Recent research on the health effects of indoor chemistry

Charles J. Weschler
Rutgers University, Technical University of Denmark, Tsinghua University

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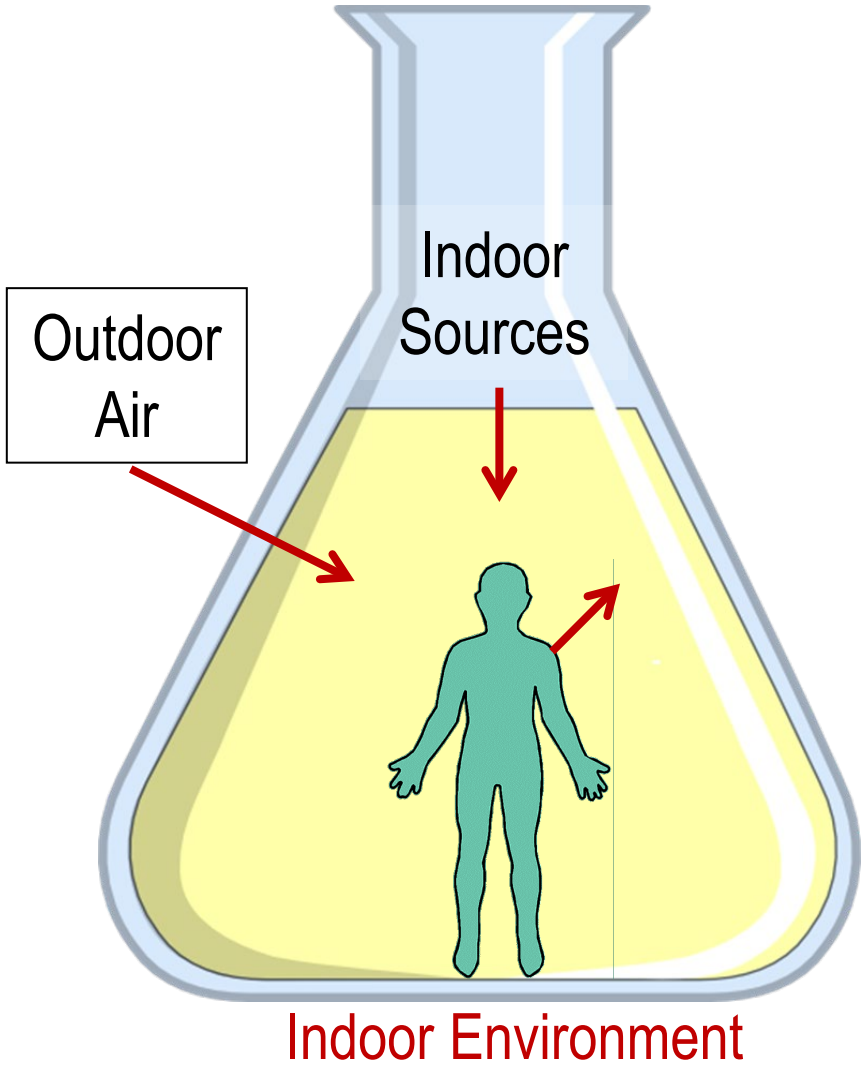
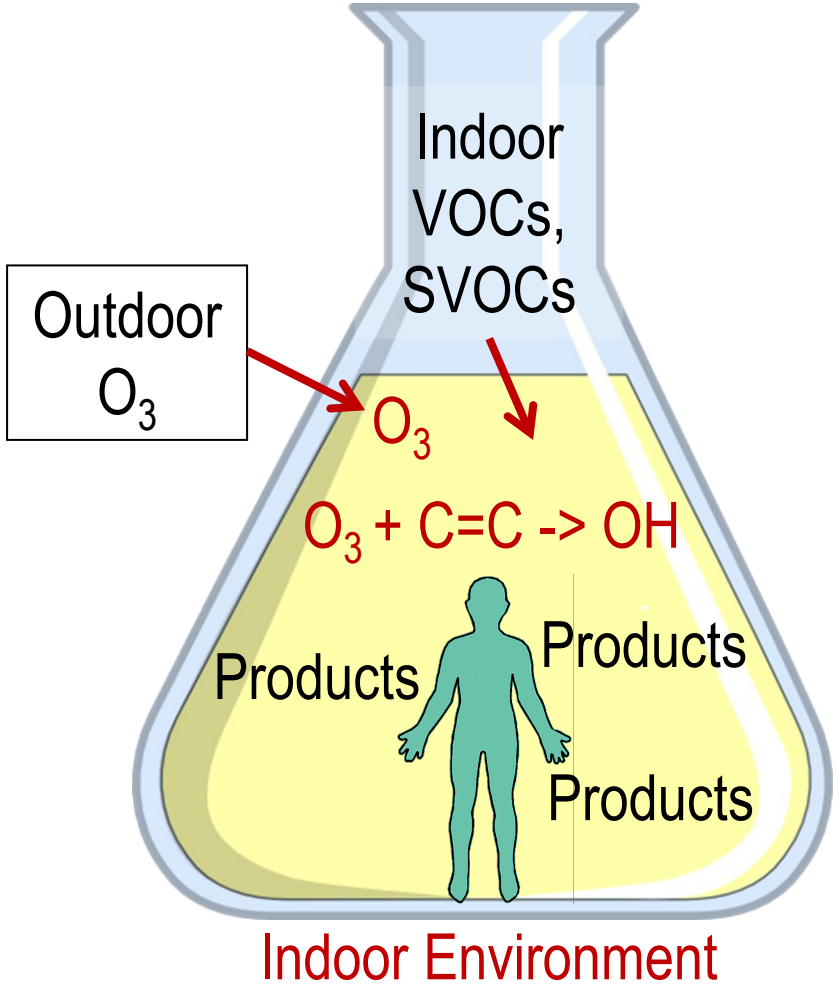
What is indoor chemistry?

Indoor chemistry:
Chemical transformations that occur in indoor air (both gas- and particle-phase) and on indoor surfaces, as well as the associated transport and partitioning phenomena.



