Digital Transformation of Droplet/Aerosol Infection Risk Assessment Realized on "Fugaku" for the Fight against COVID-19

Kazuto Ando*[1], Rahul Bale*[1], ChungGang Li*[1,2], Satoshi Matsuoka*[1,3], Keiji Onishi*[1] and Makoto Tsubokura*[1,2]

[1]RIKEN Center for Computational Science

[2]Kobe University

[3]Tokyo Institute of Technology

*All authors are listed in alphabetical order by surnames

COVID-19 and Droplet/Aerosol Infection

- Several ways of transmission…

Caused by airway secretions

Contact
Norovirus…

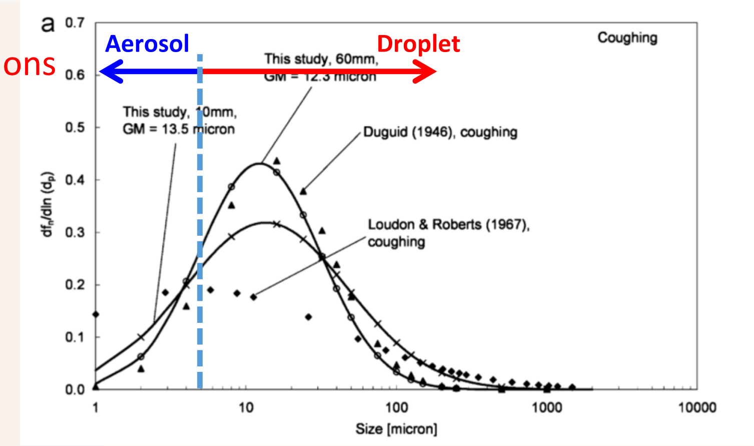
Blood-borne
Hepatitis…

Airborne
Tuberculosis, Measles…
Far distance

Droplet
Influenza, Rubella…
Close distance: 2m or less

And more…

Distribution of droplet size when coughing



C.Y.H. Chao et al./Aerosol Science 40(2009)122-133

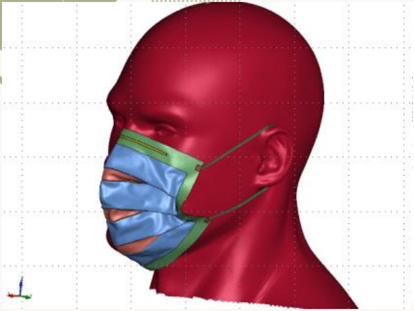
- Difficulty in the COVID-19 transmission.
  - Emerging infection disease rapidly spread all over the world.
  - Inhalation of dense aerosol emitted from an infected person at relatively close distance, intermediate bet. Airborne/droplet.

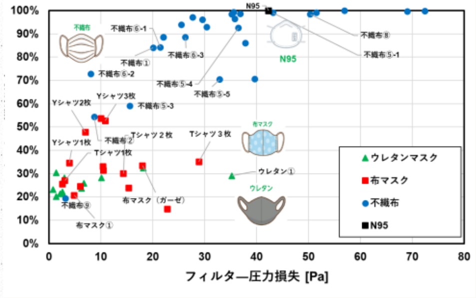
→ No scientific data under strict lock-down.

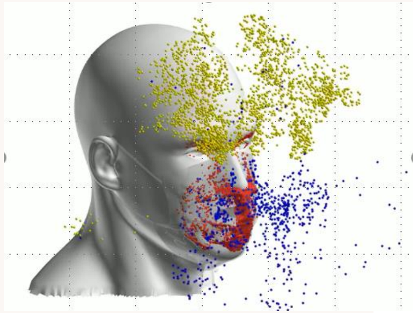
→ Risk strongly affected by indoor air condition.
Enormous risk evaluations must carried out independently.

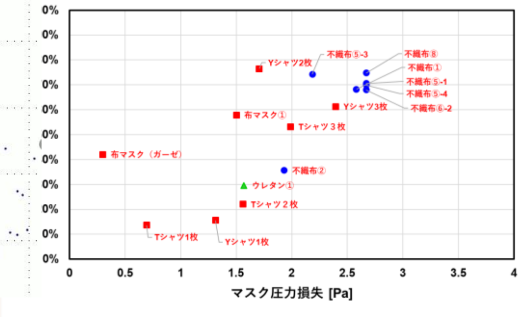
Utilizing massively parallel resources for tons of virtual infection risk assessments and proposal of each countermeasure!

