Infection modelling from CO_2 measurements

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Before the 2020-2021 academic year:

What role do schools play in COVID-19 transmission ?

Can the risk of airborne transmission be estimated ?

What is the effect of seasons ?

COVID-19 transmission routes

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CONTACT OR TOUCH

DROPLET OR SPRAY

AEROSOL OR AIRBORNE

- Focus on far-field airborne transmission.
- Small infected respiratory droplets and aerosols remain suspended.
- Mixed and transported by ventilation.

Assessing the risk of airborne infection

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Wells-Riley for steady state:

$$P_I = 1 - \exp\left(-\frac{Iqpt}{Q}\right)$$

- q: quanta generation rate
- I: number of infected people
- p: pulmonary ventilation rate
- Q: room ventilation rate
- t: exposure time

- Number of infectious airborne particle required to infect someone
- Varies with disease, individual and activity levels
- Has to be estimated from the analysis of outbreaks

Rudnick & Milton (2003):

$$P = 1 - \exp\left[\frac{I}{N} q \int_0^T f(t)dt\right]$$

- N: number of occupants
- f : rebreathed fraction

CO_2 measurements

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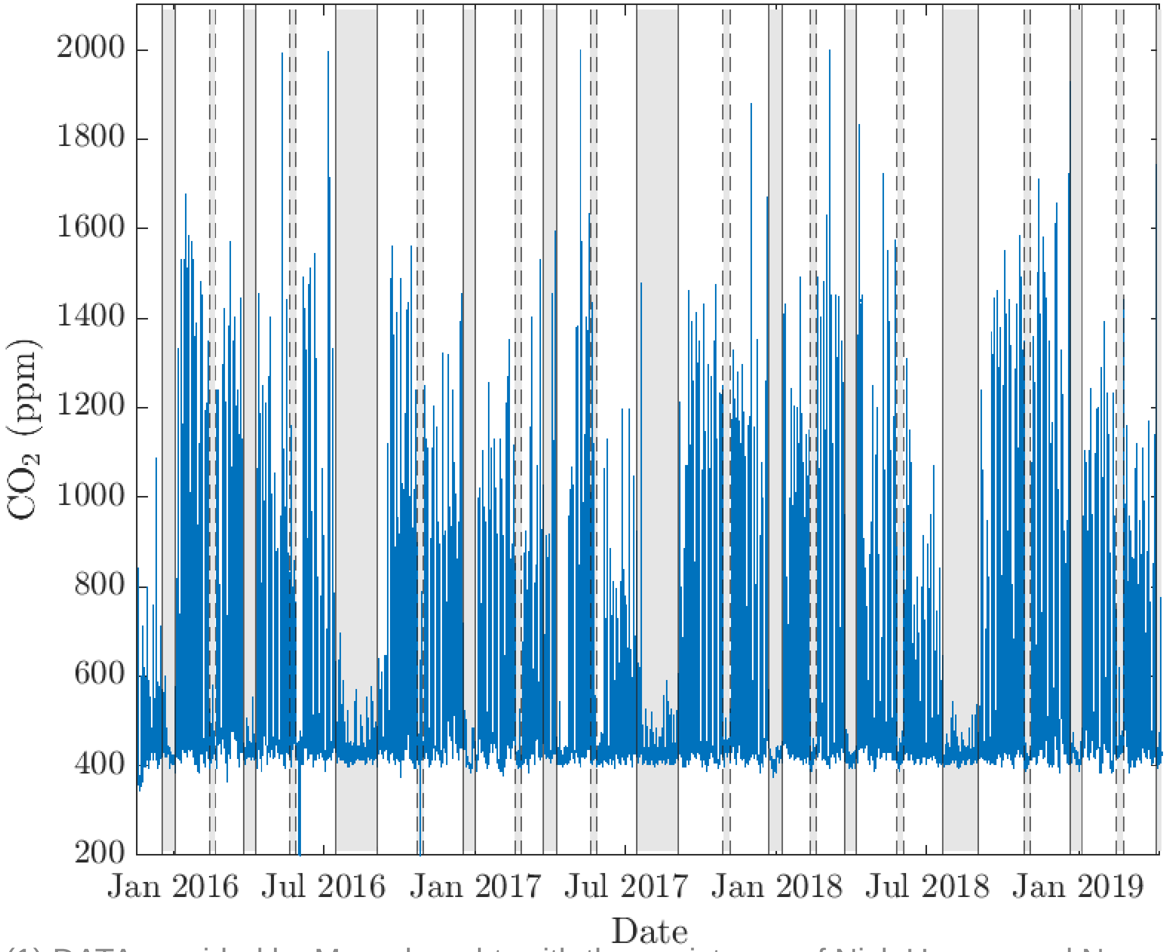

