

## 人間・建築を中心とした環境概論7 : 2021/05/23, 13:40-15:10

- 建築関連の空気環境リスク, 特に, COVID-19問題で伝えたいこと

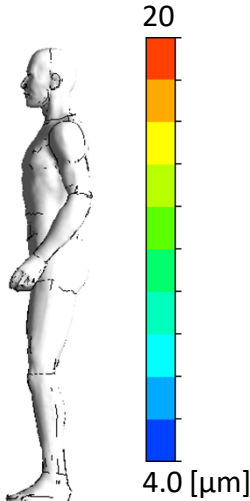
## 飛沫(Droplet)と飛沫核(Droplet Nuclei)

- 飛沫感染: 5 $\mu$ m以上の粒子の飛散に伴う感染
- 飛沫核感染(空気感染): 5 $\mu$ m以下の粒子の飛散に伴う感染
- COVID-19パンデミック以前には、恐らく、**エアロゾル感染**といった医学用語はなかった
  - エアロゾル: 気体中に浮遊する微小な液体または固体の粒子と周囲の気体の混合体

# Droplet Dispersion and Droplet Nuclei Dispersion



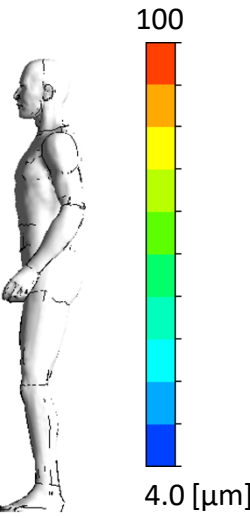
$D_p=20\mu\text{m}$ , constant



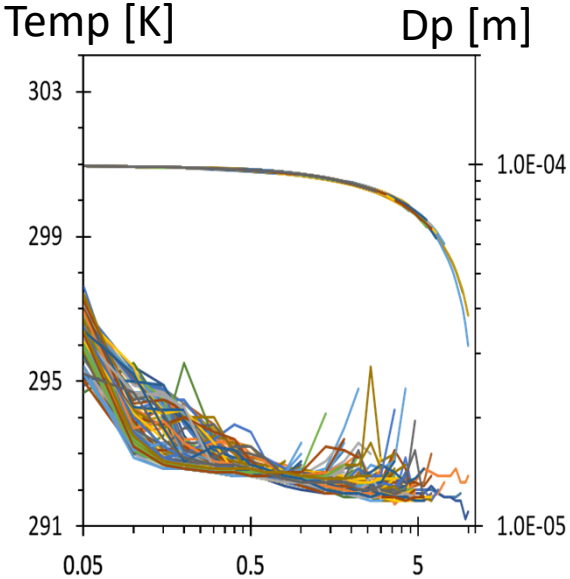
Initial  $D_p=20\mu\text{m}$ , Evaporation



$D_p=100\mu\text{m}$ , constant

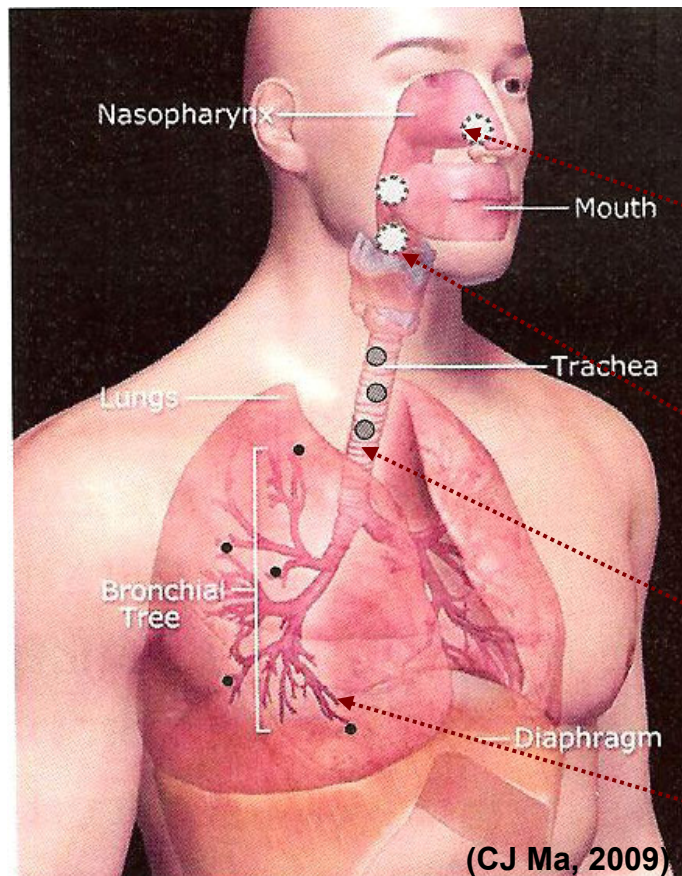


Initial  $D_p=100\mu\text{m}$ , Evaporation



# 呼吸器系の感染防御

粒径別の健康影響: 上気道沈着(数 $\mu\text{m}$ 以上), 肺深部まで侵入(0.1 $\mu\text{m}$ 以下)  
→ アンダーセンサンプラのコンセプト



## 呼吸器の7つの異物除去機構

鼻腔

- (1) 鼻毛
- (2) 鼻腔内の粘膜・線毛
- (3) くしゃみ反射(ハクシヨン!)

