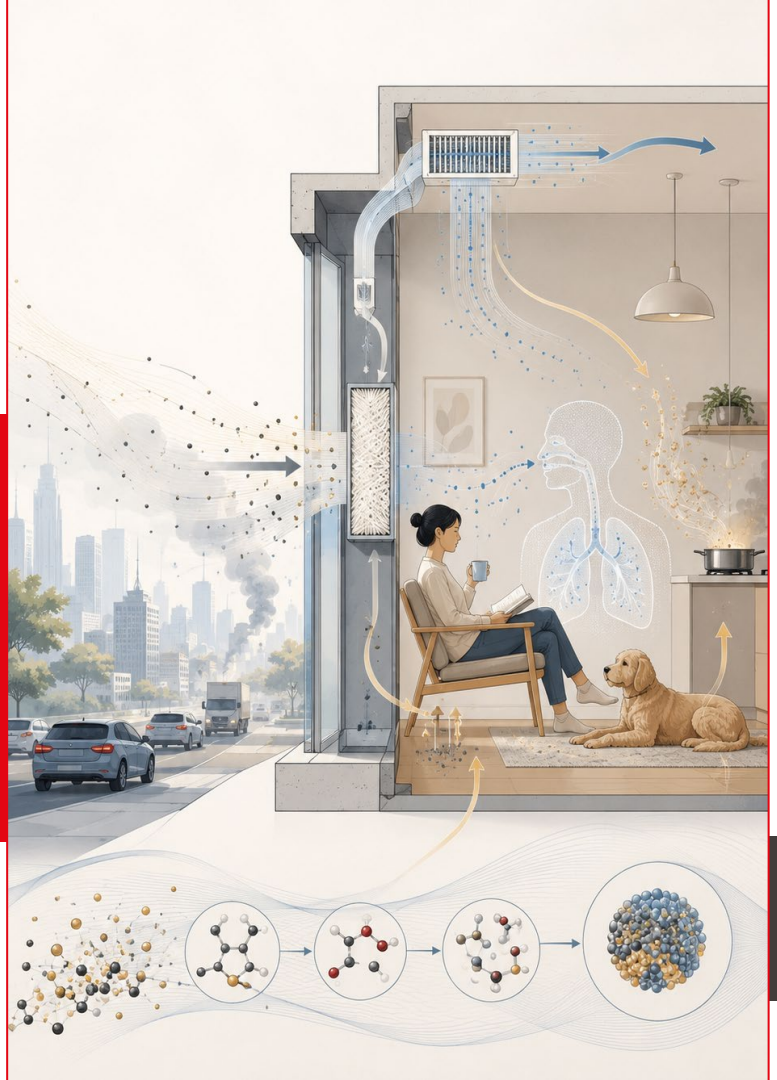
Indoor ultrafine particles in occupied spaces: sources, transformations, and exposure-relevant dynamics



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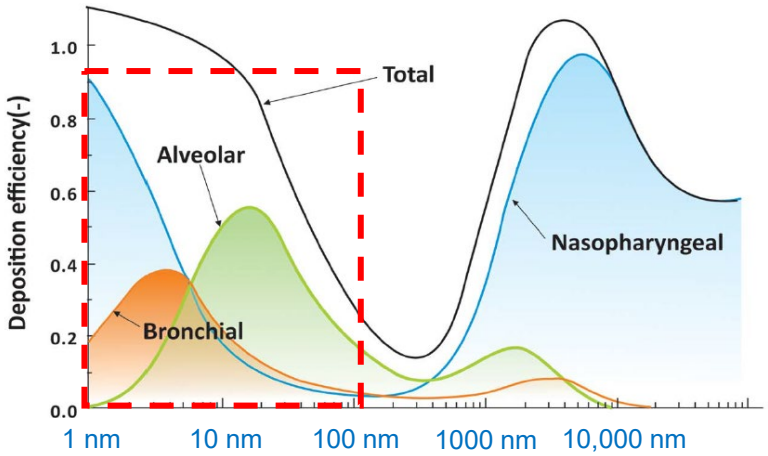
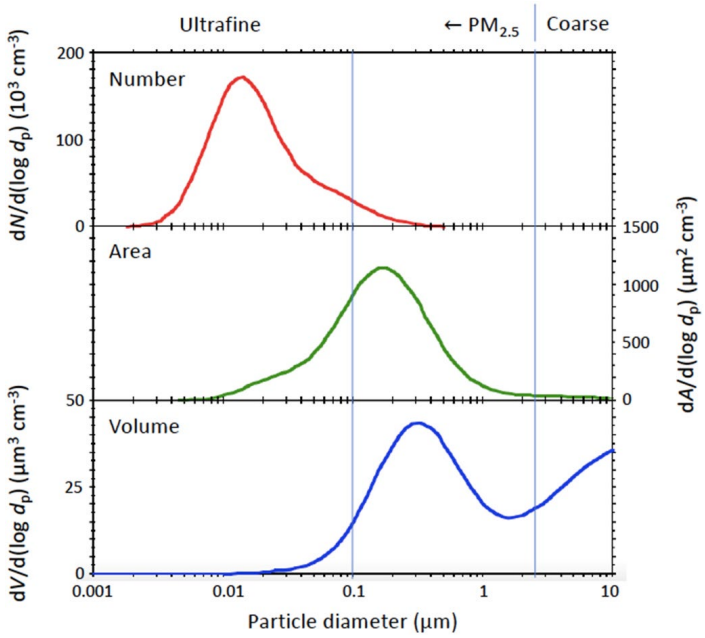
3 June, 2026

