

# Airborne Infection Risk Calculator

**DRAFT PRELIMINARY**

**User's Manual for**

**Version 3.0 *Beta***

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Alex Mikszewski

The City University of New York

CIUS Building Performance Lab

New York, New York, USA

[alexander.mikszewski@hdr.qut.edu.au](mailto:alexander.mikszewski@hdr.qut.edu.au)

Giorgio Buonanno, Luca Stabile, and Antonio Pacitto

University of Cassino and Southern Lazio

Department of Civil and Mechanical Engineering

Cassino, Frosinone, Italy

Lidia Morawska

Queensland University of Technology

School of Earth and Atmospheric Sciences

International Laboratory for Air Quality and Health (ILAQH)

Brisbane, Queensland, Australia

## **DISCLAIMER**

The Airborne Infection Risk Calculator (AIRC) is made available on an as-is basis without guarantee or warranty of any kind, express or implied. Neither the authors nor reviewers accept any liability resulting from the use of AIRC or its documentation. This is a preliminary decision-support tool that will be revised as the science surrounding airborne transmission of SARS-CoV-2 and other pathogens advances. **Implementation of AIRC and interpretation of its calculations are the sole responsibility of the user.**

## **VERSION 3.0 BETA ACKNOWLEDGEMENT**

The authors thank Dr. Ivan Lunati at the Laboratory for Multiscale Studies in Building Physics, Empa - Swiss Federal Laboratories for Materials Science and Technology, Switzerland, for his quantitative review of Version 2.1 of the tool.

## **VERSION HISTORY**

Initial Release Version 1.0 – July 9, 2020

Version 2.0 – September 9, 2020.

- Added stationary exposure conditions (SEC) model with complete solution of the infection risk equations (AIRC SEC).
- Changed default values by activity level to 66<sup>th</sup> and 90<sup>th</sup> percentile instead of 85<sup>th</sup> percentile for the Version 1.0 modeling sheet, now termed the AIRC transitional exposure conditions (TEC) model. The 66<sup>th</sup> percentile values are used for probability of infection estimates and the 90<sup>th</sup> percentile values are used for room occupancy calculations.
- Changed Version 1.0 terminology of “individual infection risk” estimates to “probability of infection” estimates for the AIRC TEC model (see new Glossary).
- Added ability to model any number of infectious occupants present at time zero.
- Added ability to specify two separate custom emission rates and inhalation rates for different occupants for the AIRC TEC model.

Version 2.1 – October 6, 2020.

- Added the option to use a fixed, or certain, quanta emission rate ( $ER_q$ ) for the SEC model, which can be entered on the “SEC Calculations” tab and then selected from the dropdown activity lists on the “AIRC SEC” tab.
- Corrected the  $PI(ER_q)$  plot on the activity #1,  $t_1$  graph on the “SEC Method” tab.

Version 3.0 – April 29, 2021.

- Updated SARS-CoV-2  $ER_q$  distributions and included SARS-CoV-2 variant multiplier and four additional pathogens based on our pre-print: <https://doi.org/10.1101/2021.01.26.21250580>.
- Included  $R_{event}$  calculations and secondary transmission histograms based on a specified occupancy for the SEC model.
- Updated the SEC model to include stochastic  $ER_q$  distributions for up to 10 infectious occupants.
- Changed default values for the TEC model to the 75<sup>th</sup> percentile (adjustable).
- Changed the maximum occupancy calculation from using the 90<sup>th</sup> percentile  $ER_q$  value to  $1/R$  (SEC) and  $1/P_i$  (TEC).
- Corrected the SEC integration calculation to account for unequal spacing of the  $\log_{10}(ER_q)$  values.

### Updated Glossary of Key AIRC Terms

AIRC Stationary Exposure Conditions (SEC) Model: A constant emission source and exposure model that considers the full range of possible quanta emission rates for a selected respiratory activity and their respective probabilities of occurrence with no time limit. Infectious and susceptible occupants are modeled as being together in perfect coincidence.

AIRC Transitional Exposure Conditions (TEC) Model: An update to the model provided in AIRC 1.0, where transitional exposure scenarios of both infectious and susceptible persons coming and going can be modeled for a total exposure period of up to 8 hours.

Room Volume (V): The volume of the room or space being modeled, within which air can be assumed to be reasonably well mixed.

Air Exchange Rate (AER): The rate at which air in the room or space is replaced with fresh air through mechanical or natural means, measured in the number of air changes per hour.

Susceptible Occupant A: A susceptible person who can enter and leave the room in the AIRC TEC model at any points in time.

Continuous Occupant: A susceptible person who is in the room in the AIRC TEC model for the full length of the simulation.

Infectious Occupants at Time Zero: An infectious person or group of persons who are initially present in the room in the AIRC TEC model, and who all must leave the room together at the same time.

Infectious Occupant A: An infectious person who can enter and leave the room in the AIRC TEC model at any points in time.

Quanta Emission Rate ( $ER_q$ ): A quantum is the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons. The quanta emission rate is the number of quanta released into the air per unit time as a function of infectious occupant expiratory activities, respiratory parameters, and activity levels.

Probability of Infection ( $P_i$ ): The percent chance of infection of an exposed susceptible occupant receiving a calculated dose of quanta generated by a fixed, or certain, quanta emission rate.

Infection Risk (R): The percent chance of infection of an exposed susceptible occupant taking into account all possible  $ER_q$  values for a certain activity as defined by a probability density function.

Event Reproduction Number ( $R_{event}$ ): The average number of secondary cases (C) expected to result from an infectious occupants at an event (can be more than one in the AIRC tool), calculated as the product of the infection risk (R) and the number of exposed susceptible persons (S) at the event. AIRC calculates the maximum number of occupants to maintain  $R_{event}$  below 1 as  $1/R$  for the SEC model, and  $1/P_i$  for the TEC model. The term  $R_{event}$  replaces the term 'basic reproduction number,  $R_0$ ' in prior versions of AIRC.

## VERSION 3.0 BETA PREFACE & NEW EXAMPLES

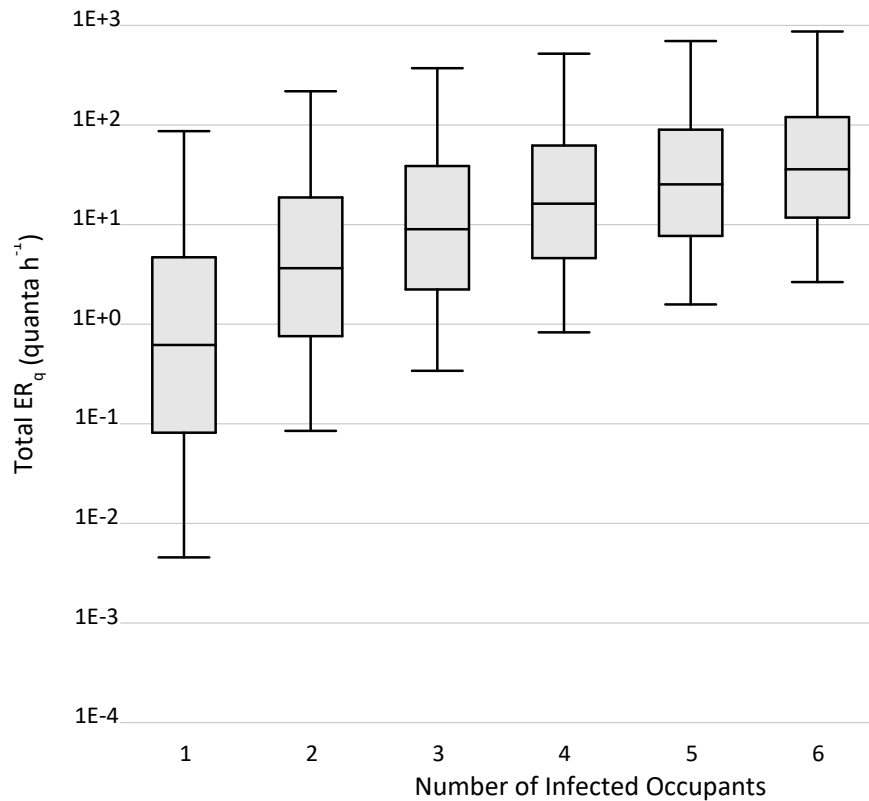
This Preface briefly documents changes to the AIRC tool included in the Version 3.0 Beta release. A comprehensive update to the User Manual will be posted once the Beta review is complete. An annotated version of the AIRC 2.1 User Manual is included as an appendix to this document, which will ultimately be updated and combined with this Preface.

The Version 3.0 edition of AIRC includes updates to the quanta emission rate ( $ER_q$ ) distributions for SARS-CoV-2, and includes  $ER_q$  distributions for four other pathogens in addition to SARS-CoV-2 as documented in <https://www.medrxiv.org/content/10.1101/2021.01.26.21250580v1> :

- Seasonal influenza virus (“flu”);
- Human rhinovirus (“HRV”);
- Measles virus (“MeV”); and
- *Mycobacterium tuberculosis*, including a distribution based on the bacillary load of active, untreated cases (“TB”), and that after approximately two weeks of treatment (“TB OT”).

All  $ER_q$  distributions are lognormal and parameters can be found on the ‘ERq’ tab of the workbook. In addition, an  $ER_q$  multiplier is provided to account for increased transmissivity of SARS-CoV-2 variants (“CoV-2 (V)”), with a default suggested value of 2.0.

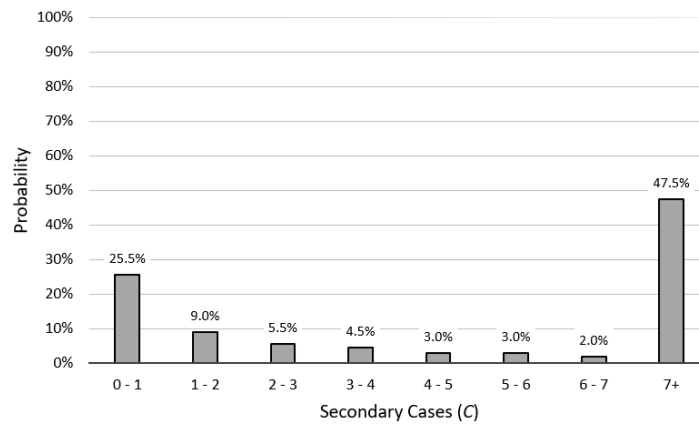
An additional upgrade for the Version 3.0 Beta edition is the inclusion of  $ER_q$  distributions for up to 10 infectious occupants in the SEC version created using Monte Carlo simulation (e.g. randomly sampling the  $ER_q$  distribution up to 10 times and summing the results). For over-dispersed pathogens such as SARS-CoV-2, TB, and MeV this provides a more accurate quantification of the higher expected cumulative emission from multiple infected occupants in a shared airspace, as opposed to using the simple product of the number of infecteds times the  $ER_q$  for one infected occupant. Note that custom, user-defined  $ER_q$  distributions or fixed  $ER_q$  values still use the simple multiplication approach. The stochastic effect of multiple infecteds is shown on the box-whisker plot on the following page for the resting, oral breathing  $ER_q$  distribution for TB ( $\log_{10}$  average and standard deviation of -0.21 and 1.3, respectively).



In this plot the box spans the interquartile range, the whiskers extend from the 5<sup>th</sup> to 95<sup>th</sup> percentile values, and the median is denoted by the horizontal line in the box. The median ER<sub>q</sub> for one infected occupant is 0.62 quanta per hour (h<sup>-1</sup>), but this rises over an order of magnitude to 9.7 quanta h<sup>-1</sup> with three infected occupants sharing the airspace and rises to 40 quanta h<sup>-1</sup> with 6 infected occupants. The above plot clearly demonstrates the challenge presented by congregate living and working settings (e.g. care homes, abattoirs, prisons), where a single superspreading event (SSE) can initiate a massive outbreak due to the high cumulative airborne emission *expected* from the second generation. It also shows why the simultaneous introduction of *multiple* infecteds into such a micro-environment is much more likely to cause an explosive airborne outbreak than introducing a single case.

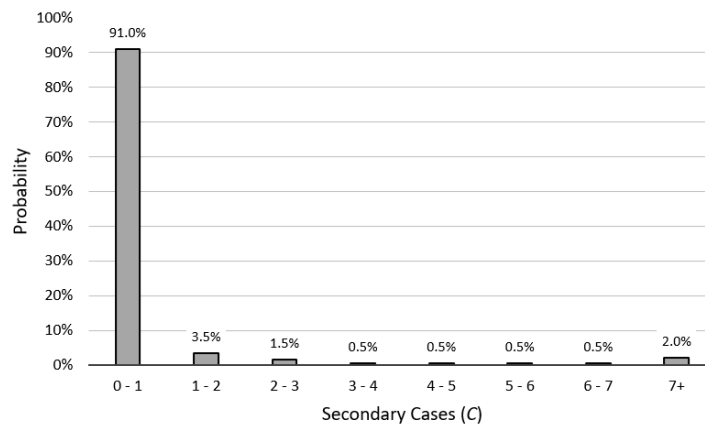
Another important upgrade in Version 3.0 Beta is the inclusion of histograms showing the probability distribution of secondary cases for the SEC model.  $R_{event}$  (see Glossary) is the expected number of secondary cases arising on average from this distribution. These histograms help visualize the effect of over-dispersion in airborne contagion and assess the probability of SSEs. For example, the histogram on the following page for a high emitting activity shows a probability of at least 7 secondary cases of approximately 50%, approximately twice as likely as the probability of <1 secondary case:

Emission #1 = CoV-2: Light Exercise, Loudly Speaking; Exposure Time #1 = 2.5 hr			
Scenario Air Exchange Rate	AER	0.7	hr <sup>-1</sup>
Number of Susceptible Occupants in Room	S	60	persons
Average Number of Secondary Cases	R <sub>event</sub>	16.3	infections



Alternatively, a low emitting activity (resting, oral breathing) histogram is presented below:

Emission #6 = CoV-2: Resting, Oral Breathing; Exposure Time #3 = 2.5 hr			
Scenario Air Exchange Rate	AER	0.7	hr <sup>-1</sup>
Number of Susceptible Occupants in Room	S	60	persons
Average Number of Secondary Cases	R <sub>event</sub>	0.4	infections



Our calculation of R<sub>event</sub> is based on a numerical integration approximating the average value that would result from performing the calculation using a Monte Carlo simulation randomly drawing from the lognormal ER<sub>q</sub> distribution and calculating P<sub>I</sub>. An unrestricted Monte Carlo simulation would result in a slightly higher R<sub>event</sub> value due to increased draws from extreme percentile values. The histograms are useful because they present the probability of specific secondary transmission outcomes independent of the averaged, over-dispersed R<sub>event</sub> calculation (for example, the probability of <1 secondary case).

An important consideration with the inclusion of additional pathogens is that the airborne inactivation rate will vary between pathogens with markedly different behavior depending on ambient relative humidity (RH). Subsequent versions of this tool may automate this, but in the interim we have developed the below table which may be of assistance to users. Overall, the data are consistent with the general observation that viruses with lipid envelopes (influenza, coronaviruses, respiratory syncytial

virus [RSV] and measles) remain active for longer in air with lower RH, versus the converse for viruses with non-lipid envelopes (adenovirus, rhinovirus, coxsackievirus). Please note values should be considered approximate because in some cases they were digitized from graphs.

Literature Summary of Viral Inactivation Rates in Aerosol (hr<sup>-1</sup>)

Relative Humidity	SARS-CoV-2 (Dabish et al., 2020)	Measles (De Jong and Winkler, 1964)	Influenza (Yang and Marr, 2011)	EMC virus (De Jong et al., 1975)	Adenovirus 4 (Miller and Artenstein, 1967)	RSV (Rechsteiner and Winkler, 1969)
20%	0.07	0.48	0.5	15.4	3.0	1.2
30%	0.26	0.53	0.8	14.8	--	2.5
40%	0.64	0.70	1.0	14.8	--	1.4
50%	1.00	1.56	1.3	10.8	2.2	1.8
60%	1.39	4.01	1.6	1.06	--	1.6
70%	1.73	6.70	1.8	0.16	--	3.4
80%	--	5.66	2.1	0.05	0.9	5.1

Table References:

Dabisch P, Schuit M, Herzog A, et al. The influence of temperature, humidity, and simulated sunlight on the infectivity of SARS-CoV-2 in aerosols, *Aerosol Science and Technology*. 2021;55(2):142-153.

De Jong JG, Winkler KC. Survival of measles virus in air. *Nature*. 1964;201:1054-1055. doi:10.1038/2011054a0

Yang W, Marr LC. Dynamics of airborne influenza A viruses indoors and dependence on humidity. *PLoS One*. 2011;6(6):e21481. doi:10.1371/journal.pone.0021481

De Jong JG, Harmsen M, Trouwborst T. Factors in the inactivation of Encephalomyocarditis virus in aerosols. *Infect Immun*. 1975;12(1):29-35. doi:10.1128/IAI.12.1.29-35.1975

Miller WS, Artenstein MS. Aerosol stability of three acute respiratory disease viruses. *Proc Soc Exp Biol Med*. 1967 May;125(1):222-7. doi: 10.3181/00379727-125-32054. PMID: 4290945.

Rechsteiner J, Winkler KC. Inactivation of respiratory syncytial virus in aerosol. *Journal of General Virology*, 1969;5:405-410.

### AIRC 3.0 EXAMPLES

Four new examples are provided in this section to highlight the inclusion of the four additional pathogens (TB, MeV, HRV, and flu) and to compare tool output to the seminal works on airborne contagion. Emphasis is placed on comparing model predictions to the proportion of infected occupant introductions that failed to reproduce infection (e.g. < 1 secondary case). Please note to better reflect the methodology used in seminal works, the inactivation rate and particle deposition rate terms are omitted from the examples. Their inclusion would further increase the proportion of zeros in each example.

## TB EXAMPLE

An  $ER_q$  of 1.25 quanta  $h^{-1}$  is often cited for a TB patient on treatment, based on Riley et al. (1962), but this represents a cumulative average emission rate over 2 years produced from a ward with 5 patients at a time, with the most infectious laryngeal case producing 60 quanta  $h^{-1}$ . This is similar to the Riley et al. (1959) report of the earlier 2-year study that found a cumulative  $ER_q$  of 0.62-0.83 quanta  $h^{-1}$  from 6 patients on the ward.

Of epidemiological significance is the *proportion of zeros* that can be derived from these studies, representing the probability a TB patient failed to infect any guinea pigs. For the two-year period documented in the 1962 paper, 130 total patients occupied the ward, 107 of which were sputum smear positive. 63 guinea pigs were infected from the smear positive group only, and the patient responsible for infection was identified for 50 of the 63 guinea pigs. Combining Tables 4 and 5 of Riley et al. (1962) shows that of 50 guinea pigs with identified infectors, 43 (86%) were caused by 10 of 67 initially untreated patients (15%), and the remaining 7 (14%) were caused by 2 of 40 (5%) treated patients. For simplicity, we combine these two groups to produce the following secondary case distribution (of guinea pigs) from the 107 sputum smear positive patients using Table 3 of Riley et al. (1962):

- 95/107 (89%) patients infected zero guinea pigs;
- 5/107 (4.7%) patients infected 1 guinea pig;
- 2/107 (1.9%) patients infected 2 guinea pigs; and
- 5/107 (4.7%) patients infected 5 or more guinea pigs.

The guinea pig reproduction number for this group was 50 infections/107 patients = 0.47.

The human to guinea pig transmission studies of Riley et al. were remarkably reproduced by Escombe et al. (2007 and 2008), involving 97 pulmonary TB patients with HIV co-infection, 66 of whom were sputum-culture positive. Over 505 days, 292 guinea pigs were exposed to ward air, and 135 developed culture-positive TB infections. Of these, spoligotyping results were available for 125 guinea pigs, and could be traced to 12 different patients. Thus we can assume the following distribution for the 125 identified infections from the group of 66 (Escombe et al., 2008):

- 54/66 (82%) patients infected zero guinea pigs;
- 7/66 (10%) patients infected 1 guinea pig;
- 3/66 (4.5%) patients infected 2 guinea pigs;
- 1/66 (1.5%) patients infected 4 guinea pigs; and
- 1/66 (1.5%) patients infected 108 guinea pigs.

The guinea pig reproduction number for this group was 125 infections/66 patients = 1.9, which is obviously highly over-dispersed due to the extreme infectiousness of the one patient (see Meslew et al. [2019] for epidemiological quantification of TB over-dispersion).

