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Risk Modelling for ASHRAE 241

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Acknowledgements

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Marwa Zaatari
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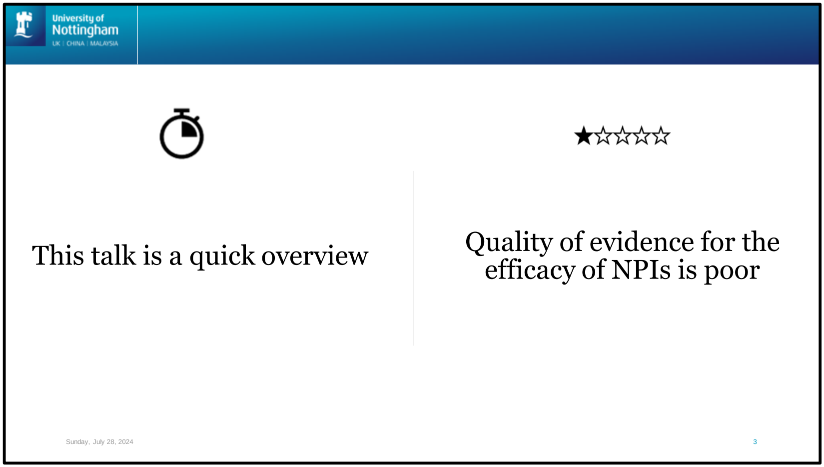
Richard Bruns
Johns Hopkins

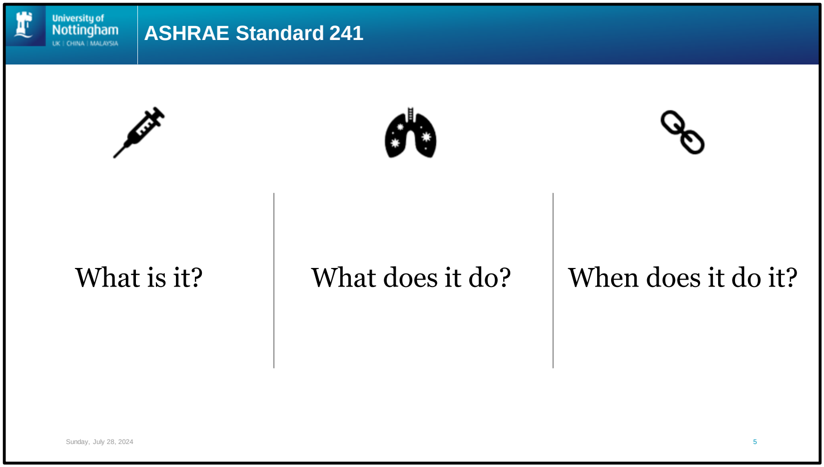


Royal Society review on NPI categorised evidence from very-low to high.
When looking at Environmental measures, such as ventilation and air-cleaners, 14,000 papers -> 19 (peer reviewed articles)
12 on ventilation
4 on air cleaning
5 on surface disinfection
1 on barriers
All are LOW CONFIDENCE because there are lots of confounding issues.

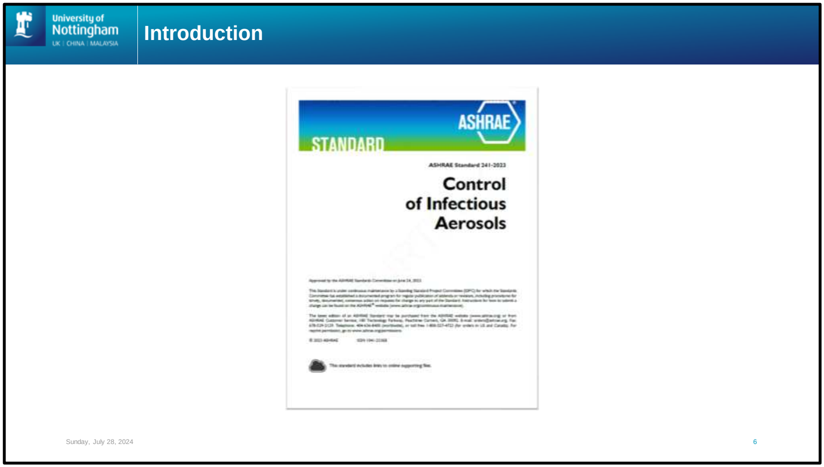
Far-field exposure where there is some distance between infected and susceptible people