Why UFP deserve attention – especially indoors?

- UFP dominates number concentration (99%)
  - UFP: Typical number conc. ~10'000 particles/cm^3
  - 10 µg/m^3 of $PM_{2.5}$, if represented by 0.5 µm particles, corresponds to ~150 particles/cm^3
- Respiratory deposition depends strongly on size
- Most UFP exposure occurs indoors
- Indoor sources & dynamics reshape exposure

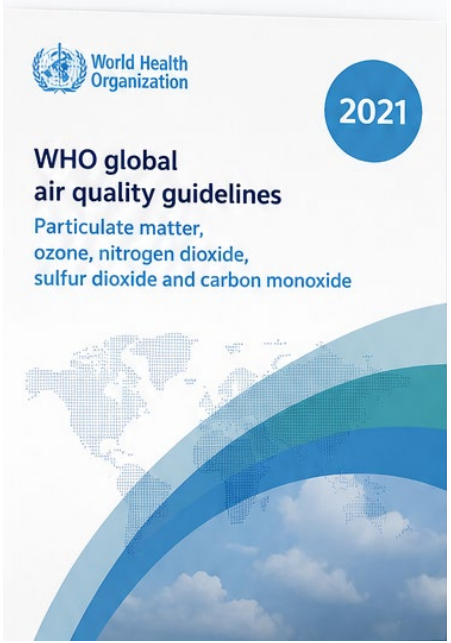




(Source: Nazaroff, Building and Environ. 2023)

UFPs: not yet a regulated exposure metric

- UFP are health-relevant, but not yet guideline-ready
- Exposure–response evidence remains weaker than for $PM_{2.5}$
- WHO 2021: no quantitative air-quality guideline value for UFP
- Good-practice direction: expand UFP / PNC monitoring
- Key challenge: which metric, source and microenvironment predict health?



"For ultrafine particles (UFP), WHO provides good-practice statements, but not quantitative air quality guideline values."

Nazaroff framing: health, dynamics and buildings

Building and Environment 243 (2023) 110641

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Check for updates

Ten questions concerning indoor ultrafine particles

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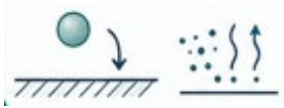
How do they evolve?

Airflow & surfaces



How they disappear?

