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Integrating IAQ Control Strategies to Reduce the Risk of COVID 19 Infection

by

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Overview

- Introduction
  - Indoor air pollution processes and control
  - What are the major transmission pathways for COVID 19?
  - How to estimate the risk of infection due to aerosol transmission?

- IAQ control principle

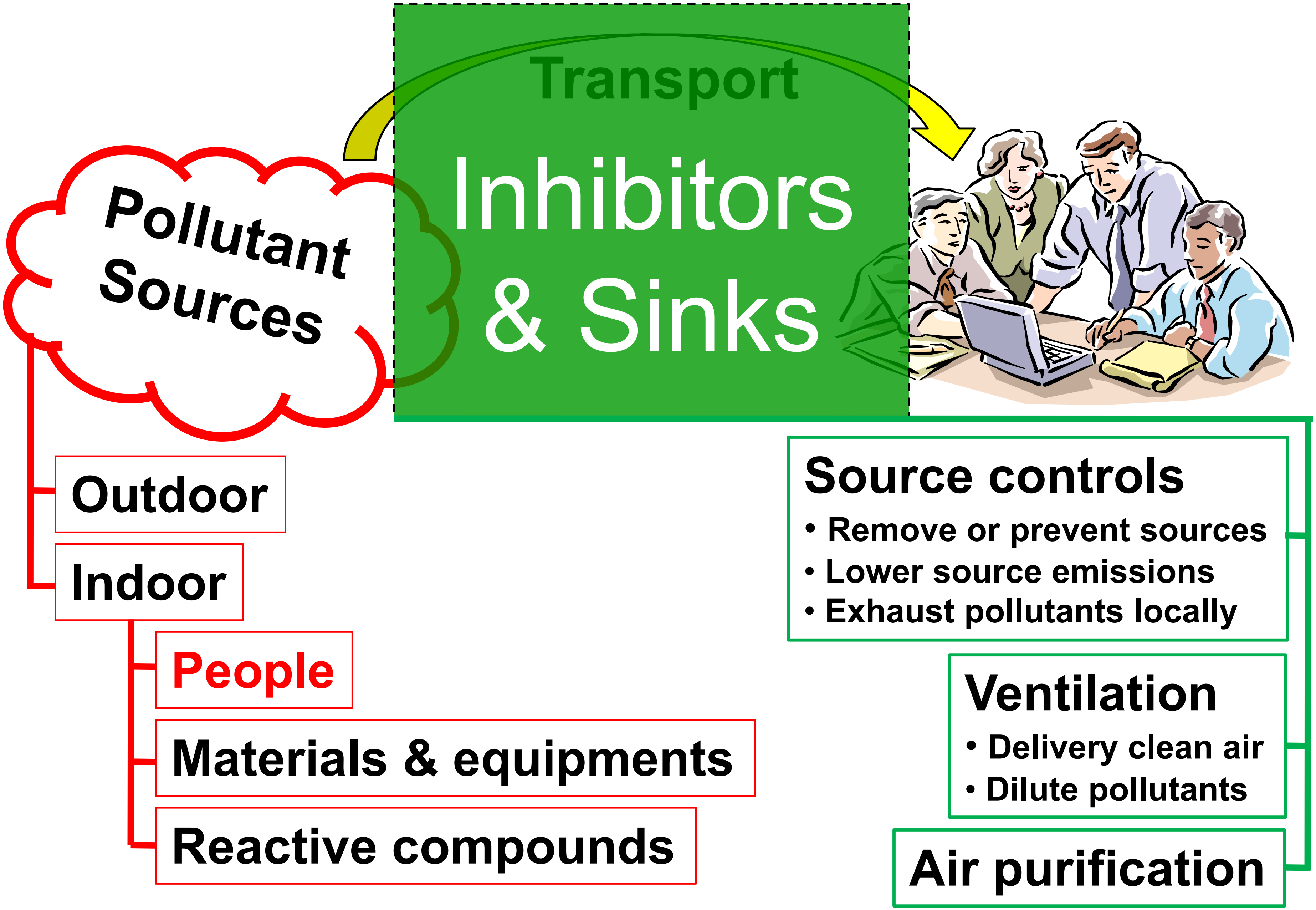
- Effectiveness of IAQ control strategies
  - Source control
  - Ventilation
  - Air cleaning

- Integrating IAQ control strategies to reduce the the risk of infection
  - Classrooms
  - Open plan offices

- How do we know if the strategies are working?

Jensen Zhang (2020) Integrating IAQ control strategies to reduce the risk of asymptomatic SARS CoV-2 infections in classrooms and open plan offices, Science and Technology for the Built Environment, 26:8, 1013-1018, DOI: 10.1080/23744731.2020.1794499

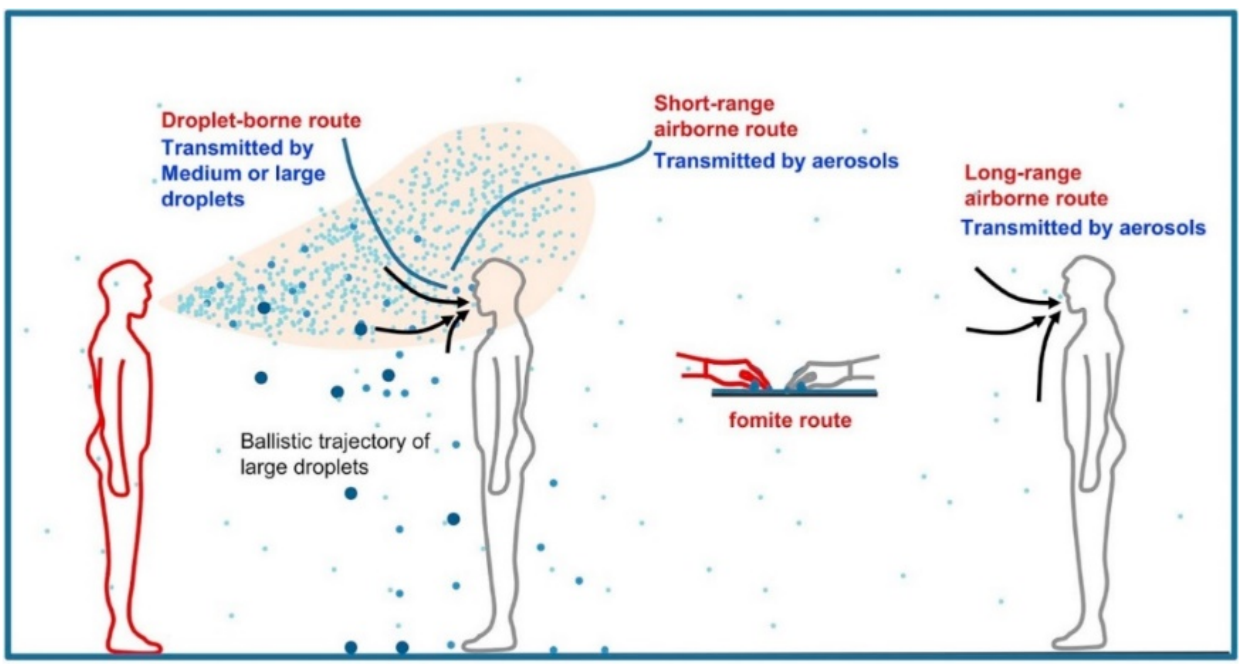
Air Pollution Processes and Control



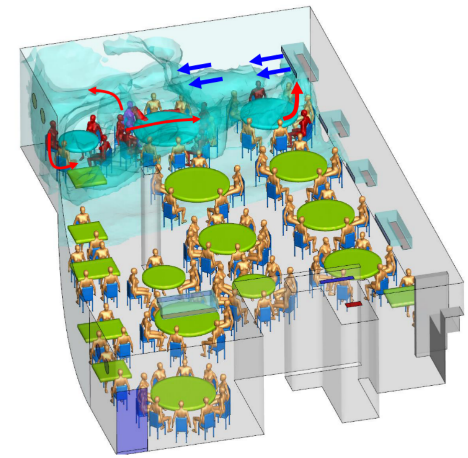
Three Major Infection Pathways for COVID 19

