BranchPattern

Facility Infection Risk Estimator, V2.1

Users Guide

https://branchpattern.com/research/facility-infection-risk-estimator-v2-0/

Version 2.1 of BranchPattern's Facilities Infection Risk EstimatorTM module is designed to estimate a) the aerosol viral particle removal efficiency resulting from several different removal mechanisms, and b) the associated probability of infection for adults and children.

BranchPattern (https://branchpattern.com/)
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Overview

This module is compatible with all browsers except Microsoft Explorer 11. The information provided in this user guide is intended to supplement the instructions given in the information bubbles associated with module's input and output.

BranchPattern's Facility Infection Risk Estimator^{TM} module is intended to estimate a) the aerosol viral particle removal efficiency resulting from several different removal mechanisms and b) the associated probability of infection for adults and children, given a set of input conditions including space parameters, demographic factors, and time.

This module is one component of our Health and Productivity Performance Estimator (happē^{TM}) tool. The initial version of the tool was developed in 2009 to estimate the impact various indoor environmental quality (IEQ) conditions have on productivity and health. Based on IEQ peer reviewed research, it provides both percentage impacts and dollar amounts using weighted average salary dollars.

BranchPattern uses happē^{TM} as part of pre- and post-occupancy evaluations to assess the impacts that existing space conditions are having on occupants. It's also used during retrocomissioning and design to assess the relative impacts of different energy conservation measures (ECMs) or system types on productivity and health. BranchPattern has also found that making life cycle cost analyses more comprehensive increases the likelihood for sustainable and health/wellness focused decision-making throughout the design/construction process.

Summary of Changes to v2.1 of the Facility Infection Risk Estimator^{TM}

- Mask selections have been updated to reflect ongoing changes to the types of mask technology available and new research/testing of effective mask efficiencies.
- Vaccination for SARS-CoV-2 is now included for adults.

New variants of SARS-CoV-2 continue to evolve and spread within our communities. Research regarding the degree of infectiousness, mortality risk, and resistance to vaccines of these variants is ongoing. Data available for the B.1.1.7 (UK) variant indicates an increase in infectiousness by 1.4 to 1.7. If attempting to assess the risk from this variant, we recommend multiplying the probability of infection results by 1.5. As new information becomes available for this and other variants, we will update this recommendation.

This module has been peer reviewed by Josephine Lau, Ph.D., Associate Professor of Durham School of Architectural Engineering and Construction, University of Nebraska – Lincoln.

Disclaimer

This module was developed by employees of BranchPattern and is being made available for public use. The studies and models used for this module (referenced below) are based primarily on a) Influenza (in general and Influenza A in particular) and b) what we know as of 09/01/2020 for SARS-CoV-2. Influenza output is therefore most relevant to Influenza A but general interpretations could be made relative to Influenza B. Interpretations of output for SARS-CoV-2 should be made with the recognition we still have much to learn about SARS-CoV-2 and the resulting COVID-19 illness.

Also note that the mathematical models used by this module represent a simplified version of reality. The Facility Infection Risk Estimator™ is designed to act as a simple heuristic for comparing the relative impacts from a baseline and design set of conditions. It is important that the user be aware of these simplifications, and that actual removal efficiencies and probabilities of infection will vary from the results given in this module. The results are intended to supplement, not replace, the judgement of qualified individuals competent in the knowledge domains of mechanical engineering, industrial hygiene, indoor air quality, infection control, and particle/pathogen airborne transmission.

The module is provided 'as is' without any warranty of any kind, either express, implied, or statutory, including, but not limited to, any warranty that the module will conform to specifications, any implied warranties of merchantability, fitness for a particular purpose, and freedom from infringement, and any warranty that the documentation will conform to the module, or any warranty that the module will be error-free. In no event shall BranchPattern be liable for any damages, including, but not limited to, direct, indirect, special or consequential damages, arising out of, resulting from, or in any way connected with this module, whether or not based upon warranty, contract, tort, or otherwise, whether or not injury was sustained by persons or property or otherwise, and whether or not loss was sustained from, or arose out of the results of, or use of, the module provided hereunder.

Inputs and Calculations

This module provides removal efficiencies and probabilities of infection for a baseline and design set of conditions, looking at either influenza or SARS-CoV-2. The decreases in estimated probabilities of infection ($P_{infection\text{-}total}$) per day and per year, the estimated decreases in number of adults or children infected, the estimated decreases in salary dollars lost, and the estimated decreases in child days lost all represent a subtraction of the design results from the baseline results. Future versions of this module may examine other viruses or pathogens, though the removal efficiencies currently calculated would generally be applicable to most viruses.

Removal Efficiency Calculations

The removal mechanisms addressed in this module include settling (via gravity), ventilation (via outdoor air), filtration (via the building HVAC system, portable air cleaners, and/or mask wearing), and virus inactivation (via relative humidity and/or upper room UVGI). The equations used to calculate the removal efficiencies for settling, ventilation, inactivation, and the total are from Yang and Marr (2011) – equations 10, 11, 12, and 13, respectively. The filtration removal efficiency calculations are based on applying equation 3 ($k_{filtration} = \lambda_{recirculation} * \eta_{filter}$) from Stephens (2012) in a similar manner:

- $E_{filtration} = 1 - \exp(-k_{filtration} * t_{rem})$ (A)

Building on these references, this module's equation for calculating the total removal efficiency involving all potentially included removal factors is:

- $E_{total} = 1 - \exp(-((k_{settling} + \lambda_{ventilation} + k_{filtration} + \lambda_{aircleane} + k_{mask} + [k_{RHinactivationIVA} \text{ or } k_{RHinactivationSC2}] + [k_{UVGIinactivationIVA} \text{ or } k_{UVGIinactivationSC2}]) * t_{rem})$ (B)
  - E_{total} = total removal efficiency for the removal factors employed

- $k_{settling}$ = settling removal factor, discussed further below
- $\lambda_{ventilation}$ = ventilation removal factor, discussed further below
- $k_{filtration}$ = building system filtration removal factor, discussed further below
- $\lambda_{aircleane}$ = portable air cleaner removal factor, discussed further below
- k_{mask} = mask removal factor, discussed further below
- $k_{RHinactivationIVA}$ or $k_{RHinactivationSC2}$ = RH inactivation removal factor, discussed further below
- $k_{UVGIinactivationIVA}$ or $k_{UVGIinactivationSC2}$ = upper room UVGI inactivation removal factor, discussed further below

A removal time (t_{rem}) of 15 minutes, or 0.25 hours, is the default selection for comparing the outputs from different removal mechanism inputs. The removal efficiency outputs essentially represent a snapshot in time providing the percentage of viral particles, droplets, and/or droplet nuclei removed by different removal mechanisms after a single expiratory event. The outputs provide one means for evaluating the effectiveness of different removal mechanisms under different contextual conditions. However, you may play with different removal times as part of your analysis.

Two limitations inherent in the model used by Yang and Marr (2011) are a) its basis on limited data obtained from laboratory experiments and b) the viral concentration calculations assume that droplets are instantaneously, continuously, and evenly distributed throughout the room. As with all models, this is a simplified version of what exists in reality.

Settling Removal Factor

To calculate the settling removal efficiency ($E_{settling}$), the initial and equilibrium droplet/droplet nuclei diameters are needed. Table A below in the Tables/Figures section provides the average initial droplet/droplet nuclei diameters used by this module for the following expiratory means: breathing, speaking normally, speaking loudly, singing, coughing, and sneezing. The references consulted are given in the table. To coordinate with the quanta generation by expiratory means (see discussion below), speaking loudly and singing were combined into a single expiratory event, using the initial droplet/droplet nuclei diameters for speaking loudly.

For the referenced studies where it was possible, the following method, inspired by Stephen (2012), was used to calculate the weighted average GM (geometric mean diameter) values listed in Table 1. To do this, the percentages of infectious particles contained w/in each droplet/droplet nuclei distribution range were multiplied by the GM from each droplet/droplet nuclei distribution range and then these products added together to get the weighted average GM for each referenced study.

Unfortunately, only a few studies actually involved infected volunteers. Therefore, additional studies involving healthy individuals also had to be referenced, using the percentage concentration for each range as opposed to infectious particles in those cases. To estimate the initial weighted average GM, an evaporation factor of 0.5 was used based on Johnson et al. (2011). These weighted average GM values are only used to calculate the removal efficiencies (settling primarily). They aren't used to calculate the probably of infection – quanta rates by activity level and expiratory event are estimated separately from other studies (discussed further below).

Equilibrium particle diameters were calculated using an average of the model based on experimentally derived respiratory droplet size transformation ratios given in Table 2 from Yang and Marr (2011). Settling velocities are calculated using the particle densities given in Sharp et al. (1945) and the Stokes Law formula given in Yang and Marr (2011). The final formula for $k_{settling}$ is then:

- $k_{settling} = v/H$ (C)
    - v = settling velocity
    - H = height of the room/space

Ventilation Removal Factor

Ventilation removal efficiency ($E_{ventilation}$) is dependent on ventilation rates for the room/space in question and entered as the total OA CFM (outside air cubic feet per minute) per room/space. In v1 this was entered as OA CFM per person. But as the subsequent back of house OA ACH (air changes per hour) calculations required multiplying this by the number of occupants (adults plus children) per room, it made analyses looking at varying OA rates and number of occupants more difficult. Making this change has allowed ventilation rates to be divorced from the number of occupants for the back of house calculations. $k_{ventilation}$ simply equates to the outside air changes per hour for the room/space, calculated using the entered OA cfm/space and the space volume.

If you're unclear what value to use here for OA cfm/space, for either the baseline or design condition, work with a consulting engineer, commissioning agent, and/or facility manager to make that determination for the space/room in question. For existing buildings, estimates can be obtained from design drawings, a building's BIM settings, or measured using techniques like those laid out here: https://schools.forhealth.org/ventilation-guide/.