Occupancy & activities

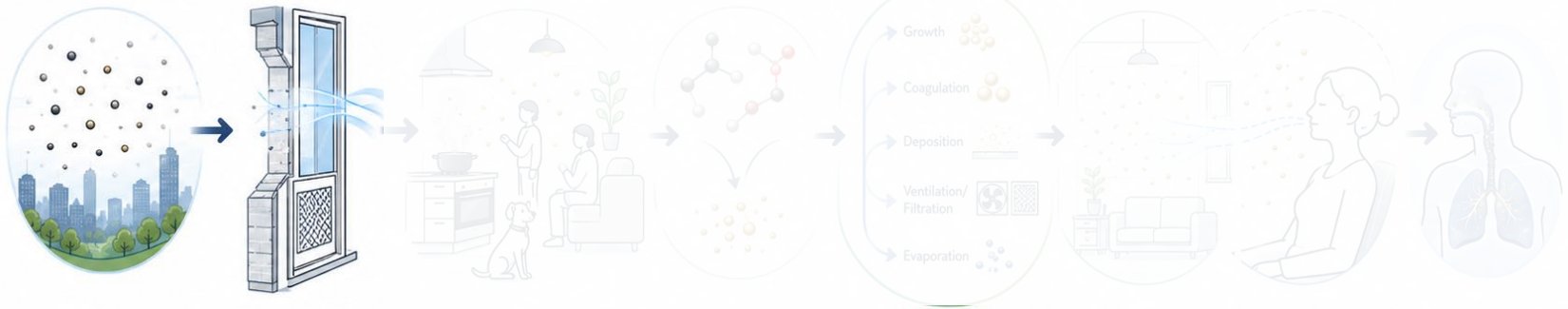
Indoor UFP exposure is a dynamic chain

Outdoor particles

Indoor sources: Primary emissions

Transformation and removal

Breathing zone concentration



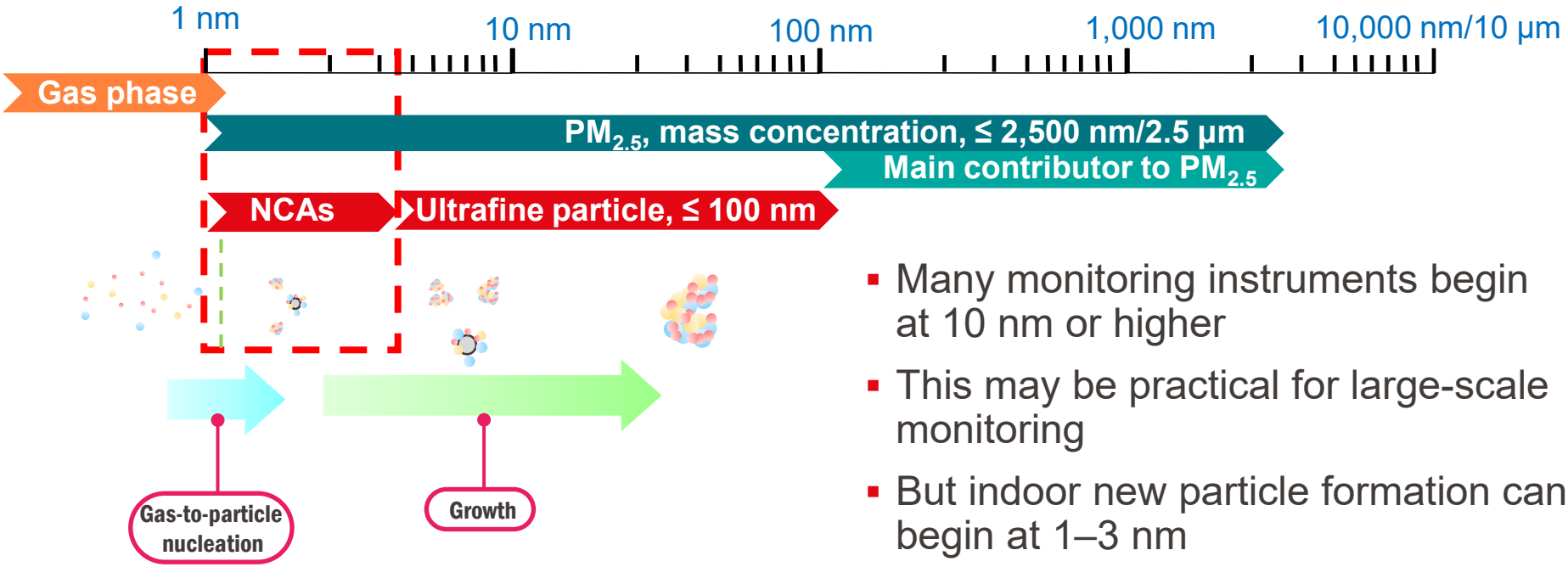
Building entry: filtration and air leakage

