Airborne COVID transmission and AQ

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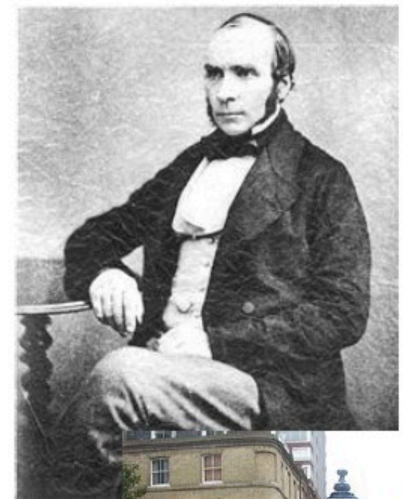
Environment and Health

- 1850’s: Miasma theory – diseases caused by “bad air”
- 1854: Cholera outbreak in Soho area of London
- John Snow mapped cases and realised geographical significance
- Removal of handle from Broad Street pump stopped outbreak
- Proved Cholera is water-borne

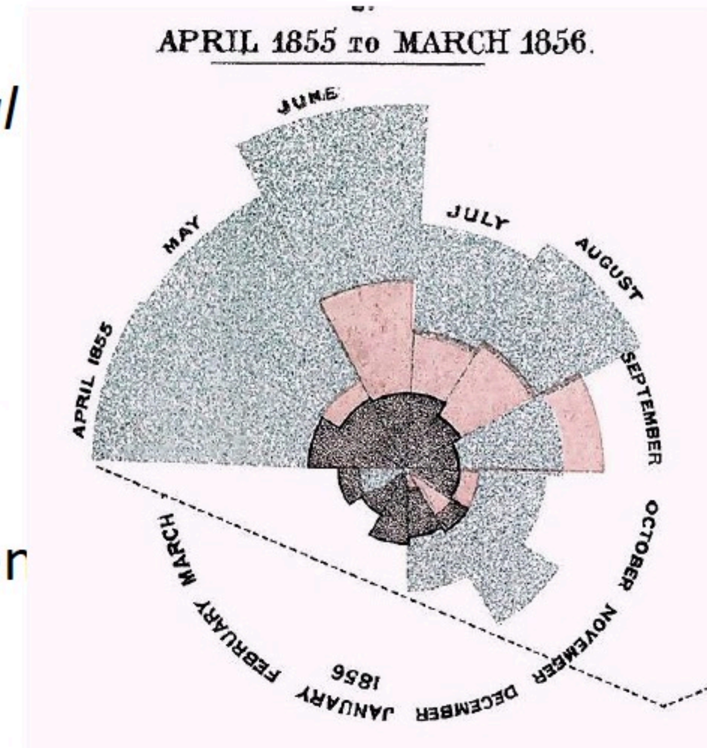


Indoor air and health

"…..the very first requirement in a hospital is that it should do the sick no harm"

Florence Nightingale, 1859, Notes on Hospitals

- High ceilings, natural light, ventilation, bed spacing in hospitals
- Social reformer supporting improvemen in sanitary living conditions
- Pioneer of statistical methods



Nightingale rose diagram

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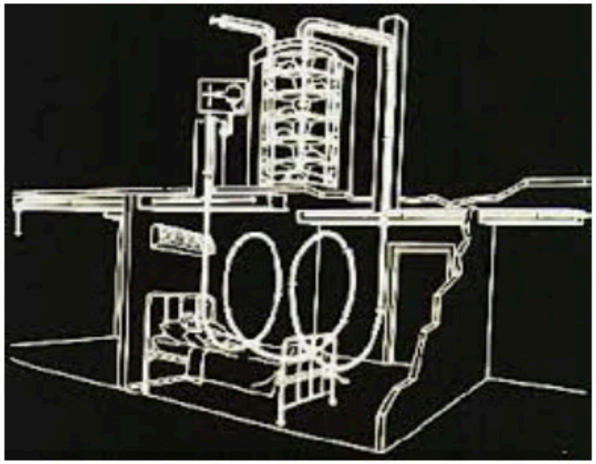
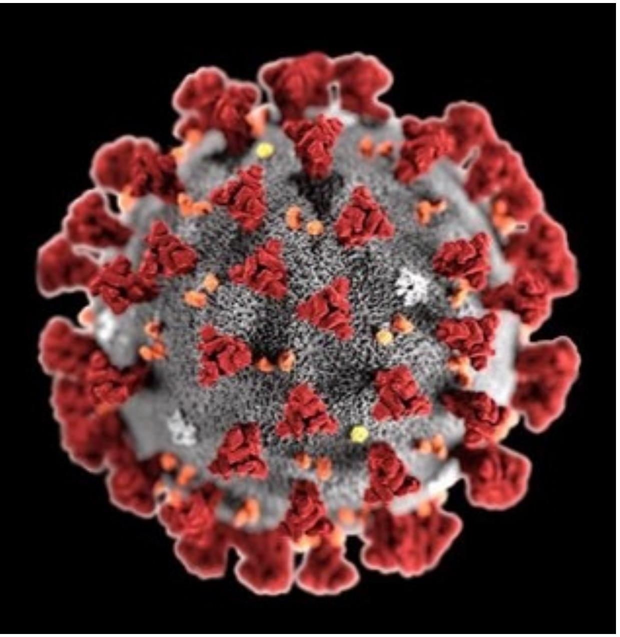
Airborne Transmission

