The Influence of Sources of Indoor Fine Particulate Matter on the Characterization of Exposure and Evaluation of Health Effects

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NASEM INDOOR PM EXPOSURE WORKSHOP

SESSION II: INDOOR SOURCES OF INDOOR PARTICULATE MATTER

14 APRIL 2021

Clarkson™
CIVIL & ENVIRONMENTAL ENGINEERING

TECHNICAL PAPER

ISSN 1047-3289 *J. Air & Waste Manage. Assoc.* **46**: 98-126

Indoor Particles: A Review

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ABSTRACT

This paper reviews studies of particle concentrations and sources in homes and buildings. Three major studies of indoor and outdoor concentrations in U.S. homes are

Most studies showed poor correlations of personal exposures with outdoor concentrations. However, for those studies with seven or more repeated measurements, longitudinal regressions on exposures of individual subjects showed much

Wallace, 1996 *JAWMA*

Wallace (1996) findings:

- major sources of indoor PM were smoking, cooking & “unexplained”
- “personal cloud” observed but not yet investigated
- personal $PM_{2.5}$ exposures poorly correlated with outdoor $PM_{2.5}$, except for longitudinal regressions for individuals

What have we learned in the past 25 years?

Some relevant research questions

1. How does the indoor environment impact the level and composition of indoor $PM_{2.5}$?
   (sources, occupants, building operation, pollutant/microbial cycling)
2. How does indoor $PM_{2.5}$ impact human health (acute, chronic) and how should we assess health risks of indoor $PM_{2.5}$?
3. What are the structural influences on disparate $PM_{2.5}$ exposures across communities?
4. What are the best approaches to mitigate indoor $PM_{2.5}$ exposures?

Sources of indoor fine particulate matter

Already discussed today:

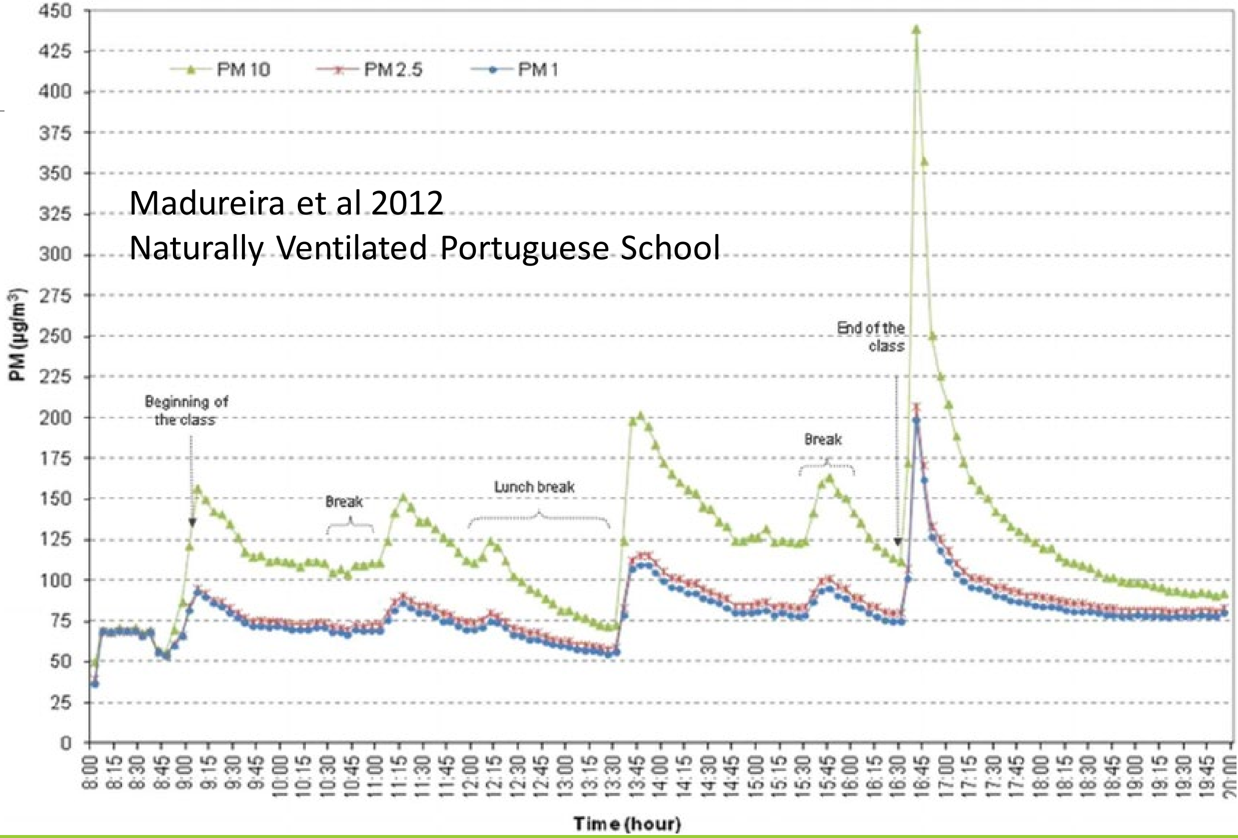
- Outdoor sources of indoor $PM_{2.5}$ & disparities in associated exposures
- Indoor to outdoor transport & chemical transformations
- Indoor sources of indoor $PM_{2.5}$: cooking; SOA; third-hand smoke, indoor microbiome
- Partitioning of SVOCs and inorganic gases (affects $PM_{2.5}$ composition)

