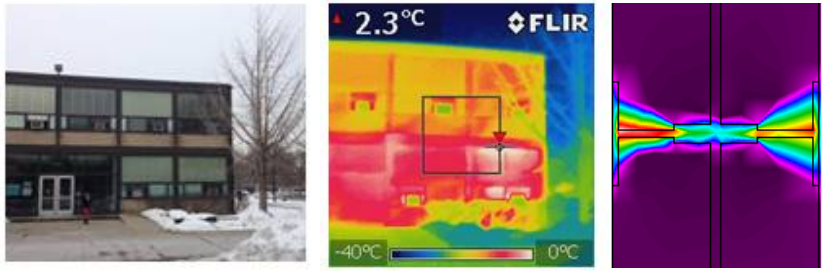
CAE 331/513 Building Science

Fall 2019



October 29, 2019

Ventilation and indoor air quality (part 1)

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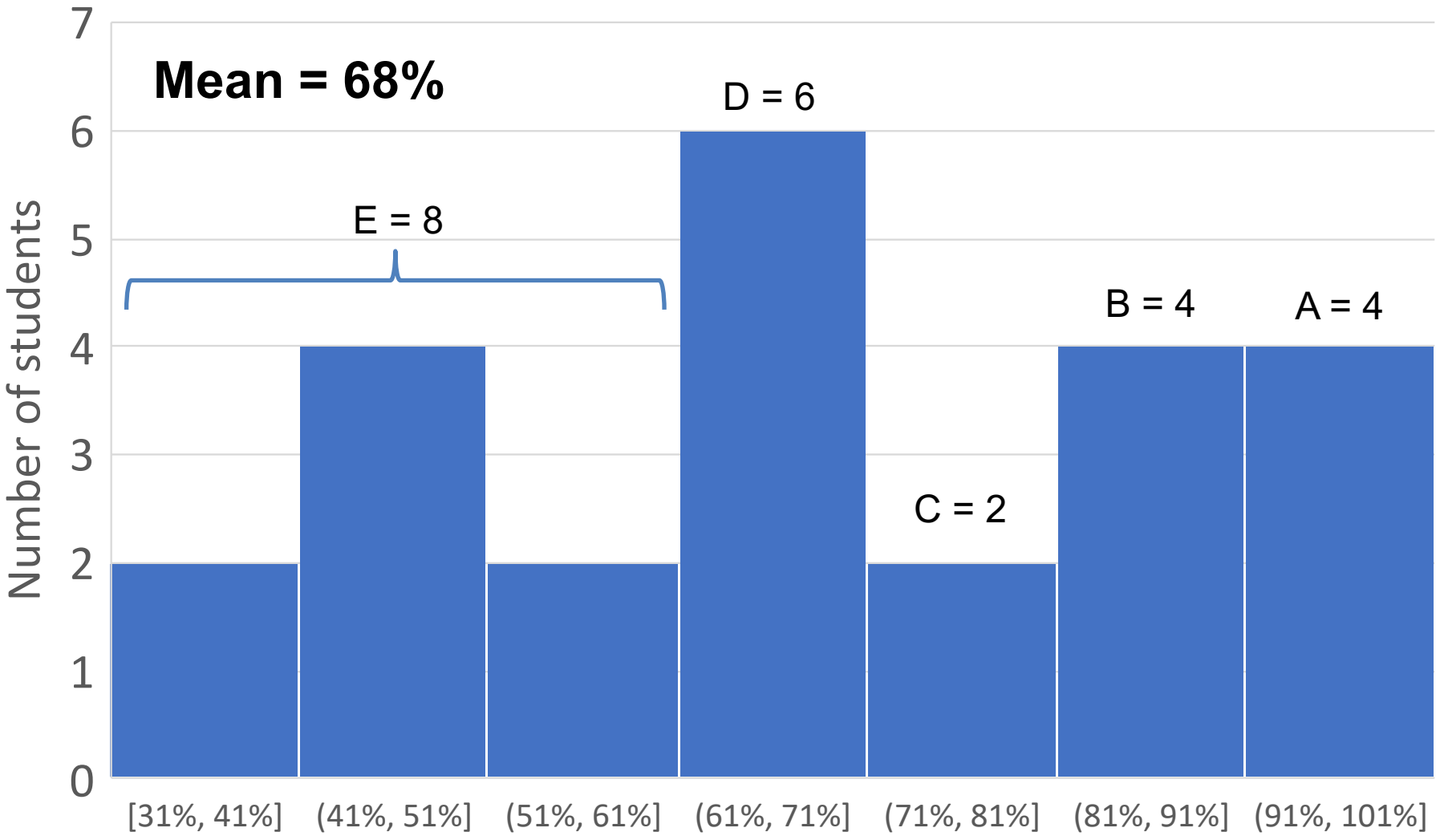
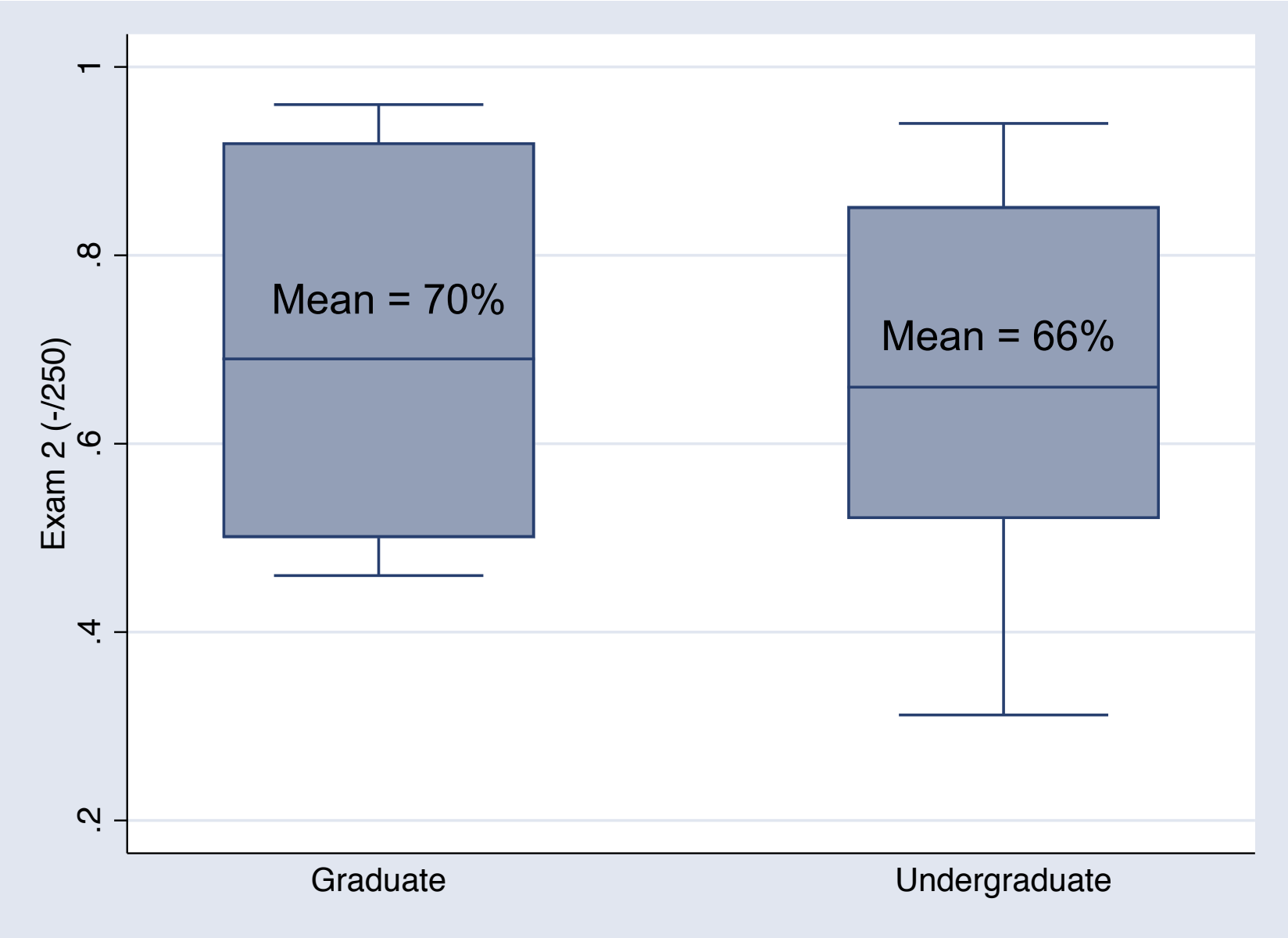
Exam 2: grade summary



Exam 2: grade summary



Exam 2: grade summary

- Problem 1
  - Average = 74%
  - Min = 20%
  - Max = 100%
- Problem 2
  - Average = 80%
  - Min = 27%
  - Max = 100%
- Problem 3
  - Average = 59%
  - Min = 0%
  - Max = 100%

Exam 2: Moving forward

- You can take your exam home and apply corrections
- Resubmit by Thursday, October 31 at the beginning of class
- I will grade and adjust upwards up to 50% of the points you missed

Graduate student project topics

Student name	Project topic
Chen, Lingzhou	
Jiang, Fengyuan	
Joseph, Ann Maria S.	
Lee, Jongki	
Siddiqui, Areej	Impacts of modular construction on energy use [?]
Tan, Jiapei	
Torres Mailleux, Nicole	
Vizcaino Gonzalez, Sergio	Impact of closing supply registers in central residential HVAC systems on energy and comfort
Wang, Mingyu	
Yan, Haotian	

Today's objectives

- Introduce ventilation and indoor air quality (IAQ)
  - Covered in the next 2+ lectures

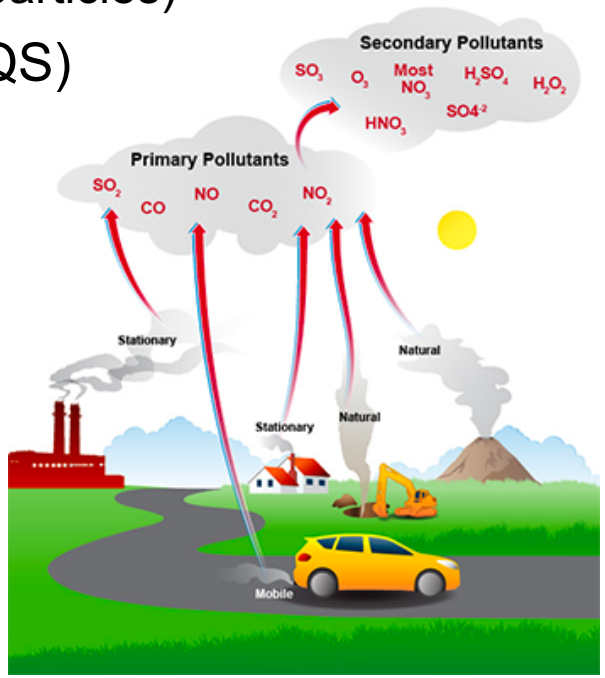
VENTILATION AND IAQ

Air quality inside and out

Why should we care about air quality, both indoors and outdoors?

