Effectiveness of multi-scale IAQ strategies for reducing the risk of airborne infection of SARS-CoV-2

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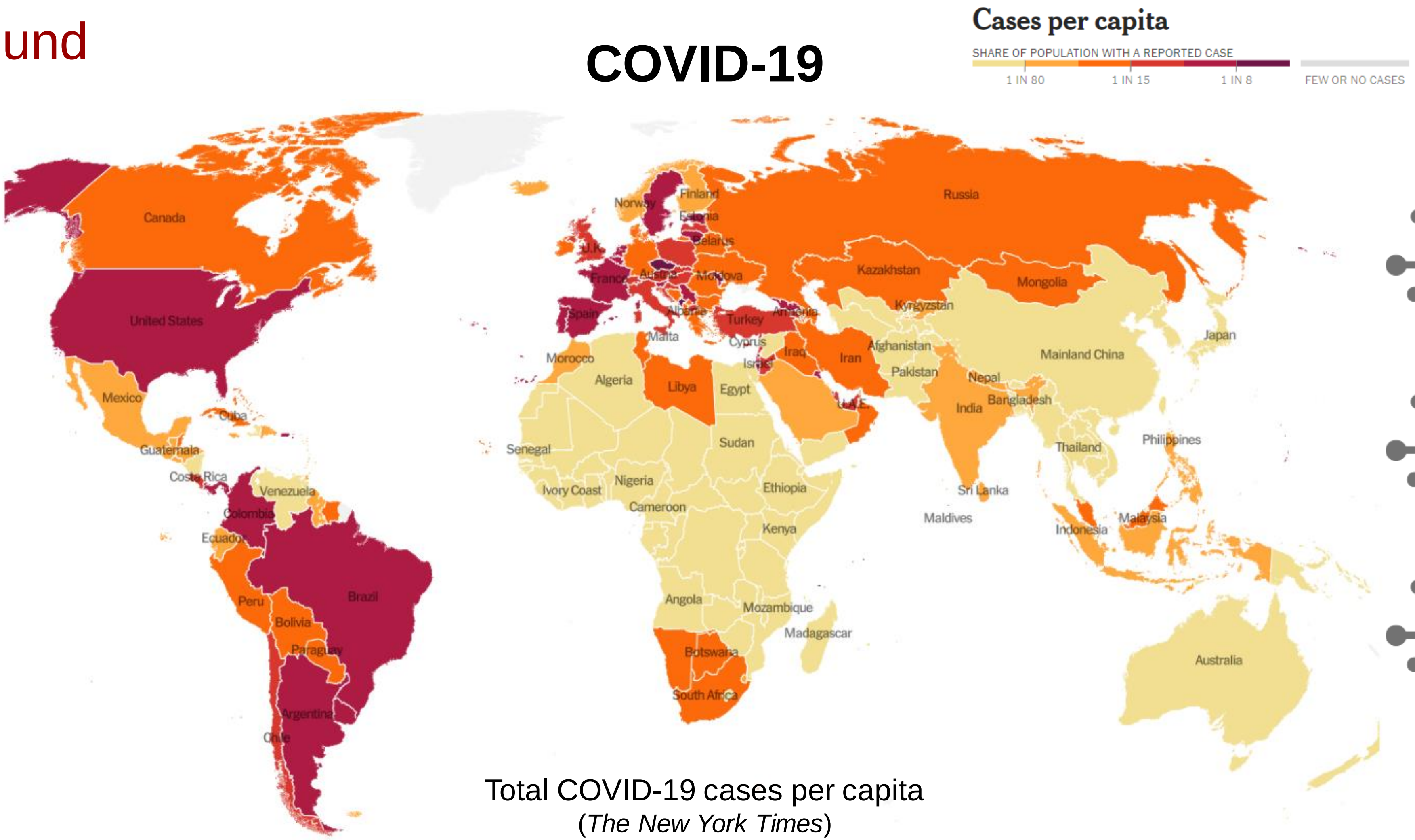
Introduction

Background

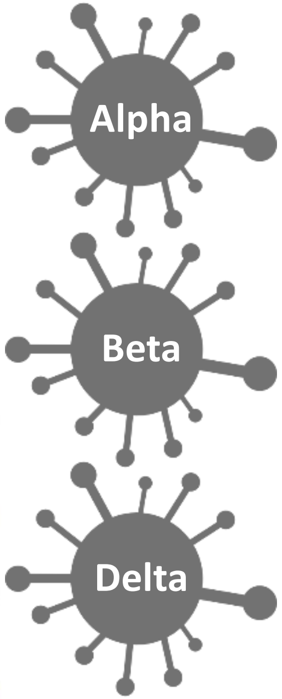
>200M
cases

>4.2M
deaths

COVID-19



Total COVID-19 cases per capita
(*The New York Times*)

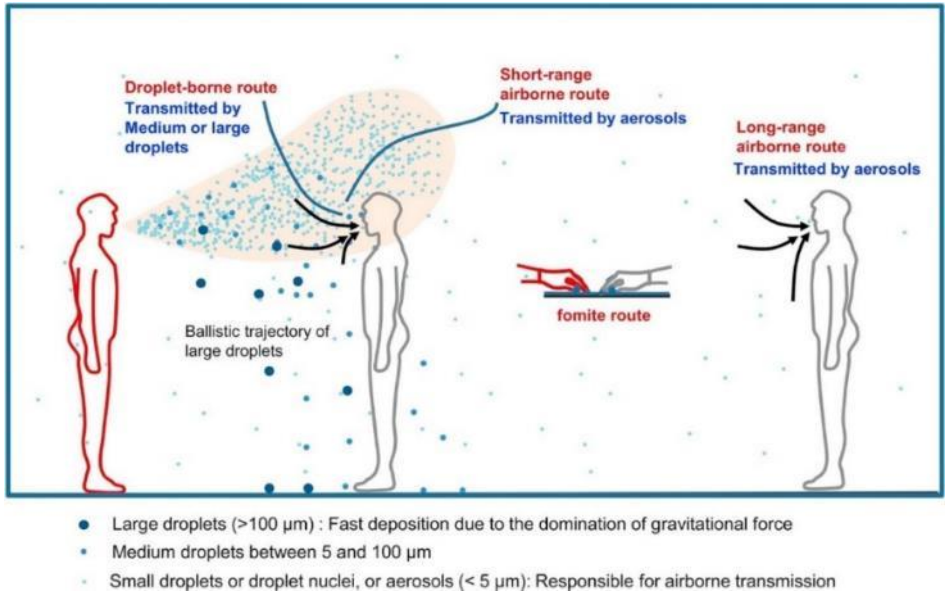


Introduction

Airborne transmission

Transmission routes of respiratory diseases

- Fomite route (building surface, skin...)
- Droplet-borne route (medium or large droplets)
- Short-range/long-range airborne route (by **aerosols**)



