COVID-19 Aerosol Transmission Estimator

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Developed by:	Prof. Jose L Jimenez & Dr. Zhe Peng, Dept. of Chem. & CIRES, Univ. Colorado-Boulde	**Shortcut:**	**https://tinyurl.com/covid-estimator**
Short description of this tool in CIRES Press Release:	Simplified version of this tool by Nat Geographic		**Direct copy in Google Drive (as Google Sheet)**
For more info: https://tinyurl.com/FAQ-aerosols	Other languages: https://tinyurl.com/preguntas-espanol		**Direct download into Excel**
5 min. read on aerosol evidence:	Patterns of transmission	Extensive discussion in my Twitter Threads	**Come back for new versions**
Recorded webinar on this tool:	1. Description & Tour (watch first)	2. Q&A session	3. Short intro by A. Mishra
Informacion en espanol / castellan	1. Descripcion y demonstracion	2. Entrevista PF	3. Entrevista HA
El Pais Simulation based on this:	English Version	Version en español	
Subscribing to email list for tool:	https://groups.google.com/forum/#!forum/covid-estimator		
Feedback to improve this tool:	http://tinyurl.com/estimator-feedback		
Using extensive input and feedback from many people (But any mistakes are my own):	Linsey Marr, Shelly Miller, Giorgio Buonnano, Lidia Morawska, Don Milton, Julian Tang, Jarek Kurnitski, Xavier Querol, Matthew McQueen, Charles Stanier, Joel Eaves, Alfred Trukenmueller, Ty Newell, Greg Blonder, Andrew Maynard, Nathan Skinner, Clark Vangilder, Roger Olsen, Alex Mikszewski, Prasad Kasibhatla, Joe Bruce, Paul Dabisch, Yumi Roth, Andrew Persily, Susan Masten, Sebastien Tixier, Amber Kraver, Howard Chong, John Fay, Dustin Poppendieck, Jim Bagrowski, Gary Chaulklin, Richard Meehan, Jarrell Wenger, Alex Huffman, Bertrand Waucquez, Elizabeth Goldberg (only listing the most important here, many others have contributed feedback as well over email and Twitter. Thanks a lot to everyone!)		
Version & date	3.5.1	23-Apr-21	

What we are trying to estimate

The propagation of COVID-19 by aerosol transmission ONLY

The model is based on a standard model of aerosol disease transmission, the Wells-Riley model. It is calibrated to COVID-19 per recent literature on quanta emission rate

This is NOT an epidemiological model, rather can take input from such models for the average rate of infection for a given location and time period. Or it could possibly be used as a sub-component of an epi-model, to estimate aerosol transmission as a function of various parameters

This model does NOT include droplet or contact / fomite transmission, and assumes that 6 ft / 2 m social distancing is respected. Otherwise higher transmission will result

This model does NOT include transmission to the people present, when they are in locations other than the one analyzed here

The model can easily be adapted to other situations, such as offices, shops etc.

Simplicity and uncertainties - IMPORTANT, PLEASE READ

The model is kept simple so that it can be understood and changed easily. The goal is to get the order-of-magnitude of the effects quickly, and to explore the trends.

Several parameters are uncertain, and have been estimated based on current knowledge. Alternative estimates can be entered to explore their effect in the results.

The model is consistent with known superspreading events of COVID-19. It represents the situation in which someone highly infectious is present in the space. Note that many people are much less infectious (e.g. Ma et al., 2020, Clinical Infectious Diseases, https://doi.org/10.1093/cid/ciaa1283), and for those the number of infected people will be too high.

More complex and realistic models can be built, however the parametric uncertainty may still dominate the total uncertainty

Parameters based on new research can be incorporated as they become available. Pls send them my way

Disclaimer: this model is our best scientific estimate, based on the information currently available. It is provided in the hope that it will be useful to others, based on us receiving a large number of requests for this type of information. We trust most the relative risk estimates (when changing parameters such as wearing a mask or not) of two runs of the model. We also trust the order-of-magnitude of the risk estimates, if the inputs are correct. The exact numerical results for a given case have more uncertainty. For example if you obtain a 1% chance of infection, in reality it could be 0.2% or 5%. But it won't be 0.001% or 100%. Results also have to be interpreted statistically, i.e. the result is the average number of transmission cases, across many realizations of a given event. I.e. if 1000 similar events were conducted, this would be the average probability. Any one event may have much fewer or many more transmission cases.

How to use the estimator

This online version will be kept up-to-date. We can't allow people to make changes to the online version, as otherwise people would overwrite each other's changes

People interested in using the model should download an Excel version from File --> Download or make a G Sheets copy with File --> Make a copy

Or you can download an Excel version with the direct link above

The online model will continue to be updated, so you may want to re-download the file later on, if you continue to use it, to get the latest updates

See the version log at the bottom of this sheet for a brief description of the updates

Inputs and Outputs

Most important inputs are colored in orange

Inputs are colored in yellow. These are the cells you should change to explore different cases.

Descriptions and intermediate calculations are not colored. Do not overwrite the calculations or you will break the estimator.

Outputs are colored in blue. These are the final results of the model for each case. Do not overwrite them or you will break the estimator.

Note that in some cases, the case in a sheet assumes that an infected person is present (e.g. in the classroom). While in other cases we use the prevalence of the disease in the populat

an input on the calculations. They can be converted easily, but pay attention to what each specific sheet is doing.

All sheets are self-contained, except for the University case

For the University case

Approximately scaled for a large University in the Western US for the Fall 2020 semester

First, results are calculated for a typical classroom ("Classroom Sheet"), assuming either one student or the professor are infected

Assumes enhanced social distancing and masks in place

Classroom size does not matter much, since students will scale with it

Then, results are scaled to the whole campus ("Campus Sheet"), taking into account the probability of infection in the population

Suggestions and improvements									
Please email me for any suggestions for improvements, additional input data etc.				jose.jimenez@colorado.edu					
Scientific Approach									
The model combines two submodels: (1) a standard atmospheric "box model", which assumes that the emissions are completely mixed across a control volume quickly (such as an indoor room or other space). See for example Chapter 3 of the Jacob Atmos. Chem. textbook, and Chapter 21 of the Cooper and Alley Air Pollution Control Engineering Textbook for indoor applications. This is an approximation that allows easy calculation, is approximately correct as long as near-field effects are avoided by social distancing, and is commonly used in air quality modeling. (2) a standard aerosol infection model (Wells-Riley model), as formulated in Miller et al. 2020, and references therein									
	Miller et al. Skagit Choir Outbreak	https://doi.org/10.1111/ina.12751							
	Original Wells-Riley model:	https://academic.oup.com/aje/article-abstract/107/5/421/58522							
	Buonnano et al. (2020a)	https://www.sciencedirect.com/science/article/pii/S0160412020312800							
	Buonnano et al. (2020b)	https://doi.org/10.1016/j.envint.2020.106112							
Key parameters, sources, and uncertainties									
The most uncertain parameter is the quanta emission rates for SARS-CoV-2									
	See FAQ sheet for the definition of quanta								
	970 q / h	This is from the Miller et al. choir superspreading case			https://doi.org/10.1111/ina.12751				
			This value is at the high end of the Buonnano et al. values provided below, consistent with this being a superspreading event						
			which was likely influenced by a very high emission rate of quanta from the specific index case						
			We do not think that this very high value should be applied to all situations, as that would overestimate the infection risk.						
	Buonnano et al. (2020a, b) provides a range of estimates. Recommended values by the author are:					Paper 1	Paper 2		
		IMPORTANT: The uncertainty of these values is high, probably at factor of 5 or 10. We just don't know enough about this disease yet. Also there are likely superspreaders which are less frequent but may have higher emissions (as in the choir case). Thus don't take abs. probabilities of infection at face value, just look at the order-of-magnitude (i.e. it is of the order of 0.001% or 0.01% or 0.1% or 1% or 10% or approaching 100%?. It is the relative effect of control measures, disease prevalence etc. that is most useful from this estimator, given the current state of knowledge.							
		For a professor delivering a lecture:4.4, 21, and 134 for oral breathing, speaking and aloud speaking (or singing)							
		For a student sitting on a lecture: 4, 16, 97 for oral breathing, speaking and aloud speaking (or singing)							
		For a more general set of activities, provided by the same author, based on their 2nd paper:							
			Resting – Oral breathing = 2.0 quanta/h						
			Resting – Speaking = 9.4 quanta/h						
			Resting – Loudly speaking = 60.5 quanta/h						
			Standing – Oral breathing = 2.3 quanta/h						
			Standing – Speaking = 11.4 quanta/h						

Standing – Loudly speaking = 65.1 quanta/h

Light exercise – Oral breathing = 5.6 quanta/h

Light exercise – Speaking = 26.3 quanta/h

Light exercise – Loudly speaking = 170 quanta/h

Heavy exercise – Oral breathing = 13.5 quanta/h

Heavy exercise – Speaking = 63.1 quanta/h

Heavy exercise – Loudly speaking = 408 quanta/h

For children as a first approximation I would reduce these numbers proportionally to body mass.

For comparison, values for measles can be over 5500 q h-1 (Riley et al. above). So COVID-19 is much less transmissible through the air than measles, but it can still be transmitted through aerosols under the right circumstances (indoors, lower ventilation, crowding, longer duration, activities that favor higher emission rates of respiratory aerosols such as singing, talking, aerobic exercise etc.) If you are curious, change the quantum emission rate to 5500 to see what measles would do, if it encountered a susceptible population with its high infectivity.

To our knowledge the measurements of exhaled particle sizes and concentrations have never been reported for children (L. Morawska, pers. comm.). Therefore we recommend scaling the adult measurements by body weight.

Inhalation (Breathing) Rates

In the current formulation of the estimator, these matter for the susceptible person. For the infected person, they are part of what causes the quanta emission rate to increase with activity. But e.g. talking increases quanta emission far more than what the breathing rate increases, because the emission of respiratory particles increases much more than breathing.

Recommended values from US EPA Exposure Factors Handbook (Chapter 6), depend on age and activity level

Table 6-1 for a daily average (includes sleeping though!), but use Tables below for a more accurate estimate

https://www.epa.gov/expobox/exposure-factors-handbook-chapter-6

Table 6-1. Recommended Long-Term Exposure Values for Inhalation (males and females combined)

Age Group[a]	Mean (m^3/day)	Sources Used for Means	95th Percentile[b] (m^3/day)	Sources Used for 95th Percentiles	Multiple Percentiles
Birth to <1 month	3.6	c	7.1	c	
1 to <3 months	3.5	c, d	5.8	c, d	
3 to <6 months	4.1	c, d	6.1	c, d	
6 to <12 months	5.4	c, d	8.0	c, d	
Birth to <1 year	5.4	c, d, e, f	9.2	c, d, e	
1 to <2 years	8.0	c, d, e, f	12.8	c, d, e	
2 to <3 years	8.9	c, d, e, f	13.7	c, d, e	See Table 6-4, Table 6-6

3 to <6 years	10.1	c, d, e, f	13.8	c, d, e	through Table 6-8, Table 6-10, Table 6-14 Table 6-15 [none available for Stifelman (2007)]
6 to <11 years	12.0	c, d, e, f	16.6	c, d, e	
11 to <16 years	15.2	c, d, e, f	21.9	c, d, e	
16 to <21 years	16.3	c, d, e, f	24.6	c, d, e	
21 to <31 years	15.7	d, e, f	21.3	d, e	
31 to <41 years	16.0	d, e, f	21.4	d, e	
41 to <51 years	16.0	d, e, f	21.2	d, e	
51 to <61 years	15.7	d, e, f	21.3	d, e	
61 to <71 years	14.2	d, e, f	18.1	d, e	
71 to <81 years	12.9	d, e	16.6	d, e	
≥81 years	12.2	d, e	15.7	d, e	

[a] When age groupings in the original reference did not match the U.S. EPA groupings used for this handbook, means from all age groupings in the original reference that overlapped U.S. EPA's age groupings by more than one year were averaged, weighted by the number of observations contributed from each age group. Similar calculations were performed for the 95th percentiles. See Table 6-25 for concordance with U.S. EPA age groupings.

[b] Some 95th percentile values may be unrealistically high and not representative of the average person.

[c] Arcus-Arth and Blaisdell (2007).

[d] Brochu et al. (2006b).

[e] U.S. EPA (2009a).

[f] Stifelman (2007).

Table 6-2. Recommended Short-Term Exposure Values for Inhalation (males and females combined)

Activity Level	Age Group (years)	Mean (m^3/minute)	95th Percentile (m^3/minute)	Multiple Percentiles
Sleep or Nap	Birth to <1	3.0E−03	4.6E−03	
	1 to <2	4.5E−03	6.4E−03	
	2 to <3	4.6E−03	6.4E−03	
	3 to <6	4.3E−03	5.8E−03	
	6 to <11	4.5E−03	6.3E−03	
	11 to <16	5.0E−03	7.4E−03	
	16 to <21	4.9E−03	7.1E−03	
	21 to <31	4.3E−03	6.5E−03	
	31 to <41	4.6E−03	6.6E−03	
	41 to <51	5.0E−03	7.1E−03	
	51 to <61	5.2E−03	7.5E−03	
	61 to <71	5.2E−03	7.2E−03	
	71 to <81	5.3E−03	7.2E−03	
	≥81	5.2E−03	7.0E−03	

	≥81	5.2E−03	7.0E−03	
Sedentary/ Passive	Birth to <1	3.1E−03	4.7E−03	See Table 6-17 and Table 6-19
	1 to <2	4.7E−03	6.5E−03	
	2 to <3	4.8E−03	6.5E−03	
	3 to <6	4.5E−03	5.8E−03	
	6 to <11	4.8E−03	6.4E−03	
	11 to <16	5.4E−03	7.5E−03	
	16 to <21	5.3E−03	7.2E−03	
	21 to <31	4.2E−03	6.5E−03	
	31 to <41	4.3E−03	6.6E−03	
	41 to <51	4.8E−03	7.0E−03	
	51 to <61	5.0E−03	7.3E−03	
	61 to <71	4.9E−03	7.3E−03	
	71 to <81	5.0E−03	7.2E−03	
	≥81	4.9E−03	7.0E−03	
Light Intensity	Birth to <1	7.6E−03	1.1E−02	
	1 to <2	1.2E−02	1.6E−02	
	2 to <3	1.2E−02	1.6E−02	
	3 to <6	1.1E−02	1.4E−02	
	6 to <11	1.1E−02	1.5E−02	
	11 to <16	1.3E−02	1.7E−02	
	16 to <21	1.2E−02	1.6E−02	

Mask efficiencies in reducing virus emission (as they come out the nose and mouth of an infected person)

Note that mask fit may be as important as the type of mask, see this video: *https://twitter.com/jljcolorado/status/1280935408398766080*

50%	Default value for the general population, with a variety of types of masks (cloth, surgical) and also variation on how well they are worn
	Reference: Davies et al. (2013) https://pubmed.ncbi.nlm.nih.gov/24229526/
	This number can vary widely from about 10% to about 80%, depending on the quality of masks and how they are worn.
90%	For N95 masks (KN95, FF2). If well fitted and worn their efficiency for the large particles that most likely contain the viruses is 99% or more. However we use a lower value for their use in the community in the real world, since most people are not fitted, and they are not worn perfectly and can have leaks. 90% may even be optimistic in that situation.
0%	For N95 masks that have an exhalation valve. Most of the air is exhausted through the valve, and there is little filtering
	See for example this article for a picture of that type of mask: https://www.healthline.com/health-news/certain-type-n95-mask-harm-covid19-spread

		Such masks are good for occupational exposure, if a worker is sanding, drilling etc. But they don't protect against exhaled particles.			
	65%	For surgical masks, from Milton et al. (2013)			https://journals.plos.org/plospathogens/article?id=10.1371/journal.ppat.1003205
		This is probably too high for the general population, which won't wear surgical masks as well as in a research study. We suggest using 50%			
	23%	For face shields worn without a mask. This is a guess, since the one study available is for inhalation, not for emission. But it makes sense that efficiency would be low, due to limited inertia of exhaled particles under normal breathing or talking. From https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4734356/ https://www.youtube.com/watch?v=eGONzm3vdul			
Mask efficiencies in reducing virus inhalation by a susceptible person (for virus already in aerosol particles floating in the air)					
	The physical flows during exhalation and inhalation are different, and affect aerosol particles differently. Therefore the efficiencies are typically different				
	30%	Davies et al. (2013; https://pubmed.ncbi.nlm.nih.gov/24229526/) reported a filtration efficiency of 50% for homemade cloth masks that people put on themselves. After discussion w/ Linsey Marr, we "discounted" this to be conservative, given imperfect wearing and fit in the community. We think 30-50% is a reasonable number. The higher value for situations with more conscientious people who pay more attention to keeping the mask well fit at all times.			
	90%	For N95 masks (KN95, FF2). If well fitted and worn their efficiency for the large particles that most likely contain the viruses is 99% or more. However we use a lower value for their use in the community in the real world, since most people are not fitted, and they are not worn perfectly and can have leaks. 90% may even be optimistic in that situation.			
	23%	For face shields worn without a mask, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4734356/ https://www.youtube.com/watch?v=eGONzm3vdul Also note misconception that "face shields protect from falling aerosols". Aerosols actually RISE around the human body, driven by personal thermal plume. See https://doi.org/10.1016/j.buildenv.2015.04.010			
Building ventilation rates					
	This refers only to replacement of indoor air with outdoor air. Recirculation of air with filtering is under "additional control measures"				
	Note that e.g. a ventilation rate of 1 h-1 does not mean that 100% of the air is replaced in 1 h. That's the "plug flow" assumption, the air inside is displaced by the new air. But due to mixing it doesn't work that way. A better approximation is that the fraction of the intial air that remains in the space vs time is exp (-ACH * time) * 100%. So after 1 h, what remains is exp(-1 * 1) =* 100% = 36%, after 2 h, what remains is exp(-1 * 2) = 14% and so on.				
	An MIT calculator for natural ventilation (through cracks, windows etc.) can be downloaded here: http://coolvent.mit.edu/				
	This can be measured approximately for a given space with a fast (few minutes response) CO2 meter such as this one				
		See this post which explains how to do it with some graphs: https://medium.com/@jjose_19945/how-to-quantify-the-ventilation-rate-of-an-indoor-space-using-a-cheap-co2-monitor-4d8b6d4dab44?source=friends_link&sk=6cda52f5682a4a450a10691f07d1ad2c			
		How: go into the space, be there breathing for a while (more people would help). Then leave quickly. Look at the data later, and look at the point at which the CO2 - 400 ppm was 63% of the peak. That is the time constant, and the ventilation rate is 1 divided by that. See calculator below.			
			CO2 at peak	1495	ppm (for your particular measurement)
			CO2 outdoors	415	ppm (global atmospheric background, don't change unless you know what you are doing)
			Excess CO2	1080	ppm
			CO2 at 63% deca	812	ppm (you need to estimate how long it took from the peak till it reached this level)
			Time of 63% val	0.85	h
			Ventilation rate	1.18	h-1 (this is the result that you have to enter in the Master spreadsheet for ventilation rate

