastrointestinal virus *[airborne via vomit, toilet flushing, resuspension from infected surface]*
- **SARS-CoV-1, SARS-CoV-2:** Severe Acute Respiratory Syndrome Coronavirus *[airborne via infected host, toilet flushing]*
- **Tuberculosis:** Bacterial infection impacting respiratory and other organs (infects unvaccinated) *[airborne via infected host]*

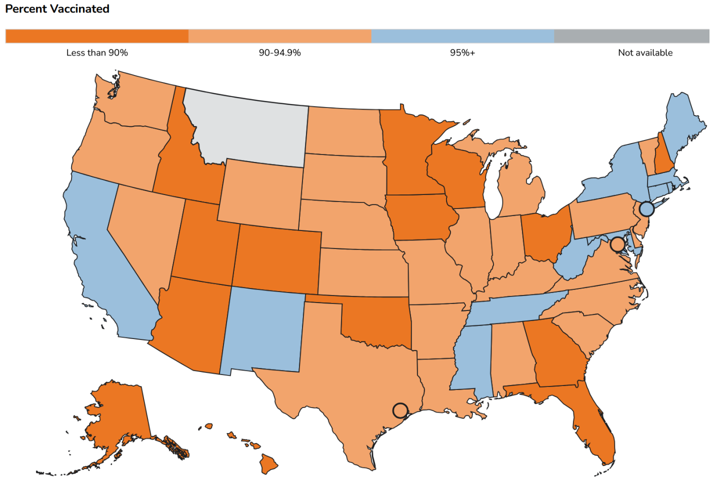
Airborne Infectious Microorganisms

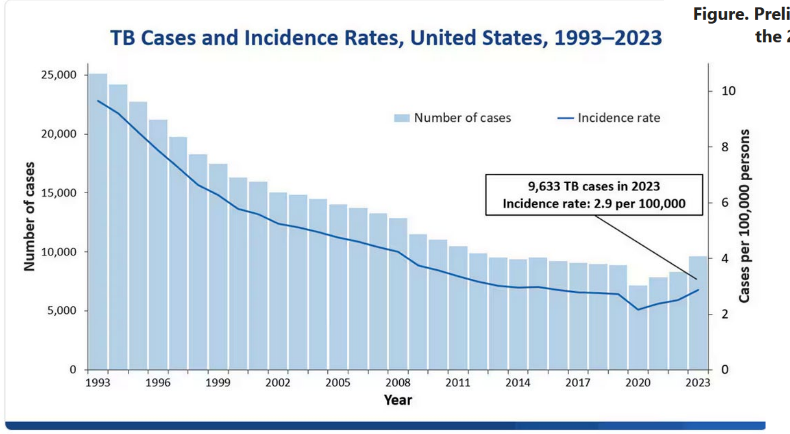
Measles, Tuberculosis, Influenza are All on the Increase in US

Weekly measles cases by rash onset date

2023–2025* (as of February 27, 2025)







During 2023, the United States reported 9,633 TB cases, an incidence rate of 2.9 cases per 100,000 persons.

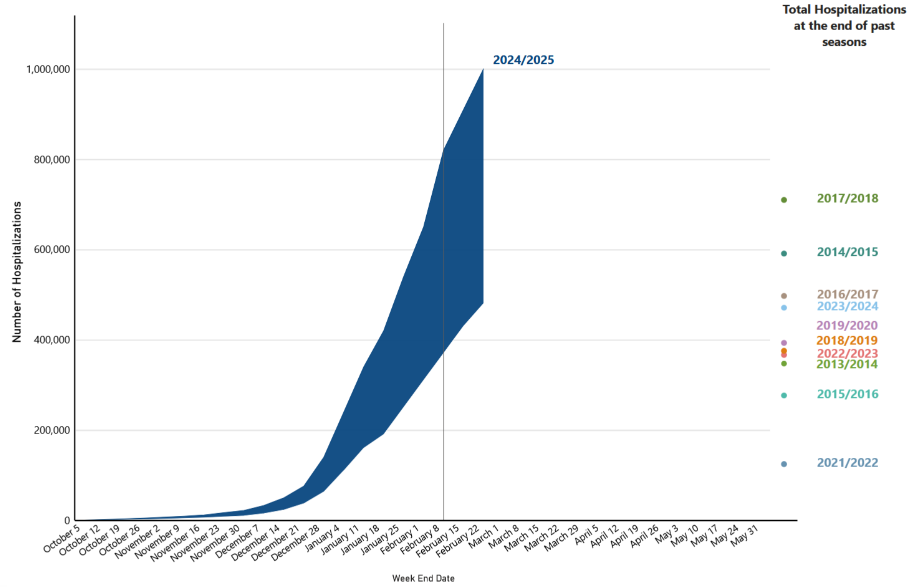


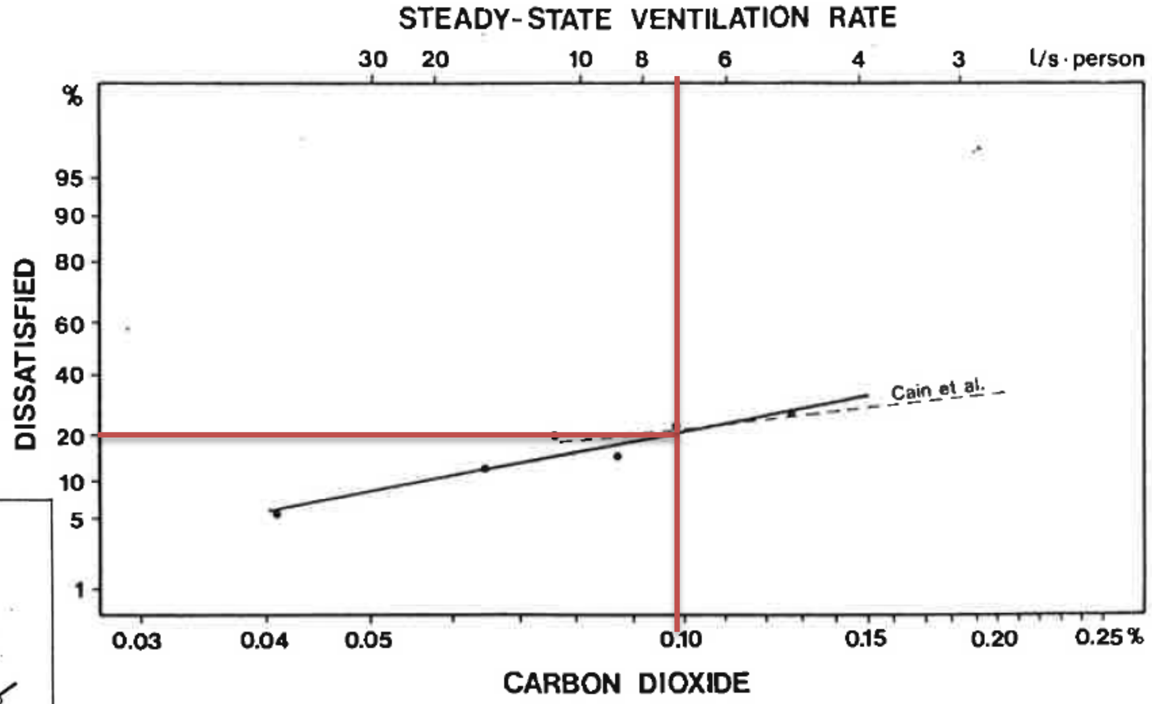
Figure. Preliminary Upper and Lower Estimates of Cumulative Flu-Related Hospitalizations by Week for the 2024-2025 Flu Season Compared to Total Hospitalizations from Past Seasons

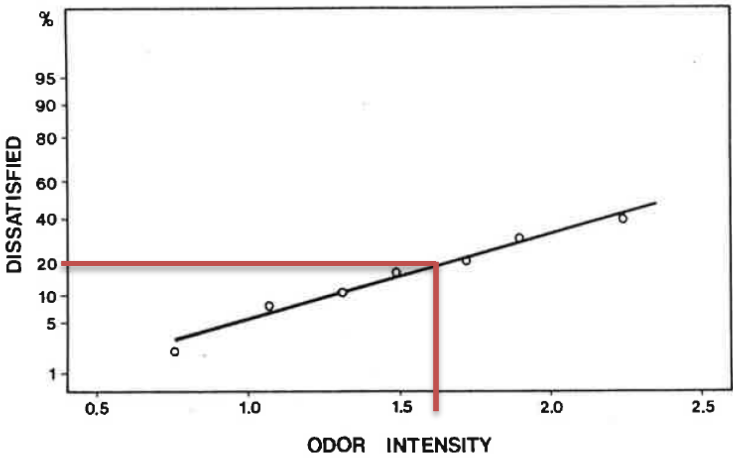
Source: U.S. CDC

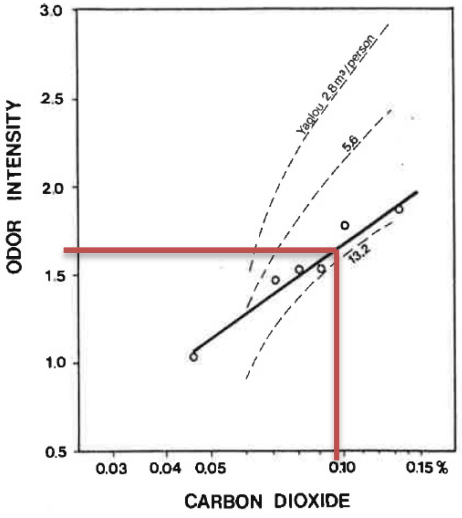
It's All About Body Odor

Ventilation for 80% Acceptability

Denmark 1980's
P. Ole Fanger
International Centre for Indoor Environment and Energy, TUD

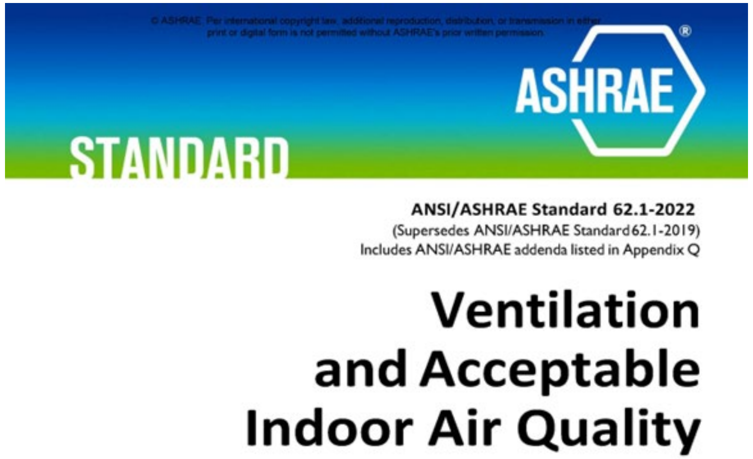






What is Acceptable

Ventilation for 80% Acceptability



Office Buildings

Office space	Occupant activity is primarily sedentary (seated). There are no significant space-related contaminants

Educational Facilities

Classrooms	Occupant activity is primarily sedentary (seated or light walking). However, occupants are generally more vocal.(age 9 plus) Also, the occupants are primarily children with higher metabolic rates and often more bioeffluents. There are some significant space-related contaminants, typically stored arts-and-crafts supplies and cleaning agents.
Lecture classroom	Occupant activity is primarily sedentary (seated or light walking). However, occupants are generally more vocal, resulting in higher metabolic rates. There are no significant space-related contaminants.

