HEALTH IMPACTS OF INDOOR AIR QUALITY

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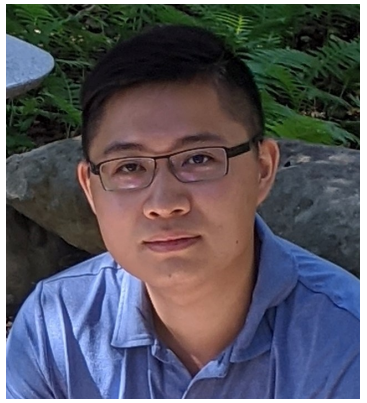
Mitch Thompson



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ACKNOWLEDGEMENTS TO MY LAB'S SPONSORS

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WHOLE COMMUNITIES WHOLE HEALTH
A UT Grand Challenge

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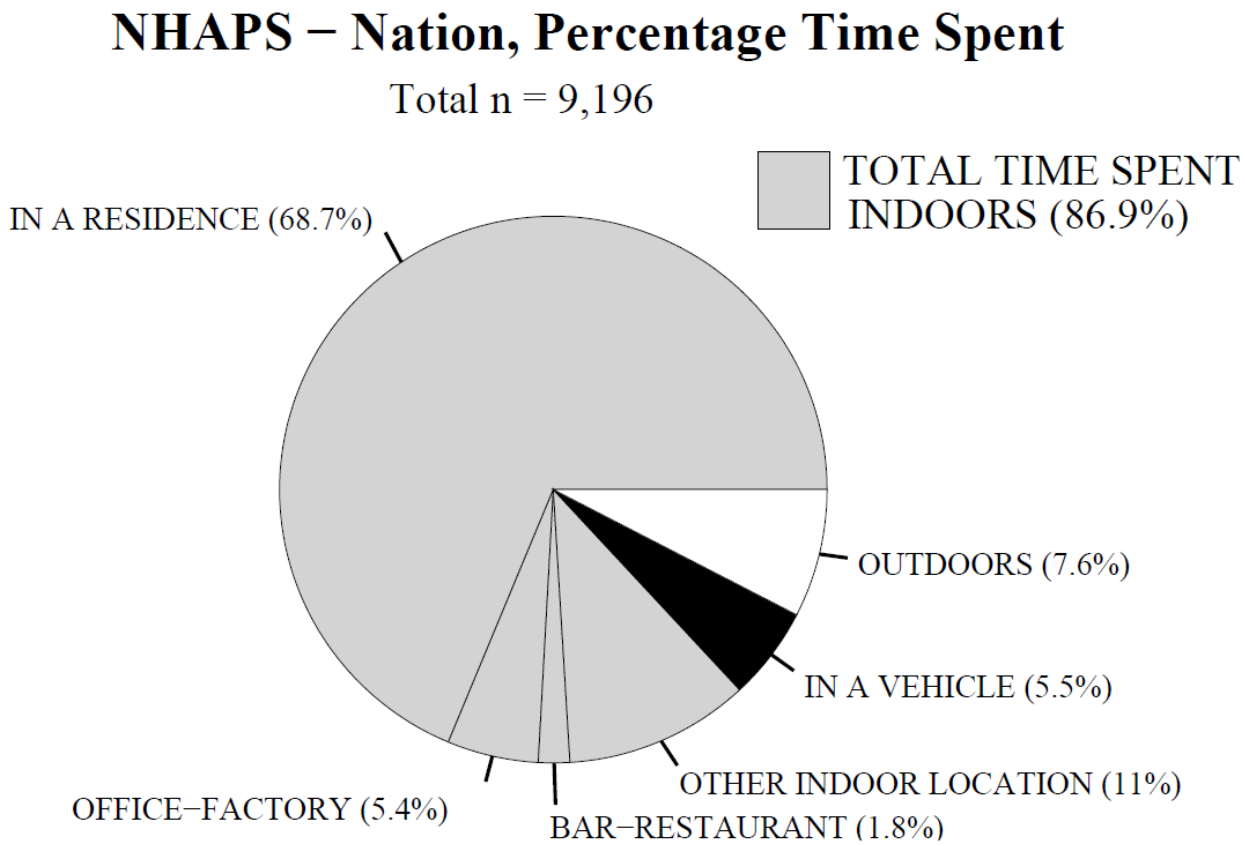
What fraction of our life do we spend indoors?



The National Human Activity Pattern Survey
(Klepeis *et al.*, 2001)

The Corsi Code

79 69 54 26 4.3 6

Air quality matters: global burden of disease

Leading global health risk factors (2016)

Males	Females
1. Smoking	1. High blood pressure
2. High blood pressure	2. High body-mass index
3. Low birthweight & short gestation	3. High fasting plasma glucose
7. Ambient particulate matter	6. Ambient particulate matter
10. Household air pollution	8. Household air pollution
16. Unsafe water	13. Unsafe water
21. Unsafe sanitation	16. Unsafe sanitation
23. No access to handwashing	20. No access to handwashing
30. Second-hand smoke	21. Second-hand smoke

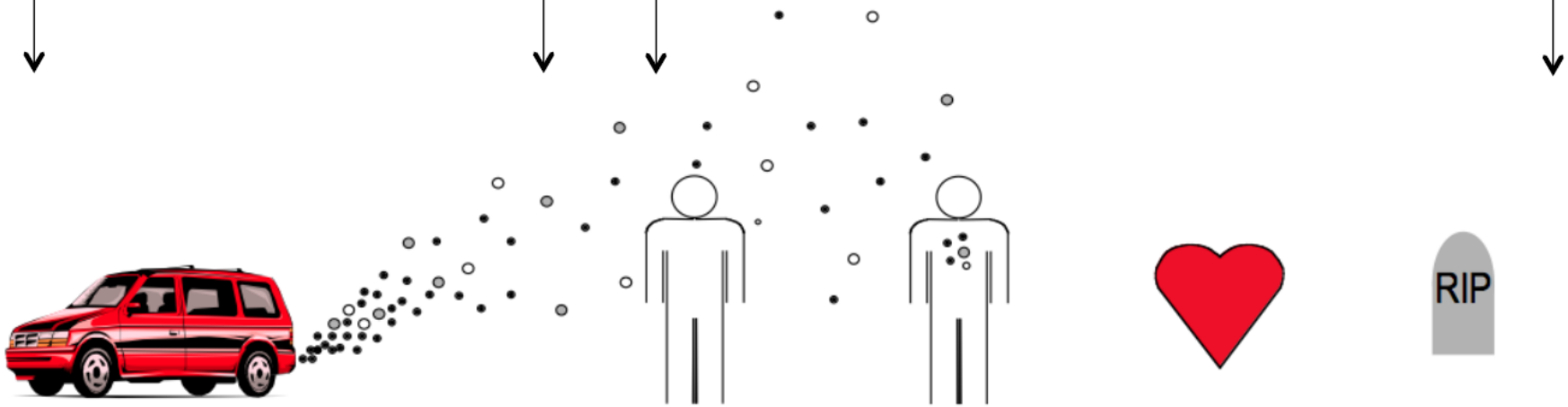
- Among 30 causes of global ill health, 3 (10%) are from air pollution
- Exposures to air pollution occur predominantly indoors

After Nazaroff 2018. Reference: GBD 2016 Risk Factors Collaborators, *Lancet* **390**: 1345-1422, 2017.

Air pollution paradigm: Sources to health effects

Traditional domain
for air quality engineering (AQE)

Traditional domain
of environmental health scientists (EHS)



emissions → concentration → exposure → intake → dose → health effects

Opportunity to bridge the AQE/EHS gap

Adapted from Nazaroff, 2018

Harvard Six Cities Cohort Study

The New England
Journal of Medicine

Volume 329 DECEMBER 9, 1993 Number 24

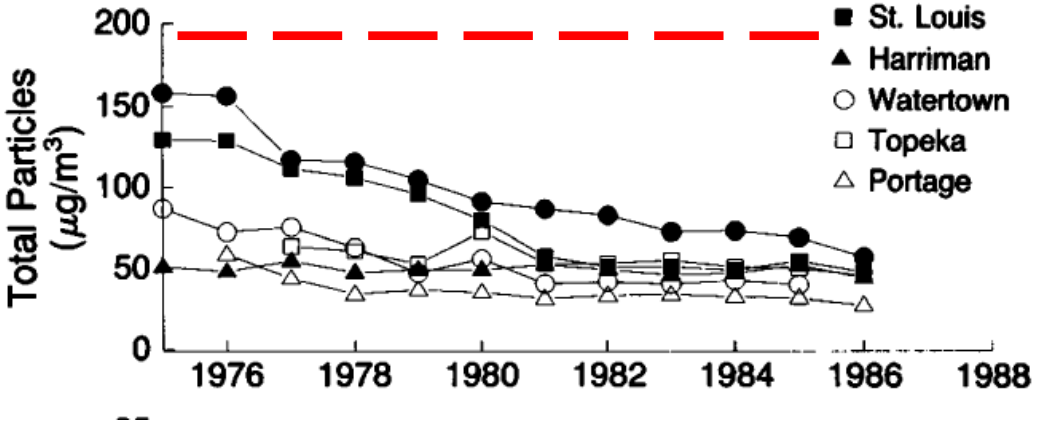
AN ASSOCIATION BETWEEN AIR POLLUTION AND MORTALITY IN SIX U.S. CITIES

Douglas W. Dockery, Sc.D., C. Arden Pope III, Ph.D., Xiping Xu, M.D., Ph.D.,
John D. Spengler, Ph.D., James H. Ware, Ph.D., Martha E. Fay, M.P.H.,
Benjamin G. Ferris, Jr., M.D., and Frank E. Speizer, M.D.

Abstract *Background.* Recent studies have reported associations between particulate air pollution and daily mortality rates. Population-based, cross-sectional studies of metropolitan areas in the United States have also found associations between particulate air pollution and annual

other risk factors, we observed statistically significant and robust associations between air pollution and mortality. The adjusted mortality-rate ratio for the most polluted of the cities as compared with the least polluted was 1.26 (95 percent confidence interval, 1.08 to 1.47). Air pollution

Stir-fry dinner PM2.5 (HOMECHEM)



[HTML] An **association between air pollution** and **mortality** in **six US cities**

DW Dockery, CA Pope, X Xu... - ... England journal **of** ..., 1993 - Mass Medical Soc Paperpile

Background Recent studies have reported associations between particulate air pollution and daily mortality rates. Population-based, cross-sectional studies of metropolitan areas in the United States have also found associations between particulate air pollution and annual mortality rates, but these studies have been criticized, in part because they did not directly control for cigarette smoking and other health risks. Methods In this prospective cohort study, we estimated the effects of air pollution on mortality, while controlling for individual risk ...

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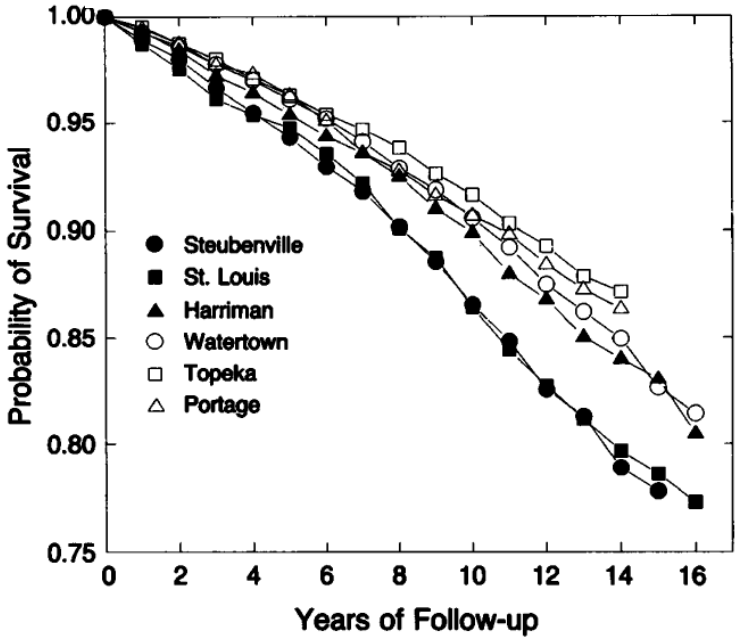
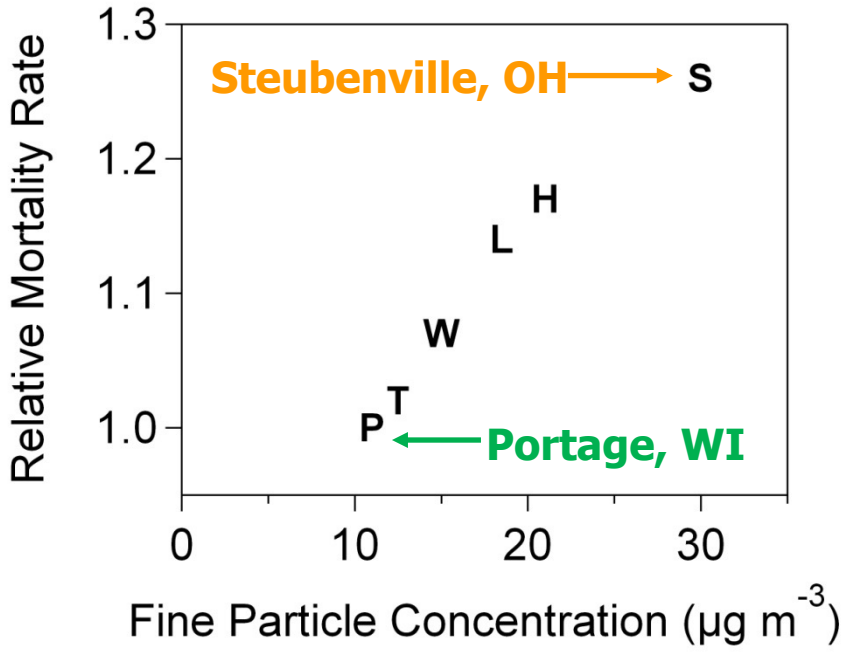


Figure 2. Crude Probability of Survival in the Six Cities, According to Years of Follow-up.