You can estimate what the code minimum required ventilation (OA) rates are for a given space using ASHRAE 62.1. A read only version can be accessed here – https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards. Current and previous versions are provided, for both non-residential and residential facilities. Select the year that likely applies/applied to the design of your facility and open it up. Find the *Minimum Ventilation Rates in Breathing Zone* tables, and then the space type listed that is the most applicable to your room or space in question.

First, estimate the number of occupants per space using the *Default Occupancy Density* value. These values are listed as the number of occupants per 1000 ft^2 (or 100 m^2). The number of occupants is therefore this density value multiplied by the area of your space or room, divided by 1000 ft2 (or 100 m2). You can then calculate the required ventilation by using the values listed in the *People Outdoor Air Rate* R_p and *Area Outdoor Air Rate* R_a columns as follows: Ventilation Air per Space = [Number of Occupants per Space * People Outdoor Air Rate (cfm/person)] + [Space Area * Area Outdoor Air Rate (cfm/area)]. Enter this value into the tool. The procedure for estimate residential ventilation rates differs from this in detail but reference the associated ASHRAE 62.1 standard for more details.

It's important to recognize that a) designs don't always comply with this, b) even when they do ventilation rates commonly don't meet code minimums for certain times of the year, typically during the more extremes of summer and winter, and c) even code minimums won't address pathogen concerns (or concerns regarding cognitive performance). Many aerosol scientists are recommending a minimum of 5 ACH of OA per space to effectively minimize the transmission of SARS-CoV-2 via the airborne route. Unfortunately, a large percentage of existing buildings' HVAC systems are unable to deliver that without extensive upgrades.

Filtration – Building System Filtration Removal Factor

The building system filter removal efficiency (η_{filter}) percentages for various MERV and HEPA ratings used for the back of house calculations are taken from droplet nuclei-weighted values given in Table 4 from Stephens (2012). The available MERV and HEPA input selections are limited to the levels used in this table. Select the value closest to your existing and/or proposed conditions. Recirculated air changes per hour ($\lambda_{recirculation}$), entered as CFM per space, are needed to calculate the overall filtration removal efficiency ($E_{filtration}$), per equation (A). As with ventilation rates, coordinate with a consulting engineer, commissioning agent, and/or facility manager if you are unable to determine this. You may be able to determine the total room supply air rate from existing drawings. If so, the recirculated air rate is the total supply air rate minus the ventilation air rate. If you don't have existing drawings, a rough rule of thumb is that the ventilation air rate is 20% of the total supply air rate. Though it would be better to work with an engineer to verify this. The final formula for $k_{filtration}$ is then:

- $k_{filtration} = \lambda_{recirculation} * \eta_{filter}$ (D)
  - $\lambda_{recirculation}$ = recirculated air changes per hour for the room/space
  - η_{filter} = building system filter removal efficiency

Equation 2 from Kirkman et al. (2020) is used to determine the removal efficiency of any portable air cleaners used (E_{PAC}). The removal rate per portable air cleaner, $\lambda_{aircleaner}$, equals the CADR (clean air delivery rate) value from the manufacturer divided by the space volume (V):

- $\lambda_{aircleaner} = CADR / V$ (E)

This value is then multiplied by the number of portable air cleaners being used per space to provide the total removal rate (1/h). To calculate the removal efficiency, E_{PAC}, in the back of house calculations, this number is then plugged into equation (A) in place of the $k_{filtration}$. To select the appropriate CADR value to use, reference the manufacturer data and enter the average of the CADR values given for smoke and dust. Also recognize that CADR rating values are based on the maximum rated removal rate of the portable air cleaner (fan on high speed). You can estimate CADR values at lower fan speeds using ratios of the different fan speed settings.

Filtration – Mask Removal Factor

The mask removal efficiency (E_{mask}) is calculated looking at the following two components, added together.

Mask Removal Efficiency, Part 1: This part consists of the amount of droplets/particles removed from the room air by the masks of the non-infected individuals as they breath in (indicated by the red text in the formula below). It's a small contribution compared to the other component described below but is nevertheless included. It's calculated using the mask effective efficiency (η_{mask}), the number of non-infected individuals wearing them, and the estimated breathing generated air change rate across an individual mask of 1.2 cfm.

This estimated breathing generated air change rate comes from the value used by Konda et al. (2020a) to represent respiration rates at rest (approx. 35 l/min). While the air change rate across the masks will be larger at more intensive activity levels, additional effort to determine this was not expended, as this part provides such a small contribution overall. The mask effective efficiency value also includes a "Mask

Tightness Factor" or "Face Seal Leakage" factor to account for the reality of leakage around the mask edges. The mask effective efficiency calculation comes from Gammaitoni and Nucci (1997:338):

- Mask Effective Efficiency (η_{mask}) = Mask Efficiency * (1 – Face Seal Leakage) (F)

At this point version 2.1 uses the fourteen mask types shown in Table B in the Tables/Figures section below. See the figures/tables here - https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/2774266 - for photos of mask types to help select the most relevant type for your building population.

The Fitted Filtration Efficiency (FFE), or the Mask Effective Efficiency, values come directly from *Table. Face Mask FFE Against Submicron particle Penetration* (Clapp et al. 2020:E4). This study directly measured the FFE (accounting for both mask efficiency and face seal leakage, or mask fit), and so it wasn't necessary to use equation F above as it was in version 2.0. In Clapp et al. (2020), the FixTheMask add on consisted of a rubber band configuration mimicking the impacts of the FixTheMask mask fitter (https://www.fixthemask.com/), resulting in a measured FFE of 78.2%. Another study, Rothamer et al. (2020) actually tested the manufactured FixTheMask mask fitter on a procedure mask using a similar particle range as the above study, though manikins were used instead of a real person. The effective mask efficiency, or fitted filtration efficiency, was found to be 94.9%. For the calculator, it was decided to average these two values, giving an FFE of 86.6%.

The much wider range of mask types to select from in version 2.1 includes a wider variety of materials for cloth masks, as well as different mask modifiers available to improve efficiency and fit (e.g., inserts, aluminum nose bridge, FixTheMast, etc.). To our knowledge there isn't research available looking at the effective mask efficiencies for double masking. If that becomes available we will consider updating the tool.

Mask Removal Efficiency, Part 2: This part consists of the amount of particles removed by the masks from the air breathed out by the infected individual(s), before they enter the room air (indicated by the green text in the formula below). For the removal efficiency calculation, this only looks at a single coughing, speaking, etc. event. The removal occurs just once and doesn't increase over time as it does for the other removal strategies. Therefore, this part of the equation isn't multiplied by the removal time. It's just the mask removal efficiency multiplied by the percentage of infected people wearing a mask. So, for the removal efficiency calculation, k_{mask} is more complicated than the other removal factors because part of it is multiplied by t_{rem} (red text below) to obtain the associated removal efficiency while part of it isn't (green text below). The final equation for the Mask Removal Efficiency (E_{mask}) is then:

- E_{mask} = 1 – exp (-((((1.2cfm * % non-infected wearing mask * number of non-infected occupants) * 60minutes/hr / room volume) * mask effective efficiency * t_{rem}) + (mask effective efficiency * % infected wearing a mask))) (G)

Inactivation – RH Inactivation Removal Factor

Because a) interior temperatures do not range widely enough to significantly impact the results of the inactivation calculations and b) the dynamic viscosity of air doesn't vary substantially with typical interior temperature ranges, an interior temperature of 22.5°C (72.5°F) and associated dynamic viscosity of air of $1.83x10^{-5}$ is assumed. Essentially the contribution of the interior temperature to virus inactivation is assumed to be fixed.

The Influenza A virus inactivation rate ($k_{RHinactivationIVA}$) due to relative humidity (RH) entered is calculated from the linear equation (2) given in Figure 2 from Yang and Marr (2011):

- $k_{RHinactivationIVA}$ = (0.0438 * RH) – 0.00629 (H)

This result is then used in Yang and Marr's (2011) equation 12 to calculate the inactivation removal efficiency due to RH ($E_{RHinactivation}$). For SARS-CoV-2, the inactivation rate ($k_{RHinactivationSC2}$) is calculated using the following formula:

- $k_{RHinactivationSC2}$ = (0.0135 * RH) – 0.0028 (I)

The formula was developed using an online calculator developed by the Department of Homeland Security: https://www.dhs.gov/science-and-technology/sars-airborne-calculator. Decay rates were determined using this calculator for a UV Index of 0 (inside) & an interior assumed temperature of 72 degrees F (22.2 degrees C) to correspond to assumptions made for influenza and droplet evaporation. These decay rates, in hours, are shown in Table C below in the Tables/Figures section. The Department of Homeland Security calculator only provided values between an RH of 20+% and 70%.

Table D then converts these values to 1/min, which were then graphed (Figure 1 in the Tables/Figures section) and the linear equation (I) formulated for the 99% decay rate values. Similar to Influenza, this SARS-C0V-2 inactivation rate ($k_{RHinactivationSC2}$) is plugged into Yang and Marr's (2011) equation 12 to calculate the inactivation removal efficiency due to RH ($E_{RHinactivation}$).

Inactivation – Upper Room UVGI Removal Factor

The upper room UVGI coefficient of inactivation (or removal factor) is calculated by multiplying the UVGI system's upper room average irradiance or fluency (E) by the relevant susceptibility parameter (Z) for either influenza or SARS-CoV-2 (First et al. 1999a, 1999b; Kowalski et al. 2000; McDevitt et al. 2012; Miller et al. 2002; Mphaphlele et al. 2015; Noakes et al. 2003, 2004, 2015; Nunayon et al. 2019):

- [$k_{UVGIinactivationIVA}$ or $k_{UVGIinactivationSC2}$] = E * Z (J)

Sources, including the 2009 NIOSH application guideline, recommend that the upper room average irradiance (E) should generally fall within the range of 30 - 50 $\mu W/cm^2$ for most pathogens (Miller et al. 2002; Mphaphlele et al. 2015).

