Ventilation effects in workplaces
Challenges to consider for transmission modelling

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PROTECT
A COVID-19 National Core Study

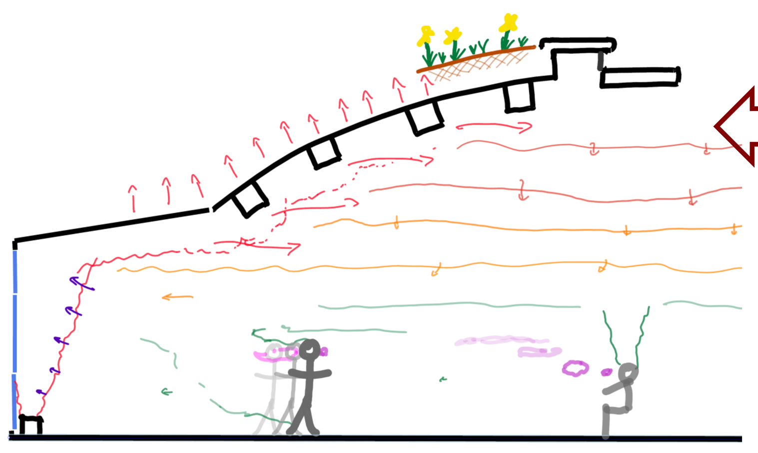
UNIVERSITY OF CAMBRIDGE

Introduction and objective

- NCS PROTECT WP 2.2.2: Ventilation Effects.
- Use of proxies for potentially infectious exhaled air.
- Examination of ventilation flows: how person and room-scale details affect risk profiles of airborne transmission
  - ✓ In workplace scenarios.
  - ✓ Monitoring challenges not captured by conventional ventilation models.

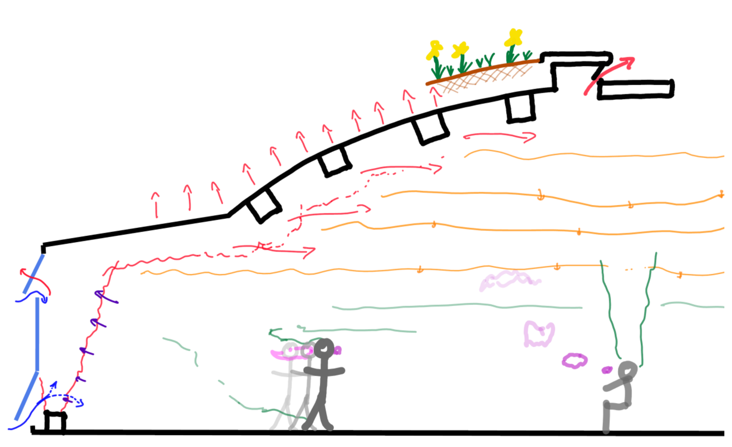
Analysis of spaces: winter months

Natural ventilation: large space, high occupancy, variety of uses: Cross-flow and buoyancy-driven ventilation. Stratification. Careful strategy to avoid lock-up layer and thermal discomfort.

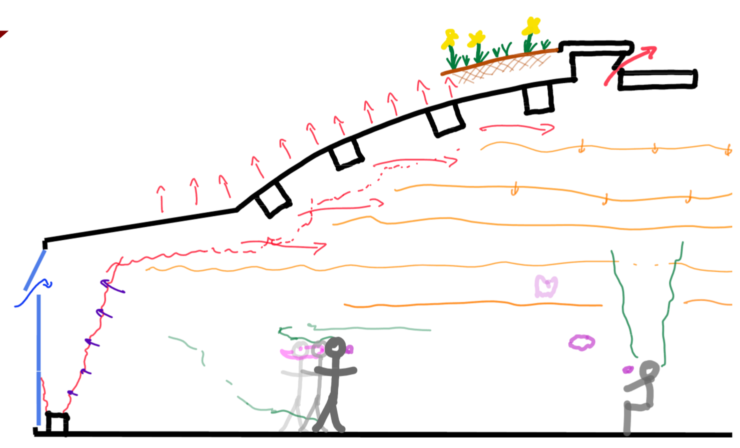


All vents closed: entrainment to radiator plumes. Gravity currents. **Strategy needed** to avoid lock-up layer and thermal discomfort.

Artificial smoke shows accumulation within the breathing zone. **Risk of infectious aerosols being trapped in a lock-up layer.**



All vents opened: most incoming air into the plume. Some causing cold drafts at floor level. **Thermal discomfort.** Some ventilation by air entrainment into the plume. Less strong **internal stratification.**



Revised ventilation strategy: lower-level windows closed: $\downarrow H$ but Q compensated by $\uparrow \Delta T$ (cooler outside temperatures). .

