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Influence of ventilation and room air movement on formation and growth of 1-20 nm particles via ozone-human chemistry

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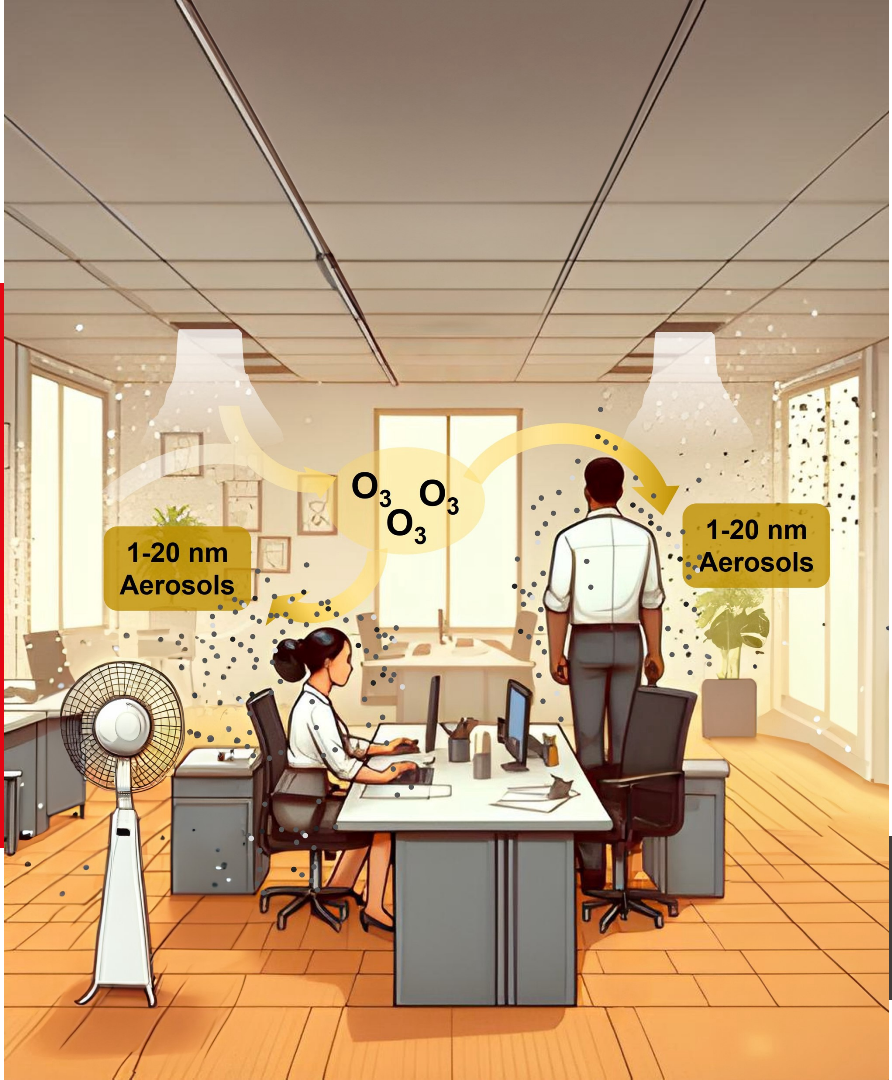

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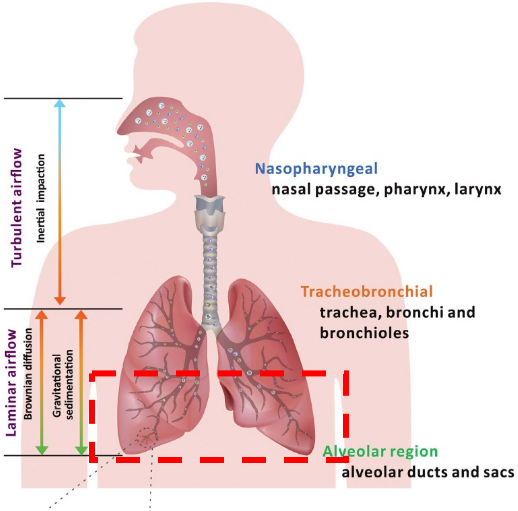
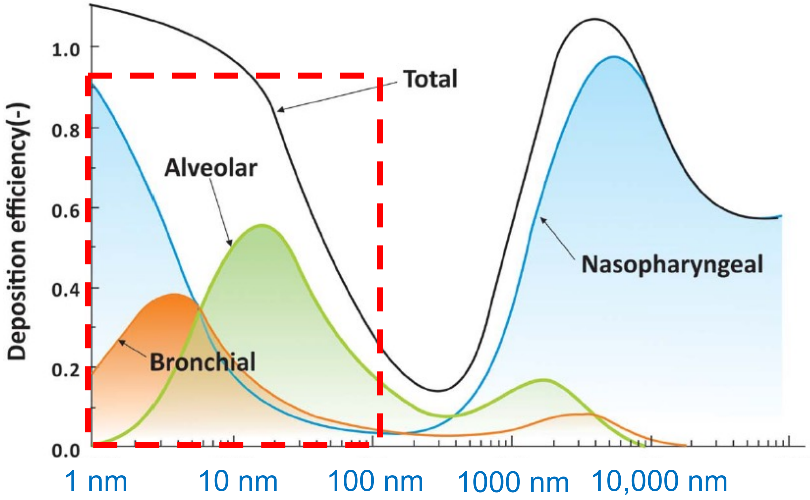
Why are indoor ultrafine particles important?