咽頭

- (4) Waldeyer(ワルダイエル)咽頭輪  
鼻腔背後と咽頭入口に並ぶ扁桃の輪

気管支

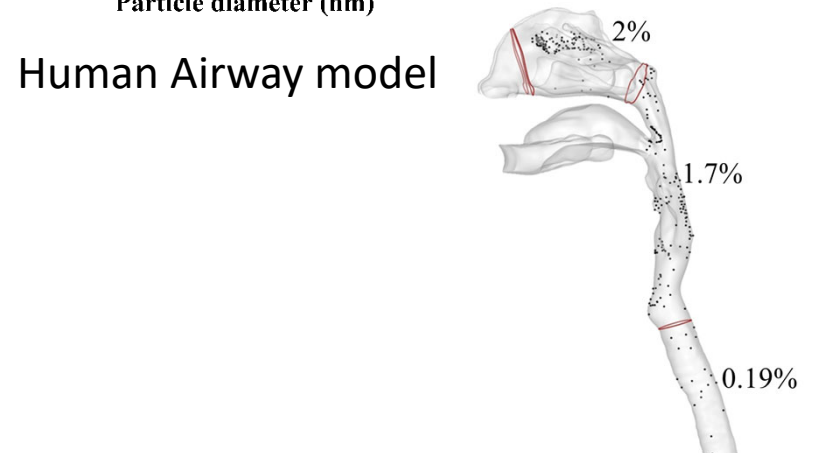
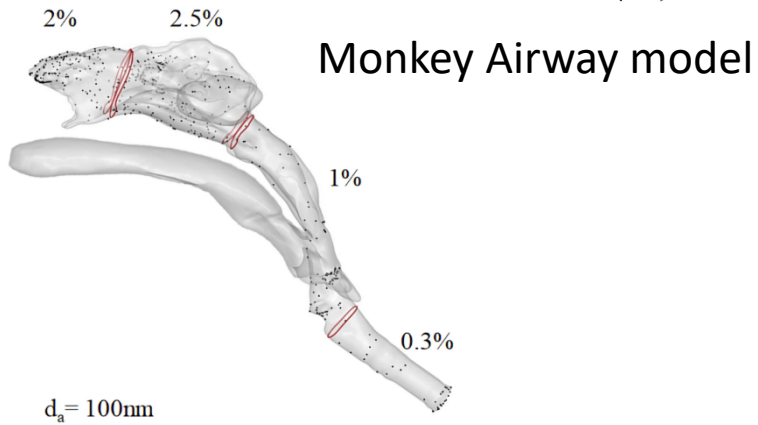
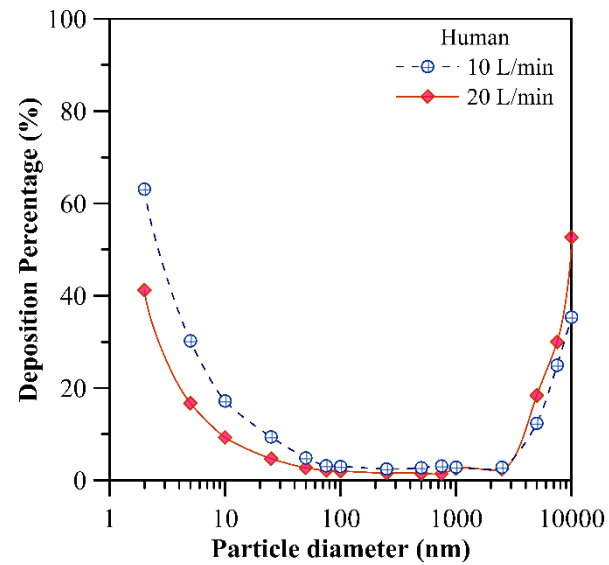
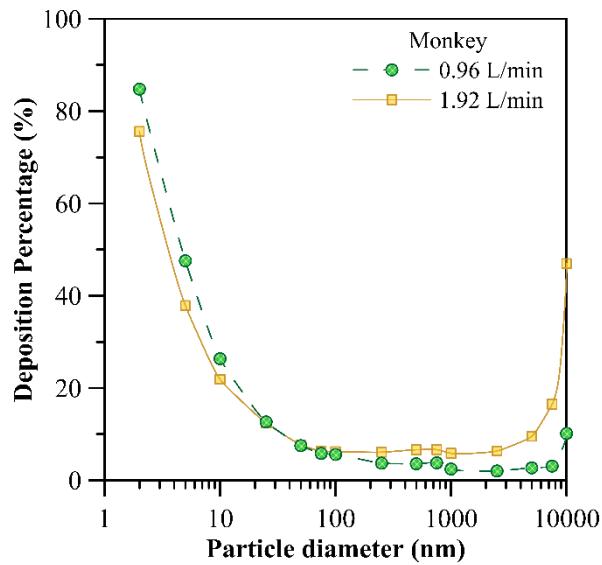
- (5) 気管支の粘液・線毛
- (6) 咳嗽反射(ゴホッ, ゴホッ)  
(がいそう)

肺胞

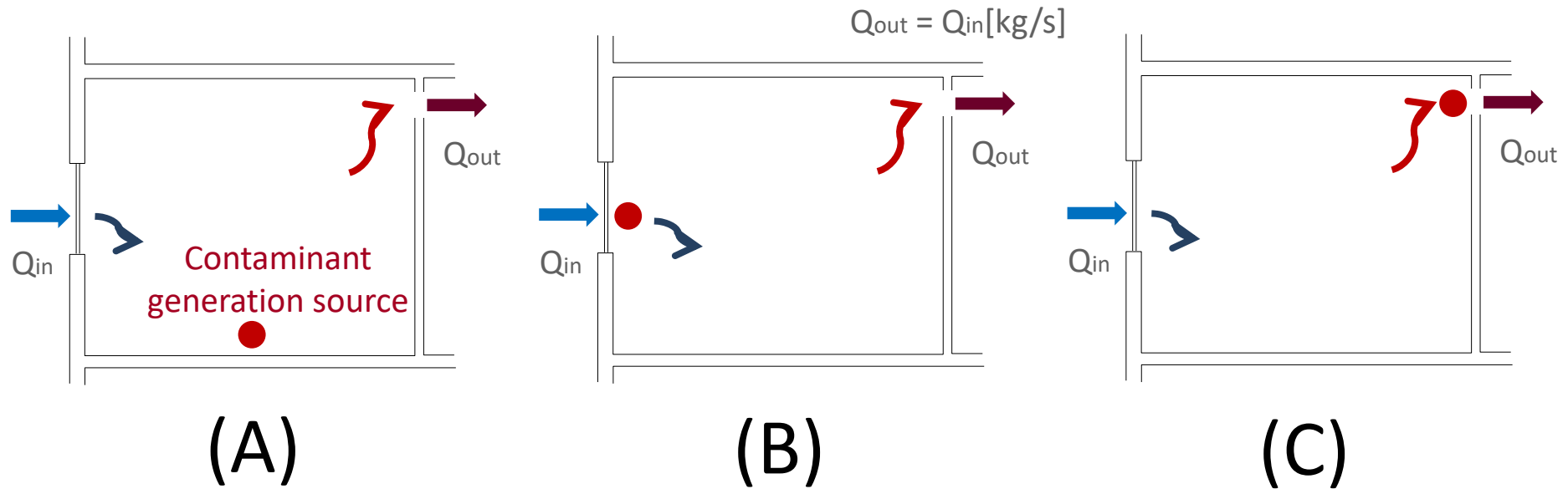
- (7) 肺胞マイクロファージ

# 気道内沈着の粒径依存性

- サルとヒトの上気道内粒子沈着確率  
– ブラウン拡散と重力沈降



# Representative Contaminant Concentration?



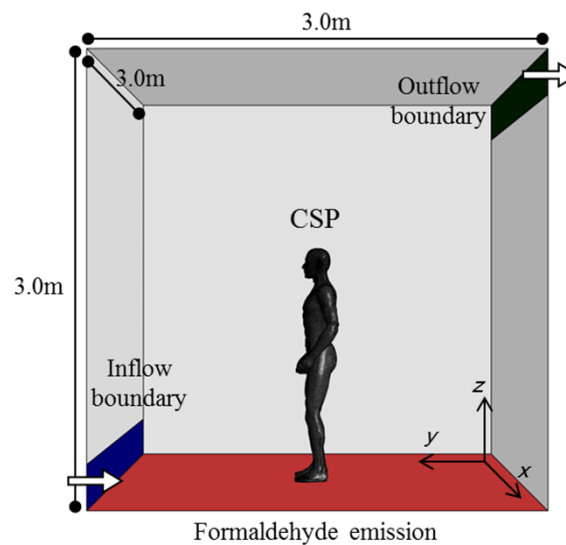
$$C = \frac{q}{Q}$$

Perfect Mix. ( $=q/Q$ )  $\neq$  Volume Averaged Con.  $\neq$  Point Con. at center

# Gas-phase Formaldehyde Concentration Criteria in Indoors

# $100\mu\text{g}/\text{m}^3$

Time-averaged HCHO concentration for 30min at a certain point in a room



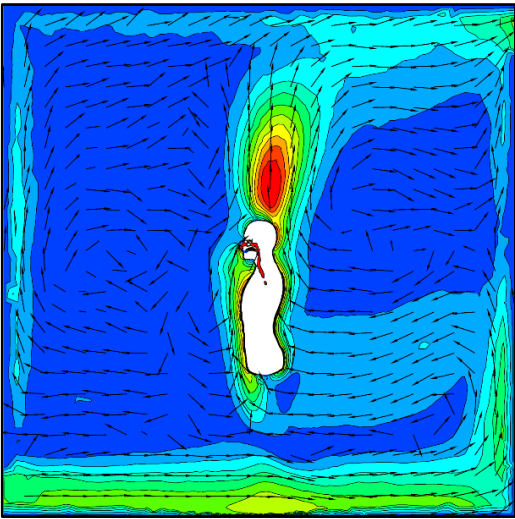
# Heterogeneity / Non-uniformity in Indoor Environmental Quality



