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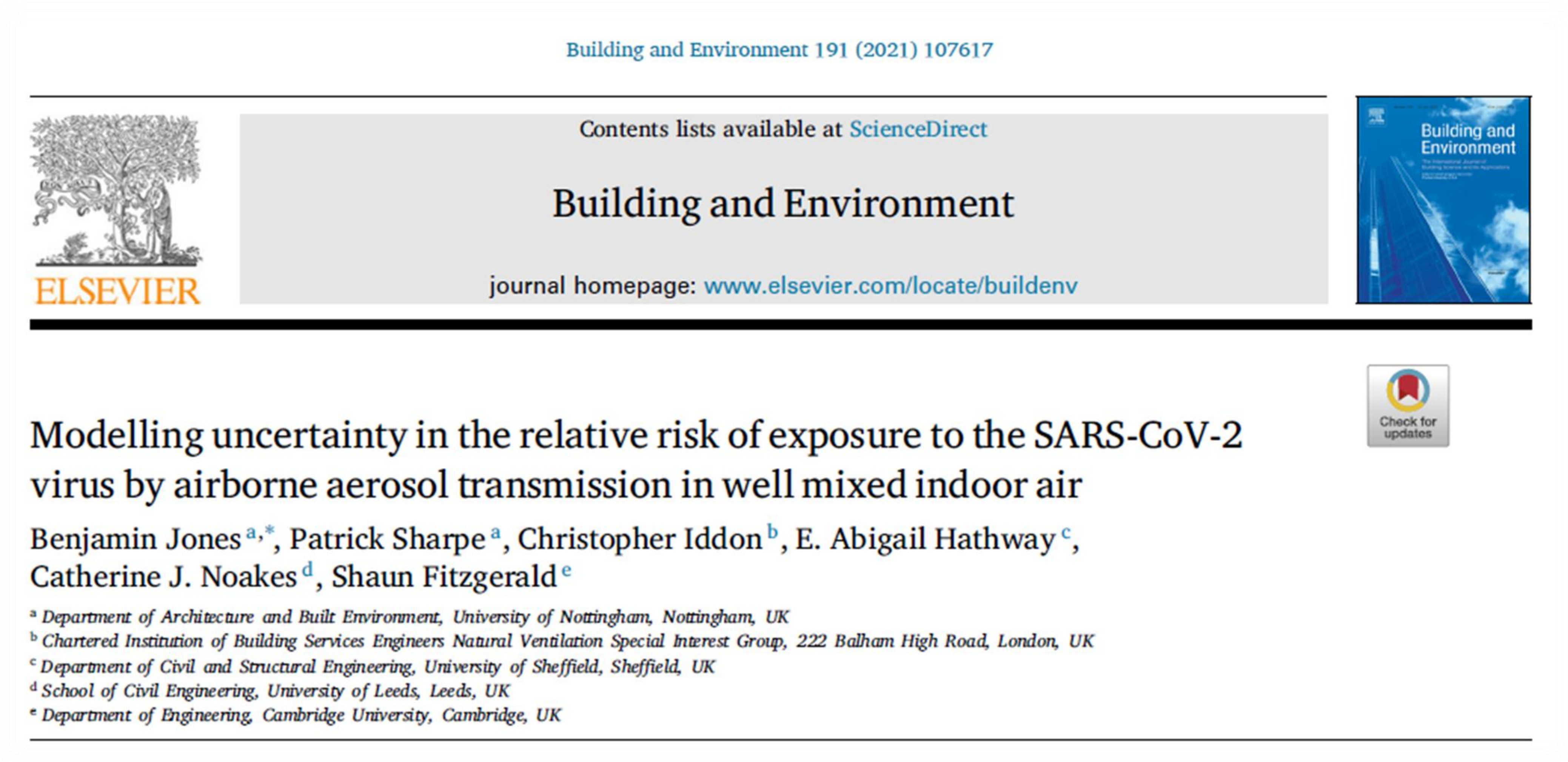
Estimating the Risk of Exposure to SARS-CoV-2 by Airborne Aerosols

