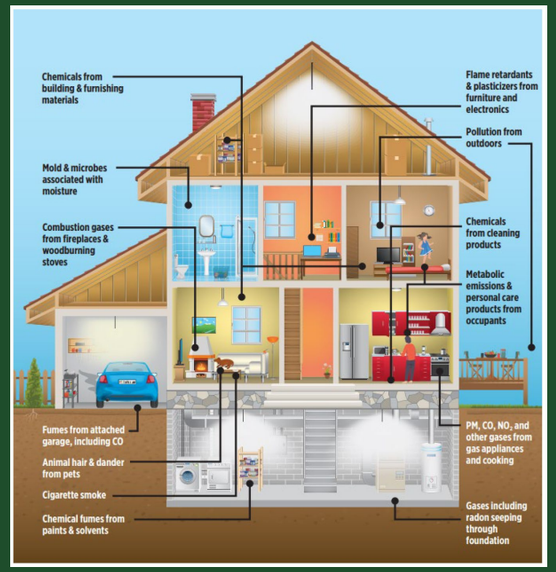
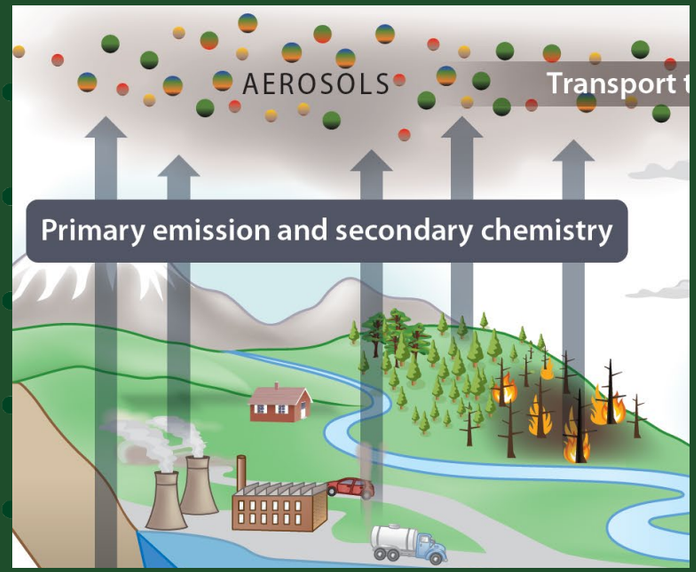
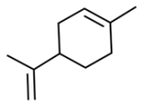
Emerging Questions in Urban Air:
Links between indoor and outdoor chemistry

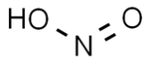


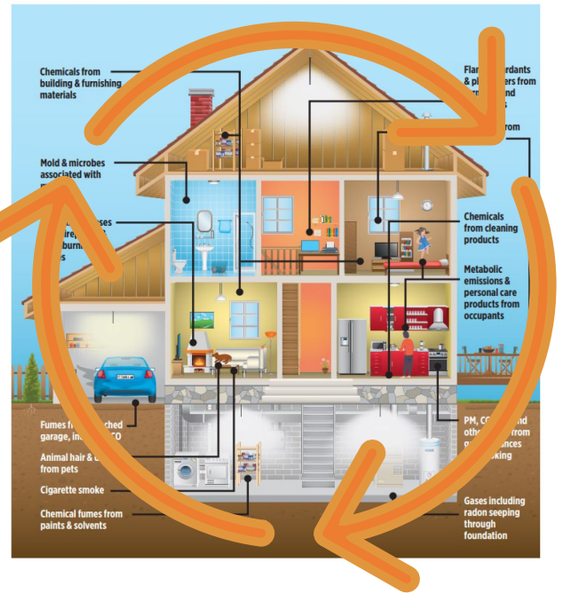


Delphine Farmer
Department of Chemistry
Colorado State University

How do indoor and outdoor air chemically interact?



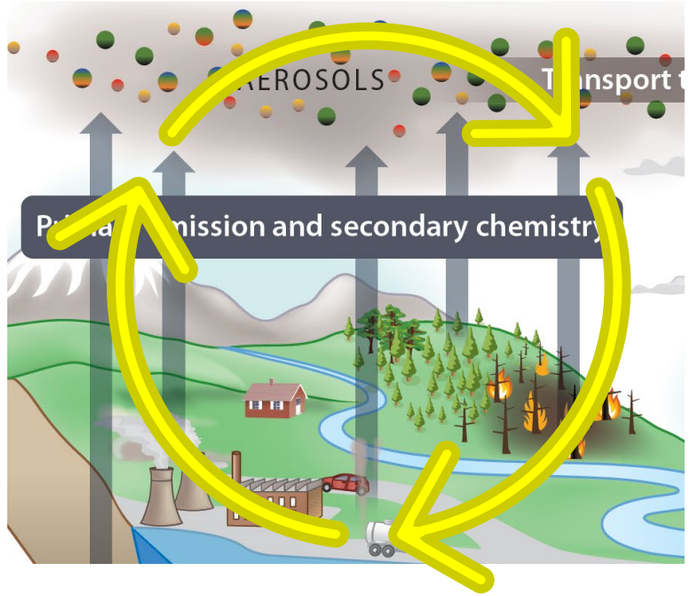




VOCs (indoor)

VOCs (outdoor built surfaces)

Outdoor pollutants impact indoor air
e.g. Link et al. Env Sci Tech. 2023
Li et al. Sci Adv. 2023



O_3

NO_x

Smoke

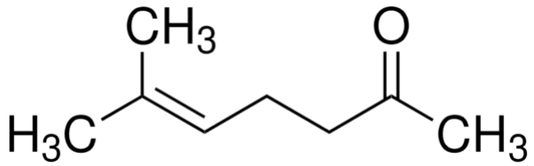
Indoor air as a source for outdoor air
e.g. Mattila et al. Env Sci Tech. 2021
Coggon et al. ACP. 2024
Molinier et al. ACS ES&T Air. 2024

How do <u>outdoor sources</u> influence indoor air?