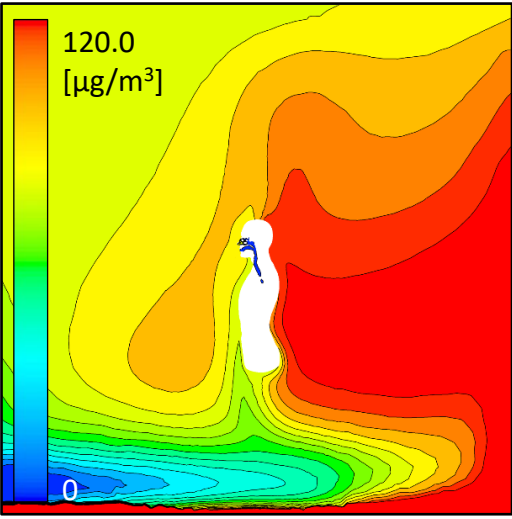
Max. **0.25m/s**

**70%** of air from Floor

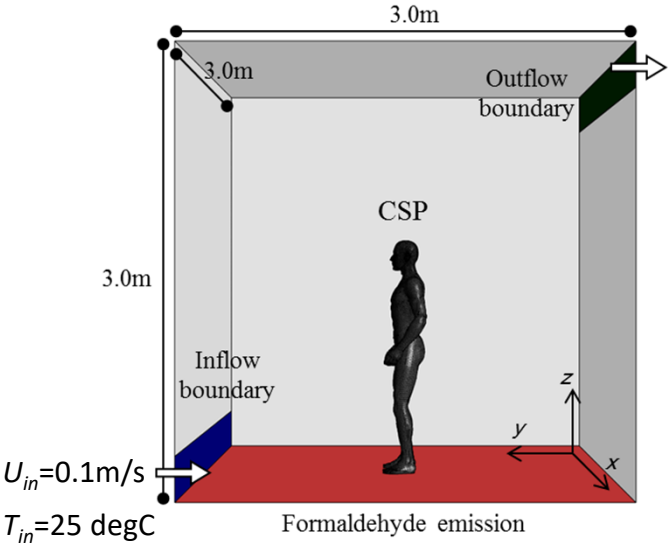
Unsteady Re-breathing region



Velocity distribution

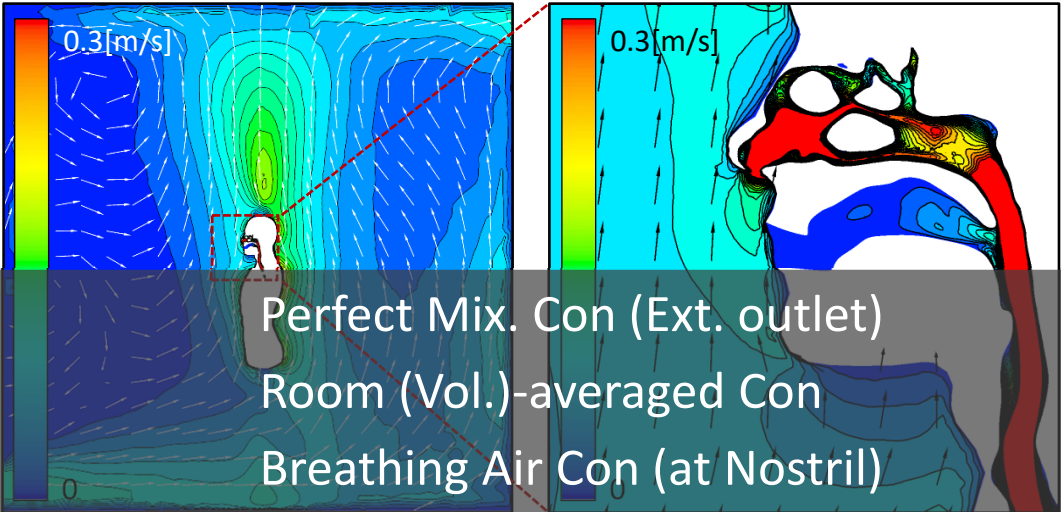


Formaldehyde concentration distribution





# What is the Representative Concentration to Control?

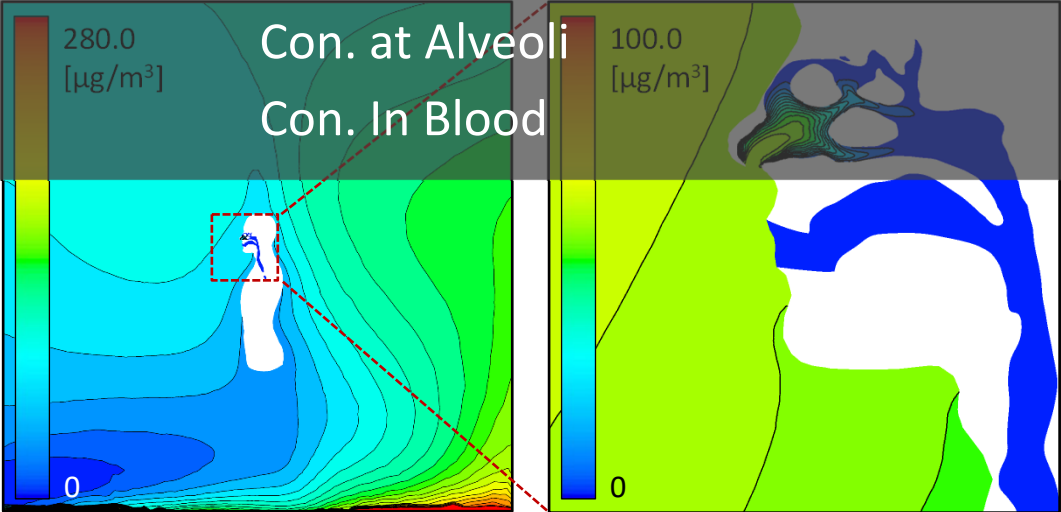


Perfect Mix. Con (Ext. outlet)  
 Room (Vol.)-averaged Con  
 Breathing Air Con (at Nostril)

: 100.0  $\mu\text{g}/\text{m}^3$  (air)  
 : 91.1  $\mu\text{g}/\text{m}^3$  (air)  
 : 62.7  $\mu\text{g}/\text{m}^3$  (air)

Con. at Nasal Mucosal Tissue

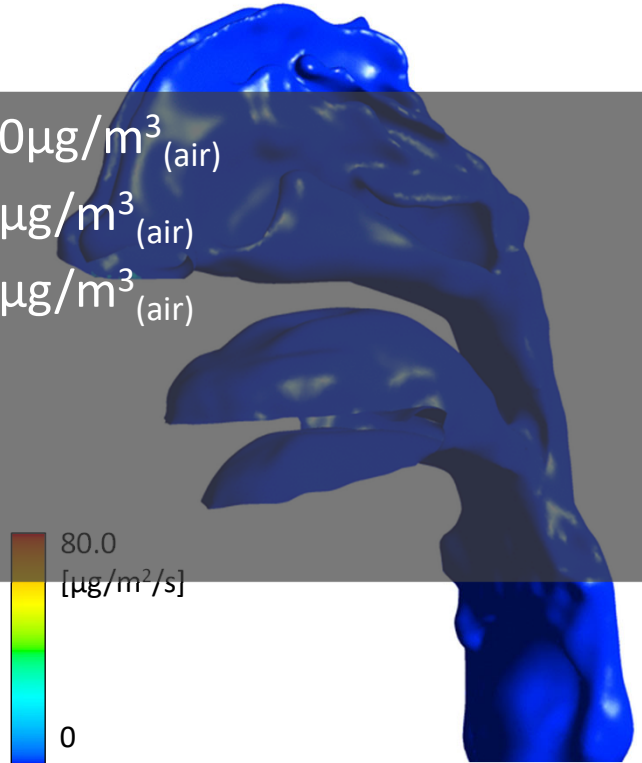
?:  
 ?  
 ?



