A hygiene ventilation renovation

Systematic partial engineering control for small sharing room with ceiling mixing ventilation and filter effect for “corona-proof”

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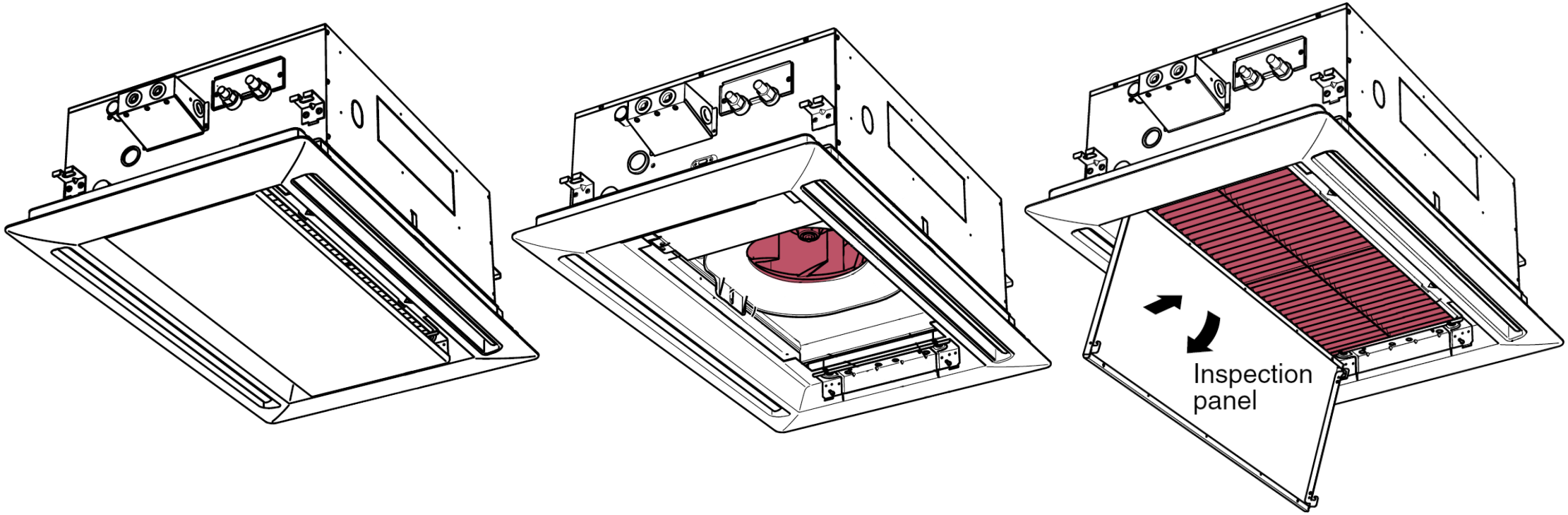
P5 presentation

12/04/2022

Efficient local air recirculation at ceiling level promote the ***performance of purifiers*** and *anti-epidemic efficiency* of mixing ventilation in a small shared rooms

* *"purifiers"* here means any end equipment that has the capacity to remove or inactivate the virus nuclei laid airborne particles

* *Small shared rooms* here means the shared place within 20 m2, and clear height less than 2.8 m, without vigorous activities



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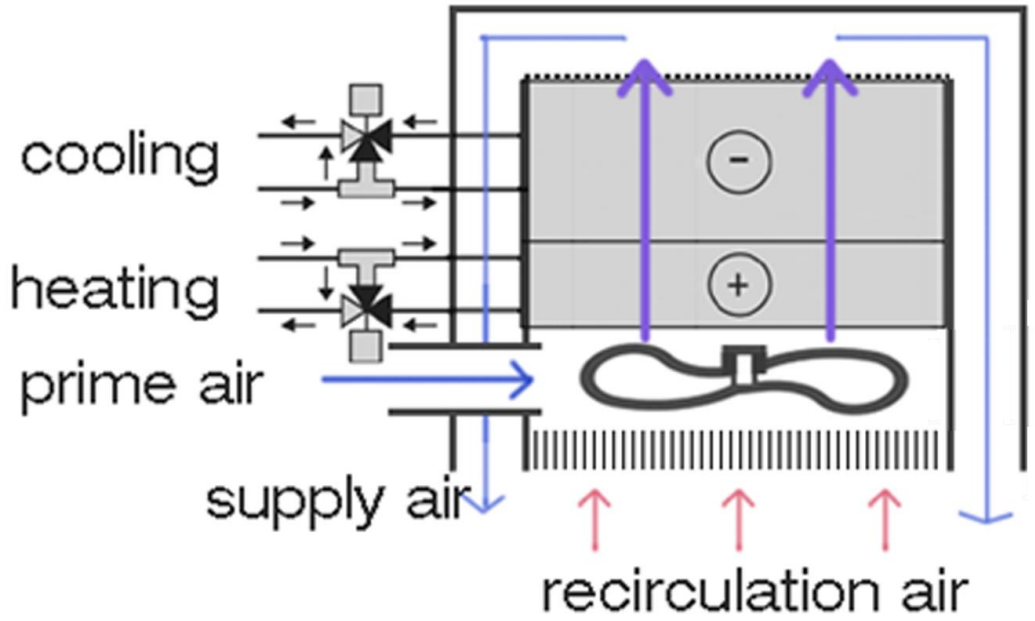
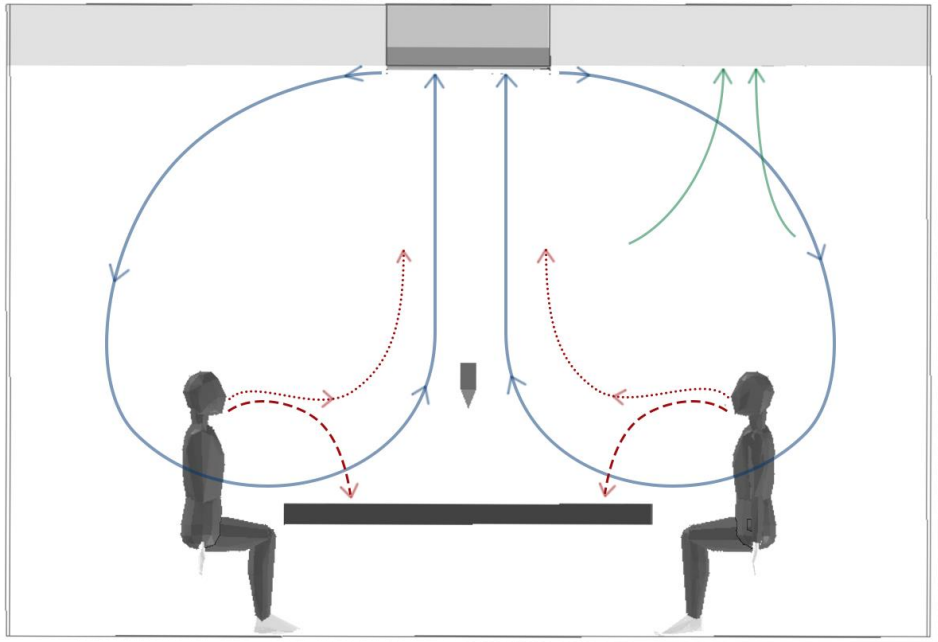
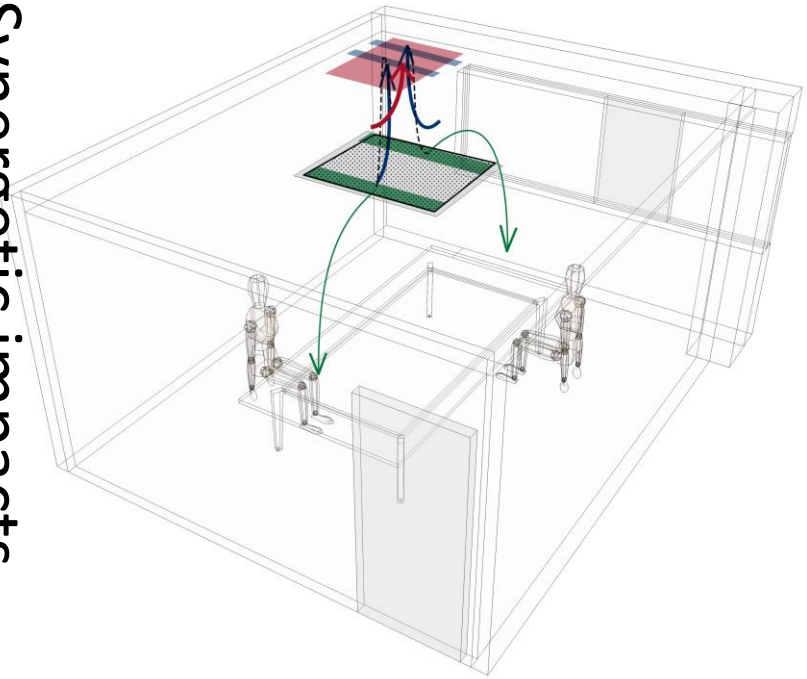
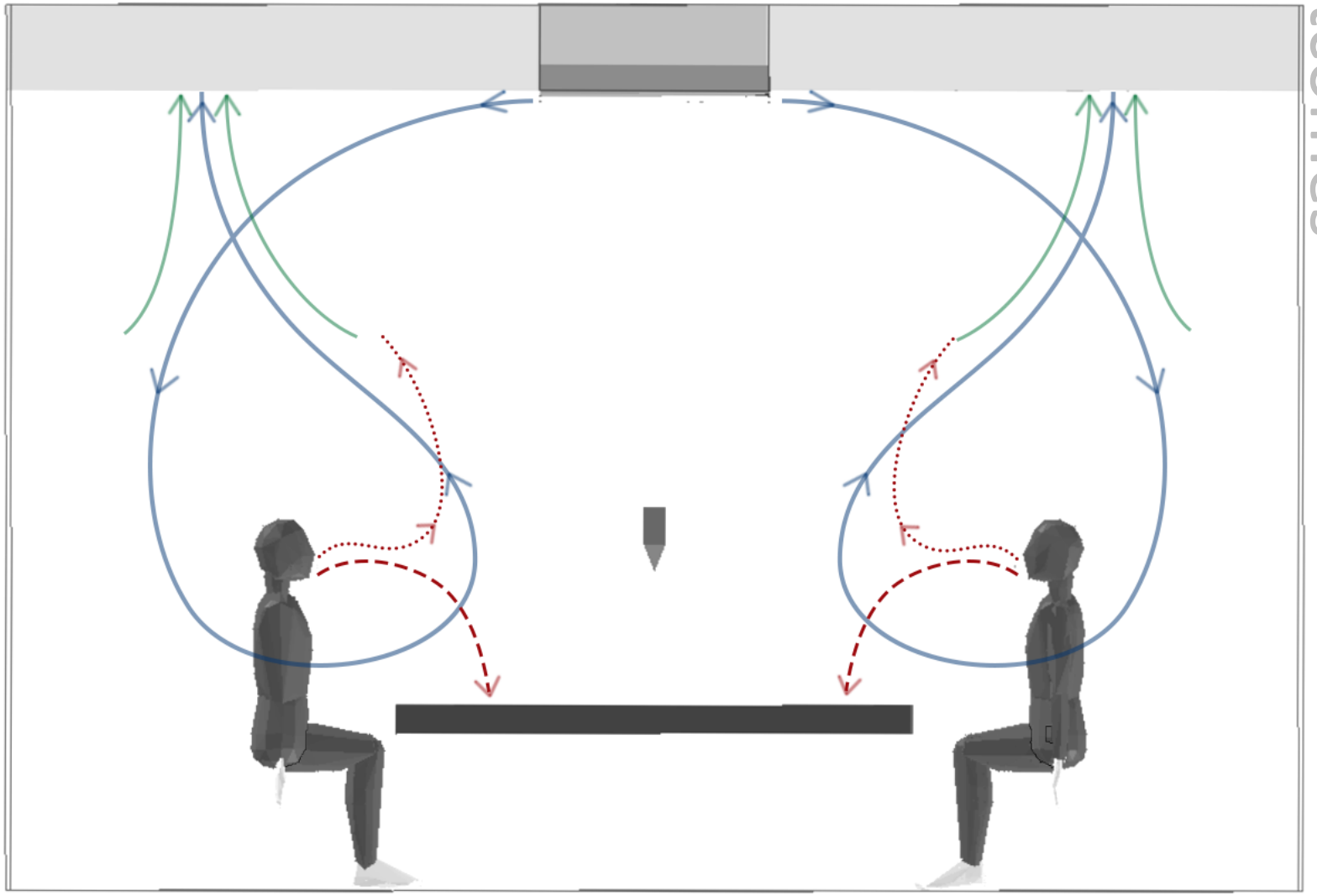




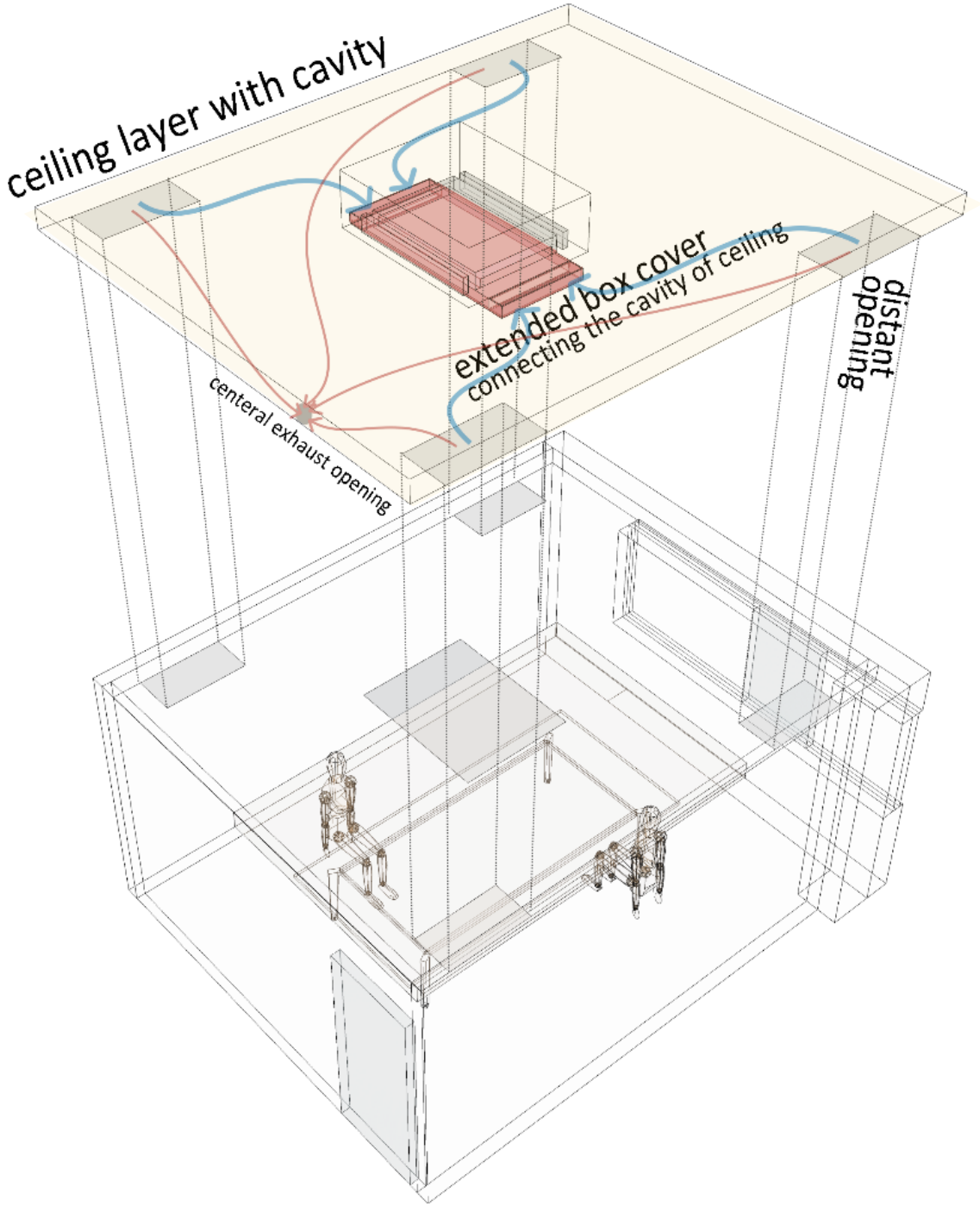
Is there the secondary pollution from the air recirculation?



Avoid the air recirculation airflow shortcut



2 Ventilation renovation strategy



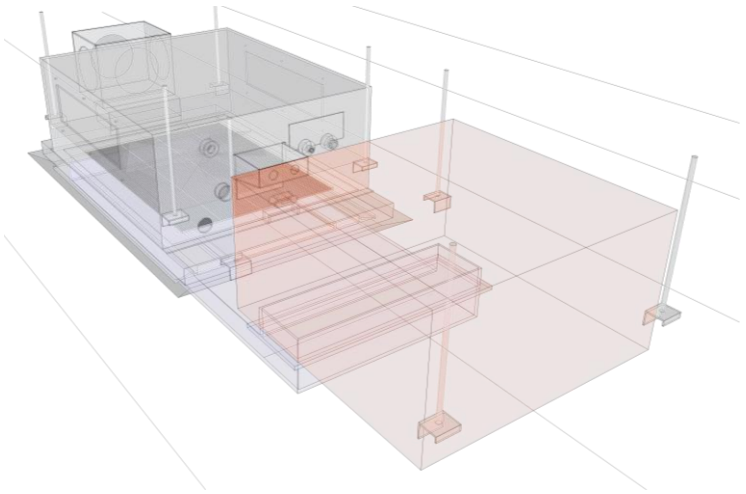
Outcomes

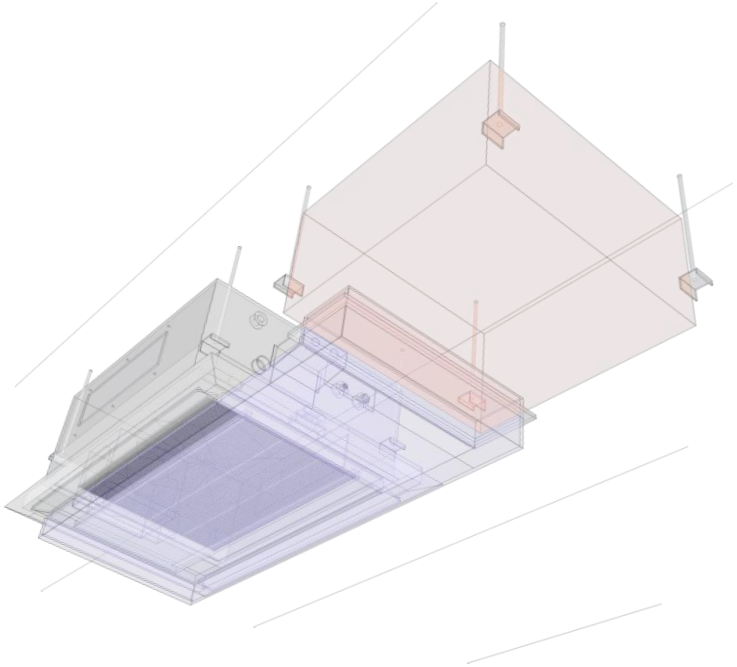
- Partial control
- Keep the max. fan speed in the indoor end unit
- Enlarge the distance between distance between return and resupply openings [m] & distance between supply and exhaust openings [m]
- Update the filter effect at least to ePM1 90%

- Application of CFD
- Predict the ventilation shadow
- “corona-proof” efficiency
- Avoid short cut airflow (both general ventilation and air recirculation pattern)

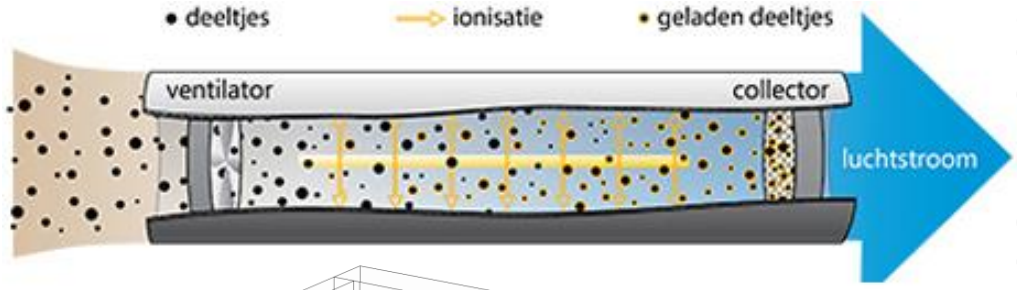
- Experience from cleanrooms
- Direct supply air for the main working area
- Prefabricated ventilation element for installation

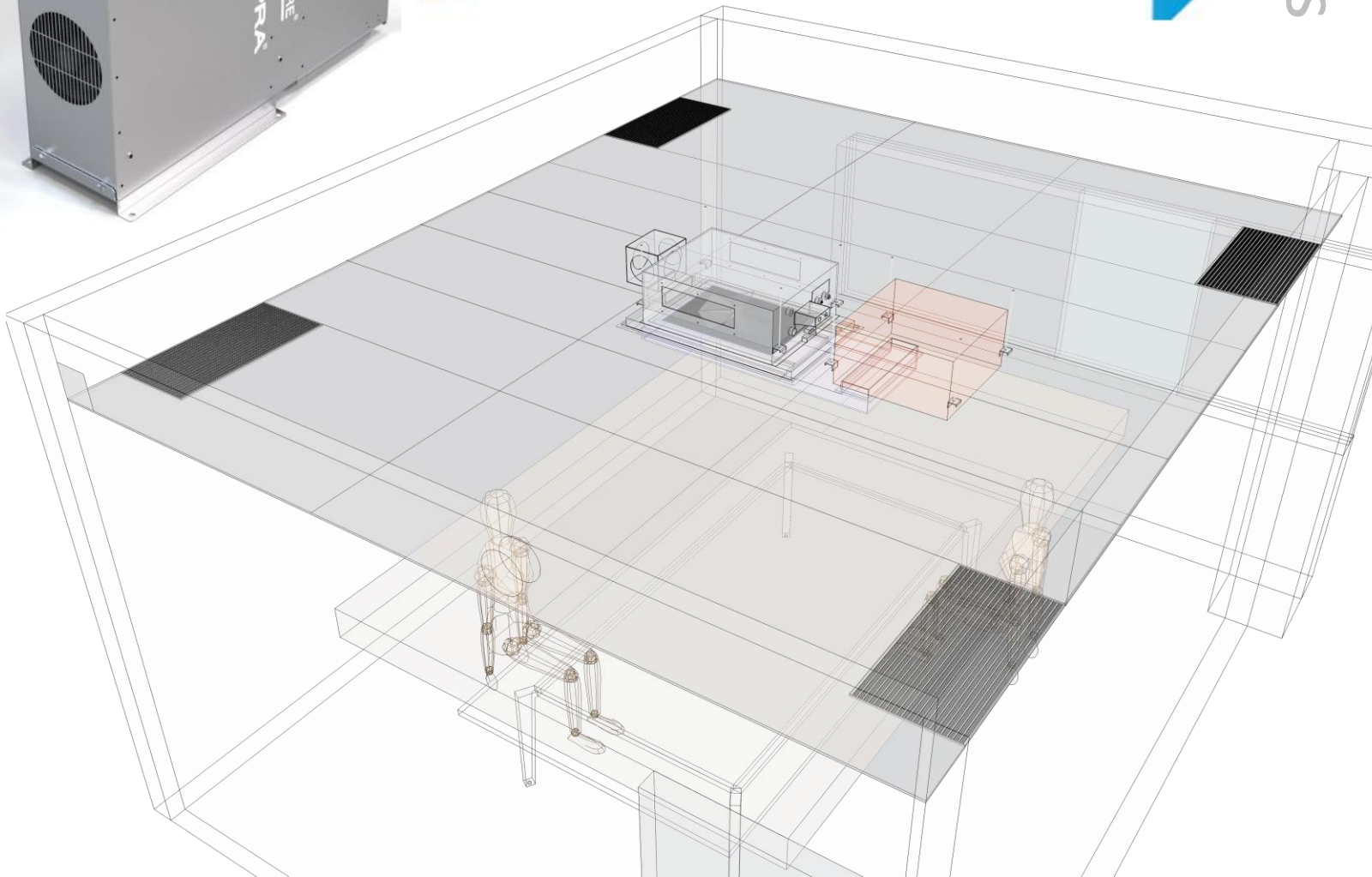
ESP integrated ventilation product





Electrostatic precipitator





Process

How to deal with coronavirus in built environment?