Work for the UK Government's Pandemic Response

Credit



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

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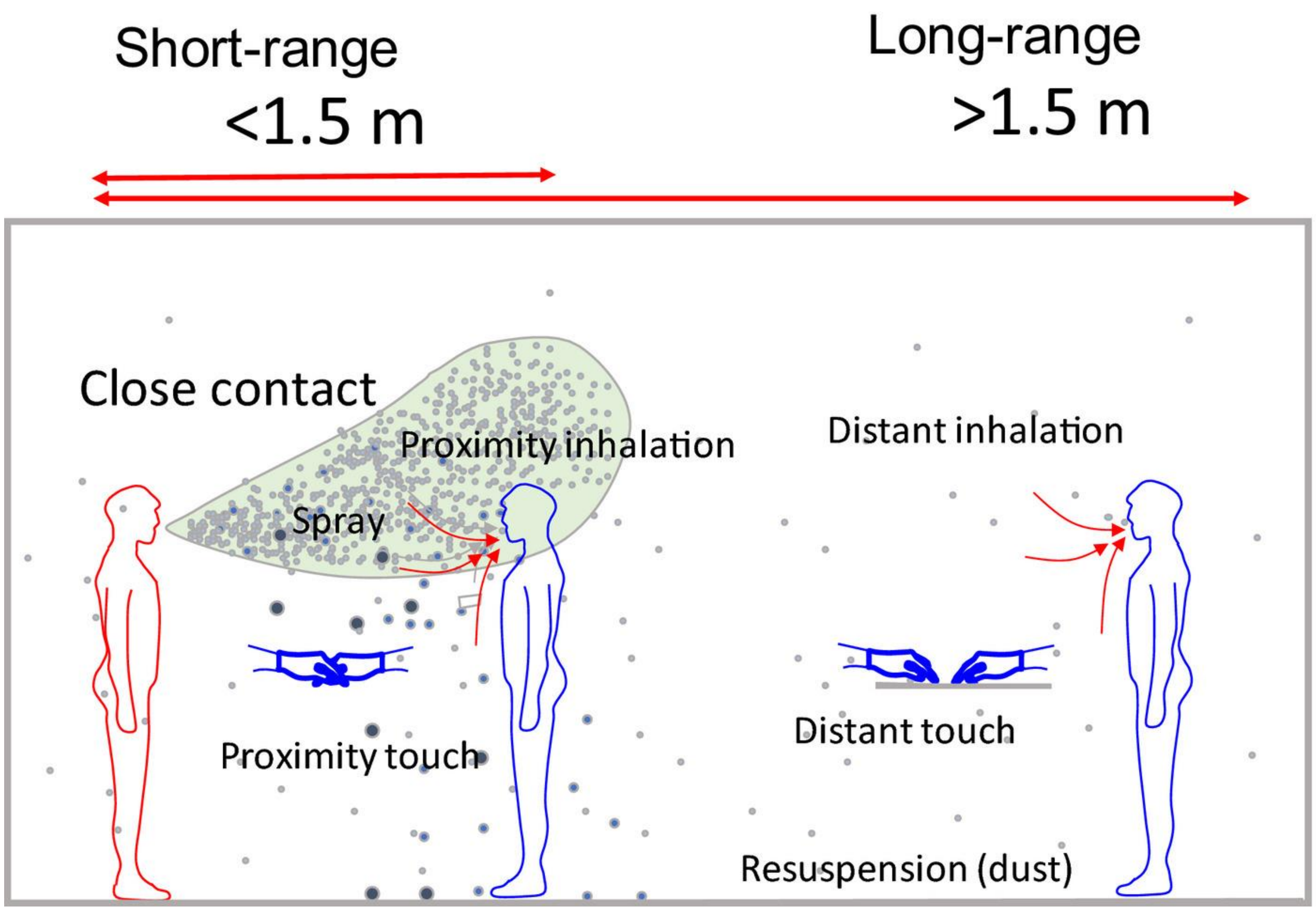
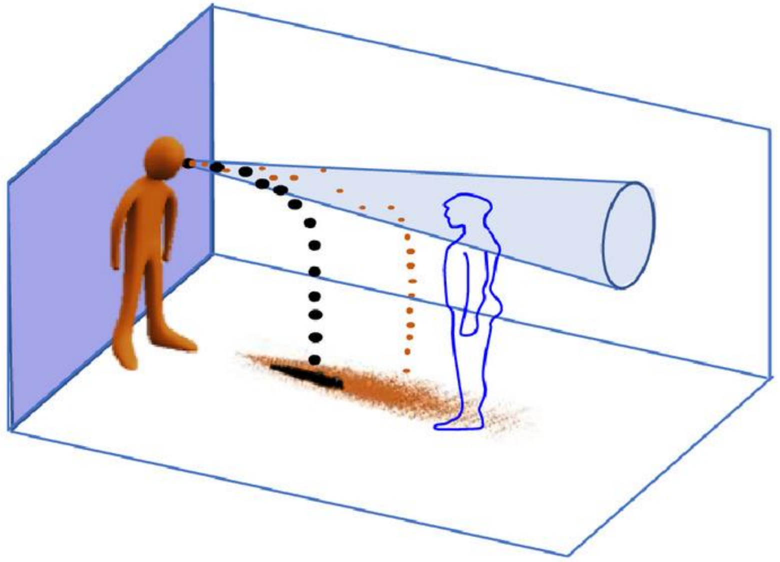
Virus Transmission





https://doi.org/10.1111/ina.12786

THE RELATIVE SIZE OF PARTICLES

From the COVID-19 pandemic to the U.S. West Coast wildfires, some of the biggest threats now are also the most microscopic.