Con. at Alveoli  
 Con. In Blood

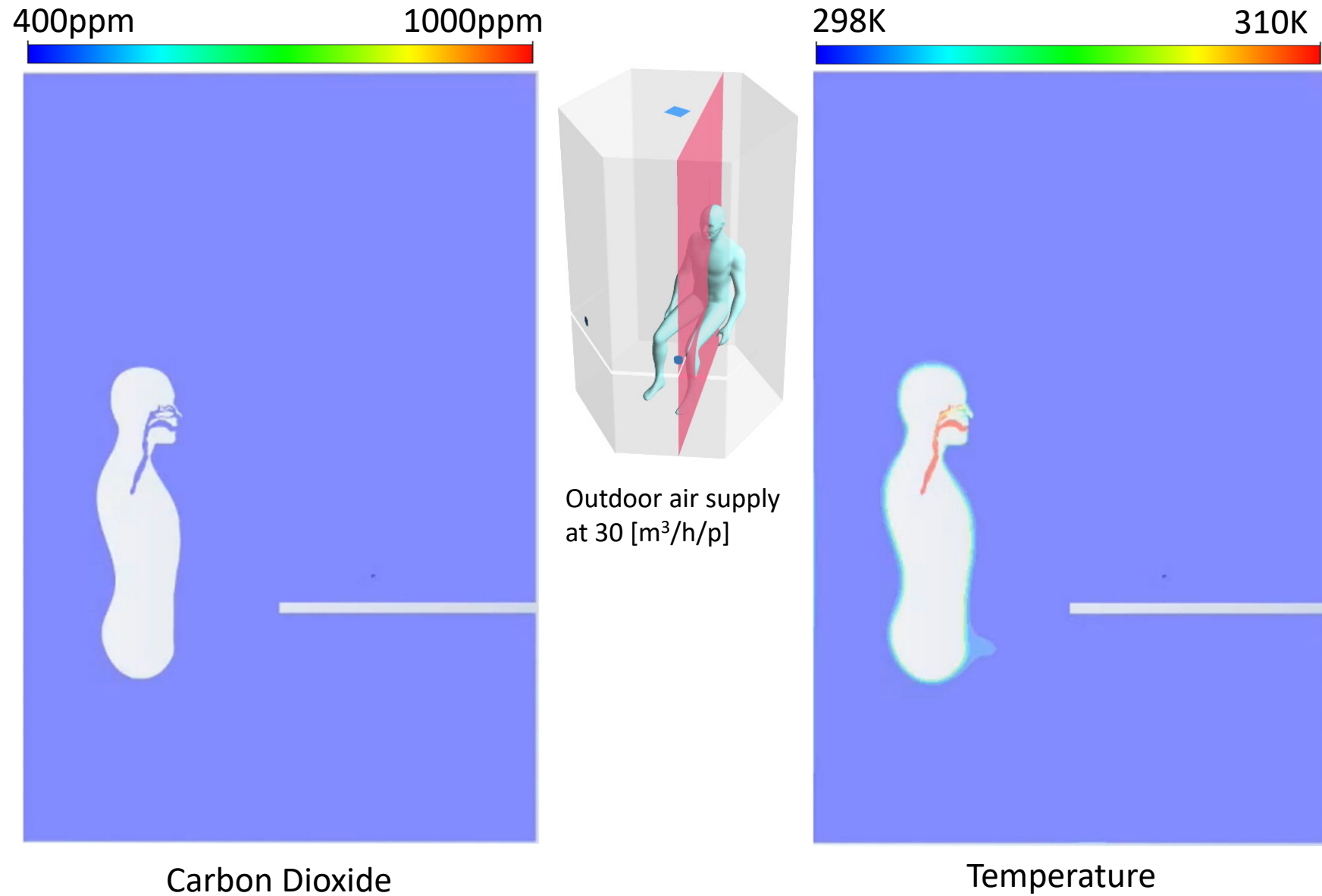
100.0  
 $[\mu\text{g}/\text{m}^3]$

Formaldehyde concentration distribution



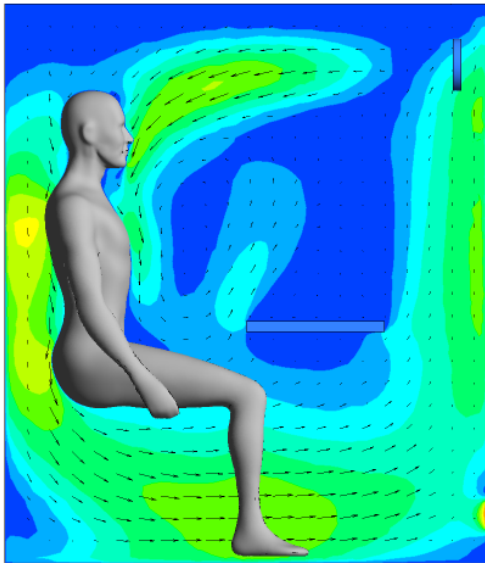
Formaldehyde adsorption flux distribution  
 (1 breathing cycle)