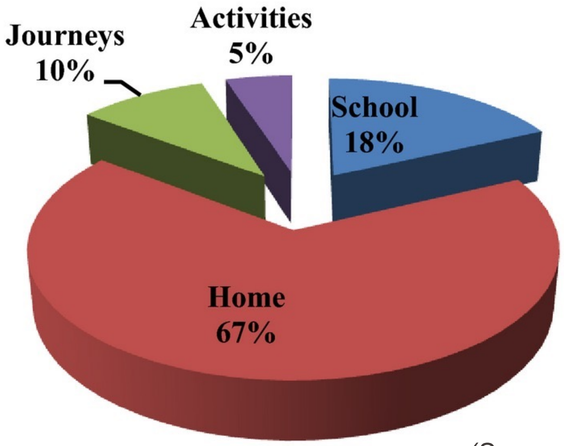
- Inhaling UFP poses health risks
- UFP can deposit throughout the respiratory tract
  - Non-linear dependence on particle size
- Translocation from the deposition site to other locations in the body





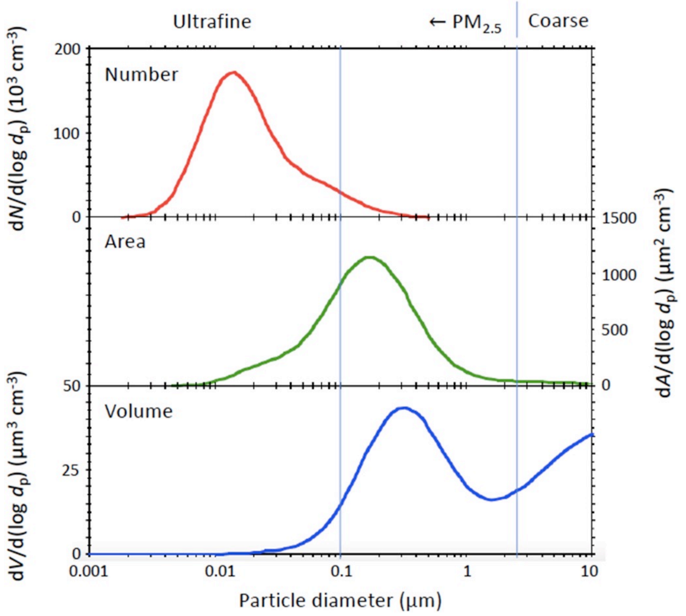
Indoor ultrafine particles characteristics

- UFP dominates number concentration (99%)
  - UFP: Typical number conc. ~10’000 particles/cm^3
  - $PM_{2.5}$: Typical number conc. for 10 µg/m^3 (assuming d=0.5 µm, ρ=1 g/cm^3) ~150 particles/cm^3
- Most UFP exposure occurs indoors
- Building factors influence exposures



Total UFP exposure in Paris schoolchildren

(Source: Paunescu et al., Indoor Air 2017)

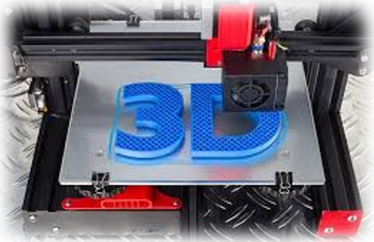


(Source: Nazaroff, Building and Environ. 2023)