To illustrate the utility of the provided  $ER_q$  distributions in the AIRC tool, we can simulate these two experiments using some simplifying assumptions within the SEC framework as follows:



Riley et al. (1962) experiment – TB OT ER<sub>q</sub> distribution (TB on treatment)

- One infectious occupant with activity level of resting, oral breathing;
- 14 day exposure period (two weeks on the ward);
- Room volume of 1 m<sup>3</sup> and AER of 390 h<sup>-1</sup> (to achieve the reported flow rate at steady-state of 390 m<sup>3</sup> h<sup>-1</sup>, or 230 cubic feet per minute);
- Inhalation rate of 0.0095 m<sup>3</sup> h<sup>-1</sup> for the guinea pigs; and
- 120 exposed guinea pigs

Escombe et al. (2008) experiment – TB ER<sub>q</sub> distribution (Active, untreated TB)

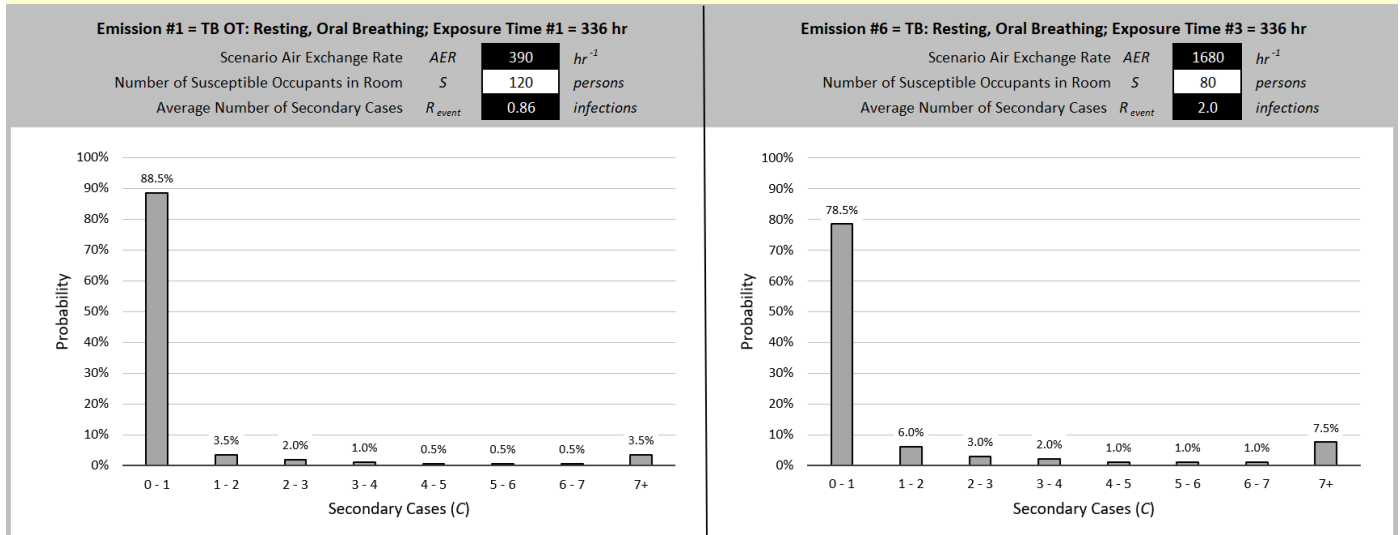
- One infectious occupant with activity level of resting, oral breathing;
- 14 day exposure period (two weeks on the ward);
- Room volume of 1 m<sup>3</sup> and AER of 1,680 h<sup>-1</sup> (to achieve the reported flow rate at steady-state of 1,680 m<sup>3</sup> h<sup>-1</sup>, or 28 cubic meters per minute);
- Inhalation rate of 0.0095 m<sup>3</sup> h<sup>-1</sup> for the guinea pigs; and
- 80 exposed guinea pigs (the median monthly chamber occupancy).

The SEC input screen for this scenario is below:

Airborne Infection Risk Calculator v3 Beta			AIRC		Mikszewski, Buonanno, Stabile, Pacitto, Morawska contact: alexander.mikszewski@hdr.qut.edu.au		60	1. Input Value	1.4	3. Model Calculates Value	
Stationary Exposure Conditions							Resting	2. Select Value			
1. MODEL INPUT PARAMETERS						2. MODEL RESULTS					
Room Area	A	1	m <sup>2</sup>	Select Infectious Occupant	Median	Infection Risk (%)			Max. Occupancy for R <sub>event</sub> < 1		
Ceiling Height	h	1	m	Activities From List Below	ER <sub>q</sub>	336 hr	336 hr	336 hr	336 hr	336 hr	336 hr
Room Volume	V	1	m <sup>3</sup>	1. TB OT: Resting, Oral Breathing	0.02	0.7%	0.7%	0.7%	139	139	139
Air Exchange Rate	AER	390	hr <sup>-1</sup>	2. CoV-2: Resting, Oral Breathing	0.55	5.2%	5.2%	5.2%	19	19	19
Particle Deposition Rate	k	0.00	hr <sup>-1</sup>	3. Flu: Resting, Oral Breathing	0.04	0.1%	0.1%	0.1%	735	735	735
Viral Inactivation Rate	λ	0.00	hr <sup>-1</sup>	4. HRV: Resting, Oral Breathing	0.21	0.8%	0.8%	0.8%	130	130	130
Total Viral Removal Rate	IVRR	390	hr <sup>-1</sup>	5. MeV: Resting, Oral Breathing	3.1	20.3%	20.3%	20.3%	4.0	4.0	4.0
Number of Infectious Occupants	I	1	persons	6. TB: Resting, Oral Breathing	0.62	6.8%	6.8%	6.8%	14	14	14
Exposure Time #1	t <sub>1</sub>	336	hr	AER Sensitivity Analysis for Emission Rate #6	500	5.8%	5.8%	5.8%	17	17	17
Exposure Time #2	t <sub>2</sub>	336	hr	Enter AER Values in hr <sup>-1</sup>	750	4.5%	4.5%	4.5%	22	22	22
Exposure Time #3	t <sub>3</sub>	336	hr		1000	3.7%	3.7%	3.7%	27	27	27
Susceptible Inhalation Rate	IR	0.0095	m <sup>3</sup> /hr		1300	3.1%	3.1%	3.1%	32	32	32
Susceptible Activity Level		Custom IR #1	Select		1680	2.6%	2.6%	2.6%	39	39	39

The R<sub>event</sub> screen is as follows:

Stationary Exposure Conditions Model:  $R_{event}$  & Secondary Transmission Histograms



For a two-week period, the TB OT distribution predicts an 89% probability of less than 1 guinea pig infection for the Riley et al. (1962) airflow rate with 120 exposed guinea pigs, whereas the TB distribution predicts a 79% likelihood of less than 1 guinea pig infection for the Escombe et al. (2008) airflow rate with 80 exposed guinea pigs, showing good agreement with the experimental data in terms of the proportion of zeros.

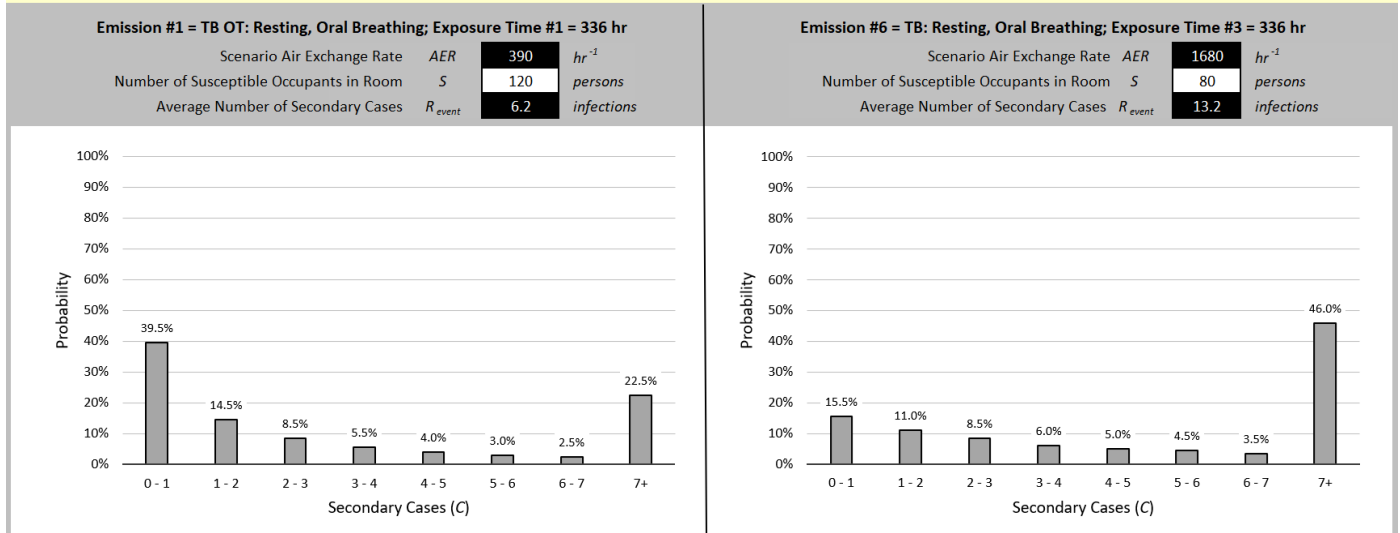
Instead of modeling a single patient, we can model six patients on the ward together by changing the number of infectious occupants to 6. The same two screens are as follows:

**Airborne Infection Risk Calculator v3 Beta** **AIRC** Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
contact: alexander.mikszewski@hdr.qut.edu.au

60 1. Input Value 1.4 3. Model Calculates Value  
Resting 2. Select Value

1. MODEL INPUT PARAMETERS				2. MODEL RESULTS						
Parameter	Value	Units	Activity	Median $ER_q$	Infection Risk (%)			Max. Occupancy for $R_{event} < 1$		
					336 hr	336 hr	336 hr	336 hr	336 hr	336 hr
Room Area	1	$m^2$	1. TB OT: Resting, Oral Breathing	1.7	5.2%	5.2%	5.2%	19	19	19
Ceiling Height	1	$m$	2. CoV-2: Resting, Oral Breathing	27.04	30.2%	30.2%	30.2%	3	3	3
Room Volume	1	$m^3$	3. Flu: Resting, Oral Breathing	0.70	0.9%	0.9%	0.9%	108	108	108
Air Exchange Rate	390	$hr^{-1}$	4. HRV: Resting, Oral Breathing	4.14	5.1%	5.1%	5.1%	19	19	19
Particle Deposition Rate	0.00	$hr^{-1}$	5. MeV: Resting, Oral Breathing	445.3	75.5%	75.5%	75.5%	1.0	1.0	1.0
Viral Inactivation Rate	0.00	$hr^{-1}$	6. TB: Resting, Oral Breathing	40	37.7%	37.7%	37.7%	2	2	2
Total Viral Removal Rate	390	$hr^{-1}$	AER Sensitivity Analysis for Emission Rate #6 Enter AER Values in $hr^{-1}$							
Number of Infectious Occupants	6	persons								
Exposure Time #1	336	hr								
Exposure Time #2	336	hr								
Exposure Time #3	336	hr								
Susceptible Inhalation Rate	0.0095	$m^3/hr$	500	33.4%	33.4%	33.4%	2	2	2	
Susceptible Activity Level	Custom IR #1	Select	750	27.0%	27.0%	27.0%	3	3	3	
			1000	22.9%	22.9%	22.9%	4	4	4	
			1300	19.5%	19.5%	19.5%	5	5	5	
			1680	16.5%	16.5%	16.5%	6	6	6	

**Stationary Exposure Conditions Model:  $R_{event}$  & Secondary Transmission Histograms**



With six patients on a ward the probability of <1 guinea pig infections over a two week period is substantially lower, as expected. The median  $ER_q$  for the six-patient TB resting and oral breathing scenario is 40 quanta  $h^{-1}$ , consistent with the value of 34 quanta  $h^{-1}$  calculated for the cumulative emission from a 6-bed ward with masks in use in the most recent guinea pig transmission experiments of Dharmadhikari et al. (2012). The cumulative  $ER_q$  of 138 quanta  $h^{-1}$  for the unmasked 6-patient cohort occurs at the 76<sup>th</sup> percentile value of the 6-person resting, oral breathing distribution, which is approximately the value that we define as the default  $ER_q$  for the TEC version of the AIRC tool (Dharmadhikari et al., 2012).

**TB Example References:**

Riley RL, Mills CC, O’Grady F, et al. Infectiousness of air from a tuberculosis ward. Ultraviolet irradiation of infected air: comparative infectiousness of different patients. *Am Rev Respir Dis* 1962; 85:511-525.

Riley RL, Mills CC, Myka W, et al. Aerial dissemination of pulmonary tuberculosis a two-year study of contagion in a tuberculosis ward. *American Journal of Epidemiology* 1959; 70(2):185-196.

Escombe AR, Oeser C, Gilman RH, et al. The detection of airborne transmission of tuberculosis from HIV-infected patients, using an in vivo air sampling model. *Clin Infect Dis*. 2007;44(10):1349-1357.

Escombe AR, Moore DAJ, Gilman RH, et al. The infectiousness of tuberculosis patients coinfecting with HIV. *PLOS Medicine* 2008; 5(9):e188.

Dharmadhikari AS, Mphahlele M, Stoltz A, et al. Surgical face masks worn by patients with multidrug-resistant tuberculosis: impact on infectivity of air on a hospital ward. *American Journal of Respiratory and Critical Care Medicine* 2012; 185(10): 1104–1109.

Melsew YA, Gambhir M, Cheng AC, et al. The role of super-spreading events in Mycobacterium tuberculosis transmission: evidence from contact tracing. *BMC Infect Dis*. 2019;19(1):244. Published 2019 Mar 12. doi:10.1186/s12879-019-3870-1

## MeV EXAMPLE

Riley et al. (1962) also documents the  $ER_q$  for the average child with measles to be  $18 \text{ quanta h}^{-1}$ . This is based on a calculated probability of infection of 11% for a three-day prodromal exposure in a well-ventilated classroom reported in Wells (1955). We can reproduce the  $18 \text{ quanta h}^{-1}$  calculation based on Page 196 of Wells (1955) using a steady-state quanta concentration of  $\sim 0.014 \text{ quanta m}^{-3}$  (from 2,500 cubic feet per infective unit) and an average room ventilation rate of  $\sim 1,300 \text{ m}^3 \text{ h}^{-1}$  (from 30 cubic feet per minute per pupil times 25 pupils, or 750,000 cubic feet divided by three 5.5-hour days).

This is a total average emission rate from multiple years of data with over 100 introductions of individual measles cases into irradiated and unirradiated classrooms. The 11% probability of infection comes from Table VIII of Wells (1955) Pages 180-181, obtained by dividing 87 secondary cases by 791 susceptibles exposed for the unirradiated classrooms. Table VIII is further described on Pages 245-246 with respect to the proportion of zeroes, or the percent of measles introductions that failed to reproduce infection (43% in unirradiated classrooms, 75% in irradiated classrooms).

Using Table VIII, we created a secondary case distribution using the “single exposure” category for the unirradiated classrooms with 6-10 susceptibles (the most populated group). Adding two classrooms with 6-10 susceptibles and non-functional UV lights to this group (one with 3 infections, the other with 7), and we get the following distributions of secondary cases from 29 measles-infected student introductions:

- 13/29 (45%) infected zero classmates;
- 9/29 (31%) infected 1 classmate;
- 3/29 (10%) infected 2 classmates;
- 3/29 (10%) infected 3 classmates; and
- 1/29 (1.5%) infected 7 classmates.

To evaluate this scenario in the SEC model, we use a classrooms size of  $198 \text{ m}^3$  (7,000 cubic feet from Wells [1943]), an air exchange rate of  $6.5 \text{ h}^{-1}$  calculated from the parameters presented in the first paragraph of this example, and the resting, oral breathing distribution for a 16.5 hour exposure (3 days). We can also simulate the irradiated rooms by increasing the air exchange rate to  $65 \text{ h}^{-1}$  based on the order of magnitude increase in sanitary ventilation estimated by Wells (1955). The SEC input screen and  $R_{\text{event}}$  results screen (with 9 susceptible occupants) are on the following page:

**Airborne Infection Risk Calculator v3 Beta** **AIRC** Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
 Stationary Exposure Conditions contact: alexander.mikszewski@hdr.qut.edu.au

60 1. Input Value Resting 2. Select Value 1.4 3. Model Calculates Value

1. MODEL INPUT PARAMETERS				2. MODEL RESULTS								
Parameter	Symbol	Value	Units	Select Infectious Occupant	Median	Infection Risk (%)			Max. Occupancy for $R_{event} < 1$			
				Activities From List Below	$ER_q$	16.5 hr	16.5 hr	16.5 hr	16.5 hr	16.5 hr	16.5 hr	
Room Area	$A$	66	$m^2$	1. MeV: Resting, Oral Breathing	3.1	18.3%	18.3%	18.3%	5	5	5	
Ceiling Height	$h$	3	$m$	2. CoV-2: Resting, Oral Breathing	0.55	4.3%	4.3%	4.3%	23	23	23	
Room Volume	$V$	198	$m^3$	3. Flu: Resting, Oral Breathing	0.04	0.1%	0.1%	0.1%	965	965	965	
Air Exchange Rate	$AER$	6.5	$hr^{-1}$	4. HRV: Resting, Oral Breathing	0.21	0.6%	0.6%	0.6%	170	170	170	
Particle Deposition Rate	$k$	0.00	$hr^{-1}$	5. MeV: Resting, Speaking	14.1	30.5%	30.5%	30.5%	3.0	3.0	3.0	
Viral Inactivation Rate	$\lambda$	0.00	$hr^{-1}$	6. MeV: Resting, Oral Breathing	3.1	18.3%	18.3%	18.3%	5	5	5	
Total Viral Removal Rate	$IVRR$	6.5	$hr^{-1}$	AER Sensitivity Analysis for Emission Rate #6		1	33.3%	33.3%	33.3%	3	3	3
Number of Infectious Occupants	$I$	1	persons	Enter AER Values in $hr^{-1}$		2	27.3%	27.3%	27.3%	3	3	3
Exposure Time #1	$t_1$	16.5	hr			3	24.0%	24.0%	24.0%	4	4	4
Exposure Time #2	$t_2$	16.5	hr			5	20.2%	20.2%	20.2%	4	4	4
Exposure Time #3	$t_3$	16.5	hr			65.0	6.6%	6.6%	6.6%	15	15	15
Susceptible Inhalation Rate	$IR$	0.49	$m^3/hr$									
Susceptible Activity Level		Resting	Select									

**Stationary Exposure Conditions Model:  $R_{event}$  & Secondary Transmission Histograms**

**Emission #1 = MeV: Resting, Oral Breathing; Exposure Time #1 = 16.5 hr**

Scenario Air Exchange Rate  $AER$  6.5  $hr^{-1}$

Number of Susceptible Occupants in Room  $S$  9 persons

Average Number of Secondary Cases  $R_{event}$  1.7 infections

**Emission #6 = MeV: Resting, Oral Breathing; Exposure Time #3 = 16.5 hr**

Scenario Air Exchange Rate  $AER$  65.0  $hr^{-1}$

Number of Susceptible Occupants in Room  $S$  9 persons

Average Number of Secondary Cases  $R_{event}$  0.6 infections

The results of the data set and the AIRC model are fairly consistent in terms of the individual risk and expected number of secondary cases for the unirradiated classrooms (1.7 in AIRC versus 1.1 indicated by the data [31 infections/29 introductions, also consistent with an 11% infection risk with 9 susceptible occupants]); however, the secondary case distribution is more over-dispersed in the model than indicated by the Wells data. In other words, the model calculates a higher proportion of zeros and a higher probability that nearly all susceptibles in the class will become infected.