# CO2濃度をセンシングする価値はあるか？

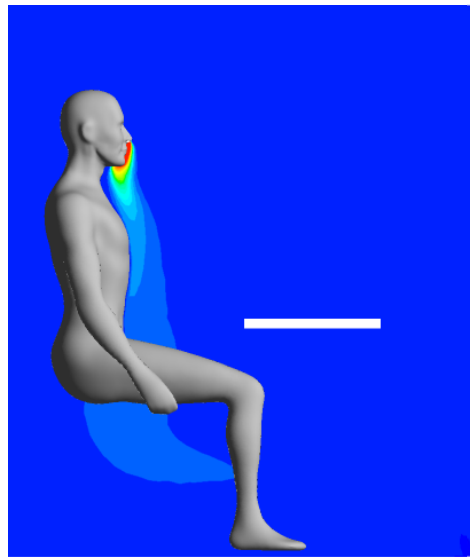


# 呼吸空気の勢力範囲

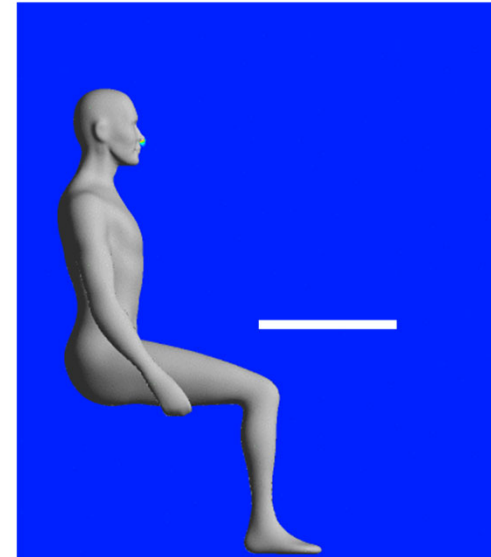
- 鼻呼吸する場合、呼吸する空気は室下部から輸送されてくる



PWE内の流れ場解析結果

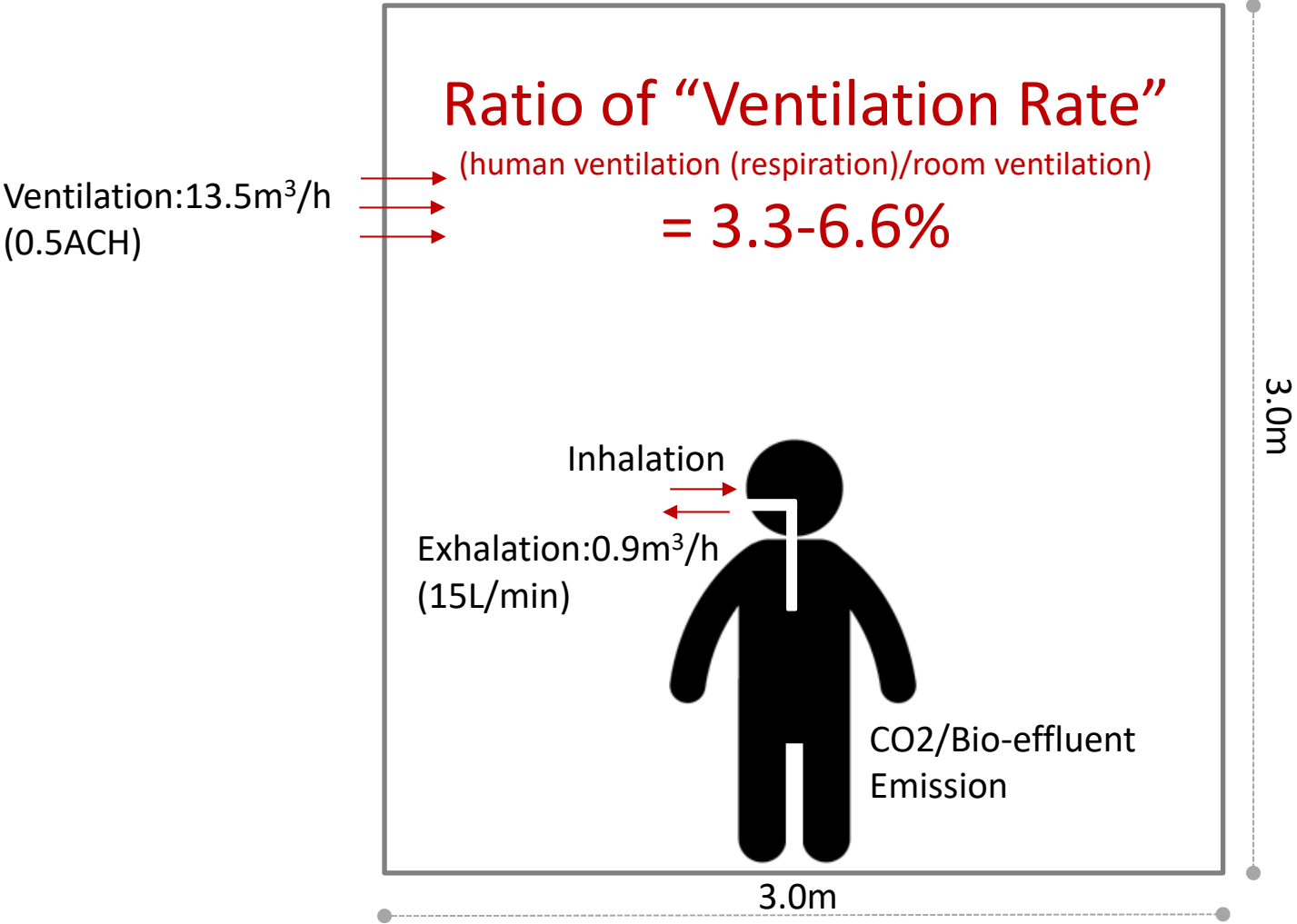


呼吸域勢力範囲(定常解析)



呼吸域勢力範囲(非定常解析)

# Human Body in Indoor Environment (Air Quality)

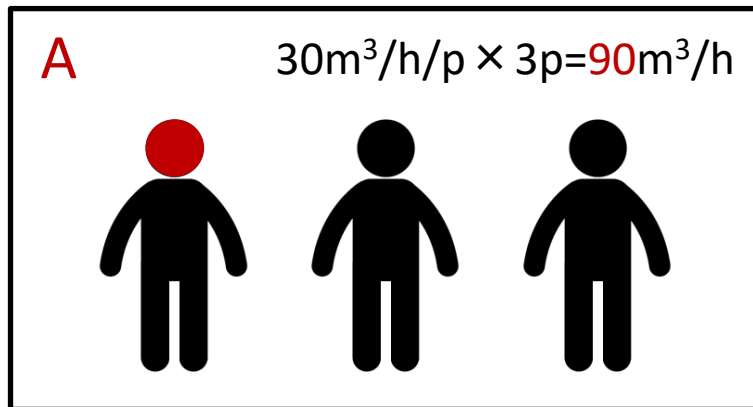


# 法定換気量による濃度制御

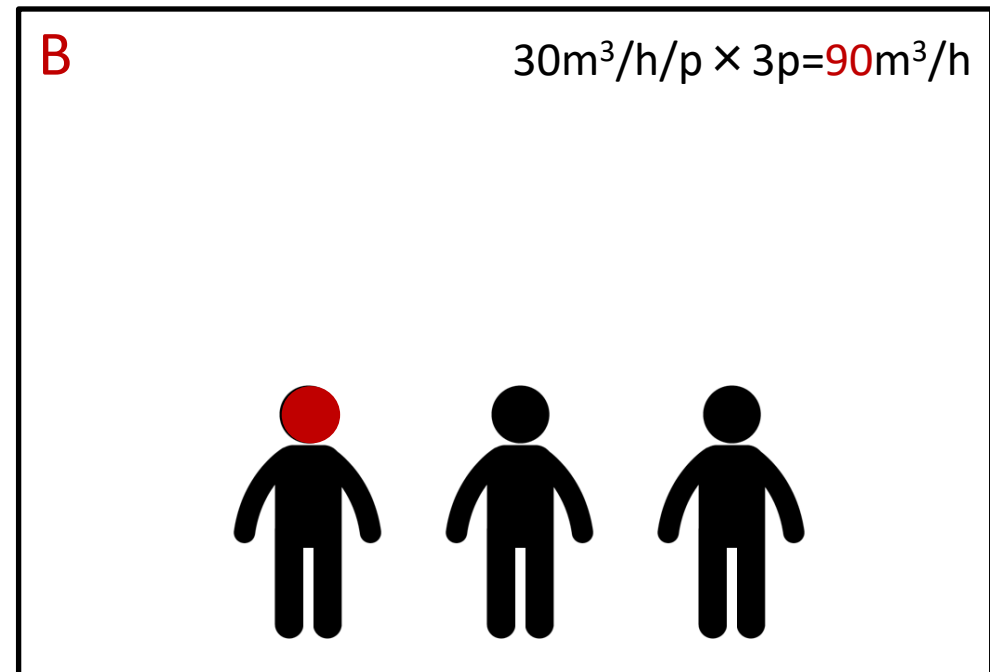
- 建築基準法:  $20\text{m}^3/\text{h}/\text{人}$
- 建築物衛生法:  $30\text{m}^3/\text{h}/\text{人}$