Common outdoor air pollutants

- Common outdoor air pollutants include:
  - Particulate matter
    - Particulate matter less than 10 micrometers (PM_{10})
    - Particulate matter less than 2.5 micrometers ($PM_{2.5}$)
    - Particulate matter less than 0.1 μm (ultrafine particles)
  - Gases (Criteria pollutants regulated by NAAQS)
    - Ozone (O_3)
    - Nitrogen dioxide (NO_2)
    - Sulfur dioxide (SO_2)
    - Carbon monoxide (CO)
    - Lead (Pb)
    - Mercury (Hg)

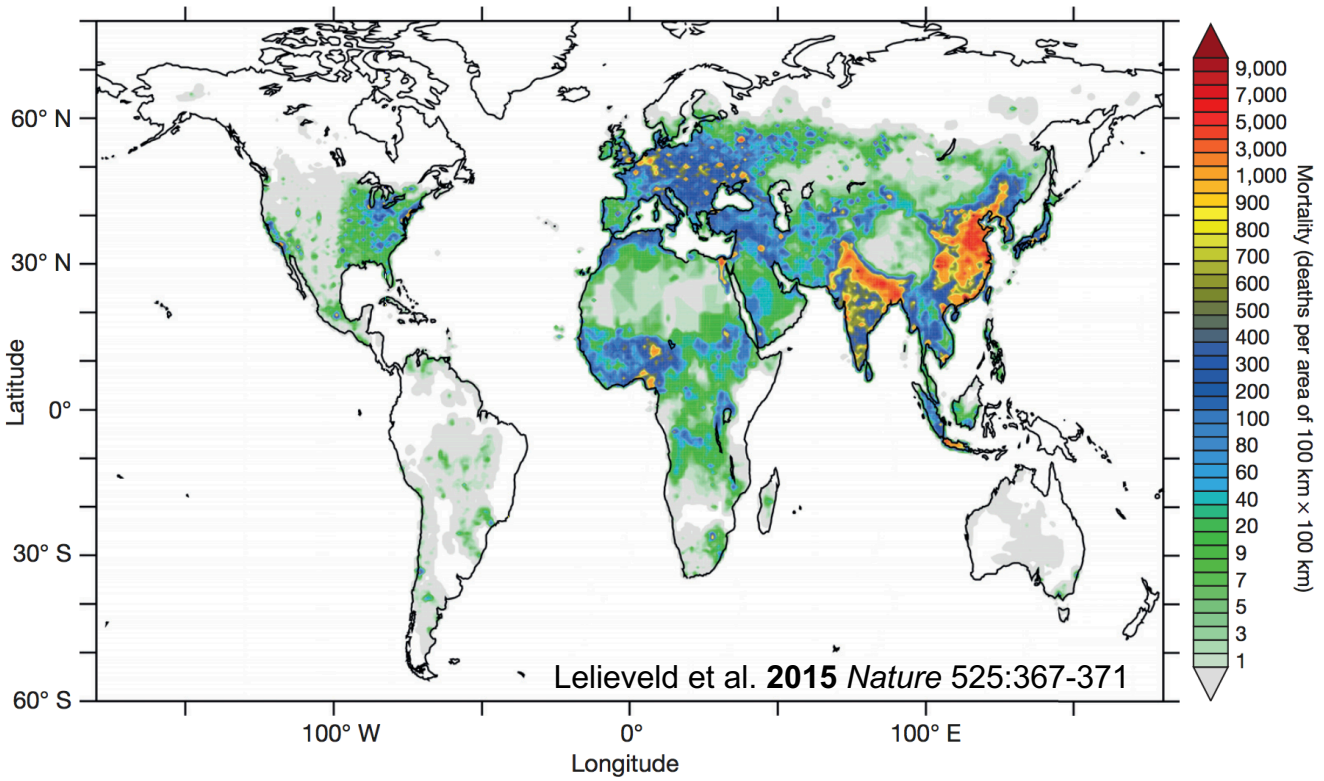


Plug: if you want to learn more about air pollution, take CAE 402 Intro to Environmental Engineering & Sustainable Design in Spring 2020

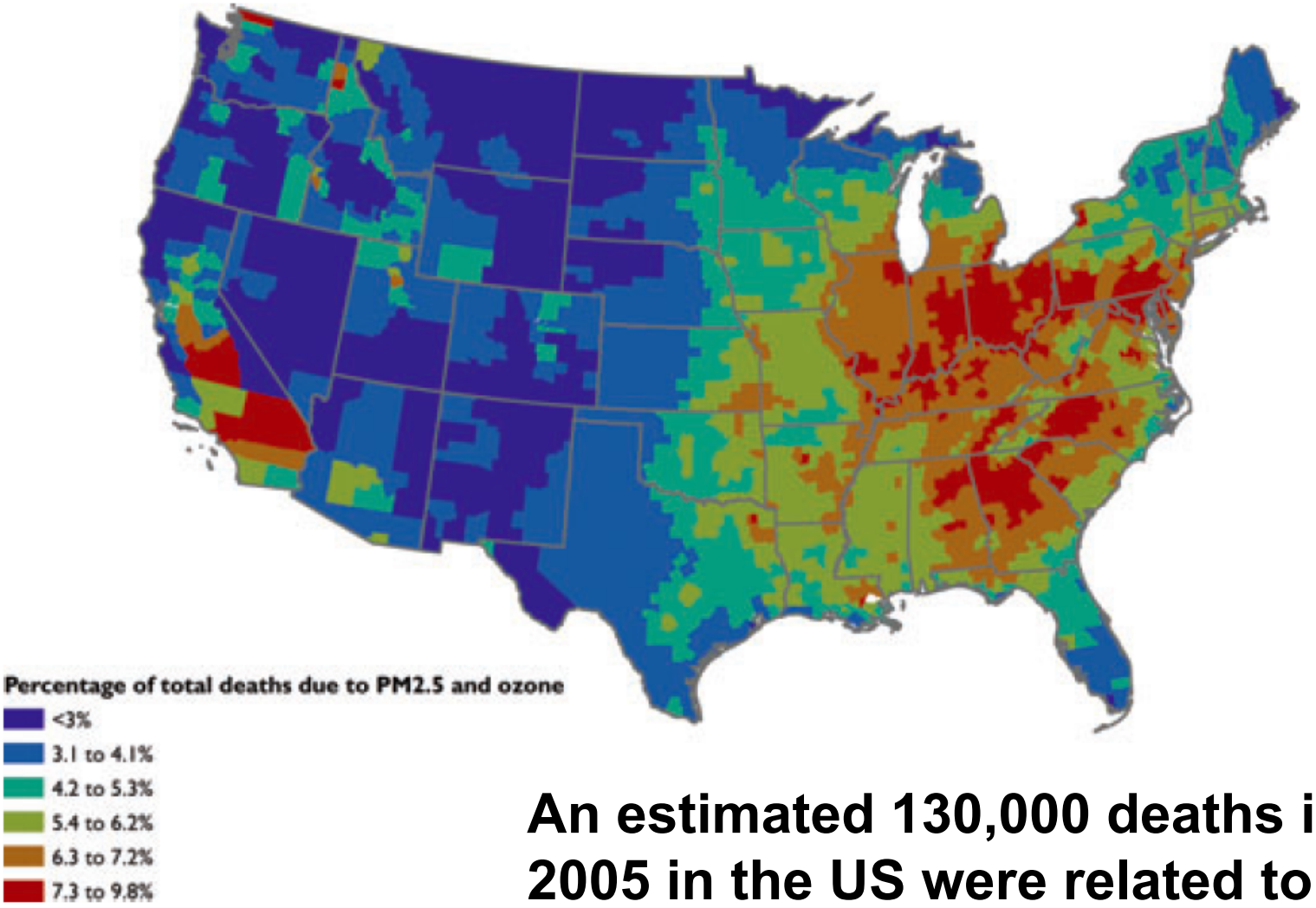
Outdoor air pollution and health

- Documented health effects include:
  - Stroke
  - Heart disease
  - Lung cancer
  - Chronic & acute respiratory diseases (including asthma)
  - Mortality

Outdoor air
3.3 million premature deaths globally in 2010



Outdoor air pollution and health



An estimated 130,000 deaths in 2005 in the US were related to outdoor $PM_{2.5}$ (and 4,700 w/ O_3)

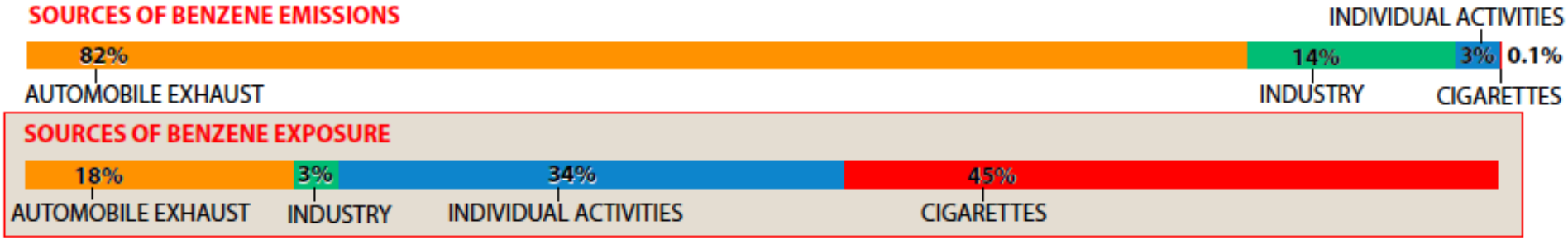
Fann et al., **2012** *Risk Analysis*

Where do we spend most of our time?

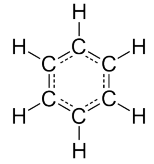
- We spend most of our time indoors
  - Nearly 90% of the time, on average in the developed world
  - Approximately 18 hours indoors for every 1 hour outdoors
- We bring materials, furnishings, appliances, and activities into buildings, many of which emit or release a variety of substances
  - Some harmful, some not
- Buildings also exchange air without the outdoors
  - Outdoor air pollution can both dilute or become indoor air pollution
- Indoor air is a dominant environmental exposure
  - Most of the body's intake of air is done so inside buildings
  - 80-90% inhaled in buildings generally

Why do we care about indoor air quality?

