Air cleaning and disinfection devices in a hospital setting - approaches and pitfalls

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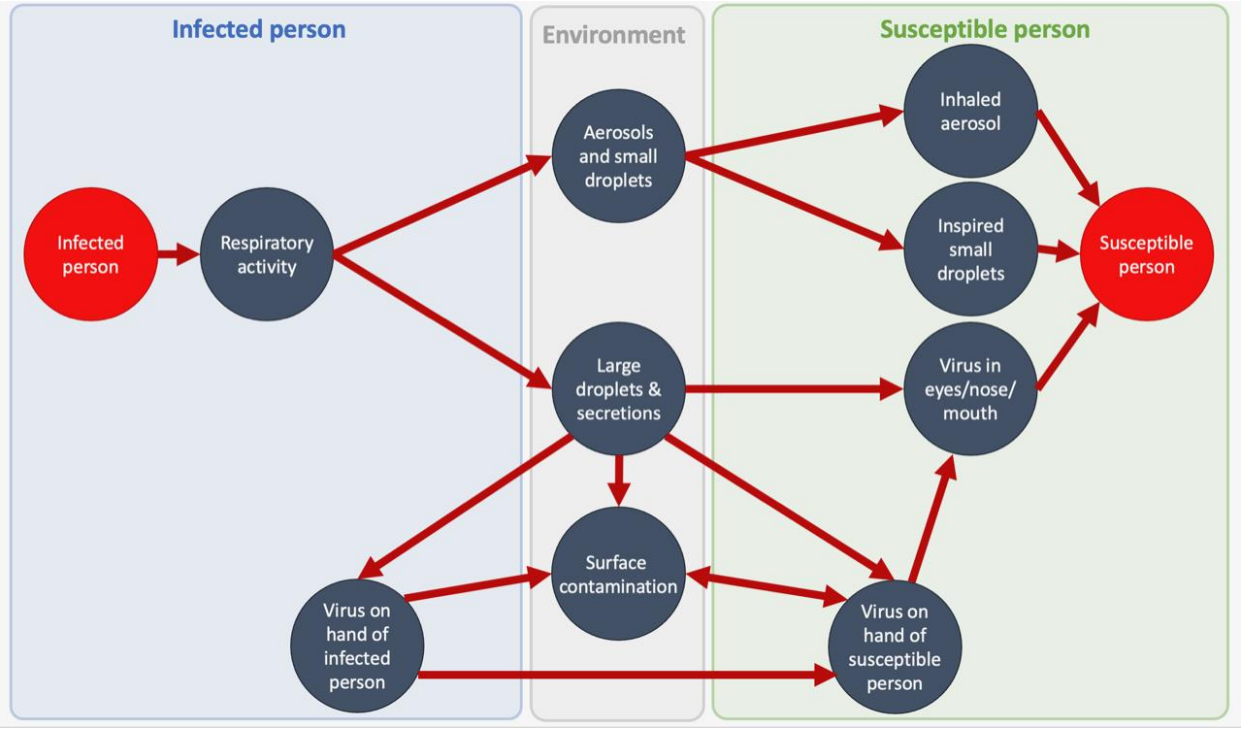
SARS-CoV-2 transmission routes

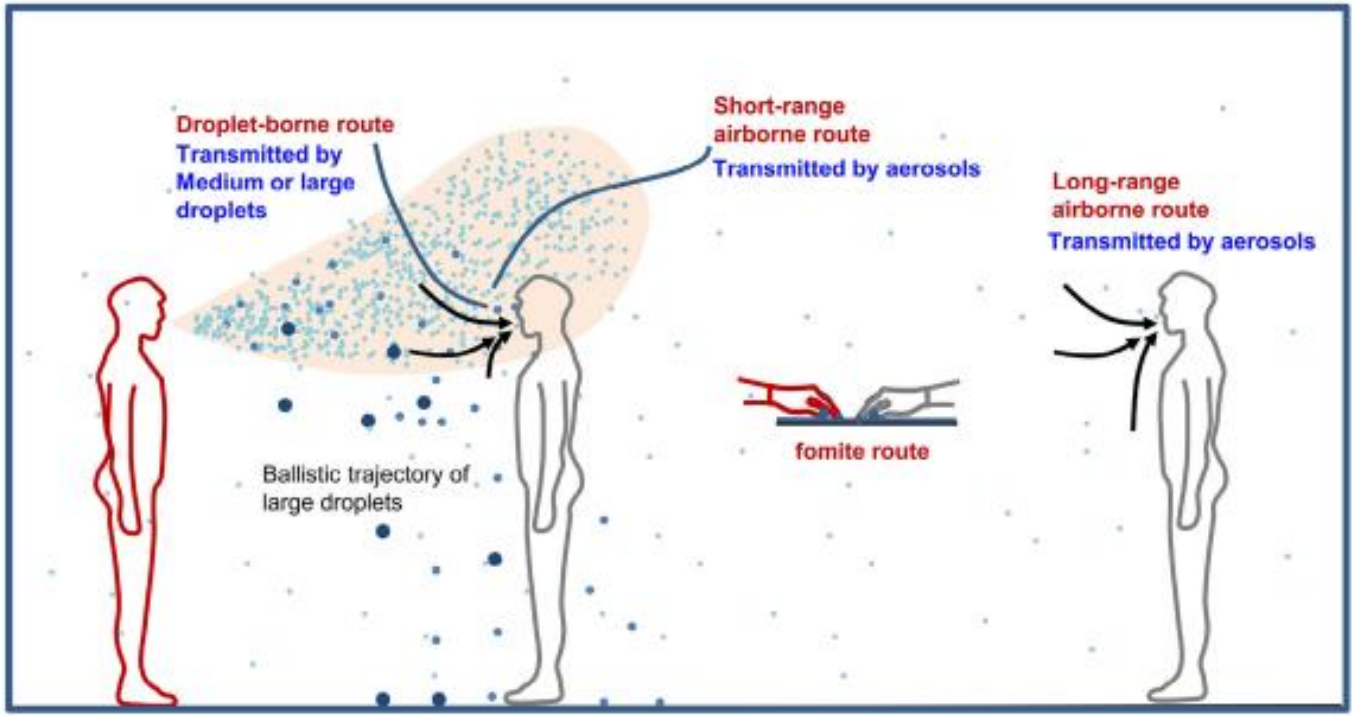


Airborne – via aerosols (>2m) in a shared room

Close range –via aerosols and droplets (<2m)

Surfaces - via contaminated hands

Respiratory particles in the environment

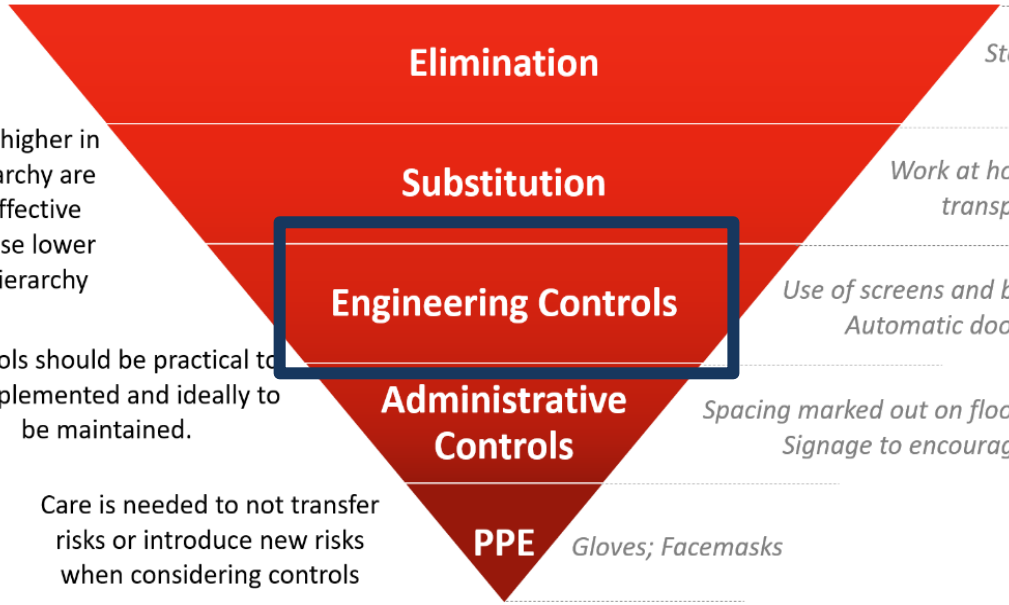


J. Wei, Y. Li, American Journal of Infection Control 44 (2016) S102-S108

Hierarchy of Risk Controls

Ron McBeth, HSE

Start at the top of the *Hierarchy of controls* and identify possible control measures within a category before moving down to the next category in the hierarchy



Controls higher in the hierarchy are more effective than those lower in the hierarchy

Controls should be practical to be implemented and ideally to be maintained.