- Rebreathed fraction $f = \frac{C - C_{out}}{C_a}$
- C : measured CO_2.
- C_{out} : ambient CO_2 (average between 05:00 and 06:00).
- C_a : CO_2 in the exhaled breath (=37,500 ppm).
- Measurements obtained for 45 classrooms in England(1)

School	Type	County	Rooms	Data span
1	Primary	Yorkshire	22	Nov/15 – Mar/19
2	Secondary	Berkshire	1	Nov/19 – Mar/20
3	Primary	Somerset	1	May/17 – Mar/18
4	Primary	Surrey	1	Dec/17 – May/18
5	Primary	Cambridgeshire	2	Aug/17 – Jan/18
6	Primary	Not disclosed	3	Dec/18 – Feb/19
7	Primary	Essex	4	Oct/16 – Dec/17
8	Secondary	Kent	1	Mar/18 – Apr/19
9	Primary	Surrey	4	Aug/17 – Aug/18
10	Primary	Kent	1	Aug/17 – Jul/18
11	Secondary	Hertfordshire	5	Sep/18 – Mar/20

(1) DATA provided by Monodraught, with the assistance of Nick Hopper and Nyssa Hayes, and by the K2n platform, with the assistance of Professor Ian Knight.

Airborne infection risk for variable occupancy

Rudnick and Milton (2003) for monitored transient environmental conditions:

$$P = 1 - \exp\left[\frac{I}{N} q \int_0^T f(t)dt\right]$$

But occupancy N will vary.

If we assume every occupant is equally likely to be infected:

$$P = 1 - \exp\left[q \int_0^T \frac{I(t)}{N(t)} f(t)dt\right]$$

Number of secondary infections

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- Adapted from Rudnick & Milton (2003), likelihood of infection when the space is occupied (0 otherwise):

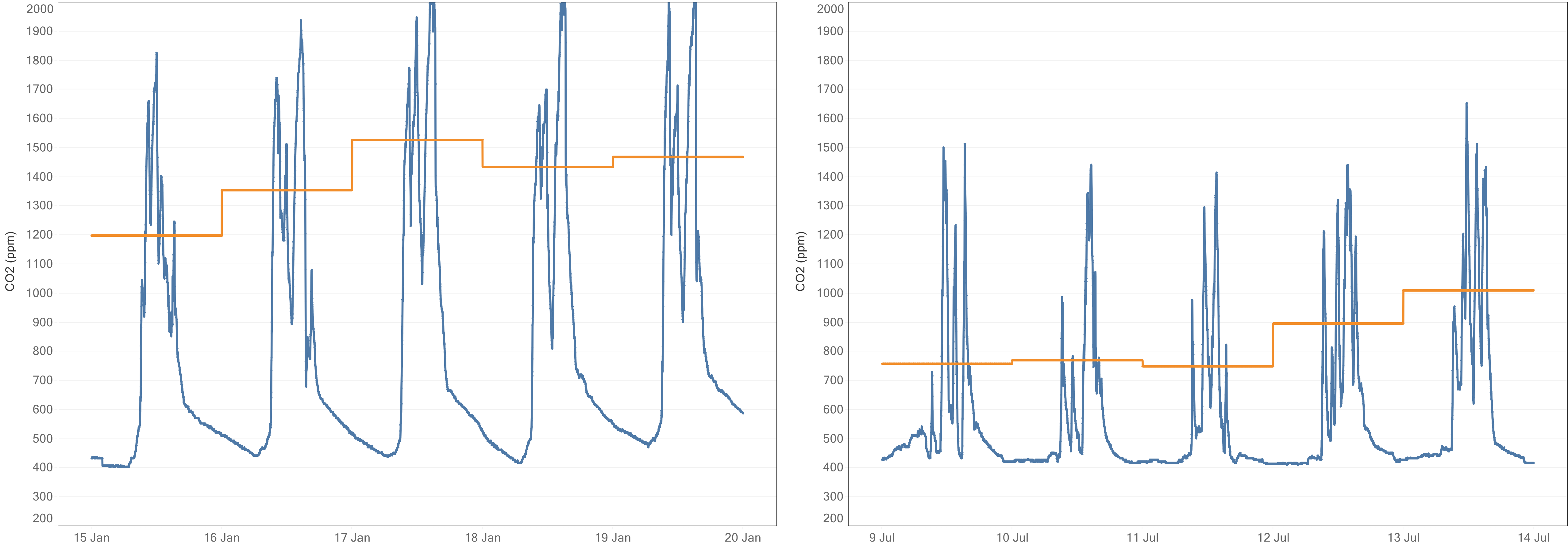
$$P_A = 1 - \exp\left(-\int_0^T \frac{1}{N(t)}\, f\, q\, dt\right)$$