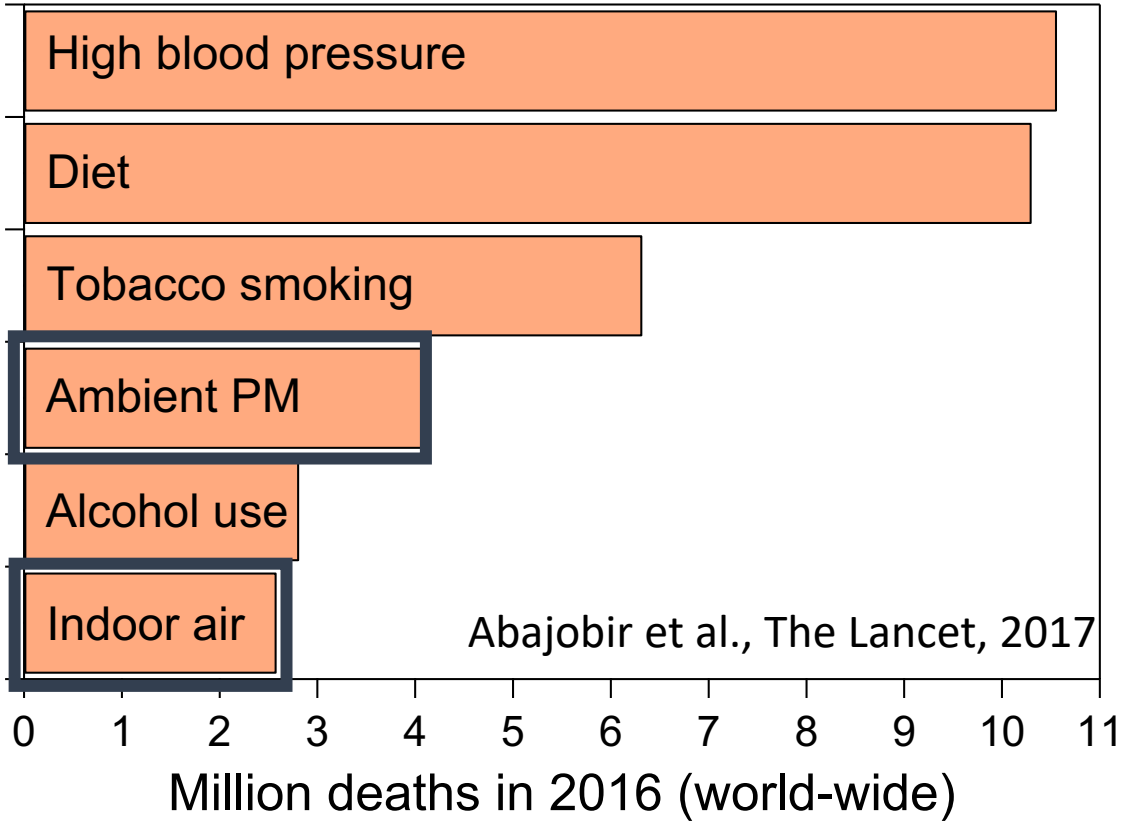
Health Impacts of Particulate Matter

Epidemiology data from the Six-Cities Study



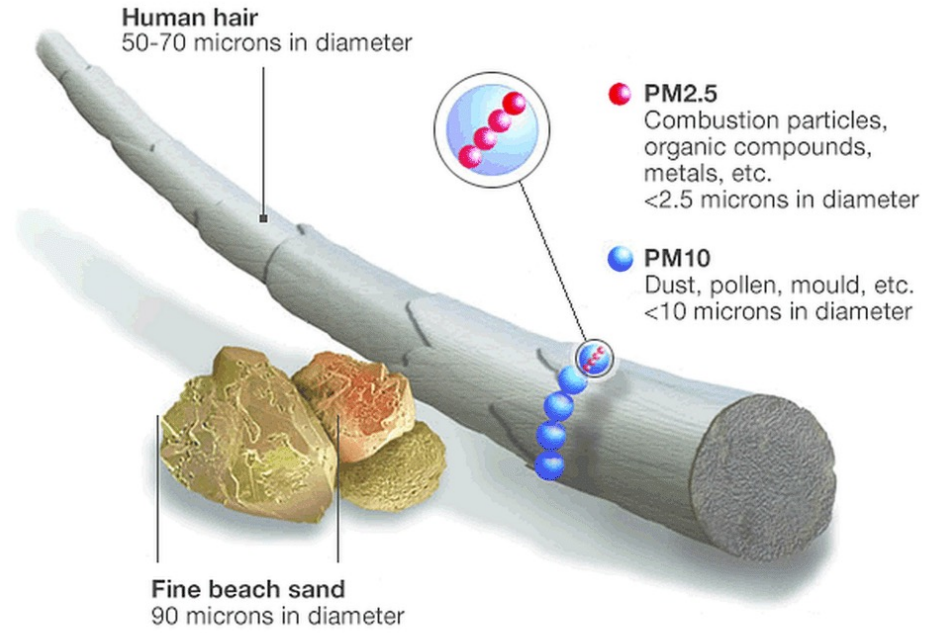
Dockery *et al.*, 1993

Global Burden of Disease

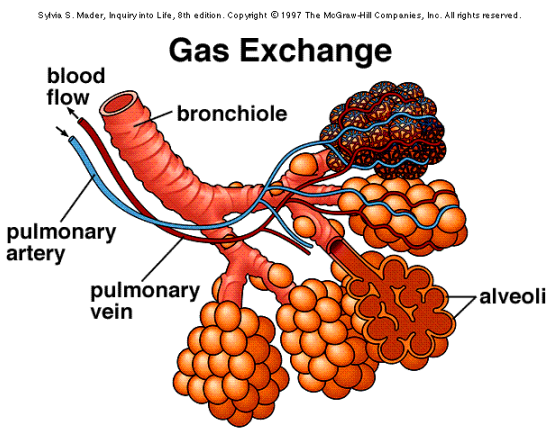


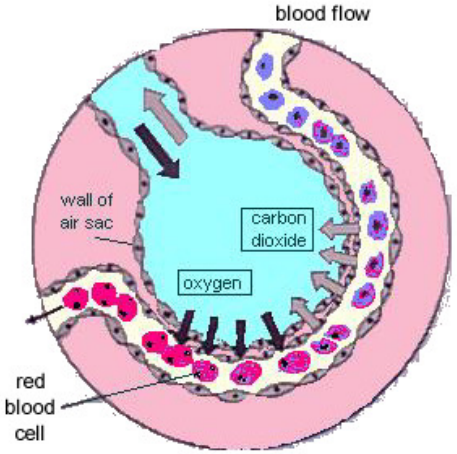
The fate of indoor air pollutants in alveoli

- 500-700 million alveoli in lungs
- 70 – 100 m^2
- 200 µm each
- ≈ 70% covered with blood capillaries
- Critical for O_2 transfer to body
- Critical for expelling CO_2 from body
- Poorly soluble pollutant transport to blood
- Expulsion of pollutants from blood

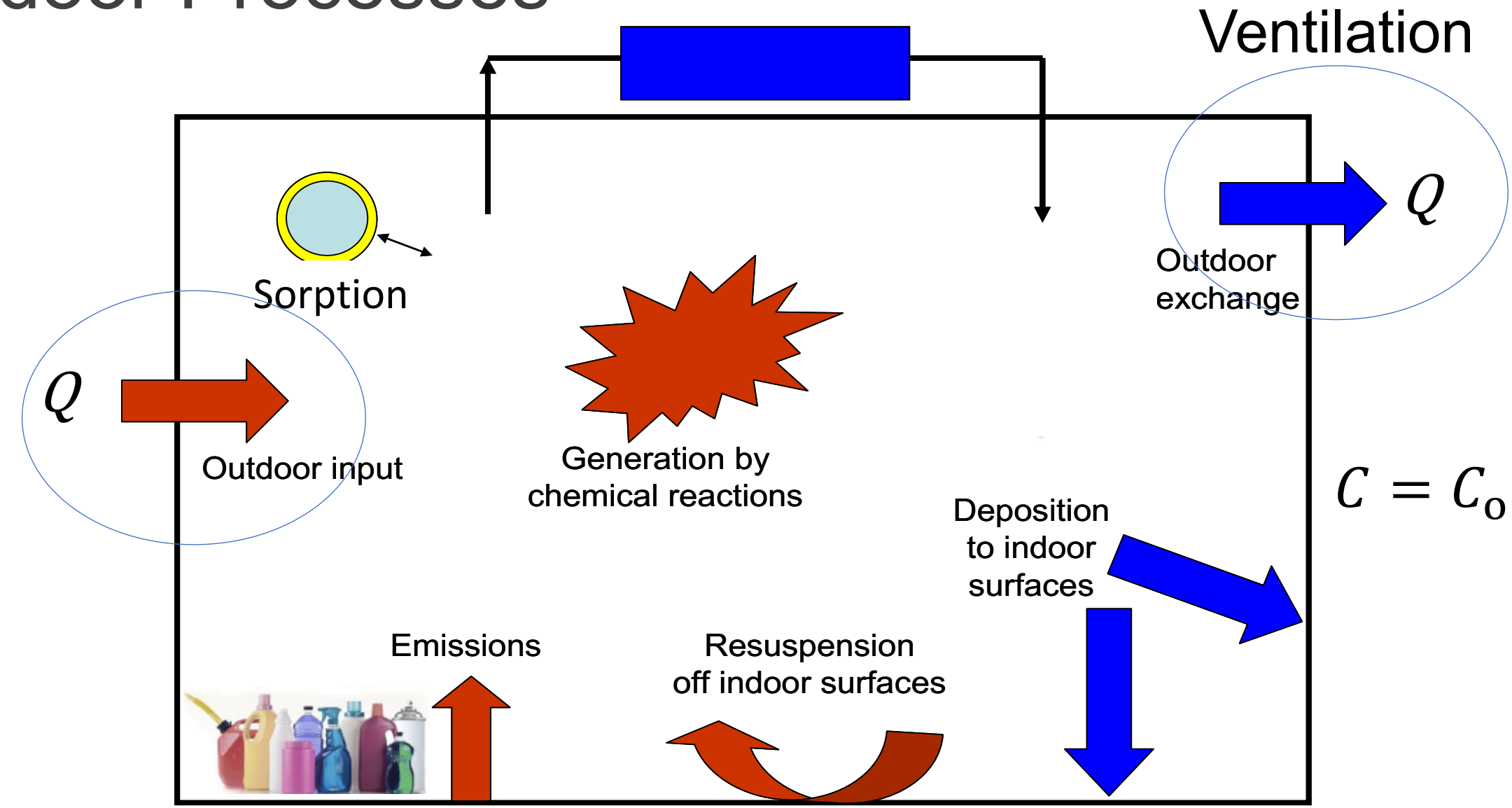


Source: US EPA





Indoor Processes



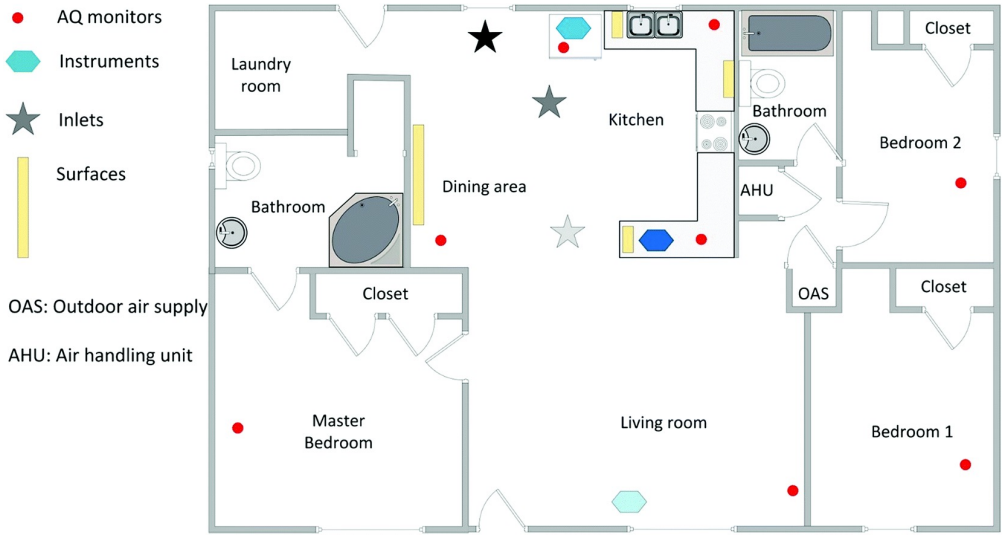
$$C = C_o + \frac{E}{\underbrace{\lambda V}_{Q}}$$

Courtesy: R. Corsi

What are Major Indoor Air Pollutants?

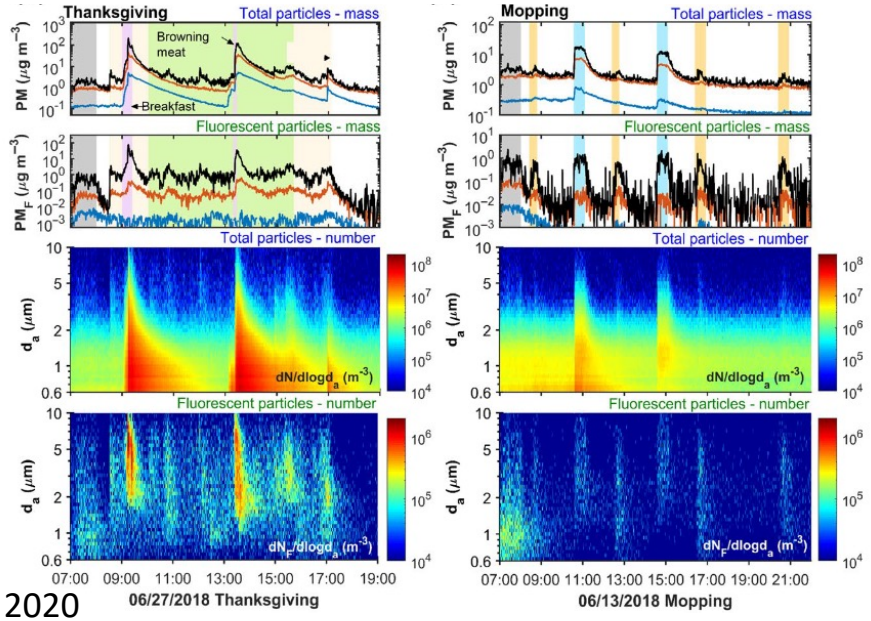
HOMEChem: House Observations of Microbial and Environmental Chemistry

[“A Stir-fry experiment”]

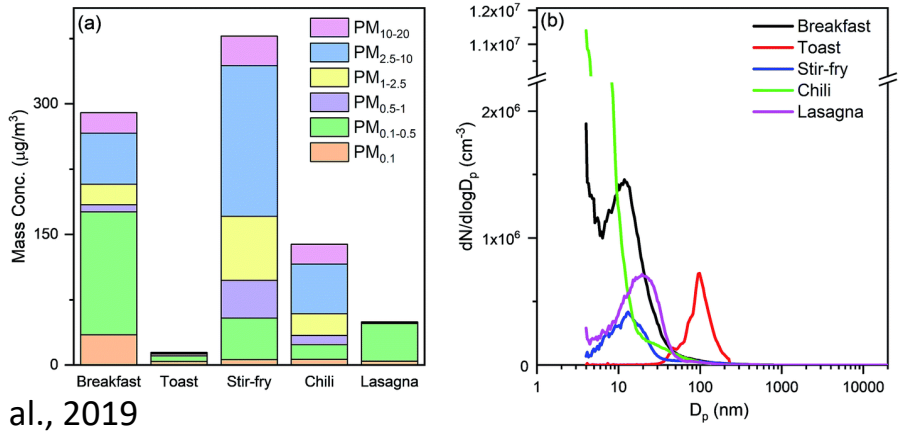


[“The Hidden Air Pollution in Our Homes” - New Yorker Article]

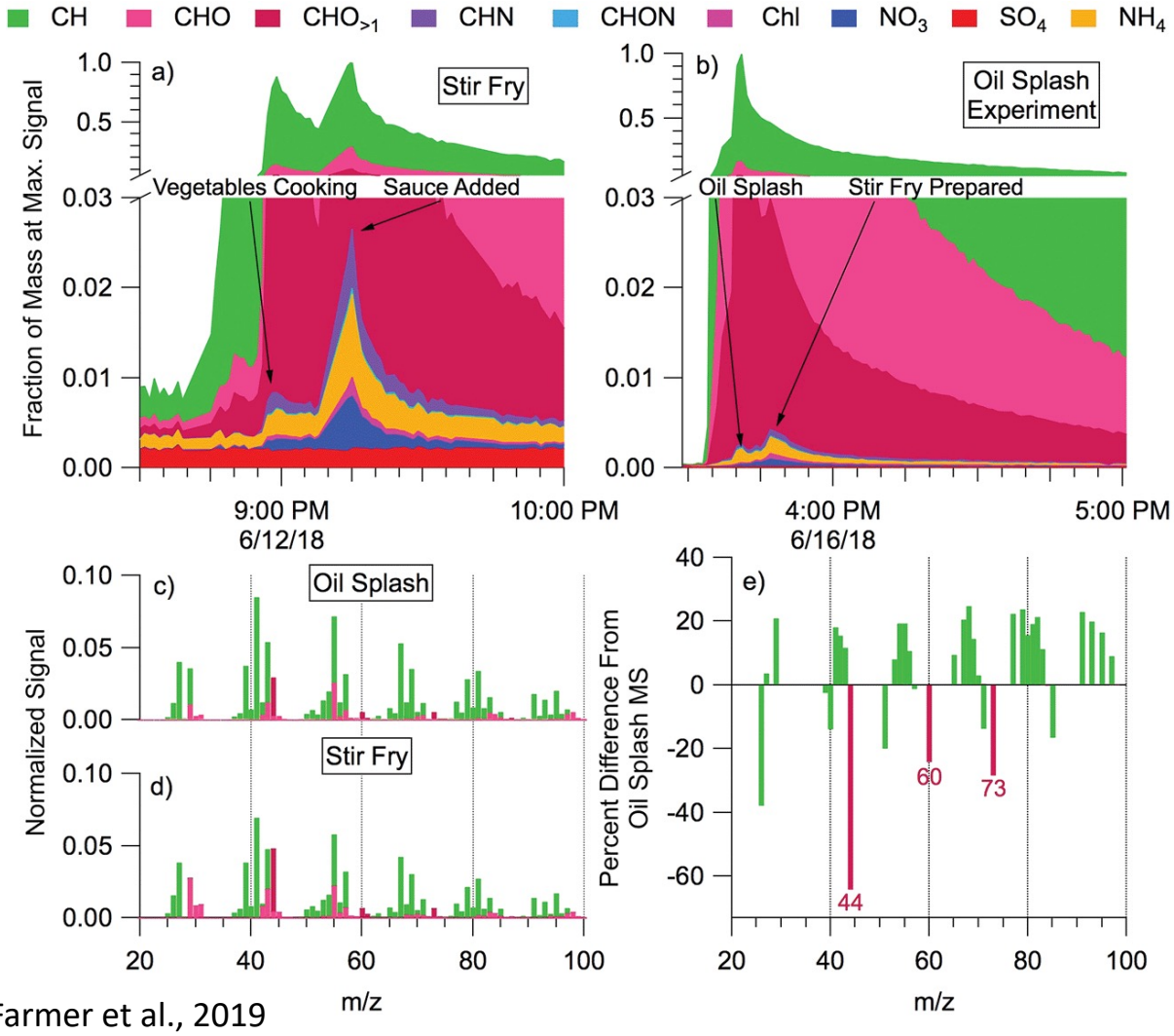
What are major sources of indoor exposure to particles?



