Using pathogen-free air to reduce infection risks in buildings

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Airborne Infection Reduction through Building Operation and Design for SARS-CoV-2 (AIRBODS)

- UKRI funded
- Lead by Professor Malcolm Cook
- Loughborough University, University College London, the University of Cambridge, the University of Nottingham, the University of Sheffield and London South Bank University
- Aims to quantify the risk of transmission of SARS-CoV-2 in buildings, and thereby offer guidance on the ventilation operation and future design of non-domestic buildings
- Participating in the UK Government's Events Research Programme

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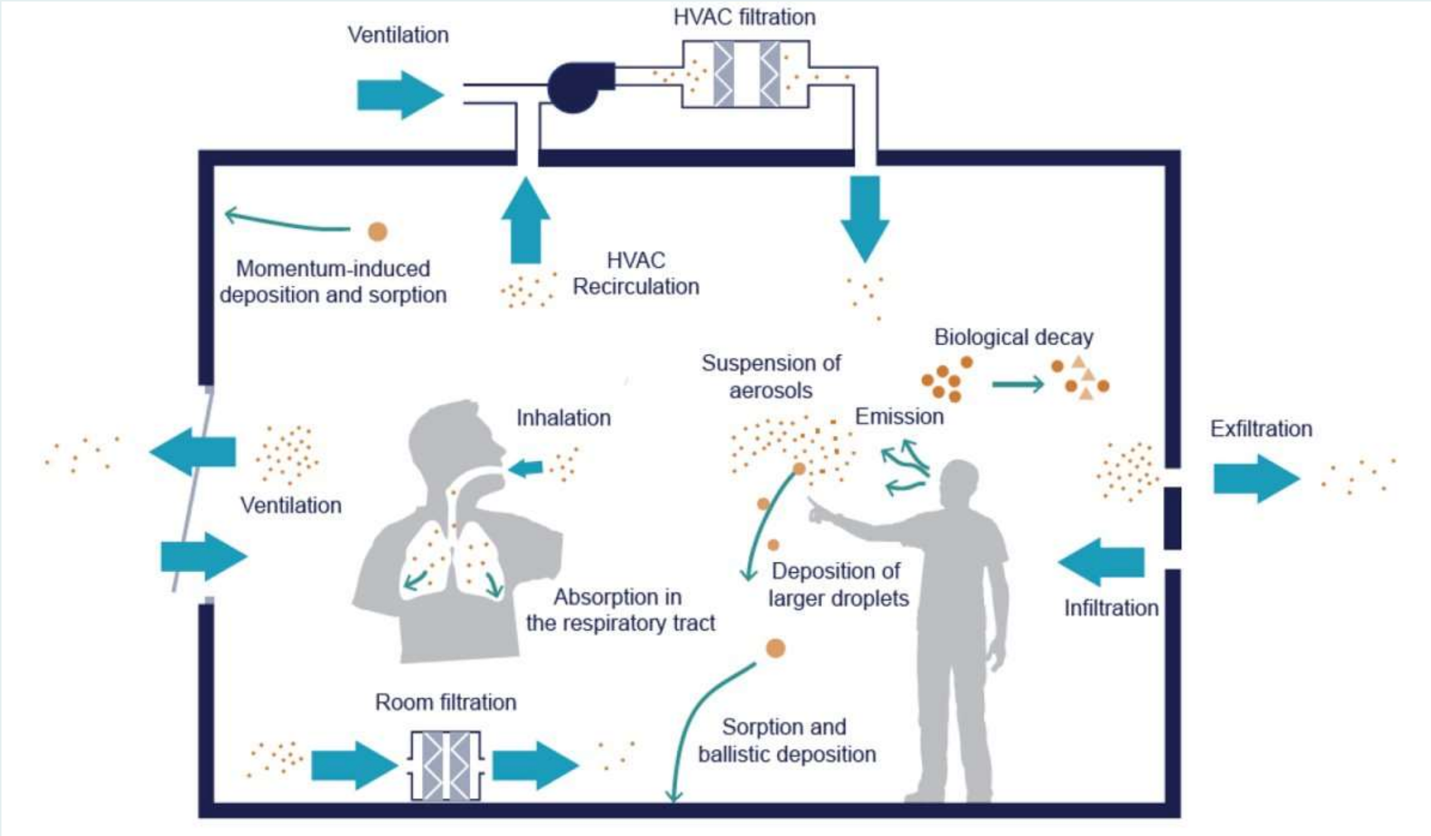
Overview

- Mass balance model
- Uncertainty in viral emission rates
- Personal risk
- Population risk

Mass balance model



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Mass balance model

1. Gains
   1. Emission from a person, G (#/s)
   2. Entry from outside via ventilation [none]
   3. Entry from outside via infiltration [none]
   4. Virus already present in the space [none]
2. Losses
   1. Dilution via ventilation, ψ (s^{-1})
   2. Surface deposition, ϒ (s^{-1})
   3. Biological decay and UVC denaturing, λ (s^{-1})
   4. Respiratory tract absorption, ζ (s^{-1})
   5. Filtration, ω (s^{-1})

Here, $\phi = \psi + \Upsilon + \lambda + \zeta + \omega$

The steady state number of viral genome copies in a space as a function of time is:

$$n_{ss} = \frac{G}{\phi}$$

The concentration of viral genome copies is space dependent

$$n_{ss}/m^3$$

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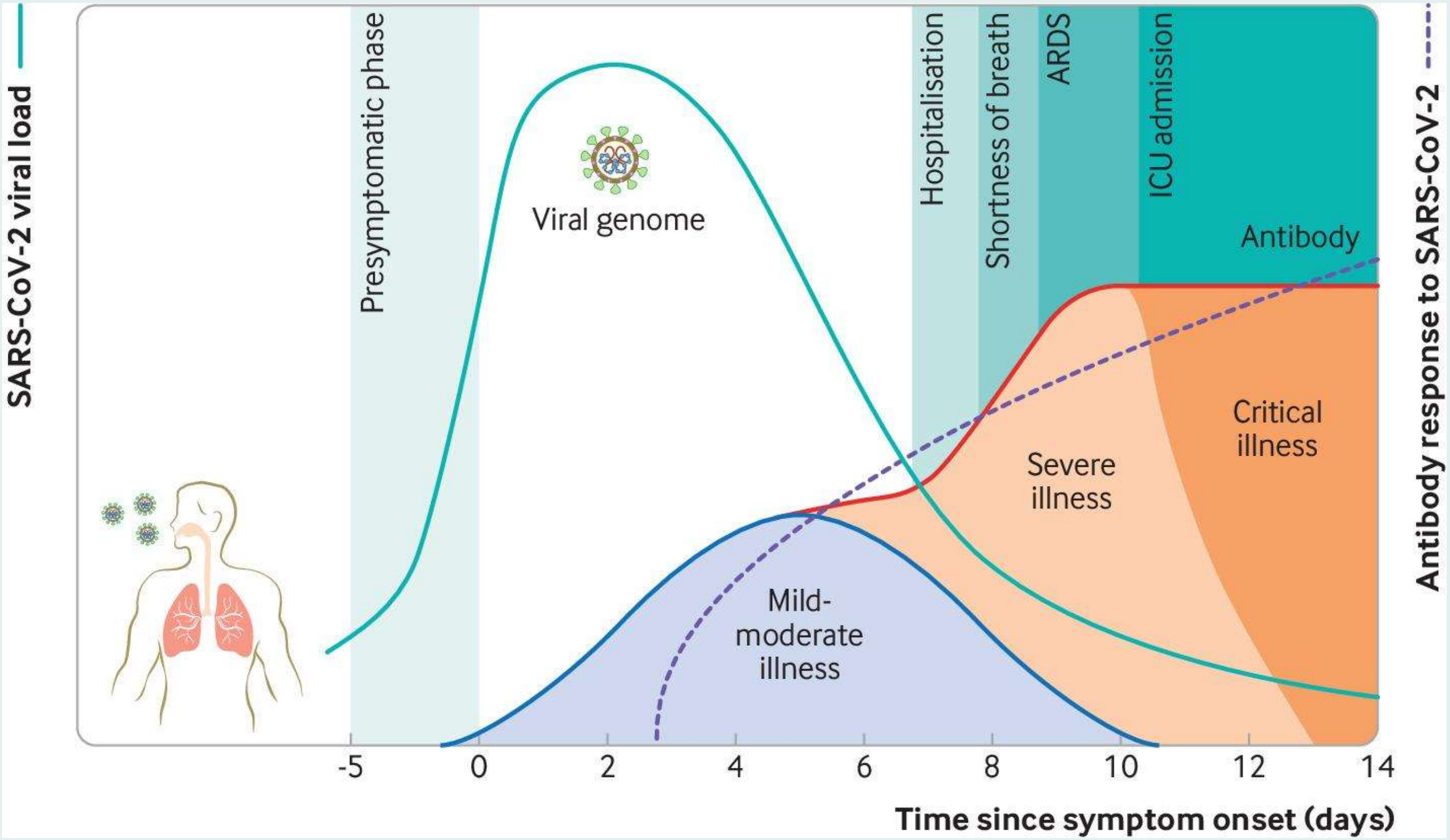
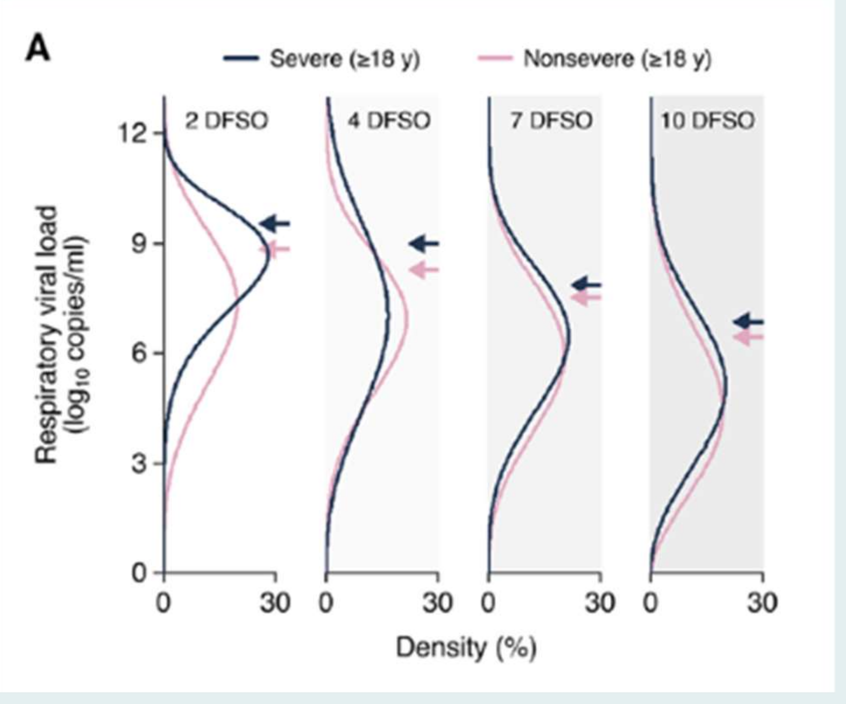
Viral load