Literature values for several situations in h-1 (= ACH, air-changes-per-hour)		
0.5-1.5	Houses	Typical values with the windows closed. Depends on how airtight the construction is. Older buildings tend to have higher values
3-15	Windows open	Estimate for open windows. Value varies a lot depending on outdoor wind speed and geometry.
0.1-8	Primary school	https://www.sciencedirect.com/science/article/abs/pii/S1352231007008758
2.5	Univ classroom	https://link.springer.com/article/10.1007/s00420-008-0301-9
0.4-5	Univ classroom	https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12111
5-6	Univ classroom	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1600-0668.2012.00769.x
2-11	Univ classroom	https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12272
Varies	ASHRAE 62	https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2
		This is for commercial buildings. Per Prof. Shelly Miller: "If it was commissioned and maintained properly then this is probably a
		reasonable first estimate (if you can't measure or get hard data from facilities folks) (Link)
		Table from ASHRAE Std 62.1, 2013 version (I don't have the most recent version, and it cost $125 to purchase. I have asked an ASHRAE contact whether they could provide the more updated version). The design airflow is the sum of the people (max capacity) and the area terms. Applies to USA
		The standards from the table below will have been applied in the US for buildings built recently. Older buildings will have followed older standards. Old standards can also be obtained from the same ASHRAE page. E.g. for a building built in the US in 2005, look up the standard that was valid in 2005. Note that researchers do say that ventilation systems in old buildings are not always performing at the level they were designed to, due to a variety of maintenance problems.
		To use in the other sheets, use the calculation below (example of daycare):

Rp	5	L/s/person	From standard
Ra	0.9	L/s/m2	From standard
Occupant density	25	per / 100 m2	From standard
Surface area	100	m2	For a specific location
Height of room	3	m	For a specific location
Volume of room	300	m3	Product of two above, for a specific location
N occupants	25	people	Calculated according to standard, per values above
Vent Rate	215	L/s	Calculated according to standard, per values above
Vent. in h-1	2.58	h-1	This is the parameter you need to enter in the other sheets for vent. rate

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone

(Table 6.2.2.1 shall be used in conjunction with the accompanying notes.)

			Default Values	
	People Outdoor Air Rate R_p	Area Outdoor Air Rate R_a	Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)

Occupancy Category	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2	Notes	#/1000 ft^2 or #/100 m^2	cfm/ person	L/s· person	Air Class
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	H	65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3	H	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
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3	H	35	12	5.9	1
Multiuse assembly	7.5	3.8	0.06	0.3	H	100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	7	3.5	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

Below are the additional tables from the standard, for other situations - enlarge the images to look for your situation of interest

TABLE 6.2.2.1 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 cfm/person	People Outdoor Air Rate R_p L/s·person	Area Outdoor Air Rate R_a cfm/ft²	Area Outdoor Air Rate R_a L/s·m²	Notes	Default Values: Occupant Density (see Note 4) #/1000 ft² or #/100 m²	Default Values: Combined Outdoor Air Rate (see Note 5) cfm/person	Default Values: Combined Outdoor Air Rate (see Note 5) L/s·person	Air Class
Coffee stations	5	2.5	0.06	0.3		20	8	4	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	—	—	0.06	0.3		—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
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 NOTES FOR TABLE 6.2.2.1
1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1
A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
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Freezer and refrigerated spaces (<50°F)	10	5	0	0	E	0	0	0	2
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	10	5	0.12	0.6	B	2	70	35	2
Sorting, packing, light assembly	7.5	3.8	0.12	0.6		7	25	12.5	2
Telephone closets	—	—	0.00	0.0		—			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	10	5	0.06	0.3	B	—			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	—	—	0.06	0.3					1

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D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
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Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.12	0.6		20	14	7.0	2
Sports and Entertainment									
Gym, sports arena (play area)	20	10	0.18	0.9	E	7	45	23	2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	—	—	0.48	2.4	C	—			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	2
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

GENERAL NOTES FOR TABLE 6.2.2.1
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Standards for other regions should be roughly similar, but follow guidelines from other associations or national governments.

Decay rate of the virus infectivity in aerosols (indoors and outdoors)

There are several studies for this parameter that don't quite agree. I am consulting with the authors about what they recommend we use as a default

Literature values in h-1

0.63	https://www.nejm.org/doi/full/10.1056/nejmc2004973
~0	https://www.medrxiv.org/content/10.1101/2020.04.13.20063784v1 (lower confidence in this result due to lack of replicates)
0.2 - 1	https://www.tandfonline.com/doi/full/10.1080/22221751.2020.1777906
0.48	https://academic.oup.com/jid/advance-article/doi/10.1093/infdis/jiaa334/5856149

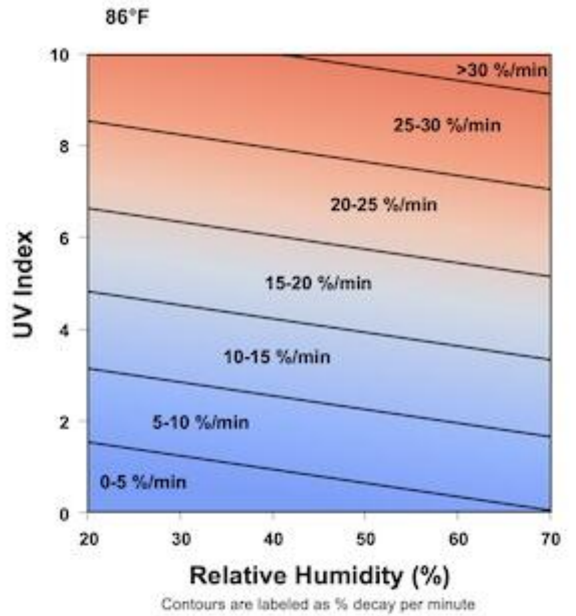
Online estimator based on above (includes UV = 0, which is what should be used in most indoor spaces)

The equation in the estimator is also implemented below. Enter your RH, T, UV index (0 indoors) to get decay estimate

Graciously provided by Dr. Paul Dabisch, Dept. of Homeland Security, USA

T (C) =	20	This is the input
T (F) =	68	For display only
RH (%)	60	(20 to 70, in % units)
UV index	0	0 (indoors) to 10 (full sun noon)
Virus decay	1.621	h-1

$$
\begin{aligned}
&7.56923714795655\\
&+ 1.41125518824508 * \left(\frac{\text{Temp (degC)} - 20.54}{10.66}\right)\\
&+ 0.02175703466389 * \left(\frac{\text{RH (\%)} - 45.235}{28.665}\right)\\
&+ 7.55272292970083 * \left(\frac{\text{Solar (W/m\^{}2 UVB)} - 50}{50}\right)\\
&+ \left(\frac{\text{Temp (degC)} - 20.54}{10.66}\right) * \left(\frac{\text{Solar (W/m\^{}2 UVB)} - 50}{50}\right) * 1.3973422174602
\end{aligned}
$$



Deposition of virus-containing aerosol to surfaces

An important uncertainty is the size range of the infective particles. Here we assume 1-5 um, based on our read of the literature

Literature values in h-1

0.2-2	https://www.sciencedirect.com/science/article/abs/pii/S1352231002001577	(depends on air speed, particle size range)
0.24	https://www.sciencedirect.com/science/article/abs/pii/S1296207418305922?via%3Dihut	(as interpreted in Buonnano et al. 2020a)

Virus removal rate of other control measures

For a portable HEPA filter unit, use this calculation (metric units):

HEPA flow rate	440	m3 h-1	
Room size	147	m3	
Removal rate	3.0	h-1	Enter this value in cell for additional control measures

HEPA filter calculation (US units):

HEPA flow rate	260	cfm (cubic feet per minute)	
Room size	5200	ft3	
Removal rate	3.0	h-1	Enter this value in cell for additional control measures

A more elaborate calculator for HEPA filters can be found here: https://tinyurl.com/portableaircleanertool

For recirculated air, either with or w/o filter, w or w/o germicidal UV or other measures

For air that is recirculated through an HVAC system, there are also particle losses. We know since virus RNA has been found in the surfaces of HVAC system, and also from basic aerosol dynamics and losses in tubing. This will happen even if there is no filtration, and will be enhanced by length of ducting and bends. If there are filters in the HVAC system, that will increase the removal. See the calculator below (HT Jim Bagrowski)

If you have some other "air cleaner" in the ducts (ionic system etc.), you also need to estimate it in the same way as the previous item, depending on the rate of recirculation, and the efficiency of the system in removing particles.

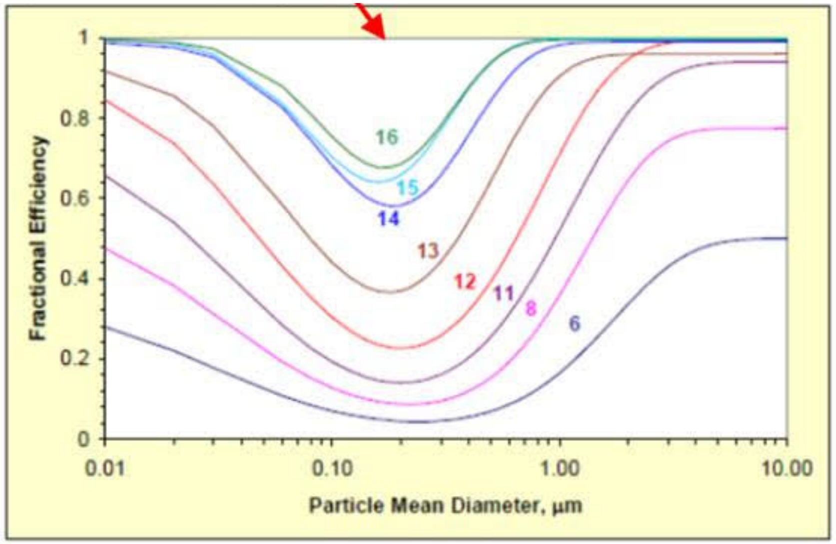
Recirculated flow rate =	300	m3 / h	Can also enter values in cubic feet per hour, if next row is in cubic feet
Volume of room =	100	m3	
Filter efficiency =	20%		Enter from table below, I recommend value in 1-3 microns. Example = MERV 8
Removal in ducts, air handler =	10%		Assuming some losses in bends, air handler surfaces etc. Just a guess
Other removal measures =	0%		Germicidal UV (or other systems), from specs or the system
ACH for additional control meas =	0.9	h -1	Enter this value in cell for "Additional control measures"

- Table of filter efficiency from https://www.nafahq.org/understanding-merv-nafa-users-guide-to-ansi-ashrae-52-2/ We are not sure the particle size that contains more virus, but suspect it is 1-10 um mostly, based on our read of the literature. Therefore using 1-3 um to be conservative.
- The curves are useful to understand the size dependence of filtering for different MERV grades in more detail. See this link https://www.nafahq.org/merv-filter-models/ for the details about the curves, and a lot more technical information on filtering.

TABLE 3: MERV PARAMETERS

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm: Range 1 (0.3-1.0)	Range 2 (1.0-3.0)	Range 3 (3.0-10.0)	Average Arrestance, %
1	n/a	n/a	E3 < 20	A_{avg} < 65

2	n/a	n/a	E3 < 20	$65 \le A_{avg} < 70$
3	n/a	n/a	E3 < 20	$70 \le A_{avg} < 75$
4	n/a	n/a	E3 < 20	$75 \le A_{avg}$
5	n/a	n/a	20 ≤ E3	n/a
6	n/a	n/a	35 ≤ E3	n/a
7	n/a	n/a	50 ≤ E3	n/a
8	n/a	$20 \le E_2$	70 ≤ E3	n/a
9	n/a	$35 \le E_2$	75 ≤ E3	n/a
10	n/a	$50 \le E_2$	80 ≤ E3	n/a
11	$20 \le E_1$	$65 \le E_2$	85 ≤ E3	n/a
12	$35 \le E_1$	$80 \le E_2$	90 ≤ E3	n/a
13	$50 \le E_1$	$85 \le E_2$	90 ≤ E3	n/a
14	$75 \le E_1$	$90 \le E_2$	95 ≤ E3	n/a
15	$85 \le E_1$	$90 \le E_2$	95 ≤ E3	n/a
16	$95 \le E_1$	$95 \le E_2$	95 ≤ E3	n/a



[Disease prevalence in your area - Probability of someone being infected in a given region and time period]()

This depends on the state of the pandemic in a given region and time period, as well as the dynamics of the disease and its infectivity in different types of cases, which are not known very precisely

For the US, you could use the online tools below to find the current estimated fraction of infectious people in a given county

https://sites.google.com/compassfortcollins.org/coronavirusrisk/home

https://www.descarteslabs.com/resources/covid-19-now

https://covid19risk.biosci.gatech.edu/

On a simple test for Boulder on 22-Jul, the tools give 0.08%, 0.25%, 0.49% infectious respectively. I have asked for input from epi folks about which may be more accurate, or whether the uncertainty is that large

For other countries, this tool has country-level estimates of the current fraction of infected

https://covid19-projections.com/

For the UK, you can get estimates from here: https://covid.joinzoe.com/data

This parameter is not easy to quantify accurately, but one can hope to get the order-of-magnitude right from the disease prevalence data and/or the epidemiological models. People are thought to be contagious mostly the week around the onset of symptoms, so that has to be taken into account in the estimates. Also there is a fraction of undetected contagious cases (asymptomatic / presymptomatic), which will increase transmission. Plus one would hope that a major fraction of the cases that are in quarantine or a hospital and not transmitting the disease much. The uncertainty on the fraction of contagious individuals in the community is one more reason why the absolute risk values will be uncertain, but the relative risks will still be robust.

A range of values is estimated below to provide some bounds. An in-between value of 0.3% is used as default, as the approx. geometric mean of the results below

One estimate for New York City (NYC) at the height for their large outbreak in March-May 2020

		Fraction of of the population that got infected over a period of 2 month	20%	
		Duration of infective period	7	days
		Fraction of population infective at a given time:	2.3%	
	Another estimate for Boulder, CO in early June 2020 (low prevalence):			
		New cases per day per 100,000 people (from NYT database)	1.8	
		Fraction of asymptomatic or unreported cases	50%	
		Duration of infective period	7	days
		Fraction of population infective at a given time:	0.03%	

Fraction of inmune people

As the disease progresses, the fraction of the population that has had the disease and has some immunity is not negligible any more, and may be higher than 20% in some areas like New York City. This reduces the number of people who could possibly get infected.