- TB suspected airborne disease
- Wells – 1934 proposed concept of a “droplet nuclei”
- Riley and Wells TB Baltimore study – 1958-1962
  - Ward air extracted and passed through guinea pig houses
  - 134 infected over 4 years
  - Proof that TB is airborne
  - Also showed that UV air disinfection is a potential control



Infection risks in schools



- What roles do schools play ?
- How do you estimate risk ?
- What is the effect of seasons ?

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Assessing the risk of airborne infection

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) :

$$P = 1 - \exp\left(\frac{\bar{f}Iqt}{N}\right)$$

- N: number of occupants
- f : rebreathed fraction

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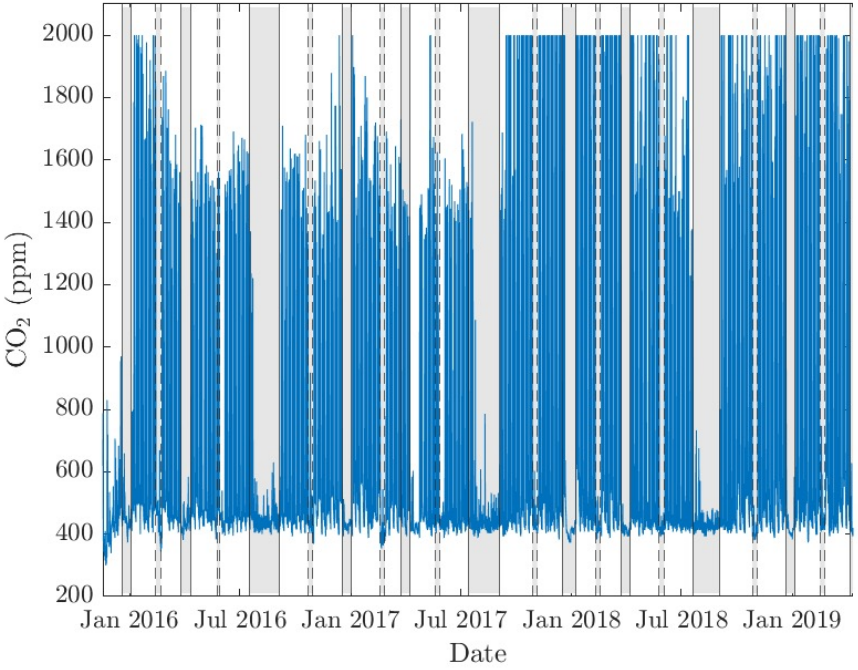
CO_2 measurements



- 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.

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Number of secondary infections

