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Building Simulation and Airborne Infection

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Key questions

- What are the key airborne infection simulation and analysis **tools characteristics and considerations**?
- What **new tools and applications** are on the horizon?
- What *could* **moving forward** using these tools and applications look like?

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Tools characteristics and considerations

Some spatial, temporal and building science disparities

Experimental / fieldwork
- Limited measurements sometimes single point by zone
- Sometimes high frequency sampling (not if identification needed)
- Sample resilience from capture to testing
- Proxies versus limited biology & epidemiology at microscale

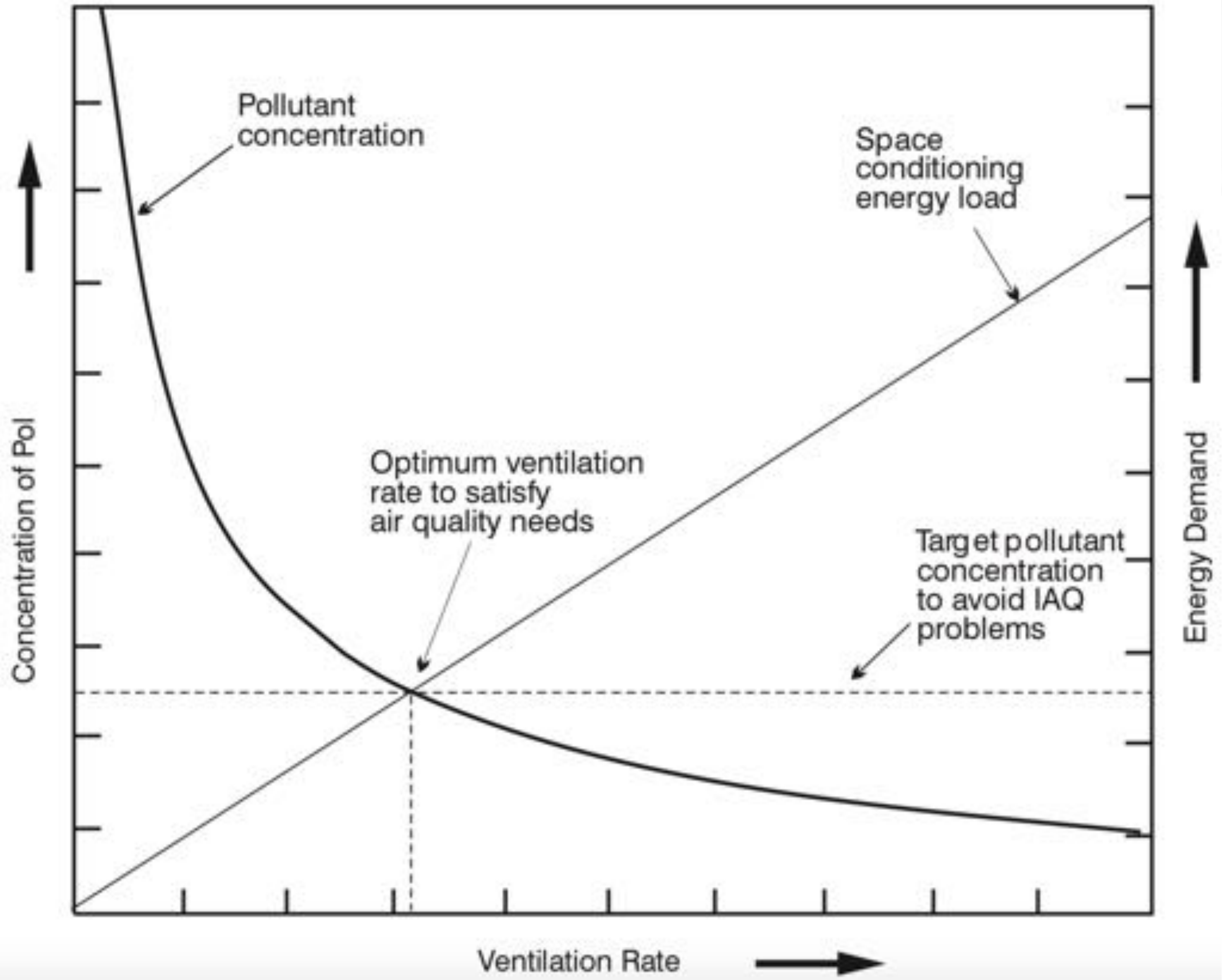
Analytical / simple (?) tools
- Single point / mixed-zone outputs
- Steady state or transient defined by calculation type
- Simple or complex physics