室内完全混合濃度:  $C = \frac{q}{Q}$

- 在室者数と感染者数が比例する場合
- 床面積に関わらず在室者数が一定の場合



Floor Area:  $30\text{m}^3$

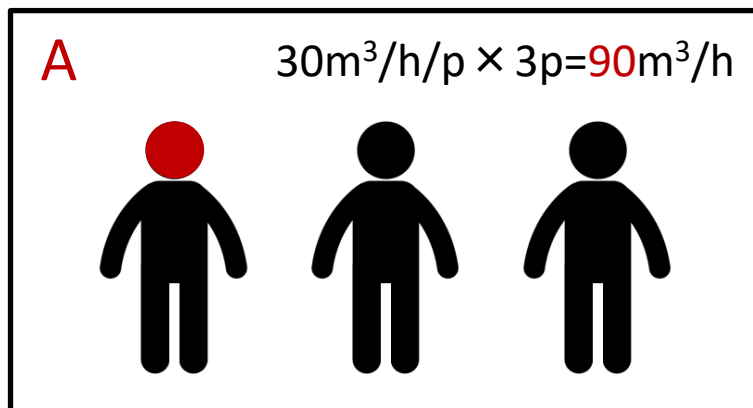


Floor Area:  $60\text{m}^3$

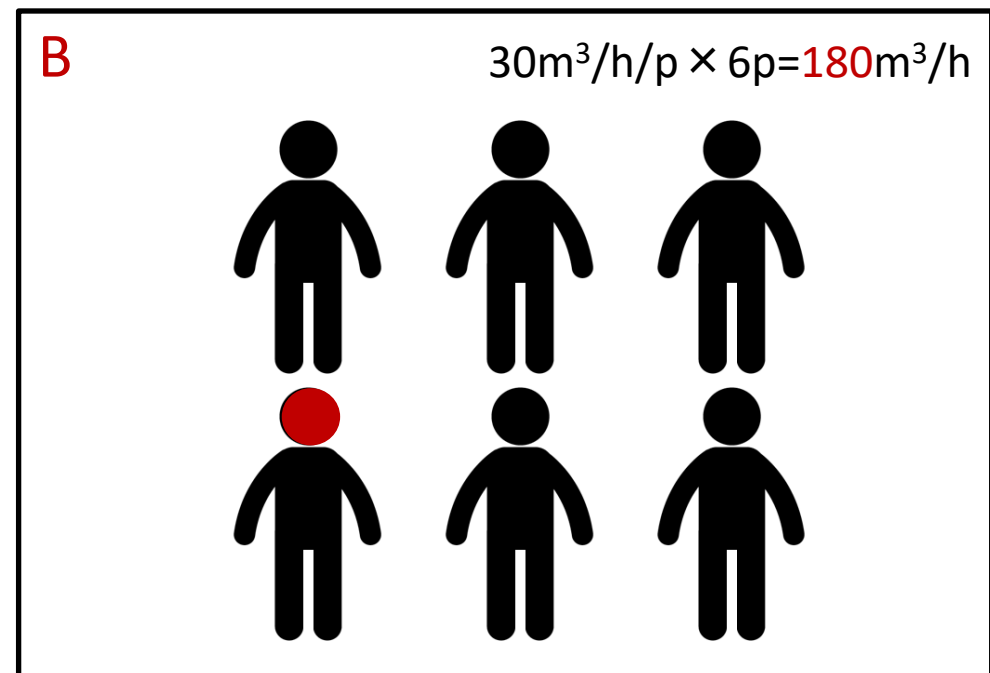
# 法定換気量による濃度制御

- 建築基準法:  $20\text{m}^3/\text{h}/\text{人}$
- 建築物衛生法:  $30\text{m}^3/\text{h}/\text{人}$
- 例えば, 感染者数が1の場合
- 床面積と在室者数が比例する場合

室内完全混合濃度:  $C = \frac{q}{Q}$



Floor Area:  $30\text{m}^2$



Floor Area:  $60\text{m}^2$

## Contact Probability

$$\frac{32,461}{5,110,000} = 0.00276 = 0.6\%$$

1

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# SIR型疫学モデルとWells-Rileyモデル

## SIR (KM) model

Susceptible

$$\frac{dS}{dt} = -\beta SI \quad (1)$$

Infective

$$\frac{dI}{dt} = -\gamma I + \beta SI \quad (2)$$

Recovered

$$\frac{dR}{dt} = \gamma I \quad (3)$$

Basic Reproduction number

$$R_o = \frac{\beta}{\gamma} S_0 \quad (4)$$

$$S_0 + I_0 = S + I$$

$\beta$ : contact rate,  $\gamma$ : recover rate

## Wells-Riley model

$$P_I = \frac{C}{S} = 1 - \exp\left(-\frac{Iqpt}{Q}\right) \quad (5)$$

感染初期で  $I = \text{const.}$ ,  $\gamma = 0$  を仮定

$$S = S_0 \exp(-\beta It)$$

$$I - I_0 = S_0 - S_0 \exp(-\beta It)$$

$$P_I = \frac{I - I_0}{S_0} = 1 - \exp(-\beta It)$$

$$\beta = p \underbrace{\frac{q}{Q}}_{\text{濃度次元}} \quad (6)$$

$P_I$ : 感染確率[-]  
 $I$ : 感染者数[person]  
 $C$ : 新たな感染者数[person]  
 $p$ : 呼吸量[m<sup>3</sup>/s]  
 $Q$ : 換気量[m<sup>3</sup>/s]  
 $q$ : quanta 発生量[quanta/s]  
 $t$ : 曝露時間[s]



# Preliminary Calculation by Wells-Riley model

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

$P_I$  : 感染確率[-]  
 $I$  : 感染者数[person]  
 $p$  : 呼吸量[m<sup>3</sup>/h]  
 $Q$  : 換気量[m<sup>3</sup>/h]  
 $q$  : **quanta** 発生量[quanta/h/person]  
 $t$  : 曝露時間[h]

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

Inhalation Dose:  $pC_{res}$

$$P_I = 1 - \exp\left(-\frac{p}{Q} Iqt\right) = 1 - \exp(-\varepsilon q't)$$

$$\text{Dilution Efficiency: } \varepsilon = \frac{p}{Q} = \frac{0.5}{30} = \frac{1}{60}$$

# Preliminary Calculation by Wells-Riley model

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

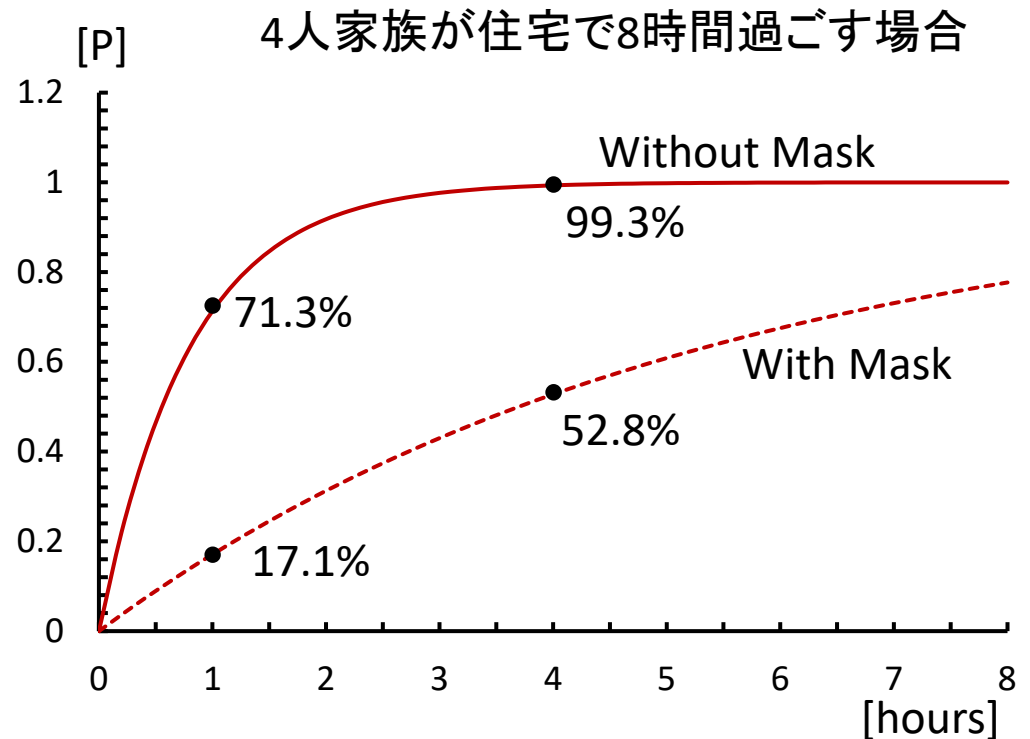
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- $I=1$  [person]
- $p=0.5$  [ $\text{m}^3/\text{h}$ ]
- $Q=30$  [ $\text{m}^3/\text{h}/\text{person}$ ]  $\times$  residents [person]