Relationships between concentration, dose, and the removal mechanisms

Equivalent clean air per person



1. A standard to Control infectious Aerosols in buildings
2. The standard establishes minimum equivalent clean airflow rates per person needed to reduce the risk of long-rage airborne disease transmission indoors.
3. During periods of high infection risk. The standard does not define when infection risk is high. But, when deemed *high enough* by authorities or building users, then the building is run in **Infection Risk Management Mode**, in accordance with 241.

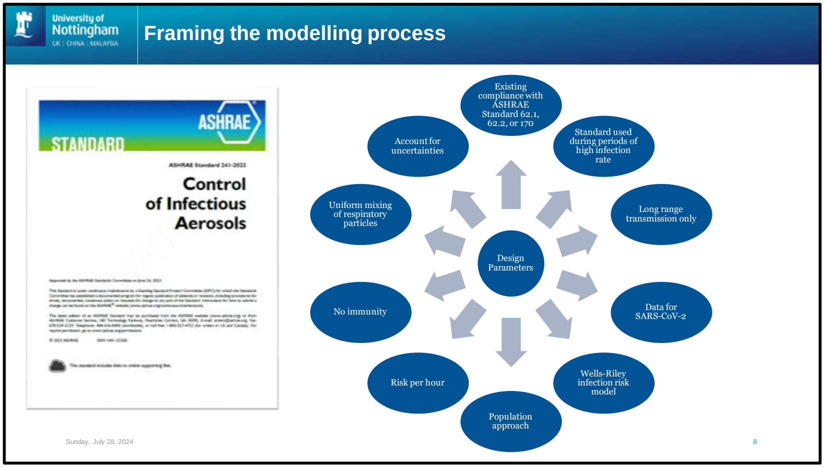


The first publication of its kind anywhere in the world.
Standards normally developed using the ANSI consensus process, which is designed to balance the interests of all materially affected parties.
It involves multiple time-consuming public reviews that stretch the length of the development period of several years.
Requested by the White House COVID-19 Response Team, who asked that is be developed in only a few months to coincide with the ending of emergency restrictions.
ANSI requirements waived, although the project committee met ASNI balance requirements as the standard underwent an advisory public review.

>1000 comments.
Final draft completed in 108 days. Only 6 months to get ASHRAE board authorisation.
Standing Standard Project Committee comprised 48 people divided into groups.
One focussed on infection risk modelling, led by Marwa Zaatari and me.