Virus-laden aerosols can be expelled through respiratory activities by the infectors and remain suspended in the air **over a longer time (hours) and distance (>2m)**.

Wei J and Li Y 2016 Airborne spread of infectious agents in the indoor environment Am. J. Infect. Control 44 S102–8

Introduction

Airborne transmission

Evidences of airborne transmission for SARS-CoV-2

- **Onsite virus detection** in air or aerosol samples
  - Viral RNA was vastly detected in air samples
  - Viable (infectious) virus was detected in some samples
- **Laboratory experiments** observed viable virus on aerosols
- **Retrospective analyses** on real outbreak events
  - Virus spreading in some outbreaks cannot be explained by other routes
- **Animal experiments** observed airborne transmission

→ **Predominant** transmission of COVID-19 in some scenarios

Introduction

Outbreaks in indoor environments

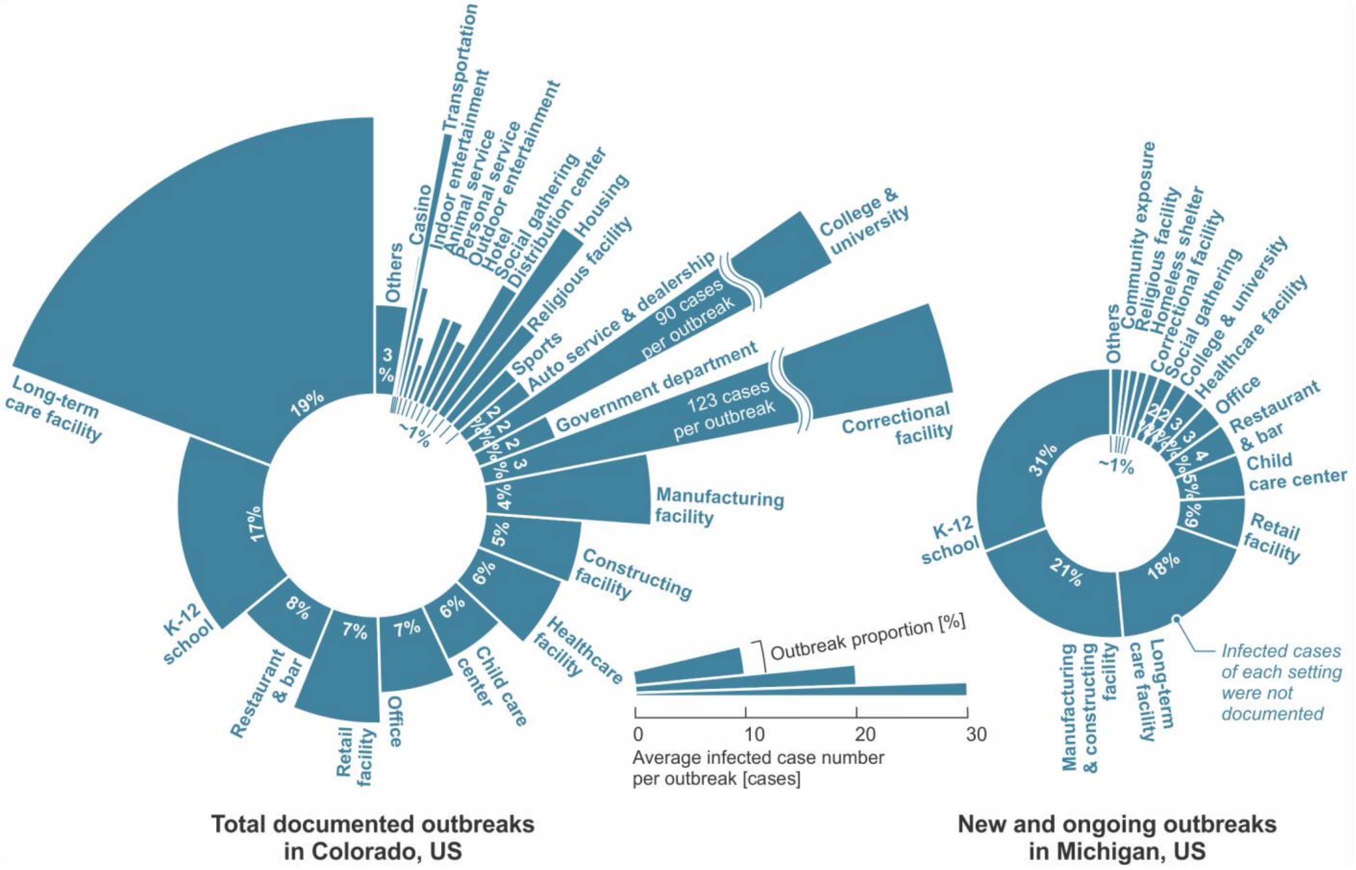
Indoor COVID-19 outbreaks

- Home-based outbreaks: 79.9%
- Transportation-based outbreaks: 34.0%

→ **Poor ventilation** indoors increases the infection risk through airborne transmission

Hotspots of indoor outbreaks

- Long-term care facilities
- K-12 schools
- Restaurants
- Retail facilities
- Offices
- …



Qian H, Miao T, Liu L, Zheng X, Luo D and Li Y 2020 Indoor transmission of SARS-CoV-2 Indoor Air ina.12766