VOC partitioning to indoor surfaces was the subject of a recent NASEM webinar, including discussion of smoke

*see recording on NASEM Indoor Chemistry webpage

Infiltration of outdoor O_3 consistently and persistently impacts oxidation of indoor VOCs

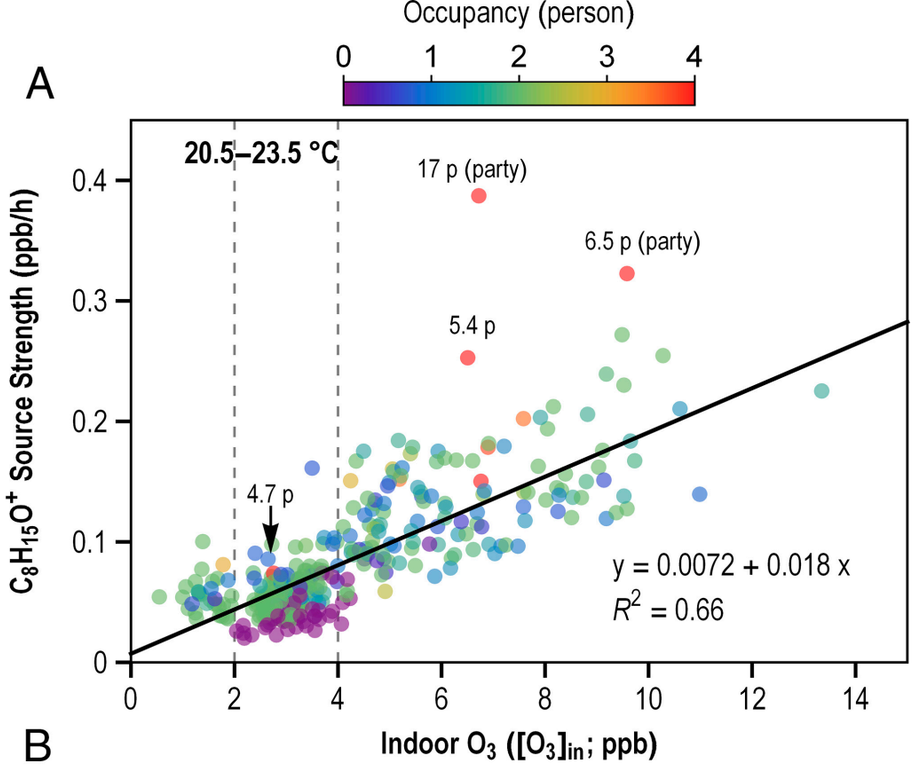


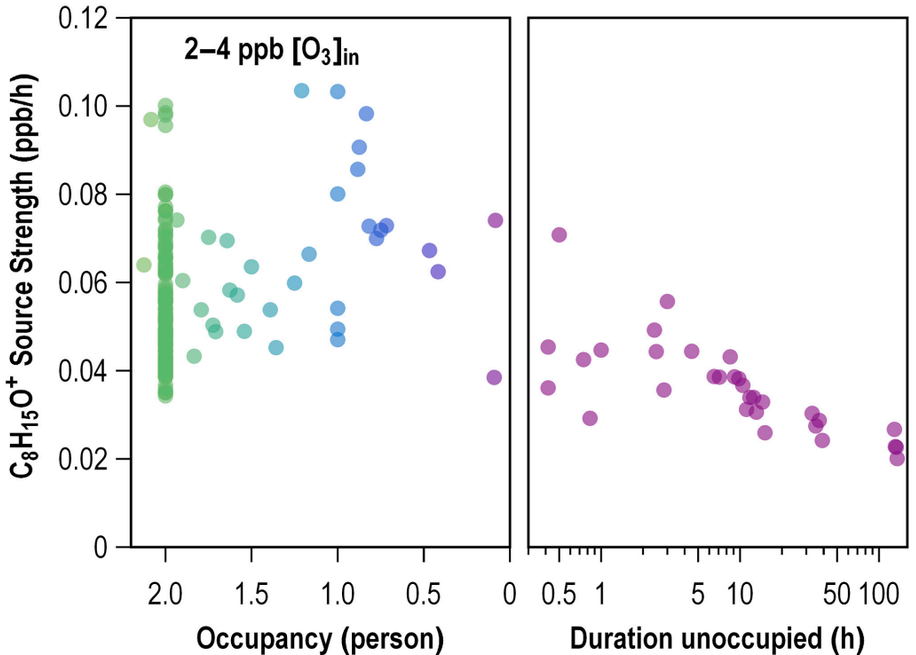
6-MHO
6-methyl-5-hepten-2-one

Product of skin lipids + O_3

Key Finding: Outdoor O_3 impacts indoor oxidation despite apparent low levels and slow decay rates

Question: What are the implications of on indoor air chemistry – and health?