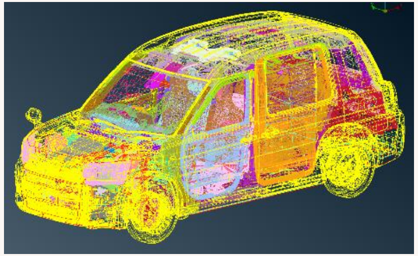
DX of the Aerosol Infection Risk Assessment

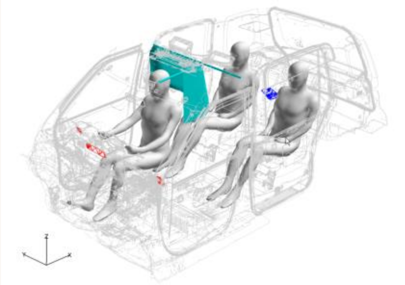


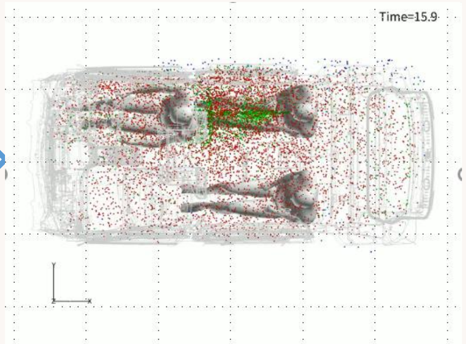


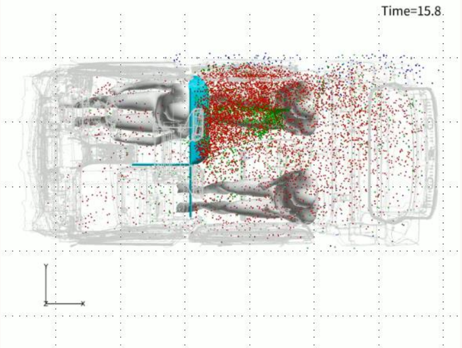


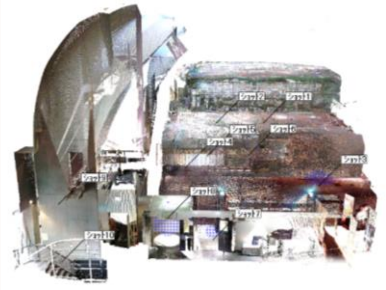