Cevik, M. *et al.* (2020) ‘Virology, transmission, and pathogenesis of SARS-CoV-2’, *BMJ (Clinical research ed.)*, 371, p. m3862. doi: 10.1136/bmj.m3862

Viral load



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Chen et al (2021) SARS-CoV-2 shedding dynamics across the respiratory tract, sex, and disease severity for adult and pediatric COVID-19 https://doi.org/10.7554/eLife.70458

Viral load – historical perspective

Variability in the infectivity of different patients was far greater than we realized at the time of the previous report. It is now apparent that a statistical mean infectivity for far advanced tuberculosis cannot be approximated by taking the average infectivity of any 6 patients in this stage of the disease. Two of our patients produced 19 out of 22 infections in guinea pigs even though 62 patients occupied the ward during the period under consideration. The astounding infectivity of these two patients in comparison with the others was related in part to the infectivity of their sputum. The number of organisms seen on smear was high and the infectivity for guinea pigs exposed to artificially atomized sputum was also high.

Aerial dissemination of pulmonary tuberculosis: A two year study of contagion in a tuberculosis ward
Riley *et al* 1959

These calculations suggest that the index case may have been exceptionally infectious and that the secondaries may have been, on the average, only about one tenth as infectious

Airborne spread of measles in a suburban elementary school
Riley *et al* 1978

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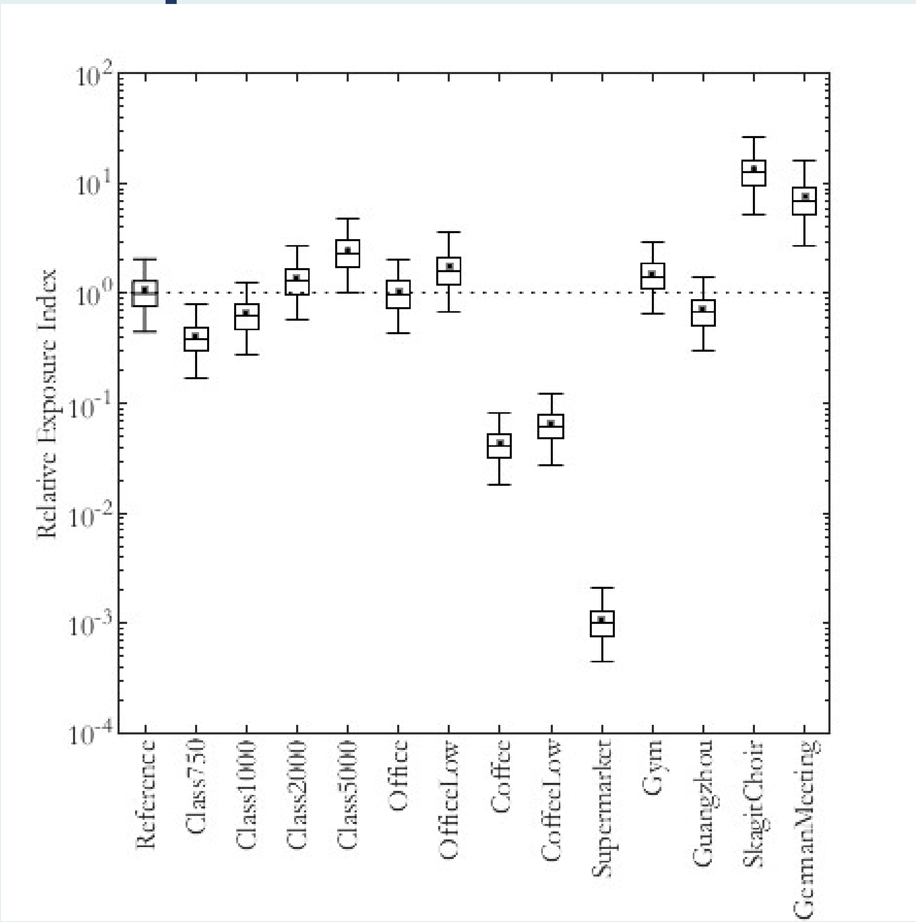
doi 10.1093/oxfordjournals.aje.a120069
doi 10.1093/oxfordjournals.aje.a112560

Relative Exposure Index

$$Relative\ Exposure\ Index = \frac{\sum n_{Scenario\ \ x}}{\sum n_{Defined\ \ scenario}}$$

Input	Value
Room Volume	148.5m^3
Number of Occupants	32
Breath rate	0.44m^3/hr
Respiratory activity	75% breathing, 25% talking
Occupation time	7 hr
Air flow rate	160l/s (equivalent 5l/s/p)

Relative Exposure Index



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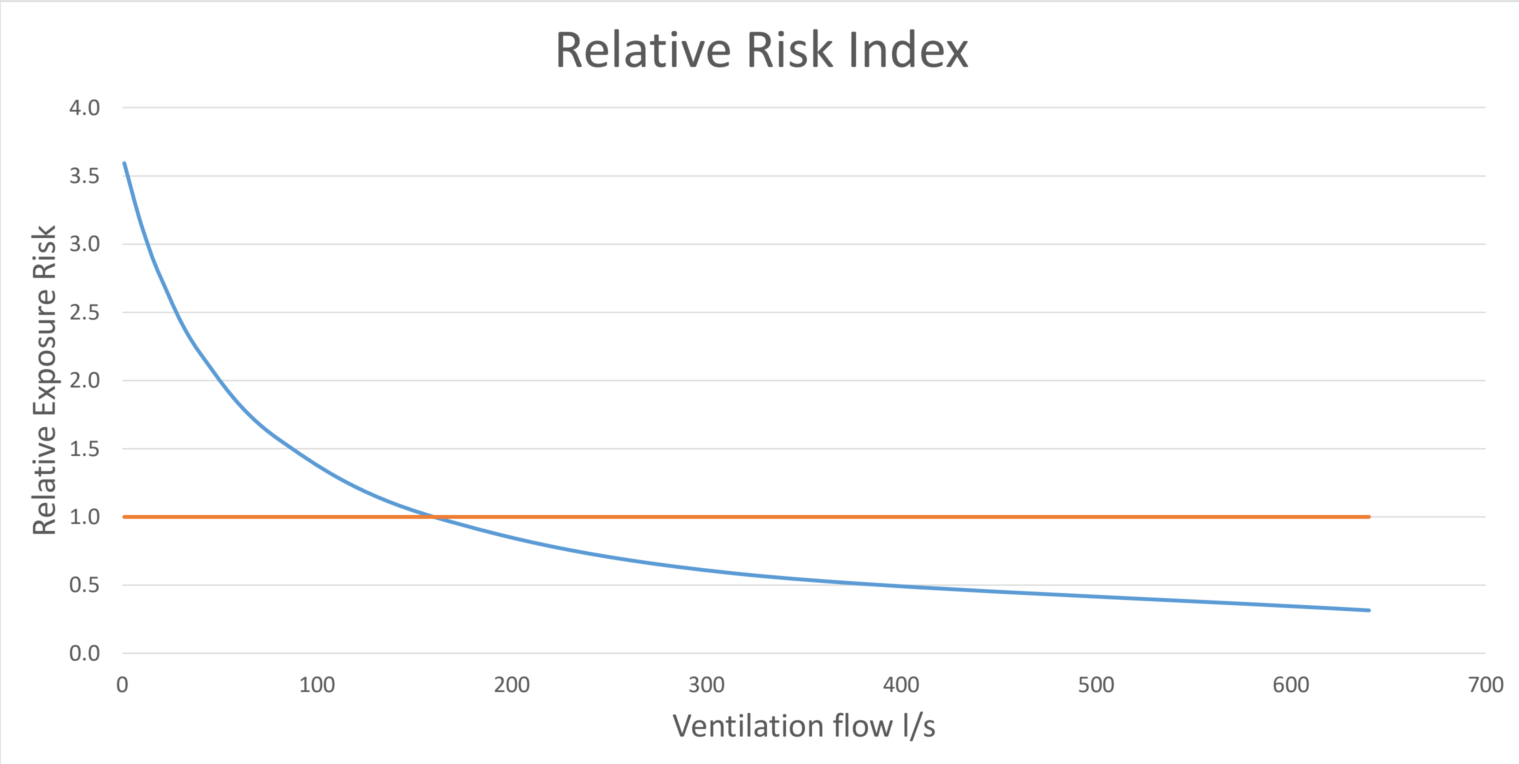
Jones, B. *et al.* (2020) 'Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission in Buildings', *Building and Environment*. 191:107617 doi:10.1016/j.buildenv.2021.107617