Focus of this presentation: oxidation reactions

- Given our limited time, we will focus on one type of indoor chemistry: **oxidation reactions**
- Ozone (O_3) tends to be the driver of indoor oxidation, supported by the hydroxyl radical (OH)
- Other oxidants (e.g., the nitrate radical, chlorine containing species, hydrogen peroxide) have impacts that are more episodic



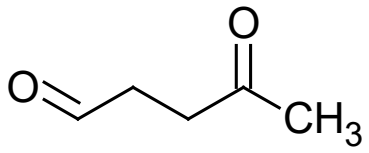
Why do we care?

- The net concentration of organic compounds in indoor air is roughly an order of magnitude larger than in outdoor air
- More than 90% of the organic compounds in indoor air have been emitted indoors
- Organic compounds of indoor origin tend to have low oxygen-to-carbon ratios (O/C)
- Indoor air contains oxidants (e,g., O_3 and $OH\cdot$)
- Oxidation increases the O/C ratio of the compounds that have been emitted indoors
- This increases their water solubility, decreases their volatility, and increases the time they spend in the lungs
- Crudely speaking, oxidation of indoor VOCs tends to increase the adverse health effects associated with the indoor VOC mix

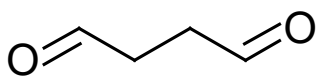
Why do we care? (surface chemistry example)

Beneficial chemicals in human skin oil can react with O_3 to produce a mix of noxious oxidation products:

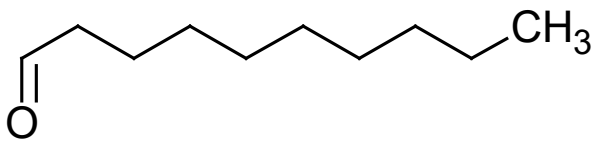
- 4-Oxopentanal (4-OPA)



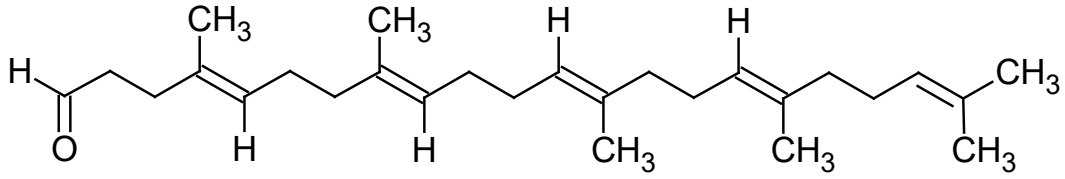
- 1,4-Butanedial



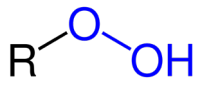
- Decanal

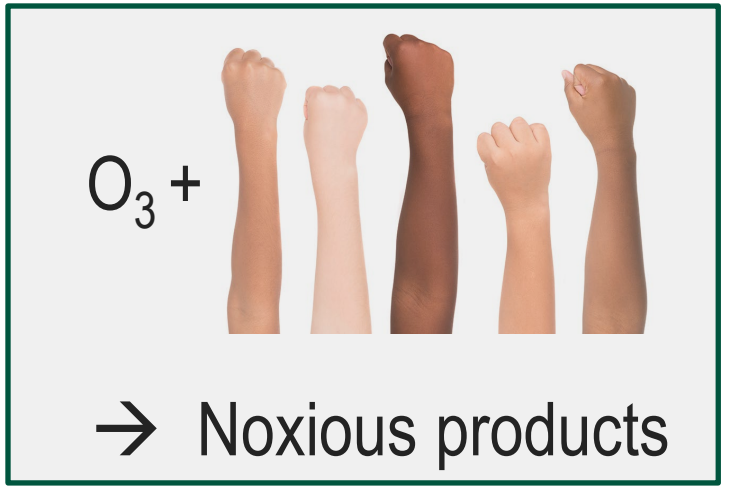


- C27-pentaenal



- Organic hydroperoxides

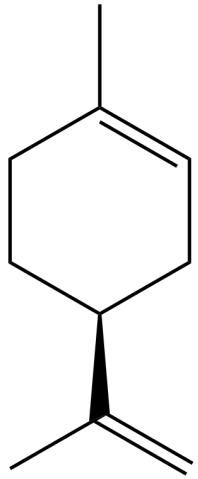




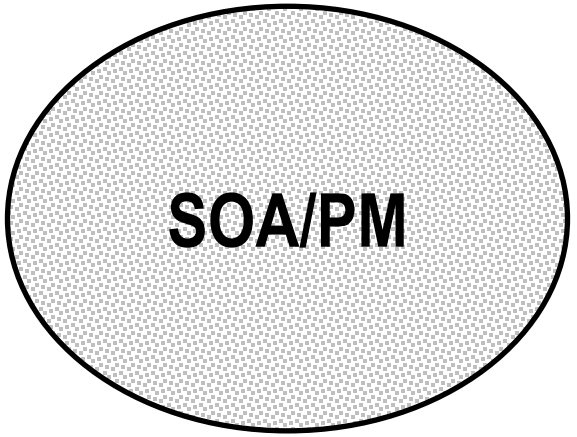
Wisthaler and Weschler, PNAS, 107, 6568, 2010

Why do we care? (gas phase chemistry example)

Limonene (pleasant scent) can react with O_3 or OH· to produce formaldehyde and secondary organic aerosols (both unhealthy)



+ O_3 or OH· → formaldehyde +



limonene

SOA: secondary organic aerosols

Ozone reaction products (ORPs)