1. PURPOSE

1.1 The purpose of this standard is to specify minimum ventilation rates and other measures intended to provide indoor air quality (IAQ) that is acceptable to human occupants and that minimizes adverse health effects.

acceptable indoor air quality (IAQ): air in which there are no known contaminants at harmful concentrations, as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

ASHRAE 62.1 Ventilation

Definition of Ventilation and Filtration

ventilation air: that portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable IAQ.

air-cleaning system: a device or combination of devices applied to reduce the concentration of airborne contaminants such as microorganisms, dusts, fumes, respirable particles, other particulate matter, gases, vapors, or any combination thereof.

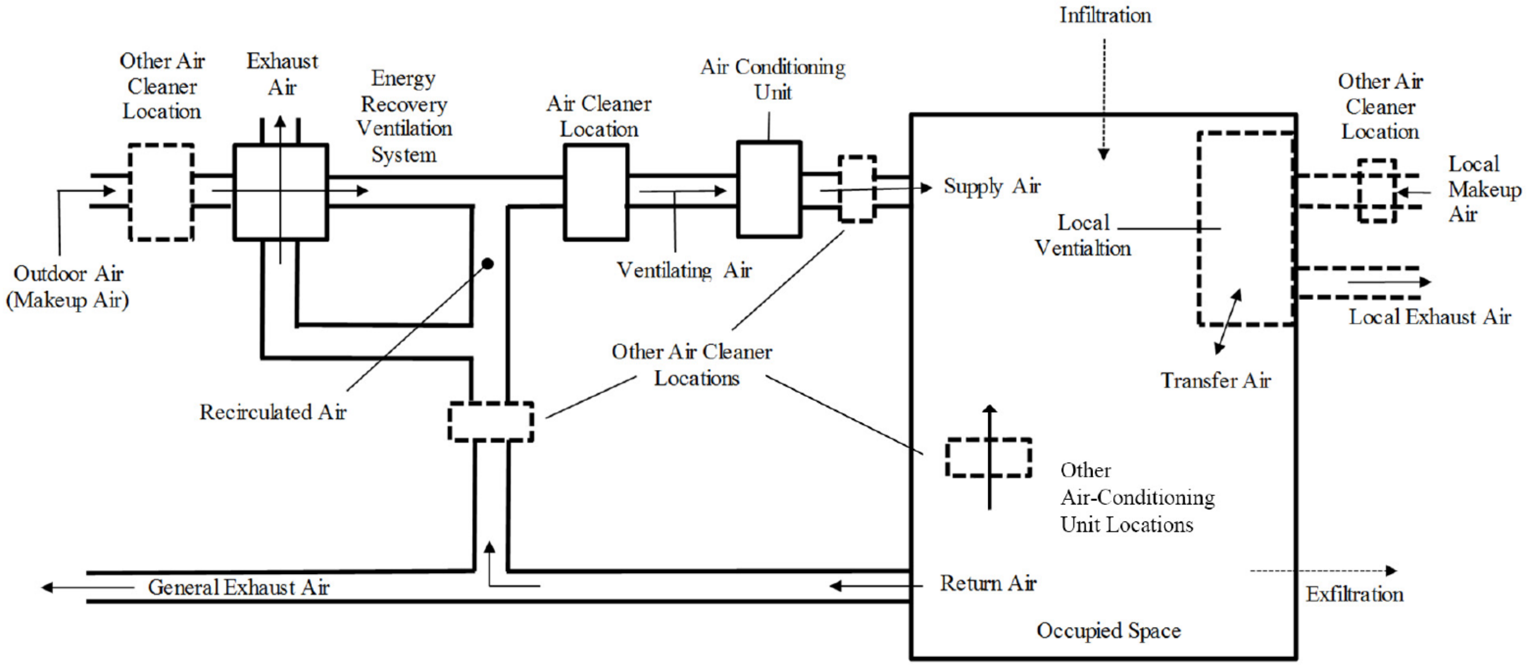


Figure 3-1 Ventilation system.

Filter Requirements

Minimum Efficiency Requirements of Mechanical Filtration

5.5 Particulate Matter Removal. Particulate matter filters or air cleaners having either

a. a MERV of not less than 8 where rated in accordance with ASHRAE Standard 52.2 or
b. the minimum efficiency within ISO ePM10 where rated in accordance with ISO 16890 shall be provided upstream of all cooling coils or other devices with wetted surfaces through which air is supplied to an occupiable space.

Exception to 5.5: Cooling coils that are designed, controlled, and operated to provide sensible cooling only.

SECTION 605
AIR FILTERS

605.1 General. Heating and air-conditioning systems shall be provided with *approved* air filters. Filters shall be installed such that all return air, outdoor air and *makeup air* is filtered upstream from any heat exchanger or coil. Filters shall be installed in an *approved* convenient location. Liquid adhesive coatings used on filters shall have a flash point not lower than 325°F (163°C).

605.2 Approval. Media-type and electrostatic-type air filters shall be *listed* and *labeled*. Media-type air filters shall comply with UL 900. High-efficiency particulate air filters shall comply with UL 586. Electrostatic-type air filters shall comply with UL 867. Air filters utilized within *dwelling units* shall be designed for the intended application and shall not be required to be *listed* and *labeled*.

605.3 Airflow over the filter. Ducts shall be constructed to allow an even distribution of air over the entire filter.

1. **Air filtration.**

   A. Mechanical system types specified in Subsections i, ii and iii below shall be designed to ensure that all recirculated air and all outdoor air supplied to the occupiable space is filtered before passing through any system thermal conditioning components. Air filters shall conform to the requirements of Sections 120.1(c)1B, 120.1(c)1C and 120.1(c)1D.

      i. Mechanical space-conditioning systems that supply air to an occupiable space through ductwork exceeding 10 ft (3 m) in length.

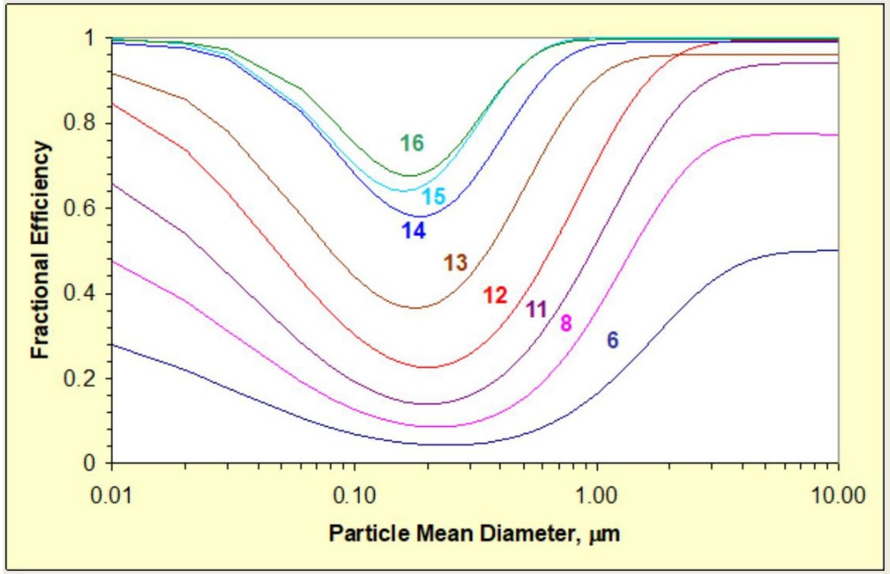
      ii. Mechanical supply-only ventilation systems and makeup air systems that provide outside air to an occupiable space.

      iii. The supply side of mechanical balanced ventilation systems, including heat recovery ventilation systems and energy recovery ventilation systems that provide outside air to an occupiable space.

   B. Air filter efficiency. The filters shall have a designated efficiency equal to or greater than MERV 13 when tested in accordance with ASHRAE Standard 52.2, or a particle size efficiency rating equal to or greater than 50 percent in the 0.30–1.0 μm range, and equal to or greater than 85 percent in the 1.0–3.0 μm range when tested in accordance with AHRI Standard 680; and

Filter Characteristics

Efficiency of Mechanical Filtration



Representative MERV rated filter performance (Kowalski and Bahnfleth 2002)

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, %
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

Table 4. Constant Pressure Drop Initial Efficiency Reporting Values.