A particle needs to be 10 microns (µm) or less before it can be inhaled into your respiratory tract. But just how small are these specks?

Here's a look at the relative sizes of some familiar particles ↘

HUMAN HAIR 50-180µm ›
FOR SCALE

FINE BEACH SAND 90µm ›

GRAIN OF SALT 60µm ›

WHITE BLOOD CELL 25µm ›

GRAIN OF POLLEN 15µm ›

DUST PARTICLE (PM10) <10µm ›

RED BLOOD CELL 7-8µm ›

RESPIRATORY DROPLETS 5-10µm ›

DUST PARTICLE (PM2.5) 2.5µm ›

BACTERIUM 1-3µm ›

WILDFIRE SMOKE 0.4-0.7µm ↘

CORONAVIRUS 0.1-0.5µm ↘

T4 BACTERIOPHAGE 0.225µm ↘

ZIKA VIRUS 0.045µm ›

Pollen can trigger allergic reactions and hay fever—which 1 in 5 Americans experience every year.
Source: Harvard Health

The visibility limits for what the naked eye can see hovers around 10-40µm.

Respiratory droplets have the potential to carry smaller particles within them, such as dust or coronavirus.

Wildfire smoke can persist in the air for several days, and even months.

SOURCES Cleanstream, Daniel Loverbey, EPA, Financial Times, News Medical, Science Direct, SCMP, Susan Sokolowski, Petroclear, U.S. Dept. of Energy

COLLABORATORS **RESEARCH + WRITING** Carmen Ang, Iman Ghosh | **DESIGN + ART DIRECTION** Harrison Schell