MeV Example References:

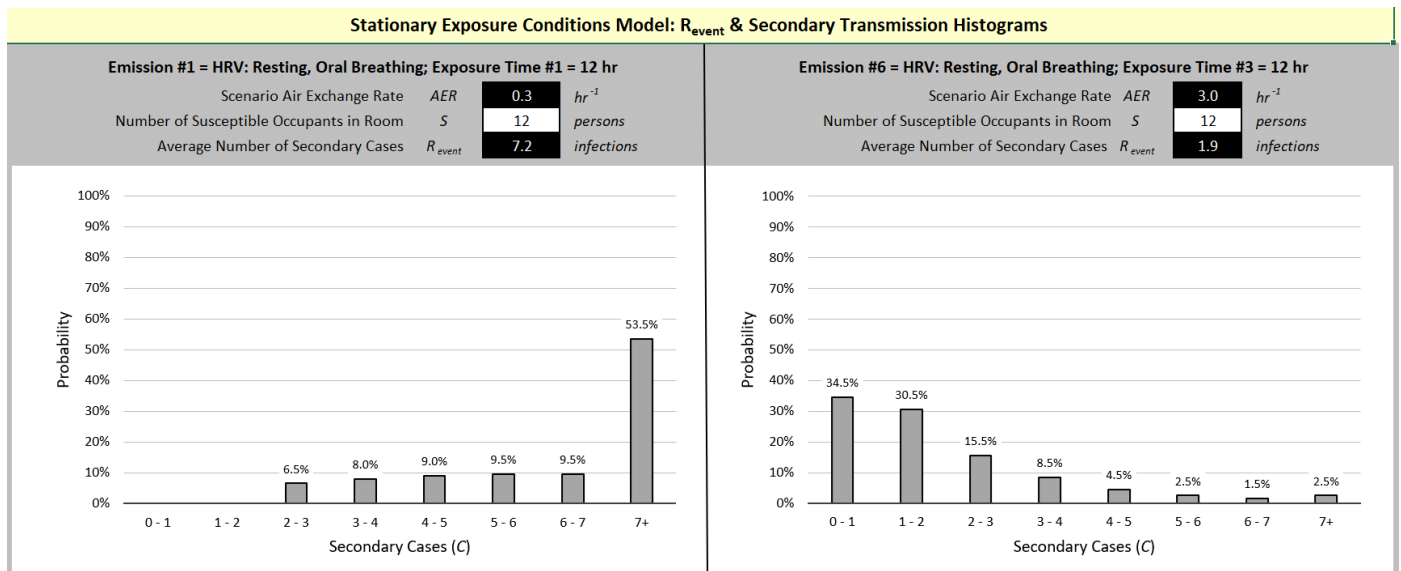
Wells WF. Airborne Contagion and Air Hygiene. Cambridge, Mass.: Harvard University Press; 1955:423.

Wells WF. Air disinfection in day schools. American Journal of Public Health 1943; 33:1436-1443.

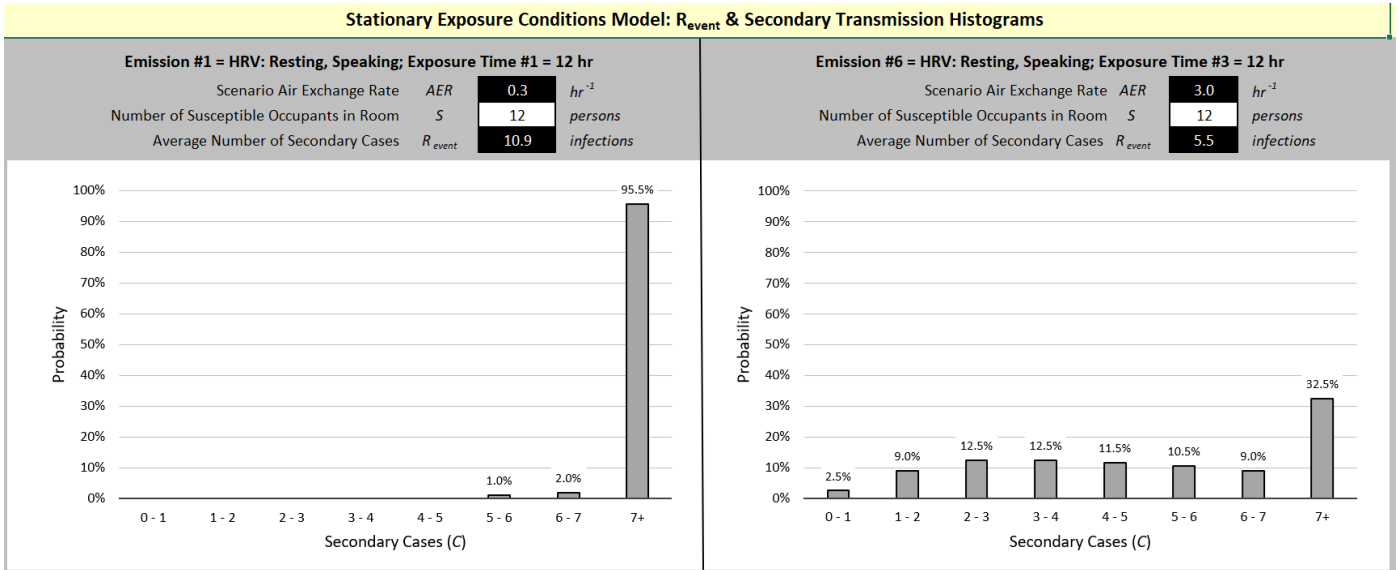
## HRV EXAMPLE

Airborne transmission of HRV colds was conclusively demonstrated by Dick et al. (1987) through a series of transmission trials involving 12-hour poker games. There were three poker games played with 8 infected subjects and 12 susceptible subjects each, which yielded 5, 6, and 12 secondary cases for an overall attack rate of 61%, or 7.7 secondary cases per poker game. As an AIRC example we can evaluate a 12-hour poker game in the SEC model based on a room volume of 92 m<sup>3</sup> and air exchange rates of 0.3 h<sup>-1</sup> and 3.0 h<sup>-1</sup> (used by Rudnick and Milton [2003] to model this experiment) at the resting, oral breathing and resting, speaking activity levels for HRV. The SEC input and R<sub>event</sub> output screens are presented below:

Airborne Infection Risk Calculator v3 Beta				AIRC		Mikszewski, Buonanno, Stabile, Pacitto, Morawska contact: alexander.mikszewski@hdr.qut.edu.au		60 1. Input Value 1.4 3. Model Calculates Value Resting 2. Select Value					
Stationary Exposure Conditions													
1. MODEL INPUT PARAMETERS					2. MODEL RESULTS								
Room Area	A	38.5	m <sup>2</sup>	Select Infectious Occupant	Median	Infection Risk (%)			Max. Occupancy for R <sub>event</sub> < 1				
Ceiling Height	h	2.4	m	Activities From List Below	ER <sub>q</sub>	12 hr	12 hr	12 hr	12 hr	12 hr	12 hr		
Room Volume	V	92	m <sup>3</sup>	1. HRV: Resting, Oral Breathing	6.1	59.6%	59.6%	59.6%	1	1	1		
Air Exchange Rate	AER	0.3	hr <sup>-1</sup>	2. CoV-2: Resting, Oral Breathing	44.6	89.9%	89.9%	89.9%	1	1	1		
Particle Deposition Rate	k	0.00	hr <sup>-1</sup>	3. Flu: Resting, Oral Breathing	1.0	19.2%	19.2%	19.2%	5	5	5		
Viral Inactivation Rate	λ	0.00	hr <sup>-1</sup>	4. HRV: Resting, Oral Breathing	6.12	59.6%	59.6%	59.6%	1	1	1		
Total Viral Removal Rate	IVRR	0.3	hr <sup>-1</sup>	5. MeV: Resting, Oral Breathing	833	98.3%	98.3%	98.3%	1.0	1.0	1.0		
Number of Infectious Occupants	I	8	persons	6. HRV: Resting, Oral Breathing	6.1	59.6%	59.6%	59.6%	1	1	1		
Exposure Time #1	t <sub>1</sub>	12	hr	AER Sensitivity Analysis for Emission Rate #6			0.1	73.4%	73.4%	73.4%	1	1	1
Exposure Time #2	t <sub>2</sub>	12	hr	Enter AER Values in hr <sup>-1</sup>			1	34.5%	34.5%	34.5%	2	2	2
Exposure Time #3	t <sub>3</sub>	12	hr				2	21.5%	21.5%	21.5%	4	4	4
Susceptible Inhalation Rate	IR	0.49	m <sup>3</sup> /hr				6	8.6%	8.6%	8.6%	11	11	11
Susceptible Activity Level	Resting		← Select				3	15.6%	15.6%	15.6%	6	6	6



Airborne Infection Risk Calculator v3 Beta			AIRC		Mikszewski, Buonanno, Stabile, Pacitto, Morawska contact: alexander.mikszewski@hdr.qut.edu.au		60	1. Input Value	1.4	3. Model Calculates Value	
Stationary Exposure Conditions							Resting	2. Select Value			
<b>1. MODEL INPUT PARAMETERS</b>						<b>2. MODEL RESULTS</b>					
Room Area	A	38.5	m <sup>2</sup>	Select Infectious Occupant	Median	Infection Risk (%)			Max. Occupancy for R <sub>event</sub> < 1		
Ceiling Height	h	2.4	m	Activities From List Below	ER <sub>q</sub>	12 hr	12 hr	12 hr	12 hr	12 hr	12 hr
Room Volume	V	92	m <sup>3</sup>	1. HRV: Resting, Speaking	27.3	90.7%	90.7%	90.7%	1	1	1
Air Exchange Rate	AER	0.3	hr <sup>-1</sup>	2. CoV-2: Resting, Oral Breathing	44.6	89.9%	89.9%	89.9%	1	1	1
Particle Deposition Rate	k	0.00	hr <sup>-1</sup>	3. Flu: Resting, Oral Breathing	1.0	19.2%	19.2%	19.2%	5	5	5
Viral Inactivation Rate	λ	0.00	hr <sup>-1</sup>	4. HRV: Resting, Oral Breathing	6.12	59.6%	59.6%	59.6%	1	1	1
Total Viral Removal Rate	IVRR	0.3	hr <sup>-1</sup>	5. MeV: Resting, Oral Breathing	833	98.3%	98.3%	98.3%	1.0	1.0	1.0
Number of Infectious Occupants	I	8	persons	6. HRV: Resting, Speaking	27.3	90.7%	90.7%	90.7%	1	1	1
Exposure Time #1	t <sub>1</sub>	12	hr	AER Sensitivity Analysis for Emission Rate #6	0.1	95.6%	95.6%	95.6%	1	1	1
Exposure Time #2	t <sub>2</sub>	12	hr	1	1	72.8%	72.8%	72.8%	1	1	1
Exposure Time #3	t <sub>3</sub>	12	hr	2	2	56.2%	56.2%	56.2%	1	1	1
Susceptible Inhalation Rate	IR	0.49	m <sup>3</sup> /hr	6	6	29.6%	29.6%	29.6%	3	3	3
Susceptible Activity Level		Resting	Select	3	3	45.8%	45.8%	45.8%	2	2	2



The resting, breathing ER<sub>q</sub> distribution appears sufficient to approximately reproduce the attack rate at the low ventilation rate, whereas vocalization appears necessary at the higher ventilation rate (to be expected playing poker). The “donor” poker players were also symptomatic, so periodic coughing could also account for the additional emissions at a higher ventilation rate.

HRV Example References:

Dick EC, Jennings LC, Mink KA, Wartgow CD, Inhorn SL. Aerosol transmission of rhinovirus colds. J Infect Dis 1987;156(3):442-8.

Rudnick SN, Milton DK. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. Indoor Air 2003;13:237-45.



## FLU EXAMPLE

To illustrate an AIRC example for seasonal influenza, we constructed a scenario resembling that of the human challenge transmission trial documented in Nguyen-Van-Tam et al. (2020), with related quantitative analysis documented in Bueno de Mesquita et al. (2020). Our scenario consists of a 69 m<sup>3</sup> room shared by 3 infected occupants and 10 susceptible occupants for a total of 60 hours. Risk is evaluated at air exchange rates of 0.3 h<sup>-1</sup> and 3.0 h<sup>-1</sup>, as with the HRV scenario. Input and results tabs are presented below:

**Airborne Infection Risk Calculator v3 Beta**

Stationary Exposure Conditions

# AIRC

Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
contact: alexander.mikszewski@hdr.qut.edu.au

60 1. Input Value 1.4 3. Model Calculates Value

Resting 2. Select Value

---

**1. MODEL INPUT PARAMETERS**

Room Area	A	23	m <sup>2</sup>
Ceiling Height	h	3	m
Room Volume	V	69	m <sup>3</sup>
Air Exchange Rate	AER	3.0	hr <sup>-1</sup>
Particle Deposition Rate	k	0.00	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.00	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	3.0	hr <sup>-1</sup>
Number of Infectious Occupants	I	3	persons
Exposure Time #1	t <sub>1</sub>	60	hr
Exposure Time #2	t <sub>2</sub>	60	hr
Exposure Time #3	t <sub>3</sub>	60	hr
Susceptible Inhalation Rate	IR	0.49	m <sup>3</sup> /hr
Susceptible Activity Level		Resting	← Select

Select Infectious Occupant Median  
Activities From List Below ER<sub>3</sub>

1. Flu: Resting, Oral Breathing	0.25
2. CoV-2: Resting, Oral Breathing	7.4
3. CoV-2 (V): Resting, Oral Breathing	14.8
4. HRV: Resting, Oral Breathing	1.46
5. MeV: Resting, Oral Breathing	84
6. Flu: Resting, Oral Breathing	0.25

AER Sensitivity Analysis for Emission Rate #6

Enter AER Values in hr<sup>-1</sup>

0.1	57.4%	57.4%	57.4%
1	16.7%	16.7%	16.7%
2	9.6%	9.6%	9.6%
6	3.6%	3.6%	3.6%
0.3	36.1%	36.1%	36.1%

**2. MODEL RESULTS**

	Infection Risk (%)			Max. Occupancy for R <sub>event</sub> < 1		
	60 hr	60 hr	60 hr	60 hr	60 hr	60 hr
1. Flu: Resting, Oral Breathing	6.8%	6.8%	6.8%	14	14	14
2. CoV-2: Resting, Oral Breathing	58.7%	58.7%	58.7%	1	1	1
3. CoV-2 (V): Resting, Oral Breathing	70.0%	70.0%	70.0%	1	1	1
4. HRV: Resting, Oral Breathing	26.4%	26.4%	26.4%	3	3	3
5. MeV: Resting, Oral Breathing	83.4%	83.4%	83.4%	1.0	1.0	1.0
6. Flu: Resting, Oral Breathing	6.8%	6.8%	6.8%	14	14	14
0.1	57.4%	57.4%	57.4%	1	1	1
1	16.7%	16.7%	16.7%	5	5	5
2	9.6%	9.6%	9.6%	10	10	10
6	3.6%	3.6%	3.6%	27	27	27
0.3	36.1%	36.1%	36.1%	2	2	2

---

**Stationary Exposure Conditions Model: R<sub>event</sub> & Secondary Transmission Histograms**

**Emission #1 = Flu: Resting, Oral Breathing; Exposure Time #1 = 60 hr**

Scenario Air Exchange Rate	AER	3.0	hr <sup>-1</sup>
Number of Susceptible Occupants in Room	S	10	persons
Average Number of Secondary Cases	R <sub>event</sub>	0.7	infections

**Emission #6 = Flu: Resting, Oral Breathing; Exposure Time #3 = 60 hr**

Scenario Air Exchange Rate	AER	0.3	hr <sup>-1</sup>
Number of Susceptible Occupants in Room	S	10	persons
Average Number of Secondary Cases	R <sub>event</sub>	3.6	infections

The results indicate low secondary transmission risk for the room with an air exchange rate of 3 h<sup>-1</sup>, with a 79% probability of <1 secondary case and overall infection risk of 6.8%. This is generally consistent with the findings of Nguyen-Van-Tam et al. [2020], in which only 1 transmission trial resulted in a single secondary transmission. Decreasing the ventilation rate by an order of magnitude significantly increases infection risk and reduces the probability of <1 secondary case to 19%, showing the importance of ventilation at reducing infection risk for long exposures to relatively low emission rates.



Flu Example References:

Nguyen-Van-Tam JS, Killingley B, Enstone J, et al. Minimal transmission in an influenza A (H3N2) human challenge-transmission model within a controlled exposure environment. *PLoS Pathog.* 2020;16(7):e1008704.

Bueno de Mesquita PJ, Noakes CJ, Milton DK. Quantitative aerobiologic analysis of an influenza human challenge-transmission trial. *Indoor Air* 2020; 00:1– 10.

# **Appendix: Annotated V2.1 Manual**

## **Airborne Infection Risk Calculator**

**User's Manual**

**Version 2.1**

**[TO BE UPDATED COMPREHENSIVELY  
AFTER BETA REVIEW OF VERSION 3.0  
IS COMPLETE – SEE NOTES ADDED  
THROUGHOUT]**

**October 2020**

**Alex Mikszewski**

The City University of New York  
CIUS Building Performance Lab  
New York, New York, USA

**Giorgio Buonanno, Luca Stabile, and Antonio Pacitto**

University of Cassino and Southern Lazio  
Department of Civil and Mechanical Engineering  
Cassino, Frosinone, Italy

**Lidia Morawska**

Queensland University of Technology  
School of Earth and Atmospheric Sciences  
International Laboratory for Air Quality and Health (ILAQH)  
Brisbane, Queensland, Australia

## **DISCLAIMER**

The Airborne Infection Risk Calculator (AIRC) is made available on an as-is basis without guarantee or warranty of any kind, express or implied. Neither the authors nor reviewers accept any liability resulting from the use of AIRC or its documentation. This is a preliminary decision-support tool that will be revised as the science surrounding airborne transmission of SARS-CoV-2 and other pathogens advances. **Implementation of AIRC and interpretation of its calculations are the sole responsibility of the user.**

## **ACKNOWLEDGEMENTS**

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*For additional information and resources on SARS-CoV-2 infection risk modeling, the authors refer readers to a modeling tool developed by Prof. Jimenez and available at:*  
<https://cires.colorado.edu/news/covid-19-airborne-transmission-tool-available>

Piet Jacobs, MSc  
TNO – Delft, NL

Neven Kresic, Ph.D  
Geosyntec Consultants, Washington, D.C.

Honey Berk, MSc  
Managing Director, CIUS Building Performance Lab  
New York, New York

Jane Gajwani, PE  
New York City Department of Environmental Protection  
Director of the Office of Energy and Resource Recovery

Mackenzie Kinard, CEM, CBCP  
Energy Project Manager  
The New York Public Library

Benedetto Schiraldi  
Senior Energy Manager  
New York City Department of Sanitation

Rebecca Isacowitz, Daniel Donovan, and Steven Caputo  
New York City Department of Citywide Administrative Services

## Table of Contents

VERSION HISTORY .....	3
GLOSSARY.....	4
SECTION I: INTRODUCTION.....	5
SECTION II: AIRC CONCEPTUAL MODEL.....	7
SECTION III: THE INFECTION RISK MODEL .....	10
SECTION IV: AIRC DATA ENTRY & RESULTS .....	13
SECTION V: EXAMPLE APPLICATIONS .....	25
1. Squash .....	25
2. Seafood Market.....	28
3. Abattoir 2.0.....	30
4. Hospital Waiting Area.....	32
SECTION VI: REFERENCES .....	34

### **VERSION HISTORY**

Initial Release Version 1.0 – July 9, 2020

Version 2.0 – September 9, 2020.

- Added stationary exposure conditions (SEC) model with complete solution of the infection risk equations (AIRC SEC).
- Changed default values by activity level to 66<sup>th</sup> and 90<sup>th</sup> percentile instead of 85<sup>th</sup> percentile for the Version 1.0 modeling sheet, now termed the AIRC transitional exposure conditions (TEC) model. The 66<sup>th</sup> percentile values are used for probability of infection estimates and the 90<sup>th</sup> percentile values are used for room occupancy calculations.
- Changed Version 1.0 terminology of “individual infection risk” estimates to “probability of infection” estimates for the AIRC TEC model (see new Glossary).
- Added ability to model any number of infectious occupants present at time zero.
- Added ability to specify two separate custom emission rates and inhalation rates for different occupants for the AIRC TEC model.

Version 2.1 – October 6, 2020.

- Added the option to use a fixed, or certain, quanta emission rate ( $ER_q$ ) for the SEC model, which can be entered on the “SEC Calculations” tab and then selected from the dropdown activity lists on the “AIRC SEC” tab.
- Corrected the  $PI(ER_q)$  plot on the activity #1,  $t_1$  graph on the “SEC Method” tab.

## SECTION 1. INTRODUCTION

The Airborne Infection Risk Calculator (AIRC) is an airborne contagion modeling tool programmed in Microsoft Excel and designed to assist facility managers, building engineers, and public and occupational health professionals in prospectively evaluating individual infection and community transmission risks associated with specific indoor environments. AIRC can help users address two primary questions related to the risks associated with occupying an indoor space when community transmission of an infectious airborne pathogen, such as SARS-CoV-2, is occurring:

1. What is the potential infection risk associated with varying lengths of stay in the space?
2. What number of occupants helps maintain a basic reproduction number ( $R_0$ ) less than one to prevent the exposure from further contributing to disease spread in the population?