Introduction

IAQ control strategies for mitigating airborne transmission

IAQ control strategies

- Source control
- Ventilation
- Air cleaning

⇩

- Building scale
- Room scale
- Personal microenvironment
- Breathing zone

⇨

Benefits

- IAQ improvement
- Infection risk mitigation

Costs

- Capital cost
- Energy consumption

⇨

Effectiveness

Methodology

Wells-Riley model (steady-state well-mixed air)

Source emission

$$P = \frac{new\ cases}{susceptible} = 1 - e^{-R_S R_I \frac{Iqpt}{V\lambda}} = 1 - e^{-\frac{(IqR_I)}{(V\lambda)}(R_S pt)}$$

Inhalation

Dilution (ventilation or disinfection)

disinfection, removal by air cleaner

$$\lambda = \lambda_{HVAC}\varepsilon_{vent} + k_{UV} + k_{deposition} + k_{AirCleaner} + k_{inactivation}$$

equivalent fresh air supply, particle deposition, natural inactivation rate

$$\lambda_{HVAC} = \lambda_{outdoor} + \lambda_{recirculated}\eta_{filter}$$

outdoor air, filtered recirculated air

P: infection probability.

R: fraction of infectious particles penetrating through the mask of the susceptible (R_S) and infected (R_I).

I: initial infected patient number.

q: infectious quanta generation rate per initial virus carrier (1/h).

p: pulmonary ventilation rate of a person (m^3/h).

t: exposure time (h).

V: room volume (m^3).

λ: total effective air change rate for dilution in the space.

The basic reproduction number (R0) can be calculated by

$$R_0 = \frac{N_C}{I}$$

Stephens B 2012 Wells-Riley & HVAC Filtration for infectious airborne aerosols NAFA Foundation Report HVAC filtration and the Wells-Riley approach to assessing risks of infectious airborne diseases Final Report Prepared for: The National Air Filtration Association (NAFA)

Methodology

Wells-Riley model (steady-state well-mixed air)

Viral quanta generation rate model:

$$q = c_v \cdot c_i \cdot p \cdot \int_{0}^{10\mu m} N_d(D) \cdot dV_d(D)$$

Depends on

- **viral load of sputum** (10^9 RNA copies/mL, $c_i = 0.02$),
- **pulmonary rate**, and
- **particle number concentration and size distribution.**

Age group	Age [years]	Short-term pulmonary rates (Mean±SD) [m^3/h]		
		Sedentary or light activities	Moderate-intensity activities	High-intensity activities
Children	<16	0.3±0.2	1.3±0.85	2.5±1.75
Adults	16-61	0.3±0.2	1.6±1.15	3.0±2.3
Elders	>61	0.3±0.2	1.6±1.0	2.8±2.0

Particle size distribution (uniform distribution in each bin):

0.3-1μm: 10-20%
1-3μm: 20-30%
3-10μm: 50-70%

Viral quanta generation rate

Group	Age [years]	Infectious quantum generation rate (Mean±SD) [h^{-1}]		
		Sedentary or light activities	Moderate-intensity activities	High-intensity activities
Children	<16	58±31	251±134	492±270
Adults	16-61	58±31	318±177	610±347
Elders	>61	58±31	305±158	555±307

Viral quanta generation rates in the literature

Activity	*ER* [h^{-1}]	Introduction	Reference
Estimated from retrospective analysis on real outbreak events			
Standing + singing	970±390	Skagit Valley Chorale superspreading event	Miller et al. (2020)
Standing + singing	341	Skagit Valley Chorale superspreading event	Buonanno et al. (2020)
Standing + singing	870	Skagit Valley Chorale superspreading event	Bazant et al. (2021)
Seated + vocalization	61	Guangzhou restaurant outbreak event	Buonanno et al. (2020)
Resting + breathing	45	Zhejiang tour coach outbreak event	Bazant et al. (2021)
Resting + breathing	30	Diamond Princess cruise ship outbreak event	Bazant et al. (2021)
Resting + breathing	29	Wuhan city outbreaks	Bazant et al. (2021)
Resting + breathing	185.63	Diamond Princess cruise ship outbreak event	Chen et al. (2021)
Estimated using the viral load model			
Resting Intermediate Light activity + vocalization	<1 ≤100 >100	Estimated based on the viral load in the sputum	Buonanno et al. (2020)
Resting + breathing/whispering[a] Standing + breathing/whispering Light activity + breathing/whispering Resting + speaking[b] Standing + speaking Light activity + speaking	3 3 9 50 56 142[c]	Estimated based on $c_v = 10^9$ RNA copies/mL and $c_i = 0.02$	Buonanno et al. (2020)
Estimated using statistical methods			
Sedentary state	14-48	Estimated based on the fitting curve between *ER* and R_0 from the data of other respiratory diseases (e.g. influenza and SARS-CoV-1)	Dai and Zhao (2020b)

Methodology

Baseline indoor environments

Baselines are created based on:

- U.S. DOE and PNNL prototypes of typical commercial buildings in accordance with ASHRAE 90.1 and IECC standards.
- Design guidelines or real practices (cases that were not defined by DOE and PNNL).
- Occupant number and activities are determined by ASHRAE 62.1 or the available data from literature or practices.
- Required outdoor ventilation rate are calculated based on the data in ASHRAE 62.1 or data from literature or typical practices.