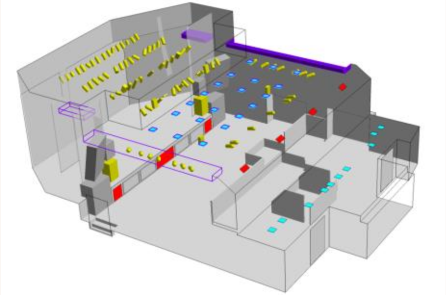


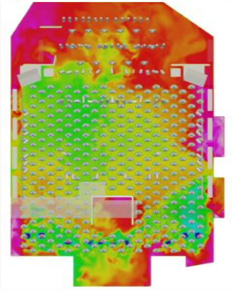


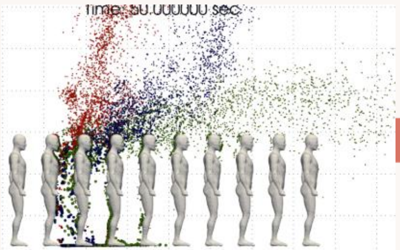






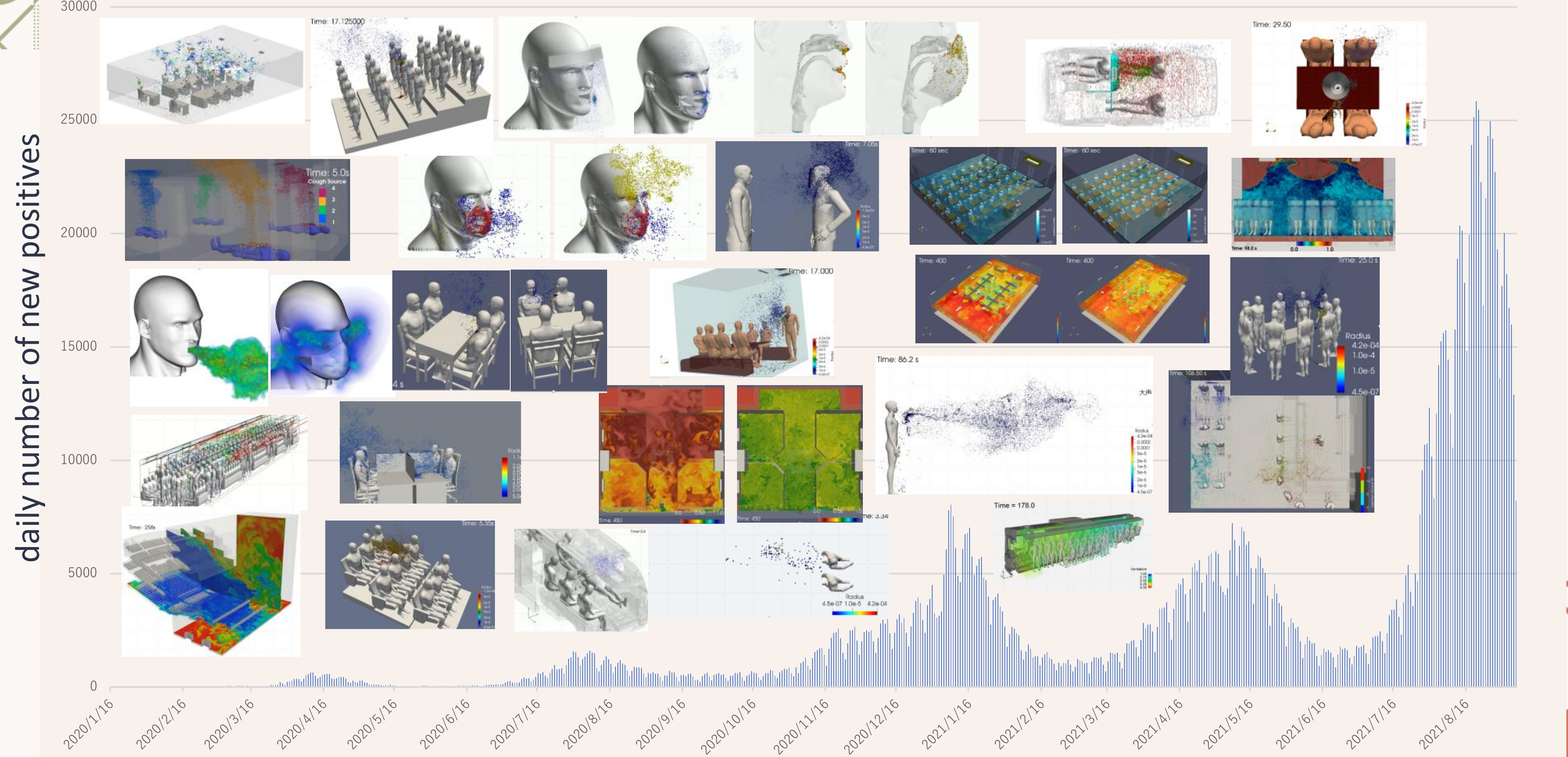






Our 17 months' Fight against COVID-19 on "Fugaku"