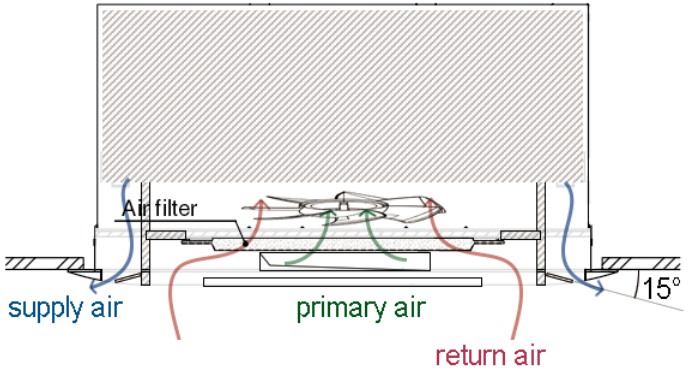
INFECTION RISK ⟷ SPACE

Infection risk for airborne transmission

Space is a small shared room (area < 30m2; height < 2.8m)

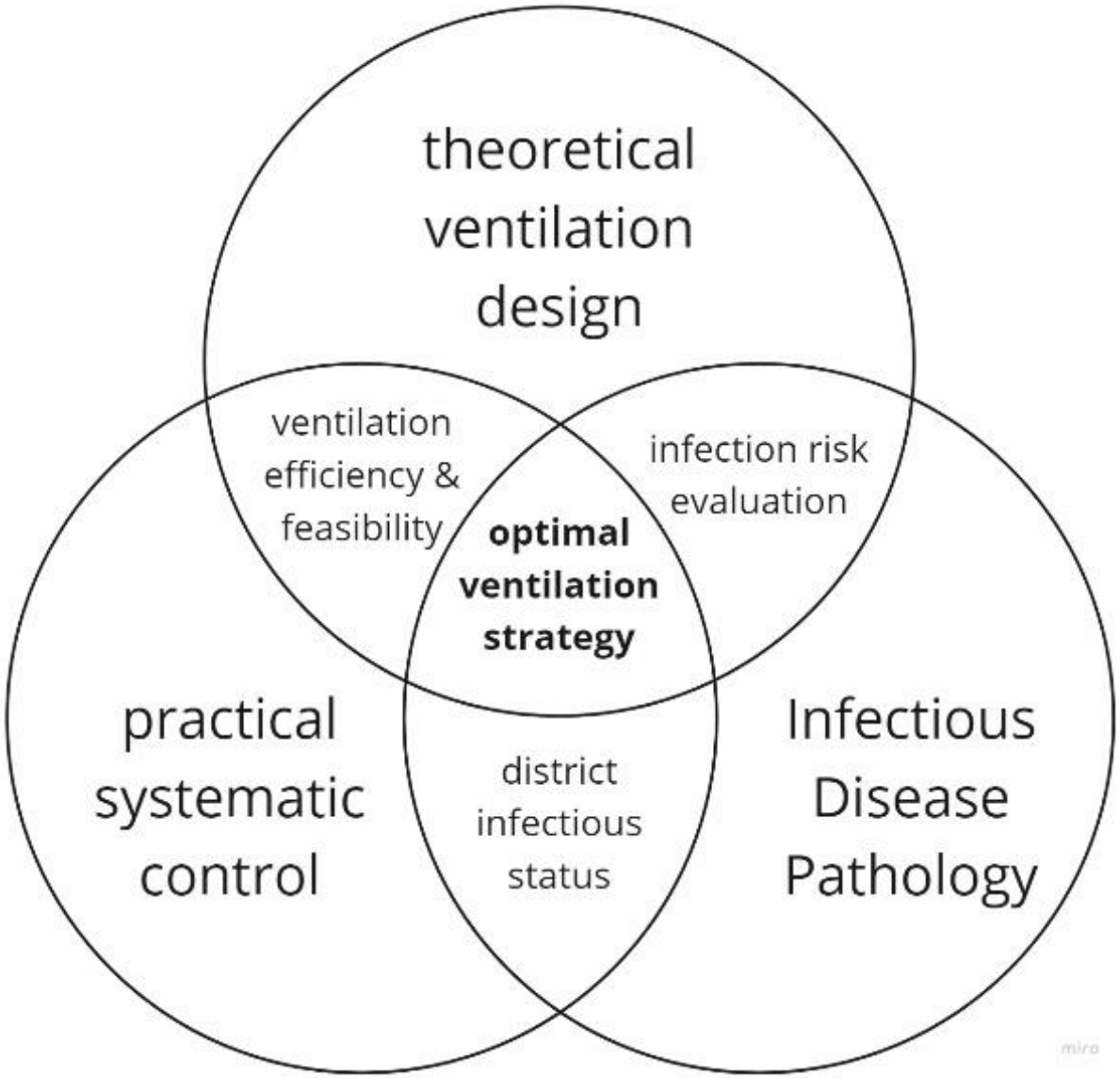
Design product focuses ventilation airflow routine

Ventilation pattern – **air recirculation**



Parameter system – **CO2 & particle**

Evaluation system – **Wells-Reily** calculation model
local contaminant **concentration**

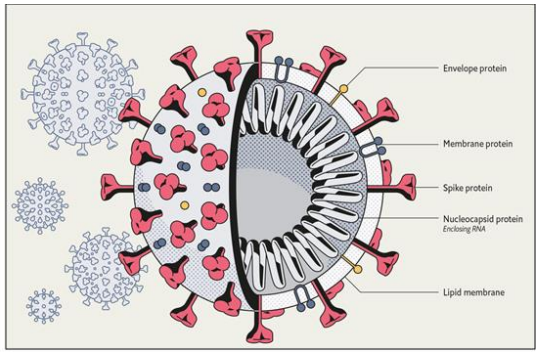

theoretical ventilation design
ventilation efficiency & feasibility
infection risk evaluation
optimal ventilation strategy
practical systematic control
district infectious status
Infectious Disease Pathology
miro

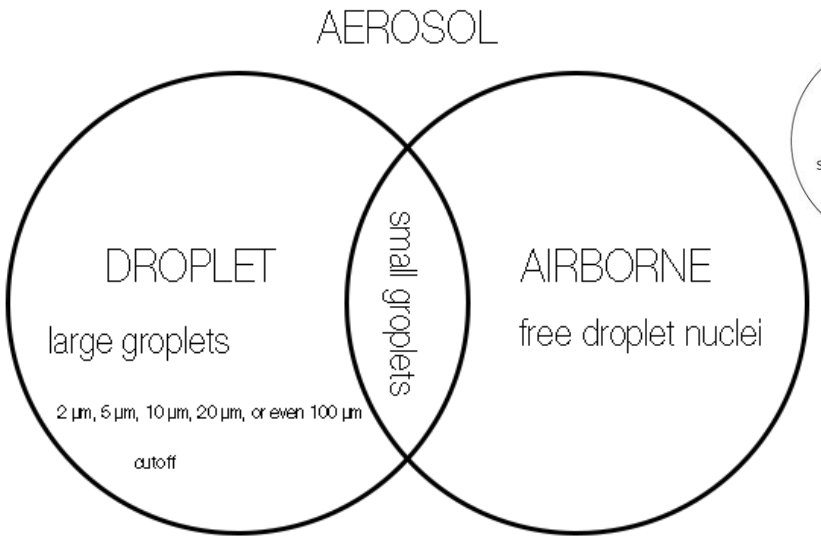
1

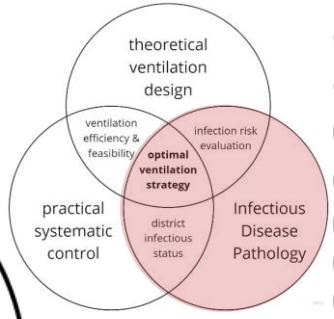
Scope down – airborne transmission

Pathology - VIRUS

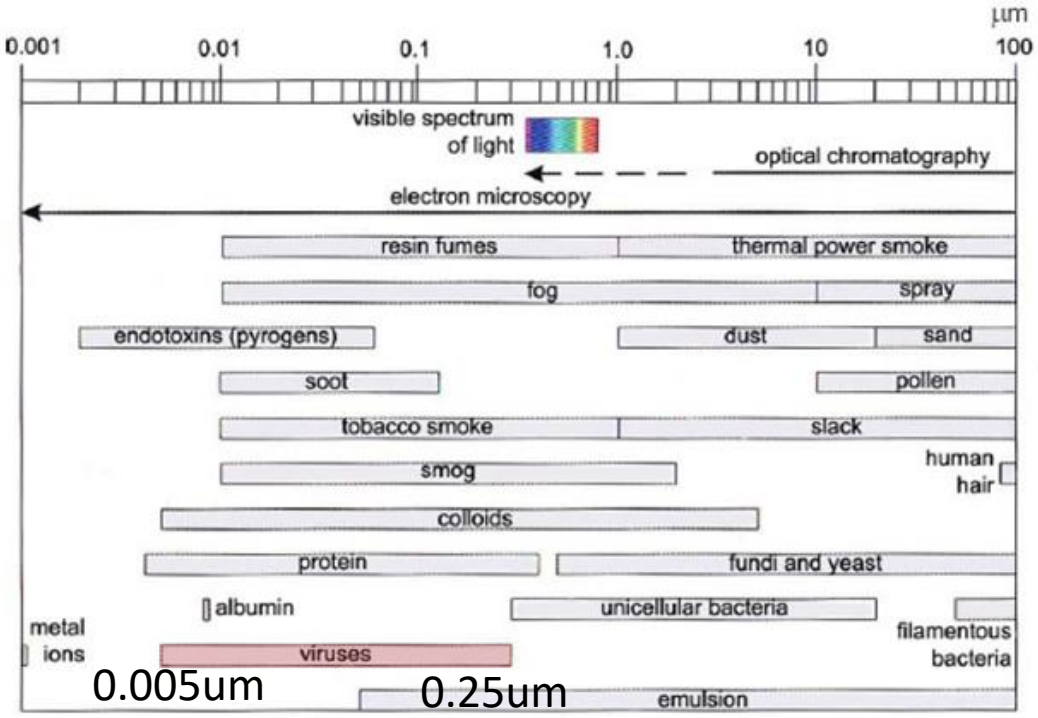
- SIZE
- Pathological features

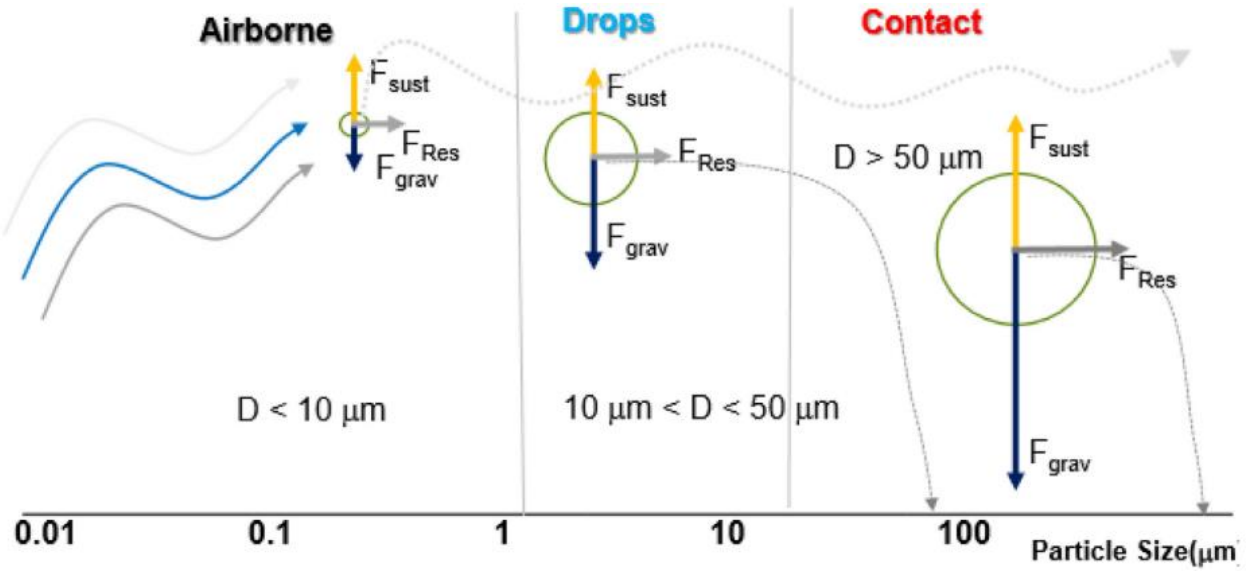






Process

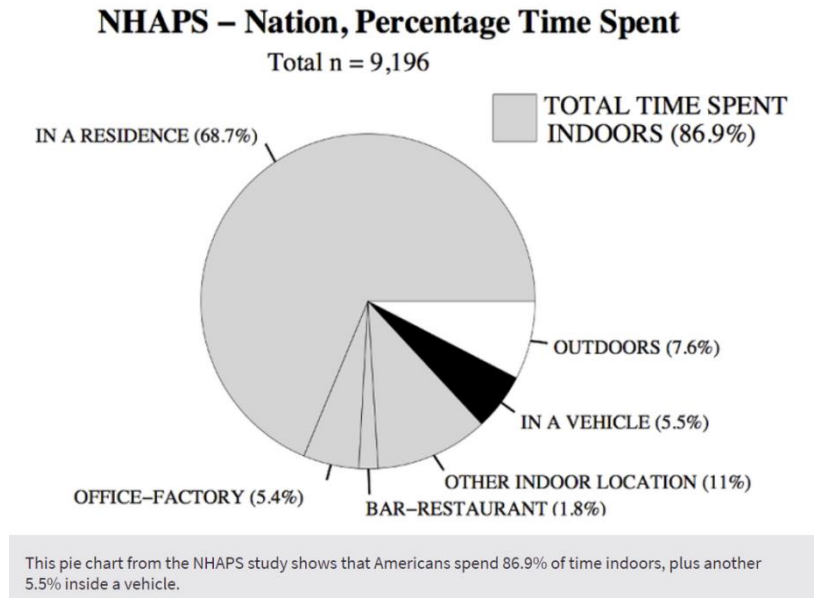




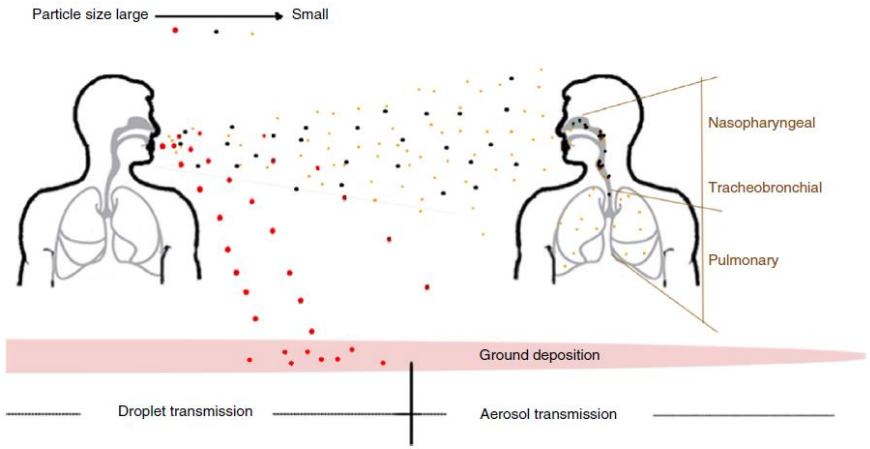
Why is airborne transmission?

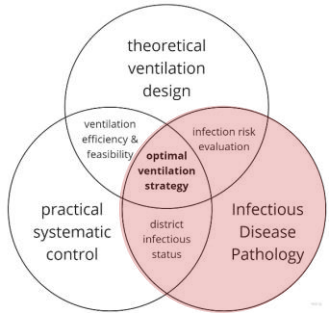
1 Scope down – airborne transmission

Pathology – INDOOR TRANSMISSION



This pie chart from the NHAPS study shows that Americans spend 86.9% of time indoors, plus another 5.5% inside a vehicle.





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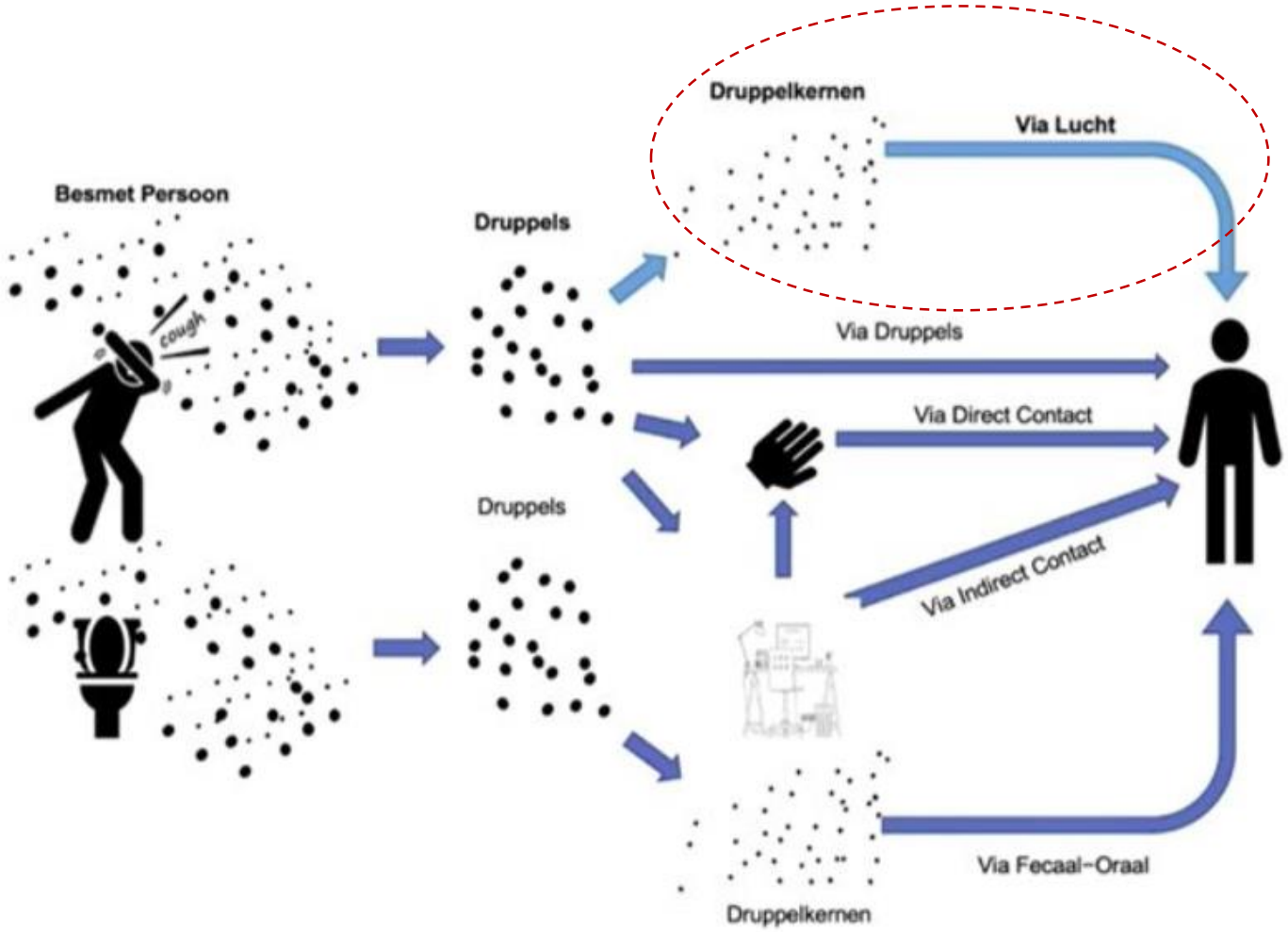
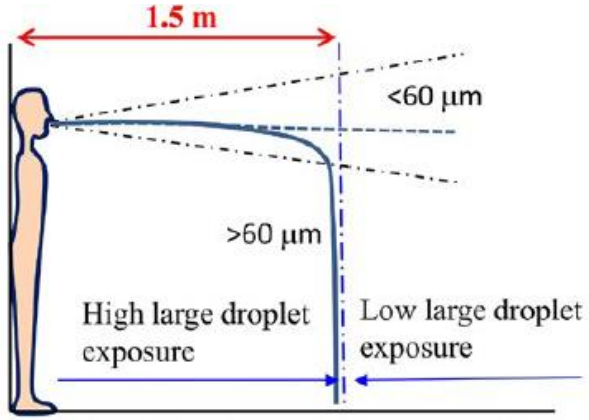


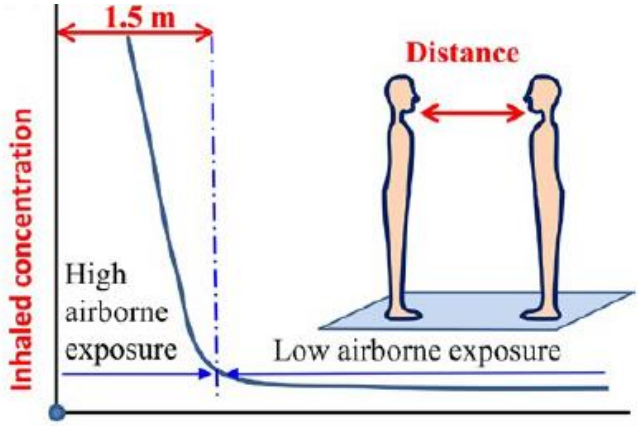
Why is airborne transmission?

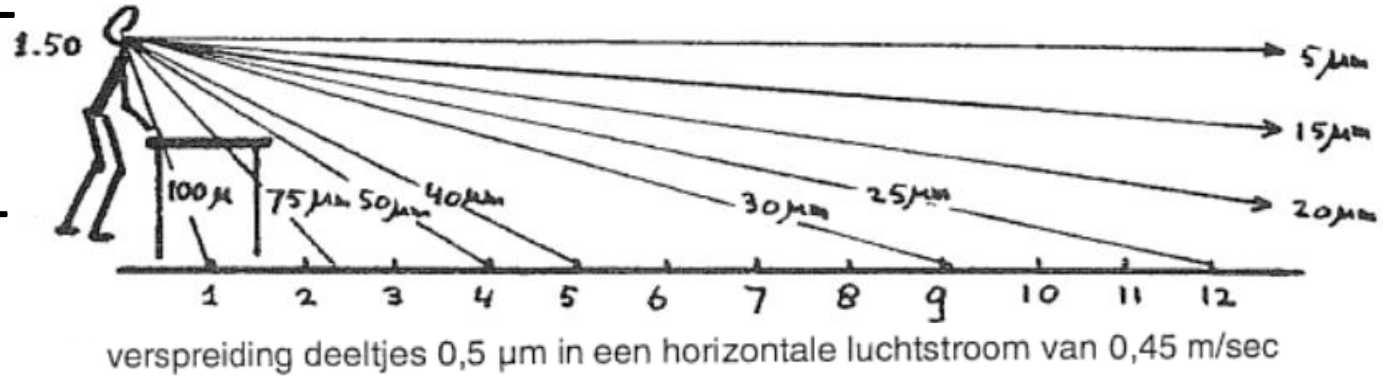
1

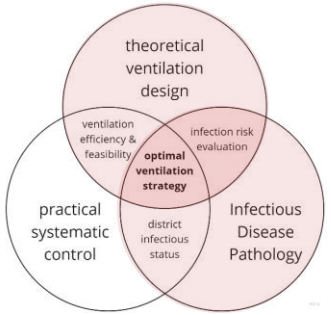
Pathology -> Building Technology

Scope down – airborne transmission



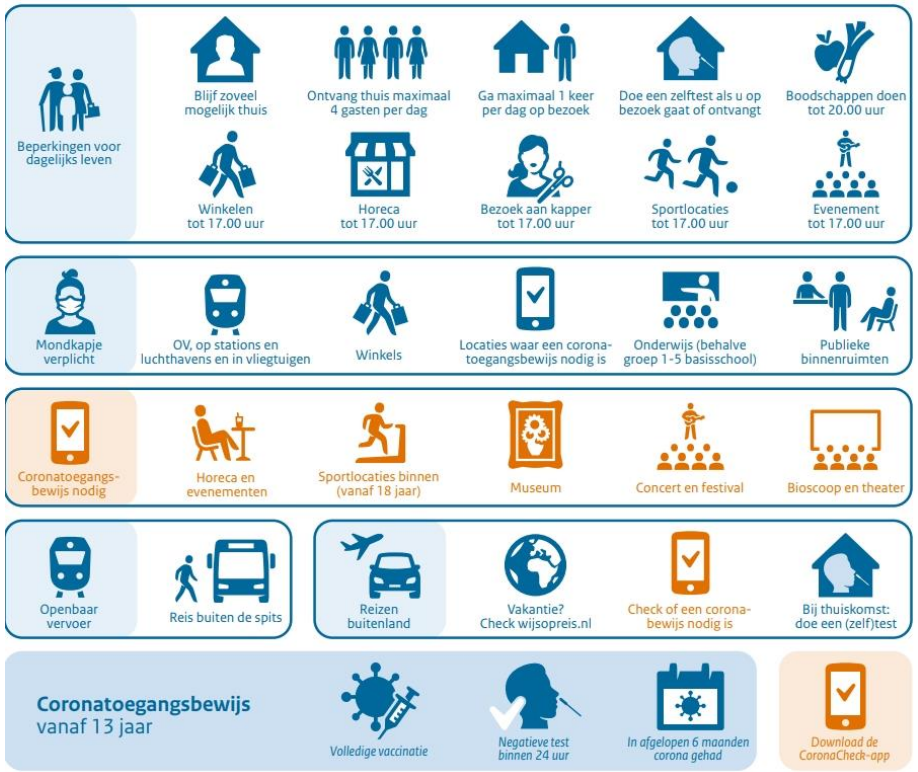




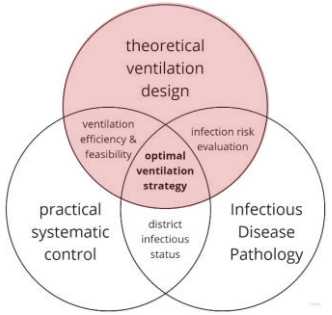


Process

Why is airborne transmission?