Modelling approach

Section 2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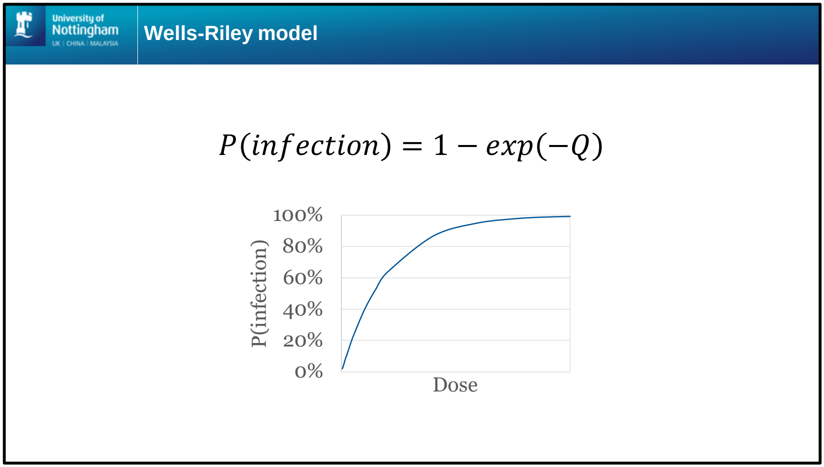
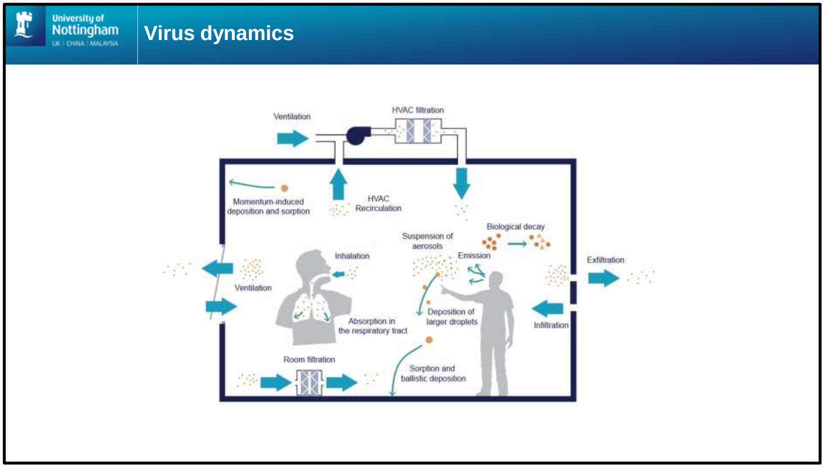
Framing the modelling process
ASHRAE
STANDARD
ASHRAE Standard 241-2023
Control of Infectious Aerosols
Existing compliance with ASHRAE Standard 62.1, 62.2, or 170
Standard used during periods of high infection rate
Long range transmission only
Data for SARS-CoV-2
Wells-Riley infection risk model
Population approach
Risk per hour
No immunity
Uniform mixing of respiratory particles
Account for uncertainties
Design Parameters
Sunday, July 28, 2024
8



Information contained in the exponent is obtained from an outbreak.



Biological decay, deposition, ventilation, filtration.
Assumes transmission is by far-field (impossible to determine).
Don’t know the number of index cases.
As we will show it doesn’t account for changes in virus dynamics, and inter-personal emission and immunity differences, breathing rates.

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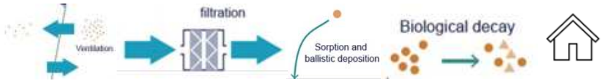
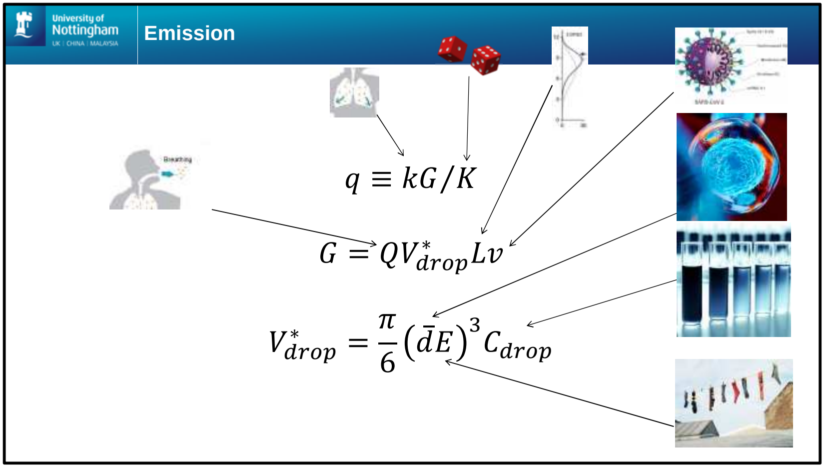
Terms

Next slide

$$Q = \frac{-PBR.D.(1-\mu^2)\sum_{i=1}^{I_0} QER_i}{\phi.VOL}$$



Breathing rate: varies by a factor of 6 depending on the activity. We use one for sitting male occupants LN(0.56,0.056)
Duration: 1 hour
Quanta emission: expand on in a moment
Sigma_Volume: considered an equivalent ventilation rate. When the ventilation component is converted to a per capita airflow rate, then it is the equivalent