It can be estimated from studies such as this one: https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/2768834

You can estimate this number for US States and many countries using the total number of ever infected at: https://covid19-projections.com/

CO2 Emission Rates

See FAQs for the usefulness and limitations of this method

The method and tables are from Persily and de Jonge (2017)

First determine the metabolic rate (met) for the activity of interest from Table 3

Then, determine the CO2 generation rate based on the age, gender, and metabolic rate

If met > 4 on table 3, you can use the highest value (for met = 4) in Table 4, or one could use the equations in the paper. For A Persily (pers comm): "when you get above 4, people usually can't sustain such activity levels for very long, except maybe real athletes, and how their body responds depends a lot on physical conditioning, etc. One can still use equations 9 and 11 in Persily and de Jonge (2017), at high values but the uncertainties are likely to be higher for the reasons I just tried to explain"

Then enter the value you determine on the spreadsheet for calculation

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

			CO_2 generation rate (L/s)						
			Level of physical activity (met)						
Age (y)	Mean body mass (kg)	BMR (MJ/day)	1.0	1.2	1.4	1.6	2.0	3.0	4.0
Males									
<1	8.0	1.86	0.0009	0.0011	0.0013	0.0014	0.0018	0.0027	0.0036
1 to <3	12.8	3.05	0.0015	0.0018	0.0021	0.0024	0.0030	0.0044	0.0059

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

Activity	*M* (met)	Range
Calisthenics—light effort	2.8	
Calisthenics—moderate effort	3.8	
Calisthenics—vigorous effort	8.0	
Child care		2.0 to 3.0
Cleaning, sweeping—moderate effort	3.8	
Custodial work—light	2.3	
Dancing—aerobic, general	7.3	
Dancing—general	7.8	
Health club exercise classes—general	5.0	
Kitchen activity—moderate effort	3.3	
Lying or sitting quietly		1.0 to 1.3
Sitting reading, writing, typing	1.3	
Sitting at sporting event as	1.5	

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3 to <6	18.8	3.90	0.0019	0.0023	0.0026	0.0030	0.0038	0.0057	0.0075
6 to < 11	31.9	5.14	0.0025	0.0030	0.0035	0.0040	0.0050	0.0075	0.0100
11 to <16	57.6	7.02	0.0034	0.0041	0.0048	0.0054	0.0068	0.0102	0.0136
16 to <21	77.3	7.77	0.0037	0.0045	0.0053	0.0060	0.0075	0.0113	0.0150
21 to < 30	84.9	8.24	0.0039	0.0048	0.0056	0.0064	0.0080	0.0120	0.0160
30 to <40	87.0	7.83	0.0037	0.0046	0.0053	0.0061	0.0076	0.0114	0.0152
40 to <50	90.5	8.00	0.0038	0.0046	0.0054	0.0062	0.0077	0.0116	0.0155
50 to <60	89.5	7.95	0.0038	0.0046	0.0054	0.0062	0.0077	0.0116	0.0154
60 to <70	89.5	6.84	0.0033	0.0040	0.0046	0.0053	0.0066	0.0099	0.0133
70 to <80	83.9	6.57	0.0031	0.0038	0.0045	0.0051	0.0064	0.0095	0.0127
≥80	76.1	6.19	0.0030	0.0036	0.0042	0.0048	0.0060	0.0090	0.0120
Females									
<1	7.7	1.75	0.0008	0.0010	0.0012	0.0014	0.0017	0.0025	0.0034
1 to <3	12.3	2.88	0.0014	0.0017	0.0020	0.0022	0.0028	0.0042	0.0056
3 to <6	18.3	3.59	0.0017	0.0021	0.0024	0.0028	0.0035	0.0052	0.0070
6 to < 11	31.7	4.73	0.0023	0.0027	0.0032	0.0037	0.0046	0.0069	0.0092
11 to < 16	55.9	6.03	0.0029	0.0035	0.0041	0.0047	0.0058	0.0088	0.0117
16 to <21	65.9	6.12	0.0029	0.0036	0.0042	0.0047	0.0059	0.0089	0.0119
21 to < 30	71.9	6.49	0.0031	0.0038	0.0044	0.0050	0.0063	0.0094	0.0126
30 to < 40	74.8	6.08	0.0029	0.0035	0.0041	0.0047	0.0059	0.0088	0.0118
40 to <50	77.1	6.16	0.0029	0.0036	0.0042	0.0048	0.0060	0.0090	0.0119
50 to <60	77.5	6.17	0.0030	0.0036	0.0042	0.0048	0.0060	0.0090	0.0120
60 to <70	76.8	5.67	0.0027	0.0033	0.0038	0.0044	0.0055	0.0082	0.0110
70 to <80	70.8	5.45	0.0026	0.0032	0.0037	0.0042	0.0053	0.0079	0.0106
≥80	64.1	5.19	0.0025	0.0030	0.0035	0.0040	0.0050	0.0075	0.0101

[illegible] spectator	[illegible]
Sitting tasks, light effort (e.g, office work)	1.5
Sitting quietly in religious service	1.3
Sleeping	0.95
Standing quietly	1.3
Standing tasks, light effort (e.g, store clerk, filing)	3.0
Walking, less than 2 mph, level surface, very slow	2.0
Walking, 2.8 mph to 3.2 mph, level surface, moderate pace	3.5

Version log		
1.0	15-Jun-2020	Started development of the estimator, adapting previous work
2.0	23-Jun-2020	Made public through Twitter
2.1-2.4	23-Jun-2020	Made various clarifications and references to the text
2.5	23-Jun-2020	Some more clarifications, fixed some issues with text, added outdoors and demonstration cases

2.6 and later	24-27 June	Some clarifications to the text, added FAQs sheet and more detail on the input parameters
2.7.0 and later	28-29 June	Fixed mistake in description of Campus / B11 and / B12. Added and reorganized FAQs. Added ASHRAE Standards calculator
2.7.7 and later	30-Jun-20	Fixed error in Outdoors and Demonstration tabs (in conversion to m/s). New results are even lower for transmission outdoors
		Colored duration of event as an input, was white in several of the sheets. Clarified some of the labels. Added several FAQs and explanations.
2.7.9 and later	1-Jul-20	Text clarifications, added FAQs
2.8.0 and later	2-3 July	Added efficiency for face shields, added FAQs
2.9.0 and later	4-Jul-20	Updated calculation of students in "Classroom" sheet, so that it can be calculated from the surface area per student. Updated FAQs
3.0.0 and later	6-Jul & later	Added calculator for portable HEPA filters in Readme sheet. Updated several FAQs
		Clarified that the number of instructors = 1 in the classroom is an assumption and is not an input.
		Minor adjustments to outdoors case to match Skagit choir event, except outdoors instead of indoors (There were some small differences)
		Changed units of occupant density to people per 100 m2 to match the standard, as people / m2 was causing confusion
3.0.9 and later	14-Jul-20	Fixed bug in classroom sheet, instructor was using student breathing rate instead of instructor (not a big change in results)
		Added link to Shelly Miller's report on air cleaners and table of rec. cleaners in the US (FAQs)
3.1.0	16-Jul & later	Added conditional vs absolute probability to Choir case
		Updated multiple FAQs
		Tried implementing DHS virus decay rate on readme page. However results don't agree with online tool yet, checking w/ authors
3.2.0	20-Jul-20	Released beta sheet with new format, for testing and comments
		Added some steps towards the CO2 estimation
3.2.6 & later	21-Jul-20	Completed CO2 estimation, fixed multiple bugs in beta sheet (thanks to Prasad Kasibhatla for his eagle eyes!)
		Finished calculator of Dabish DHS virus decay rates (consulting with him and other experts about what is best to use for that rate)
		Updated breathing rates with EPA report, clearly higher quality than what I was using before (thanks to Susan Masten)
		Added direct links for Copy to G Drive & download to Excel, since File doesn't work at > 100 users (thx Joe Bruce for pointing out this was possible)
		Fixed error in Campus sheet, N students in classroom was missing from calc of student cases (thanks to Prasad Kasibhatla)
		Clarified on each sheet which results are conditional vs. absolute, which seemed to be the most confusing feature
		Replaced "airborne" with "aerosol" everywhere to avoid confusion
		Updated multiple FAQs and readme descriptions
3.3.0 & later	22-Jul & later	Added the fraction of inmune people to the Master sheet
		Updated class sheet using new master sheet
		Removed breathing rate of index case since it does not enter the calculations
		Updated Subway sheet to new master sheet
3.3.8 & later	24-July & later	Added calculator for other removal measures (HT Jim Bragowski)
		Added calculator to estimate ventilation rate from decay of CO2 after leaving location
		Añadido enlace a charla grabada en espanol / castellano, describiendo la herramienta, y demostrando cómo usarla

		Spelled checked whole document (HT Gary Chaulklin)
		Updated breathing rate for Class from sedentary to avg of sedentary and light activity for 16-21 yr old (Adapt as needed for your case)
		Highlighted that ventilation in L/s/person is what really matters for disease transmission
		Updated references for typical mask inhalation efficiency in the community (HT Linsey Marr)
		Updated calculation of ventilation in L/s/per to use total ppl present (as using susceptible + infected, no longer accurate if immune ppl present)
		Moved location of L/s/per and density of people to make those intermediate outputs clearer
3.4.0 & later	31-Jul & later	Updated FAQs
		Added stadium sheet based on a case study
		Added supermarket case
		Added additional tables from 2013 ASHRAE standard (sorry, I hadn't realized there were more pages when I first added this info)
	3-Aug & later	Updated absolute probability from (1-exp(-B67*B89/B38)) to 1 - (1 - B70*B57)^B40. Only matters for high probs (HT Prasad Kasibhatla)
3.4.8	6-Aug & later	Added ratio of infection probability to excess CO2 breathed, to better quantify risk of inhaled CO2 under different situations
		Added ppm CO2 levels for certain levels of risk for conditional and absolute cases
		Found better way to keep tables in FAQ in places, they kept jumping up every few days somehow
		Added more info to FAQ and Readme pages
		Fixed typo on background CO2 in readme, should be 415 pm not 550 ppm
		Labeled all sheets on the old format as "_Old" on their tab names. I intend to transfer those to the new format as soon as I can, hopefully the coming weekend. The new format is much clearer, in particular the difference between conditional and absolute probabilities is very confusing to a lot of people, so it helps to have them shown separately.
3.4.14		Updated "for any one person" --> "for a given person" on the results label, as the former was being confused with being for all persons present
3.4.17	5-Sep-20	Fixed error in calculator of fraction of infective population (Readme/row 398 at present, was dividing by asympt/unreported fraction, need to divide by 1-that
3.4.18	29-Sep-20	Added feedback form
3.4.19	27-Oct-20	Updating of references
3.4.20	28-Nov-20	Clarification of Readme page
3.4.21	29-Dec-20	Fixing typo on several of the case sheets
3.4.22	1-Feb-21	Updated Miller reference
3.4.23	26-Mar-21	Added Dr. Zhe Peng as co-developer
3.4.24	26-Mar-21	Fixed typo on cell B88 in Subway, Superm., and Stadium sheets (RH was being used erroneously instead of background CO2 level). HT Bill Mason
3.5.1	23-Apr-21	Added location and explanation for risk parameters from Peng et al. (2021) preprint. Parameter calculation to be added soon
Planned Improvements at time allows		
During March-April 2021		
	Add risk parameters and updated BMJ table with the risk parameters	

	Add discussion of more contagious variants
Other possible improvements	
	Add a time-dependent solution for one case, with a graph
	Explain quanta in this tool vs MonteCarlo tools
	Add an initial condition of quanta, to reflect a previous run with a previous use of the space (that just decays exponentially)
	Add drop down menus for quanta, breathing rates to master sheet
	Adapting all the current cases into the updated general master sheet
	Adding an estimate of the close contact situation
	Adding the Guangzhou restaurant super-spreading event as an example
	Adding a hospital situation (need to ask people who work at hospitals for details)

Frequently Asked Questions (FAQs) about Estimator of COVID-19 Aerosol Transmission

FAQs about the estimator: big picture

Is there some general explanation of your tool for a general audience?

Yes, see this CIRES Press Release: https://cires.colorado.edu/news/covid-19-airborne-transmission-tool-available

National Geographic has created a simplified version of this tool, which is easier to use to compare different cases: https://www.nationalgeographic.com/science/2020/08/how-to-measure-risk-airborne-coronavirus-your-office-classroom-bus-ride-cvd/

Also this presentation: https://twitter.com/jljcolorado/status/1283868965849059328

Robin Lloyd has published a short summary in Scientific American: https://www.scientificamerican.com/article/coronavirus-news-roundup-for-june-20-june-26/

It has been covered in other news articles, too many to keep track of them here

Are there examples where you or others have applied the estimator to investigate some cases in more detail?

There has been limited time to document cases. I list below some useful cases that people have reported using the tool. If you run the tool for a given case, do share your results in some form, e.g. blog post, Twitter, or just a Google Doc that's publicly viewable, and send me the link for posting here.

This blog post from Prof. Andrew Maynard applies the model to a one semester course at his University and explores the trends in the results

Ryan Davis (a PhD graduate of our program at CU-Boulder) summarized his results for college classroom situations in Twitter

How can I let other people know about the estimator?

You can send them the link to this online document: https://tinyurl.com/covid-estimator

Some people have trouble with the tinyurl links, in that case you can share the direct (if more cumbersome) link: https://docs.google.com/spreadsheets/d/16K1OQkLD4BjgBdO8ePj6ytf-RpPMlJ6aXFg3PrIQBbQ/edit#gid=519189277

If more than 100 people are trying to view the document, Google sends extra people automatically to the View-only version, which does not allow use of the File menu. In that case the links on the green area on the top right of the Readme page allow making a copy into Google Drive, or downloading into Excel

If you use Twitter, you can also re-tweet the original release Tweet: https://twitter.com/jljcolorado/status/1275466006312304640

I get some Excel errors when I open the spreadsheet, do these matter?

	The downloaded spreadsheet can give some nominal errors when opening in Excel, but if you say "yes" it seems to run fine, so we don't think those affect anything. Nobody has told me that it doesn't work for them, once they download.
	I don't know how to change that, since it is a native GSheet and Google is converting it into Excel. Sorry for the confusion this may cause. (If any of you knows how to fix this detail, let me know)
¿Puede traducir esta herramienta al castellano / español? (Can you translate this tool into Spanish?)	
	En principio podría porque soy de Zaragoza (España), aunque llevo 27 años en Estados Unidos. Pero también lo pueden hacer los usuarios poniendo el texto en el traductor de Google. De momento estamos cambiando cosas varias veces al dia, añadiendo explicaciones, corrigiendo algún error, añadiendo nuevos aspectos del cálculo, añadiendo casos etc. Así que recomendamos siempre bajar la ultima version antes de empezar a usar la herramienta. Y mantener dos versiones me llevaria mas tiempo de el que tengo ahora. Si las cosas se calman y la herramienta no esta cambiando (y todavía es útil), entonces haria el esfuerzo.
How do I cite this estimator?	
	Something like "J.L. Jimenez, COVID-19 Aerosol Transmission Estimator, https://tinyurl.com/covid-estimator, accessed 1-Jul-2020" for scientific documents, or just the link for online documents should be sufficient. I do intend to keep the document online indefinitely. For scientific documents you should also cite the papers in which it is based (Miller et al., Buonnano et al. 1 & 2, Riley et al.)
I would like to use this estimator, but this is very difficult to understand. What can I do?	
	The experience so far from the feedback we are getting is that scientists (or people with quantitative backgrounds in other professions) are able to quickly understand the estimator and put it to use, sometimes asking us a question or two. People without a science or quantitative background have more trouble. I can't support users with limited background individually, unfortunately. If you are in the latter situation, I would reach out to someone you know who may be more familiar with science, physics, math, computer programming etc. and see if they can help.
FAQs about the estimator: parameters and model formulation	
What is the structure of the model?	
	It is a box model to track a pollutant (in this case the virus) in an indoor space, see for example Chapter 3 of Daniel Jacob's book http://acmg.seas.harvard.edu/people/faculty/djj/book/bookchap3.html#pgfId=112721, plus the Wells-Riley model of infection https://academic.oup.com/aje/article-abstract/107/5/421/58522
I don't use feet or square feet, can I just work on metric units?	

	Yes, the sheets take the dimensions in feet, but they immediately convert them to meters, and use the meters in all subsequent calculations. So you can type your values in m or m2 directly into those cells (and ignore the ones in feet), and the spreadsheet will work the same.
	One exception is the surface area per student in the "Classroom" sheet. You will need to update that calculation to work with students / m2
How do I model a situation in which only some people are wearing masks?	
	You can run two cases, one with masks and one without, and that will bound the probability of infection.
	To get the average effect, you can multiply the mask efficiency by the fraction of the people wearing masks, for both emission and inhalation. So for example if 50% of the people are wearing surgical / clothy masks, you would enter 25% (0.5 * 50%) for emission efficiency, and 15% (0.5 * 30%) for inhalation efficiency
	To estimate a specific case (e.g. infected person not wearing a mask, susceptible person is wearing a mask), just adjust the efficiencies of emission and inhalation accordingly in the sheet.
If I use the classroom-campus sheets, and I double the class duration and half the number of classes, the number of cases increases. Is this a bug?	
	If you shorten the semester to 6.5 weeks, double number of class periods, to get the same h/ semester for student and instructor, the number of cases stays the same
	If you double the class period to 100 min, but reduce the number of class periods (for students) from 2 to 1 in the default case, the number of cases increases from 593 to 704 student cases. This is slightly non-linear because the longer class period allows more accumulation of infectious quanta in the room, so the second 50 min. have a higher probability of infection than the first 50 min.
How good is the assumption that the air is well mixed within the room?	
	How good this assumption is depends on the specific situation. If a 6ft / 2 m distance is kept, it should apply approximately in many situations. And on average, inhomogeneities will partially cancel out. For example, assume an extreme example of a room where 1/2 of the volume has 0 quanta / m3 and the other 1/2 has twice the average quanta concentration. As long as the number of inhaled quanta is low (< 0.3 or so), the infection risk is linear with the quanta (1- exp(-qi) ~ qi, per https://en.wikipedia.org/wiki/Taylor_series#Exponential_function), and the average number of infections will be the same as it would be in a well-mixed room. At higher concentrations the well-mixed situation is riskier, due to the saturation of the infection probability due to the exponential function.
What is a quanta?	