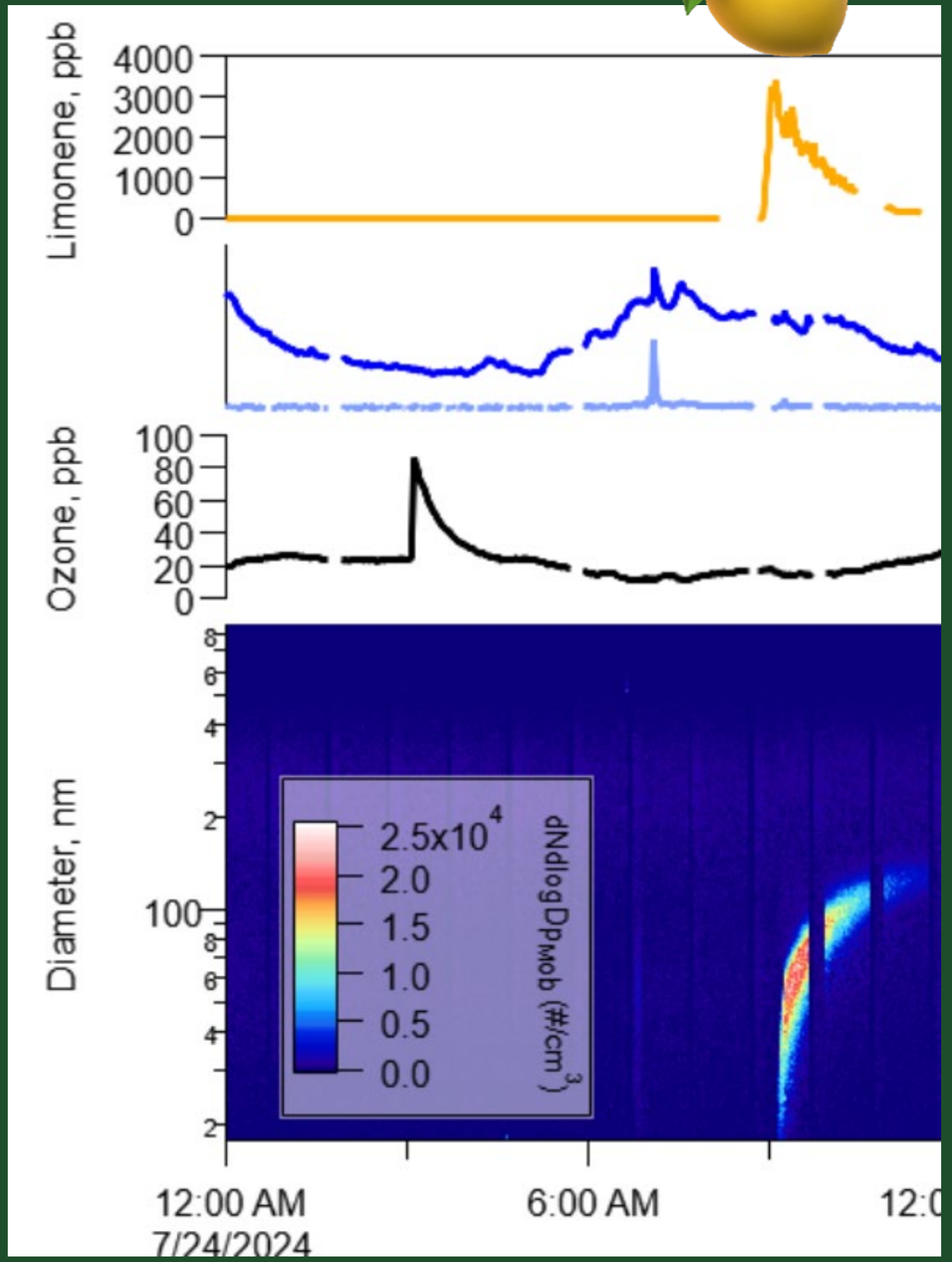


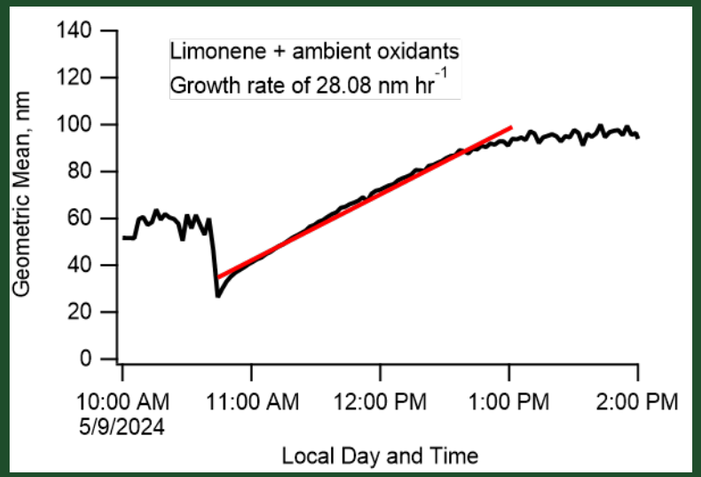
Observing ozone chemistry in an occupied residence

Yingjun Liu, Pawel K. Misztal, Caleb Arata, +2, and Allen H. Goldstein Authors Info & Affiliations

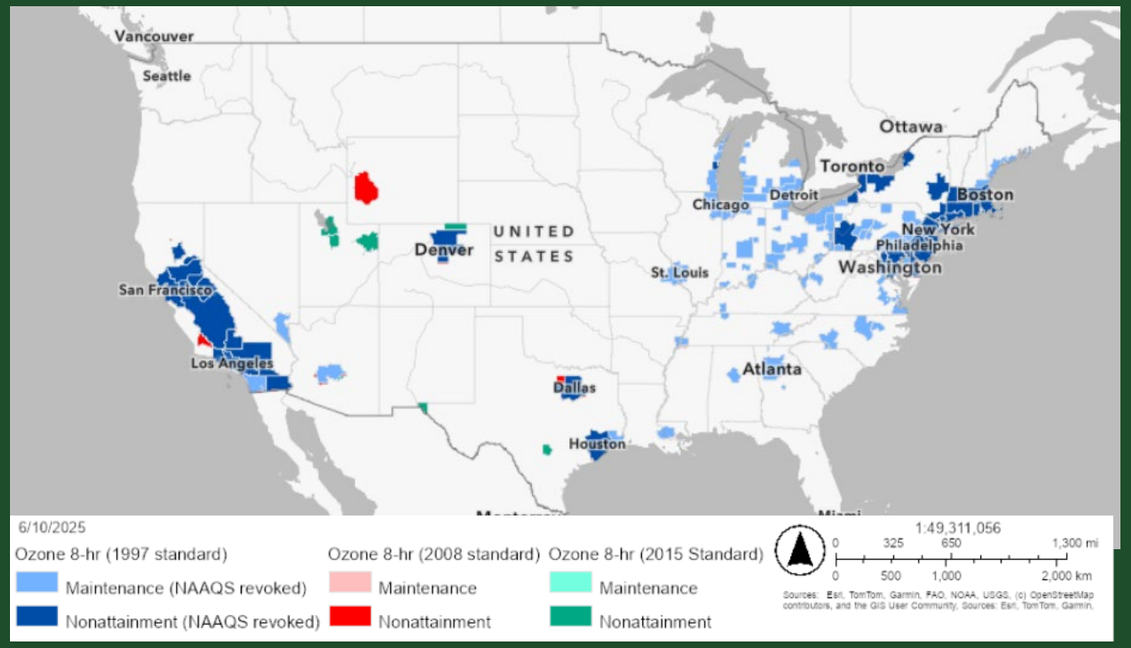
February 1, 2021 | 118 (6) e2018140118 | https://doi.org/10.1073/pnas.2018140118

Infiltrated O_3 + indoor VOCs can produce ultrafine particles





- Very fast new particle formation
- Requires monoterpenes AND O_3
- High outdoor O_3 with air change rates will impact indoor gases and particles



Lauren Garofalo et al., In prep.