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

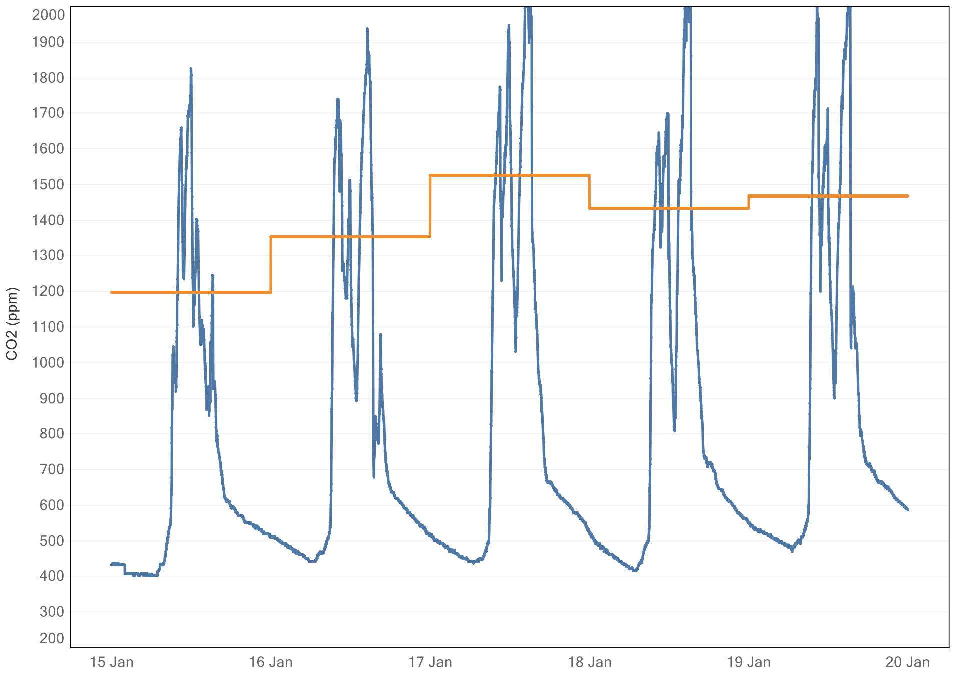
$$P_A = 1 - \exp\left(-\frac{1}{N}\int_0^T f\, q\, dt\right)$$

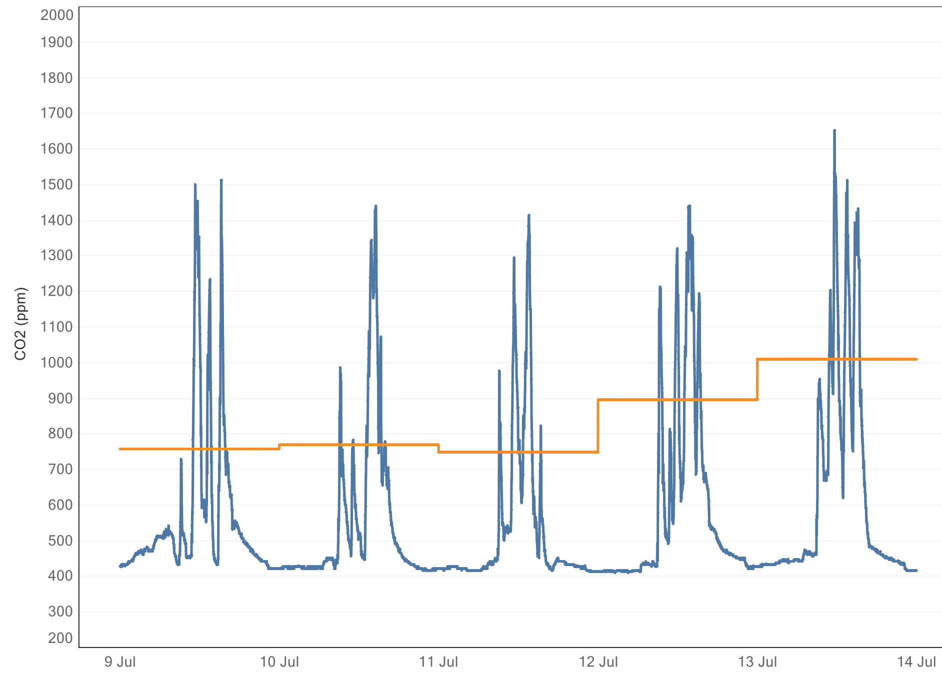
- N: total number of occupants (32 in a UK classroom)
- q: quanta generation rate (1 quanta/hr from Buonanno *et al.,* 2020)
- T: exposure time (5 weekdays)
- f : rebreathed fraction

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.





