16th ROOMVENT CONFERENCE

HIGH PERFORMANCE VENTILATION FOR HEALTHY AND ENERGY EFFICIENT BUILDINGS

Estimation of infection risk through airborne transmission in large open spaces with different air distributions

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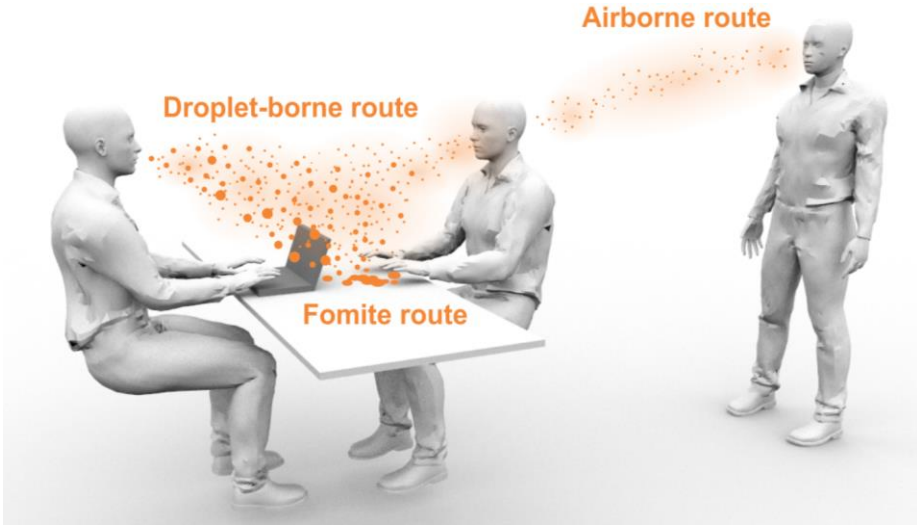
LIVE

1 Introduction

Infection transmission usually includes 3 routes:

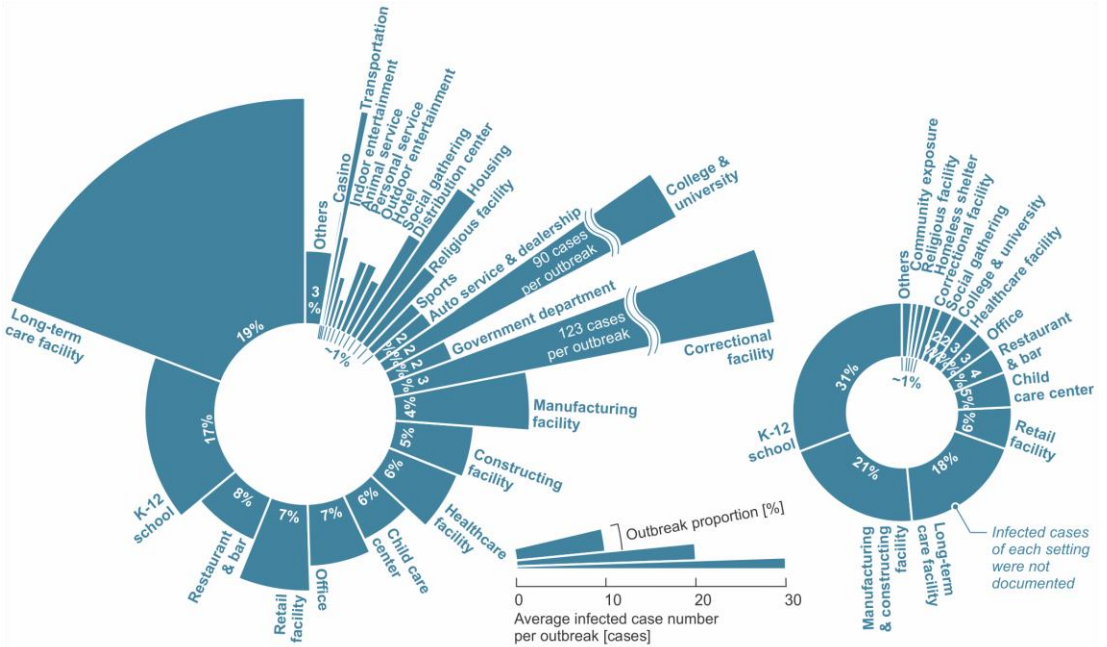
1. Fomite route (building surface, skin...)
2. Droplet-borne route (medium or large droplets)
3. Short-range/long-range **airborne route** (by aerosol)



Most COVID-19 outbreaks occurred indoors

Hotspots of indoor outbreaks

- Long-term care facilities
- K-12 schools
- Restaurants
- Retail facilities
- Offices
- …



Qian, H.; Miao, T.; Liu, L.; Zheng, X.; Luo, D.; Li, Y. 2020. https://doi.org/10.1111/ina.12766.
Shen, J.; Kong, M.; Dong, B.; Birnkrant, M. J.; Zhang, J. 2021. https://doi.org/10.1080/23744731.2021.1977693.

1 Introduction

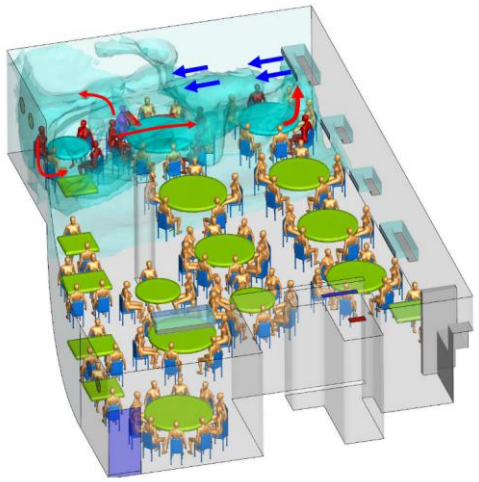
Air distribution in indoor space is significant to the airborne transmission of virus

Most indoor spaces use mixing ventilation, but indoor air is usually not perfectly mixed

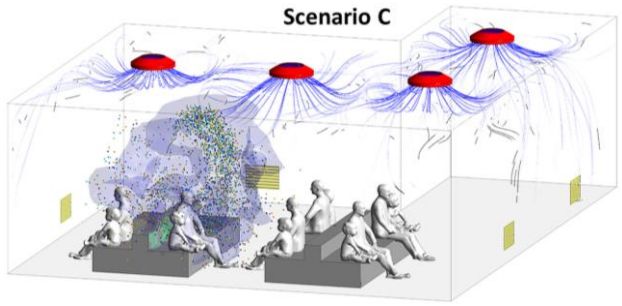
Simulation results showed that infection risk and reproduction number in large spaces are typically higher

Airflow patterns in large open spaces (e.g. hotel banquet rooms and open plan offices), are of particular concern → accommodate more occupants → spread diseases more rapidly leading to outbreaks

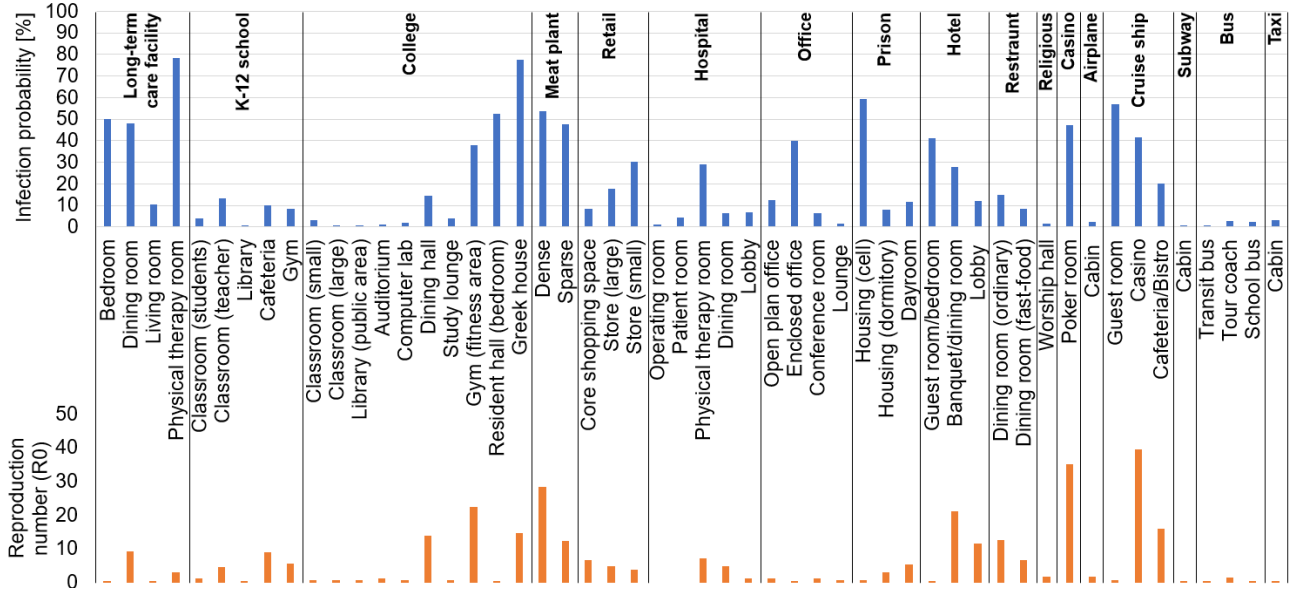
Airflow pattern and infection risk in a typical hotel ballroom under theater and banquet scenarios



Restaurant (Jan 2020)



Hospital waiting room



Infection risks in different scenarios (per Wells-Riley model)

Wei, J.; Li, Y. 2016. https://doi.org/10.1016/j.ajic.2016.06.003.
Borro L, Mazzei L, Raponi M, Piscitelli P, Miani A, Secinaro A. https://doi.org/10.1016/j.envres.2020.110343.
Shen, J.; Kong, M.; Dong, B.; Birnkrant, M. J.; Zhang, J. 2021. https://doi.org/10.1016/j.buildenv.2021.107926.