- Contact: direct and indirect
- Droplets
- Aerosols

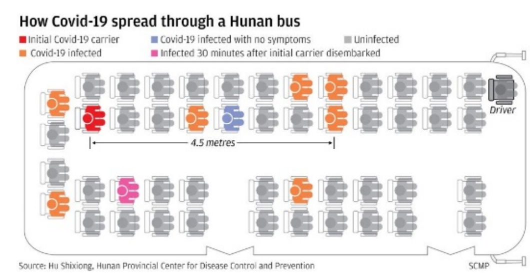
- Aerosol transmission is considered a major route



- Large droplets (>100 μm) : Fast deposition due to the domination of gravitational force
- Medium droplets between 5 and 100 μm
- Small droplets or droplet nuclei, or aerosols (< 5 μm): Responsible for airborne transmission



Guangzhou restaurant case (Jan 2020)
9 out of 88 people were infected



Hunan coach case (Mar 2020)
8 out of 48 people were infected

[1] Y. Li, H. Qian, J. Hang, X. Chen, L. Hong, P. Liang, J. Li, S. Xiao, J. Wei, L. Liu, M. Kang, Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant, MedRxiv. (2020) 2020.04.16.20067728.

[2] Stephen Chen, Coronavirus can travel twice as far as official ‘safe distance’ and stay in air for 30 minutes, Chinese study finds, South China Morning Post. (2020) 1–9.

How to estimate the risk of infection?

Wells-Riley model*

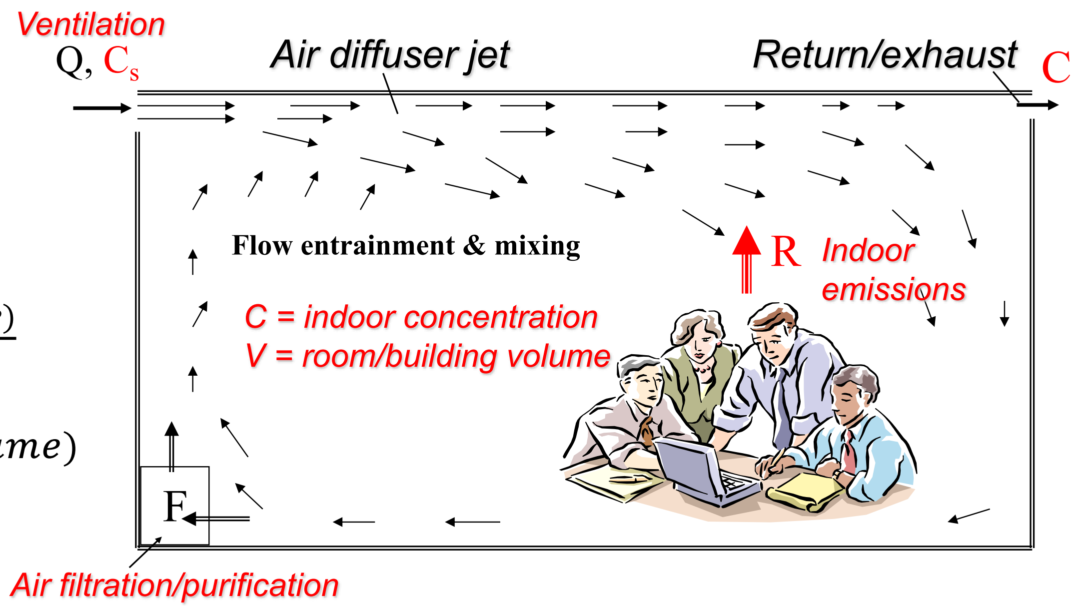
Probability of infection in a well-mixed space:

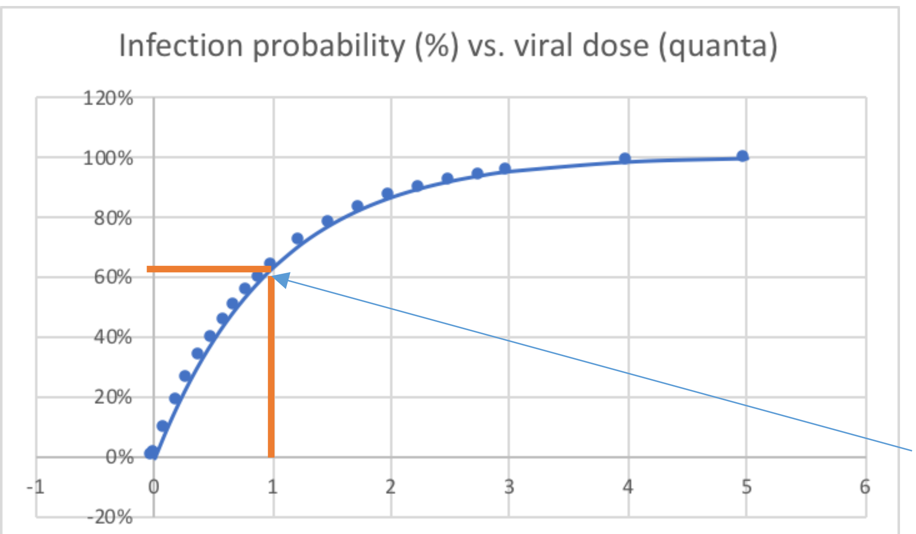
$$P = \frac{new\ cases}{susceptible} = 1 - e^{-\frac{Iqpt}{Q}}$$

$$= 1 - e^{-\frac{(generation\ rate)(inhaled\ air\ volume)}{Ventilation\ rate}}$$