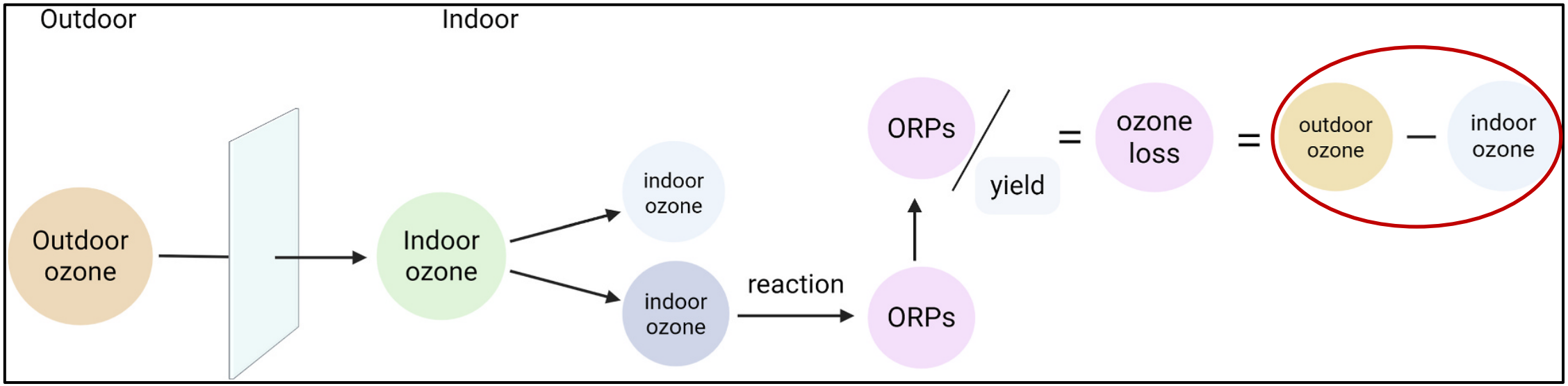
A fraction of the O_3 transported indoors reacts with organics:

On surfaces

O_3 + human skin oil → 4-OPA, 6-MHO, GA

In the air

O_3 + limonene → HCHO, SOA



Weschler and Nazaroff, Environ Sci & Technol, 57, 13569, 2023;
Li, Jian, et al., Environ Pollution, 389, 127416, 2026

What are some oxidation products of concern?

- Stable species
  - Saturated & unsaturated aldehydes, ketones, and dicarbonyls
  - Hydrogen peroxide, organic peroxides including organic hydroperoxides (e.g., α-hydroxyhydroperoxides) and secondary ozonides (thermally stable, but react quickly with water)
  - Organic nitrates and peroxyacyl nitrate-type species (PAN)
  - Nitrosamines
  - Secondary organic aerosols (SOA)
- Short-lived, highly reactive species
  - Stabilized Criegee intermediates (carbonyl oxides)
  - Hydroxyl radicals (OH·), hydroperoxy radicals (HO_2·), alkylperoxy radicals (RO_2·), nitrate radicals (NO_3·)/dinitrogen pentoxide (N_2O_5)

Exploratory analysis: influence of ORPs on health biomarkers?

Aim: to examine the independent health biomarker effects of personal exposure to ozone compared to personal exposure to ozone reaction products (ORPs)

- Define O_3 loss as $([O_3]_{outdoor} - [O_3]_{indoor})$
- $[ORPs]_{indoor}$ proportional to O_3 loss
- Use O_3 loss to assess exposure to ORPs

This analysis uses data from the two previously published studies:

1) 89 healthy adults living at a factory campus in Changsha
2) 43 children with asthma living in residences in Shanghai

He … Zhang, Am J Resp Crit Care Medicine, 207, 1243, 2023

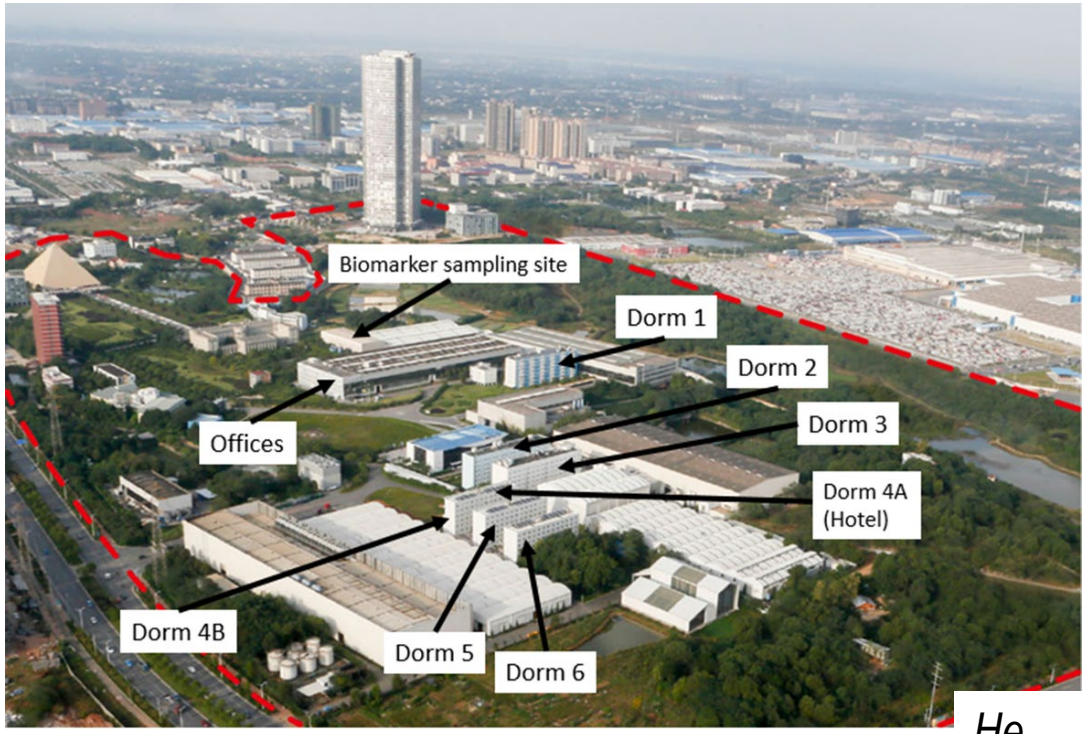
Adverse effects of exposure to O_3 or ORPs – Adults' study

Biomarker	O_3	ORPs
EBC NN: lung inflammation		adverse
EBC MDA: lung oxidative stress		
FeNO: lung inflammation		adverse
Urinary 8-OHdG: oxidative stress		adverse
20-HETE: vasoconstriction		adverse
P-selectin: risk for thrombosis	adverse	adverse
VWF: blood clotting	adverse	
Diastolic BP		adverse
Systolic BP		adverse
AI: arterial stiffness		
PWV: arterial stiffness		

He … Zhang, Am J Resp Crit Care Medicine, 207, 1243, 2023

Conclusions – Healthy Adults' study

- Exposure to ORPs was associated (adversely) with **7** biomarkers of deep lung and cardiovascular effects, after controlling for exposure to ozone and $PM_{2.5}$
- Exposure to O_3 was associated (adversely) with **2** biomarkers of cardiovascular effects, after controlling for exposure to ORPs and $PM_{2.5}$