K: probability that a single virion initiates an infection. Known for SARS1

k: respiratory tract absorption 0.43-0.63

G: emission of viable virions

Q: breathing rate of the infector (already covered)

L: load of viral genomic material in the respiratory fluid (MORE LATER!)

v: viable fraction 1 in 100 to 10,000 (shown up to 10^6)

V_{drop}*: ratio of total volume expelled aerosols (respiratory fluid) in $1m^3$ of exhaled air

d: mean droplet diameter Breathing:Talking 75:25 Marowska LN(1.91,0.191)e(-6)

E: evaporation coefficient. Diameter likely to be smaller when measured than when released so thought to reduce 2-5 fold

C_{drop}: aerosols per unit volume of exhaled air Marowska LN(1.54,0.15)e5

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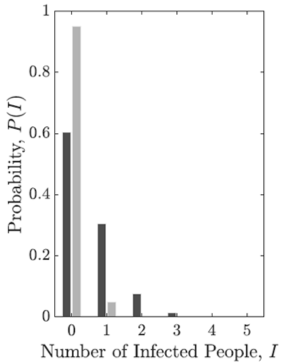
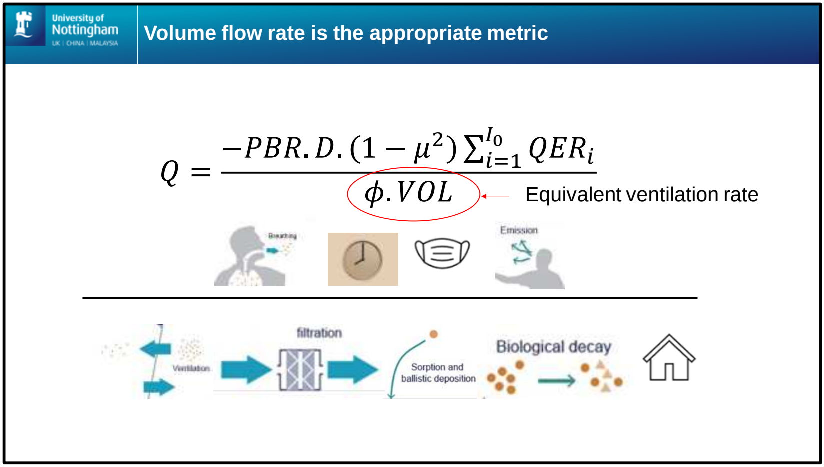
Number of infected people



5-person space

50-person space

1% Community Infection Rate



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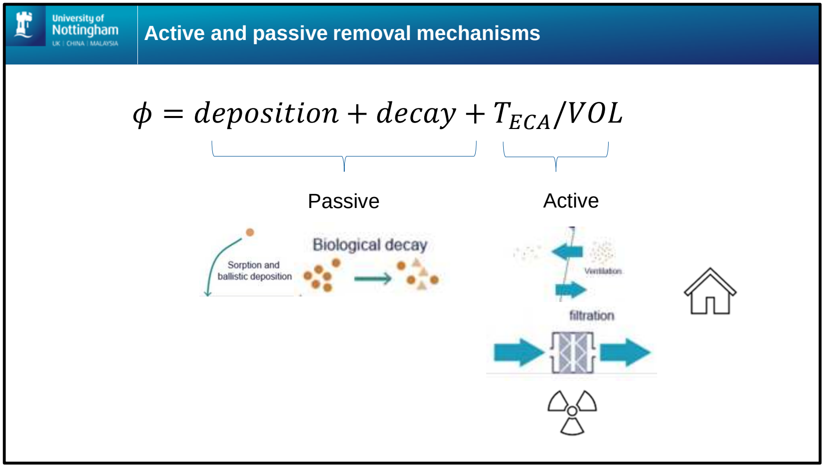