Tian et al., 2020



Farmer et al., 2019



Farmer et al., 2019

Cooking is a major source of PM exposure. The size and composition of particles depends on the type of food fried.

Not chemical but the dose makes the poison

"Sola dosis facit venenum"

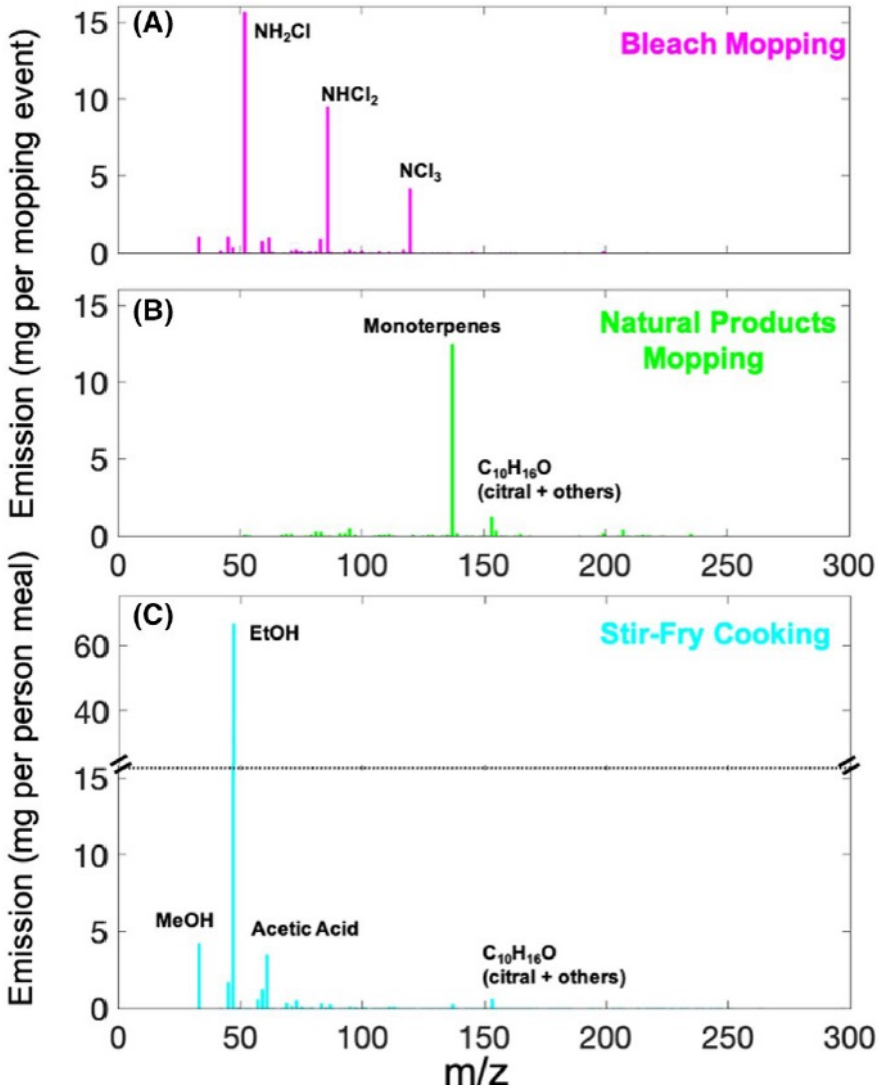
Paracelsus

Indoor Volatile Organic Compounds

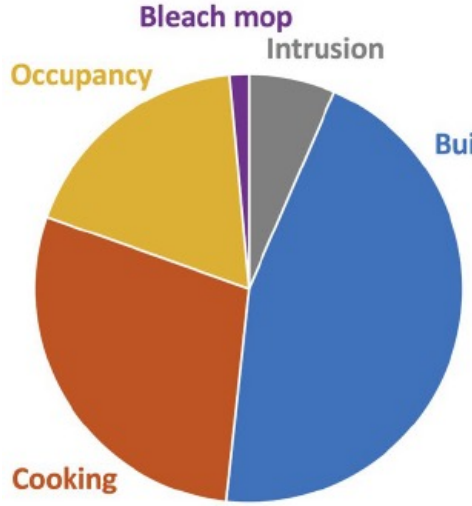
$<10^{-15}$ [ppq]	Abundance →	10^{-6} [ppm]
$<10^{-8}$ [year]	Atmospheric Lifetime (τ) →	> 1 [year]
$<10^{-9}$ [g/kg]	← Toxicity (LD_{50})	>10 [g/kg]
0 [# reports]	Level of understanding →	>1000 [# reports]

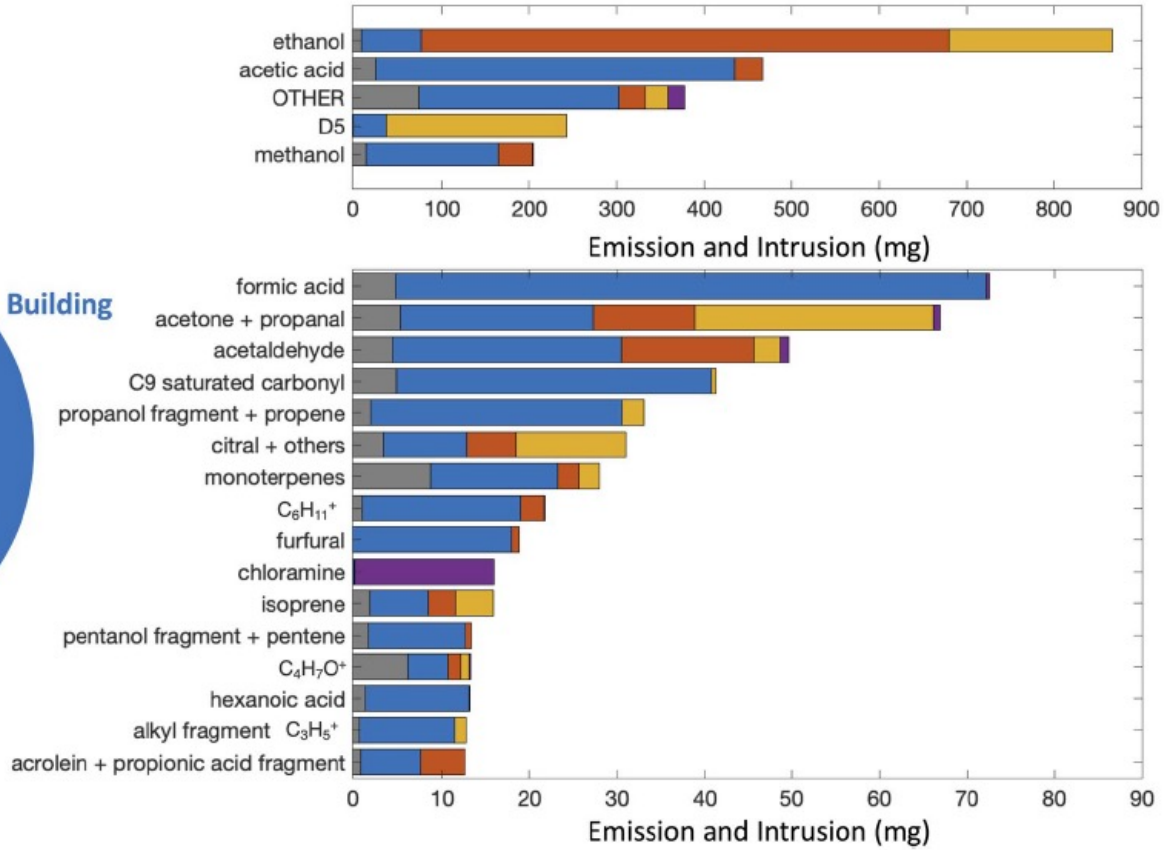
With better technologies we are able to resolve trace levels of pollutants in indoor air

Indoor Air Pollutant Signatures and Source Categories



Arata et al., 2021

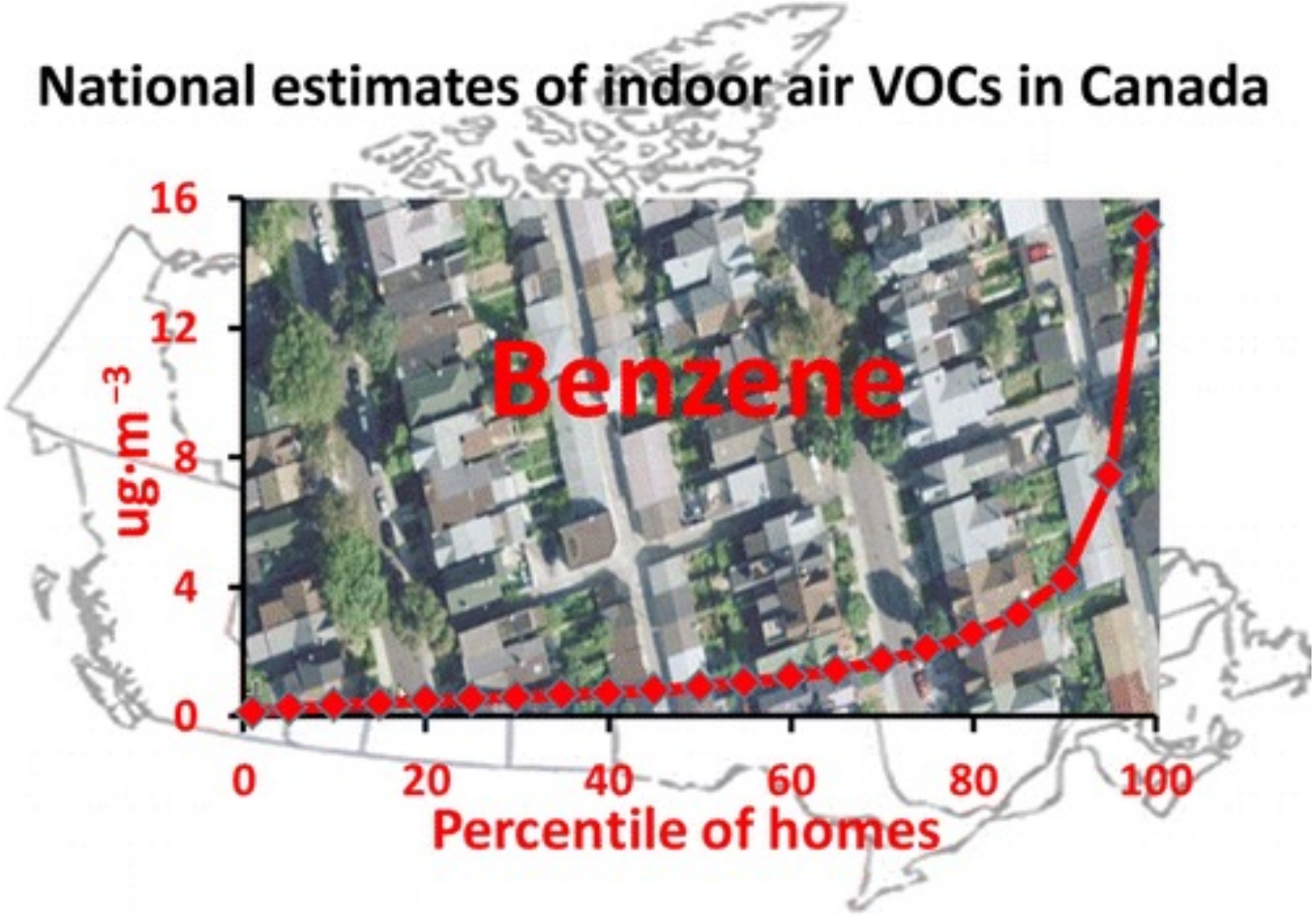




Arata et al., 2021

Building, Cooking, and Humans dominate indoor gas-phase pollutant emissions!

