AIVC International Workshop, Tokyo, Japan, May 19, 2023

Aerosol transmission route of respiratory pathogens and their mitigation strategies

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Topics

- Transmission route of infectious respiratory pathogens
- Physical and biological characteristics of SASR-CoV-2 in the air
- Primary engineering mitigation strategies for respiratory infections
  - Ventilation
  - Filtration
  - GUV（Germicidal Ultraviolet）

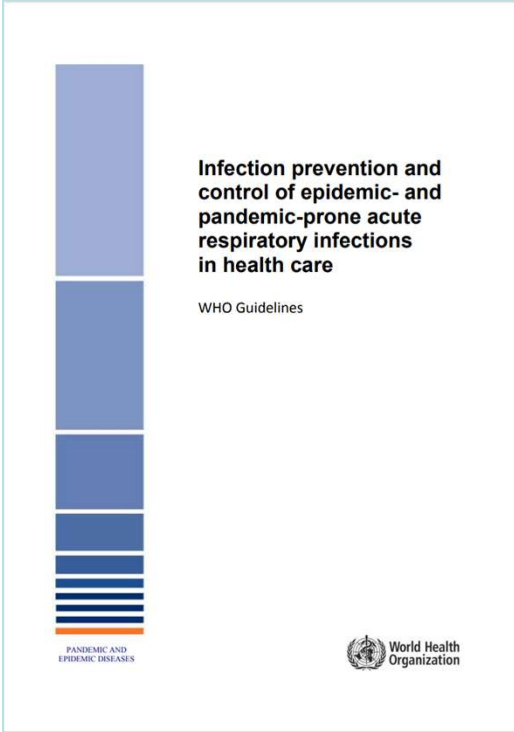
Transmission route of infectious respiratory pathogens

Traditional definition of transmission route

The mode of transmission of respiratory infections have been classified as contact, droplet, and airborne.

The World Health Organization (WHO) defines respiratory aerosols with a particle size of >5 μm as droplets and dried respiratory aerosols with a particle size ≤ 5 μm as droplet nuclei (i.e., residue of dried respiratory aerosols). Droplet and airborne infections are defined by droplet transmission and droplet nucleus transmission, respectively.

WHO Guidelines. Infection prevention and control of epidemic-and pandemic-prone acute respiratory infections in health care. 2014



The recommended distance to avoid infection varies from 1 m per WHO and in parts of Europe, to 1.5 m in Australia, to 2 m in the USA, Canada and the UK.

Randall K., et al. How did we get here: what are droplets and aerosols and how far do they go? A historical perspective on the transmission of respiratory infectious diseases. Interface Focus ***11****: 20210049. https://doi.org/10.1098/rsfs.2021.0049*

Classifying droplet infection and airborne infection with 5 μm as the threshold diameter is a dualistic medical dogma that has not been proven by direct measurements.

Greenhalgh T, et al. Ten scientific reasons in support of airborne transmission of SARS-CoV-2. *Lancet* 2021;397:1603-5. doi:10.1016/S0140-6736(21)00869-2.

William Wells was the first person to rigorously study the size of spray-borne droplets vs. airborne aerosols. In the 1930s, he conceptualized a dichotomy of spray-borne droplets (≳100 μm) that reach the ground before they dry, vs. aerosols (≲100 μm) that dry before they reach the ground (thus referred to as "droplet nuclei").

Jose L. Jimenez et al. What were the historical reasons for the resistance to recognizing airborne transmission during the COVID-19 pandemic? *Indoor Air*. 2022;32:e13070. https://doi.org/10.1111/ina.13070

In fact, ≳5 μm of SARS-CoV-2 has been detected in the air.

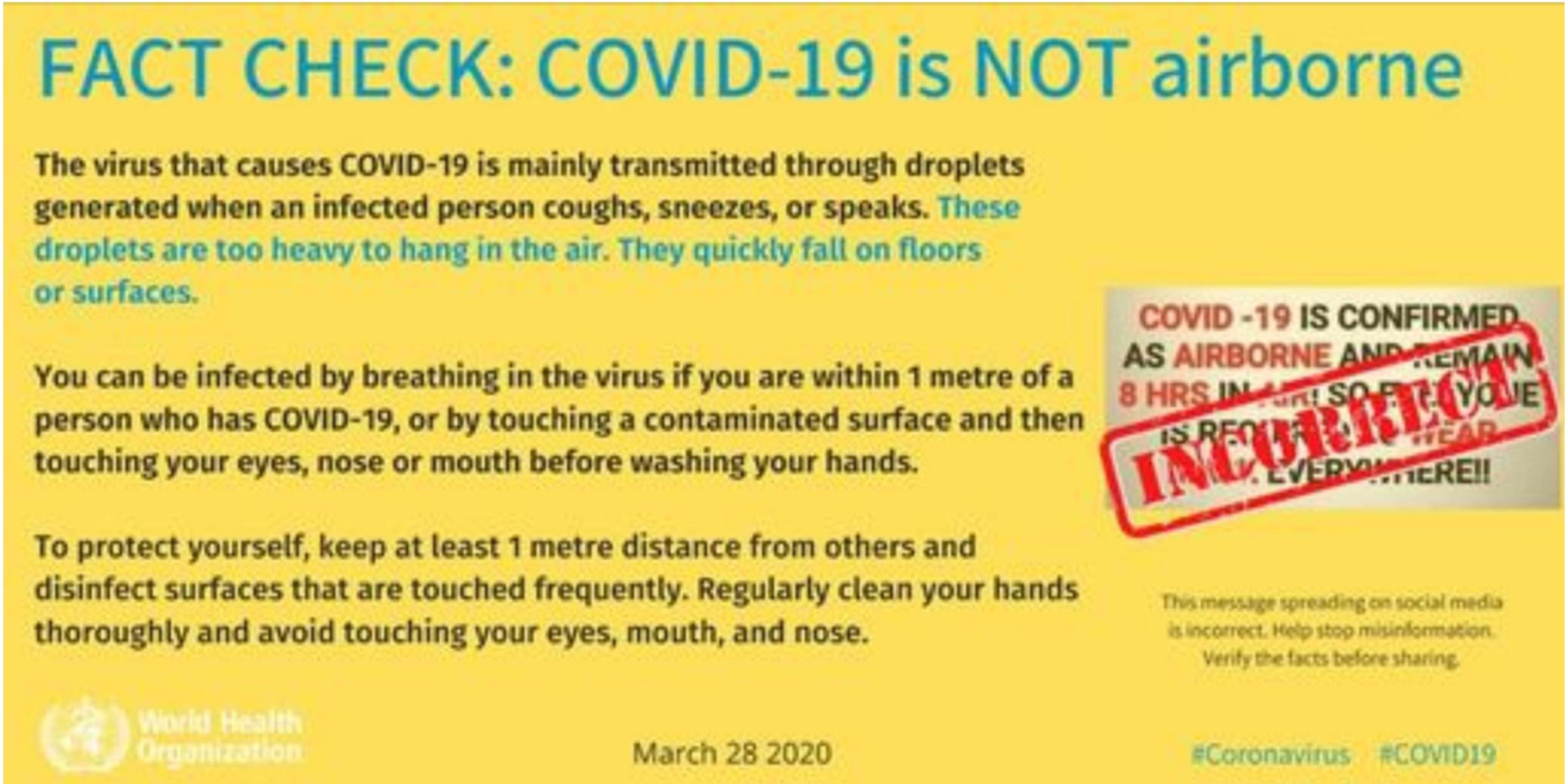
Table 1 Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) detections in the air of hospital rooms of infected patient.

Patient	Day of illness	Symptoms reported on day of air sampling	Clinical Ct value[a]	Airborne SARS-CoV-2 concentrations (RNA copies m^{-3} air)	Aerosol particle size	Samplers used
1	9	Cough, nausea, dyspnea	33.22	ND	>4 μm	NIOSH
				ND	1-4 μm	
				ND	<1 μm	
				ND	-	SKC filters
2	5	Cough, dyspnea	18.45	2,000	>4 μm	NIOSH
				1,384	1-4 μm	
				ND	<1 μm	
3	5	Asymptomatic[b]	20.11	927	>4 μm	NIOSH
				916	1-4 μm	
				ND	<1 μm	

ND none detected.
[a]PCR cycle threshold value from patient's clinical sample.
[b]Patient reported fever, cough, and sore throat until the day before the sampling. Patient reported no symptoms on the day of sampling, however was observed to be coughing during sampling.

Chia PY, et al. Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients. *NatureCommunications* (2020) 11:2800 https://doi.org/10.1038/s41467-020-16670-2

The WHO emphatically declared on March 28, 2020, that SARS-CoV-2 was not airborne



Transmission of SARS-CoV-2: implications for infection prevention precautions

Scientific brief

9 July 2020

World Health Organization

This document is an update to the scientific brief published on 29 March 2020 entitled "Modes of transmission of virus causing COVID-19: implications for infection prevention and control (IPC) precaution recommendations" and includes new scientific evidence available on transmission of SARS-CoV-2, the virus that causes COVID-19.

Overview

Outside of medical facilities, some outbreak reports related to indoor crowded spaces *(40)* have suggested the possibility of aerosol transmission, combined with droplet transmission, for example, during choir practice *(7)*, in restaurants *(41)* or in fitness classes.*(42)* In these events, short-range aerosol transmission, particularly in specific indoor locations, such as crowded and inadequately ventilated spaces over a prolonged period of time with infected persons cannot be ruled out. However, the detailed investigations of these clusters suggest that droplet and fomite transmission could also explain human-to-human transmission within these clusters. Further, the close contact environments of these clusters may have facilitated transmission from a small number of cases to many other people (e.g., superspreading event), especially if hand hygiene was not performed and masks were not used when physical distancing was not maintained.*(43)*

Fomite transmission

Respiratory secretions or droplets expelled by infected individuals can contaminate surfaces and objects, creating fomites

Another person can then contract the virus when infectious particles that pass through the air are inhaled at short range (this is often called short-range aerosol or short-range airborne transmission) or if infectious particles come into direct contact with the eyes, nose, or mouth (droplet transmission).

World Health Organization

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Home / Newsroom / Questions and answers / Coronavirus disease (COVID-19): How is it transmitted?

Coronavirus disease (COVID-19): How is it transmitted?

23 December 2021 | Q&A

The English version was updated on 23 December 2021.

How does COVID-19 spread between people?

We know that the disease is caused by the SARS-CoV-2 virus, which spreads between people in several different ways.