But the final average value depends on the number of lamps, their individual output, fixture configuration, fixture layout, and room parameters. Measured and modeled values often fall below this range (Miller et al. 2002; Mphaphlele et al. 2015; Nunayon et al. 2019), so to be conservative the default input value has been set to 20 $\mu W/cm^2$. To fine-tune this selection, it may be necessary to coordinate with a design engineer and/or manufacturer. For these calculations, the effective average irradiance (E) for the whole space was determined by multiplying the upper room average irradiance by the ratio of upper room volume to total room volume (e.g. Miller et al. 2002; Mphaphele et al. 2015).

Reported susceptibility parameter (Z), or UV rate constant, values (m^2/J) for influenza A include 0.15 (Kowalski et al.2000), 0.27 (Sung and Kato 2011), 0.22 at 25-27% RH (McDevitt et al. 2012), 0.27 at 50-54% RH (McDevitt et al. 2012), and 0.29 at 81-84% RH (McDevitt et al. 2012). In order to tie the Z value to RH, the McDevitt et al. (2012) reference was used; see Table E in the Tables/Figures section below. The non-highlighted portions are taken from Table 1 (McDevitt et al. 2012), but the highlighted RH range column was added to tie it to the RH ranges accounted for by this module.

Reported susceptibility parameter (Z), or UV rate constant, values (m^2/J) for SARS-CoV-2 include Beggs and Avital (2020) suggestion for 0.377 (best-case) and 0.0377 m^2/J (worst-case) and Kowalski et al. (2020) suggestion of 0.05524 m^2/J. At this point there are no known studies linking the susceptibility parameter (Z) for SARS-CoV-2 to RH, so for the purposes of this module, an average of 0.377 and 0.0377 m^2/J was used (0.207 m^2/J).

The relationship between ACH/ventilation and UVGI is not fully known (Gammaitoni and Nucci 1997), though various studies have looked at it. Greater ACH levels within lower ranges can positively impact room mixing, aiding in UVGI's effectiveness by increasing the percentage of pathogens exposed at a faster rate. But greater ACH rates also decrease its effectiveness relative to delivered dosage by decreasing the amount of exposure time for the pathogens in question. Future versions may look at incorporating these parameters, but for now the effective average irradiance for the whole space is used to partially account for the impacts of ACH on delivered dosage. Similar to the other removal efficiency calculations, the UVGI Inactivation Removal Efficiency ($E_{UVGIinactivation}$) is then:

- $E_{UVGIinactivation} = 1 – \exp(-[k_{UVGIinactivationIVA} \text{ or } k_{UVGIinactivationSC2}] * t_{rem})$ (K)

Probability of Infection Calculations

The Wells-Riley model is used to calculate estimates of the probability of infection, and the version used for this module originates from Stephens (2012), equation 2. That equation includes removal terms for ventilation, building system filtration, and settling. BranchPattern's module has modified the equation to also include removal terms for portable air cleaners, masks, inactivation from RH, and inactivation from upper room UVGI. The modified equation is as follows:

- $P = (1 - (\exp(-((q * I * p * s * t) / V) / (k_{settling} + \lambda_{ventilation} + k_{filtration} + k_{RHinactivation} + k_{UVGIinactivation} + k_{aircleaner} + k_{mask})))) * v_{adjusted}$ (L)
  - P = probability of infection
  - q = quantum of infection, discussed further below
  - I = number of infected individuals, discussed further below
  - p = pulminary ventilation rate, discussed further below
  - s = modified p scaling factor for masks, discussed further below
  - t = time of exposure, discussed further below
  - V = volume of the room/space.
  - k and λ = the various removal factors mentioned above. These are generally the same as the removal factors used to calculate the removal efficiencies discussed in the previous section. Where they differ, these will be discussed further below.
  - $v_{adjusted}$ = adjusted vaccination factor, discussed further below

Quantum of Infection

The Wells-Riley model has been around since the late 1970's but modified over the subsequent years to suit various researchers' and practitioners' purposes. It's "… based on a concept of 'quantum of infection, whereby the rate of generation of infectious airborne particles (or *quanta*) can be used to model the likelihood of an individual in a steady-state well-mixed indoor environment being exposed to the infectious particles and subsequently succumbing to infection" (Stephens 2012:8).

Version 1 of the module assumed a fixed value of 100 quanta per hour for Influenza. However, version 2 has been updated to vary the quanta per hour by selected activity level and expiratory event, for either Influenza or SARS-CoV-2/COVID-19. Both activity level, primarily through breathing (or pulmonary ventilation) rates, and expiratory means (speaking, breathing, coughing, etc.) influence the initial size and quantity of the virus containing droplets/droplet nuclei, the varying concentration levels of virus particles w/in the droplets/droplet nuclei, the potential for a non-infected individual to breath them in, and the potential that they'll reach deep enough in the lungs to cause an infection. Therefore, they impact the quantum of infection value.

Table F in the Tables/Figures section below lists the quantum generation rates by expiratory means / activity level for both Influenza and SARS-CoV-2 that are used in this module. In addition, separate values are provided for low, medium, and high shedders. The high shedding selection should generally be limited to superspreading events. These values are taken directly from and/or estimated from the values and sources listed in Tables G, H, and I. For additional information on how these values were determined, contact BranchPattern. Due to conflicting data and opinions in the research relative to varying quantum generation rates between adults and children (e.g., Chen and Liao 2008; Jimenez 2020; Josephine Lau, personal communication 2020), the module currently assumes the same rate for both children and adults.

Number of Infected Individuals

The number of infected individuals defaults to one but may be adjusted. More than one infected individual may have relevance for examining the probabilities of infection on a per hour or per day basis under different conditions. And community spread rates may be such that more than one infected individual is likely, depending on the number of occupants within the space. However, using a value greater than one could be problematic for exploring the probability of infection across an estimated 5 month flu season for Influenza or throughout the year for SARS-CoV-2. At this scale, one, two, more, or no infected individuals may be present on any given day or even any given hour over the course of these time spans. It's more conservative to use one person and estimate the number of hours or percentage of time that at least one infected person may be present over the relevant period of time.

Pulmonary Ventilation (Breathing)

Breathing rate is important to consider as it impacts the amount of virus potentially inhaled. It's also important to factor in the variation between adults and children. Adult and Child pulmonary ventilation rates are determined using Table 6-31 (p. 6-67) from U.S. EPA (2011). The Total Daily IR (inhalation rate) value for an adult average, divided by 24 hours, was used to provide the adult pulmonary ventilation rate for these calculations, representing ages 18 and older. The Total Daily IR value for a 10-year-old child, divided by 24 hours, was used to provide the child pulmonary ventilation rate for these calculations, representing ages less than 18 years of age.

Modified p Scaling Factor (Masks)

The probability of infection calculations for mask wearing (listed below under the Removal Factors heading) are based in part on the mathematical models from Gammaitoni and Nucci (1997). Mask filter efficiencies and face-seal leakage values (combined to achieve the mask effective efficiency value as described above in the removal efficiency calculation section) are used to calculate a scaling factor that scales the rate at which quanta of infection are breathed in resulting from wearing a mask. The equation for this is as follows:

- modified p scaling factor (s) = 1 – (mask effective efficiency * % non-infected wearing a mask). (M)

The unmodified p scaling factor (1 – mask effective efficiency) comes from Gammaitoni and Nucci (1997:338). It was modified to account for the potential that not all non-infected individuals are wearing a mask. The module allows one to input the percentage of infected and non-infected individuals wearing a mask. The unmodified p scaling factor values used in the back of house calculations for the different mask types are listed in Table B, discussed previously in the Removal Efficiency Calculations.

Currently the module does not assume different mask efficiencies for inhalation vs. exhalation, though some models have attempted to account for that. As a result, these calculations may slightly underestimate the inhalation efficiencies, and therefore slightly underestimate the probability of infection.

Time of Exposure

Exposure Time Per Day: A default value of 4.00 hours is provided for the exposure time per day, however this will vary quite a bit by a) facility type, b) the different occupants present in the facility, and c) the different activities they undertake during the day. For example, if an infected individual is present in a room, the exposure time of elementary students could be significantly more than an office worker meeting with an infected coworker for 20 minutes in a conference room. It may be better to approach this as looking at a best-case (potential exposure of only 30 minutes or less) and worst-case scenario (potential exposure over the course of the entire work or school day).

Exposure Time Per Viral Season: This number is used to estimate the impacts on productivity/performance in either lost salary dollars or lost child days over the course of a viral season (5 months for Influenza, 12 months for SARS-CoV-2). And it's likely most useful to back into the estimated time of exposure per viral season. Tokars et. al (2018) found that on average 3% to 11% of the U.S. population is infected with the flu per flu season, resulting in actual symptomatic flu illness. If both symptomatic and asymptomatic illness is considered that percentage ranges from 5% to 20%. To calculate a seasonal probability of infection that falls within the general realm of these percentages, the percentage of time exposed per flu season will need to be low, likely less than 10% or even less than 5% of an assumed five-month flu season. This is still the case even though the module accounts for vaccinations for influenza. The default value is set for 5%, though it very well could be less than this. Likely not more.

For SARS-CoV-2, we have even less data to work with to make such an assumption. At this point it's likely best to play around with lower percentages similar to Influenza and treat it as a hypothetical comparison between a baseline and design condition.