- N: total number of occupants (32 in a UK classroom)
- q: quanta generation rate (1 quanta/hr from Buonanno *et al.*, 2020)
- f : rebreathed fraction
- T: exposure time (5 weekdays)

Number of secondary infections: $S_I = (N-1)P_A$

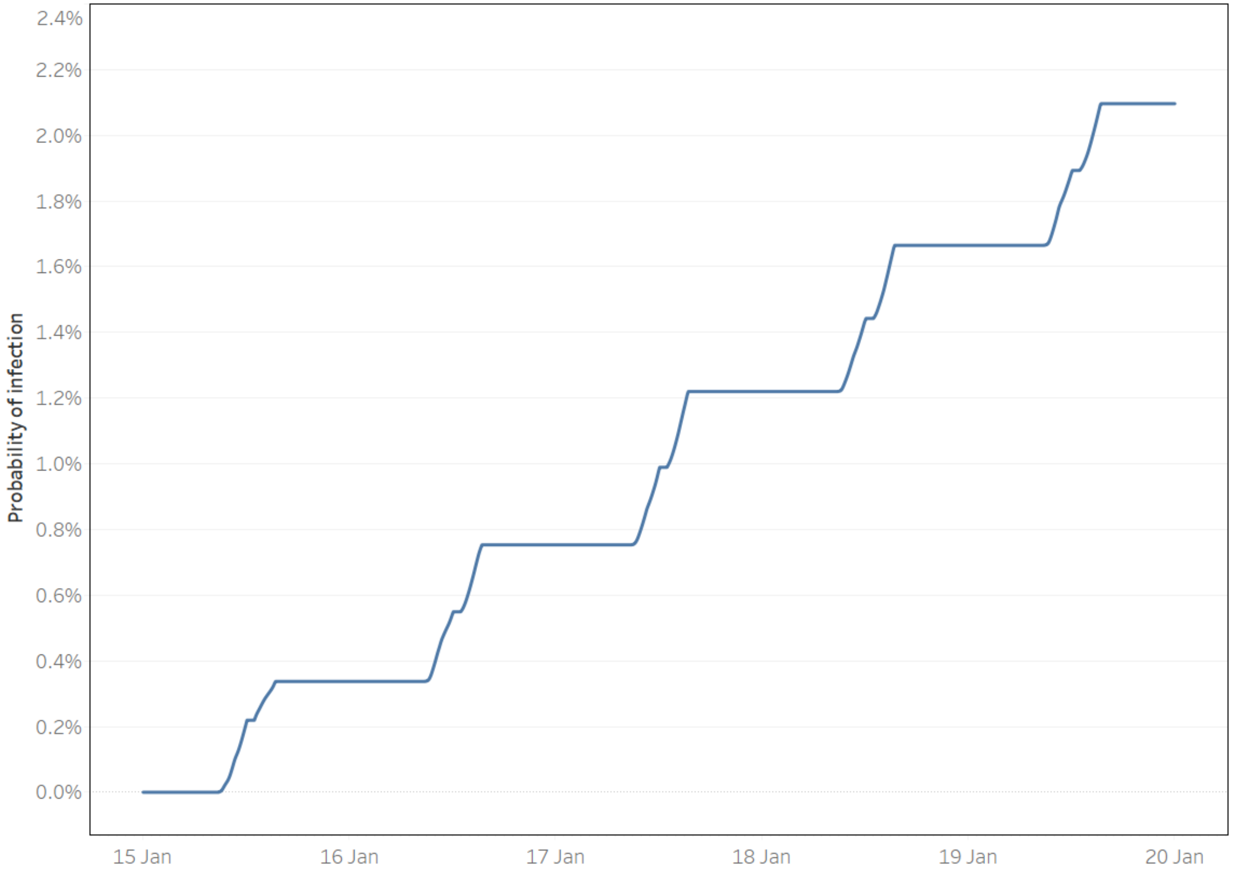
Example over a week (January and July 2018)