- Current evidence suggests that the virus spreads mainly between people who are in close contact with each other, for example at a conversational distance. The virus can spread from an infected person's mouth or nose in small liquid particles when they cough, sneeze, speak, sing or breathe. Another person can then contract the virus when infectious particles that pass through the air are inhaled at short range (this is often called short-range aerosol or short-range airborne transmission) or if infectious particles come into direct contact with the eyes, nose, or mouth (droplet transmission).
- The virus can also spread in poorly ventilated and/or crowded indoor settings, where people tend to

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WHO TEAM

WHO Headquarters (HQ)

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Transmission of SARS-CoV-2: implications for infection prevention precautions

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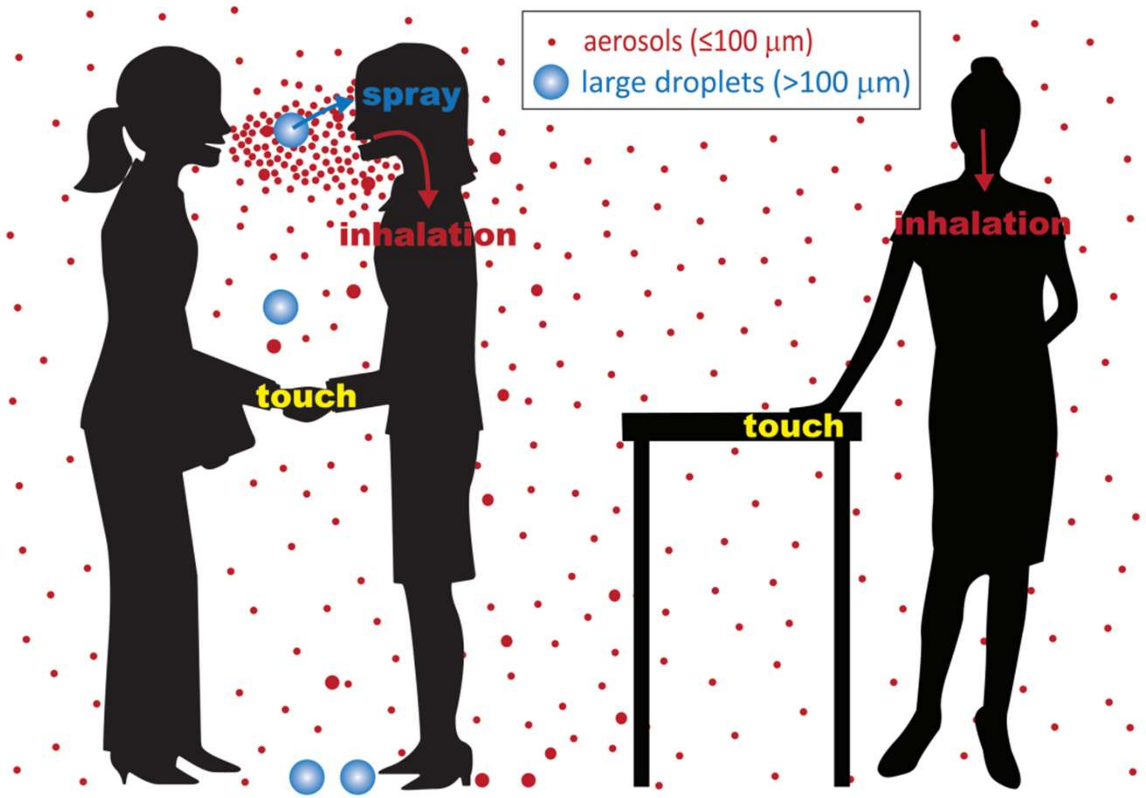


Traditional definitions of “airborne” and “droplet” transmission have been shown to be misleading, and revised definitions of transmission routes are more closely aligned with the actual mechanisms by which pathogens are transferred from one person to another (Marr and Tang 2021). These revised routes are (1) inhalation of aerosols, (2) spray of large droplets, and (3) touching a contaminated surface

Source: Marr LC, Tang JW. A paradigm shift to align transmission routes with mechanisms. Clin Infect Dis 2021; 73 (10): 1747-1749. https://doi.org/10.1093/cid/ciab722

Source: ASHRAE Positions on Infectious Aerosols.
Approved by the ASHRAE Board of Directors October 13, 2022
Expires October 13, 2025

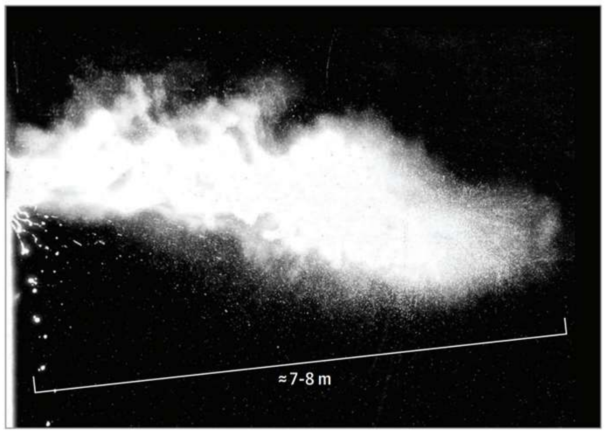
Physical and biological characteristics of SASR-CoV-2 in the air

※**Aerosol** A suspension of solid or liquid particles in a gas. The term aerosol includes both the particles and the suspending gas, which is usually air. Particle size ranges from 0.002 to more than 100 μm. (currently a generation definition: 0.001 - 100 μm)
(William C. Hinds. Aerosol Technology, Second Edition, 1999)

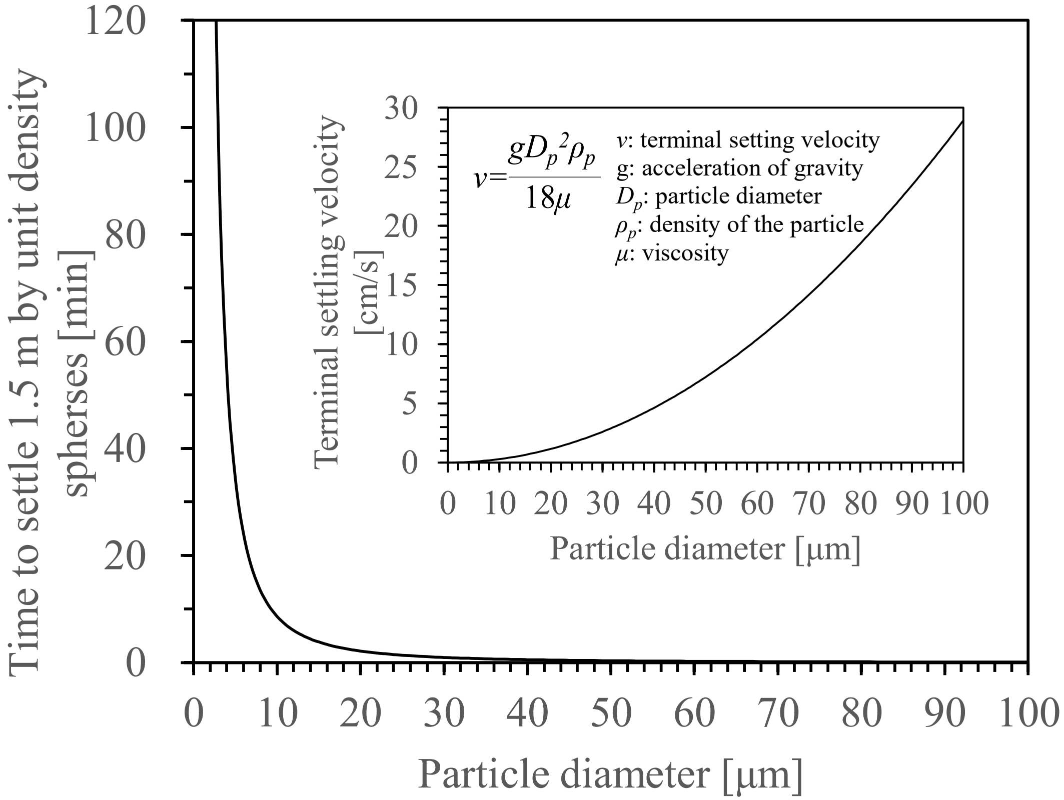
※**Bioaerosol** is an aerosol comprising particles of biological origin or activity which may affect living things through infectivity, allergenicity, toxicity, pharmacological or other processes. Particle sizes may range from aerodynamic diameter of circa 0.5 to 100 μm.
(Christopher MW. and Christopher SC. Bioaerosols handbook. Lewis publishers. 1995

※Since SARS-CoV-2 is released from the mouth with the air, so it is in the state of aerosols in environment

Figure. Multiphase Turbulent Gas Cloud From a Human Sneeze



← Source
Turbulent Gas Clouds and Respiratory Pathogen Emissions Potential Implications for Reducing Transmission of COVID-19. *JAMA*.2020;323(18):1837-1838. https://doi.org/10.1001/jama.2020.4756



It turns out that particles ≤10 μm are suspended in still air for a longer time (1 μm for 14.4 hours; 5 μm for 35 minutes; and 10 μm for 9 minutes).

Field measurement results show the highest and average velocities in occupant spaces are 0.4 m/s and 0.1 m/s, respectively 0.1-0.4 m/s（10～40cm/s）. Therefore, aerosol particle ≤10 μm are easily transported over a long-range (even up to the inlet air) in the indoor airflow during the operation of air-conditioning and/or ventilation equipment.