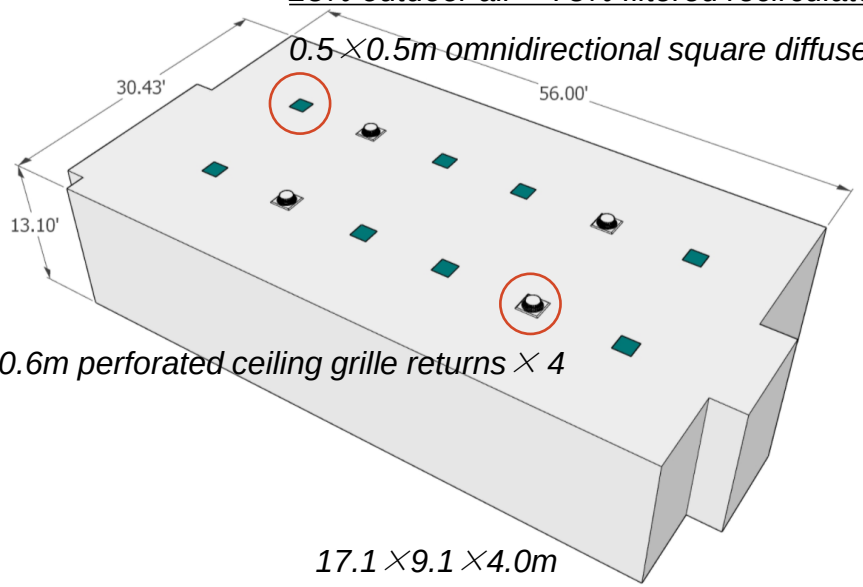
2 Methodology

Space layout and ventilation settings

A ballroom in Marriot Hotel in Syracuse, NY with regular ceiling ventilation (mixing)

Theater + Banquet scenarios

501.2 m^3/h supply air × 8
25% outdoor air + 75% filtered recirculated air

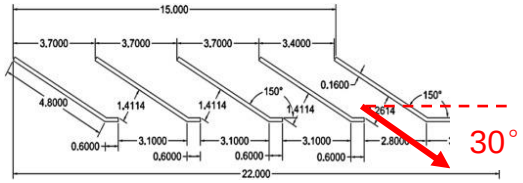


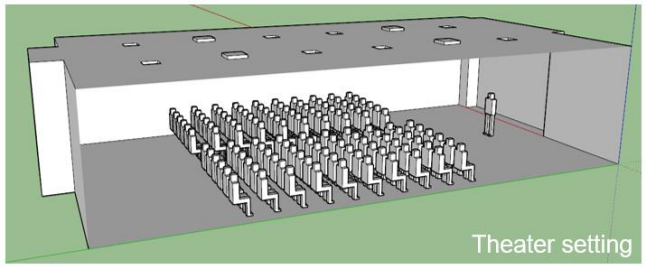
0.5 ×0.5m omnidirectional square diffusers × 8

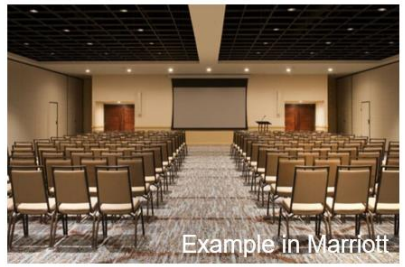
0.6 ×0.6m perforated ceiling grille returns × 4

17.1 ×9.1 ×4.0m

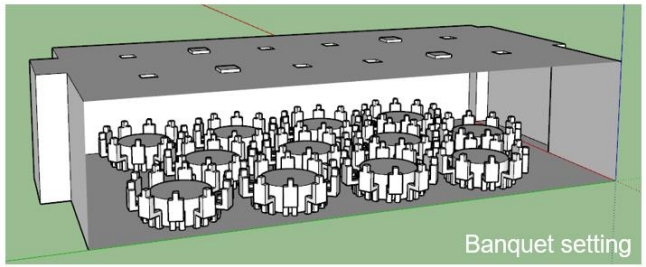
Square ceiling diffuser (3 cone)







120 audience (10 rows)
Seated, resting
+
1 presenter
Standing, speaking



120 guests (12 tables)
Seated, eating & talking

Setting		Theater	Banquet
Occupant density [#/m^2]	Marriott Hotel Guidance	0.68	0.65
	ASHRAE standard	0.35 (school theater)	0.70
Occupant activities		Audience seated; Presenter standing and talking	Seated around round tables; Eating and talking

2 Methodology

CFD settings

Mesh resolution:

0.2m for global mesh sizing;

0.02m for mesh close to people and diffusers;

Inlet flow:

501.2 m^3/h + 20 degC for each diffuser (30° to horizontal)

Simulation tool:

ANSYS Fluent

Viscous model:

Realizable K-epsilon

Scheme:

SIMPLE

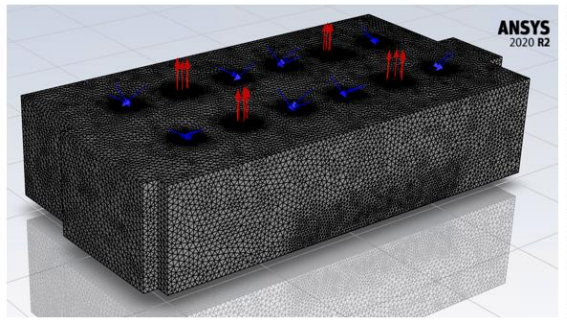
People:

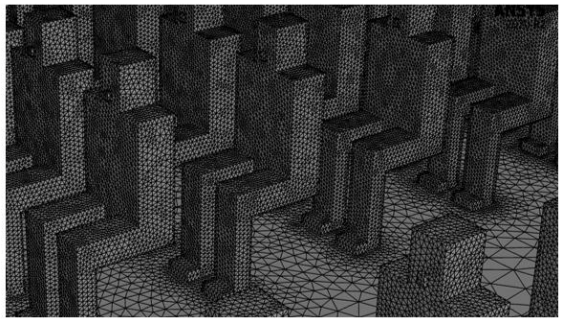
Convective heat flux = 20.7W/m^2 (body surface, 1.72 m^2)

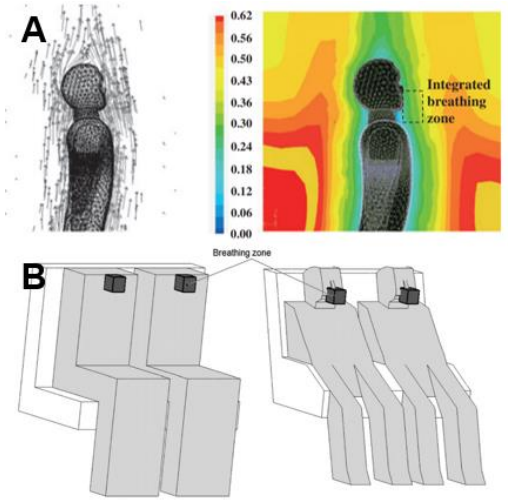
Pollutant emission:

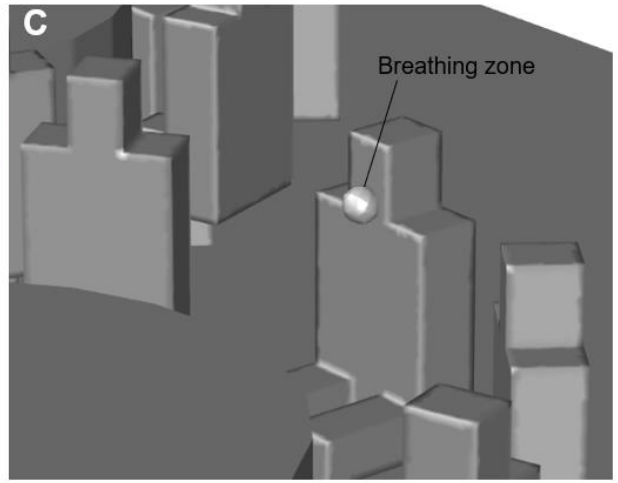
Constant passive source in the breathing zone

- Breathing zone: a 4"-diameter sphere below the nose (volume: ~0.523 L; ref. to 0.5 L in literature)
- Passive source: aerosols (typically < 1 μm in diameter)









Yan Y, Li X, Yang L, Tu J. https://doi.org/10.1016/j.enbuild.2016.06.030.
Rai AC, Chen Q. https://doi.org/10.1016/j.atmosenv.2012.02.010.
Rim D, Novoselec A, Morrison G. https://doi.org/10.1111/j.1600-0668.2009.00595.x.