89 healthy adults,
(22–52 yr old)
Broad Town Campus,
Changsha

He … Zhang, Am J Resp Crit Care Medicine, 207, 1243, 2023

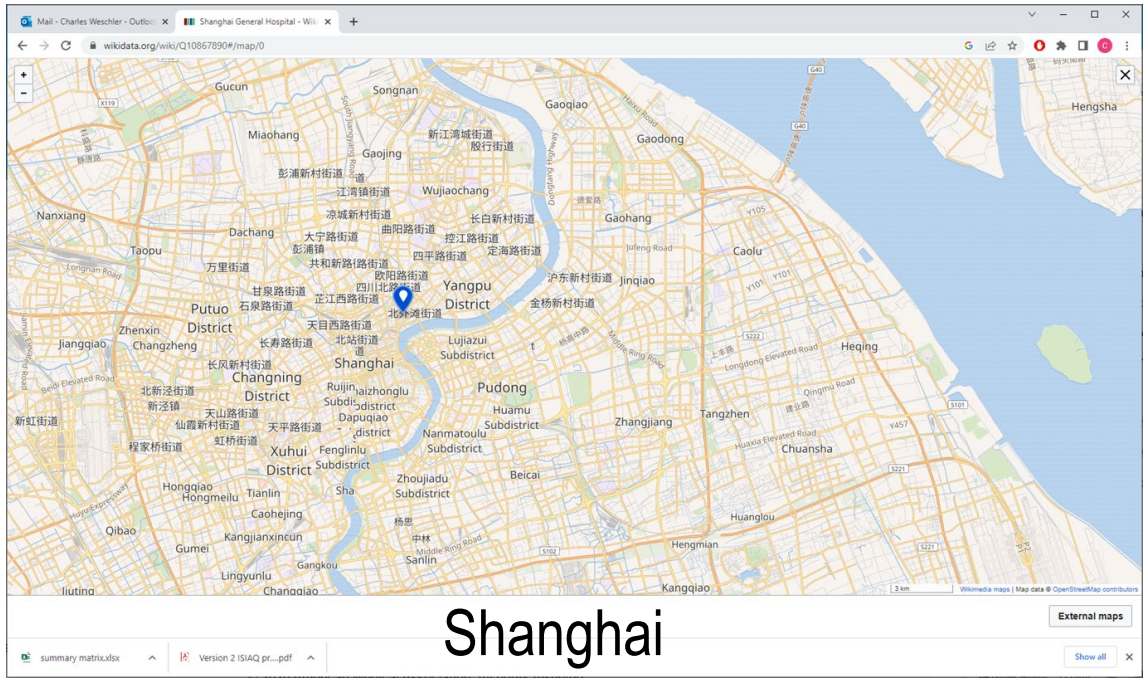
Adverse effects of exposure to O_3 or ORPs – Children's study

Biomarker	O_3	ORPs
Nasal MDA: upper respiratory tract oxidative stress	adverse	
FeNO: airway inflammation		adverse
Z_5: airway impedance		adverse
X_5: airway reactance		adverse
Fres: airway reactance		adverse
FEV_1/FVC: airflow obstruction risk		adverse

He … Zhang, Am J Resp Crit Care Medicine, 207, 1243, 2023

Conclusions – Asthmatic Children's study

- Exposure to ORPs was associated (adversely) with **5** biomarkers of deep lung and cardiovascular effects, after controlling for exposure to ozone and $PM_{2.5}$
- Exposure to O_3 was associated (adversely) with **1** biomarker of upper airway oxidative stress, after controlling for exposure to ORPs and $PM_{2.5}$

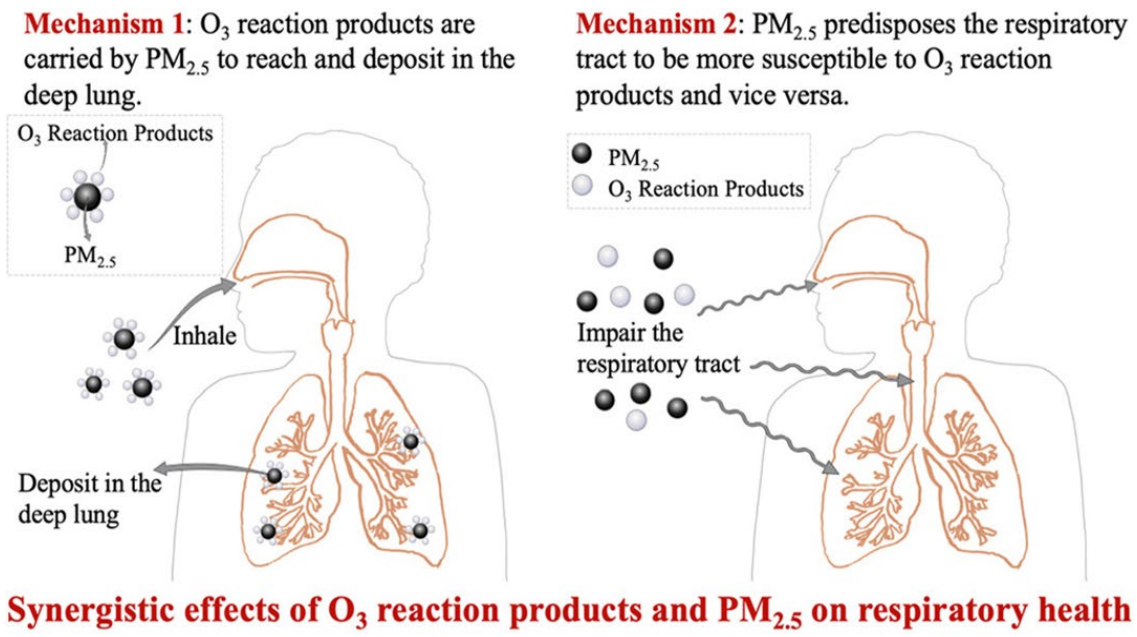


43 children with asthma
(5–13 yr old)
Homes in the vicinity of
Shanghai General Hospital