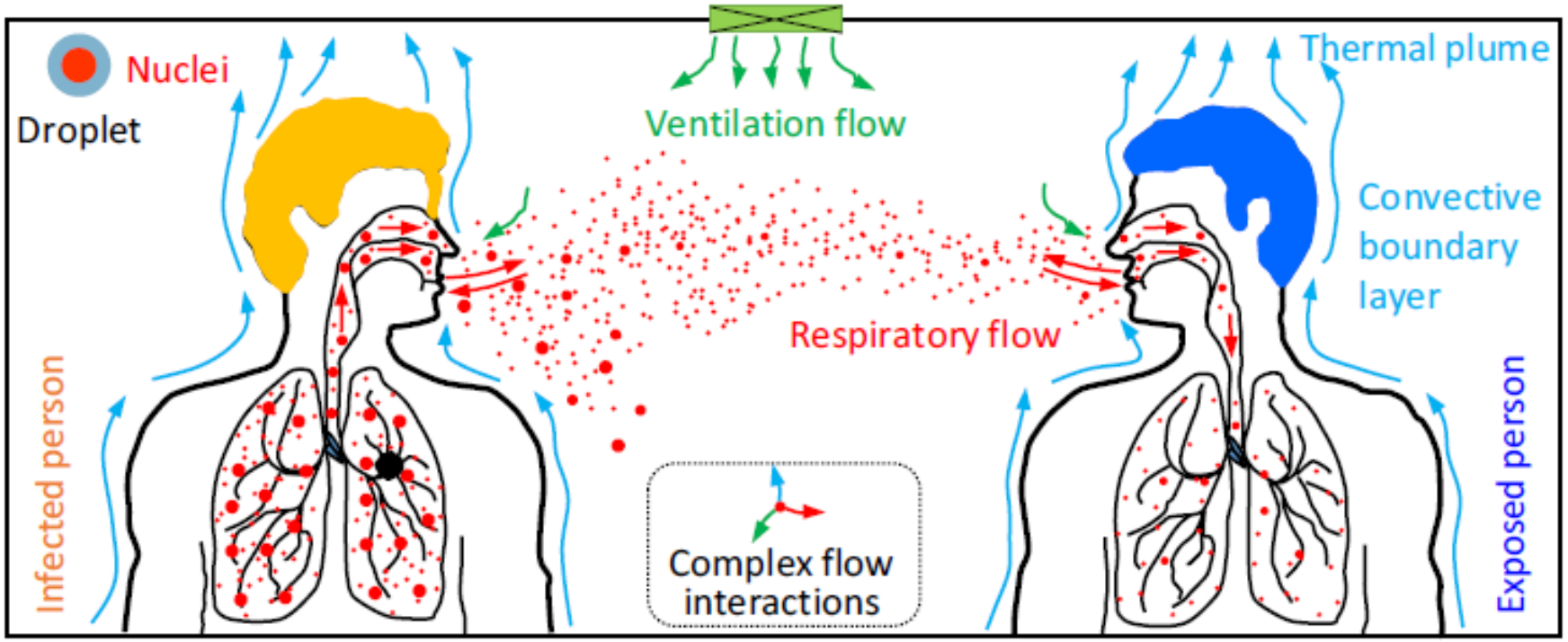


Building Technology – MICRO-CLIMATE



- ventilation flow
- human body boundary layer flow
- respiratory flow

medium-scale environment

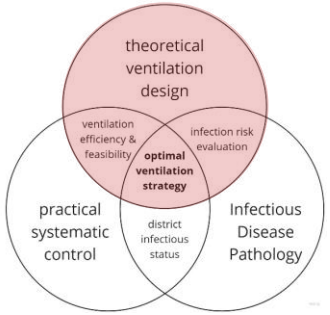


What are the impacts of ventilation?

2

Scope down – small shared room

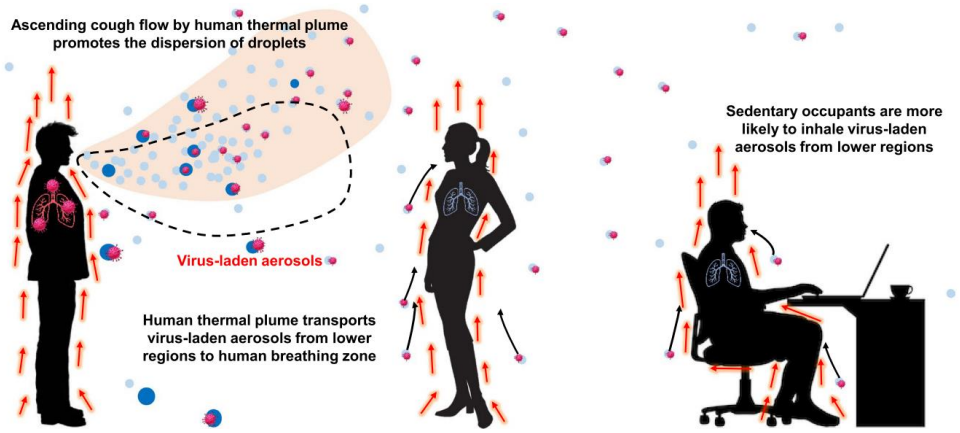
Building Technology – Air distribution patterns in room climate

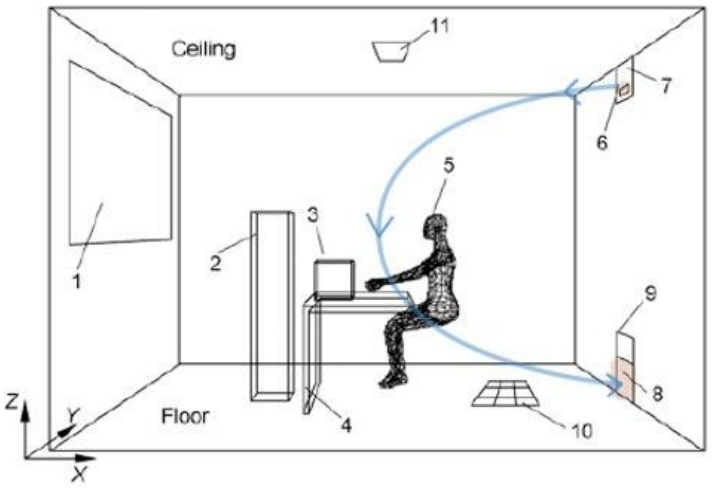


Process

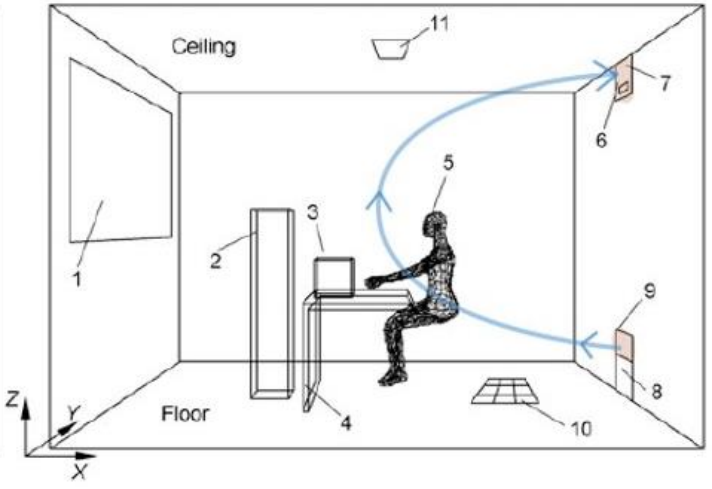
What are the impacts of ventilation?

- Mixing ventilation
- Displacement ventilation
- Under-floor air distribution

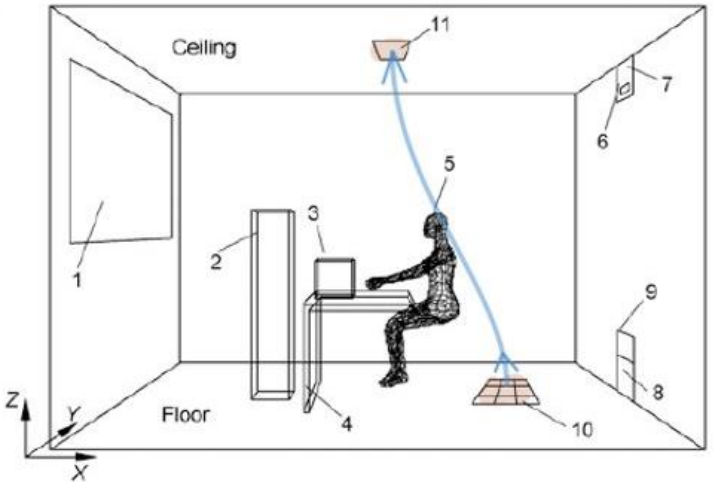




MV



DV

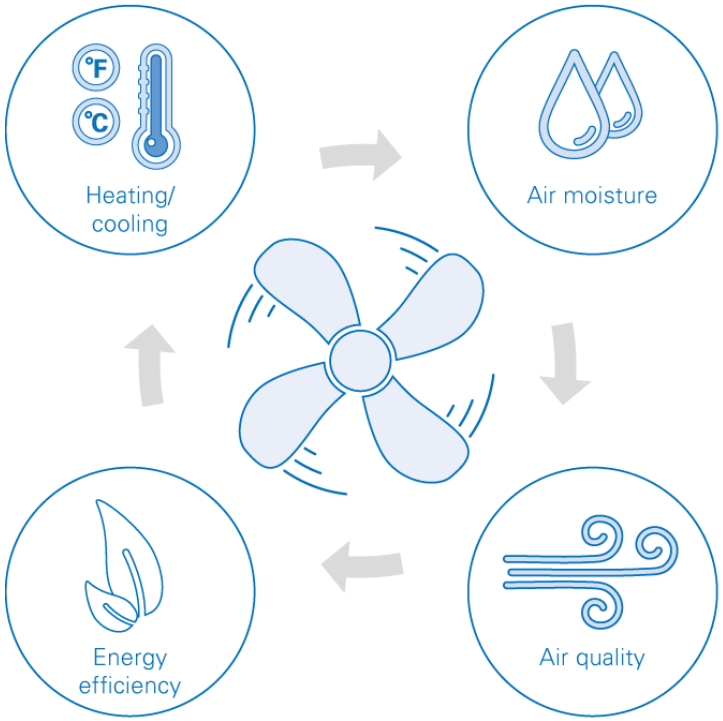


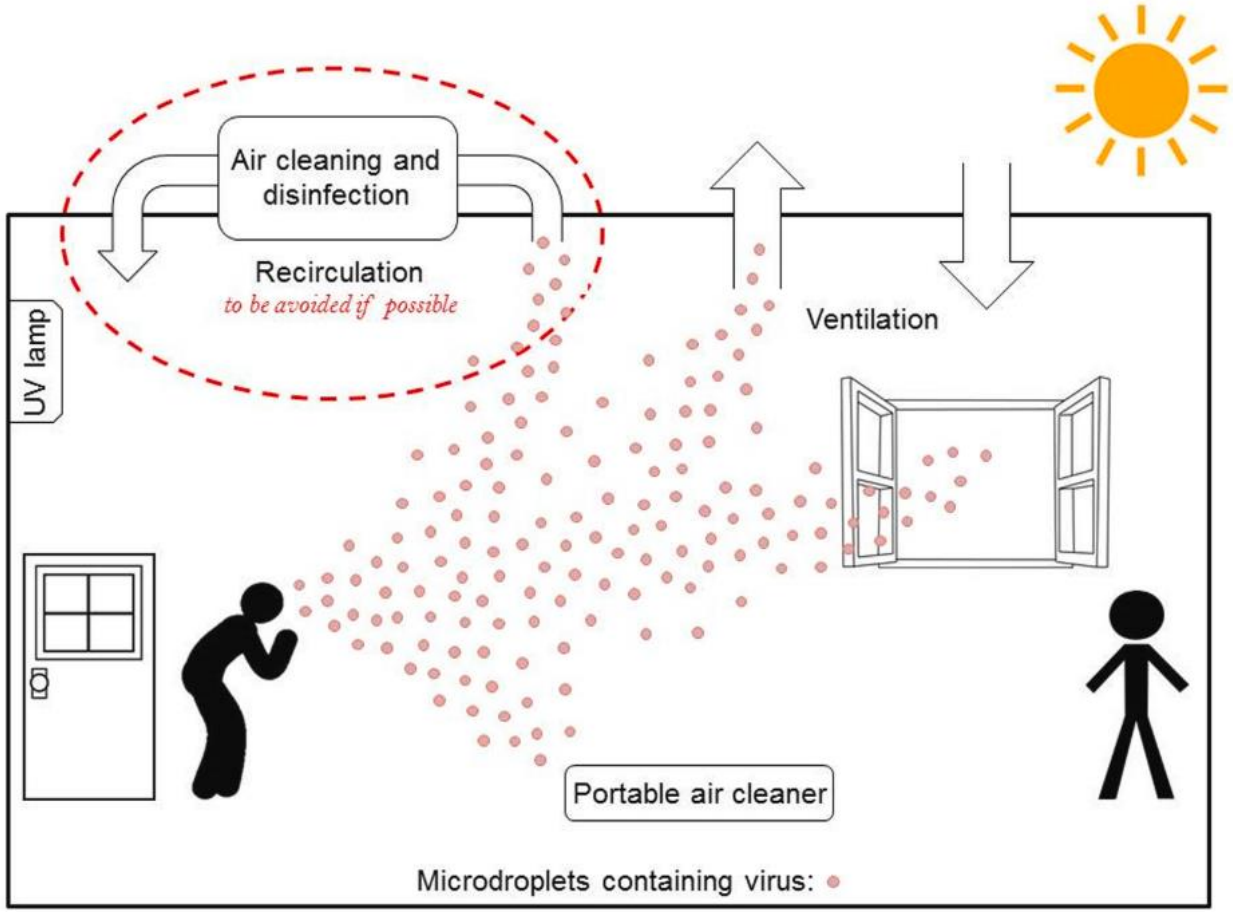
UFAD

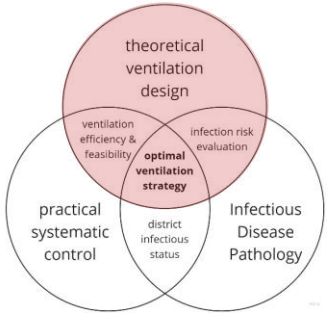
2 Scope down – small shared room

Building Technology - VENTILATION

- Higher **outside air fractions → 95%**
- higher **air change hourly rates → 3**
- Humidity → 40%-60%
- *Temperature? around 20℃*



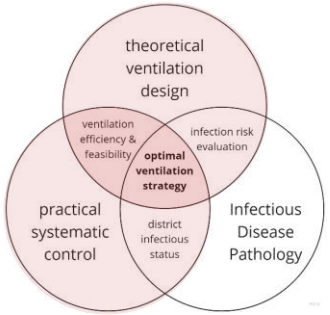




Process

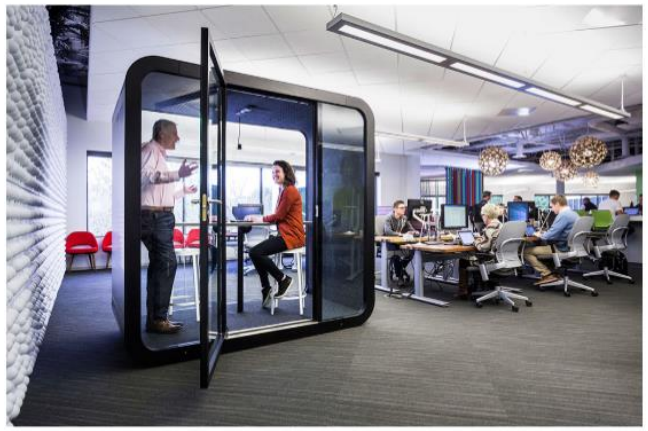
What is ventilation?

Building Technology – Engineering Practice



High economic **productivity value** for *real estate investment*

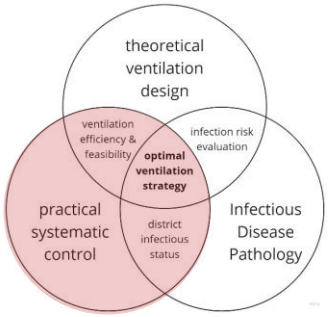
- Small meeting room
- Building system
- High-end ventilation practice
  (cleanroom design experience)



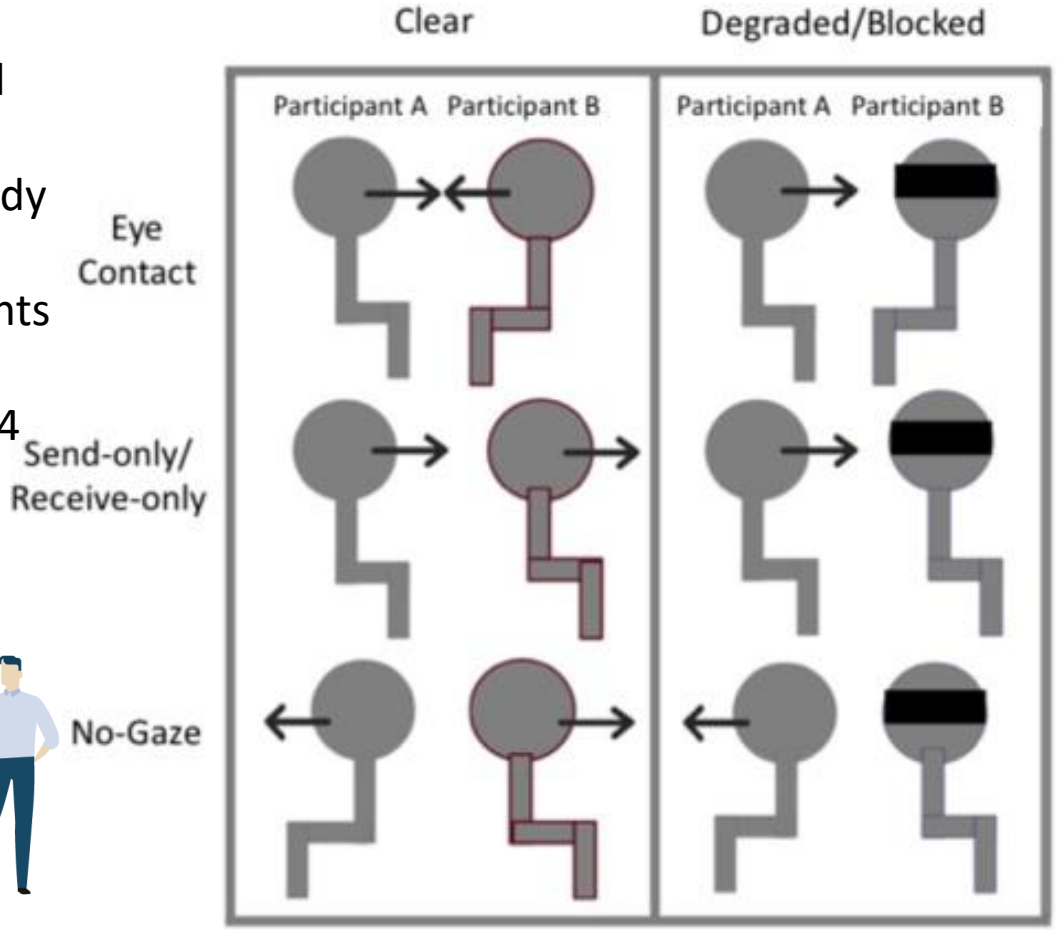
Why is the small meeting room in Kuipers, Leiden?

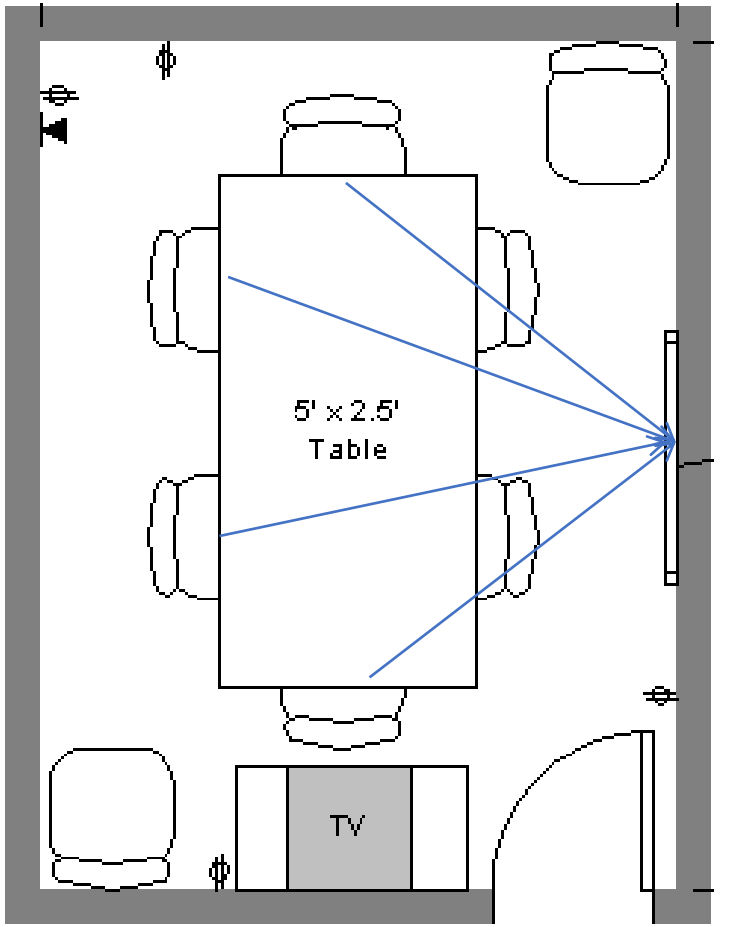
Kuijpers

Engineering Practice – meeting room



- Position is settled by the furniture;
- Long-staying steady activity
- Spacy requirements for eye contact
- Small Capacity 2-4 people



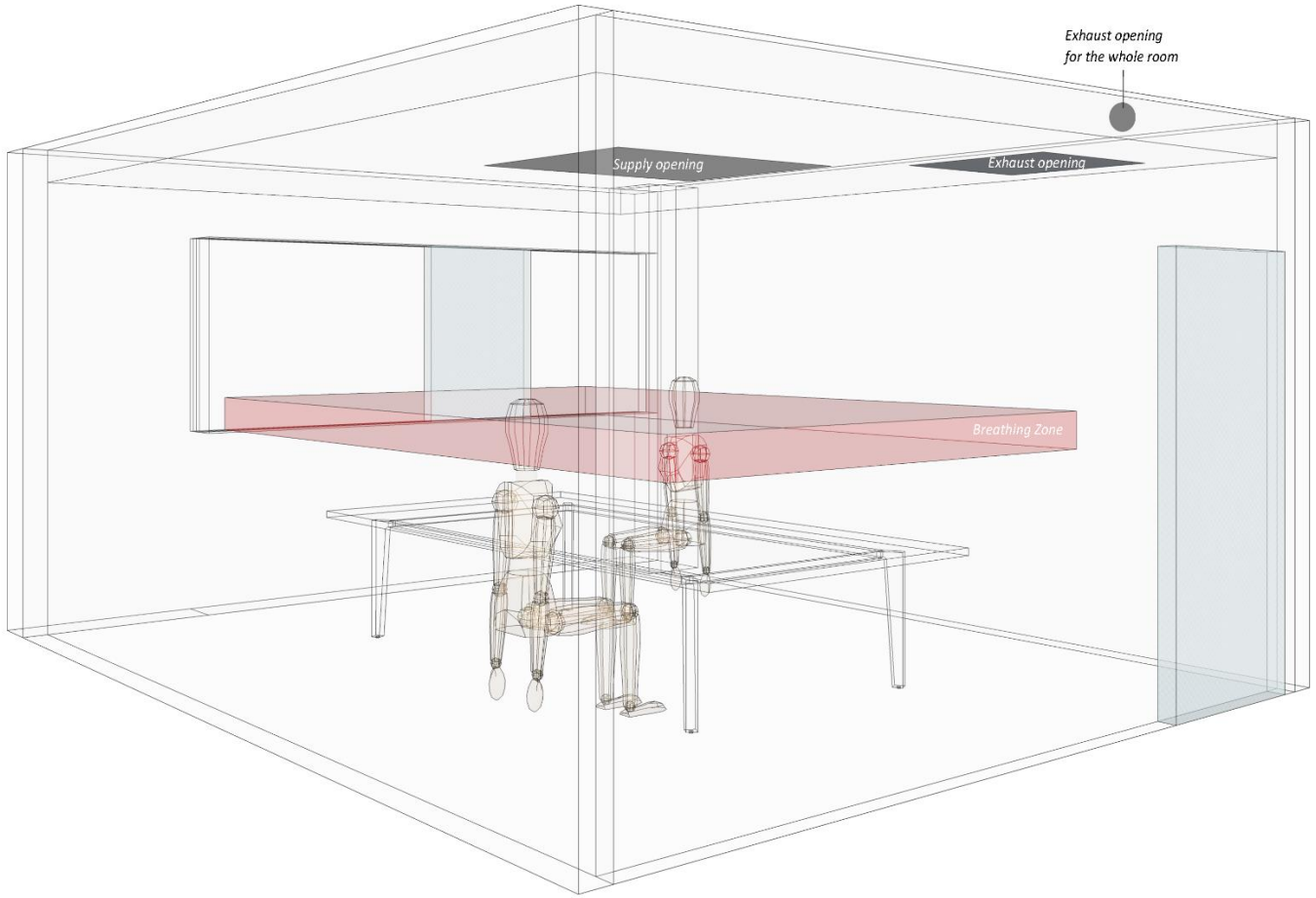


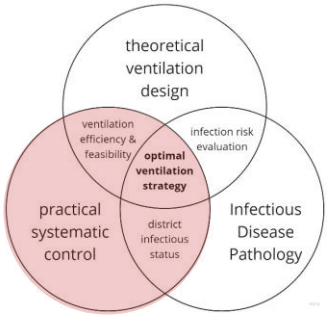
What is the small meeting room?