2 Methodology

Pollutant emission settings and exposure calculation

Emission rate (ER) of passive pollutant:

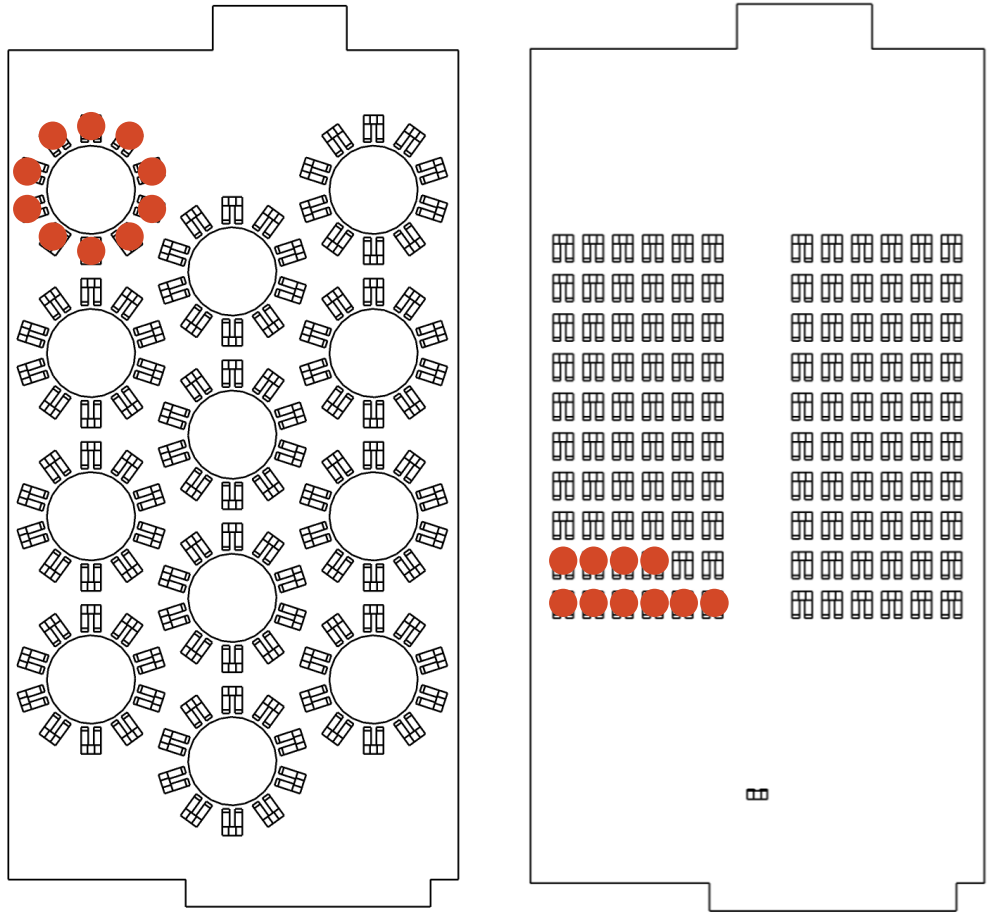
ER = 200 quanta/h (per viral load model for SARS-CoV-2)

Pollutant sources were set up at **each breathing zone** in sequence, and the average concentrations/infection risks in other breathing zones were sampled and estimated.

Infection probability estimation through **Wells-Riley** model based on occupant **exposure to the quanta of viral virus** in the air.
(inhaled 1 quanta → 63% infection)

Assumptions:

ER = 200 quanta/h
IR = 0.56 m3/h (inhalation rate)
Exposure time = 1 h



$$P = \frac{N_C}{N_S} = 1 - e^{-inhalation} = 1 - e^{-\eta_{mask} \cdot Q_{inhale} \cdot C_{vir} \cdot \Delta t} = 1 - e^{-\eta'_{mask} \cdot \frac{I \cdot ER \cdot Q_{inhale} \cdot \Delta t}{V\Lambda}}$$

Shen, J.; Kong, M.; Dong, B.; Birnkrant, M. J.; Zhang, J. 2021. https://doi.org/10.1080/23744731.2021.1977693.

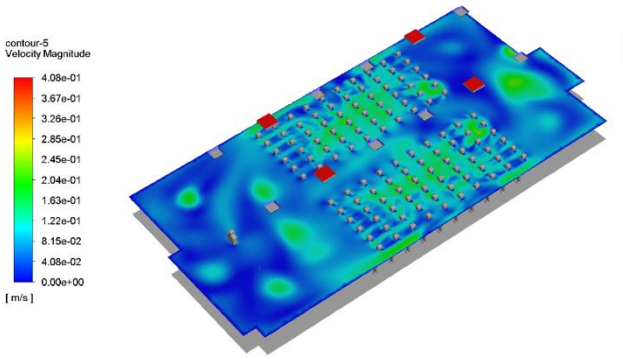
3 Results & Discussions

Airflow patterns – Theater scenario

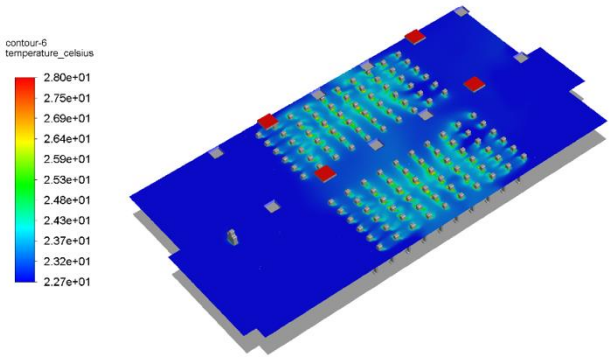
Average air temperature = 23 – 24 degC

Air temperature around occupants is higher

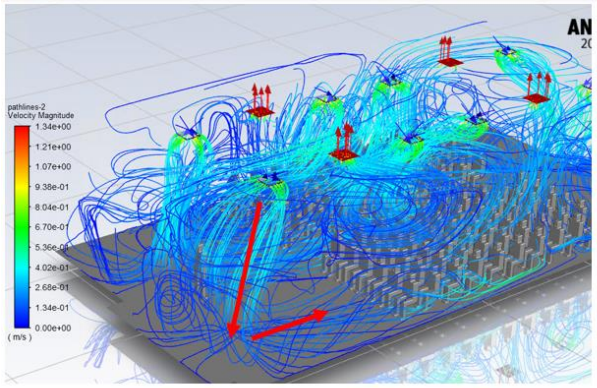
Thermal plume in the occupied area impacts air distribution