	A quanta is defined as an infectious dose of the aerosol pathogen, whose inhalation leads to infection. Quanta are discrete and present at very low concentration. For example a given room may have 3 quanta (analogous to pathogen-loader aerosol particle(s)) floating in it, and a susceptible person may or may not be "lucky" enough to inhale at least one of the quanta, given a certain breathing time in the room. The exponential form of the probability equation reflects the probability of a susceptible person in the room inhaling at least one quanta, based on a Poisson statistical distribution of the number of discrete quanta inhaled by a susceptible person present in the space, given a certain aerosol quanta concentration in the room and an inhalation time. As a result, if the average inhaled amount is one quanta, then 63% of the susceptibles will be infected. It is part of the Wells-Riley model of aerosol infection, see https://academic.oup.com/aje/article-abstract/107/5/421/58522
	Quanta are specific for each disease. They lump together in an empirical parameter the rate of emission of viruses as part of respiratory particles in exhaled breath, the infectivity of the viruses upon emission, the particle size distribution of the emissions, the deposition efficiency and deposition location in the respiratory track of the susceptible person of those particles, and the probability that deposition leads to infection. Trying to model each of those parameters explicitly is daunting. As each parameter by itself is quite uncertain, especially for a new disease like COVID-19, the resulting uncertainty of the fully detailed model would be enormous. We can instead use the concept of quanta, and calibrate the emission rate to known outbreaks of the disease. In this way we can do realistic modeling (as in this tool) even with incomplete information about all those factors.
What quanta should I use for singing or shouting?	
	We believe the value of 970 q h-1 is realistic for the Skagit Choir case. It does seem that this was probably a "super-emitter" case, i.e. a person who was emitting an unusually high amount of virus. It is suspected that such "super-emitters" may be partially responsible for super-spreading events (see https://www.sciencemag.org/news/2020/05/why-do-some-covid-19-patients-infect-many-others-whereas-most-don-t-spread-virus-all), in addition to environmental conditions that help the virus transmit at the room-level. Values for loudly speaking / singing recommended by Buonnano range 60-400 q h-1 depending on the level of activity of the person (see "Readme" sheet). So it depends what you are trying to simulate. If you want to see the probability for a worst-case scenario, then use 970 q h-1. For a more typical case, we would recommend 150 q h-1. In any case it is the RELATIVE risk when you change something (ventilation, masking...) that is most meaningful, and that will be much more similar for the two emission rates.
What about resuspension of virus-laden particles that have settled on the floor?	
	This is a concern. I.e. large drops or aerosol particles settle to the floor (this is accounted for in the estimator for the aerosols). The people walking in the room, or while vacuum cleaning, put some of those particles back into the air. Ideally we would add that to the model, but it is quite uncertain and complex to do so. (If you have ideas about how to implement a quick estimate, let me know)
The air within a room is not always well mixed. Doesn't that lead to over- or under-estimating infection risk?	

	One limitation, really of the box model of mixing and dilution (not of the Wells-Riley infection model) is that the air is assumed to be well mixed in the space. On average, this effect will cancel out: e.g. (to make a simple extreme example) if in a room 1/2 of the air contains all the virus, due to poor mixing, and the other 1/2 contains no virus. Then the people on the first half will have twice the chance of infection, while the people on the other half will have zero chance of infection. So that the average probability of infection will be the same. This holds at low quanta concentrations, relevant for most situations, because the infection model is linear to a very good approximation there.
	At very high concentrations, then the model is non-linear and such an average will underestimate the risk (but given all the uncertainties in the model, this is a small problem).
	If you have enough information for a specific situation, you can model one room as several sub-rooms in the estimator. Just one copy of the master sheet per sub-room, each with its particular parameters, and then add the results for the whole room. This will be quite complex in most situations, and in particular airflow patterns in rooms are extremely dependent on the specific room, ventilation pattern, location of occupants etc. but experts and researchers might derive useful information this way.
The estimator only considers one space, but what if a person moves through a building, spending time in multiple spaces?	
	Run the estimator for each space, sum the quanta inhaled, and then apply the Wells-Riley infection probability equation (1-exp(-total quanta inhaled))
Are there limitations to the Wells-Riley model formulation?	
	The W-R model can no doubt be made more sophisticated with attention from the scientific community. A possible example is listed below.
	High exertion activities (HEA) may lead to more efficient infection. Two effects are already accounted for in the model: (a) HEA lead to more respiratory particle exhalation by the infective (which translate to higher quanta emission rates), and (b) also to more virus inhalation by the susceptible due to a higher breathing rate (both effects are already in the model). But a possible third effect is not captured by the model: (c) that the virus in the air is more infective under certain high flow breathing situations. HEA lead to increased breathing velocity and depth of inhalation. Velocity would affect the natural filtration via nose hairs or the upper respiratory tract. Depth of inhalation would determine the amount of quanta inhaled into the recesses of the lungs, versus a shallow breath. A final mechanism is that mouth breathing vs nose breathing may have different risk profiles. This could potentially apply to choirs, and also to singing in a karaoke, or aerobic exercise in a gym. (HT Howard Chong)
	Conversely, the model does not predict how the severity of the infection may vary with the dose. For COVID-19, there is emerging evidence that the severity of the infection is lower at low doses than at high doses, which is a benefit of wearing masks. See this article which summarizes the science as of mid-July 2020: https://www.latimes.com/california/story/2020-07-21/masks-help-avoid-major-illness-coronavirus
	The W-R model has been used by a small community for years, while the majority of the infectious diseases field mostly ignored aerosol transmission of diseases. With the intense current focus of the scientific community on this topic, it is very likely that multiple improvements and tweaks to the W-R model will be proposed. However, W-R is the best we have now, and it should capture the first-order effects, given all the uncertainties.
Is there a threshold of inhaled quanta below which there is no infection?	

	The Wells-Riley model does not have a threshold in its usual formulation. Simply the probability of infection goes down as the number of quanta inhaled goes down. I am not aware of any evidence of a threshold for COVID-19, so I would not assume that one exists. But if the quanta inhaled is very low, the probability of infection will be very low too.
What happens if the infected person leaves after X min, but the susceptible person stays? Or if a 2nd infected person comes in after Y	
	This type of model can easily account for those situations. In this case I am choosing to keep things simple, so that they are more understandable. For those with calculus abilities, just follow the derivation of the solution in Miller et al. and you can use equation 3 in there, and stitch together different periods. You can modify the solution for the case of interest there, and then just modify the formula in the spreadsheet.
	The tool released by Buonnano et al. does include a slightly more complex scenario, so you could try it with that tool.
Since the parameters are uncertain, shouldn't the inputs and outputs be represented as probability distributions?	
	Yes. In this model I am choosing to keep things simple so that it is easier to understand. But one could implement a MonteCarlo simulation using the probability distributions of the parameters and the model here.
	The tool released by Buonnano et al. (based on https://doi.org/10.1016/j.envint.2020.106112) is based on a model which includes this methodology. The first version will not include the MonteCarlo option, but a subsequent version may do so. The tool released by Prasad Kasibhatla does allow performing MonteCarlo simulations, see link below.
What level of infection risk is acceptable?	
	First, keep in mind that the uncertainties are high, given that we have limited information about the quanta emissions in particular, and you shouldn't overinterpret the results. If you get 1% for a case, it may really be 0.3% or 4%, but it won't be 0.001% or 100%.
	Second, which infection risk is tolerable is a question for the people involved, not for me. I.e. we all do activities that involve some risk, and we tolerate it because the risk is low enough compared to the benefit. For example we go places in cars and planes, even though there is a small chance of death or injury by doing those things, because we value the travel more. For example, given the odds of dying in car and airplane travel, we are accepting a risk of 0.00006% and 0.00001% each time we travel respectively (estimated from odds of death from https://www.nsc.org/work-safety/tools-resources/injury-facts/chart, assuming traveling by car 1/2 of the days, by plane 8 times a year, during a 75 yr lifespan). For things like cancer risk, the US EPA uses a chance of 1 in a million (0.0001%) as the limit. Some researchers have suggested that people may be willing tolerate a chance of 1 in 1000 (0.1%) of COVID-19 infection across all their activities (not just one activity which you may simulate with the estimator such as going to class). But you should be the one to determine this for yourself and your situation.
Why haven't you included eye protection?	
	We do know that COVID-19 can be transmitted through the eyes. So if virus-laden aerosol particles land on the eyes, infection can result.
	For this reason we recommend wearing eye protection, such as glasses, goggles, etc. in indoor or crowded outdoor situations.

	However, there is no information we know of about the relative importance of transmission through inhalation or through the eyes, so it is not possible to quantitatively include the impact of eye protection. The estimator assumes that the inhalation route is dominant.
Can I use the estimator to model the time series of infections for the students in my class over an academic year?	
	You would need a more complex model than this one. This is for two reasons: (a) this model only accounts for aerosol transmission, but students may transmit the disease (during school time) through the contact or droplet routes as well, e.g. if distancing is not well followed. (b) most importantly, the students are part of a larger society, they may get COVID-19 outside school, e.g. from a sibling that goes to a different school, their parents, their friends when they interact outside of school or at a party, when they travel out of town etc. So one really needs an epidemiological time series model that approximately accounts for all the interactions in society. This aerosol model addresses a smaller piece, and can perhaps be used to fine-tune some of the parameters that go into epidemiological models.
Can I use the estimator to model the transmission of other diseases that have some fraction of aerosol transmission?	
	Yes, the mathematical model is the same. Mainly two parameters change: the quanta emission rate, and the decay rate of the infectious agent. Some quanta emission rates from the literature are below *in italics* (from https://www.medrxiv.org/content/10.1101/2020.06.15.20132027v2 and references therein). For tuberculosis, the decay rate is ~0. For the other diseases, I would assume the same as for COVID-19 as a first approximation, or search the literature for more accurate rates.
	Influenza: 15-128 q h-1
	Measles: 5580 q h-1
	Tuberculosis: 1.25 - 30,480 q h-1 (Decay rate ~ 0)
	SARS: 28 q h-1 (The decay rate for SARS is very similar than for COVID-19, see: https://www.nejm.org/doi/full/10.1056/nejmc2004973)
	In reality, much like the COVID-19 quanta emission rate can be quite variable, the same is the case for other diseases. The table below for tuberculosis summarizes several studies, and illustrates the range of variability. Ref: https://www.ingentaconnect.com/content/iuatld/ijtld/2003/00000007/00000011/art00002

Table Quanta production rate data for TB and measles outbreaks, as reported by various sources

Disease	Description	Reported quanta per hour	Reported by	Original source
TB	Average TB patient	1.25	Nardell et al.[13]	Riley et al.[15]
TB	Outbreak in office building	12.7	Nardell et al.[13]	Nardell et al.[13]
TB	Laryngeal case of TB	60	Nardell et al.[13]	Riley et al.[15]
TB	Bronchoscopy-related outbreak	250	Nardell et al.[13]	Catanzaro[14]
TB	Bronchoscopy-related outbreak	360	Gammaitoni & Nucci[11]	Catanzaro[14]
TB	Outbreak related to jet irrigation of abscess	2 280	Gammaitoni & Nucci[11]	Hutton et al.[16]
TB	Autopsy outbreak	5 400	Gammaitoni & Nucci[11]	Kantor et al.[17]
TB	Intubation-related outbreak	30 840	Gammaitoni & Nucci[11]	Haley et al.[18]
Measles	Outbreak in a school (index case)	5 580	Riley et al.[9]	Riley et al.[9]

An additional detail is that the particle size distribution containing the infective agents may vary between the different diseases, which in turn will affect the deposition rate (per e.g. https://www.sciencedirect.com/science/article/abs/pii/S1352231002001577). The impact of this uncertainty can be evaluated by varying the deposition rate, see Readme Sheet.

FAQs about using CO2 as an indicator of risk

This method described in Milton et al. (2003). Since both virus-containing respiratory particles and CO2 are exhaled, high CO2 conce

The CO2 emission rate is a function of the person's age, gender, and body mass, as well as the level of activity. Find the emission rate relevant to your case in the tables in the Readme page.

A tool developed by Dr. Andy Persily of NIST to model CO2 vs. time in indoor spaces can be found here: https://pages.nist.gov/CONTAM-apps/webapps/CO2Tool/#/ It allows comparison with the results of our tool, and exploring the effect of some variables in a graphical way.

There are several limitations of this method:
(a) the emission of respiratory particles increases mores strongly with talking and singing, while CO2 changes less for those activities
(b) masks can filter exhaled respiratory particles but not CO2
(c) the virus loses infectivity while in aerosols, but CO2 is inert and is only lost to ventilation
(d) virus-containing particles are deposited to the ground / walls / furniture, and the virus decays in them, while those effect do not happen for CO2
(e) virus-containing particles are only emitted by the infected person, while everyone emits CO2
(f) Cooking or heating with natural gas, propane, wood etc. can emit CO2 which is unrelated to breathing
(g) Outdoor CO2 background can decrease due to crop uptake during the growing season in agricultural areas, or increase due to pollution. These changes are generally below +/-50 ppm, and thus are small compared to the range of interest for indoor air quality

	Some colleagues have recommended to keep indoor CO2 below 600-800 pm to reduce the chance of COVID transmission (per this paper https://onlinelibrary.wiley.com/doi/pdf/10.1111/ina.12639). That sounds like a reasonably low level, although I have not seen a quantitative justification (pls send it my way if you find it). For a more robust result, it is recommended to build a curve of infection risk vs CO2 concentration for your situation of interest. A CO2 sensor can be used to monitor an indoor space.
	Indoor CO2 sensors with a display are available in the ~$100 range. E.g. https://www.amazon.com/Aranet4-Home-Temperature-Ink-Configuration/dp/B07YY7BH2W and https://www.amazon.com/GZAIR-Temperature-Relative-Mountable-0-5000ppm/dp/B08644N7QD I've reached out to colleagues about recommendations, but that type of sensor is what you would need for an indoor space
	The global background CO2 concentration increases over time due to fossil fuel burning. The changes are small compared to the changes in indoor levels due to human breath, but for completeness you can look them up here: https://www.esrl.noaa.gov/gmd/ccgg/trends/
FAQs about improvements to this estimator	
Can you add other outbreaks such as the Guangzhou restaurant or others?	
	Yes. The Guangzhou restaurant has already been analyzed with a similar model by Buonnano et al. (2020b) and can be explained by the model. I will add it here as time allows. For many outbreaks the problem is lack of information on ventilation, which is critical for a quantitative analysis.
FAQs about comparison of this estimator to other related models	
Are there other models available to try to address this problem?	
	Yes, there are multiple other models. So far all try to do the same thing, estimate room-level transmission (away from "close contact" situations like talking face-to-face at 1-2 m), using a box model for the room, and the Wells-Riley infection model.
	I am listing here all the models that I know of that are public. There are many more private ones that people are developing, so far all different versions of the same ideas, often customized for a specific situation of interest. If you know of a model that's not listed here, let me know.
	Yes. The Guangzhou restaurant has already been analyzed with a similar model by Buonnano et al. (2020b) and can be explained by the model. I will add it here as time allows. For many outbreaks the problem is lack of information on ventilation, which is critical for a quantitative analysis.
	Prof. Prasad Kasibhatla of Duke Univ. has adapted the classroom / campus sheets here to take into account the ranges of uncertainty of the parameters through a MonteCarlo simulation at https://tinyurl.com/yxfd23kr (also a Google Sheet that can be downloaded and run in Excel). His version will be useful for advanced researchers who are familiar with the MonteCarlo technique. If you don't know what that is, stay with my tool. A web version of this tool, specific for classrooms, is posted at http://covid-exposure-modeler-data-devils.cloud.duke.edu/
	Alfred Trukenmueller in Germany <alfred.trukenmueller@gmx.de> has developed a similar spreadsheet (in German) based on the Buonnano et al. model. He has made it available at https://www.magentacloud.de/share/e7esxr9ywc

	M. Evans has submitted paper with a similar model: https://www.medrxiv.org/content/10.1101/2020.05.21.20108894v3 No software is available to our knowledge
	Prof. Charles Stainer at the Univ. of Iowa has developed a similar tool (developing part of it independently, and adapting the infection model in our tool), into a custom tool for that University. The results are consistent with ours. It is available here: https://www.stanierlab.org/post/covid-19-aerosol-transmission-calculator-customized-to-iowa A news story on their tool is here: https://dailyiowan.com/2020/07/16/university-of-iowa-researchers-use-aerosol-transmission-calculator-assess-classroom-safety/
	NIST has also released the FaTIMA model, see next FAQ
	So far the results of all the models are very similar in the comparisons we have done. Nathan Skinner (Park Street Church, Boston) has compared this model with the Buonnano and Evens models for their case, and found consistent results. If you find any discrepancies let us know. Perfect agreement is not expected due to small differences in the model parameters or structures used.
Is your model similar to the FaTIMA model from NIST?	
	FaTIMA is at https://www.nist.gov/services-resources/software/fatima
	Yes, both tools are trying to address the same problem and using similar physics and experimental results, but do it slightly differently. Both should be useful to those interested
	FaTIMA currently has more detail on the building and control measures and one can enter those parameters more directly, while in our estimator those are entered as first order rates already.
	FaTIMA does not include an infection model, however, while our estimator does. So with FATIMA you can estimate relative exposures, but not infection rates.
	FaTIMA also does not presently include the effect of masks, or of the breathing rate (which varies with activity level)
	Our estimator has all the equations exposed in the spreadsheet formulas, so it is easier to figure out what's going on. Neither model is that complicated mathematically, but having the code be "open source" may get more people to understand what we are doing, and then potentially incorporate it into other tools etc. Documentation for FaTIMA is at https://doi.org/10.6028/NIST.TN.2095
	Due to the format it may be easier for our estimator to expose different cases, classroom, bus, protest, choir... and have them all there as different sheets. This is only about communication, not the model per se.
	The most important output is to estimate the relative risk of different actions, and that can be done with both tools (except for masks)
	This specific FAQ was written in 25-Jun-2020. Both tools may evolve in the future.
Can I develop my own model or tool, using the information here?	
	This model is distributed under the GNU Public License https://www.gnu.org/licenses/gpl-3.0.en.html
	You are free to adapt this model in any way that would be useful (as long as you don't charge others for the model itself). That was an important reason to make the tool available in this "open source" way, so that we could demystify aerosol transmission modeling, and so that smart people everywhere could do creative things building on this knowledge. But please make sure that you understand the model well. Importantly, I recommend that you compare ("benchmark") your results of a new tool against those of this tool, but multiple sets of parameters, to gain confidence that the new tool is free of bugs.