Measurements of chemical exposure



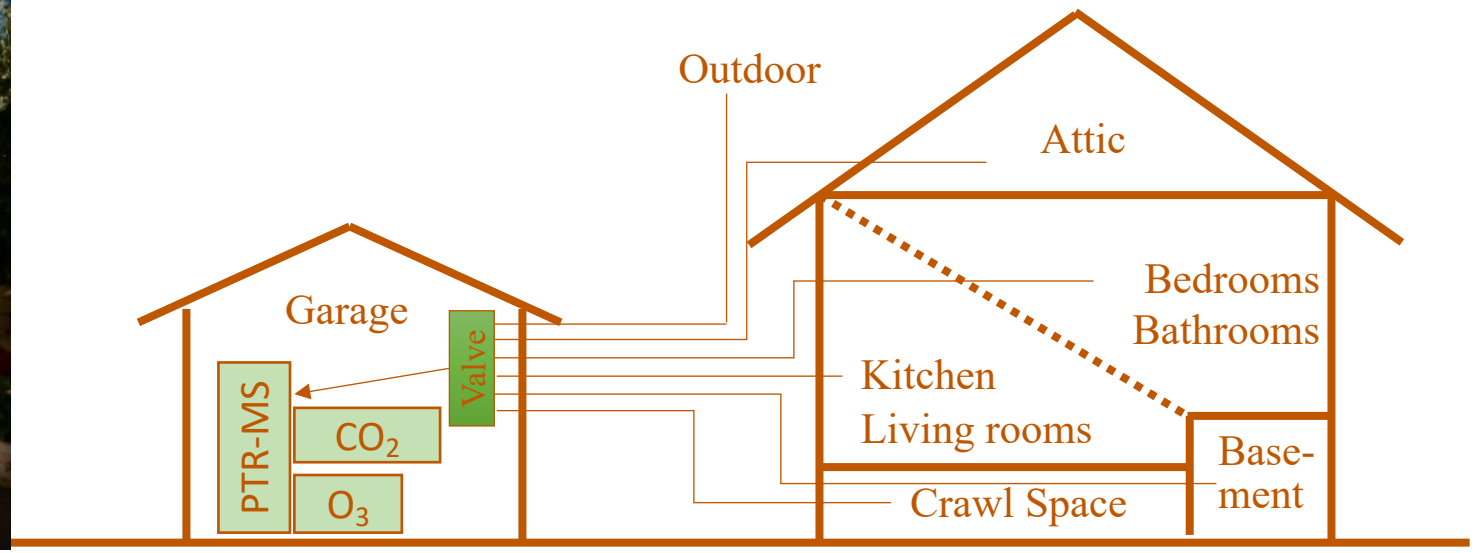
Environmental Science & Technology

Nationally Representative Levels of Selected Volatile Organic Compounds in Canadian Residential Indoor Air: Population-Based Survey

Jiping Zhu, Suzy L. Wong, and Sabit Cakmak
Environmental Science & Technology **2013** *47* (23), 13276-13283
DOI: 10.1021/es403055e

Novel methodologies for indoor air quality studies

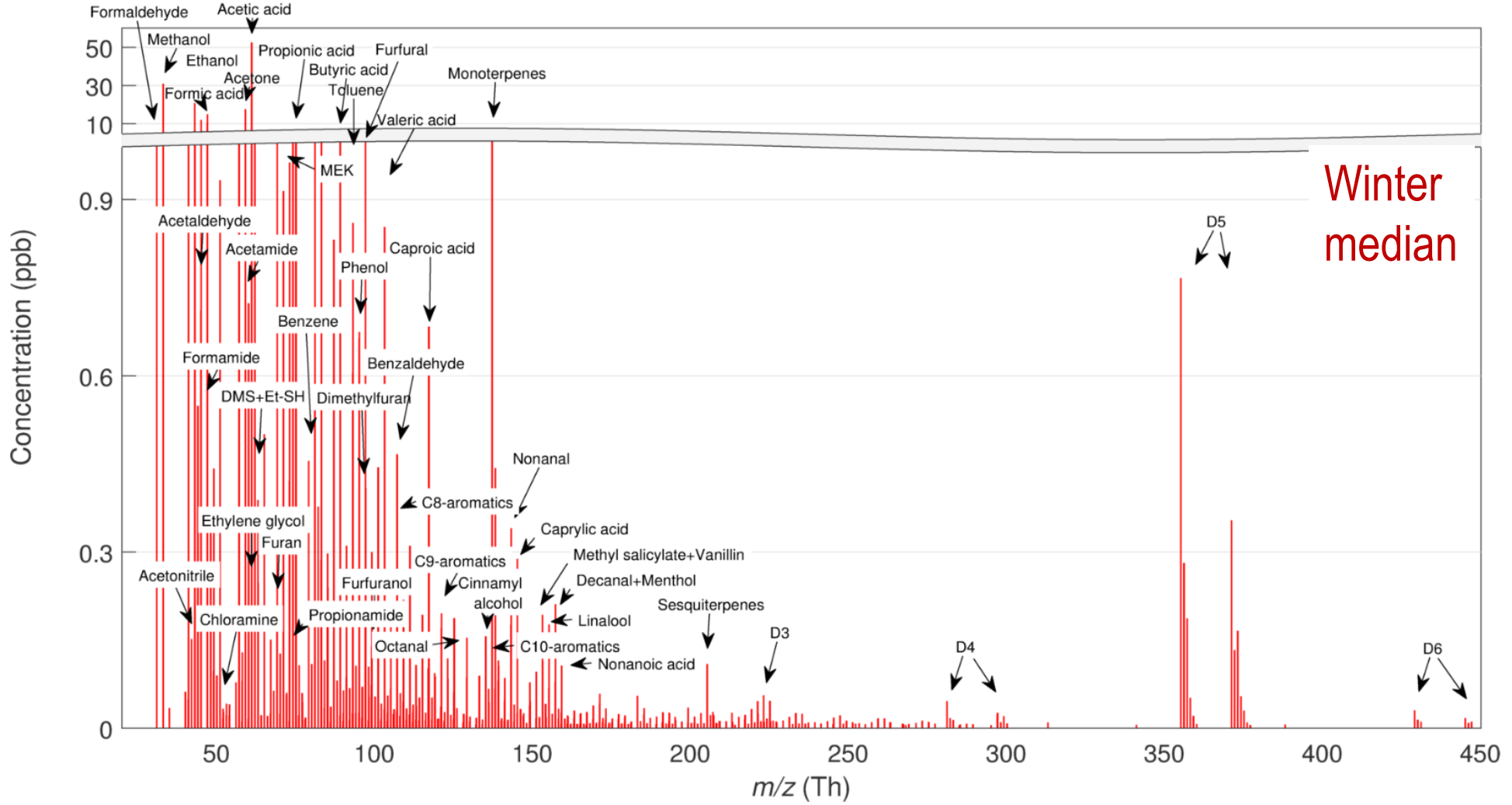
Continuous automated spatial and temporal sampling



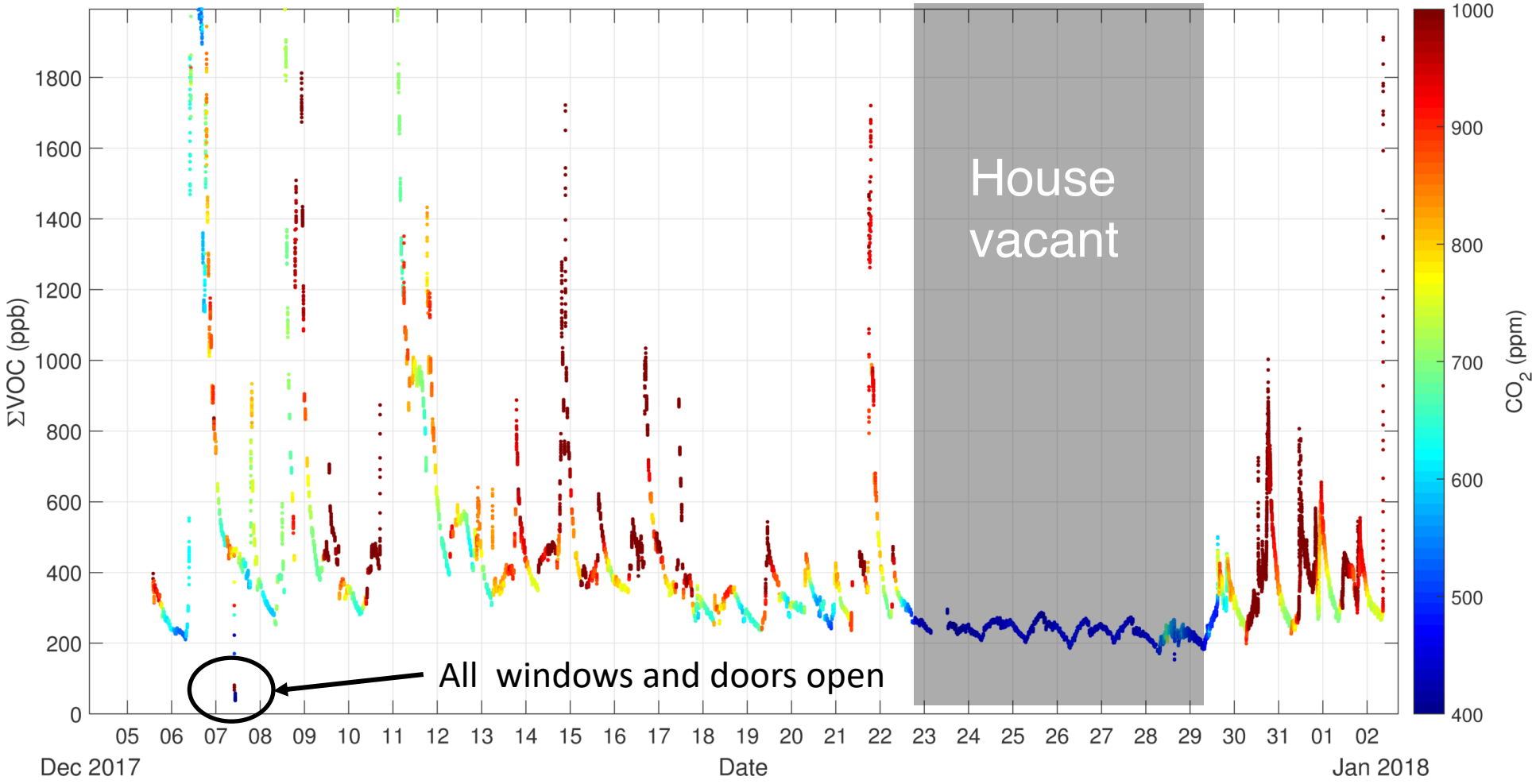
Liu, Misztal et al., 2019

VOC composition of indoor air

(mass spectrum including > 200 VOCs)