Ventilation of outdoor NO_x and O_3 impacts indoor chemistry

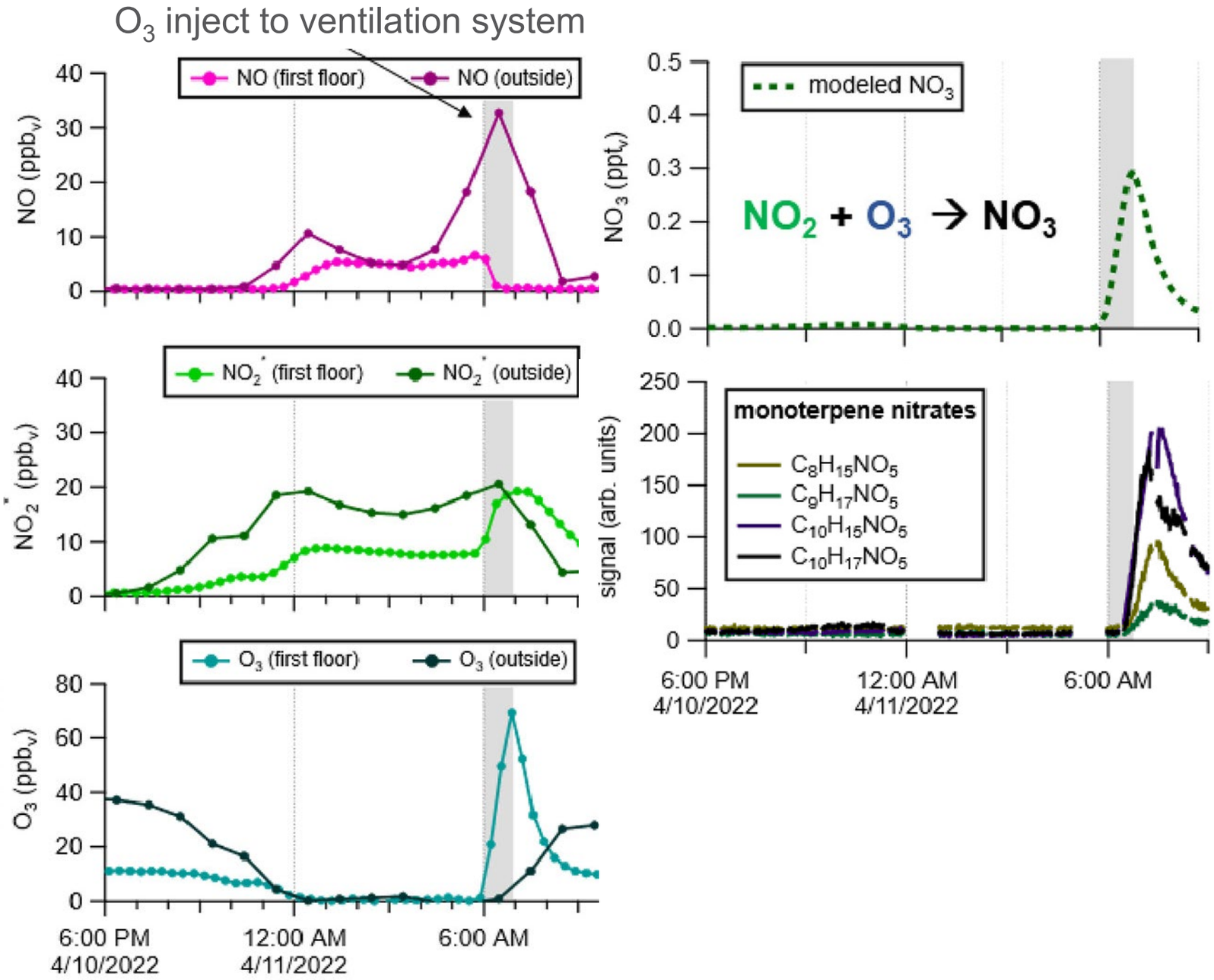
During ambient outdoor NO_x events,

$$NO + O_3 \rightarrow NO_2 + O_2$$

Elevated will suppress NO_3

If this NO_x event coincides with enhanced O_3, then enhanced formation of NO_3, N_2O_5, $ClNO_2$, and even organic nitrates ($RONO_2$)