2

Engineering Practice – current ventilation

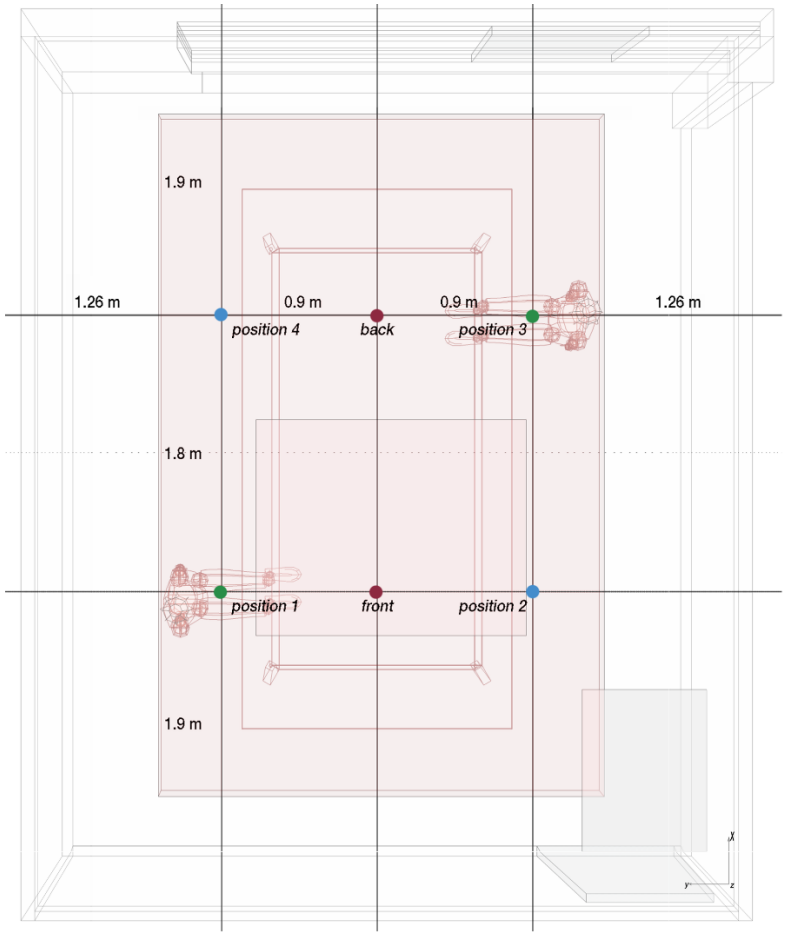
Scope down – small shared room





Process

What is the small meeting room?

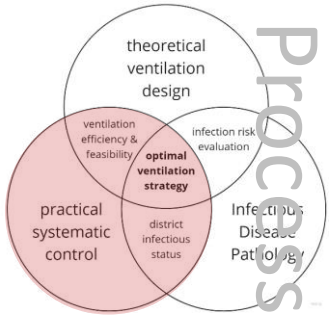


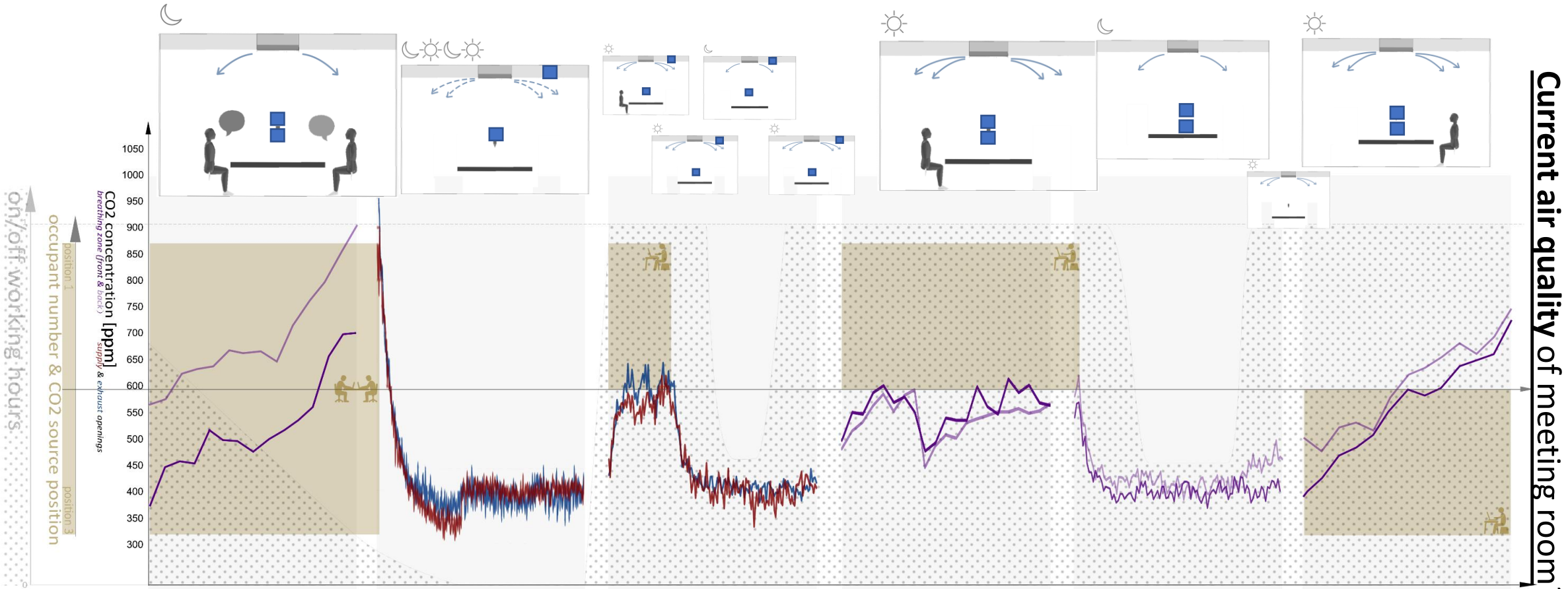
2

Engineering Practice – current ventilation

Scope down – small shared room

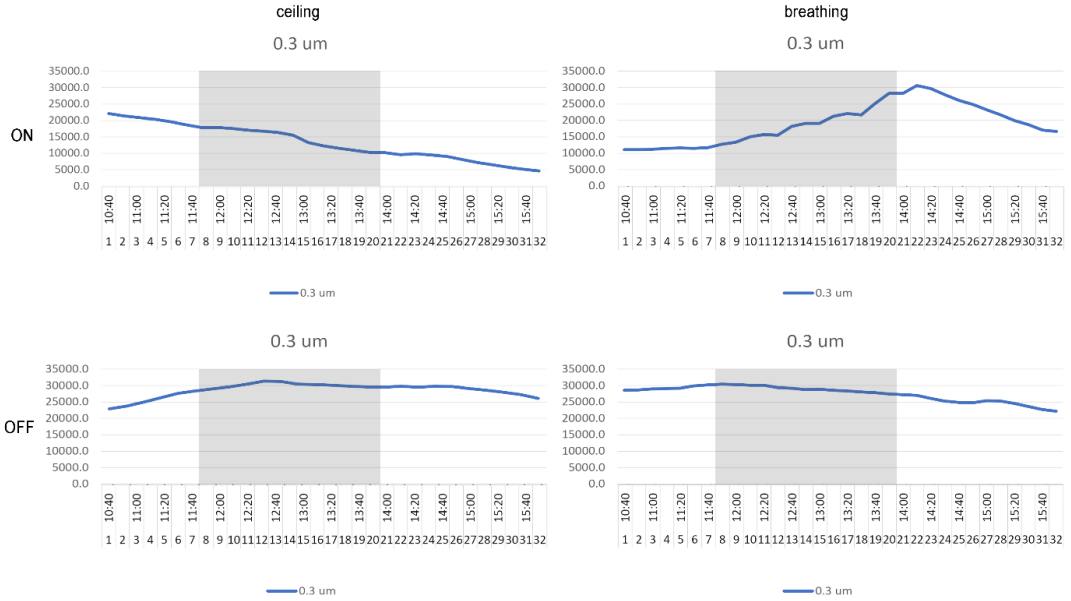
- air-recirculation mode
- Temperature-based control HVAC system
- Totally active ventilation system during working hours

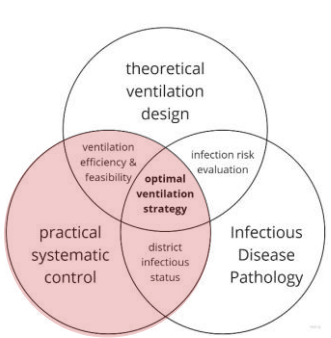


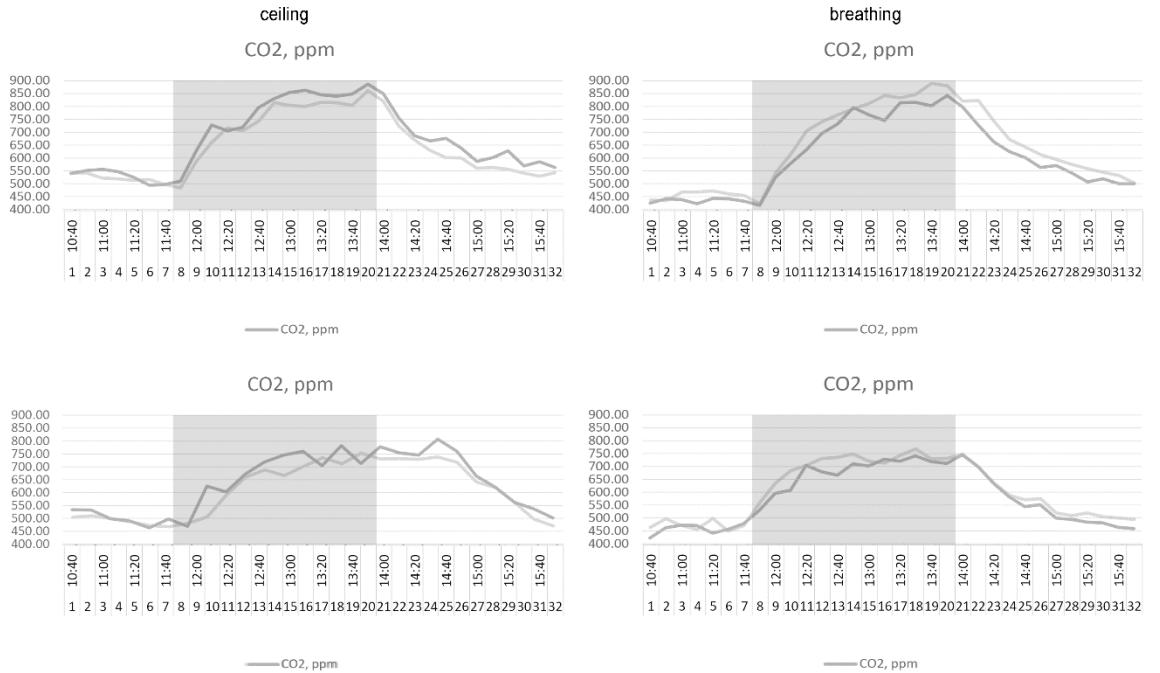


2 Engineering Practice – current indoor end unit

Scope down – small shared room







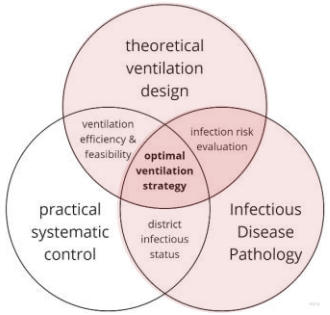
Process

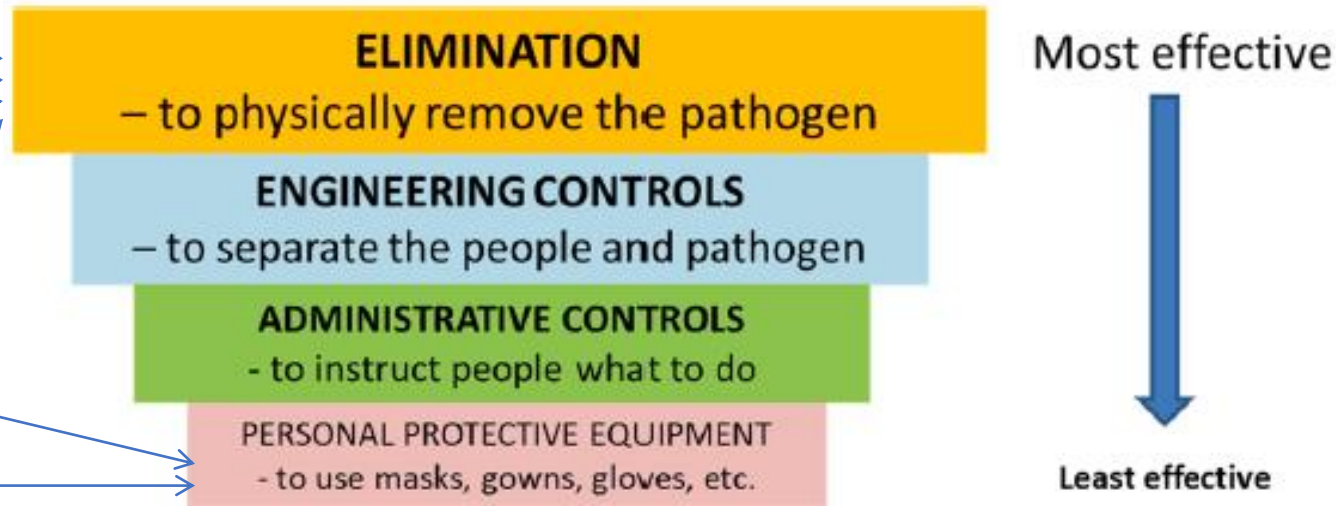
Possible secondary pollution in small meeting room?

Scope down – partial ventilation control

Building Technology- EFFICIENCY

- Ventilation
- Mechanical air filters
- UV lights
- Electrostatic precipitator (EPS)
- Biopolar ionization generators
- Ozone Generating air cleaners



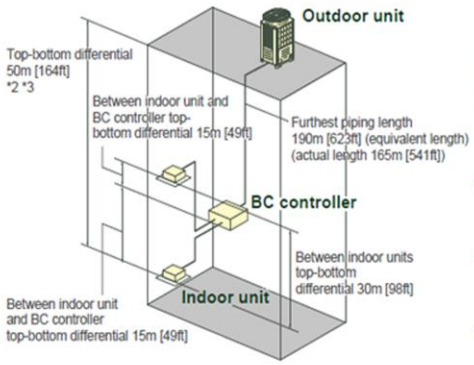


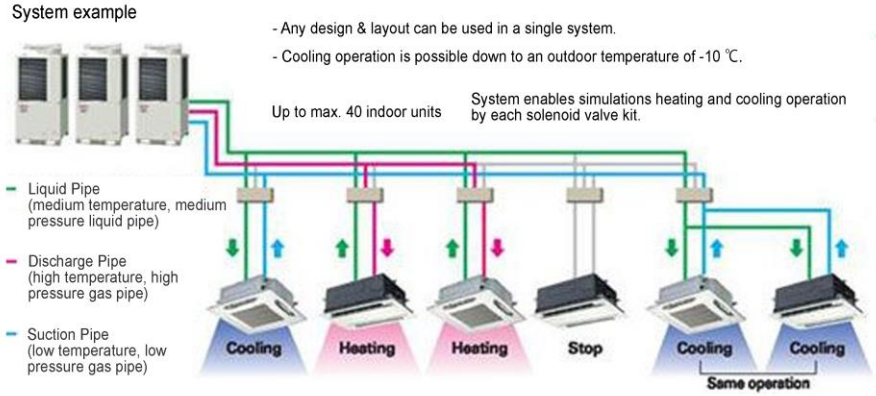
Traditional infection control pyramid adapted from the US Centers for Disease Control (CDC, 2015).

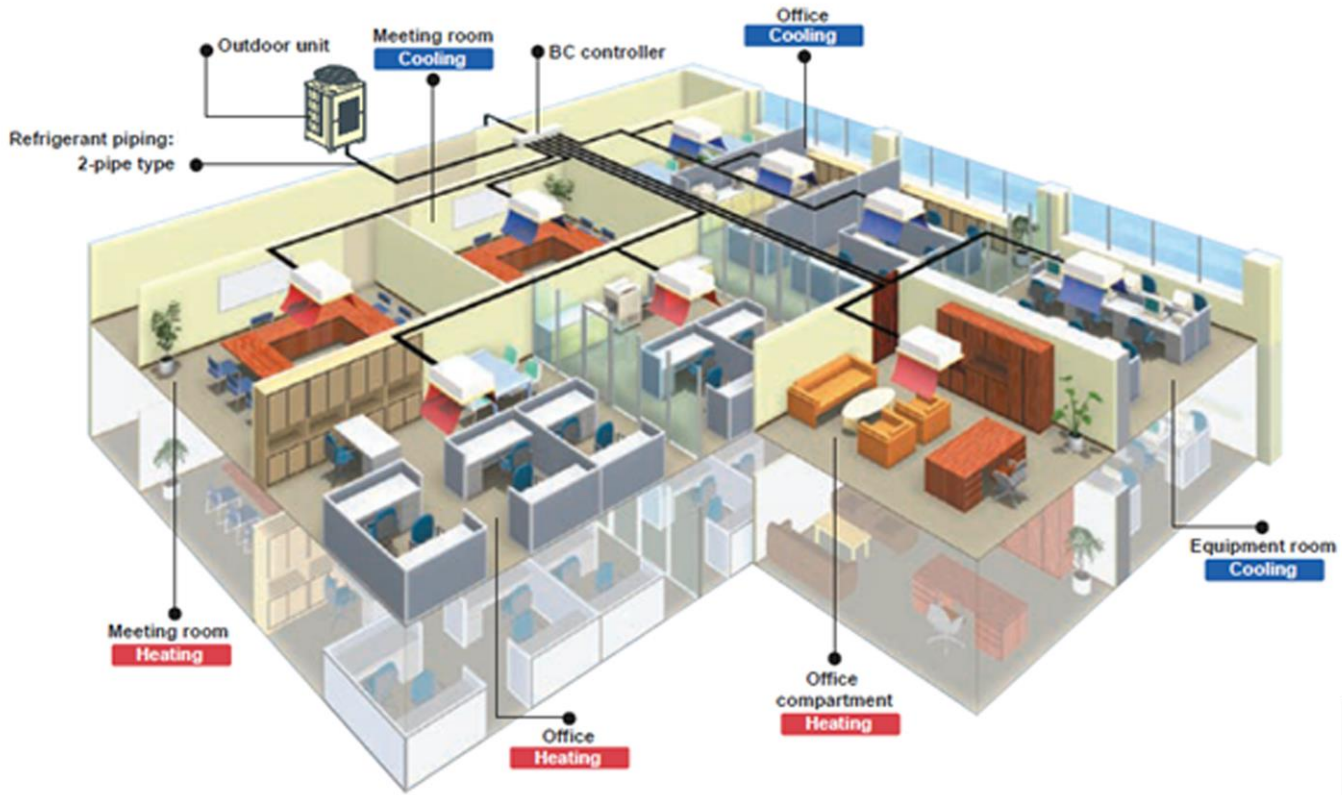
Process **How** to control airborne transmission?

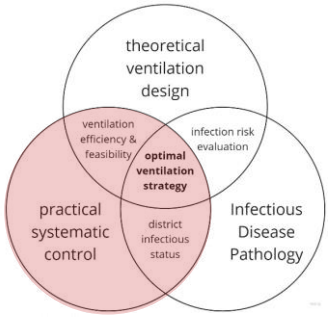
Scope down – partial ventilation control

Engineering Practice – current building system

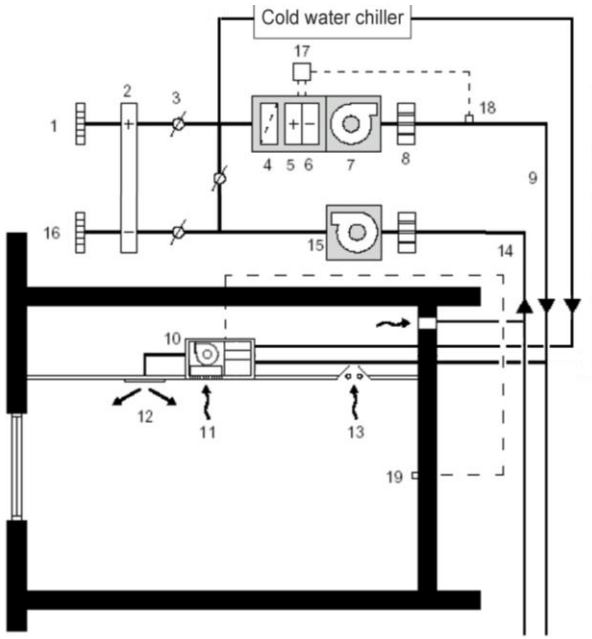






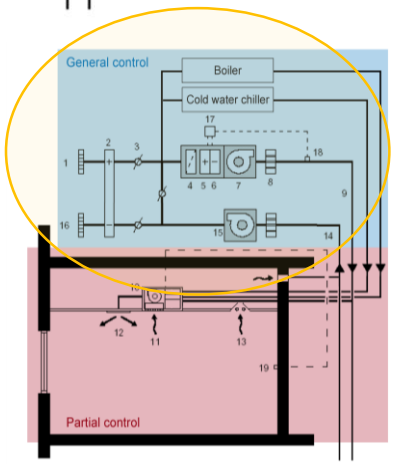


Process



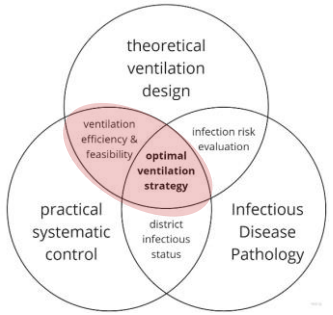
1. External air intake grille
2. Heat exchanger
3. Fresh air control dampers
4. Air filter
5. Primary heating air heat exchanger
6. Primary air cooling heat exchanger
7. Supply air fan
8. Silencer
9. Primary air supply duct
10. Fan-coil indoor device (with filter)
11. Secondary air
12. Primary + secondary air
13. Peturn air
14. Return duct
15. Return fan
16. Exhaust air outlet
17. Primary air temperature controller
18. Primary air temperature sensor
19. Room temperature controller

What is the base of small meeting room?