Sources of indoor ultrafine particles

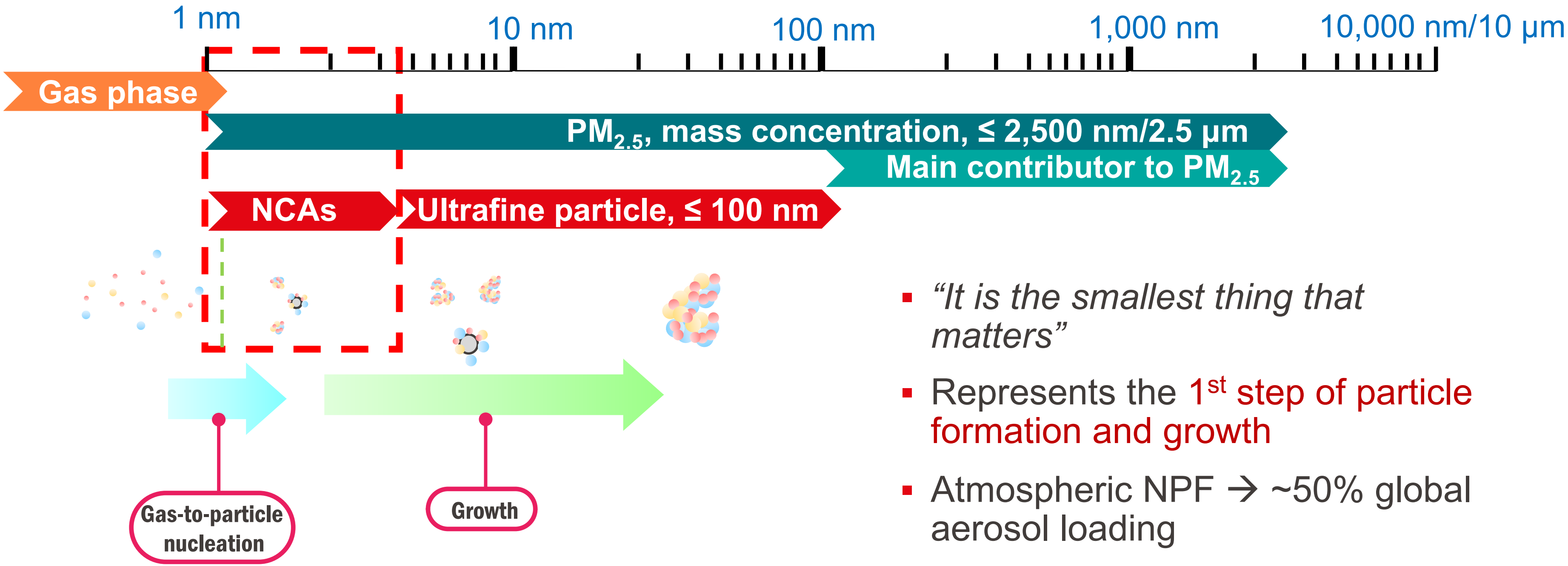
COMBUSTION

HEATING PROCESSES



CHEMISTRY

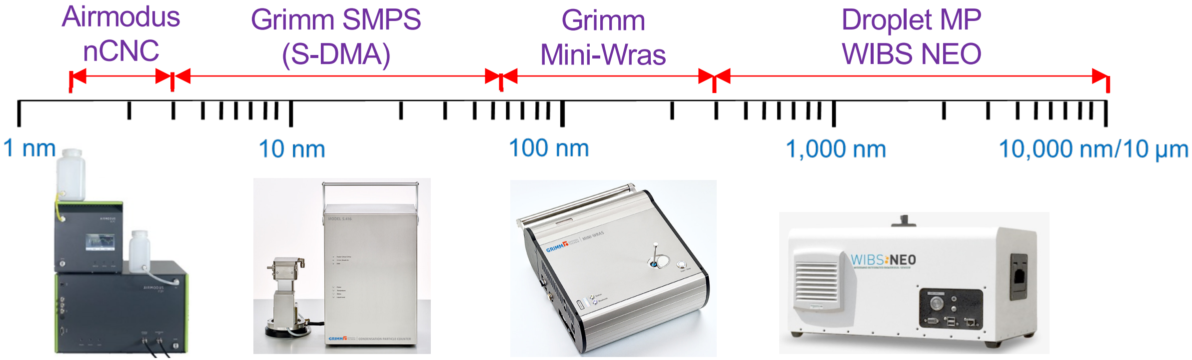
Nanocluster aerosols (NCA)



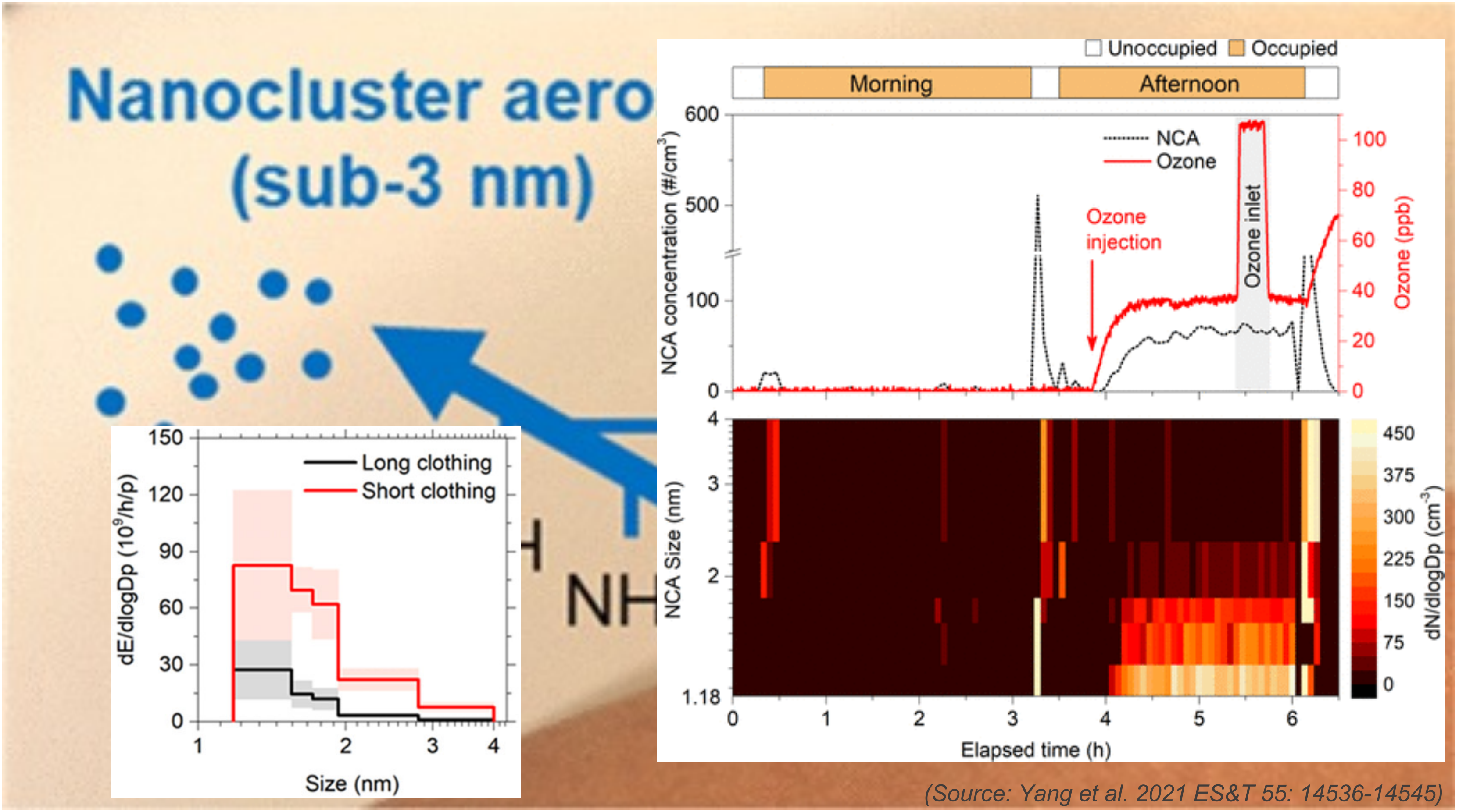
- *"It is the smallest thing that matters"*
- Represents the 1st step of particle formation and growth
- Atmospheric NPF → ~50% global aerosol loading
- Unknown but expectedly adverse health impact on humans

ICHEAR: Human chemical and aerosol emissions

(Beko et al. 2020 Indoor Air; Yang et al. 2021 ES&T)