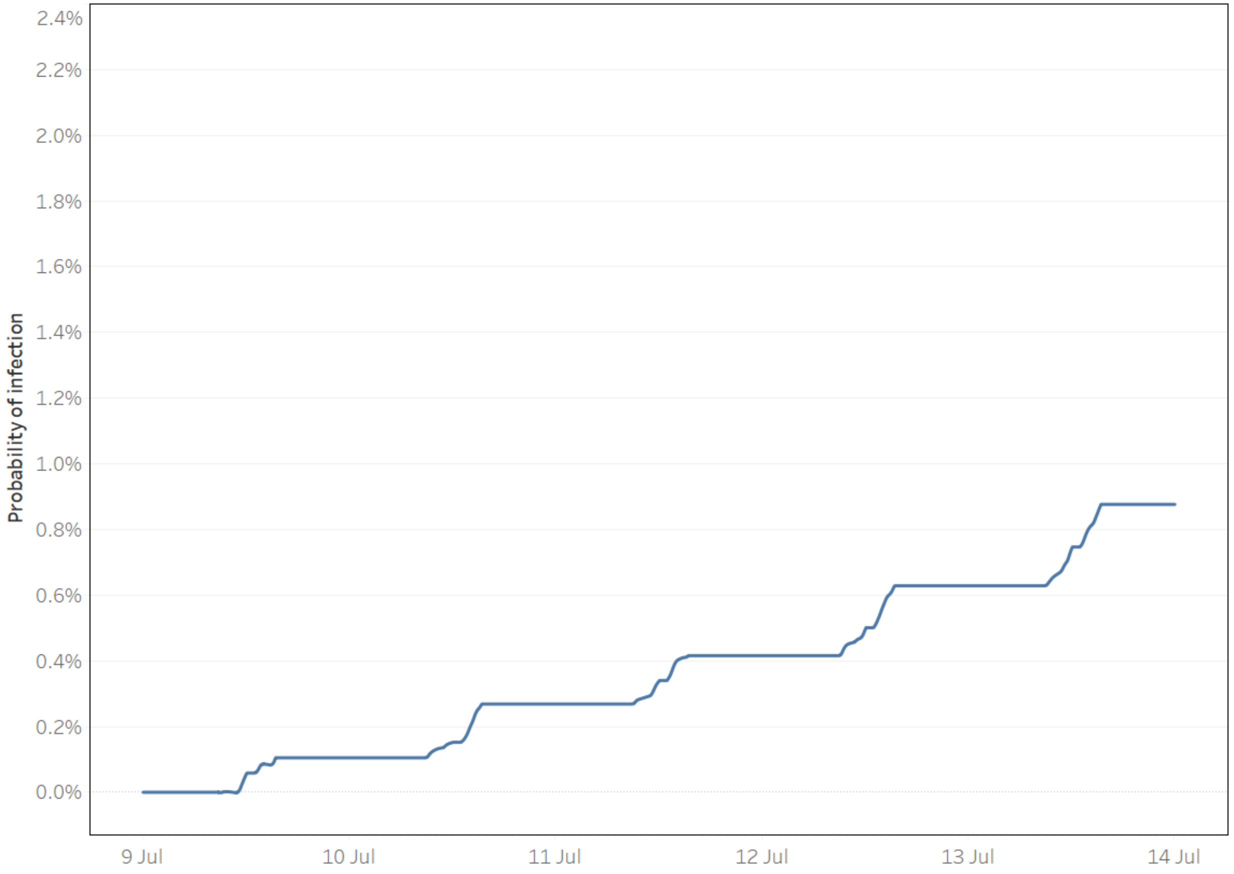
CO_2 variations in a given classroom. Daily average is shown in orange.



Example over a week (January and July 2018)

Calculated probability of infection in a given classroom.