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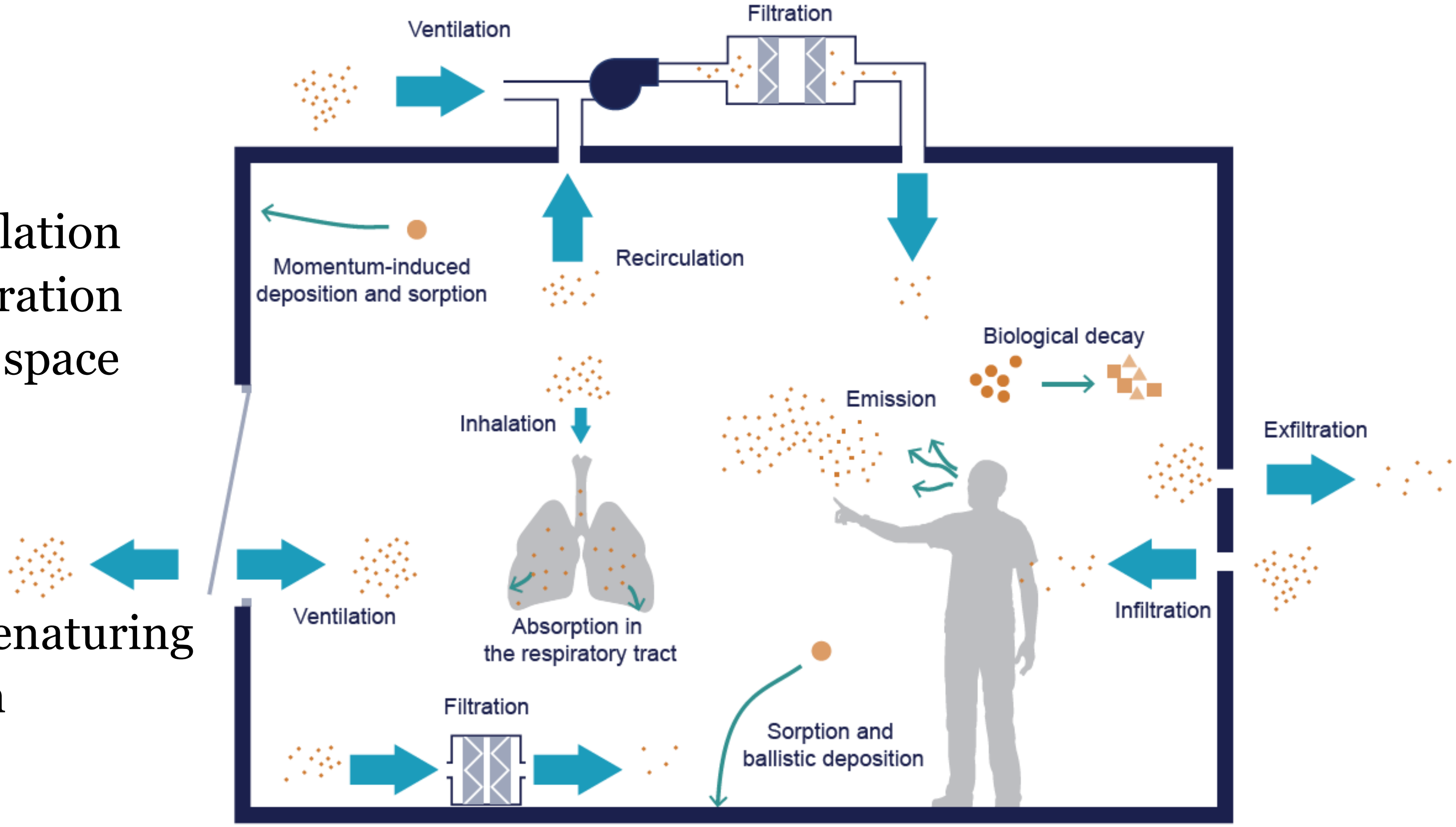
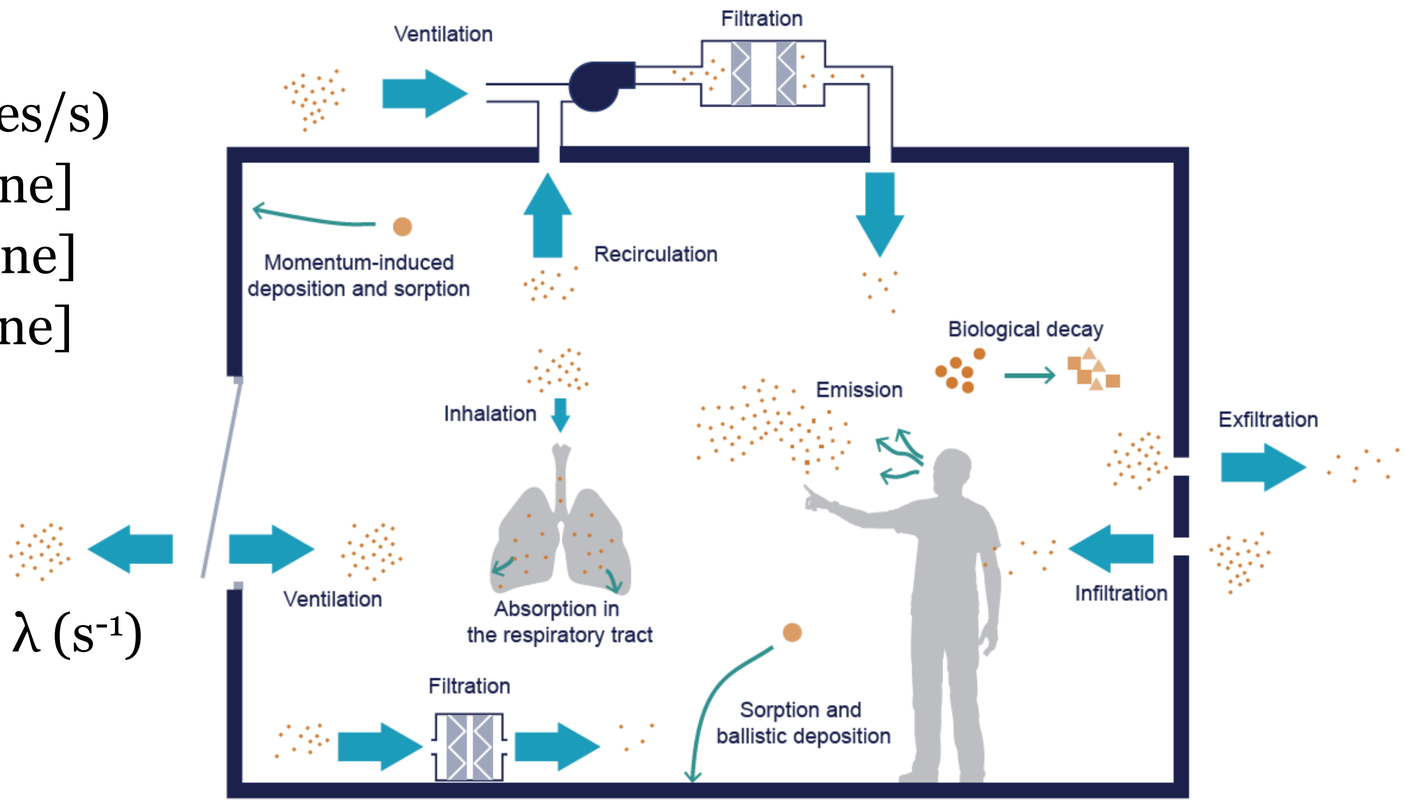
Mass balance

1. Gains
    1. Emission from a person
    2. Entry from outside via ventilation
    3. Entry from outside via infiltration
    4. Virus already present in the space
2. Losses
    1. Dilution via ventilation
    2. Surface deposition
    3. Biological decay and UVC denaturing
    4. Respiratory tract absorption
    5. Filtration



Mass balance

1. Gains
    1. Emission from a person, G (RNA copies/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, $\phi = \psi + \Upsilon + \lambda + \zeta + \omega$