Shen J, Kong M, Dong B, Birnkrant M J and Zhang J 2021 A systematic approach to estimating the effectiveness of multi-scale IAQ strategies for reducing the risk of airborne infection of SARS-CoV-2 Build. Environ. 107926

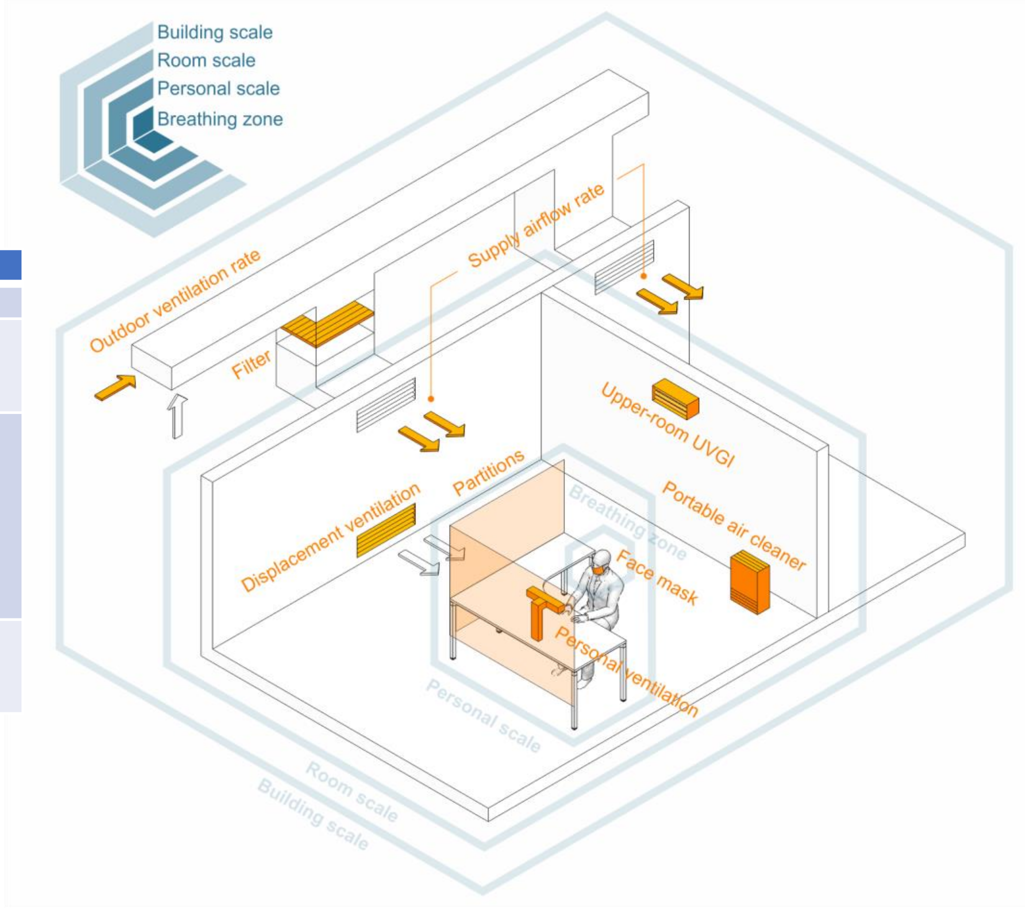
Scenario		Space type	Space layout		Occupant configuration			Ventilation
			Area [m^2]	Height [m]	Number [person]	Duration [h]	Activity level[c] [-]	Ventilation rate[d] [L/s]
Long-term care facility		Bedroom (double resident)	36.8	3.0	2	11	Elder Sed.	16.0
		Dining room	70.0	3.0	20	2	Elder Mod.	139.0
		Living room	50.0	3.0	5	2	Elder Sed.	27.5
		Physical therapy room[b]	23.2	3.0	5	2	Elder Mod.	32.0
Educational	K-12	Classroom	99.0	4.0	35	4[e]	Child Sed.[e]	234.4
		Library	840.1	4.0	84	1	Child Sed.	714.1
		Cafeteria/dining room	624.0	4.0	624	1	Child Mod.	2932.8
		Gym	1976.2	8.0	138	1	Child High	3158.6
	College	Classroom (small)	51.5	3.0	25	2	Adult Sed.	155.9
		Classroom (large)	150.0	4.0	96	2	Adult Sed.	570.0
		Library (public study area)	338.6	6.0	96	2	Adult Sed.	443.2
		Auditorium	1134.0	14.6	1500	2	Adult Sed.	6040.2
		Computer lab	84.3	4.0	38	2	Adult Sed.	240.6
		Dining hall	573.5	4.0	574	1	Adult Mod.	2697.4
		Study lounge	84.3	4.0	21	2	Adult Sed.	103.1
		Gym (fitness area)	256.0	8.0	60	2	Adult High	830.4
		Resident hall (bedroom)	21.5	3.0	2	8	Adult Sed.	11.5
		Greek house (social gathering)	50.0	3.0	20	4	Adult Mod.	65.0
Manufacturing facility	Meat plant	Processing room (dense)	434.0	4.0	108	8	Adult Mod.	930.6
		Processing room (sparse)	434.0	4.0	27	8	Adult Mod.	525.6
Retail	Standalone	Core shopping space	1600.4	6.0	240	1	Adult Mod.	1872.2
	Strip mall	Store (large)	348.4	5.2	28	1	Adult Mod.	210.9
		Store (small)	174.2	5.2	14	1	Adult Mod.	105.5
Healthcare facility	Hospital	Operating room	55.7	4.3	3	4	Adult Sed.	198.2
		Patient room (patient+doctor)	20.9	4.3	2	1	Adult Sed.	49.6
		Physical therapy room	487.6	4.3	26	2	Adult Mod.	186.0
		Dining room	696.5	4.3	75	1	Adult Mod.	902.4
		Lobby	1474.3	4.3	21	1	Adult Mod.	499.3
Office	Medium	Open plan office	191.9	2.7	10	8	Adult Sed.	82.6
		Enclosed office	42.3	2.7	2	8	Adult Sed.	17.7
		Conference room	43.2	2.7	22	2	Adult Sed.	68.0
		Lounge	89.6	2.7	45	1	Adult Sed.	166.3
Correctional facility	Prison	Housing (double resident cell)	10.0	3.0	2	8	Adult Sed.	11.0
		Housing (dormitory)	160.0	3.0	40	8	Adult Sed.	196.0
		Dayroom	160.0	6.0	48	12	Adult Sed.	168.0
Lodging	Hotel	Guest room/bedroom	39.0	3.0	2	8	Adult Sed.	16.7
		Banquet/dining room	331.7	3.0	232	2	Adult Mod.	1180.1
		Lobby	1308.2	4.0	392	1	Adult Mod.	1882.1
Other public facilities	Restaurant	Dining room (ordinary)	371.7	3.0	260	1	Adult Mod.	1322.5
		Dining room (fast-food)	116.1	3.0	81	0.5	Adult Mod.	412.3
	Religious	Worship hall	204.0	4.0	200	2	Adult Sed.	561.2
	Casino	Poker room	253.1	4.0	304	4	Adult Mod.	1383.0
Transportation spaces	Airplane	Cabin	101.8	2.2	160	4	Adult Sed.	560
	Cruise ship	Guest room (double resident)	17.0	3.0	2	8	Adult Sed.	10.1
		Casino	635.5	3.0	763	4	Adult Mod.	3471.4
		Cafeteria/Bistro	80.0	3.0	80	2	Adult Mod.	376.0
	Subway	Cabin	40.7	2.5	176	0.5	Adult Sed.	480.5
	Bus	Transit bus	30	2.5	60	0.5	Adult Sed.	210
		Tour coach	30	2.5	50	2	Adult Sed.	175
		School/shuttle bus	15.4	2.2	16	0.5	Child Sed.	56
	Taxi	Cabin	3	1.3	4	0.5	Adult Sed.	41.2