Dynamic thermal modelling (DTM)
- Multi-mixed-zone DTM (often coarse zones)
- Typically one hour time steps − limited to 6min intervals?
- Detailed systems models and controls possible
- Good capture of surface temperatures important for buoyancy-driven flows

Computational fluid dynamics (CFD) modelling
- Detailed air movement − advanced aerosol turbulence / mixing / transport capture
- Mainly steady-state but could be minutes (not practically hours)
- Some detailed source or receptor models possible

Limited biology & epidemiology in tools / models but still useful for design purposes!

Finding the balance between environmental quality / safety and environment efficiency



As ventilation rate ↑, concentration ↓ and energy demand ↑

A Guide to Energy Efficient Ventilation, Liddament 1996

CIBSE Event 'Indoor air quality, air distribution and ventilation: Striking a balance between quality and efficiency', January 2012

Treatment of sources and receptors

Figure 1-1: Views of a hospital ward showing (left) a zonal source for bedmaking and (right) a point source to represent a cough.

Many questions to translate into accepted simulation and analysis inputs, for example:

- On source side, is a different approach needed for masks and impact of air movement over body?
- On receptor side, what can we learn from previous inhaler effectiveness research to guide our ventilation risk models (smaller droplets deposit deeper into respiratory tract)?

Simpler multi-zone models are compared to CFD and found to perform well at simulating the bioaerosol decay within large spaces that can be assumed to be well mixed, however they are not refined enough to simulate the detail required to study the transfer of infection between individual patients.

Dr Abigail Hathway 'CFD Modelling of Pathogen Transport due to Human Activity', University of Leeds PhD, 2008 (now University of Sheffield & AIRBODS)

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Defining acceptable tolerances

- Filling unknown epidemiological ranges with ‘sensible assumptions’ (low, medium or high) or more simplified calculations until more accurate information and methods become available
- Recognizing sensitivity of proposed ventilation strategies with their associated sizing through sensitivity testing
- Is it possible to define an acceptable tolerance in real world scenarios (outside test chambers) noting spatial, temporal and building science disparities?
- Does this really matter when objective is to specify practical, viable design solutions with sufficient operational flexibility?

Design of scenarios

- Batching of sources for design purposes, e.g. does a highly infectious scenario with a mask equate to a less infectious one without one?
- Tabulating different activity / face covering scenarios for different tools and models, e.g. recognizing different input formats
- Positioning of receptors, e.g. manikins versus mixed-zone or breathing zone for a child in pushchair
- Occupancy density with single or multiple activities
- What boundaries are recommended for performance-led design?
- How much standardization is needed in support of design consistency?