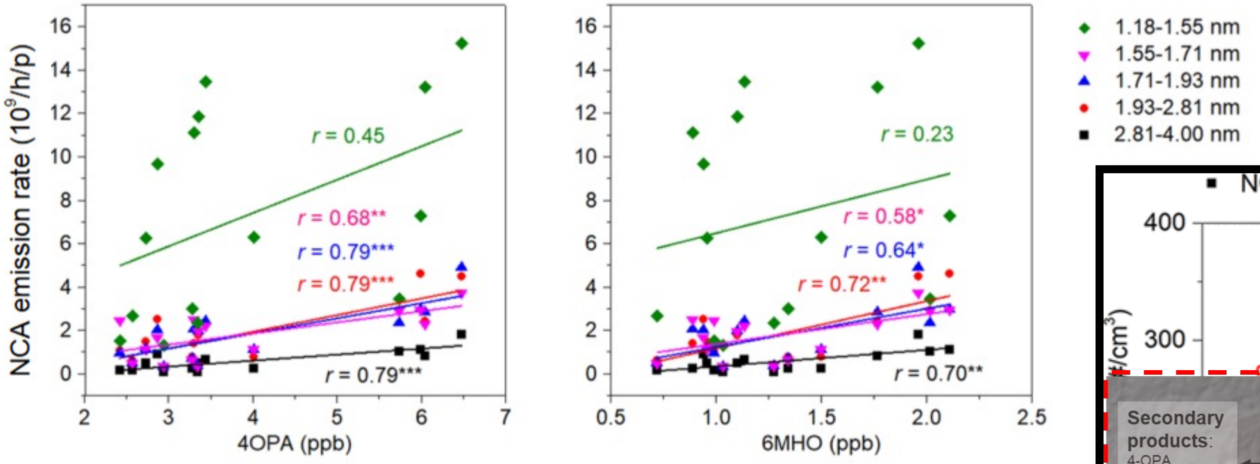


Ozone initiates human-derived emission of NCA

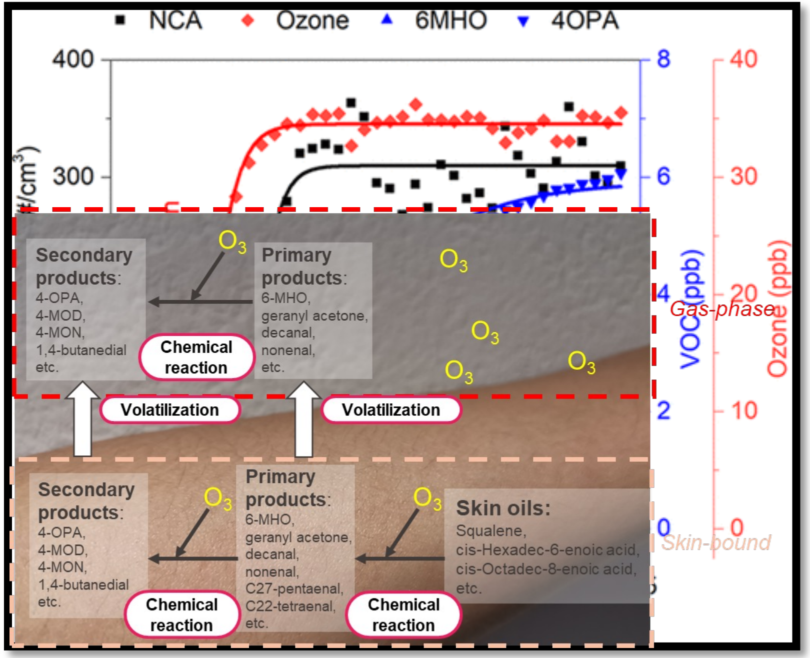


(Source: Yang et al. 2021 ES&T 55: 14536-14545)

Positive correlation with ozonolysis products of skin

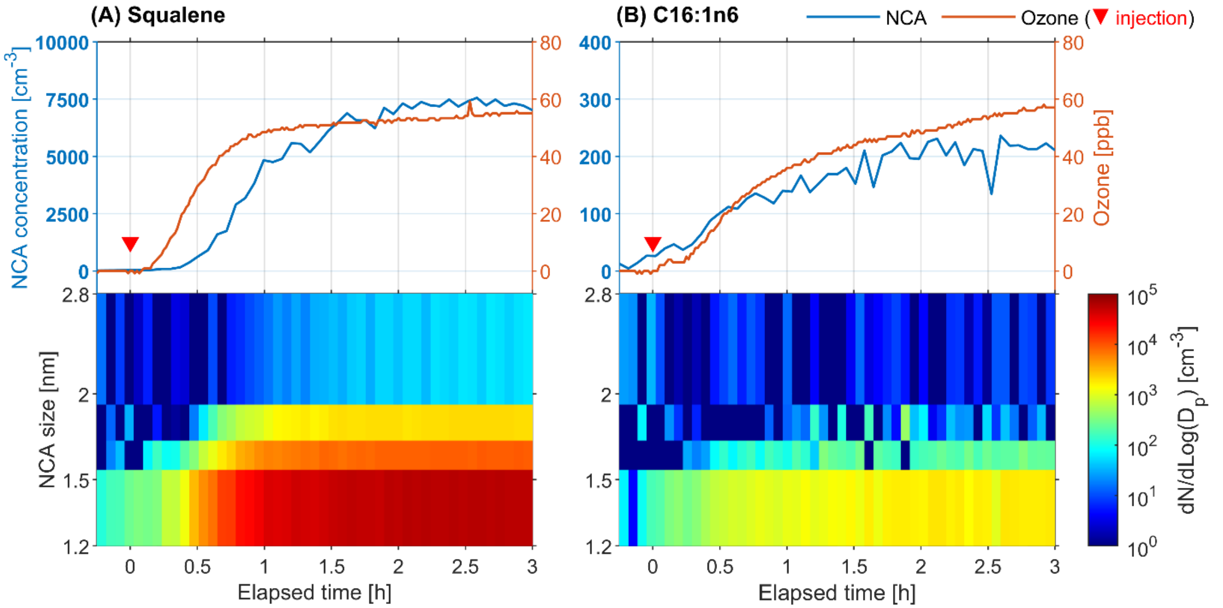


Pearson correlations between steady-state concentrations of selected organic compounds (4OPA, 6MHO) and size-resolved NCA emissions



(Source: Yang et al. 2021 ES&T 55: 14536-14545)