Filter Type	MERV 7				MERV 11				MERV 14			
Bypass Gap	No Bypass	0.25 in. (6.4 mm)	0.75 in. (19.1 mm)	1.25 in. (31.8 mm)	No Bypass	0.25 in. (6.4 mm)	0.75 in. (19.1 mm)	1.25 in. (31.8 mm)	No Bypass	0.25 in. (6.4 mm)	0.75 in. (19.1 mm)	1.25 in. (31.8 mm)
Straight	6	6	6	6	10	10	8	8	14	12	8	8
U-Shaped	6	6	6	6	10	10	8	8	14	13	11/12	8

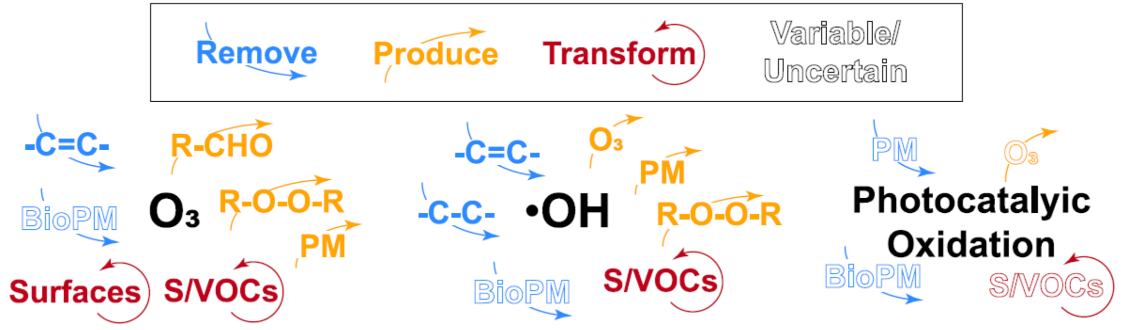
Source: Laboratory Measurements to Quantify the Effect of Bypass on Filtration Efficiency – ASHRAE Transactions 2009

Air Cleaning

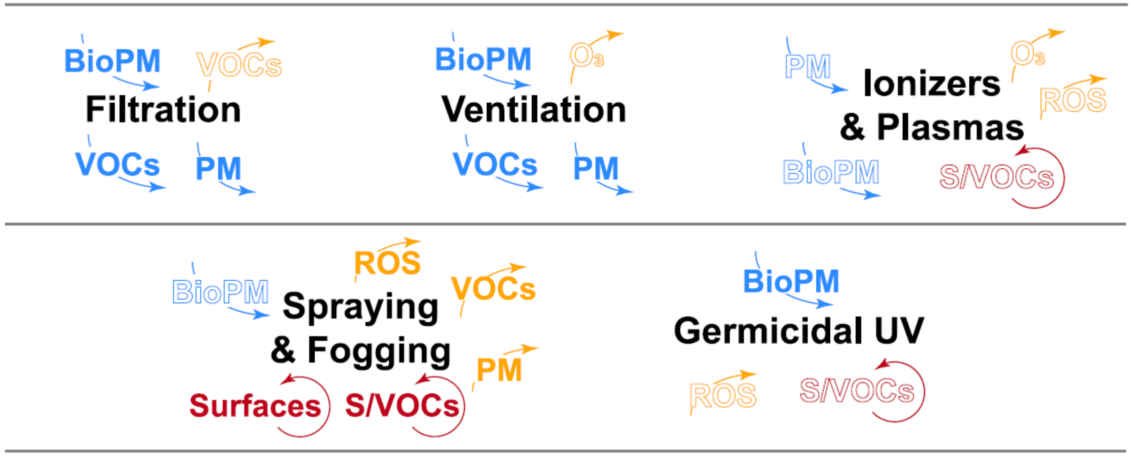
Impact to Indoor Air

	DEFINITION	EXAMPLES
"SUBTRACTIVE" TECHNOLOGIES	Remove or inactivate targeted contaminants from indoor air when they come in contact with the technology (filters, UV light)	Filters (mechanical filters such as MERV and HEPA filtration), sorbent media (remove gases), UVGI/GUV (inactivate viruses, bacteria, and fungi)

School IAQ Fact Sheet: Electronic Air Cleaners – USGBC 2022



Unintended Consequences of Air Cleaning Chemistry
Environ. Sci. Technol. 2021, 55, 12172–12179



Air Cleaning Chemistry

Be Aware of the Science

ASHRAE®

Environmental Health Committee (EHC) Emerging Issue Brief

January 9, 2024

Indoor Reactive Oxygen and Nitrogen Species

<u>What is the issue?</u>

Reactive oxygen species (ROS) and reactive nitrogen species (RNS) are unstable oxygen- and/or nitrogen-containing radicals and non-radical species. Exposure to extracellular (produced in the environment) ROS and RNS, as well as endogenous (produced inside the body) reactive species production, can result in oxidative stress in humans, which can exacerbate or lead to multiple adverse health impacts, including asthma, diabetes, chronic obstructive pulmonary disease (COPD), and cancer.[1–3] ROS and RNS species include superoxide ($O_2^{\bullet-}$), hydroxyl ($HO^{\bullet}$), hydroperoxyl ($HOO^{\bullet}$), alkylperoxides ($ROO^{\bullet}$), hydrogen peroxide (H_2O_2), organic peroxides (ROOR), hypochlorite (OCl^-), peroxynitrite ($ONOO^-$),[4–6] nitrogen oxides (NO_2, NO; collectively NO_x), nitrous acid (HONO)[7], and chlorine nitrite ($ClNO_2$).[8] Here we focus on indoor extracellular reactive species present in the particle- and gas-phase, rather than intracellular reactive species (generated endogenously).

ELSEVIER
Building and Environment
Volume 227, Part 1, January 2023, 109804

Large-scale evaluation of microorganism inactivation by bipolar ionization and photocatalytic devices

ELSEVIER
Building and Environment
Volume 195, 15 May 2021, 107750

Evaluating a commercially available in-duct bipolar ionization device for pollutant removal and potential byproduct formation

Environmental Science & Technology Letters
pubs.acs.org/journal/estlcu
Letter

Model Evaluation of Secondary Chemistry due to Disinfection of Indoor Air with Germicidal Ultraviolet Lamps

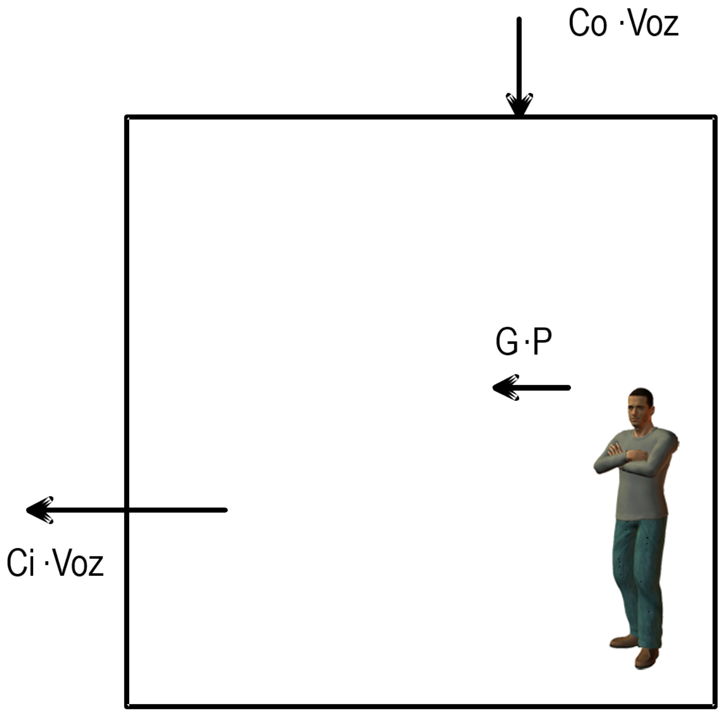
Environmental Science & Technology
Open Access

pubs.acs.org/est
Article

Indoor Air Quality Implications of Germicidal 222 nm Light

Relationship Between CO_2 and Ventilation

It is Very Occupant Dependent



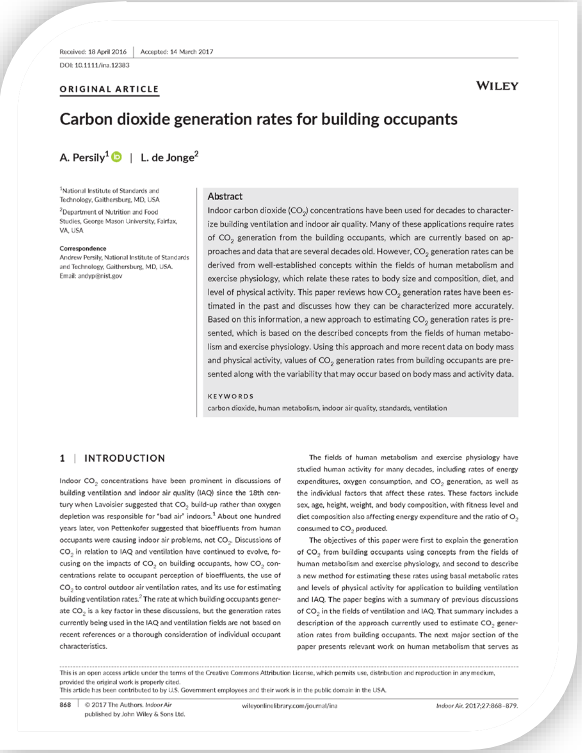
Co = Outdoor CO_2 concentration (ft^3 CO_2/ft^3 air)
Ci = Indoor CO_2 concentration (ft^3 CO_2/ft^3 air)
Voz = Q_{OA} = Outside Airflow Rate (ft^3air/min)
Vo=Outside Airflow Rate/Person ((ft^3air/min)/person)
G = CO_2 generation rate of the occupant (ft^3 CO_2/min)
P = Number of occupants

Steady-state Mass Balance: In = Out

Co·Voz + G·P = Ci·Voz

Can be rearranged as:

G / (Ci – Co) = Voz/P = Vo = OA CFM/person



Received: 18 April 2016 | Accepted: 14 March 2017
DOI: 10.1111/ina.12383
ORIGINAL ARTICLE
WILEY

Carbon dioxide generation rates for building occupants

A. Persily[1] | L. de Jonge[2]

[1]National Institute of Standards and Technology, Gaithersburg, MD, USA
[2]Department of Nutrition and Food Studies, George Mason University, Fairfax, VA, USA

Correspondence
Andrew Persily, National Institute of Standards and Technology, Gaithersburg, MD, USA.
Email: andyp@nist.gov

Abstract

Indoor carbon dioxide (CO_2) concentrations have been used for decades to characterize building ventilation and indoor air quality. Many of these applications require rates of CO_2 generation from the building occupants, which are currently based on approaches and data that are several decades old. However, CO_2 generation rates can be derived from well-established concepts within the fields of human metabolism and exercise physiology, which relate these rates to body size and composition, diet, and level of physical activity. This paper reviews how CO_2 generation rates have been estimated in the past and discusses how they can be characterized more accurately. Based on this information, a new approach to estimating CO_2 generation rates is presented, which is based on the described concepts from the fields of human metabolism and exercise physiology. Using this approach and more recent data on body mass and physical activity, values of CO_2 generation rates from building occupants are presented along with the variability that may occur based on body mass and activity data.