- Indoor concentrations of most pollutants are higher than outside
  - Global average of ~3:1 indoor/outdoor ratio
    - Large variability between pollutants
- We keep sensitive equipment/precious artifacts inside buildings
- We regulate outdoor air based on emissions
  - No indoor air regulations
    - Other than smoking bans and product emission controls at manufacture stage
    - Canada just initiated residential NO_2 guideline
  - Disconnect between <u>emissions</u> and <u>exposure</u>
    - Benzene example (outdoor sources include auto exhaust and industry):



C_6H_6



Ott and Roberts, 1998 *Scientific American*

Indoor air pollution and health

- Residential indoor air pollution is estimated to result in **5-14%** of the annual non-communicable, non-psychiatric **disease burden** in the U.S.
  - Excludes SHS and radon

Logue et al., *Environ. Health Perspect.* **2012**, 120, 216-222

- Cumulative lifetime **cancer risks** of **1-10** excess cases **per 10,000** people

Wallace et al., *Environ. Health Perspect.* **1991**, 95, 7-13
Sax et al., *Environ. Health Perspect.* **2006**, 114, 1558-1566
Hun et al., *Environ. Health Perspect.* **2009**, 117, 1925-1931

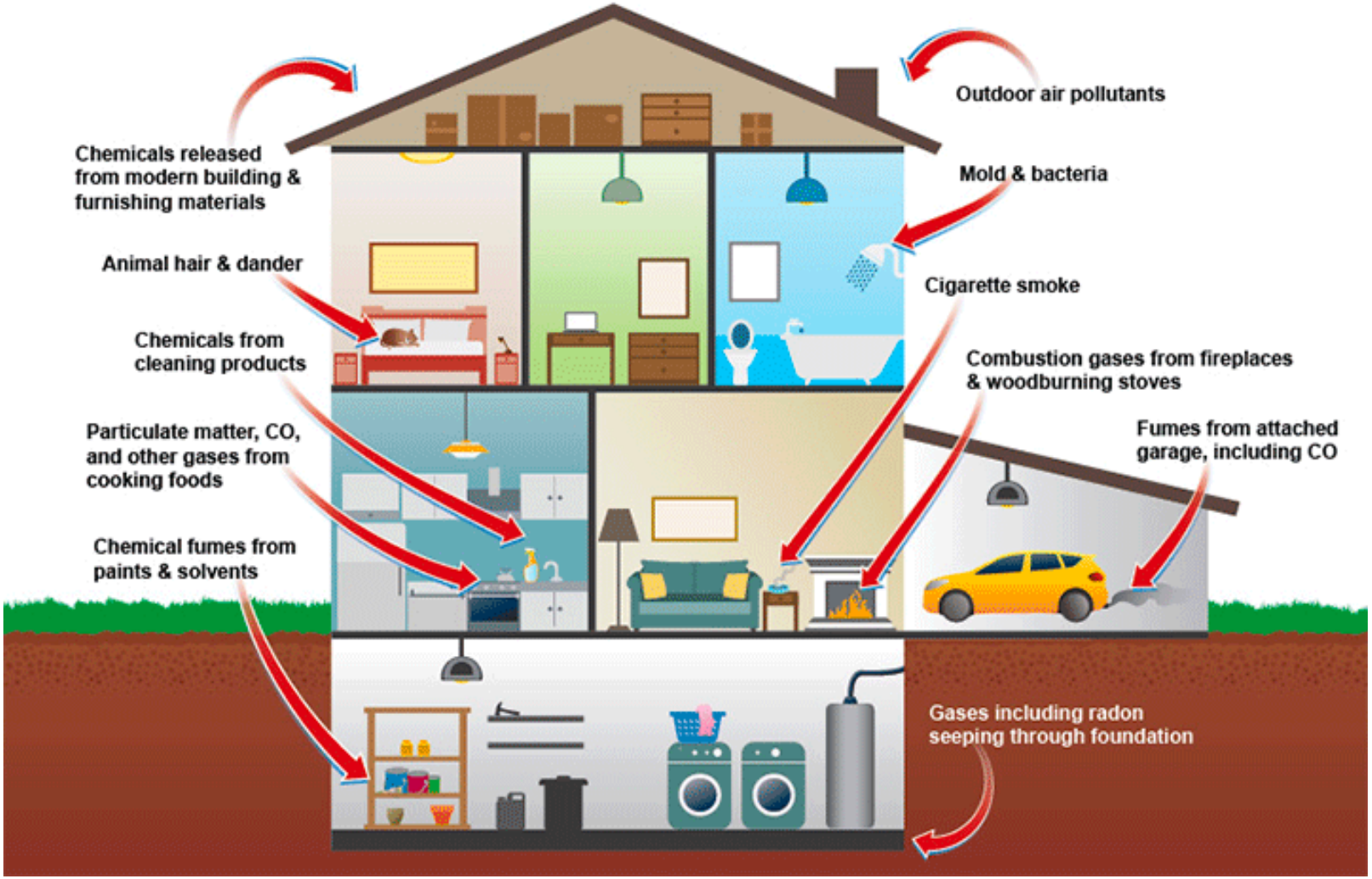
- Indoor air is a **dominant** environmental exposure!

Important classes of indoor pollutants

- Inorganic gases
  - Combustion products: carbon monoxide (CO) and nitrogen oxides (NO_x)
  - Ammonia (NH_3), ozone (O_3), hydrogen sulfide (H_2S), radon, metals
- Organic gases
  - Volatile organic compounds (VOCs)
    - Hundreds of these
  - Aldehydes (e.g., formaldehyde)
  - Semi-volatile organic compounds (SVOCs)
    - Polycyclic aromatic hydrocarbons (PAHs), phthalates, pesticides, brominated flame retardants
- Particulate matter (PM)
  - Solid and liquid aerosols
    - Size, shape, mass, constituents (e.g., chemical species, metals)
  - Fibers (e.g., asbestos)
  - Biological particles
    - Viruses, bacteria, fungi, endotoxins, allergens (pollen, dander)

Godish 2001 *Indoor Environmental Quality*; Spengler et al. 2001 *Indoor Air Quality Handbook*

Types of indoor emission sources



https://www.epa.gov/expobox/exposure-assessment-tools-media-air

Types of indoor emission sources

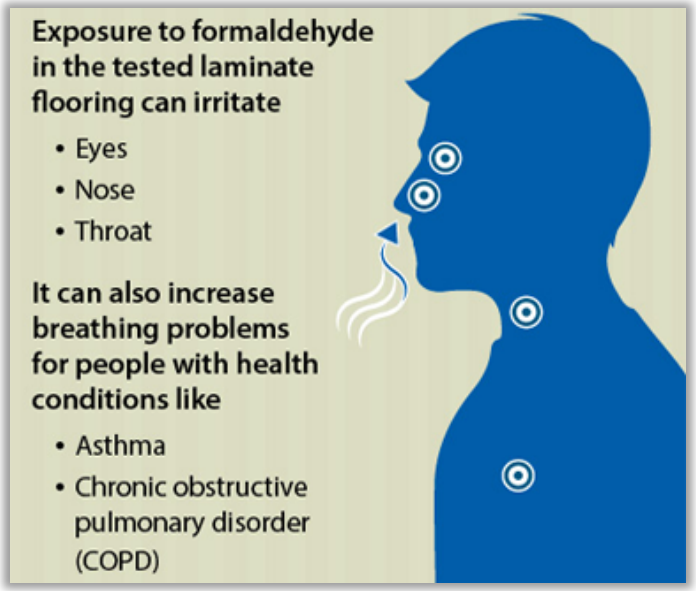
- Building materials (VOC/SVOC)
  - Wood and composite wood
  - Gypsum wallboard
  - Concrete
  - Carpet
  - Vinyl flooring
- Furnishings (VOC/SVOC)
  - Bedding
  - Tables
  - Couches/chairs
  - Drapes
- Architectural coatings (VOC/SVOC)
  - Paints
  - Stains
  - Varnishes
- Outdoor-to-indoor transport (all)
- Consumer products (VOC/SVOC)
  - Cleaners
  - Fragrances
  - Personal care products
- Combustion (VOC/PM/SVOC/other)
  - Cigarettes, cigars, pipes
  - Gas stoves
  - Space heaters
  - Candles
  - Incense
- Electronics (PM/VOC/SVOC/other)
  - Laser printers
  - Computers
  - Photocopiers
- Volatilization from water (VOC)
- Soil vapor intrusion (VOC/radon)
- People, pets, insects (biological)

Indoor pollutant exposures and health

Formaldehyde: a sensory irritant and known human carcinogen (IARC Group 1)

Formaldehyde and Other Volatile Organic Chemical Emissions in Four FEMA Temporary Housing Units

Maddalena et al. **2009** *Environ Sci Technol*



Formaldehyde in the Indoor Environment

Salthammer et al. **2010** *Chem Rev*

Emission Rates of Formaldehyde from Materials and Consumer Products Found in California Homes

Kelly et al. **1999** *Environ Sci Technol*

Indoor pollutant exposures and health

NO_x, CO, ultrafine particles, some organics

Association between gas cooking and respiratory disease in children

Melia et al. **1977** *British Medical Journal*

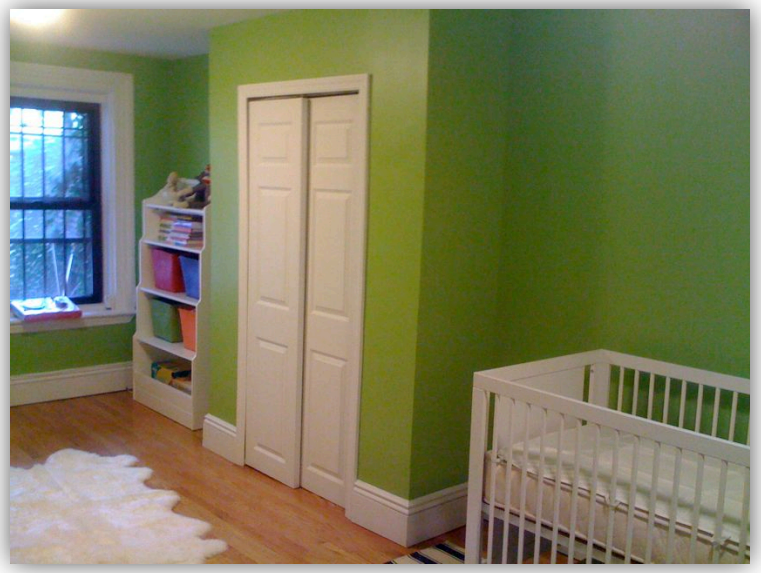
Indoor Air Pollution and Asthma

Ostro et al. **1994** *Am J Respir Crit Care Med*

Respiratory Symptoms in Children and Indoor Exposure to Nitrogen Dioxide and Gas Stoves

Garrett et al. **1998** *Am J Respir Crit Care Med*

VOCs



Association of domestic exposure to volatile organic compounds with asthma in young children

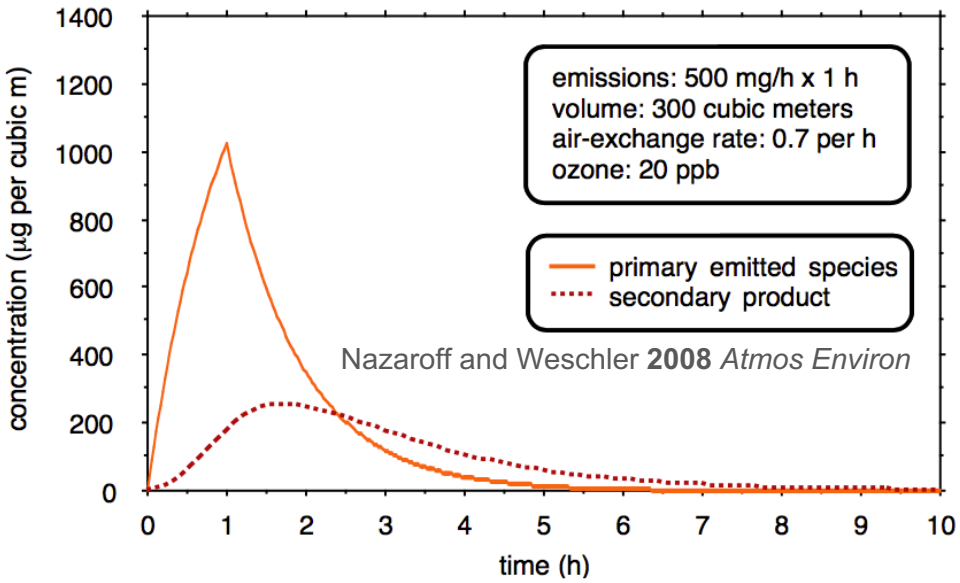
Rumchev et al. **2004** *Thorax*

Cancer Risk Disparities between Hispanic and Non-Hispanic White Populations: The Role of Exposure to Indoor Air Pollution