Care is needed to not transfer risks or introduce new risks when considering controls

The use of multiple different independent controls give defence in depth through different layers of protection

Ordering technology interventions

1. Source control – remove/reduce the source of the pathogen if possible (isolation, testing, zoning) + source control masks
2. Ventilation – necessary beyond COVID so should be the first step to control far-field risks
3. Additional technology solutions – surface tech, air cleaning devices
4. Respiratory protection - manage exposure to residual aerosol – needed during AGP to manage close range risk

Ventilation vs Air Cleaning

- Ventilation
  - Contaminant removal and dilution
  - Thermal comfort
  - Odour and humidity control
- Air cleaning
  - Contaminant reduction ONLY
  - Some only deal with biological particles – eg UV-C
  - Some deal with particulates – filters, electrostatic approaches
  - Some may impact on VOC's and other contaminants – the jury is out
- Air cleaning is NOT a substitute for good ventilation
- Air cleaning may be an effective alternative to increasing ventilation

Ventilation definitions

Air change rate = $\frac{\text{flow rate } (m^3/hr)}{\text{room volume}}$

Each air change removes 63% of aerosols

1 ACH would remove 63% in 1 hour

6 ACH would remove 90% in 23 min – 1 log reduction

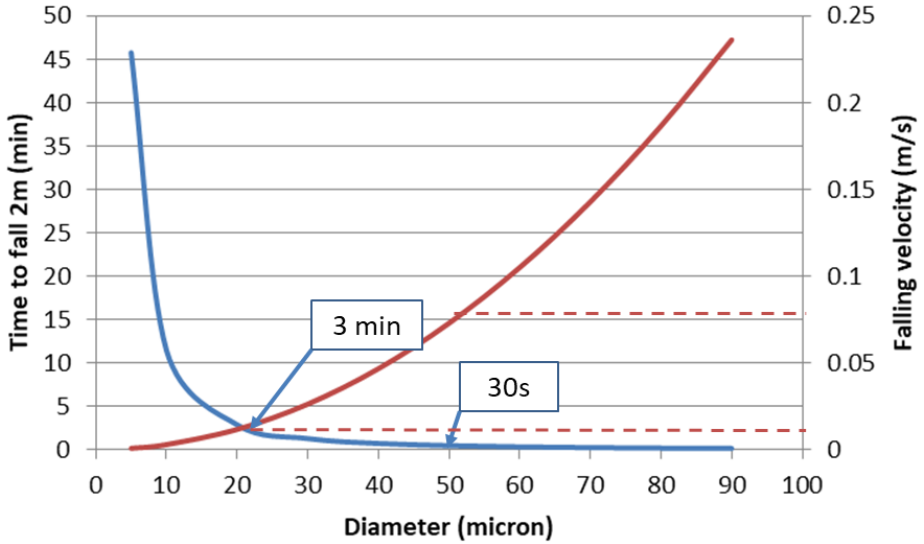
99% in 46 min – 2 log reduction

99.9% in 69 min – 3 log reduction

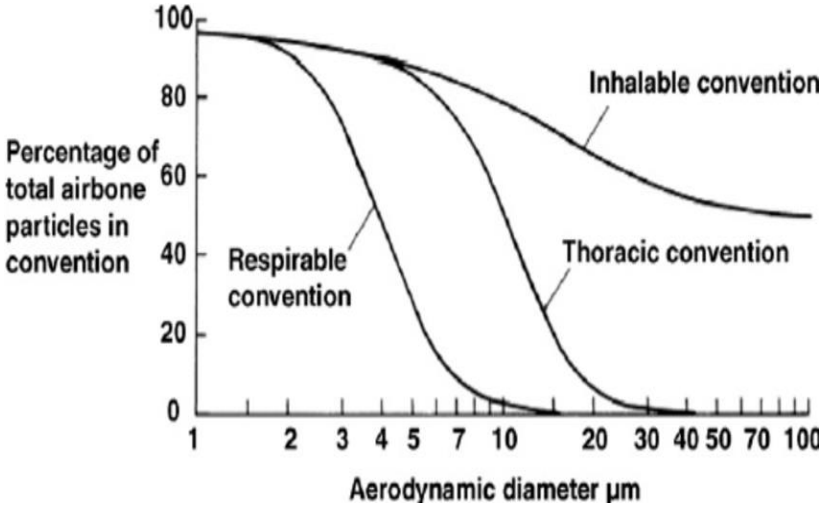
Some further removal happens through deposition