Removal Factors

These are generally the same calculations used for the removal factors discussed in the Removal Efficiency Calculations section. The one exception is the mask removal factor which requires some additional clarification. The k_{mask} factor (1/hr) is composed of the same two parts used to calculate the removal efficiency:

- k_{mask}= (((1.2cfm * % non-infected wearing mask * non-infected occupants * 60min/hr / (room volume)) * mask effective efficiency) + (mask effective efficiency * % infected wearing a mask) (N)

However, in this case we are looking at continuous expiratory events over the course of the selected exposure time. So the second half of the equation in green text (the amount of particles removed by the masks from the air breathed out by the infected individual(s) before it enters the room, i.e., source control) does not have to be separated from the time of exposure as it did for the time of removal in the removal efficiency calculations. We aren't looking at just a single expiratory event.

The final mask probability of infection equation is shown below (taking only mask wearing into account). It accounts for 1) particle removal via the mask a non-infected individual is wearing (orange text in equation O below), 2) source control relative to the infected individuals wearing a mask (green text in equation N), and 3) the small amount of particles removed from the air via all of the masks worn by others in the room (red text in equation N). Parts two and three make up the k_{mask} factor in equation O.

- $P_{infection-mask}$ = 1 - (exp(-((modified p scaling factor * pulmonary ventilation rate * number of infected people * quantum of infection per infected person * exposure time) / (room height * room area)) / (k_{mask})))) * adjusted vaccination factor (O)

Adjusted Vaccination Factor

The module also accounts for the impacts of vaccination (or lack thereof). Default Influenza U.S. coverage rates for children and adults are provided based on averages of nine consecutive flu seasons for each, calculated from data provided by the CDC (Centers for Disease Control 2019). However, these averages hide a lot of variation by further age group breakdown and geographic location (for example the elderly typically vaccinate at a much higher rate than younger adults). You may want to consider fine tuning these percentages based on your building geographic location, occupant age groups, and other demographic factors. For SARS-CoV-2, vaccination is only relevant for adults, as the FDA has yet to approve vaccinations for people under 16 years of age. As COVID vaccinations are still rolling out (as of 2/18/2020), it is recommended that you use local vaccination percentages to guide your input for the percentage of adults vaccinated. Check with your county's health department.

To integrate the impact of vaccination into these calculations, the relationship between the probability of infection calculated by this module and the basic reproduction number, R_0 is used. R_0 is "... defined as the expected number of secondary cases produced by a single (typical) infection in a completely susceptible population" (Jones 2007), and the probability of infection is one of three factors multiplied by each other to calculate R_0.

The impact of vaccination on the reproduction number can be estimated using the following formula:

- $R_{0p} = (1-p) * R_0$ (P)

"where R_{0p} is the R_0 under vaccination and p is the vaccination coverage rate of the population who have been vaccinated" (Chen and Liao 2007:1039). This module uses the relationship between R_0 and the probability of infection to estimate the impact of vaccination on the probability of infection, essentially multiplying it by (1-p). As vaccinations aren't 100% effective, the p value for children and adults is also multiplied by estimates of vaccination efficacy. For Influenza, this value is estimated at 0.70 for children and 0.62 for adults (Chen and Liao 2013). This provides the adjusted vaccination factor ($v_{adjusted}$ = 1 – (p * vaccination efficacy)).

For SARS-CoV-2, adult efficacy percentages for the most prominent vaccines are listed in Table J for the various known major variants. These have been obtained from the links listed for each vaccine below the table. Cells highlighted yellow indicate that the efficacy wasn't broken down between moderate to severe and severe symptoms. Grayed out cells indicate no formal efficacy values are available at this point. Though preliminary data does indicate the efficacy of the Pfizer and Moderna vaccines is less for the variants. Because there are still a lot of unknowns and the variant landscape seems to be rapidly changing, it was decided to use one estimated efficacy value, averaging all of the percentages listed in Table J together, resulting in a value of 0.80.

Outputs

Risk Impact Summary

These summary tables and associated figures provide a) the estimated number of adults/children infected per room per day (or time of exposure) under the baseline and design conditions, b) the deltas between those values, c) the estimated number of adults/children infected per building per viral season, d) the deltas between those values, e) the estimated salary dollars and child days lost under the baseline and design conditions, and f) the delta between those values. The estimated number of adults/children infected is calculated by multiplying the relevant estimated probabilities of infection by the number adults/children per space or per building. The number per building is calculated by multiplying employee/adults per room by the total number of these rooms per building entered (in actuality or as an approximation to provide an estimate of the entire building population).

The estimated salary dollars lost is calculated using the following formula:

- Estimated salary dollars lost = (number of adults infected per viral season * sick days/adult infection * 8 work hours/day / 2080 work hours/year) * weighted average salary $/year (L)

The average salary (in any currency) should be of all of the FTE employees, weighted by the average salaries of the different employee categories (i.e., Administrative, Custodian, Manager, CEO, etc.) and number of employees within each category. Employee categories refer to those occupants who are paid to work in the facility. The salary should include the base salary along with associated recruitment expenses, benefits, and training. If this isn't provided by the organization's HR department, some references are provided to help determine this for the U.S. in the Weighted Average Salary Sources (U.S.) section below.

For the influenza sick days per adult infection, a value of 5 days was used as the default value (though you may vary it). Keech and Beardsworth (2008) reported an average of 3.38 days lost to the flu from being out sick, averaged from three separate studies. Other sources have reported recovery times of 1 to 2 weeks, and Jilani et. al. 2020 states an infected patient should be isolated 5 days. The 5-day value was used as a compromise among these varied reports.

For the COVID-19 sick days per adult infection, a value of 17 days was used as the default value (though you may vary it here as well). A weighted average of 17.6 days ((80%* 14 days) + (20% * 32 days) = 17.6 days) was calculated from data in a WHO Report from February, 2020 (https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf), pp. 12-15. A weighted average of 13.1 days ((70% * 10.63) + 30% (18.7) = 13.1 days) was calculated from data in Wu et al. (2020). Barman et al. (2020) reported 21 days. Averaging these three values results in 17.2 days, and so the default value was rounded down to 17 days.

It's important to remember that this only represents the loss directly attributed to actual sick days taken, for both influenza and COVID-19. Presenteeism and other associate domino impacts are not included. But it's also true that some individuals could work from home before fully recovered while others who can't work from home would need to remain isolated.

The estimated child dollars lost is calculated using the following formula:

- Estimated child days lost = number of children infected per viral season * sick days/child infection. (Q)

The sick days per adult infection were also used for the sick days per child infection (so these are the same default values). Though you may vary these as well.

While all of the output should be viewed as results of a simplified model of reality, the probability of infection per viral season in particular should be viewed as a simple heuristic primarily useful for a relative comparison of the baseline and design conditions. In addition to the model's simplifications being compounded over a longer period of time, the exposure time per viral season itself is difficult to estimate accurately, as discussed above.

Probability of Infection

These summary tables and associated figures provide a) the estimated adult/child probability of infection per day (or time of exposure) relative to each design removal factor, b) the estimated adult/child probability of infection per day (or time of exposure) relative to all removal factors under the baseline and design conditions, c) the deltas between those values, d) the estimated adult/child probability of infection per viral season relative to all removal factors under the baseline and design conditions, and e) the deltas between those values. The calculations for these were discussed above in the previous two sections.

Hypothetical R Value

As alluded to above in the discussion of vaccination rates, the R value is the number of secondary infection cases produced by a single infected individual – it's the ratio of secondary infected individuals to initial infected individuals (Adam 2020; Delamater et al. 2019; Jones 2007). A specific variant of R, R_0, assumes everyone in the population is susceptible, while R_{0p} is the R_0 under vaccination. The common interpretation is generally that an R value greater than 1 indicates an outbreak is expected to continue while a value less than 1 indicates it's on its way to ending. The reality is more complex, and the reader is referred to the above references for additional information.

To provide an additional indication of the potential severity of the resulting probability of infection calculations given the module inputs, a Hypothetical R value is reported for the baseline and design conditions. It is based on the combined adult and children values for the initial and secondary numbers of infected individuals. It is only applicable to this single space over the course of a single day (exposure time per day). If the number is greater than 1.0, some additional thought should likely be given at reducing either the probability of infection or the number of people within the space.

Aerosol Viral Particle Removal Efficiency Output

This summary table and associated figure provide a) the estimated removal efficiencies for each design removal factor and b) the estimated total removal efficiencies of all of the removal factor measures employed under the design and baseline conditions. The calculations for these were discussed above in the Removal Efficiency Calculations section. It's important to remember that these values provide a snapshot in time (at the removal time entered) of the efficiencies of the removal factors employed. The removal efficiencies are also relative to the droplet/droplet nuclei (and associated viral particles) released by an infected individual(s) from a single expiratory event.

References

Adam, D. (2020) A guide to R — The Pandemic's Misunderstood Metric: What the Reproduction Number Can and Can't Tell Us about Managing COVID-19. *Nature, News Feature*. 07/03/2020. https://www.nature.com/articles/d41586-020-02009-w.

Barman, M. P., T. Rahman, K. Bora, C. Borgohain (2020) COVID-19 Pandemic and its Recovery Time of Patients in India: A Pilot Study. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews* 14:1205-1211. https://www.sciencedirect.com/science/article/pii/S1871402120302502.

Beggs, C. B. and E. J. Avital (2020) Upper-room Ultraviolet Air Disinfection Might Help to Reduce COVID-19 Transmission in Buildings. *medRxiv* June 14, 2020. https://doi.org/10.1101/2020.06.12.20129254.

Buonanno, G. and S. Morawska (2020a) Estimation of Airborne Viral Emission: Quanta Emission Rate of SARS-CoV-2 for Infection Risk Assessment. *Environmental International* 141. https://www.sciencedirect.com/science/article/pii/S0160412020312800.