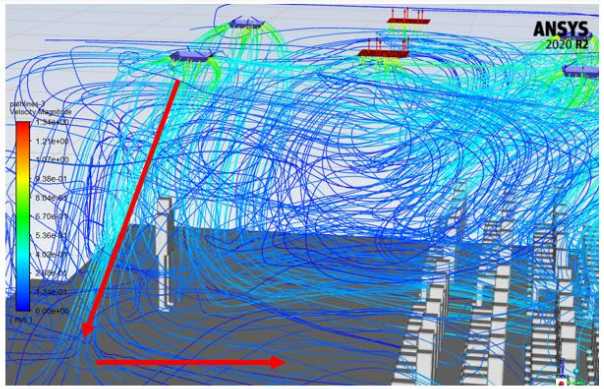


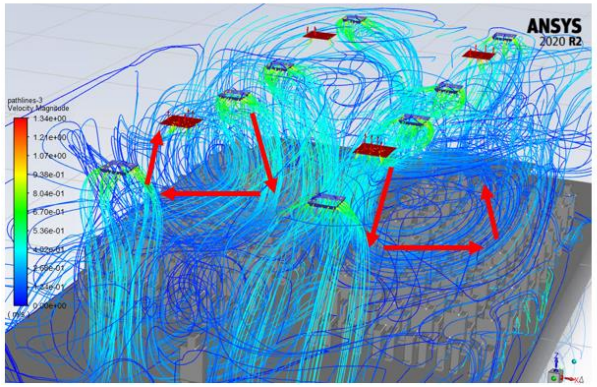
Airflow velocity distribution

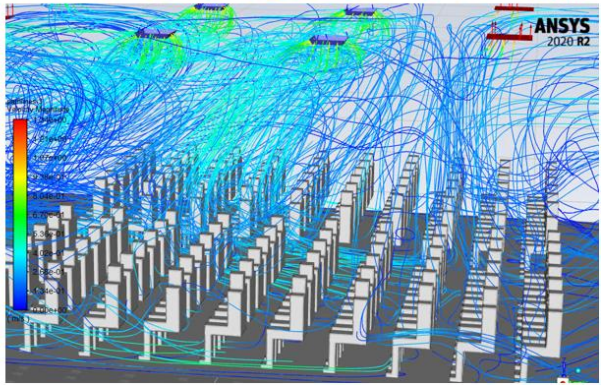


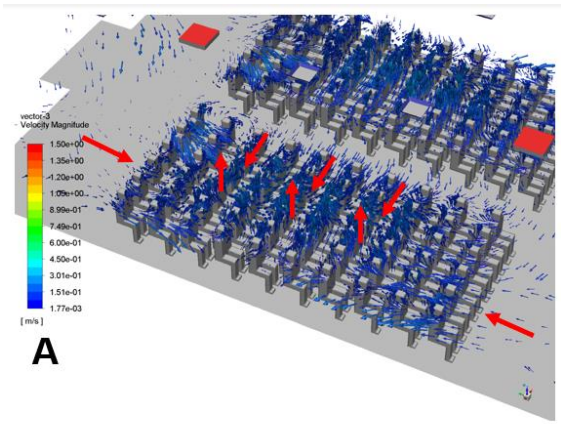
Air temperature distribution

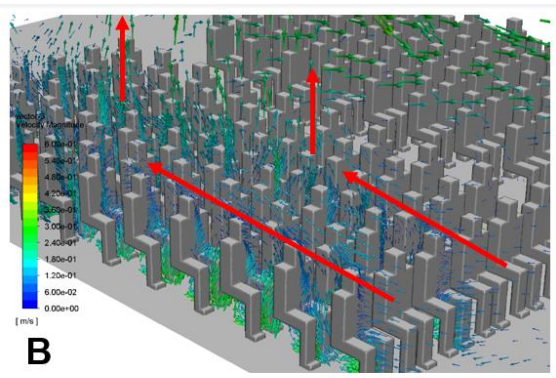


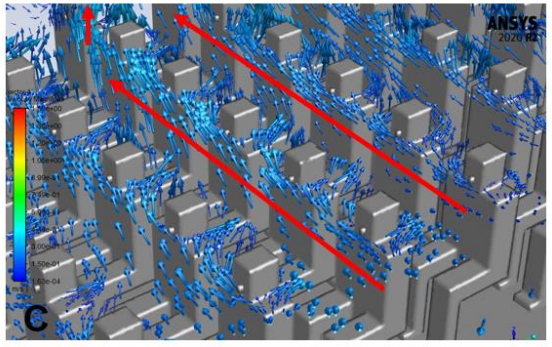


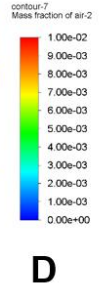


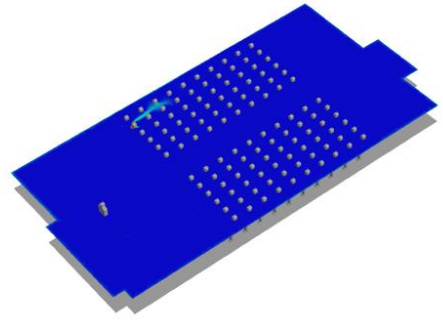












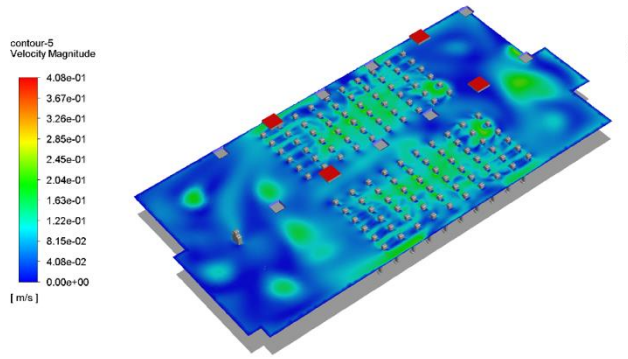
3 Results & Discussions

Airflow patterns – Theater scenario

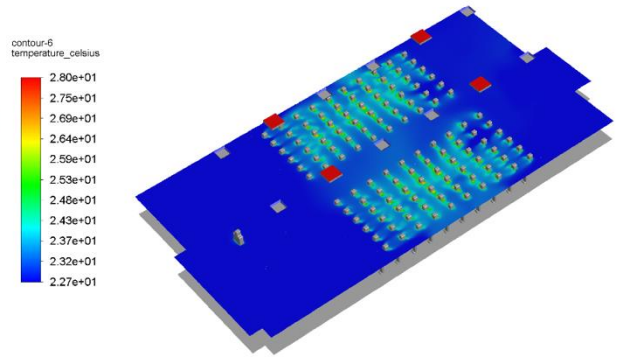
Supply airflow pattern:

Front & back (Unoccupied) → Middle (Occupied)

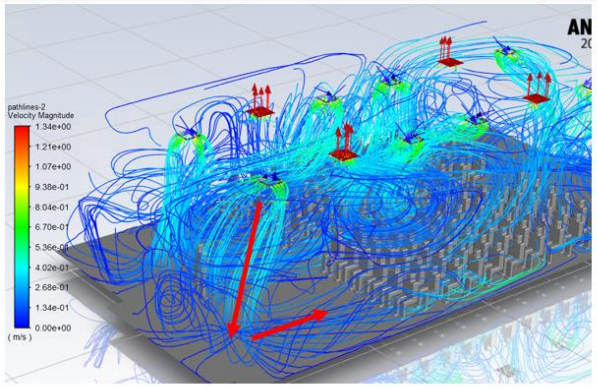
Center → Lateral (Left & Right)