KEYWORDS
carbon dioxide, human metabolism, indoor air quality, standards, ventilation

1 | INTRODUCTION

Indoor CO_2 concentrations have been prominent in discussions of building ventilation and indoor air quality (IAQ) since the 18th century when Lavoisier suggested that CO_2 build-up rather than oxygen depletion was responsible for "bad air" indoors.[1] About one hundred years later, von Pettenkofer suggested that bioeffluents from human occupants were causing indoor air problems, not CO_2. Discussions of CO_2 in relation to IAQ and ventilation have continued to evolve, focusing on the impacts of CO_2 on building occupants, how CO_2 concentrations relate to occupant perception of bioeffluents, the use of CO_2 to control outdoor air ventilation rates, and its use for estimating building ventilation rates.[2] The rate at which building occupants generate CO_2 is a key factor in these discussions, but the generation rates currently being used in the IAQ and ventilation fields are not based on recent references or a thorough consideration of individual occupant characteristics.

The fields of human metabolism and exercise physiology have studied human activity for many decades, including rates of energy expenditures, oxygen consumption, and CO_2 generation, as well as the individual factors that affect these rates. These factors include sex, age, height, weight, and body composition, with fitness level and diet composition also affecting energy expenditure and the ratio of O_2 consumed to CO_2 produced.

The objectives of this paper were first to explain the generation of CO_2 from building occupants using concepts from the fields of human metabolism and exercise physiology, and second to describe a new method for estimating these rates using basal metabolic rates and levels of physical activity for application to building ventilation and IAQ. The paper begins with a summary of previous discussions of CO_2 in the fields of ventilation and IAQ. That summary includes a description of the approach currently used to estimate CO_2 generation rates from building occupants. The next major section of the paper presents relevant work on human metabolism that serves as

1000 ppm = what ventilation rate?

ASHRAE 62.1 Addendum ab

Providing New Approach and Correcting Improper Application

ASHRA

ADDENDA

ANSI/ASHRAE Addendu
ANSI/ASHRAE Standard 6

Ventilation a
Acceptable Indo
Air Qual

Approved by ASHRAE and the American National Standards Institute on October 31, 2023.

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

The latest edition of an ASHRAE Standard may be purchased on the ASHRAE website (www.ashrae.o ASHRAE Customer Service, 180 Technology Parkway, Peachtree Corners, GA 30092. E-mail: orders@ashr 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and C reprint permission, go to www.ashrae.org/permissions.

 ISSN 1041-2336

Occupancy Category	Maximum CO_2 above Ambient, $\Delta C_{6.1}$
Animal Facilities	
Animal exam room (veterinary office)	NA
Animal imaging (MRI/CT/PET)	NA
Animal operating rooms	NA
Animal postoperative recovery room	NA
Animal preparation rooms	NA
Animal procedure room	NA
Animal surgery scrub	NA
Large-animal holding room	NA
Necropsy	NA
Small-animal-cage room (static cages)	NA
Small-animal-cage room (ventilated cages)	NA
Correctional Facilities	
Booking/waiting	1200
Cell	NA
Dayroom	1500
Guard stations	1200
Educational Facilities	
Art classroom	NA
Classrooms (ages 5 to 8)	600
Classrooms (age 9 plus)	600
Computer lab	600
Daycare sickroom	NA
Daycare (through age 4)	NA
Lecture classroom	1200
Lecture hall (fixed seats)	1200
Libraries	600
Media center	600
Multiuse assembly	1200
Music/theater/dance	2100
Science laboratories	NA
University/college laboratories	NA
Wood/metal shop	NA
Food and Beverage Service	
Bars, cocktail lounges	1200
Cafeteria/fast-food dining	900
Kitchen (cooking)	NA
Restaurant dining rooms	1500
General	
Breakrooms	1500
Coffee stations	1200
Conference/meeting	1500
Corridors	NA

Occupancy Category	Maximum CO_2 above Ambient, $\Delta C_{6.1}$
Occupiable storage rooms for liquids or gels	NA
Hotels, Motels, Resorts, Dormitories	
Barracks sleeping areas	900
Bedroom/living room	600
Laundry rooms, central	NA
Laundry rooms within dwelling units	NA
Lobbies/prefunction	1500
Multipurpose assembly	1800
Miscellaneous Spaces	
Banks or bank lobbies	900
Bank vaults/safe deposit	600
Computer (not printing)	600
Freezer and refrigerated spaces (<50°F [10°C])	NA
Manufacturing where hazardous materials are not used	600
Manufacturing where hazardous materials are used (excludes heavy industrial and chemical processes)	NA
Pharmacy (prep. area)	900
Photo studios	NA
Shipping/receiving	700
Sorting, packing, light assembly	900
Telephone closets	NA
Transportation waiting	1800
Warehouses	700
Office Buildings	
Breakrooms	1500
Main entry lobbies	1200
Occupiable storage rooms for dry materials	700
Office space	600
Reception areas	2100
Telephone/data entry	1800
Public Assembly Spaces	
Auditorium seating area	1800
Courtrooms	1500
Legislative chambers	1800
Libraries	600
Lobbies	1800
Museums (children's)	1800
Museums/galleries	1500
Places of religious worship	1800

Occupancy Category	Maximum CO_2 above Ambient, $\Delta C_{6.1}$
Sales (except as below)	900
Barbershop	NA
Beauty and nail salons	NA
Coin-operated laundries	900
Mall common areas	2100
Pet shops (animal areas)	NA
Supermarket	1500
Sports and Entertainment	
Bowling alley (seating)	900
Disco/dance floors	1500
Gambling casinos	1200
Game arcades	900
Gym, sports arena (play area)	900
Health club/aerobics room	1500
Health club/weight rooms	1500
Spectator areas	1500
Stages, studios	1500
Swimming (pool and deck)	NA
Transient Residential	
Common corridors	NA
Dwelling unit	NA
Outpatient Health Care Facilities	
Birthing room	NA
Class 1 imaging rooms	NA
Dental operatory	NA
General examination room	NA
Other dental treatment areas	NA
Physical therapy exercise area	NA
Physical therapy individual room	NA
Physical therapeutic pool area	NA
Prosthetics and orthotics room	NA
Psychiatric consultation room	NA
Psychiatric examination room	NA
Psychiatric group room	NA
Psychiatric seclusion room	NA
Speech therapy room	NA
Urgent care examination room	NA
Urgent care observation room	NA
Urgent care treatment room	NA
Urgent care triage room	NA

Default ΔCO_2 Limits

Occupant Density Adjustment

Sensor Placement & Calibration

Control Requirements

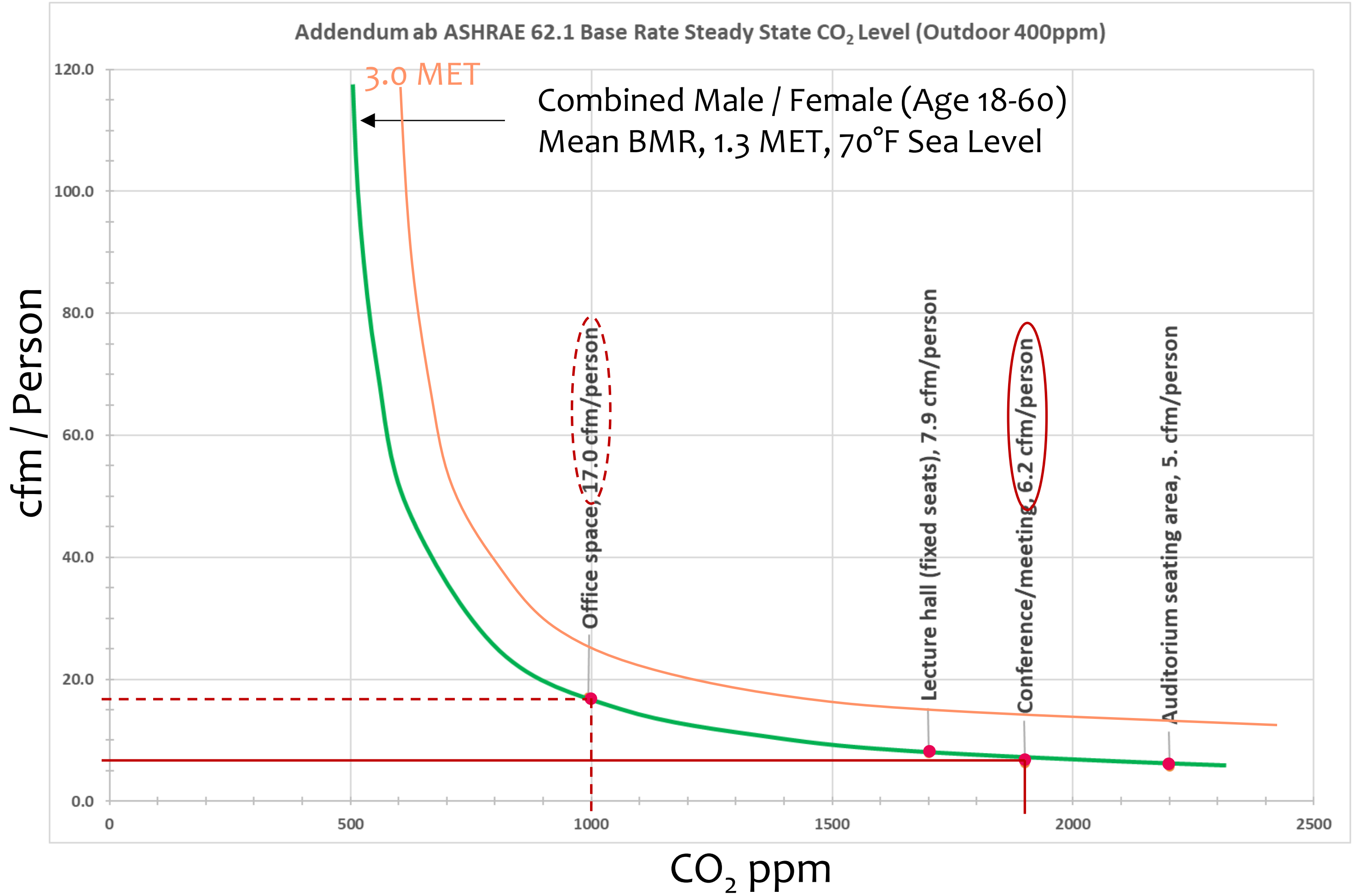
Conference/meeting
Auditorium seating area