Key Finding: Ventilation of outdoor pollution impacts indoor oxidation

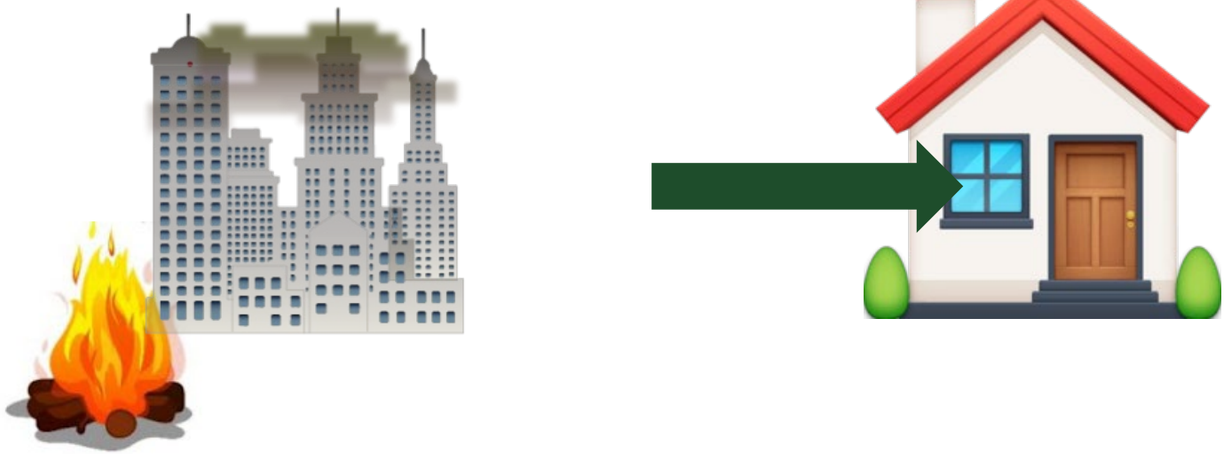


Environmental Science & Technology

pubs.acs.org/est

Ventilation in a Residential Building Brings Outdoor NO_x Indoors with Limited Implications for VOC Oxidation from NO_3 Radicals

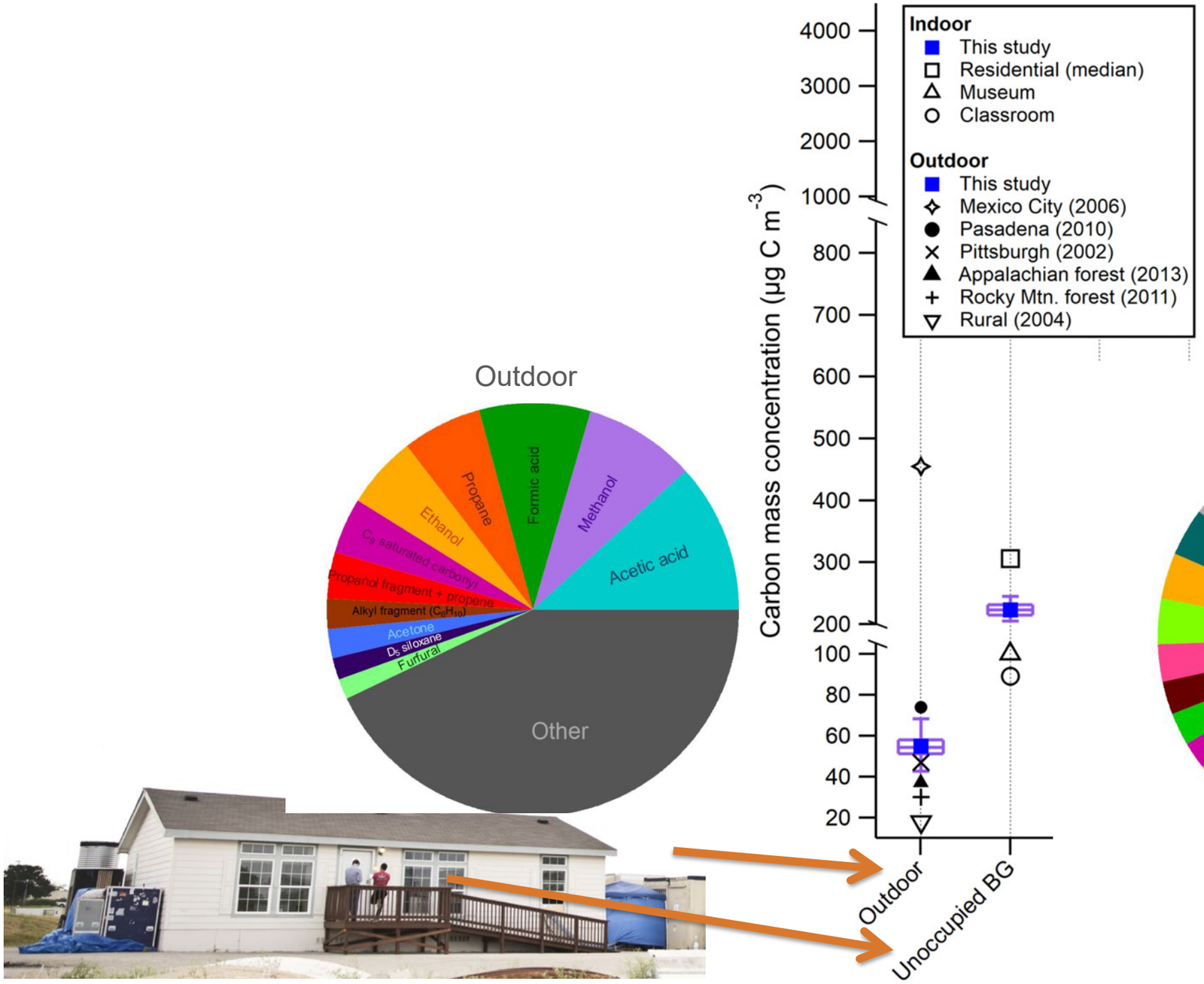
Michael F. Link,* Jienan Li, Jenna C. Ditto, Han Huynh, Jie Yu, Stephen M. Zimmerman, Katelyn L. Rediger, Andrew Shore, Jonathan P.D. Abbatt, Lauren A. Garofalo, Delphine K. Farmer, and Dustin Poppendieck*

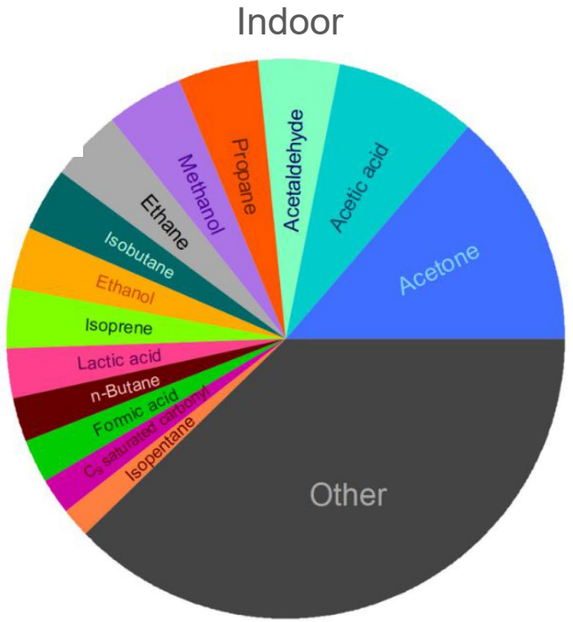


How do outdoor sources influence indoor air?