And, ϕ is known as an *equivalent* air change rate

Number of RNA copies inhaled, Σ*n*

For a step response scenario where $n(0)=0$,

$$\sum n = \frac{k q_{sus} G T}{\phi^2 V}\left(T\phi + e^{-\phi T} - 1\right)$$

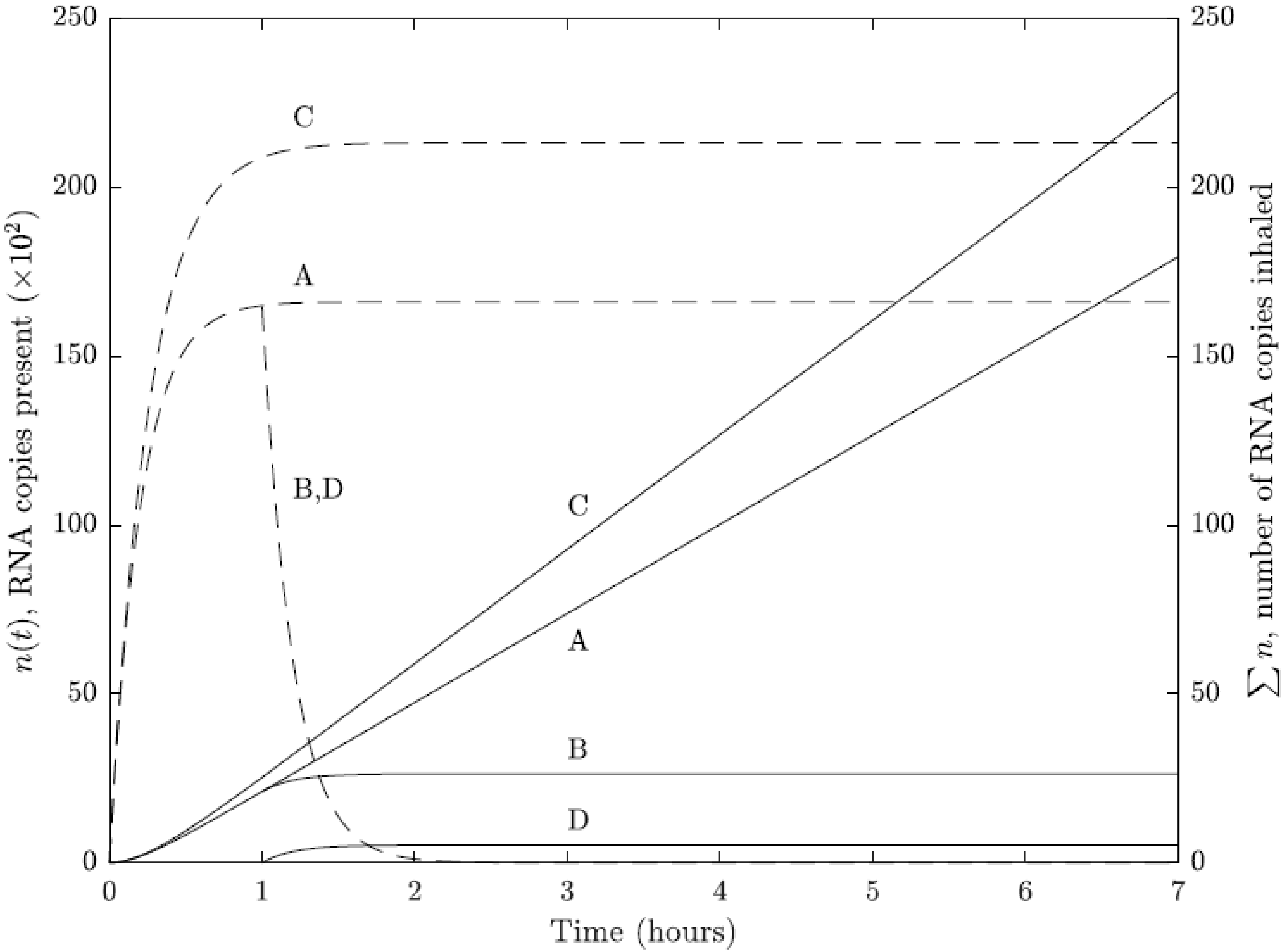
- ***k*** ratio ratio of the number of aerosol particles that are absorbed by the respiratory tract to the total number of aerosol particles that are passed through it [-]
- $\boldsymbol{q_{sus}}$ volume flow rate through the respiratory tract of a susceptible person [$m^3\ s^{-1}$]
- **G** is the emission rate of RNA copies [RNA copies s^{-1}]
- **T** is the exposure period [s]
- **V** is the room volume [m^3]
- $\boldsymbol{\phi}$ is the dilution rate [s^{-1}]