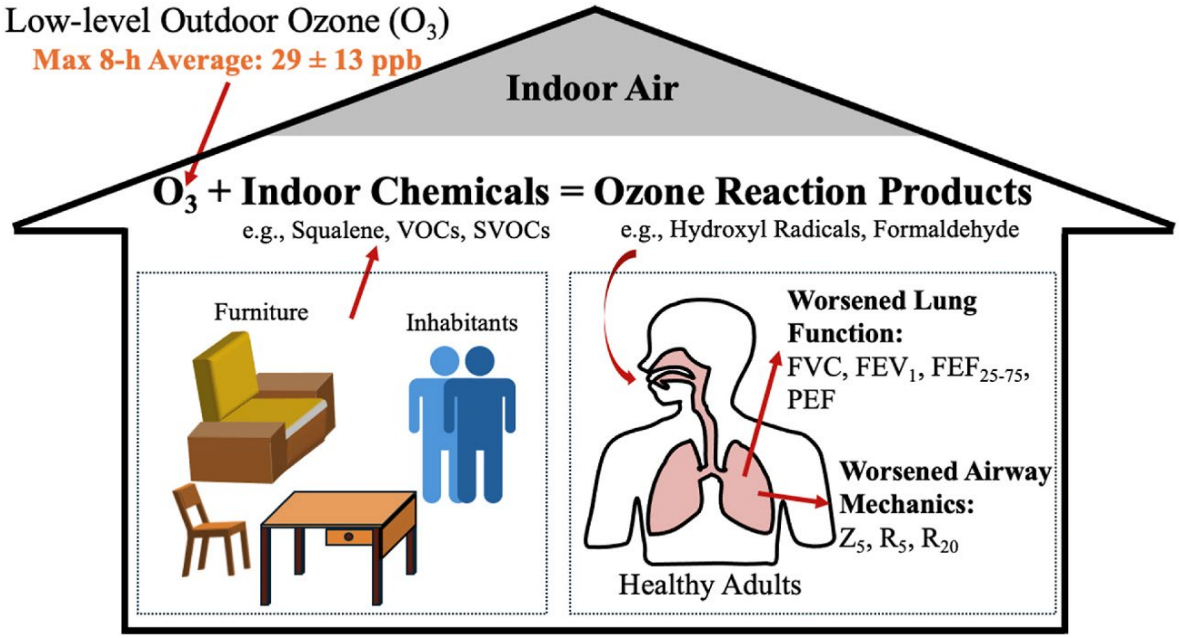
He … Zhang, Am J Resp Crit Care Medicine, 207, 1243, 2023

Recent papers supporting the preliminary findings of He et al. 2023

He … Zhang, Synergistic effects of ORP and $PM_{2.5}$ on Respiratory Pathophysiology in Children with Asthma, Environ Sci & Technol Air, 1, 908, 2024



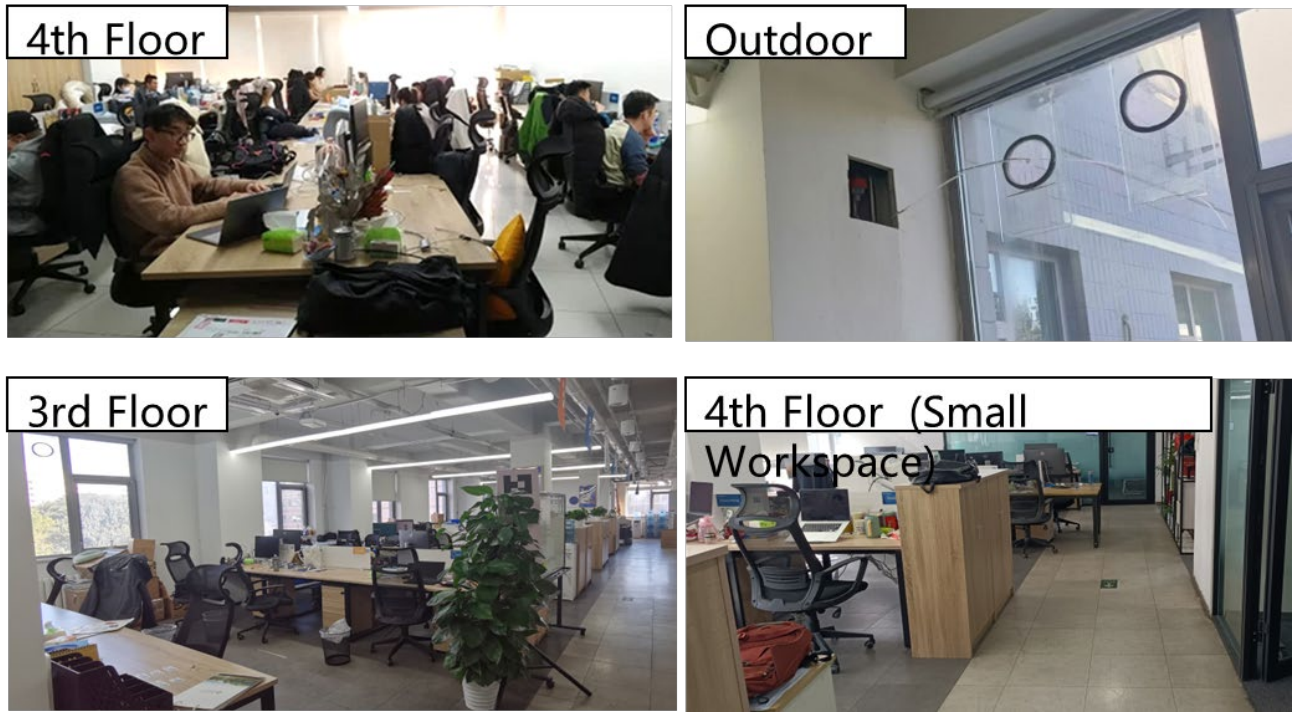
Synergistic effects of O_3 reaction products and $PM_{2.5}$ on respiratory health



He … Zhang, Indoor ozone reaction products: Contributors to the respiratory health effects associated with low-level outdoor ozone, Atmos Environ, 340, 120920, 2025