Hun et al. **2009** *Environ Health Perspect*

Indoor pollutant exposures and health

Primary & secondary VOCs + ultrafine particles



Frequent use of chemical household products is associated with persistent wheezing in pre-school age children

Sherriff et al. **2005** *Thorax*

The Use of Household Cleaning Sprays and Adult Asthma

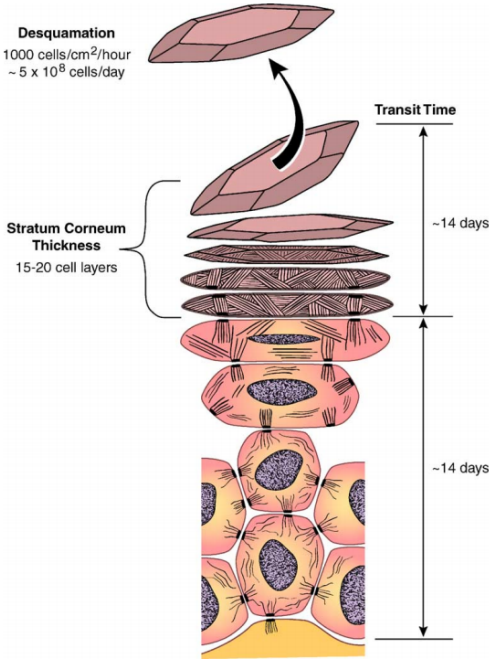
Zock et al. **2007** *Am J Respir Crit Care Med*

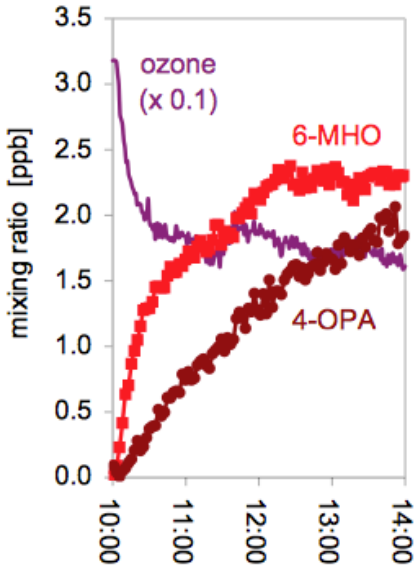
Indoor pollutant exposures and health

Epidermal desquamation

Milstone **2004** *J Dermatol Sci*

We shed our entire outer layer of skin every 2-4 weeks





Ozone + skin oils → organics + ultrafine particles

Reactions of ozone with human skin lipids: Sources of carbonyls, dicarbonyls, and hydroxycarbonyls in indoor air

Wisthaler and Weschler **2010** *Proc Nat Acad Sci*

Indoor pollutant exposures and health

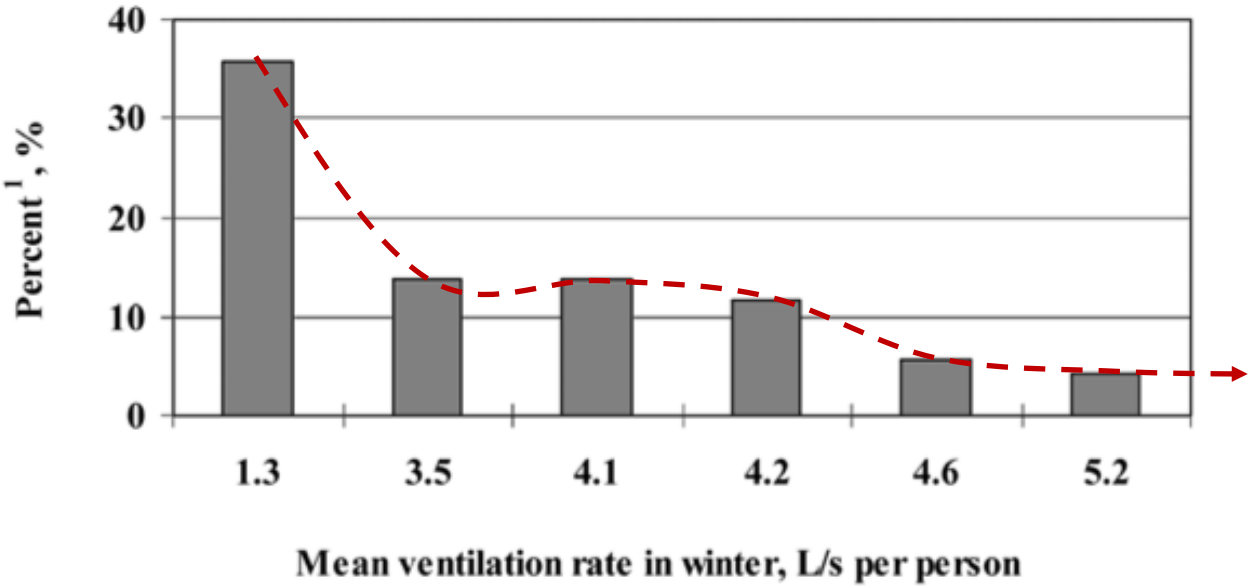
Infectious disease transmission

Evidence of Airborne Transmission of the Severe Acute Respiratory Syndrome Virus

Yu et al. **2004** *New Engl J Med*

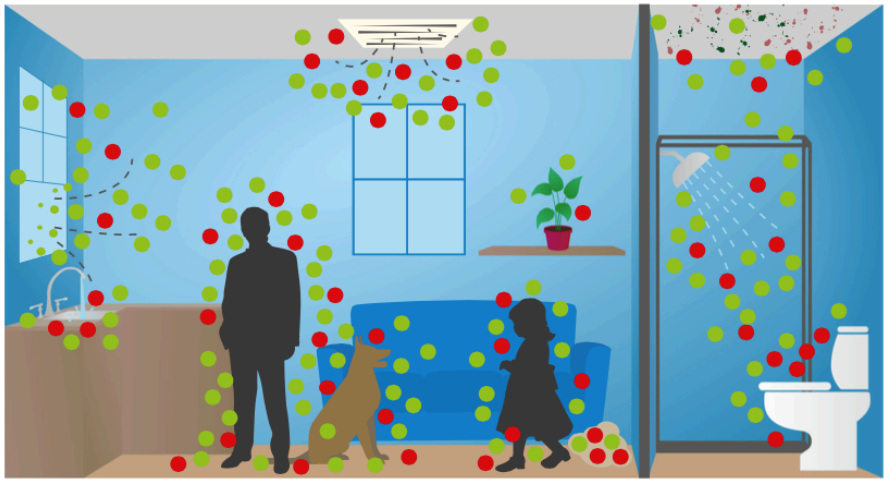
In China, Students in Crowded Dormitories with a Low Ventilation Rate Have More Common Colds: Evidence for Airborne Transmission

Sun et al. **2011** *PLoS ONE*



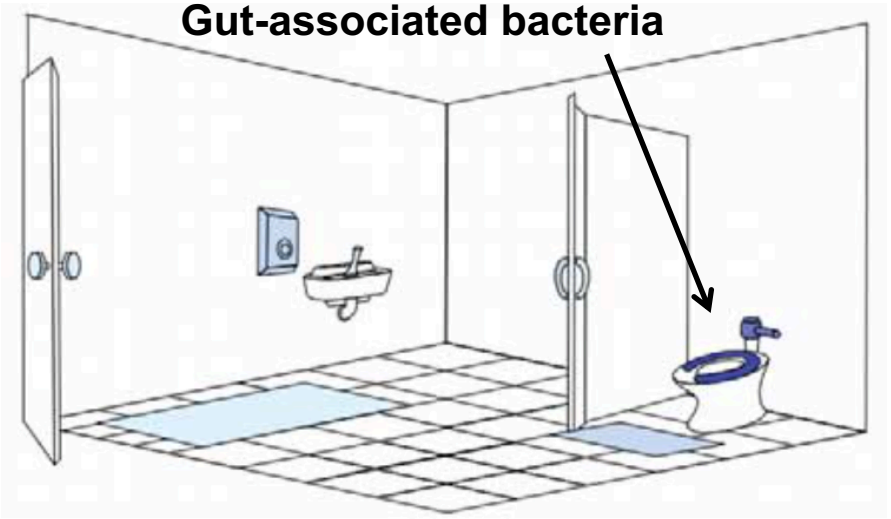
Indoor pollutant exposures and health

Indoor microbiome



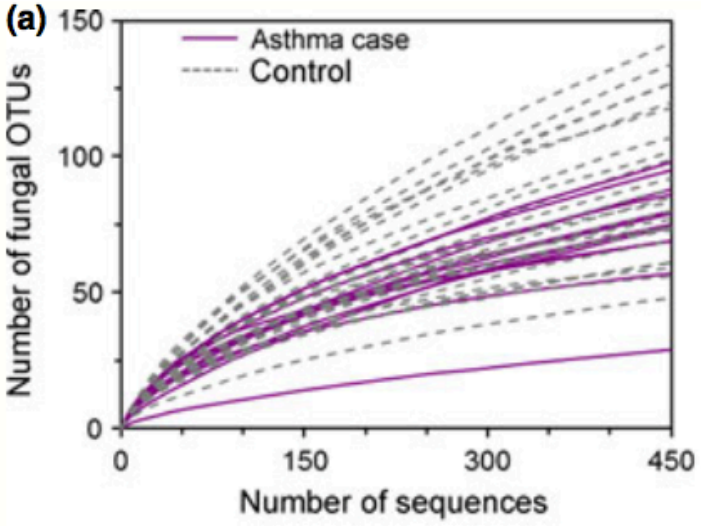
Prussin and Marr **2015** *Microbiome*

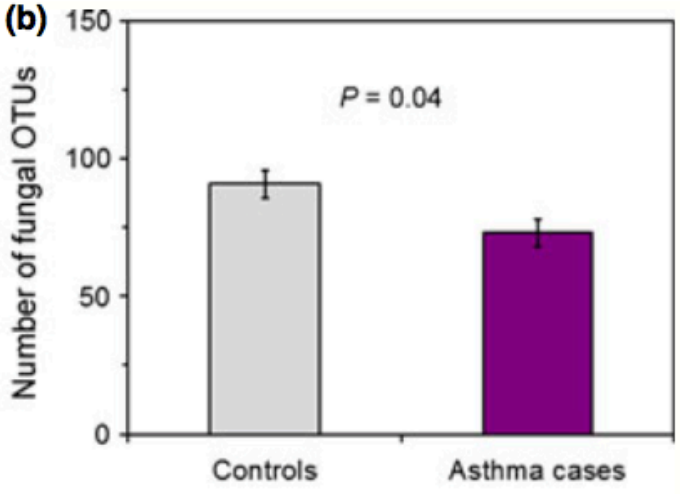
Gut-associated bacteria



Flores et al. **2011** *PLoS ONE*

Exposure to microbial diversity (i.e., the '**right**' **microbes** and the '**right**' **time**) may be **beneficial** for health





Dannemiller et al. **2014** *Indoor Air*

Indoor pollutant exposures and health

Air cleaning

Health benefits of particle filtration

Fisk **2013** *Indoor Air*

Photo from M.S. Waring and J.A. Siegel

Air cleaners typically reduce indoor PM concentrations by ~50%

Documented health improvements with air cleaners include:

- Improvements in lung function in asthmatics
- Fewer asthma-related doctor visits
- Improvements in cardiovascular and pulmonary function

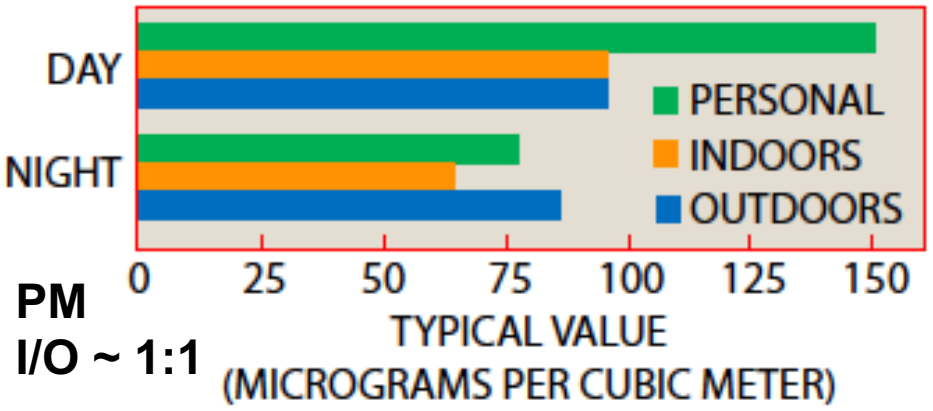
Indoor pollutant concentrations are often greater than outdoors

Everyday Exposure to Toxic Pollutants

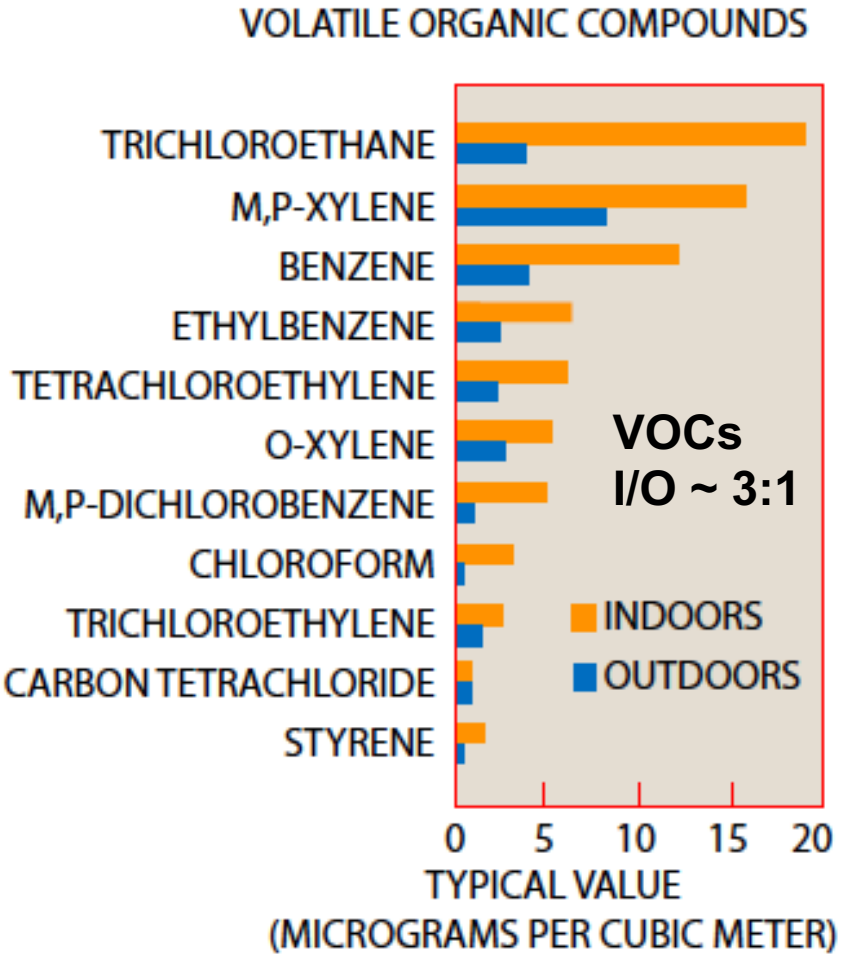
Environmental regulations have improved the quality of outdoor air. But problems that persist indoors have received too little attention

by Wayne R. Ott and John W. Roberts

Scientific American February 1998



PM
I/O ~ 1:1



VOCs
I/O ~ 3:1

Indoor Environmental Quality (IEQ): Not just IAQ

- "Indoor Environmental Quality (IEQ) encompasses the conditions inside a building—air quality, lighting, thermal conditions, ergonomics—and their effects on occupants or residents. Strategies for addressing IEQ include those that protect human health, improve quality of life, and reduce stress and potential injuries. Better indoor environmental quality can enhance the lives of building occupants, increase the resale value of the building, and reduce liability for building owners."
  - USGBC, 2014

Solutions: use daylighting; install operable windows; give occupants temperature and ventilation control; give occupants lighting control; conduct occupant surveys; provide ergonomic furniture; include appropriate acoustic design

Building upgrades can improve IAQ/IEQ

Element	Impact on Productivity *	Context	Reference
Outdoor Air	**1.75%** increase on office worker productivity per doubling of outdoor air rate	Commercial office	[26]
Indoor Air Quality	**6%**–9% decreased productivity in poor indoor air quality environments	Commercial office	[3]
Daylighting	Learning progress showed **7%** to 26% improvement in highly daylit rooms compared with low levels of daylight	Schools	[28]
	Learning progress showed 19%–20% improvement when skylight providing additional access to daylight compared with non-daylit rooms	Schools	[28]
	Average length of stay (hospitalization) decreased from 16% to 41% in highly-daylit rooms	Hospitals (patients)	[29]
Access to views	Learning progress showed **15%** to 23% improvement in classrooms with largest windows	Schools	[28]
Openable windows	Ranges from 7% to 8% improvement in classrooms with operable *vs*. not operable windows	Schools	[28]
Illumination level control	**4.5%** increase in productivity at workstations with lighting control	Manufacturing	[38]

McArthur et al. **2015** *Buildings*

QUANTIFYING IAQ

Units of measurement for air pollutants

- **Number concentrations** (# per volume of air, #/m^3)
  - # of molecules per m^3 (highly reactive species, e.g., OH radical)
  - # of particles per m^3 (particulate matter)
  - # of cells or colony forming units per m^3 (biological)
- **Mass concentrations** (mass per volume of air)
  - ng/m^3 typical for metals and SVOCs
  - $\mu g/m^3$ typical for indoor VOCs and particulate matter
  - mg/m^3 big sources, e.g., ETS, cooking, industrial hygiene
- **Molar concentrations** (variations on $y_i = \mathrm{mol}_i/\mathrm{mol}_{air}$)
  - Mole fraction (y_i) = mol/mol
  - % concentration = moles per 100 moles = 100*y_i
  - Parts per million by **volume** (ppm_v) (or just "ppm")

$$1\ \mathrm{ppm} = \frac{1\ \mathrm{mol\ of}\ i}{10^6\ \mathrm{moles\ of\ air}} = 10^{-6}\ \frac{\mathrm{moles\ of}\ i}{\mathrm{moles\ of\ air}} = 10^{-6} * y_i$$

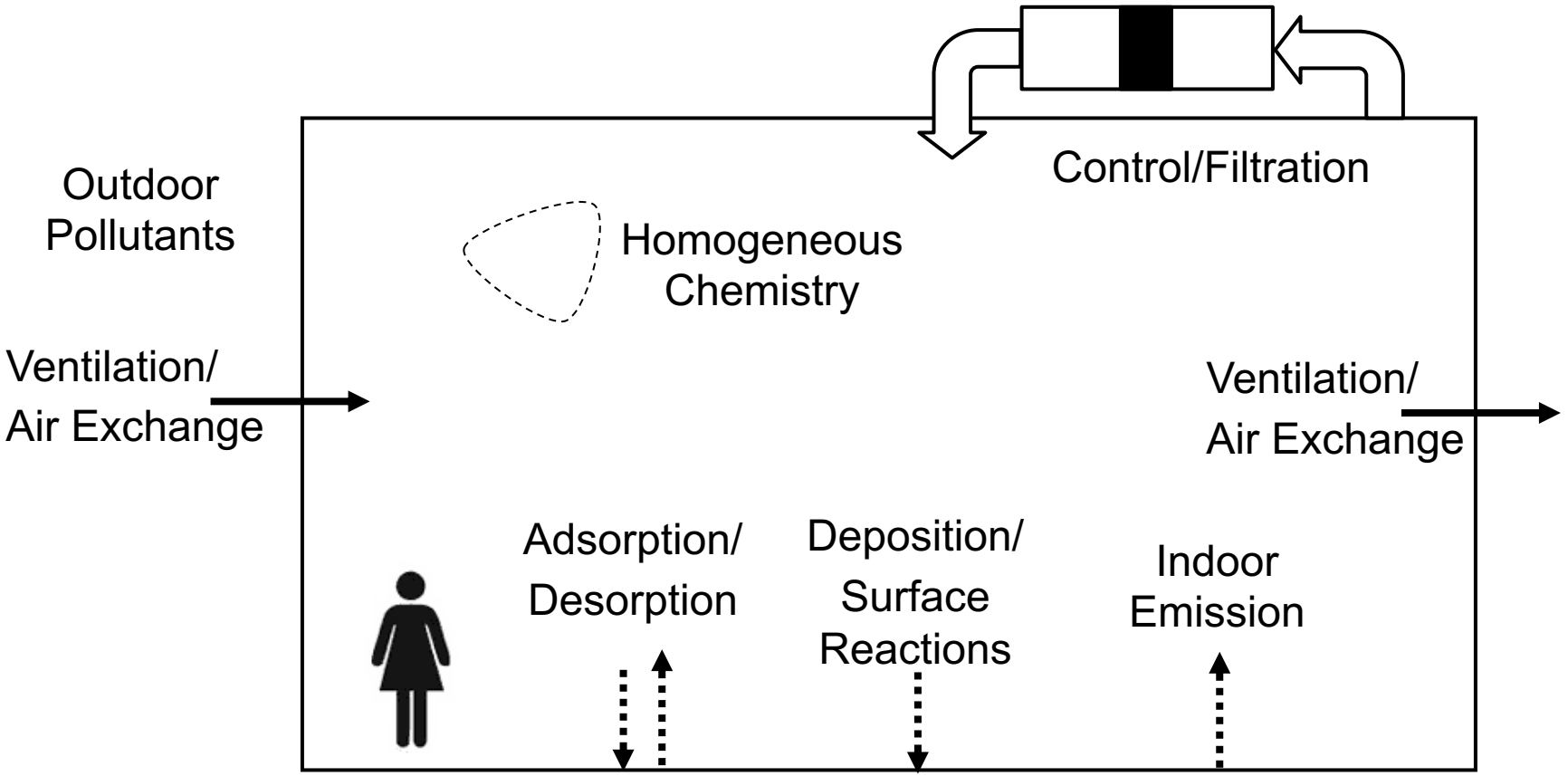
  - Parts per billion by **volume** (ppb_v) (or just "ppb")

$$1\ \mathrm{ppb} = \frac{1\ \mathrm{mol\ of}\ i}{10^9\ \mathrm{moles\ of\ air}} = 10^{-9}\ \frac{\mathrm{moles\ of}\ i}{\mathrm{moles\ of\ air}} = 10^{-9} * y_i$$