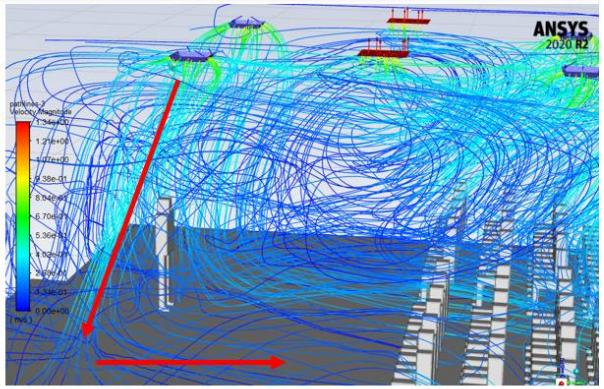


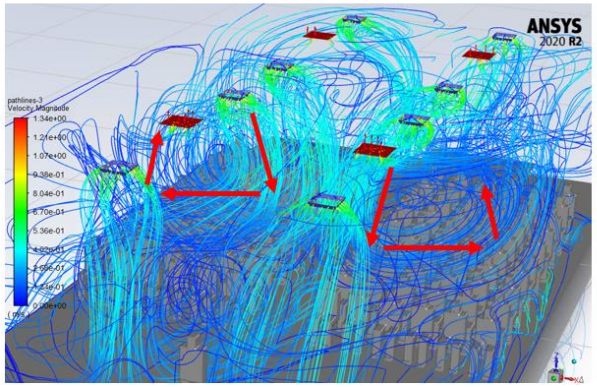
Airflow velocity distribution

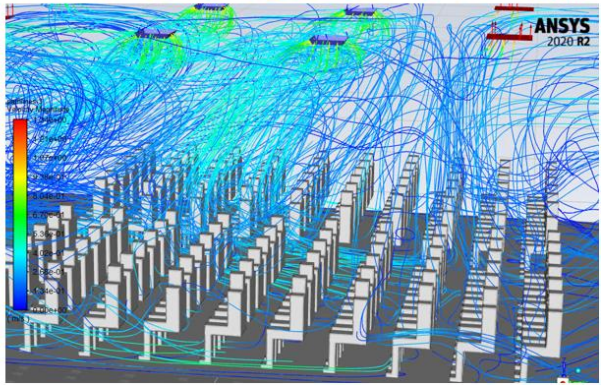


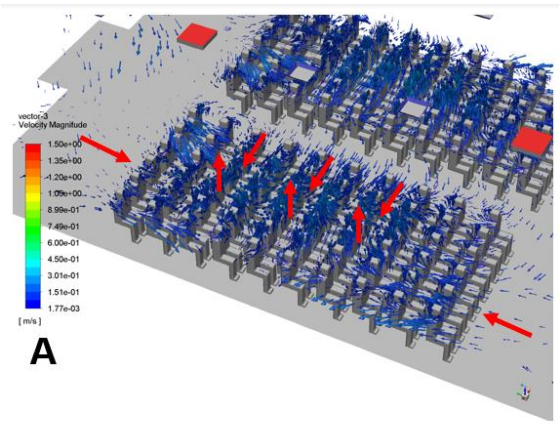
Air temperature distribution

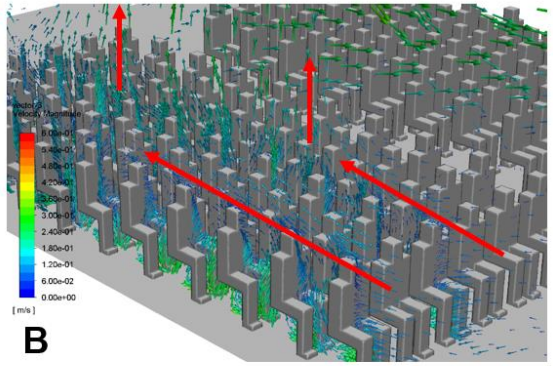


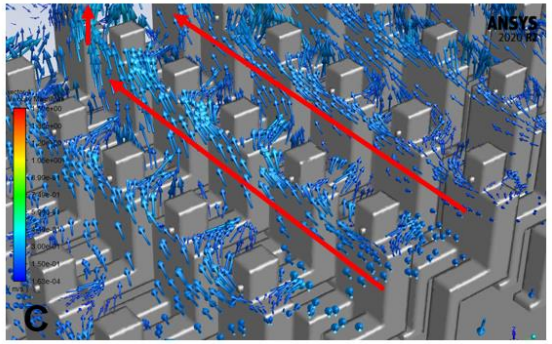


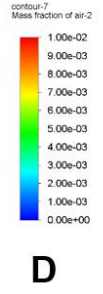


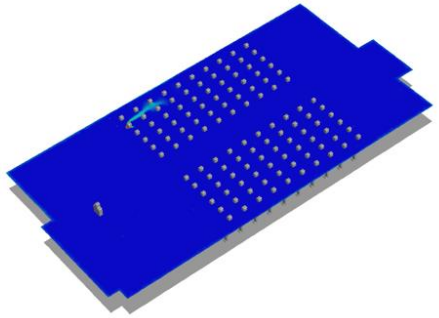












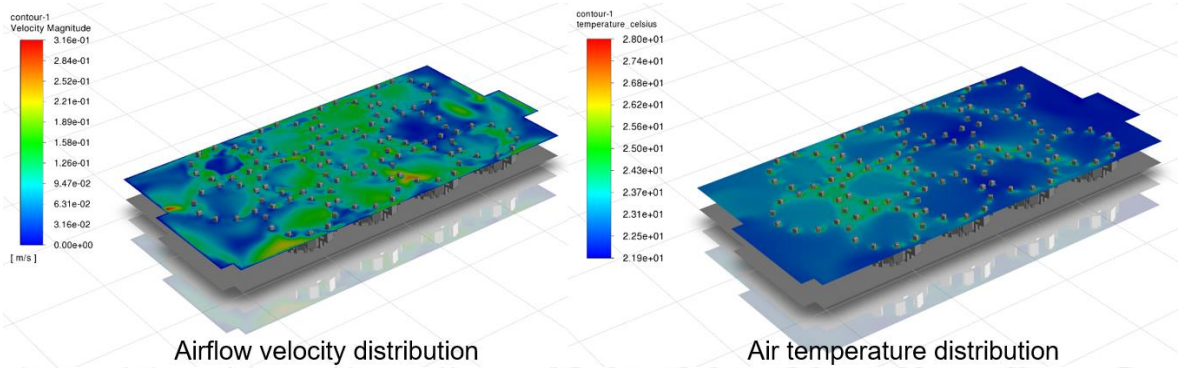
3 Results & Discussions

Airflow patterns – Banquet scenario

Airflow pattern is more complicated and less organized than the theater scenario

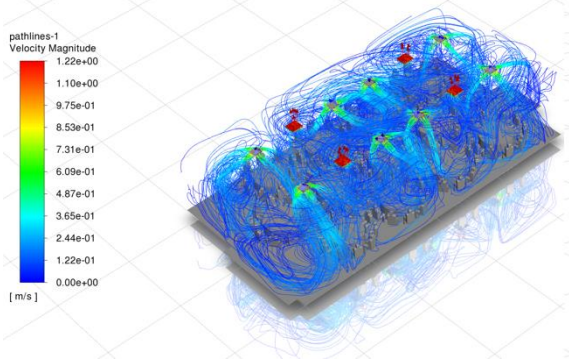
Pollutant can be spread in a longer distance and affect more people

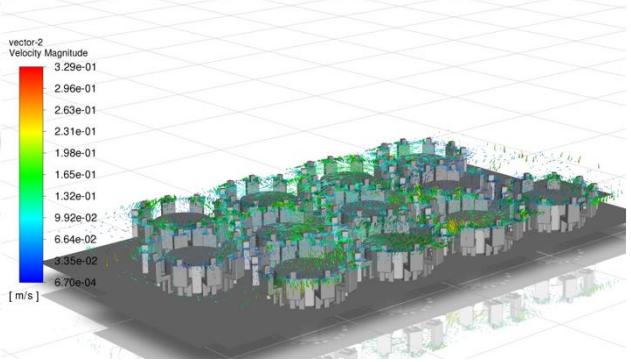
People on the same table are likely exposed to higher risks when they are on the same table as the infector. But cross-table contamination/infection is still possible.