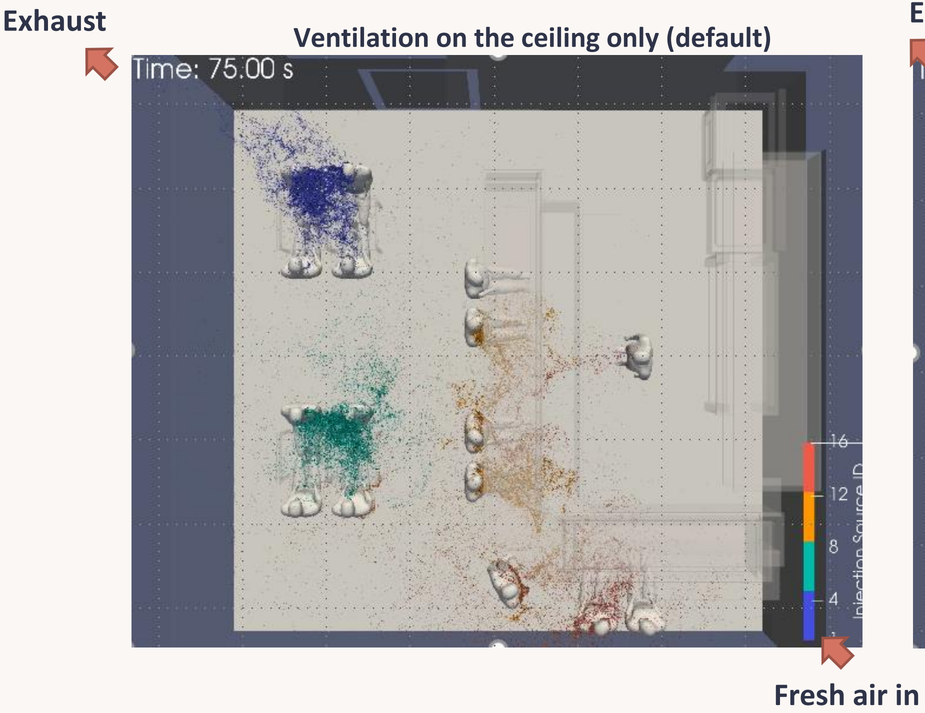
Face masks, public facilities, public transportations…



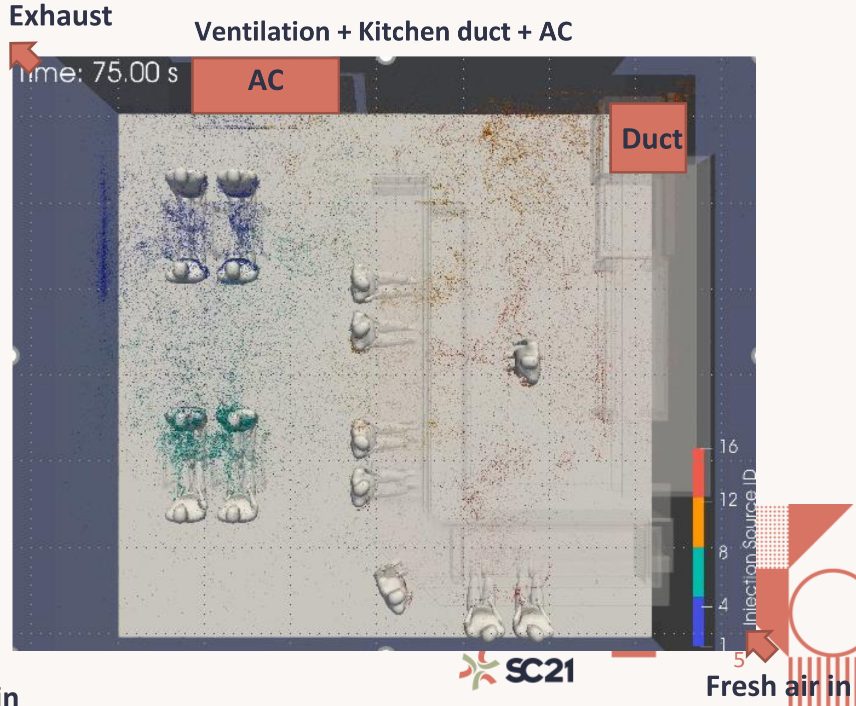
Quantitative Risk Assessment Simulation for Policy and Guideline Making

- Droplet/aerosol dispersion simulation in a Japanese pub restaurant.
- Infection risk assessment and effect of measures in the whole room.