Methodology

IAQ control strategies

Possible IAQ control strategies in different scales

Strategies	Scales			
	Building	Room	Personal	Breathing zone
Source control	• Reducing occupants	• Reducing occupants • Intermittent occupancy	• Local air exhaust	• Face masking
Ventilation	• Increased ventilation supply airflow • Elevated outdoor air fraction for ventilation system	• Semi-open partition • Displacement ventilation	• Personal ventilation	
Air cleaning	• High-efficiency filters for ventilation system	• Portable air cleaners • Upper-room UVGI		• Face masking



Methodology

Simulation

- Wells-Riley model for estimating infection probability (based on inhalation dose)
- Stochastic Monte Carlo approach is applied to consider for the possible variation of the input data and increase the representativeness of the estimation (the simulation trials for each case are 100,000)

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Configurations of baseline and proposed cases

Strategies		Baseline	Proposed
Ventilation system	Ventilation rate (outdoor air)	• Reference values (25% outdoor air)	• Baseline supply air, 50% outdoor air • Baseline supply air, 75% outdoor air • Baseline supply air, 100% outdoor air
	Total supply airflow rate	• Estimated based on ventilation rate and reference outdoor air fraction (25%)	• 50% more supply air, 25% outdoor air • Double supply air, 25% outdoor air
	Air distribution[a]	• Mixing	• Displacement ventilation • Partitions (semi-open space) • Displacement ventilation + Partitions • Personal ventilation
	Filter	• MERV 8[b]	• MERV 13 • HEPA
Standalone devices	Portable air cleaners	• None	• CADR = $12 m^3/(h \cdot m^2)$ × room area
	Upper-room UVGI system	• None	• Equivalent ACH[c] = $12 h^{-1}$ or $9.6 h^{-1}$
PPE	Mask	• None	• Cloth mask • Surgical mask • N95 mask

[a] Mixing ventilation: ε_{vent} = 1; Displacement ventilation: ε_{vent} = 1.2 to 2; Semi-open space with partitions installed: ε_{vent} = 2 to 3; Displacement ventilation with partitions installed: ε_{vent} = 14 to 100; Personal ventilation: ε_{vent} = 1.4 to 10; all assuming uniform distribution.

[b] HEPA filter is used in the baseline cases of hospital operating room and airplane cabin. All other spaces use MERV 8 filter as the baseline setup.

[c] Equivalent ACH = $12 h^{-1}$ for mixing ventilation and equivalent ACH = $9.6 h^{-1}$ for displacement ventilation.

Results

Baseline infection risk in different spaces

- Spaces in long-term care facilities, colleges, meat plants, hotels, restaurants, casinos and cruise ships are facing considerably higher infection probabilities (over 30%) and have a higher potential to result in a serious outbreak event (R0 > 10)

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Infection probabilities > 10% and the R0 > 5 are marked

Scenario		Space type	Infection probability [%]		R_0 [-]	
			Mean	SD	Mean	SD
Long-term care facility		Bedroom (double)	50.0	29.9	0.5	0.3
		Dining room	48.2	28.7	9.2	5.5
		Living room	10.6	9.4	0.4	0.4
		Physical therapy room	78.3	29.0	3.1	1.2
Educational	K-12	Classroom (between students)	3.8	3.6	1.3	1.2
		Classroom (teacher is the infector)	13.2	12.0	4.5	4.1
		Library	0.3	0.2	0.2	0.2
		Cafeteria/dining room	10.1	8.9	8.9	7.9
		Gym	8.3	7.7	5.6	5.2
	College	Classroom (small)	3.1	2.9	0.7	0.7
		Classroom (large)	0.9	0.8	0.8	0.8
		Library (public study area)	0.9	0.8	0.8	0.8
		Auditorium	1.1	1.1	1.1	1.1
		Computer lab	2.0	1.9	0.7	0.7
		Dining hall	14.6	12.8	13.8	12.1
		Study lounge	3.8	3.6	0.8	0.7
		Gym (fitness area)	38.0	27.0	22.4	15.9
		Resident hall (bedroom)	52.5	30.4	0.5	0.3
		Greek house (social gathering)	77.5	30.2	14.7	5.7
Manufacturing facility	Meat plant	Processing room (dense)	53.7	31.2	28.5	16.5
		Processing room (sparse)	47.8	29.9	12.4	7.8
Retail	Standalone	Core shopping space	8.4	7.8	6.6	6.2
	Strip mall	Store (large)	17.8	15.4	4.8	4.1
		Store (small)	30.1	23.0	3.9	3.0
Healthcare facility	Hospital	Operating room[a]	1.0	0.9	0.0	0.0
		Patient room (patient+doctor)	4.5	4.2	0.0	0.0
		Physical therapy room	29.0	22.4	7.2	5.6
		Dining room	6.4	6.1	4.8	4.5
		Lobby	6.7	6.5	1.3	1.3
Office	Medium	Open plan office	12.6	11.0	1.1	1.0
		Enclosed office	39.8	26.7	0.4	0.3
		Conference room	6.2	5.7	1.3	1.2
		Lounge	1.4	1.3	0.6	0.6
Correctional facility	Prison	Housing (double resident cell)	59.5	31.4	0.6	0.3
		Housing (dormitory)	7.9	7.2	3.1	2.8
		Dayroom	11.6	10.2	5.4	4.8
Lodging	Hotel	Guest room/bedroom	41.0	27.2	0.4	0.3
		Banquet/dining room	27.8	21.5	21.2	16.4
		Lobby	12.0	10.8	11.6	10.5
Other public facilities	Restaurant	Dining room (ordinary)	14.7	12.8	12.6	11.0
		Dining room (fast-food)	8.4	7.8	6.7	6.2
	Religious	Worship hall	1.7	1.6	1.7	1.6
	Casino	Poker room	47.0	29.6	35.2	22.2
Transportation spaces	Airplane	Cabin	2.3	2.2	1.8	1.7
	Cruise ship	Guest room (double resident)	56.7	31.1	0.6	0.3
		Casino	41.7	27.9	39.4	26.4
		Cafeteria/Bistro	20.3	16.3	16.0	12.9
	Subway	Cabin	0.6	0.5	0.5	0.5
	Bus	Transit bus	0.6	0.6	0.4	0.4
		Tour coach	2.9	2.7	1.4	1.3
		School/shuttle bus	2.2	2.1	0.3	0.3
	Taxi	Cabin	3.2	3.0	0.1	0.1