Ozone reaction products and negative emotions

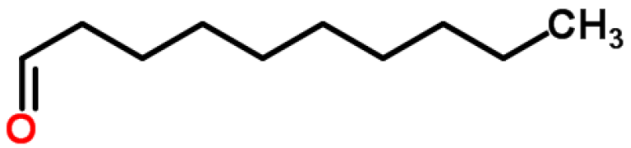
- Ozone reaction products associated with negative emotions among office workers during repeated evaluations (surveys and biomarkers) over 21 workdays in September and October of 2022



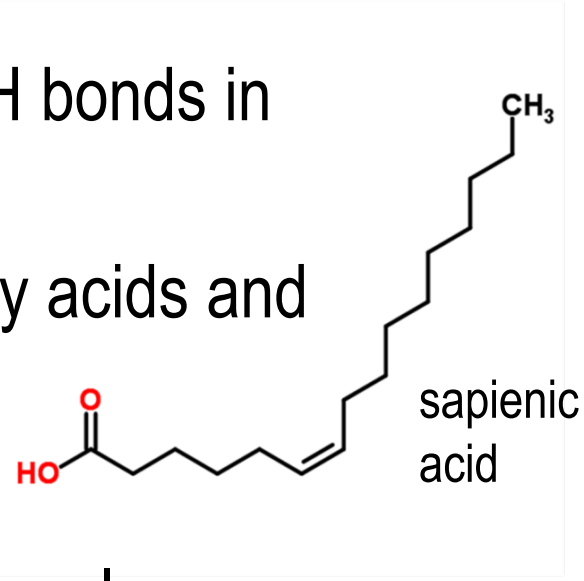
- Continuous monitoring of VOCs by PTR-MS; outdoor & indoor ozone by UV instruments
- 141 participants: 2 times/day completed survey to evaluate emotional state
- 52 participants: repeated collection of relevant biomarkers

Yuekun Qu … Yingjun Liu, to be submitted

Decanal is indicative of O_3/skin oil chemistry

- Decanal: 

- Decanal is a major product when O_3 reacts with CH=CH bonds in ω-10 acyl groups (i.e., $CH_3(CH_2)_8CH{=}CH$-)
- About 1/3 of the double bonds in skin oil come from fatty acids and triglycerides with ω-10 acyl groups

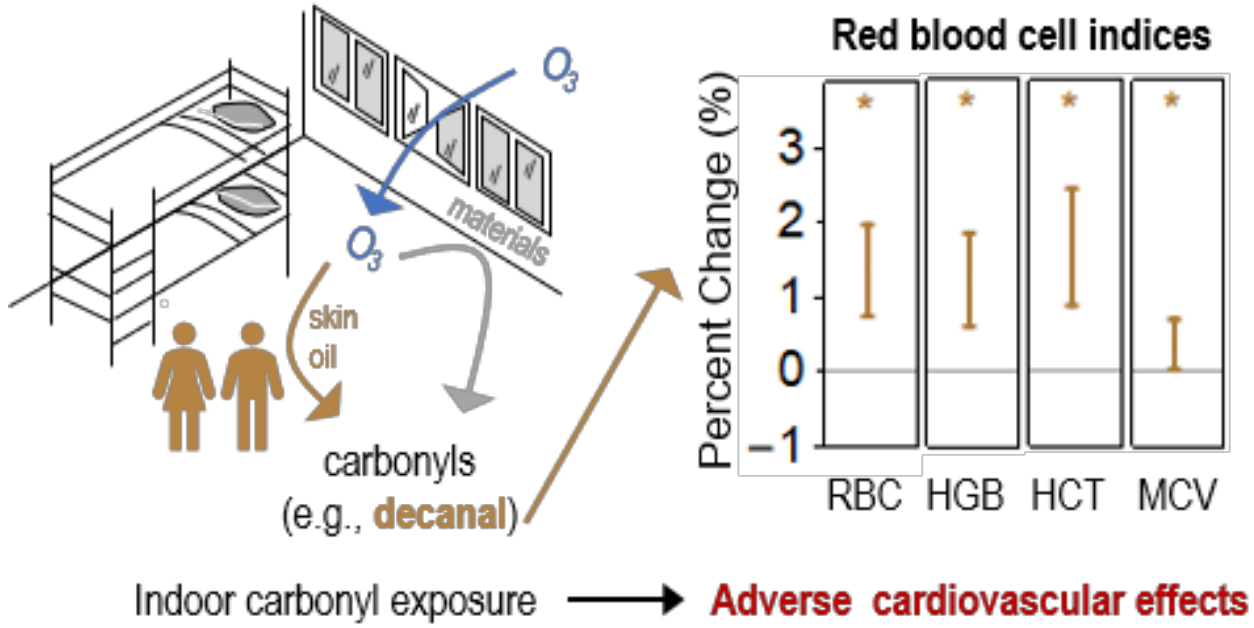


- Very few other compounds found indoors contain ω-10 acyl groups
- Decanal does not itself react with ozone
- Decanal well-suited for estimating the *ozone reaction products* derived from O_3/skin oil chemistry