Variations within a school

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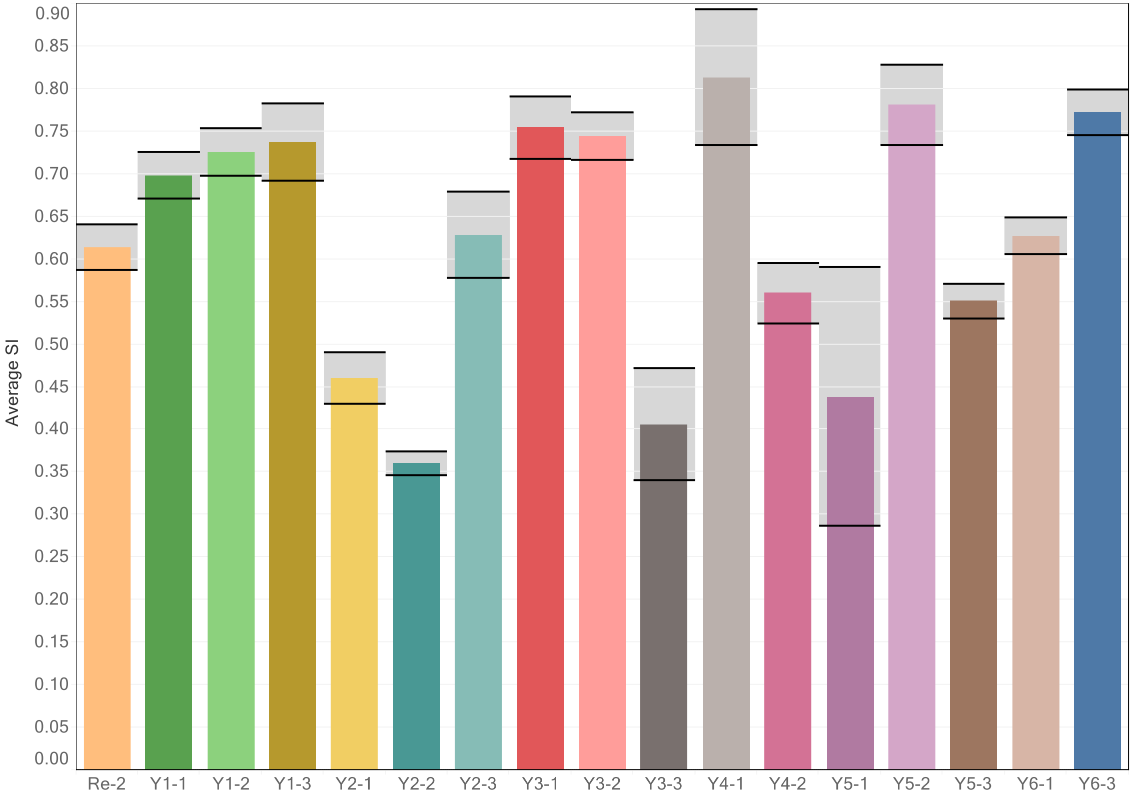
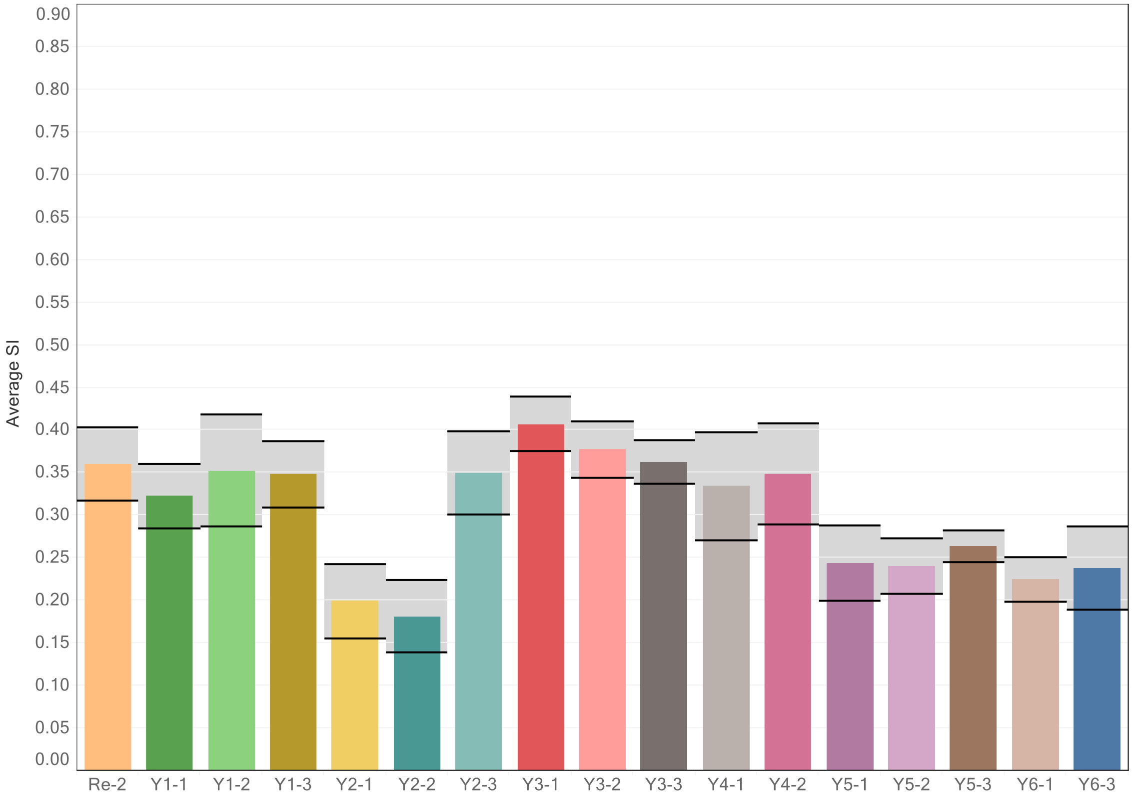
Classrooms within the same building and supplied with the same ventilation system