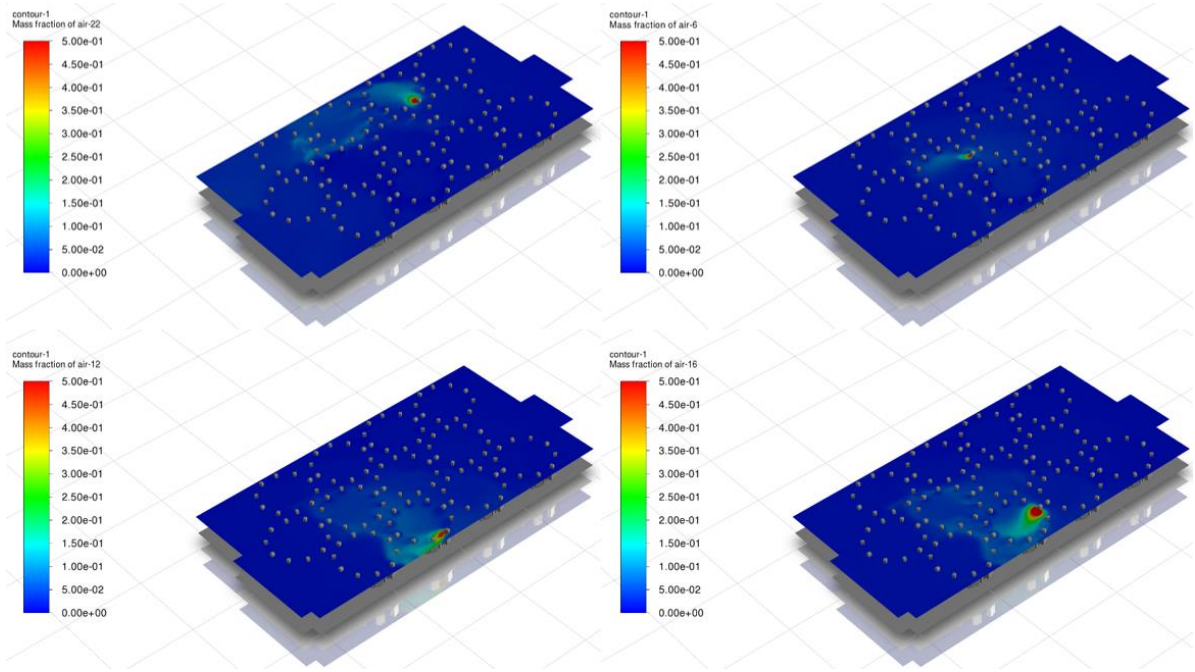


Airflow velocity distribution

Air temperature distribution







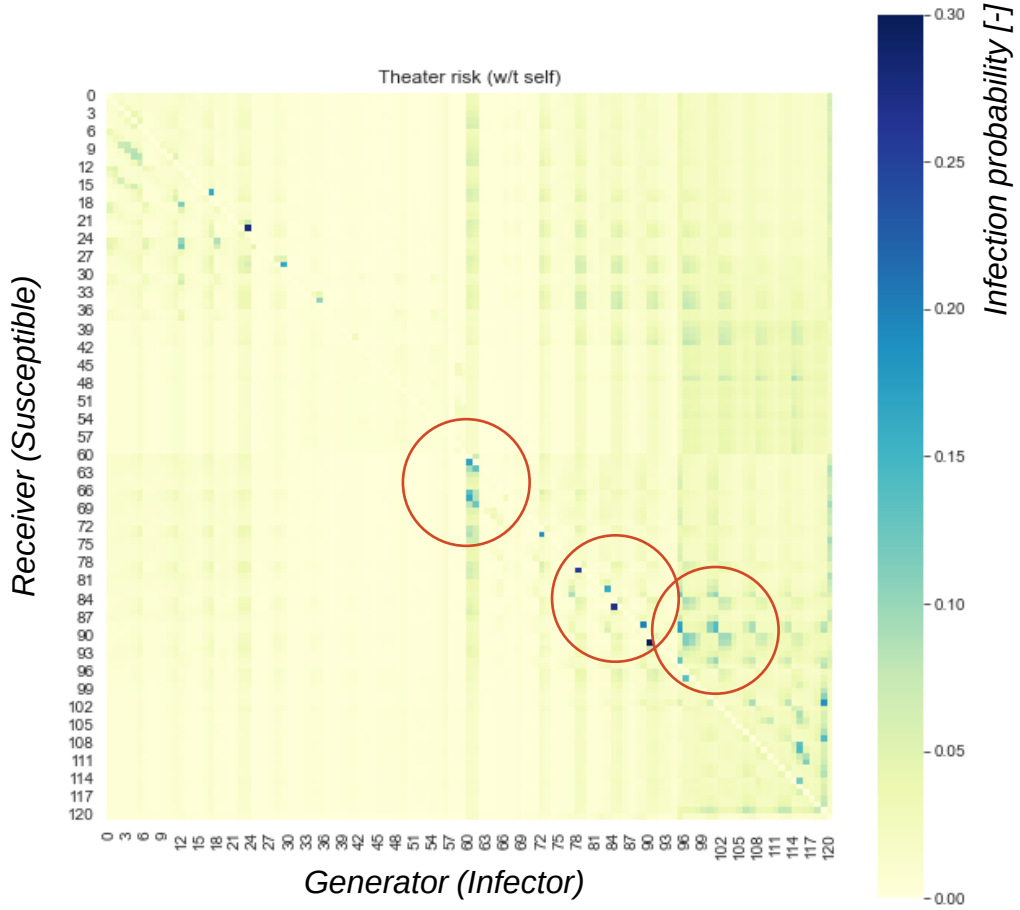
3 Results & Discussions

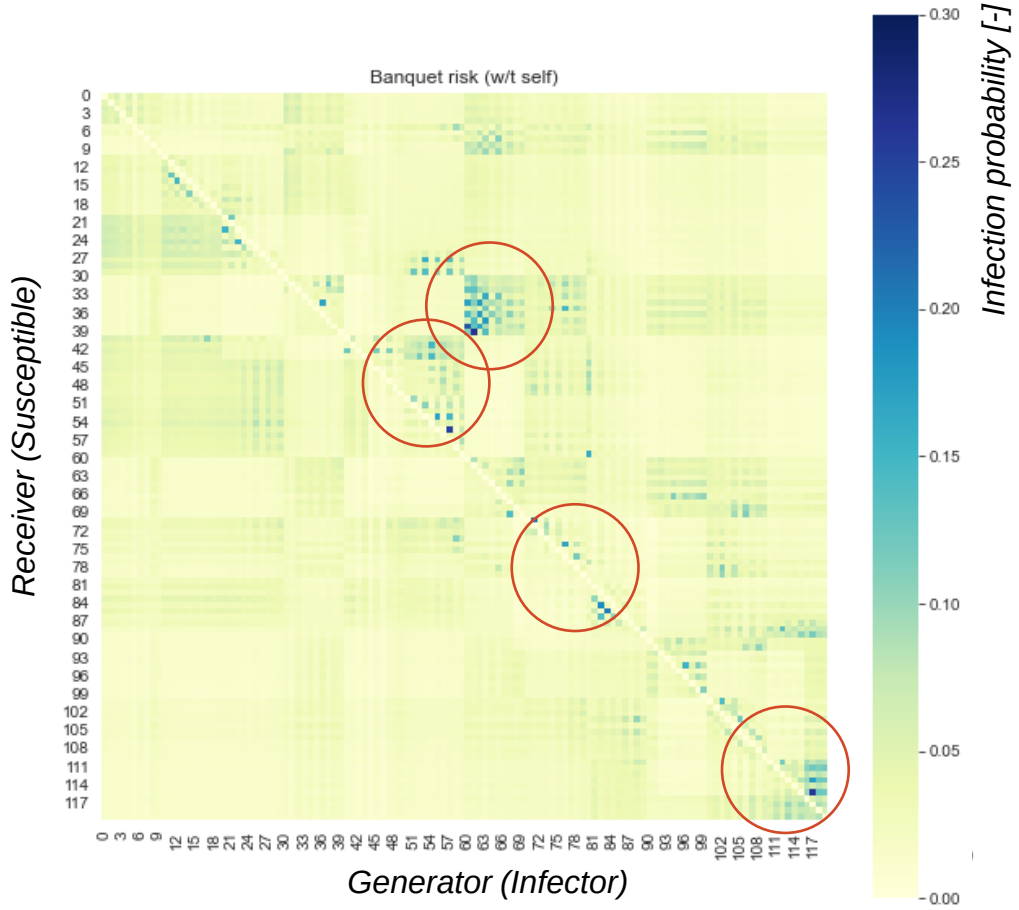
Infection probability – Overview of all datasets

120 receivers x 120 infectors (121 x 121 for theater)

Highest risk is close to 30% in some areas

Risks in banquet are generally higher than in theater



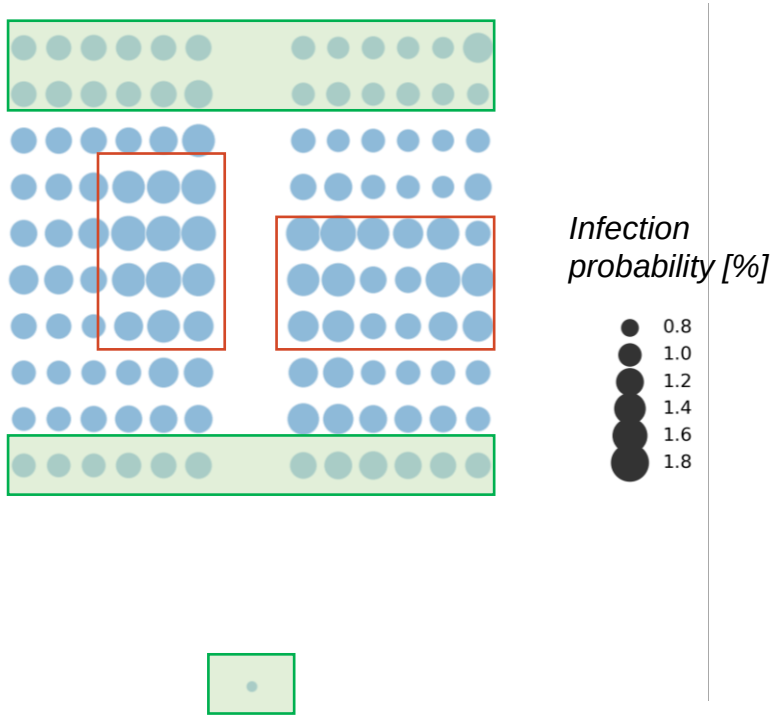


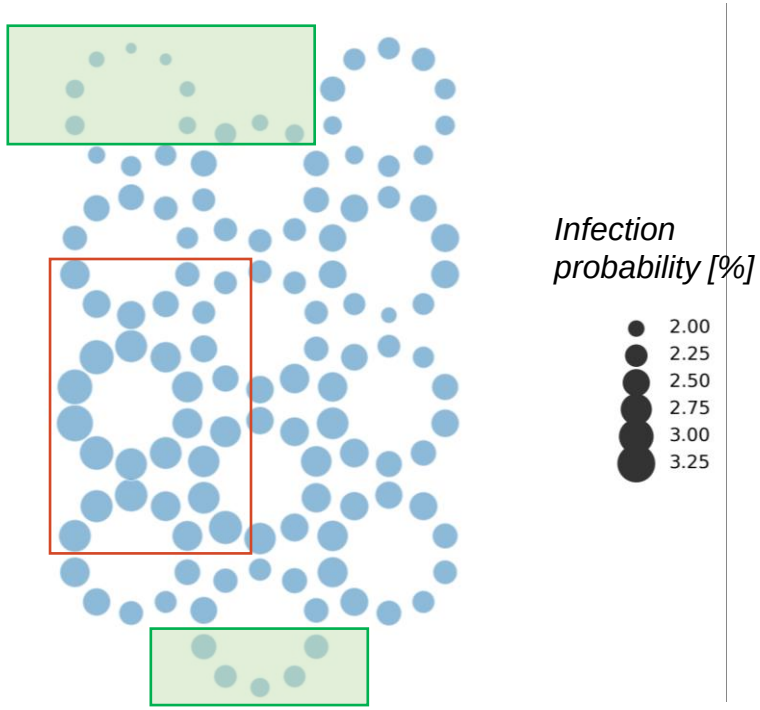
3 Results & Discussions

Infection probability – Average risk in each spot

Theater: higher risks in the middle; back and front rows expose to lower risks; presenter has lowest risk;

Banquet: less organized; back and front sides expose to lower risks;



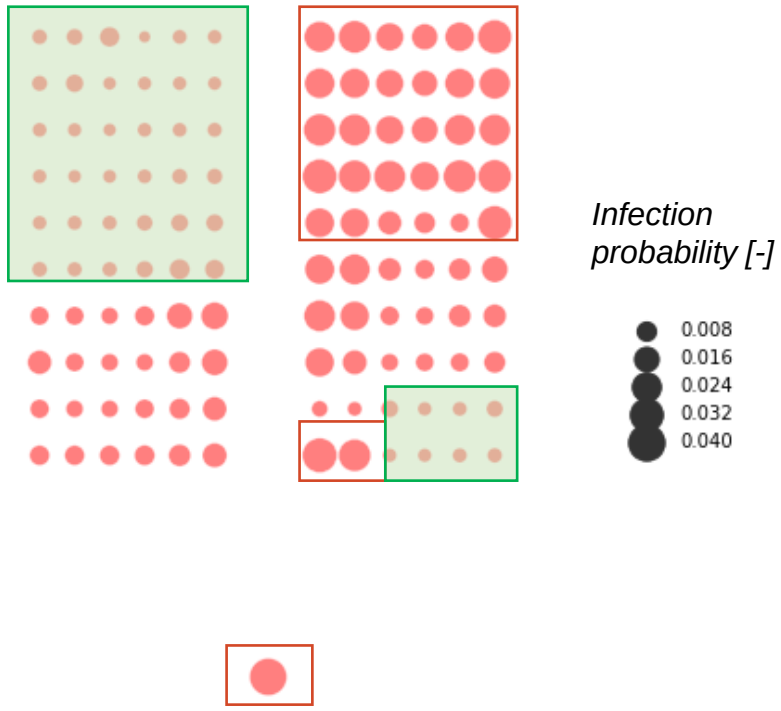


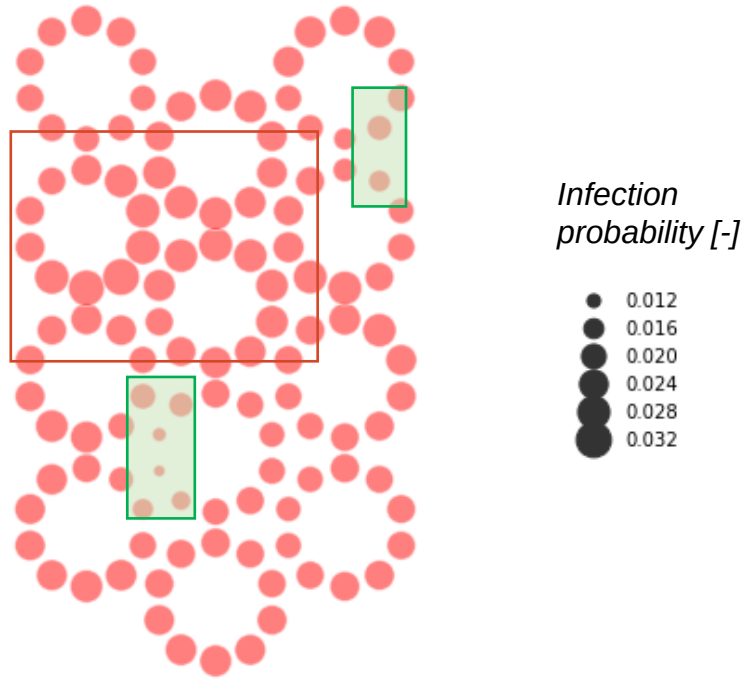
3 Results & Discussions

Infection probability – Who can infect more people?