Scope down – partial ventilation control

Building Technology + Engineering Practice



Process

-Higher **outside air fractions → 95%**
-higher **air change hourly rates → 3**

ACH=1.104 (0.8 – 1.4)

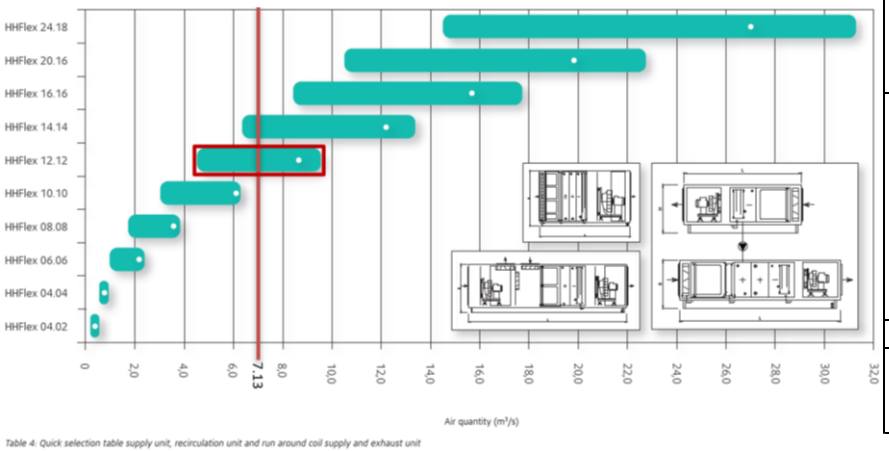


Table 4: Quick selection table supply unit, recirculation unit and run around coil supply and exhaust unit

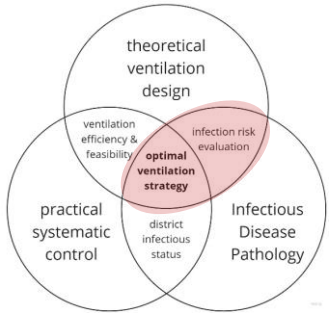
	Is it a prerequisite?	*personalised controlability*	*relationship to engineering*	*Influenced by spatial geometry*	*indicators*		***How worth is it for ceiling mixing ventilation in modelling & design phase?***
					for dessign	*for evalucation*	
Temperature	no	high	high	medium	temperature [°C] [°F]	temperature [°C] [°F]	low
Humidity	no	high	medium	medium	relative humidity [%]	relative humidity [%]	low
Fan speed	no	medium	high	low	airflow velocity [m/s] [m^3/s]	airflow velocity [m/s] [m^3/s]	low
Outdoor air portion	no	low	high	low	outdoor air amount/recycled air amount from the whole system [%]	outdoor air amount/recycled air amount from the whole system [%]	medium
Air exchange rate	no	low	high	high	hourly air exchange rate [times per hour]	hourly air exchange rate [times per hour]	**high**
Airflow pattern	yes	low	high	high	none, directly related to the location of supply and exhaust openings and indoor end unit types	none, indirectly illustrated by direct airflow divertion and mixing level of the supply air	**high**
Working hours	no	medium	low	low	hours, tensity	hours, tensity	none
Maintenance	no	medium	medium	low	frequency, maintance scale	frequency, maintance scale	none

What is the base of small meeting room?

Scope down – partial ventilation control

Pathology + Building Technology

Engineering strategies / Criteria / weight / Scheme	Virus-removal efficiency	Comfort impact	Economy		Energy	Adjustability	Overall rating
			First cost	Maintainance			
	30%	20%	10%	10%	15%	15%	
Ventilation	10	8	5	9	8	10	8.7
HEPA filter	9	9	4	8	9	6	8.0
UV lights	4	10	10	10	10	10	8.2
Biopolar ionization generators	8	6	7	5	10	5	7.1
Ozone Generating air cleaners filter	6	6	6	6	10	7	6.8
Electrostatic precipitator (ESP)	8	7	9	8	8	9	8.1



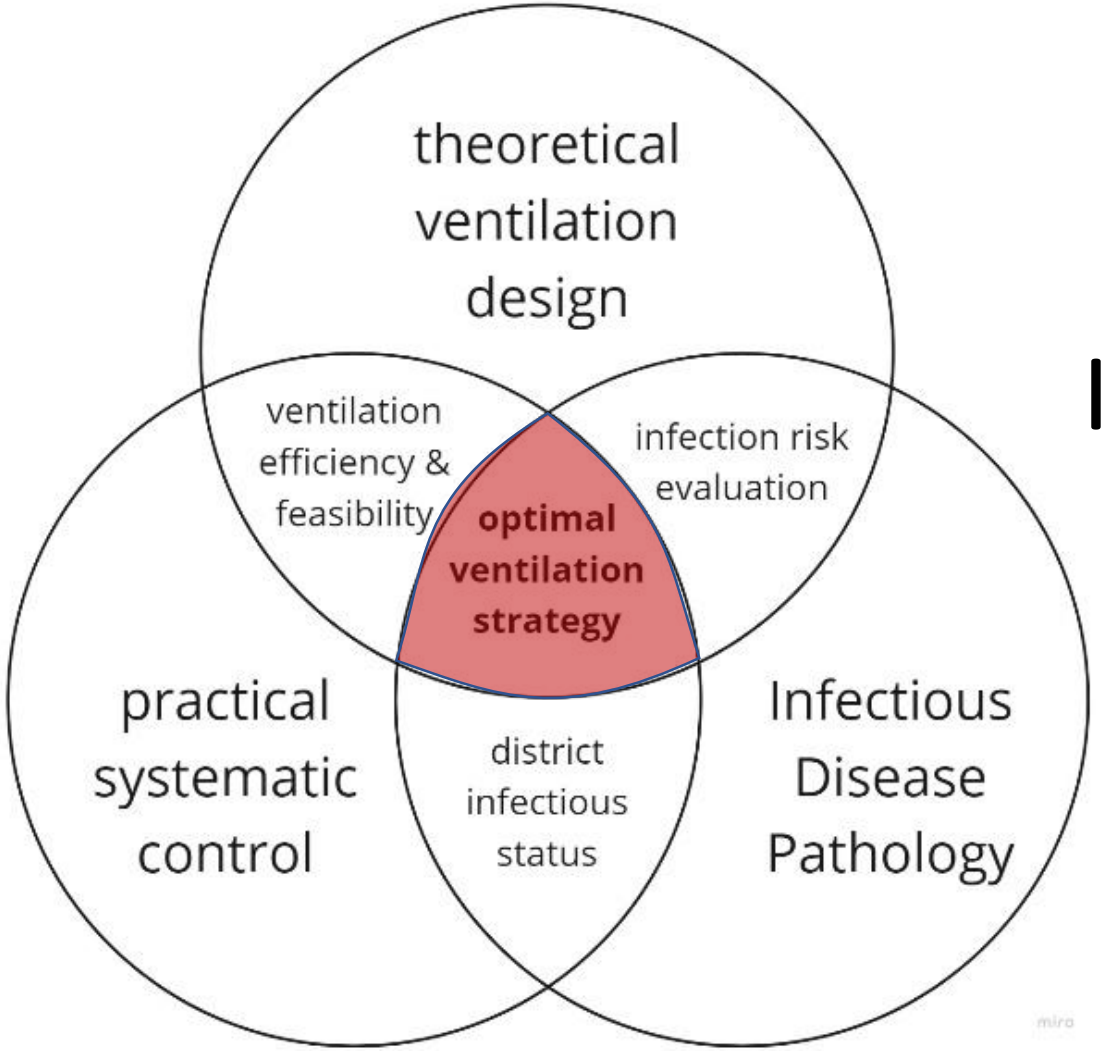
Process

What is the base of small meeting room?

Detail

Process

Pathology – Building technology - Engineering Practice

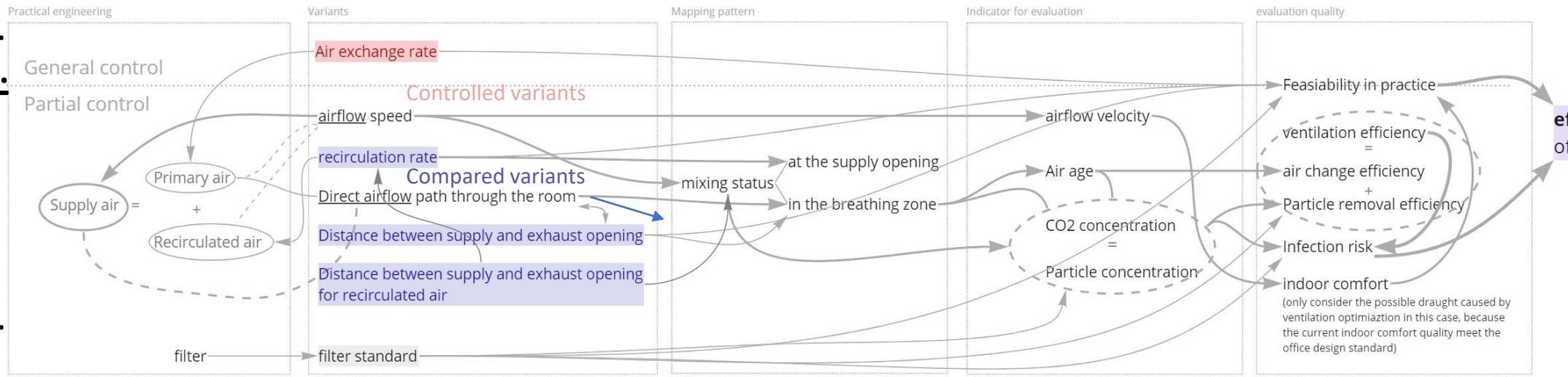


Integration of Interdisciplinary thesis

Pathology – Building technology - Engineering Practice

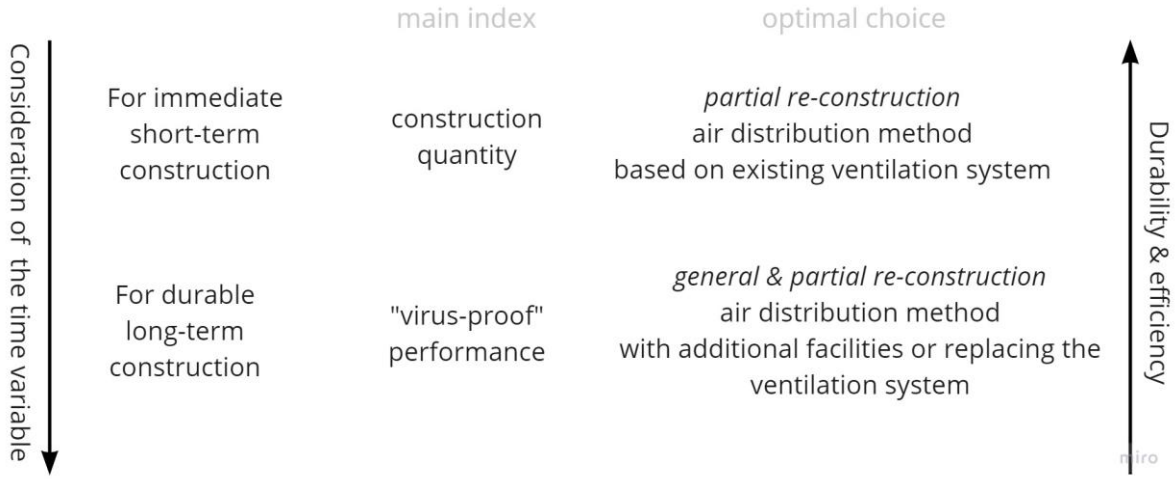
Process

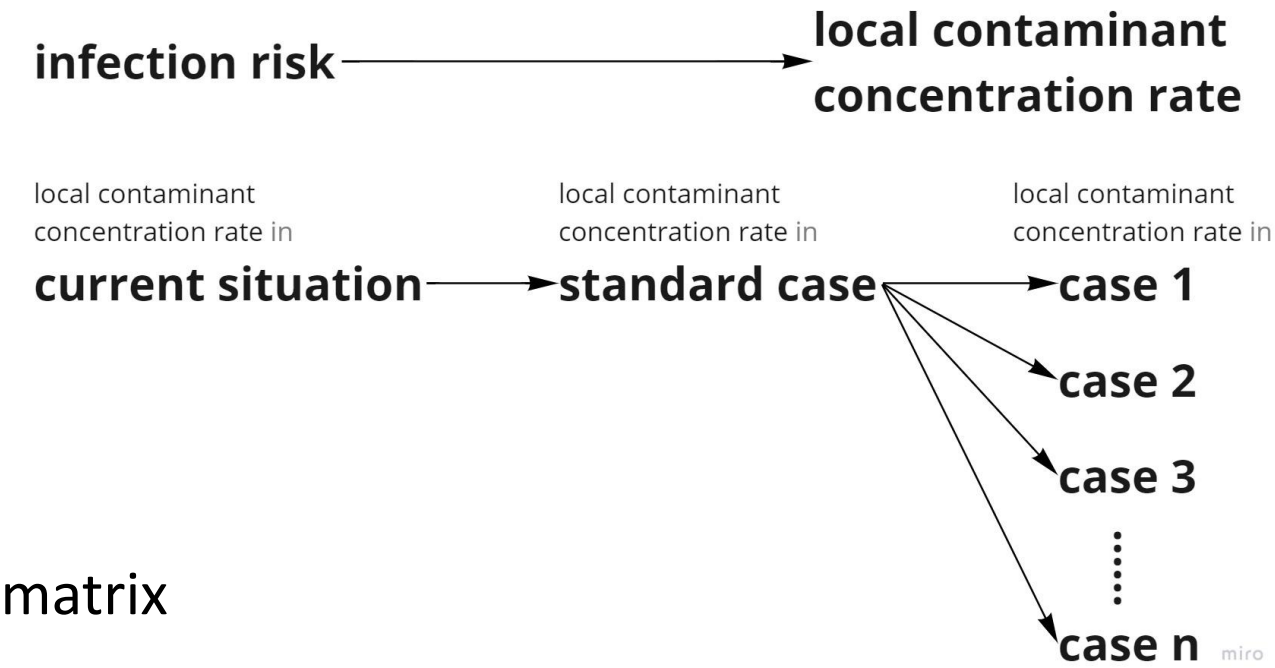
Detail – parameter system



Infection risk – ventilation efficiency – construction feasibility

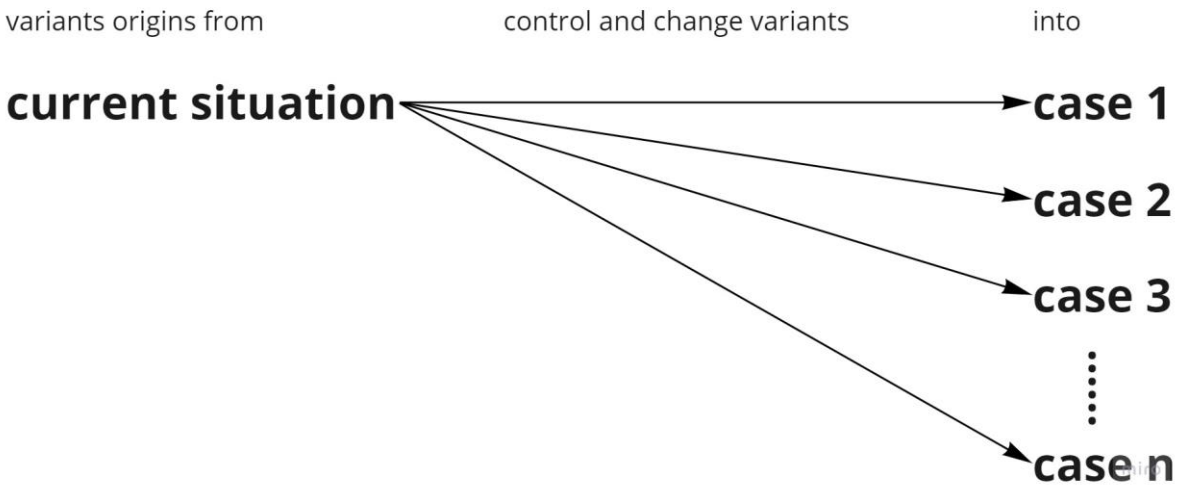
Use of ceiling suspensions





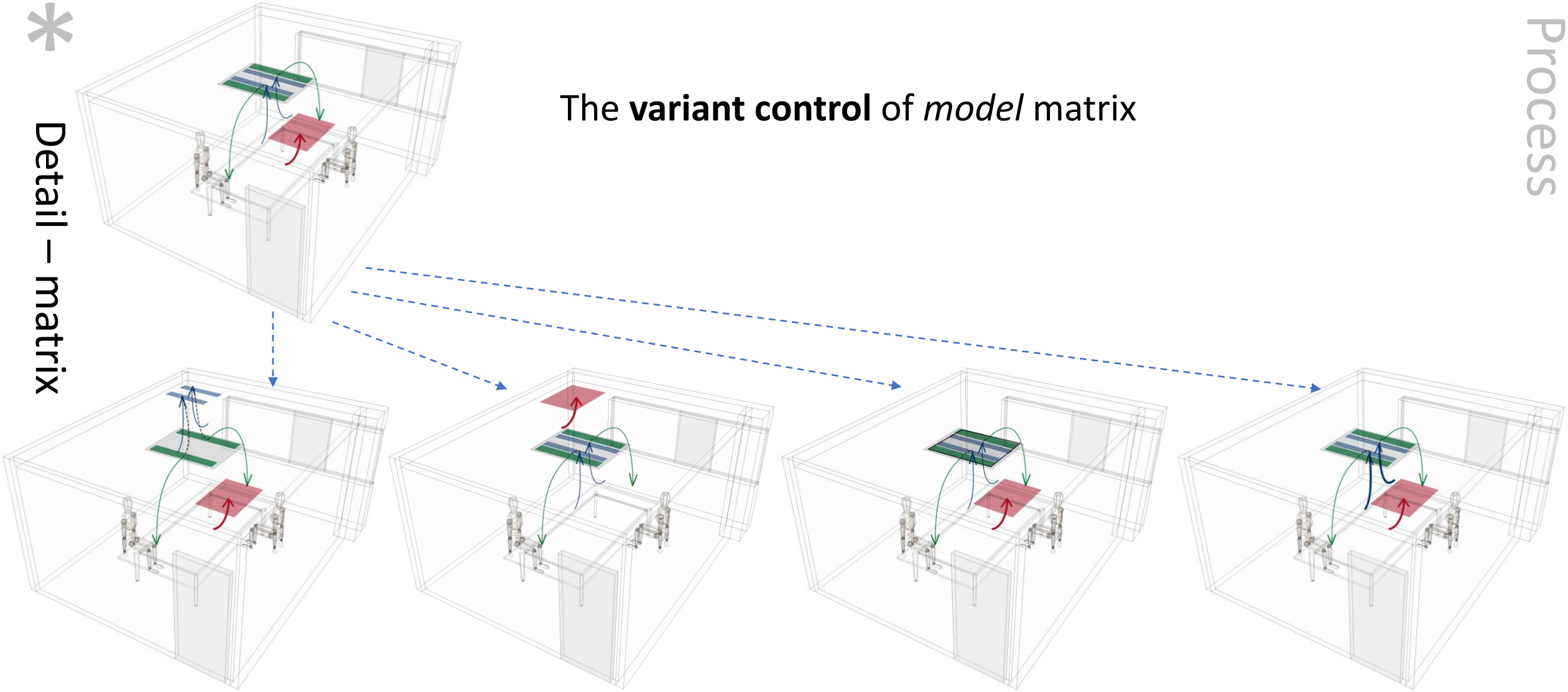
The **mapping** of
the *evaluation system* & *model* matrix

partial				
ventilation pattern			additional method - filter	
recirculation rate	distance between return and resupply openings [m]	distance between supply and exhaust openings [m]	filter level	ISO ePM1



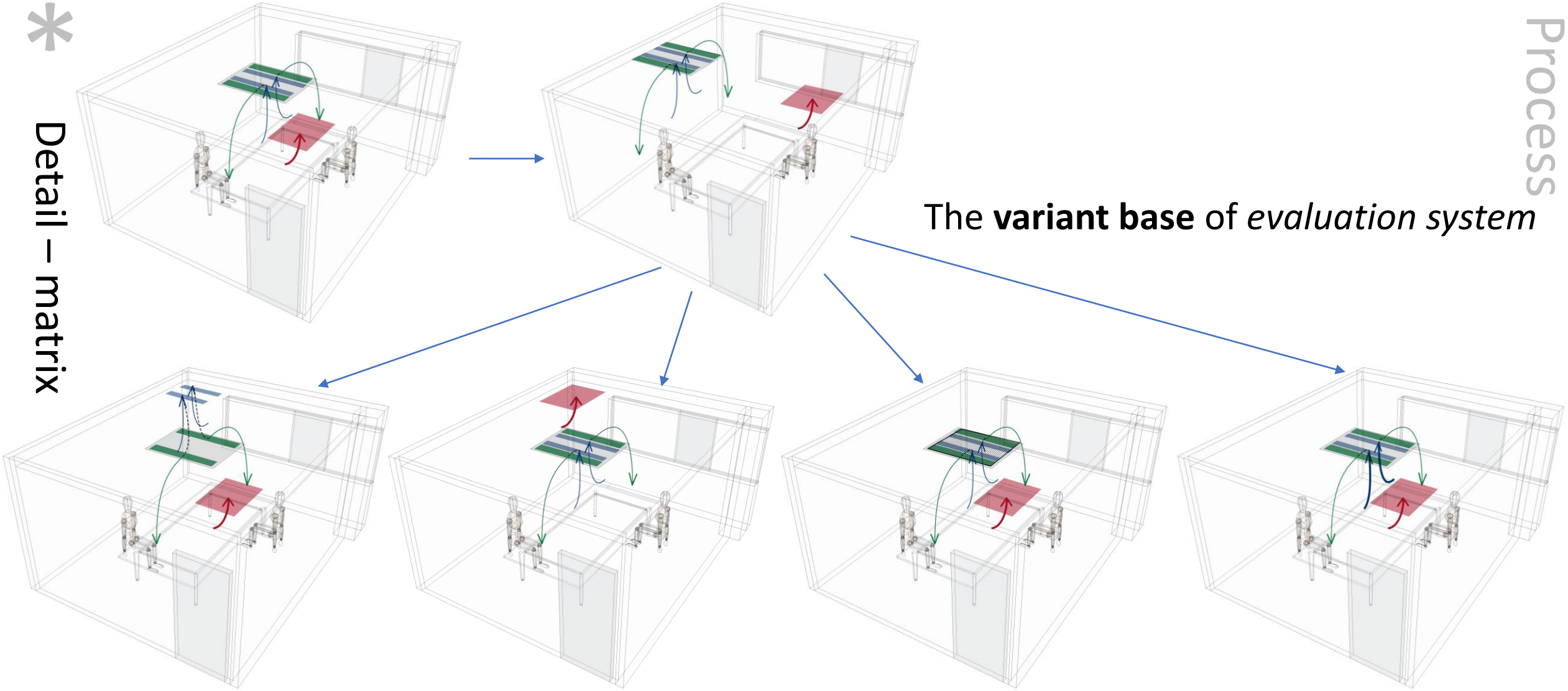
Detail – matrix

The **variant control** of *model* matrix



To analyse the ceiling renovation → based on EXISTING model → variant matrix reference

Detail – matrix



The **variant base** of *evaluation system*

To apply Wells-Riley Model → build STANDARD model for well mixing condition → evaluation reference

* the centrosymmetric layout of the user locations & asymmetric layout of the ventilation facilities to equalize the pollutant distribution under current ventilation pattern for the standard case

Engineering Practice + Pathology

Detail – acceptable infection risk

"Acceptable" infection risk – 1%

- More than 100 USA schools survey related to local infection rate
- Building survey in the Netherlands, the 'Green' environments are 1% - 5%

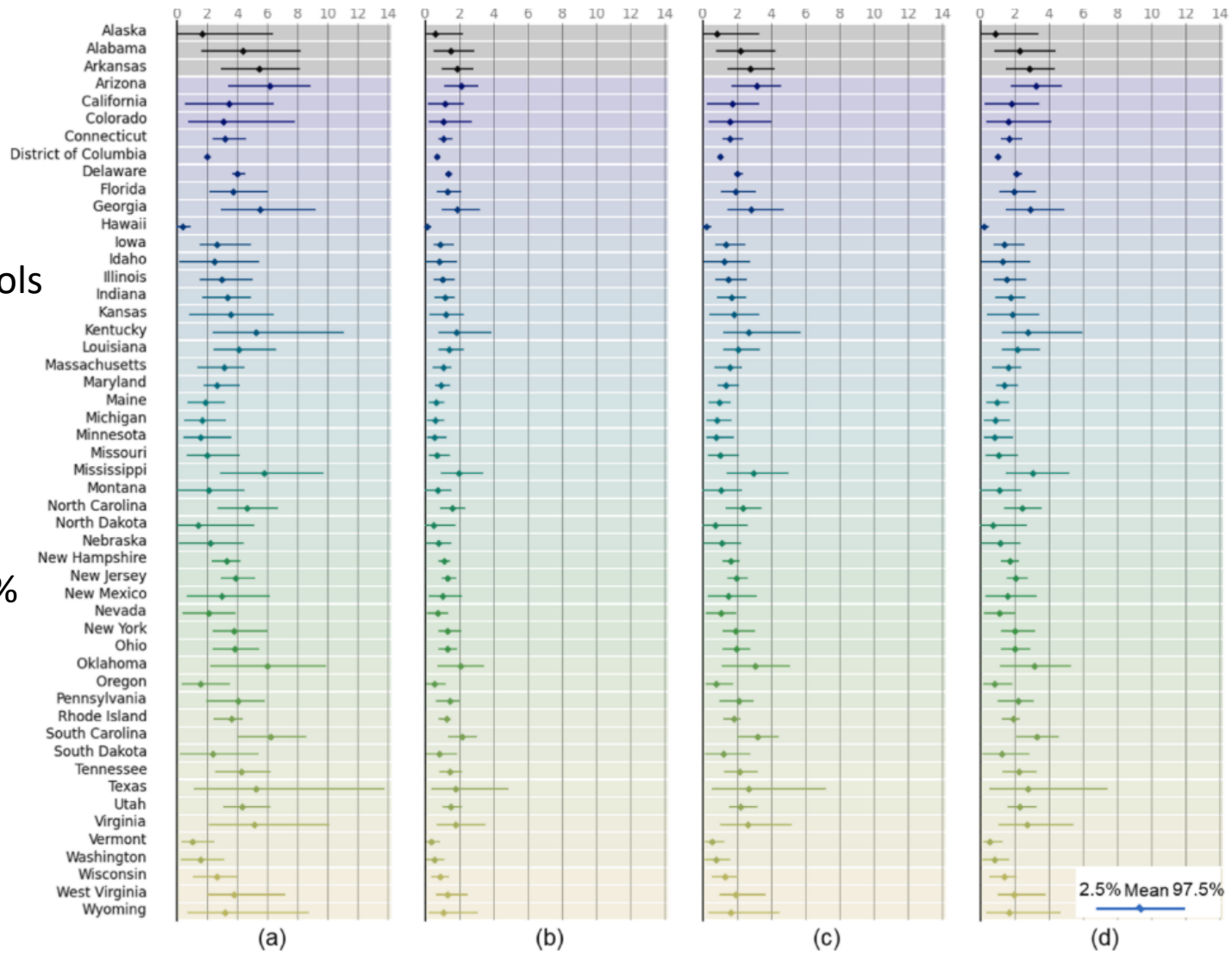
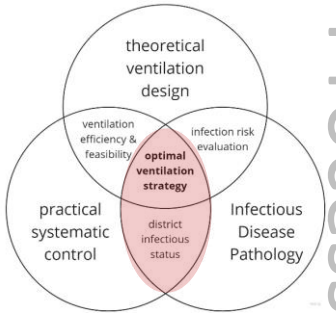


Fig. 5. Infection risk for each state with different intervention strategies: (a) the baseline scenario; (b) with MERV 13 filtration; (c) with 50% of students learning online; and (d) when increasing the ventilation rate by 100%.