Secondary sources: chemistry and formation

Indoor concentration

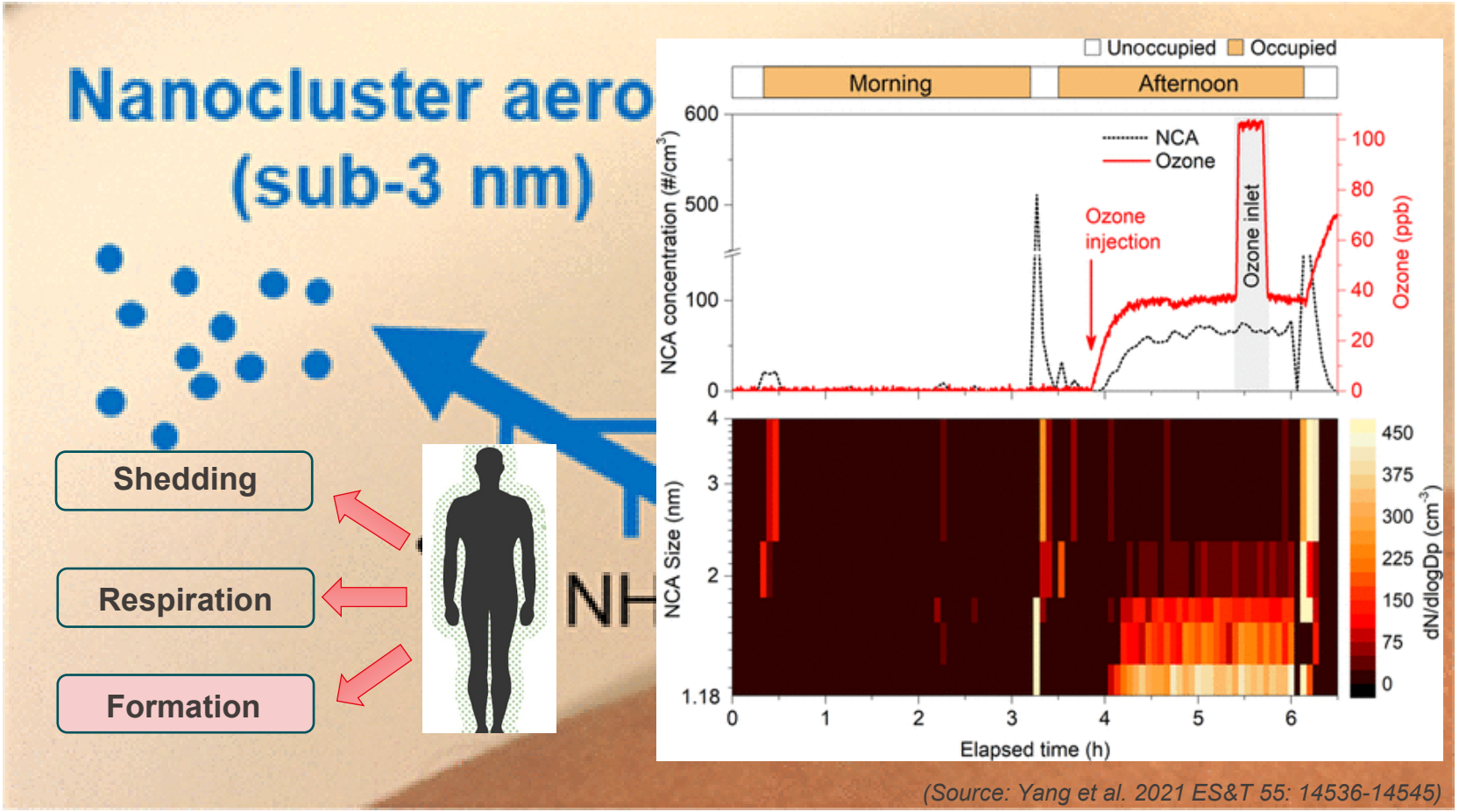
Personal exposure & dose

Nanocluster aerosols: the first step of UFP formation



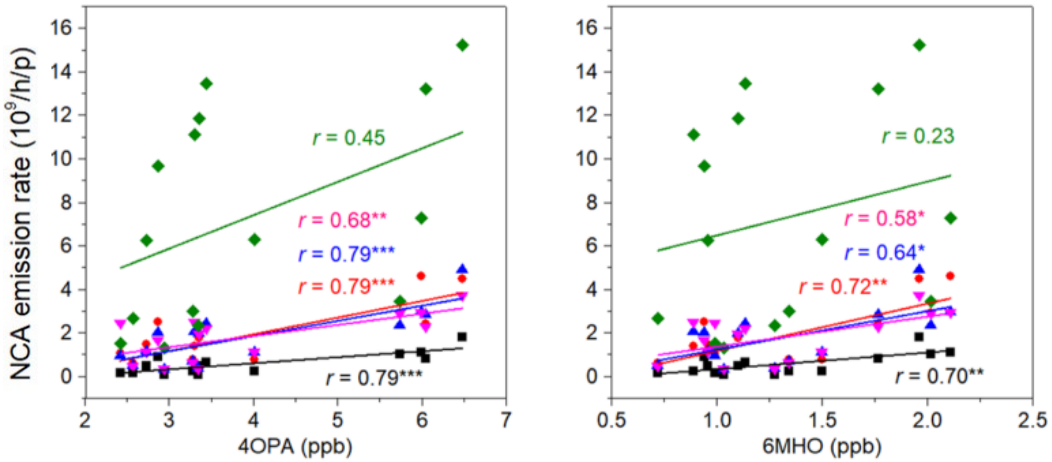
- Many monitoring instruments begin at 10 nm or higher
- This may be practical for large-scale monitoring
- But indoor new particle formation can begin at 1–3 nm
- Missing the first few nanometers can mean missing the mechanism

Humans are reactive surfaces

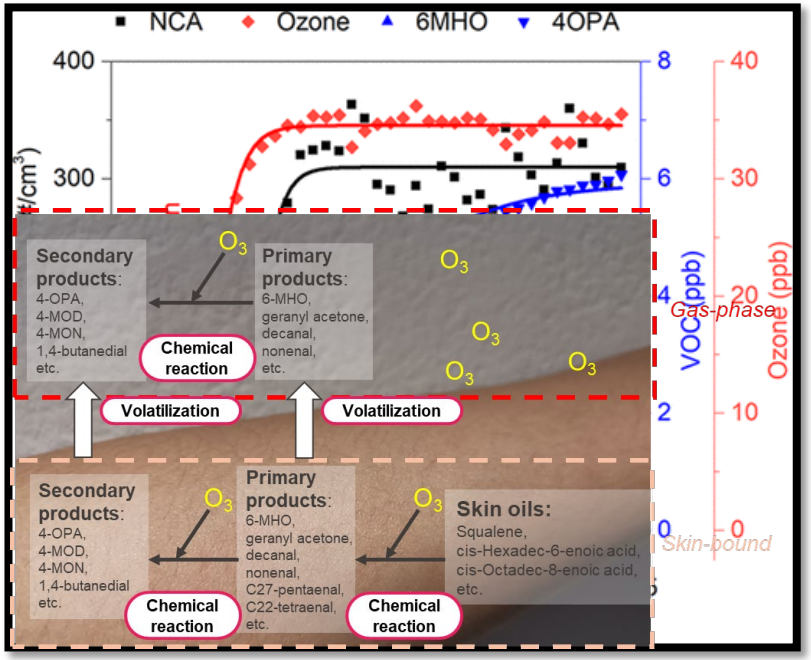


(Source: Yang et al. 2021 ES&T 55: 14536-14545)

Ozone-human chemistry: from surface reservoir to aerosol source



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)

Pets reveal the complexity of real occupied spaces

FOUR SMALL DOGS

THREE BIG DOGS

Indoor UFP formation can emerge from interactions — not only from obvious sources

Dogs alter IAQ in m pathways:

1. Metaboli
CO_2, N

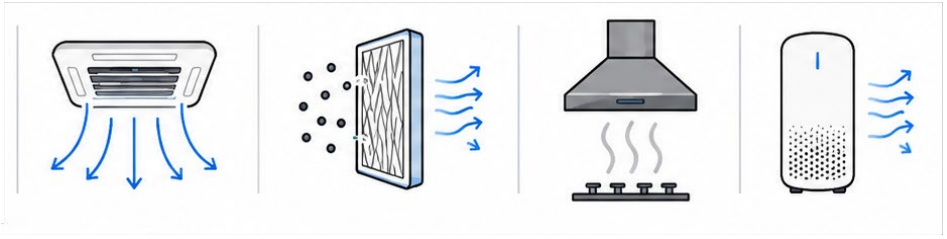
and microbial emissions
e particles, bacteria, fungi,
esuspended material