Size of particles

Fate of droplets and aerosols

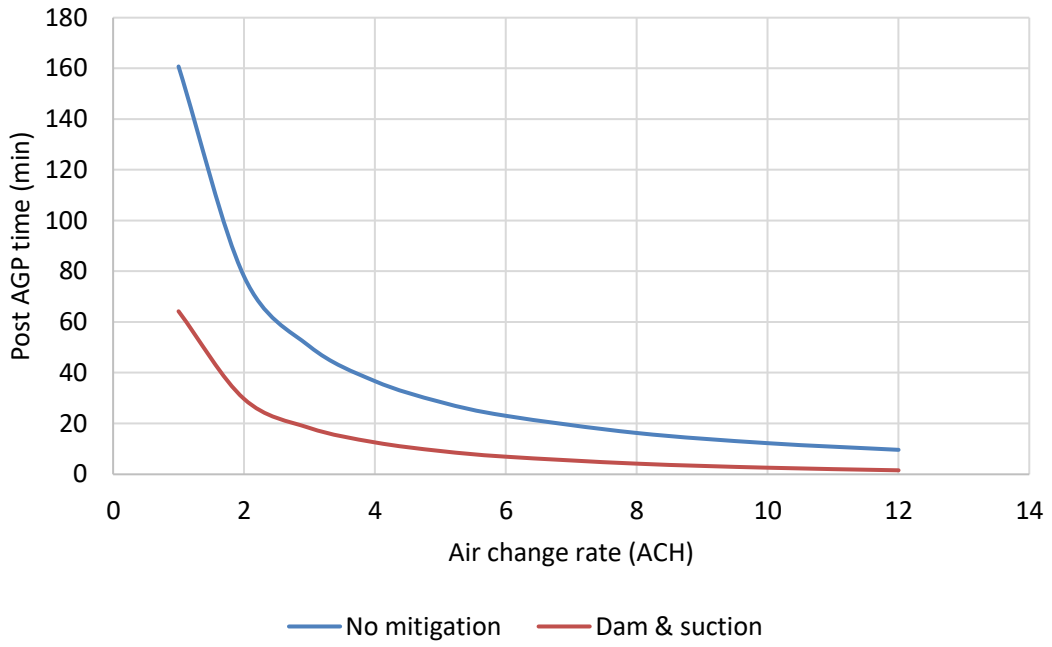


Exposure routes



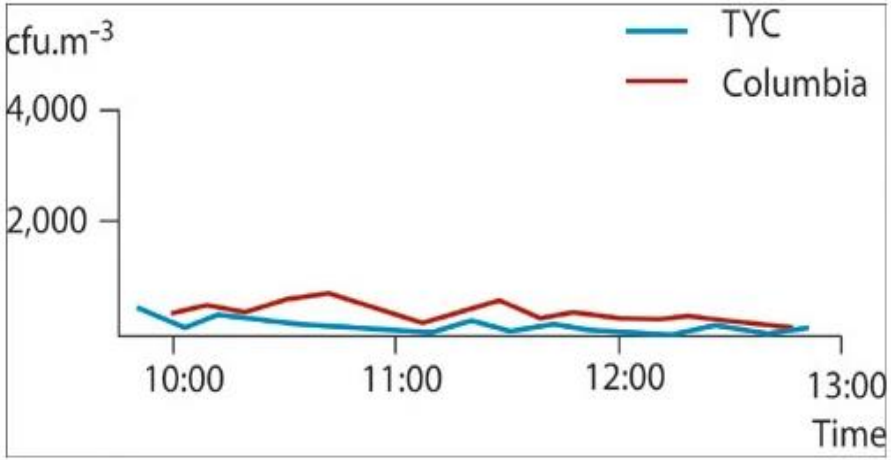
Relationship with ventilation

- Time to remove 90% aerosol for 10 min AGP
- Assumes a well mixed room
- Assumes uniform aerosol distribution
- Idealised relationship
- No deposition