$$= 1 - e^{-(concentration)(inhaled\ air\ volume)}$$

$$= 1 - e^{-(inhaled\ viral\ dose)}$$



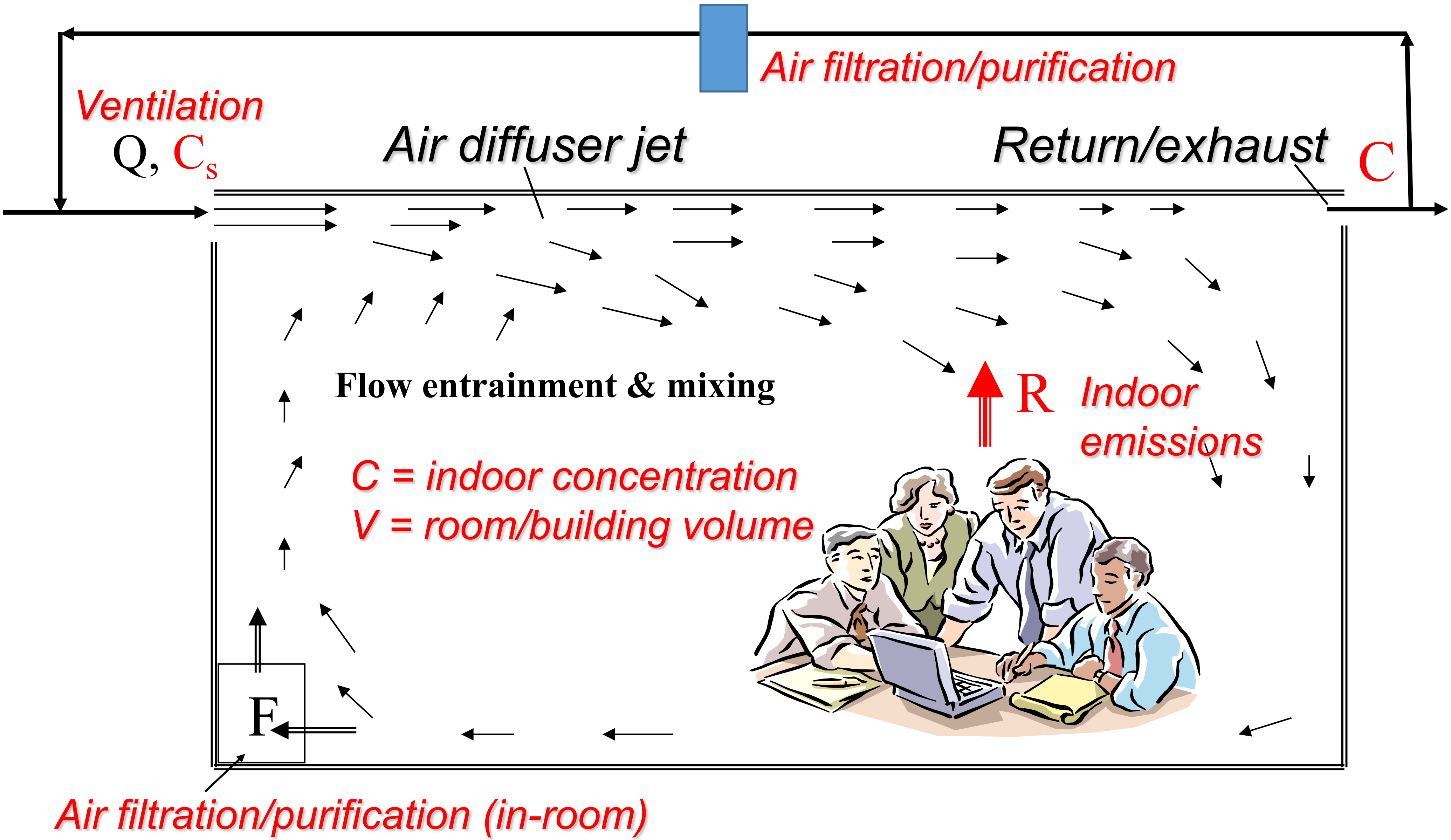


- Risk of infection depends on the inhaled viral dose
- Inhaled viral dose depends on the viral concentration and the inhaled air volume
- Inhaled air volume depends on inhalation airflow rate and exposure time
- **How can the viral concentration in the inhaled air be reduced by IAQ strategies?**

1 quantum of viral dose => 63% risk of infection

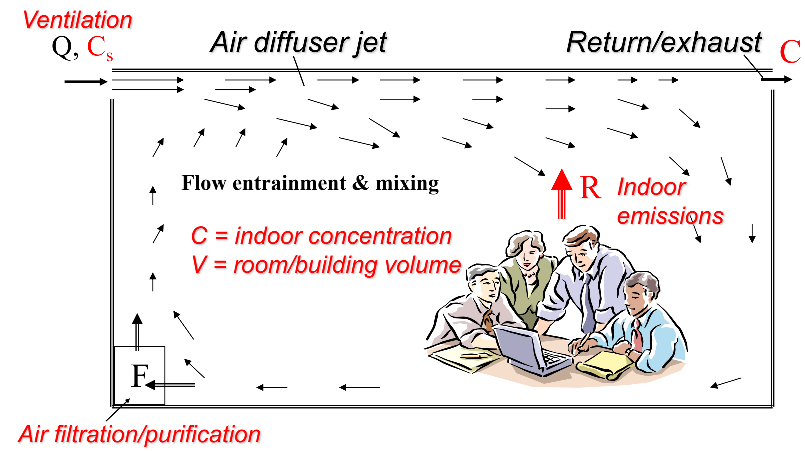
*Riley, E. C., G. Murphy, and R. L. Riley. 1978. Airborne spread of measles in a suburban elementary school. *American Journal of Epidemiology* 107 (5):421–32. doi:10.1093/oxfordjournals.aje.a112560

Principle of IAQ Control



Principle of IAQ Control

For a target pollutant…



- Goal:

$$C < C_{criteria}$$

- Governing equation:

$$V\,dC/dt \;=\; R(t) \;-\; \eta_v Q(t)\,[C(t) - C_s(t)] - F(t)$$

Rate of contaminant accumulation | *Rate of source emission* | *Rate of dilution by ventilation* | *Rate of reduction by air cleaning*

1. Source control
2. Ventilation
3. Air cleaning (for target pollutants)

IAQ Control Strategies

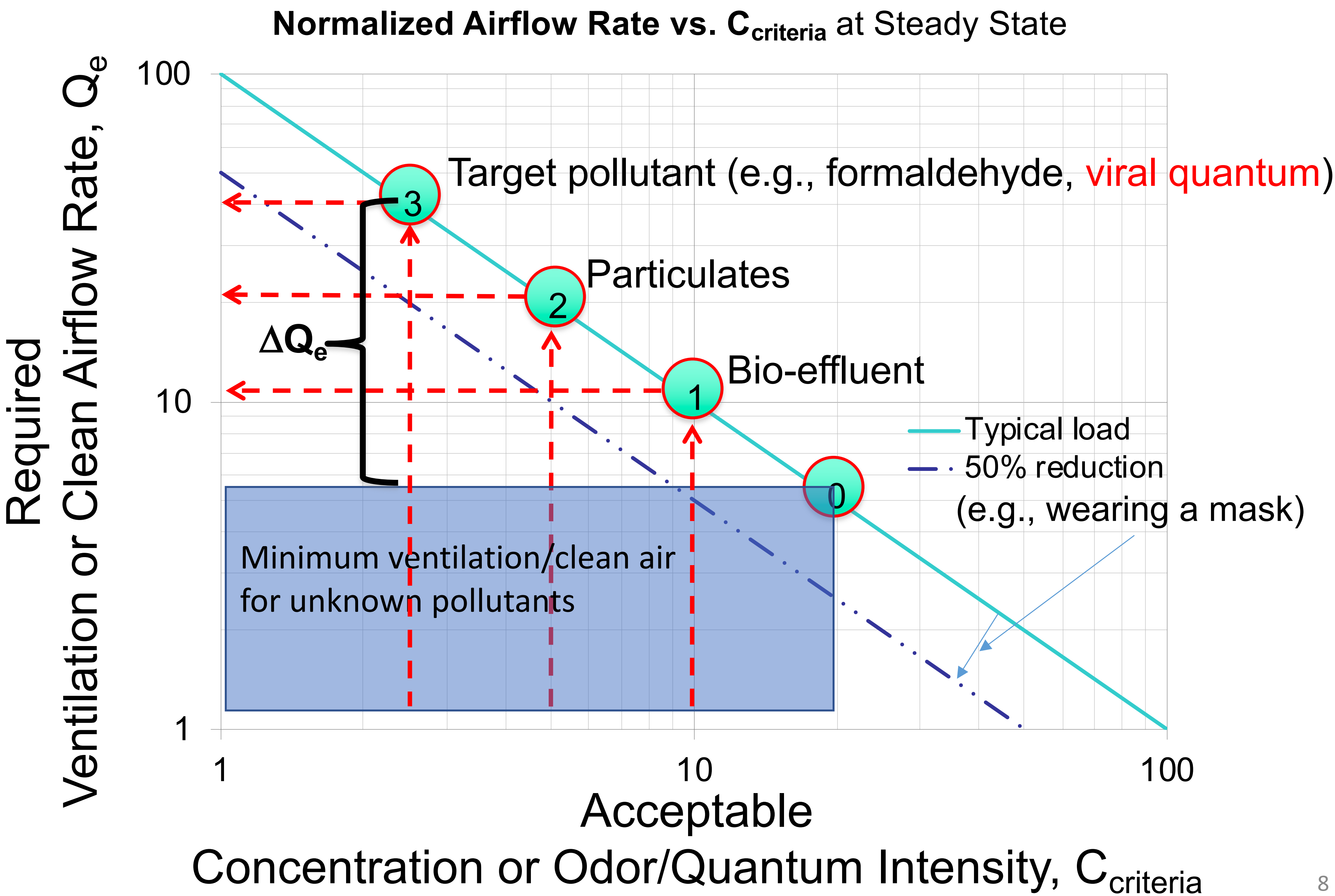
Q_eC

At steady state: $C=R/Q_e$

Q_e: "Equivalent" total ventilation rate

How much total "equivalent" ventilation rate is needed?