Ozone-squalene & -fatty acid reaction *

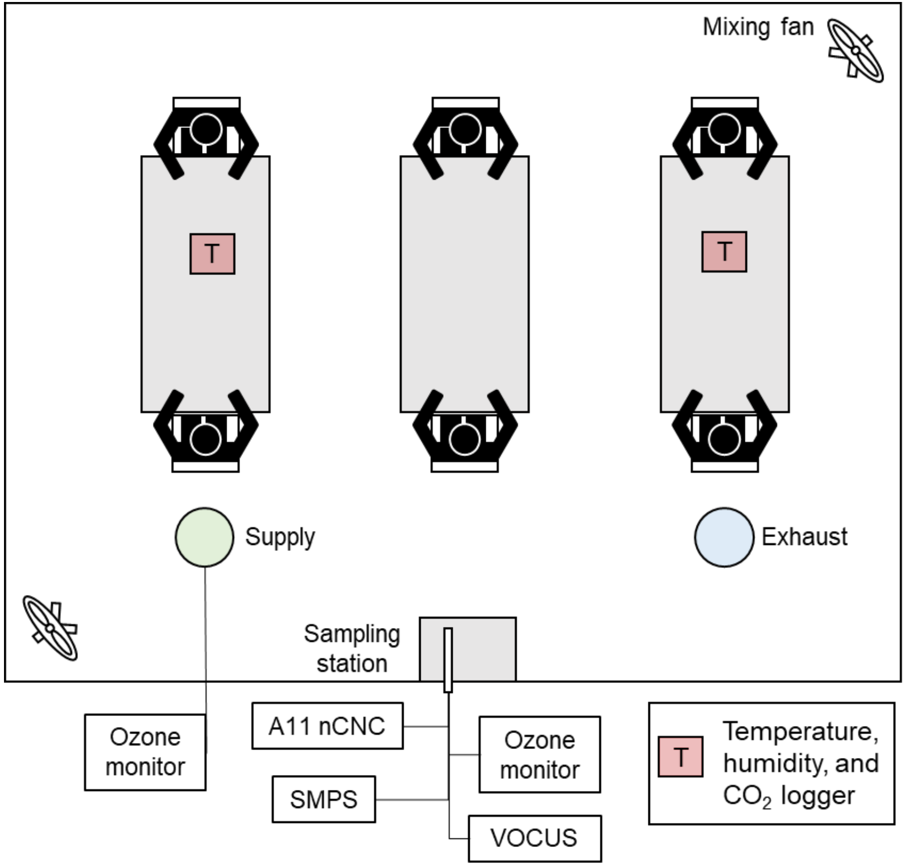


With a typical ratio of amount in human skin lipids (4:1), squalene generated 40 times more NCAs than 6-hexadecenoic acid (C16:1n6), and thus dominated the NCA formation during ozone-human chemistry

** Dr. Shen Yang presented a posted on this topic yesterday; please contact him for more information*

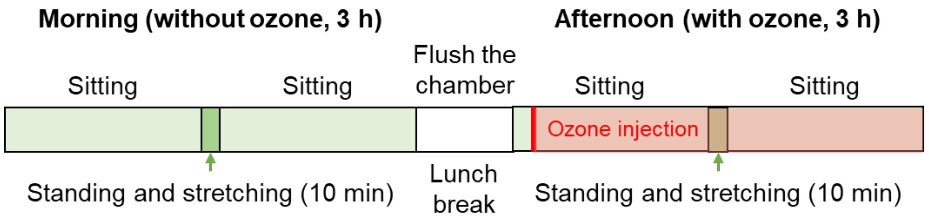
Experimental design and setup

Air change rate:
0.5 h^{-1}, 1.5 h^{-1}, 3.0 h^{-1}
Air mixing:
Fans ON, Fans OFF

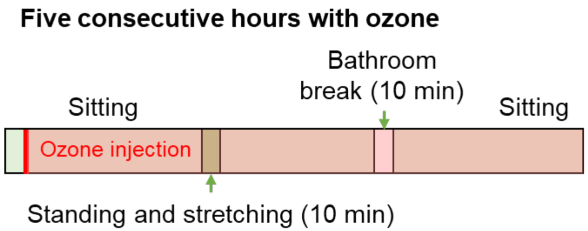


Experimental procedure

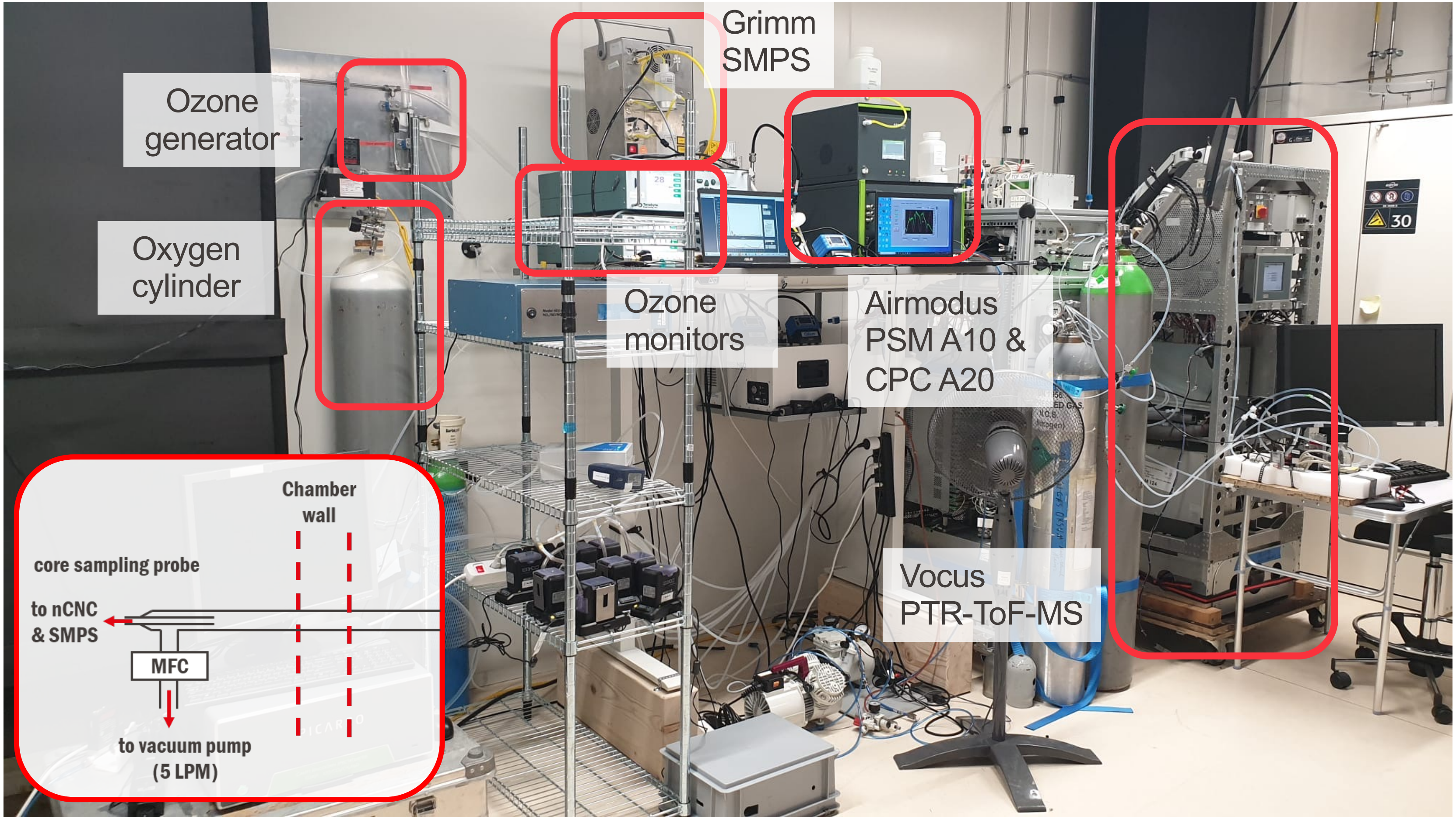
ACR: **3.0** h^{-1} / **1.5** h^{-1}
Mixing fan **on**
Mixing fan **off**