For gases, we can use the ideal gas law to convert between molar and mass concentrations

Indoor environment: Mass balances

To understand the levels of airborne pollutants that we are exposed to, we need to understand the underlying physical, chemical, and biological mechanisms that drive pollutant emission, transport, and control



Indoor environment: Mass balance

- Simplest case (**inert gas**)
  - Neglecting indoor physics/chemistry
    - No deposition, no reaction

Mass accumulation rate [mass / time]	=	Mass flow in [mass / time]	-	Mass flow out [mass / time]	+	Mass emitted [mass / time]

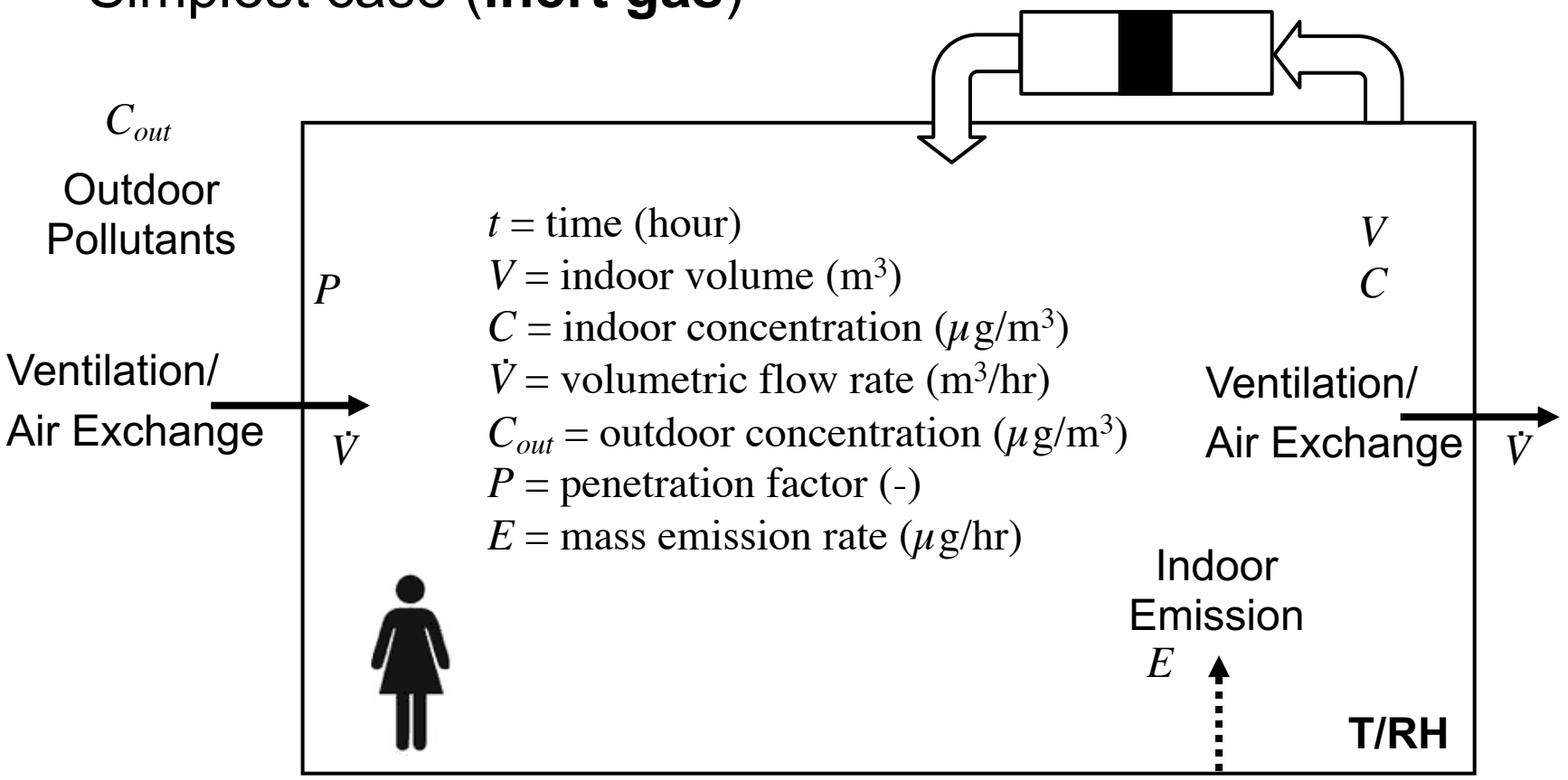
$$\frac{dm}{dt} = \frac{dCV}{dt} = V\frac{dC}{dt} + C\underbrace{\frac{dV}{dt}}_{0}$$

Assumptions:

- Building/room can be treated as well-mixed

Indoor environment: Mass balance

- Simplest case (**inert gas**)



$$V\frac{dC}{dt} = P\dot{V}C_{out} - \dot{V}C + E$$

Indoor environment: Mass balance

- Simplest case (**inert gas**)

$$V\frac{dC}{dt} = P\dot{V}C_{out} - \dot{V}C + E$$

- Divide by volume:

$$\frac{dC}{dt} = P\frac{\dot{V}}{V}C_{out} - \frac{\dot{V}}{V}C + \frac{E}{V}$$

$$\boxed{\frac{dC}{dt} = P\lambda C_{out} - \lambda C + \frac{E}{V}}$$

$$\lambda = \frac{\dot{V}}{V} = \text{air exchange rate } (\frac{1}{\text{hr}})$$

Indoor environment: Mass balance

- Assume steady-state conditions:

$$\underbrace{\frac{dC}{dt}}_{0} = P\lambda C_{out} - \lambda C + \frac{E}{V} \longrightarrow \boxed{C_{ss} = PC_{out} + \frac{E}{\lambda V}}$$

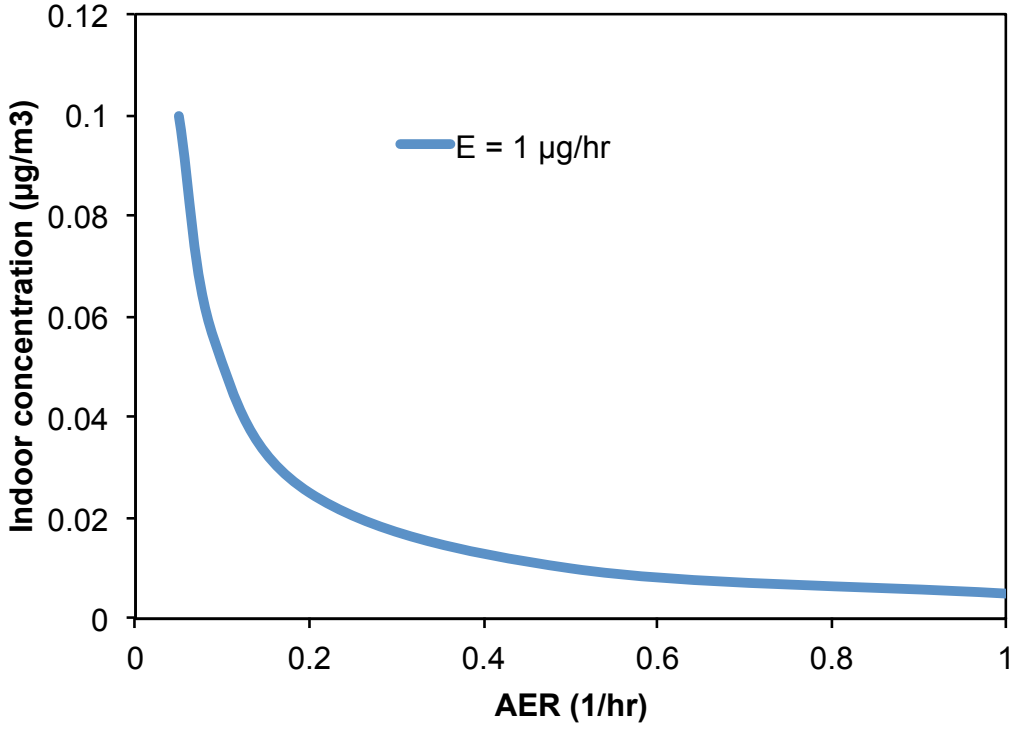
Assumptions:

- Building/room can be treated as well-mixed
- Ventilation/air exchange rate is constant
- Outdoor pollutant concentration is constant
- Indoor sources emit at a constant rate

- If λ is large (and/or E is small): $PC_{out} >> E/\lambda V$
  - C approaches C_{out} (depending on P)
  - This means outdoor sources are relatively more important
- If λ is small (and/or E is large): $PC_{out} << E/\lambda V$
  - C approaches $E/\lambda V$
  - This means indoor sources are relatively more important

Steady state mass balance and air exchange

- Example steady state calculations: $C_{ss} = PC_{out} + \frac{E}{\lambda V}$
- Assume $C_{out} = 0$: $C_{ss} = \frac{E}{\lambda V}$
- Assume V = 200 m^3 and E = 1 µg/hr: how are C_{ss} and λ related?



What impacts air exchange rates?

Outdoor air exchange can be divided into two main categories:

Ventilation

Intentional introduction of outdoor air into a building

Subdivided into:

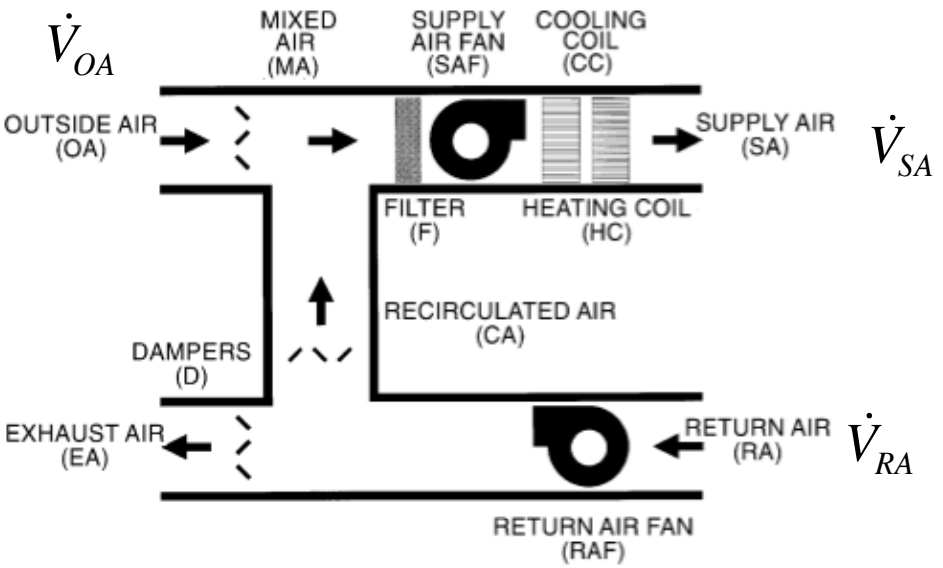
- **Mechanical (forced) ventilation:** The intentional movement of air into and out of a building using fans, intake vents, and exhaust vents
- **Natural ventilation:** The flow of air through open windows, doors, grilles, and other planned envelope penetrations, driven largely by natural or artificially induced pressure differences