How do indoor sources influence outdoor air?

Indoor air has much more organic carbon than outdoor air



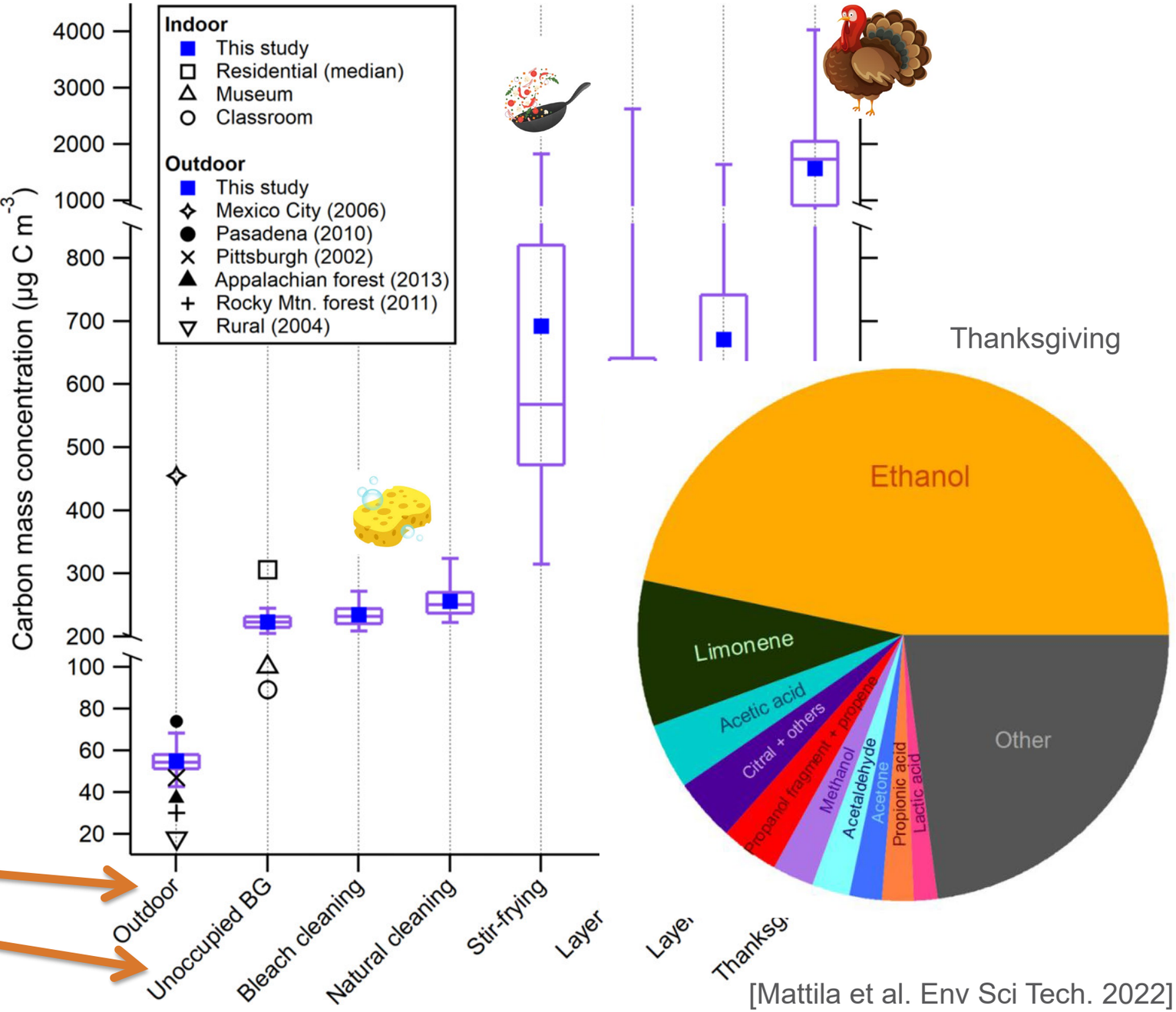


HOMEChem

[Mattila et al. Env Sci Tech. 2022]

Indoor air has much more organic carbon than outdoor air

- Homes are strong sources of reactive organic C
- Unoccupied, the HOMEChem house emitted ~0.7 g reactive organic C/day, or ~2 gC m^{-2} yr^{-1} (about ½ of orange grove!)

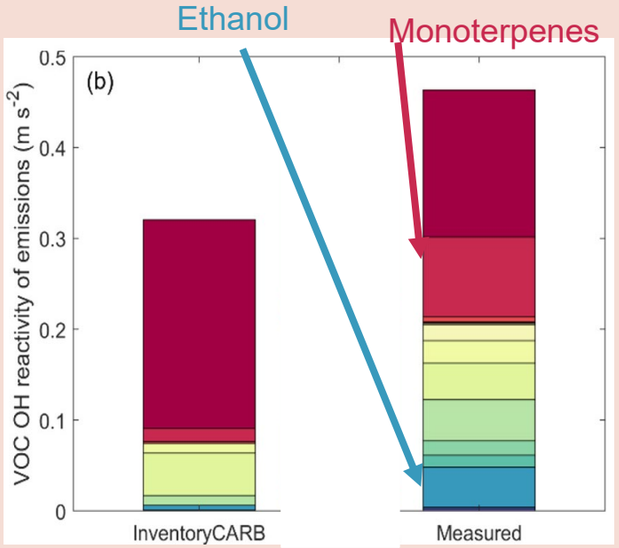


[Mattila et al. Env Sci Tech. 2022]

If indoor environments have so many VOCs, shouldn’t that matter outdoors?