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New tools and methods

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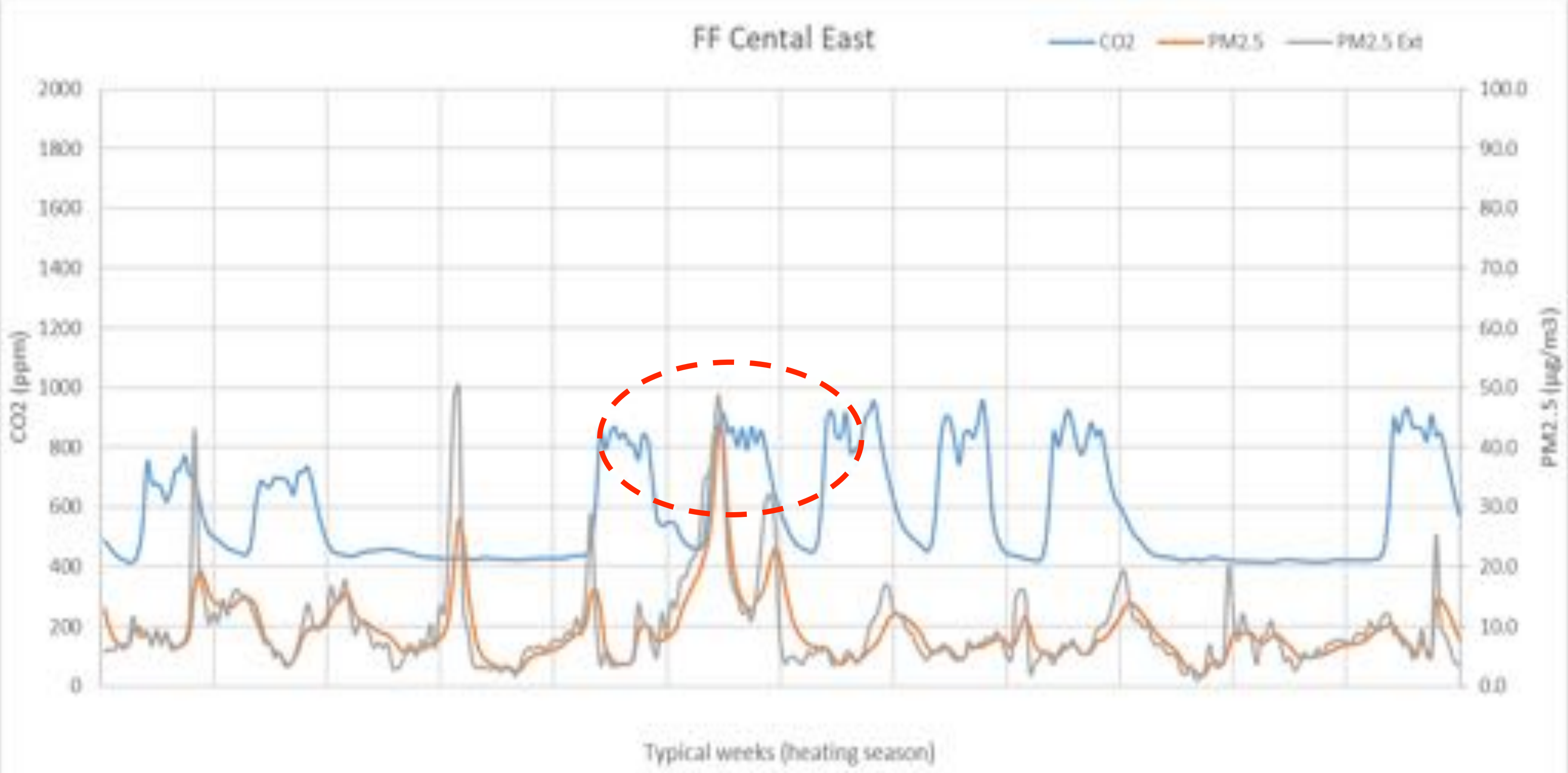
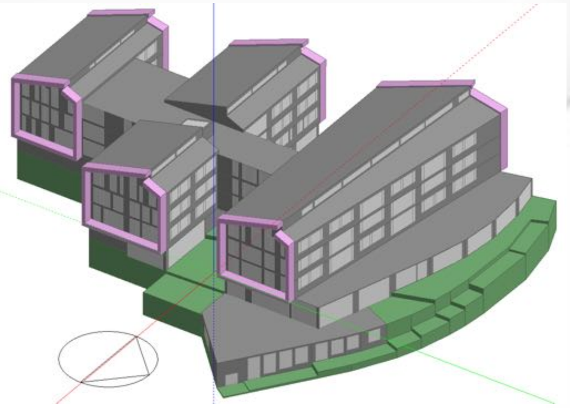
DTM with advanced controls