Buonanno, G, L. Morawska, and L. Stabile (2020b) Quantitative Assessment of the Risk of Airborne Transmission of SARS-CoV-2 Infection: Prospective and Retrospective Applications. *Environmental International* 145. https://www.sciencedirect.com/science/article/pii/S0160412020320675?via%3Dihub.

Centers for Disease Control and Prevention (2019) Flu Vaccination Coverage, United States, 2018–19 Influenza Season. Accessed 06/12/2020. https://www.cdc.gov/flu/fluvaxview/coverage-1819estimates.htm

Chen, S. C., and C. M. Liao (2008) Modelling Control Measures to Reduce the Impact of Pandemic Influenza among Schoolchildren. *Epidemiology & Infection* 136:1035-1045. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2870896/

Chen, S. C., and C. M. Liao (2013) Cost-effectiveness of Influenza Control Measures: a Dynamic Transmission Model-based Analysis. *Epidemiology & Infection* 141(12):2581-2594. https://www.cambridge.org/core/journals/epidemiology-and-infection/article/costeffectiveness-of-influenza-control-measures-a-dynamic-transmission-modelbased-analysis/983D7586168881E60C80B8614EA2E009

Clapp, P. W., E. E. Sickbert-Bennett, J. M. Samet, et al. (2020) US Centers for Disease Control and Prevention Epicenters Program. Evaluation of Cloth Masks and Modified Procedure Masks as Personal Protective Equipment for the Public During the COVID-19 Pandemic. *JAMA Internal Medicine* 2020 Dec 10:e208168. doi: 10.1001/jamainternmed.2020.8168. Epub ahead of print. PMID: 33300948; PMCID: PMC7729588. https://pubmed.ncbi.nlm.nih.gov/33300948/.

de Mesquita, P. J., C. J. Noakes, and D. K. Milton (2020) Quantitative Aerobiologic Analysis of an Influenza Human Challenge-transmission Trial. *Indoor Air* June 15, 2020. https://publons.com/publon/10.1111/ina.12701.

Dai, H. and B. Zhao (2020) Association of Infected Probability of COVID-19 with Ventilation Rates in Confined Spaces: a Wells-Riley Equation-based Investigation Preprint. *medRxiv* 2020.04.21.20072397. doi: https://doi.org/10.1101/2020.04.21.20072397. https://www.medrxiv.org/content/10.1101/2020.04.21.20072397v1.

Delamater, P. L., E. J. Street, T. F. Leslie, Y. T. Yang, and K. H. Jacobsen (2019) Complexity of the Basic Reproduction Number (R0). *Emerging Infectious Diseases* 25(1):1-4. https://dx.doi.org/10.3201/eid2501.171901.

Duguid JP (1946) The Size and the Duration of Air-carriage of Respiratory Droplets and Droplet-nuclei. *J Hyg* 44: 471–479. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2234804/

Fabian, P., J. J. McDevitt, W. H. DeHaan, R. O. P. Fung, B. J. Cowling, K. H. Chan, G. M. Leung, D. K. Milton (2008) Influenza Virus in Human Exhaled Breath: An Observational Study. *PLoS ONE* 3(7): e2691. https://doi.org/10.1371/journal.pone.0002691.

Fabian, P, J. Brain, E. A. Houseman, J. Gern, D. K. Milton (2011) Origin of Exhaled Breath Particles from Healthy and Human Rhinovirus-Infected Subjects. *Journal of Aerosol Medicine and Pulmonary Drug Delivery* 24(3): 137–147. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3123971/.

First, M. W., E. A. Nardell, W. Chaisson, and R. Riley (1999a) Guidelines for the Application of Upper-Room Ultraviolet Germicidal Irradiation for Preventing Transmission of Airborne Contagion—Part I: Basic Principles. *ASHRAE Transactions 1999*, V. 105, Pt. 1. https://www.osti.gov/biblio/20002362-guidelines-application-upper-room-ultraviolet-germicidal-irradiation-preventing-transmission-airborne-contagion-part-basic-principles.

First, M. W., E. A. Nardell, W. Chaisson, and R. Riley (1999b) Guidelines for the Application of Upper-Room Ultraviolet Germicidal Irradiation for Preventing Transmission of Airborne Contagion—Part II: Design and Operation Guidance. *ASHRAE Transactions* 1999, V. 105, Pt. 2. https://www.ghdonline.org/uploads/GUIDELINES_PART_2.PDF.

Gammaitoni, L., Nucci, M.C. (1997) Using a Mathematical Model to Evaluate the Efficacy of TB Control Measures. *Emerging Infectious Disease* 3:335–342. https://pubmed.ncbi.nlm.nih.gov/9284378/.

Gregson, F. K. A., N. A. Watson, C. M. Orton, A. E. Haddrell, L. P. McCarthy, T. J. R. Finnie, N. Gent, G. C. Donaldson, P. L. Shah, J. D. Calder, B. R. Bzdek, D. Costello, and J. P. Reid (2020) Comparing the Respirable Aerosol Concentrations and Particle Size Distributions Generated by Singing, Speaking and Breathing. *ChemRxiv*. Preprint. Accessed 9/22/2020. https://doi.org/10.26434/chemrxiv.12789221.v1.

Grinshpun, S. A., H. Haruta, R. M. Eninger, T. Reponen, R. T. McKay, and S. Lee (2009) Performance of an N95 Filtering Facepiece Particulate Respirator and a Surgical Mask During Human Breathing: Two Pathways for Particle Penetration. *Journal of Occupational and Environmental Hygiene* 6:593–603. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7196699/.

Han Z. Y., W. G. Weng and Q. Y. Huang (2013) Characterizations of Particle Size Distribution of the Droplets Exhaled by Sneeze Journal of the Royal Society Interface. 10:20130560 http://doi.org/10.1098/rsif.2013.0560.

Harper GJ (1961) Airborne Micro-organisms: Survival Tests with Four Viruses. *J Hyg* 59: 479–486. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2134455/

Jilani, T. N., R. T. Jamil, A. H. Siddiqui (2020) H1N1 Influenza (Swine Flu). *StatPearls [Internet]*, 07/20/2020. https://www.ncbi.nlm.nih.gov/books/NBK513241/.

Jimenez, J. L. (2020) COVID-19 Aerosol Transmission Estimator. Accessed 9/23/2020. https://docs.google.com/spreadsheets/d/16K1OQkLD4BjgBdO8ePj6ytf-RpPMlJ6aXFg3PrIQBbQ/edit#gid=519189277.

Johnson, G. R., L. Morawska; Z. D. Ristovski; M. Hargreaves; K. Mengersen; C. Y.H. Chao; M. P. Wan; Y. Li; X. Xie; D. Katoshevski; S. Corbett (2011) Modality of Human Expired Aerosol Size Distributions. *Journal of Aerosol Science*, ISSN: 0021-8502, 42(12):839-851. https://www.sciencedirect.com/science/article/pii/S0021850211001200.

Jones, J. H. (2007). Notes on R_0. Accessed on 06/12/2020. https://web.stanford.edu/~jhj1/teachingdocs/Jones-on-R0.pdf.

Keech M, Beardsworth P. (2008) The Impact of Influenza on Working Days Lost. *Pharmacoeconomics*. 26(11):911–24. https://www.ncbi.nlm.nih.gov/pubmed/18850761

Kirkman, S., J. Zhai, & S. L. Miller (2020) Effectiveness of Air Cleaners for Removal of Virus-Containing Respiratory Droplets: Recommendations for Air Cleaner Selection for Campus Spaces. Report. 05/31/2020. https://shellym80304.files.wordpress.com/2020/06/air-cleaner-report.pdf.

Konda, A., A. Prakash, G. A. Moss, M. Schmoldt, G. D. Grant, and S. Guha. (2020a) Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. *ACS Nano* 14(5): 6339–6347 https://pubs.acs.org/doi/10.1021/acsnano.0c03252.

Konda, A., A. Prakash, G. A. Moss, M. Schmoldt, G. D. Grant, and S. Guha. (2020b) Response to Letters to the Editor on Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks: Revised and Expanded Results. *ACS Nano* 14: 10764−10770. https://dx.doi.org/10.1021/acsnano.0c04897.

Kowalski W. J., W.P. Bahnfleth, D. L. Witham, B. F. Severin, and T. S. Whittam (2000) Mathematical Modeling of Ultraviolet Germicidal Irradiation for Air Disinfection. *Quantitative Microbiology* 2:249–270. https://link.springer.com/article/10.1023/A:1013951313398.

Kowalski W. J, T. J. Walsh, and V. Petraitis (2020) 2020 COVID-19 Coronavirus Ultraviolet Susceptibility. March 2020. Technical Report number: COVID-19_UV_V20200312. https://www.researchgate.net/publication/339887436_2020_COVID-19_Coronavirus_Ultraviolet_Susceptibility.

Liao, C. M., S. C. Chen, and C. F. Chang (2008) Modelling Respiratory Infection Control Measure Effects. *Epidemiology and infection* 136(3):299–308. https://doi.org/10.1017/S0950268807008631.

Lindsley, W. G., F. M. Blachere, R. E. Thewlis, A. Vishnu, K. A. Davis, G. Cao, et al. (2010) Measurements of Airborne Influenza Virus in Aerosol Particles from Human Coughs. *PLoS ONE* 5(11): e15100. https://doi.org/10.1371/journal.pone.0015100.

Lindsley, W. G., J. D. Noti, F. M. Blachere, et al. (2015) Viable Influenza A Virus in Airborne Particles from Human Coughs. *Journal of Occupational and Environmental Hygiene*. 12(2):107-113. https://doi.org/10.1371/journal.ppat.1003205.

McDevitt, J. J., S. N. Rudnick, and L. J. Radonovich (2012) Aerosol Susceptibility of Influenza Virus to UV-C Light. *Applied and Environmental Microbiology* 78(6): 1666–1669. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3298127/.