-- It depends on the acceptable concentration/intensity of target pollutants



How effective are different IAQ strategies?

1. Source control

- Test and quarantine
- Hand washing, sanitize surfaces and flush out disinfectant residuals before occupancy
- Wearing a mask - reducing the emission from asymptomatic virus carrier by 30% to 95% (Mueller et al. 2020)

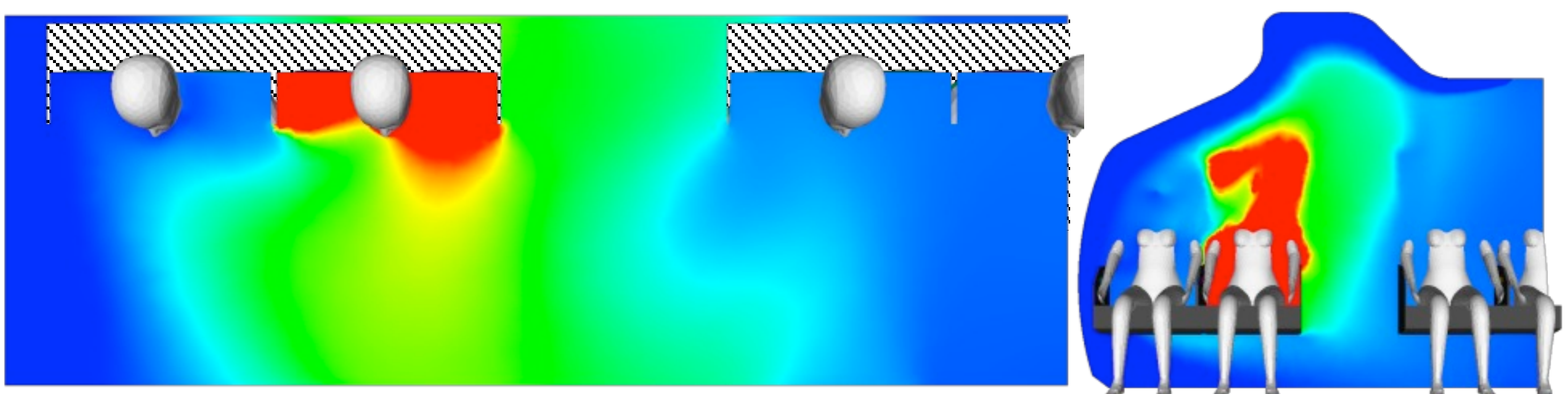
Cloth mask (50% or a factor of 2)

Surgical mask (75% or a factor of 4)

N95 mask (95% or a factor of 20)

- Local exhaust – reduce cross contamination by a factor of 2

Overhead suction w/privacy dividers



*By Ryan K. Dygert & Thong Q. Dang (2009)

A. Mueller, M. Eden, J. Oakes, C. Bellini, L. Fernandez, Quantitative Method for Comparative Assessment of Particle Removal Efficiency of Fabric Masks as Alternatives to Standard Surgical Masks for PPE, Matter. (2020). https://doi.org/10.1016/j.matt.2020.07.006.

Experimental Verification

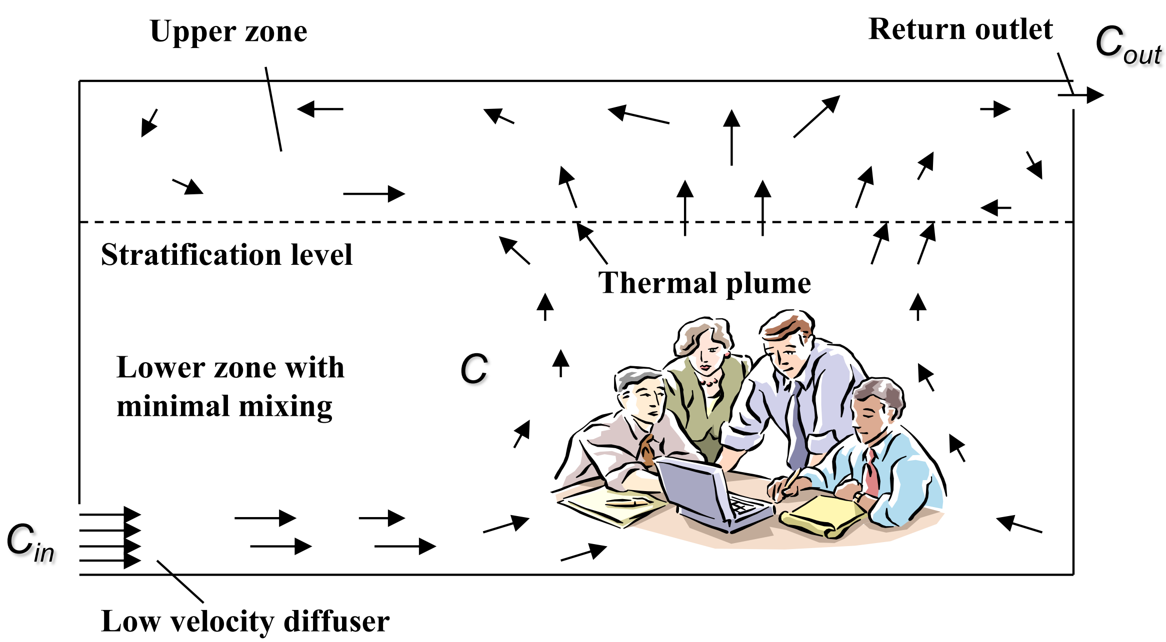
Local suction concept has the potential to reduce pollution due to occupants by a factor of 2 without increase of energy consumption.

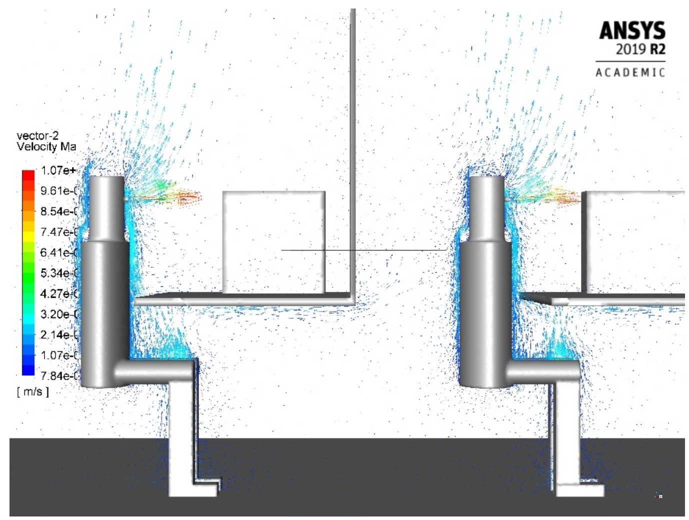
How effective are different IAQ strategies?