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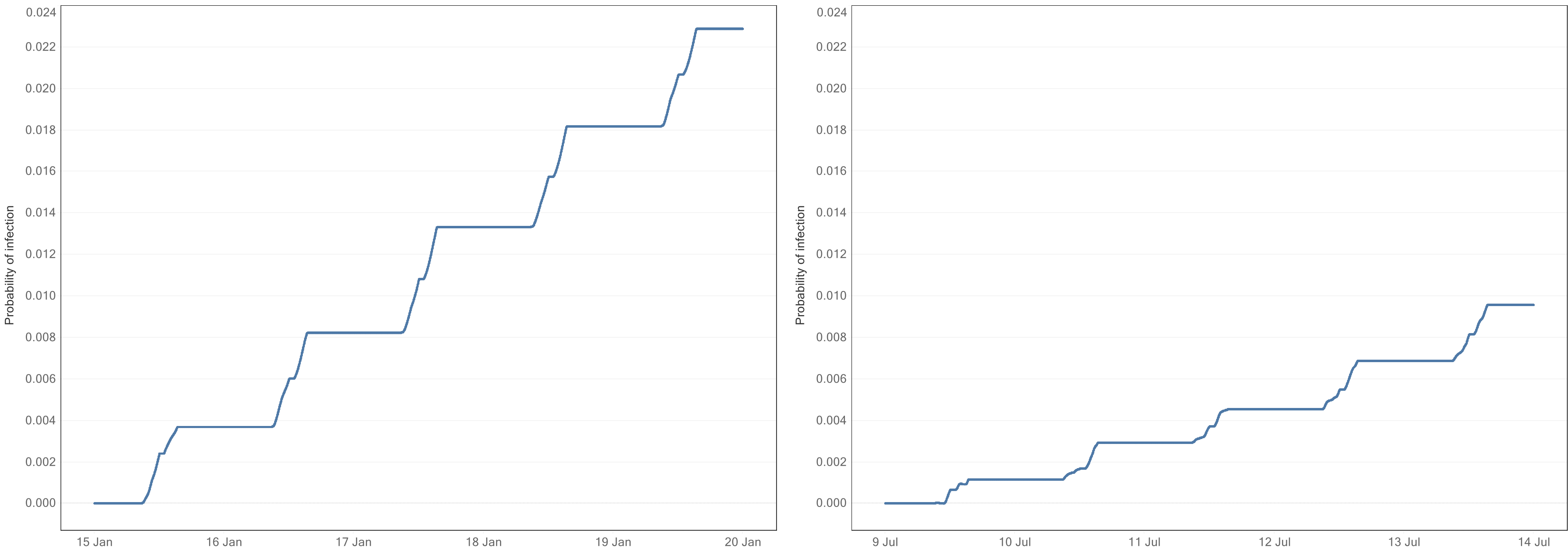
Example over a week (January and July 2018)

Calculated probability of infection in a given classroom.



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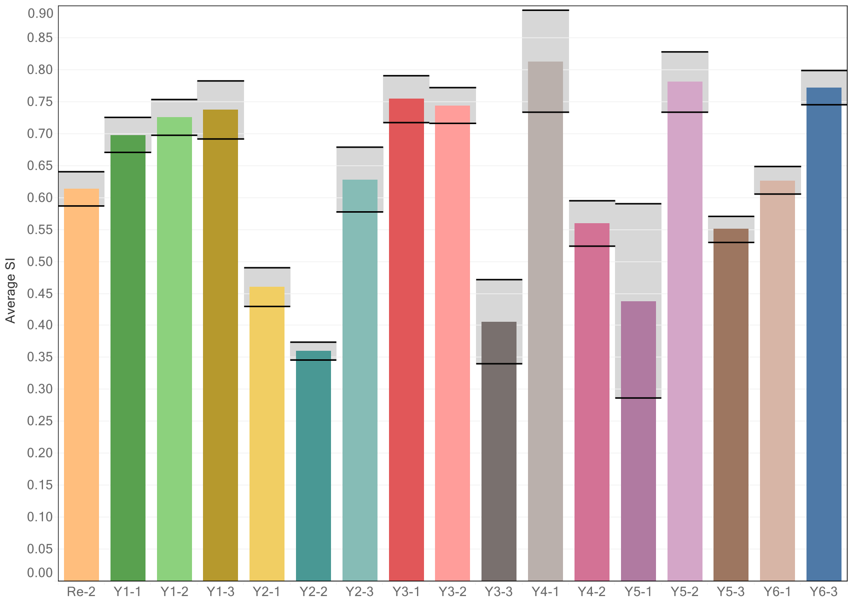
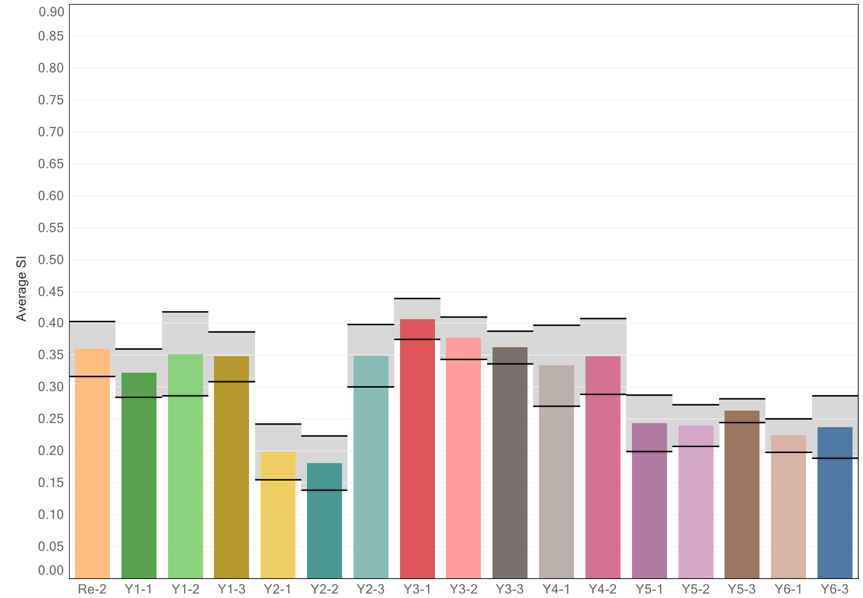
Variations within a school