Other major indoor $PM_{2.5}$ sources:

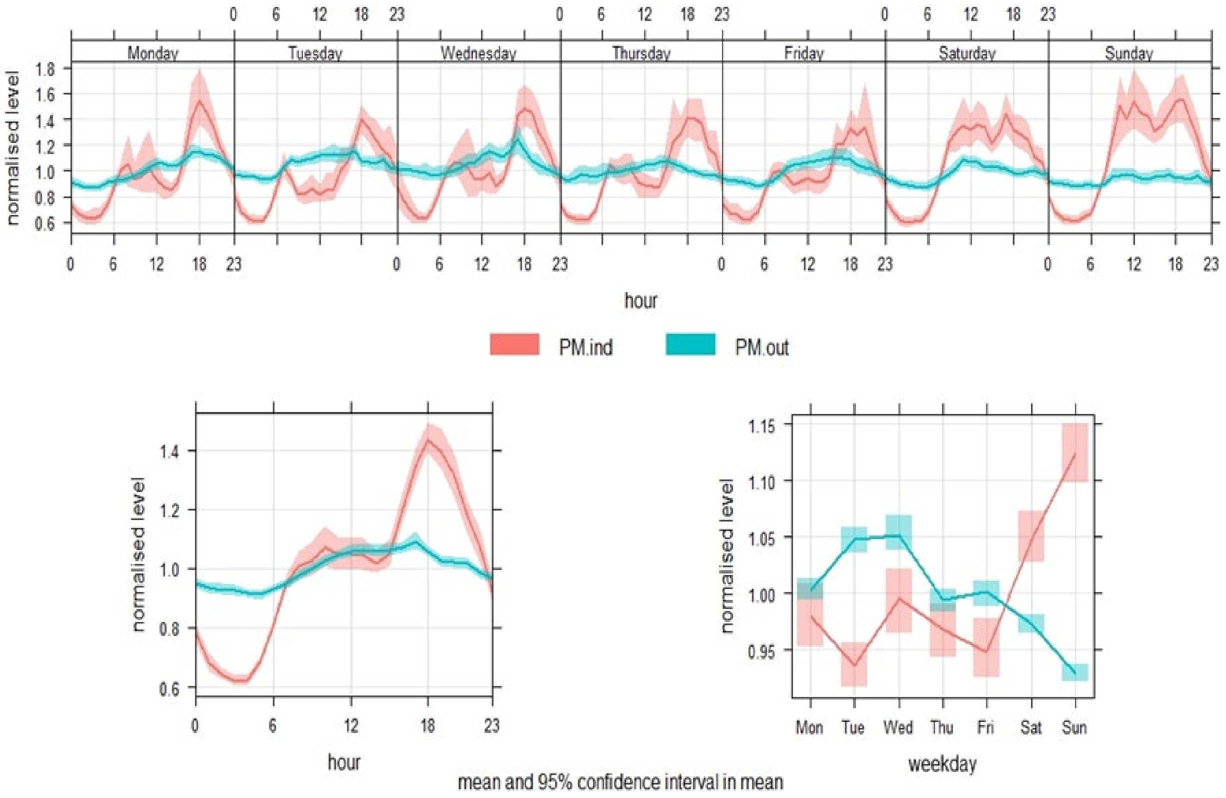
- Other combustion sources: smoking; candles & incense; heating
- Shedding and resuspension (chemical & biological components)

Indoor PM sources are often episodic

- Indoor sources often result in short term, high concentration pulse (e.g. cooking, smoking, human activity, SOA event)
- Some indoor sources are more continuous (e.g., stove pilot, heating source)



Indoor and outdoor $PM_{2.5}$ temporal patterns can be very different



Weekly and diurnal trends of indoor and outdoor $PM_{2.5}$

Indoor-outdoor $PM_{2.5}$ data for 25 homes during heating season in Rochester, NY (Ferro et al, 2021, in revision)