Relative Exposure Index



148m[3] junior classroom, 32 person, 7 hour, 25% talking, 75% breathing

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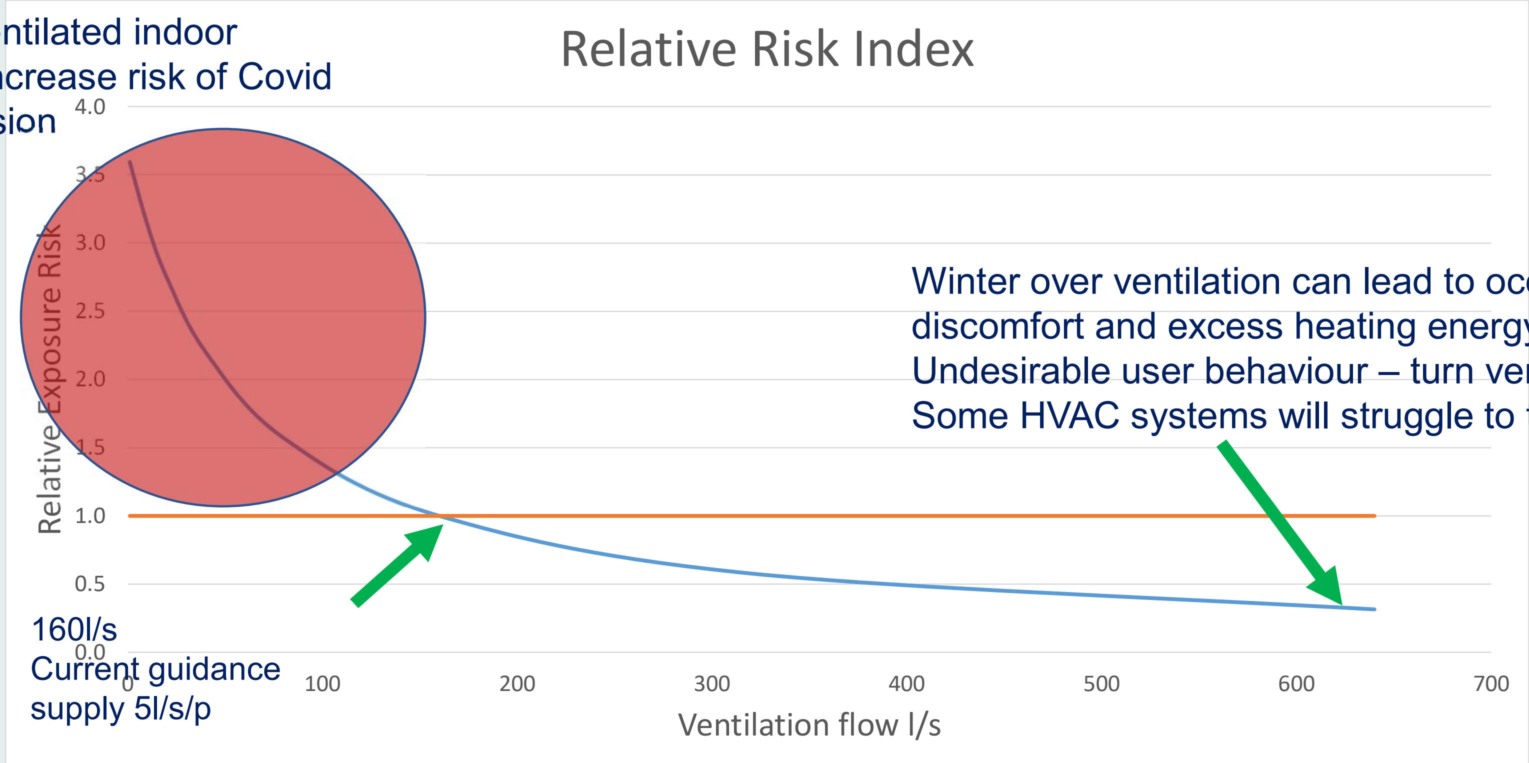
Jones, B. *et al.* (2020) 'Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission in Buildings', *Building and Environment*. 191:107617 doi:10.1016/j.buildenv.2021.107617

Relative Exposure Index

Poorly ventilated indoor spaces increase risk of Covid transmission



Winter over ventilation can lead to occupant discomfort and excess heating energy
Undesirable user behaviour – turn ventilation off
Some HVAC systems will struggle to temper air

160l/s
Current guidance supply 5l/s/p

148m^3 junior classroom, 32 person, 7 hour, 25% talking, 75% breathing

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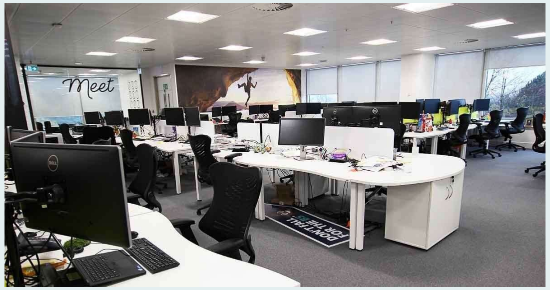
Jones, B. *et al.* (2020) 'Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission in Buildings', *Building and Environment*. 191:107617 doi:10.1016/j.buildenv.2021.107617

5 person office REI = 10

Input	Value
Room Volume	150m^3 (30m^3/person)
Number of Occupants	5
Breath rate	0.54m^3/hr
Respiratory activity	75% breathing, 25% talking
Occupation time	8 hr
Ventilation air flow rate ψ	50l/s (≡ 10l/s/p, 1.2ach)
Biological decay λ	0.6ach (≡ 25l/s)
Deposition γ	0.4ach (≡ 17l/s)
Total removal (equivalent ventilation) φ	2.2ach (≡ 92l/s)

50 person office REI = 1



Input	Value
Room Volume	1500m^3 (30m^3/person)
Number of Occupants	5
Breath rate	0.54m^3/hr
Respiratory activity	75% breathing, 25% talking
Occupation time	8 hr
Ventilation air flow rate ψ	500l/s (≡ 10l/s/p, 1.2ach)
Biological decay λ	0.6ach (≡ 250l/s)
Deposition γ	0.4ach (≡ 170l/s)
Total removal (equivalent ventilation) φ	2.2ach (≡ 920l/s)

Probability of Infector

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Probability of Infector

$$P(I) = \frac{C^I(1-C)^{(N-I)}N!}{I!(N-I)!}$$

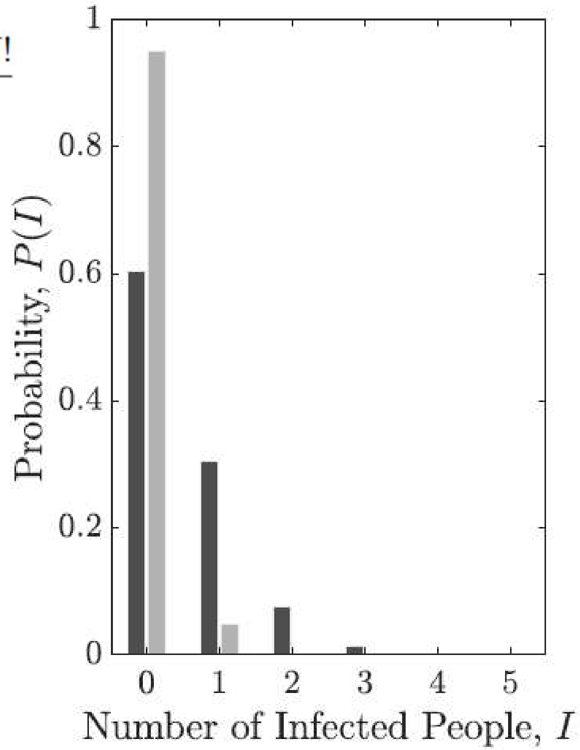

Figure 1: The probability of a number of infected people, I, present in the Big Office (dark) and Small Office (light), $P(I)$, when $C = 1\%$.

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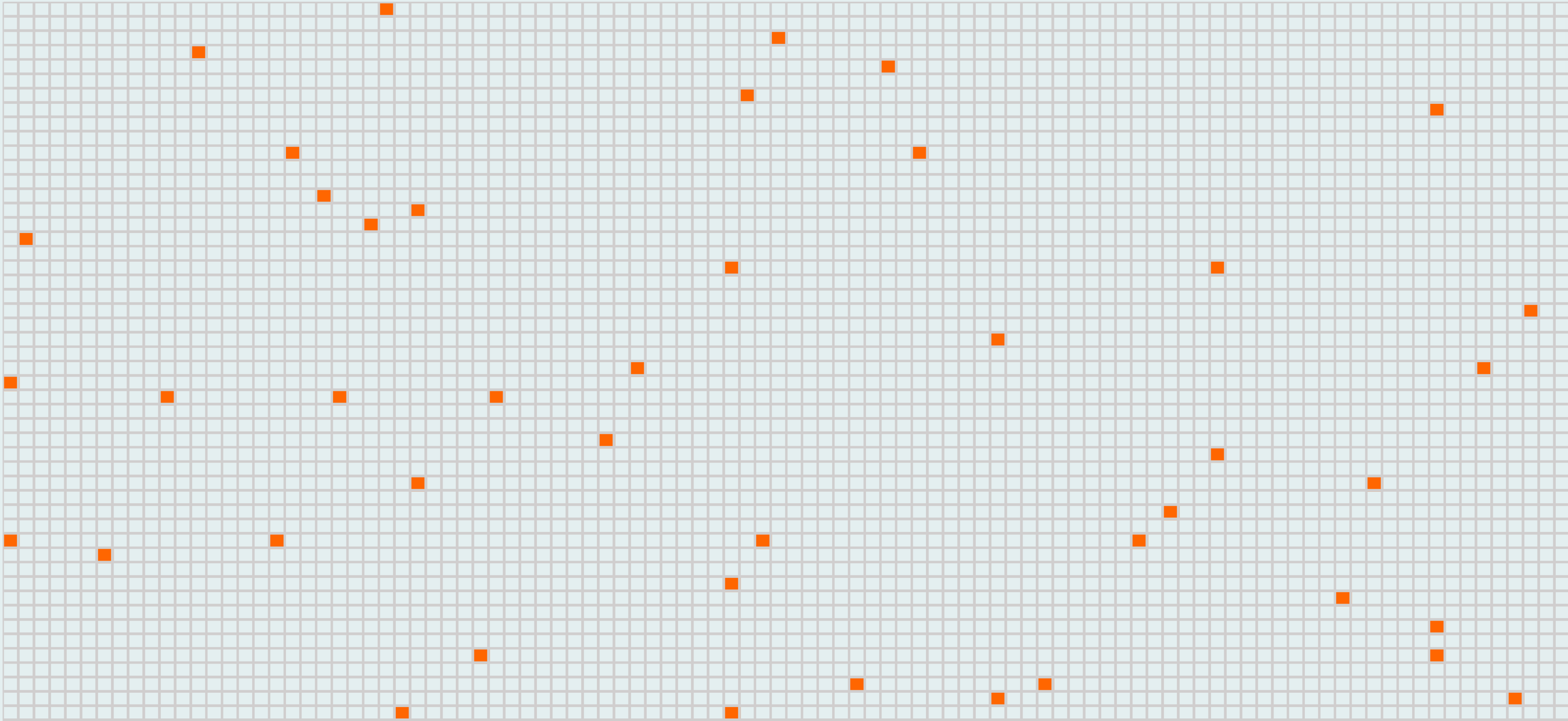
Proportion susceptible