Hayashi M, Yanagi U, Azuma K, Kagi N, Ogata M, Morimoto S, et al. Measures against COVID-19 concerning Summer Indoor Environment in Japan. *Jpn Archit Rev*. 3(4):423–434, 2020. https://doi.org/10.1002/2475-8876.12183

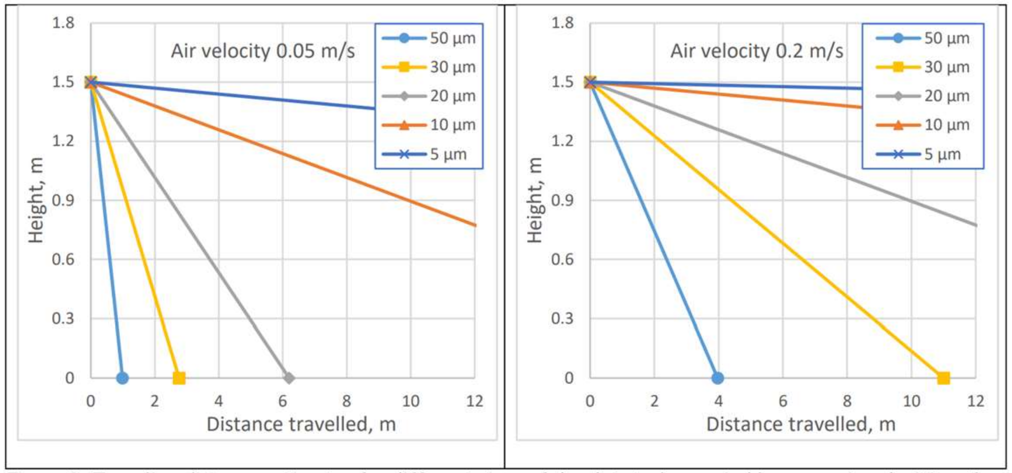
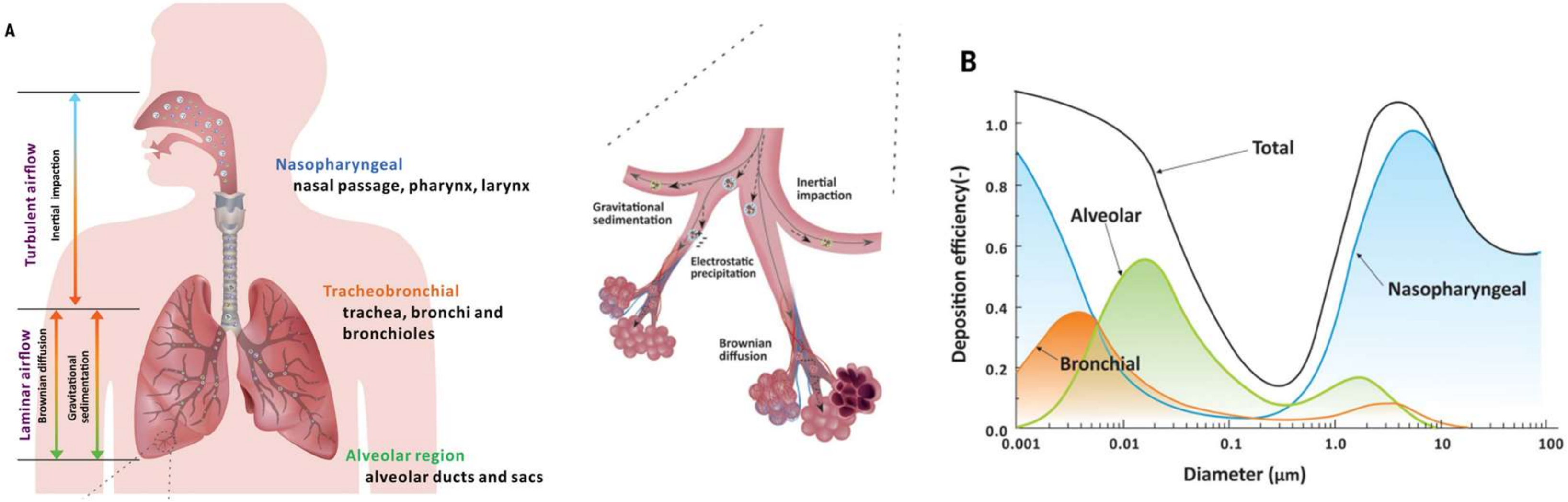


Figure 2. Traveling distance estimates for different sizes of droplets to be carried by room air velocities of 0.05 and 0.2 m/s before settling 1.5 m under the influence of gravity. The travelled distance accounts for movement after the initial jet has relaxed and is calculated with the equilibrium diameter of completely desiccated respiratory droplets (μm values in the figure refer to equilibrium diameters). With turbulence distance travelled is less, but settling time is longer.

REHVA COVID-19 guidance document, Ver 4.1, How to operate HVAC and other building service systems to prevent the spread of the coronavirus (SARS-CoV-2) disease (COVID-19) in workplaces, 20210415.



Phase 1 → **Phase 2** → **Phase 3**

Generation and exhalation

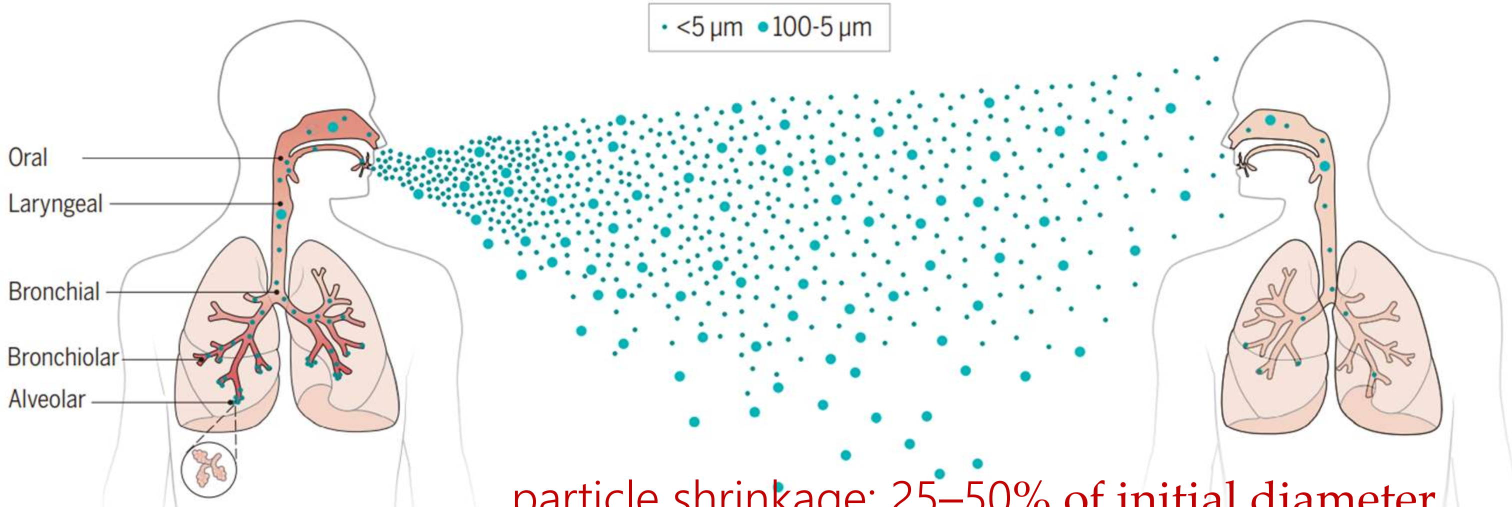
- Generation mechanisms
- Viral load at generation sites
- Size distribution of exhaled aerosols
- Number of virions in aerosol

Transport

- Settling velocity and residence time in air
- Size change during transport
- Persistence of viruses in aerosols
- Environmental factors: temperature, humidity, airflow and ventilation, UV radiation

Inhalation, deposition and infection

- Size distribution of inhalable aerosols
- Deposition mechanisms
- Size-dependent deposition sites
- Deposition site susceptibility

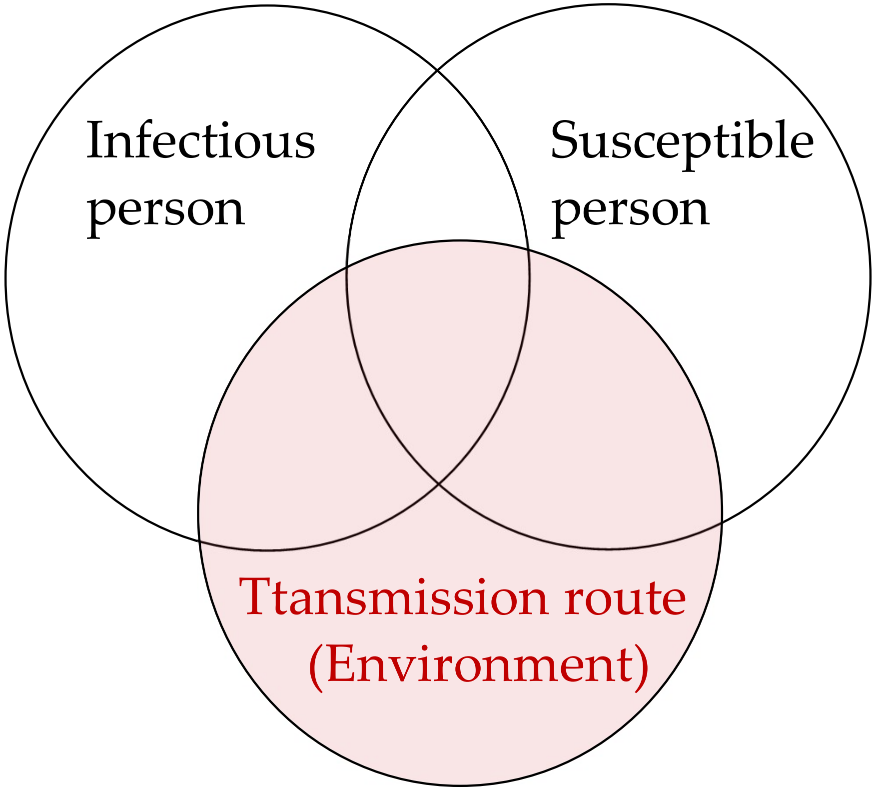


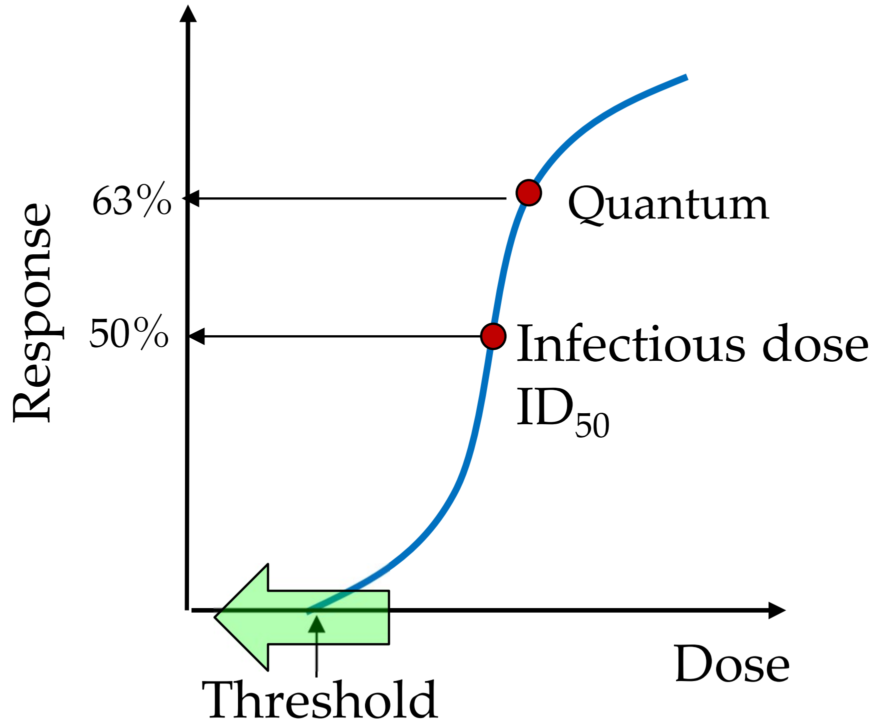
particle shrinkage: 25–50% of initial diameter

Fig. 1. Airborne transmission of respiratory viruses. Phases involved in the airborne transmission of virus-laden aerosols include (i) generation and exhalation; (ii) transport; and (iii) inhalation, deposition, and infection. Each phase is influenced by a combination of aerodynamic, anatomical, and environmental factors. (The sizes of virus-containing aerosols are not to scale.)