IAQ control strategy with high CO_2 set point



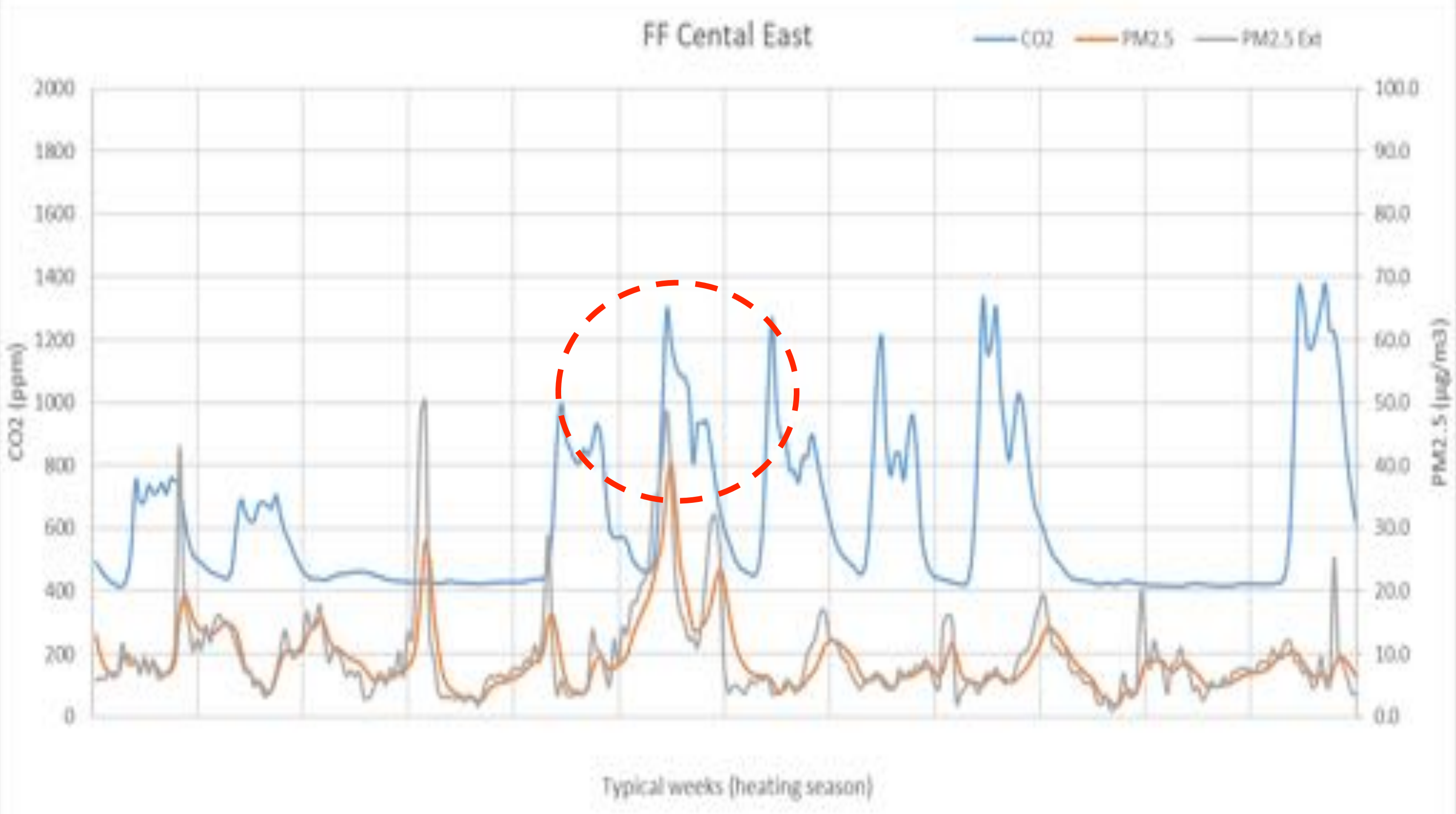
Standard CO_2 control:

- Vents open at 1000ppm
- Low CO_2

Highlights:

- High air change rate
- High $PM_{2.5}$ (peak above 40 µg/m³)
- Energy use (heating) 145 Wh/m²/day

DTM with advanced controls



Holistic IAQ control strategy requiring extra coding

Revised control strategy:

- Relax CO_2 setpoint (1500ppm)
- Close vents if outdoor $PM_{2.5}$ above threshold

Highlights:

- Outdoor $PM_{2.5}$ above indoor $PM_{2.5}$ (peak below 40 µg/m³)
- Energy use (heating) 105 Wh/m²/day (28% less due to relaxation of CO_2 limit)