Theater: presenter can infect more people;

Banquet: less organized;



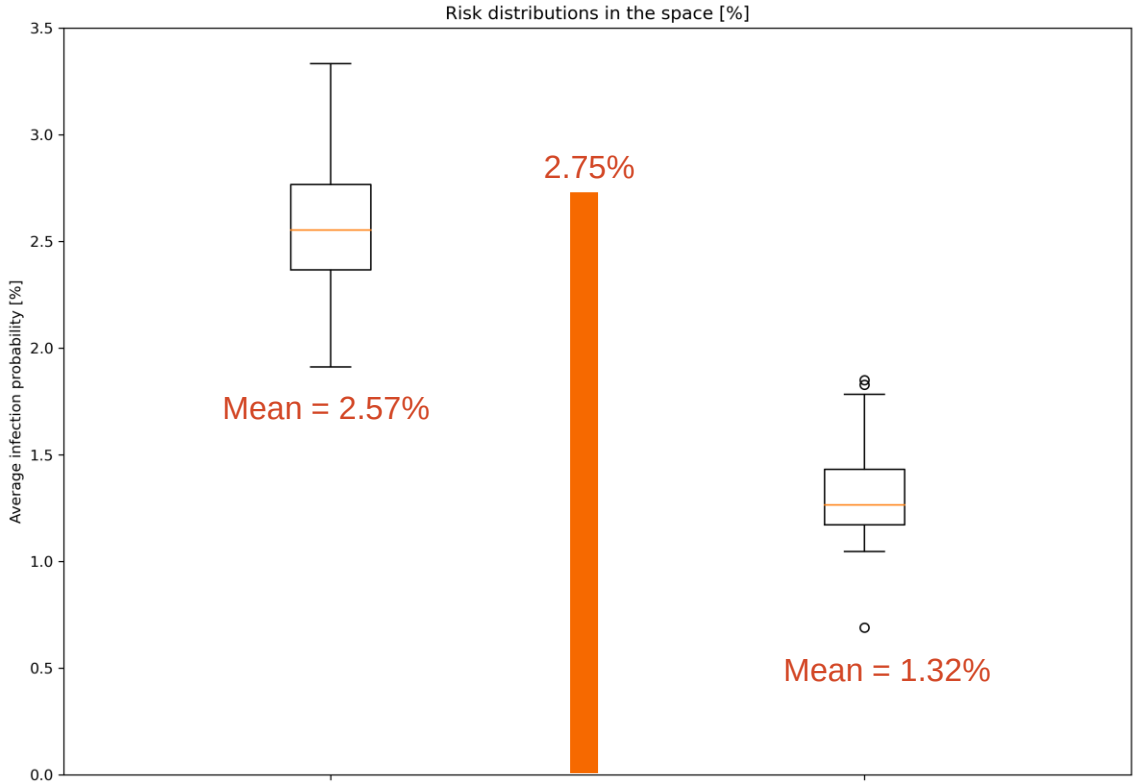


3 Results & Discussions

Infection probability – Comparison between banquet and theater

Average risk (infection probability) in banquet scenario is almost double of the risk in theater scenario (2.57% to 1.32%)

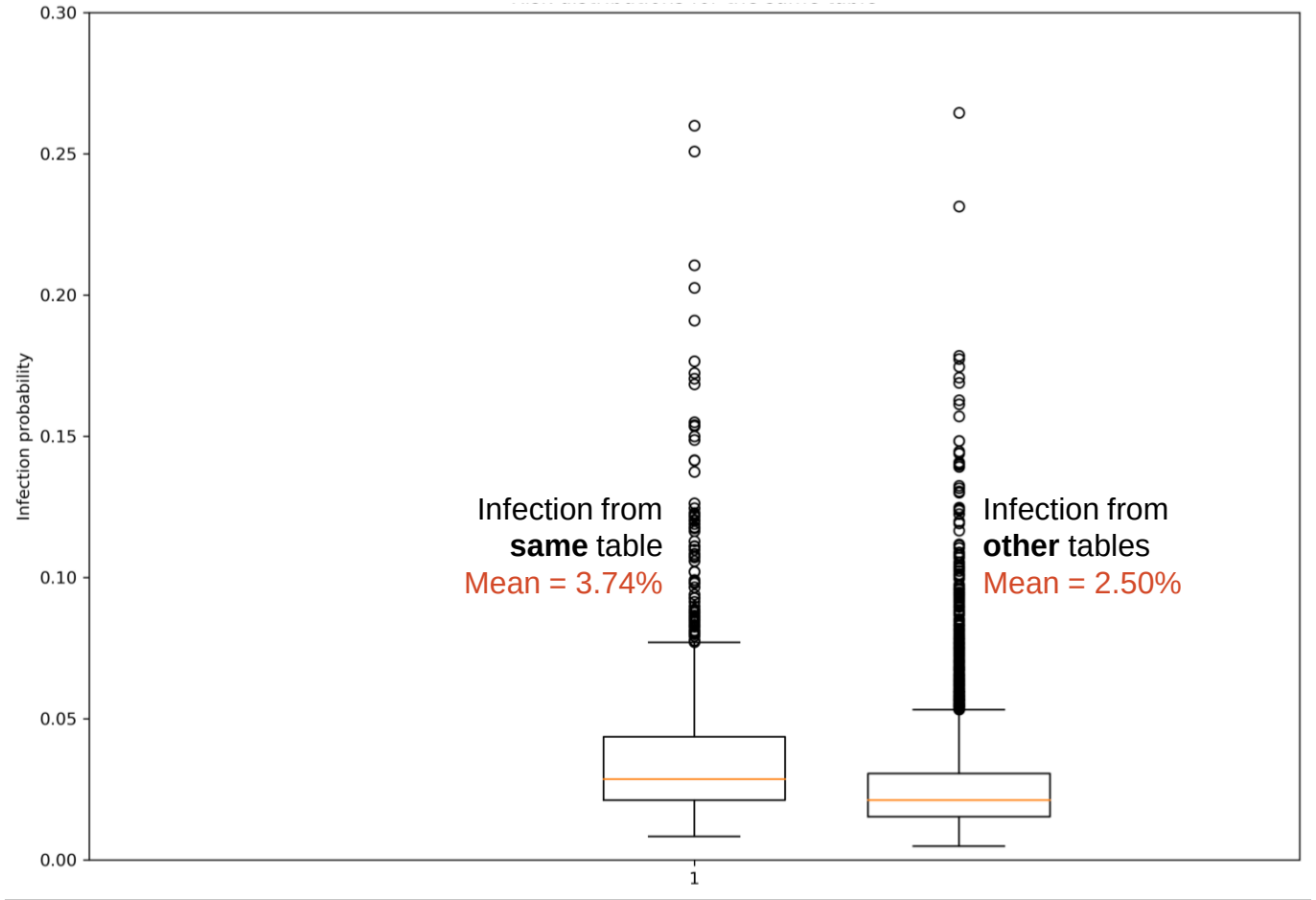
Using well-mixing assumption for calculation in banquet is fine, but may overestimate in theater (airflow in banquet is more perfectly mixed)



3 Results & Discussions

Infection probability – Banquet scenario: Where are the risks from?

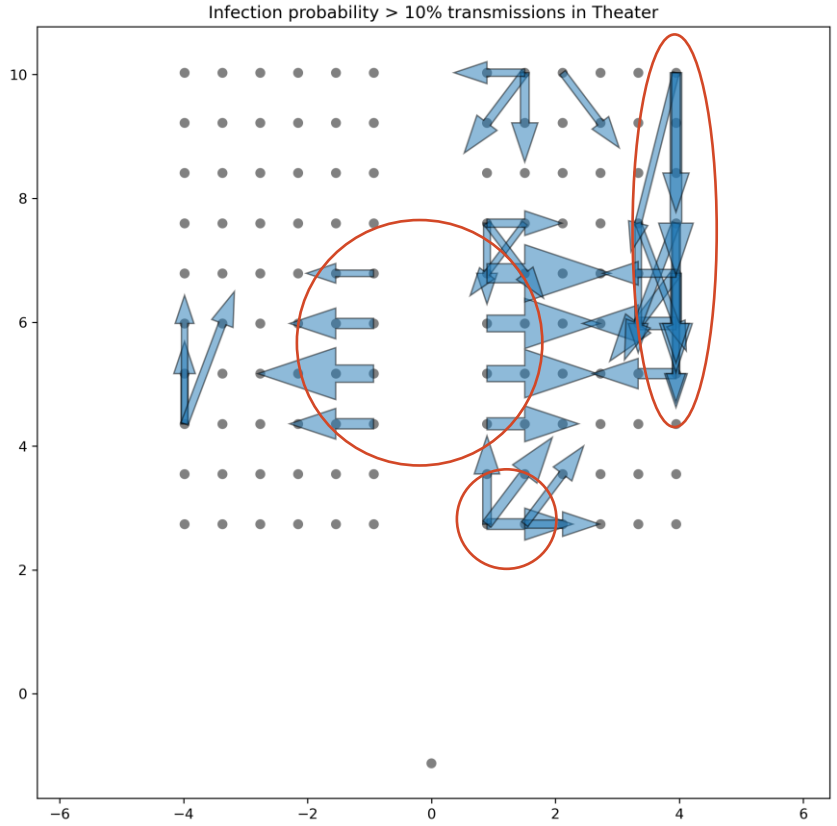
In general, infection risks from the infectors sitting in the same table are higher than risks from people in other tables (3.74% to 2.50%), but the result is not very significant.