FAQs about mitigation techniques for COVID-19 aerosol transmission	
What do you recommend in terms of masks, face shields etc?	
	Wear the best face mask you can get. N95 / FFP2 are best if you pay attention to fitting it well around your face and closing gaps, but in many countries there is still limited supply, so we shouldn't deplete their availability for health care and other essential workers. But if you already have one, do wear it by all means. Otherwise surgical masks are the next best, followed by cloth masks. Cloth masks can be quite good if fitted well. See this video to understand the fit: https://twitter.com/jljcolorado/status/1280935408398766080 (and don't stand behind someone with a poorly fitted mask). Face shields provide very little protection, see this thread and its references: https://twitter.com/jljcolorado/status/1278691722449481729
	In addition, since we do know that COVID-19 can be transmitted through the eyes, wear some eye protection. Ideally some safety glasses that are pretty closed around your eyes, limiting the airflow and thus the potential for aerosols to deposit there (see e.g. https://www.mcmaster.com/safety-glasses/). Prescription safety glasses can be obtained from e.g. https://www.rx-safety.com/shop/master-safety-glasses/prescription-safety-glasses/prescription-safety-glasses-rx-jy7/# (I bought one from them and it is ok). Otherwise regular glasses or sunglasses will help some, but not as much.
	This precautions are most important indoors away from your home, or outdoors in crowded situations. In less crowded situations outdoors I wear a surgical mask and my regular glasses.
I see that ventilation can be used to reduce transmission. What can I do for my specific case?	
	See this article for ideas: https://www.sciencedirect.com/science/article/pii/S0160412020317876
	Note that "ventilation" in this context means replacing indoor air with outdoor air. Or potentially filtering indoor air, or subjecting it to germicidal UV light. Moving the air with fans or similar is not "ventilation" but "mixing". It probably hurts by spreading virus-laden particles around faster. It also has a compensating positive effect as the turbulence leads to faster particle deposition to walls and ground.
Is a portable HEPA filter unit useful?	
	A portable HEPA filter system is very useful, as it can remove virus particles from the air. These can be used at home or office situations. They do need to be of a size appropriate to the size of the room. If it is a big room, you may need a couple. Units that have been tested and certified by the Assoc of Home Appliance Manufacturers are listed at https://ahamverifide.org Prof. Shelly Miller of CU-Boulder is an expert on this area and has written a blog post about this: https://shellym80304.com/2020/06/15/a-hopefully-helpful-short-report-on-air-cleaners/ You can download her report from that page. The table below is from that report. But there are many more good filters that are not listed on that table. Follow the instructions in Prof. Miller's blog. This one was purchased by a very knowledgeable colleague for her home: https://www.sylvane.com/coway-airmega-300-air-purifier.html You will see for this one that the clean air delivery rate (CADR) is 260, and the units are cubic feet per minute. So divide by the volume of your room, and multiply by 60 min/hour to get the air exchange rate that you are adding to your room by running the air cleaner.
	See the calculation in the Readme page.

Table 1. Recommended air filters available in the USA, organized by the type of filter

Brand	Model	Tech	Max room size (ft^2)	Smoke CADR	Dust CADR	Pollen CADR	AHAM	CARB	Cost $
Oransi	EJ120	Activated Carbon & HEPA filter	500	323	332	360	✓		899.00
Airgle	AG500	Activated Carbon & HEPA filter	369	238	239	253	✓	✓	1500.00
Winix	D360	Activated Carbon & HEPA filter	360	233	230	235	✓		249.99
Honeywell	HPA600B	HEPA filter	325	210	184	205	✓	✓	769.99
Honeywell	HPA200	Activated Carbon & HEPA filter	310	200	190	180	✓	✓	217.79
Samsung	Cube Air Purifier	Washable pre-filter, Activated Carbon & HEPA filter	310	200	205	185		✓	699.00
Braun	SensorAir Diagnostic Filtration System	Washable pre-filter and filter, Activated Carbon filter	300	200	194	190	✓	✓	446.90
Honeywell	HPA100	Activated Carbon & HEPA filter	155	100	106	100	✓	✓	153.99
Sharp	FPF30UH	HEPA filter	143	101	92	109	✓	✓	119.99
Whirlpool	WPT60	Activated Carbon & HEPA filter	104	67	86	86	✓	✓	115.99

Is reducing the duration of indoor interactions useful?

Yes, this is very useful. In principle the number of infectious particles inhaled will increases proportionally to the duration of the event. But it is worse than that: the risk of infection increases more than linearly with the duration of the event. This is because (assuming the air is clean at the start) the infectious particles accumulate in the room, and e.g. the second 30 min. have a higher concentration than the first 30 min. This can be explored with the estimator, change the duration of the event and look at the output vs duration (e.g. in a graph). So we recommend to keep all indoor activities as short as feasible for that activity.

Is germicidal UV a good idea?

Generally yes, as long as the UV is away from people to avoid serious eye damage, and as long as ozone is not produced.

See this webinar from Prof. Shelly Miller about it: https://shellym80304.files.wordpress.com/2020/05/isiaq-guv-2-compiled.pdf

New systems using 222 nm light are very promising, as (unlike older systems based on 254 nm light) it seems to be safe for people. See: https://www.nature.com/articles/s41598-020-67211-2

	That said, it is being marketed very aggressively by the companies supplying it, and it is not always the most cost-effective solution (purchase, installation, and maintenance are all significant). Improved ventilation and mask wearing should come first. See this paper for an overview of the building-level strategies: https://www.sciencedirect.com/science/article/pii/S0160412020317876
A company is promoting an air cleaning system using ions, plasmas, or OH radicals. Do these systems work?	
	Be very careful with that type of system. They are being promoted very aggressively, but often there is very little detail given about how the system really works. In some cases claims are made that are obviously wrong or suspicious. See this NYT article as an example: https://www.nytimes.com/2020/06/23/us/politics/trump-arizona-church-covid.htm Oxidation systems will turn volatile organic compounds (VOCs) in the air into more oxidized species, NOT into CO2 and water, and the oxidized species and aerosols formed may actually be worse for health than the original VOCs.
	My group has done extensive research on similar systems, from the point of view of atmospheric chemistry applications, see https://doi.org/10.1039/C9CS00766K. I have not seen a lot of peer-reviewed analyses of the details of these "advanced" cleaning systems. There is one in this paper: https://iopscience.iop.org/article/10.1088/1361-6463/ab1466
?Tiene recomendaciones en espanol / castellano?	
	Si, leerlas aqui: https://twitter.com/jljcolorado/status/1280516427158560781
FAQs about COVID-19 aerosol transmission	
How can I learn more about aerosol transmission of COVID-19?	
	I posted a series of 3 threads in Twitter in mid July-2020 with my views at the time. There are many arguments supporting aerosol transmission, and no good arguments against it that I have found (but there are a lot of misunderstandings and errors about aerosols, especially in the medical community). All 3 are linked here: https://twitter.com/jljcolorado/status/1283972530869420035
	There are many resources out there. We would recommend starting with the Miller et al. and Buonnano et al. papers (and their references) and Linsey Marr's Twitter feed: https://twitter.com/linseymarr See a profile of Prof. Marr at: https://www.nytimes.com/2020/06/12/well/live/Coronavirus-aerosols-linsey-marr.html
	Read her tweets from the start of the pandemic starting from now and in reverse chronological order, and you will find links to many many resources, and discussion of many of the important topics
Some in the medical community deny that COVID-19 can be transmitted through aerosols. What do you think of this?	
	Aerosol transmission has been controversial, but now Germany (https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Steckbrief.html), the UK (https://www.gov.uk/government/publications/review-of-two-metre-social-distancing-guidance), the European CDC (https://www.ecdc.europa.eu/sites/default/files/documents/Ventilation-in-the-context-of-COVID-19.pdf), and the US CDC (describes it without using the name, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html) have accepted aerosol transmission of COVID-19. WHO has recently shifted its position to allow for the possibility of aerosol transmission.

	Also REHVA (the European Federation of Heating and Ventilation and Air Conditioning Associations) and ASHRAE (the American Society of Heating, Refrigeration, and Air Conditioning Engineers) have already acknowledged aerosol transmission and recommended measures for their control: https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_ver2_20200403_1.pdf http://ashrae.org/file library/about/position documents/pd_infectiousaerosols_2020.pdf
	There are 3 ways of transmission: contact / fomite, when a person shakes hands or touches an object that an infected person has touched (and the infected person had virus in their hands from touching their nose, a cough etc.). However this is thought to be unlikely (see this from the US CDC https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html) , in particular because enveloped viruses like SARS-CoV-2 may have trouble surviving on hands though the studies are contradictory (https://pubmed.ncbi.nlm.nih.gov/6282993 https://www.medrxiv.org/content/10.1101/2020.07.01.20144253v1). The second way is droplet transmission, when large ballistic droplets in a cough or sneeze land on the eyes, nostrils, or mouth of another person. And the third is aerosol transmission, when particles smaller than ~50 microns (not 5 um as it is often repeated in error) are inhaled by a health person. The pandemic is likely being driven by asymptomatic or pre-symptomatic spread, and those people don't cough, leaving aerosol transmission as the main likely route. It is also likely being driven by super-spreading events, and those (like the Skagit choir) are very very hard to explain without aerosol transmission. See also the next FAQ.
	Unfortunately part of the medical community is literally stuck in science from 1910, and is only changing very slowly and with a lot of resistance. Wells in 1934 (https://academic.oup.com/aje/article-abstract/20/3/611/280025) already got it right, but he and others faced extreme resistance to the evidence. For historical / sociological reasons it has been very difficult to change this stance, despite accumulating evidence, including for COVID-19. For example, it is nearly impossible to explain the Skagit Choir case without aerosol transmission. I am part of a group of experts trying to change this, and I am also collaborating with Profs. Linsey Marr and Lydia Bourouiba and two historians on a paper on how things got to be this way historically. But we can't wait for the medical community to change its understanding before we get the pandemic under control.
	A problem with the WHO committee on disease transmission is that they rely most strongly on evidence from hospitals. That is where a lot of their experts work, and that is where they know the circumstances well. Cases from the community are much more difficult to analyze. They say that if transmission in hospitals is limited even when using surgical masks, therefore it must not go through the air. BUT hospitals have high ventilation, e.g. change the ventilation rate to 12 ACH (typical of hospital) in one of the cases in this model, and transmission goes down dramatically. And everyone is wearing at least surgical masks. And people appear to be more infectious around the onset of disease (when they are in the community) and less when they are very sick in a hospital. And the patients are not talking loudly or singing, they are mostly just breathing, which greatly reduces the quanta emission rate. Therefore it makes a lot of sense that aerosol transmission is limited in hospitals, but it doesn't disprove that it is major in the community. Together with "an anti-aerosol" bias of some critical experts, this partly explains why they are being so slow to accept the risk.
WHO does accept that intubation in hospitals creates an aerosol risk, but aerosols are not important otherwise. What do you think?	
	Intubation and similar procedures create huge amounts of aerosols, so transmission can happen even over short times and with high ventilation. It is also easy to detect. As described above in these FAQs, tuberculosis can release 30,000 infectious doses (quanta) per hr during intubation. But 12 doses / hr were enough to cause an outbreak in an office! We think the same is going on with COVID-19: WHO recognizes the obvious intubation source, but ignores that it happens at a much lower level all the time, and with longer times and low ventilation, it does matter.

COVID-19 does not have a high reproductive number (R0). Thus can't we rule out that it is transmitted via aerosols?	
	No. This is an argument often made by some in the medical community to argue that COVID-19 is not transmitted by aerosols at all. However the argument is flawed and based on a logic error. The argument is based on the assumption that a disease is either "airborne," and then it will display the high transmission characteristics of measles or chickenpox, or otherwise it is not transmitted by aerosols at all. No intermediate cases are possible. This assumption makes no sense, and there is no basis for it.
	The reproductive number R0 is not indicative of aerosol transmission. Anthrax or hantavirus (in N. America) are transmitted exclusively through aerosols, but their R0 = 0 for humans (not for other species). I.e. people get it from aerosols produced in other ways, not expired by humans. But after infection, the human respiratory system does not produce any infective aerosols, and person-to-person transmission does not occur. Very high values of R0 (e.g. measles, chickenpox, with well accepted values of 10-15, pers. comm. J. Tang) are indicative of aerosol transmission. Lower values do not rule out less-efficient aerosol transmission. Clearly if R0 can be 15 measles or it can be 0 (hantavirus) for diseases acquired through aerosols, it can be something in between (COVID-19).
	Different diseases have different fractions and ease of transmission via the aerosol route. For example tuberculosis is only transmitted via aerosols. COVID-19 is transmitted in several ways, including through aerosols. And it is a lot less transmissible than measles or chickenpox through aerosols, but that does not mean that it is not transmissible. We call it "opportunistic airborne" or "aerosol", meaning that it will transmit well through aerosols only under certain conditions: indoors, crowding, low ventilation, long duration (which can be quantified by the estimator), and likely, the presence of a "super-spreader" that emits a high amount of virus particles into the air.There is a lot of evidence to support this, see for example https://www.journalofhospitalinfection.com/article/S0195-6701(20)30245-0/fulltext and https://www.medrxiv.org/content/10.1101/2020.06.15.20132027v1
	No. This is an argument often made by some in the medical community to argue that COVID-19 is not transmitted by aerosols at all. However the argument is flawed and based on a logic error. The argument is based on the assumption that a disease is either "airborne," and then it will display the high transmission characteristics of measles or chickenpox, or otherwise it is not transmitted by aerosols at all. No intermediate cases are possible. This assumption makes no sense, and there is no basis for it.
	This can actually be explored with the estimator. To simulate measles, enter quanta emission rates in the range 5500 q h-1, and you will see that the infection rates are much greater than for typical COVID-19 situations.
	Tuberculosis is only transmitted through aerosols, but its R0 is difficult to quantify due to latency and other issues. But it can be high depending on the situation.
But we are not absolutely certain, so why should we take precautions against aerosol transmission?	
	Because of the precautionary principle: https://en.wikipedia.org/wiki/Precautionary_principle . The cost of doing nothing, if aerosol transmission is happening, is much higher than the cost of doing something, if aerosol transmission ended up being unimportant. Many measures to reduce aerosol transmission, such as reducing indoor crowding, masks etc. also limit other ways of transmission. And remember that absence of (complete) evidence is not evidence of (complete) absence.
My question is not here	
	Shoot me an email at <jose.jimenez@colorado.edu>

Estimation of COVID-19 aerosol transmission: master spreadsheet, adapt this one to your case - Default values are for Skagit Choir outbreak

This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom*

Important inputs as highlighted in orange - change these for your situation

Other, more specialized inputs are highlighted in yellow - change only for more advanced applications

Calculations are not highlighted - don't change these unless you are sure you know what you are doing

Results are in blue -- these are the numbers of interest for most people

Environmental Parameters

	Value			Value in other units		Source / Comments
Length of room	30	ft		9.2	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Width of room	60	ft	=	18.3	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
	1800	sq ft		167	m2	Can overwrite the m2 one. If you want to enter sq ft, enter "=B15*0.305^2" in the m2 cell, where B15 is the cell w/ sq ft
Height	16	ft	=	4.8	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Volume				810	m3	Volume, calculated. (Can also enter directly, then changing dimensions does not work)
Pressure	0.95	atm				Used only for CO2 calculation
Temperature	20	C				Use **web converter** if needed for F --> C. Used for CO2 calculation, eventually for survival rate of virus
Relative Humidity	50	%				Not yet used, but may eventually be used for survival rate of virus
Background CO2 Outdoors	415	ppm				See readme
Duration of event	30	min		0.5	h	Value for your situation of interest
Number of repetitions of event	1	times				For e.g. multiple class meetings, multiple commutes in public transportation etc.
Ventilation w/ outside air	0.7	h-1				Value in h-1: Readme: Same as "air changes per hour". Value in L/s/per to compare to guidelines (e.g. ASHRAE 62.1)
Decay rate of the virus	0.62	h-1				See Readme, can estimate for a given T, RH, UV from DHS estimator
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. filtering of recirc. air, HEPA air cleaner, UV disinfection, etc. See FAQs, Readme for calc for portable HEPA filter
Total first order loss rate	1.62	h-1				Sum of all the first-order rates
Ventilation rate per person	2.6	L/s/person				This is the value of ventilation that really matters for disease transmission. Includes additional control measures