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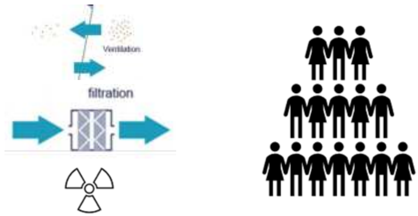
Equivalent clean air per person

$$ECA_i = T_{ECA}/I_0$$



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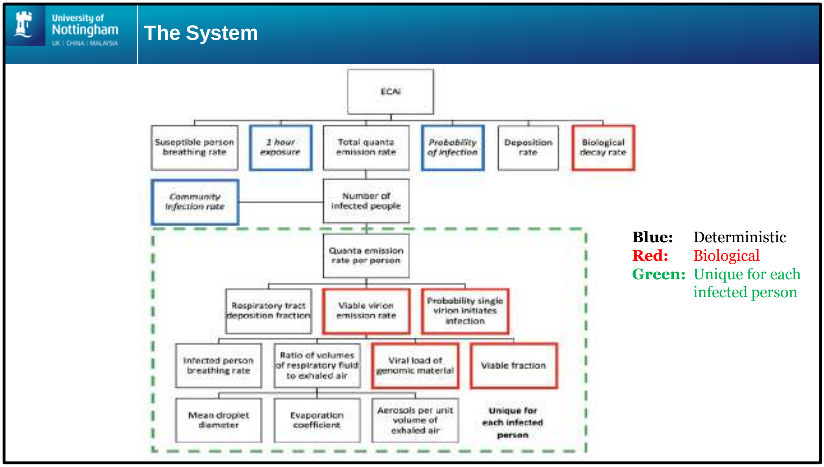
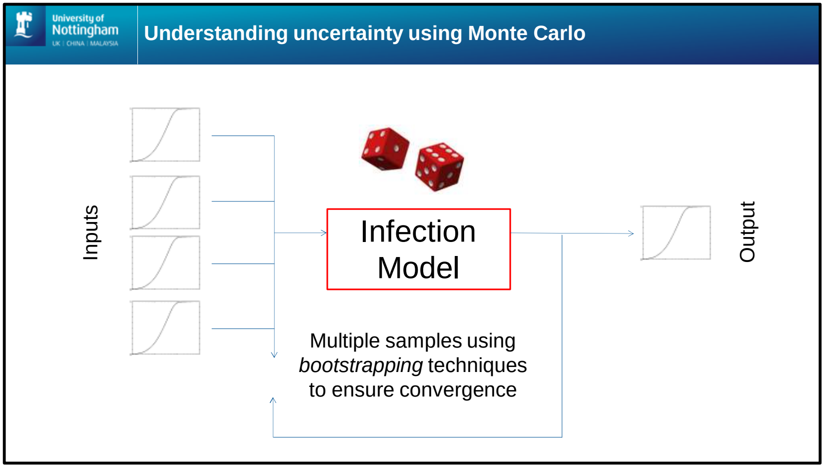


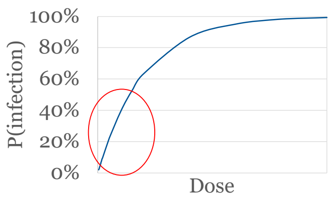
Assume 1 infected person because it makes the analysis easier, although for a 1% CIR P(0)=60% 0 infectors P(1)=30%.



OUTPUTS
Concentrations, exposure, dose

Relative Risk

$$RR = \frac{P(infection)_{before}}{P(infection)_{after}} = \frac{Q_{before}}{Q_{after}} = \frac{\phi_{before} \cdot I_{0\,after}}{\phi_{after} \cdot I_{0\,before}}$$



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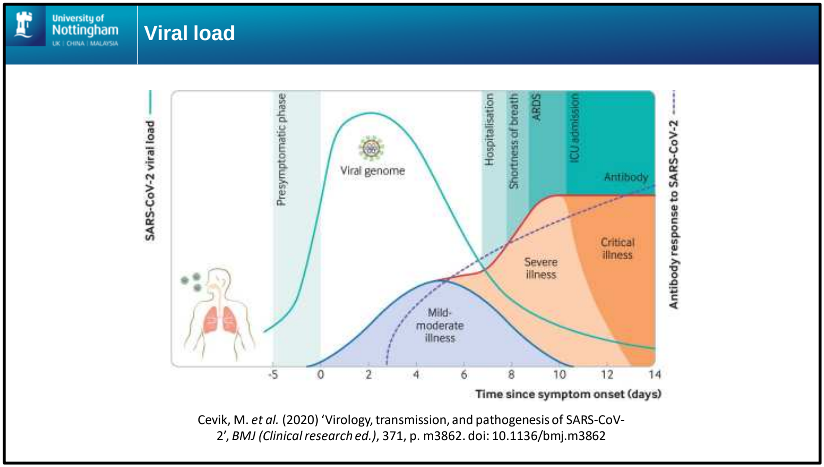
Clinical Data