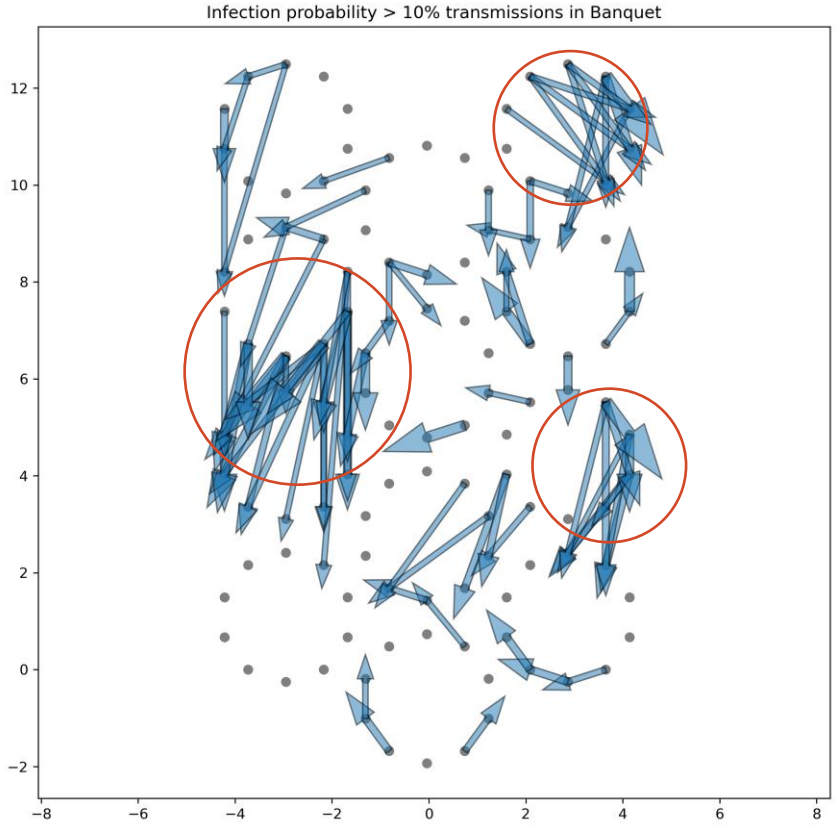


3 Results & Discussions

Infection probability – Where do the high-risk transmissions occurred

Transmissions with infection probability > 10% (infector → receiver)



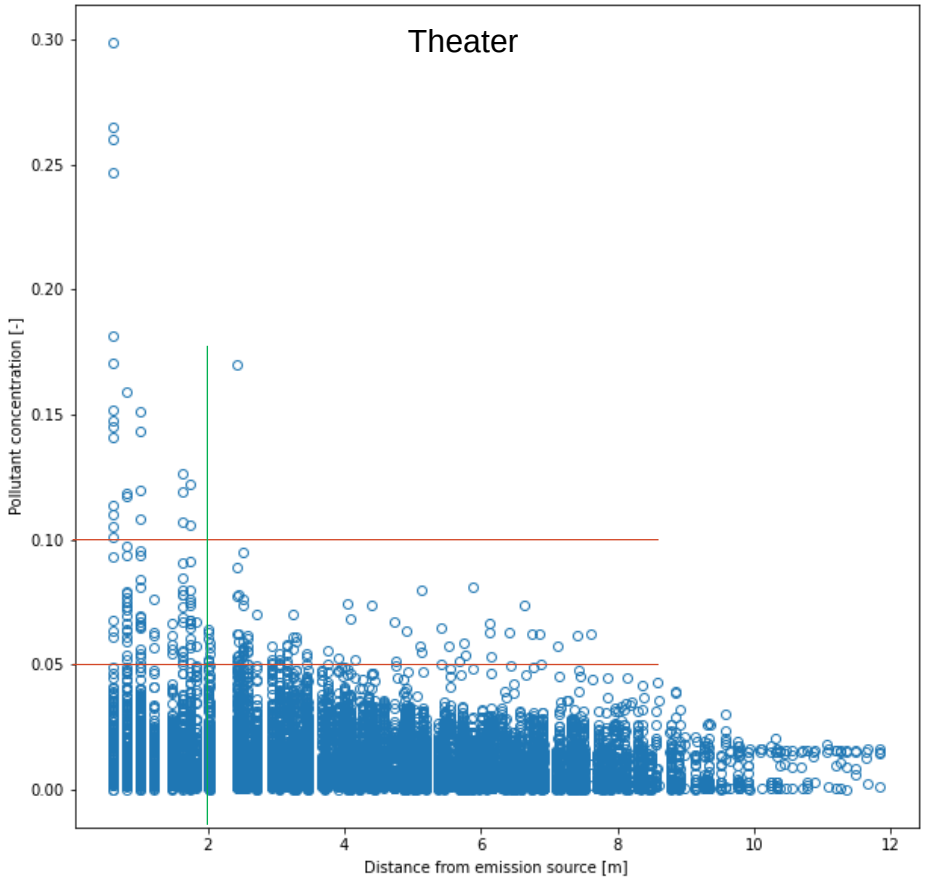


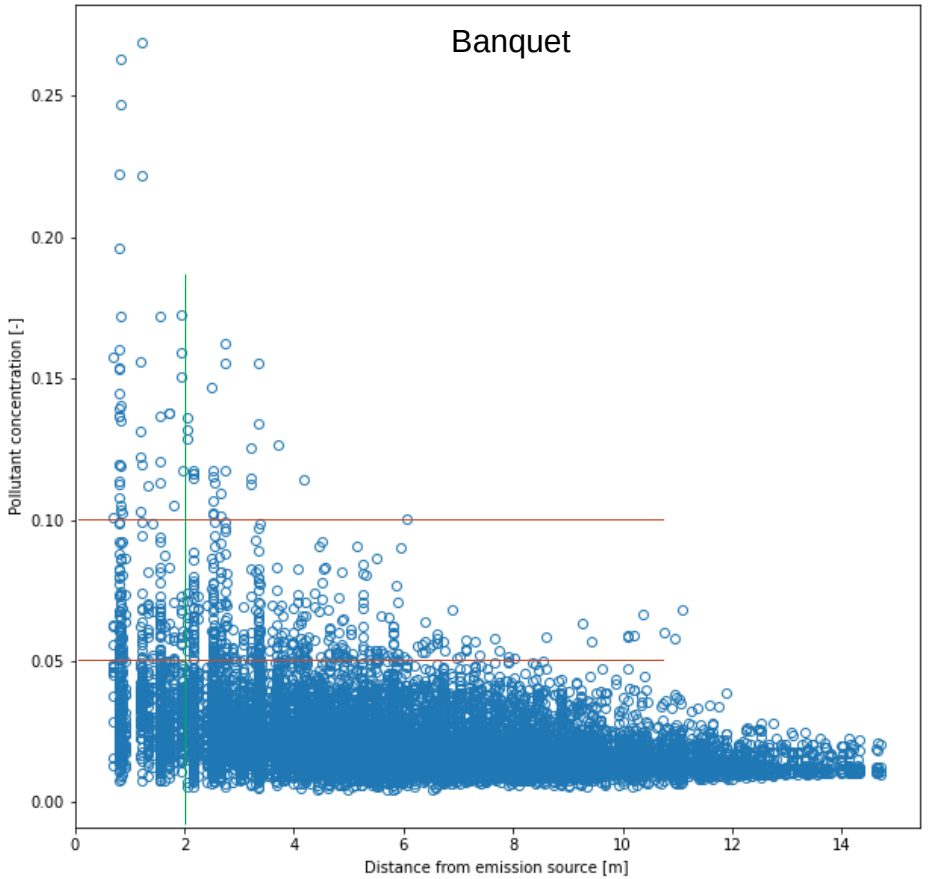
3 Results & Discussions

Infection probability – Risk vs Distance

Transmissions with infection probability > 10% (infector → receiver)

In general, people in closer distances to the infector are exposed to higher risks, particularly for high-risk transmissions (>10%)





4 Conclusions

- The infection risks in a space can be very different when it was used for different purposes (even with same number of occupants, same respiratory activities)
- Thermal plume plays a significant role in affecting the indoor airflow pattern
- People in banquet scenario are exposed to almost double of the risk in theater scenario
- Well-mixing assumption is fine for banquet scenario, but may overestimate the risk in theater scenario
- In theater scenario, people sitting in the middle area are exposed to higher risks; The presenter is exposed to the lowest risk but can infect more people
- Same-table infection risk is higher than cross-table infection for banquet scenario, but not significantly. High-risk cross-table infection is still possible
- High-risk infection is more likely occurred within a closer distance between the infector and the receiver

Thank You!

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