2. Ventilation

- Double outdoor air → a factor of 2
  - Mechanical
  - Open windows
  - Open window + exhaust box fan
- Displacement ventilation → a factor of 2

- Semi-open partitions
  - With mixing ventilation
  - → a factor of 2
  - With displacement ventilation
  - → a factor 20

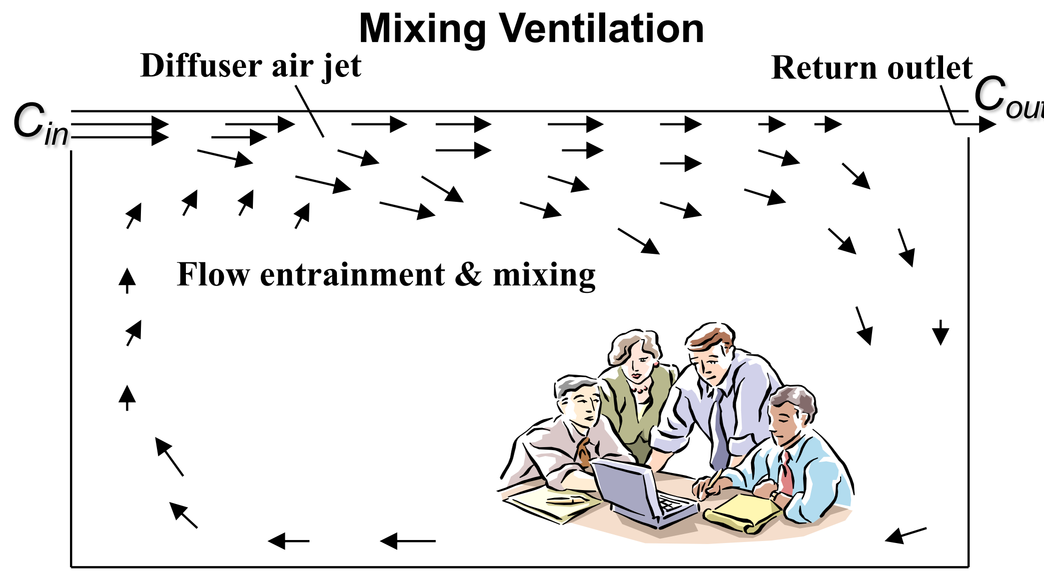


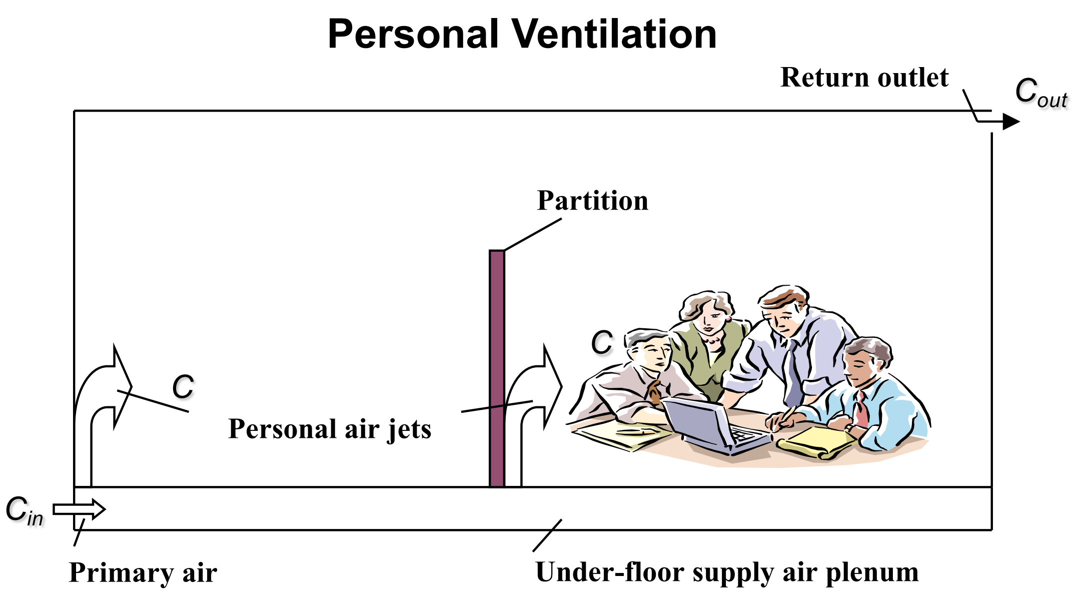


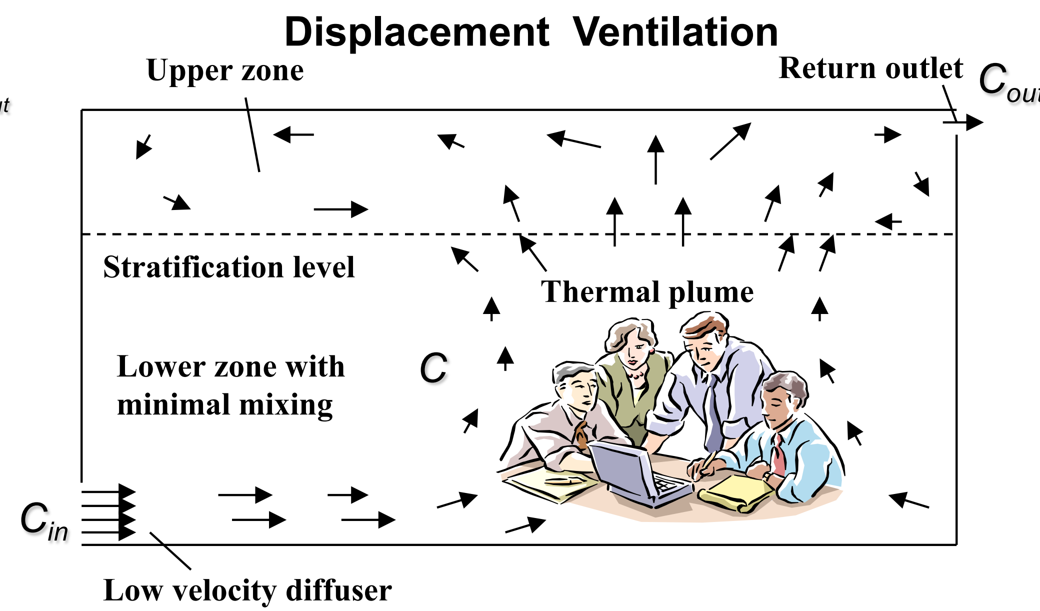
- Personal environmental control with local air supply and local exhaust – ultimate protection (PPE)

Ventilation

- Deliver clean air to occupants
- Dilute/remove pollutants



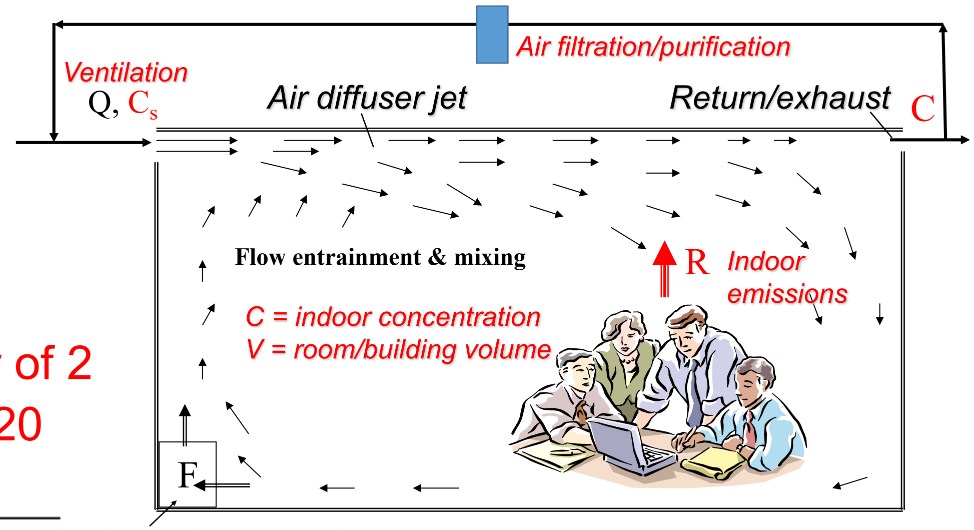




How effective are different IAQ strategies?