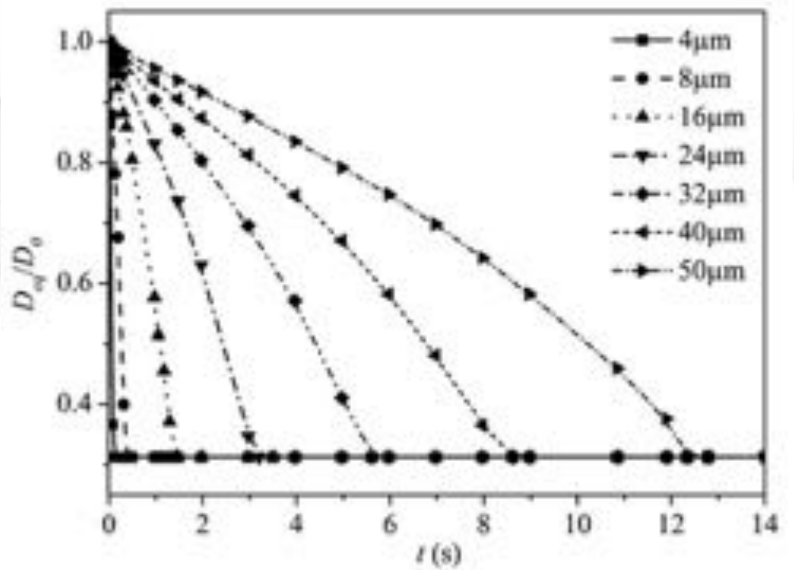
What would an airborne infection control strategy look like?
Use of IAQ proxies for airborne infection?
Calculating UV & filtration system value?

CFD with biophysics

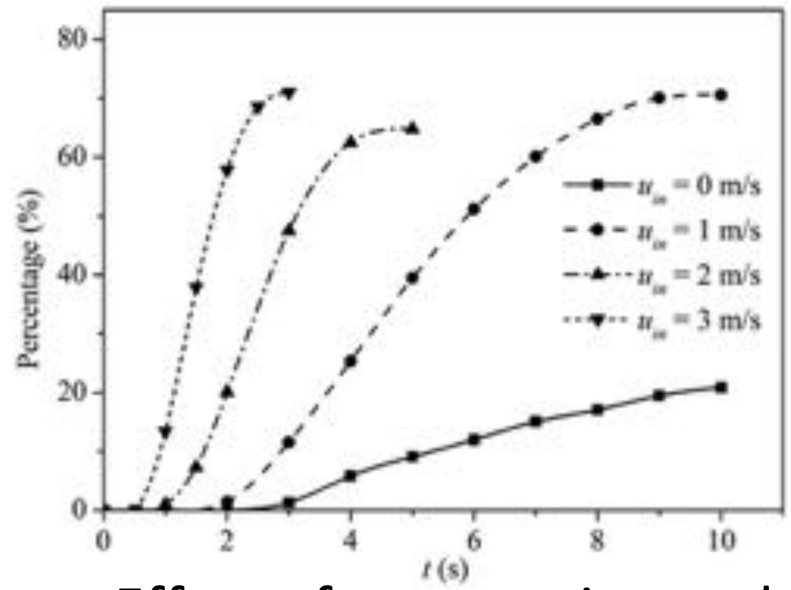
User defined functions based upon experimental data

<u>Highlights</u>

- Evaporation + Langrangian particle tracking + aerosol droplet nuclei (dispersion) models - two-phase flow
- Evaporation rate dependent upon moisture content and air temperature
- Sticky or non-sticky surfaces for particle deposition
- Grid of sources 1.5m above floor level applied to fixed vector field
- Near field larger droplets and aerosols continuum size change and transport (horizontally and vertically)