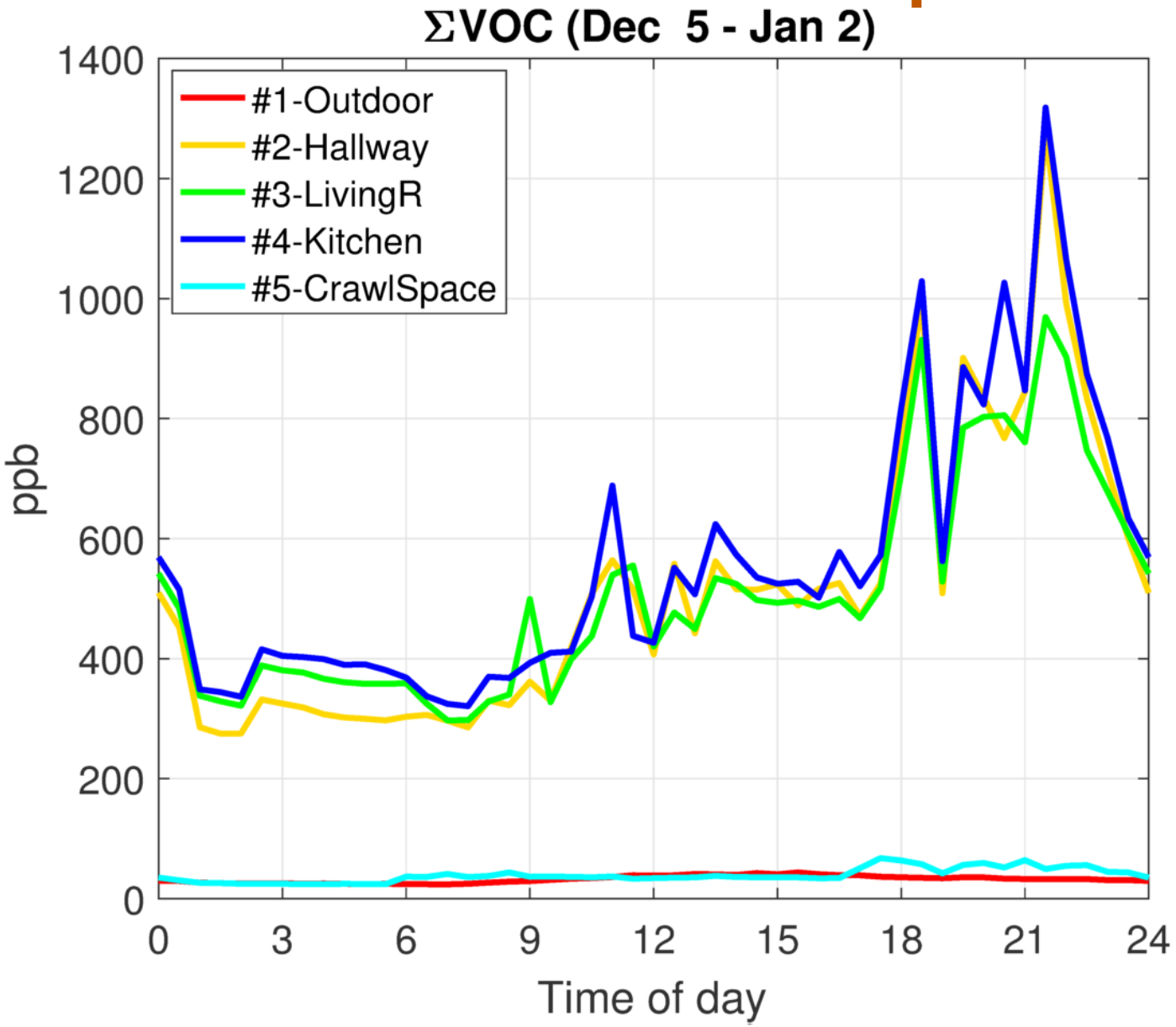


ΣVOC in H2 Living Room: One-month timeline

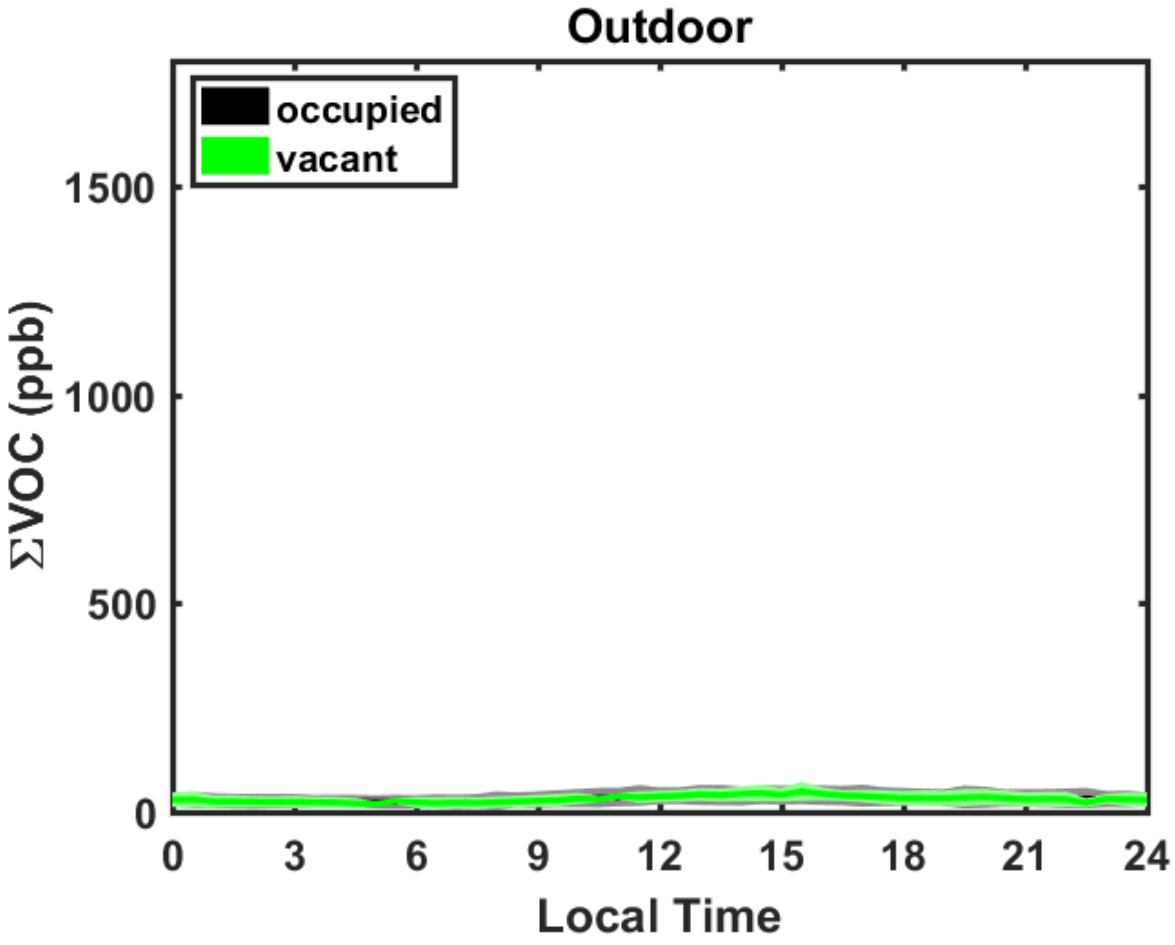


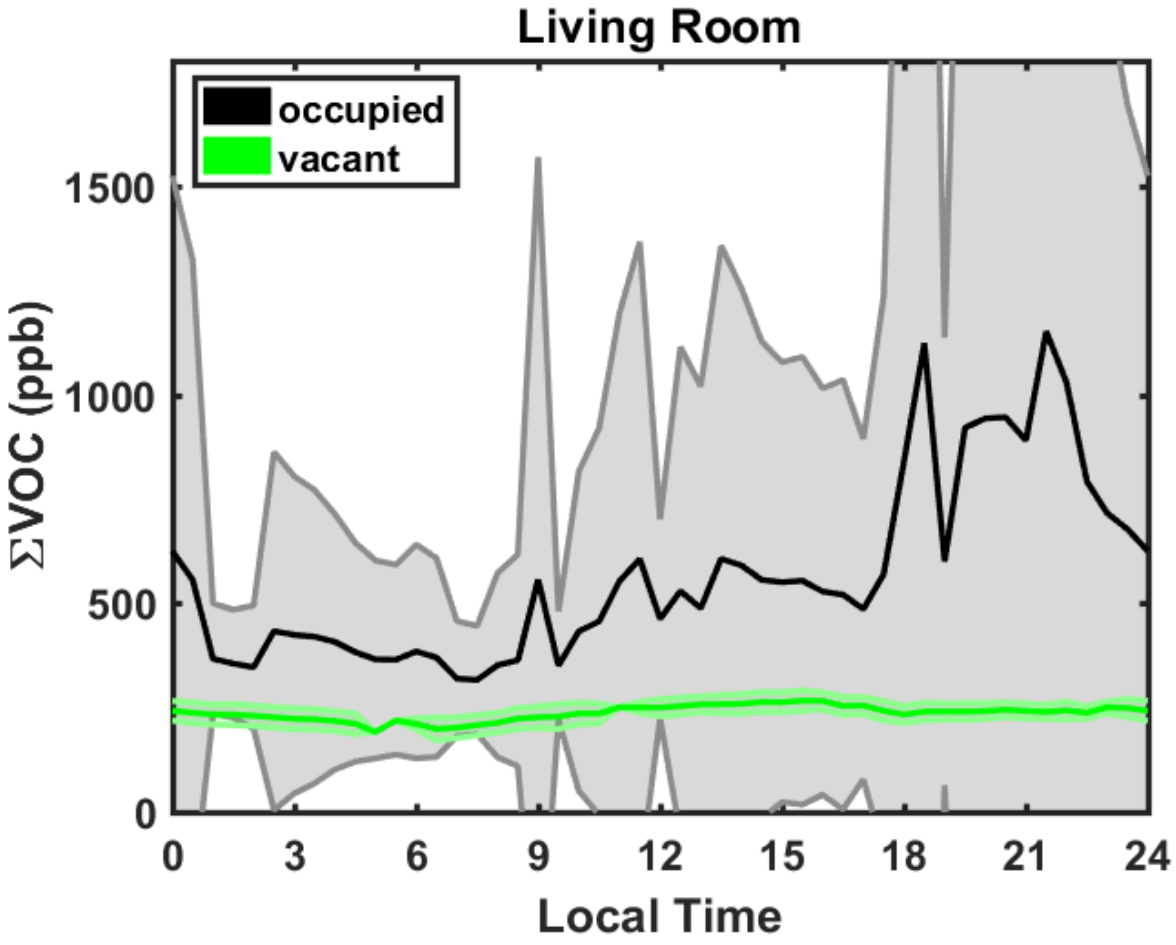
indicates majority of emissions are caused by humans

ΣVOC: One month on diel pattern



ΣVOC: Occupied vs vacant





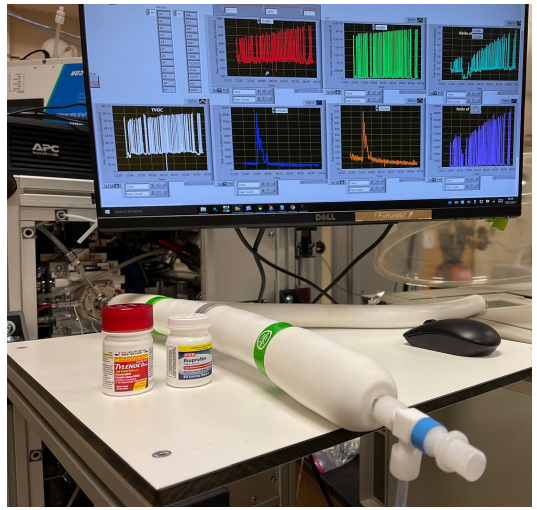
How to embrace complexity of human exposures to understand their effect on human health?

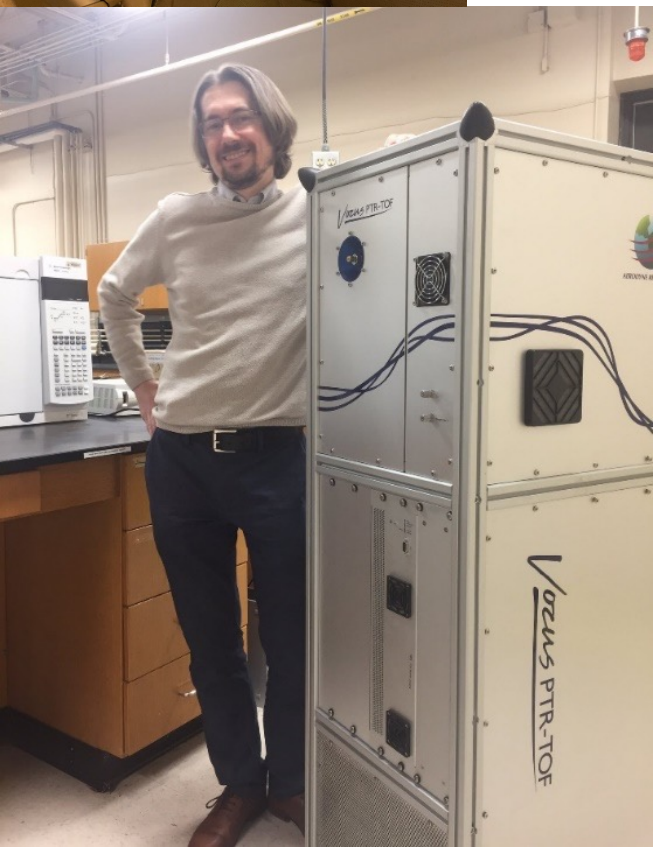
Novel methods of "sniffing" chemical composition

Vocus 2R PTR-ToF (The "Sniffer")

$$H_3O^+ + R \rightarrow RH^+ + H_2O$$

Soft chemical ionization (proton transfer)





- Real Time (<1 s)
- Ultra-high mass resolution
- Sensitive to a broad range of compounds
- Limit of detection <1 ppt
- >1000 compounds measured at once
- Revolutionary applications in medical, environmental and industry

What is indoor exposure to disinfectant byproducts?

Source: Reports and Data

Global disinfection market expected to reach $30 billion by 2027

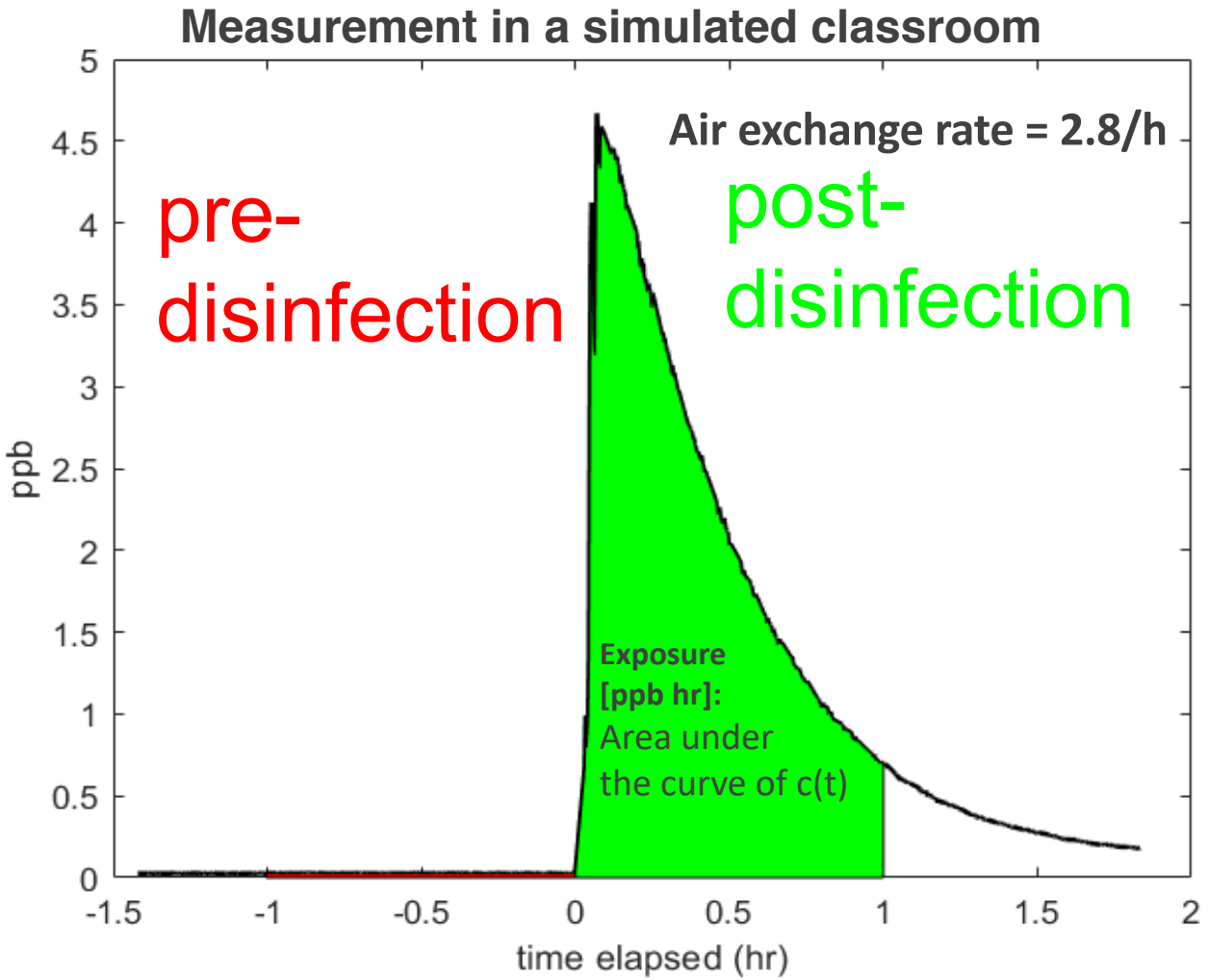
Texas ISDs: "… use fogging, spraying and misting technologies with a blend of high-powered disinfectants, cleaners and RAZOR Antimicrobial Coating"

Should we care what's in our cleaners?
Are there risks of disinfectant exposure?

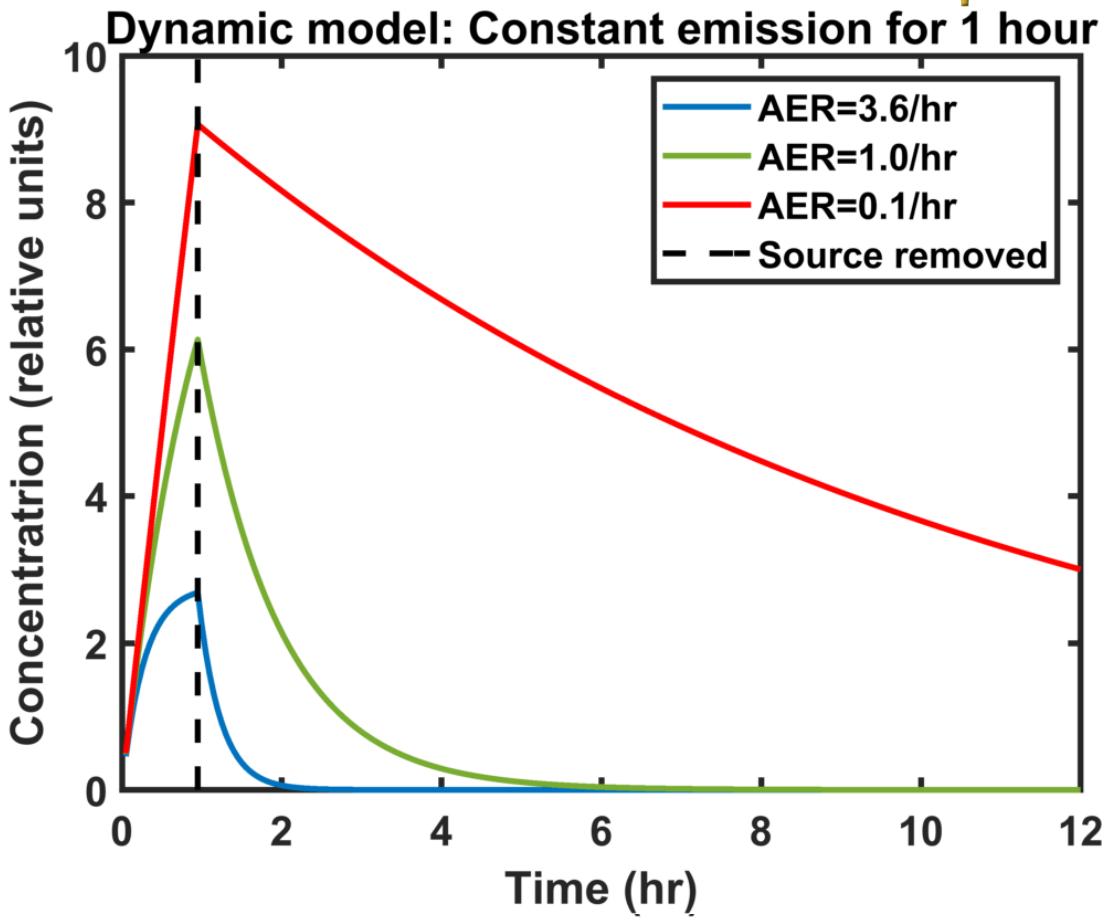
Disinfection Project Team

Daniel Blomdahl

How to reduce the exposure to disinfectants?