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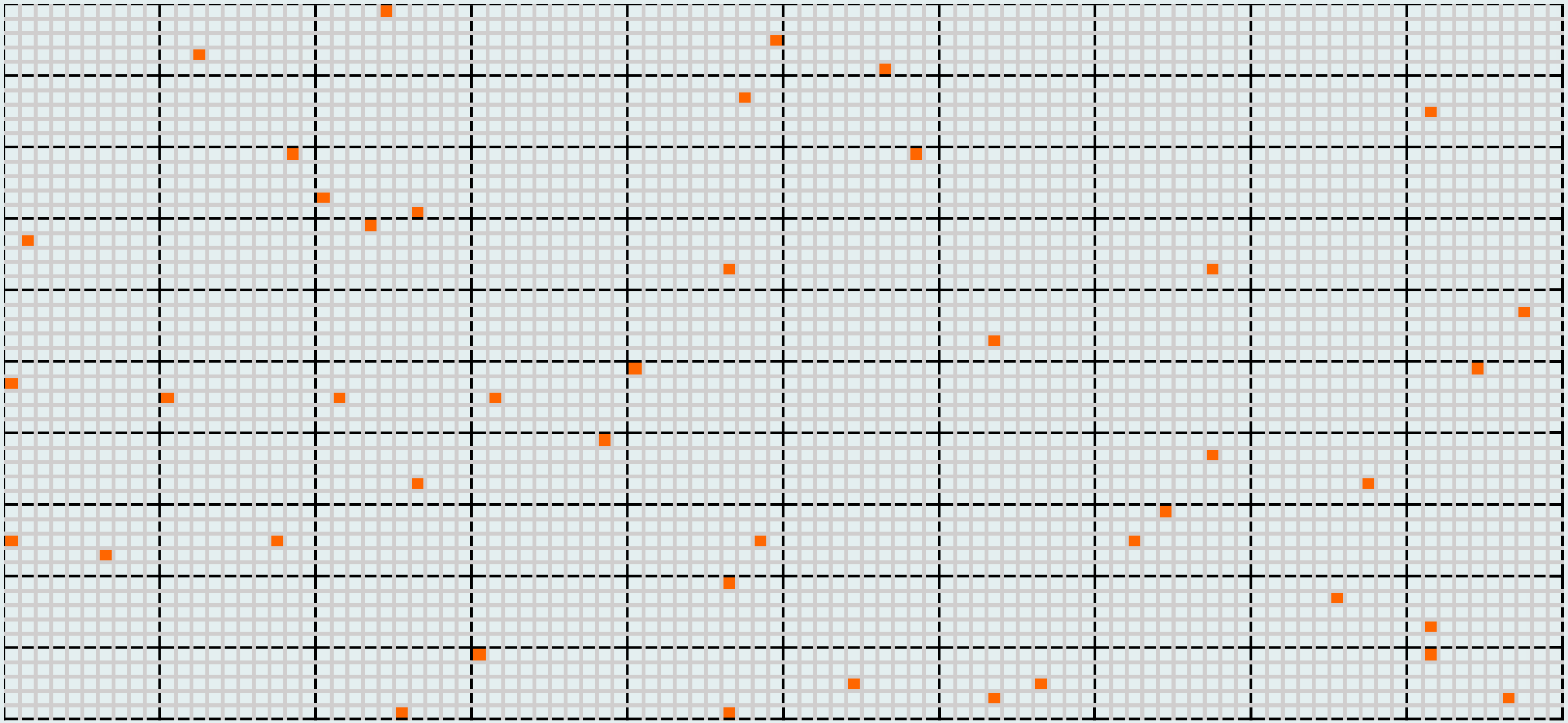
Proportion susceptible



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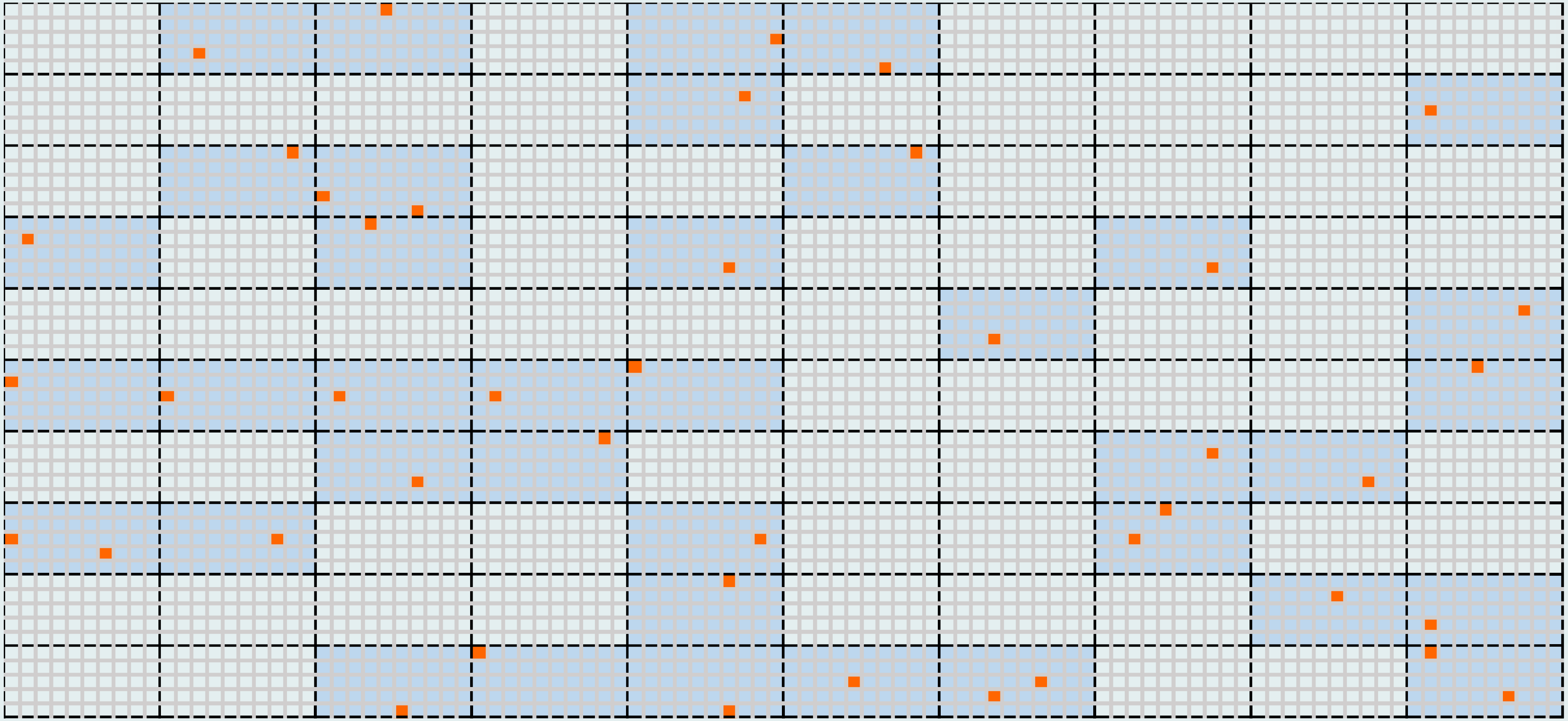
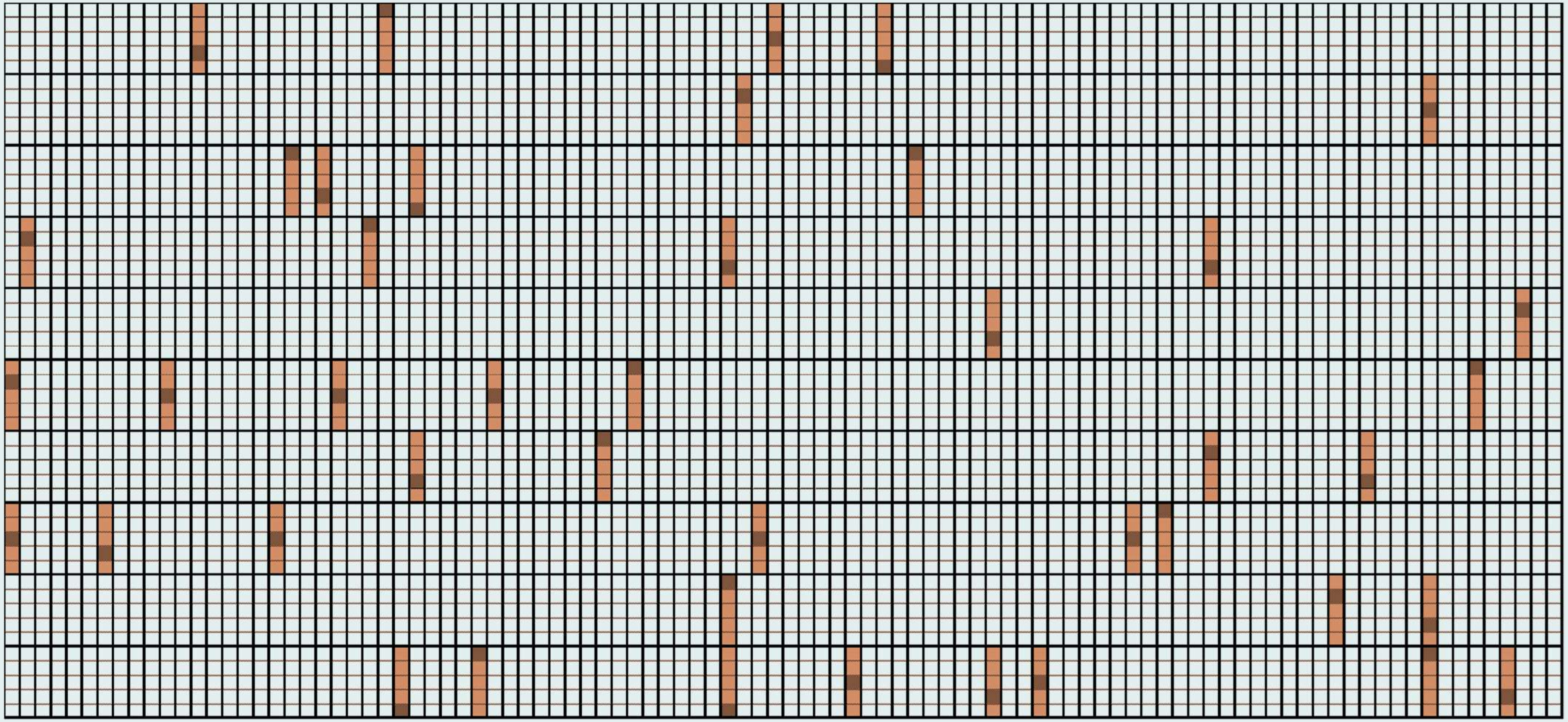
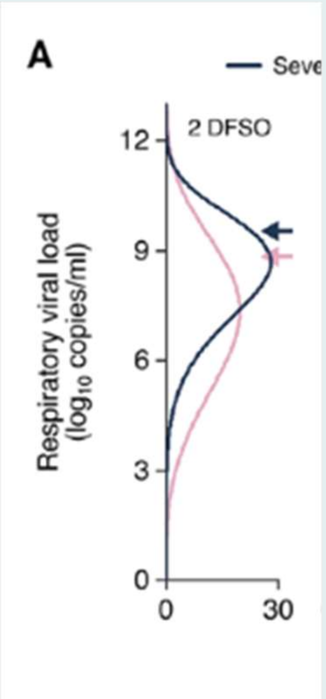
Proportion susceptible