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.

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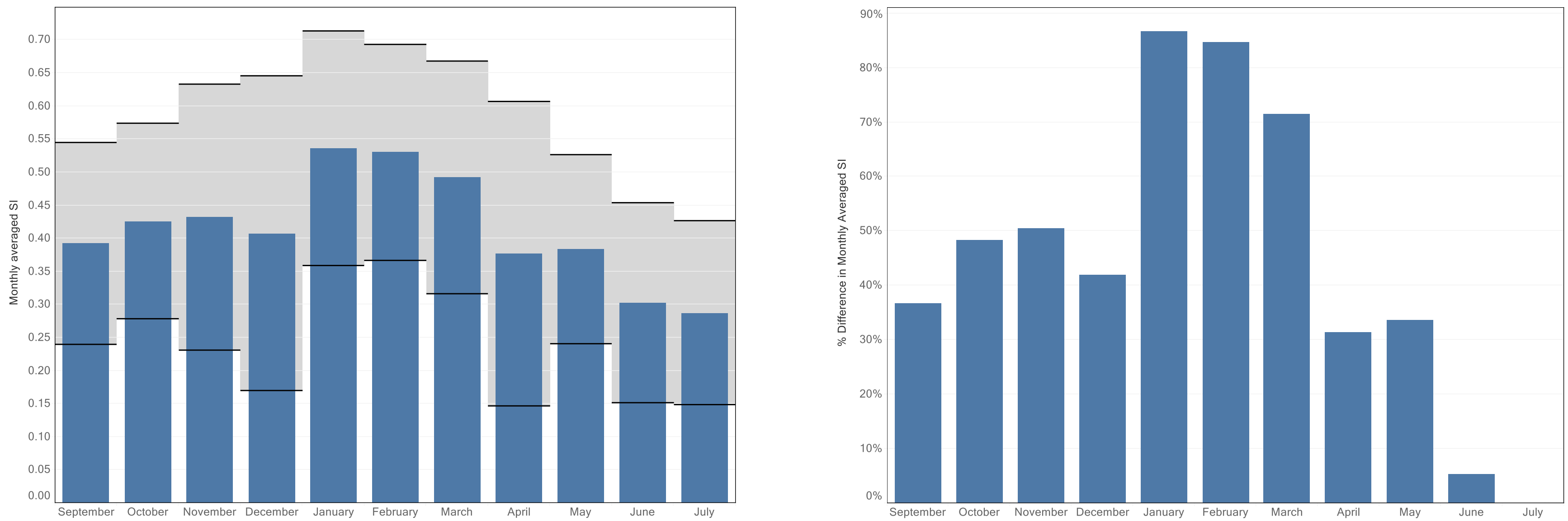
Seasonal variations