Parameters related to people and activity in the room

Total N people present	61		Value for your situation of interest
Infective people	1	person	Keep this at one unless you really want to study a different cases - see conditional and absolute results
Fraction of population inmune	0%		From seroprevalence reports, will depend on each location and time, see Readme
Susceptible people	60	people	Value for your situation of interest

Density (area / person) in room	30	sq ft / person	
Density (people / area) in room	0.36	persons / m2	
Density (volume / person) in room	13.3	m3 / person	
Breathing rate (susceptibles)	1.56	m3 / h	See Readme sheet - varies a lot with activity level
CO2 emission rate (1 person)	0.0091	L/s (@ 273 K and 1 atm)	From tables in Readme page. This does not affect infection calculation, only use of CO2 as indicator, could ignore
CO2 emission rate (all persons)	0.6271	L/s (@ at actual P & T of room)	Previous, multiplied by number of people, and applying ideal gas law to convert to ambient P & T
Quanta exhalation rate (infected)	970	infectious doses (quanta) h-1	See Readme file. Depends strongly on activity, also like person.This is the most uncertain parameter, try different values.
Exhalation mask efficiency	0%		0 if infective person is not wearing a mask. See Readme sheet
Fraction of people w/ masks	0%		Value for your situation. It is applied to everybody for both emission & inhalation. Modify formulas manually if needed
Inhalation mask efficiency	0%		See Readme sheet
Parameters related to the COVID-19 disease			
Probability of being infective	0.011%		Very important parameter, specific for each region and time period. For ABSOLUTE results (prob. given prevalence of disease in the population). See Readme sheet
Hospitalization rate	20%		From news reports. Varies strongly with age and risk factors
Death rate	4%		From news reports. Varies strongly with age and risk factors (1% typical - Higher for older / at risk people)
CONDITIONAL result for ONE EVENT: we assume the number of infected people above, and get the results under that assumption			
More appropriate to simulate known outbreaks (e.g. choir, restaurant etc.), and an worst-case scenario for regular events (if one is unlucky enough to have infective people in attendance of a given event)			
Net emission rate	970	infectious doses (quanta) h-1	Includes the number of infective people present
Avg Quanta Concentration	0.23	infectious doses (quanta) m-3	Analytical solution of the box model. Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.18	infectious doses (quanta)	
Conditional Results for A GIVEN PERSON & ONE EVENT (assuming number of infected above, typically 1)			
Probability of infection (1 person)	16.6%		Applying Wells-Riley infection model to the amount of infectious doses inhaled. Equation (1) in Miller et al. (2020)
Prob. of hospitalization (1 person)	3.3%		
Prob. of death (1 person)	0.7%		
Ratio to risk of car travel death	11061	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Conditional Results for ALL ATTENDEES & ONE EVENT (assuming number of infected above, typically 1)			
Number of COVID cases arising	9.95		Number of people. Multiplies probability of one person, times the number of susceptible people present
N of hospitalizations arising	1.99		Number of people
N of deaths arising	0.40		Number of people
Airborne Infection Risk Parameters (From Peng et al., 2021, submitted)			
Infection Risk Parameter (H)		h2 person / m3	Indicator of risk in terms of OUTBREAK SIZE. Low risk: H<0.05; Med: H<0.5; High: H>0.5; Peng et al. (2021, submitted)
Relative Inf. risk Parameter (Hr)		h2 / m3	Indicator of risk in terms of ATTACK RATE. Low risk: Hr< 0.001; Med< 0.01; High>0.01 From Peng et al. (2021, submitte

Results for CO2 as an indicator of risk (not needed for infection estimation, can ignore for simplicity)			
Avg CO2 mixing ratio	1037	ppm (including 400 ppm background)	Analytical solution of the box model. Equation (4) in Miller et al. (2020). See FAQ page for differences w/ quanta calc
Avg CO2 concentration	1.08	g m-3 (excluding 400 ppm background)	Conversion from Atmos. Chem. Cheat Sheet, plus ideal gas law
Exhaled CO2 re-inhaled per person	0.84	grams (excluding 400 ppm background)	This parameter is the most analogous to risk. See FAQ page for limitations
Exhaled CO2 re-inhaled per person	311.07	ppm * h (maybe easier units, excludes 400 ppm background	This parameter is the most analogous to risk. See FAQ page for limitations
Exhaled CO2 re-inhaled per person	0.0311	%CO2 * h (same as above, different unit, for use next)	
Ratio of prob of infection to Ex_CO2	5.334	% chance of infection for 1 person per %CO2 * h inhaled	
CO2 to inhale 1 hr for 1% infect.	434	ppm	This is another metric of risk
ABSOLUTE result for ONE EVENT: we use the prevalence of the disease in the community to estimate how many infected people may be present in our event, and calculate results based on that			
More appropriate for general risk estimation, e.g. in a college classroom, indoor gathering etc., where often infective people will not be present			
N of infective people present	0.007		It has to be interpreted statistically. This would be the average over e.g. 100 repetitions of the event in a given location
Absolute results for A GIVEN PERSON & ONE EVENT (using disease prevalence in community)			
Probability of infection (1 person)	0.11%		
Prob. of hospitalization (1 person)	0.02%		
Prob. of death (1 person)	0.00%		
Ratio to risk of car travel death	72	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Absolute results for ALL ATTENDEES & ONE EVENT (using disease prevalence in community)			
Number of COVID cases arising	0.06		Number of people
N of hospitalizations arising	0.01		Number of people
N of deaths arising	0.00		Number of people
CO2 to inhale 1 hr for 1% infect.	3300	ppm	This is another metric of risk
ABSOLUTE result for events that are REPEATED MULTIPLE TIMES (e.g. many class meetings during a semester, or a daily commute on public transportation) - Ignore for a single event			
Absolute results for A GIVEN PERSON & MULTIPLE EVENTS (using disease prevalence in community)			
Probability of infection (1 person)	0.11%		
Prob. of hospitalization (1 person)	0.02%		
Prob. of death (1 person)	0.00%		
Ratio to risk of car travel death	72	times larger risk (than traveling same N of days)	See FAQs for rough estimate of death traveling by car on a given day
Absolute results for ALL ATTENDEES & MULTIPLE EVENTS (using disease prevalence in community)			
Number of COVID cases arising	0.06		Number of people
N of hospitalizations arising	0.01		Number of people
N of deaths arising	0.00		Number of people
Specific notes for this case			

Probability of death is set higher because of the higher age of choir members (75% of those ill were >= 65 yr old). Suggest changing to 1% for general applications	
Probability of being infective calculated from prevalence of the disease in the county at the time (7 cases * 2 to account for undetected cases / 129000 population of county), see Miller et al. 2020	

Estimation of COVID-19 aerosol transmission: master spreadsheet, adapt this one to your case - Default values are for Skagit Choir outbreak

This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom*

Important inputs as highlighted in orange - change these for your situation

Other, more specialized inputs are highlighted in yellow - change only for more advanced applications

Calculations are not highlighted - don't change these unless you are sure you know what you are doing

Results are in blue -- these are the numbers of interest for most people

Environmental Parameters						
	Value			**Value in other units**		**Source / Comments**
Length of room	25	ft		7.6	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Width of room	20	ft	=	6.1	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
	500	sq ft		47	m2	Can overwrite the m2 one. If you want to enter sq ft, enter "=B15*0.305^2" in the m2 cell, where B15 is the cell w/ sq ft
Height	10	ft	=	3.1	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Volume				142	m3	Volume, calculated. (Can also enter directly, then changing dimensions does not work)
Pressure	0.95	atm				Used only for CO2 calculation
Temperature	20	C				Use **web converter** if needed for F --> C. Used for CO2 calculation, eventually for survival rate of virus
Relative Humidity	50	%				Not yet used, but may eventually be used for survival rate of virus
Background CO2 Outdoors	415	ppm				See readme
Duration of event	50	min		0.8	h	Value for your situation of interest
Number of repetitions of event	180	times				For e.g. multiple class meetings, multiple commutes in public transportation etc.
Ventilation w/ outside air	3	h-1				Value in h-1: Readme: Same as "air changes per hour". Value in L/s/per to compare to guidelines (e.g. ASHRAE 62.1)
Decay rate of the virus	0.62	h-1				See Readme, can estimate for a given T, RH, UV from DHS estimator
Deposition to surfaces	0.3	h-1		0.62		Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. filtering of recirc. air, HEPA air cleaner, UV disinfection, etc. See FAQs, Readme for calc for portable HEPA filter
Total first order loss rate	3.92	h-1				Sum of all the first-order rates
Ventilation rate per person	11.8	L/s/person				This is the value of ventilation that really matters for disease transmission. Includes additional control measures
Parameters related to people and activity in the room						
Total N people present	10					Value for your situation of interest
Infective people	1	person				Keep this at one unless you really want to study a different cases - see conditional and absolute results
Fraction of population inmune	0%					From seroprevalence reports, will depend on each location and time, see Readme
Susceptible people	9	people				Value for your situation of interest

Density (area / person) in room	50	sq ft / person	
Density (people / area) in room	0.21	persons / m2	
Density (volume / person) in room	14.2	m3 / person	
Breathing rate (susceptibles)	0.52	m3 / h	See Readme sheet - varies a lot with activity level
CO2 emission rate (1 person)	0.005	L/s (@ 273 K and 1 atm)	From tables in Readme page. This does not affect infection calculation, only use of CO2 as indicator, could ignore
CO2 emission rate (all persons)	0.0565	L/s (@ at actual P & T of room)	Previous, multiplied by number of people, and applying ideal gas law to convert to ambient P & T
Quanta exhalation rate (infected)	25	infectious doses (quanta) h-1	See Readme file. Depends strongly on activity, also like person.This is the most uncertain parameter, try different values.
Exhalation mask efficiency	50%		0 if infective person is not wearing a mask. See Readme sheet
Fraction of people w/ masks	100%		Value for your situation. It is applied to everybody for both emission & inhalation. Modify formulas manually if needed
Inhalation mask efficiency	30%		See Readme sheet
Parameters related to the COVID-19 disease			
Probability of being infective	0.20%		Very important parameter, specific for each region and time period. For ABSOLUTE results (prob. given prevalence of disease in the population). See Readme sheet
Hospitalization rate	20%		From news reports. Varies strongly with age and risk factors
Death rate	1%		From news reports. Varies strongly with age and risk factors (1% typical - Higher for older / at risk people)
CONDITIONAL result for ONE EVENT: we assume the number of infected people above, and get the results under that assumption			
More appropriate to simulate known outbreaks (e.g. choir, restaurant etc.), and an worst-case scenario for regular events (if one is unlucky enough to have infective people in attendance of a given event)			
Net emission rate	12.5	infectious doses (quanta) h-1	Includes the number of infective people present
Avg Quanta Concentration	0.02	infectious doses (quanta) m-3	Analytical solution of the box model. Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.00	infectious doses (quanta)	
Conditional Results for A GIVEN PERSON & ONE EVENT (assuming number of infected above, typically 1)			
Probability of infection (1 person)	0.48%		Applying Wells-Riley infection model to the amount of infectious doses inhaled. Equation (1) in Miller et al. (2020)
Prob. of hospitalization (1 person)	0.1%		
Prob. of death (1 person)	0.005%		
Ratio to risk of car travel death	79	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Conditional Results for ALL ATTENDEES & ONE EVENT (assuming number of infected above, typically 1)			
Number of COVID cases arising	0.04		Number of people. Multiplies probability of one person, times the number of susceptible people present
N of hospitalizations arising	0.01		Number of people
N of deaths arising	0.00		Number of people
Results for CO2 as an indicator of risk (not needed for infection estimation, can ignore for simplicity)			
Avg CO2 mixing ratio	717	ppm (including 400 ppm background)	Analytical solution of the box model. Equation (4) in Miller et al. (2020). See FAQ page for differences w/ quanta calc
Avg CO2 concentration	0.53	g m-3 (excluding 400 ppm background)	Conversion from Atmos. Chem. Cheat Sheet, plus ideal gas law

Exhaled CO2 re-inhaled per person	0.23	grams (excluding 400 ppm background)				This parameter is the most analogous to risk. See FAQ page for limitations	
Exhaled CO2 re-inhaled per person	251.97	ppm * h (maybe easier units, excludes 400 ppm background				This parameter is the most analogous to risk. See FAQ page for limitations	
Exhaled CO2 re-inhaled per person	0.0252	%CO2 * h (same as above, different unit, for use next)					
Ratio of prob of infection to Ex_CO2	0.189	% chance of infection for 1 person per %CO2 * h inhaled					
CO2 to inhale 1 hr for 1% infect.	944	ppm				This is another metric of risk	
ABSOLUTE result for ONE EVENT: we use the prevalence of the disease in the community to estimate how many infected people may be present in our event, and calculate results based on that							
More appropriate for general risk estimation, e.g. in a college classroom, indoor gathering etc., where often infective people will not be present							
N of infective people present	0.020					It has to be interpreted statistically. This would be the average over e.g. 100 repetitions of the event in a given location	
Absolute results for A GIVEN PERSON & ONE EVENT (using disease prevalence in community)							
Probability of infection (1 person)	0.01%					0.00008571742813	
Prob. of hospitalization (1 person)	0.00%						
Prob. of death (1 person)	0.00%						
Ratio to risk of car travel death	1	times larger risk				See FAQs for rough estimate of death traveling by car on a given day	
Absolute results for ALL ATTENDEES & ONE EVENT (using disease prevalence in community)							
Number of COVID cases arising	0.00					Number of people	
N of hospitalizations arising	0.00					Number of people	
N of deaths arising	0.00					Number of people	
CO2 to inhale 1 hr for 1% infect.	29811	ppm				This is another metric of risk	
ABSOLUTE result for events that are REPEATED MULTIPLE TIMES (e.g. many class meetings during a semester, or a daily commute on public transportation) - Ignore for a single event							
Absolute results for A GIVEN PERSON & MULTIPLE EVENTS (using disease prevalence in community)							
Probability of infection (1 person)	1.53%						
Prob. of hospitalization (1 person)	0.31%						
Prob. of death (1 person)	0.02%						
Ratio to risk of car travel death	1	times larger risk (than traveling same N of days)				See FAQs for rough estimate of death traveling by car on a given day	
Absolute results for ALL ATTENDEES & MULTIPLE EVENTS (using disease prevalence in community)							
Number of COVID cases arising	0.14					Number of people	
N of hospitalizations arising	0.03					Number of people	
N of deaths arising	0.00					Number of people	
Specific notes for this case							
Breathing rate							
	Using 1/2 of sedentary and light activity, 16-21 yrs old as default. BR only matters for susceptible. To study transmission from students to teacher, need to increase this value accordingly.						
	To study transmission to young children, BR also needs to be adjusted according to Readme table						
Quanta emission rate							

	Current value is for a teacher talking a lot			
	For teenagers, use values from readme, according to activity			
	Small children are thought to be less contagious, and also breathe less air, so perhaps reduce the quanta emission rate by x5			

Estimation of COVID-19 aerosol transmission: case of a subway car (specific to a given city)

This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom*

Important inputs as highlighted in orange - change these for your situation

Other, more specialized inputs are highlighted in yellow - change only for more advanced applications

Calculations are not highlighted - don't change these unless you are sure you know what you are doing

Results are in blue -- these are the numbers of interest for most people

Environmental Parameters

	Value			Value in other units		Source / Comments
Length of room	44	ft		13.4	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Width of room	10	ft	=	3.1	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
	440	sq ft		41	m2	Can overwrite the m2 one. If you want to enter sq ft, enter "=B15*0.305^2" in the m2 cell, where B15 is the cell w/ sq ft
Height	12	ft	=	3.7	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Volume				150	m3	Volume, calculated. (Can also enter directly, then changing dimensions does not work)
Pressure	0.95	atm				Used only for CO2 calculation
Temperature	20	C				Use **web converter** if needed for F --> C. Used for CO2 calculation, eventually for survival rate of virus
Relative Humidity	50	%				Not yet used, but may eventually be used for survival rate of virus
Background CO2 Outdoors	415	ppm				See readme
Duration of event	20	min		0.3	h	Value for your situation of interest
Number of repetitions of event	60	times				For e.g. multiple class meetings, multiple commutes in public transportation etc.
Ventilation w/ outside air	5.7	h-1				Value in h-1: Readme: Same as "air changes per hour". Value in L/s/per to compare to guidelines (e.g. ASHRAE 62.1)
Decay rate of the virus	0.62	h-1				See Readme, can estimate for a given T, RH, UV from DHS estimator
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	3.6	h-1				E.g. filtering of recirc. air, HEPA air cleaner, UV disinfection, etc. See FAQs, Readme for calc for portable HEPA filter
Total first order loss rate	10.22	h-1				Sum of all the first-order rates
Ventilation rate per person	11.1	L/s/person				This is the value of ventilation that really matters for disease transmission. Includes additional control measures

Parameters related to people and activity in the room

Total N people present	35		Value for your situation of interest
Infective people	1	person	Keep this at one unless you really want to study a different cases - see conditional and absolute results
Fraction of population inmune	15%		From seroprevalence reports, will depend on each location and time, see Readme
Susceptible people	28.9	people	Value for your situation of interest