Results

Baseline infection risk in different spaces

- Common areas with higher occupant density (e.g. dining room) in long-term care facilities or hotels face higher potentials of viral spreading.
- For K-12 classrooms, a teacher (13.2%) is much more likely to spread the disease to the class members, than a student patient (3.8%).
- Gym, dining hall and Greek house in a social gathering in colleges are exposed to very high infection risks (than studying spaces).
- Superspreading event is likely to happen in the meat processing room with dense employees (R0 > 28).
- Casinos have a very high potential for superspreading outbreak, considering the high-intensity activities and crowded occupancy (R0 = 35.2).
- Cruise ship has the highest infection risk among transportation scenarios since it contains casinos and dining spaces, where viruses can spread out readily.
- Infection risks during shorter transits are typically lower than the risks during longer transits.

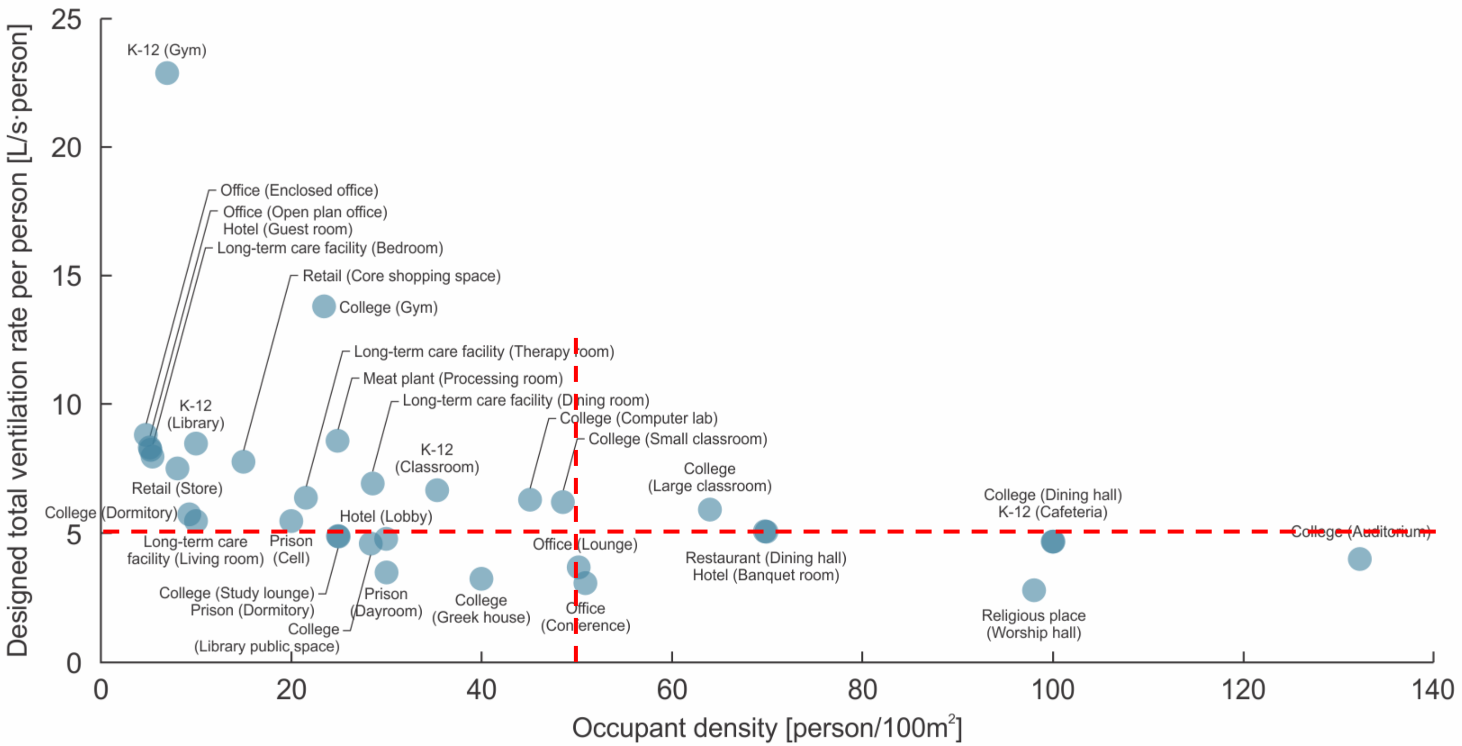
Infection probabilities > 10% and the R0 > 5 are marked