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

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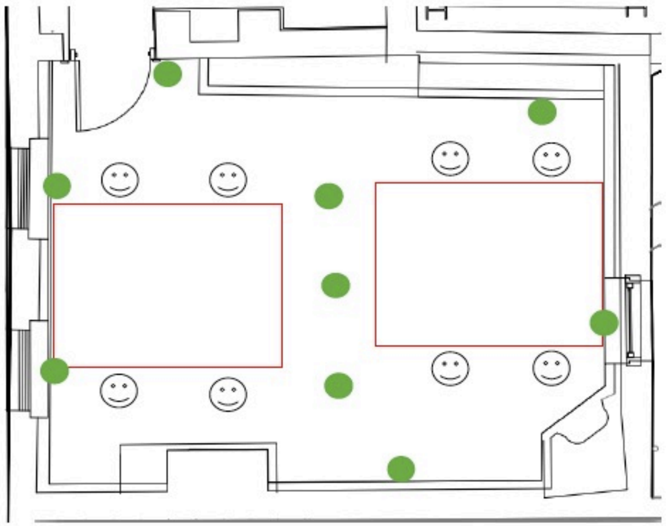
Case study room

Sensor Network



Indoor Sensor Network

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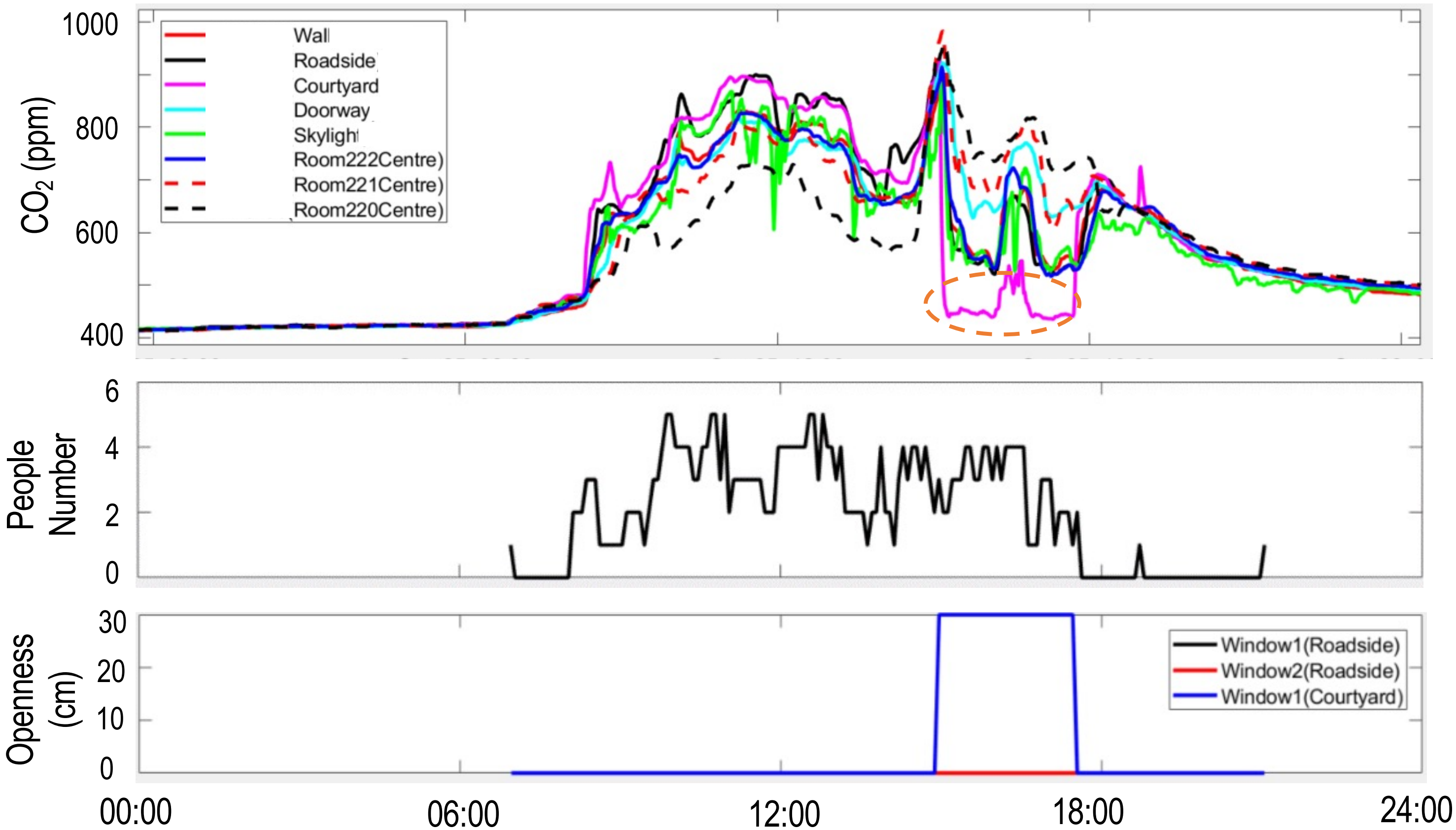
Indoor CO_2 – Single-sided Ventilation