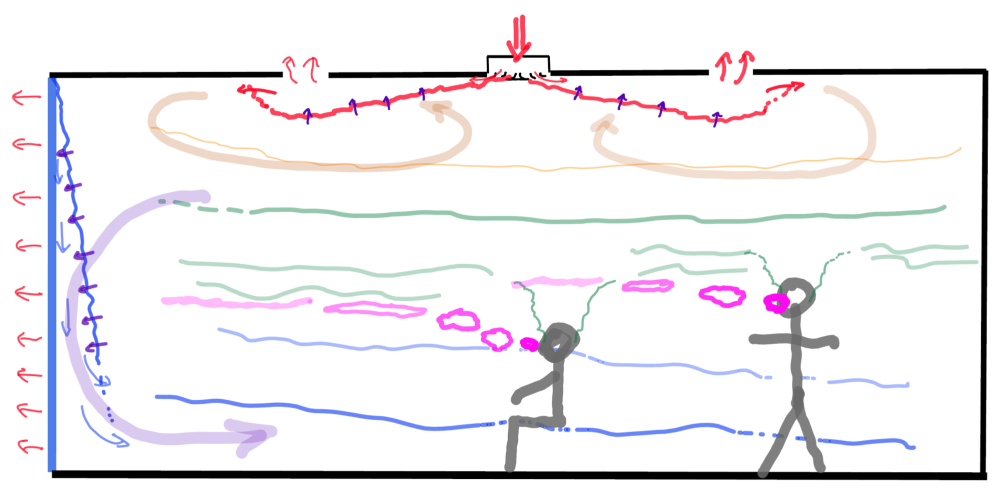
$\downarrow$T = $\uparrow$ buoyancy-driven flows: $Q = cA^* \sqrt{\frac{\Delta T}{T_0} gH}$

Mechanical ventilation: large heat losses through their external surfaces and a ventilation system designed for cooling

Ceiling jet in summer months: cool air buoyancy forces act to disrupt the jet = good distribution of fresh air.

Ceiling jet in winter months: buoyancy forces keep jet at the ceiling, with exhaust vents also in the ceiling = large fraction of fresh air is short-circuited.

Heat loss through the glass façade generates a cold plume that descends towards the floor.



Net effect: establishment of a **strong internal stratification and very low effective ventilation rate.**

Mitigation strategy:
Deflectors: greater penetration into the stratified environment and greater degree of mixing.
Fan to pre-mix the room before ventilation start.

Key findings

- Inhomogeneous temperatures (mostly associated to thermal stratification) in mechanical and natural ventilation systems.
- Smoke tests can be used to assess interzonal flows.
- Smoke tests allow for direct comparison with models of leakage-driven, buoyancy-driven and contaminated air flow exchanges.

Methodology

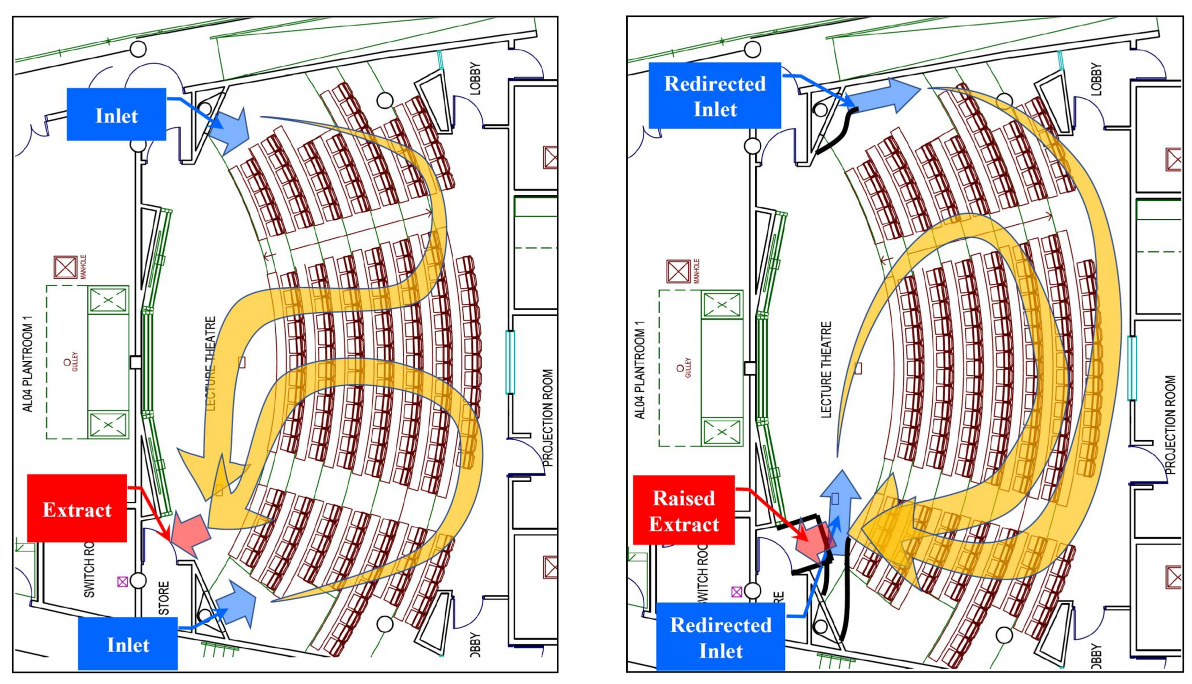
- Variety of ventilation systems, uses, occupancy and geometries.
- Artificial smoke (theatrical fog):
  - Buoyancy of the breath, droplets < ~5 μm.
  - Flows and decay rate.
  - Passive visual tracer (laser illumination).
- Longitudinal temperature and CO_2 monitoring.
- Environmental (with TVOC) sensors and CO_2 decay rates.