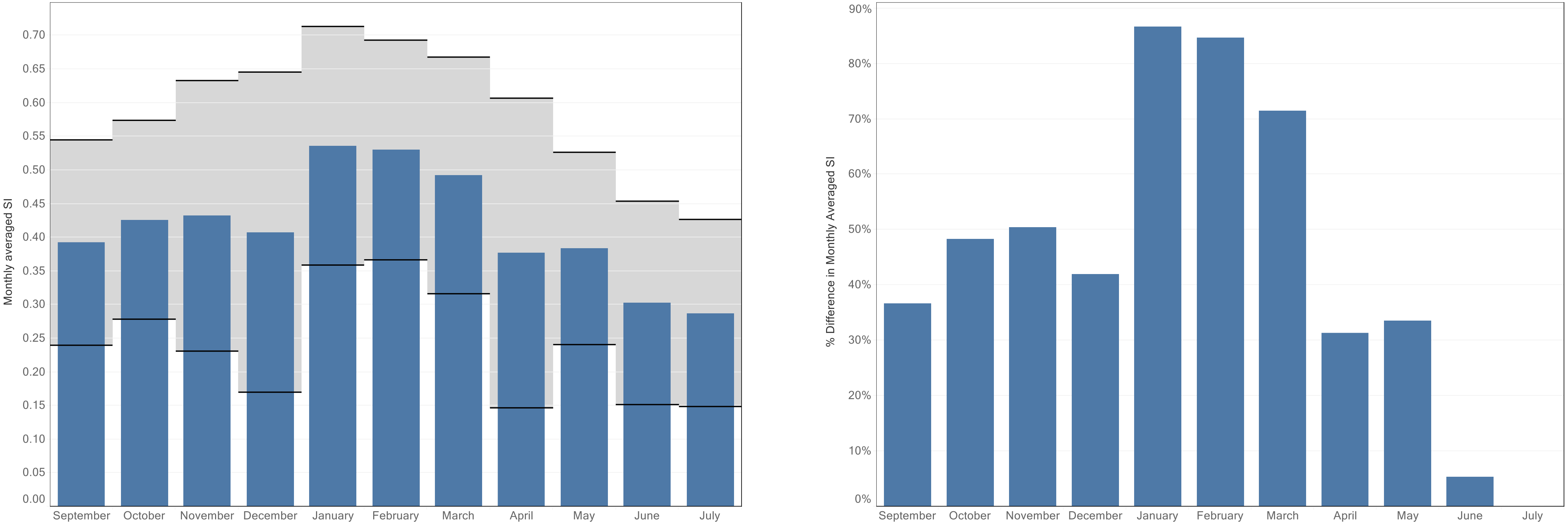


Average number of secondary infections in each classroom in January (left) and July (right) 2018.

Standard deviations are shown in grey.