ACR: **0.5** h^{-1}
Mixing fan **on**



Instrumentation setup

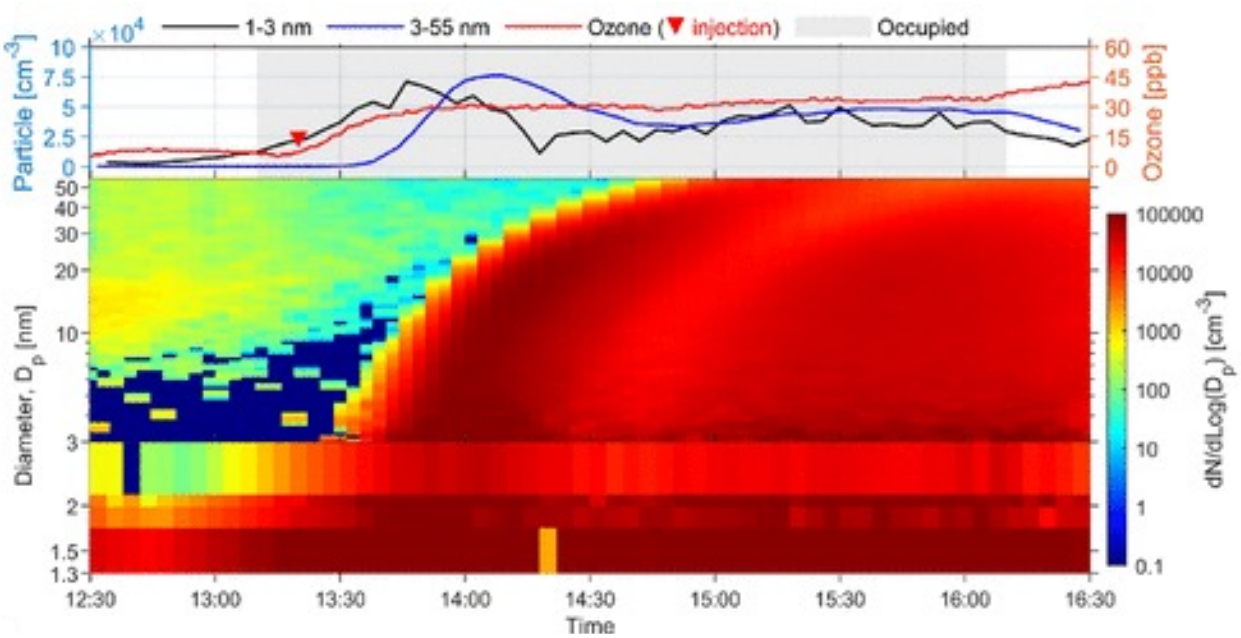


Data analysis

$$E_{D_p} = \frac{V}{n}\left(N_{D_p}\cdot\left(\sum_{D_p} K_{D_p} + \frac{GR}{\Delta D_p} + \beta + \lambda\right) + \frac{dN_{D_p}}{dt}\right)$$

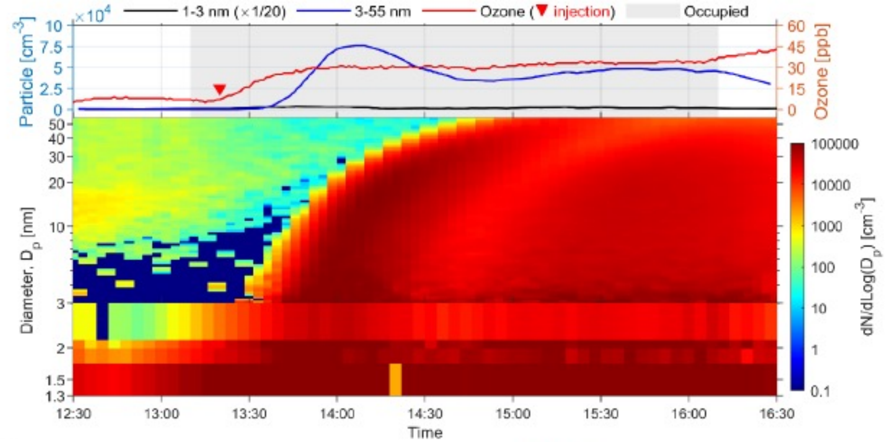
- E_{D_p}: size-resolved UFP formation rate per person
- V/n: chamber volume / number of persons
- N_{D_p}: size-resolved particle number concentration
- $\sum K_{D_p}$: size-resolved net coagulation sink rate
- GR: size-resolved particle growth rate
- β: particle deposition rate
- λ: air change rate
- dN_{D_p}/dt: particle concentration change rate