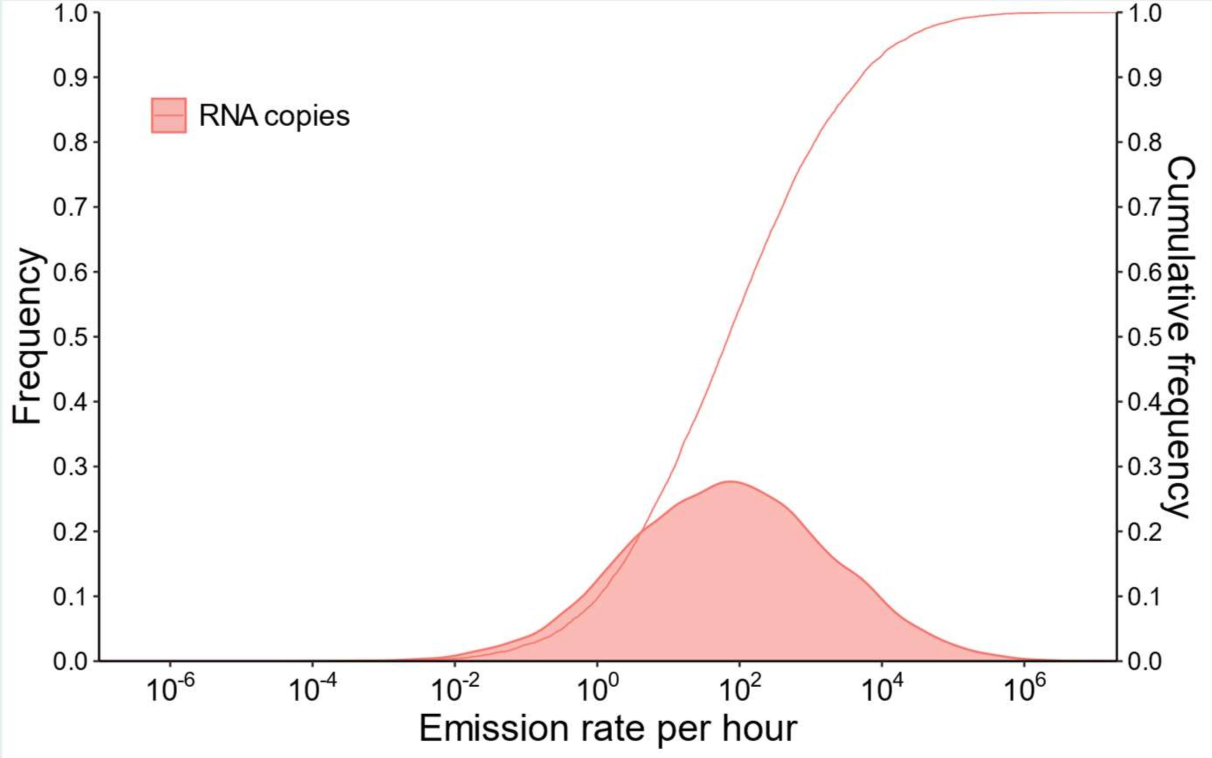


Proportion susceptible



Viral load





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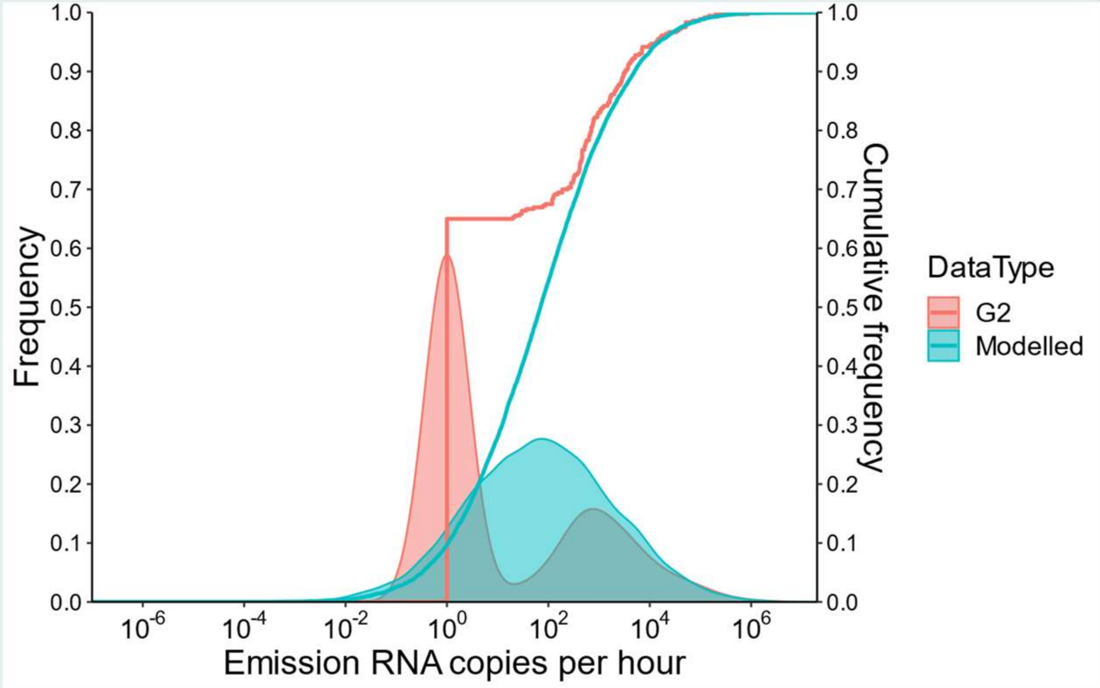
http://www.sciencedirect.com/science/article/pii/S0360132321000305
https://www.sciencedirect.com/science/article/pii/S0360132322005431

Viral load

Figure 1. Schematic representation of expiratory sample collection using the G-II exhaled breath collector inside the COVID-19 patient room. Abbreviation: COVID-19, coronavirus disease 2019.



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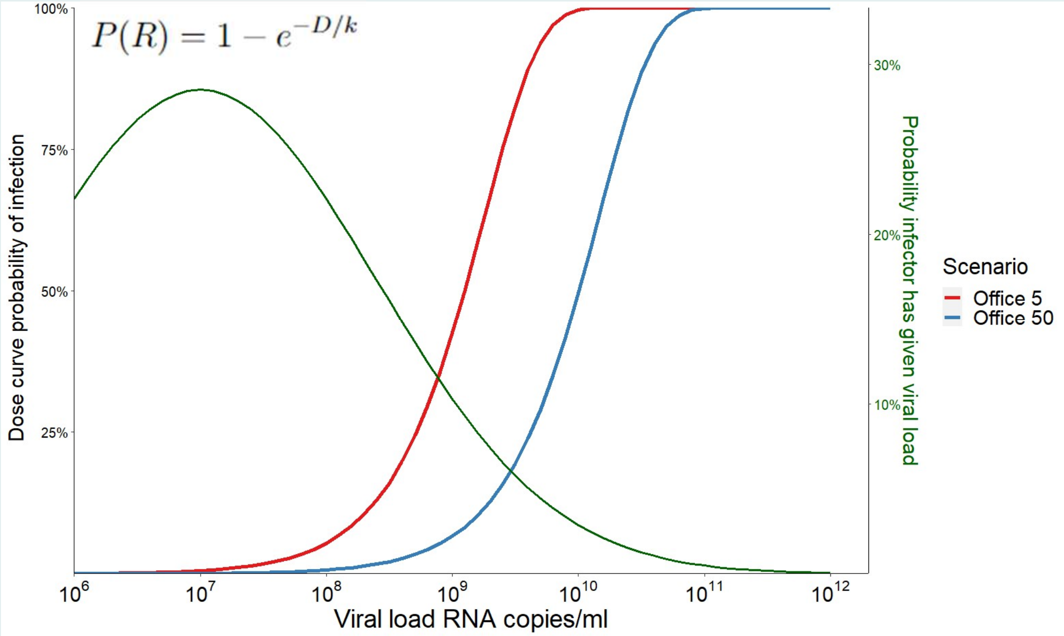
https://doi.org/10.1093/cid/ciab691