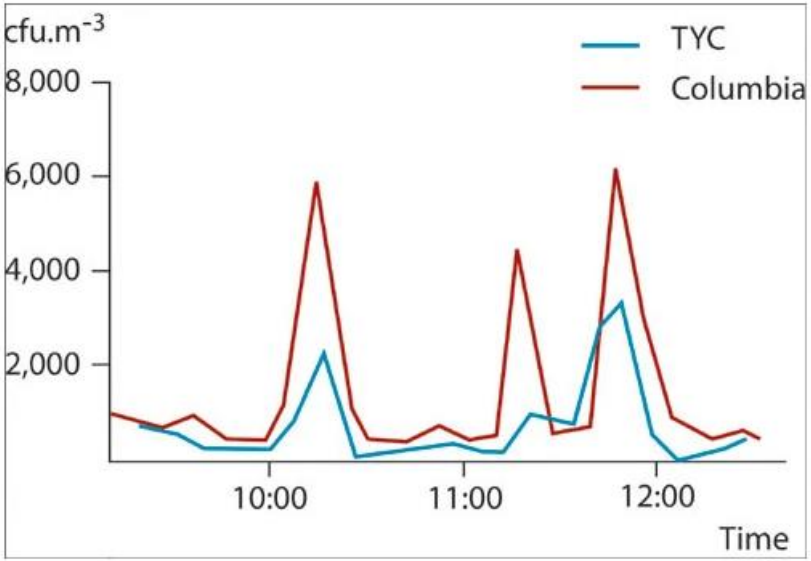


Real-world microorganisms

Bennett et al (2002) British Dental Journal 189: 664

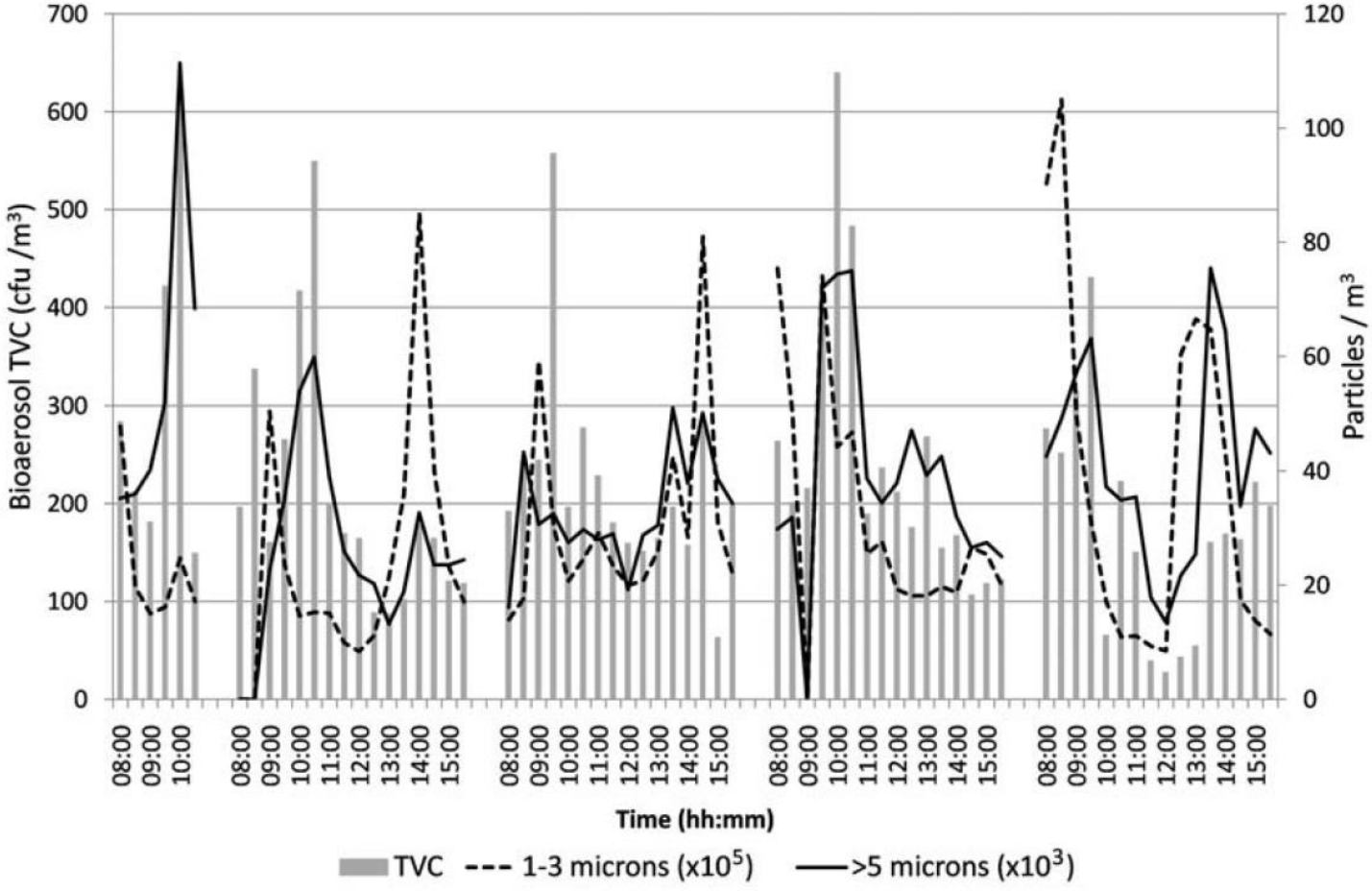


Surgery A



Surgery E

Real-world variations



Air Cleaning Approaches

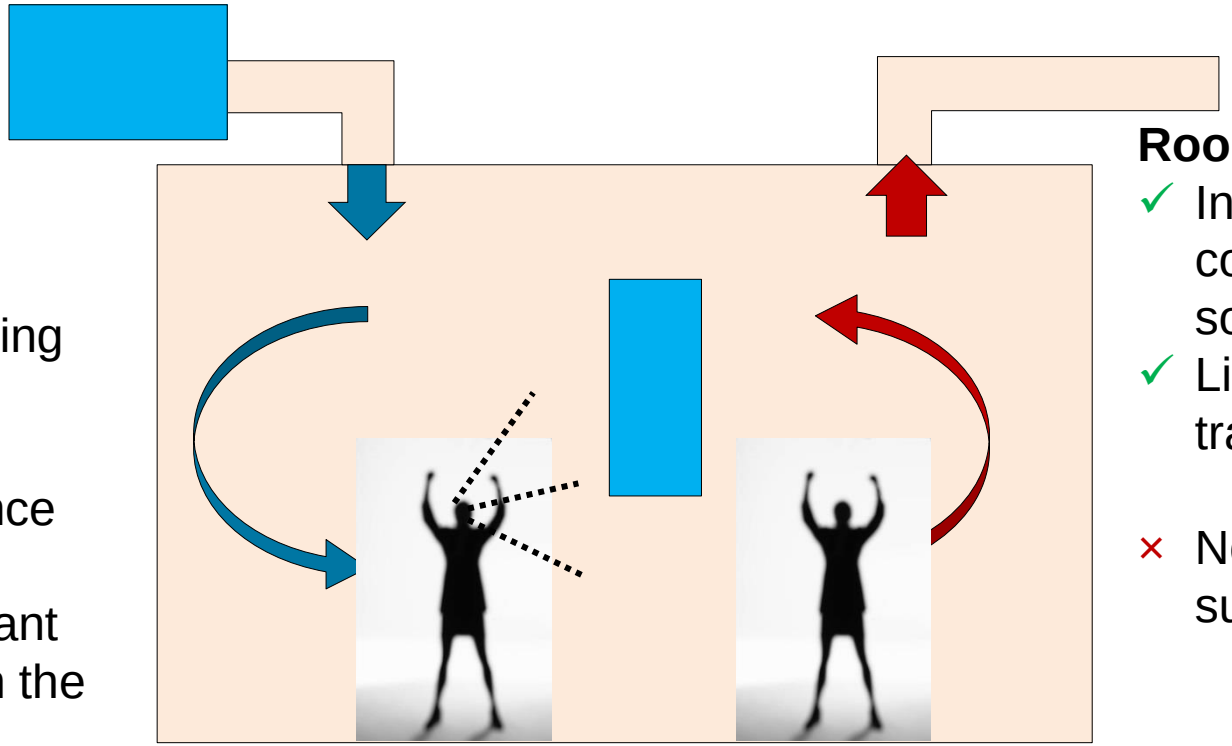
- Application of technology to remove or inactivate microorganisms
  - Not a reason to reduce ventilation
- Wide range of technologies – HEPA, UVC, far UV, ionisation, plasma, chemical, PCO
- What is the efficacy of the technology, and the evidence for this? Real world or lab?
- Are there additional benefits? Energy, IAQ?
- What are the risks? Exposure to other pollutants?

Ventilation or Room Air?

Supply Air

- ✓ High risk patients
- ✓ Recirculating systems
- ✓ HVAC performance

- × Contaminant sources in the room

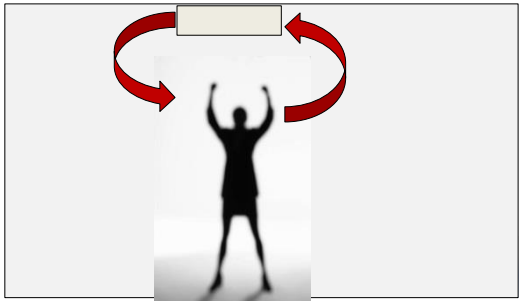


Room

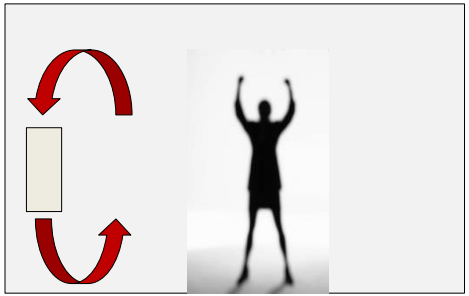
- ✓ In room contaminant sources
- ✓ Limit local transmission

- × No impact on supply air

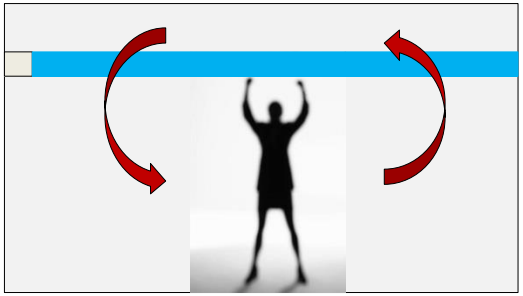
Room approaches



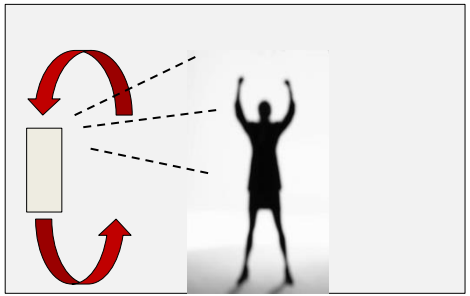
Installed single pass



Local single pass



Upper Room - UV



Room reactor

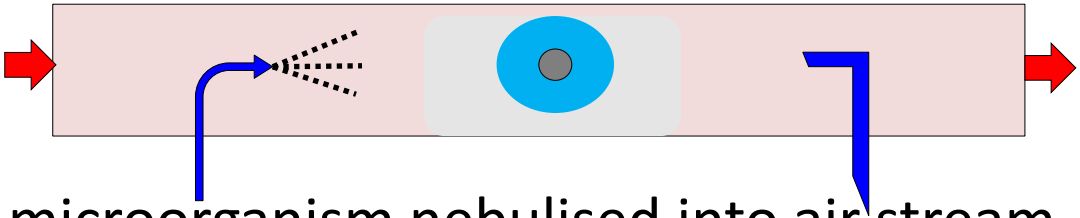
Disinfection unit

Assessing effectiveness

- Fundamental laboratory studies
  - underpinning data on microorganism response and safety
- Controlled performance studies
  - Application focused tests to characterize device performance against aerosols
  - Device output, single-pass effectiveness, room-scale effectiveness
- Modelling based studies
  - Computational fluid dynamics and zonal models – in device and room
  - Risk and cost-benefit models
- Real-world data
  - Measurement of surrogates (particles, bioburden)
  - Measurement of infection outcomes
  - Acceptability, energy, safety

Single Pass Effectiveness

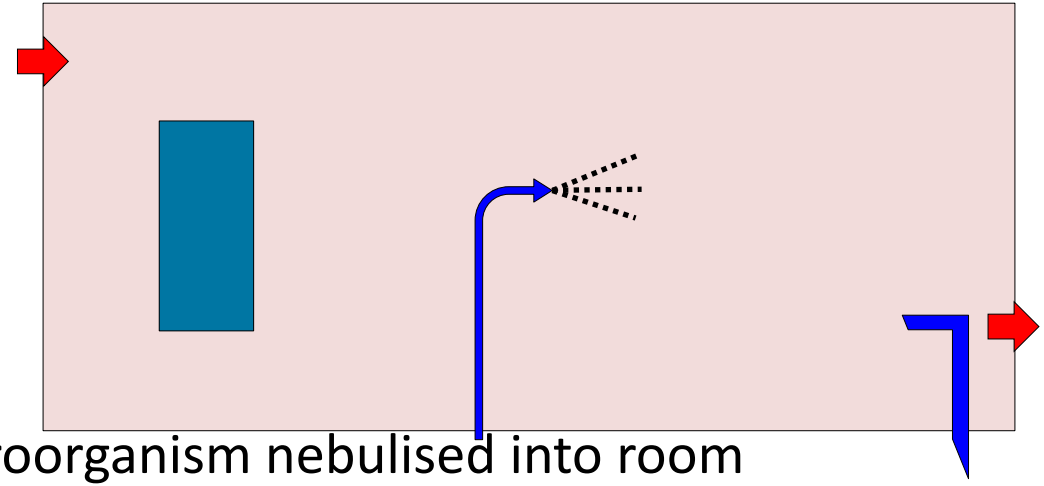
- Duct mounted and enclosed box devices



- Test microorganism nebulised into air stream
- Sample with and without device operational
- Calculation of reduction - % or log reduction
- Mean + standard deviation
- Result depends on device, flow rate and microorganism