Mikszewski, A. (2020) Airborne Infection Risk Calculator, User's Manual, Version 1.0. Accessed 8/1/2020. https://www.unicas.it/media/4952018/AIRC%20Users%20Manual%201.0%20July%202020.pdf.

Miller, S. H., et. al. (2002) Efficacy of Ultraviolet Irradiation in Controlling the Spread of Tuberculosis. Centers for Disease Control and Prevention National Institute for Occupational Safety and Health. October 12, 2002. https://www.cdc.gov/niosh/nioshtic-2/20022472.html.

Miller, S. H., W. W. Nazaroff, J. L. Jimenez, A. Boerstra, G. Buonanno, S. J Dancer, J. Kurnitski, L. C. Marr, L. Morawska, and C. Noakes (2020) Transmission of SARS-CoV-2 by Inhalation of Respiratory Aerosol in the Skagit Valley Chorale Superspreading Event. *medRxiv* Preprint 6/18/2020 https://www.medrxiv.org/node/86329.external-links.html.

Milton D.K., M. P. Fabian, B. J. Cowling, M. L. Grantham, J. J. McDevitt (2013) Influenza Virus Aerosols in Human Exhaled Breath: Particle Size, Culturability, and Effect of Surgical Masks. *PLoS Pathogens* 9(3): e1003205. https://doi.org/10.1371/journal.ppat.1003205.

Mphaphlele, M. et al. (2015) Institutional Tuberculosis Transmission: Controlled Trial of Upper Room Ultraviolet Air Disinfection: A Basis for New Dosing Guidelines. *American Journal of Respiratory and Critical Care Medicine* 192(4):477-484. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4595666/.

Morawska, L., G.R. Johnson, Z.D. Ristovsk, M. Hargreaves, K. Mengersen, S. Corbett, C.Y.H. Chao, Y. Li, and D. Katoshevsk. 2009. Size Distribution and Sites of Origin of Droplets Expelled from the Human Respiratory Tract During Expiratory Activities. *Journal of Aerosol Science*. 40(3):256-259. https://www.sciencedirect.com/science/article/pii/S0021850208002036.

Noakes, C. J., C. B. Beggs, and P. A. Sleigh (2003) Effect of Room Mixing and Ventilation Strategy on the Performance of Upper Room Ultraviolet Germicidal Irradiation Systems. https://www.researchgate.net/publication/268274237_Effect_of_Room_Mixing_and_Ventilation_Strategy_on_the_Performance_of_Upper_Room_Ultraviolet_Germicidal_Irradiation_Systems.

Noakes, C. J., C. B. Beggs, and P. A. Sleigh (2004) Modelling the Performance of Upper Room Ultraviolet Germicidal Irradiation Devices in Ventilated Rooms: Comparison of Analytical and CFD Methods. https://www.researchgate.net/publication/247731684_Modelling_the_Performance_of_Upper_Room_Ultraviolet_Germicidal_Irradiation_Devices_in_Ventilated_Rooms_Comparison_of_Analytical_and_CFD_Methods.

Noakes, C. J., M. Amirul, I. Khan and C. A. Gilkeson (2015) Modeling Infection Risk and Energy Use of Upper-Room Ultraviolet Germicidal Irradiation Systems in Multi-Room Environments. *Science and Technology for the Built Environment* 21(1):99-111. https://doi.org/10.1080/10789669.2014.983035.

Nunayon, S. S., H. Zhang, and A. C. K. Lai. 2019. Comparison of Disinfection Performance of UVC-LED and Conventional Upper-room UVGI Systems. *Indoor Air* 30(1):180-191. https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12619.

Rothamer, D. A., S. Sanders, D. Reindl, T. H. Bertram (2020) Strategies to minimize SARS-CoV-2 transmission in classroom settings: Combined impacts of ventilation and mask effective filtration efficiency. *medRxiv* 2020.12.31.20249101; doi: https://doi.org/10.1101/2020.12.31.20249101.

Rudnick S. N. and D. K. Milton (2003) Risk of Indoor Airborne Infection Transmission Estimated from Carbon Dioxide Concentration. *Indoor Air* 13(3):237-245. doi:10.1034/j.1600-0668.2003.00189.x.

Sharp, D. G., A. R. Taylor, I. W. McLean, Jr., Dorothy Beard, and J. W. Beard. Densities and Sizes of the Influenza Viruses A (PR8 Strain) and B and the Swine Influenza Virus *J. Biol. Chem*. 1945 159: 29-. https://www.jbc.org/content/159/1/29.citation

Stephens, B. (2012) HVAC Filtration and the Wells-Riley Approach to Assessing Risks of Infectious Airborne Diseases, Final Report. Prepared for The National Air Filtration Association (NAFA) Foundation. https://www.nafahq.org/wp-content/uploads/WellsRileyReport.pdf

Sung, M. and S. Kato (2011) Estimating the Germicidal Effect of Upper-Room UVGI System on Exhaled Air of Patients Based on Ventilation Efficiency. *Building and Environment* 46(11): 2326–2332. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7127715/.

Tokars, J., S. J. Olsen, C. Reed (2018) Seasonal Incidence of Symptomatic Influenza in the United States. *Clinical Infectious Diseases*. 66(10): 1511–1518. https://doi.org/10.1093/cid/cix1060

U.S. EPA, 2011. Exposure Factors Handbook: 2011 Edition (No. EPA/600/R-09/052F). National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington, DC. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252

Wu, J., W. Li, X. Shi, Z. Chen, B. Jiang, J. Liu, D. Wang, C. Liu, Y. Meng, L. Cui, J. Yu, H. Cao, and L. Li (2020) Early Antiviral Treatment Contributes to Alleviate the Severity and Improve the Prognosis Of Patients with Novel Coronavirus Disease (COVID-19). *Journal of Internal Medicine*. Preprint. March 27, 2020. https://onlinelibrary.wiley.com/doi/full/10.1111/joim.13063.

Yang W, Marr LC (2011) Dynamics of Airborne Influenza A Viruses Indoors and Dependence on Humidity. *PLoS ONE* 6(6): e21481. https://doi.org/10.1371/journal.pone.0021481.

Zemouri C., S. F. Awad, C. M. C. Volgenant, W. Crielaard, A. M. G. A. Laheij, and J. J. de Soet (2020) Modeling of the Transmission of Coronaviruses, Measles Virus, Influenza Virus, Mycobacterium Tuberculosis, and Legionella Pneumophila in Dental Clinics. *Journal of Dental Research* 99(10):1192-1198. https://doi.org/10.1177/0022034520940288.

Additional Sources of Information

FAQs on Protecting Yourself from Aerosol Transmission:
https://docs.google.com/document/u/0/d/1fB5pysccOHvxphpTmCG_TGdytavMmc1cUumn8m0pwzo/mobilebasic

5 Step Guide to Checking Ventilation Rates in Classrooms: https://schools.forhealth.org/ventilation-guide/

ASHRAE COVID-19 (Coronavirus) Preparedness Resources: https://www.ashrae.org/technical-resources/resources

ASHRAE Position Document on Infectious Aerosols:
https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf

ASHRAE Position Document on Airborne Infectious Diseases: https://www.ashrae.org/File Library/About/Position Documents/Airborne-Infectious-Diseases.pdf

fitwel COVID-19 Resources: https://www.fitwel.org/covid-19/

RESET: https://www.reset.build/

- RESET COVID-19 Index: https://reset.build/resources/COVID

New LEED Guidance to Address COVID-19 and Support Buildings with Reopening Strategies:
https://www.usgbc.org/articles/usgbc-releases-new-leed-guidance-address-covid-19-andsupport-buildings-reopening

WELL Health-Safety Rating: https://www.wellcertified.com/health-safety/

REHVA COVID-19 Guidance: https://www.rehva.eu/activities/covid-19-guidance

AIA COVID-19 Resources for Architects: https://www.aia.org/pages/6280670-covid-19-member-resources-

AIA Re-Occupancy Assessment Tool: https://www.aia.org/press-releases/6292741-architects-release-new-resource-for-safer-

COVID-19: A Path Forward (Harvard T.H. Chan School of Public Health, Center for Communicable Disease Dynamics, and Healthy Buildings): https://covidpathforward.com/

Ten Facts about UV Radiation and COVID-19:
https://www.tandfonline.com/doi/full/10.1080/15502724.2020.1760654

IES Committee Report: Germicidal Ultraviolet (GUV) – Frequently Asked Questions:
https://www.ies.org/standards/committee-reports/

CIE 155:2003 Technical Report – Ultraviolet Air Disinfection: http://files.cie.co.at/cie155-2003%20(free%20copy%20March%202020).pdf

Viruses in Droplets and Aerosols Presentation, by Dr. Linsey Marr, Charles P. Lunsford Professor of Civil and Environmental Engineering at Virginia Tech:
https://www.youtube.com/watch?v=dD1gKaaQg6k&feature=yout

How can Airborne Transmission of CoV-2 Indoors be Minimized presentation, by Dr. Shelly Miller, Professor of Mechanical Engineering at the University of Colorado Boulder and faculty member of the Environmental Engineering Program:
https://www.youtube.com/watch?v=jK6Cef5A8FQ&feature=youtu.be

Managing HVAC Systems to Reduce Infectious Disease Transmission presentation, by Dr. Bill Bahnfleth, professor and director of the Indoor Environment Center in the Department of Architectural Engineering at The Pennsylvania State University:
https://betterbuildingssolutioncenter.energy.gov/webinars/managing-hvac-systems-reduce-infectious-disease-transmission

Airborne, Droplets, and HVAC presentation, by Travis English, PE, CEM, LEED AP, Engineering Manager for Kaiser Permanente (KP) National Facilities Planning group, and KP's designated Chief Engineer of Design Excellence: https://www.youtube.com/watch?v=_3K-w_ZGXBM&feature=youtu.be

Weighted Average Salary Sources (U.S.)