Source: Wang CC, et al. Airborne transmission of respiratory viruses, *Science* 373, 981 (2021). https://doi.org/10.1126/science.abd9149

Primary engineering mitigation strategies for respiratory infections





Three elements; infectious agent, host and environment

Mitigation strategies for respiratory infections by transmission route

Contact (direct, indirect)

- Hand hygiene
- Surfaces cleaning

In my presentation, <100μm particles classified to aerosol; aerosols contain droplets;
>100μm particles classified to droplets.
In the medical field, particles <5μm are called droplet nuclear.

Droplet, >100μm

- Avoid the 3Cs
- Wear a mask
- Ensure social distancing

>100μm; terminal settling velocity >0.3m/s
It only takes about 5 seconds for the lease to fall from a height of 1.5 meter to the floor.
Indoor airflow velocity 0.1m/s : estimate traveling distance
100μm: 0.5m; 50μm: 2m; 10μm: 52m; 5μm:324m

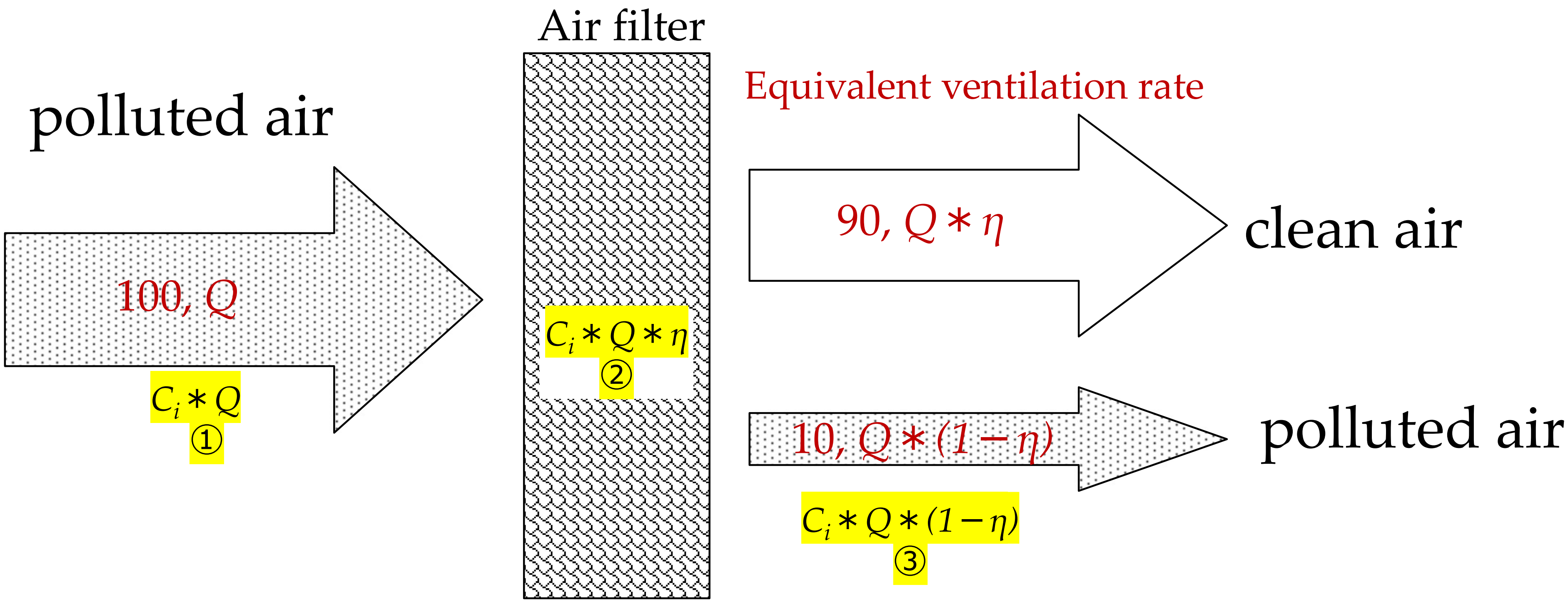
Aerosol, < 100μm

- Behavior change（avoid 3Cs、wear a mask）
- Ventilation
- Air purification（central system air filtration, local air filtration）
- GUV

Ventilation

Equivalent ventilation rate (air changes)

In case of the collection efficiency of the air filter is 90%

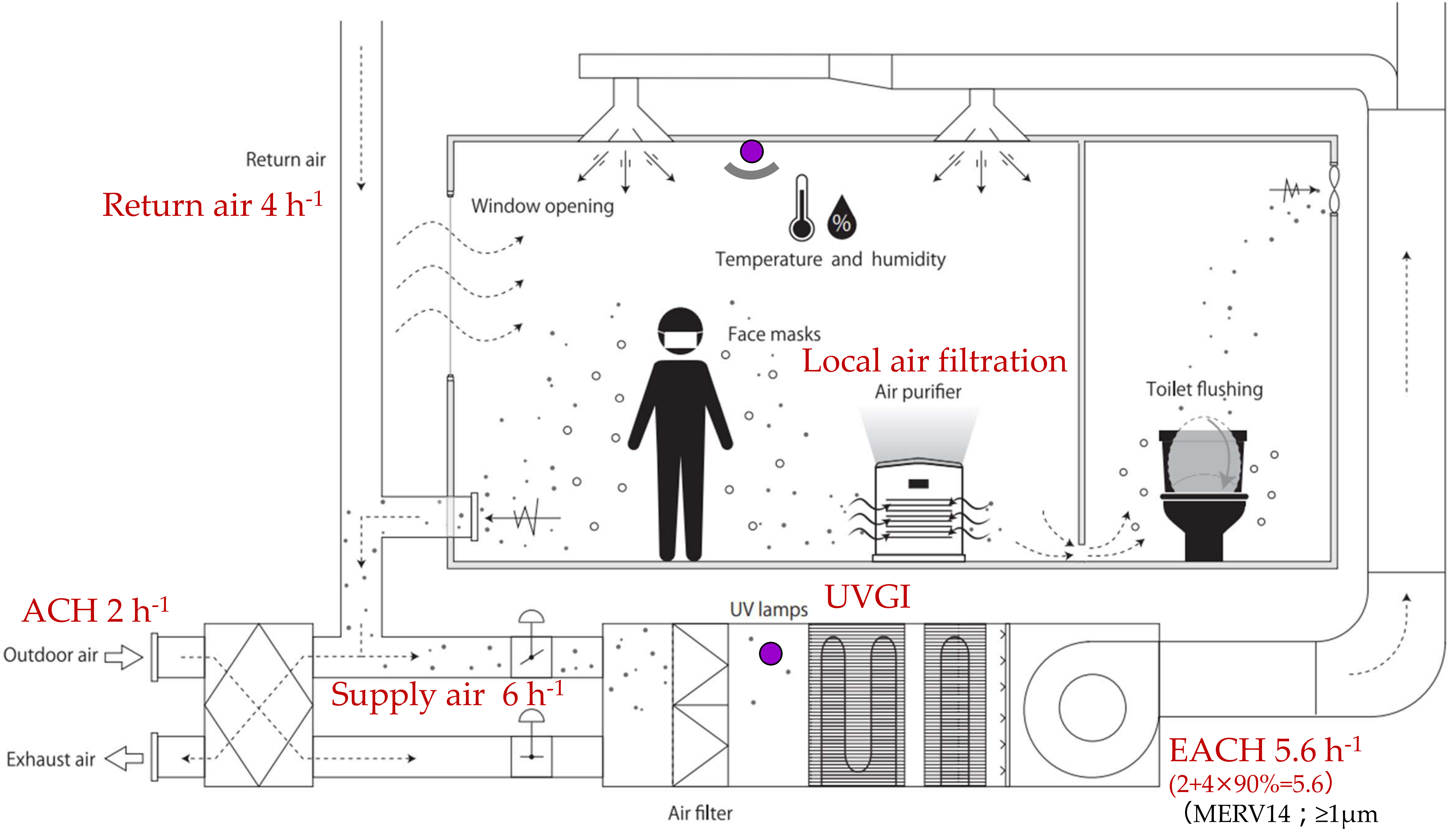


Mass balance: $C_i * Q - C_i * Q * \eta = C_i * Q * (1-\eta)$

C: concentration, viruses/m^3; Q: ventilation rate, m^3/h

Central air conditioning system

Joseph G. Allen; Andrew M. Ibrahim. Indoor Air Changes and Potential Implications for SARS-CoV-2 Transmission. JAMA May 25, 2021 Volume 325, Number 20



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Azuma et al. Environmental Health and Preventive Medicine (2020) 25:66
https://doi.org/10.1186/s12199-020-00904-2

Environmental Health and Preventive Medicine

REVIEW ARTICLE Open Access

Environmental factors involved in SARS-CoV-2 transmission: effect and role of indoor environmental quality in the strategy for COVID-19 infection control

Kenichi Azuma[1*], U Yanagi[2], Naoki Kagi[3], Hoon Kim[4], Masayuki Ogata[5] and Motoya Hayashi[6]

$$P_I = \frac{C}{S} = 1 - e^{-\frac{Iqpt}{Q}}$$

P_I = probability of infection (-)
C = the number of infection cases (p)
S = number of susceptible individuals (p)
I = number of infector individuals
p = pulmonary ventilation rate of a person (m^3/hr)
q = quanta generation rate (1/hr)
t = exposure time (hr)
Q = room ventilation rate with clean air (m^3/hr)