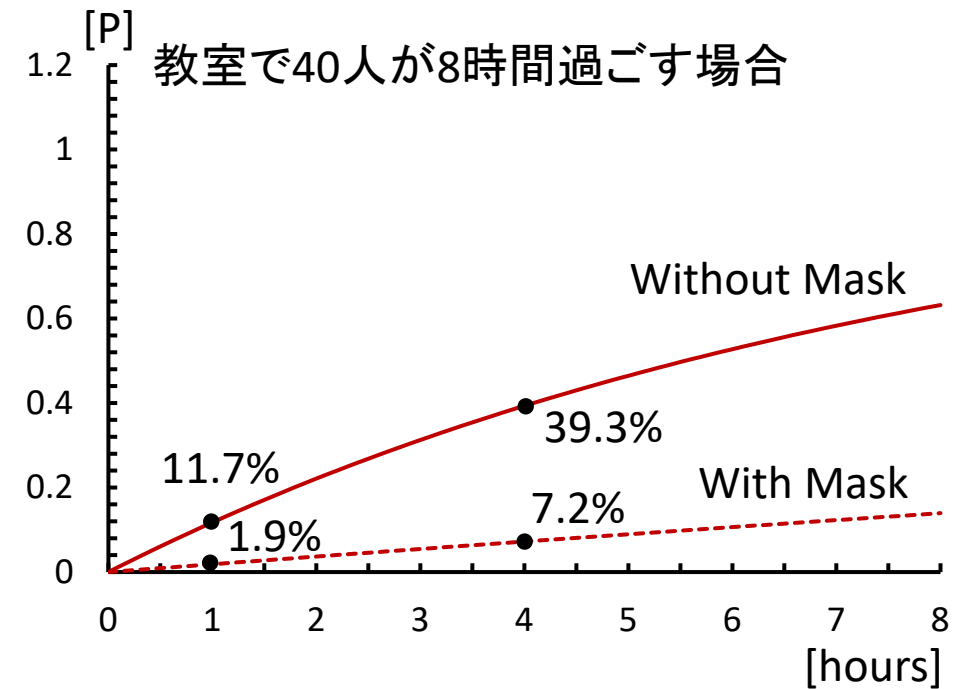
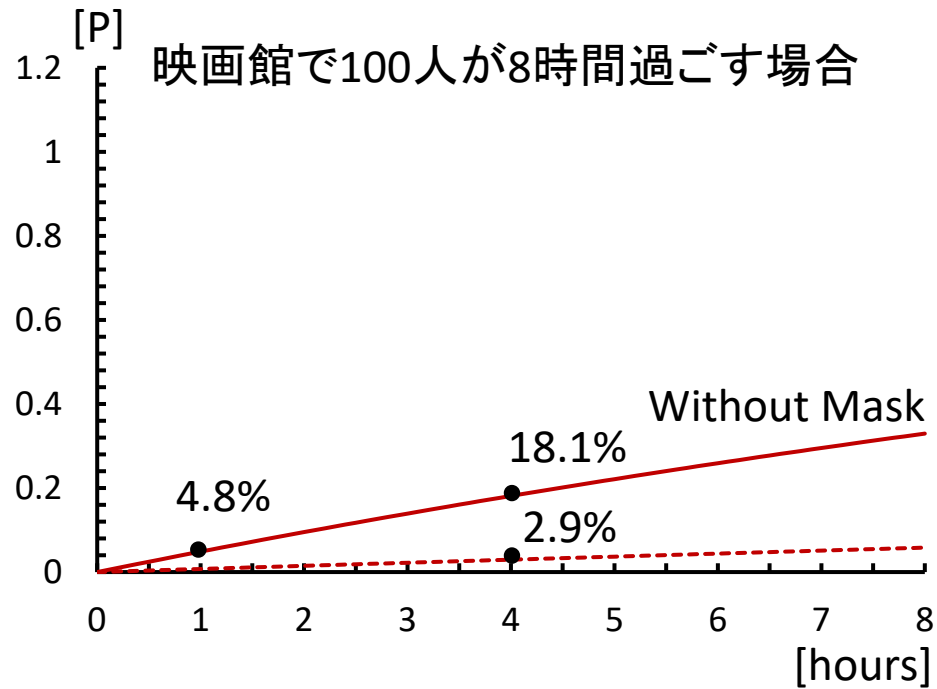
1 quanta = 1,000 viral RNA Copies

(Super Spreader/Emitter)

SARS-CoV-2: **300 - 2000** quanta/h  
(Mara Prentiss et al, 2020)



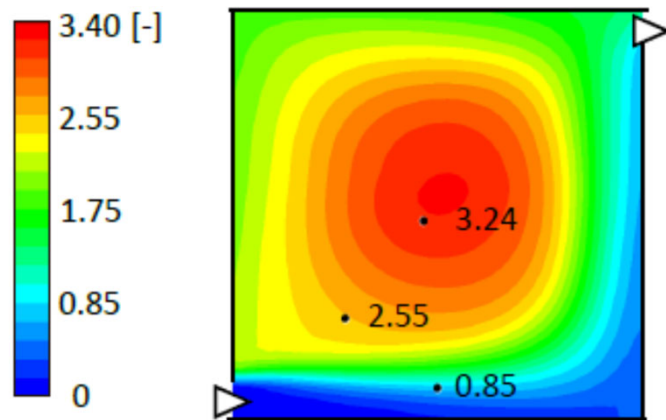
# Cluster Events by Super Spreader/Emitter



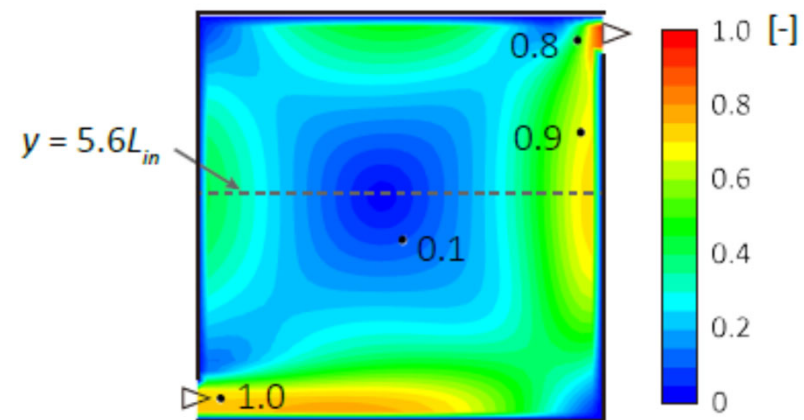
$$P_I = 1 - \exp\left(-\frac{Iqpt}{Q}\right) = 1 - \exp(-pC_{res} \cdot t)$$