AIRC is directly based on the novel risk modeling approach developed for SARS-CoV-2 by Buonanno et al. (2020a) and Buonanno et al. (2020b). As stated by Buonanno et al. (2020a):

*“This approach, based on the principle of conservation of mass, represents a tool to connect the medical area, concerned with the concentration of the virus in the mouth, to the engineering area, dedicated to the simulation of the virus dispersion in the environment.”*

While AIRC and its underlying methods were created in direct response to the SARS-CoV-2 pandemic, the hope is that AIRC becomes a useful risk management tool for other airborne pathogens such as influenza, tuberculosis, and rhinovirus. The foundation for AIRC was provided by quantification of the quanta emission rate data of SARS-CoV-2 as a function of different respiratory activities, respiratory parameters, and activity levels. A quantum is the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons (Buonanno et al., 2020a). AIRC applies this quanta emission rate in an acknowledged infection risk model to simulate the individual infection risk associated with customized exposure scenarios, and the average number of infected people resulting from this scenario, i.e.  $R_0$  (the basic reproduction number). **[CHANGED TO EVENT REPRODUCTION NUMBER]**

New to Version 2.0, AIRC has two different risk modeling frameworks, both contained within the same workbook:

**#1) AIRC Stationary Exposure Conditions (SEC)** – a constant emission source and exposure model that considers the full range of possible quanta emission rates for a selected respiratory activity and their respective probabilities of occurrence. The risk equations are completely solved for three (3) different user-defined exposure times without a time limit.

**#2) AIRC Transitional Exposure Conditions (TEC)** – an update to the model provided in AIRC 1.0, where transitional exposure scenarios of both infectious and susceptible persons coming and going can be modeled for a total exposure period of up to 8 hours.

For both model types, the viral emission rate for each infectious individual, and the inhalation rate for susceptible individuals, can be selected based on a list of activities, and the user can specify the dimensions of the occupied indoor space and an infectious viral removal rate term accounting for three mechanisms: particle deposition, viral inactivation, and site-specific ventilation rate. Data input and

results presentation were simplified to facilitate ease of use by non-quantitative professionals, while also providing some flexibility for more advanced users.

### Limitations

The primary limitation of AIRC is its adoption of a completely mixed box model approach to simplify extremely complex indoor fluid dynamics processes. The result of this simplification is a viral exposure concentration that is uniform across the room, instead of a three-dimensional, spatially variable plume with higher exposure concentrations closer to the source of the viral emissions. Additional limitations include the adoption of uniform values representing particle deposition and viral inactivation rates that do not vary according to site-specific environmental conditions, and the maximum TEC simulation length of 8 hours. Secondary engineering and administrative controls, such as air filtration, UV disinfection, and mask-wearing, are not explicitly included in AIRC, but more advanced users can adjust input parameters to account for these interventions. Additional discussion of AIRC concepts and their limitations are provided in Section II, with specifics surrounding the useful scale of AIRC applications. Lastly, a major epidemiological limitation is the requirement to specify the number of infectious occupants in a space and their constant emissions-generating activity, rather than adopting a probabilistic approach taking into consideration the overall prevalence of the virus in the community and the likelihood of infectious person occupancy times and activities. Additionally, the selected dose-response model does not consider variation in host sensitivity to the pathogen of interest, for example immunity from prior exposure or vaccination.

AIRC is a risk screening tool that approximates more complicated processes occurring in reality. As such, conservative assumptions should be used for input parameters, with special attention given to the quanta emission rate and room air exchange rate. More sophisticated numerical models should be applied for situations where high-resolution, spatially representative results are required, or where needed for detailed design of secondary engineering controls in high-risk, complex settings. For CFD examples, see Vuorinen et al. (2020), Hosotani et al. (2013), and Chen et al. (2012).

### Target Users

The target users of AIRC are building managers, engineering consultants, and public, occupational, and environmental health scientists. Users should be proficient in Microsoft Excel and have a basic understanding of building systems and indoor air quality. Users would also benefit from a basic understanding of human health risk assessment (see <https://www.epa.gov/risk/conducting-human-health-risk-assessment> for an overview). More generally, the target users are the technical professionals working to minimize the risk of airborne disease transmission by implementing the five-step framework outlined by Morawska et al. (2020):

1. Use engineering controls to reduce the risk of airborne infection;
2. Use existing systems to increase ventilation rates (outdoor air change rate) and enhance ventilation effectiveness;
3. Eliminate air-recirculation within ventilation systems so as to just supply fresh (outdoor) air;
4. Supplement ventilation with filtration systems to capture airborne microdroplets; and
5. Avoid over-crowding

## SECTION II: AIRC CONCEPTUAL MODEL

To understand the airborne transmission pathway, it is helpful to advance the conceptual model presented in Morawska and Cao (2020), Morawska (2006), and Li et al. (2005). For purposes of AIRC, “airborne transmission” refers to inhalation of airborne droplet nuclei, or aerosols, at separation distances that can be greater than 2 meters away from an infectious emission. This conceptual model represents the concentration of virus-laden small droplets as a plume, where expired viral content is diluted immediately upon expiration and as it travels in the air carried by the air flow. As a result, the concentration of the virus does not increase uniformly in the interior environment of the enclosed space but is found at higher concentrations closer to the infectious subject.

Unfortunately, due to the complexity of indoor computational fluid dynamics (CFD), modeling this spatiotemporal plume presents a challenge to the broader public and occupational health community. As with other environmental contaminants in air and water, it is helpful instead to simplify the spatial component of fate and transport and use a completely mixed box model approach for risk calculation purposes. AIRC adopts this completely mixed box modeling approach, directly following the process outlined in Buonanno et al. (2020a) and Buonanno et al. (2020b). The emission of virus-laden small droplets is assumed to be instantaneously and completely mixed into a box representing an enclosed indoor environment or room, creating a time-dependent exposure concentration to susceptible occupants inside the box. A conceptual representation of airborne transport and the box-model simplification for AIRC is presented as Figure 1.

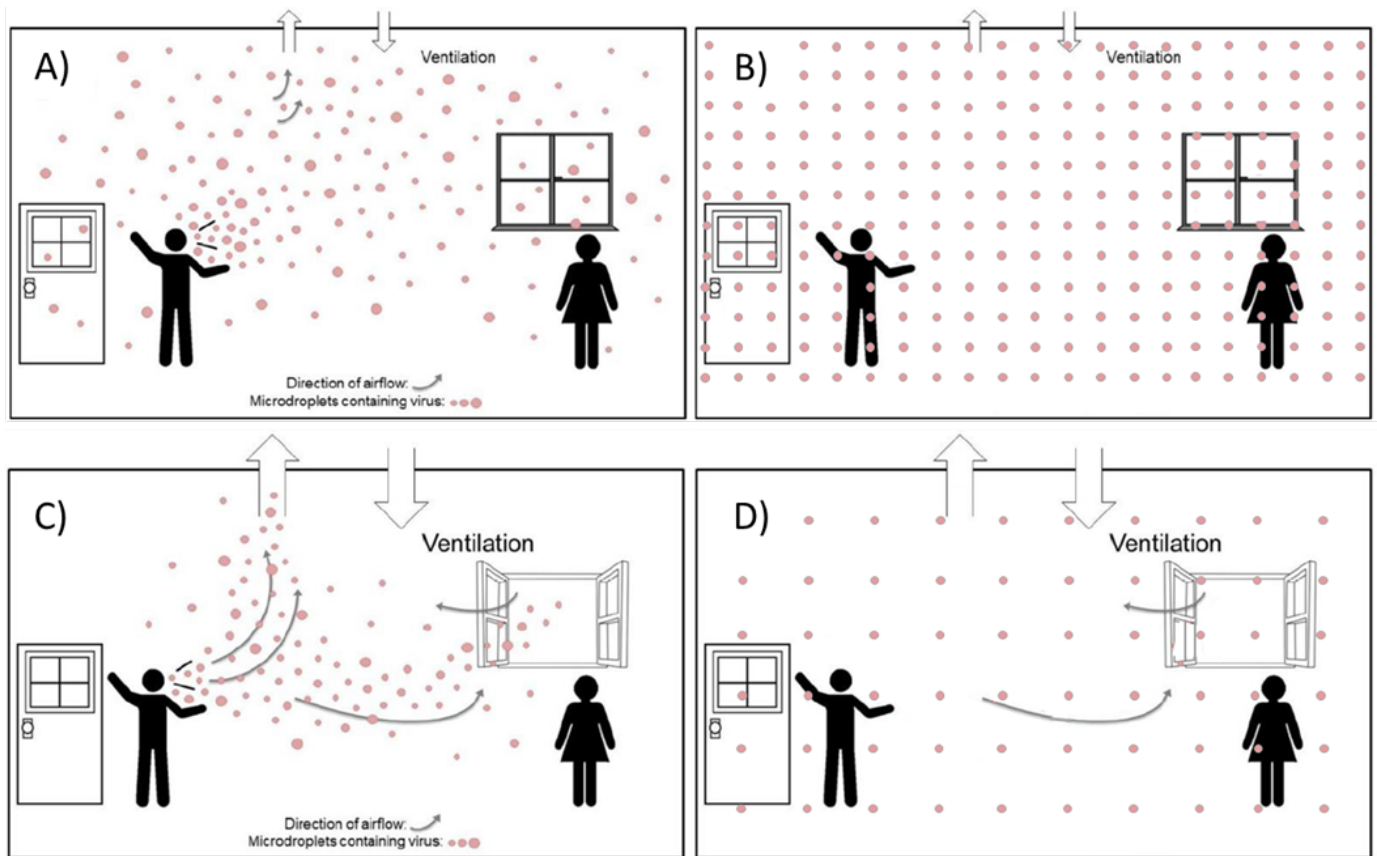


Figure 1: Small Droplet Transport and AIRC Box Model Approach Modified from Morawska and Milton (2020)

Figure 1 (A) illustrates the creation of an infectious droplet plume spreading throughout a poorly ventilated room. Concentrations are higher closer to the emission source and decay moving further away and will reach a pseudo steady-state profile in time if conditions are held approximately constant. Figure 1 (B) shows the corresponding completely mixed box model for this scenario, where the concentration in time becomes uniform across the room, and susceptible individuals are therefore exposed to the same concentration regardless of their position in the room. Differences in exposure risk between susceptible occupants in the room is therefore reduced to a function of exposure duration rather than spatial location. Figure 1 (C) shows the conceptual effect of increasing the ventilation rate in the room. The plume is reduced in intensity and extent, and the susceptible occupant is exposed to lower viral concentrations and consequentially has reduced infection risk. Figure 1 (D) illustrates the completely mixed box model approach for the room with improved ventilation. The susceptible occupant is exposed to a lower concentration and thus has a lower probability of infection for the same exposure time.

With the box model simplification, it becomes straightforward for AIRC to calculate changes in room concentration over time. Depending on the strength and duration of the emission rate and the ventilation rate in the room, the viral droplet concentration profile versus time will assume a predictable curve shape. Three common concentration curves are presented in Figure 2.



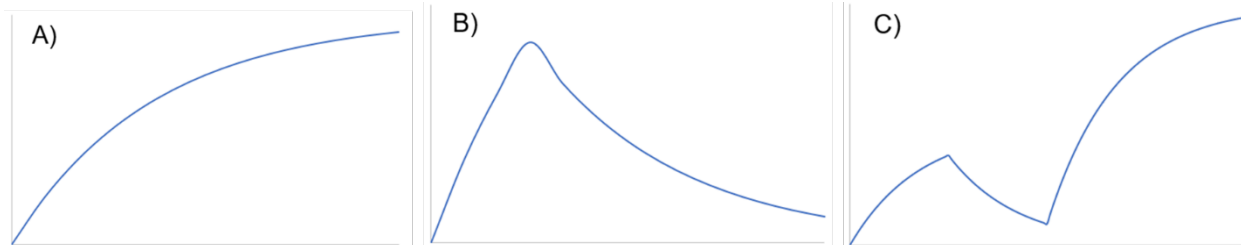


Figure 2: Common concentration versus time curves for different contaminant source scenarios on a linear scale, based on concept presented in NEEC (2015). Figure 2 (A) represents the concentration profile in a room with a constant emission source and constant ventilation rate, showing how the concentration approaches a steady-state asymptote. Figure 2 (B) presents a scenario where the same emission is eliminated and concentrations decay accordingly due to constant ventilation. Figure 2 (C) shows a more dynamic scenario where there are two separate, non-overlapping emission periods, with the second period resulting in higher concentration either due to a higher emission rate or a lower ventilation rate.

With its simplifying assumptions, the accuracy and utility of AIRC becomes a question of scale. In general, the smaller the enclosed space and the more completely mixed the air, the more the results will approximate reality. An upper limit to the appropriate room size for AIRC cannot be definitively provided at this time, but applications to indoor spaces that are thousands of square meters in area with complex HVAC zoning are unlikely to produce useful risk predictions. Alternatively, a room of approximately 500 square meters or less comprising a single HVAC zone is more likely to be a good candidate for AIRC application. A practical way to accommodate larger buildings or spaces with complex zoning is to divide the area into sub-zones, each represented by an AIRC model. The process is conceptually illustrated in Figure 3, which depicts a multi-zone modeling approach to characterize the March 2003 outbreak of SARS-CoV-1 in Ward 8A at the Prince of Wales Hospital in Hong Kong (Li et al., 2005 and Xiao et al., 2017).

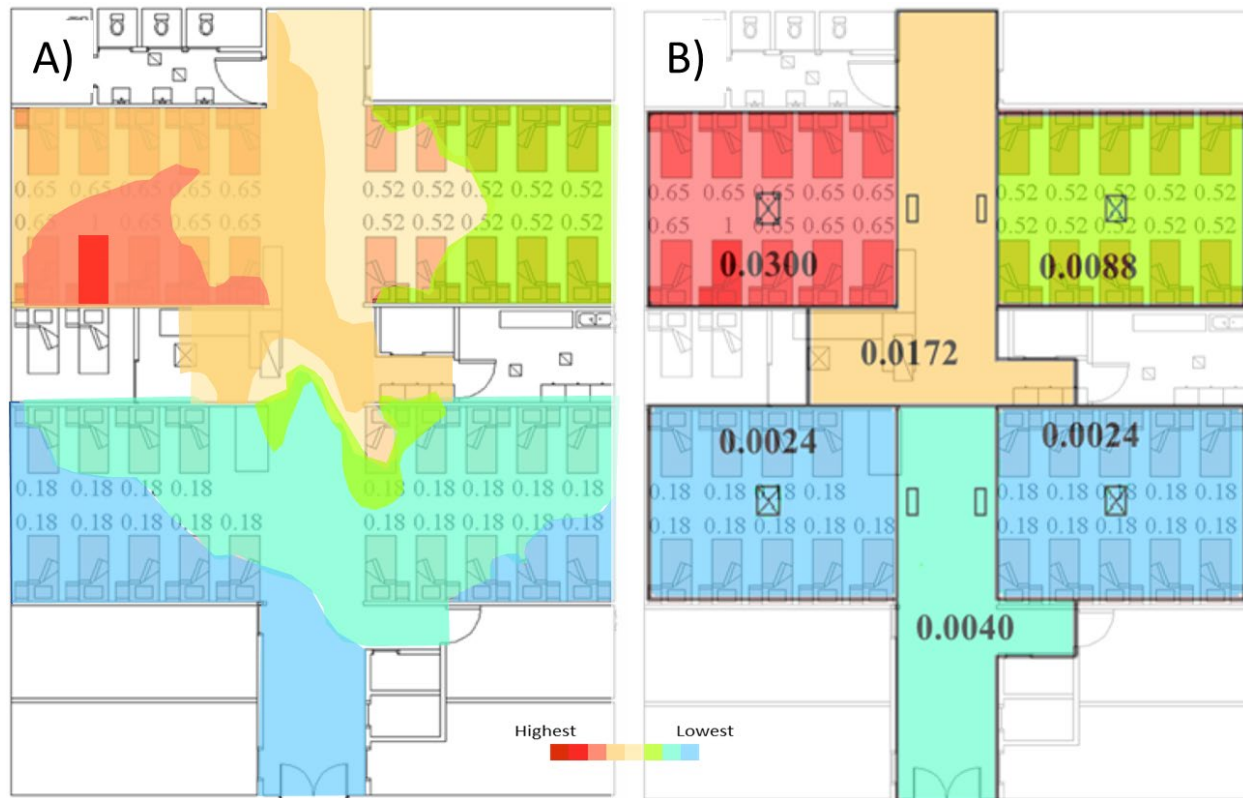


Figure 3: Simulated infectious aerosol distribution using a complex CFD model (A) and a simplified multi-zone approach (B), modified from Xiao et al., 2017. Predicted aerosol concentrations for each approach are overlaid on top of the reported SARS-CoV-1 attack rate in the zone. The index patient was located in the top left zone.

Figure 3 (A) presents a more realistic spatial representation of aerosol distribution, characterized by a plume emanating from the index patient. However, the multi-zone approach on Figure 3 (B) is likely sufficient to calculate infection risk, especially where conservative assumptions are used. Wagner et al. (2009) takes a similar approach by implementing a Sequential Box Model (SBM) that incorporates air exchange between zones.

Retrospective assessments of the AIRC risk modeling approach are provided in Buonanno et al. (2020b), simulating the outbreaks of SARS-CoV-2 at a restaurant in Guangzhou, China and a choir rehearsal in Skagit, WA, USA. The ability of the AIRC approach to reasonably reproduce these airborne “superspreading events” indicate its validity for risk screening purposes, especially when considering the urgent and time-critical need for quantitative tools to inform decision making during the SARS-CoV-2 pandemic. Furthermore, as noted in Buonanno et al. (2020a), in epidemic modeling quantifying community transmission, it is impossible to specify the geometries, the ventilation, and the locations of all infectious sources in each microenvironment. Therefore, adopting the completely mixed box model approach is generally more reasonable than hypothesizing about myriad complex environments because results must be interpreted on a statistical basis (Sze To and Chao, 2010).

## SECTION III: THE INFECTION RISK MODEL

The detailed modeling approach implemented in AIRC and described in this section directly follows from Buonanno et al. (2020a) and Buonanno et al. (2020b).

The model used to quantify airborne infection risk in AIRC was developed by Gammaitoni and Nucci (Gammaitoni and Nucci, 1997), and was successfully applied in previous papers estimating the infection risk due to different diseases (e.g. influenza, SARS, tuberculosis, rhinovirus) in various settings such as airplanes (Wagner et al., 2009), cars (Knibbs et al., 2011), and hospitals. The model calculates the quanta concentration ( $n$ ) in an indoor environment over time, subject to a constant quanta emission rate and removal rate. As a reminder, a quantum is the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons (Buonanno et al., 2020a). The full equation for  $n(t)$ , including an initial concentration term ( $n_0$ ), is presented below:

$$n(t) \left( \frac{\text{quanta}}{m^3} \right) = n_0 e^{-IVRR \cdot t} + \frac{ER_q \cdot I}{IVRR \cdot V} (1 - e^{-IVRR \cdot t})$$

where  $IVRR$  ( $hr^{-1}$ ) represents the total infectious viral removal rate,  $I$  is the number of infectious subjects,  $V$  is the volume of the indoor air environment, and  $ER_q$  is the abovementioned quanta emission rate (quanta/hr) characteristic of the specific disease/virus under investigation. The  $IVRR$  term is the sum of three contributions, all expressed in  $hr^{-1}$ : the air exchange rate (AER) via ventilation (typically measured in the number of air changes per hour), the particle deposition rate on surfaces ( $k$ , e.g. via gravitational settling), and the viral inactivation rate ( $\lambda$ ) (Yang and Marr, 2011). Details on specification of these three parameters are provided in Section IV.

In addition to the constant  $ER_q$  and  $IVRR$  values, it is assumed that the latent period of the disease is longer than the time scale of the model, and the droplets are instantaneously and evenly distributed in the room, using the box model approach described in Section II (Gammaitoni and Nucci, 1997). Once again, the latter represents a key assumption for the application of the model as it considers that the air is well-mixed within the modelled space. The risk associated with an exposure is dependent on the dose of quanta and duration of exposure, as well as the probability of occurrence of this exposure condition. The dose of quanta ( $D_q$ ) received by a susceptible subject can be obtained by integrating the calculated quanta concentration over the total exposure time ( $T$ ), as follows:

$$D_q (\text{quanta}) = IR \int_0^T n(t) dt$$

where  $IR$  is the inhalation rate of the exposed subject ( $m^3/hr$ ) which is a function of the subject's activity level. To determine the probability of infection ( $P_I$ , %) of exposed susceptible occupants for a fixed  $ER_q$ , a simplified exponential dose-response model is used as presented below:

$$P_I (\%) = 1 - e^{-D_q}$$

The probability of infection assumes different values based on the selected quanta emission rate. As such it is defined as a conditional probability for a discrete quanta emission rate, or  $P_I(ER_q)$ . To evaluate the individual risk (R) of an exposed person for a given exposure scenario, the probability of occurrence of each  $ER_q$  value ( $P_{ER_q}$ ), which is defined by an  $ER_q$  probability density functions ( $pdf_{ER_q}$ ), must also be evaluated. Since the probability of infection ( $P_I(ER_q)$ ) and the probability of occurrence  $P_{ER_q}$  are independent events, the individual risk for a given  $ER_q$ ,  $R(ER_q)$ , can be evaluated as the product of the two terms:

$$R(ER_q)(\%) = P_I(ER_q) \cdot P_{ER_q}$$

where  $P_I(ER_q)$  is the conditional probability of the infection, given a certain  $ER_q$ , and  $P_{ER_q}$  represents the relative frequency of the specific  $ER_q$  value. The individual risk (R) of an exposed person, considering the full spectrum of possible  $ER_q$  values within a defined distribution, can then be calculated by integrating the  $pdf_R$  for all possible  $ER_q$  values, i.e. summing up the  $R(ER_q)$  values as follows:

$$R(\%) = \int_{ER_q} R(ER_q) dER_q = \int_{ER_q} (P_I(ER_q) \cdot P_{ER_q}) dER_q$$

The individual risk R also represents the ratio between the number of infection cases (C) and the number of exposed susceptible individuals (S) for a given exposure scenario and taking into account all possible  $ER_q$  values for the infectious subject under investigation (Buonanno et al., 2020b). In retrospective analyses of documented outbreaks, the known C/S ratio is typically defined as the “attack rate”.