Scenario		Space type	Infection probability [%]		R_0 [-]	
			Mean	SD	Mean	SD
Long-term care facility		Bedroom (double)	50.0	29.9	0.5	0.3
		Dining room	48.2	28.7	9.2	5.5
		Living room	10.6	9.4	0.4	0.4
		Physical therapy room	78.3	29.0	3.1	1.2
Educational	K-12	Classroom (between students)	3.8	3.6	1.3	1.2
		Classroom (teacher is the infector)	13.2	12.0	4.5	4.1
		Library	0.3	0.2	0.2	0.2
		Cafeteria/dining room	10.1	8.9	8.9	7.9
		Gym	8.3	7.7	5.6	5.2
	College	Classroom (small)	3.1	2.9	0.7	0.7
		Classroom (large)	0.9	0.8	0.8	0.8
		Library (public study area)	0.9	0.8	0.8	0.8
		Auditorium	1.1	1.1	1.1	1.1
		Computer lab	2.0	1.9	0.7	0.7
		Dining hall	14.6	12.8	13.8	12.1
		Study lounge	3.8	3.6	0.8	0.7
		Gym (fitness area)	38.0	27.0	22.4	15.9
		Resident hall (bedroom)	52.5	30.4	0.5	0.3
		Greek house (social gathering)	77.5	30.2	14.7	5.7
Manufacturing facility	Meat plant	Processing room (dense)	53.7	31.2	28.5	16.5
		Processing room (sparse)	47.8	29.9	12.4	7.8
Retail	Standalone	Core shopping space	8.4	7.8	6.6	6.2
	Strip mall	Store (large)	17.8	15.4	4.8	4.1
		Store (small)	30.1	23.0	3.9	3.0
Healthcare facility	Hospital	Operating room[a]	1.0	0.9	0.0	0.0
		Patient room (patient+doctor)	4.5	4.2	0.0	0.0
		Physical therapy room	29.0	22.4	7.2	5.6
		Dining room	6.4	6.1	4.8	4.5
		Lobby	6.7	6.5	1.3	1.3
Office	Medium	Open plan office	12.6	11.0	1.1	1.0
		Enclosed office	39.8	26.7	0.4	0.3
		Conference room	6.2	5.7	1.3	1.2
		Lounge	1.4	1.3	0.6	0.6
Correctional facility	Prison	Housing (double resident cell)	59.5	31.4	0.6	0.3
		Housing (dormitory)	7.9	7.2	3.1	2.8
		Dayroom	11.6	10.2	5.4	4.8
Lodging	Hotel	Guest room/bedroom	41.0	27.2	0.4	0.3
		Banquet/dining room	27.8	21.5	21.2	16.4
		Lobby	12.0	10.8	11.6	10.5
Other public facilities	Restaurant	Dining room (ordinary)	14.7	12.8	12.6	11.0
		Dining room (fast-food)	8.4	7.8	6.7	6.2
	Religious	Worship hall	1.7	1.6	1.7	1.6
	Casino	Poker room	47.0	29.6	35.2	22.2
Transportation spaces	Airplane	Cabin	2.3	2.2	1.8	1.7
	Cruise ship	Guest room (double resident)	56.7	31.1	0.6	0.3
		Casino	41.7	27.9	39.4	26.4
		Cafeteria/Bistro	20.3	16.3	16.0	12.9
	Subway	Cabin	0.6	0.5	0.5	0.5
	Bus	Transit bus	0.6	0.6	0.4	0.4
		Tour coach	2.9	2.7	1.4	1.3
		School/shuttle bus	2.2	2.1	0.3	0.3
	Taxi	Cabin	3.2	3.0	0.1	0.1

Results

Baseline ventilation in different spaces

- ASHRAE 62.1 regulates the minimum ventilation rates based on the estimation of required ventilation per person and floor area
- When ASHRAE standard 62.1 is used, it penalizes smaller rooms so that high occupant density per floor area means less ventilation comparing to larger rooms (with the same occupants).
- Ventilation delivered to each person in scenarios with higher occupant density is generally lower than the ventilation in scenarios with lower occupant density.
- Ventilation designed based on ASHRAE 62.1 may not always be sufficient for occupants, particularly considering the requirements for mitigating infection risks.
- A pathogen-source-based or health-based design criteria for indoor ventilation is probably more applicable for infection prevention.



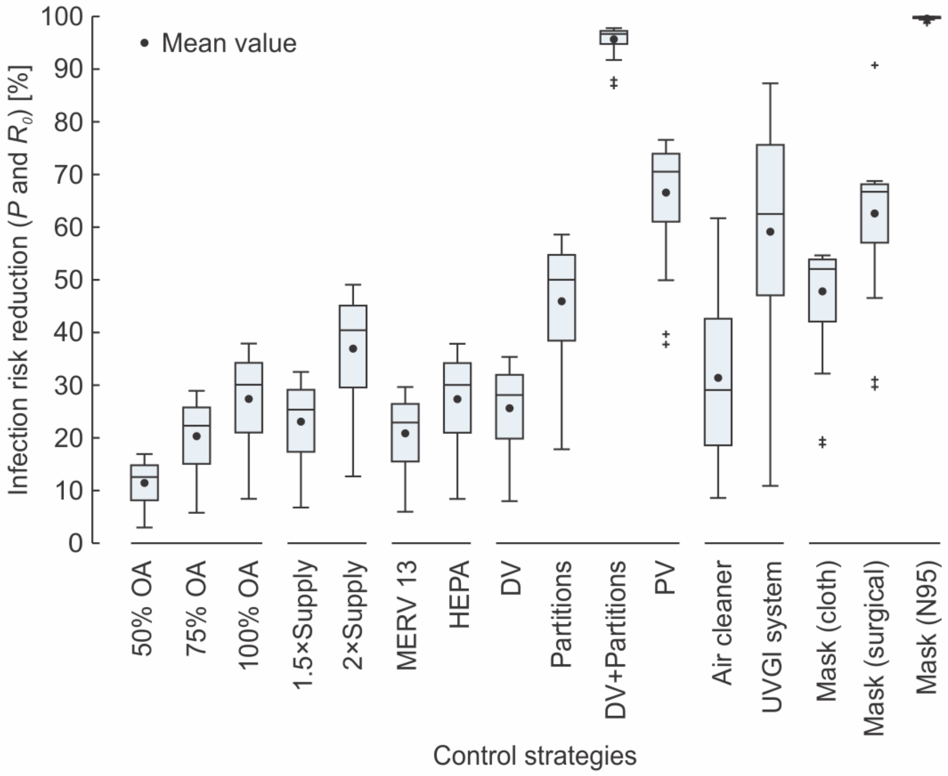
Relationship between occupant density and designed total ventilation rate per person in different scenarios based on ASHRAE 62.1