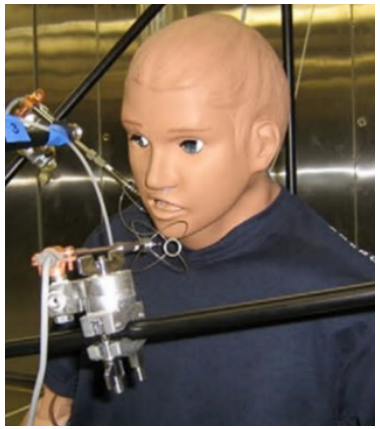


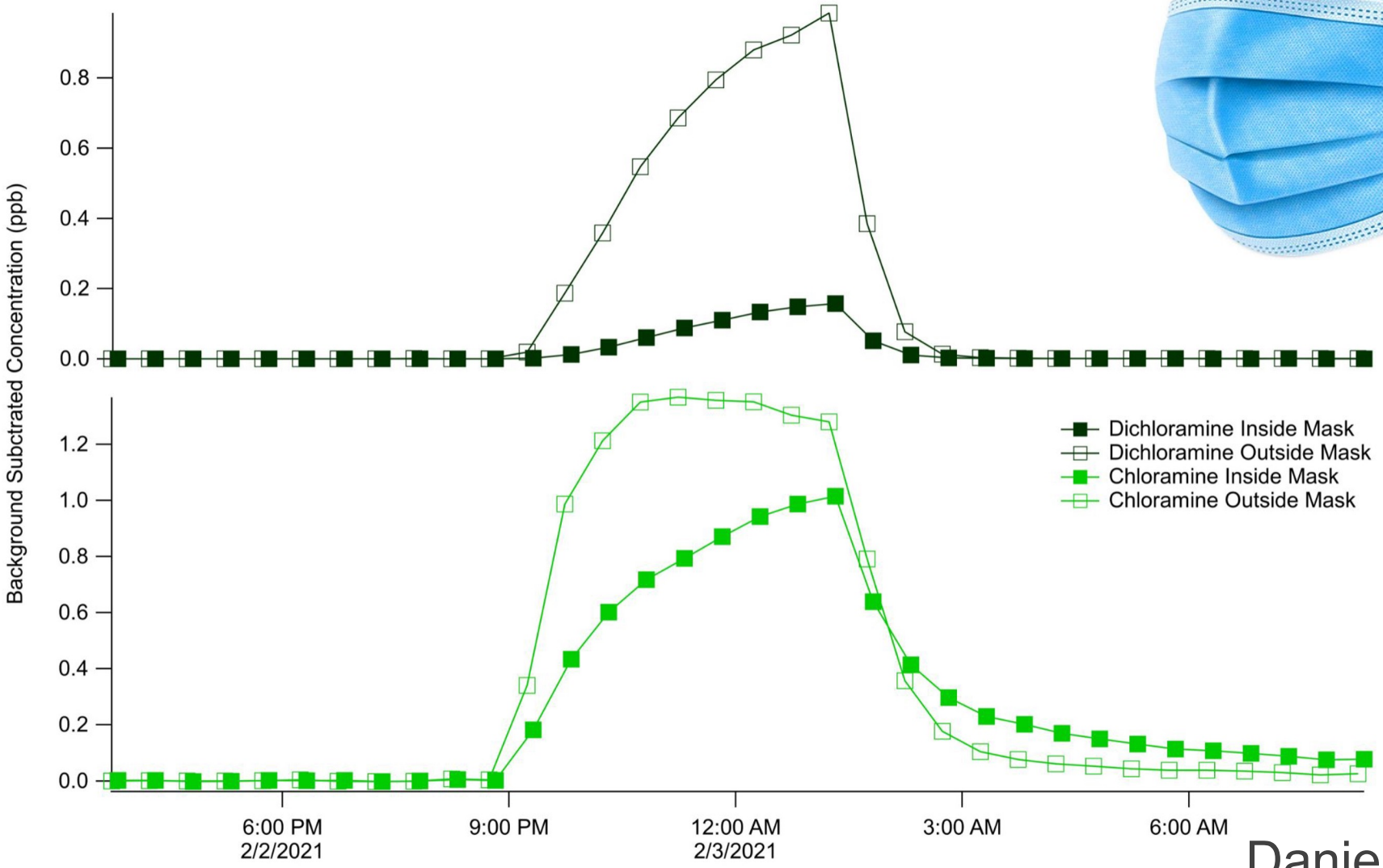
Daniel Blomdahl et al., in prep.



Huge effect of ventilation on reducing exposure!

How do masks affect exposure to disinfection byprodcts?





Daniel Blomdahl et al., in prep.

How does indoor process affect exposure to material emissions?

Building and Environment 205 (2021) 108290

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

ALFRED P. SLOAN
FOUNDATION

Check for updates

Varying humidity increases emission of volatile nitrogen-containing compounds from building materials

Emma C. Hall [a], Sarah R. Haines [b,c,d], Katarzyna Marciniak [e], Allen H. Goldstein [f], Rachel I. Adams [g], Karen C. Dannemiller [c,d,h], Pawel K. Misztal [a,*]

[a] Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, TX, 78712, USA
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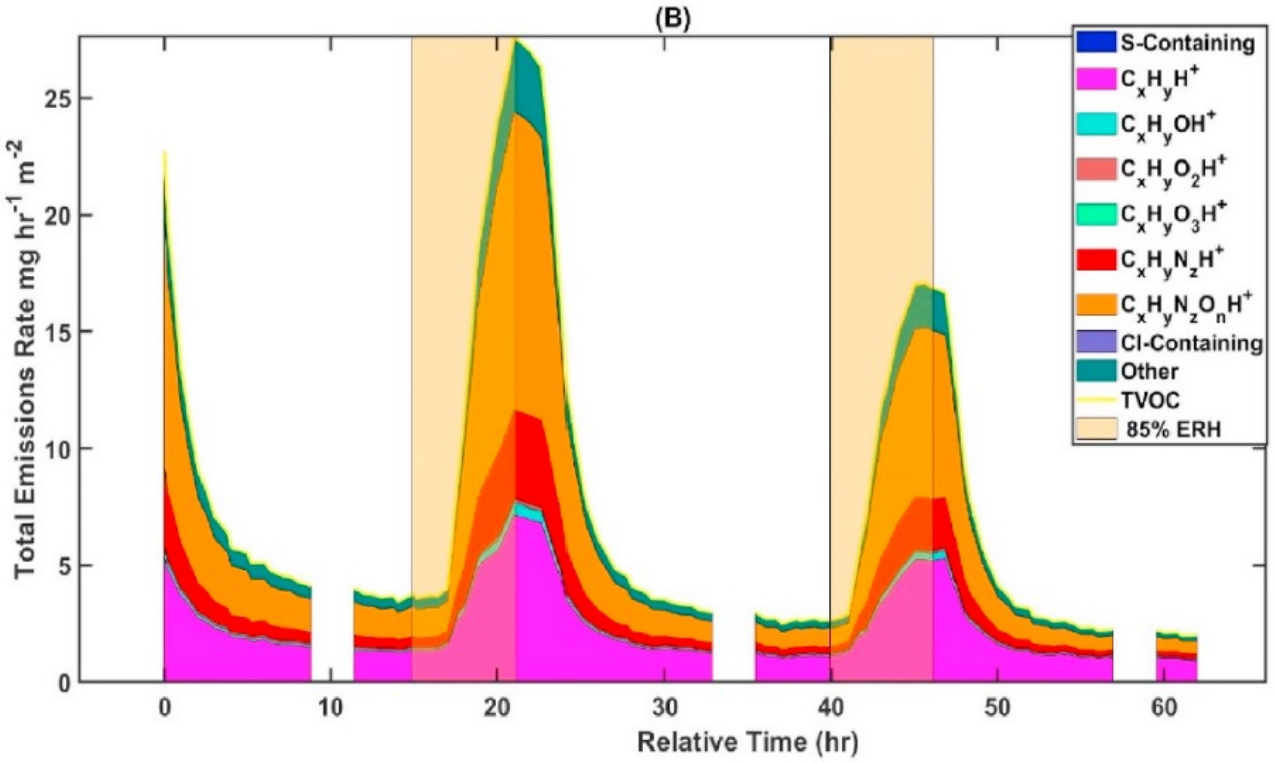
[d] Division of Environmental Health Sciences, College of Public Health, Ohio State University, Columbus, OH, 43210, USA
[e] School of Chemistry, The University of Edinburgh, Edinburgh, EH9 3FJ, UK
[f] Department of Environmental Science, Policy and Management, University of California, Berkeley, CA, 94720, USA
[g] Department of Plant and Microbial Biology, University of California, Berkeley, CA, 94720, USA
[h] Sustainability Institute, Ohio State University, Columbus, OH, 43210, USA

The drying and rewetting process results in higher emission of material degradation markers.

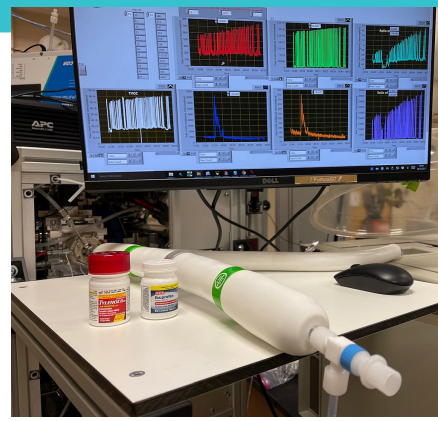


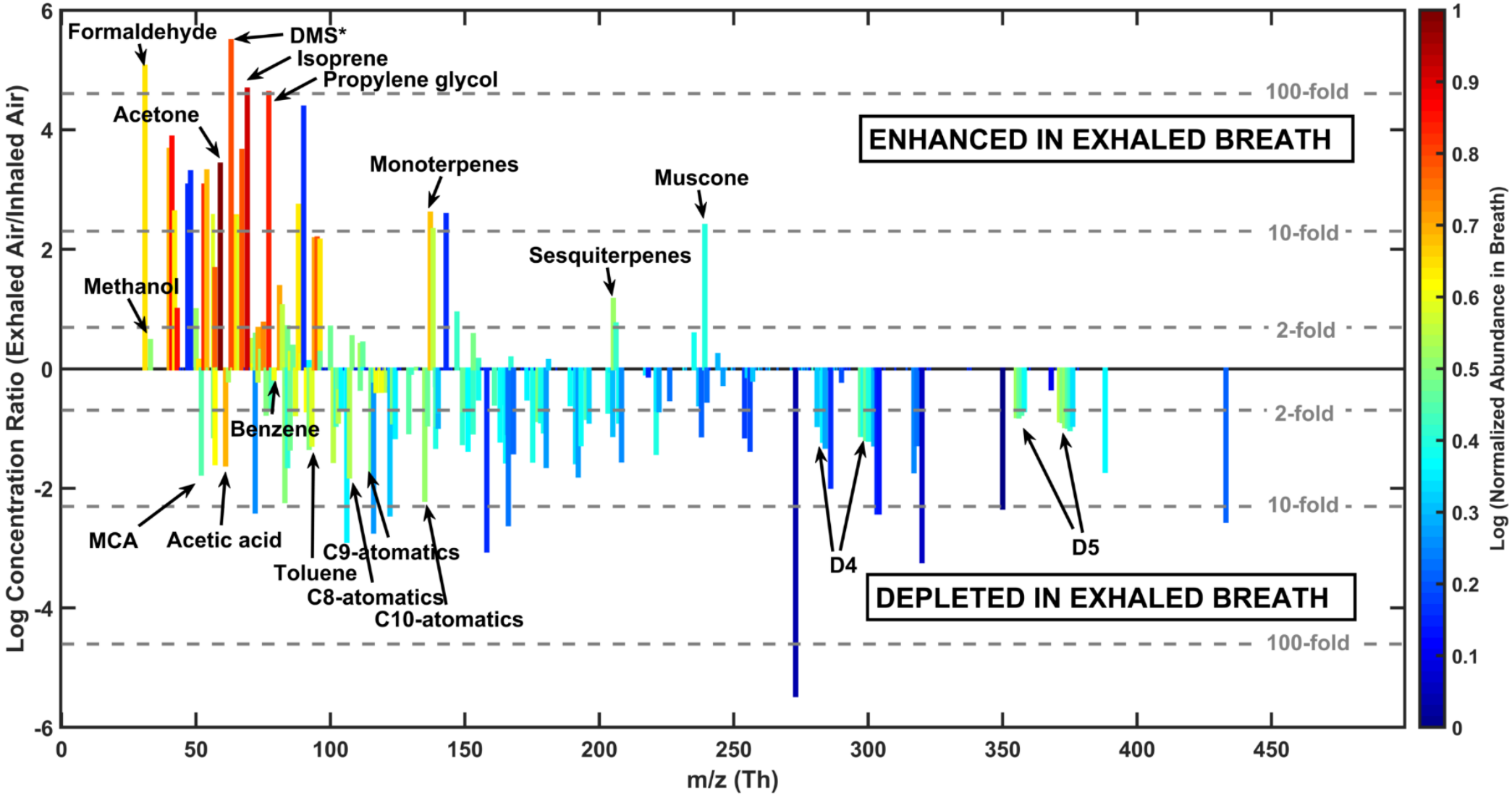
Do we measure everything that relevant for quantifying chemical exposure?

Figure credit: Salthammer et al. 2018 Angewandte Chemie ***https://doi.org/10.1002/anie.201711023***

Little understanding of chronic effects. Need to build on what we know but stay openminded!

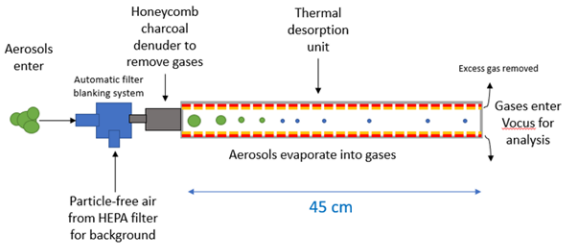
Human breath analysis provides valuable insight on exposure



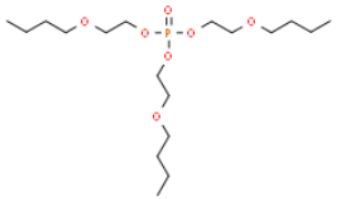


Paulien Aerts et al., in prep.

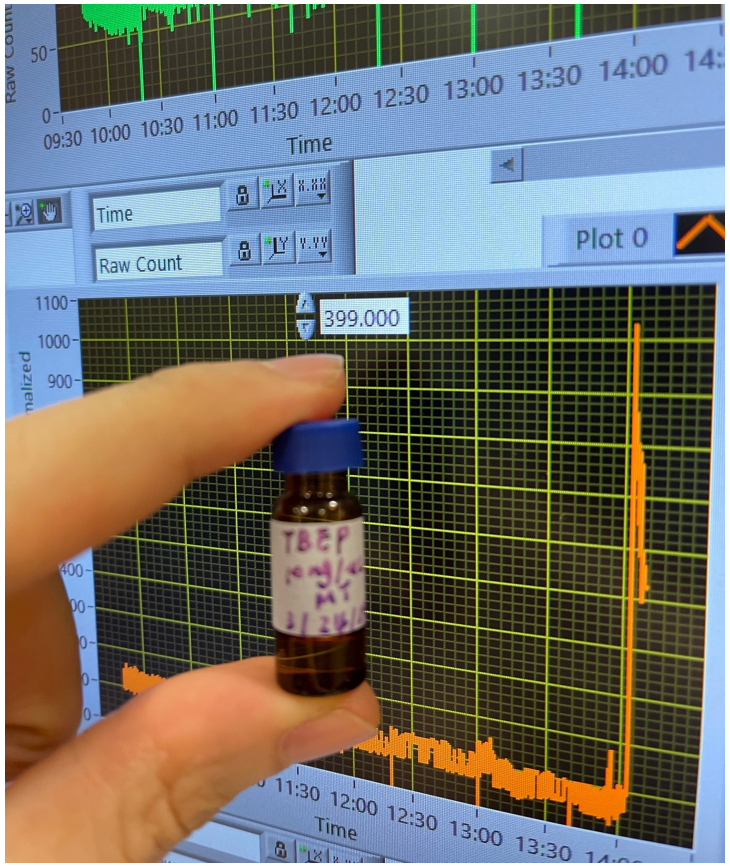
SVOC measurements in liquids and aerosol



Vocus Inlet for Aerosol (VIA)



Molecular Formula	$C_{18}H_{39}O_7P$
Average mass	398.472 Da
Monoisotopic mass	398.243347 Da
ChemSpider ID	6292