New to Version 2.0, AIRC includes a stationary exposure conditions model (“AIRC SEC”) that fully implements the above method to calculate individual risk taking into account all possible  $ER_q$  values for an assumed infectious occupant activity. However, where the room ventilation, volume, subject activity, etc. are treated as constant values, Buonanno et al. (2020b) shows that a simplified estimate of R can be calculated by using the  $ER_q$  value assumed with a probability of occurrence  $P_{ER_q}=1$  (i.e. considered as a certain emission) which induces a  $P_I(ER_q)$  equal to the risk R as shown through the full integration analysis. This certain emission value is calculated to be the 66<sup>th</sup> percentile  $ER_q$  value. Therefore, when the 66<sup>th</sup> percentile  $ER_q$  value is used, the individual risk can be assumed to approximately equal to the probability of infection. AIRC therefore provides the 66<sup>th</sup> percentile values for a range of respiratory activities and recommends these values to be used in risk calculations for the AIRC Version 1.0 update with transitional exposure conditions, now termed “AIRC TEC” (Buonanno et al., 2020b). **[CHANGED TO 75<sup>th</sup> PERCENTILE {ADJUSTABLE} IN VERSION 3.0 BETA FOR NEW EMISSION DISTRIBUTION WITH INCREASED OVERDISPERSION]** The key distinction between AIRC SEC and AIRC TEC is the type of exposure scenario being evaluated. AIRC SEC assumes perfect coincidence in the presence of the two subjects as they enter together and leave the environment together. AIRC TEC allows consideration of more dynamic scenarios where infectious and susceptible occupants can come and go and different times, and susceptible occupants can be exposed to residual viral droplets in the air. When the exact same scenario is evaluated using AIRC SEC and AIRC TEC, the results will be nearly identical for short exposures (<4 hours), but for longer exposures (e.g. 8 hours) the results may be slightly different due to the 66<sup>th</sup> percentile approximation adopted in AIRC TEC. **[CONSISTENCY BETWEEN SEC AND TEC WILL VARY BY PATHOGEN, THE TEC PERCENTILE IS ADJUSTABLE]**

On a population level, the basic reproduction number  $R_0$ , representing the number of susceptible people infected after the exposure time, can be determined by multiplying the probability of infection ( $P_i$ , %) by the number of exposed individuals. For purposes of AIRC, however, reproductive effects are calculated differently to provide the maximum number of occupants that may keep the  $R_0$  below 1 for the scenario in question. In this way the user can obtain a potential occupancy or crowding index that considers the need to reduce community transmission. **[CHANGED TERMINOLOGY TO EVENT REPRODUCTION NUMBER]**

This maximum occupancy calculation uses the following equation, rounded down to the nearest integer:

$$\text{Max. Occupants for } R_0(t) < 1 = \frac{1}{P_i(t)}$$

For both AIRC SEC and AIRC TEC, the  $P_i$  value corresponding to the 90<sup>th</sup> percentile  $ER_q$  value is used as the maximum  $R(ER_q)$  values occur in the narrow range of 90<sup>th</sup>-95<sup>th</sup> percentile for the scenarios evaluated by Buonanno et al. (2020b). **[WITH THE IMPROVED EMISSION DISTRIBUTION THE MAXIMUM OCCUPANCY IS NOW CALCULATED AS 1/R FOR THE SEC VERSION AND 1/ $P_i$  FOR THE TEC VERSION]**

## SECTION IV: AIRC DATA ENTRY & RESULTS

There are two tabs for the user to enter data in AIRC and view model output, the first tab entitled “AIRC SEC” (new to Version 2.0) and the second tab entitled “AIRC TEC”. These two modeling sheets are completely independent. If a user is only interested in one approach, the other one can be ignored. For both sheets the user must enter a value into all cells with white fill and black text. All cells with black fill and white text are calculated by AIRC and are locked to the user. Cells with gray fill are informational and are not used by AIRC. In addition, drop-down lists in cells with yellow fill are used on both tabs to select the desired activities for infectious and susceptible occupants. Based on the assumption that users are most concerned with SARS-CoV-2, quanta emission rates associated with the selected activities are for SARS-CoV-2. These values are defined on the “SEC Calculations” tab and the “TEC ERq IR” tabs for the two different modeling approaches.

A description of each tab in the AIRC 2.0 workbook is provided below. All tabs associated with AIRC SEC are shaded blue, all tabs associated with AIRC TEC are shaded yellow.

### **AIRC SEC Tabs**

#### **AIRC SEC Tab 1 Name: AIRC SEC**

**Description:** This tab contains model input and results for the constant source and exposure, termed “stationary exposure conditions” model (SEC) new to AIRC Version 2.0. The individual infection risk and maximum room occupancy is calculated for six different selectable infectious occupant activities for three different exposure lengths. In addition, a sensitivity analysis on the air exchange rate parameter is presented for one infectious occupant activity where the user can enter five different air exchange rates to see how model results change.

#### **Model Input Parameters:**

##### **1. Room Dimensions**

The room dimension parameters for the user to enter are the floor plan area (in m<sup>2</sup>) and the ceiling height of the occupied indoor space to be modeled (in m). The product of the area and ceiling height is the room volume (m<sup>3</sup>).

##### **2. Infectious Viral Removal Rate**

As defined in Section III, the Infectious Viral Removal Rate (IVRR) is the sum of the air exchange rate (AER) via ventilation (also termed the number of air changes per hour), the particle deposition rate on surfaces ( $k$ , e.g. via gravitational settling), and the viral inactivation rate ( $\lambda$ ). Entry details on these three parameters are presented below.

Parameter	Air Exchange Rate (AER)																				
Units	hour (hr <sup>-1</sup> )																				
Recommended Values	Use site-specific measured values, or design or estimated values if field measurements are unavailable. For natural ventilation (infiltration only), values of 0.2 – 0.5 hr <sup>-1</sup> are recommended. For the opening of doors and windows on one side of a room, values of 1.0 – 5.0 hr <sup>-1</sup> are suggested. It is noted that ventilation rates through windows are highly site-specific and the user is cautioned against making assumptions on the higher end of this provided range.																				
Notes/Estimation Methods	<p>The AER is the most important site-specific parameter in the model and the largest contributor to virus removal. Therefore, site-specific measurements or design values are the best sources for parameter input. AER can be simply calculated as the total fresh outdoor airflow (OA) divided by the volume of the room. <u>Recirculated airflow should not be included in the AER calculation as it represents fresh airflow only.</u></p> <p>If actual total and outdoor airflows cannot be measured directly, the percent OA delivered to a space is commonly estimated using air handler carbon dioxide (CO<sub>2</sub>) concentrations in parts per million (ppm) as follows:</p> $\% \text{ OA} = \frac{CO_2 \text{ Return Air} - CO_2 \text{ Mixed Air}}{CO_2 \text{ Return Air} - CO_2 \text{ Outside Air}}$ <p>Note that the above calculation is also routinely performed using temperatures instead of CO<sub>2</sub> concentrations, but that it is less accurate, especially when temperature differences are small. Another common method of estimating ventilation rate is using “rule of thumb” values per person based on steady-state CO<sub>2</sub> concentrations achieved in offices and classrooms with ASHRAE 62n default occupancy rates, as follows (NEEC, 2015):</p> <table border="1"> <thead> <tr> <th>Zone CO<sub>2</sub> (ppm)</th> <th>Outside Air (CFM per person)</th> <th>Outside Air (Liters (L)/s per person)</th> <th>Outside Air (m<sup>3</sup>/hr per person)</th> </tr> </thead> <tbody> <tr> <td>2,500</td> <td>5</td> <td>2.4</td> <td>8.5</td> </tr> <tr> <td>1,400</td> <td>10</td> <td>4.7</td> <td>17</td> </tr> <tr> <td>1,000</td> <td>15</td> <td>6.9</td> <td>25</td> </tr> <tr> <td>750</td> <td>30</td> <td>14</td> <td>51</td> </tr> </tbody> </table>	Zone CO <sub>2</sub> (ppm)	Outside Air (CFM per person)	Outside Air (Liters (L)/s per person)	Outside Air (m <sup>3</sup> /hr per person)	2,500	5	2.4	8.5	1,400	10	4.7	17	1,000	15	6.9	25	750	30	14	51
Zone CO <sub>2</sub> (ppm)	Outside Air (CFM per person)	Outside Air (Liters (L)/s per person)	Outside Air (m <sup>3</sup> /hr per person)																		
2,500	5	2.4	8.5																		
1,400	10	4.7	17																		
1,000	15	6.9	25																		
750	30	14	51																		

	<p>AIRC follows the risk minimization framework outlined by Morawska et al. (2020), in which enhanced ventilation is the primary reliable and readily available line of defense against airborne transmission in indoor air environments. Secondary measures where ventilation alone may be insufficient, such as enhanced filtration, ultraviolet germicidal irradiation (UVGI), and/or room humidification, are not explicitly included in AIRC. Advanced users of AIRC can include filtration in the model by adding “equivalent” air exchanges to the AER term.</p> <p>Azimi and Stephens (2013) provide a comprehensive review of infectious droplet nuclei filtration efficiencies (see Figure 4). To incorporate filtration removal in AIRC, the user can calculate the equivalent AER in <math>hr^{-1}</math> as follows:</p> $AER_{filtration} (hr^{-1}) = \frac{Q_{recirculated} \cdot \eta_{filter}}{V}$ <p>where <math>Q_{recirculated}</math> is the airflow rate recirculated from the space through the filter, <math>\eta_{filter}</math> is the infectious droplet removal efficiency of the filter, and <math>V</math> is the volume of the room.</p> <p>The recirculated airflow plus the fresh outdoor airflow will equal the total airflow rate of the air handler. Remember that the air exchange rate is calculated using only the fresh outdoor airflow rate, and if air is recirculated the AER will be reduced. Example Application 3 presents how this calculation is performed for an air handler serving an office space.</p>
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Parameter	Particle Deposition Rate (k) (SARS-CoV-2)
Units	$hr^{-1}$
Recommended Value	0.24
Notes/Estimation Methods	The recommended value is from Buonanno et al. (2020a), which calculated the deposition rate as the ratio between the settling velocity of super-micrometric particles (roughly $1.0 \times 10^{-4} m s^{-1}$ as measured by Chatoutsidou and Lazaridis [2019]) and the height of the emission source (1.5 m). A site-specific computational fluid dynamics (CFD) model may be needed to quantify this parameter more accurately.



Parameter	Viral Inactivation Rate ( $\lambda$ ) (SARS-CoV-2)
Units	hr <sup>-1</sup>
Recommended Value	0.63
Notes/Estimation Methods	<p>The recommended viral inactivation rate is calculated from the SARS-CoV-2 half-life (1.1 hr) detected by van Doremalen et al. (2020) as follows:</p> $\lambda \text{ (hr}^{-1}\text{)} = \frac{0.693}{t_{1/2}}$ <p>Users should follow the evolving literature on SARS-CoV-2 with a view towards refinement of this parameter. Fears et al. (2020) reports retained infectivity and virion integrity of SARS-CoV-2 for up to 16 hours in respirable-sized aerosols. For a resource to help incorporate UV treatment or relative humidity into this parameter, the user is referred to: <a href="https://www.dhs.gov/science-and-technology/sars-airborne-calculator">https://www.dhs.gov/science-and-technology/sars-airborne-calculator</a> (Schuit et al., 2020).</p>

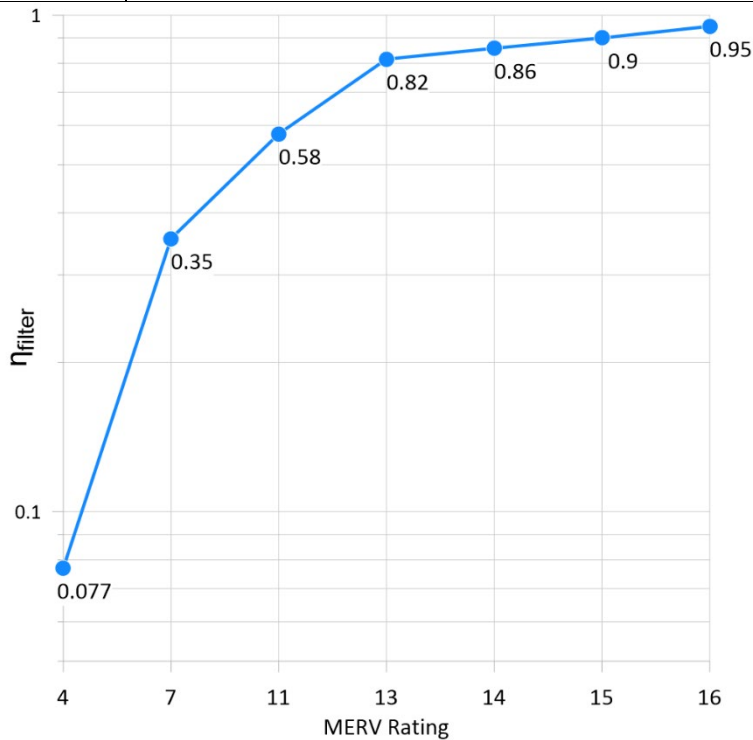


Figure 4: Infectious droplet nuclei filtration efficiency ( $\eta_{\text{filter}}$ ) as a function of HVAC filter MERV rating, using the minimum reported values from Azimi and Stephens (2013).

### 3. Number of Infectious Occupants

New to Version 2.0, the user can model infectious occupants as a group of multiple individuals in the room for the same defined period of time. For AIRC SEC, the infected group is in the room for the full length of the simulation with the susceptible individuals. Any positive integer may be entered for this value. **[NOW SELECTABLE FOR UP TO 10 INFECTIOUS OCCUPANTS]**

### 4. Initial Quanta Concentration

The initial quanta concentration term, in quanta/m<sup>3</sup>, has been provided in the event the user wants to model a scenario where residual viral emissions are present in indoor air at time zero. This is a useful function where the user wants to begin a new simulation using the final quanta concentration of a previous simulation. If the indoor air environment is expected to be free of airborne virus at the start of the simulation, the user should enter zero for this parameter.

### 5. Exposure Time

AIRC SEC calculates infection risk and maximum occupancy for three different exposure times that the user can enter in hours (with no time limit).

### 6. Susceptible Inhalation Rate

The user can select from a list of pre-determined activity levels (resting, standing, light exercise, heavy exercise) to quantify the inhalation rate of susceptible occupants in the model. If a user would like to enter a custom inhalation rate value, this may be done on the SEC Calculations tab.

### 7. Infectious Occupant Activities

The user can select six (6) different pre-determined activity levels from the list provided in Table 1 to quantify the viral emission rate (ER<sub>q</sub>) of infectious occupants of the room, from Buonanno et al. (2020b).

**Table 1: Selectable Infectious Occupant Activities and Associated ER<sub>q</sub> Values**

**[SUPERCEDED – SEE ‘ERQ’ TAB OF VERSION 3.0 BETA FOR UPDATED DISTRIBUTIONS FOR SARS-COV-2 AND OTHER PATHOGENS]**

The results represent six different model realizations for the same scenario, not different infectious occupants doing different things in the same room. This can be conceptualized as a sensitivity analysis on the selected ER<sub>q</sub> distribution for the model. If a user would like to enter a custom ER<sub>q</sub> distribution or a fixed ER<sub>q</sub> value for use in the model, this may be done on the SEC Calculations tab.

### 8. AER Sensitivity Analysis

To help the user assess how model results change based on air exchange rate, the user may enter five different AER values that will re-calculate results for infectious occupant activity #6 only.

### 9. Model Results

This section presents the model results as the individual infection risk for exposed susceptible occupants for the three different exposure times, and as the estimated maximum number of occupants to maintain a reproductive number less than one for the modeled scenario. In total the results reflect 33 different

model runs: 6 different infectious occupant activities at 3 different exposure times for the primary AER (18 runs), and 5 different AERs at 3 different exposure times for infectious occupant activity #6 (15 runs).

**AIRC SEC Tab 2 Name:** SEC Graphs

**Description:** This tab contains graphical results of the 33 different simulations run for AIRC SEC for the user's input parameters. Results are presented in four (4) different graphs. The top graphs present infection risk as a function of the quanta emission rate at the fixed user-entered AER, and as a function of AER using infectious occupant activity #6. The bottom graphs simply present the estimated maximum room occupancy instead of the infection risk. Graphs will update automatically as user's change input parameters, including titles.

**AIRC SEC Tab 3 Name:** SEC Method **[CHANGED TO REVENT CALCULATION PAGE WITH DEFINED OCCUPANCY AND SECONDARY TRANSMISSION PROBABILITY HISTOGRAMS]**

**AIRC SEC Tab 4 Name:** SEC Calculations

**Description:** This tab contains the calculations for the stationary exposure conditions implementation of AIRC. Advanced users can enter a fixed (certain)  $ER_q$  value, custom  $ER_q$  probability distributions and inhalation rates for use in the model. **[A CUSTOM SARS-COV-2 VARIANT MULTIPLIER CAN ALSO BE ENTERED ON THIS TAB]**

**AIRC TEC Tabs**

**AIRC TEC Tab 1 Name:** AIRC TEC

**Description:** This tab contains the updated version of the Version 1.0 AIRC model with transitional exposure conditions. New to Version 2.0, the user selects the infectious occupant and susceptible occupant activities directly on the input and results tab, now named AIRC TEC. For this version of the model, the total time of occupancy, in minutes, represents the maximum duration of continuous occupancy of the modeled room by any person. The maximum simulation length supported by AIRC is 480 minutes (8 hours), therefore, the maximum value for this parameter is 480. This parameter must be entered as an integer value. AIRC calculates the continuous occupancy risk and maximum room occupancy based on the total time of occupancy entered by the user. The total time of occupancy value entered by the user should be greater than the time of exit values for Infectious Occupant #1, Infectious Occupant #2, and Susceptible Occupant A.

To define an exposure scenario, the user enters the time of entry and time of exit for infectious occupants and one susceptible occupant. All times are to be entered in minutes and represent minutes after the start of the simulation. Any number of non-zero infectious occupants can be assumed to be present at the start of the simulation (time zero), but all of these occupants must leave the room at the same time. **[FOR VERSION 3.0 BETA UP TO 10 CAN BE SELECTED AS WITH SEC]** Infectious Occupant A can be omitted from the model by selecting "No" from the drop-down list next to the "Include in Model?" field. The values for quanta emission rate ( $ER_q$ ) for each infectious occupant, and the value for inhalation rate (IR) for Susceptible Occupant A and a continuous occupant of the space are pulled from the TEC  $ER_q$  IR Tab.