Section 3



Viral load changes over the course of the disease, and varies from person to person. By several orders of magnitude

Viral load and emission rate

More pea….

…than planet.

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UK infection surveys

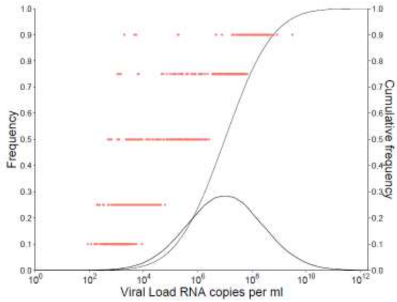


Figure 1: Frequency distribution of SARS-CoV-2 genomic viral load in RNA copies per ml modelled using the assumptions of Chen *et al.*, black line. Superimposed red dots are the weekly 10th, 25th, 50th, 75th and 90th percentile viral loads of SARS-CoV-2 PCR positive cases from the ONS infection survey from April 27th 2020 to February 27th 2023.

Human challenge study

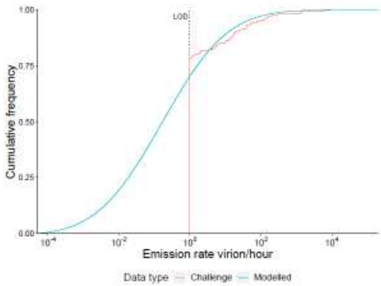


Figure 3: Frequency distributions of the estimated viable virion h^{-1} from the human challenge study [13] compared with the modelled emission rates in viable virion h^{-1} for a respiratory activity ratio of 75:25 breathing to talking using the inputs given in Table 1.

G-II

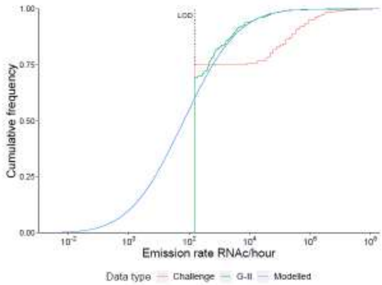
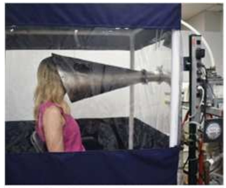


Figure 4: Frequency distribution of emission rates in RNA copies h^{-1} of an infected person. Here the modelled data is for a 75:25 breathing:speaking respiratory activity emitter calculated as described in Table 1. The G-II data type is the combined data from all G-II studies [32, 34, 33, 31] described in Section 2.2 and Challenge is the estimated RNA copies h^{-1} from the human challenge study [13] described in Section 2.3. Dotted line denotes the LOD for G-II RT-qPCR and thus represent all emission rates between 0 and 150 RNA copies h^{-1}.



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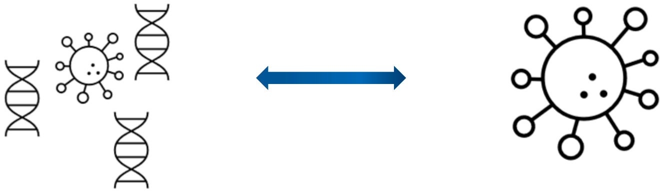
RNA and viability



Between 1:100 and 1:10,000 RNA copies are viable virions that can cause an infection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Setting ECA_i
Section 4