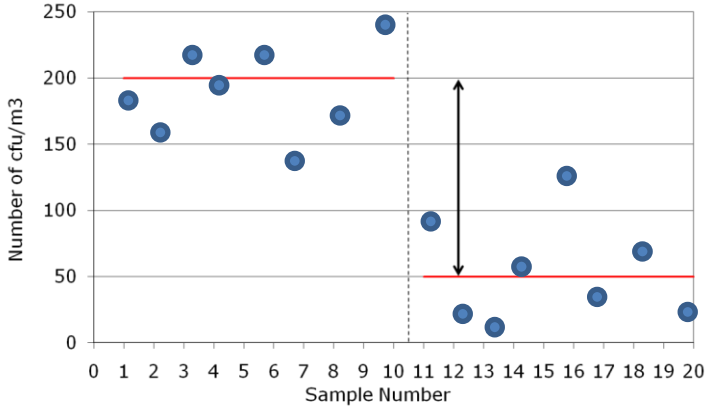
Room Effectiveness

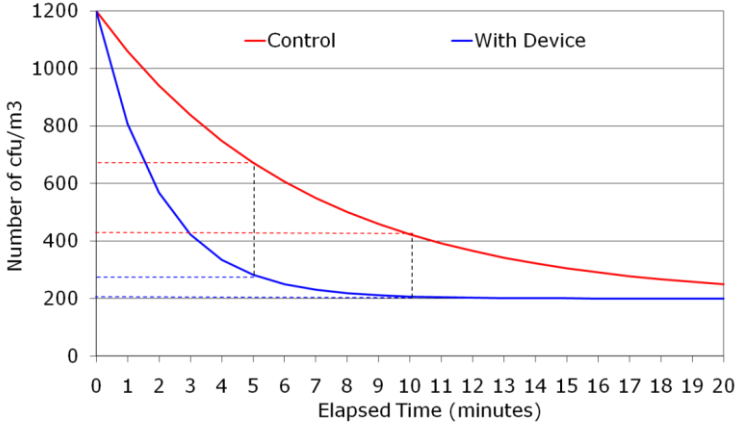
- Valid for all “in-room” devices



- Test microorganism nebulised into room
- Sample with and without device operational
- Calculate % reduction or difference in decay time

Steady state vs decay





Steady state test – continuous occupancy

- Room is subject to a continuous source of contamination
- Samples with the device switched off and on
- Difference is reduction due to the device - % or log reduction

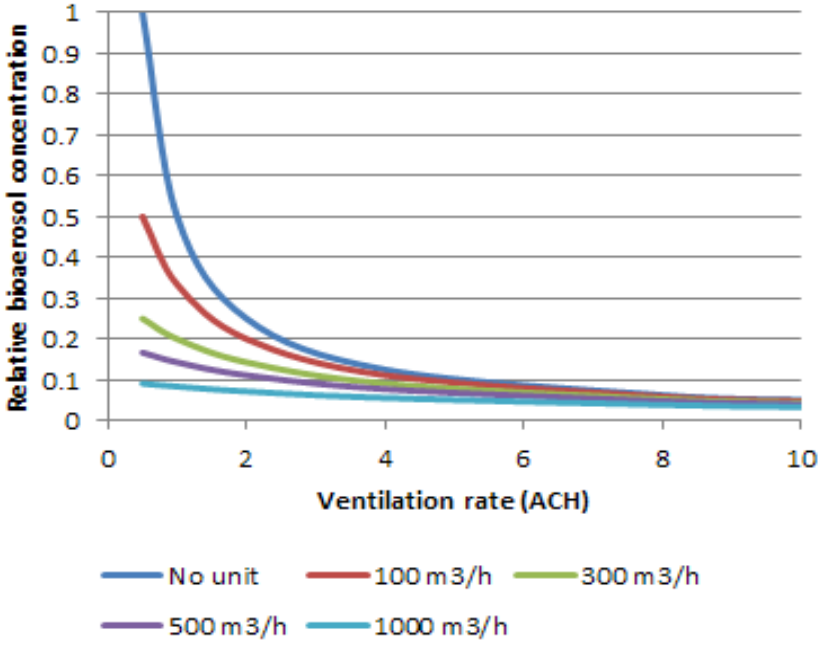
Decay test – removal rate

- Short term contamination event
- Samples during decay with device off, and device on
- Difference in decay rate indicates the efficacy of the device

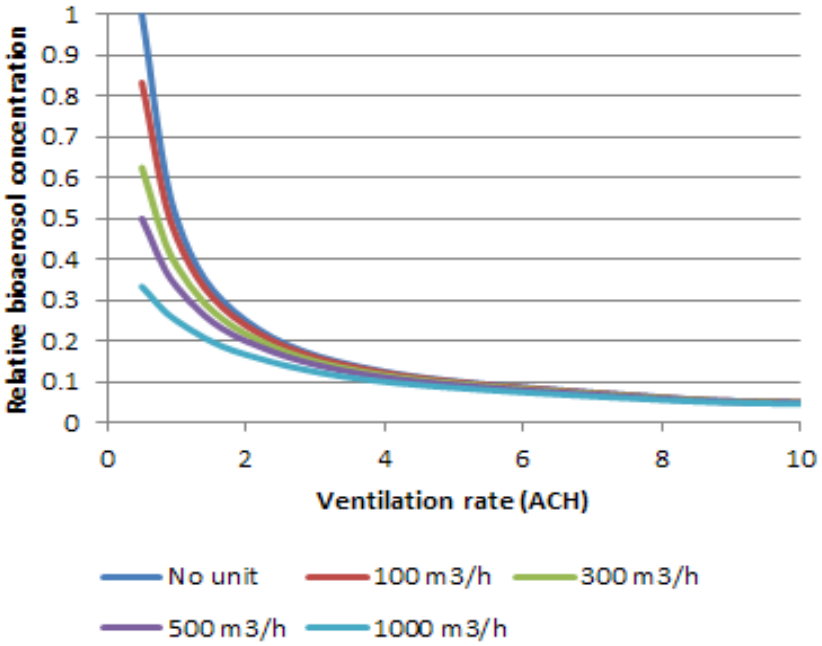
Room effectiveness

- Beware the test conditions - result depends on many factors
  - Microorganism species
  - Device – technology and flow rate
  - Room ventilation, rate and strategy – or no ventilation
  - Temperature and humidity
  - Size of room, layout, device location
  - Sampling technique - decay or steady state, variability
- Specialist testing requiring custom facilities
  - Need containment facility to enable bioaerosol tests
  - No set standards for testing – different device provide different information
  - Bioaerosol sampling is labour intensive, especially at multiple locations