3. Ozone-driven chemistry
O_3 + transferred human skin residues on fur → ozonized VOCs + 1–3 nm nanocluster aerosols

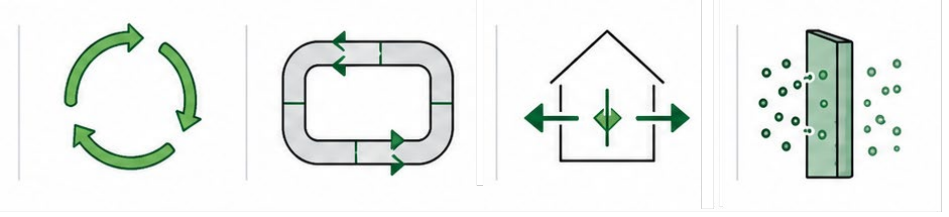
(Source: Yang et al. 2026 ES&T 60: 6404-6414)

From control strategies to exposure-shaping conditions

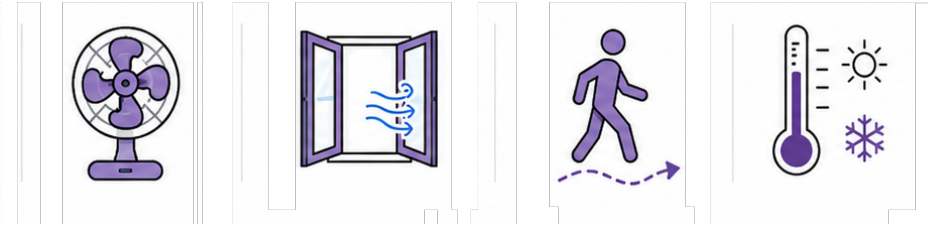
INTENTIONAL IAQ CONTROLS



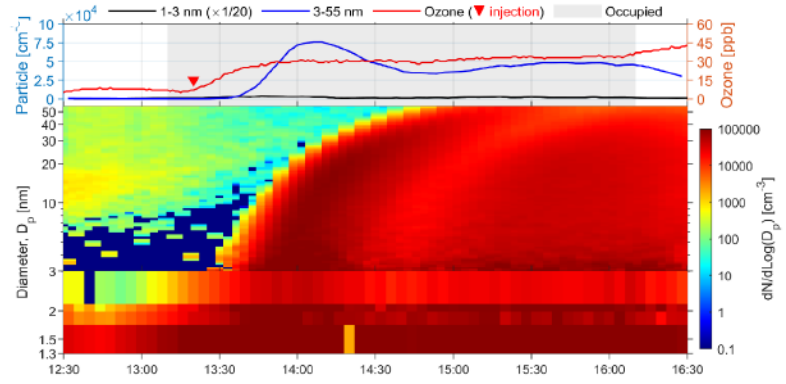
BUILDING OPERATION VARIABLES

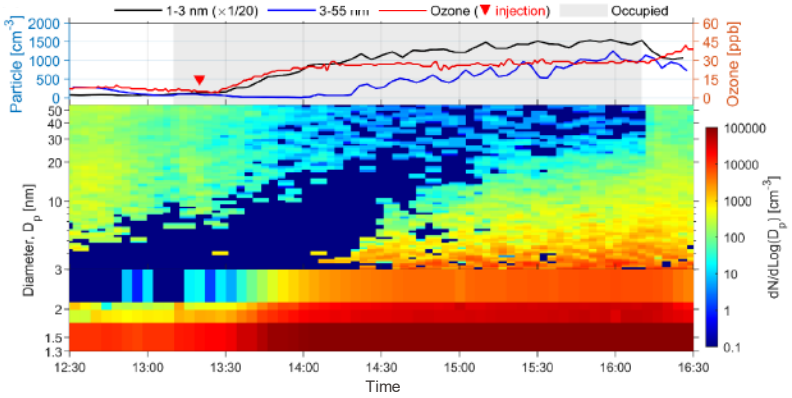


COMFORT INTERVENTION WITH IAQ CONSEQUENCES



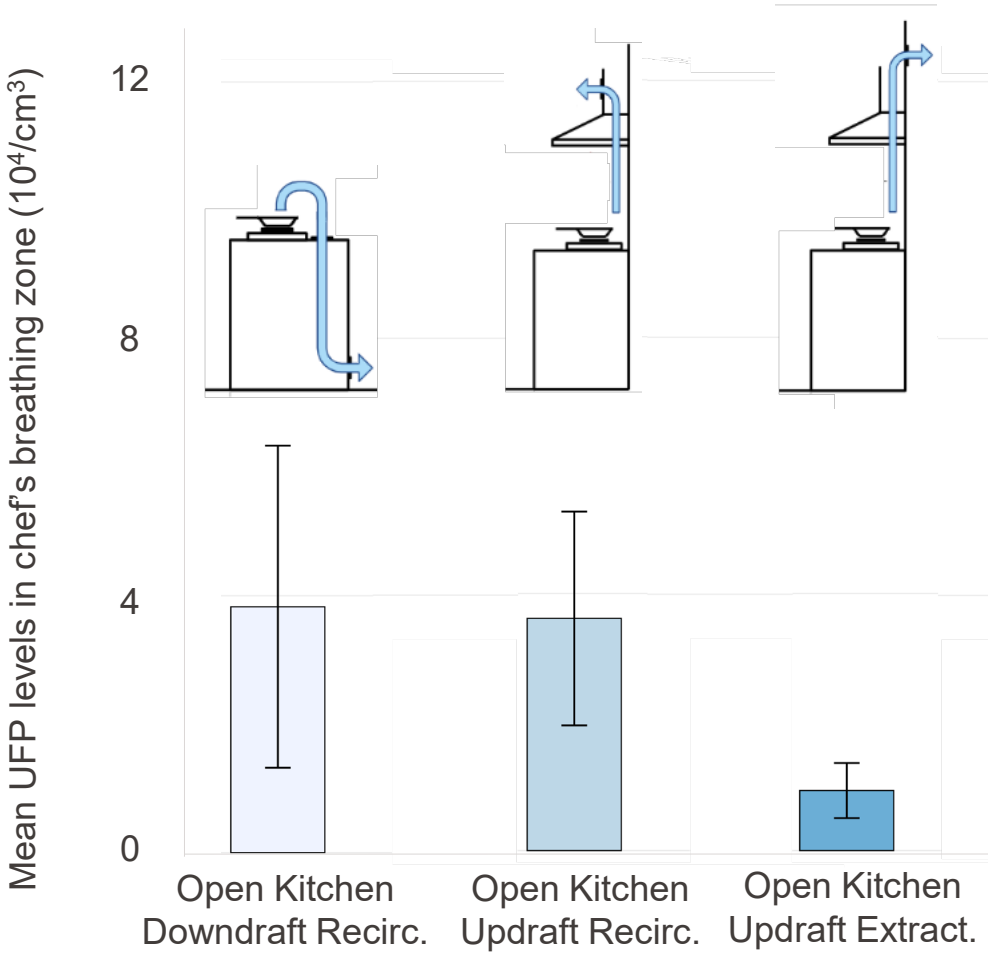
When comfort intervention changes UFP exposure





(Source: Yang et al. 2024 ES&T)

Control at the source: what cooking hoods teach us



(Source: Dedesko et al. In prep.)

From monitoring networks to personal exposure and health relevance

WHAT THE FIELD NEEDS AT SCALE

Harmonized UFP monitoring

Long-term outdoor & indoor datasets

Exposure-response studies

Source apportionment at population scale

WHAT INDOOR UFP RESEARCH MUST ADD

Personal & breathing zone exposure measurements

Primary vs secondary source attribution

Size-resolved dynamics, inc. sub-10 nm

Composition, oxidative potential and toxicity

Indoor UFP: from sources to what people inhale

1. **Indoor UFP are not only emitted — they are formed.**
   Occupants, surfaces, ozone, and activities can create new particles.

2. **They are not only present – they evolve.**
   Indoor dynamics determine whether they grow, deposit, disappear, or persist.

3. **They are not only measured in rooms — they are inhaled by people.**
   The key challenge is linking sources and dynamics to personal exposure.