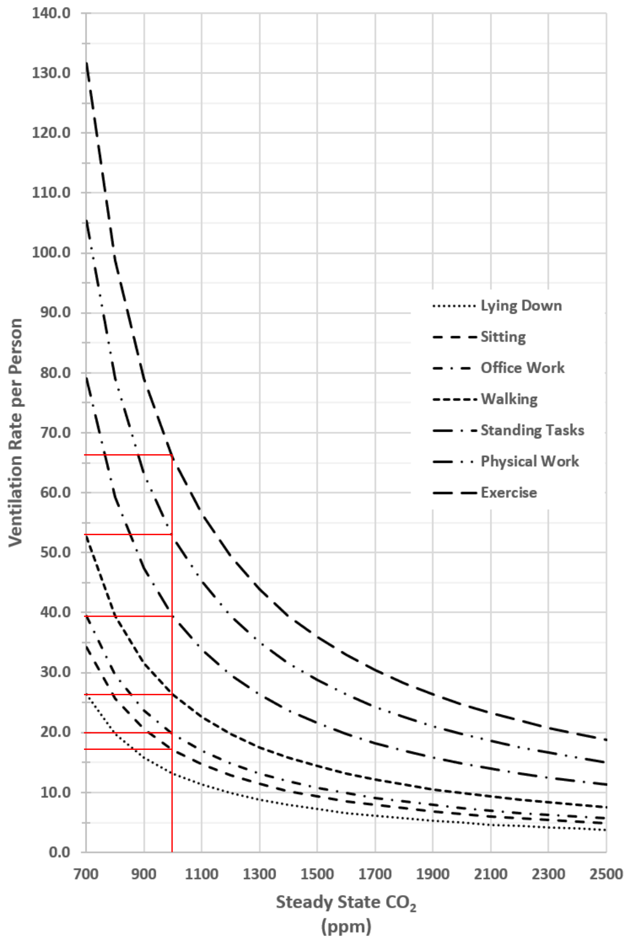
$\underline{1500} + 400 = 2500\text{ppm}$

$\underline{1800} + 400 = 2200\text{ppm}$

Demand Control Ventilation (DCV)

Is Often Misunderstood and Can Over-ventilate or Under-ventilate





Other Sources or Removal of CO_2

Additive Air Cleaning Technologies may Add or Remove CO_2

Challenge Gas	Efficiency Measured by RTI Lab[1]
Ozone	70%
Hexane	74%
Xylene	60%
Isopropanol	77%
Toulene	52%
Benzene	87%
Formaldehydle	55%
Carbon dioxide	57%

[1]Efficiency used in design calculations

With our technology the level of CO2 will be decreased by 10-20% by normal operation. That means that even if a facility was set up under the VRP method of OA, and demand ventilation is employed, we will benefit the end user because removing 10-20% of the CO2 is going to drive the overall CO2 level below the set point far more often resulting in modulating away for OA. This is the only way an

Outdoor Air Flow Type	Constant				
Indoor Contaminants Generated By People & From Outdoors	**Maximum Threshold Value (PPM)**	**Steady State Using the VRP* (Prescribed OA) Plasma Off**	**Steady State Using the IAQ Method (Reduced OA) Plasma On**	**Is Steady State Level Acceptable at Reduced OA Levels?**	**Contaminant Generation Rate (PPM)**
Acetaldehyde	100.0	0.01112	0.00360	Yes	0.00048
Acetone	250.0	0.00175	0.00144	Yes	0.00654
Ammonia	25.00	0.01771	0.03469	Yes	0.21460
Benzene	1.0000	0.00252	0.00083	Yes	0.00022
2- Butanone (MEK)	200.0	0.00020	0.00024	Yes	0.00133
Carbon dioxide**	5000	1115	2802	Yes	441

ASHRAE 62.1 Addendum ab

CO2 DCV Only When Source from People and Dilution Only with Outdoor Air

6.2.6.1 Demand Control Ventilation (DCV). DCV shall be permitted as an optional means of dynamic reset.

6.2.6.1.1 For DCV *ventilation zones* in the occupied mode, breathing zone outdoor airflow (Vbz) shall be reset in response to current population. Current population estimates or indicators used in DCV control calculations shall not result in ventilation rates that are less than those required by the actual population when averaged over the time period determined in accordance with Section 6.2.5.2 or one hour, whichever is less.

6.2.6.1.2 For DCV *ventilation zones* in the occupied mode, breathing zone outdoor airflow (Vbz) shall be not less than the building component ($Ra \times Az$) for the zone.

6.2.6.1.3 CO_2 sensors shall be permitted to be used for DCV in accordance with the following subsections.

Exception to 6.2.6.1.3: CO2-based DCV shall not be applied in zones with indoor sources of CO2 other than occupants, or with CO2 removal mechanisms, such as gaseous air cleaners.

ASHRAE 62.1 Addendum ab Calculation

CO2 DCV Doesn't Work With Air Cleaning Addition or Removal of CO2

$$G_{CO2} = RQ \times BMR \times M \times (T/P) \times 0.000034$$

$RQ = 0.85$ 47.9% carbohydrates, 33.6% fat, and 15.9% protein

Middle School Classroom

$$G = 0.85 \times 7.0 \times 1.3 \times (531/14.7) \times 0.000034$$

$$G = 0.0095 \text{ cfm } (0.0045 \text{ L/s})$$

62.1 / IMC / UMC Ventilation Rate

10 cfm, 0.12 cfm, 35/1000 sqft

$$MinV = (10 \times 35) + (0.12 \times 1000)$$

$$MinV = 470 \text{ cfm } (13.4 \text{ cfm/p})$$

Solve for Steady State CO_2

$$ppm = 420 + (0.0095/13.4) \times 10^6$$

$ppm = 1129$ *30% Removal Eff*

$$\text{cfm/p} = 0.0095 \times 10^6/(790-420)$$

$$\text{cfm/p} = 25.7$$

TABLE 4 CO_2 generation rates at 273 K and 101 kPa for ranges of ages and level of physical activity (based on mean body mass in each age group)

			CO_2 generation rate (L/s)						
			Level of physical activity (met)						
Age (y)	Mean body mass (kg)	BMR (MJ/day)	1.0	1.2	1.4	1.6	2.0	3.0	4.0
Males									
<1	8.0	1.86	0.0009	0.0011	0.0013	0.0014	0.0018	0.0027	0.0036
1 to <3	12.8	3.05	0.0015	0.0018	0.0021	0.0024	0.0030	0.0044	0.0059
3 to <6	18.8	3.90	0.0019	0.0023	0.0026	0.0030	0.0038	0.0057	0.0075
6 to < 11	31.9	5.14	0.0025	0.0030	0.0035	0.0040	0.0050	0.0075	0.0100
11 to <16	57.6	7.02	0.0034	0.0041	0.0048	0.0054	0.0068	0.0102	0.0136
16 to <21	77.3	7.77	0.0037	0.0045	0.0053	0.0060	0.0075	0.0113	0.0150
21 to < 30	84.9	8.24	0.0039	0.0048	0.0056	0.0064	0.0080	0.0120	0.0160
30 to <40	87.0	7.83	0.0037	0.0046	0.0053	0.0061	0.0076	0.0114	0.0152
40 to <50	90.5	8.00	0.0038	0.0046	0.0054	0.0062	0.0077	0.0116	0.0155
50 to <60	89.5	7.95	0.0038	0.0046	0.0054	0.0062	0.0077	0.0116	0.0154
60 to <70	89.5	6.84	0.0033	0.0040	0.0046	0.0053	0.0066	0.0099	0.0133
70 to <80	83.9	6.57	0.0031	0.0038	0.0045	0.0051	0.0064	0.0095	0.0127
≥80	76.1	6.19	0.0030	0.0036	0.0042	0.0048	0.0060	0.0090	0.0120
Females									
<1	7.7	1.75	0.0008	0.0010	0.0012	0.0014	0.0017	0.0025	0.0034
1 to <3	12.3	2.88	0.0014	0.0017	0.0020	0.0022	0.0028	0.0042	0.0056
3 to <6	18.3	3.59	0.0017	0.0021	0.0024	0.0028	0.0035	0.0052	0.0070
6 to < 11	31.7	4.73	0.0023	0.0027	0.0032	0.0037	0.0046	0.0069	0.0092
11 to < 16	55.9	6.03	0.0029	0.0035	0.0041	0.0047	0.0058	0.0088	0.0117
16 to <21	65.9	6.12	0.0029	0.0036	0.0042	0.0047	0.0059	0.0089	0.0119
21 to < 30	71.9	6.49	0.0031	0.0038	0.0044	0.0050	0.0063	0.0094	0.0126
30 to < 40	74.8	6.08	0.0029	0.0035	0.0041	0.0047	0.0059	0.0088	0.0118
40 to <50	77.1	6.16	0.0029	0.0036	0.0042	0.0048	0.0060	0.0090	0.0119
50 to <60	77.5	6.17	0.0030	0.0036	0.0042	0.0048	0.0060	0.0090	0.0120
60 to <70	76.8	5.67	0.0027	0.0033	0.0038	0.0044	0.0055	0.0082	0.0110
70 to <80	70.8	5.45	0.0026	0.0032	0.0037	0.0042	0.0053	0.0079	0.0106
≥80	64.1	5.19	0.0025	0.0030	0.0035	0.0040	0.0050	0.0075	0.0101

DOI: 10.1111/ina.12383

A. Persily, L. de Jonge2

TABLE 3 Values of physical activity levels (M) from compendium [41]