The results section reports calculated risk values of interest for Susceptible Occupant A and for other susceptible persons who occupy the space for the entirety of the simulation (i.e. the total time of occupancy parameter). The following values are reported:

- **Modeled Exposure Time:** For Susceptible Occupant A this will be the time of exit minus the time of entry in minutes. For continuous occupants this will be equal to the total time of occupancy parameter.
- **Probability of Infection:** The probability of infection,  $P_i$  (%), represents an estimate of the percent chance of infection for exposure to the quanta concentration profile integrated across the modeled exposure time for a certain, known emission rate. When the 66<sup>th</sup> percentile value of  $ER_q$  is used, the probability of infection is assumed to be approximately equal to the infection risk taking into account all possible  $ER_q$  values for the infectious subject under investigation. However, since this is an approximation and a user may enter a custom value for  $ER_q$ , AIRC TEC uses the probability of infection term instead of individual risk.
- **Exposure Time for 0.1%  $P_i$ :** This value is the exposure time in minutes associated with a 0.1% probability of infection, or a threshold of  $10^{-3}$ . If the exposure time is less than this value,  $P_i$  is estimated to be less than 0.1%, and vice versa. The quanta concentration profile for Susceptible Occupant A will be different from that of the continuous occupants; hence, calculated exposure times may be different. If Susceptible Occupant A or the continuous occupants do not exceed the 0.1%  $P_i$  threshold during the simulation, AIRC presents a result of greater than (“>”) the modeled exposure time. If a user enters extreme value parameters such as a very high  $ER_q$  combined with a very small room volume, a #N/A value may result, meaning that the  $P_i$  threshold is already exceeded at the first time step of 1 minute.
- **Exposure Time for 1.0%  $P_i$ :** This value has the same characteristics as the above parameter but uses a higher  $P_i$  threshold of 1% (or  $10^{-2}$ ). The calculated exposure time for 1%  $P_i$  will be higher than that of 0.1%  $P_i$ . The decision of what threshold to use for risk management purposes is up to the user and should depend on the type of occupancy and characteristics of the inhabitants and should appreciate the screening-level intent of the tool. Calculated exposure times associated with other risk thresholds can be evaluated on the Model Graph.
- **Maximum Room Occupancy for  $R_0 < 1$ : [CHANGED TO REVENT]** This parameter represents the maximum number of occupants allowable in the room for the exposure time and quanta concentration profile of the designated scenario (e.g. Susceptible Person A or continuous occupancy) in order to keep the basic reproduction number ( $R_0$ ) below 1 for that exposure. In other words, more than one person may be expected to become infected if the occupancy increases beyond this number. Conceptually this is easier to understand for the continuous occupancy calculation as it represents the allowable number of occupants who will be present for the entire simulation. For Susceptible Occupant A, the maximum room occupancy calculation applies to a cohort of persons sharing the same exact exposure profile as Susceptible Occupant A (i.e. entering and leaving at the same time). If a user is interested in the calculated  $R_0$  value for a pre-determined number of occupants, it can be obtained by dividing the pre-determined occupancy by the maximum room occupancy calculated by AIRC. It is reiterated that the maximum room occupancy is for a specific exposure scenario up to a maximum of 8 hours (480 minutes). If this exposure scenario is expected to occur repeatedly, such as daily, the user may want to reduce the calculated occupancy further as  $R_0$  would be expected to exceed 1 over time. Alternatively, these cases could be evaluated as long-term exposures using the AIRC

SEC model. As the reproduction number scales linearly with occupancy, reducing the AIRC calculated occupancy by one-half corresponds to an estimated  $R_0$  of 0.5.

**AIRC TEC Tab 2 Name:** TEC ERq IR

**Description:** This tab provides the  $ER_q$  and IR rates used in the AIRC TEC model in quanta/hr and  $m^3/hr$ , respectively, associated with the selectable activity levels. Two reference value tables are provided, one for infectious occupant quanta emission rates, and one for susceptible occupant inhalation rates. Summary tables are provided that show what values are used in the model based on the user's selections. If Infectious Occupant A is not included in the model as indicated on the AIRC TEC tab, its displayed value will be greyed out. If the user would like to use a custom value for IR or  $ER_q$ , the user can enter values on this tab. Separate custom emission rates can be entered and selected for the group of infectious occupants present at time zero, and for Infectious Occupant A if included in the model.

All provided values of  $ER_q$  in the lookup tables are specific to the SARS-CoV-2 virus and represent the 66<sup>th</sup> and 90<sup>th</sup> percentile value of a lognormally distributed data set (base 10), as reported in Buonanno et al. (2020b). The 66<sup>th</sup> percentile value is provided because the total individual risk is expected to be approximately equal to the probability of infection at this "certain emission"  $ER_q$  value (Buonanno et al., 2020b). Hence the 66<sup>th</sup> percentile values are used for calculation of the probability of infection. The 90<sup>th</sup> percentile value is used for calculation of the maximum room occupancy, as the maximum  $R(ER_q)$  values occur in the narrow range of 90<sup>th</sup>-95<sup>th</sup> percentile for the scenarios evaluated by Buonanno et al. (2020b). **[CHANGED TO 75<sup>TH</sup> PERCENTILE VALUE AS DEFAULT WHICH CAN BE ADJUSTED BY THE USER – THIS VALUE IS ALSO USED TO CALCULATE THE MAXIMUM ROOM OCCUPANCY]**

All values of IR for the susceptible occupant are also provided from Buonanno et al. (2020a). As with  $ER_q$ , a custom entry option is provided for IR for advanced users, and different IR values can be specified for Susceptible Occupant A and a continuous occupant of the space.

AIRC TEC also calculates the exposure scenario probability of infection for four additional fixed quanta emission rates on TEC ERq Analysis tab. In Version 1.0, these emission rates were labeled to be associated with other pathogens. Since all other parameters are held constant, Version 2.0 reframes this as an  $ER_q$  sensitivity analysis. However, the user may relabel the headers corresponding to the alternative  $ER_q$  (e.g.  $ER_q$  #2) if the goal is to characterize a specific pathogen. **[DIFFERENT PATHOGENS ARE NOW SELECTABLE ON THIS PAGE, USING EITHER THE 75<sup>th</sup> OR USER-DEFINED PERCENTILE VALUE]**

For reference, a range of literature values for  $ER_q$  for different pathogens is presented in Figure 5, alongside the range of SARS-CoV-2 values reported in Buonanno et al. (2020b). Quanta emission rates used in similar risk modeling analyses are presented in Table 2 and Table 3, the latter table for tuberculosis only based on Internal Clinical Guidelines Team (UK) (2016). **[TO BE UPDATED]**

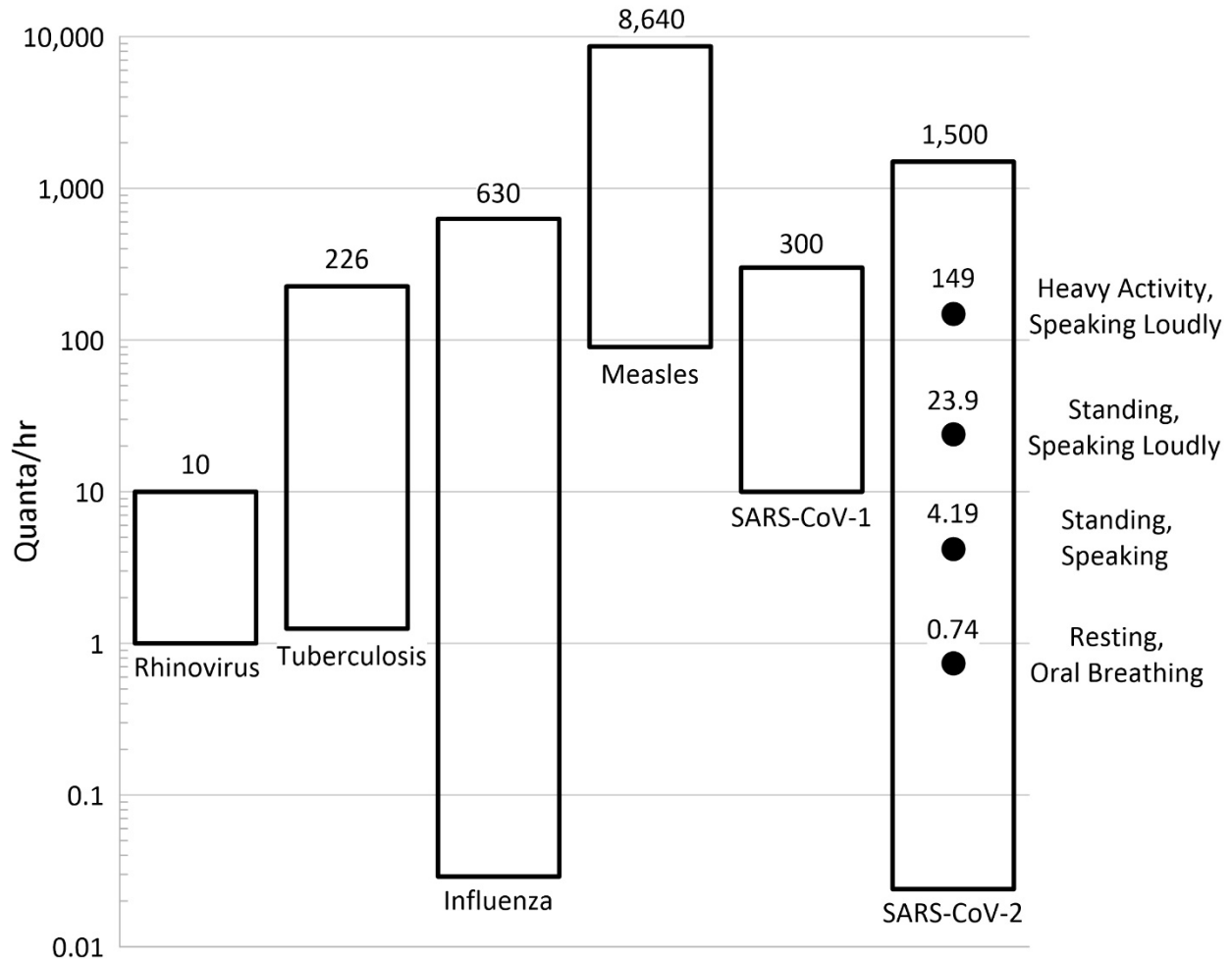


Figure 5: Range of published quanta emission rates for six pathogens. Range for rhinovirus from Rudnick and Milton (2003) and for SARS-CoV-1 from Azimi and Stephens (2013). For SARS-CoV-2, the range and 66<sup>th</sup> percentile values for different activities are presented from Buonanno et al. (2020b). See Tables 2 and 3 for influenza, measles and tuberculosis (TB) references (chart excludes estimates from aerosol-producing procedures for TB).

**Table 2: Quanta Emission Rates from Published Risk Modeling Studies [TO BE UPDATED]**

Pathogen	Modeled or Calculated ER <sub>q</sub> (Quanta/hr)	Modeling Application	Reference
Influenza	0.029 – 0.17 95 <sup>th</sup> % = 53, max = 630	University of Maryland Human-Challenge Transmission Trial	Bueno de Mesquita et al. (2020), Yan et al. (2018)
	A (H1N1) = 9; A (H3N2) = 7 B = 7; p-H1N1 = 21	Derived Emission Rates from Elementary School Modeling	Cheng and Liao (2013)
	CA04 = 15.9 Rg-WH359 = 10.6	Influenza Aerosol Experiments and Analytical System for Ferrets	Zhou et al. (2018)
	67	Derived Emission Rate from School Influenza Surveillance Reports	Liao et al. (2005)
	50-128	Assessment of Airborne Influenza Transmission on an Airplane	Wagner et al. (2009), after Rudnick and Milton (2003)
Measles	log <sub>10</sub> (ER <sub>q</sub> ): average = 2.78, stand. dev = 0.415	Analysis of Measles Epidemics in Elementary Schools	Riley (1980)
	1,925 (elementary school); 2,765 (high school)	Multi-Zone Transient Wells-Riley Modeling Study	Azimi et al. (2020)
	8,640	Airborne Transmission in a Physician's Office	Remington et al. (1985)
SARS-CoV-2	61	Guangzhou Restaurant Superspreading Event	Buonanno et al. (2020b)
	970	Skagit Valley Chorale Superspreading Event	Miller et al. (2020)

**Table 3: Tuberculosis Quanta Emission Rates from Published Risk Modeling Studies [TO BE UPDATED]**

Calculated ER <sub>q</sub> (Quanta/hr)	Modeling Application	Controlled Experiment with Guinea Pigs	Reference
1.25	TB patient on treatment	x	Riley et al. (1962)
1.8 – 226 (average of 37)	Drug susceptible and MDR-TB, HIV co-infected patients	x	Escombe et al. (2008)
12.7	Untreated TB case causing outbreak in an office		Nardell et al. (1991)
34 (masks worn) 138 (no masks)	MDR-TB patients with mixed HIV status	x	Dharmadhikari et al. (2012)
60	Laryngeal case of TB	x	Riley et al. (1962)
108	Outbreak from an infectious MDR-TB case on a long flight		Ko et al. (2004)
250; 360	Bronchoscopy-related outbreak		Nardell et al. (1991), Gammaitoni & Nucci (1997)
2,280	Outbreak related to jet-irrigation of an abscess		Gammaitoni & Nucci (1997)
5,400	Autopsy outbreak		Gammaitoni & Nucci (1997)
30,840	Intubation-related outbreak		Gammaitoni & Nucci (1997)

As shown in Figure 5, the quanta emission rate for SARS-CoV-2 is highly variable depending on the emitting activity of the infectious individual. The emissions rate for oral breathing at rest is comparable to the reported range for rhinovirus, whereas the emissions rate for speaking loudly during heavy activity (for example, singing), falls within the range of the highly infectious measles virus. This may explain why SARS-CoV-2 superspreading events have been reported at nightclubs, choir practices and other settings where people are speaking loudly or singing at high activity levels in enclosed spaces. On a population level, Dai and Zhao (2020) estimated the quantum generation rate of SARS-CoV-2 at 14-48 per hour using a reproductive number-based curve fitting approach. Dai and Zhao (2020) also report an  $ER_q$  range of 6-140 quanta/hr for Middle East Respiratory Syndrome (MERS) virus, but the original source of this estimate could not be verified. To derive an independent estimate of  $ER_q$  for MERS and other viruses, AIRC can be used as an inverse model to back-calculate the quantum generation rate for a known airborne transmission scenario with a measured attack rate.

With respect to mask wearing, Wood et al. (2018) found that at 2 meters from the source, both surgical and N95 masks reduced aerosols containing viable *Pseudomonas aeruginosa* in the droplet nuclei size range by over 90% during voluntary coughing in people with Cystic Fibrosis. The findings were consistent with Driessche et al. (2015), which found an 86% reduction in environmental detection of airborne *Pseudomonas aeruginosa* concentration during mask wearing compared with the reference group (coughing without a surgical mask) in a controlled laboratory model. While mask wearing therefore has the potential to be a highly effective measure reducing the quanta emission rate of an infectious subject, masks may be worn improperly or intermittently in indoor environments. Therefore, the user is advised against using custom quanta emission rates where the provided percentile values are significantly reduced to account for mask wearing.

The Institute for Health Metrics and Evaluation (IHME) at the University of Washington performed a meta-analysis of peer-reviewed scientific studies and medRxiv pre-prints to assess mask efficacy, the results of which suggest a reduction in infection for mask wearers by at least one-third (33%) compared to control groups (IHME, 2020). Therefore, reducing the calculated risk value by a factor of 33% or less to account for effective mask wearing of both infectious and susceptible occupants may be a reasonably defensible approach.

### **AIRC TEC Tabs 3, 4 Names: TEC Graph 2 hr, 8 hr**

**Description:** To help the user visualize how model calculations change in time based on the entered parameters, a graph of model results is presented including the following data series:

- The calculated quanta concentration in the room in quanta/m<sup>3</sup>;
- The probability of infection for Susceptible Occupant A;
- The probability of infection for a person continuously occupying the space; and
- The calculated maximum occupancy to maintain  $R_0 < 1$  for continuous occupants of the space (e.g. the number of occupants allowable for a cohort entering at time zero).

As the user may create scenarios of varying time scales, two graphs are provided: one limited to 120 minutes and the second displaying results for the maximum 480 minutes. The graphs are the same and two versions are only provided to facilitate data visualization for times of interest.



**AIRC TEC Tabs 5-7 Names: TEC ERq Analysis and ERq Graph 2 hr, 8 hr**

**Description:** These tabs in AIRC summarize the results of the TEC exposure scenario modeling using four different user-entered quanta emission rates. On TEC ERq Analysis tab, the user can input any quanta emission rate for both the infectious occupants initially occupying the space, and Infectious Occupant A. Probabilities of infection and exposure time thresholds for Susceptible Occupant A and a continuous occupant are also presented on this tab. Probability of infection graphs for continuous occupancy are presented on the ERq Graph tabs. These graphics are provided to establish a frame of reference for the model results and facilitate use of AIRC for deterministic sensitivity analysis for his or her original simulation, as all other parameters remain the same.

**AIRC TEC Tabs 8, 9 Names: Calculations 66 and Calculations 90 [NOW JUST 'CALCULATIONS 75']**

**Description:** These tabs of AIRC allows users to see the Excel formulas used to implement the TEC modeling approach. Users can click on individual cells to see formulas and cell references and can adjust formatting if a time step is of interest. The implementation approach is straightforward, and the formulas can be copied and pasted into a different spreadsheet program as needed. The “66” tab uses the 66<sup>th</sup> percentile ER<sub>q</sub> values to calculate the probability of infection, while the “90” tab uses the 90<sup>th</sup> percentile ER<sub>q</sub> values to calculate the maximum occupancy for  $R_0 < 1$ .

## SECTION V: EXAMPLE APPLICATIONS [TO BE UPDATED, RISK ESTIMATES WILL BE HIGHER IN VERSION 3.0 BETA WITH ALL INPUT PARAMETERS THE SAME, DIFFERENCES WILL BE LESS FOR OCCUPANCY CALCULATIONS AS VERSION 2.0 CONSERVATIVELY USED THE 90<sup>TH</sup> PERCENTILE ER<sub>q</sub>]

Four example applications are provided in this manual for AIRC 2.0 to assist the user in the process of creating a conceptual exposure model, entering input data, and visualizing and interpreting results. Note that with the changes to the provided quanta emission rates and risk calculation, model output with AIRC 2.0 will not exactly match the example applications described in the AIRC 1.0 User Manual. However, the risk modeling concepts remain the same.

### 1. Squash

Scenario Description: Brlek et al. (2020) present a retrospective analysis of a cluster of five COVID-19 cases linked to playing squash at a sports facility in Slovenia. The authors conclude that viral transmission may have occurred through aerosol inhalation as all subjects shared the exact same poorly ventilated squash hall, and the aerosol emission rate for the infectious index case would have been high for strenuous physical activity. While indirect transmission in the locker room or other parts of the facility through fomites (e.g. doorknobs), large respiratory droplets, or aerosols could not be ruled out, for purposes of this illustrative example we assume that all transmission occurred through aerosols within the squash hall.

The sequence of events within the shared squash hall and the timeline for AIRC TEC modeling is described below (Brlek et al., 2020). There were three independent squash matches and therefore three separate AIRC TEC scenarios are necessary. Susceptible occupant A represents the susceptible squash players in each of the three successive matches and AIRC models:

- The index case (infectious occupant at time zero) played squash with a susceptible occupant for one hour in the squash hall. This match and exposure period for susceptible occupant A spans 0-60 minutes in the AIRC model;
- Two different susceptible persons started playing squash in the same squash hall 45 minutes after the prior match ended and played for 45 minutes. This match and exposure period for susceptible occupant A spans 105-150 minutes in the second AIRC model;
- Two different susceptible persons started playing squash just after the prior match ended and also played for 45 minutes. This match and exposure period for susceptible occupant A spans 150-195 minutes in the third AIRC model;
- All 5 susceptible persons were infected with COVID-19 (100% attack rate for shared occupants of the squash hall). Of the five employees at the facility, none developed COVID-19 symptoms and the one employee who was tested received a negative result.

Brlek et al. (2020) does not provide the room dimensions of the squash hall. However, assuming the design followed the World Squash Federation (WSF) standard for a singles-court, we model the room as having an area of 62.4 m<sup>2</sup> and a ceiling height of 5.64 m, for a room volume of 352 m<sup>3</sup> (WSF, 2013). As the squash hall was described as poorly ventilated, we assume an air exchange rate of 0.2 hr<sup>-1</sup>. An

activity level of heavy exercise, loudly speaking is selected for the index case, and inhalation rates of heavy exercise are selected for all susceptibles.