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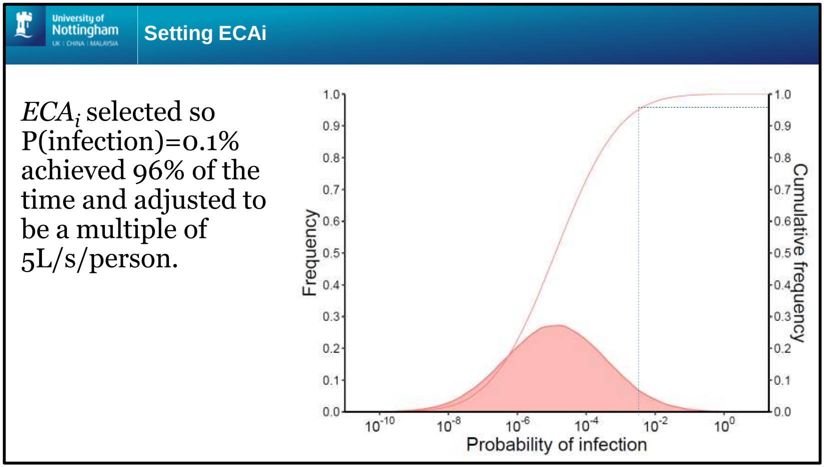
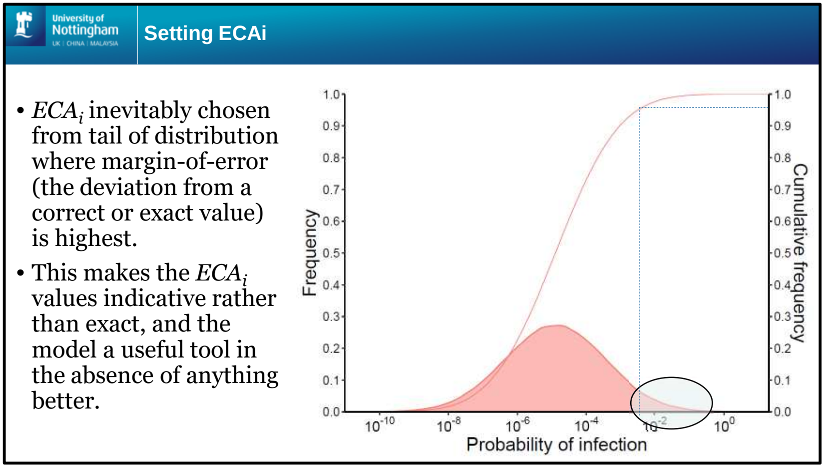
Occupancy Categories

Occupancy Category	Floor area, (m^2)	Space volume, VOL (m^3)	Default occupancy density, (people per 100 m^2)	Maximum occupants, I_0	Probability susceptible people present	People outdoor airflow rate ($L\,s^{-1}$ per person)	Area outdoor airflow rate ($L\,s^{-1}\,m^2$)
Correctional Facilities							
Cell	120	320	25	30	0.25	2.5	0.6
Dayroom	100	600	30	30	0.25	2.5	0.3
Commercial/Retail							
Food and beverage facilities	100	360	50	50	0.38	3.8	0.9
Gym	500	1900	36	180	0.83	10	0.3
Office	1000	2700	5.0	50	0.38	2.5	0.3
Retail	1000	6000	15	150	0.77	3.8	0.6
Transportation waiting	1000	10000	10	100	0.62	3.8	0.3
Educational Facilities							
Classroom	120	320	25	30	0.25	5.0	0.6
Lecture hall	200	1800	75	150	0.77	2.5	0.3
Industrial							
Manufacturing	1000	12000	7.0	70	0.50	5.0	0.3
Sorting, packing, light assembly	400	4800	5.0	20	0.17	5.0	0.3
Warehouse	100	1200	20	20	0.17	5.0	0.3
Health Care							
Exam room	15	41	20	3	0.057	7.5	0.0
Group treatment area	100	270	20	20	0.43	7.5	0.0
Patient room	30	81	10	3	0.057	15	0.0
Resident room	30	81	10	3	0.057	15	0.0
Waiting room	100	270	30	30	0.57	5.0	0.0
Public Assembly/ Sports/Entertainment							
Auditorium	500	4600	30	150	0.77	2.5	0.3
Place of religious worship	200	2400	90	180	0.83	2.5	0.3
Museum	1000	10000	40	400	0.97	3.8	0.3
Convention	1000	10000	40	400	0.97	3.8	0.3
Spectator area	300	6300	33	100	0.62	3.8	0.3
Lobbies	120	320	10	12	0.10	0.0	0.3
Residential							
Common space	120	320	10	12	0.10	0.0	0.3
Dwelling unit	200	540	3.0	6	0.049	6.8	0.0