Droplet diameter decay over time

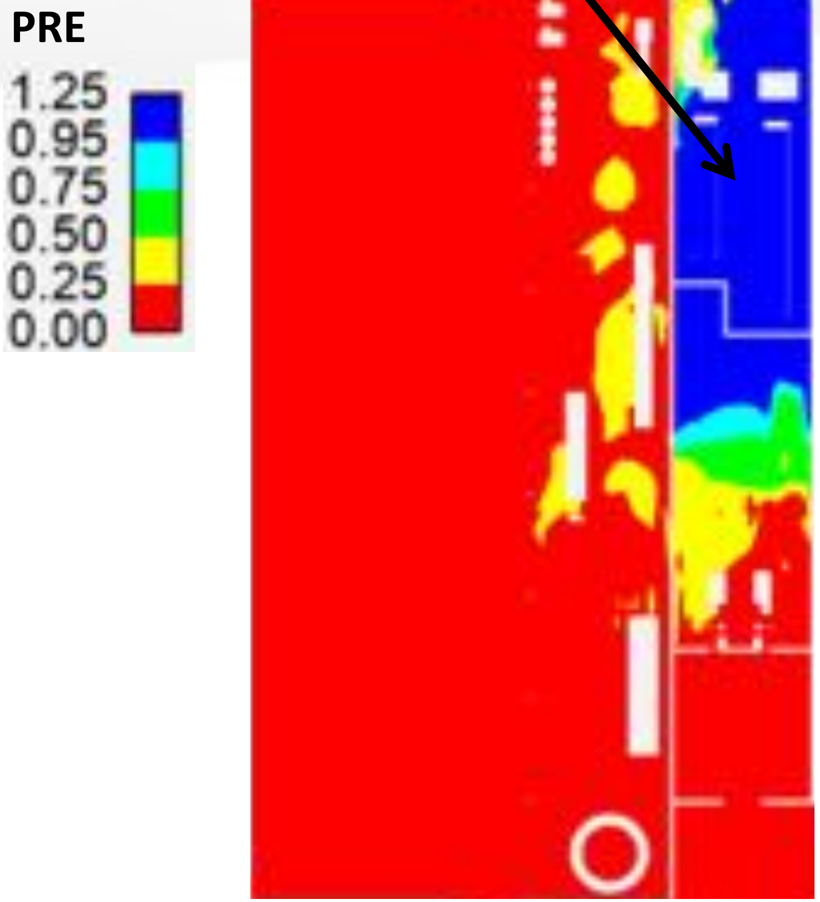


Effect of evaporation and air speed on droplet size

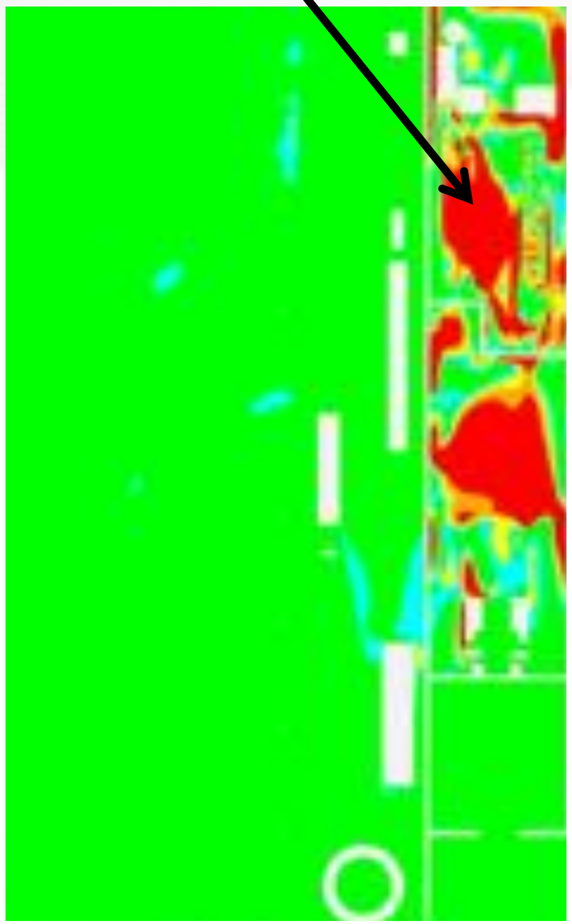
CFD with biophysics

High PRE good?