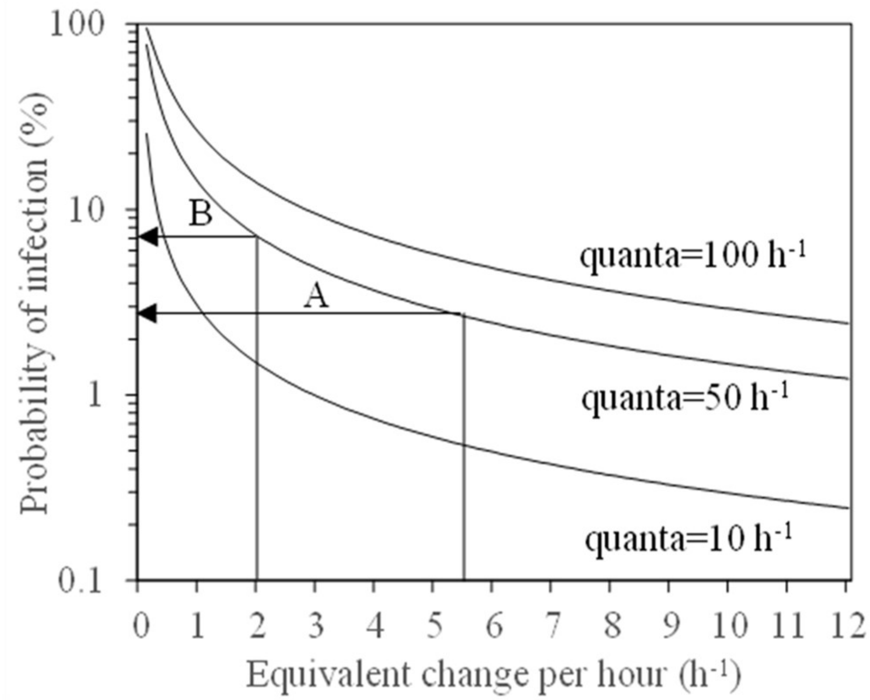


Figure 2. Probability of infection vs. equivalent change per hour
Conditions: I = 1 person; p = 0.48 m^3/hr; t = 8 hours; floor aera = 500 m^2; room volume =1,300 m_3

Ventilation rate for mitigating aerosol transmission

In the early 20th century, Billings proposed, and ASHRAE's predecessor society ASHVE recommended, outdoor airflow rates of 30 cfm/person (14.2 L/s-person) (51 m^3/h-person) based on considerations of infection prevention (Janssen. 1999)

systematic reviews of research on the quantitative relationship between risk of infection and ventilation rate have concluded that sufficient data to specify minimum ventilation rates for infection control does not exist (Li et al. 2007).

WHO recommended minimum outdoor airflow rates of 10 L/s-person (21.2 cfm/person) (36 m^3 /h-person) for nonhealthcare facilities and 60 L/s-person (127 cfm/person) (216 m^3 /h-person) for most spaces in health care facilities (WHO 2021).

Source: ASHRAE Positions on Infectious Aerosols.
Approved by the ASHRAE Board of Directors October 13, 2022
Expires October 13, 2025

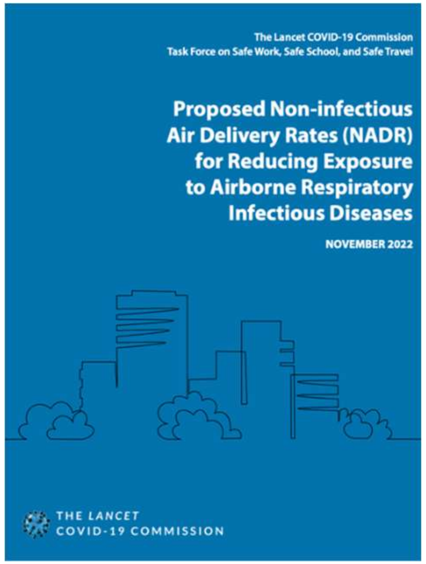
TABLE 1.

Proposed Non-infectious Air Delivery Rates (NADR) for Reducing Exposure to Airborne Respiratory Diseases; The Lancet COVID-19 Commission Task Force on Safe School, Safe Work, and Safe Travel

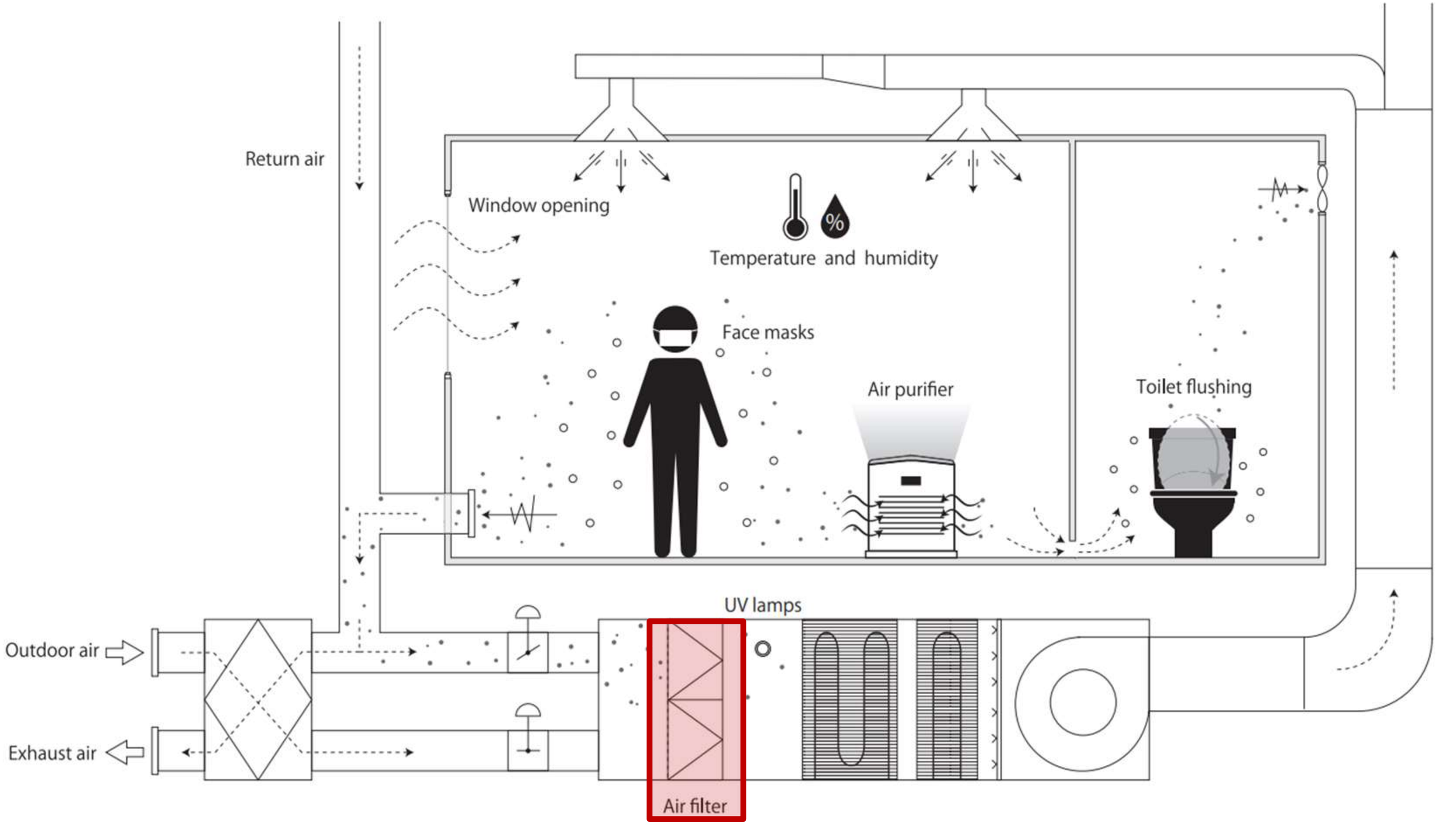
	Volumetric flow rate per volume	**Volumetric flow rate per person**		**Volumetric flow rate per floor area**	
	ACHe	cfm/person	L/s/person	cfm/ft^2	L/s/m^2
Good	4	21	36 m^3/h · person 10	0.75 + ASHRAE minimum outdoor air ventilation	3.8 + ASHRAE minimum outdoor air ventilation
Better	6	30	50 m^3/h · person 14	1.0 + ASHRAE minimum outdoor air ventilation	5.1 + ASHRAE minimum outdoor air ventilation
Best	> 6	> 30	> 14	> 1.0 + ASHRAE minimum outdoor air ventilation	> 5.1 + ASHRAE minimum outdoor air ventilation

LANCET COVID-19 COMMISSION TASK FORCE ON SAFE WORK, SAFE SCHOOL, AND SAFE TRAVEL. NOVEMBER 2022.

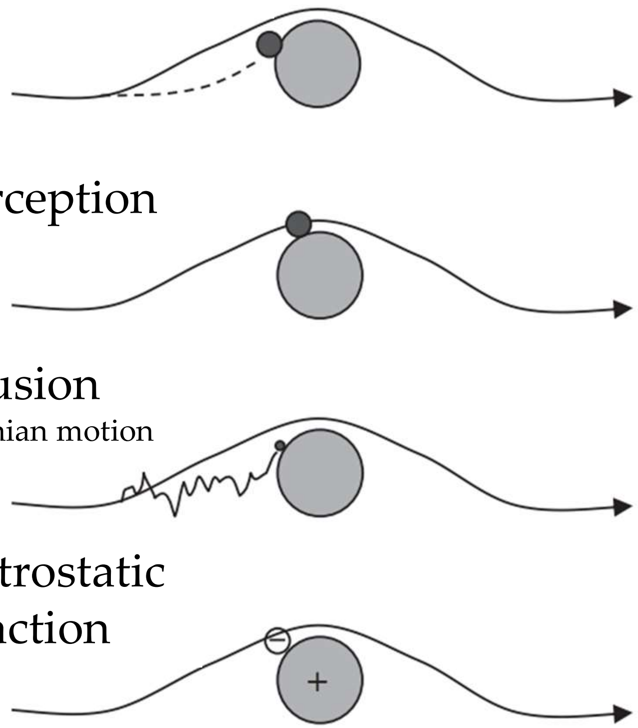
https://static1.squarespace.com/static/5ef3652ab722df11fcb2ba5d/t/637740d40f35a9699a7fb05f/1668759764821/Lancet+Covid+Commission+TF+Report+Nov+2022.pdf



Filtration



Return air
Window opening
Temperature and humidity
Face masks
Air purifier
Toilet flushing
Outdoor air
Exhaust air
UV lamps
Air filter