Air cleaner theoretical performance

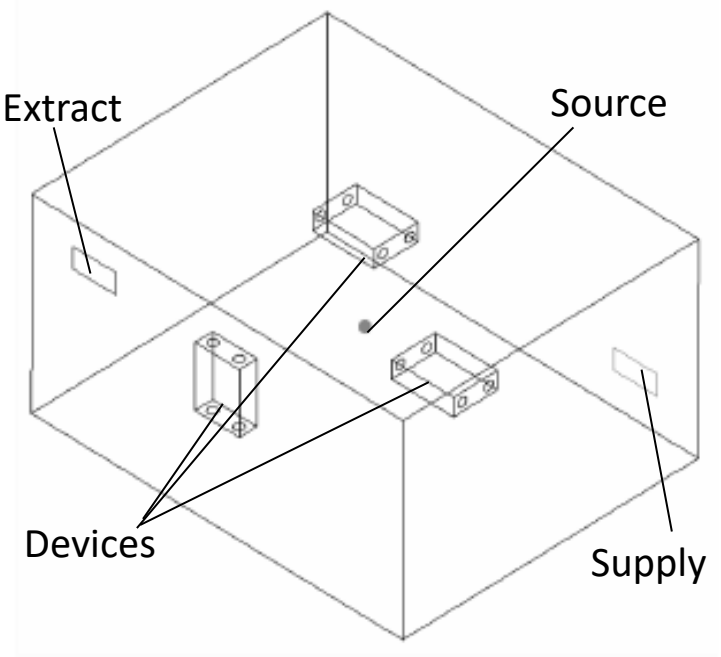


100 m3 room



500 m3 room

Chamber performance



Device location	AC/h	CFD	Experiment (Stdev)
Wall	1.5	90.9	76.9 (5.4)
	3	31.1	23.5 (9.4)
	6	43.8	19.1 (7.0)
Close to Source	1.5	98.0	78.6 (5.9)
	3	98.3	19.2 (3.6)
	6	72.3	*No data*
Ceiling	6	-14.4	-11.0 (8.2,)

Filtration based devices

- Physically traps aerosols in filter
- Particle size depends on filter – typically to around 0.3 micron
- Can remove other particulate pollutants
- Can be noisy
- Needs filter changes and cleaning

Clean Air Delivery Rate (CADR)

Equivalent amount of clean air produced by device
Encompasses flow rate and efficacy
May vary within a device for different particle sizes/pollutants
Usually in CFM, but may be in m3/h

Germicidal Ultraviolet (GUV)

- UV-C light damages DNA of microorganisms – sufficient exposure leads to lethal damage

$$C(t) = C_o e^{-kD}$$

- Inactivation depends on:
  - Microorganism species – virus, bacteria, fungi
  - Climatic conditions – harder to inactivate at higher humidity
  - UV Dose, D = UV irradiance (W/m^2) * exposure time
  - Some data for coronavirus, k = 0.37 J/m^2 (Walker & Ko 2007)
- GUV around 254nm, far UV emerging tech at 222nm
- Some other wavelengths can produce ozone as by product

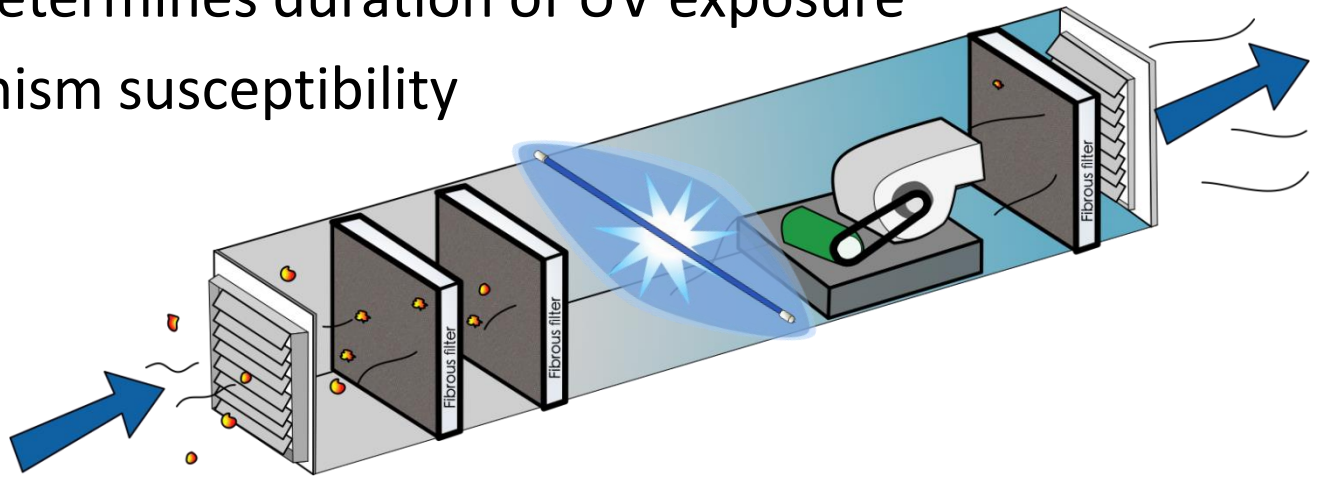
Evidence for effectiveness

- Laboratory studies
  - Several studies showing inactivation of microorganisms on surfaces and in air including one study on a coronavirus
- Clinical focus on TB transmission and upper-room UV-C
  - Original guinea pig trials - Wells, Riley and co-workers in 1950's/60's
  - TB shelter study - Harvard School of Public Health
  - Recent clinical studies in Peru (Escombe et al, PLoS Med 2009) and South Africa
- More recent interest in application against other pathogens
  - Office studies showed reduction in absentism (Menzies et al, Lancet 2003)
  - Potential reduction in surface contaminantion (eg. Anderson et al, ICHE 2006)

In-duct systems

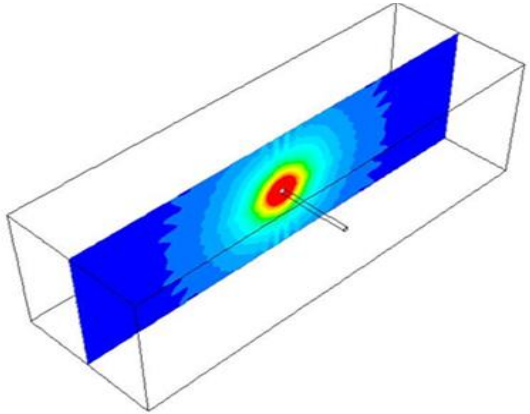
Depends on:

- Lamps – number, location, intensity
- Airflow – determines duration of UV exposure
- Microorganism susceptibility

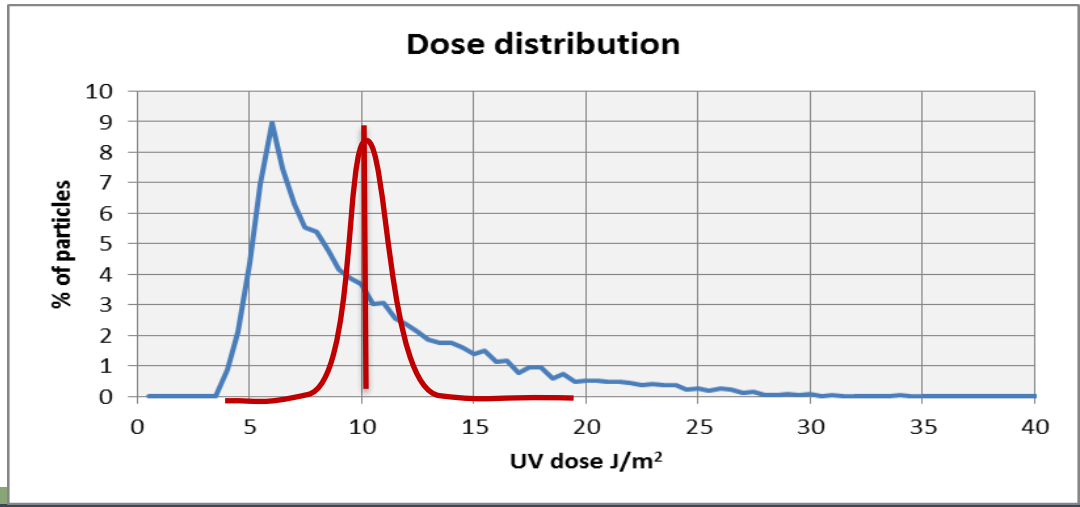


Modelled UV dose

- Mean CFD compares well to experiment
- CFD shows distribution
  - Some pathogens over irradiated
  - Many are under irradiated