AIRC TEC Screenshots:

**Airborne Infection Risk Calculator v2.0** **AIRC** Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
 Transitional Exposure Conditions Technical support: amikszewski@cunybpl.org

60	1. Input Value	1.4	3. Model Calculates Value
Resting	2. Select Value		

**1. MODEL INPUT PARAMETERS**

Room Area	A	62.4	m <sup>2</sup>
Ceiling Height	h	5.64	m
Room Volume	V	352	m <sup>3</sup>
Air Exchange Rate	AER	0.2	hr <sup>-1</sup>
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	1.1	hr <sup>-1</sup>
Initial Quanta Concentration	n <sub>0</sub>	0.0E+0	quanta/m <sup>3</sup>
Total Time of Occupancy	t	60	minutes

**3. INFECTIOUS OCCUPANTS AT TIME ZERO**

Infectious Occupants	1	persons
Time of Exit	60	minutes

Heavy Exercise, Loudly Speaking ← Select

**4. INFECTIOUS OCCUPANT A**

Include in Model? No ← Select

**6. MODEL RESULTS**

Susceptible Occupant A

Modeled Exposure Time (minutes)	=	60
Probability of Infection (P <sub>i</sub> %)	=	40.0%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	1
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	6
Maximum Room Occupancy for R <sub>0</sub> < 1	=	1

Continuous Occupant

Modeled Exposure Time (minutes)	=	60
Probability of Infection (P <sub>i</sub> %)	=	40.0%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	1
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	6
Maximum Room Occupancy for R <sub>0</sub> < 1	=	1

**2. SUSCEPTIBLE OCCUPANT ACTIVITY LEVELS**

Susceptible Occupant A	Heavy Exercise	← Select
Continuous Occupant	Heavy Exercise	← Select

**5. SUSCEPTIBLE OCCUPANT A**

Time of Entry	0	minutes
Time of Exit	60	minutes

**Airborne Infection Risk Calculator v2.0** **AIRC** Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
 Transitional Exposure Conditions Technical support: amikszewski@cunybpl.org

60	1. Input Value	1.4	3. Model Calculates Value
Resting	2. Select Value		

**1. MODEL INPUT PARAMETERS**

Room Area	A	62.4	m <sup>2</sup>
Ceiling Height	h	5.64	m
Room Volume	V	352	m <sup>3</sup>
Air Exchange Rate	AER	0.2	hr <sup>-1</sup>
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	1.1	hr <sup>-1</sup>
Initial Quanta Concentration	n <sub>0</sub>	0.0E+0	quanta/m <sup>3</sup>
Total Time of Occupancy	t	150	minutes

**3. INFECTIOUS OCCUPANTS AT TIME ZERO**

Infectious Occupants	1	persons
Time of Exit	60	minutes

Heavy Exercise, Loudly Speaking ← Select

**4. INFECTIOUS OCCUPANT A**

Include in Model? No ← Select

**6. MODEL RESULTS**

Susceptible Occupant A

Modeled Exposure Time (minutes)	=	45
Probability of Infection (P <sub>i</sub> %)	=	18.4%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	1
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	0
Maximum Room Occupancy for R <sub>0</sub> < 1	=	1

Continuous Occupant

Modeled Exposure Time (minutes)	=	150
Probability of Infection (P <sub>i</sub> %)	=	68.2%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	1
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	6
Maximum Room Occupancy for R <sub>0</sub> < 1	=	1

**2. SUSCEPTIBLE OCCUPANT ACTIVITY LEVELS**

Susceptible Occupant A	Heavy Exercise	← Select
Continuous Occupant	Heavy Exercise	← Select

**5. SUSCEPTIBLE OCCUPANT A**

Time of Entry	105	minutes
Time of Exit	150	minutes

**Airborne Infection Risk Calculator v2.0** **AIRC** Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
 Transitional Exposure Conditions Technical support: amikszewski@cunybpl.org

60	1. Input Value	1.4	3. Model Calculates Value
Resting	2. Select Value		

**1. MODEL INPUT PARAMETERS**

Room Area	A	62.4	m <sup>2</sup>
Ceiling Height	h	5.64	m
Room Volume	V	352	m <sup>3</sup>
Air Exchange Rate	AER	0.2	hr <sup>-1</sup>
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	1.1	hr <sup>-1</sup>
Initial Quanta Concentration	n <sub>0</sub>	0.0E+0	quanta/m <sup>3</sup>
Total Time of Occupancy	t	195	minutes

**3. INFECTIOUS OCCUPANTS AT TIME ZERO**

Infectious Occupants	1	persons
Time of Exit	60	minutes

Heavy Exercise, Loudly Speaking ← Select

**4. INFECTIOUS OCCUPANT A**

Include in Model? No ← Select

**6. MODEL RESULTS**

Susceptible Occupant A

Modeled Exposure Time (minutes)	=	45
Probability of Infection (P <sub>i</sub> %)	=	8.7%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	1
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	2
Maximum Room Occupancy for R <sub>0</sub> < 1	=	3

Continuous Occupant

Modeled Exposure Time (minutes)	=	195
Probability of Infection (P <sub>i</sub> %)	=	70.9%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	1
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	6
Maximum Room Occupancy for R <sub>0</sub> < 1	=	1

**2. SUSCEPTIBLE OCCUPANT ACTIVITY LEVELS**

Susceptible Occupant A	Heavy Exercise	← Select
Continuous Occupant	Heavy Exercise	← Select

**5. SUSCEPTIBLE OCCUPANT A**

Time of Entry	150	minutes
Time of Exit	195	minutes

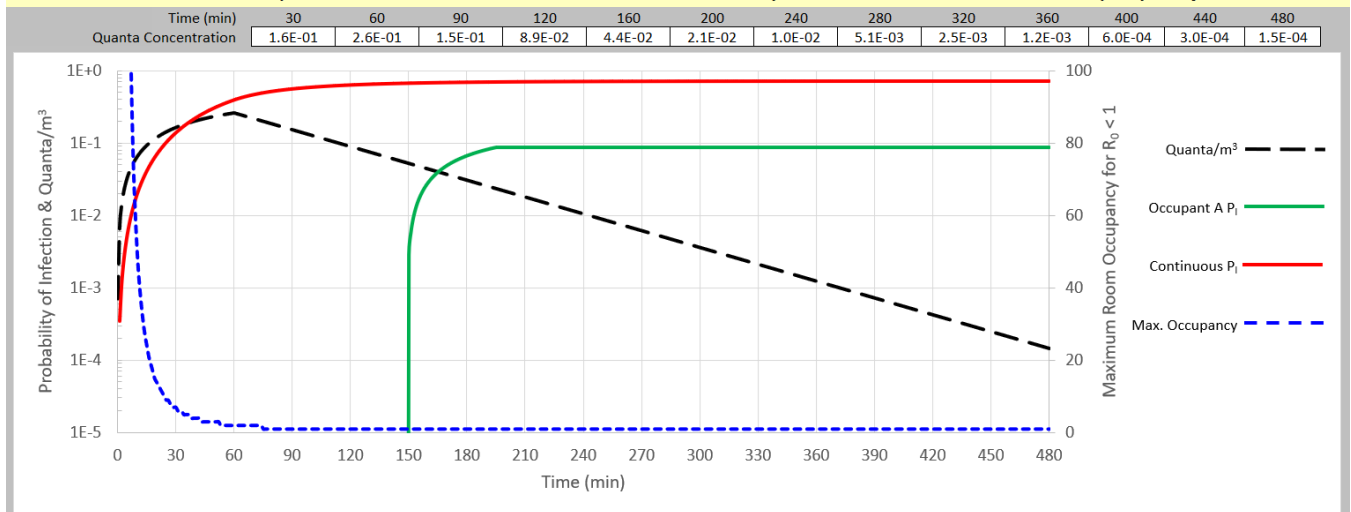
**Quanta Emission Rate (ER<sub>q</sub>) and Inhalation Rate (IR) Selection Summary for Transitional Exposure Conditions Model**

SARS-CoV-2 ER <sub>q</sub> Percentile Values (Quanta/hr)			Inhalation Rate		Selection Summary & Model Values			
Activity	66 <sup>th</sup>	90 <sup>th</sup>	Activity	IR (m <sup>3</sup> /hr)		Time Zero Infectious Occupants	Infectious Occupant A	
Resting, Oral Breathing	0.74	3.11	Resting	0.49	Selected Activity	<b>Heavy Exercise, Loudly Speaking</b>		
Resting, Speaking	3.46	14.6	Standing	0.54	66 <sup>th</sup> Percentile ER <sub>q</sub>	<b>149</b>		
Resting, Loudly Speaking	22.2	93.9	Light Exercise	1.38	90 <sup>th</sup> Percentile ER <sub>q</sub>	<b>628</b>		
Standing, Oral Breathing	0.85	3.57	Heavy Exercise	3.3				
Standing, Speaking	4.2	17.7	Custom IR #1	0.75				
Standing, Loudly Speaking	23.9	101	Custom IR #2	0.48	Selected Activity	<b>Heavy Exercise</b>	<b>Continuous Occupant</b>	
Light Exercise, Oral Breathing	2.1	8.76			IR (m <sup>3</sup> /hr)	<b>3.3</b>	<b>Heavy Exercise</b>	
Light Exercise, Speaking	9.9	41.8						
Light Exercise, Loudly Speaking	62.7	265						
Heavy Exercise, Oral Breathing	5.0	21						
Heavy Exercise, Speaking	23.2	97.9						
Heavy Exercise, Loudly Speaking	149	628						
Custom ER <sub>q</sub> #1	628	628						
Custom ER <sub>q</sub> #2	600	2000						

Notes:

- 1) This sheet presents the quanta emission and inhalation rate values used in the model based on the activity level selections made on the Input and Results tab.
- 2) The 66<sup>th</sup> percentile value for the selected activity is used for the probability of infection calculations. The 90<sup>th</sup> percentile value is used for the maximum occupancy calculations.
- 3) If you would like to input your own value for ER<sub>q</sub> or IR, enter your values in the Custom ER<sub>q</sub> or IR fields, and select Custom ER<sub>q</sub> or Custom IR from the drop-down lists on the Input and Results tab.

**Transitional Exposure Conditions Results: Quanta Concentration, Probability of Infection, and Maximum Room Occupancy for R<sub>0</sub> < 1**



**Discussion:** The model calculates probability of infection estimates of approximately 40% for the susceptible person who played with the index case from 0-60 minutes, 18% for susceptible persons who played a match in the same hall from 105-150 minutes, and 8.7% for the susceptible persons who played a match in the same hall from 150-195 minutes. These estimated attack rates were calculated using the 66<sup>th</sup> percentile value for a person speaking loudly while exercising heavily. Since they are lower than the remarkable 100% infection rate observed in this case study, if all infections were related to aerosol exposure in the shared squash hall it is likely that the index case was a so-called “supershedder” or “superspreader” whose emission rate represents a high percentile value. Indeed, if we use the 95<sup>th</sup> percentile value of the ER<sub>q</sub> distribution for heavy exercise, loudly speaking (1,150 quanta/hr), the probability of infection estimates increase to approximately 98%, 79%, and 50% for susceptible squash players in the three different matches. Alternatively, other pathways of transmission may have played a role beyond aerosol inhalation.

These results are consistent with the retrospective modeling presented in Buonanno et al. (2020b), which estimated emission values occurring in the 92<sup>nd</sup>-94<sup>th</sup> percentile range for the well-publicized COVID-19 superspreading events in the restaurant in Guangzhou and the choir rehearsal in Skagit Valley. Similarly, Bueno de Mesquita et al. (2020) re-evaluated the well-studied 1977 outbreak of influenza

A/H3 in a Boeing 737 airliner and found the estimated emission rate to be consistent with the 95<sup>th</sup> percentile value of measurements of RNA shed in exhaled breath fine aerosols by symptomatic influenza cases described in Yan et al. (2018). Lastly, in his paper presented at the Airborne Contagion conference held November 7-9, 1979 by the New York Academy of Sciences, Edward C. Riley noted that the often cited emission rate of approximately 5,600 quanta/hr for measles virus “would be expected only about one time in one hundred observations” (Riley, 1980). The user can explore how increasing the ventilation rate alone reduces the probability of infection for the squash example in both the average case and the case of the supershedder.

## 2. Seafood Market

**Scenario Description:** This example application is based on a modeling study presented in Zhang et al. (2020) that quantified the airborne transmission risk of SARS-CoV-2 during the initial phase of the outbreak at the South China Seafood Market in Wuhan, China in December 2019. A zone model of 650 m<sup>2</sup> by 5 m high dimension was used to represent Street No. 7 of the naturally ventilated market. A dose-response model by Monte Carlo simulation was used to estimate the risk of infection to consumers spending one hour in the market, and shopkeepers working 12-hour days in the market for the entire month of December. The model assumed one infected shopkeeper working inside Street No. 7 with a viral emission rate of 50 plaque-forming units (PFU)/hr. This emission rate corresponds to approximately 0.24 quanta/hr assuming 210 PFU/quanta as in Buonanno et al. (2020b), or the 40<sup>th</sup> percentile value of the resting, oral breathing activity level.

For the AIRC TEC representation of this model, an activity level of standing, oral breathing is selected for the infectious shopkeeper as it is likely that the shopkeeper would be standing for a significant fraction of the day and talking occasionally. Susceptible Occupant A is a consumer spending one hour in the market in the middle of the day at an activity level of light exercise due to the need to walk through the market. The continuous occupant of the market is a susceptible shopkeeper with an activity level of standing. An air exchange rate of 0.5 hr<sup>-1</sup> is assumed to reflect the natural ventilation of the market. The same parameters are used in the SEC version of the model with a maximum modeled exposure time of 360 hours (30 days at 12 hours/day) to reflect an entire month worked by the susceptible shopkeeper in the presence of a fellow shopkeeper infected with SARS-CoV-2.

### AIRC TEC Screenshots:

Airborne Infection Risk Calculator v2.0		AIRC		Mikszewski, Buonanno, Stabile, Pacitto, Morawska		60		1. Input Value		1.4		3. Model Calculates Value		
Transitional Exposure Conditions				Technical support: amikszewski@cunybpl.org				Resting		2. Select Value				
<b>1. MODEL INPUT PARAMETERS</b>														
Room Area	A	630	m <sup>2</sup>	<b>3. INFECTIOUS OCCUPANTS AT TIME ZERO</b>										
Ceiling Height	h	5	m	Infectious Occupants	1	persons								
Room Volume	V	3,150	m <sup>3</sup>	Time of Exit	480	minutes								
Air Exchange Rate	AER	0.5	hr <sup>-1</sup>	Standing, Oral Breathing			← Select							
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>	<b>4. INFECTIOUS OCCUPANT A</b>										
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>	Include in Model?	No	← Select								
Total Viral Removal Rate	IVRR	1.4	hr <sup>-1</sup>	<b>5. SUSCEPTIBLE OCCUPANT A</b>										
Initial Quanta Concentration	n <sub>0</sub>	0.0E+0	quanta/m <sup>3</sup>	Time of Entry	210	minutes								
Total Time of Occupancy	t	480	minutes	Time of Exit	270	minutes								
<b>2. SUSCEPTIBLE OCCUPANT ACTIVITY LEVELS</b>														
Susceptible Occupant A	Light Exercise		← Select											
Continuous Occupant	Standing		← Select											
<b>6. MODEL RESULTS</b>														
<b>Susceptible Occupant A</b>														
Modeled Exposure Time (minutes) =										60				
Probability of Infection (P, %) =										0.028%				
Exposure Time for 0.1% P <sub>i</sub> (minutes) =										>60				
Exposure Time for 1.0% P <sub>i</sub> (minutes) =										>60				
Maximum Room Occupancy for R <sub>0</sub> < 1 =										866				
<b>Continuous Occupant</b>														
Modeled Exposure Time (minutes) =										480				
Probability of Infection (P, %) =										0.077%				
Exposure Time for 0.1% P <sub>i</sub> (minutes) =										>480				
Exposure Time for 1.0% P <sub>i</sub> (minutes) =										>480				
Maximum Room Occupancy for R <sub>0</sub> < 1 =										308				

**Quanta Emission Rate (ER<sub>q</sub>) and Inhalation Rate (IR) Selection Summary for Transitional Exposure Conditions Model**

SARS-CoV-2 ER <sub>q</sub> Percentile Values (Quanta/hr)			Inhalation Rate		Selection Summary & Model Values			
Activity	66 <sup>th</sup>	90 <sup>th</sup>	Activity	IR (m <sup>3</sup> /hr)	Time Zero Infectious Occupants		Infectious Occupant A	
Resting, Oral Breathing	0.74	3.11	Resting	0.49	Selected Activity	Standing, Oral Breathing		
Resting, Speaking	3.46	14.6	Standing	0.54	66 <sup>th</sup> Percentile ER <sub>q</sub>	0.85		
Resting, Loudly Speaking	22.2	93.9	Light Exercise	1.38	90 <sup>th</sup> Percentile ER <sub>q</sub>	3.57		
Standing, Oral Breathing	0.85	3.57	Heavy Exercise	3.3				
Standing, Speaking	4.2	17.7	Custom IR #1	0.75				
Standing, Loudly Speaking	23.9	101	Custom IR #2	0.48	Selected Activity	Light Exercise		Continuous Occupant
Light Exercise, Oral Breathing	2.1	8.76			IR (m <sup>3</sup> /hr)	1.38		Standing
Light Exercise, Speaking	9.9	41.8						
Light Exercise, Loudly Speaking	62.7	265						
Heavy Exercise, Oral Breathing	5.0	21						
Heavy Exercise, Speaking	23.2	97.9						
Heavy Exercise, Loudly Speaking	149	628						
Custom ER <sub>q</sub> #1	0.24	1.0						
Custom ER <sub>q</sub> #2	600	2000						

Notes:

- 1) This sheet presents the quanta emission and inhalation rate values used in the model based on the activity level selections made on the Input and Results tab.
- 2) The 66<sup>th</sup> percentile value for the selected activity is used for the probability of infection calculations. The 90<sup>th</sup> percentile value is used for the maximum occupancy calculations.
- 3) If you would like to input your own value for ER<sub>q</sub> or IR, enter your values in the Custom ER<sub>q</sub> or IR fields, and select Custom ER<sub>q</sub> or Custom IR from the drop-down lists on the Input and Results tab.

**AIRC SEC Screenshots:**

**Airborne Infection Risk Calculator v2.0**  
Stationary Exposure Conditions

**AIRC**

Mikszewski, Buonanno, Stabile, Pacitto, Morawska  
Technical support: amikszewski@cunybl.org

60 1. Input Value 1.4 3. Model Calculates Value  
Resting 2. Select Value

---

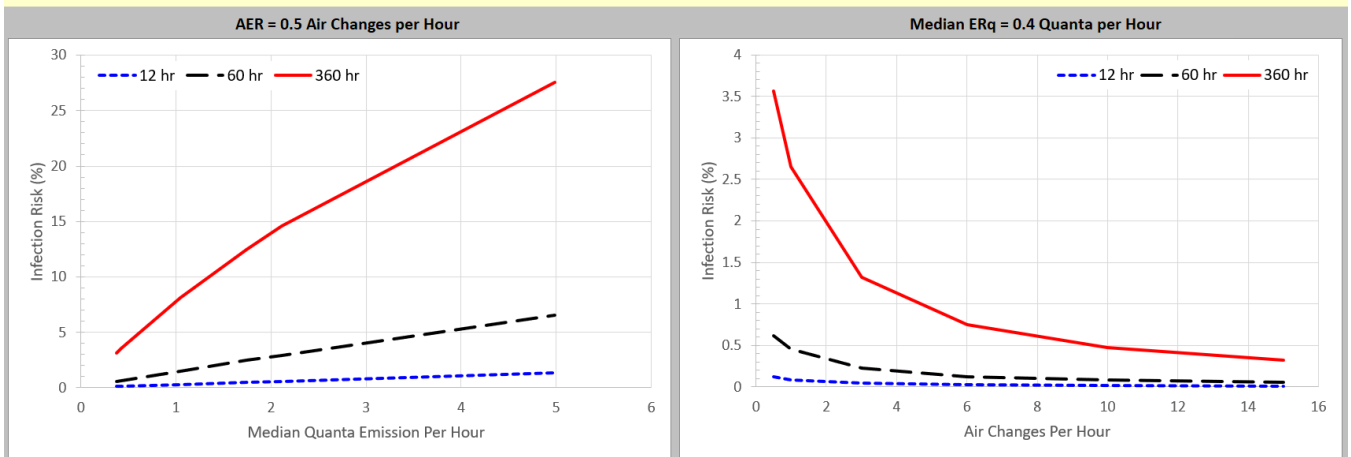
**1. MODEL INPUT PARAMETERS**

Room Area	A	630	m <sup>2</sup>
Ceiling Height	h	5	m
Room Volume	V	3,150	m <sup>3</sup>
Air Exchange Rate	AER	0.50	hr <sup>-1</sup>
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	1.37	hr <sup>-1</sup>
Number of Infectious Occupants	I	1	persons
Exposure Time #1	t <sub>1</sub>	12	hr
Exposure Time #2	t <sub>2</sub>	60	hr
Exposure Time #3	t <sub>3</sub>	360	hr
Susceptible Inhalation Rate	IR	0.54	m <sup>3</sup> /hr
Susceptible Activity Level		Standing	Select