Proportion infected



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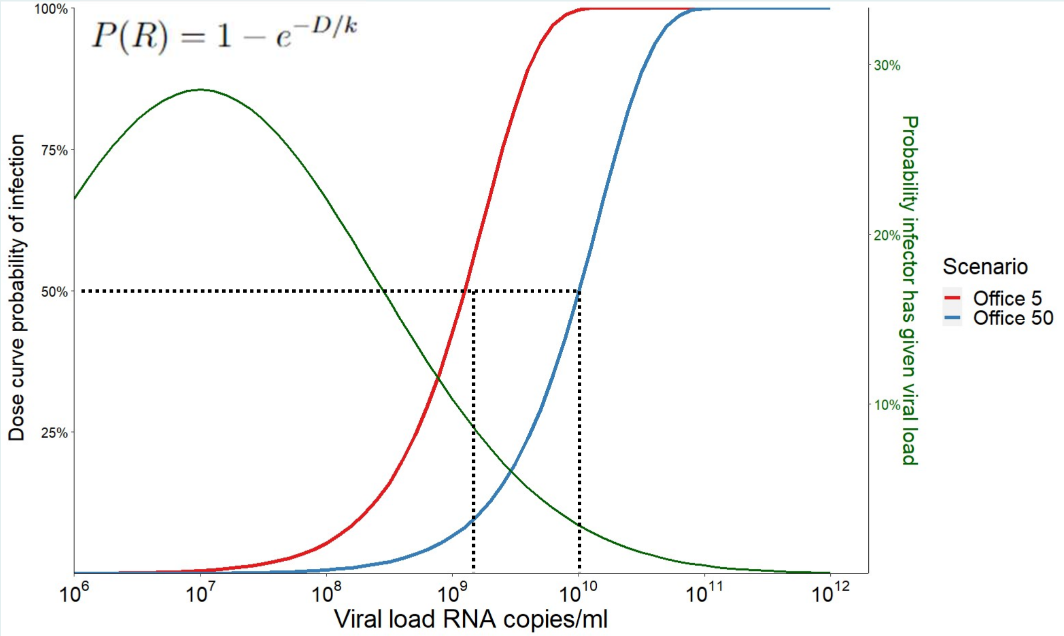
Proportion infected



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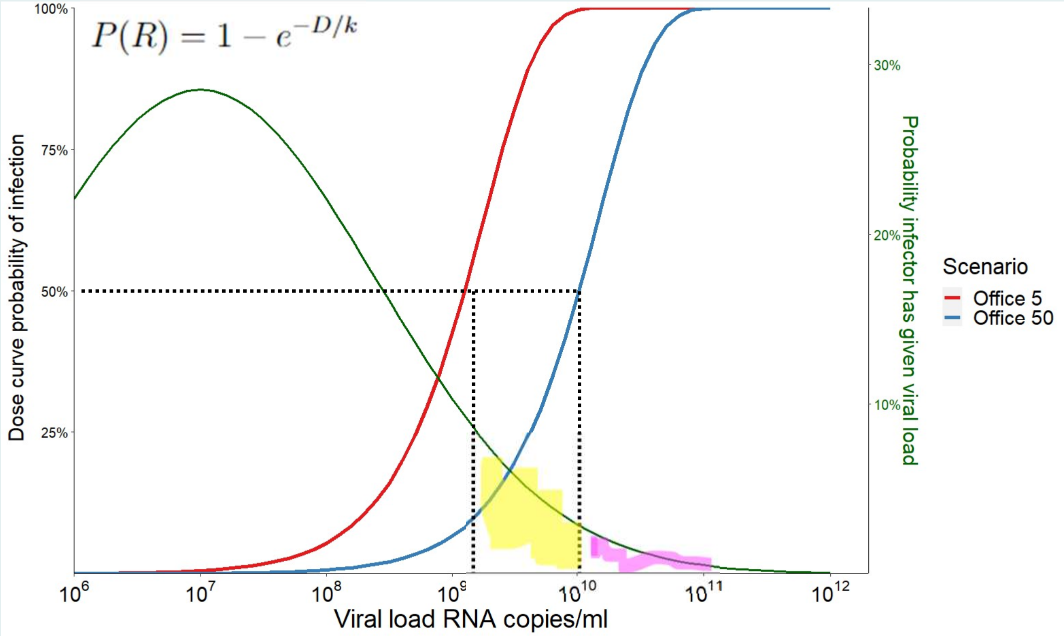
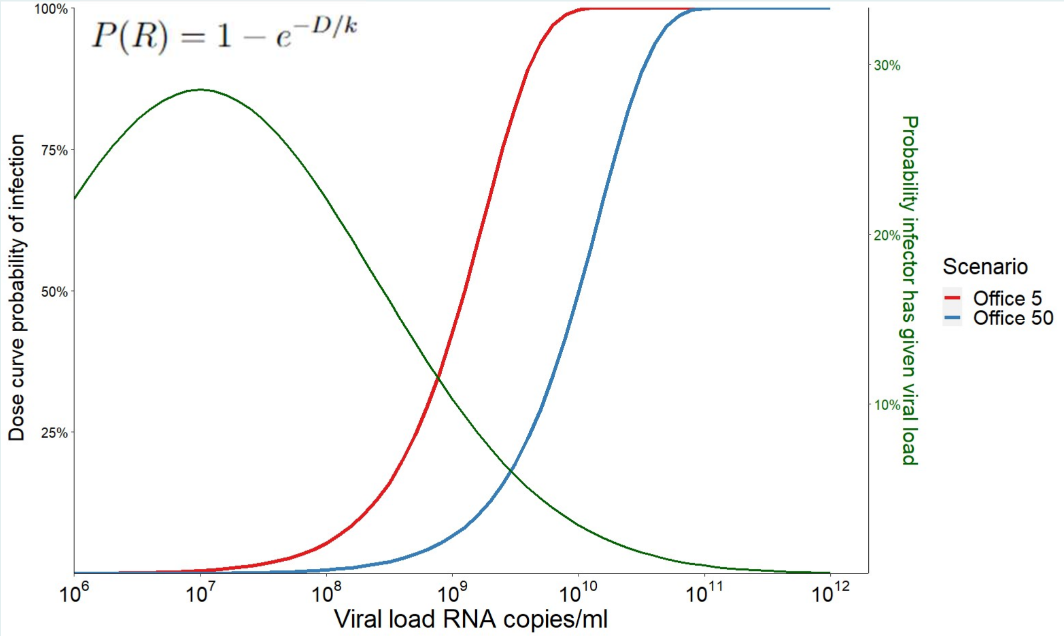
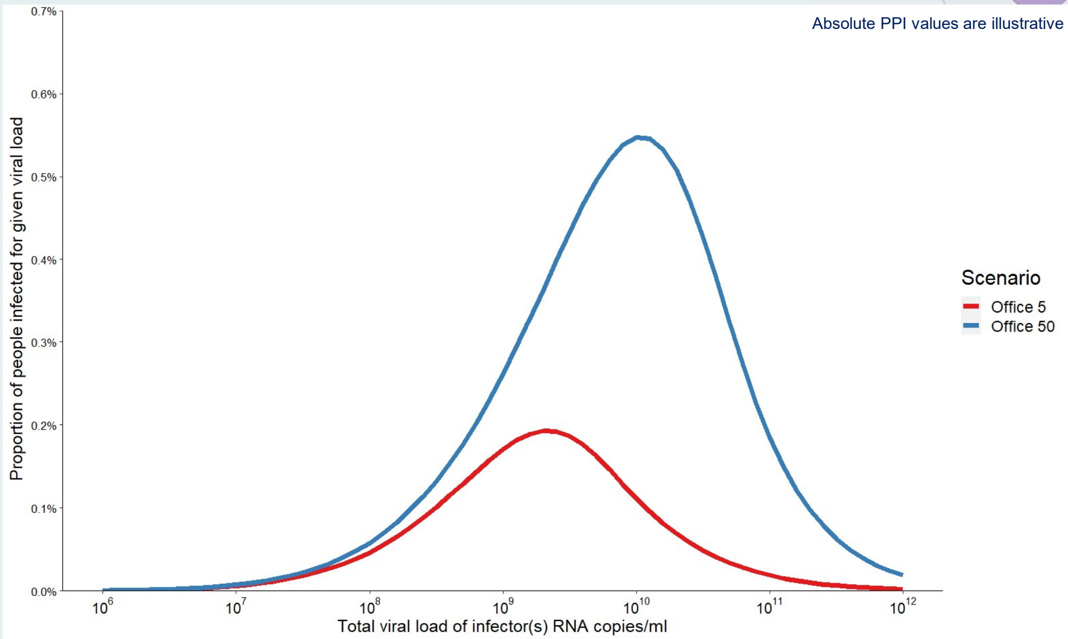
Proportion infected