Density (area / person) in room	13	sq ft / person	
Density (people / area) in room	0.86	persons / m2	
Density (volume / person) in room	4.3	m3 / person	
Breathing rate (susceptibles)	0.42	m3 / h	See Readme sheet - varies a lot with activity level
CO2 emission rate (1 person)	0.007	L/s (@ 273 K and 1 atm)	From tables in Readme page. This does not affect infection calculation, only use of CO2 as indicator, could ignore
CO2 emission rate (all persons)	0.2768	L/s (@ at actual P & T of room)	Previous, multiplied by number of people, and applying ideal gas law to convert to ambient P & T
Quanta exhalation rate (infected)	25	infectious doses (quanta) h-1	See Readme file. Depends strongly on activity, also like person.This is the most uncertain parameter, try different values.
Exhalation mask efficiency	50%		0 if infective person is not wearing a mask. See Readme sheet
Fraction of people w/ masks	100%		Value for your situation. It is applied to everybody for both emission & inhalation. Modify formulas manually if needed
Inhalation mask efficiency	30%		See Readme sheet
Parameters related to the COVID-19 disease			
Probability of being infective	0.10%		Very important parameter, specific for each region and time period. For ABSOLUTE results (prob. given prevalence of disease in the population). See Readme sheet
Hospitalization rate	20%		From news reports. Varies strongly with age and risk factors
Death rate	1%		From news reports. Varies strongly with age and risk factors (1% typical - Higher for older / at risk people)
CONDITIONAL result for ONE EVENT: we assume the number of infected people above, and get the results under that assumption			
More appropriate to simulate known outbreaks (e.g. choir, restaurant etc.), and an worst-case scenario for regular events (if one is unlucky enough to have infective people in attendance of a given event)			
Net emission rate	12.5	infectious doses (quanta) h-1	Includes the number of infective people present
Avg Quanta Concentration	0.01	infectious doses (quanta) m-3	Analytical solution of the box model. Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.00	infectious doses (quanta)	
Conditional Results for A GIVEN PERSON & ONE EVENT (assuming number of infected above, typically 1)			
Probability of infection (1 person)	0.06%		Applying Wells-Riley infection model to the amount of infectious doses inhaled. Equation (1) in Miller et al. (2020)
Prob. of hospitalization (1 person)	0.01%		
Prob. of death (1 person)	0.00%		
Ratio to risk of car travel death	10	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Conditional Results for ALL ATTENDEES & ONE EVENT (assuming number of infected above, typically 1)			
Number of COVID cases arising	0.017		Number of people. Multiplies probability of one person, times the number of susceptible people present
N of hospitalizations arising	0.003		Number of people
N of deaths arising	0.000		Number of people
Results for CO2 as an indicator of risk (not needed for infection estimation, can ignore for simplicity)			
Avg CO2 mixing ratio	1045	ppm (including 400 ppm background)	Analytical solution of the box model. Equation (4) in Miller et al. (2020). See FAQ page for differences w/ quanta calc
Avg CO2 concentration	1.12	g m-3 (excluding 400 ppm background)	Conversion from Atmos. Chem. Cheat Sheet, plus ideal gas law

Exhaled CO2 re-inhaled per person	0.16	grams (excluding 400 ppm background)			This parameter is the most analogous to risk. See FAQ page for limitations	
Exhaled CO2 re-inhaled per person	214.86	ppm * h (maybe easier units, excludes 400 ppm backgrounc			This parameter is the most analogous to risk. See FAQ page for limitations	
Exhaled CO2 re-inhaled per person	0.0215	%CO2 * h (same as above, different unit, for use next)				
Ratio of prob of infection to Ex_CO2	0.027	% chance of infection for 1 person per %CO2 * h inhaled				
CO2 to inhale 1 hr for 1% infect.	4078	ppm			This is another metric of risk	
ABSOLUTE result for ONE EVENT: we use the prevalence of the disease in the community to estimate how many infected people may be present in our event, and calculate results based on that						
More appropriate for general risk estimation, e.g. in a college classroom, indoor gathering etc., where often infective people will not be present						
N of infective people present	0.030				It has to be interpreted statistically. This would be the average over e.g. 100 repetitions of the event in a given location	
Absolute results for A GIVEN PERSON & ONE EVENT (using disease prevalence in community)						
Probability of infection (1 person)	0.0017%					
Prob. of hospitalization (1 person)	0.0003%					
Prob. of death (1 person)	0.0000%					
Ratio to risk of car travel death	0.3	times larger risk			See FAQs for rough estimate of death traveling by car on a given day	
Absolute results for ALL ATTENDEES & ONE EVENT (using disease prevalence in community)						
Number of COVID cases arising	0.0005				Number of people	
N of hospitalizations arising	0.0001				Number of people	
N of deaths arising	0.0000				Number of people	
CO2 to inhale 1 hr for 1% infect.	127176	ppm			This is another metric of risk	
ABSOLUTE result for events that are REPEATED MULTIPLE TIMES (e.g. many class meetings during a semester, or a daily commute on public transportation) - Ignore for a single event						
Absolute results for A GIVEN PERSON & MULTIPLE EVENTS (using disease prevalence in community)						
Probability of infection (1 person)	0.10%					
Prob. of hospitalization (1 person)	0.02%					
Prob. of death (1 person)	0.00%					
Ratio to risk of car travel death	0	times larger risk (than traveling same N of days)			See FAQs for rough estimate of death traveling by car on a given day	
Absolute results for ALL ATTENDEES & MULTIPLE EVENTS (using disease prevalence in community)						
Number of COVID cases arising	0.03				Number of people	
N of hospitalizations arising	0.01				Number of people	
N of deaths arising	0.00				Number of people	
Technical appendix: ventilation calculations for this case						
Volume			150	m3		
probability of being infected	0.30%					

passengers on car	35	people				typical value	
Breathing rate	0.8	m3 / h				Estimated from Miller et al. (2020), for someone occasionally talking	
Duration of subway ride	20	min		0.33	h	Typical value	
volumetric recirc air	900	cfm		1521	m3/h	from info provided by subway operator	
	424.80	L/s					
filter efficiency	35%					assumption	
Volumetric recirc air particle free	148.7	L/s		4.25	L/s/P		
ventilation w/ filtered recirc air	3.6	h-1					
volumetric rate outside air	500	cfm		845	m3/h	from info provided by subway operator	
=	236	L/s		6.74	L/s/P		
Ventilation w/ outside air	5.6	h-1				Same as "air changes per hour"	
total volumetric rate	384.7	L/s		11.0	L/s/person		

Estimation of COVID-19 aerosol transmission: Case of supermarket worker

This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom*

Important inputs as highlighted in orange - change these for your situation

Other, more specialized inputs are highlighted in yellow - change only for more advanced applications

Calculations are not highlighted - don't change these unless you are sure you know what you are doing

Results are in blue -- these are the numbers of interest for most people

Environmental Parameters

	Value			**Value in other units**		**Source / Comments**
Length of room	80	ft		24.4	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Width of room	50	ft	=	15.3	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
	4000	sq ft		372	m2	Can overwrite the m2 one. If you want to enter sq ft, enter "=B15*0.305^2" in the m2 cell, where B15 is the cell w/ sq ft
Height	18	ft	=	5.5	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Volume				2043	m3	Volume, calculated. (Can also enter directly, then changing dimensions does not work)
Pressure	0.95	atm				Used only for CO2 calculation
Temperature	20	C				Use **web converter** if needed for F --> C. Used for CO2 calculation, eventually for survival rate of virus
Relative Humidity	50	%				Not yet used, but may eventually be used for survival rate of virus
Background CO2 Outdoors	415	ppm				See readme
Duration of event	480	min		8.0	h	Value for your situation of interest
Number of repetitions of event	21	times				For e.g. multiple class meetings, multiple commutes in public transportation etc.
Ventilation w/ outside air	3	h-1				Value in h-1: Readme: Same as "air changes per hour". Value in L/s/per to compare to guidelines (e.g. ASHRAE 62.1)
Decay rate of the virus	0.62	h-1				See Readme, can estimate for a given T, RH, UV from DHS estimator
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. filtering of recirc. air, HEPA air cleaner, UV disinfection, etc. See FAQs, Readme for calc for portable HEPA filter
Total first order loss rate	3.92	h-1				Sum of all the first-order rates
Ventilation rate per person	22.7	L/s/person				This is the value of ventilation that really matters for disease transmission. Includes additional control measures

Parameters related to people and activity in the room

Total N people present	75		Value for your situation of interest
Infective people	1	person	Keep this at one unless you really want to study a different cases - see conditional and absolute results
Fraction of population inmune	6%		From seroprevalence reports, will depend on each location and time, see Readme
Susceptible people	69.56	people	Value for your situation of interest

Density (area / person) in room	53	sq ft / person	
Density (people / area) in room	0.20	persons / m2	
Density (volume / person) in room	27.2	m3 / person	
Breathing rate (susceptibles)	0.72	m3 / h	See Readme sheet - varies a lot with activity level
CO2 emission rate (1 person)	0.00675	L/s (@ 273 K and 1 atm)	From tables in Readme page. This does not affect infection calculation, only use of CO2 as indicator, could ignore
CO2 emission rate (all persons)	0.5719	L/s (@ at actual P & T of room)	Previous, multiplied by number of people, and applying ideal gas law to convert to ambient P & T
Quanta exhalation rate (infected)	10	infectious doses (quanta) h-1	See Readme file. Depends strongly on activity, also like person.This is the most uncertain parameter, try different values.
Exhalation mask efficiency	50%		0 if infective person is not wearing a mask. See Readme sheet
Fraction of people w/ masks	100%		Value for your situation. It is applied to everybody for both emission & inhalation. Modify formulas manually if needed
Inhalation mask efficiency	30%		See Readme sheet
Parameters related to the COVID-19 disease			
Probability of being infective	0.10%		Very important parameter, specific for each region and time period. For ABSOLUTE results (prob. given prevalence of disease in the population). See Readme sheet
Hospitalization rate	20%		From news reports. Varies strongly with age and risk factors
Death rate	1%		From news reports. Varies strongly with age and risk factors (1% typical - Higher for older / at risk people)
CONDITIONAL result for ONE EVENT: we assume the number of infected people above, and get the results under that assumption			
More appropriate to simulate known outbreaks (e.g. choir, restaurant etc.), and an worst-case scenario for regular events (if one is unlucky enough to have infective people in attendance of a given event)			
Net emission rate	5	infectious doses (quanta) h-1	Includes the number of infective people present
Avg Quanta Concentration	0.00	infectious doses (quanta) m-3	Analytical solution of the box model. Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.00	infectious doses (quanta)	
Conditional Results for A GIVEN PERSON & ONE EVENT (assuming number of infected above, typically 1)			
Probability of infection (1 person)	0.2%		Applying Wells-Riley infection model to the amount of infectious doses inhaled. Equation (1) in Miller et al. (2020)
Prob. of hospitalization (1 person)	0.0%		
Prob. of death (1 person)	0.0%		
Ratio to risk of car travel death	41	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Conditional Results for ALL ATTENDEES & ONE EVENT (assuming number of infected above, typically 1)			
Number of COVID cases arising	0.17		Number of people. Multiplies probability of one person, times the number of susceptible people present
N of hospitalizations arising	0.03		Number of people
N of deaths arising	0.00		Number of people
Results for CO2 as an indicator of risk (not needed for infection estimation, can ignore for simplicity)			
Avg CO2 mixing ratio	722	ppm (including 400 ppm background)	Analytical solution of the box model. Equation (4) in Miller et al. (2020). See FAQ page for differences w/ quanta calc
Avg CO2 concentration	0.56	g m-3 (excluding 400 ppm background)	Conversion from Atmos. Chem. Cheat Sheet, plus ideal gas law

Exhaled CO2 re-inhaled per person	3.22	grams (excluding 400 ppm background)	This parameter is the most analogous to risk. See FAQ page for limitations
Exhaled CO2 re-inhaled per person	2575.64	ppm * h (maybe easier units, excludes 400 ppm backgrounc	This parameter is the most analogous to risk. See FAQ page for limitations
Exhaled CO2 re-inhaled per person	0.2576	%CO2 * h (same as above, different unit, for use next)	
Ratio of prob of infection to Ex_CO2	0.009	% chance of infection for 1 person per %CO2 * h inhaled	
CO2 to inhale 1 hr for 1% infect.	10503	ppm	This is another metric of risk
ABSOLUTE result for ONE EVENT: we use the prevalence of the disease in the community to estimate how many infected people may be present in our event, and calculate results based on that			
More appropriate for general risk estimation, e.g. in a college classroom, indoor gathering etc., where often infective people will not be present			
N of infective people present	0.071		It has to be interpreted statistically. This would be the average over e.g. 100 repetitions of the event in a given location
Absolute results for A GIVEN PERSON & ONE EVENT (using disease prevalence in community)			
Probability of infection (1 person)	0.02%		
Prob. of hospitalization (1 person)	0.00%		
Prob. of death (1 person)	0.00%		
Ratio to risk of car travel death	3	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Absolute results for ALL ATTENDEES & ONE EVENT (using disease prevalence in community)			
Number of COVID cases arising	0.01		Number of people
N of hospitalizations arising	0.00		Number of people
N of deaths arising	0.00		Number of people
CO2 to inhale 1 hr for 1% infect.	145450	ppm	This is another metric of risk
ABSOLUTE result for events that are REPEATED MULTIPLE TIMES (e.g. many class meetings during a semester, or a daily commute on public transportation) - Ignore for a single event			
Absolute results for A GIVEN PERSON & MULTIPLE EVENTS (using disease prevalence in community)			
Probability of infection (1 person)	0.35%		
Prob. of hospitalization (1 person)	0.07%		
Prob. of death (1 person)	0.00%		
Ratio to risk of car travel death	3	times larger risk (than traveling same N of days)	See FAQs for rough estimate of death traveling by car on a given day
Absolute results for ALL ATTENDEES & MULTIPLE EVENTS (using disease prevalence in community)			
Number of COVID cases arising	0.25		Number of people
N of hospitalizations arising	0.05		Number of people
N of deaths arising	0.00		Number of people
Specific notes for this case			
Based on a specific supermarket in Boulder, Colorado.			
Horizontal dimensions estimated from Google Maps (using scale), height using pictures from Google Street View (using people present for scale)			
Ventilation rate estimated from ASHRAE standard in Readme page			
Occupancy typical daily average, based on my visits to the space pre-pandemic (may be lower now.			

Other parameters estimated per Readme for this situation					
This is for a supermarket worker. For a customer, change the time spent in the story to e.g. 1 hr, 4 times a week to simulate 1 month					

Estimation of COVID-19 aerosol transmission: Case for Soccer Match (ONLY through air beyond close proximity, so will underestimate a lot)

This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom*

Important inputs as highlighted in orange - change these for your situation

Other, more specialized inputs are highlighted in yellow - change only for more advanced applications

Calculations are not highlighted - don't change these unless you are sure you know what you are doing

Results are in blue -- these are the numbers of interest for most people

Environmental Parameters						
	Value			**Value in other units**		**Source / Comments**
Length of room	600	ft		183.0	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Width of room	300	ft	=	91.5	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
	180000	sq ft		16745	m2	Can overwrite the m2 one. If you want to enter sq ft, enter "=B15*0.305^2" in the m2 cell, where B15 is the cell w/ sq ft
Height	50	ft	=	15.3	m	Can enter as ft or as m (once entered as m, changing in ft does not work)
Volume				255354	m3	Volume, calculated. (Can also enter directly, then changing dimensions does not work)
Pressure	0.95	atm				Used only for CO2 calculation
Temperature	20	C				Use **web converter** if needed for F --> C. Used for CO2 calculation, eventually for survival rate of virus
Relative Humidity	50	%				Not yet used, but may eventually be used for survival rate of virus
Background CO2 Outdoors	415	ppm				See readme
Duration of event	90	min		1.5	h	Value for your situation of interest
Number of repetitions of event	1	times				For e.g. multiple class meetings, multiple commutes in public transportation etc.
Ventilation w/ outside air	40	h-1				Value in h-1: Readme: Same as "air changes per hour". Value in L/s/per to compare to guidelines (e.g. ASHRAE 62.1)
Decay rate of the virus	0.62	h-1				See Readme, can estimate for a given T, RH, UV from DHS estimator
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. filtering of recirc. air, HEPA air cleaner, UV disinfection, etc. See FAQs, Readme for calc for portable HEPA filter
Total first order loss rate	40.92	h-1				Sum of all the first-order rates
Ventilation rate per person	91.5	L/s/person				This is the value of ventilation that really matters for disease transmission. Includes additional control measures
Parameters related to people and activity in the room						
Total N people present	31000					Value for your situation of interest
Infective people	1	person				Keep this at one unless you really want to study a different cases - see conditional and absolute results
Fraction of population inmune	0%					From seroprevalence reports, will depend on each location and time, see Readme
Susceptible people	30999	people				Value for your situation of interest