Infiltration

Flow of outdoor air into a building through cracks, leaks, and other unintentional openings in the envelope (includes normal use of exterior doors) … i.e., *air leakage*

Dealing with ventilation vs. infiltration

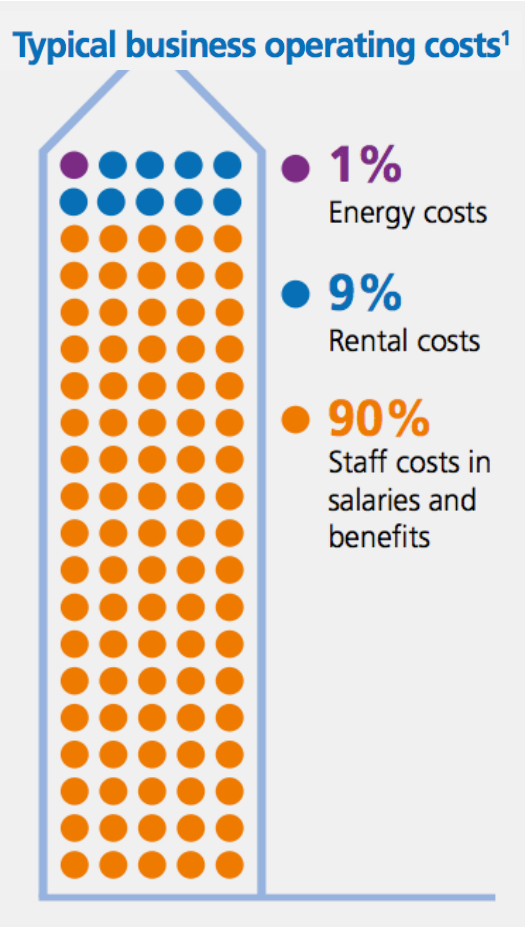
- **Mechanical ventilation** is straightforward
  - Fans move air through known openings
  - Flow rates typically known or at least measurable
- **Natural ventilation** is conceptually straightforward but physically complex
  - Known openings but highly varying wind speeds and directions
- **Infiltration** is complex
  - Typically unknown openings and multiple driving forces
- Need to know airflows through each of these in order to quantify IAQ and energy impacts



VENTILATION

“Four principles for achieving good indoor air quality”

- Minimize indoor emissions
- Keep buildings dry
- Ventilate well
- Protect against outdoor pollution

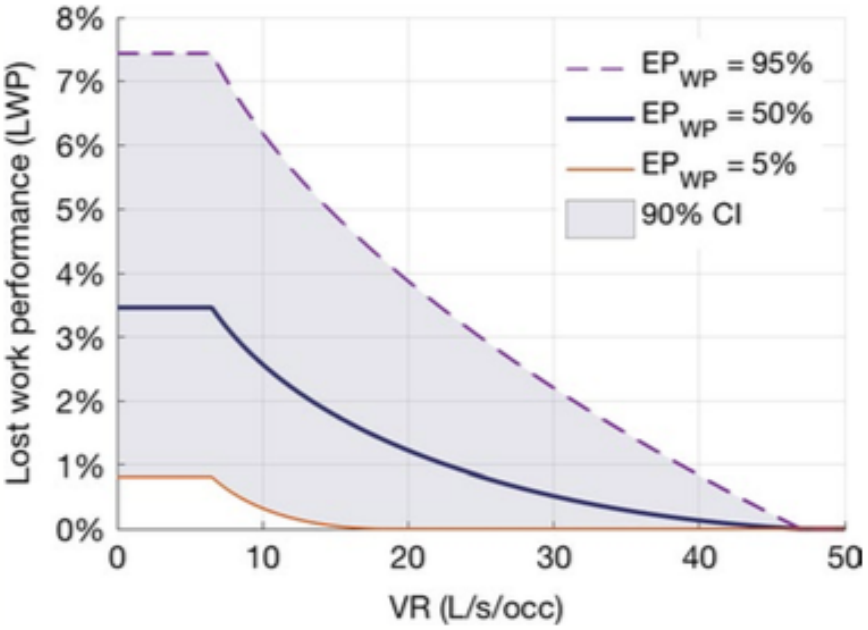


Nazaroff **2013** *Indoor Air*

Importance of ventilation

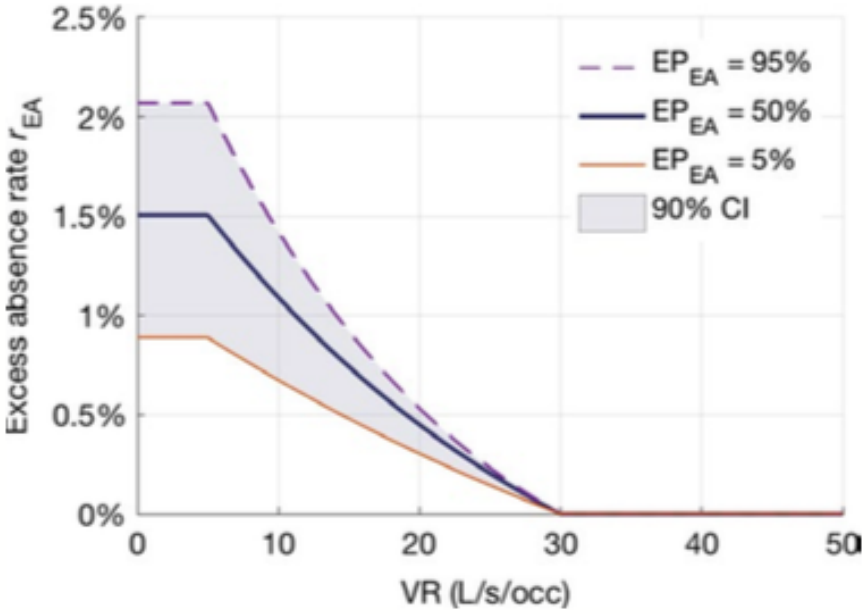
- Outdoor air ventilation dilutes indoor-generated pollutants

Worker performance



Seppänen et al. **2006** *Indoor Air*

Work absences



Milton et al. **2000** *Indoor Air*

Rackes et al. **2018** *Indoor Air*

Ventilation and CO_2

- CO_2 is often used as a surrogate for IAQ
  - Imperfect, but instructive
  - CO_2 concentrations will be elevated in poorly ventilated spaces

- The average CO_2 production rate per person at an activity level of 1.0-1.2 met is often assumed to be ~0.003 L/s
  - ~21 g/hr at standard temperature and pressure conditions

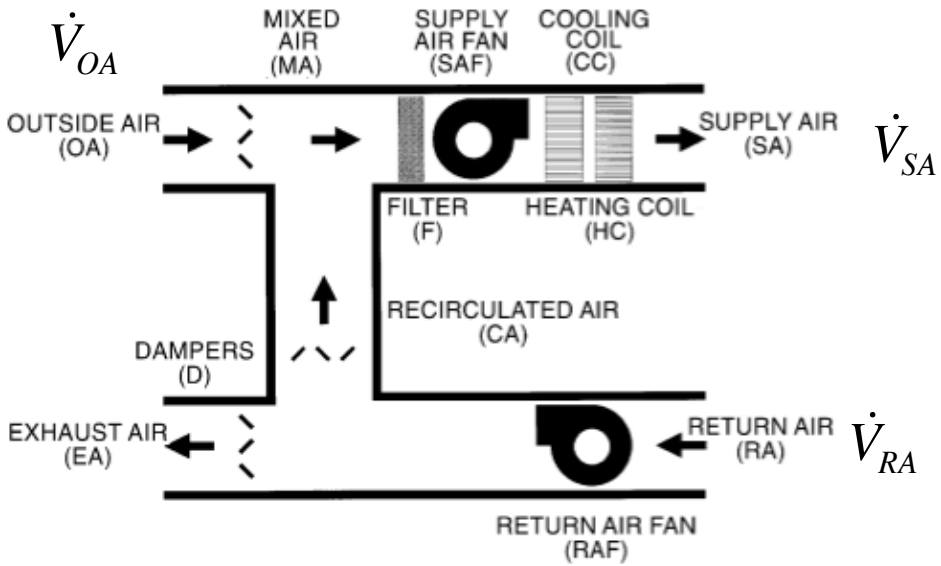
- Recent evidence also suggests that CO_2 might be a pollutant on its own
  - Affecting decision making

Ventilation and CO_2

Satish et al **2012** *Environ Health Perspectives*

Mass balance example problem w/ CO_2

- In a 150 m^3 room with 30 people present, what would be the required (a) air exchange rate, (b) outdoor airflow rate, and (c) per person ventilation flow rate to keep the indoor CO_2 concentration below 1000 ppm?
  - Assume outdoors is 400 ppm
  - And CO_2 production (activity level of 1.2 met) = 21 g/hr per person



Converting between mass and molar concentrations

- Treat air and its constituents as an ideal gas:

$$PV = nRT \longrightarrow \frac{n}{V} = \frac{P}{RT}$$

$$P_i = y_i P_{tot}$$

↑ Mole fraction

$$400 \text{ ppm} \Rightarrow \frac{n_i}{V} = y_i \frac{P_{tot}}{RT} = \frac{400 \text{ mol}_\text{i}}{10^6 \text{ mol}_\text{air}} \frac{1 \text{ atm}}{\left(8.205 \times 10^{-5} \frac{\text{atm} \cdot \text{m}^3}{\text{mol} \cdot \text{K}}\right) \times 293 \text{ K}}$$

↑ 20°C, 68°F

- Gives you # of moles per m^3 of air
- Multiply by MW_i to get g/m^3 of air

$$\#\text{ of } \frac{\text{g}}{\text{m}^3} = \frac{\#\text{ mol}_\text{i}}{\#\text{ mol}_\text{air}} * \frac{P_{tot}}{RT} MW_i$$

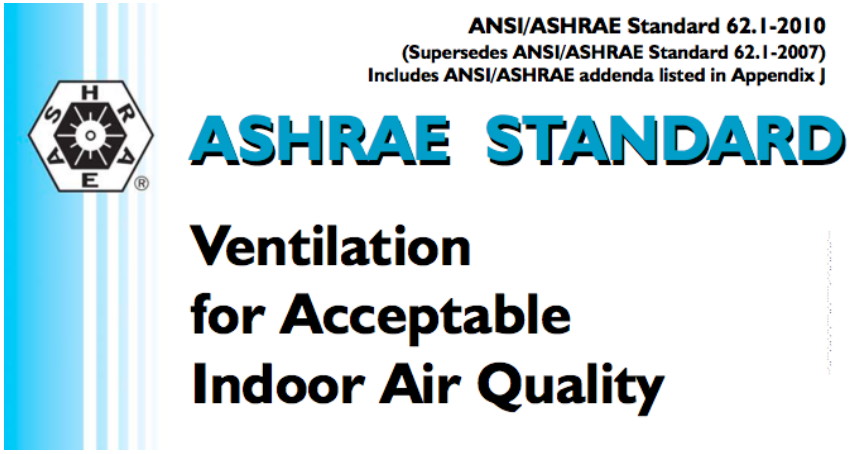
CO_2 concentration in the classroom

- Estimate the ventilation rate in this classroom using measured CO_2 concentrations

Ventilation and IAQ

- How do we determine the correct (or at least ***required***) ventilation rate?
  - ASHRAE Standard 62.1 (commercial) and 62.2 (residential)

ASHRAE Standard 62.1: Commercial buildings



1. PURPOSE

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

1.2 This standard is intended for regulatory application to new buildings, additions to existing buildings, and those changes to existing buildings that are identified in the body of the standard.