Proportion infected





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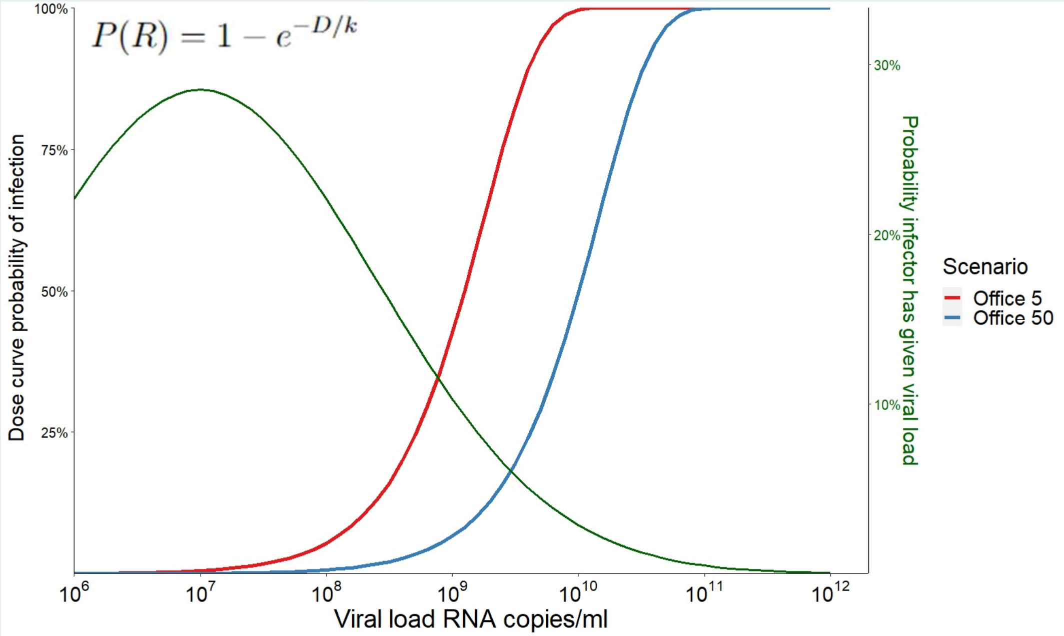
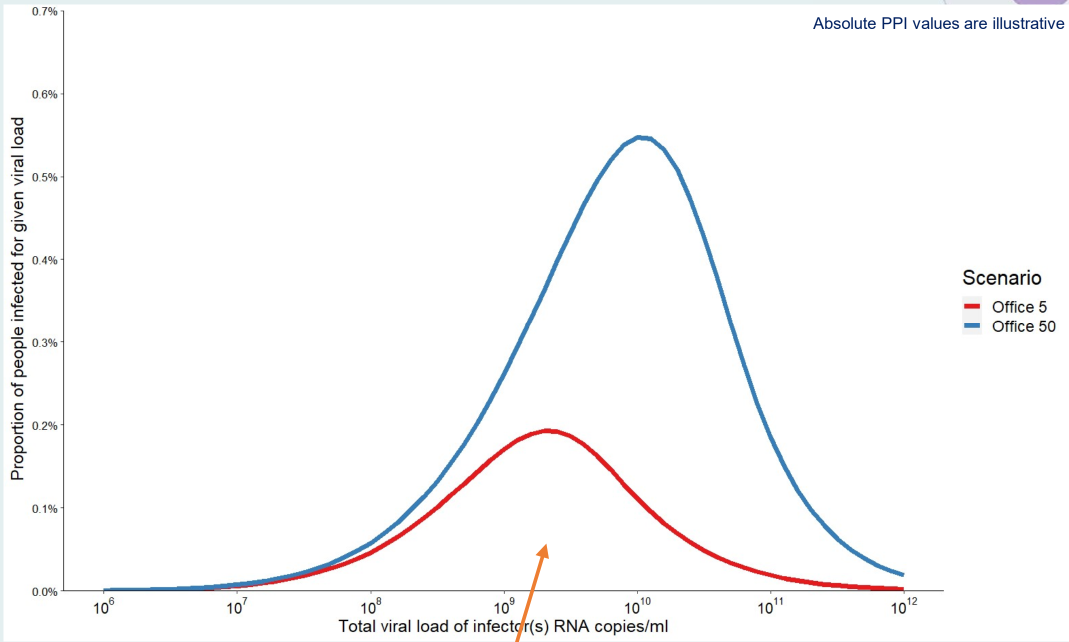
https://www.sciencedirect.com/science/article/pii/S0360132322005431

Proportion infected





Probability an infector is present
Probability infector has given viral load
Probability that the given viral load gives rise to infection

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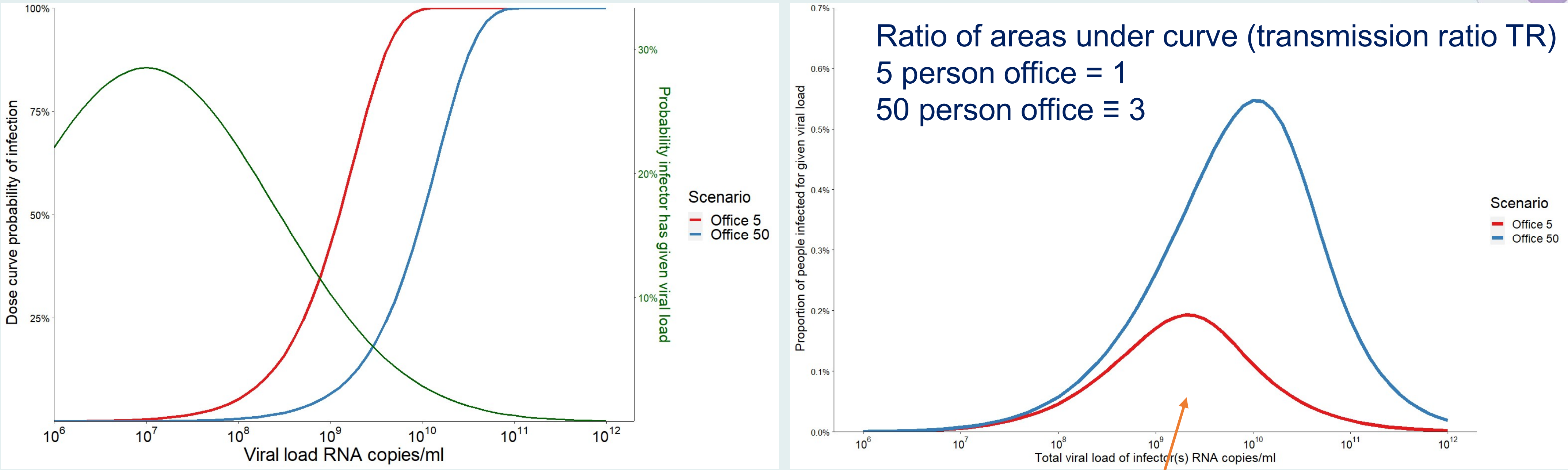
https://www.sciencedirect.com/science/article/pii/S0360132322005431

Proportion infected



Probability an infector is present
Probability infector has given viral load
Probability that the given viral load gives rise to infection

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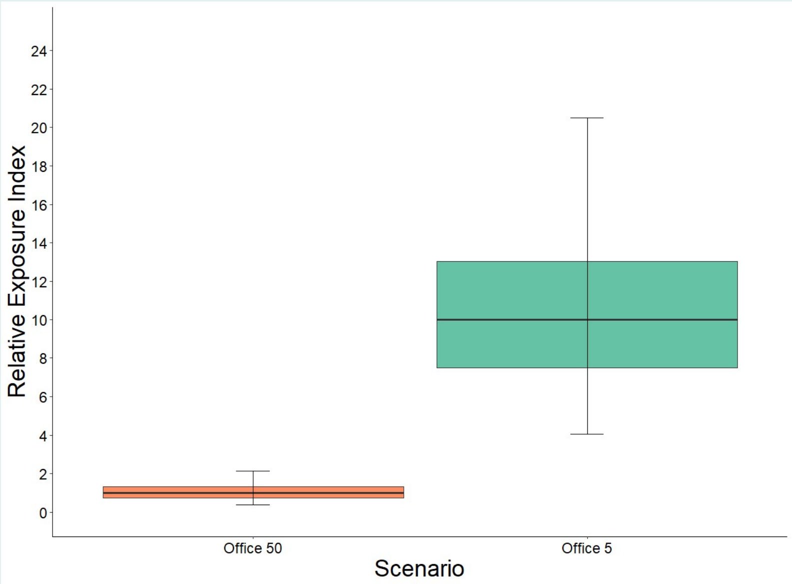
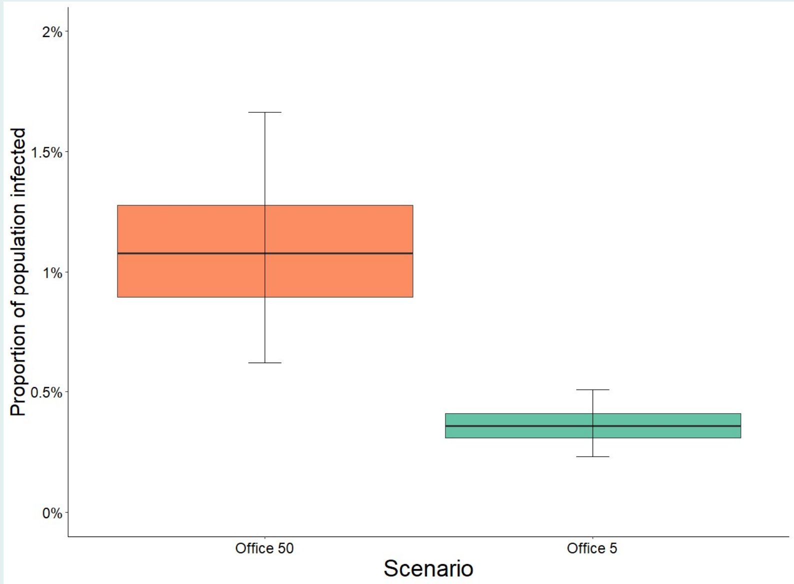
REI and PPI

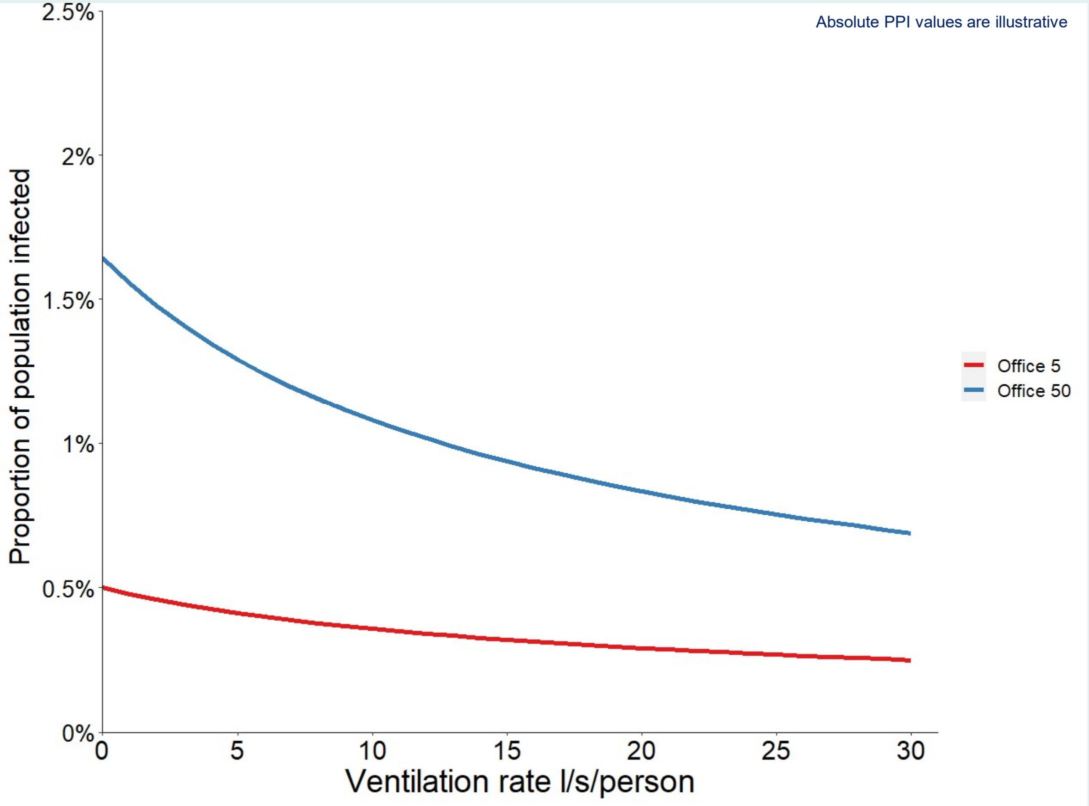


Relative Exposure Index
24
22
20
18
16
14
12
10
8
6
4
2
0
Office 50
Office 5
Scenario