Activity	M (met)	Range
Calisthenics—light effort	2.8	
Calisthenics—moderate effort	3.8	
Calisthenics—vigorous effort	8.0	
Child care		2.0 to 3.0
Cleaning, sweeping—moderate effort	3.8	
Custodial work—light	2.3	
Dancing—aerobic, general	7.3	
Dancing—general	7.8	
Health club exercise classes—general	5.0	
Kitchen activity—moderate effort	3.3	
Lying or sitting quietly		1.0 to 1.3
Sitting reading, writing, typing	1.3	
Sitting at sporting event as spectator	1.5	
Sitting tasks, light effort (e.g, office work)	1.5	
Sitting quietly in religious service	1.3	
Sleeping	0.95	
Standing quietly	1.3	
Standing tasks, light effort (e.g, store clerk, filing)	3.0	
Walking, less than 2 mph, level surface, very slow	2.0	
Walking, 2.8 mph to 3.2 mph, level surface, moderate pace	3.5	

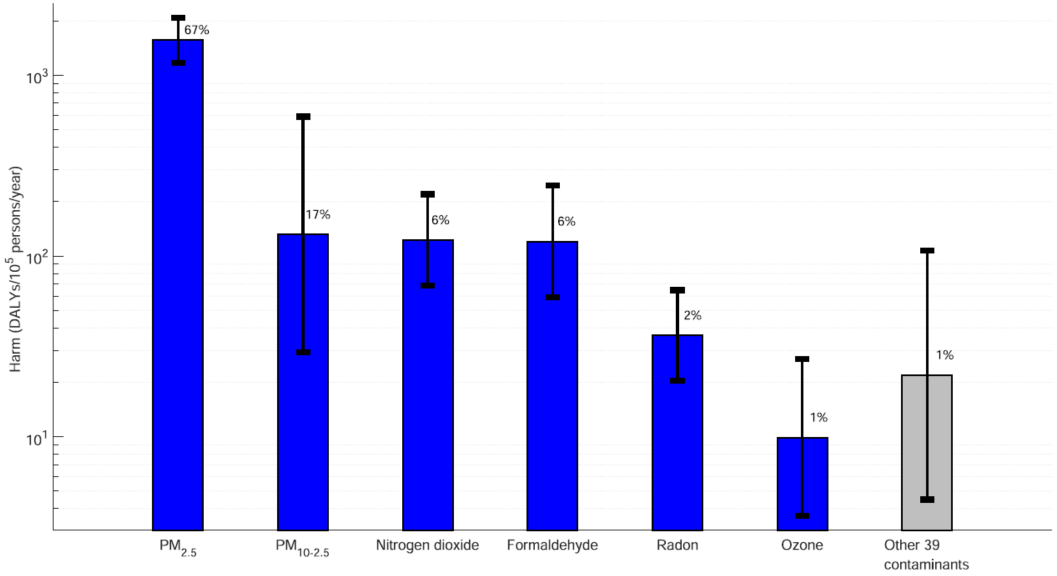
Compendium of Physical Activities

IAQP and Harm

Ventilating at Levels Near Hazzard Limits May Cause More Harm

Table 6-5 Design Compounds, PM2.5, and Their Design Limits

Compound or PM2.5	Cognizant Authority	Design Limit
Acetaldehyde	Cal EPA CREL (June 2016)	140 µg/m³
Acetone	AgBB LCI	1,200 µg/m³
Benzene	Cal EPA CREL (June 2016)	3 µg/m³
Dichloromethane	Cal EPA CREL (June 2016)	400 µg/m³
Formaldehyde	Cal EPA 8-hour CREL (2004)	33 µg/m³
Naphthalene	Cal EPA CREL (June 2016)	9 µg/m³
Phenol	AgBB LCI	10 µg/m³
Tetrachloroethylene	Cal EPA CREL (June 2016)	35 µg/m³
Toluene	Cal EPA CREL (June 2016)	300 µg/m³
1,1,1-trichloroethane	Cal EPA CREL (June 2016)	1000 µg/m³
Xylene, total	AgBB LCI	500 µg/m³
Carbon monoxide	U.S. EPA NAAQS	9 ppm
PM2.5	U.S. EPA NAAQS (annual mean)	12 µg/m³
Ozone	U.S. EPA NAAQS	70 ppb
Ammonia	Cal EPA CREL (June 2016)	200 µg/m³



Harm from Residential Indoor Air Contaminants, Environ. Sci. Technol. 2024, 58, 242–257

TABLE 1 Estimates of harm for six selected contaminants at design compound maximum limits allowed by Standard 62.1-2022.

COMPOUND	HARM INTENSITY, DALY PER µg/m³·YR PER 100,000 PEOPLE	62.1 LIMIT, µg/m³	HARM, DALY/YR PER 100,000 PEOPLE	PERSONAL HARM $/YR PERSON (AMERICAN)
Acetaldehyde	0.053	140	7.42	$56
Benzene	0.067	3	0.20	$2
Formaldehyde	4.3	33	141.90	$1,064
Naphthalene	0.36	9	3.24	$24
Ozone	1.3	137	178.10	$1,336

The monetized harm shows that for some contaminants it is not worth reducing them below these levels, but for some it very much is. Being exposed at 12 µg/m3 of PM2.5 is harming a "statistical" American over $5,000/yr, and it would easily be worth it for them, for example, to spend a thousand dollars per year to cut that in half.

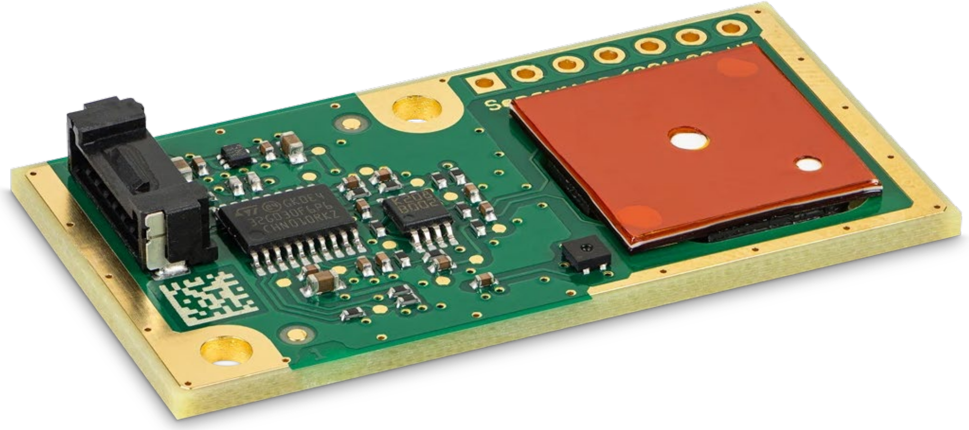
IAQ Paradigms - The Next Generation, ASHRAE Journal July 2024

IAQP and Air Cleaner Degradation

What Happens as the Air Cleaner Efficiency Degrades?

Most IAQP calculations are driven by formaldehyde, meaning formaldehyde is at the design limit with the resultant outside airflow.

For example, an air cleaner might have a first-pass removal efficiency of 99% for formaldehyde, but the removal efficiency drops down to 60% when the manufacturer recommends that the air cleaner is replaced. In a typical 10,000 ft^2 office building, the resultant outside airflow requirement would only be 315 CFM if you used that 99% efficiency value in your IAQP calculations. However, if you were to operate that building at 315 CFM, the formaldehyde concentration would actually increase up to approximately 42 $\mu g/m^3$ by the time that the air cleaner is supposed to be replaced. That resultant concentration would be well above the specified design limit.



Specification

Formaldehyde	
Measurement range	0 - 1000 ppb
Accuracy	±20 ppb or ±20% m.v.

ASHRAE Standard 241-2023

A New Approach to Cleaning and Diluting the Breathing Zone

Rate Based Standard

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

$$V_{ACS} = \left[\frac{\varepsilon_{PR}}{100}\right] \times V_{RC}$$

V_{ECAi}	minimum *equivalent clean* airflow rate required in the breathing zone to mitigate *long-range transmission* risk in *IRMM*
ECA_i	required *equivalent clean* airflow per person for infection risk mitigation
V_{ACS}	*air cleaning* system *equivalent clean* airflow rate
V_{RC}	recirculated airflow rate cleaned by the *air cleaning* system

Building Readiness Plan (**BRP**)	Normal ventilation mode (ASHRAE 62.1, 62.2, 170) or **IRMM** (*infection risk management mode)* determined by the operator and building owner, AHJ, or public health official.
Plan to include:	Measurement of outdoor, supply, return airflows & the ventilation system controls (**VSC**) and dynamic operation (DCV, VAV, Multi-Speed CV, etc). Building and space pressurization control
Commissioning & Functional Performance Tests (**FPT**)	Extensive documentation, sequences, and testing in multiple modes for ventilation delivery, filtration operation, and pressurization (ASHRAE 202, 230)

ASHRAE Standard 241-2023

Comparing ECAi to 62.1 VRP minimums

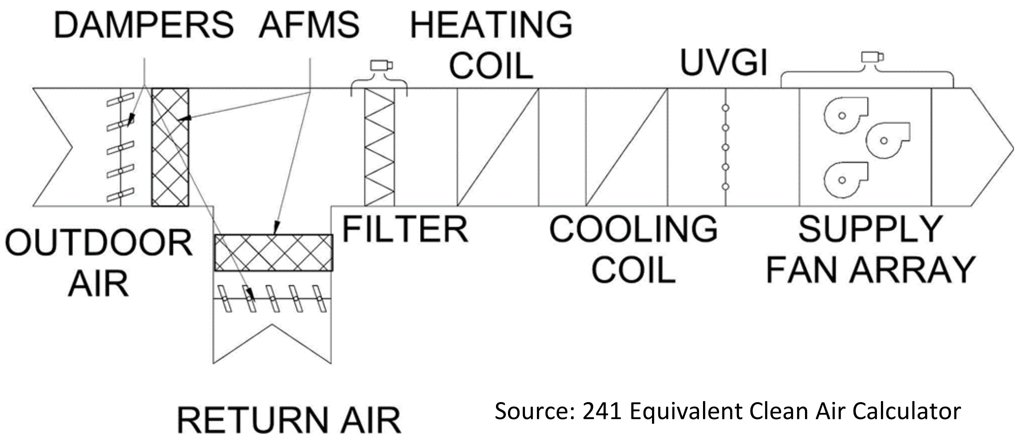
Table 5-1 Minimum Equivalent Clean Airflow per Person in Breathing Zone in IRMM