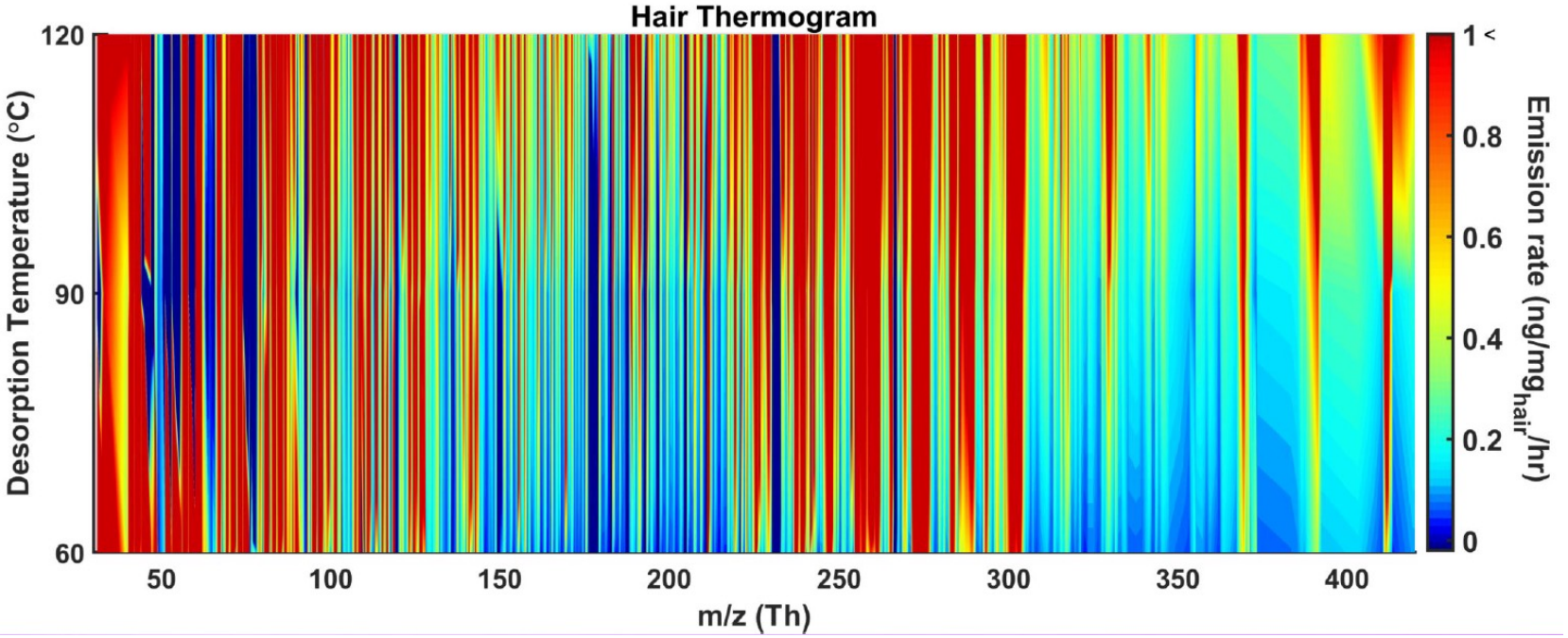


Tris-butoxyethylphosphate (TBEP) is a low volatility SVOC (bp > 400 °C) flame retardant, difficult to detect by common techniques. Here just 5 μL of the 10 ng/mL standard is injected to the VIA. *Blomdahl et al., in prep*.

Can we measure exposure in human hair?

- Hair grows ~½ in/month
- Higher accumulation of metals and toxics than in blood and breath
- Used in forensics for various toxins after segmenting to represent prior history of exposure

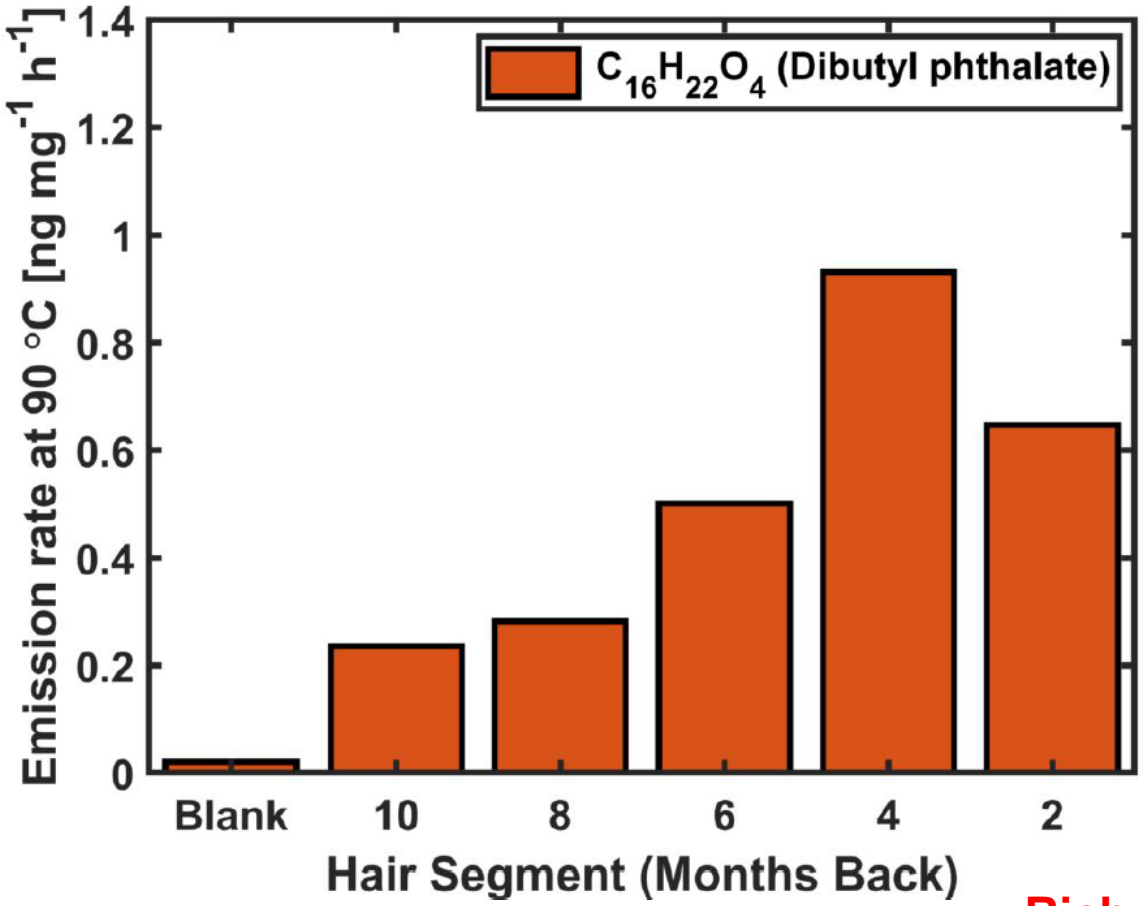
Anna Neville



Anna Neville et al., in prep.

Some higher volatility VOC evaporate completely (left), SVOC increase with T (right)

Dibutyl phthalate was the highest in the 4 months prior segment



Anna Neville

Anna Neville et al., in prep.

Rich chemical composition in hair segments

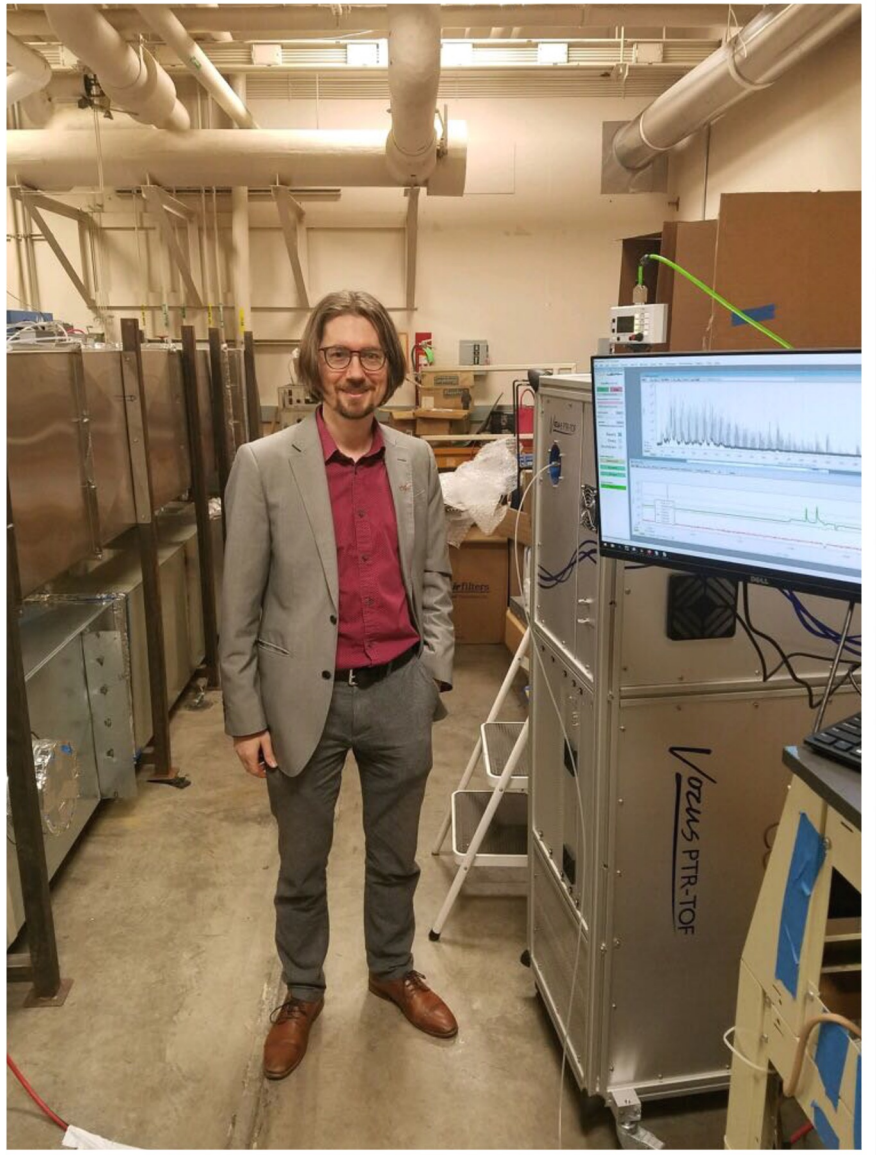
Recent exposure similar in all segments

Variance across segments points to different periods of exposure

"Solution to Indoor Pollution is Dilution"

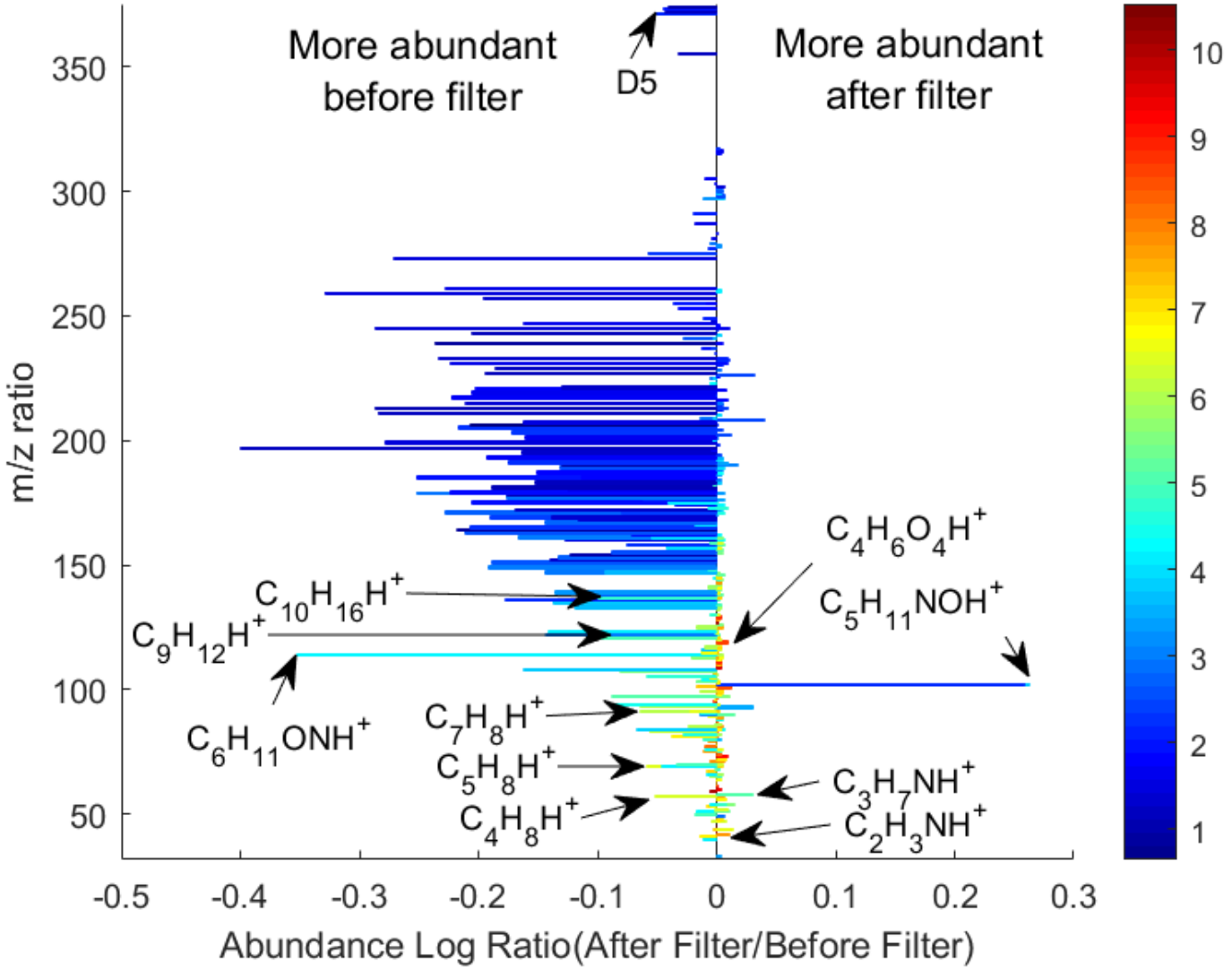
HVAC Filter Chemistry

Collaboration with Prof. Novoselac's group



- Ozone byproducts generated on filters
- Removal efficiency of broad range of chemicals
- Chemistry driven by UV

Chemistry on Carbon Filters – Example of an Efficient Filter



- Removal efficiency is compound specific!

Compounds removed	Compounds produced
Vast majority of VOCs – tendency to high molecular weight compounds (usually unabundant) D5 siloxanes Isoprene, Styrene, etc.	$C_5H_{11}NO$ (N-methylmorpholine) C_2H_3N (acetonitrile) C_3H_7N (propyleneimine) $C_4H_6O_4$ (succinic acid) C_2H_4O (acetaldehyde) $C_2H_4O_2$ (acetic acid)

Summary and future directions

- The fact that the indoor air quality is unregulated does not mean that it has no effect on human health! → More studies needed of indoor air quality.
- Need novel measurements of both acute and chronic exposure indoors, outdoors and in body effluents (breath, sweat, blood, urine, and hair).
- Need to quantify the link between exposure and human health.
- Need to catalogue chemical signatures of major indoor sources and processes? → "you don't inhale the same air twice".
- Engineering Solutions: Source Control, Ventilation, Filtration.

HEI energy

Thank You!