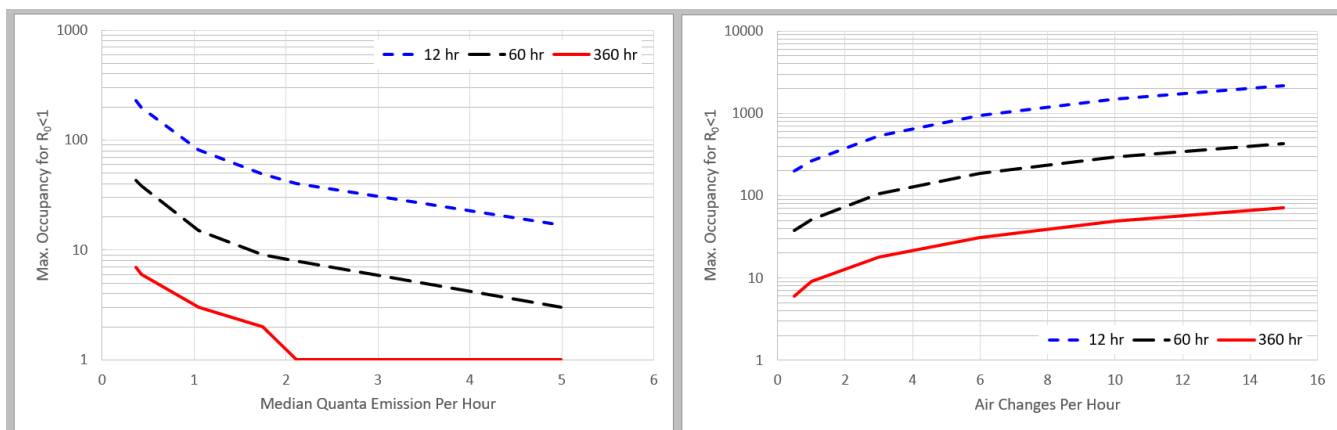
**2. MODEL RESULTS**

Select Infectious Occupant Activities From List Below	Median ER <sub>q</sub>	Infection Risk (%)			Max. Occupancy for R <sub>0</sub> < 1			
		12 hr	60 hr	360 hr	12 hr	60 hr	360 hr	
1. Light Exercise, Speaking	5.0	1.4%	6.5%	28%	17	3	1	
2. Standing, Speaking	2.1	0.58%	2.9%	15%	40	8	1	
3. Resting, Speaking	1.7	0.48%	2.5%	12%	49	9	2	
4. Light Exercise, Oral Breathing	1.0	0.29%	1.5%	8.1%	81	15	3	
5. Resting, Oral Breathing	0.37	0.10%	0.54%	3.1%	228	43	7	
6. Standing, Oral Breathing	0.43	0.12%	0.62%	3.6%	199	38	6	
AER Sensitivity Analysis for Emission Rate #6		1	0.089%	0.46%	2.7%	266	51	9
Enter AER Values in hr <sup>-1</sup>		3	0.044%	0.22%	1.3%	538	106	18
		6	0.025%	0.13%	0.75%	947	188	31
		10	0.016%	0.080%	0.48%	1491	296	49
		15	0.011%	0.055%	0.33%	2172	433	72

**Infection Risk & Occupancy Graphs for Stationary Exposure Conditions Model, Activity Level #6: Standing, Oral Breathing**







**Discussion:** The TEC model results indicate a probability of infection of 0.028% for the susceptible consumer with a one-hour exposure in the market, and the SEC model results indicate an infection risk of 3.6% for the shopkeeper working the entire month. Zhang et al. (2020) estimated the median risks for these exposures to be 0.00223% and 0.976%, respectively. The approximate order of magnitude higher AIRC estimate for the one-hour exposure is due to the higher quanta emission rate and higher inhalation rate of the susceptible consumer. If the  $ER_q$  is reduced to 0.24 quanta/hr and the inhalation rate for the susceptible consumer is reduced to  $0.6 \text{ m}^3/\text{hr}$  as modeled by Zhang et al. (2020), the AIRC probability of infection estimate is reduced to 0.0034% for the consumer, showing general consistency between the two models. We note that the Zhang et al. (2020) zone model used a significantly lower inactivation rate corresponding to a half-life of 12 hours; however, this is offset by a more complex multi-surface particle deposition rate approach.

In terms of a threshold value for acceptable risk, Zhang et al. (2020) adopts the available hospital bed capacity for COVID-19 treatment per capita in Wuhan ( $1.17 \times 10^{-3}$ , or 0.117%). Using the activity level of standing, oral breathing, an air exchange rate of  $6 \text{ hr}^{-1}$  would be needed to reduce the shopkeeper's infection risk to approximately this threshold level (0.13%) over a 60-hour workweek. If an activity level of standing and speaking is assumed for the infectious shopkeeper, which is reasonable considering some level of customer interaction occurs, the exposure of a susceptible shopkeeper would exceed this risk threshold within approximately three hours in the naturally ventilated market.

### 3. Abattoir 2.0

**Scenario Description:** This example application is based on a retrospective analysis of the superspreading event that preceded the largest SARS-CoV-2 outbreak in any German abattoir, presented in Gunther et al. (2020). The index case worked three shifts while being infected, resulting in transmission to 20 of 78 fellow workers in the same "proximal" work area of  $360 \text{ m}^2$  by 6.1 m high (25.6% attack rate). There was clear a spatial correlation to the pattern of infection, with workers stationed within 8 m of the index case experiencing an attack rate of 66%. Gunther et al. (2020) reports that cooling air was recirculated through localized ceiling-mounted fans without filtration, and the air exchange rate for the entire processing plant was less than 1 air change per hour.

This scenario is evaluated using AIRC SEC as the exposure time is long (24 hours, or three 8 hour shifts), and the index case and workers can be assumed to have a relatively consistent activity for the hours worked, and therefore relatively constant emission and inhalation rates. The model is evaluated using

both the larger shared workspace of 360 m<sup>2</sup>, as well as within the smaller 8 m separation distance where ceiling recirculating fans may have created a local airflow mixing zone. The air exchange rate is assumed to be 0.5 hr<sup>-1</sup>, and the susceptible workers are assumed to breath at a light activity level.

**AIRC SEC Screenshots:**

**Airborne Infection Risk Calculator v2.0** **AIRC** *Mikszewski, Buonanno, Stabile, Pacitto, Morawska* *Technical support: amikszewski@cunybpl.org*  1. Input Value  3. Model Calculates Value  
 Resting 2. Select Value

**Stationary Exposure Conditions**

**1. MODEL INPUT PARAMETERS**

Room Area	A	360	m <sup>2</sup>
Ceiling Height	h	6.1	m
Room Volume	V	2,196	m <sup>3</sup>
Air Exchange Rate	AER	0.50	hr <sup>-1</sup>
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	1.37	hr <sup>-1</sup>
Number of Infectious Occupants	I	1	persons
Exposure Time #1	t <sub>1</sub>	8	hr
Exposure Time #2	t <sub>2</sub>	16	hr
Exposure Time #3	t <sub>3</sub>	24	hr
Susceptible Inhalation Rate	IR	1.38	m <sup>3</sup> /hr
Susceptible Activity Level		Light Exercise	Select

Select Infectious Occupant Median  
 Activities From List Below ER<sub>q</sub>

1.	Light Exercise, Oral Breathing	1.0	0.68%	1.4%	2.1%	34	16	11
2.	Heavy Exercise, Oral Breathing	2.5	1.6%	3.3%	4.9%	14	7	4
3.	Light Exercise, Speaking	5.0	3.1%	6.2%	9.0%	7	3	2
4.	Heavy Exercise, Speaking	11.7	6.8%	13%	18%	3	2	1
5.	Standing, Loudly Speaking	12.1	7.0%	13%	19%	3	1	1
6.	Light Exercise, Loudly Speaking	31.6	16%	27%	36%	1	1	1

AER Sensitivity Analysis for Emission Rate #6

1	13%	22%	30%	2	1	1
3	7.0%	13%	18%	3	2	1
6	4.2%	7.9%	11%	5	3	2
10	2.7%	5.2%	7.6%	8	4	3
15	1.9%	3.7%	5.4%	12	6	4

Enter AER Values in hr<sup>-1</sup>

**2. MODEL RESULTS**

Infection Risk (%)			Max. Occupancy for R <sub>0</sub> < 1		
8 hr	16 hr	24 hr	8 hr	16 hr	24 hr
0.68%	1.4%	2.1%	34	16	11
1.6%	3.3%	4.9%	14	7	4
3.1%	6.2%	9.0%	7	3	2
6.8%	13%	18%	3	2	1
7.0%	13%	19%	3	1	1
16%	27%	36%	1	1	1
13%	22%	30%	2	1	1
7.0%	13%	18%	3	2	1
4.2%	7.9%	11%	5	3	2
2.7%	5.2%	7.6%	8	4	3
1.9%	3.7%	5.4%	12	6	4

**Airborne Infection Risk Calculator v2.0** **AIRC** *Mikszewski, Buonanno, Stabile, Pacitto, Morawska* *Technical support: amikszewski@cunybpl.org*  1. Input Value  3. Model Calculates Value  
 Resting 2. Select Value

**Stationary Exposure Conditions**

**1. MODEL INPUT PARAMETERS**

Room Area	A	64	m <sup>2</sup>
Ceiling Height	h	6.1	m
Room Volume	V	390	m <sup>3</sup>
Air Exchange Rate	AER	0.50	hr <sup>-1</sup>
Particle Deposition Rate	k	0.24	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.63	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	1.37	hr <sup>-1</sup>
Number of Infectious Occupants	I	1	persons
Exposure Time #1	t <sub>1</sub>	8	hr
Exposure Time #2	t <sub>2</sub>	16	hr
Exposure Time #3	t <sub>3</sub>	24	hr
Susceptible Inhalation Rate	IR	1.38	m <sup>3</sup> /hr
Susceptible Activity Level		Light Exercise	Select

Select Infectious Occupant Median  
 Activities From List Below ER<sub>q</sub>

1.	Light Exercise, Oral Breathing	1.0	3.6%	7.2%	10%	6	3	2
2.	Heavy Exercise, Oral Breathing	2.5	8.1%	15%	21%	3	1	1
3.	Light Exercise, Speaking	5.0	14%	25%	33%	1	1	1
4.	Heavy Exercise, Speaking	11.7	27%	43%	53%	1	1	1
5.	Standing, Loudly Speaking	12.1	28%	43%	54%	1	1	1
6.	Light Exercise, Loudly Speaking	31.6	49%	66%	76%	1	1	1

AER Sensitivity Analysis for Emission Rate #6

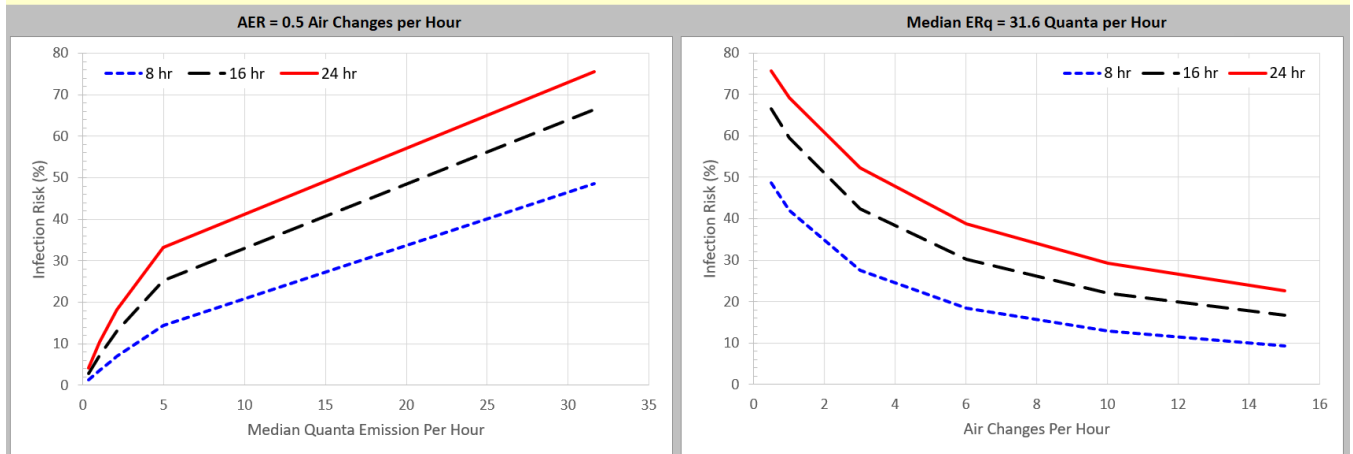
1	42%	59%	69%	1	1	1
3	28%	42%	52%	1	1	1
6	18%	30%	39%	1	1	1
10	13%	22%	29%	2	1	1
15	9.4%	17%	23%	2	1	1

Enter AER Values in hr<sup>-1</sup>

**2. MODEL RESULTS**

Infection Risk (%)			Max. Occupancy for R <sub>0</sub> < 1		
8 hr	16 hr	24 hr	8 hr	16 hr	24 hr
3.6%	7.2%	10%	6	3	2
8.1%	15%	21%	3	1	1
14%	25%	33%	1	1	1
27%	43%	53%	1	1	1
28%	43%	54%	1	1	1
49%	66%	76%	1	1	1
42%	59%	69%	1	1	1
28%	42%	52%	1	1	1
18%	30%	39%	1	1	1
13%	22%	29%	2	1	1
9.4%	17%	23%	2	1	1

**Infection Risk & Occupancy Graphs for Stationary Exposure Conditions Model, Activity Level #6: Light Exercise, Loudly Speaking**





Discussion: The model results indicate the documented attack rate of 25.6% for the larger 360 m<sup>2</sup> “proximal” work area, and 66% for the smaller 64 m<sup>2</sup> work area, corresponds to a quanta emission rate between the infectious activity levels of standing, loudly speaking and light exercise, loudly speaking for a 24-hour exposure. As the median ER<sub>q</sub> for these activities are 12.1 and 31.6 quanta/hr, respectively, this analysis shows that extreme value emission rates are not needed to cause major outbreak events where ventilation is poor, exposure periods are long, and activity levels are high. This example also illustrates that while susceptible workers closer to the index case had a higher attack rate, the model produces representative results regardless of whether the larger or smaller room volume is used. The completely mixed air assumption appears reasonable for this case. However, the AER sensitivity analysis shows that the size of the exposure area has a significant impact on the necessary virus removal rate to mitigate local infection risk. For the smaller modeled work area an AER of 15 hr<sup>-1</sup> is insufficient to reduce infection risk below 1% for an 8-hour shift. This indicates an advanced ventilation system for infection control and/or additional in-room disinfection may be needed for these types of exposures, in addition to proper personal protective equipment for workers.

#### 4. Hospital Waiting Area

Scenario Description & Discussion: This example is an AIRC reproduction of a modeling scenario presented in Beggs et al. (2010) to evaluate the risk of airborne infection in a hypothetical 132 m<sup>3</sup> hospital waiting area in the presence of one infectious occupant. This example demonstrates the utility of the ER<sub>q</sub> sensitivity analysis feature of AIRC and compares AIRC output to a similar Gammaitoni-Nucci equation application in literature. As Beggs et al. (2010) conducted a Monte Carlo simulation to evaluate the probability of infection for tuberculosis, measles, and influenza, the AIRC results are compared to the mean probability values calculated in the study for 30 minutes and 60 minutes of exposure. A comparison of AIRC output and Beggs et al. (2010) results is presented in Table 3, below, and shows strong agreement. Minor differences are potentially due to the slightly different inhalation rate, the integration approach, time step differences, and/or rounding, and are largest for measles. Input parameters are shown in the screenshots that follow.

**Table 3: Comparison of Calculated Probability of Infection, AIRC vs. Beggs et al. (2010)**

Disease	30-Minute Waiting Room Exposure		60-Minute Waiting Room Exposure	
	AIRC Probability of Infection	Beggs et al. (2010) Mean Probability of Infection	AIRC Probability of Infection	Beggs et al. (2010) Mean Probability of Infection
Tuberculosis (ER <sub>q</sub> #4)	0.34 %	0.34 %	0.89 %	0.87 %
Influenza (ER <sub>q</sub> #3)	2.66 %	2.62 %	6.83 %	6.62 %
Measles (ER <sub>q</sub> #2)	14.3 %	13.5 %	33.2 %	30.9 %

AIRC TEC Screenshots (on following page):

**1. MODEL INPUT PARAMETERS**

Room Area	A	48	m <sup>2</sup>
Ceiling Height	h	2.75	m
Room Volume	V	132	m <sup>3</sup>
Air Exchange Rate	AER	4.0	hr <sup>-1</sup>
Particle Deposition Rate	k	0.00	hr <sup>-1</sup>
Viral Inactivation Rate	λ	0.00	hr <sup>-1</sup>
Total Viral Removal Rate	IVRR	4.0	hr <sup>-1</sup>
Initial Quanta Concentration	n <sub>0</sub>	0.0E+0	quanta/m <sup>3</sup>
Total Time of Occupancy	t	60	minutes

**3. INFECTIOUS OCCUPANTS AT TIME ZERO**

Infectious Occupants	1	persons
Time of Exit	30	minutes
Resting, Speaking		← Select

**4. INFECTIOUS OCCUPANT A**

Include in Model?	Yes	← Select
Time of Entry	30	minutes
Time of Exit	60	minutes
Resting, Speaking		← Select

**2. SUSCEPTIBLE OCCUPANT ACTIVITY LEVELS**

Susceptible Occupant A	Resting	← Select
Continuous Occupant	Resting	← Select

**5. SUSCEPTIBLE OCCUPANT A**

Time of Entry	0	minutes
Time of Exit	30	minutes

**6. MODEL RESULTS**

**Susceptible Occupant A**

Modeled Exposure Time (minutes)	=	30
Probability of Infection (P <sub>i</sub> %)	=	0.09%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	>30
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	>30
Maximum Room Occupancy for R <sub>0</sub> < 1	=	254

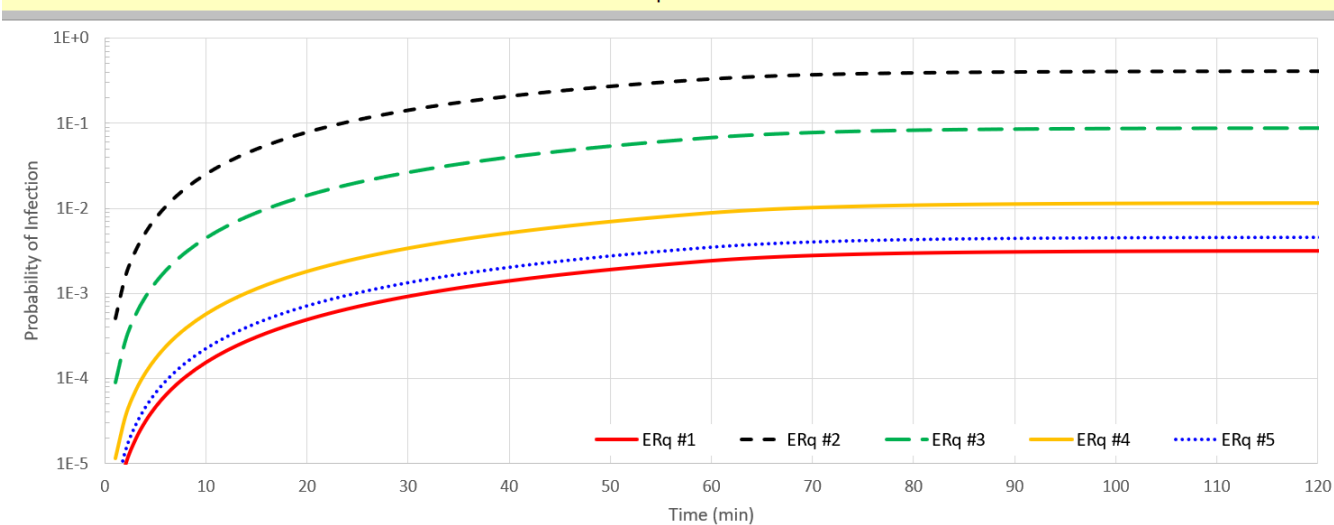
**Continuous Occupant**

Modeled Exposure Time (minutes)	=	60
Probability of Infection (P <sub>i</sub> %)	=	0.24%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	=	31
Exposure Time for 1.0% P <sub>i</sub> (minutes)	=	>60
Maximum Room Occupancy for R <sub>0</sub> < 1	=	97

**Quanta Emission Rate (ER<sub>q</sub>) Sensitivity Analysis for Transitional Exposure Conditions Model**

	ERq #1	ERq #2	ERq #3	ERq #4	ERq #5
Time Zero Infectious Occupants ER <sub>q</sub> (Quanta/hr)	3.46	570	100	12.7	5.0
Infectious Occupant A ER <sub>q</sub> (Quanta/hr)	3.46	570	100	12.7	5.0
<b>Susceptible Occupant A</b>					
Modeled Exposure Time (minutes) = 30					
Probability of Infection (P <sub>i</sub> %)	0.09%	14.3%	2.66%	0.34%	0.13%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	>30	1	4	13	24
Exposure Time for 1.0% P <sub>i</sub> (minutes)	>30	5	16	>30	>30
<b>Continuous Occupant</b>					
Modeled Exposure Time (minutes) = 60					
Probability of Infection (P <sub>i</sub> %)	0.24%	33.2%	6.83%	0.89%	0.35%
Exposure Time for 0.1% P <sub>i</sub> (minutes)	31	1	4	13	24
Exposure Time for 1.0% P <sub>i</sub> (minutes)	>60	5	16	67	>60

**Transitional Exposure Conditions ER<sub>q</sub> Sensitivity Analysis for Continuous Occupant**



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