# 全体換気と局所換気

- 室内は瞬時一様拡散，感染混合か？
- 清浄空気の供給か，発生汚染物質の効率的な排出か？
- 汚染源は特定できているか？

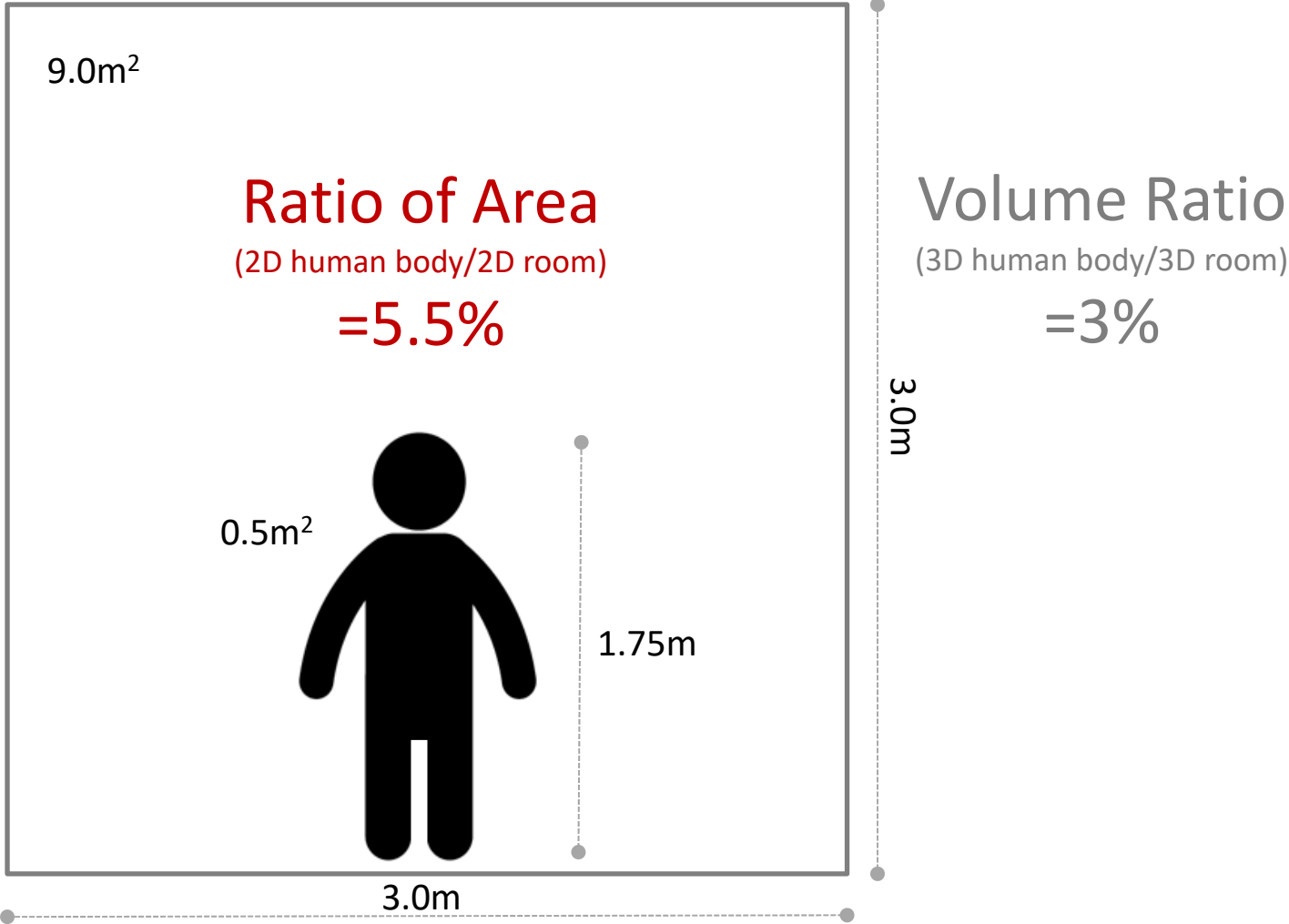


Age of air distribution



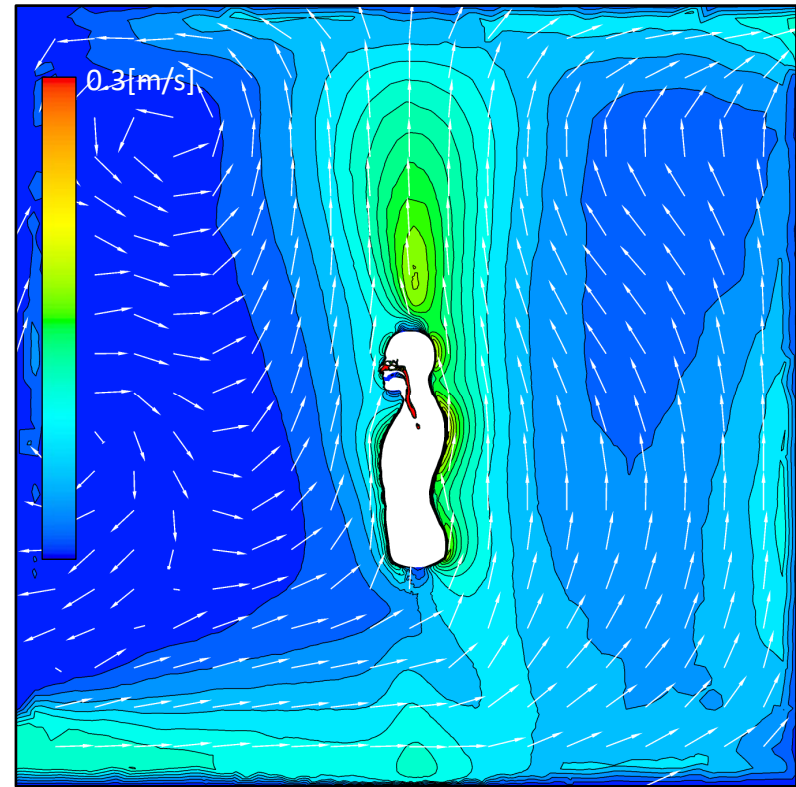
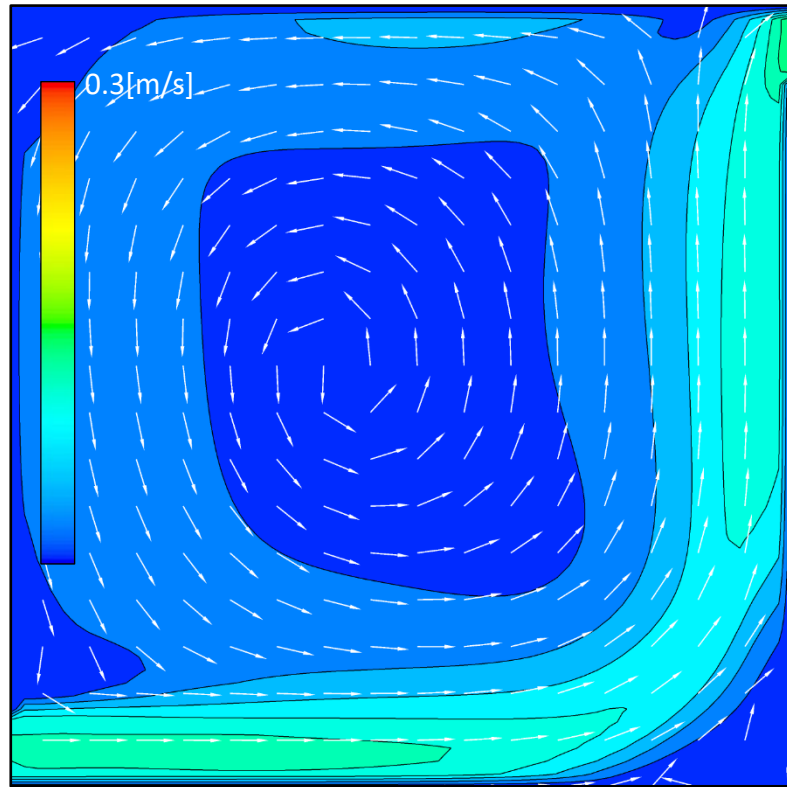
Scalar velocity distribution

# Human Body in Indoor Environment (Air flow)



Reproduction of human body geometry is essentially important for detailed analysis of indoor air flow (and vice versa)

# Impact of Human body on Indoor Air Flow



Flow pattern in displacement ventilated indoor environment with/without human body

## 飛沫・飛沫核による感染伝播に換気制御は有効か

- COVID-19対策として換気規準  $30\text{m}^3/\text{h}/\text{person}$  を目安とするならば、換気が出ることは、汚染物質発生量の  $1/60 \sim 1/30$  希釈
- 室内には平均濃度の3倍以上の高濃度領域が存在、希釈効率にも明確な不均一性あり
- SARS-CoV-2の詳細感染メカニズムが不明であれば、(化学物質曝露を参考にして)有害性評価の閾値無しモデルのVSD (Virtually Safe Dose: 実質安全率), 即ち、発生量の  $1/100,000$  希釈が一定の目安