3. Air cleaning/purification

- Filtration of recirculated air
  MERV 8 → MERV 13 or higher
  Q_e = Airflow rate x filter efficiency
- Room air cleaner
  Supplement 10 to 15 cfm/p → a factor of 2
- Personal filter (Mask) → a factor 2-20



MERV	Particle removal efficiency η_{filter} [%]			
	0.3-1μm	1-3μm	3-10μm	Particle-size-weighted[b]
1	0	0	10	5
2	0	0	10	5
3	0	0	10	5
4	0	0	10	5
5	3	17	20	16
6	3	17	35	23
7	9	17[a]	50	32
8	9	20	70	43
9	9	35	85	55
10	9	50	85	59
11	20	65	85	66
12	35	80	90	76
13	50	90	90	82
14	75	90	90	87
15	85	90	90	89
16	95	95	95	95
HEPA	99.9	99.9	99.9	99.9

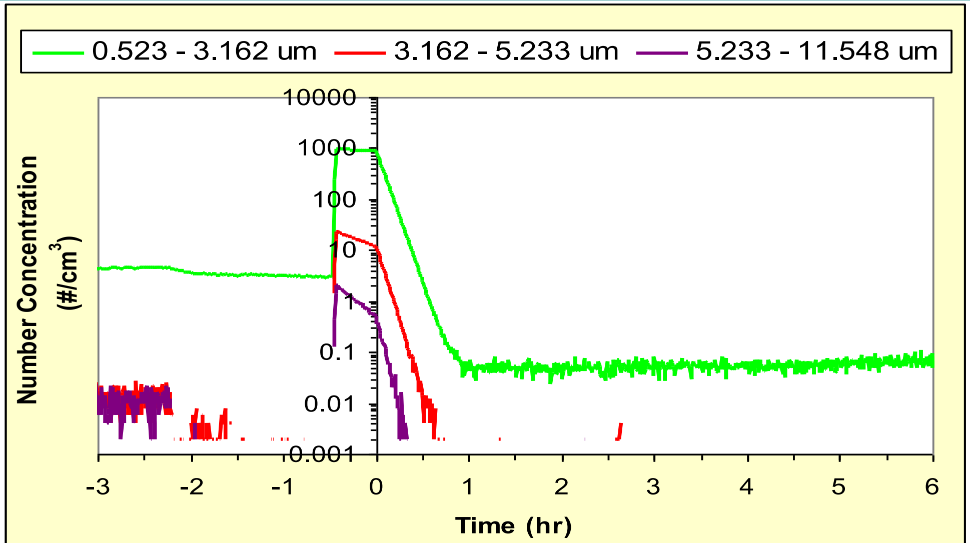
A factor of 2-3 (MERV 8 to MERV 13)

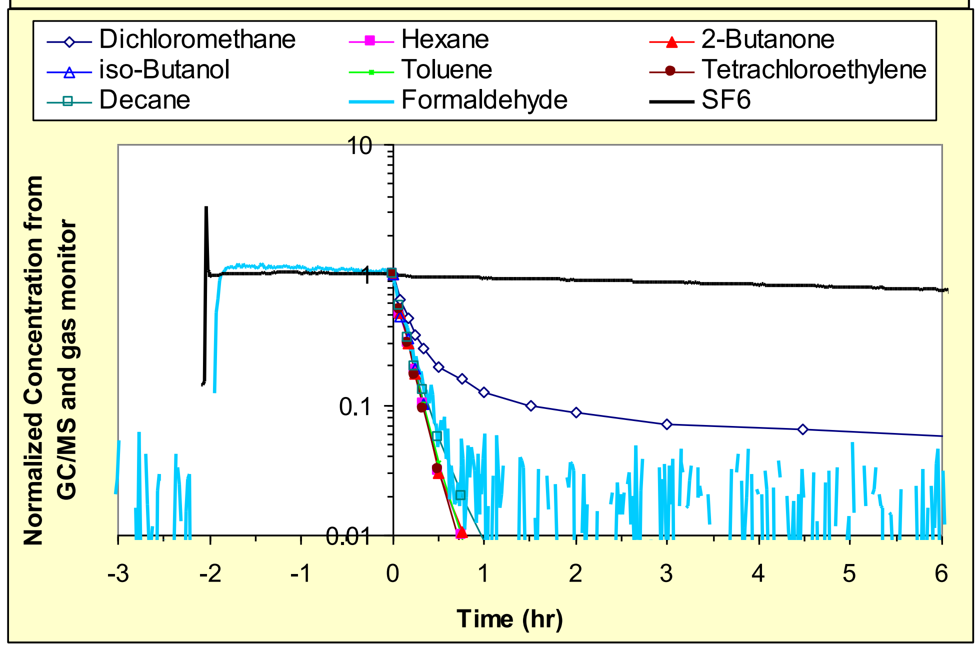
A factor of 4 (HEPA)

[1] ASHRAE, ASHRAE 52.2 Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size, 2017.
[2] M.B. Dillon, R.G. Sextro, Reducing Exposures to Airborne Particles Through Improved Filtration: A High-Level Modeling Analysis, MedRxiv. (2020) 2020.05.14.20101311. doi:10.1101/2020.05.14.20101311.

Air Cleaning for Target Pollutants

- Biological
  - UVGI
- Airborne particles
  - Mechanical filtration
  - Electrostatic precipitators
  - Electronic air cleaner + charged-media filter
  - Ion generator (Ionizers)
- VOCs
  - Sorption by filter media
  - Photo-catalytic oxidization
  - Bio-filtration
  - Others
    - Thermal decomposition
    - Non-thermal plasma decomposition

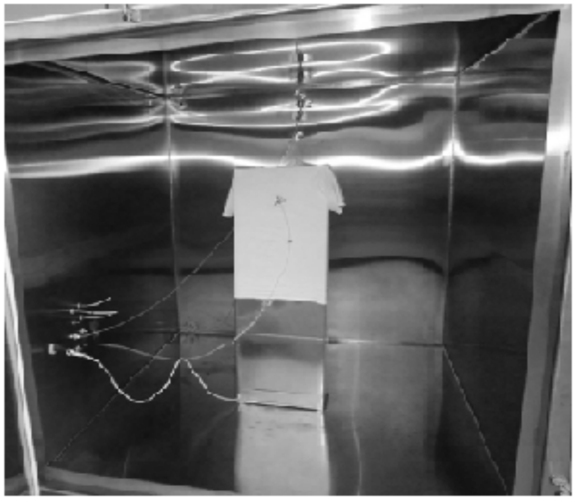




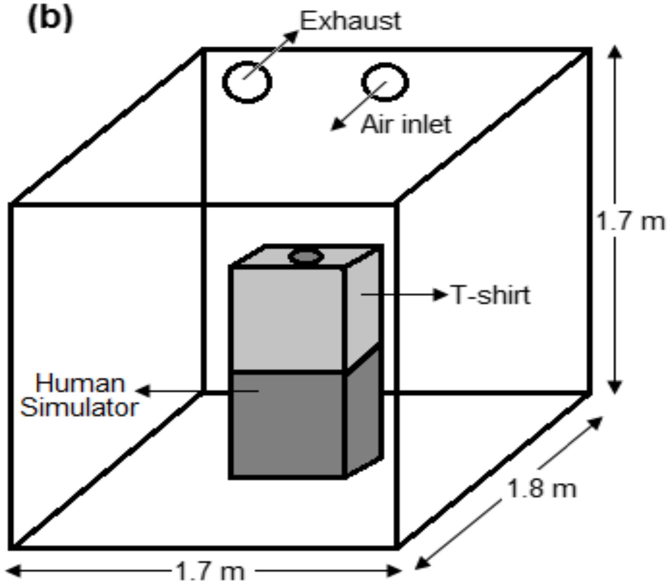
“The same technology have very different performance for different pollutants.”
“Unintended consequences such as Ozone emission must be avoided!”