Seasonal variations

Due to changes in environmental conditions

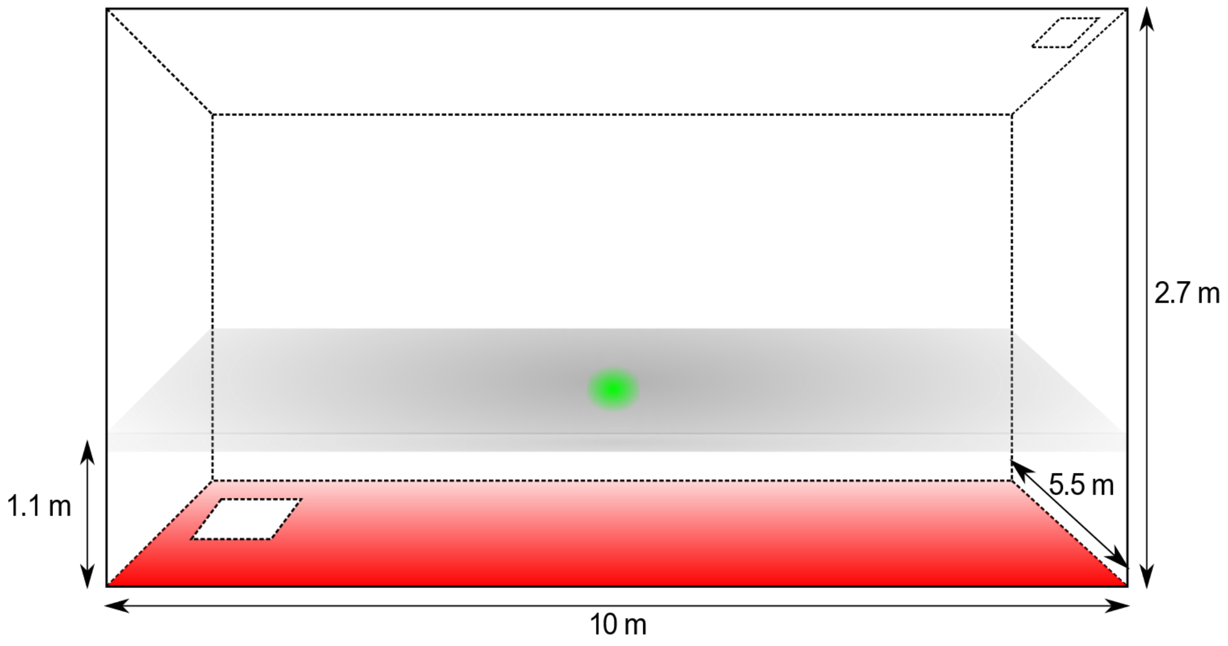


Absolute (left) and relative (right) monthly averaged number of secondary infections in all 45 classrooms over the period November 2015 to March 2020.

- More details here: Vouriot, C.V.M., Burridge, H.C., Noakes, C.J. and Linden, P.F., 2021. Seasonal variation in airborne infection risk in schools due to changes in ventilation inferred from monitored carbon dioxide. *Indoor Air*. https://doi.org/10.1111/ina.12818

Current work: How good a proxy is CO_2 ?

- OpenFOAM RANS simulations
- Primary school classroom (32 occupants)
- Naturally ventilated through high- and low-level openings
- In wintertime (ambient temperature 5ºC)
- Distributed heat input of 6.2 kW at low-level, representative of people & heating required for a thermally comfortable classroom
- Passive scalars to represent CO_2 / infected breath at breathing height



→How does CO_2 distribution vary within the room?

→How does **far-field** exposure to infected breath change with source location ?

Set up overview

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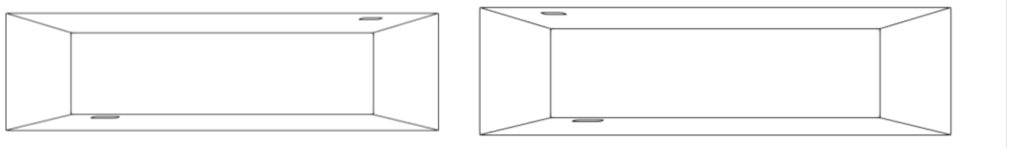
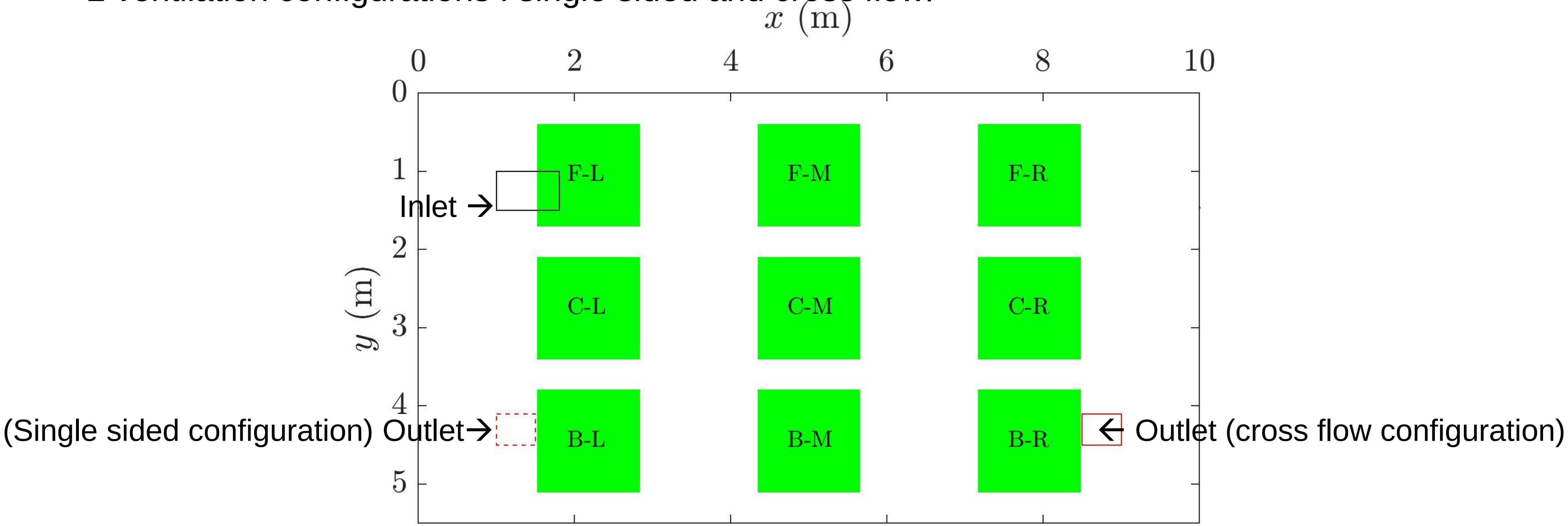


2 ventilation configurations : single sided and cross flow.