Weschler & Nazaroff, Environ Sci: Atmos, 3, 640, 2023

Decanal and cardiovascular biomarkers

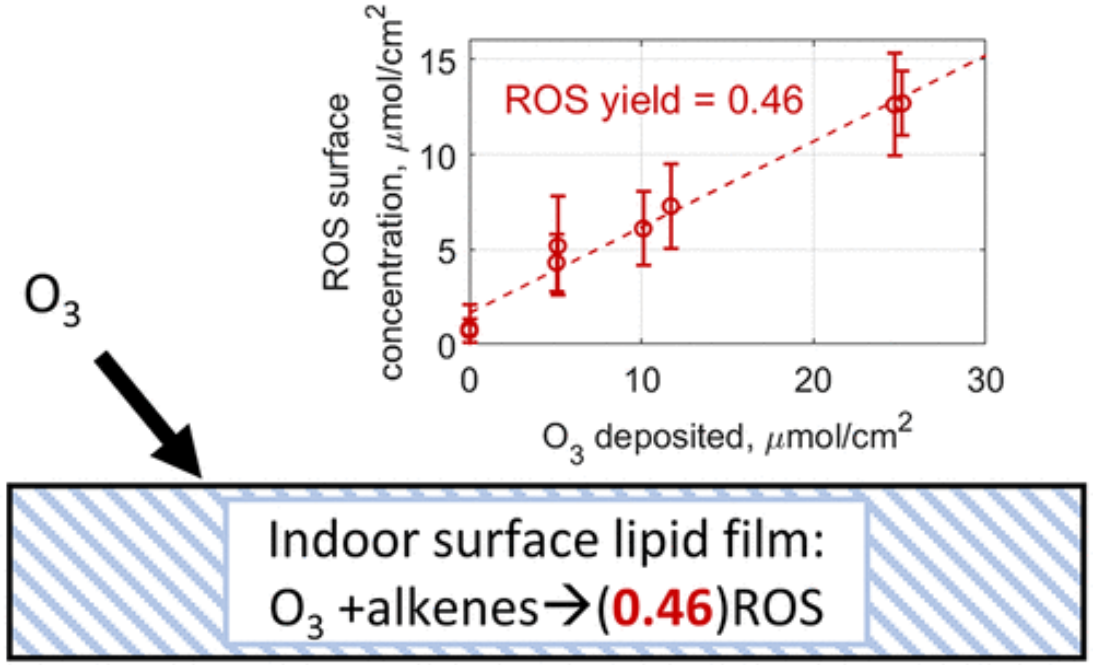
- Indoor exposure to aldehydes, especially decanal, associated with changes in cardiovascular biomarkers among healthy young adults in Tibet



Ruohong Qiao… Yingjun Liu, Indoor exposure to ozone-derived carbonyls: association with indicators of blood and cardiovascular physiology among healthy young adults, submitted, 2025

Production of reactive organic species (ROS)

ROS: hydrogen peroxide (HOOH), organic peroxides (ROOH, R_1OOR_2), and short-lived oxygen containing radicals ($RO_2\cdot$, $(R_1R_2)C\cdot O_2\cdot$)

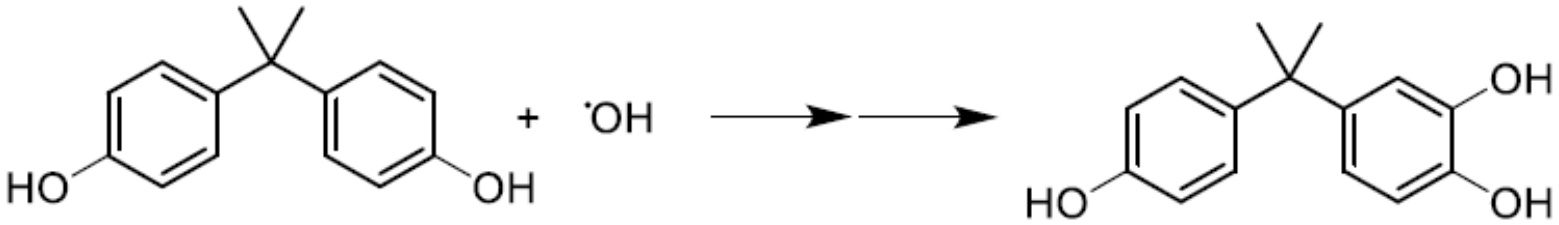


- O_3 reacts with surface lipids (mix similar to skin oil) to produce ROS with ~ 45% yield
- ROS persist on surfaces for at least a few hours
- ROS predicted to partition from surfaces to inhalable airborne PM
- Less volatile, more hydrophobic ROS (e.g., organic hydroperoxides) can remain on inhaled PM into the alveolar region

Morrison et al., Environ Sci: Processes Impacts, 24, 2310, 2022; Morrison et al., Environ Sci & Technol Letters, 10, 528, 2023

Autoxidation of unsaturated lipid films on indoor surfaces

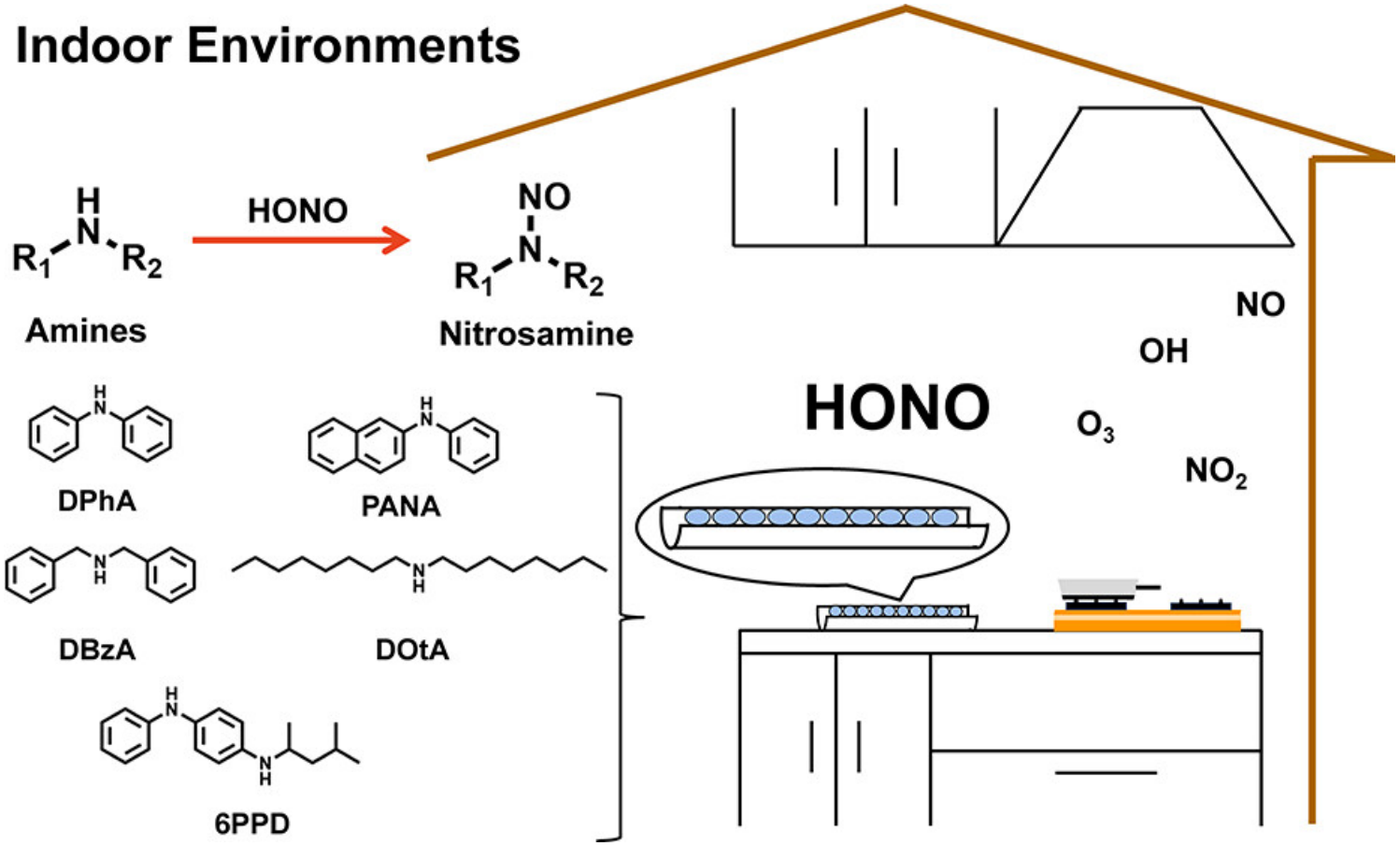
- Flow reactor, elevated [OH·]: fast autoxidation of methyl linoleate films → *organic hydroperoxides* (ROOH)
- In dark desk drawer (~ 15 ppb O_3): ROOH formation occurs at similar rate
- Autoxidation is sustained by ROS-promoted internal radical propagation and displays minimal sensitivity to the rate of radical initiation
- Process enhances oxidation of BPA added to such lipid films