Particle formation and growth, 3 ACR, Fans Off

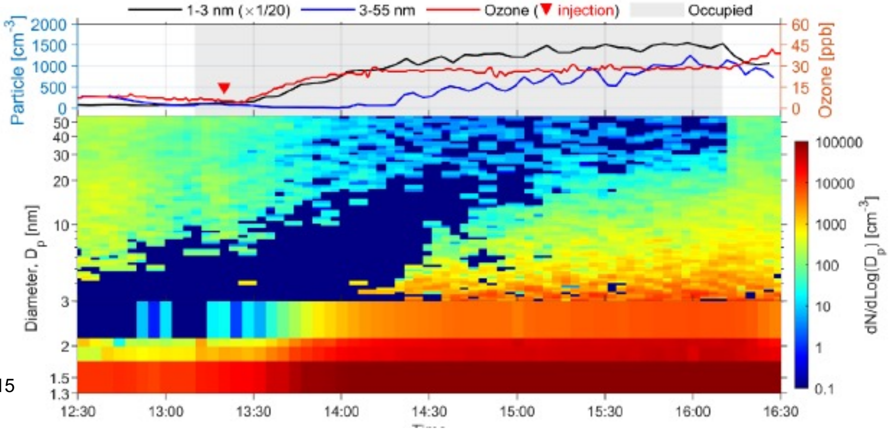


- Strong “banana-like” particle growth; 20 min delay for >3 nm particles
- After 1 hour: Second, weaker, wave of particle growth
- ~50% of ozone consumption (67 ppb inlet; 33 ppb indoor)

Impact of air mixing (Fans Off vs. Fans On)



Condition	1-3 nm GR (nm/h)	3-10 nm GR (nm/h)	10-20 nm GR (nm/h)
3.0/h ACH, Fans ON	2.1	8.0	2.0
3.0/h ACH, Fans OFF	2.7	41.4	43.0



- Fan operation prevents particle growth (higher air velocity, air cleaning effect)
- Fans also increased ozone loss
- Indoor air movement may have a more significant influence on particle dynamics and fate relative to indoor chemistry

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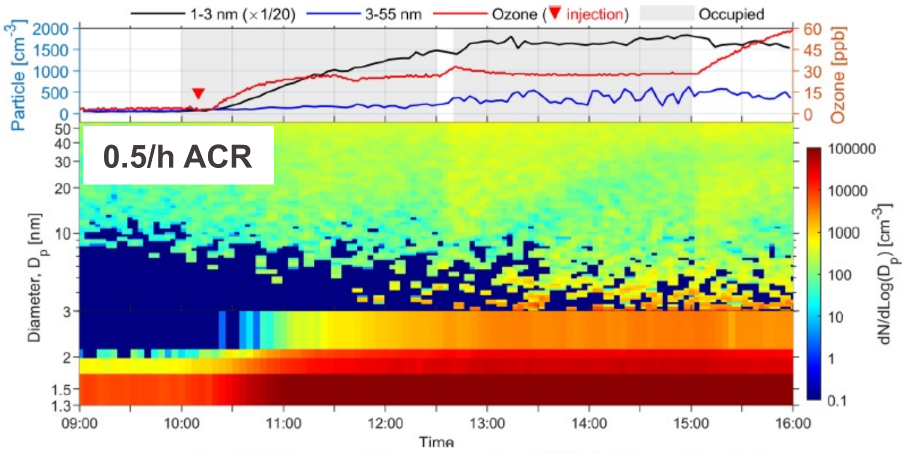
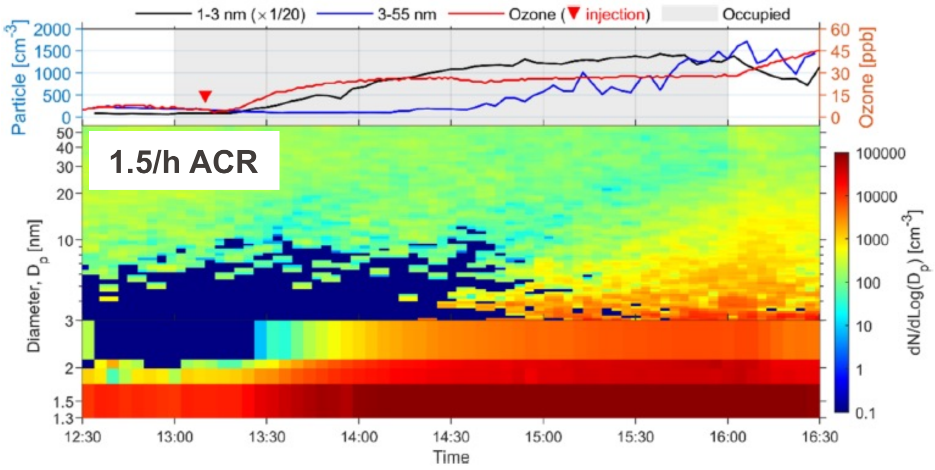
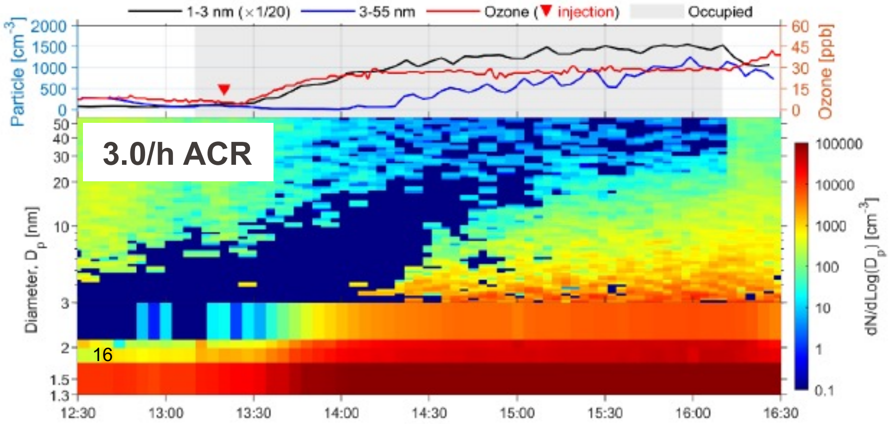
Impact of ACR (Fans ON)