Occupancy Category	62.1 Vbz (cfm/person)	ECAi (cfm/person)	Multiplier
Correctional Facilities			
Cell	9.8	30	3.1
Dayroom	7.0	40	5.7
Commercial/Retail			
Food and beverage facilities	10.1	60	5.9
Gym	21.5	80	3.7
Office	17.0	30	1.8
Retail	15.5	40	2.6
Transportation waiting	8.1	60	7.4
Educational Facilities			
Classroom	13.4	40	3.0
Lecture hall	7.9	50	6.3
Industrial			
Manufacturing	35.7	50	1.4
Sorting, packing, light assembly	24.6	20	0.8
Warehouse	13.0	20	1.5

Occupancy Category	62.1 Vbz (cfm/person)	ECAi (cfm/person)	Multiplier
Health Care			
Exam room	13.5	40	3.0
Group treatment area		70	
Patient room		70	
Resident room		50	
Waiting room		90	
Public Assembly/Sports and Entertainment			
Auditorium	5.4	50	9.3
Place of religious worship	5.5	50	9.1
Museum	9.0	60	6.7
Convention	6.2	60	9.7
Spectator area	7.9	50	6.3
Lobbies	5.4	50	9.3
Residential			
Common space		50	
Dwelling unit		30	

ASHRAE Standard 241-2023

Requirements and Validation of Air Cleaning



Source: 241 Equivalent Clean Air Calculator

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].

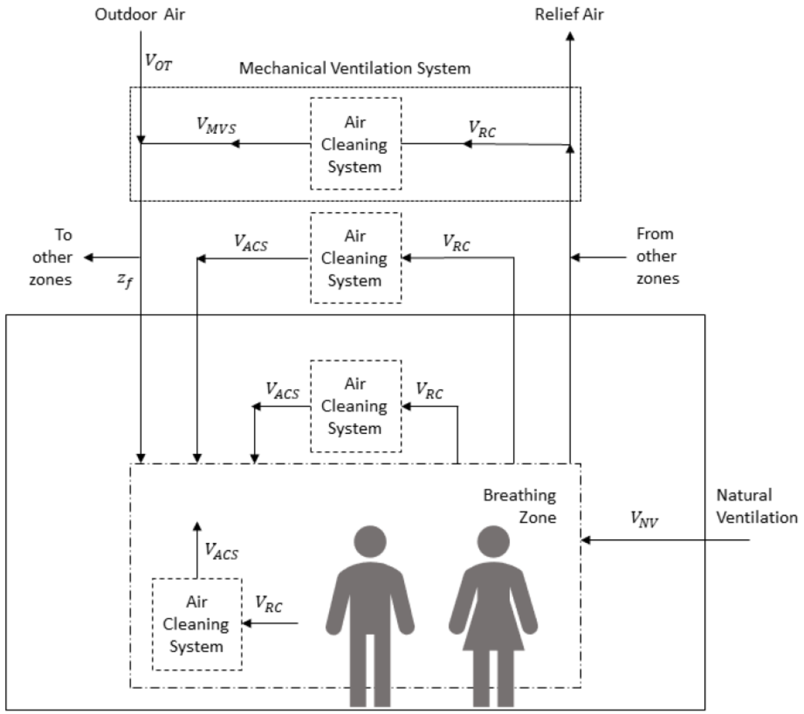


Figure 6-1 Sources of outdoor and clean air (for V_{RC}, see Section 7).

NORMATIVE APPENDIX A
DETERMINING AIR CLEANING SYSTEM EFFECTIVENESS AND SAFETY

A1. TESTING PROCEDURE

A1.2.1 Testing Laboratory. Testing shall be performed by a third-party independent laboratory. The *air cleaning* system manufacturer, or any entity owned by the system manufacturer, shall not perform the test.

ASHRAE Standard 241-2023

Equivalent Clean Air Calculator

Phase of the Process		Assessment	Planning	Planning
Name of Space / AHU / Building	**Units**	**EXISTING**	**Option 1**	**Option 2**
Description of system or Option		AHU with X,Y,Z	Description	Description
Space Type from Standard 241	Type	Office	Office	Office
Target ECAi from Standard 241 (See Instructions for Table)	CFM / Person	30	30	30
Area	Sq Ft	1,000	1,000	1,000
Average Ceiling Height	Ft	10	10	10
Volume	Cu Ft	10,000	10,000	10,000
Total Supply Air	CFM	750	750	750
Total Outdoor Air	CFM	85	150	85
Occupancy - Design (Pz)	Quantity	5	5	5
Occupancy - IRMM Target ($P_{z,IRMM}$)	Quantity	5	5	5
$V_{ECAi,t,Des}$ Airflow Target - Design Occupancy	CFM	150	150	150
$V_{ECAi,t,IRMM}$ Airflow Target - IRMM Target Occ.	CFM	150	150	150
Central AHU Filter MERV Rating	MERV	8	8	11
Method for Rating Filter	241 or DNFE	241	241	241
Filter Pathogen Removal Efficiency	εPR	0.0%	0.0%	60.0%
UV in HVAC - Single Pass Inactivation	%	0.0%	0.00%	0.00%
Air Treatment in HVAC (Impacts Space)	CFM	0	0	0
Air Treatment Device in Space	CADR	0	0	0
Number of Air Treatment Devices in Space	Quantity	0	0	0
In Room UV	CFM	0	0	0
Number of In Room UV Type	Quantity	0	0	0
In Room Air Cleaner (Fan Filter Type)	CADR	0	0	0
Number of In Room Air Cleaners (Fan Filter typ	Quantity	0	0	0
Equivalent Clean Air per Technology				
Outdoor Air	CFM	85.0	150.0	85.0
$V_{ECAi,filter}$	CFM		0.0	399.0
$V_{ECAi,uv,hvac}$	CFM	0	0	0
$V_{ECAi,rac,hvac}$	CFM		0	0
$V_{ECAi,rac,space}$	CFM	0	0.0	0.0
$V_{ECAi,irac,uv}$	CFM	0	0.0	0.0
$V_{ECAi,irac,fanfilter}$	CFM	0	0.0	0.0
Total Equivalent Clean Air	CFM	85	150	484
Occupancy Count Method (Design or IRMM)	Method	Design	IRMM	IRMM
ECAi Provided by the Option	**CFM / person**	**17.0**	**30.0**	**96.8**
DOES THIS SYSTEM MEET ECAi TARGET	Pass / Fail	**FAIL**	PASS	PASS

Phase of the Process		Assessment	Planning	Planning	Planning
Name of Space / AHU / Building	**Units**	**EXISTING**	**Option 1**	**Option 2**	**Option 3**
Description of system or Option		AHU with X,Y,Z	Description	Description	Description
Space Type from Standard 241	Type	Lecture Hall	Lecture Hall	Lecture Hall	Lecture Hall
Target ECAi from Standard 241 (See Instructions for Table)	CFM / Person	50	50	50	50
Area	Sq Ft	1,000	1,000	1,000	1,000
Average Ceiling Height	Ft	10	10	10	10
Volume	Cu Ft	10,000	10,000	10,000	10,000
Total Supply Air	CFM	750	750	750	750
Total Outdoor Air	CFM	310	620	620	550
Occupancy - Design (Pz)	Quantity	50	50	50	50
Occupancy - IRMM Target ($P_{z,IRMM}$)	Quantity	50	50	50	25
$V_{ECAi,t,Des}$ Airflow Target - Design Occupancy	CFM	2500	2500	2500	2500
$V_{ECAi,t,IRMM}$ Airflow Target - IRMM Target Occ.	CFM	2500	2500	2500	1250
Central AHU Filter MERV Rating	MERV	8	8	13	11
Method for Rating Filter	241 or DNFE	241	241	241	241
Filter Pathogen Removal Efficiency	εPR	0.0%	0.0%	77.0%	60.0%
UV in HVAC - Single Pass Inactivation	%	0.0%	0.00%	0.00%	0.00%
Air Treatment in HVAC (Impacts Space)	CFM	0	0	0	0
Air Treatment Device in Space	CADR	0	0	0	0
Number of Air Treatment Devices in Space	Quantity	0	0	0	0
In Room UV	CFM	0	0	0	0
Number of In Room UV Type	Quantity	0	0	0	0
In Room Air Cleaner (Fan Filter Type)	CADR	0	0	600	600
Number of In Room Air Cleaners (Fan Filter typ	Quantity	0	0	3	1
Equivalent Clean Air per Technology					
Outdoor Air	CFM	310.0	620.0	620.0	550.0
$V_{ECAi,filter}$	CFM		0.0	100.1	120.0
$V_{ECAi,uv,hvac}$	CFM	0	0	0	0
$V_{ECAi,rac,hvac}$	CFM		0	0	0
$V_{ECAi,rac,space}$	CFM	0	0.0	0.0	0.0
$V_{ECAi,irac,uv}$	CFM	0	0.0	0.0	0.0
$V_{ECAi,irac,fanfilter}$	CFM	0	0.0	1800.0	600.0
Total Equivalent Clean Air	CFM	310	620	2520	1270
Occupancy Count Method (Design or IRMM)	Method	Design	IRMM	IRMM	IRMM
ECAi Provided by the Option	**CFM / person**	**6.2**	**12.4**	**50.4**	**50.8**
DOES THIS SYSTEM MEET ECAi TARGET	Pass / Fail	**FAIL**	**FAIL**	PASS	PASS

Air Cleaning Test

Reading Between the Lines

OR-25-C041

Assessing Indoor Air Quality in a Comparative Study Among ASHRAE Ventilation Standards Compared to a Control with a Continuous Active In-Room Air Cleaning Device

Brett Duffy
Full Member ASHRAE

Dr. Margaret Scarlett
Full Member ASHRAE

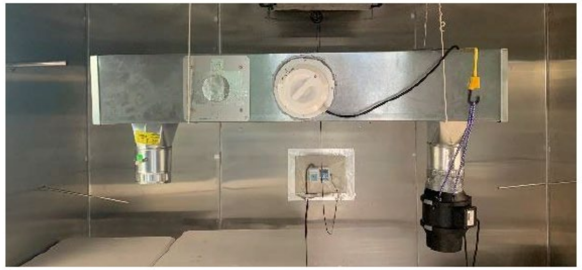


Figure 1 Partial HVAC duct used for testing in the bioaerosol test chamber.