Process

What is the base of small meeting room?

Discussion

Infection risk – ventilation efficiency – construction feasibility

- the applicability **engineering evaluation** for infection risk analysis

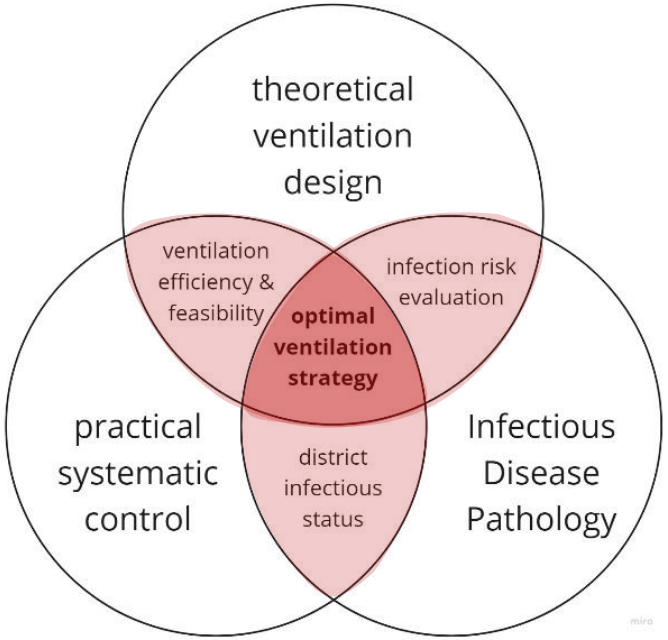
Ventilation efficiency among the optimal "corona-proof" ventilation strategies
Infection risk (50% filter) ←→ mixing level (0% filter)

- the sufficiency and necessarity of **filter** in decreasing the infection risk

Filter efficiency VS ventilation efficiency positive proportion? Or positive synergy?
Filter types (0% & 50%) ←→ local contaminant

- the possibility of **secondary pollution** of indoor end unit

Air recirculation performance VS local contaminant
Air recirculation rate (0&4&8) ←→ local contaminant concentration
Air recirculation performance (return opening distance 1.75m & 2.67m) ←→ local contaminant concentration

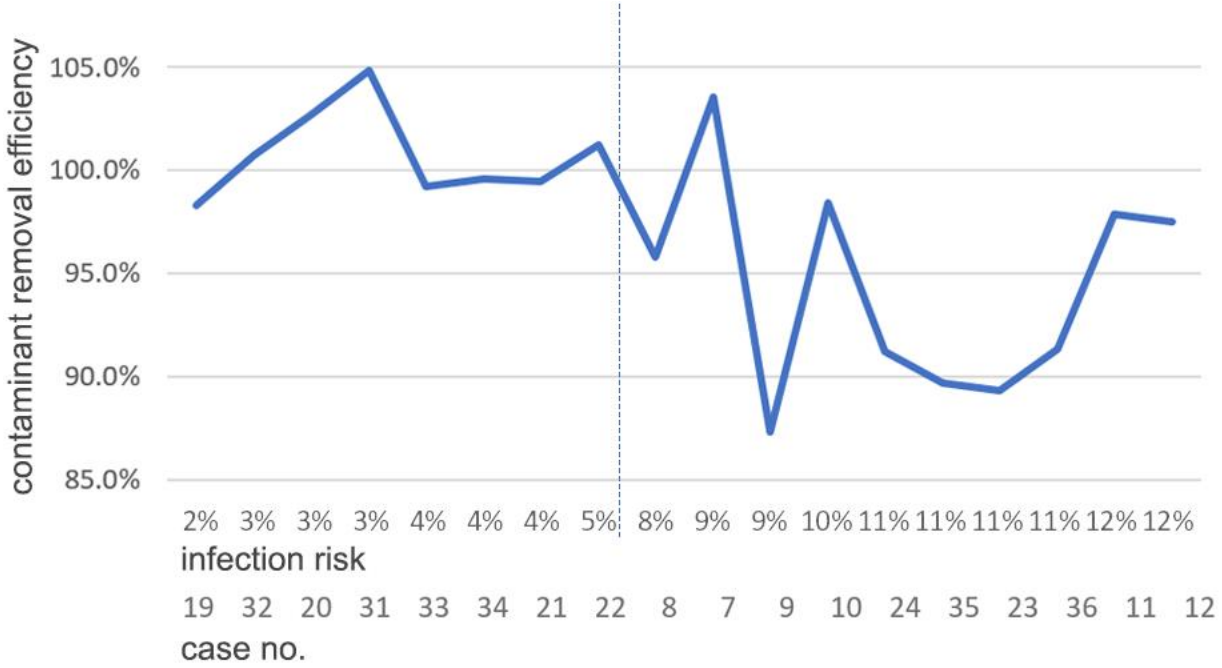


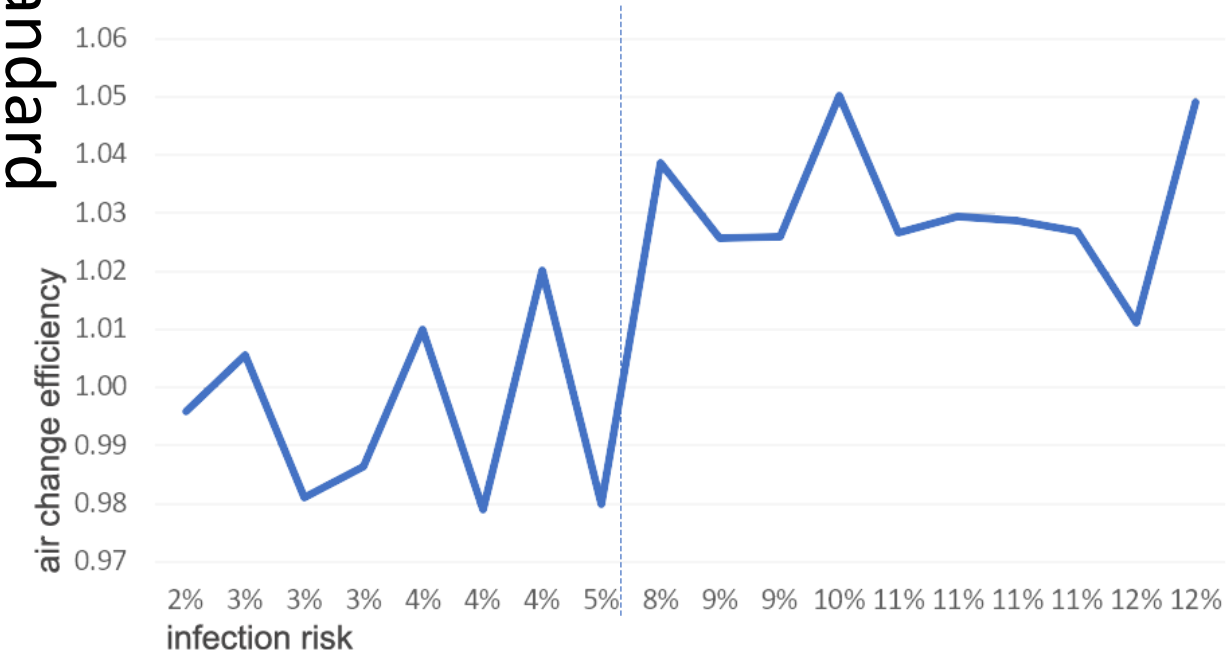
Process

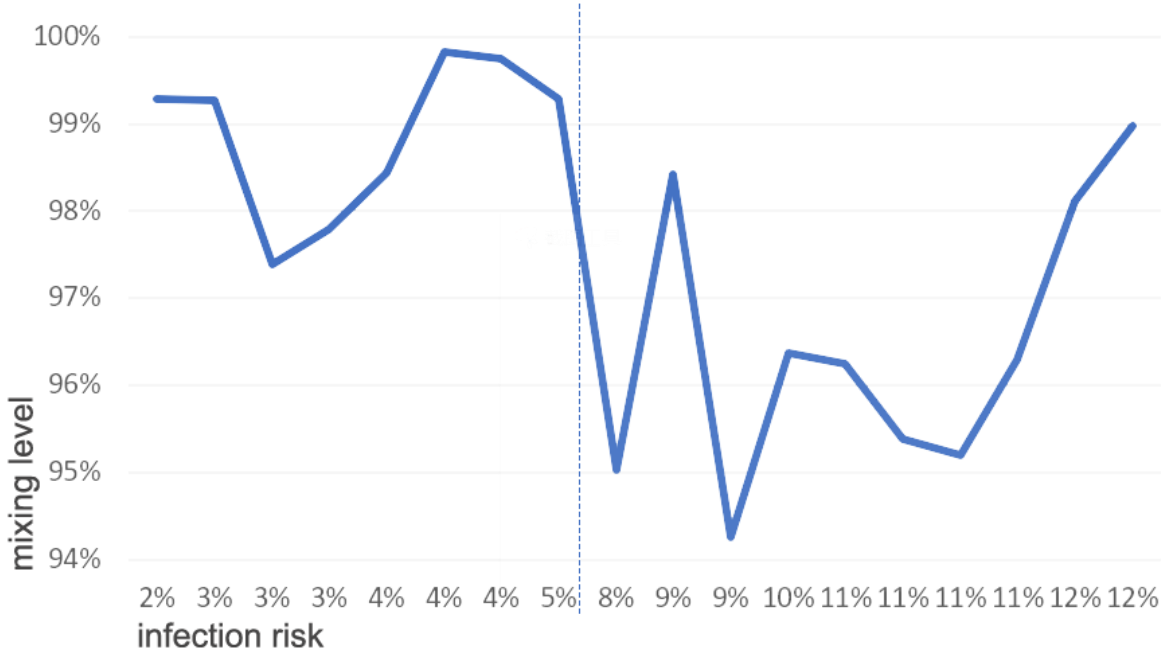
Detail – design standard

the applicability of **engineering evaluation** for infection risk analysis

no promising indicators

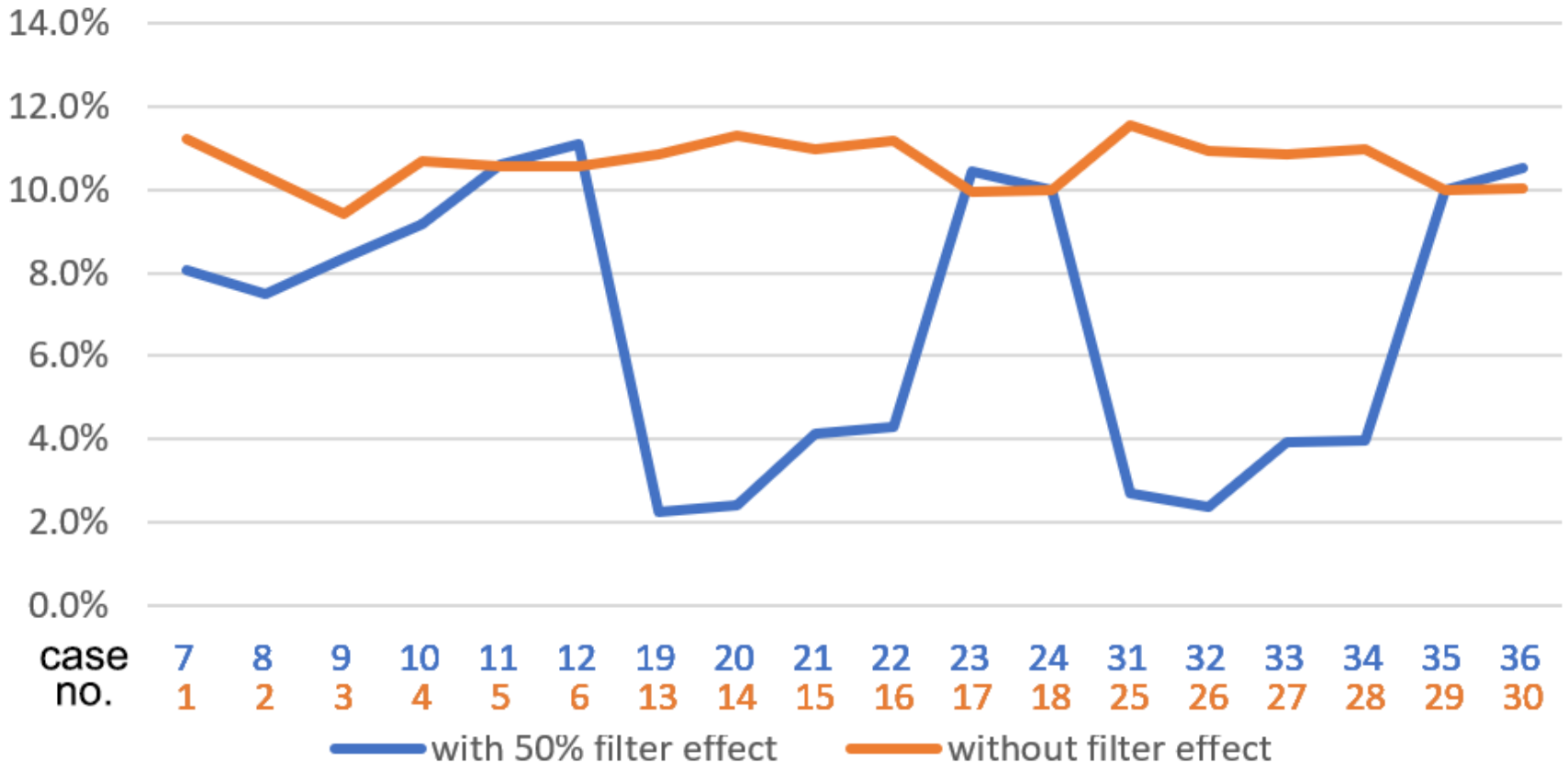






the sufficiency and necessarily of **filter** in decreasing the infection risk

necessary, especially synergetic effect with a good air recirculation condition



Detail – design standard

Further proves for the **synergetic effect** caused by the filter effect and air recirculation mode

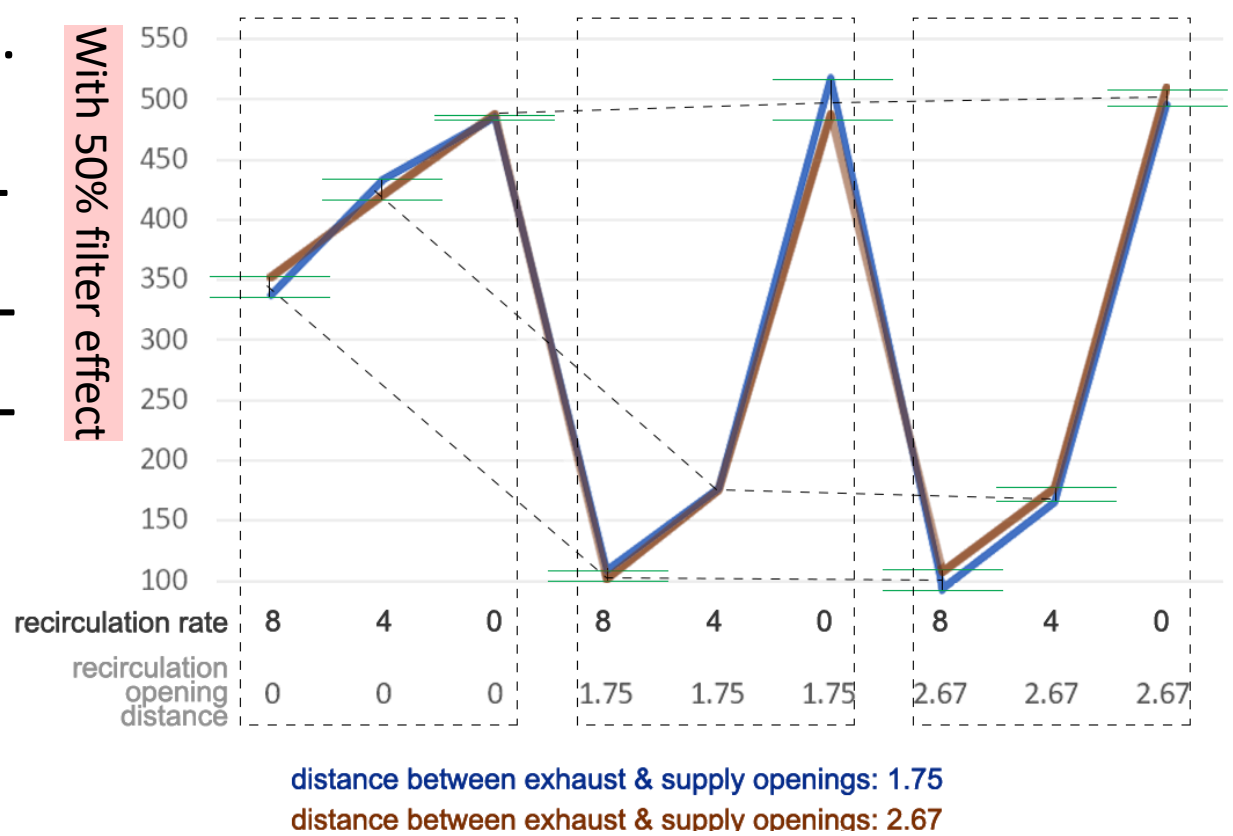
- Distance between openings for general ventilation is less effective

- The air recirculation performance will not promise a lower local contaminant concentration;

Only when there is filter effect, the better air recirculation it is, the lower local contaminant concentration it achieves

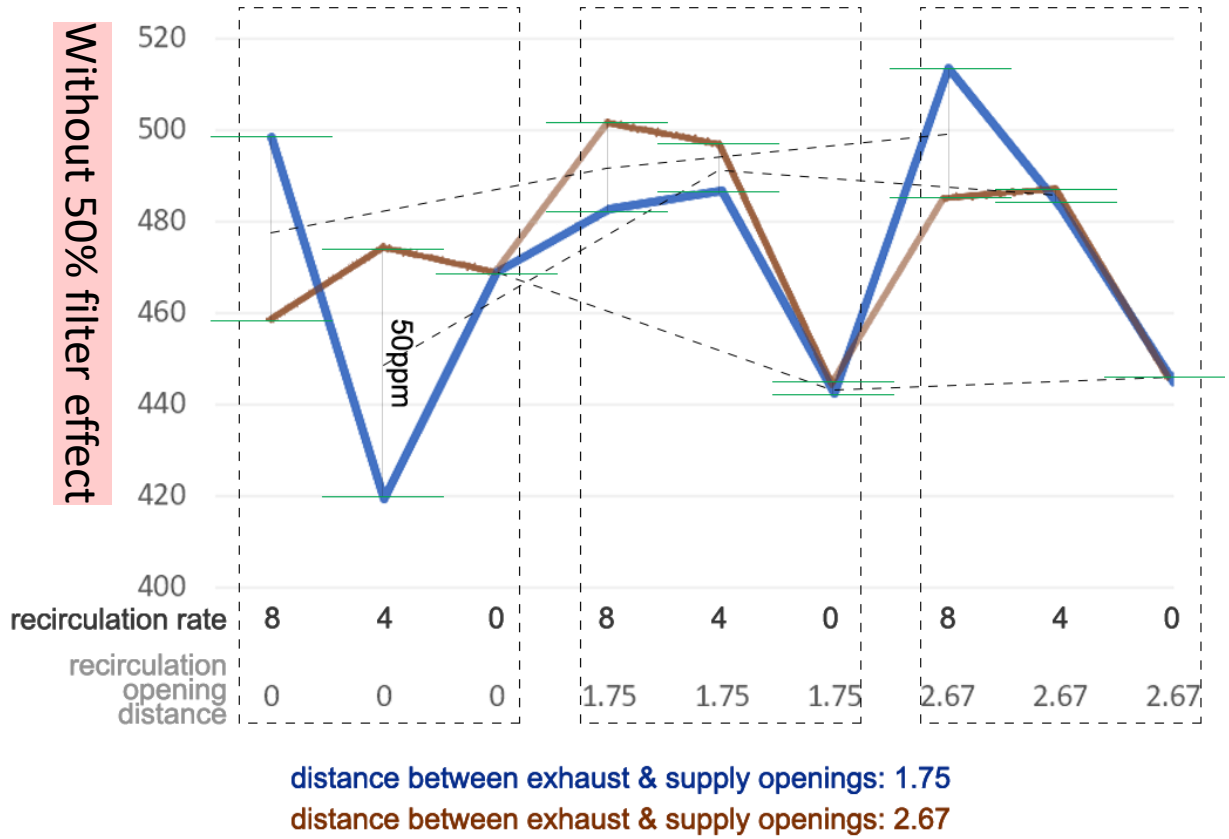
- The air recirculation distance will not promise a lower local contaminant concentration;

Only when there is filter effect, the longer air recirculation distance it is, the lower local contaminant concentration it achieves



distance between exhaust & supply openings: 1.75

distance between exhaust & supply openings: 2.67



distance between exhaust & supply openings: 1.75

distance between exhaust & supply openings: 2.67

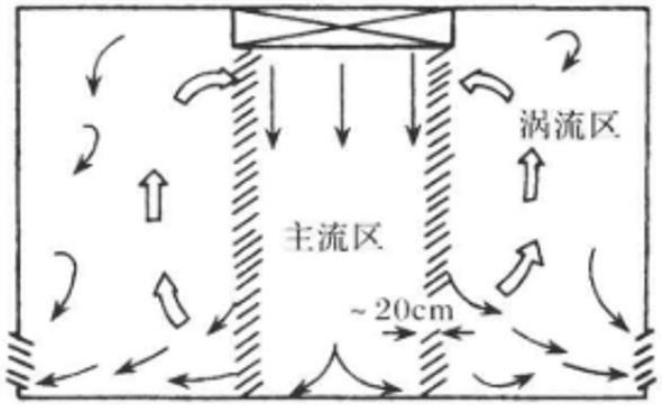
for air recirculation rate analysis in each block; for air recirculating distance analysis in dash lines; for general ventilation distance analysis in the green gaps