The reference scenario

- School classroom
  - Geometry and ventilation provision described by guidance documents (BB103 and BB101, respectively)
- Minimum floor area of 55m^2 for a junior school
- 30 student and 2 teachers
  - Occupancy density of 1.7m^2 per person
- Floor to ceiling height of 2.7m
  - Volume of 149m^3
- Maximum CO2 concentration of 1500ppm averaged over the school day
  - Corresponds to minimum of 5ls^{-1} per person
- Occupied for 7 hours continuously
  - Models a worst case scenario (like a rainy day with no play time)
- Occupants breathe for 75% of the time and talk for 25% of the time

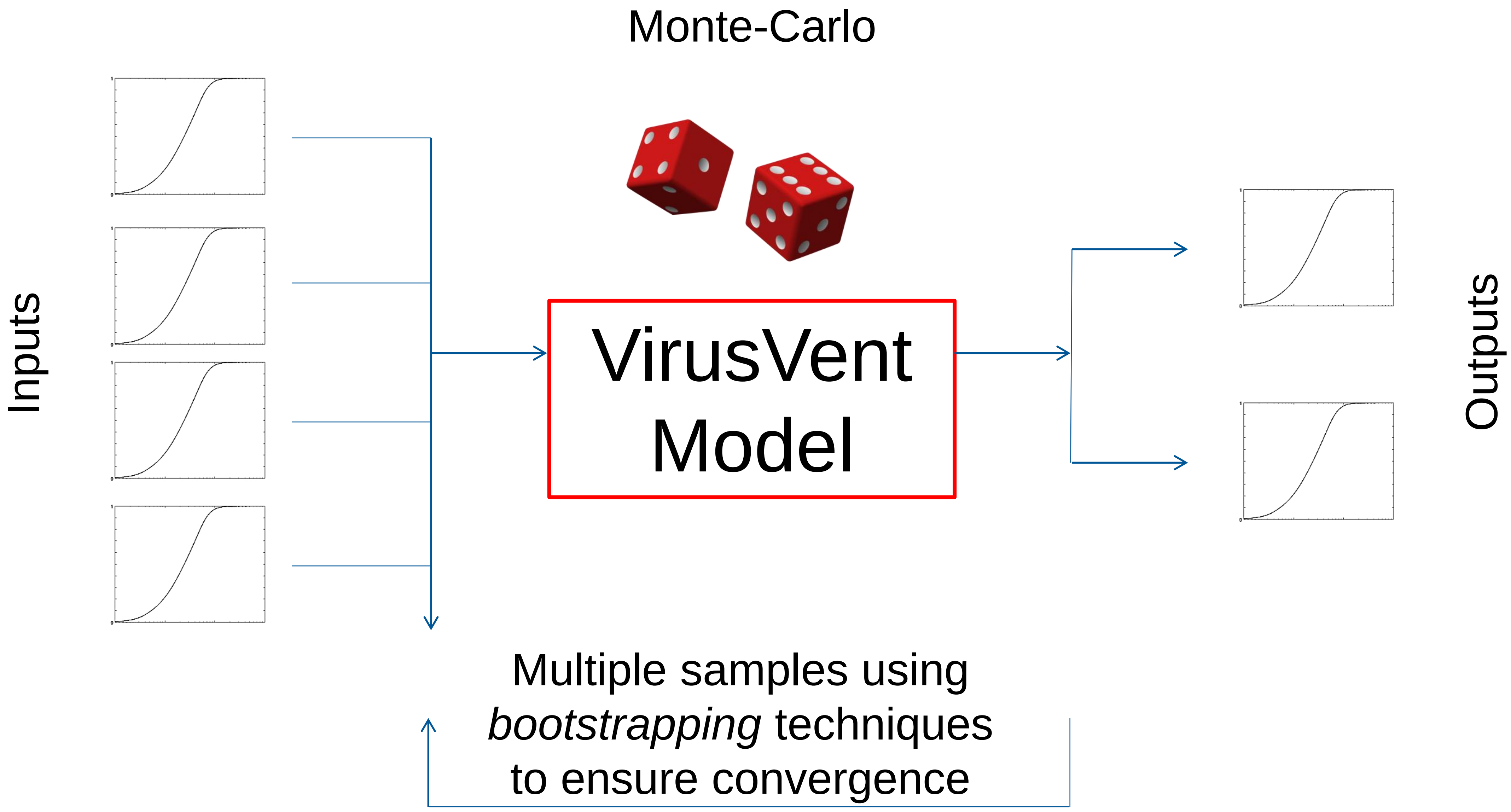
Reference scenario: school classroom

Dashed line



Smooth line

Uncertainty in metrics



Monte-Carlo

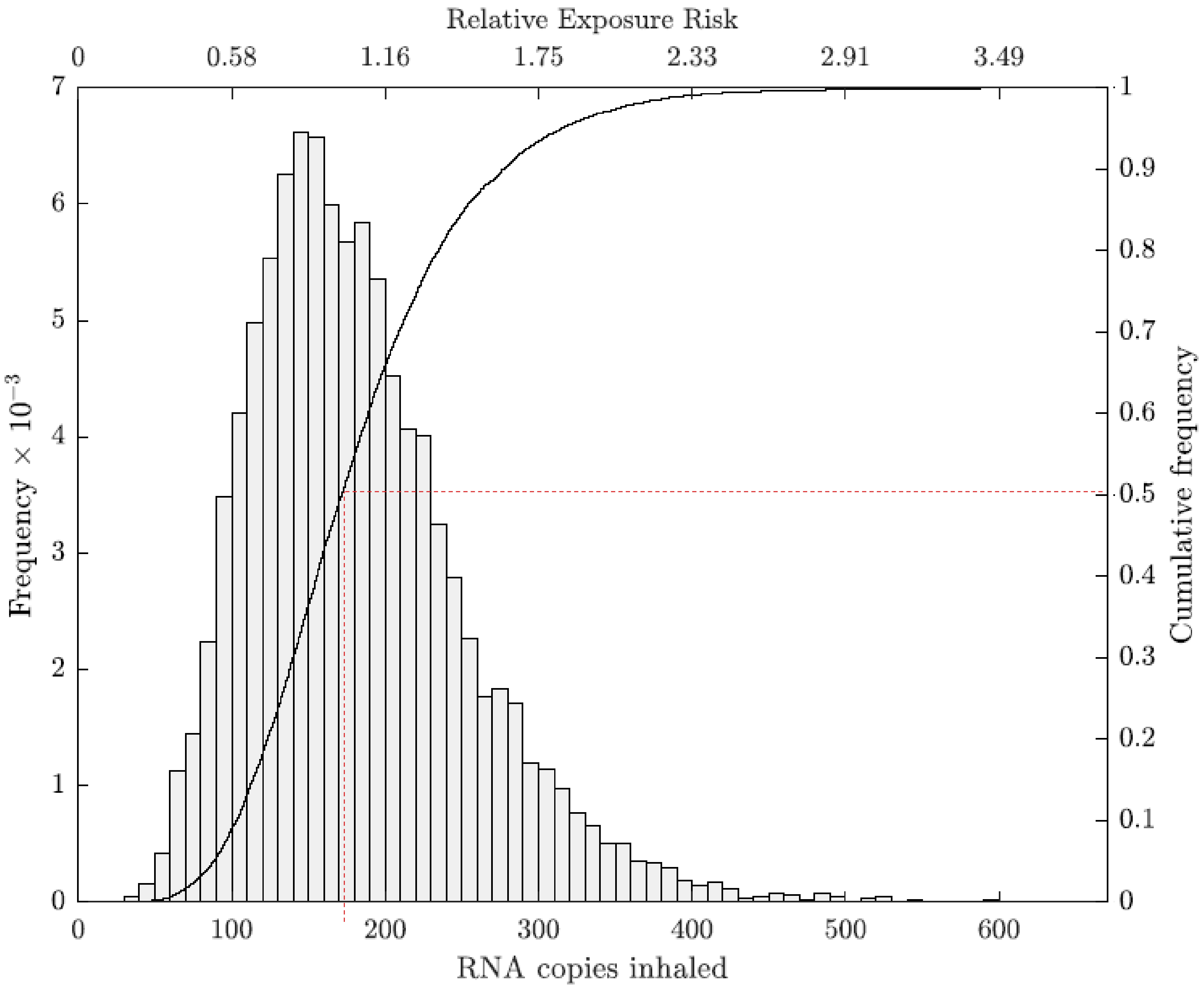
Inputs

VirusVent Model

Outputs

Multiple samples using *bootstrapping* techniques to ensure convergence

Reference scenario



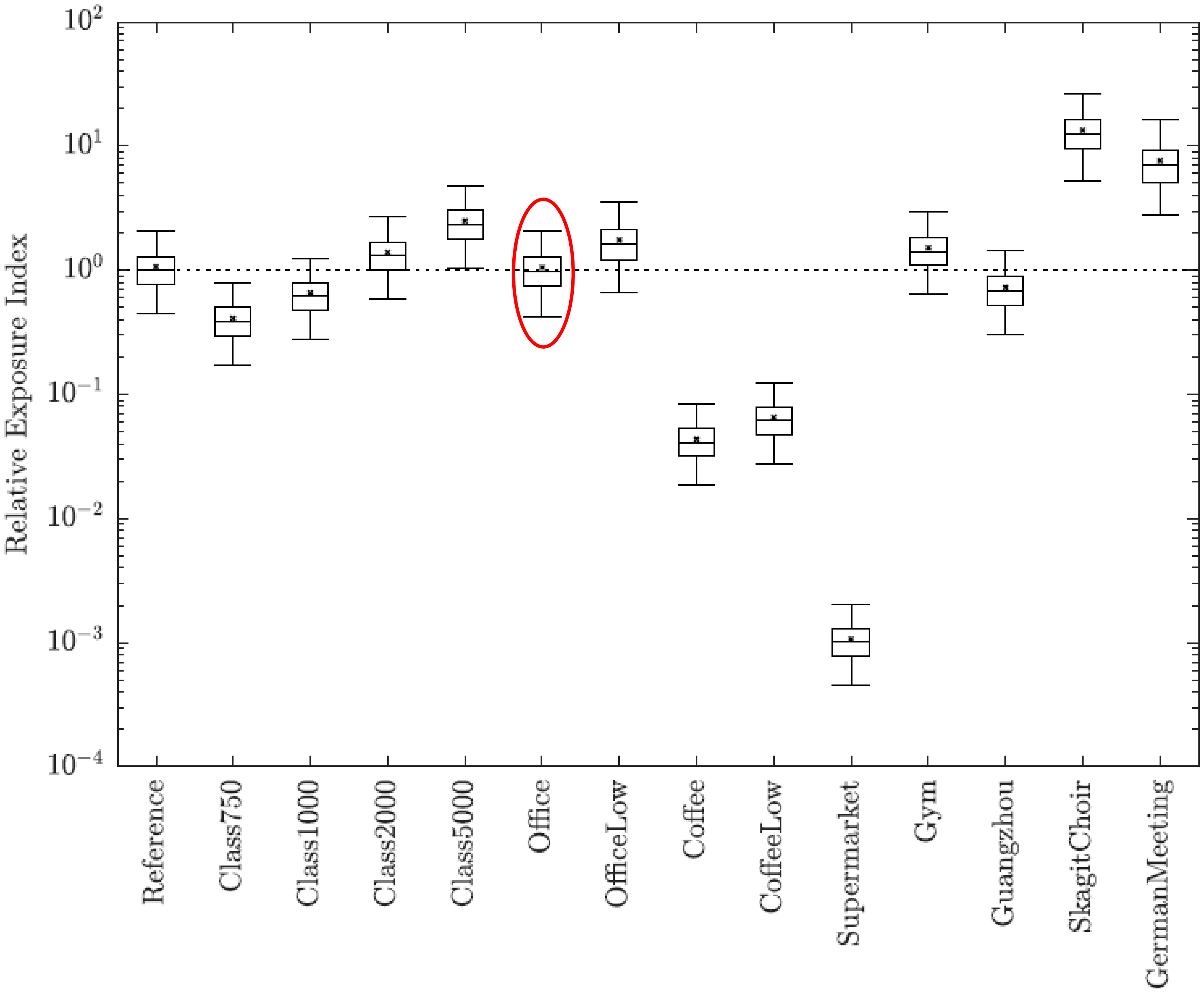
Comparing different scenarios

- To compare two different scenarios we can simply determine the ratio of the $\sum n$ predicted for each scenario