Table 1. Summary of Test Conditions (note: variability of % of outside air by standard)

Test Conditions	Outside Air Rate	Total Air Exchange Rate	Outside Air as a % of Total
Standard 62.1	0.75 ACH (13.2 cfm, 6.23 L/s)	5 ACH (88 cfm, 41.53 L/s)	15%
Standard 170	2 ACH (35 cfm, 16.52 L/s)	6 ACH (106 cfm, 50.03 L/s)	33%
Standard 241	2.05 ACH (36 cfm, 16.99 L/s)	5 ACH (88 cfm, 41.53 L/s)	41%
CA-IRAC	0 ACH (0 cfm, 0 L/s)	5 ACH (88 cfm, 41.53 L/s)	0%

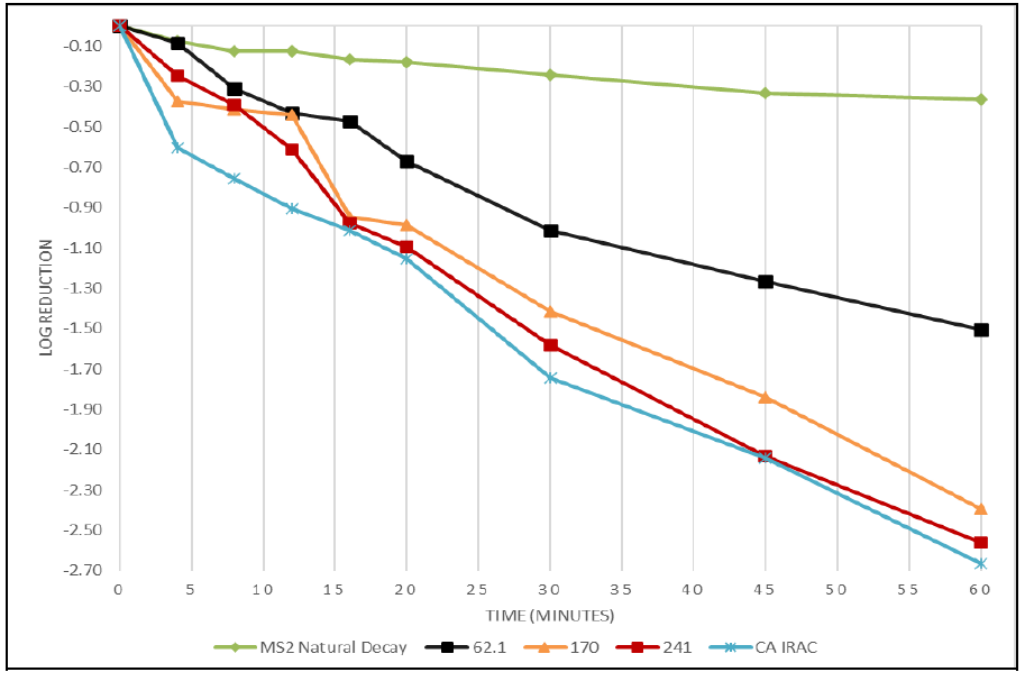
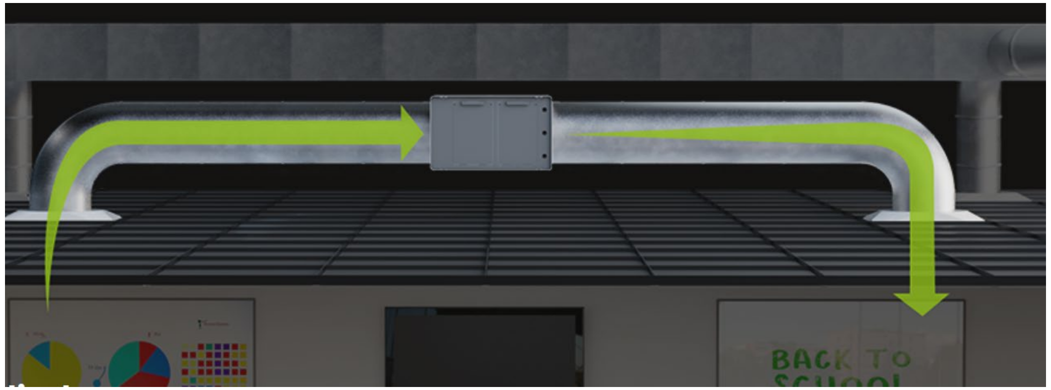


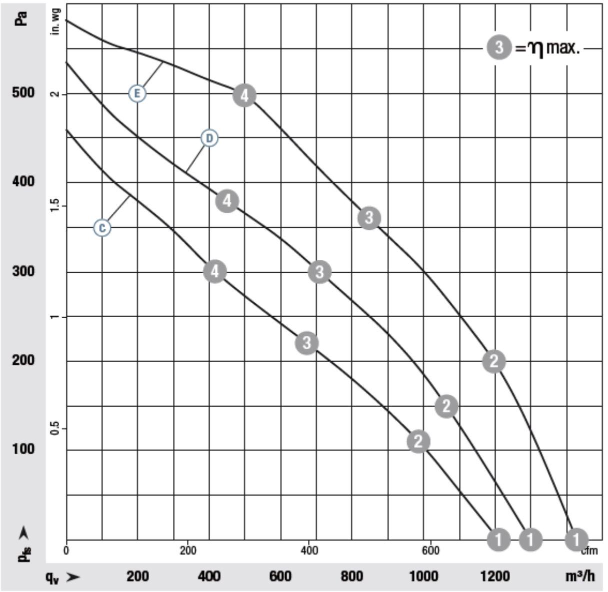
Figure 2 The comparison between ASHRAE standards, a continuous active IRAC, and MS2 natural decay plotted as log reduction for each measurement period.

ASHRAE Standard 241-2023

What is the V_{ACS} clean airflow?

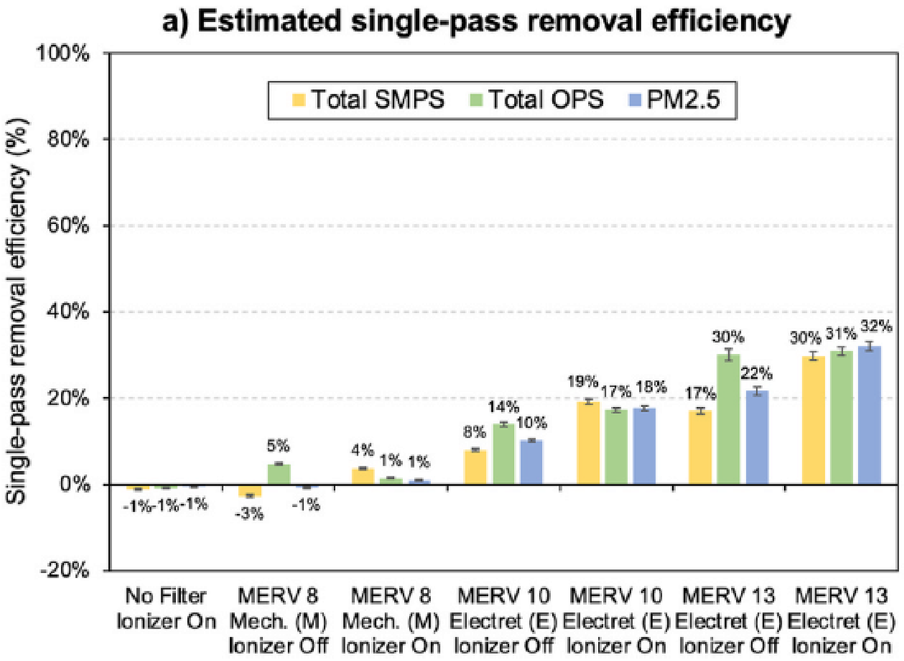


Curves:
Speed-controlled
0-10 V / PWM
PWM
MODBUS-RTU



PERFORMANCE DATA (24 x 24)

CAPACITY	FILTER DEPTH	INITIAL RESISTANCE ("w.g.)				FINAL RESISTANCE ("w.g.)
		300 fpm	375 fpm	500 fpm	625 fpm	
High	1"	0.33	0.45	–	–	1.0
	2"	–	0.25	0.39	0.56	1.0
	4"	–	0.22	0.34	0.50	1.0



Evaluation of an in-duct bipolar ionization device on particulate matter and gas-phase constituents in a large test chamber
Building and Environnement. Volume 213, 1 April 2022

Equivalent Clean Air

Could it Become a Minimum Ventilation Option?

Equivalent clean airflow (VECAp,g): The theoretical flow rate of contaminant-free air that, if distributed uniformly within the breathing zone, would have the same effect on the concentration of airborne particles and gases as the sum of actual outdoor airflow, filtered and air cleaned airflow.

Breathing zone outdoor airflow (*Vbz*). The outdoor airflow required in the breathing zone (*Vbz*) of the occupiable space or spaces in a ventilation zone shall be not less than the larger of the value determined in accordance with Equation X-2.

$$V_{bz} = VECAp,g - E_f V_{fz} \qquad \text{(X-2)}$$

where

V_{bz} = the outdoor airflow required in the breathing zone, cfm (L/s)

$E_f V_{fz}$ = formaldehyde efficiency of the air cleaner system multiplied by the volumetric airflow of the air cleaner or equivalent clean airflow of the air cleaner in the breathing zone as determined by Section 6.3.4 (addendum n), cfm (L/s)

What We Have Learned

1. Why is it important to know Mass Flow Rate?

2. Does ASHRAE 62.1 consider all contaminants in the Minimum Ventilation Rates?

3. Can CO_2 DCV be used with IAQP or with any air cleaning technology?

4. Do all air cleaners only remove matter from the air?

5. Do air cleaners always maintain the same level of performance?

Thank You

Darryl DeAngelis