Proportion of population infected
2%
1.5%
1%
0.5%
0%
Office 50
Office 5
Scenario

Ventilation



https://www.sciencedirect.com/science/article/pii/S0360132322005431

Ventilation

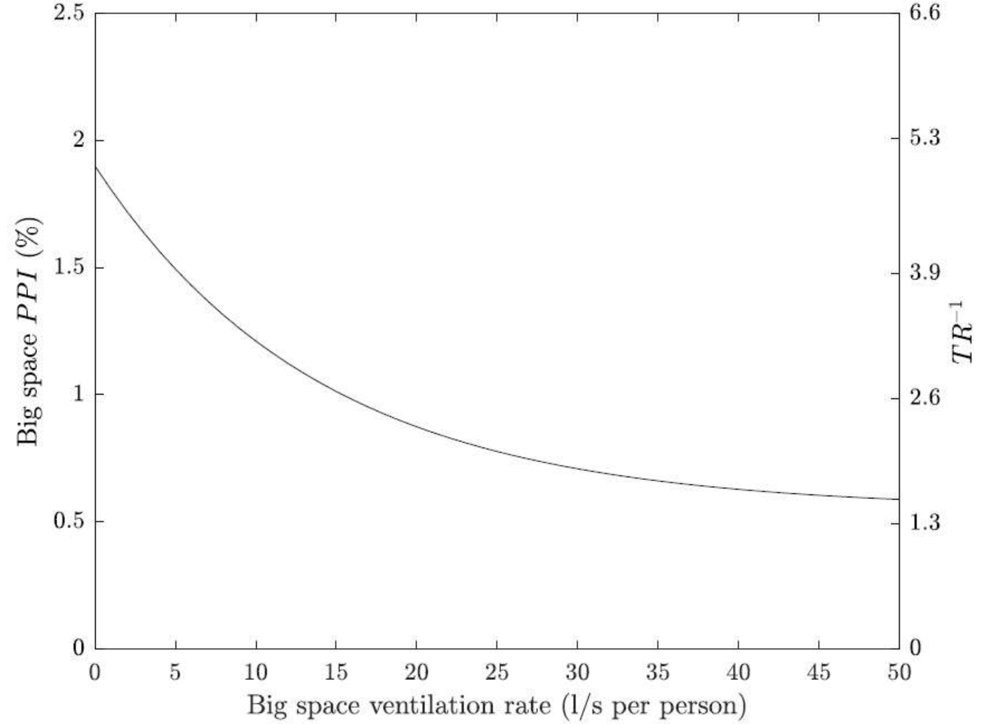


Figure 6: The effect of increasing the *per capita* ventilation rate, $\psi V N^{-1}$, in the Big Office on the *PPI* and the *TR* when the *per capita* ventilation rate in the Small Office is a constant $10\,\mathrm{l\,s^{-1}}$ per person. All values are illustrative.

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Occupancy

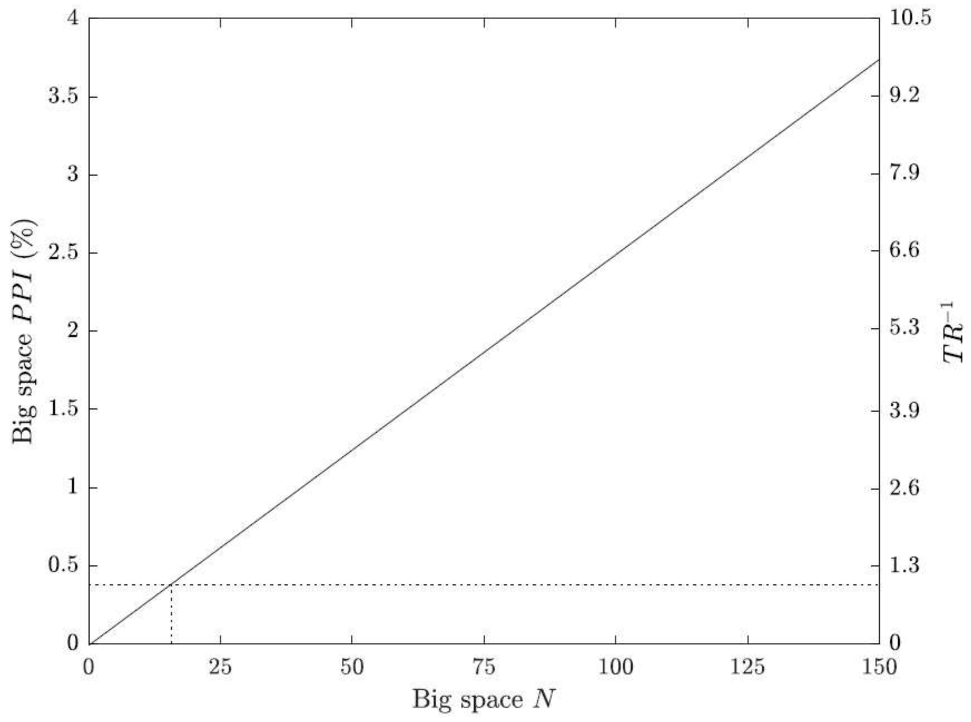

Figure 8: The effect of increasing the occupancy, N, in the Big Office where the space volume and ventilation flow rate are fixed for a designed occupancy of 50 people ($1500\,m^3$ and $500\,l\,s^{-1}$, respectively), on the PPI and TR. All values are illustrative.

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Community infection rate

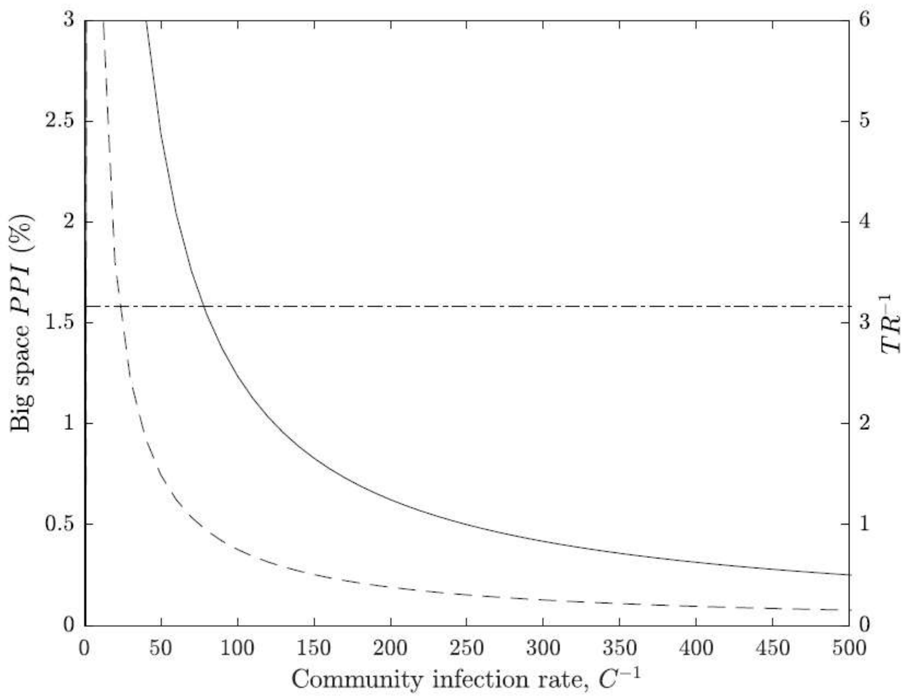

Figure 9: The effect of decreasing the community infection rate , C, on the PPI in the Big Office (solid) and the Small Office (dash) and on the TR (dot-dash). All values are illustrative.

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https://www.sciencedirect.com/science/article/pii/S0360132322005431

What next?

Part 5

What next?

- A new focus in IAQ generally
- However, there are limits to what we can do to make building resilient
- There are limits to the effect ventilation can have on transmission risk in buildings (community infection rate, high emission rate, social distancing)
- Personal and population risks are different
- When a building is occupied, there is no such thing as zero risk
- We must re-evaluate existing ventilation systems
- We must consider behavior (using systems appropriately)
- Regulation? (periodic demonstration of performance e.g. Sweden)

Publications

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

ELSEVIER

Building and Environment

Modelling uncertainty in the relative risk of exposure to the SARS-CoV-2 virus by airborne aerosol transmission in well mixed indoor air

Benjamin Jones [a,*], Patrick Sharpe [a], Christopher Iddon [b], E. Abigail Hathway [c], Catherine J. Noakes [d], Shaun Fitzgerald [e]

ELSEVIER

Building and Environment

Volume 221, 1 August 2022, 109309

Building and Environment

A population framework for predicting the proportion of people infected by the far-field airborne transmission of SARS-CoV-2 indoors

Christopher Iddon [a], Benjamin Jones [a], Patrick Sharpe [a], Muge Cevik [b], Shaun Fitzgerald [c]

- http://www.sciencedirect.com/science/article/pii/S0360132321000305
- https://www.sciencedirect.com/science/article/pii/S0360132322005431
- https://www.cibsejournal.com/general/why-space-volume-matters-in-covid-19-transmission/
- https://www.cibsejournal.com/technical/optimising-ventilation-in-the-post-covid-classroom/

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The End

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