- CO2 highly correlates to the number of occupants in the room
- CO2 reduction is clear when the window is open and CO2 by the window is close to outdoor
- CO2 spatial variation is observed

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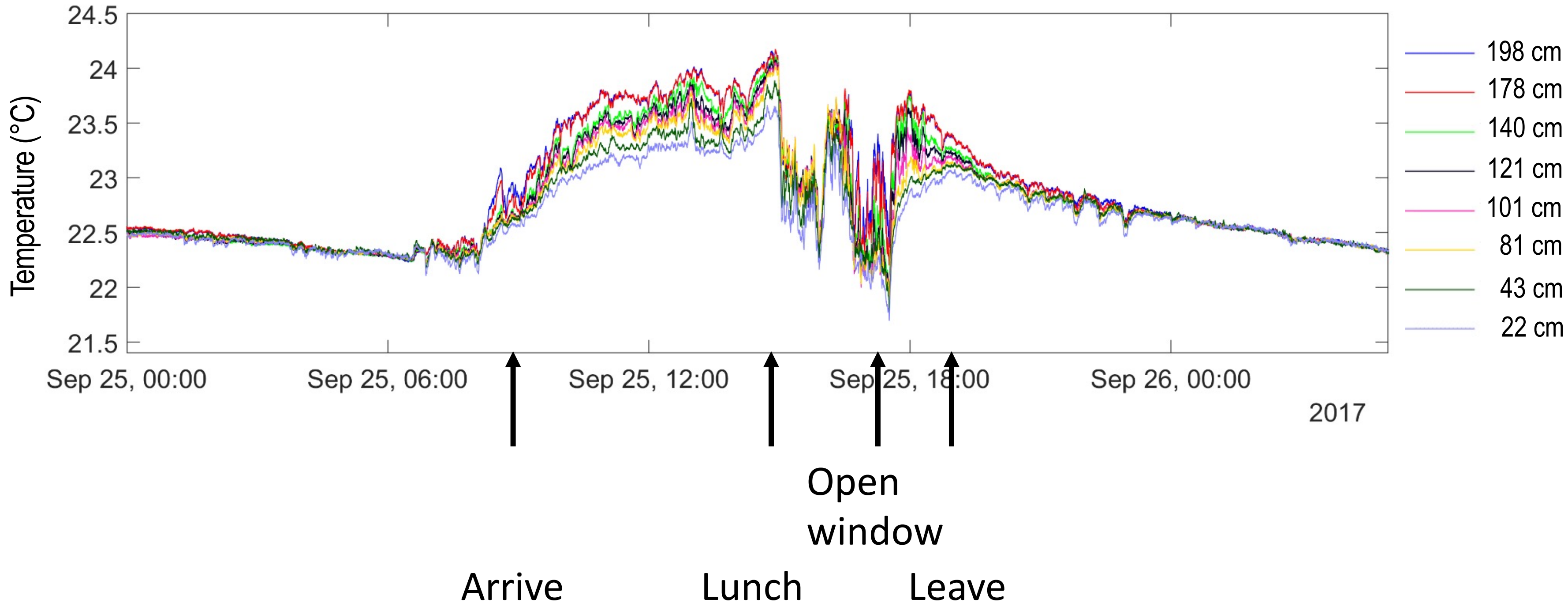
Thermal Stratification