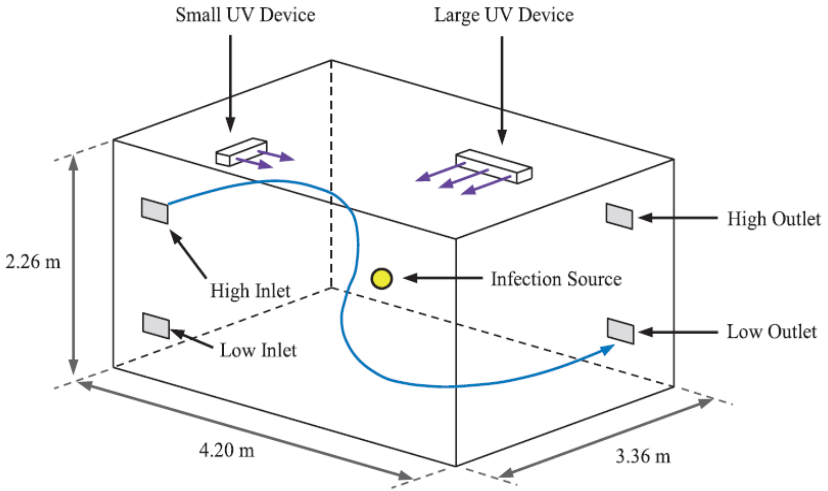


Microorganism	EPA 600/R06/050 1 lamp 9.73 J/m²	
	EPA	CFD
S. Marcescens	99%	99.46%
MS2	39%	34%
B. Atrophaeus	4%	8.72%

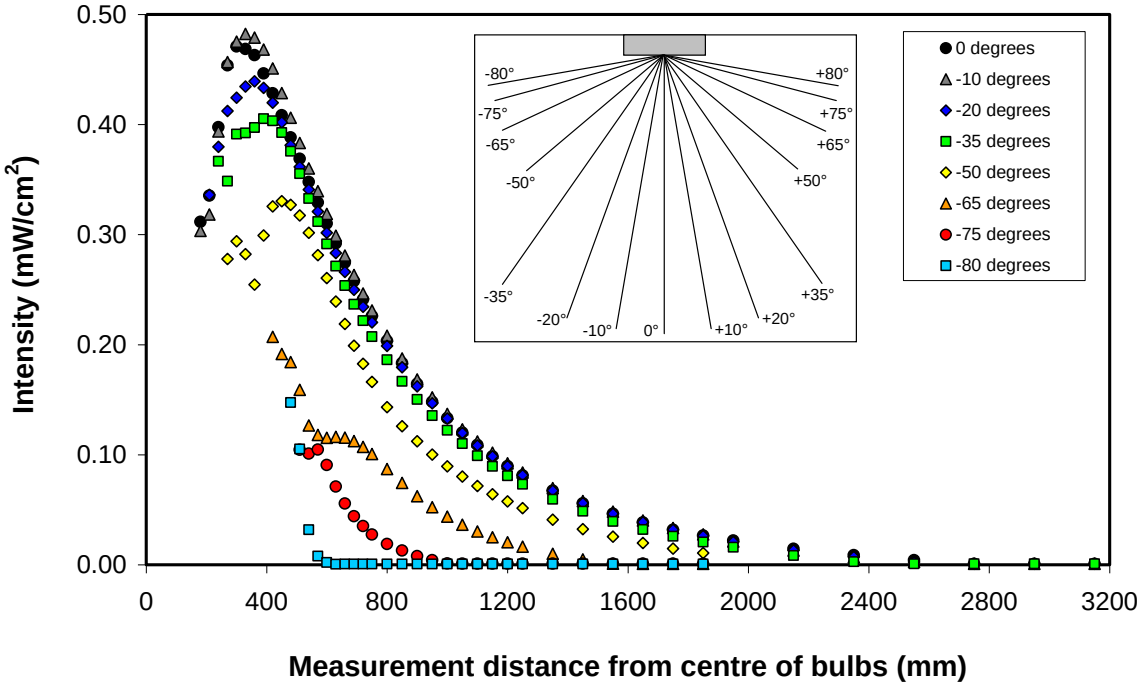


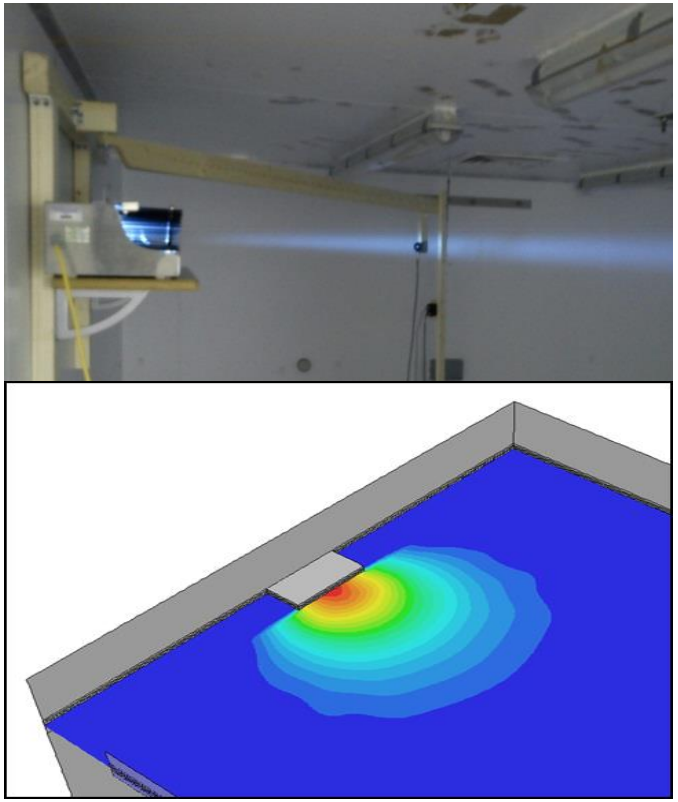
Upper room UV

- Shielded UV lamps above head height – create a UV zone
- Room airflow passes airborne microorganisms through UV field
- Analysis is complex
  - 3D Airflow patterns
  - 3D UV light fields
  - Microorganism source/dispersion
  - Microorganism susceptibility