Acute health impacts from short-term $PM_{2.5}$ exposure

- Increased **mortality** associated with short-term (<24 h) increased $PM_{2.5}$ concentrations (Lu et al., 2015; Lin et al., 2017a;b)
- More evidence is needed to assess **morbidity** from short-term exposure to $PM_{2.5}$ and specific constituents associated with $PM_{2.5}$
- Need better indoor $PM_{2.5}$ exposure estimates to assess acute health effects (e.g., myocardial infarction) from short-term exposures

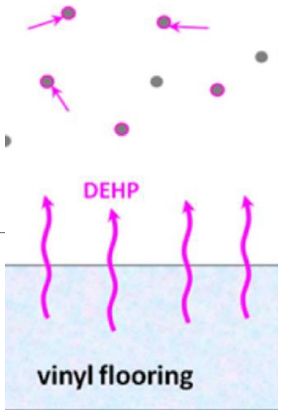
Indoor particles may be more toxic than outdoor particles

- Oeder et al., 2012 found inflammatory response and allergic reactions higher for PM_{10} collected indoors versus outdoors (6 schools, Munich)
- Long et al. (2001) found the proinflamatory response in rat alveolar macrophages higher for indoor particles than outdoor particles (14 residences in Boston)
- Happo et al., 2013, 2014 found cytotoxic effects on mouse macrophages higher for particles collected indoors versus outdoors (one residence in Finland)

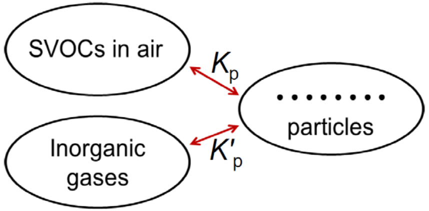
Chemical composition of indoor $PM_{2.5}$

- From both outdoor and indoor sources
- Enriched in occupant organics
  - squalene
  - cholesterol
  - fatty acids
- Enriched in chemical additives
  - plasticizers
  - flame retardants
  - surfactants

DEHP = di(2-ethylhexyl) phthalate

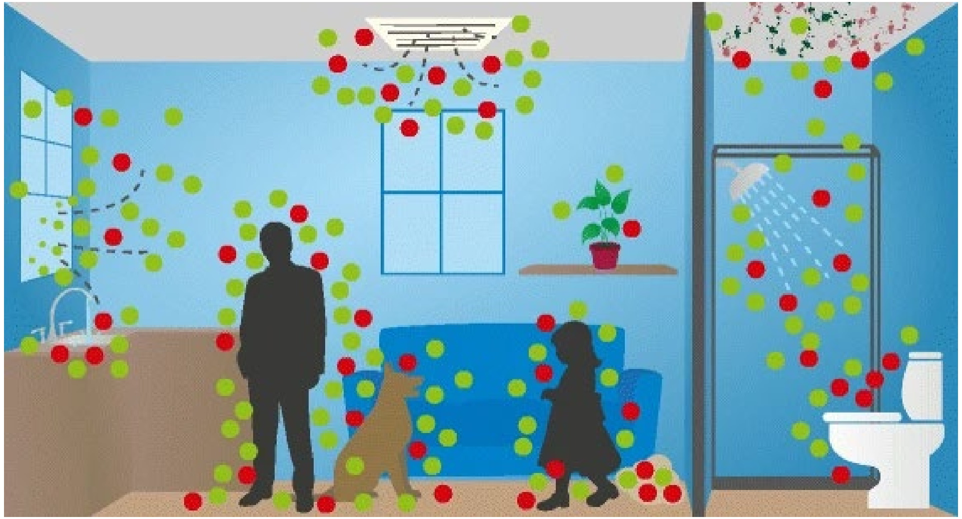


- Partitioning of volatiles between vapor phase and PM



  - Changes with temperature and RH
  - Changes with outdoor-to-indoor transport
- Chemical transformations
  - Oxidation (e.g., O_3 + organics in PM)
  - Acid-base/partitioning reactions (e.g. $NH_4NO_3 \rightarrow NH_3 + HNO_3$)

Indoor microbial bioaerosols



Sources of beneficial (green) and detrimental (red) microbial bioaerosols: humans, pets, plants, plumbing systems, heating, ventilation, and air-conditioning systems, mold, resuspension of settled dust, and outdoor air
(Prussin and Marr, 2015)