Combined natural and mechanical ventilation: medium-sized space with low-medium occupancy and variety of uses

Well-mixed internal conditions (linked to mechanical system) are compromised (thermal stratification): supplied air is warmed while cold air – heat losses or open windows – generated at external façade. Difficulties to generate guidance. **Importance of monitoring.**

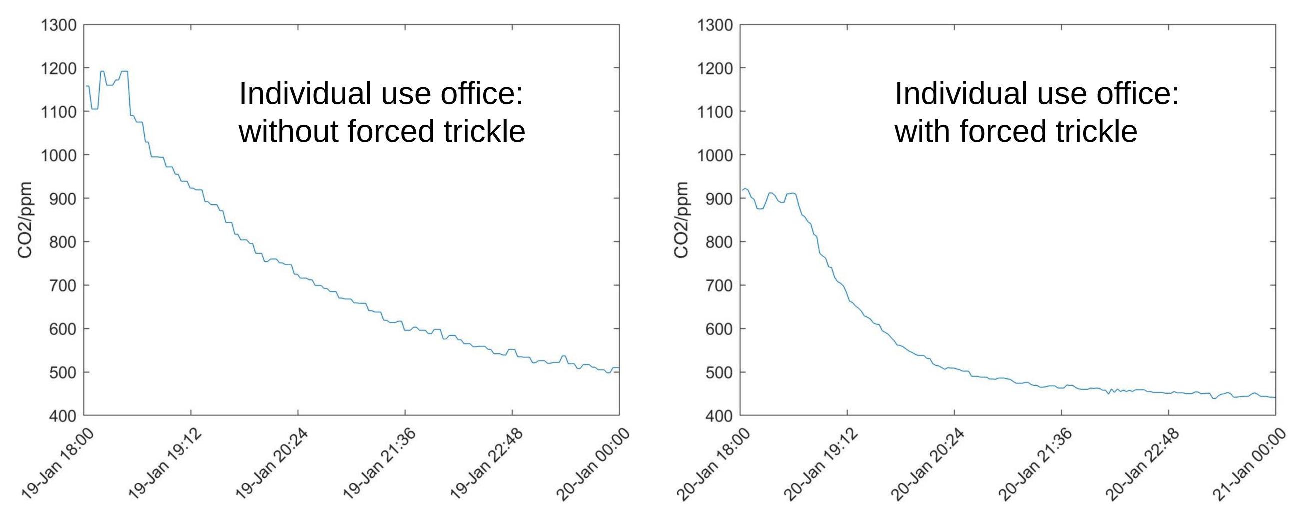
Mechanical ventilation: Tiered lecture theatre

Strategy: altering internal circulation to avoid pre-breathed air from the auditorium into the stage.



Natural ventilation in interzonal spaces: connectivity to long occupancy space

- Generally not provided with direct ventilation routes or apparatus. Rely on the exchange of air with surrounding rooms.
- Smoke tests: Qualitative prediction of the connectivity patterns and associated risks. Allow analysis to suggest and implement guidance.
- Example: decoupling ventilation of offices from the interconnected spaces. Sufficient ventilation with forced trickle venting.



Conclusions

- A range of challenges that can increase the risk of airborne transmission have been identified using artificial smoke and temperature and CO_2 data in various workplaces. The challenges are associated with thermal stratification and inadequate ventilation designs for winter times, whether in mechanically or naturally ventilated scenarios.
- These challenges highlight that is inadequate to assume (without evidence) that a space is well-mixed when considering transmission risk. Inhomogeneous temperatures and their causes have been identified in most studied spaces. These conditions are not accounted for in most analytical models and computational studies.
- Smoke tests and longitudinal monitoring allow for analysis, implementation and assessment of effectiveness of remediation strategies.

Further reading

Bhagat, R. K., Wykes, M. D., Dalziel, S. B., and Linden, P. (2020). Effects of ventilation on the indoor spread of covid-19. Journal of Fluid Mechanics, 903.

Rodriguez Rivero, M. C. & Mohamed, S. (2022), 'Evaluating transmission risk in unique workplaces: pilot study of a Victorian prison – Blog for NCS PROTECT website: https://sites.manchester.ac.uk/covid19-national-project/2022/03/30/evaluating-transmissionrisk-in-unique-workplaces-pilot-study-of-a-victorian-prison/'.