At the breathing height 10 scalars are introduced: 9 infected breath scalars + 1 background scalar. Overall gives the CO_2 distribution.

Comparing ventilation set ups

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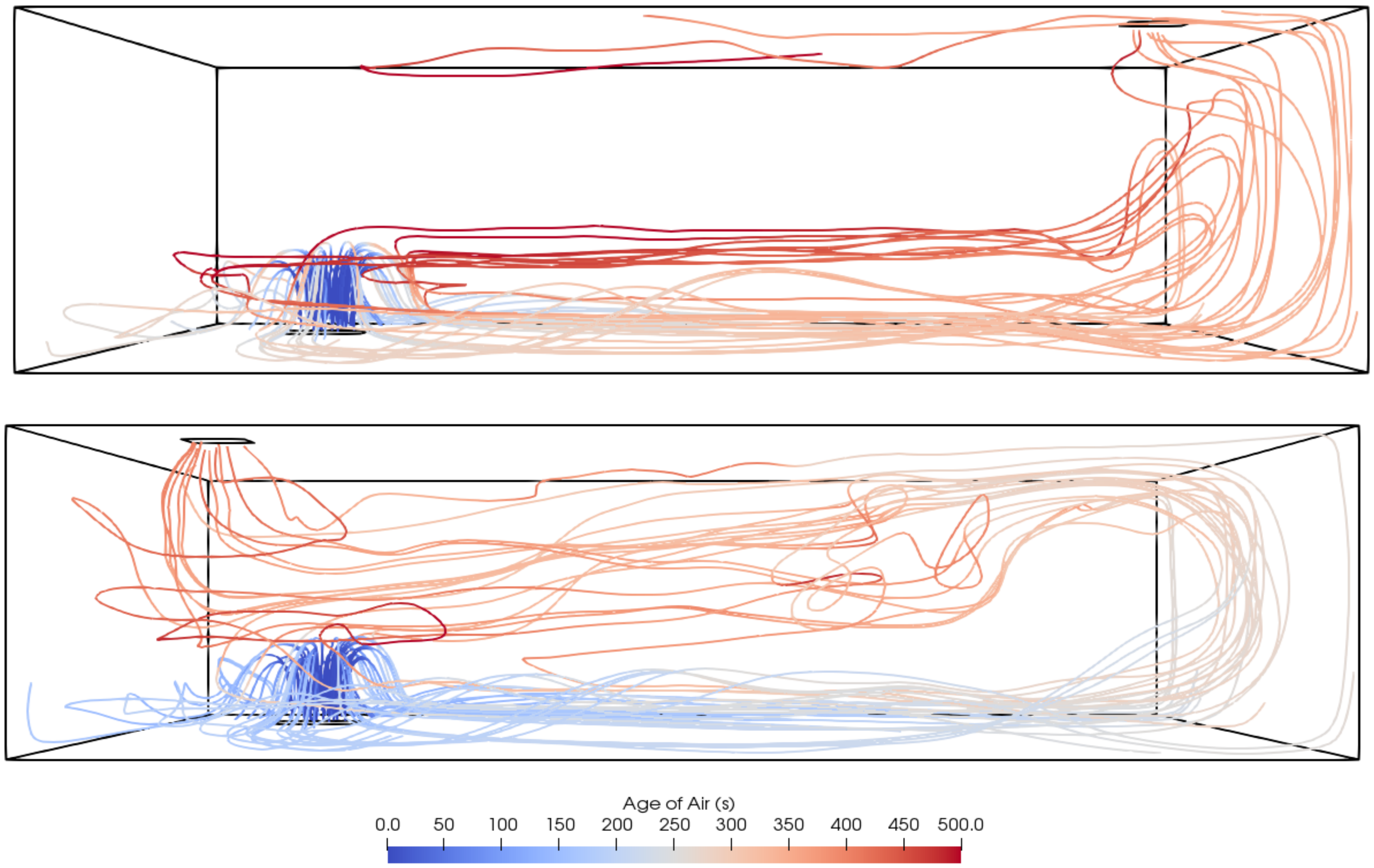

Cross flow (top)
Single sided (bottom)

CO_2 room average 822 ppm
8.3 L/s/person

CO_2 room average 828 ppm
8.3 L/s/person

Current work

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How representative is a single CO_2 measurement ?

Where should the sensors be placed ?

Is CO_2 a good proxy for **far-field** exposure to infected breath ?

How does this change with the location of infected breath?