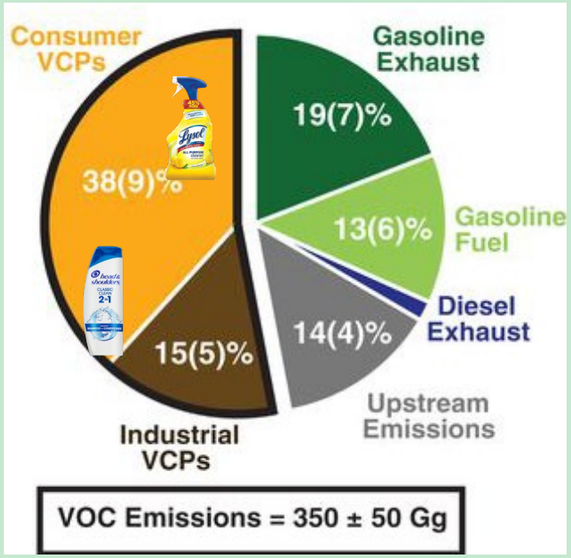



Growing evidence for building decomposition and volatile chemical products impacting urban air:



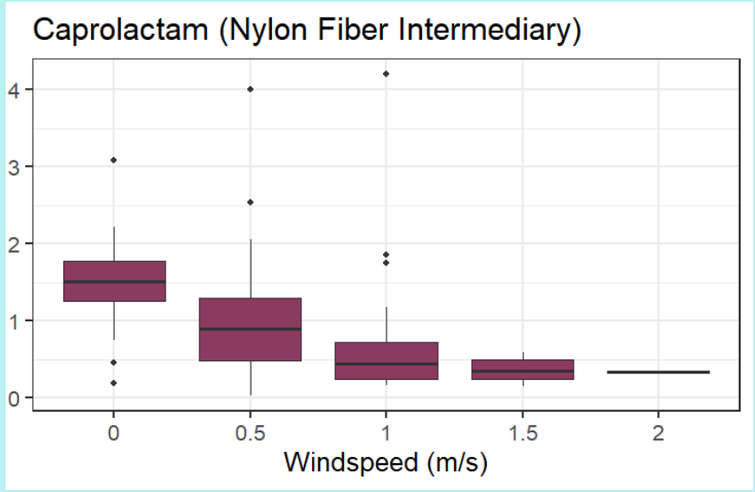
Pfannerstill et al., *ES&T*, 2023

LA urban flux study: inventories do not match VOC reactivity



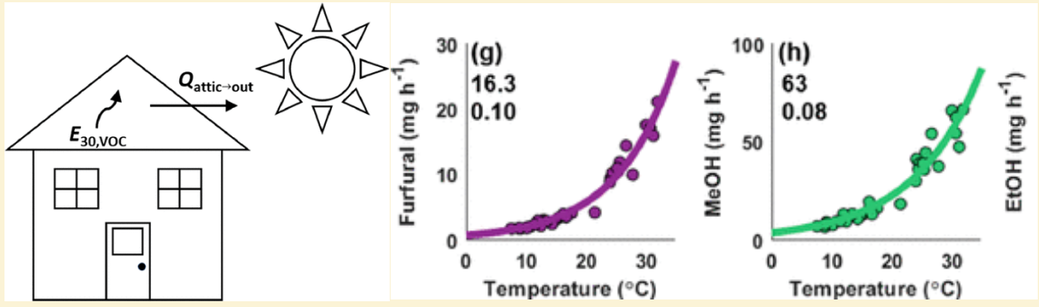
McDonald et al., *Science*, 2018

Volatile chemical products are emerging sources in LA and elsewhere…



Franklin et al., *npj Clim Atmos Sci*, 2025

…and account for 12-18% of (outdoor) sub-micron PM in NY, including building-related compounds

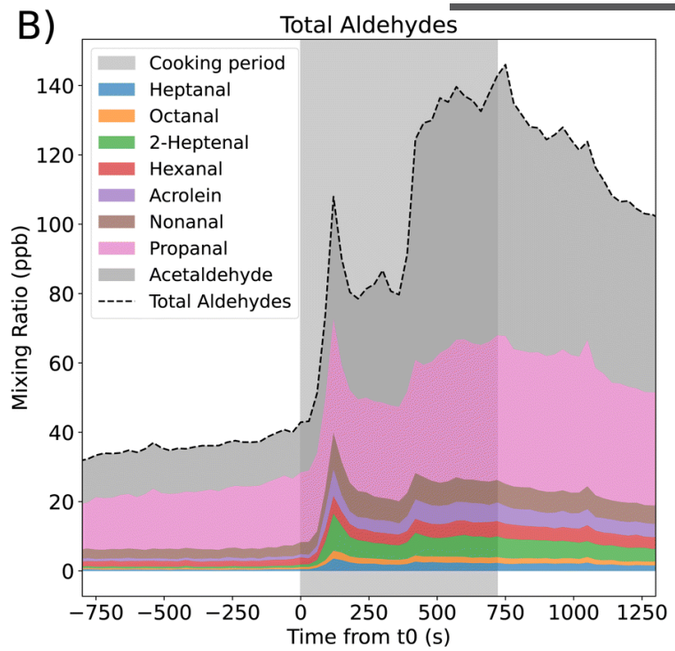


Attic wood decomposition and off-gassing emits 10× more OVOCs than inventory estimates in Oakland, CA

Molinier et al., *ACS ES&T Air*, 2024

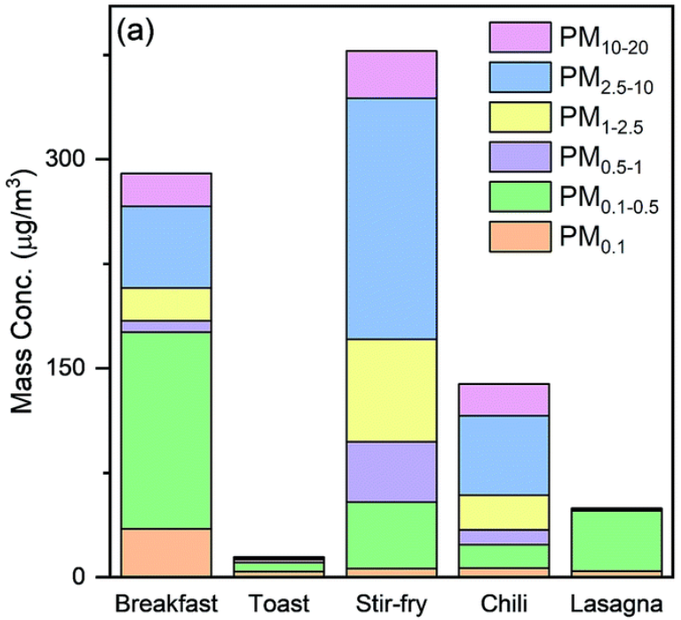
Growing evidence for cooking impacting urban air:

Cooking emits a lot of gases…



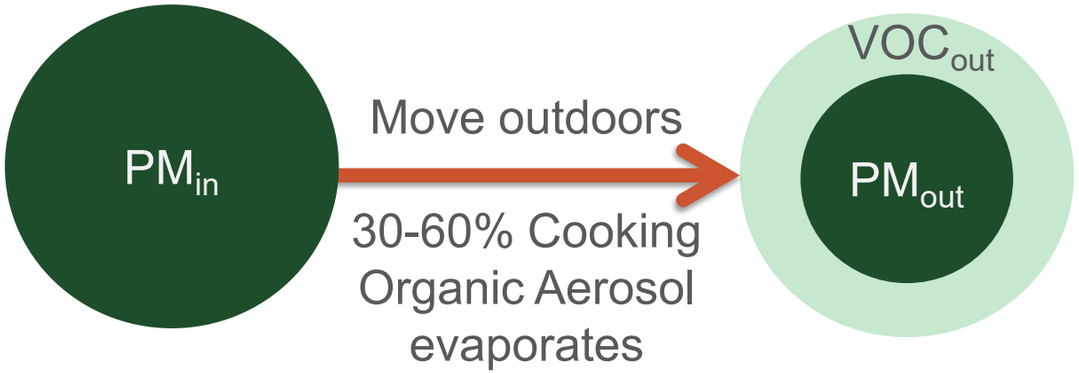
Davies et al. Env Sci:Proc Imp. 2023

…and a lot of particles



Farmer et al. Env Sci:Proc Imp. 2018; Patel et al. Env Sci Tech. 2021

Dilution-driven evaporation: (indoor) cooking organic aerosol contributes both gases and particles to outdoor air



Pothier et al. Env Sci:Proc Imp. 2023

Urban field studies: cooking contributes 10-30% of ambient organic aerosol, and ~20% of urban anthropogenic VOCs*



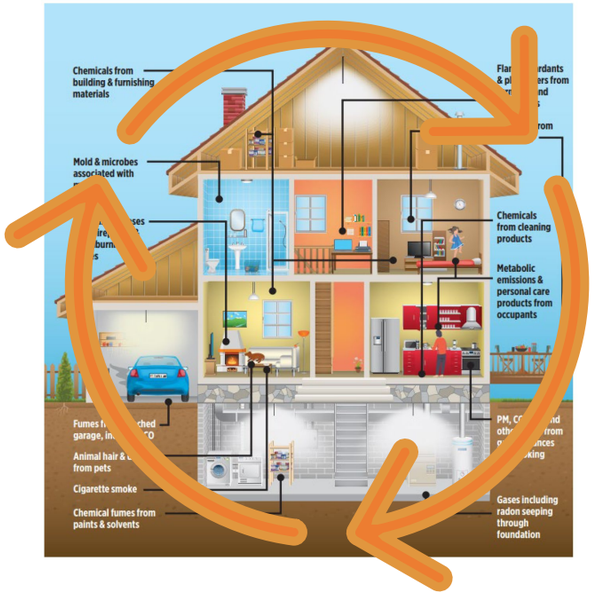

Most studies conducted in large cities in North America, Europe, Asia; VOC studies in Las Vegas

Examples of PM studies: Allan et al. Atmos Chem Phys 2010; Huang et al. Atmos chem Phys 2010; Sun et al. Atmos Env 2012; Sun et al. Atmos Chem Phys 2011; Crippa et al. Atmos Chem Phys 2013; Xu et al. Atmos Chem Phys 2019; Franklin et al. npj Clim Atmos Sci 2025

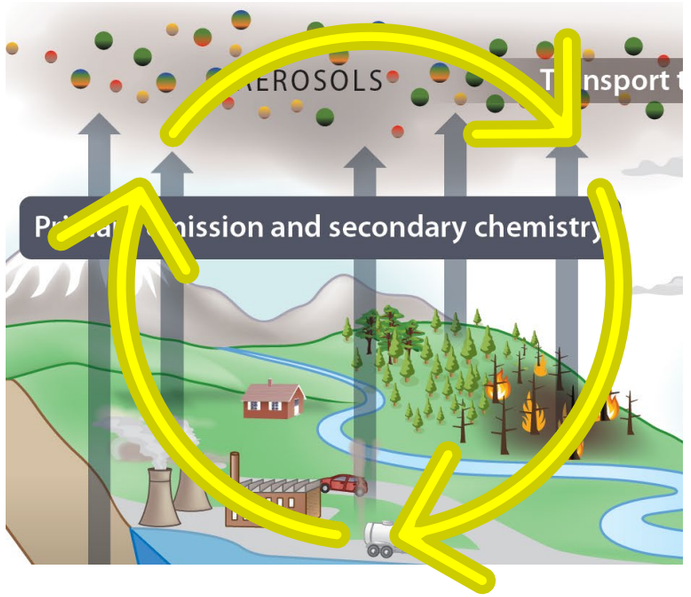
*Cooking VOC studies: Coggon et al. Atmos Chem Phys 2024 from Las Vegas, though our work in New York is suggesting a lower value in residential regions (Vermeuel et al.)

Future Directions: Indoor-outdoor exchange and impacts on air chemistry

$O_{3,out}$-VOC_{in} interactions: secondary products, new particle formation



Building surface chemistry



Indoor & building emissions as non-traditional sources of outdoor air pollution as we control fossil fuel emissions and climate changes