1.3 This standard is intended to be used to guide the improvement of indoor air quality in existing buildings.

2. SCOPE

2.1 This standard applies to all spaces intended for human occupancy except those within single-family houses, multi-family structures of three stories or fewer above grade, vehicles, and aircraft.

2.2 This standard defines requirements for ventilation and air-cleaning system design, installation, commissioning, and operation and maintenance.

ASHRAE Standard 62.1: Commercial buildings

Ventilation rate procedure (VRP)

6.2.2.1 Breathing Zone Outdoor Airflow. The outdoor airflow required in the breathing zone of the occupiable space or spaces in a *ventilation zone*, i.e., the breathing zone outdoor airflow (V_{bz}), shall be no less than the value determined in accordance with Equation 6-1.

$$V_{bz} = R_p \cdot P_z + R_a \cdot A_z \qquad (6\text{-}1)$$

where

A_z = zone floor area: the net occupiable floor area of the *ventilation zone* ft^2 (m^2)

P_z = zone population: the number of people in the *ventilation zone* during typical usage.

R_p = outdoor airflow rate required per person as determined from Table 6-1

Note: These values are based on adapted occupants.

R_a = outdoor airflow rate required per unit area as determined from Table 6-1

ASHRAE Standard 62.1: Commercial buildings VRP

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1

ASHRAE Standard 62.1: Commercial buildings VRP

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3

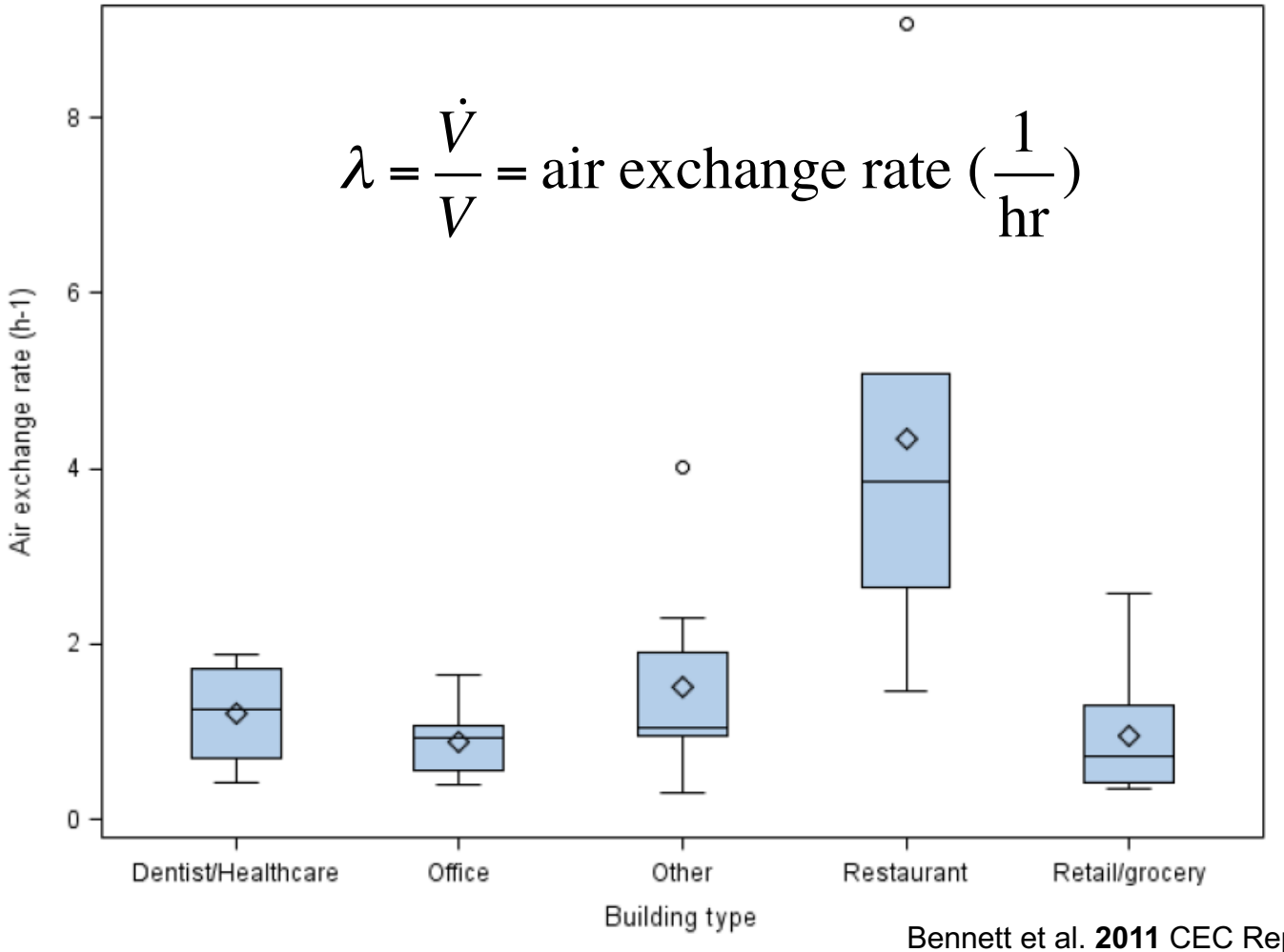
ASHRAE Standard 62.1: Commercial buildings VRP

TABLE 6-4 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, L/s·m^2	Air Class
Arenas	–	0.50	B	–	–	1
Art classrooms	–	0.70		–	3.5	2
Auto repair rooms	–	1.50	A	–	7.5	2
Barber shops	–	0.50		–	2.5	2
Beauty and nail salons	–	0.60		–	3.0	2
Cells with toilet	–	1.00		–	5.0	2
Copy, printing rooms	–	0.50		–	2.5	2
Darkrooms	–	1.00		–	5.0	2
Educational science laboratories	–	1.00		–	5.0	2
Janitor closets, trash rooms, recycling	–	1.00		–	5.0	3
Kitchenettes	–	0.30		–	1.5	2
Kitchens—commercial	–	0.70		–	3.5	2
Locker/dressing rooms	–	0.25		–	1.25	2
Locker rooms	–	0.50		–	2.5	2
Paint spray booths	–	–	F	–	–	4
Parking garages	–	0.75	C	–	3.7	2
Pet shops (animal areas)	–	0.90		–	4.5	2
Refrigerating machinery rooms	–	–	F	–	–	3
Residential kitchens	50/100	–	G	25/50	–	2
Soiled laundry storage rooms	–	1.00	F	–	5.0	3
Storage rooms, chemical	–	1.50	F	–	7.5	4

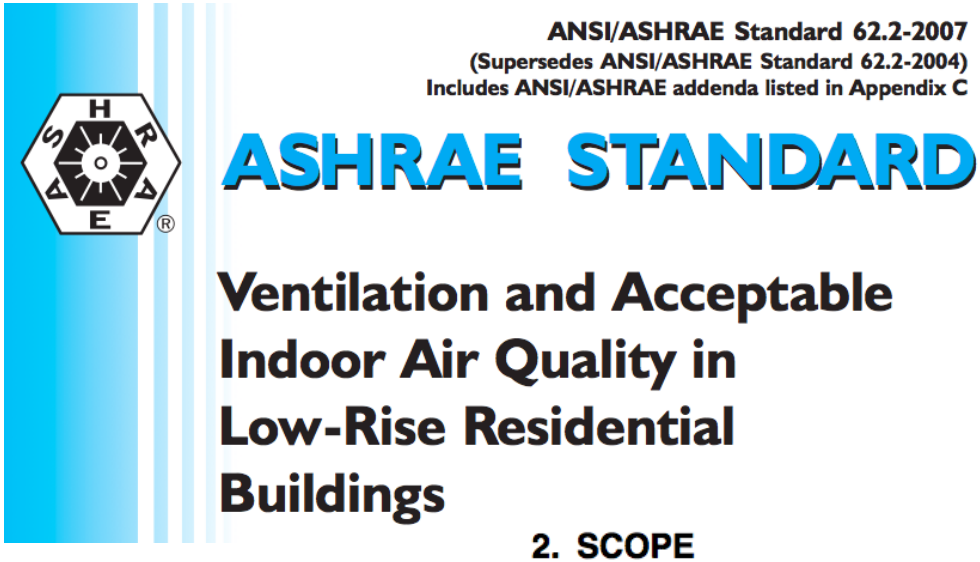
Measured air exchange rates: Commercial buildings

- Recent study of ~40 commercial buildings in California



Bennett et al. **2011** CEC Report

ASHRAE Standard 62.2: Residential ventilation



ANSI/ASHRAE Standard 62.2-2007
(Supersedes ANSI/ASHRAE Standard 62.2-2004)
Includes ANSI/ASHRAE addenda listed in Appendix C

ASHRAE STANDARD

Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

1. PURPOSE

This standard defines the roles of and minimum requirements for mechanical and natural ventilation systems and the building envelope intended to provide acceptable indoor air quality (IAQ) in low-rise residential buildings.

2. SCOPE

This standard applies to spaces intended for human occupancy within single-family houses and multifamily structures of three stories or fewer above grade, including manufactured and modular houses. This standard does not apply to transient housing such as hotels, motels, nursing homes, dormitories, or jails.

2.1 This standard considers chemical, physical, and biological contaminants that can affect air quality. Thermal comfort requirements are not included in this standard (see *ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy*).

2.2 While acceptable indoor air quality is the goal of this standard, it will not necessarily be achieved even if all requirements are met

ASHRAE Standard 62.2: Residential ventilation

4. WHOLE-BUILDING VENTILATION

4.1 Ventilation Rate. A mechanical exhaust system, supply system, or combination thereof shall be installed for each dwelling unit to provide whole-building ventilation with outdoor air each hour at no less than the rate specified in Tables 4.1a and 4.1b or, equivalently, Equations 4.1a and 4.1b, based on the floor area of the conditioned space and number of bedrooms.

$$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1) \quad (4.1a)$$

where

Q_{fan} = fan flow rate, cfm
A_{floor} = floor area, ft^2
N_{br} = number of bedrooms; not to be less than one

$$Q_{fan} = 0.05A_{floor} + 3.5(N_{br} + 1) \quad (4.1b)$$

where

Q_{fan} = fan flow rate, L/s
A_{floor} = floor area, m^2
N_{br} = number of bedrooms; not to be less than one

TABLE 4.1a (I-P)
Ventilation Air Requirements, cfm

Floor Area (ft^2)	Bedrooms				
	0–1	2–3	4–5	6–7	>7
<1500	30	45	60	75	90
1501–3000	45	60	75	90	105
3001–4500	60	75	90	105	120
4501–6000	75	90	105	120	135
6001–7500	90	105	120	135	150
>7500	105	120	135	150	165

TABLE 4.1b (SI)
Ventilation Air Requirements, L/s

Floor Area (m^2)	Bedrooms				
	0–1	2–3	4–5	6–7	>7
<139	14	21	28	35	42
139.1–279	21	28	35	42	50
279.1–418	28	35	42	50	57
418.1–557	35	42	50	57	64
557.1–697	42	50	57	64	71
>697	50	57	64	71	78

Next time

- Air filtration and other pollutant dynamics