Wang … Abbatt, Nature Comm, 16, 1557, 2025

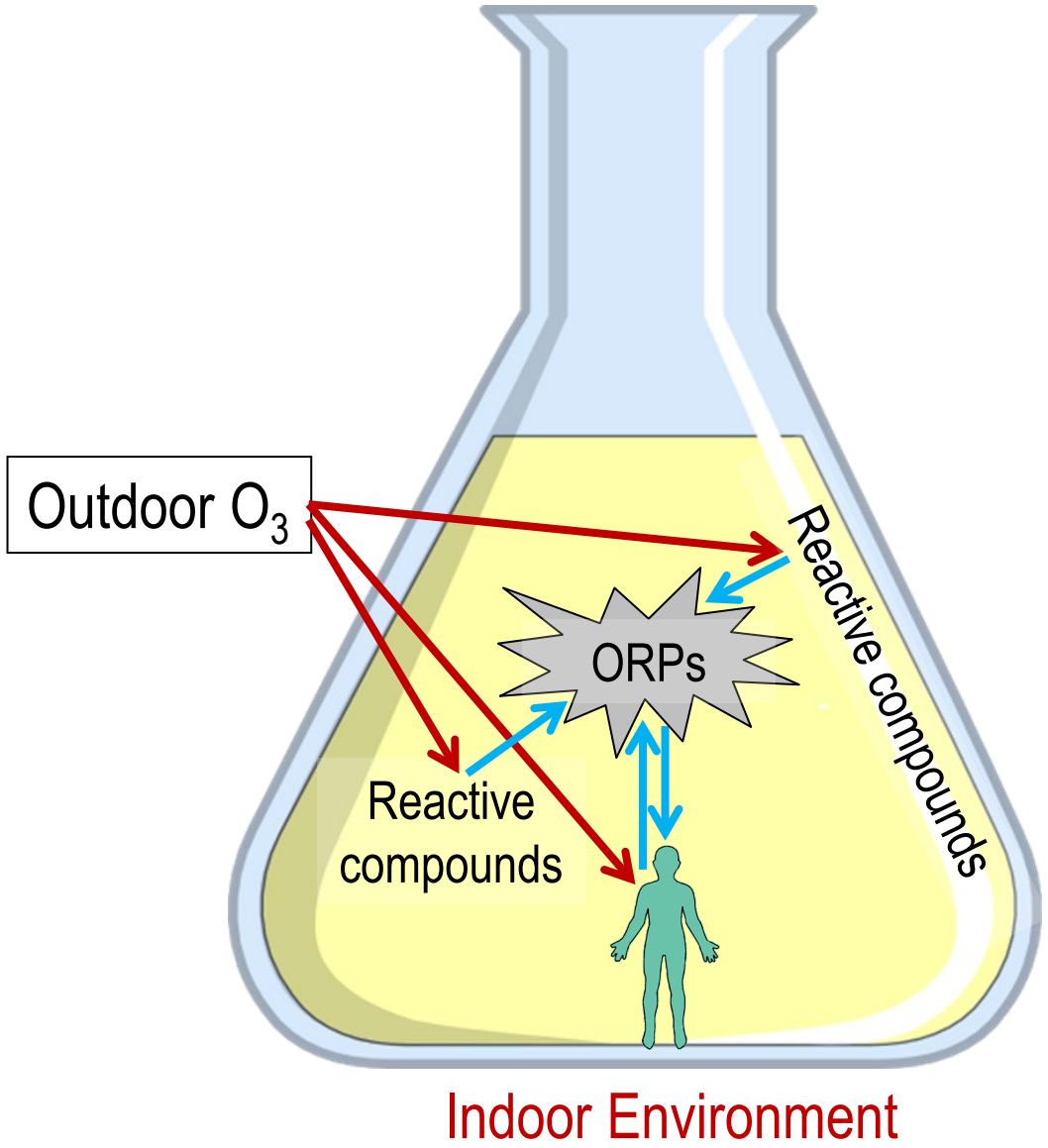
HONO + organic amines indoors → nitrosamines

- In lab experiments, HONO reacts with five different amines commonly found indoors → nitrosamines
- In a genuine indoor environment, room air exposure of 6PPD → nitroso-6PPDs and nitro-6PPDs



Zhang, Yuan … Wang, Environ Sci & Technol, 58, 18881, 2024

Summary: health effects of indoor chemistry



- "Why Indoor Chemistry Matters" National Academies Press, 2022
- Since then, multiple studies suggest adverse health effects resulting from indoor chemistry
- More definitive studies are needed:
  - Toxicology studies
  - Chamber studies
  - Panel studies

Acknowledgements

Paula J. Olsiewski

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