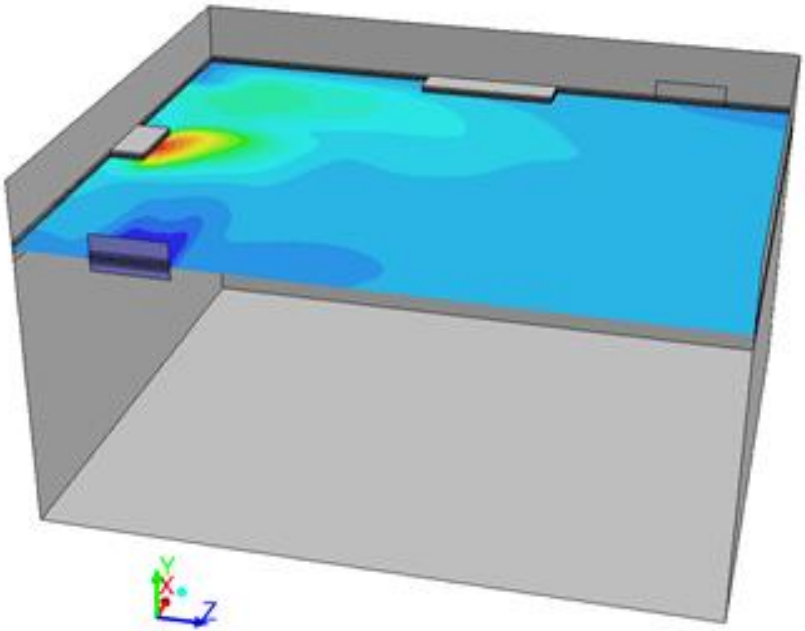


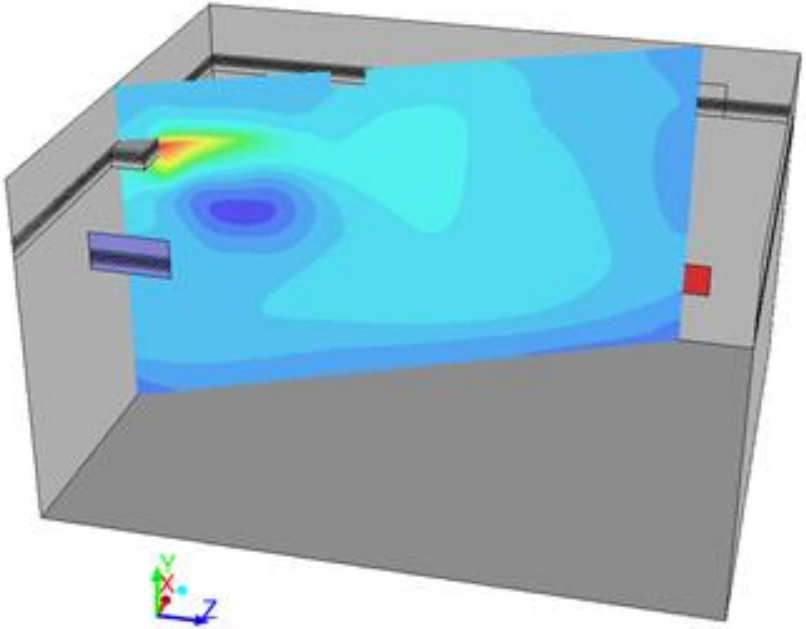
Upper-room UV field



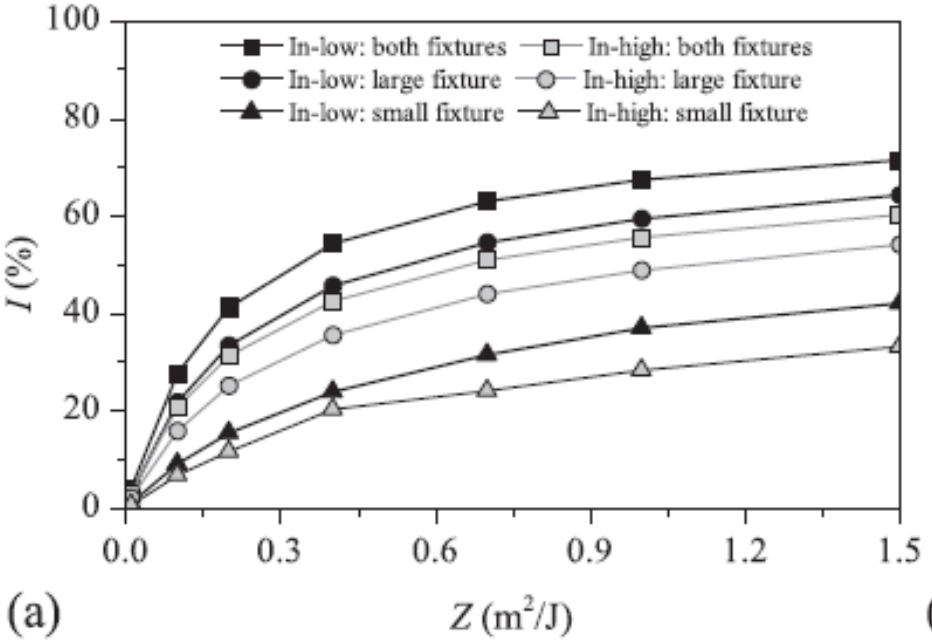


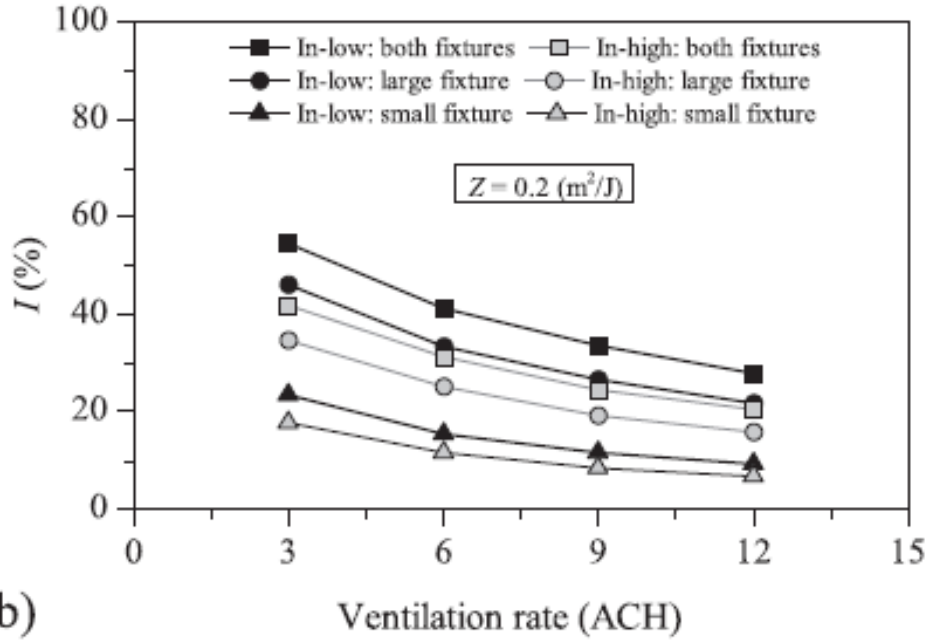
Coupled airflow UV dose





Inactivation





Other technologies

Ionisers, ESP, Plasma

- Based on charged particles
- Ionisers and plasma within room, ESP traps on collection plates
- Preferential charging an deposition primary mechanism
- May have some biocidal effects
- Some full scale data for ionisers (Acinetobacter, TB) but results mixed
- Some devices can produce secondary pollutants

Chemical based devices

- Chemical oxidation to generate ozone or hydroxyl radicals
- Lab tests show biocidal effects and can remove VOCs
- Risks of secondary pollutants – ozone, formaldehyde, ultrafine particles
- Chemical spray devices (e.g Hydrogen peroxide) not suitable for use in occupied spaces

What is in a device?

Device	Reduction (%)
Device 1 HEPA filter only, no ionisation	60.2
Device 1 HEPA filter plus ionisation	62.1
Device 1 Ionisation only, HEPA removed	25.2
Device 2 HEPA filter only, no ionisation	52.9
Device 2 HEPA filter plus ionisation	28.1
Device 2 Ionisation only, HEPA removed	1.6

Selecting a technology

- Can you mitigate risks with other means first?
- Which transmission route(s) is it mitigating?
  - Can it do this quickly enough?
- What is the principle of operation – is this clear?
- What kind of evidence is available?
  - How was the device tested?
  - Is the evidence relevant to the circumstances of use?
- Are there any knock on impacts – comfort, noise, energy, secondary pollutants, health impacts?
- How will people respond to the use of the technology? Does it influence behaviour?

Practical considerations

- What is the capital investment and ongoing costs?
- Does it need specialist design/installation?
- What will people need to do to use the technology?
  - Simple or needs training?
  - Passive or active control?
  - Patients and/or staff?
- Where will you locate it?
  - Installed as part of services
  - Portable – trip hazard?
- What maintenance is required, how frequently, and who does this?

There are no magic bullets…..

Thank you

Dr Azael Capetillo

Dr Carl Gilkeson

Dr Louise Fletcher

Dr Andy Sleigh

Dr Amir Khan

Dr Marco-Felipe King

Laura Pickin

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Any Questions?

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