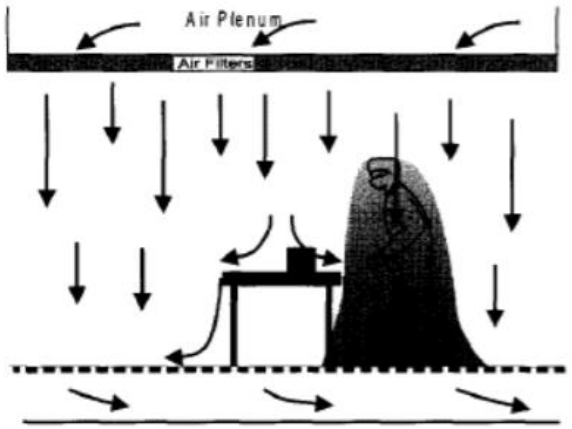
Design

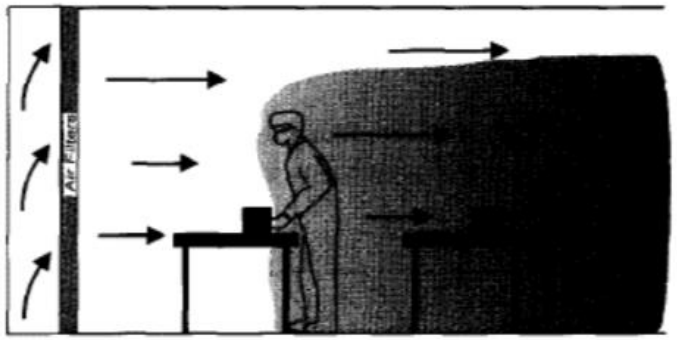
Case study – cleanroom

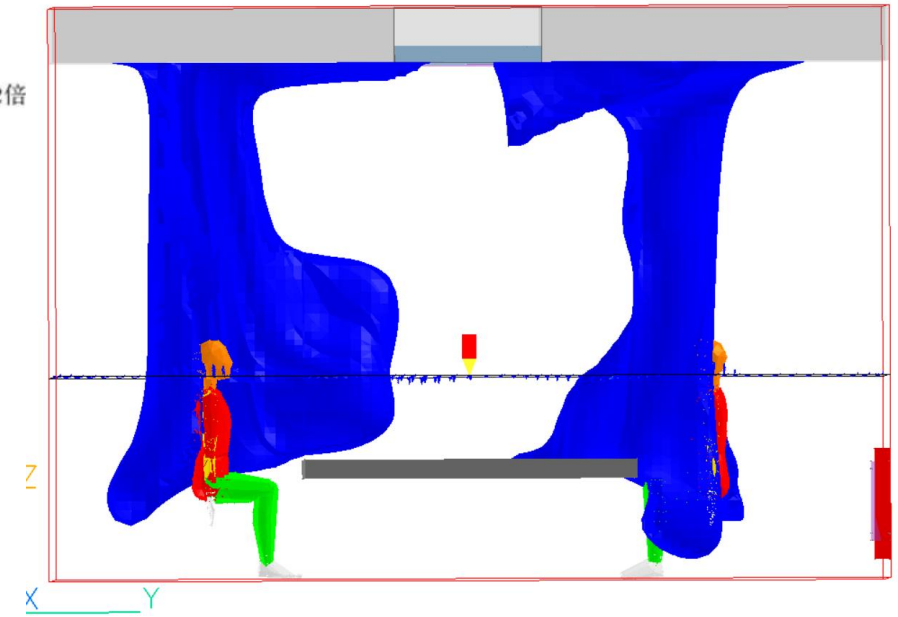
Position & Cavity prefabrication

Thermal plume caused by opening positions
Product chain possibility

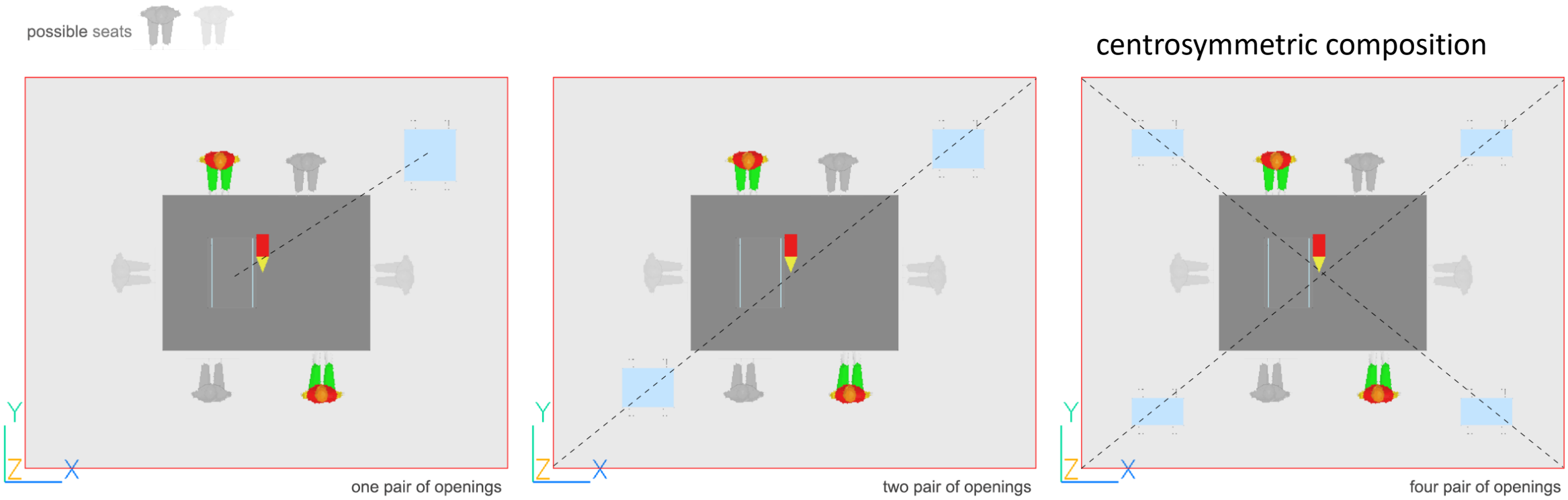








Multi-opening

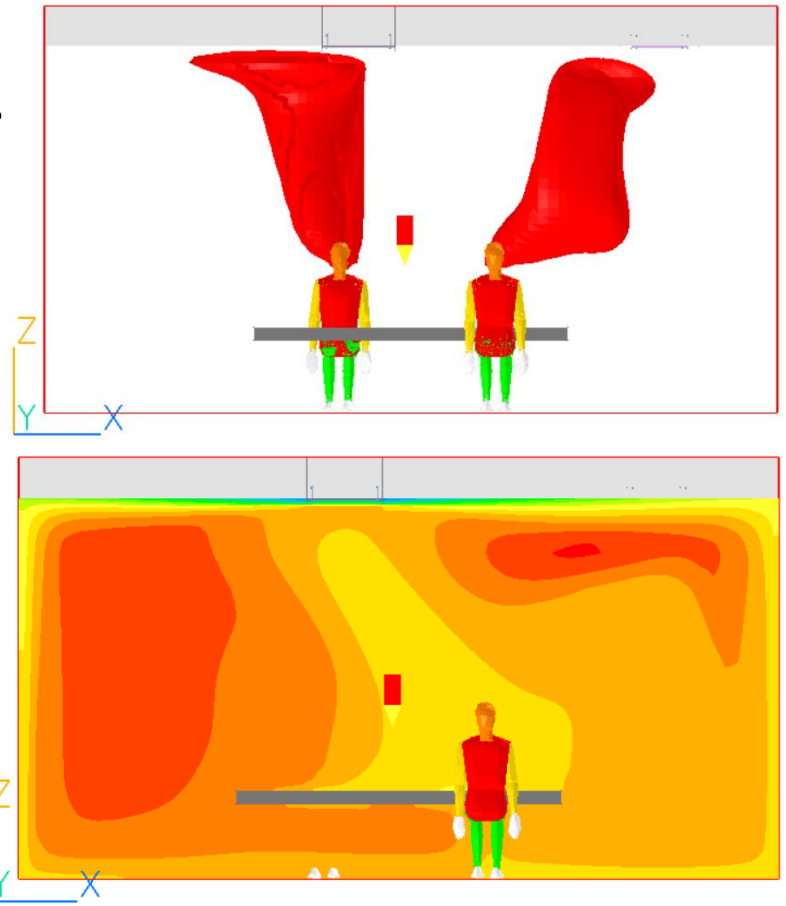


The multi-opening proposal is to **equalize the ventilation airflow distribution** in the meeting room and to ensure the design output have the similar local performance, despite of the unpredictive indoor activities and occupant locations.

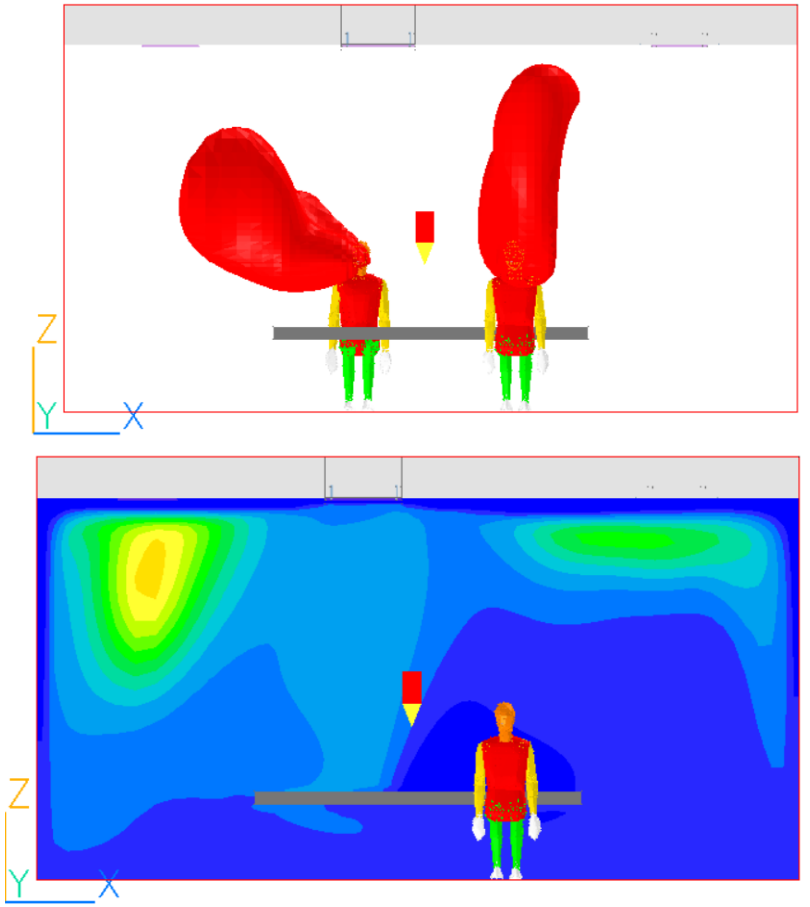
2 Multi-opening

Design

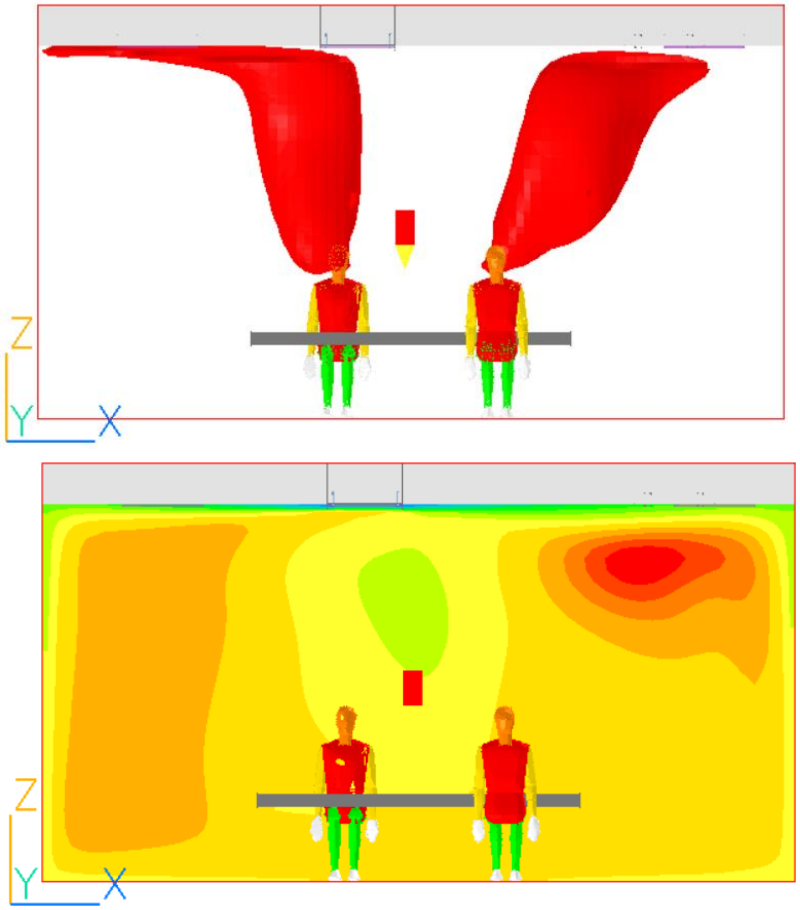
Case no.	strategic variants						engineering parameters							(min) infection risk for 1 h			object
	general	partial					local					general		breathing zone			
		ventilation pattern			additional method - filter		human produced CO2 concentration			CO2 removal efficiency	mixing level in breathing zone	Standard deviation	CFD	wells-riley		optimization rate (compared to the existing case)	
	Air exchange rate	recirculation rate	distance between return and resupply openings [m]	distance between supply and exhaust openings [m]	filter level	ISO ePM1	breathing zone (2.8,2.26,1.1)	exhaust opening	average of breathing zone			mixing level for whole space = 1-SD/AVE	fresh air exchange effectiveness=ave outflow local age / ave local age in room	average virus concentration (quanta/m3)	average risk ratio		
32	1.1	8.0	2.67	2.67	F7	50%	104.9	107.0	110.8	98.1%	94.7%	97.7%	100.5%	0.03	2.4%	80%	CO2
Two pairs of openings	1.1	8.0	1.75*1 & 2.67*1	2.67	F7	50%	158.0	152.4	158.5	103.7%	99.7%	98.2%	198.2%	0.04	3.6%	70%	CO2
Four pairs of openings	1.1	8.0	1.75*2 & 2.67*2	2.67	F7	50%	100.9	97.0	106.6	104.0%	94.7%	96.1%	298.2%	0.02	2.3%	81%	CO2



One opening



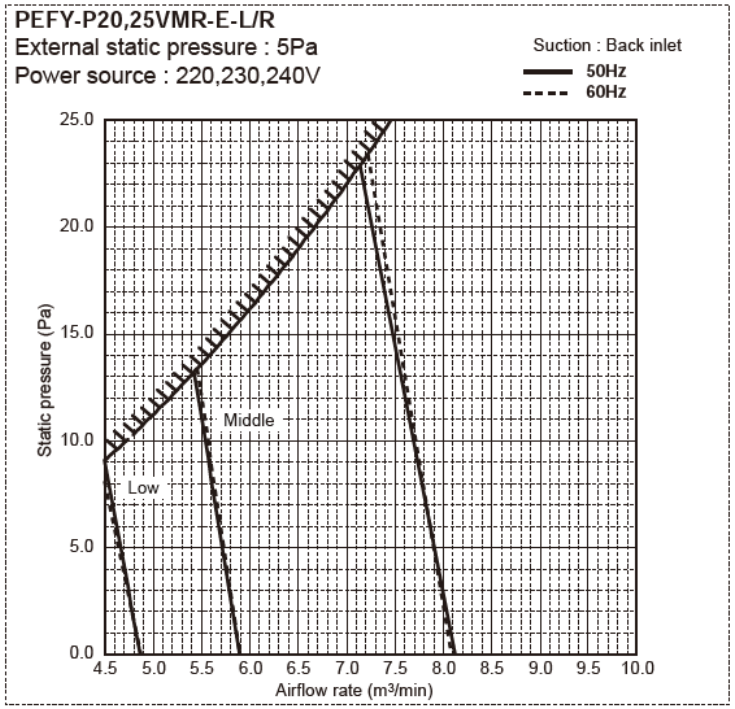
Two openings

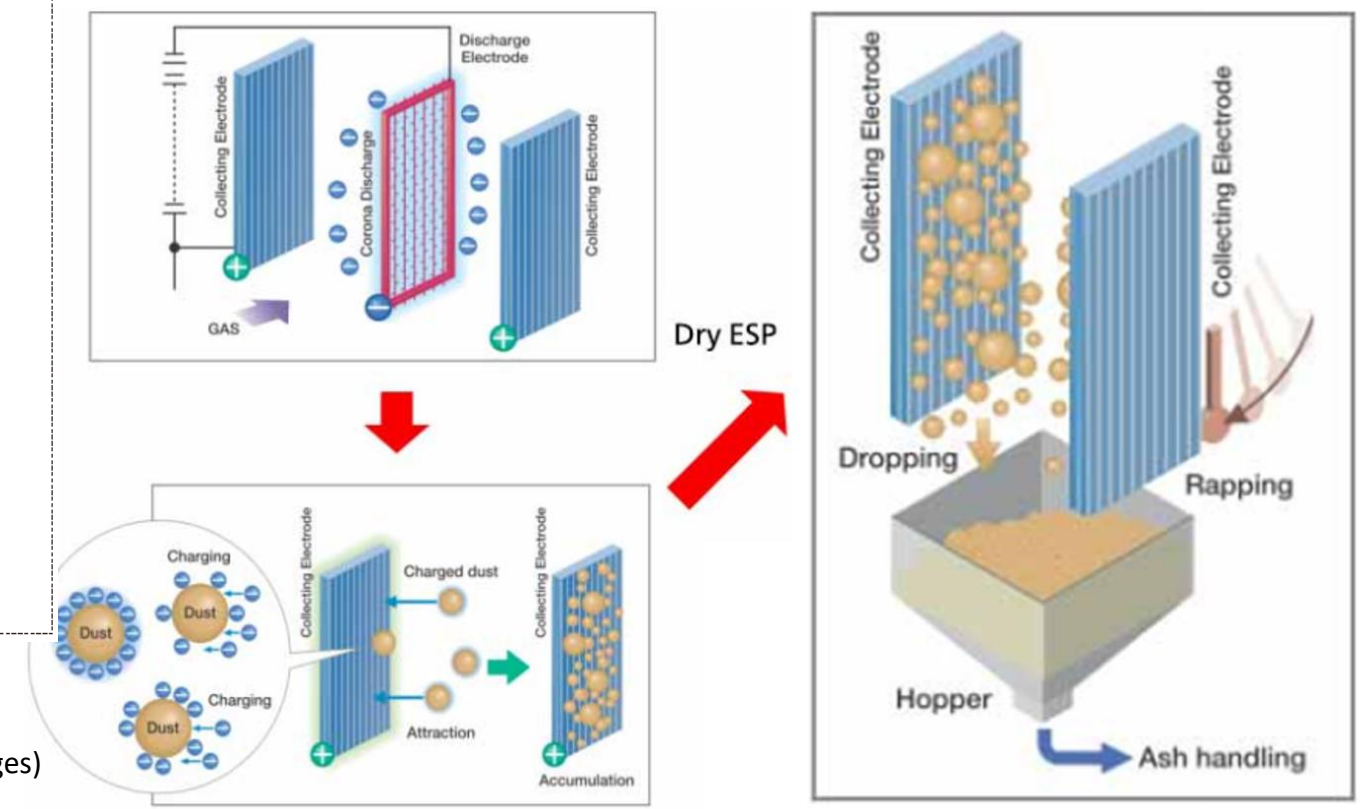


Four openings

3 Filter design

Product integration with **dry ESP**





Installation space requirement:

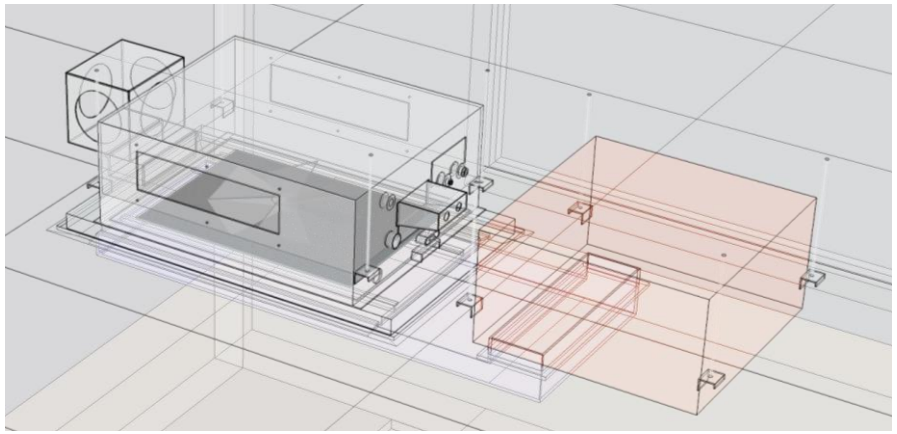
Facility size: 600mm * 307mm * ≥200mm (flexible for user's changes)

Pressure: 17 Pa

A negative side-effect of electrostatic precipitation devices is **the potential production of toxic ozone and NOx**. However, electrostatic precipitators offer benefits over other air purifications technologies, such as HEPA filtration, which require expensive filters and can become "production sinks" for many harmful forms of bacteria.