Reduce Secondary Emissions

(a)

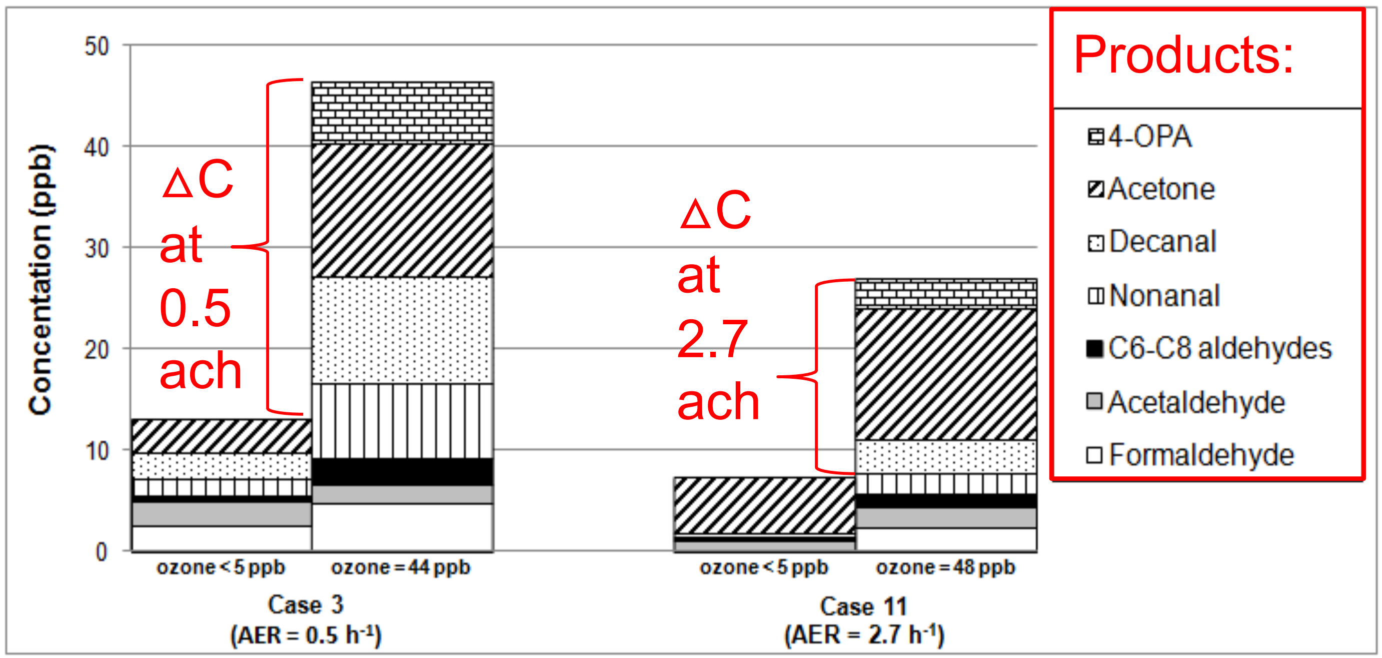


(b)



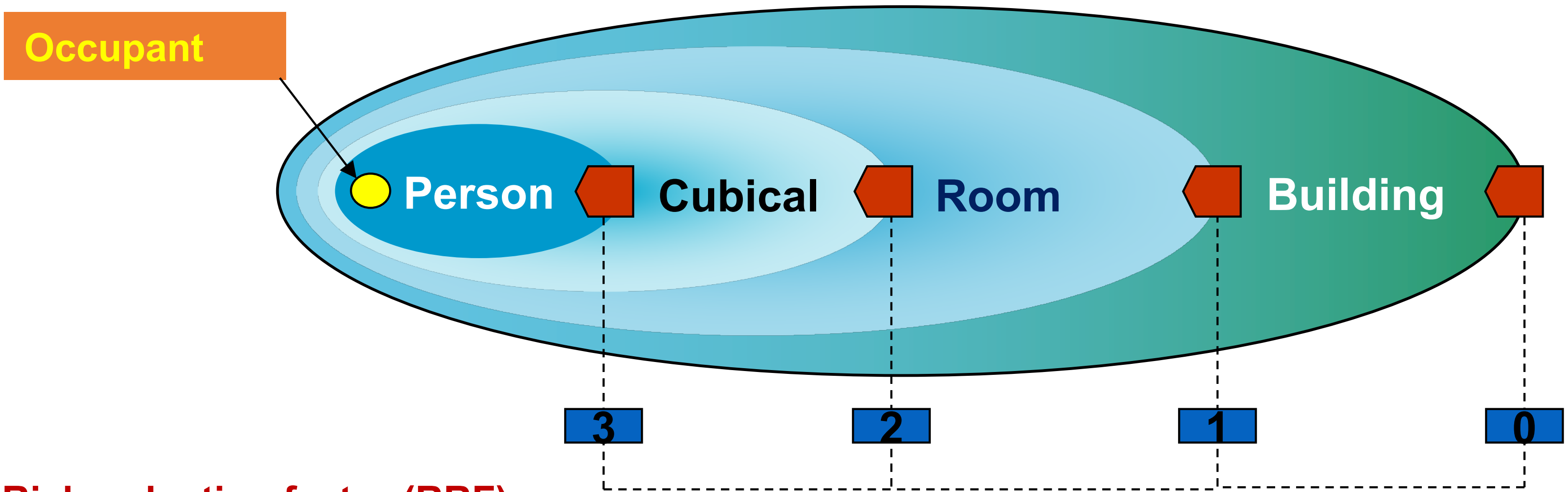
Mid-scale chamber testing of ozone initiated particle and VOC generation

Factors affecting ozone consumption and generation of volatile organic compounds in its reactions with human clothing
(Rai, Guo, Zhang & Chen 2012)



Control the sources: Reduce outdoor ozone infiltration and indoor generation.

Managing the Risk at Multiple Scales

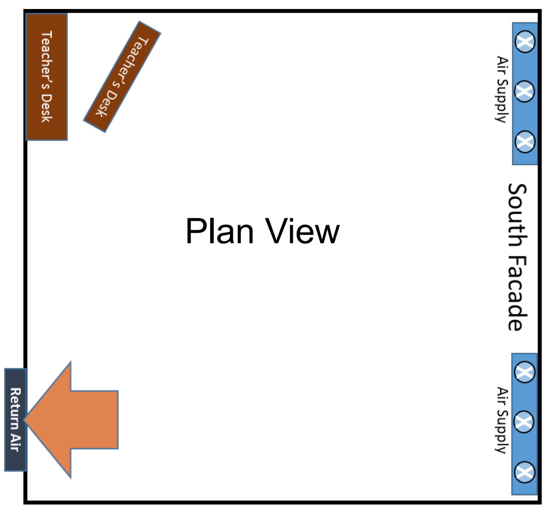


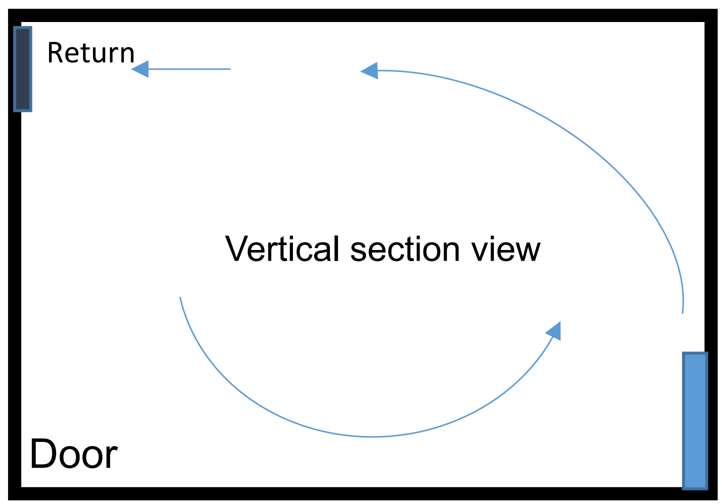
Risk reduction factor (RRF):