An air filter collects suspended particles near the filter media by mechanisms such as inertial collision, interception, diffusion, and electrostatic attraction. Besides this, there is also a gravitational sedimentation

Minimum Efficiency Reporting Values(MERVs) and Filter Efficiencies by Particle Size

MERV	0.3-1.0 μm	1.0-3.0 μm	3.0-10 μm	Colorimetric method
1	n/a	n/a	E3<20	-
2	n/a	n/a	E3<20	-
3	n/a	n/a	E3<20	-
4	n/a	n/a	E3<20	-
5	n/a	n/a	$20 \leqq E3$	-
6	n/a	n/a	$35 \leqq E3$	-
7	n/a	n/a	$50 \leqq E3$	40
8	n/a	$20 \leqq E_2$	$70 \leqq E3$	40
9	n/a	$35 \leqq E_2$	$75 \leqq E3$	50
10	n/a	$50 \leqq E_2$	$80 \leqq E3$	50
11	$20 \leqq E_1$	$65 \leqq E_2$	$85 \leqq E3$	60
12	$35 \leqq E_1$	$80 \leqq E_2$	$90 \leqq E3$	75
13	$50 \leqq E_1$	$85 \leqq E_2$	$90 \leqq E3$	90
14	$75 \leqq E_1$	$90 \leqq E_2$	$95 \leqq E3$	95
15	$85 \leqq E_1$	$90 \leqq E_2$	$95 \leqq E3$	98
16	$95 \leqq E_1$	$95 \leqq E_2$	$95 \leqq E3$	-

n/a: not available,
Source: ASHRAE Standard 52.2-2017.

Takashi Kurabuchi, U Yanagi, Masayuki Ogata, Masayuki Otsuka, Naoki Kagi, Yoshihide Yamamoto, Motoya Hayashi, Shinichi Tanabe, 2021. Operation of air-conditioning and sanitary equipment for SARS-CoV-2 infectious disease control. *Japan Architectural Review*. 4(4): 608–620.2021. https://doi.org/10.1002/2475-8876.12238

SARS-CoV-2: measurement result 1

<1μm ND
1-4μm 1384 RNA copies/m^3 (40%)
>4μm 2000 RNA copies/m^3 (60%)

When using a MERV12 filter
＝40%×80%＋60%×90%
＝86%

When using a MERV13 filter
＝40%×85%＋60%×90%
＝88%

SARS-CoV-2: measurement result 2

<1μm ND
1-4μm 916 RNA copies/m^3 (50%)
>4μm 927 RNA copies/m^3 (50%)

When using a MERV12 filter
＝50%×90%＋50%×95%
＝85%

When using a MERV13 filter
＝50%×85%＋50%×95%
＝88%

Source: Chia PY, et al. Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients. *Nature Communications* (2020) 11:2800https://doi.org/10.1038/s41467-020-16670-2

GUV（Germicidal Ultraviolet）

Microbial response to GUV exposure can be modeled as a single stage exponential decay or a two-stage exponential decay, and the response may include a shoulder.

Figure 5.1 illustrates the complete microbial decay curve.

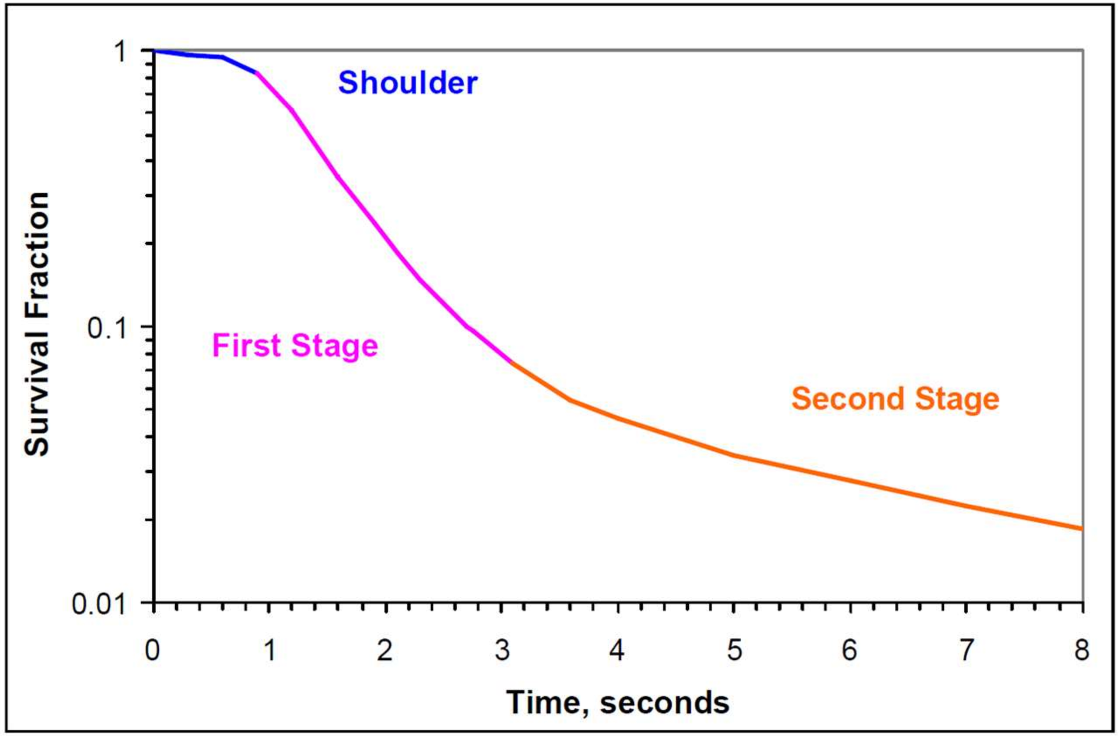


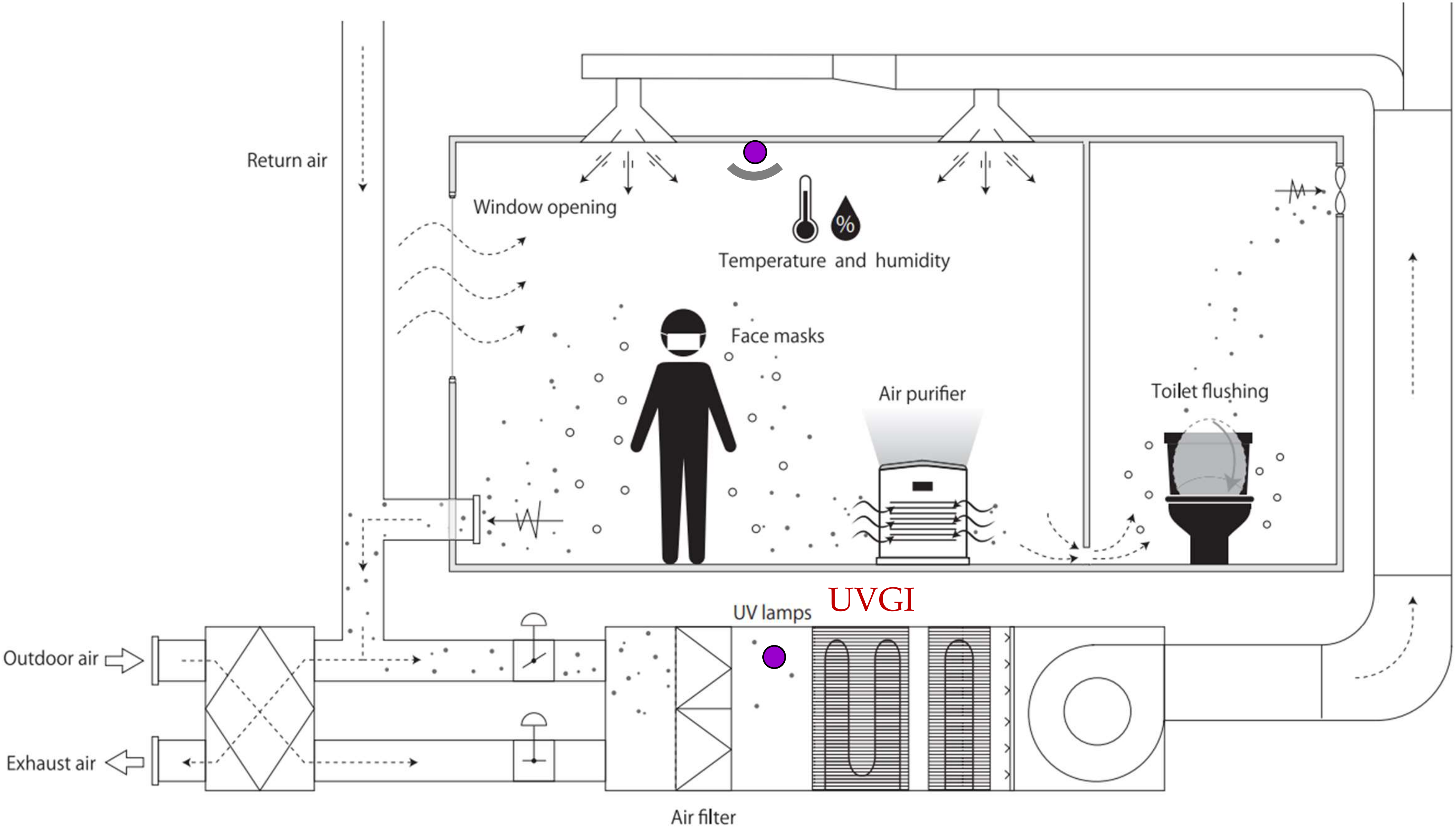
Figure 5.1: Two-stage Decay Curve with Shoulder for *Staphylococcus aureus*. Based on data from Sharp (1939).