VFA-Solutions

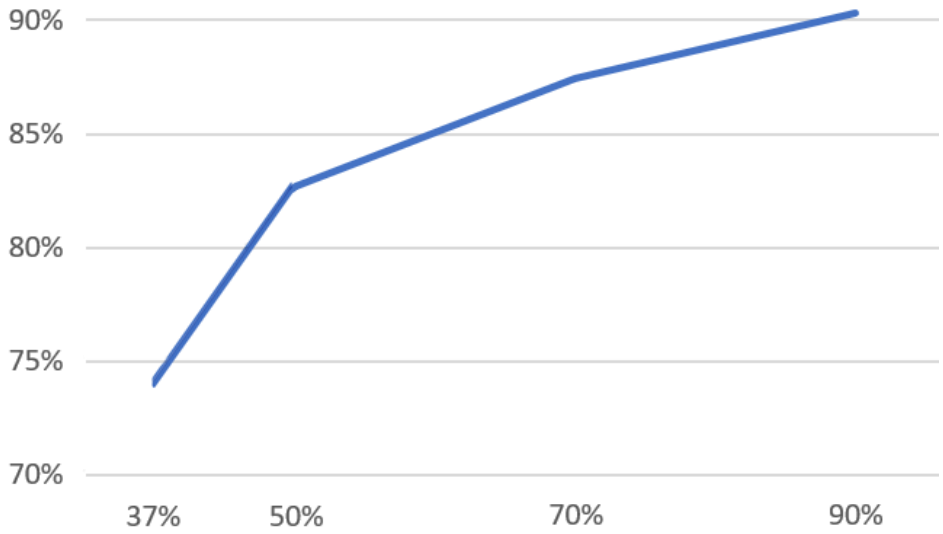
M-Care®-ASPRA



Economic choice for filter standard

Case no.	strategic variants						(min) infection risk for 1 h			object
	general	partial					breathing zone			
		ventilation pattern			additional method - filter		wells-riley		optimization rate (compared to the existing case)	
	Air exchange rate	recirculation rate	distance between return and resupply openings [m]	distance between supply and exhaust openings [m]	filter level	ISO ePM1	average virus concentration (quanta/m3)	average risk ratio		
4open90 opening separate	1.1	8.0	1.75*2 & 2.67*2	1.75*2 & 2.67*2	F7	90%	0.01	1%	90%	CO2
4open70 opening separate	1.1	8.0	1.75*2 & 2.67*2	1.75*2 & 2.67*2	F7	70%	0.02	2%	87%	CO2
4open50 opening overlap	1.1	8.0	1.75*2 & 2.67*2	1.75*2 & 2.67*2	F7	50%	0.02	2%	82%	CO2
4open50 opening separate	1.1	8.0	1.75*2 & 2.67*2	1.75*2 & 2.67*2	F7	50%	0.02	2%	83%	CO2

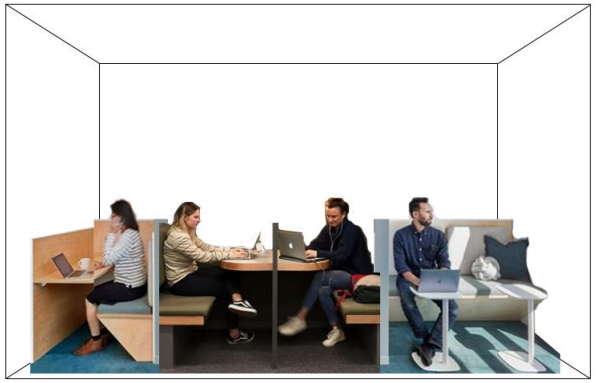
Further exploration about the filter *cost and performance* efficiency

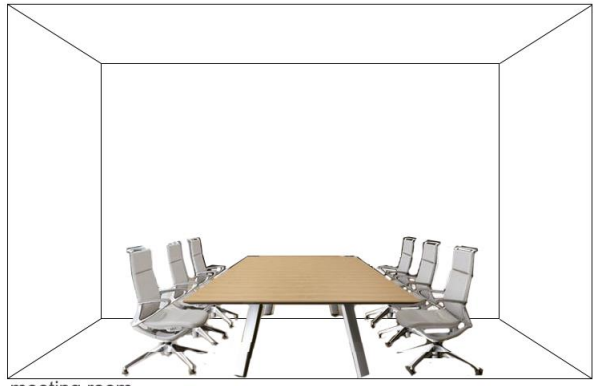


4 Work flow design


activity room for kids


chat room


study room


meeting room


activity room for kids

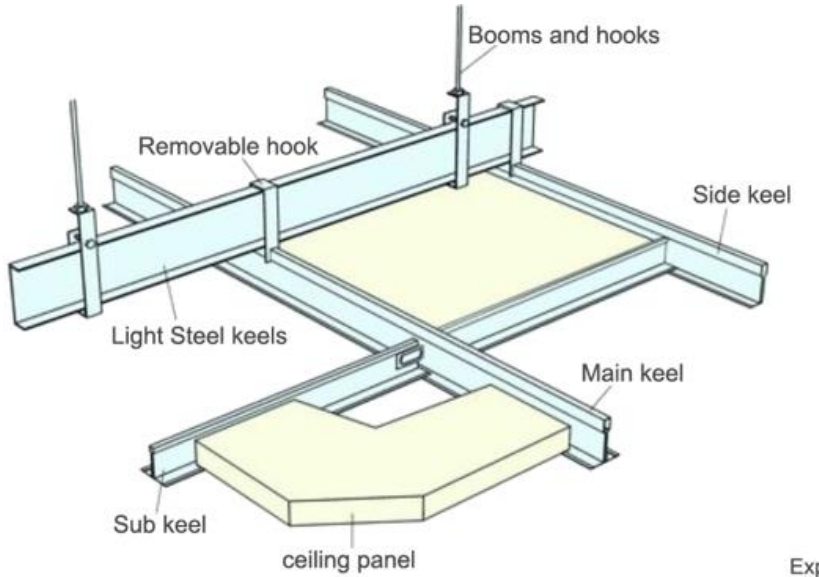

chat room

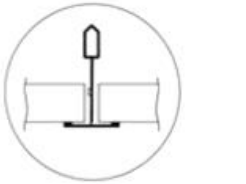

study room


meeting room

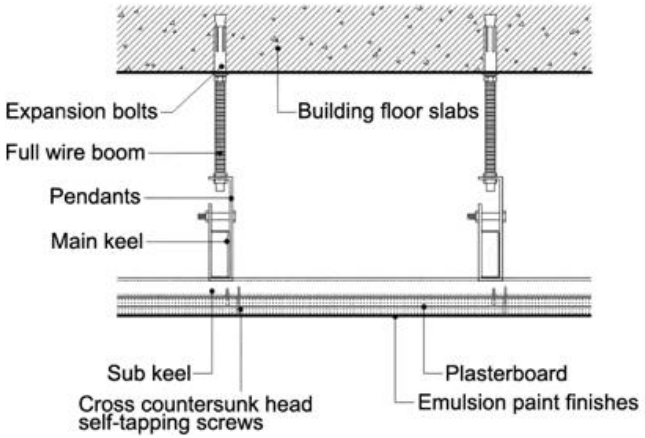
Space analysis → spatial scale definition → function area distribution → supply end in the central of main using area → exhaust & air return openings at the distant area from the supply end → layout drawing

Sub-structure adaption





Exposed grids & Panel section



Allowance of the spatial height → cavity thickness → facilities' positions (up or side) → purifier's connection with the indoor end unit (pressure resistance control: decreasing ducts)→ high flexibly for exhaust & return openings → maintenance accessory

The common scale of the panel system is 600 mm based.

separated structure for facilities is needed.

Extra rough filter for the open return opening on the dry ESP is needed.

Panel system → Double-sided dustproof design

Test

1

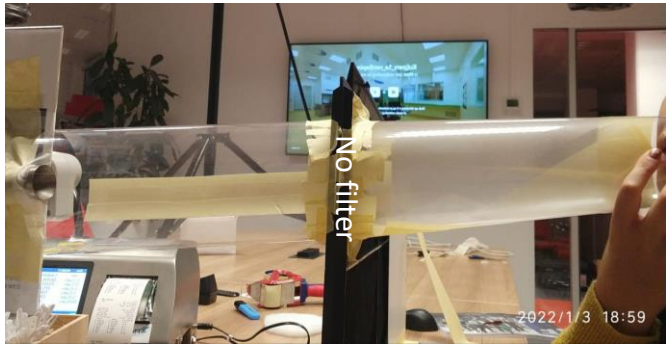
Experiment

Test

Design installation

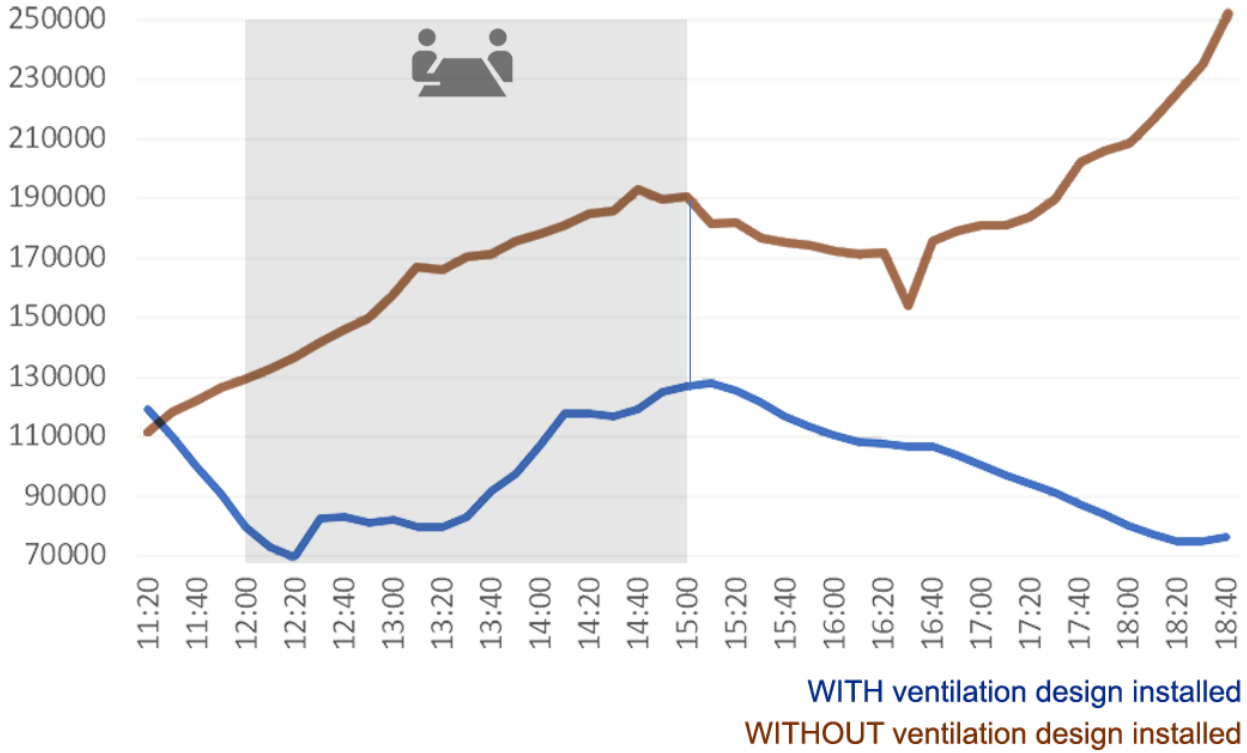
Filter cloth qualification

Particle counter & CO2 meter



mouth

0.3 um particle



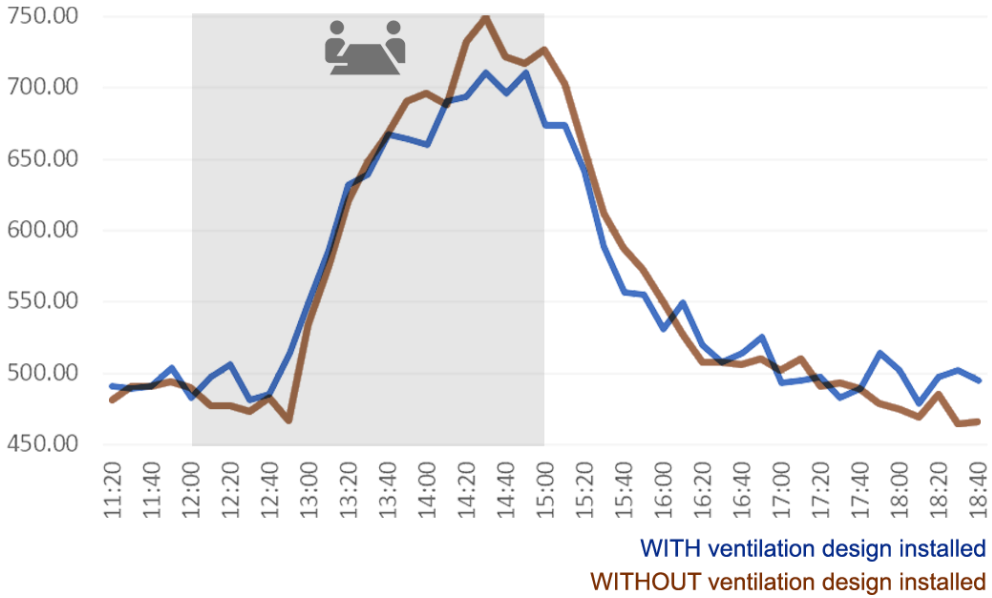
Result

Decreasing rate 1/3 → infection risk 5%

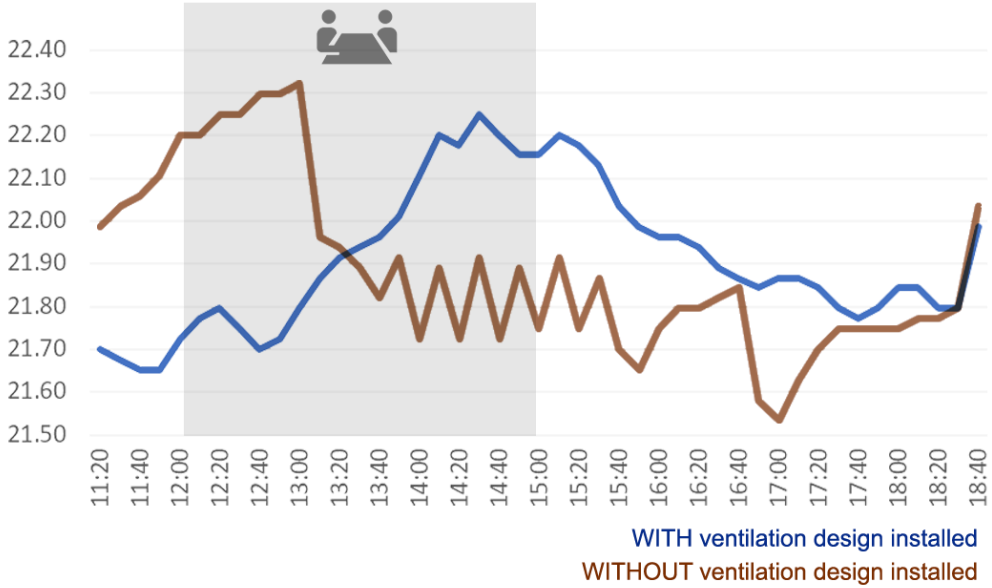
1 Experiment

Test

CO2



T

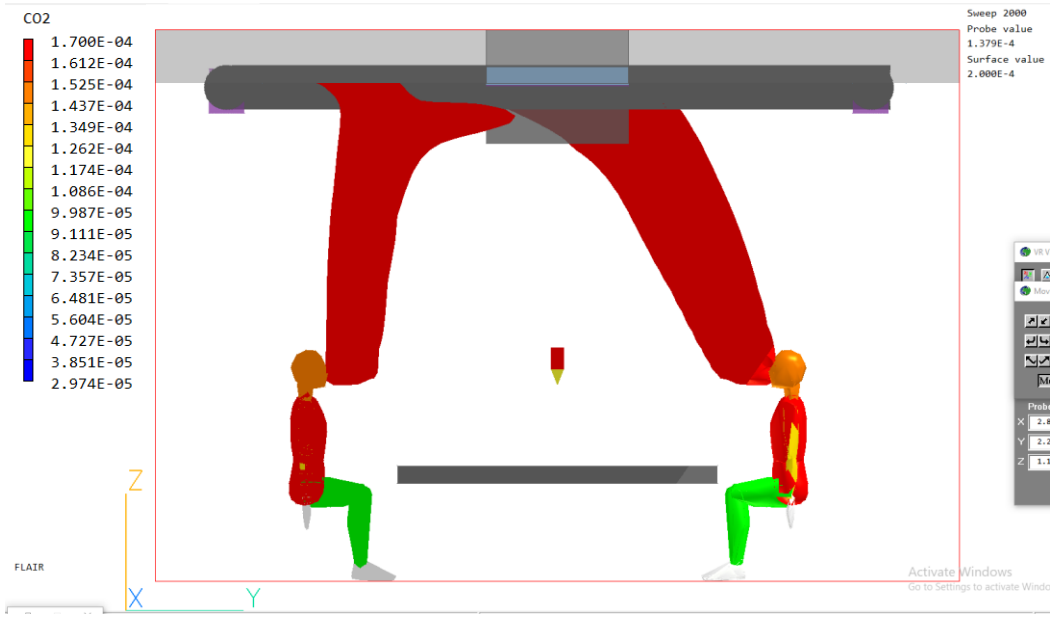


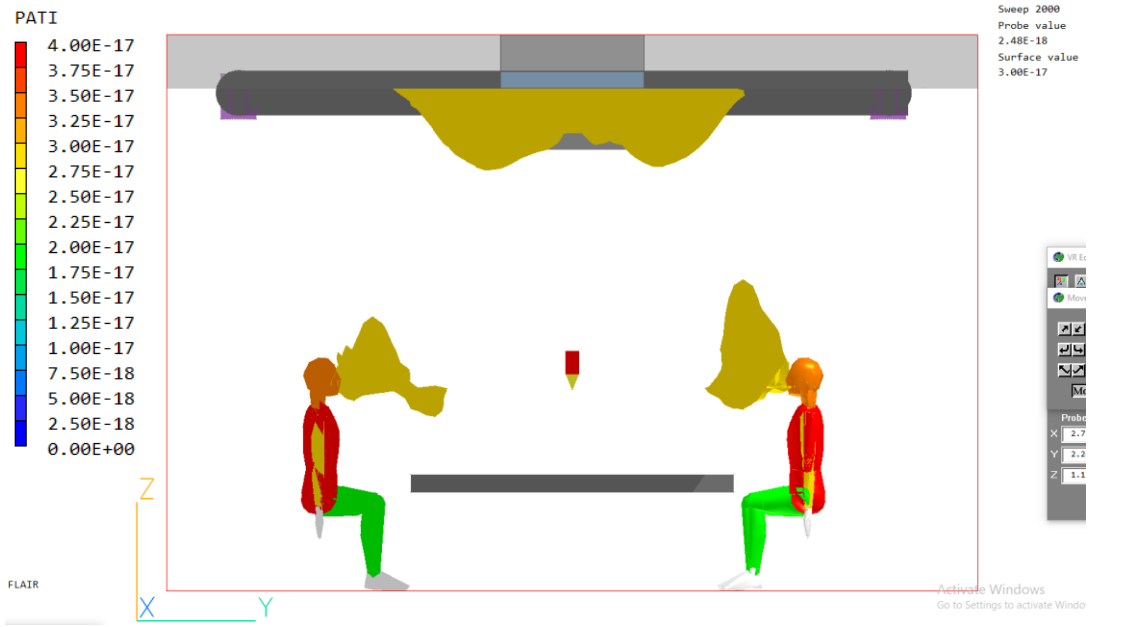
No obvious changes on indoor air quality and thermal comfort

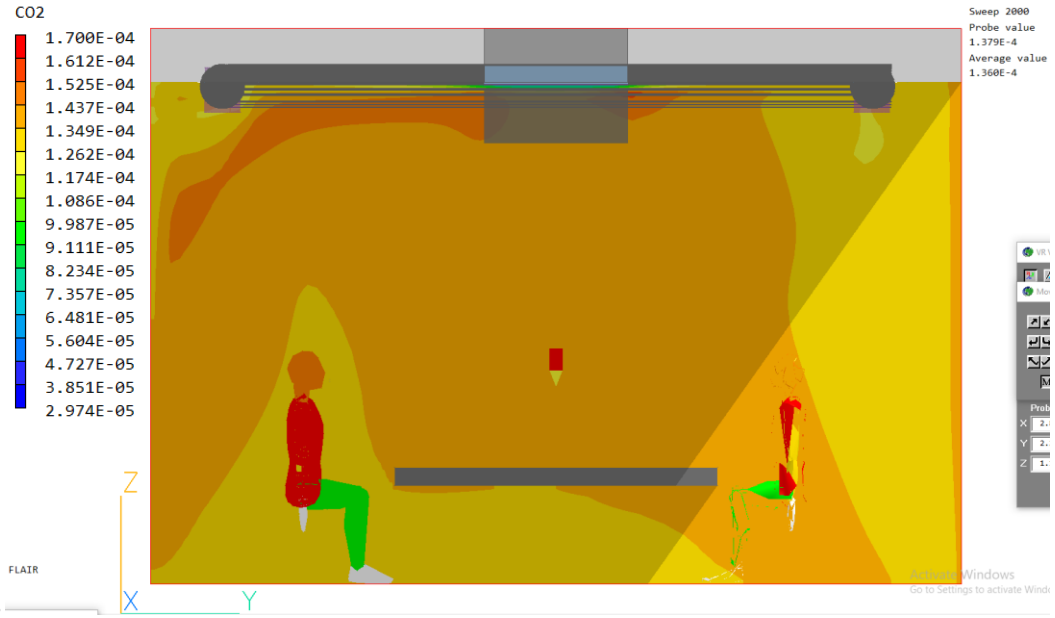
No obvious changes on smart building system controls

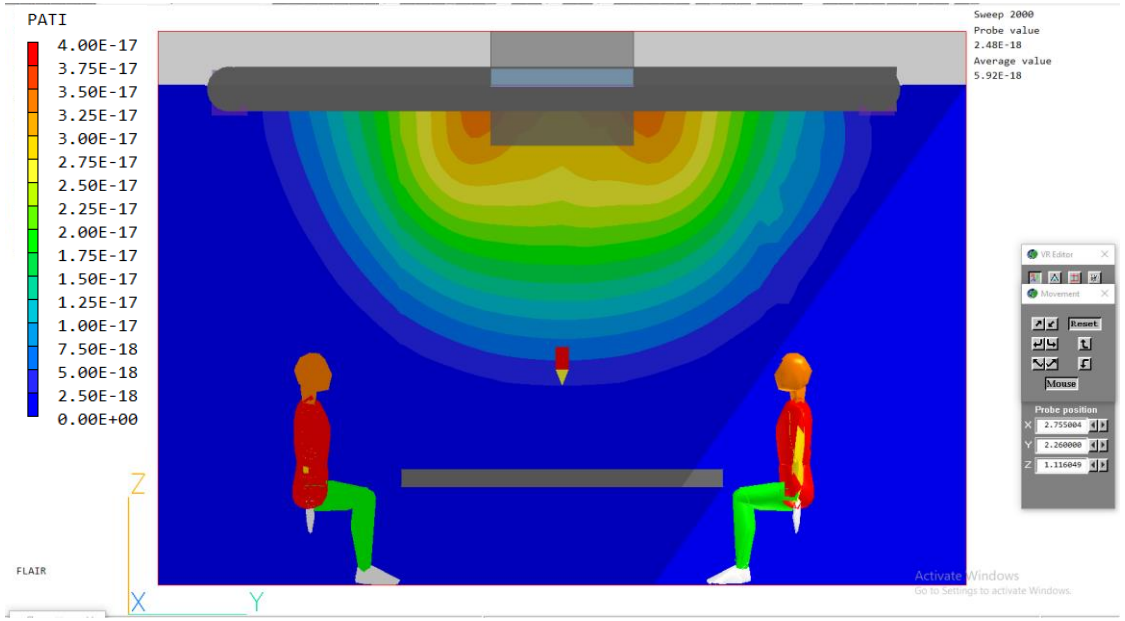
2 CFD

Test





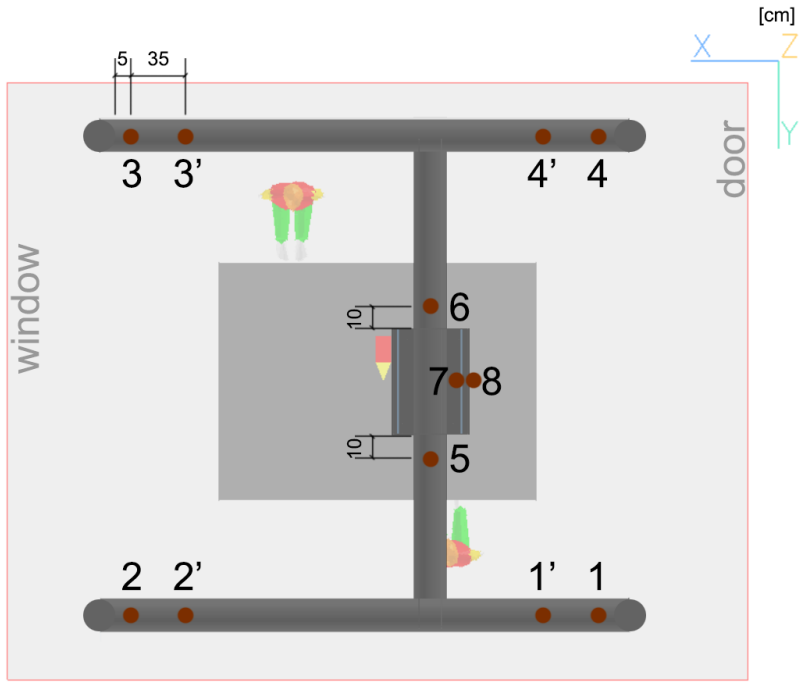


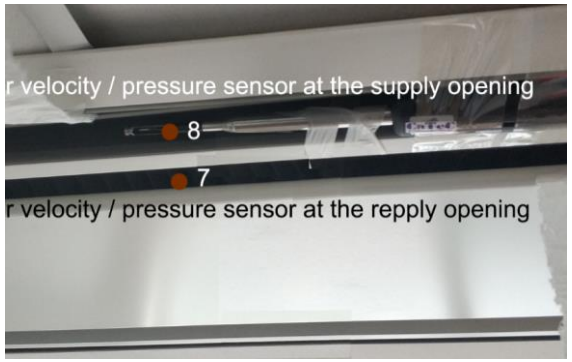


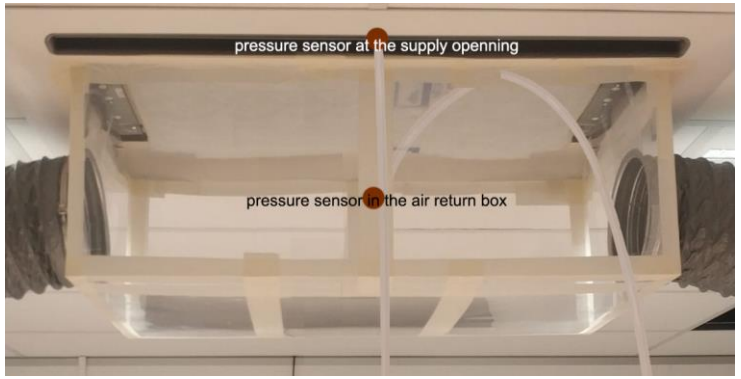
result

Infection risk 3.1%

Convergence control: the local concentration constant is added to the local 0.3 um particle concentration rate caused by human pollution source only with the impacts from the designed ventilation pattern. Then CFD results matched the onsite measurement of my design.







The draft design model may cause a relatively **high resistance** for the recirculated air. In the future design, the open cavity ceiling is preferred to decrease the resistance caused by ducts.

(a) TSI model 9535

(b) TSI model 5825

Integrated with building system control in the future –

Smart building system design to switch among working mode, hygiene working mode, resting mode and turn-off mode.

The mistakes in exhaustion air temperature setting in CFD modelling –

Limitated expectations of thermal effect from manikins.

The inexperienced convergence control in CFD modelling –

The accuracy of simulating the particle concentration in reality

THANKS