Density (area / person) in room	6	sq ft / person	
Density (people / area) in room	1.85	persons / m2	
Density (volume / person) in room	8.2	m3 / person	
Breathing rate (susceptibles)	0.72	m3 / h	See Readme sheet - varies a lot with activity level
CO2 emission rate (1 person)	0.0061	L/s (@ 273 K and 1 atm)	From tables in Readme page. This does not affect infection calculation, only use of CO2 as indicator, could ignore
CO2 emission rate (all persons)	213.6272	L/s (@ at actual P & T of room)	Previous, multiplied by number of people, and applying ideal gas law to convert to ambient P & T
Quanta exhalation rate (infected)	50	infectious doses (quanta) h-1	See Readme file. Depends strongly on activity, also like person.This is the most uncertain parameter, try different values.
Exhalation mask efficiency	0%		0 if infective person is not wearing a mask. See Readme sheet
Fraction of people w/ masks	0%		Value for your situation. It is applied to everybody for both emission & inhalation. Modify formulas manually if needed
Inhalation mask efficiency	0%		See Readme sheet
Parameters related to the COVID-19 disease			
Probability of being infective	0.100%		Very important parameter, specific for each region and time period. For ABSOLUTE results (prob. given prevalence of disease in the population). See Readme sheet
Hospitalization rate	20%		From news reports. Varies strongly with age and risk factors
Death rate	1%		From news reports. Varies strongly with age and risk factors (1% typical - Higher for older / at risk people)
CONDITIONAL result for ONE EVENT: we assume the number of infected people above, and get the results under that assumption			
More appropriate to simulate known outbreaks (e.g. choir, restaurant etc.), and an worst-case scenario for regular events (if one is unlucky enough to have infective people in attendance of a given event)			
Net emission rate	50	infectious doses (quanta) h-1	Includes the number of infective people present
Avg Quanta Concentration	0.00	infectious doses (quanta) m-3	Analytical solution of the box model. Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.00	infectious doses (quanta)	
Conditional Results for A GIVEN PERSON & ONE EVENT (assuming number of infected above, typically 1)			
Probability of infection (1 person)	0.001%		Applying Wells-Riley infection model to the amount of infectious doses inhaled. Equation (1) in Miller et al. (2020)
Prob. of hospitalization (1 person)	0.0%		
Prob. of death (1 person)	0.0%		
Ratio to risk of car travel death	0	times larger risk	See FAQs for rough estimate of death traveling by car on a given day
Conditional Results for ALL ATTENDEES & ONE EVENT (assuming number of infected above, typically 1)			
Number of COVID cases arising	0.16		Number of people. Multiplies probability of one person, times the number of susceptible people present
N of hospitalizations arising	0.03		Number of people
N of deaths arising	0.00		Number of people
Results for CO2 as an indicator of risk (not needed for infection estimation, can ignore for simplicity)			
Avg CO2 mixing ratio	474	ppm (including 400 ppm background)	Analytical solution of the box model. Equation (4) in Miller et al. (2020). See FAQ page for differences w/ quanta calc
Avg CO2 concentration	0.13	g m-3 (excluding 400 ppm background)	Conversion from Atmos. Chem. Cheat Sheet, plus ideal gas law

Exhaled CO2 re-inhaled per person	0.14	grams (excluding 400 ppm background)				This parameter is the most analogous to risk. See FAQ page for limitations	
Exhaled CO2 re-inhaled per person	111.06	ppm * h (maybe easier units, excludes 400 ppm background				This parameter is the most analogous to risk. See FAQ page for limitations	
Exhaled CO2 re-inhaled per person	0.0111	%CO2 * h (same as above, different unit, for use next)					
Ratio of prob of infection to Ex_CO2	0.0005	% chance of infection for 1 person per %CO2 * h inhaled					
CO2 to inhale 1 hr for 1% infect.	174614	ppm				This is another metric of risk	
ABSOLUTE result for ONE EVENT: we use the prevalence of the disease in the community to estimate how many infected people may be present in our event, and calculate results based on that							
More appropriate for general risk estimation, e.g. in a college classroom, indoor gathering etc., where often infective people will not be present							
N of infective people present	31.000					It has to be interpreted statistically. This would be the average over e.g. 100 repetitions of the event in a given location	
Absolute results for A GIVEN PERSON & ONE EVENT (using disease prevalence in community)							
Probability of infection (1 person)	0.02%						
Prob. of hospitalization (1 person)	0.00%						
Prob. of death (1 person)	0.00%						
Ratio to risk of car travel death	3	times larger risk				See FAQs for rough estimate of death traveling by car on a given day	
Absolute results for ALL ATTENDEES & ONE EVENT (using disease prevalence in community)							
Number of COVID cases arising	4.88					Number of people	
N of hospitalizations arising	0.98					Number of people	
N of deaths arising	0.05					Number of people	
CO2 to inhale 1 hr for 1% infect.	6035	ppm				This is another metric of risk	
ABSOLUTE result for events that are REPEATED MULTIPLE TIMES (e.g. many class meetings during a semester, or a daily commute on public transportation) - Ignore for a single event							
Absolute results for A GIVEN PERSON & MULTIPLE EVENTS (using disease prevalence in community)							
Probability of infection (1 person)	0.02%						
Prob. of hospitalization (1 person)	0.00%						
Prob. of death (1 person)	0.00%						
Ratio to risk of car travel death	3	times larger risk (than traveling same N of days)				See FAQs for rough estimate of death traveling by car on a given day	
Absolute results for ALL ATTENDEES & MULTIPLE EVENTS (using disease prevalence in community)							
Number of COVID cases arising	4.88					Number of people	
N of hospitalizations arising	0.98					Number of people	
N of deaths arising	0.05					Number of people	
Specific notes for this case							
This is a case for a soccer stadium, as discussed in this tweet: https://twitter.com/jljcolorado/status/1289254898131820550							
And based on this paper: https://www.sciencedirect.com/science/article/pii/S1352231013004494							
Note that for the infection risk, the calculator only estimates the infection risk through the air beyond close proximity. Since social distance would not be maintained in such an event, this will be a large underestimate							

Estimation of COVID-19 aerosol transmission in a university classroom

Input Parameters						
	Value			**Value in other units**		**Source**
Surface area	500	sq ft	=	46.5	m2	Typical value
Height	10	ft	=	3.1	m	Typical value
Volume				142	m3	
Faculty / instructors	1	person				Typical value - Assumed constant
Surface area per student	65	sq ft	=	6.0	m2	CU-Boulder: 60-120 sq ft / person. UNC = 36 sq ft / person. See Readme
Students	7	people				You can change this number directly, then the previous input of area per student is not used
Breathing rate (instructor)	1.1	m3/h				Estimated from Miller et al. (2020), for someone talking a lot
Breathing rate (students)	0.8	m3 / h				Estimated from Miller et al. (2020), for someone occasionally talking
Duration of class period	50	min		0.83	h	Typical value
Ventilation w/ outside air	3	h-1		15	L/s/per	First value is the same as "air changes per hour". Second is used in most guidelines now
Decay rate of the virus	0.32	h-1				Average of literature values (0 and 0.62), Miller et al. (2020)
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. UV disinfection, personal HEPA air cleaner, etc.
Total first order loss rate	3.62	h-1				
CONDITIONAL RESULT: Case in which instructor is infected, students are susceptible						
Quanta emission rate (instructor)	135	q h-1				Estimated from Miller (2020) and Buonnano et al. (2020a, 2020b). See Readme sheet
Mask efficiency for emission	50%					See readme sheet
Net emission rate	67.5	q h-1				
Avg Quanta Concentration	0.09	q m-3				Equation (4) in Miller et al. (2020)
Mask efficiency for intake	30%					See readme sheet
Quanta inhaled per student	0.04	quanta				
Probability of infection (1 student)	4%					Equation (1) in Miller et al. (2020). This assumes instructor was infected. See "Campus" sheet for more general case
Number of COVID cases arising	0.29					
CONDITIONAL RESULT: Case in which student is infected, other students and instructor are susceptible						
Quanta emission rate (student)	16	h-1				Estimated from Miller (2020) and Buonnano et al. (2020a, 2020b). See Readme sheet
Mask efficiency for emission	50%					See readme sheet / Assume potentially different masks types for students and instructor

Net emission rate	8	q h-1					
Avg Quanta Concentration	0.01	q m-3				Equation (4) in Miller et al. (2020)	
Mask efficiency for intake	30%					See readme sheet	
Quanta inhaled per person	0.007	quanta				Using instructor breathing rate	
Probability of infection (1 person)	0.7%					Equation (1) in Miller et al. (2020). This assumes 1 student was infected. See "Campus" sheet for more general case	
Number of COVID cases arising	0.048					This is for one lecture only, of the length specified above. For a whole semester, see "Campus" sheet	

Estimation of COVID-19 aerosol transmission outdoors (Skagit Choir Repeat) during daytime, relatively crowded conditions (1.3 persons / m2) - S

Input Parameters						
	Value			**Value in other units**		**Source**
Surface area	1800	sq ft	=	167.4	m2	Just assuming a value, similar to choir outbreak case
Height	16	ft	=	4.8	m	Assuming that air within this height can get mixed to respiratory height
Volume				810	m3	
Infected people	1	person				Just assuming a value, similar to choir outbreak case
Susceptible people	60	people				Just assuming a value, similar to choir outbreak case
Breathing rate (index case)	1.1	m3 / h				Estimated from Miller et al. (2020), for someone singing
Breathing rate (susceptible)	1.1	m3 / h				Estimated from Miller et al. (2020), for someone singing
Duration of event	150	min		2.50	h	Just assuming a value, similar to choir outbreak case
Wind speed	5	km/ h		1.4	m/s	1/2 of low end of average daytime US wind speed per https://sciencing.com/average-daily-wind-speed-24011.html
Ventilation w/ outside air	386	h-1				Same as "air changes per hour", calculated approximately from the wind speed
Decay rate of the virus	9.3	h-1				Estimated (UV index 5, default T & RH) from https://www.dhs.gov/science-and-technology/sars-airborne-calculator
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. UV disinfection, personal HEPA air cleaner, etc.
Total first order loss rate	396	h-1				
CONDITIONAL RESULT: Case with one person infected, everyone else is susceptible						
Quanta emission rate (infected)	970	q h-1				Just assuming a value, similar to choir outbreak case. This should be an upper limit for COVID-19. See Readme
Mass efficiency for emission	0%					No masks were worn, for comparison with choir outbreak
Net emission rate	970	q h-1				Includes the number of infected people above
Avg Quanta Concentration	0.00	q m-3				Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.0083	quanta				
Probability of infection (1 person)	0.8%					Equation (1) in Miller et al. (2020)
Number of COVID cases arising	0.5					

Estimation of COVID-19 aerosol transmission in a university campus

Input Parameters					
					Comments
Probability of a student being infected	0.30%				See readme sheet
Probability of an instructor being infected	0.30%				See readme sheet
Student population of campus	33000	people			Estimated for large Western US university
Instructors w/ in-person teaching	2000	people			Estimated for large Western US university, including TAs
Indoor classroom periods per student	2	per day			Estimated for large Western US university. Duration set in "Classroom" sheet
Indoor classroom periods per instructor	1	per day			Estimated for large Western US university. Duration set in "Classroom" sheet
Duration of semester	13	weeks	65	days	
Total class hours for student per semester	108	h / semester			
Total class hours for instructor per semeste	54	h / semester			
Probability of hospitalization for students	5%				Estimated from news reports, varies with time and location
Probability of hospitalization for faculty	20%				Estimated from news reports, varies with time and location
Probability of death for students	0.05%				Estimated from news reports, varies with time and location
Probability of death for faculty	0.50%				Estimated from news reports, varies with time and location
ABSOLUTE Results: infections, hospitalizations, and deaths					
Student cases	1144	cases			
Instructor cases	3	cases			
Student hospitalizations	57	hospitalizations			
Instructor hospitalizations	0.5	hospitalizations			
Student deaths	0.57	deaths			
Instructor deaths	0.01	deaths			

Estimation of COVID-19 aerosol transmission in an urban bus

Input Parameters

	Value			Value in other units		Source
Surface area	307	sq ft	=	28.6	m2	Provided by bus operator
Height	7.9	ft	=	2.4	m	Provided by bus operator
Volume				69	m3	
Passengers	40	people				Capacity is 50 people, provided by bus operator. Assuming 80% full for this estimation
Breathing rate	0.8	m3 / h				Estimated from Miller et al. (2020), for someone occasionally talking
Duration of trip	45	min		0.75	h	Typical value. People may come in and out for urban buses, that mixes people and will increase transmission more
Ventilation w/ outside air	3	h-1		1.4	L/s/per	First value is the same as "air changes per hour". Second is used in most guidelines now
Decay rate of the virus	0.32	h-1				Average of literature values (0 and 0.62), Miller et al. (2020)
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. UV disinfection, personal HEPA air cleaner, etc.
Total first order loss rate	3.62	h-1				
Fraction of population infected	0.30%					See readme sheet
Number of passengers infected	0.12	people				

ABSOLUTE RESULTS: probability of infection, taking into account the prevalence of the disease in the population

Quanta emission rate	10	q h-1				Estimated from Miller (2020) and Buonnano et al. (2020a, 2020b). See Readme sheet
Mask efficiency for emission	50%					See readme sheet
Net emission rate	5	q h-1				
Avg Quanta Conc. (1 infected)	0.01	q m-3				Equation (4) in Miller et al. (2020)
Avg Quanta Conc. (w/ prob of inf.	0.002					
Mask efficiency for intake	30%					See readme sheet
Quanta inhaled per person	0.00	quanta				
Probability of infection (1 person)	0.1%					Equation (1) in Miller et al. (2020)
Number of COVID cases arising	0.03					

Estimation of COVID-19 aerosol transmission outdoors during daytime, demonstration (5 people / m2)

Input Parameters						
	Value			**Value in other units**		**Source**
Surface area	1800	sq ft	=	167	m2	Just assuming a value, similar to choir outbreak case
Height	15	ft	=	5	m	Assuming that air within this height can get mixed to respiratory height
Volume				766	m3	
Prob. of demonstrator infected	0.30%					See readme sheet
Number of infected people	2.5	person				Just assuming a value, similar to choir outbreak case
Susceptible people	837	people				Assume 5 people per m2, per http://www.gkstill.com/Support/crowd-density/CrowdDensity-1.html
Breathing rate (index case)	0.8	m3 / h				Estimated from Miller et al. (2020), for someone occasionally talking
Breathing rate (susceptible)	0.8	m3 / h				Estimated from Miller et al. (2020), for someone occasionally talking
Duration of event	150	min		2.50	h	Typical value for a demonstration. Also similar to choir outbreak case
Wind speed	5	km/ h		1.4	m/s	1/2 of low end of average daytime US wind speed per https://sciencing.com/average-daily-wind-speed-24011.html
Ventilation w/ outside air	386	h-1				Same as "air changes per hour", calculated approximately from the wind speed
Decay rate of the virus	9.3	h-1				Estimated (UV index 5, default T & RH) from https://www.dhs.gov/science-and-technology/sars-airborne-calculator
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. UV disinfection, personal HEPA air cleaner, etc.
Total first order loss rate	396	h-1				
ABSOLUTE RESULTS: probability of infection, taking into account the prevalence of the disease in the population						
Quanta emission rate (infected)	100	q h-1				People talking loudly, see readme sheet
Mass efficiency for emission	40%					Assume 80% mask wearing
Net emission rate	151	q h-1				Includes the number of infected people above
Avg Quanta Concentration	0.00	q m-3				Equation (4) in Miller et al. (2020)
Quanta inhaled per person	0.00	quanta				
Probability of infection (1 person)	0.10%					Equation (1) in Miller et al. (2020)
Number of COVID cases arising	0.8					

Estimation of COVID-19 aerosol transmission in a political rally

Input Parameters						
	Value			**Value in other units**		**Source**
Surface area	146595	sq ft	=	13637.0	m2	https://en.wikipedia.org/wiki/BOK_Center and estimated from Google maps
Height	120	ft	=	36.6	m	https://en.wikipedia.org/wiki/BOK_Center
Volume				499114	m3	
Attendees	19199	people				https://en.wikipedia.org/wiki/BOK_Center
Breathing rate	0.9	m3/h				Estimated from Miller et al. (2020), for someone talking, shouting, cheering part of the time
Duration of Event	120	min		2.00	h	Typical value, includings some waiting time before event, and time to enter and exit
Area of player field	19550	sq ft	=	1818.6	m2	https://en.wikipedia.org/wiki/Ice_hockey_rink#Dimensions with buffer at the back
Rest of building area	127045		=	11818.4	m2	
Ventilation for player field	2137	L/s		7692	m3 h-1	10 L/s/person + 0.9 L/s/m2, per ASHRAE 62.1-2013
Ventilation for rest of building	83593	L/s		300934	m3 h-1	3.8 L/s/person + 0.3 L/s/m2, per ASHRAE 62.1-2013
Ventilation w/ outside air	0.62	h-1		#REF!	L/s/per	First value is the same as "air changes per hour". Second is used in most guidelines now
Decay rate of the virus	0.32	h-1				Average of literature values (0 and 0.62), Miller et al. (2020)
Deposition to surfaces	0.3	h-1				Buonnano et al. (2020), Miller et al. (2020). Could vary 0.24-1.5 h-1, depending on particle size range
Additional control measures	0	h-1				E.g. UV disinfection, personal HEPA air cleaner, etc.
Total first order loss rate	1.24	h-1				
Case in which instructor is infected, students are susceptible						
Quanta emission rate per person	50	q h-1				Estimated from Miller (2020) and Buonnano et al. (2020a, 2020b). See Readme sheet, shouting, cheering, talking
Mask efficiency for emission	15%					See readme sheet; Assuming 1/3 of people wearing masks
Net emission rate per person	43	q h-1				
Fraction of infected people in OK	0.10%					
Total emission rate	816					
Avg Quanta Concentration	0.001	q m-3				Equation (4) in Miller et al. (2020)
Mask efficiency for intake	15%					See readme sheet
Quanta inhaled per person	0.001	quanta				
Probability of infection (1 student)	0%					Equation (1) in Miller et al. (2020)

Number of COVID cases arising	24						