Kowalski WJ, 2001. Design and Optimization of UVGI Air Disinfection Systems. A Thesis in Architectural Engineering. The Pennsylvania State University The Graduate School College of Engineering

$$S_t = e^{-kIt}$$

S_t : surviving fraction of initial microbial population (−)
k : standard rate constant (cm²/μW-s)
I : intensity of UVGI irradiation (μW/cm²)
t : time of exposure (s)

Central air conditioning system



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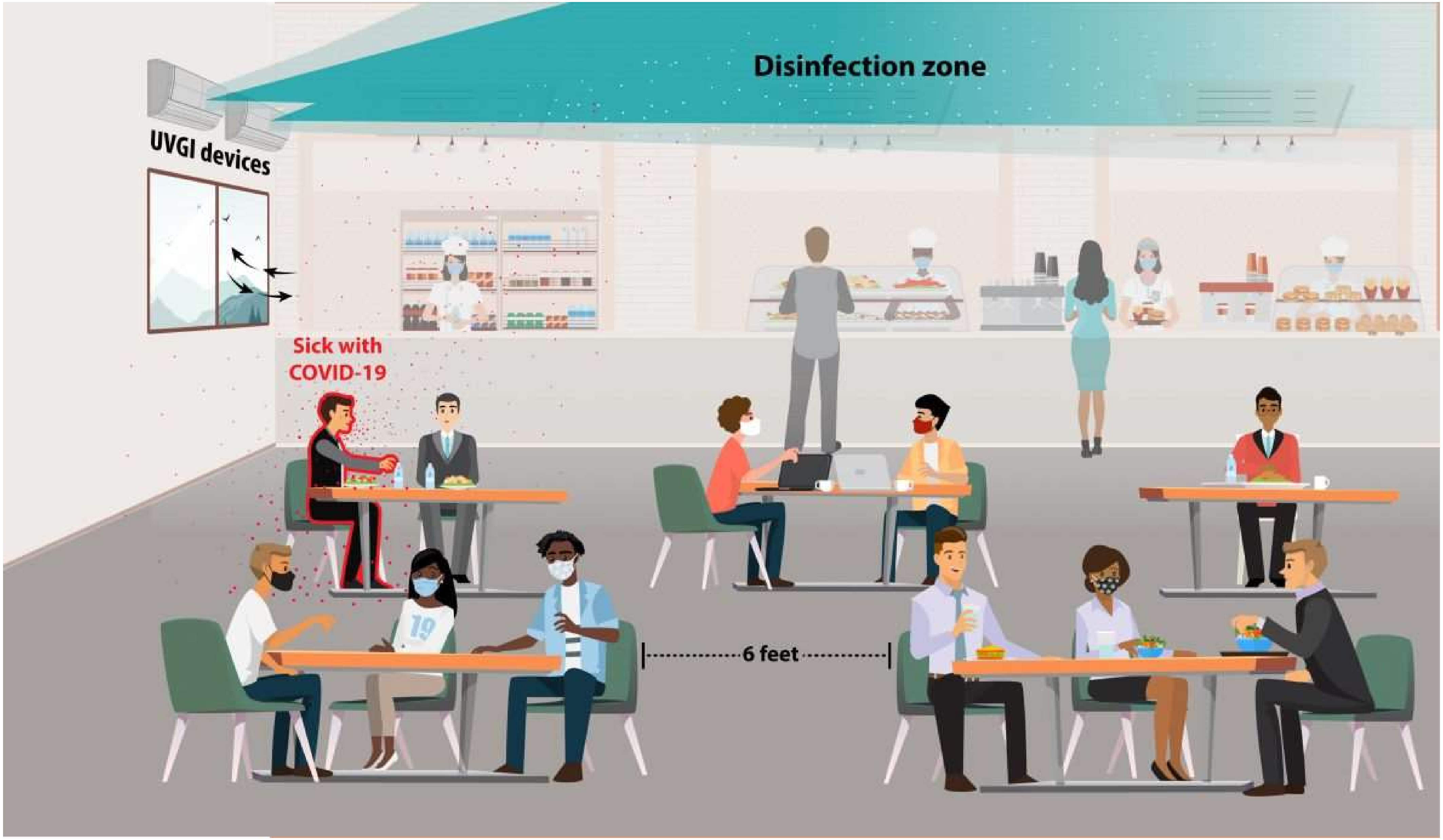
Upper-Room GUV



Source

https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation/uvgi.html

VIEWPOINT

Airborne Spread of SARS-CoV-2 and a Potential Role for Air Disinfection

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Brigham and Women's Hospital, Division of Global Health Equity, Harvard Medical School, Boston, Massachusetts.

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Beth Israel Deaconess Medical Center, Division of Infectious Diseases, Harvard Medical School, Boston, Massachusetts.

+ Supplemental content

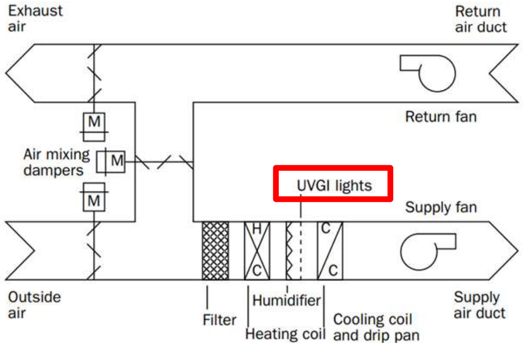
An April 2, 2020, expert consultation from the National Academies of Sciences, Engineering, and Medicine to the White House Office of Science and Technology Policy concluded that available studies are consistent with the potential aerosol spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), not only through coughing and sneezing, but by normal breathing.[1] This response to a White House request for a rapid review of the literature likely contributed to the recommendation from the US Centers for Disease Control and Prevention (CDC) that healthy persons wear nonmedical face coverings, when in public, to reduce virus spread from undiagnosed infectious cases.

Although clear evidence of person-to-person airborne transmission of SARS-CoV-2 has not been published, an airborne component of transmission is likely based on other respiratory viruses such as SARS, Middle East respiratory syndrome, and influenza. While air sampling for SARS-CoV-2, in a clinical setting, has demonstrated detectable viral RNA, the extent of transmis-

ing costs when intake air must be heated or cooled and dehumidified. Portable room air cleaners may be a potential solution, but depending on room volume, their specified clean air delivery rates generally add too few equivalent air changes per hour to provide adequate protection against airborne infection. In contrast, commercially available upper-room GUV air disinfection (with an effective rate of air mixing) has been shown, in clinical settings, to reduce airborne tuberculosis transmission by 80%, equivalent to adding 24 room air changes per hour.[3]

In resource-limited settings, where air disinfection depends on natural ventilation, upper-room GUV may be increasingly important as windows are closed due to use of ductless air conditioners in response to global warming and severe outdoor air pollution. In resource-rich settings, upper-room GUV can be retrofitted into most areas with sufficient ceiling height. GUV technology is effective against viruses that have been tested, including influenza and SARS-CoV-1.[4,5]

Effect of ultraviolet germicidal lights installed in office ventilation systems on workers' health and wellbeing: double-blind multiple crossover trial



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Summary

Background Workers in modern office buildings frequently have unexplained work-related symptoms or combinations of symptoms. We assessed whether ultraviolet germicidal irradiation (UVGI) of drip pans and cooling coils within ventilation systems of office buildings would reduce microbial contamination, and thus occupants' work-related symptoms.

Methods We undertook a double blind, multiple crossover trial of 771 participants. In office buildings in Montreal, Canada, UVGI was alternately off for 12 weeks, then turned on for 4 weeks. We did this three times with UVGI on and three times with it off, for 48 consecutive weeks. Primary outcomes of self-reported work-related symptoms, and secondary outcomes of endotoxin and viable microbial concentrations in air and on surfaces, and other environmental covariates were measured six times.

Introduction

The office or office-like indoor environment is now the workplace for more than 70% of the work force in North America and western Europe.[1,2] Most of these people work in buildings with sealed exterior shells, in which highly automated heating, ventilation, and air conditioning systems, run by only one or two operators, control the indoor environment.[3] Many reports have documented health problems related to this work environment;[2–4] their resolution could result in health benefits for as many as 15 million workers, and economic benefits of $5–75 billion per year, in the USA alone.[2]

Most occurrences of illnesses in workers in these buildings, which are termed non-specific building-related illnesses[3] or symptoms[2], remain unexplained,[2,3] but evidence suggests that microbial contamination of building air-conditioning systems plays a part. Cross-sectional studies have consistently detected increased

Table 7
The impact of UV radiation on coronaviruses.

UV type	Virus	UV irradiance	Distance	Time	Log reduction	Reference
UV-C (254 nm)	CCoV	7.1 μW/cm^2	1 m	72 h	4.8	Pratelli (2008)
UV LED (267 nm)	HCoV-OC43	6–7 mJ/cm^2	No data	60 s	3	Gerchman et al. (2020)
UV LED (297 nm)	HCoV-OC43	32 mJ/cm^2	No data	60 s	3	Gerchman et al. (2020)
UV LED (286 nm)	HCoV-OC43	13 mJ/cm^2	No data	90 s	3	Gerchman et al. (2020)
UV-C (254 nm)	MERS-CoV	–	1.22 m	5 min	5.91	Bedell et al. (2016)
UV-C (254 nm)	MERS-CoV	0.2 J/cm^2	No data		>3.8	Eickmann et al. (2018)
UV-C (254 nm)	MERS-CoV	0.05 J/cm^2	No data		2.9	Eickmann et al. (2018)
UV-A (365 nm)	SARS-CoV-1	2133 μW/cm^2	3 cm	15 min	0	Darnell et al. (2004)
UV-C (254 nm)	SARS-CoV-1	134 μW/cm^2	No data	15 min	5.3	Kariwa et al. (2006)
UV-C (254 nm)	SARS-CoV-1	134 μW/cm^2	No data	60 min	6.3	Kariwa et al. (2006)
UV-C (254 nm)	SARS-CoV-1	4016 μW/cm^2	3 cm	6 min	4 (below detection limit)	Darnell et al. (2004)
UV-C (260 nm)	SARS-CoV-1 (strain P9)	>90 μW/cm^2	80 cm	60 min	6	Duan et al. (2003)
UV-A (365 nm)	SARS-CoV-2	540 mW/cm^2	3 cm	9 min	1	Heilingloh et al. (2020)
UV-C (222 nm)	SARS-CoV-2	0.1 mW/cm^2	24 cm	10 s	0.94	Kitagawa et al. (2020)
UV-C (222 nm)	SARS-CoV-2	0.1 mW/cm^2	24 cm	30 s	2.51	Kitagawa et al. (2020)
UV-C (222 nm)	SARS-CoV-2	0.1 mW/cm^2	24 cm	60 s	2.51	Kitagawa et al. (2020)
UV-C (222 nm)	SARS-CoV-2	0.1 mW/cm^2	24 cm	300 s	2.51	Kitagawa et al. (2020)
UV-C (254 nm)	SARS-CoV-2	1940 mW/cm^2	3 cm	9 min	Complete virus inactivation	Heilingloh et al. (2020)
UV-C (254 nm)	SARS-CoV-2	3.7 mJ/cm^2	220 mm	–	3	Bianco et al. (2020)
UV-C (254 nm)	SARS-CoV-2	0.849 mW/cm^2	No data	0.8 s	Reduced below a detectable level	Storm et al. (2020)
PX-UV	SARS-CoV-2	–	1 m	1 min	3.53	Simmons et al. (2020)
PX-UV	SARS-CoV-2	–	1 m	2 min	>4.52	Simmons et al. (2020)
PX-UV	SARS-CoV-2	–	1 m	5 min	>4.12	Simmons et al. (2020)
DUV LED	SARS-CoV-2	3.75 mJ/cm^2	20 mm	1 s	0.9	Inagaki et al. (2020)
DUV LED	SARS-CoV-2	37.5 mJ/cm^2	20 mm	10 s	3.1	Inagaki et al. (2020)
DUV LED	SARS-CoV-2	225 mJ/cm^2	20 mm	60 s	>3.3	Inagaki et al. (2020)

CCoV – canine coronavirus, HCoV-OC43 – human coronavirus OC43, MERS-CoV – Middle Eastern respiratory syndrome coronavirus, SARS-CoV-1 – severe acute respiratory syndrome coronavirus 1, SARS-CoV-2 – severe acute respiratory syndrome coronavirus 2, PX-UV – pulsed-xenon ultraviolet light, UV LED – UV light-emitting diodes, DUV LED – deep ultraviolet light-emitting diode.