Not in areas where horizontal air movement dominate



>5m distance required
5m distance required
4m distance required
3m distance required
2m distance required
1m distance (minimum)



Pollutant Removal Effectiveness (basic derived output)

Contaminant vulnerability or revised social distancing (based upon user defined relationships)

Moving forward

New project scopes? (I)

- **Over-occupancy risk assessment**
  - Upgrading thermal compliance models to thermal performance models with IAQ proxies for airborne infection (0.5-1.0 days work?)
  - Test for allowable upper occupancy density in different space types
- **Breathing zone ventilation efficiency** tests
  - Include breathing zone air change rates in addition to room air change rates for minimum fresh air guidance
- Defining **airborne infection ventilation control modes**
  - For a hybrid system operating in cool natural ventilation mode, at what point does the space become too cold and too poorly ventilated for safe airborne infection limits?
  - What combination of environmental with *biophysics* measures are appropriate to drive the switch to mechanical heating mode?’

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New project scopes? (II)

- **Room corner safety checks**
  - Cooler-than-ambient surface temperatures draw polluted air downwards. What’s the risk to the corner breathing zone where air movement is reduced?
- **Designing for secure ventilation**
  - Window ventilation flow rate restricted by blind or curtain usage and may close window due to security fears
  - How can we design more *secure* ventilation systems to improve purge ventilation, e.g. *naturally tempered* supply air entry away from the building perimeter?

More air bricks plus hit & miss floor vents air-connected to the chimney stacks?

Understanding airborne infection dynamics

- Coach load of people over short period
- Persons moving and turning − impact on emission sources and turbulent mixing
- Build up and decay in different design scenarios
- Defining an airborne infection control mode in consideration of the dynamics − purge ventilation?
- Doors opening, closing and revolving
- Lifts
- Reanimation of particles off surfaces, e.g. through bed making

Time of changed thinking?

Importance of ventilation in ensuring the swift recovery of patients and reducing cross-infection

Long-term exposure to air pollution may be “one of the most important contributors to fatalities caused by the COVID-19 virus” around the world. Stunted child lung growth!!!

Department of Health & Social Care

Clean Air Programme

Prevention is better than cure

Our vision to help you live well for longer

‘Scientific advances that could see life-threatening viral outbreaks stopped before they start’

05 November 2018

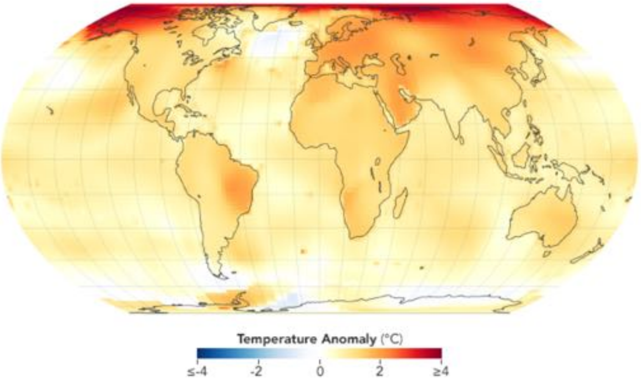
Breathing City

Future Urban Ventilation Network

Building Safety & Competence – ‘Engineers need to study disasters’ Façade focus initially moving to overheating and then pollution risk?

Holistic coupled indoor-outdoor flows

Increased airborne infection resilience through increased climate change resilience?