Results

Effectiveness of IAQ control strategies

Effectiveness = Infection risk reduction percentage (compared to the baseline case)

- Advanced air distributions (e.g. displacement ventilation + partitions) can have significant effectiveness on mitigating infection risks, but also need professional design and implementation to maximize their performance.
- Using HEPA filter has an equivalent effectiveness with using 100% outdoor air in HVAC system.
- Standalone AC and UVGI systems can be an effective solution for infection risk mitigation.
- Wearing masks is very useful for reducing infection risks.



Risk reduction distribution of the mean infection probabilities and R0 in different spaces

Results

Effectiveness, effective scales, and costs of IAQ control strategies

Effectiveness (infection risk reduction)

Effective scales (building scales, affecting the benefitted occupant number/scale)

Costs (capital costs, including first investment and maintenance costs)

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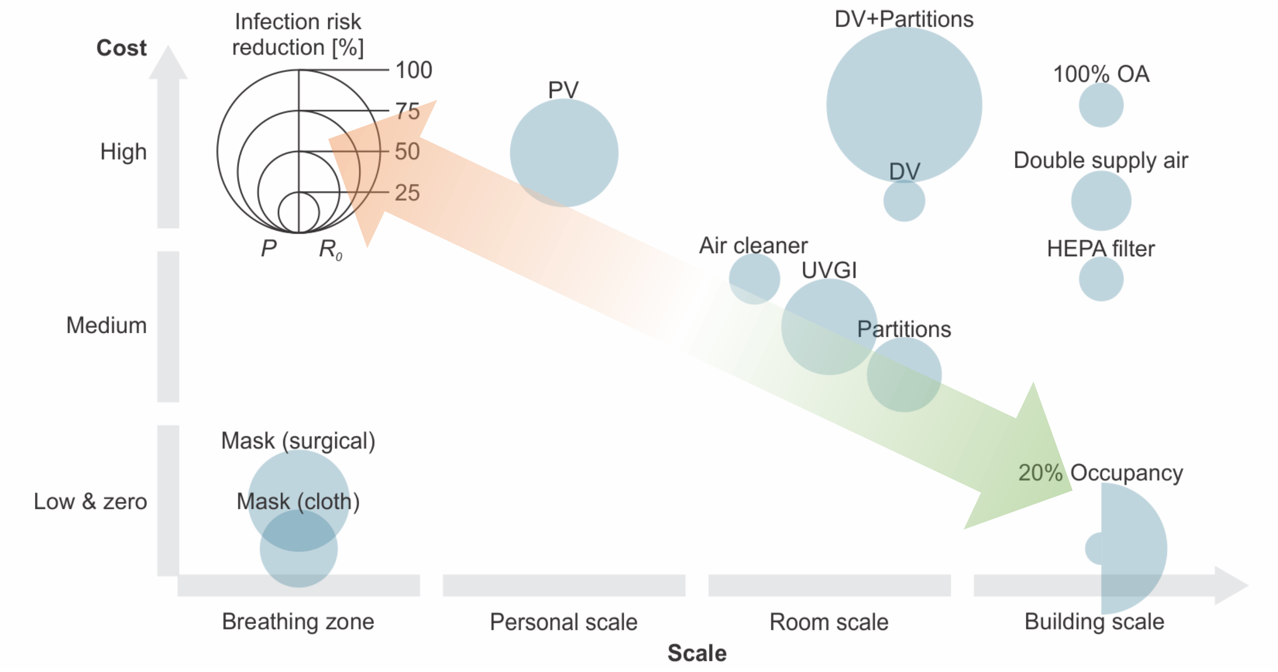
An ideal strategy:

- High effectiveness
- Larger effective scale
- Low/affordable cost



Infection risk reduction potentials and costs of control strategies in different scales

Conclusions

- Spaces in long-term care facilities, colleges, meat plants, hotels, restaurants, casinos and cruise ships are facing considerably higher infection probabilities (over 30%) and have a higher potential to result in a serious outbreak event (R0 > 10).
- Common areas with higher occupant density (e.g. dining room) face higher potentials of viral spreading.
- Ventilation designed based on ASHRAE 62.1 may not always be sufficient for occupants considering the requirements for mitigating infection risks, particularly in the spaces with higher occupant densities.
- Advanced air distributions can have significant effectiveness on mitigating infection risks, but also need professional design and implementation to maximize their performance.
- Using HEPA filter has an equivalent effectiveness with using 100% outdoor air in HVAC system, while it has a less cost on additional energy consumption.
- Standalone AC and UVGI systems can be an effective solution for infection risk mitigation.
- Wearing masks is very useful for reducing infection risks (particularly high-efficiency masks).
- An ideal infection risk mitigation strategy should have high effectiveness, larger effective scale, but affordable cost.

Related publications

Shen J, Kong M, Dong B, Birnkrant M J and Zhang J 2021 A systematic approach to estimating the effectiveness of multi-scale IAQ strategies for reducing the risk of airborne infection of SARS-CoV-2 *Build. Environ.* 107926

Kong M, Shen J, Dong B and Zhang J 2020 Effectiveness of Building Systems Strategies for Mitigation of Airborne Transmission of SARS-CoV-2 Mech. Aerosp. Eng.

Shen J, Kong M, Dong B, Birnkrant M J and Zhang J 2021 Airborne transmission of SARS-CoV-2 in indoor environments: A comprehensive review *Sci. Technol. Built Environ.* (Submitted)


Thank you!
Q&A
Welcome to Syracuse University!