Ventilation on the ceiling only (default)

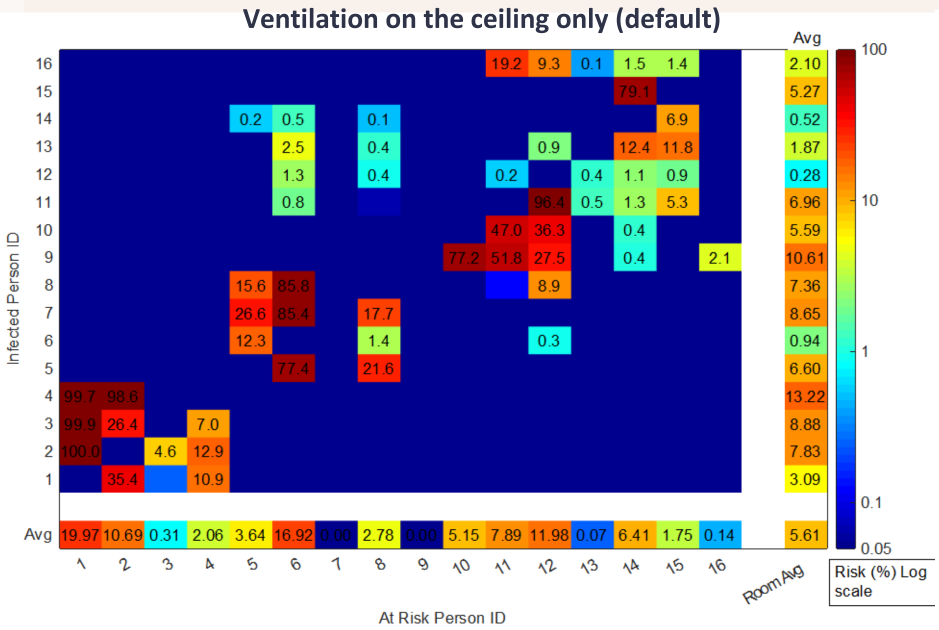


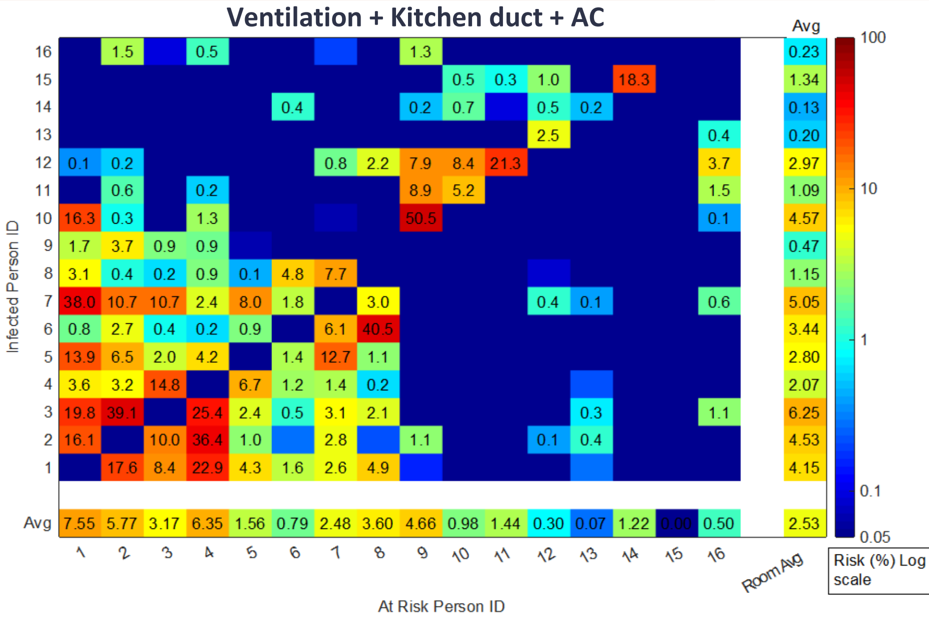
Ventilation + Kitchen duct + AC



Quantitative Risk Assessment Simulation for Policy and Guideline Making

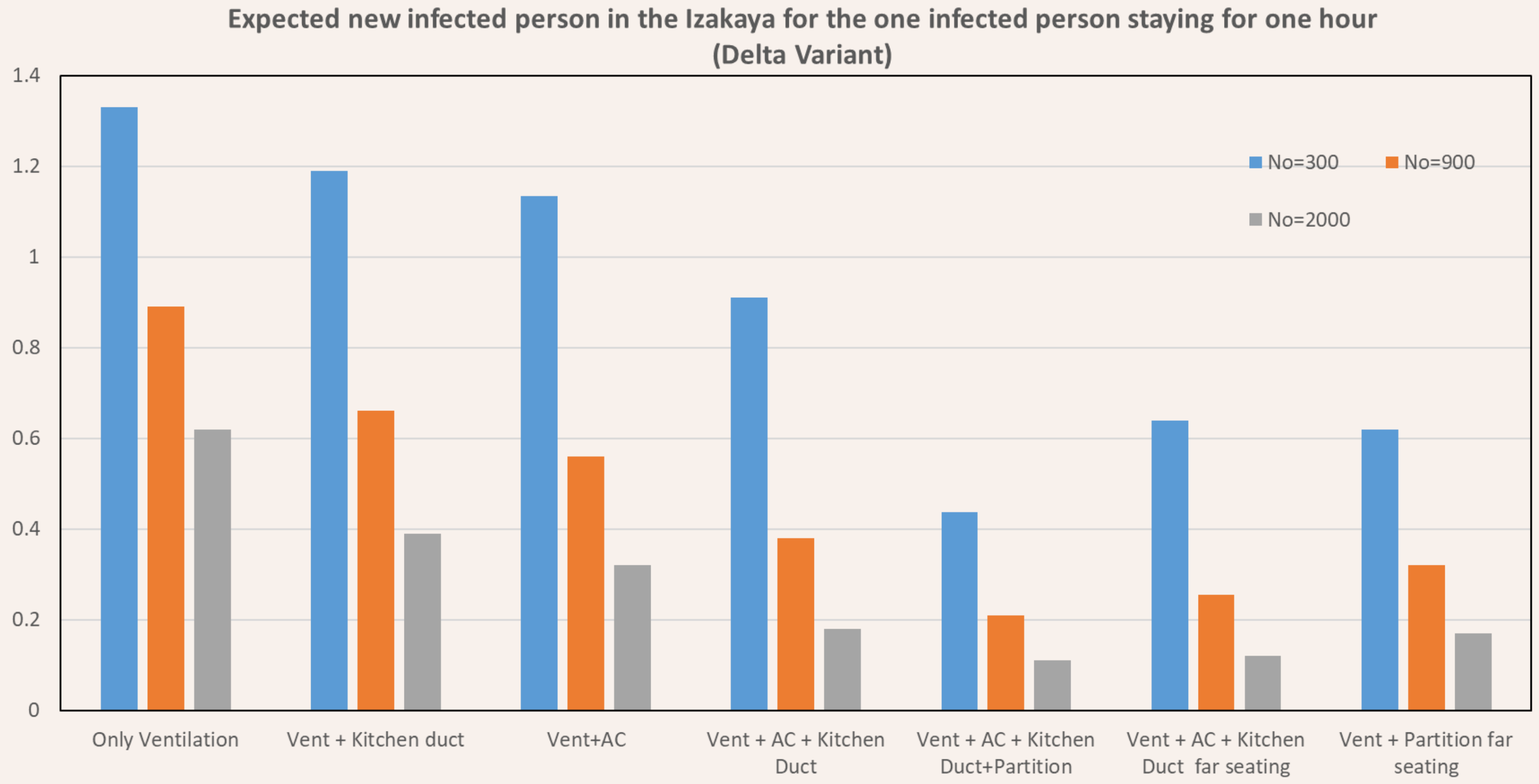
- Infection probability matrix in the room.
  - 1 person infected, staying 1 hour under the loudly speaking condition.
  - Kitchen duct and AC works to diverge the local risk in the room.
  - Risk Reduced by half!





Quantitative Risk Assessment Simulation for Policy and Guideline Making

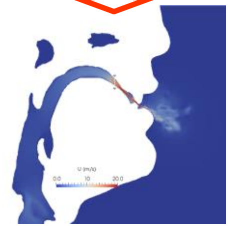
- Quantitative evaluation of effect of measures.