	Person	Cubical	Room	Building (Envelope+HVAC)
Source control (R')	• Clean hands & face • **Wear a mask** **(2, 4, 20)**	• Sanitize surfaces • Local exhaust (2 to 100)	• Sanitize surfaces • Test & screening	• Sanitize surfaces • Test & screening
Ventilation (Q_v)	• Wearable ventilator (PPE)	• Semi-open partition (SoP) with PV (2)	• Disp Vent (DV) (2) • **SoP+MV (2)** • **SoP+DV (20)**	• **Increase OA** • **Reduce occupancy (2)**
Air cleaning (Q_{ev})	• Wearable air purifier	• Local air cleaner (2) • Disinfection surfaces	• **Room air cleaner (2+)** • Disinfection surfaces	• **MERV 13 filter (2)** • HEPA filter (4)

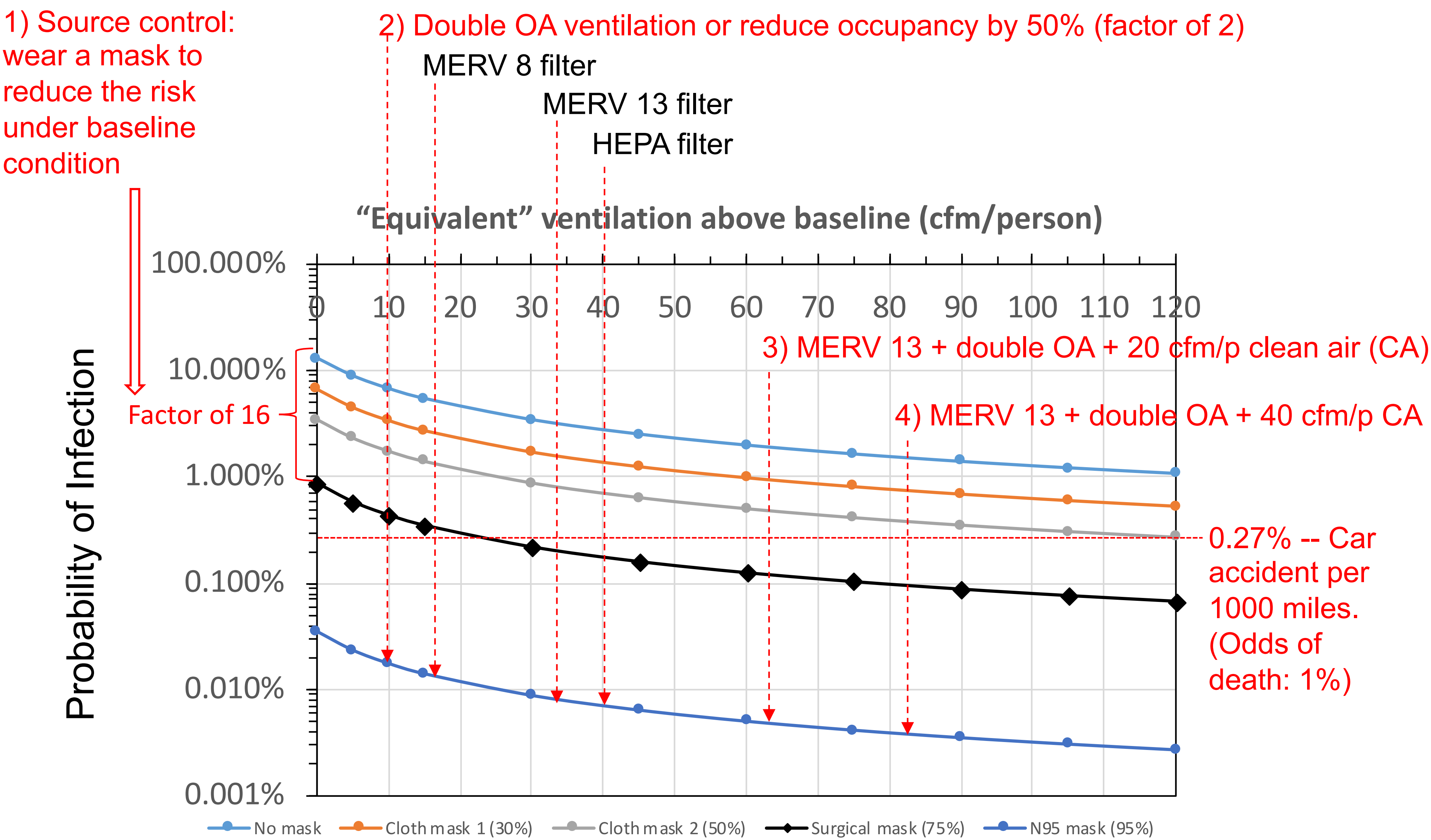
A Case Study for a Classroom

- Two air supply diffusers (under windows), one air return (above the door)
- 1099 ft^2, 10 ft high, 50 student capacity, 500 cfm OA (10 cfm/p), OA fraction 20%, 4 h exposure
- Assume 1 virus carrier with a quanta generation rate of 100 quanta/hour





How to integrate IAQ strategies to reduce risk?



How do we know if the strategies are working?

1. **System commissioning**
   - Does the system provide sufficient airflow rates?
     Both outdoor air and recirculated air
   - Are filters properly installed to avoid flow bypass?
   - Are system properly cleaned, sanitized and well flushed throughout?
2. **Monitoring**
   - CO2 concentration as an indicator of outdoor air ventilation rate
   - ASHRAE's minimum standard: ~ 1050 ppm (700 ppm above ambient level)
   - Double the ventilation would reduce it to 700 ppm
   - An "equivalent" reduction of 7 folds is needed (i.e., 450 ppm) is needed with the integrated IAQ strategies (however not reflected by measured CO2 level)
   - The alternative is to check the airflow rates monitored by building energy management system (BMS)
3. **Maintenance**
   - Replace filters every 3-6 months per supplier's recommendation/specification
   - Verify monitoring and control sensors
   - Verify the flow rates
   - Clean, sanitize and flush the system
4. **Quality assurance via training, education and enforcement of established safety protocols**
5. **Documenting – keep records of the outcomes**

Summary and Conclusions

1. **Well established IAQ control principles and strategies can be readily applied to effectively reduce the risk of COVID 19 infection**
2. **Source control is most effective**
    - “Wearing surgical masks properly by all occupants in the room can reduce the risk by a factor of 16.”
3. **Ventilation should be enhanced**
    - “Double ventilation rate per person can further reduce the risk of infection by a factor of 2. This can be achieved by increasing outdoor ventilation rate and/or reducing room occupancy.”
    - It also improves overall indoor air quality
4. **Air cleaning and filtration can play a significant role**
    - MERV 8 filters in existing HVAC systems also reduce the risk of infection
    - MERV 13 filters can typically be accommodated by exiting HVAC system fans, and can reduce the risk by a factor of 2-3
    - A higher-grade filter such as MERV 16 or HEPA filter may require major system modification while the risk reduction benefit is marginal
    - Room air cleaner is a cost-effective approach to double the “ventilation”
5. **IAQ control strategies should be integrated**
    - Basic strategies: wearing a mask + double ventilation rate per person + MERV 13 + 15 or more cfm/person from room air cleaners
    - Intermediate strategies: + semi-open partitions in coordination with with mixing, displacement or personal ventilation to minimize the cross contamination in rooms.

Any questions?

Thank you and stay safe and well!