- This gives a *Relative Exposure Index* (REI) where

$$\mathrm{REI} = \frac{\sum n_2}{\sum n_1}$$

- Then if $\sum n_1$ is a reference scenario,
  - REI>1 indicates a higher exposure risk
  - REI=1 indicates identical exposure risk
  - REI<1 indicates a lower exposure risk

Relative Exposure Risk [all scenarios]



Key findings

1. Uncertainty in our predictions is high
2. The REI is a measure of the risk of a space relative to the geometry, occupant activities, and exposure times of the reference scenario
3. The REI **is not** a measure of the probability of infection
4. Σn is effected by the
   - The emission rate of RNA copies
   - Respiratory rate of a susceptible person
   - The exposure time
   - Space volume
   - Removal rate

Key findings

5. A sensitivity analysis shows it is most sensitive to the emission rate
6. Activities such as exercise and singing increase the emission rate
7. To achieve REI≤1, a space must preserve the removal rate of the reference scenario (0.21m^3/s *per infected person*) as a *minimum* rate irrespective of the number of people present
8. Using a fixed air change rate will lead to REI>1 when the volume is smaller than that of the reference space
9. Using *per capita* flow rates can only be used with a minimum airflow rate
10. Therefore, using CO_2 sensors is problematic in some circumstances, particularly if a space is under-occupied or the volume is large

Sources of information

- Supporting paper: dx.doi.org/10.13140/RG.2.2.16867.99361
- CIBSE: https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q3Y00000HsaFtQAJ
- ASHRAE: https://www.ashrae.org/technical-resources/resources
- REHVA: https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V3_03082020.pdf
- AIVC: https://www.aivc.org/keywords/sars-cov-2
- EMG report: https://www.gov.uk/government/publications/emg-role-of-ventilation-in-controlling-sars-cov-2-transmission-30-september-2020
- NIST CO_2 Metric Analysis Tool: https://pages.nist.gov/CONTAM-apps/webapps/CO2Tool/#/
- Longer version of the talk via CIBSE #WeChampion: https://tinyurl.com/jaxu9mf3

The End

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