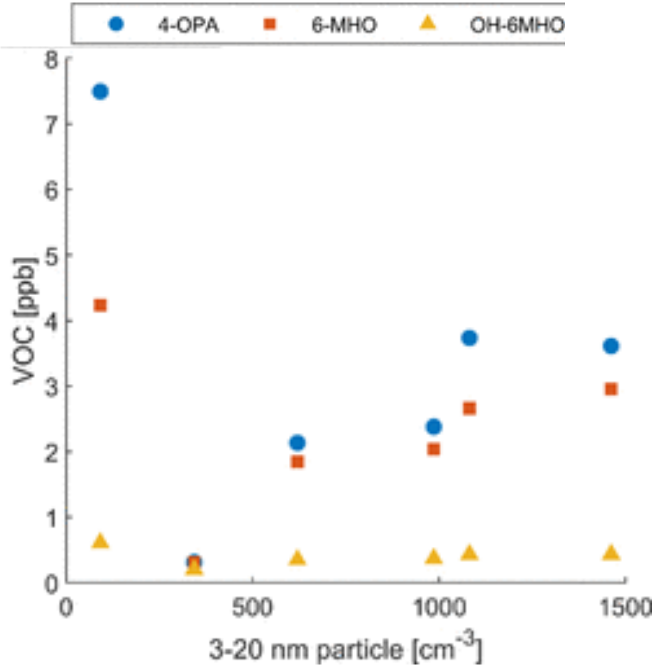


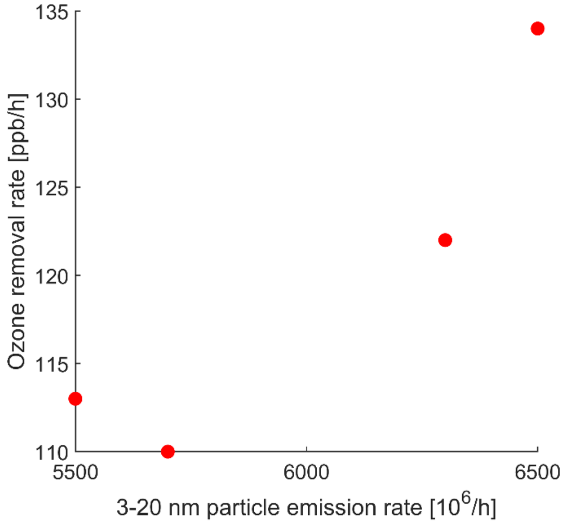




Condition	1-3 nm GR (nm/h)	3-10 nm GR (nm/h)	10-20 nm GR (nm/h)
0.5/h ACH	0.5	--	--
1.5/h ACH	0.9	6.7	1.2
3.0/h ACH	2.1	8.0	2.0

Correlation between particles and ozone-human VOCs (Fans On) *





- Positive correlation: Potential contribution of reactions generating VOCs to the growth of UFP
- Positive correlation with ozone removal rate, indicating that higher ozone flux to occupant surfaces yields higher UFP generation

** Small sample size*

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Summary and outlook

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- Ozone-human chemistry is an important yet overlooked pathway for generating UFP indoors
- Growth of newly formed particles is a function of air change rate but especially of indoor air movement; the scale of effect larger than indoor chemistry processes
- Strong implications for other empirical studies conducted with the use of mixing fans & particle models
- Upscaling through multilayer microscale and room-scale modelling
- Collaborate with toxicologists & public health experts to better understand impacts of chemistry-initiated UFP

The crew

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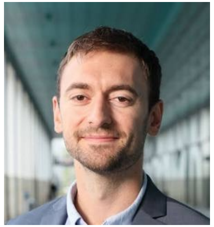
DE LA RECHERCHE SCIENTIFIQUE



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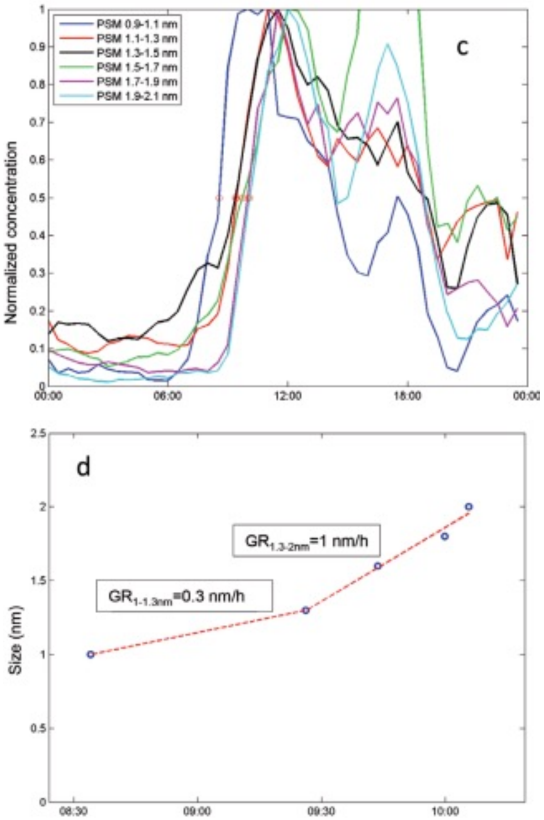
Estimating particle growth rate (1)



t_{50} method:

1) Normalize particle concentration by the C_{max}

2) Find the 50% appearance times (t_{50}) of the particles, corresponding to the elapsed time when the concentration reaches 50% of the C_{max}

3) Obtain growth rate by linear fitting between particle sizes and corresponding t_{50} after which the slope of the fitting stands for growth rate for a given size range

Estimating particle growth rate (2)

Cross-fitting method:

1) Apply time-series correlation between particle concentrations of the lower-bound size and larger sizes with adjustable time lags

2) Record the time lag where the highest coefficient is found for each size

3) Obtain particle GR by linear fitting between particle sizes and their corresponding time lags, in which the slope represents particle GR