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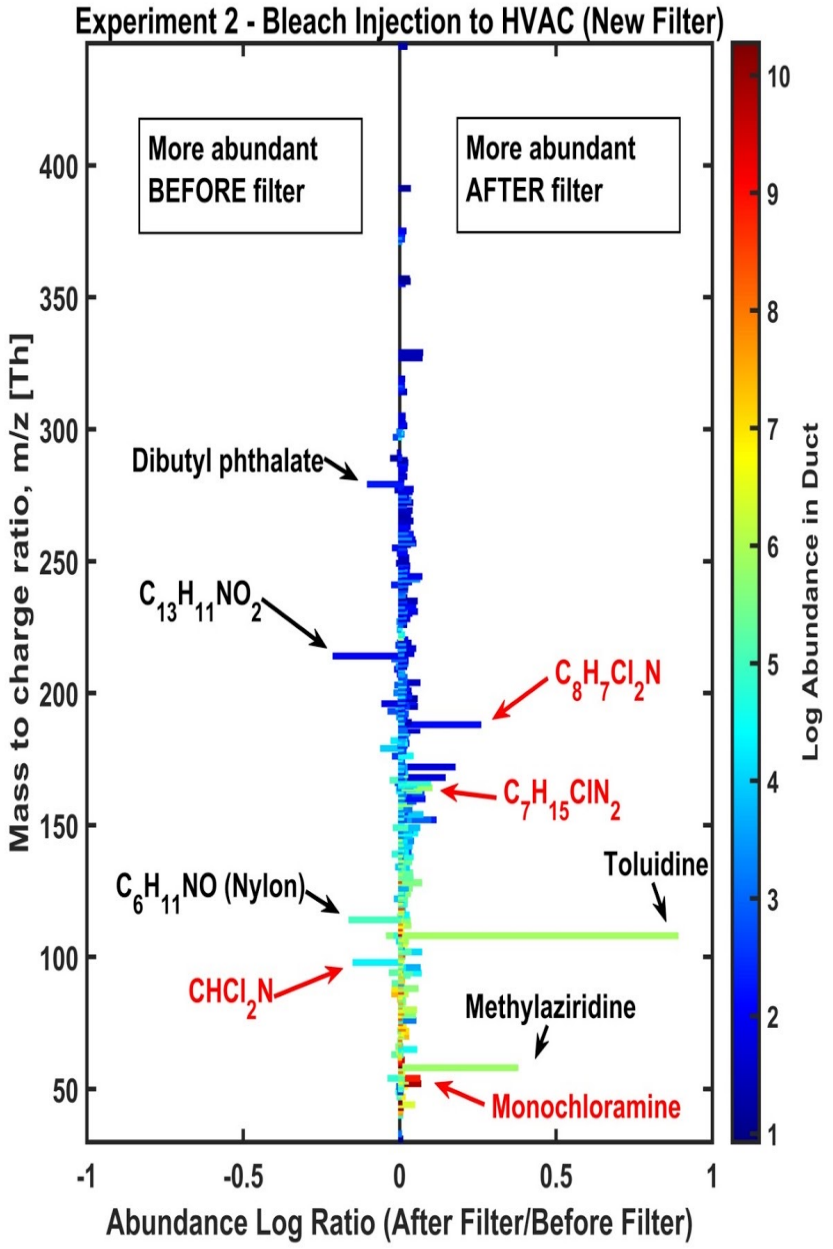
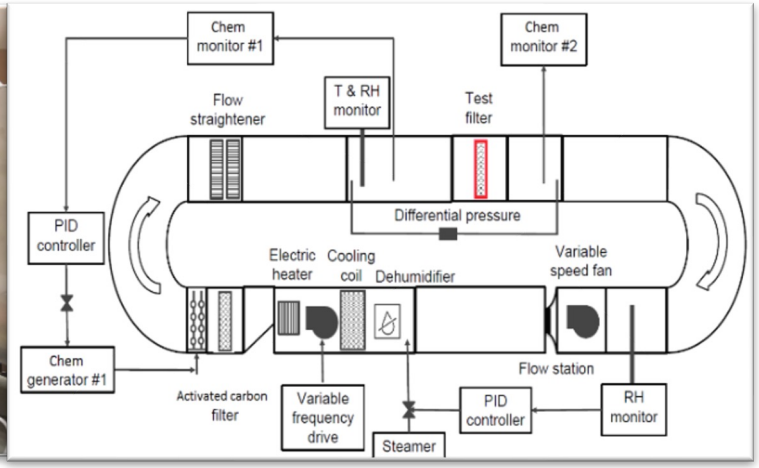
Supplementary Slides

What is the fate of disinfectants in the HVAC Ducts?

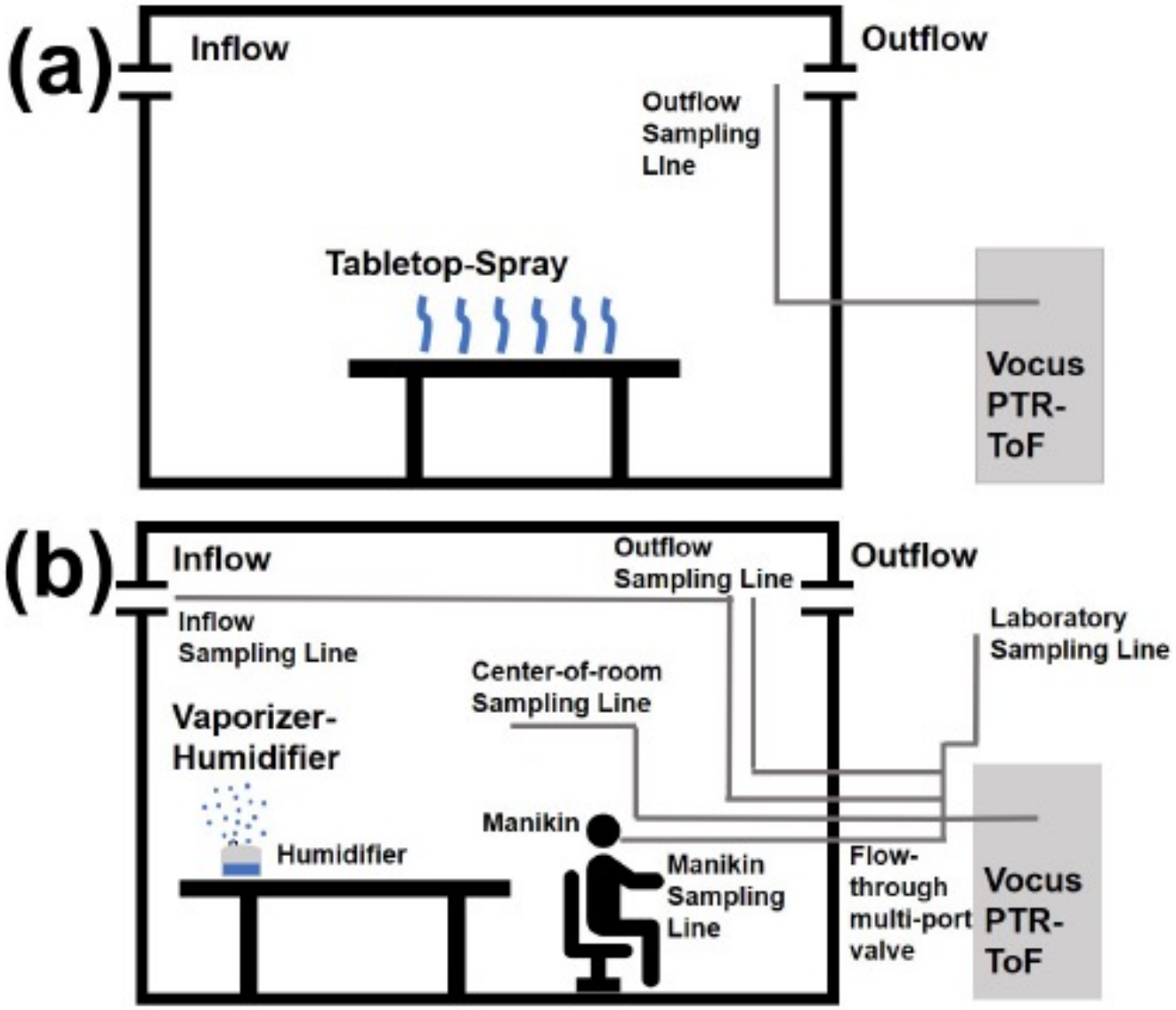




- HVAC filters can remove disinfectants
- Bleach vapor generates chlorine-initiated oxidation byproducts of HVAC filter components (don't spray bleach into your HVAC system!)

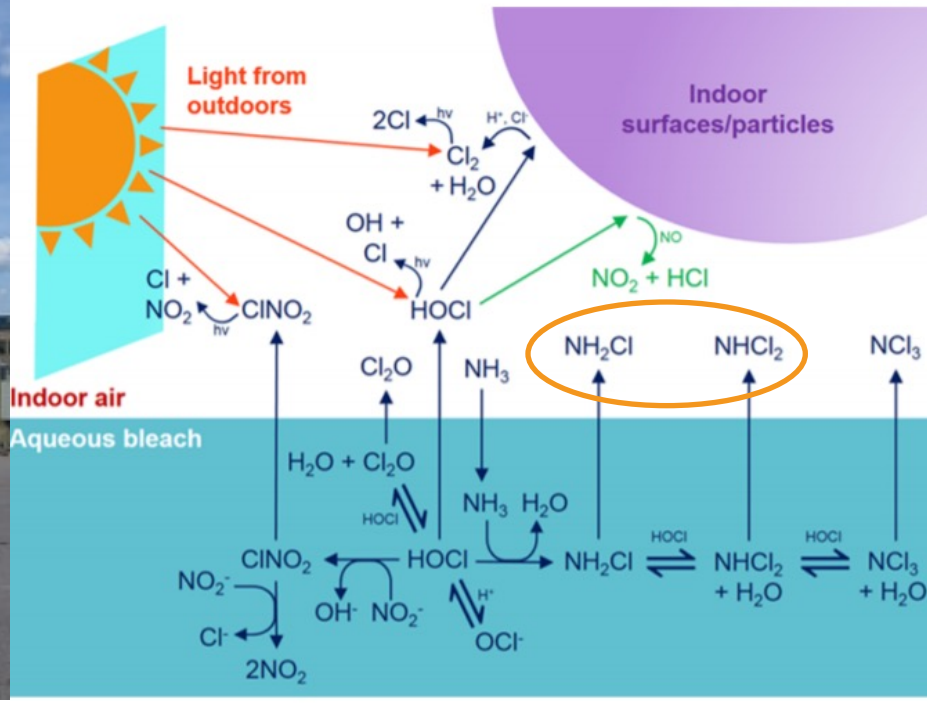
Controlled Experiments in a Simulated Classroom

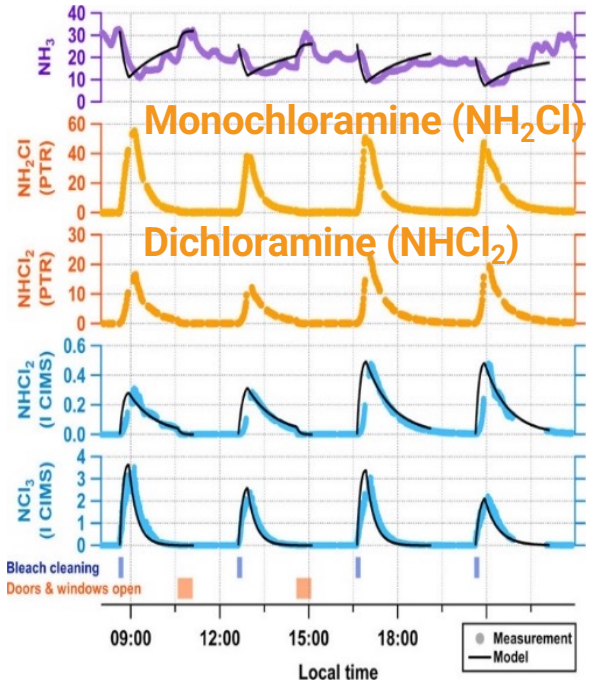
- 67 m^3 stainless steel chamber
- Air exchange rate = 2.8 h^{-1}
- Wall boards, carpet, ceiling tiles fluorescent light
- 6 tables (surface area 5.7 m^2)



What do we know about chemistry from bleach cleaning?

UT Test House HOMEChem campaign





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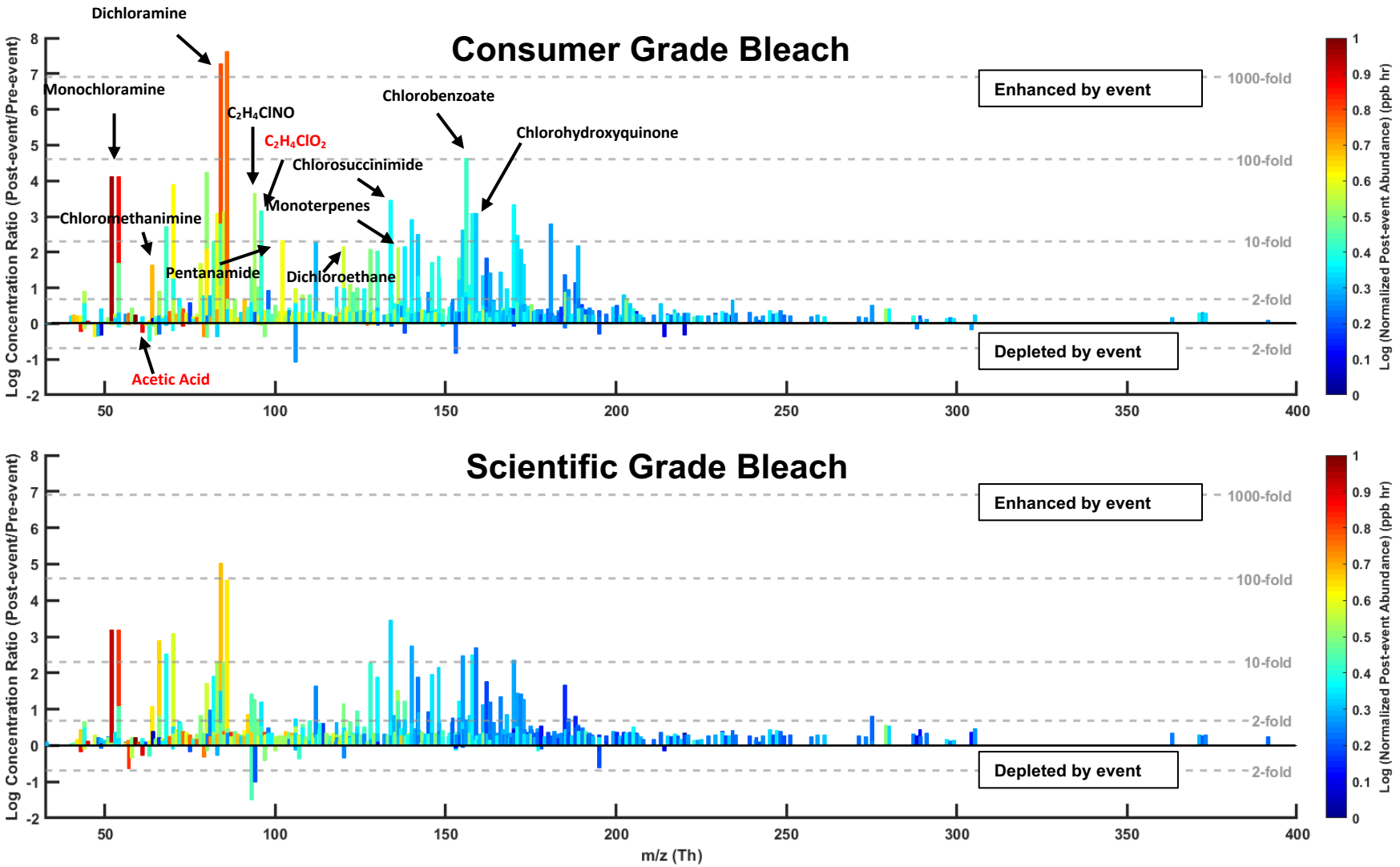
What is in the bleach (consumer vs research grade)



Rich chemical composition consistent for consumer-grade bleach and 95% purity scientific grade bleach.

Chemical composition is driven by primary compounds, byproducts, impurities, and reaction products.

Bleach reacts with acetic acid forming toxic chloroactic acid