Source

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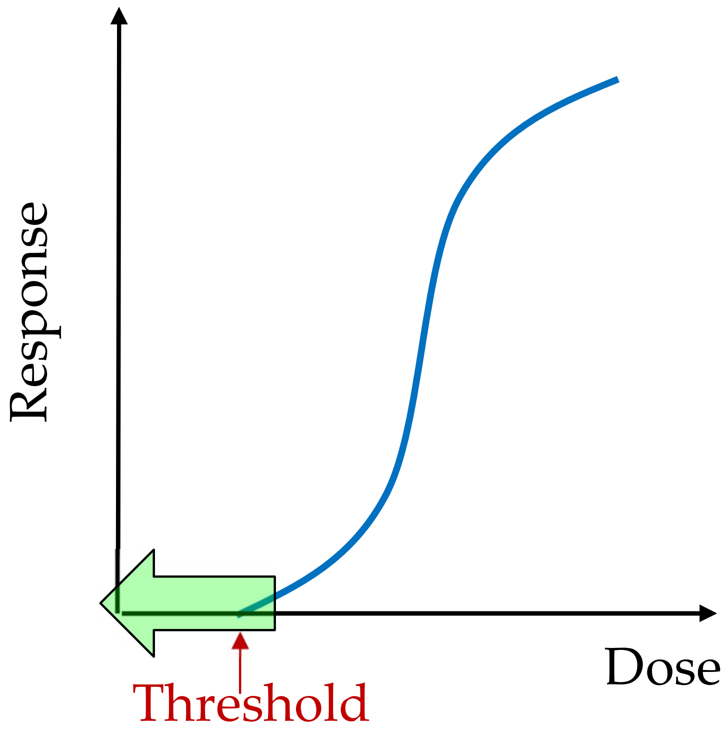
Summary



Dose-response relationship

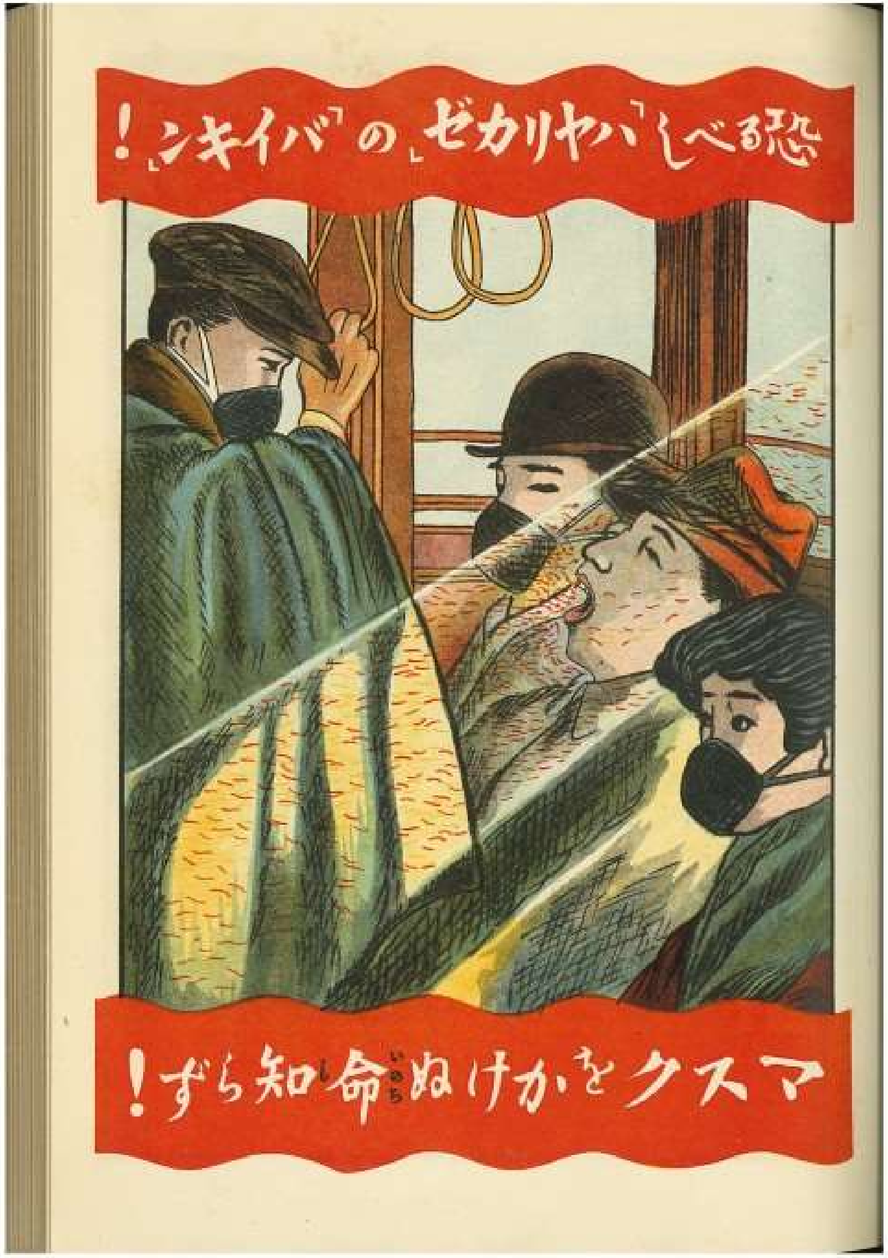
The main engineering mitigation strategies for respiratory infections is to control exposure load below the threshold, that is lowering the concentration of viable virus indoors.

1) Dilution by ventilation. Increasing the air dilution rate also means can shorten exposure time to the viruses.

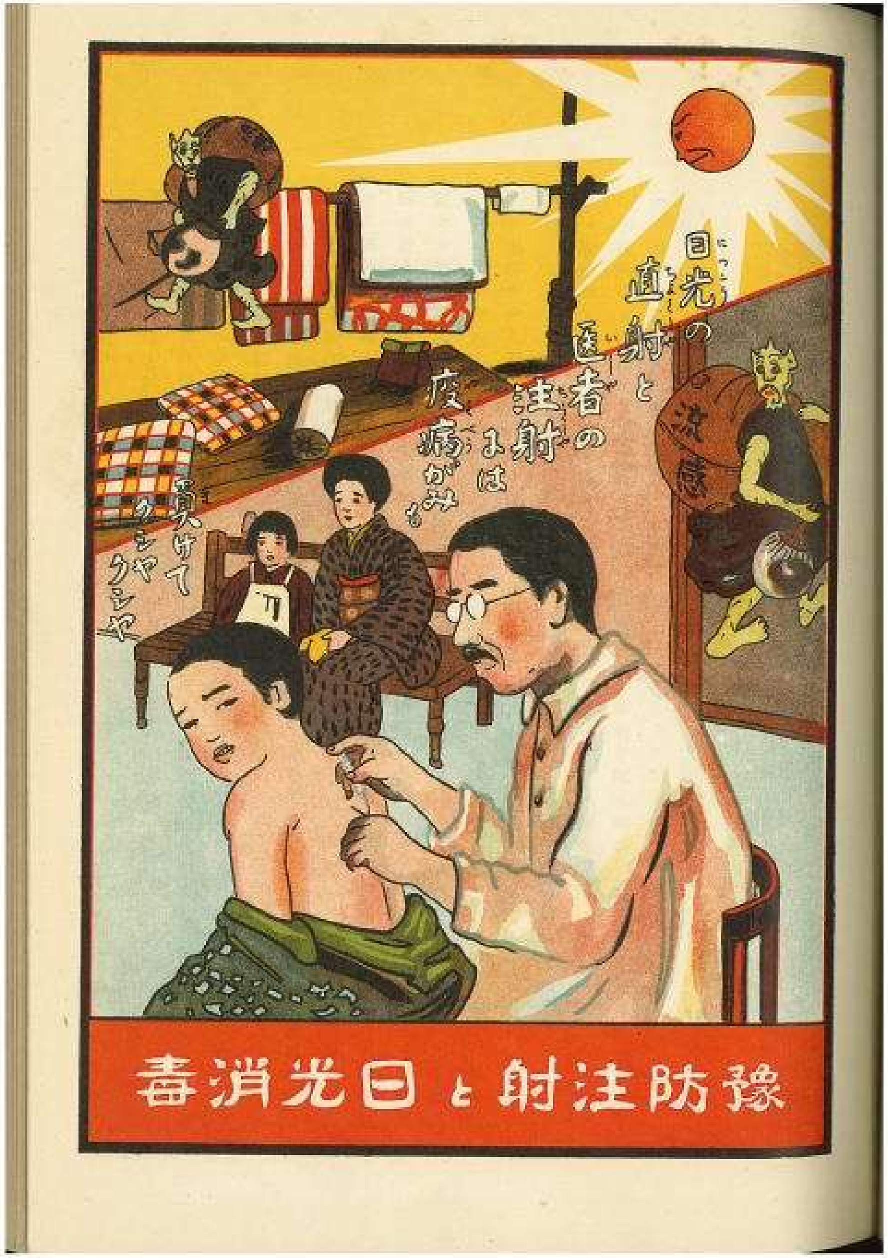
2) Removal by filtration and/or increase equivalent air changes per hour.

3) Sterilization by UV rays (GUV).

Mask: air filtration



Sunlight: UV sterilization



「Influenza」Japanese government (March, 1922)

Thank you for your attention !