ECAi inevitably chosen from the tail of the distribution where margin-of-error (the deviation from a correct or exact value) is highest.

This makes the ECAi values indicative rather than exact, and the model a useful tool in the absence of anything better.



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Equivalent clean air *per* person

Occupancy Category	Baseline outdoor airflow rate ($L s^{-1}$ per person)	ECA_i ($L s^{-1}$ per person)	RR
Correctional Facilities			
Cell	4.9	15	0.3
Dayroom	3.5	20	0.2
Commercial/Retail			
Food and beverage facilities	5.6	30	0.2
Gym	11	40	0.3
Office	8.5	15	0.6
Retail	7.8	20	0.4
Transportation waiting	6.8	30	0.2
Educational Facilities			
Classroom	7.4	20	0.4
Lecture hall	2.9	25	0.1
Industrial			
Manufacturing	9.3	25	0.4
Sorting, packing, light assembly	11	10	1.1
Warehouse	6.5	10	0.7
Health Care			
Exam room	7.5	20	0.4
Group treatment area	7.5	35	0.2
Patient room	15	35	0.4
Resident room	15	25	0.6
Waiting room	5.0	45	0.1
Public Assembly/ Sports/Entertainment			
Auditorium	3.5	25	0.1
Place of religious worship	2.8	25	0.1
Museum	4.6	30	0.2
Convention	4.6	30	0.2
Spectator area	4.7	25	0.2
Lobbies	3.0	25	0.1
Residential			
Common space	3.0	25	0.1
Dwelling unit	6.8	15	0.5

Summary

Section 5

Summary

1. Derived ECAi values higher than OA requirements for ASHRAE Standard 62.1 for most occupancy categories.
2. RR provides a rough estimate of reduction compared to 62.1 minimums, ranging from 0.1 (high reduction) to 1.1 (no reduction)
3. Some categories less protected by 62.1 minimums: healthcare waiting rooms, lecture halls, places of worship. Occupancy reduction may be easiest way to increase ECA_i.
4. Some categories need little/no addition in equivalent clean air above 62.1 minimums: warehouse, industrial sorting/packing areas
5. The viral load of infected people is the most significant source of uncertainty.

Summary

6. It is unlikely that new data on SARS-CoV-2 decreases uncertainty in ECA_i because uncertainty is an inherent part of the biology and statistics of the problem.
7. It is unlikely that data for *other* pathogens will give less uncertainty in ECA_i because uncertainty is an inherent part of the biology and statistics of the problem.
8. Inevitable that assumptions and engineering and scientific judgement are required, and so an expert elicitation process was carried out by the project committee. It is entirely possible that a different committee would have reached a different consensus.
9. Further work to establish quality empirical evidence of the effect of ventilation, and its equivalents, on the transmission of respiratory pathogens at the population scale would be a welcome addition to the knowledge base and would support future improvements to the standard.

Papers

1. Iddon C, Jones B, Sharpe P, Cevik M, Fitzgerald S. A population framework for predicting the proportion of people infected by the far-field airborne transmission of SARS-CoV-2 indoors. Building and Environment. 2022;221:109309.
2. Jones B, Iddon C, Sherman M. Quantifying quanta: Determining emission rates from clinical data. Indoor Environments. 2024;1(3):100025.
3. Jones B, Iddon C, Zaatari M, Wargocki P, Bruns R. Risk Modeling for ASHRAE Standard 241-2023 – Control of Infectious Aerosols. Indoor Environments. 2024; *In Review*.


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Back-up Slides

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2. B
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