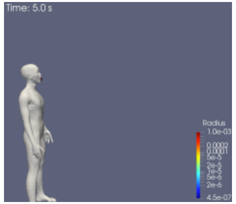


Integrated droplet/aerosol infection risk assessment system

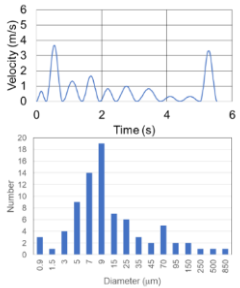
Generation of droplet/aerosol inside human body

Condition of droplet/aerosol generation (breathing, speaking, coughing, sneezing…)



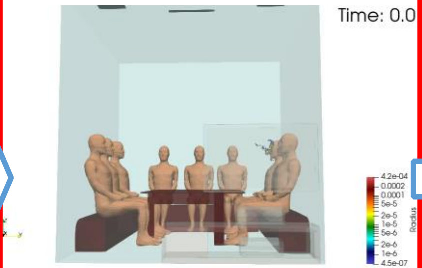


Breath flow rate, droplet size distribution

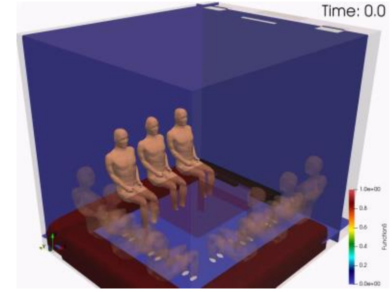


Droplet/aerosol dispersion in indoor environments

Indoor environment and human allocation



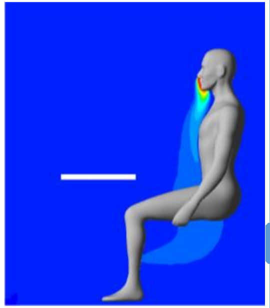
Coupling simulation of droplet/aerosol and indoor flow



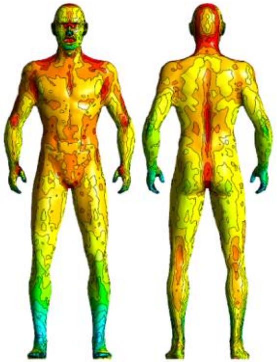
Indoor environment evaluation based on HPC simulation

Numerical human body

Biological information of an at-risk person



Precise reproduction of human breathing

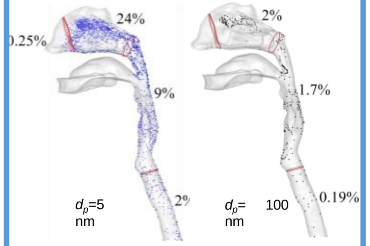


Precise reproduction of body temperature

Numerical respiratory tract

Biological information of an at-risk person

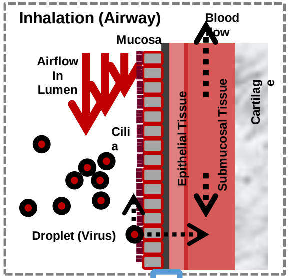
Reproduction of nasal/oral cavity and respiratory tract



Prediction of deposit distribution of droplet/aerosol on the airway surface and its dependence of droplet size.

Infection risk assessment based on the bio-regulation model

Biological information of an at-risk person and target virus



Bioregulation
(Host cells, Pathogen, Adaptive Immune System)

$$\frac{dT_T}{dt} = -\beta_T T_T V - \phi F T_T + \xi R \frac{dR}{dt} \quad \text{(Target Cells)}$$

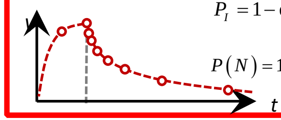
$$\frac{dI}{dt} = \beta_T T_T V - \kappa_F I F - \kappa_E I T_C - \delta_X I \quad \text{(Infected Cells)}$$

$$\frac{dV}{dt} = \beta_E I - \delta_V V - \kappa_V V A \quad \text{(Virus)}$$

$$\frac{dF}{dt} = \beta_F I - \kappa_A F \quad \text{(Interferon)}$$

$$\frac{dT_H}{dt} = \left[\frac{\pi_{H2} D_M}{\pi_{H2} + D_M}\right](1 - T_H / K_H) - \left[\frac{\delta_{H2} D_M}{\delta_{H2} + D_M}\right] T_H \quad \text{(Helper T Cells)}$$

Quantitative evaluation of infection risk



$$P_I = 1 - \exp\left(-\frac{Iqpt}{Q}\right)$$

$$P(N) = 1 - \exp\left(-\frac{N}{N_0}\right)$$