Employment Cost Trends: http://www.bls.gov/ncs/ect/home.htm - Provides wages/salaries and benefits by industry, demographic, region, etc.

FederalPay.org - Government Pay Tables, Calculators, and More Federal: https://www.federalpay.org/

General Schedule (GS) Payscale Table for 2020: https://www.federalpay.org/gs/2020

Salary Comparison and Salary Calculator: http://about.salary.com/

Tables/Figures

The tables/figures on the following pages are what has been referenced in this document.

Table A: Prior studies of respiratory droplet size distributions

Measurement Range (µm)	Status	Infected With	Expiratory Event	Droplet Size Range (µm)		Calced Droplet GM (µm)	% Infectious Droplets or Concentration	Droplet Size Range (µm)		Calced Droplet GM (µm)	% Infectious Droplets or Concentration	Droplet Size Range (µm)		Calced Droplet GM (µm)	% Infectious Droplets or Concentration	Droplet Size Range (µm)		Calced Droplet GM (µm)	% Infectious Droplets or Concentration	Droplet Size Range (µm)		Calced Droplet GM (µm)	% Infectious Droplets or Concentration	Weighted Average GM (µm)	Equilibrium vs Initial	Estimated Initial Weighted Average GM (µm)	Source
0.3-?	Infected	Influenza	Breathing	0.3	0.5	0.4	70%	0.5	1.0	0.7	17%	1.0	5.0	2.2	13%									0.7	Assumed Equil.	1.4	Fabian et al. 2008
0.3-10	Infected	Influenza	Breathing	0.3	0.5	0.4	82%	0.5	10.0	2.2	18%													0.7	Assumed Equil.	1.4	Fabian et al. 2011
0.05-50	Infected	Influenza	Breathing	0.05	0.5	0.2	90%	0.5	50.0	5.0	10%													0.7	Assumed Equil.	1.3	Milton et al. 2013
0.5-20	Healthy	NA	Breathing			0.8	86%			1.8	9%			3.5	3%			5.5	2%					1.1	Assumed Equil.	2.1	Morawska et al. 2009
0.3-20	Healthy	NA	Breathing			0.6	64%			1.1	36%													0.7	Assumed Equil.	1.5	Gregson 2020
																							~~Breathing Average~~	~~0.8~~	-	~~1.5~~	
																							Breathing Average, Infected Only	0.7		1.4	
0.5-20	Healthy	NA	Speaking softly			0.8	85%			1.8	11%			3.5	3%			5.5	1%					1.0	Assumed Equil.	2.1	Morawska et al. 2009
0.5-20	Healthy	NA	Speaking normal			0.8	73%			1.8	21%			3.5	2%			5.5	4%					1.3	Assumed Equil.	2.5	Morawska et al. 2009
0.3-20	Healthy	NA	Speaking normal			0.5	79%			1.3	21%													0.7	Assumed Equil.	1.3	Gregson 2020
0.3-20+	Healthy	NA	Speaking normal	B-mode		0.8	43%	L-mode		1.2	54%	O-mode		145	3%									5.3	Equil.	10.7	Johnson et al. 2011
0.3-20+	Healthy	NA	Speaking normal	B-mode		0.8	44%	L-mode		1.2	56%													1.0	Equil.	2.1	Johnson et al. 2011
0.5-20	Healthy	NA	Speaking loudly			0.8	69%			1.8	13%			3.5	13%			5.5	5%					1.5	Assumed Equil.	3.0	Morawska et al. 2009
0.3-20	Healthy	NA	Speaking loudly			0.5	39%			1.3	61%													1.0	Assumed Equil.	2.0	Gregson 2020
																							~~Speaking Normal Average w/ O-mode~~	~~3.4~~	-	~~4.8~~	
																							Speaking Normal Average w/out O-mode	1.0		2.0	
																							Speaking Loudly Average	1.3		2.5	
0.3-20	Healthy	NA	Singing average			0.5	44%			1.1	56%													0.9	Assumed Equil.	1.7	Gregson 2020
0.3-20	Healthy	NA	Singing loudly			0.6	34%			1.3	66%													1.0	Assumed Equil.	2.1	Gregson 2020
																							Singing Average	1.0		2.1	
?	Infected	Influenza	Cough	0.3	1.0	0.5	15%	1.0	3.0	1.7	25%	3.0	10.0	5.5	60%									3.8	Assumed Equil.	7.6	Stephens 2012
?	Infected	Influenza	Cough	0.3	1.0	0.5	35%	1.0	4.0	2.0	23%	4.0	10.0	6.3	42%									3.3	Assumed Equil.	6.6	Lindlesy et al. 2010
0.3-?	Infected	Influenza	Cough	0.3	8.0	1.5	100%																	1.5	Assumed Equil.	3.1	Lindlesy et al. 2015
0.5-20	Healthy	NA	Cough			0.8	83%			1.8	14%			3.5	2%			5.5	1%					1.0	Assumed Equil.	2.1	Morawska et al. 2009
0.3-20+	Healthy	NA	Cough	B-mode		0.8	40%	L-mode		0.8	54%	O-mode		123.0	6%									8.1	Equil.	16.3	Johnson et al. 2011
0.3-20+	Healthy	NA	Cough	B-mode		0.8	43%	L-mode		0.8	57%													0.8	Equil.	1.6	Johnson et al. 2011
																							~~Coughing Average w/ O-mode~~	~~3.6~~	-	~~7.1~~	
																							~~Coughing Average w/out O-mode~~	~~2.1~~	-	~~4.2~~	
																							Coughing Average, Infected Only	2.9		5.8	
0.1-1000	Healthy	NA	Sneeze	Unimodal distribution; size class w/ most droplets: 341.5 - 398.1 µm																				360.1	Assumed Initial	NA	Han et al. 2013
0.1-1000	Healthy	NA	Sneeze	Biimodal distribution; size class w/ most droplets: 73.6 - 85.8 µm																				74.4	Assumed Initial	NA	Han et al. 2013
?	?	?	Sneeze	1	2.0	1.4	3%	2.0	4.0	2.8	16%	4.0	8.0	5.7	35%	8.0	16.0	11.3	28%	16.0	1000	126.5	19%	29.0	Assumed Initial	NA	Duguid 1946
																							~~Sneezing Average~~	~~154.5~~		~~NA~~	
																							Sneezing Average, Excluding Unimodal distribution	51.7		NA	

Table B: Filtration efficiencies & p scaling factor		
	Fitted Filtration Efficiency (%) **0.2 µm - 3.0 µm**	**p scaling factor**
No mask	0	0
2-layer woven nylon mask w/ ear loops w/out aluminum nose bridge	44.7%	55.3%
2-layer woven nylon mask w/ ear loops, w/ aluminum nose bridge	56.3%	43.7%
2-layer woven nylon mask w/ ear loops, w/ aluminum nose bridge & 1 nonwoven insert	74.4%	25.6%
Cotton bandana, folded "bandit" style	49.0%	51.0%
Single-layer woven polyester gaiter/neck cover	37.8%	62.2%
Single-layer woven polyester/nylon mask w/ ties	39.3%	60.7%
Nonwoven polypropylene mask w/ fixed ear loops	28.6%	71.4%
3-layer woven cotton mask w/ ear loops	26.5%	73.5%
Surgical mask w/ ties	71.5%	28.5%
Procedure mask w/ ear loops	38.5%	61.5%
Procedure mask w/ ear loops & 3D printed ear guard	61.7%	38.3%
Procedure mask w/ ear loops & FixTheMask	86.6%	13.4%
N95	98.4%	1.6%

Table C: SARS-CoV-2 Inactivation / Decay Rate (hours)			
	50% Decay (HR)	90% Decay (HR)	99% Decay (HR)
10%			
20%			
21%	40.98	136.12	272.24
22%	12.78	42.44	84.88
23%	7.57	25.14	50.28
25%	4.17	13.85	27.7
30%	1.96	6.52	13.05
35%	1.28	4.27	8.53
40%	0.95	3.17	6.34
45%	0.76	2.52	5.04
50%	0.63	2.09	4.19
55%	0.54	1.79	3.58
60%	0.47	1.56	3.13
65%	0.42	1.39	2.77
70%	0.38	1.25	2.49
80%			
90%			

Table D: SARS-CoV-2 Inactivation / Decay Rate (min^{-1})			
	50% Decay (min^{-1})	90% Decay (min^{-1})	99% Decay (min^{-1})
10%			
20%			
21%	0.000406702	0.000122441	6.12205E-05
22%	0.001304121	0.000392711	0.000196356
23%	0.002201673	0.000662954	0.000331477
25%	0.003996803	0.001203369	0.000601685
30%	0.008503401	0.002556237	0.001277139
35%	0.013020833	0.003903201	0.001953888
40%	0.01754386	0.005257624	0.002628812
45%	0.021929825	0.006613757	0.003306878
50%	0.026455026	0.007974482	0.003977725
55%	0.030864198	0.009310987	0.004655493
60%	0.035460993	0.010683761	0.005324814
65%	0.03968254	0.011990408	0.006016847
70%	0.043859649	0.013333333	0.00669344
80%			
90%			