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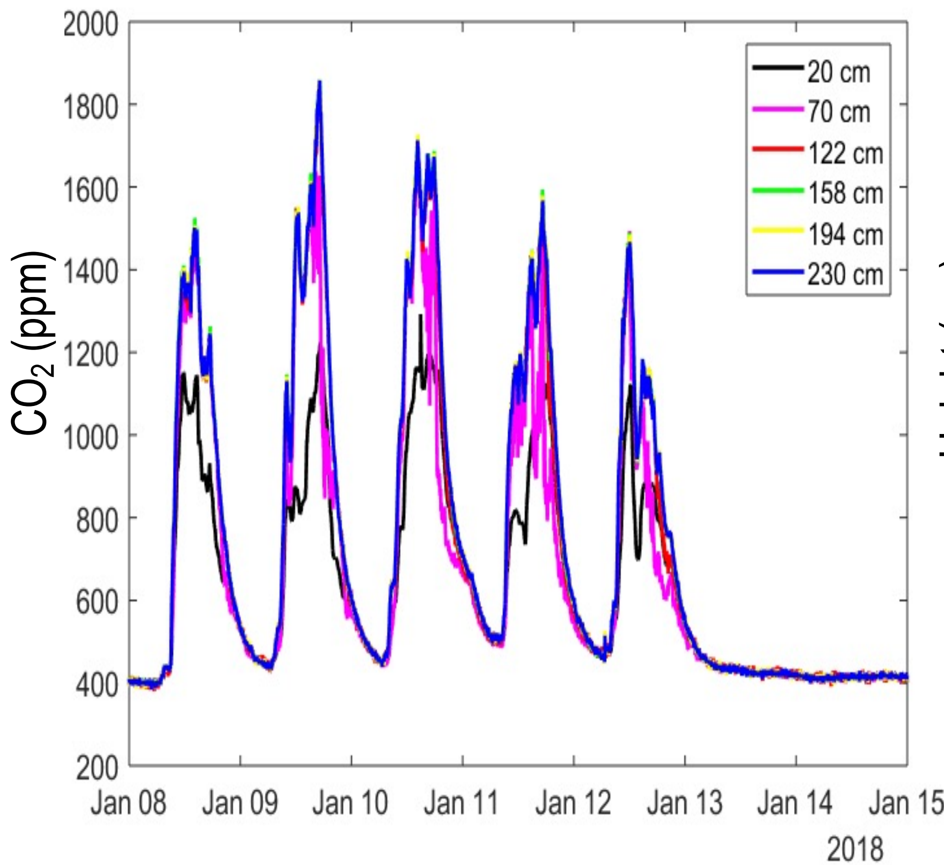
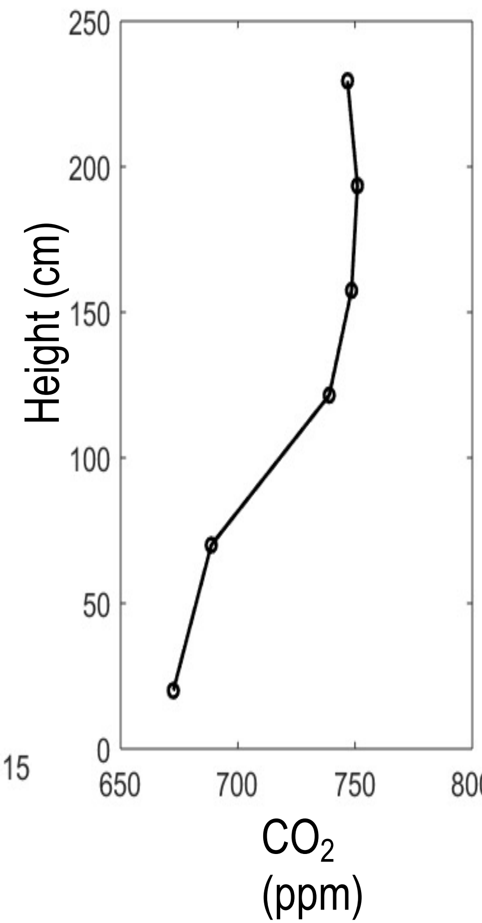
Indoor CO_2 Vertical Stratification





Evidence that breath accumulates near the ceiling

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Closing thoughts

- CO_2 provides an indication of ventilation/AQ
- Complexity in indoor airflows requires careful consideration
- Winter poses hazards both for airborne infection and AQ

Thanks to

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