https://earthobservatory.nasa.gov/world-of-change/global-temperatures
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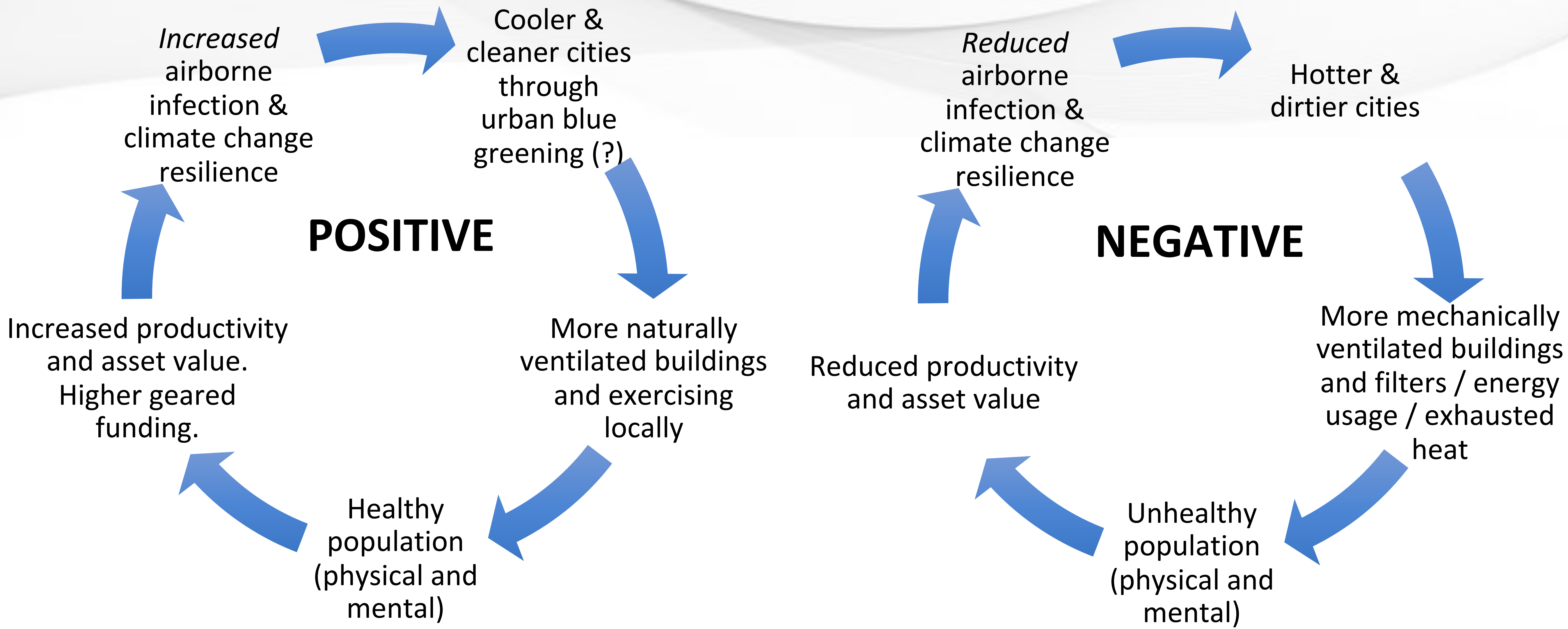
A circle of resilience and virtuosity?



We need to get a lot better at joining the dots!

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Earthwatch Europe webinar on Nature-Based Solutions, ‘Generating urban cool islands using blue green solutions’, Darren Woolf
https://us02web.zoom.us/rec/share/Sy-IqOk_R4o6m9wt1AdzXn-GuFF9geNJ-AnlHMu8YVgcZrmePm_BmRVX791DufoX.1t6Tlsm-gLnYABhz

Key considerations and challenges moving forward (I)

Improving airborne infection resilience through **better use of simulation and analysis**:

- Better understanding of tool uncertainties & tolerances with associated spatial, temporal and building science disparities
- Better design of scenarios for different approaches recognizing limitations of each approach at different design stages
- Integrating airborne infection thinking into digital twins with better control strategies
- Replacing current assumptions or simplified methods with better epidemiological evidence when it becomes available − development of biophysics models in built environment context
- Indirectly improving airborne resilience through developing better-linked building simulation and analysis tools to guide a positive ‘circle of resilience and virtuosity’
- Improved understanding of breathing zones and efficient delivery of diluting air for developing better airborne infection operational control modes

Key considerations and challenges moving forward (II)

Improving airborne infection resilience through **better design practices and improved policies**:

- Designing intelligent spaces for optimum energy / ventilation balance
- Developing better understanding of overlap between IAQ proxies and airborne infection control strategies supporting opportunities for increased health and productivity
- Incorporating lessons learnt from hospital-acquired infections, **current airborne infection research** and expert bioaerosol scientist metrics & practices (e.g. use of quanta, Wells-Riley & dose response methods) into mainstream building design practices
- Generally look at disease and ventilation control with new eyes
- Breaking silos through adopting multidisciplinary holistic design processes − better procurement of studies and services!
- Better regulations and policies in support of increased resilience, e.g. New Clean Air Act or Environmental Protection Act to incorporate airborne infection?
- We need to **promote safer environments, upskill and be better communicators!**

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