Figure 1: SARS-CoV-2 Inactivation / Decay Rate: UV Index = 0, T = 72^0F

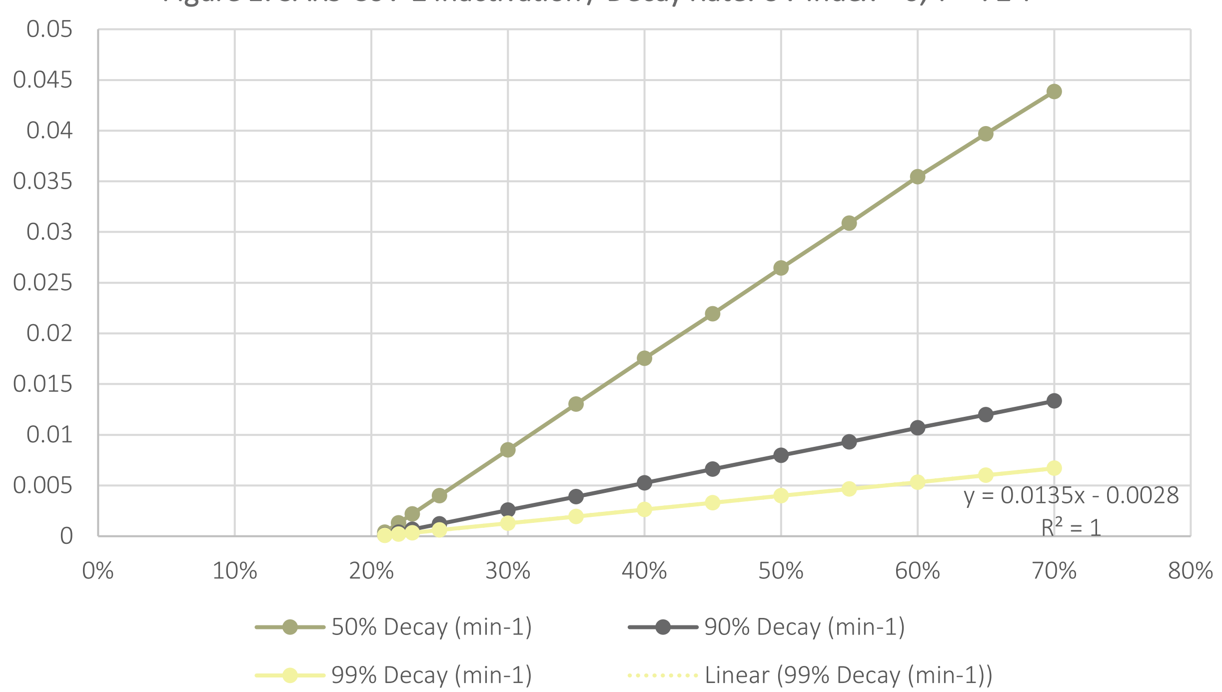

Table E: Estimated Z values for influenza aerosols determined at low, medium, & high relative humidity

RH range (%)	RH Range	Estimated Z Value (m^2/J)	95% Confidence Interval		R^2
			Lower	Upper	
25 - 27	0% - 33%	0.29	0.27	0.31	0.985
50 - 54	34% - 66%	0.27	0.26	0.31	0.991
81 - 84	67% - 100%	0.22	0.21	0.23	0.992

Table F: Quantum Generation Rate Estimate (Quanta per hour)						
Expiratory Means / Activity Level	Influenza Quantum Generation Rate Estimate (Quanta per hour)			SARS-CoV-2 Quantum Generation Rate Estimate (Quanta per hour)		
	Low Risk (Shedder)	Medium Risk (Shedder)	High Risk (Shedder)	Low Risk (Shedder)	Medium Risk (Shedder)	High Risk (Shedder)
Breathing / Sitting	3.2	35.0	68.0	4.0	15.8	28.0
Speaking (Coughing, Sneezing) / Sitting	6.6	72.3	140.5	16.0	50.2	85.7
Loudly Speaking (Singing) / Sitting	29.6	324.2	630.0	97.0	382.5	679.0
Breathing / Standing	3.5	38.5	74.8	4.4	17.4	30.8
Speaking (Coughing, Sneezing) / Standing	7.3	79.5	154.6	21.0	65.9	112.5
Loudly Speaking (Singing) / Standing	32.6	356.6	693.0	134.0	528.5	938.0
Breathing / Light Exercise	4.6	49.9	96.9	5.7	22.5	39.9
Speaking (Coughing, Sneezing) / Light Exercise	9.4	103.0	200.2	26.5	83.2	142.0
Loudly Speaking (Singing) / Light Exercise	42.2	462.0	897.8	170.0	670.4	1190.0
Breathing / Heavy Exercise	10.6	116.3	226.1	13.3	52.5	93.1
Speaking (Coughing, Sneezing) / Heavy Exercise	22.0	240.4	467.2	63.7	199.9	341.3
Loudly Speaking (Singing) / Heavy Exercise	98.6	1077.9	2094.8	408.0	1609.0	2856.0

Table G: Quantum Generation Rate Studies			
Activity	**Influenza Quantum Generation Rate Estimate (Quanta per hour)**	**Source**	**Notes**
Breathing / Sitting	15 - 128	Rudnick & Milton (2003)	Highly infectious / superspreader range
Breathing / Sitting	<3.2 - 20	Fabian et al. (2008)	High degree of uncertainty
Breathing / Sitting	LR: 15; IR: 76.18; HR: 128	Zemouri et al. (2020)	LR, IR, HR - low, intermediate, high risk
Breathing / Sitting	515	Beggs et al. (2010)	Airflight Outbreak / highly infectious
Breathing / Sitting	0.17 - 630	de Mequita (2020)	LR/symptomatic to HR/asymptomatic
Breathing / Sitting	33.9 - 67.8	Chen and Liao (2008)	No indication of level of risk / superspreader
Breathing / Sitting	68.67	Liao et al. (2008)	Mean value of Rudnick & Milton (2003) - HR

Table H: Quantum Generation Rate Studies			
Activity	**SARS-CoV-2 Quantum Generation Rate Estimate (Quanta per hour)**	**Source**	**Notes**
Breathing / Sitting	<1	Buonanno et al. (2020a)	Symptomatic infectious subject
Vocalization / Light Activity	>100 (1030)	Buonanno et al. (2020a)	Asymptomatic infectious subject; walking slowly
Speaking / Light Activity	142	Buonanno et al. (2020a)	Asymptomatic infectious subject; worst case
Breathing / Sitting	LR: 11.4; IR: 28.94; HR: 295.5	Zemouri et al. (2020)	Using SARS-CoV-1 as a proxy
Breathing / Sitting	0.36	Buonanno et al. (2020b)	Asymptomatic subject; Assuming low risk; Preprint
Breathing / Heavy Activity	2.4	Buonanno et al. (2020b)	Asymptomatic subject; Assuming low risk; Preprint
Speaking / Light Activity	4.9	Buonanno et al. (2020b)	Asymptomatic subject; Assuming low risk; Preprint
Singing / Light Activity	31	Buonanno et al. (2020b)	Asymptomatic subject; Assuming low risk; Preprint
Singing / Light Activity	970 [680-1190]	Miller et al. (2020)	Asymptomatic; High Risk (superspreader); Preprint
? (Breathing / Sitting)	14 - 48	Dai & Zhao (2020)	Fitted quantum generation rate w/ Ro; Preprint
Oral Breathing (Lecturing)	4.4	Jimenez (2020)	Assuming low risk
Speaking (Lecturing)	21	Jimenez (2020)	Assuming low risk
Loud Speaking (Lecturing) / Singing	134	Jimenez (2020)	Assuming low risk
Oral Breathing / Sitting (Student)	4	Jimenez (2020)	Assuming low risk
Speaking / Sitting (Student)	16	Jimenez (2020)	Assuming low risk
Loud Speaking (sitting) / singing	97	Jimenez (2020)	Assuming low risk

Table I: Quantum Generation Rate Studies			
Activity	**SARS-CoV-2 Quantum Generation Rate Estimate (Quanta per hour)**	**Source**	**Notes**
Oral Breathing / Resting	1.98	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Speaking / Resting	9.49	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Loudly Speaking / Resting	61.1	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Oral Breathing / Standing	2.32	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Speaking / Standing	11.5	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Loudly Speaking / Standing	65.8	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Oral Breathing / Light Exercise	5.7	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Speaking / Light Exercise	26.5	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Loudly Speaking / Light Exercise	170	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Oral Breathing / Heavy Exercise	13.3	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Speaking / Heavy Exercise	63.7	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b
Loudly Speaking / Heavy Exercise	408	Mikszewski et al. (2020)	See page 16 of manual and Buonanno et al. 2020b

Table J: SARS-CoV-2 Vaccine Efficacy

Vaccine	Adults							
	Original		B.1.1.7 (UK)		B.1.351 (South African)		P.1 (Brazil)	
	Symptomatic - moderate to severe	Symptomatic - severe	Symptomatic - moderate to severe	Symptomatic - severe	Symptomatic - moderate to severe	Symptomatic - severe	Symptomatic - moderate to severe	Symptomatic - severe
Pfizer–BioNTech	94.8%							
Moderna	94.1%							
Johnson and Johnson	72.0%	85.0%		85.0%	57.0%	85.0%	66.0%	85.0%
Novovax	95.6%		85.6%		60.0%			
Overall Average								**80.4%**

Pfizer

- https://www.statnews.com/2021/02/02/comparing-the-covid-19-vaccines-developed-by-pfizer-moderna-and-johnson-johnson/
- https://www.nejm.org/doi/full/10.1056/NEJMc2036242

Moderna

- https://www.statnews.com/2021/02/02/comparing-the-covid-19-vaccines-developed-by-pfizer-moderna-and-johnson-johnson/
- https://www.nejm.org/doi/full/10.1056/NEJMc2036242

Johnson and Johnson

- https://www.nature.com/articles/d41586-021-00119-7
- https://www.statnews.com/2021/02/02/comparing-the-covid-19-vaccines-developed-by-pfizer-moderna-and-johnson-johnson/

Novovax

- https://www.nature.com/articles/d41586-021-00268-9