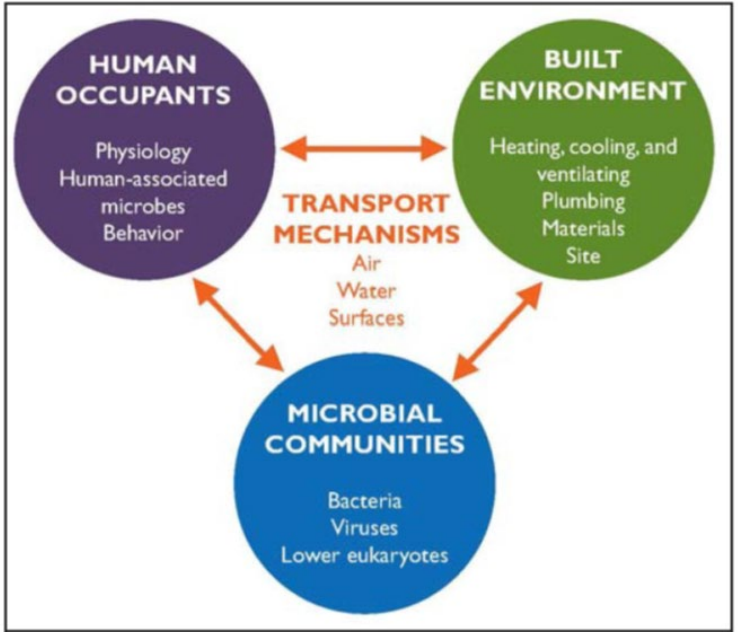
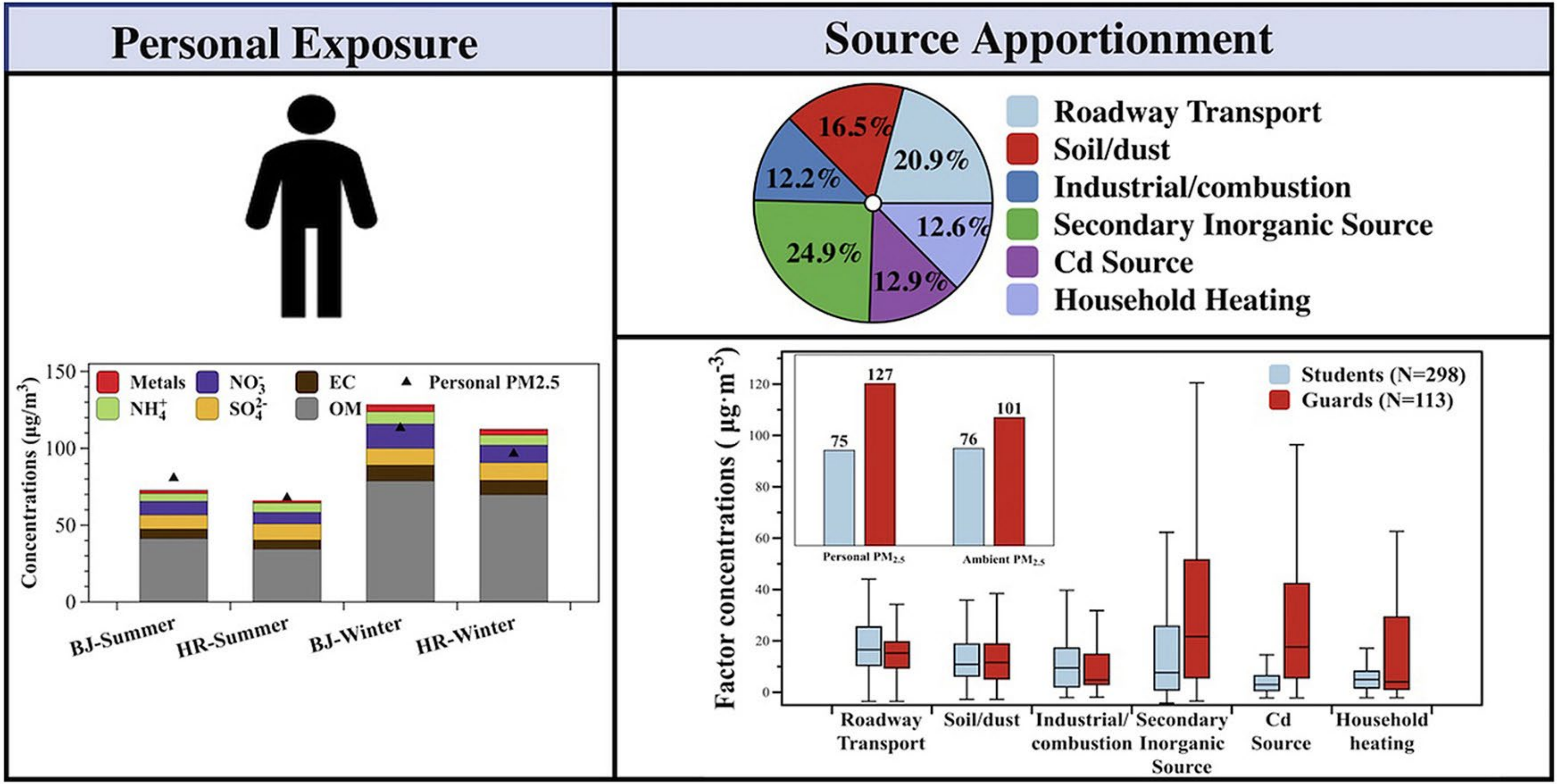


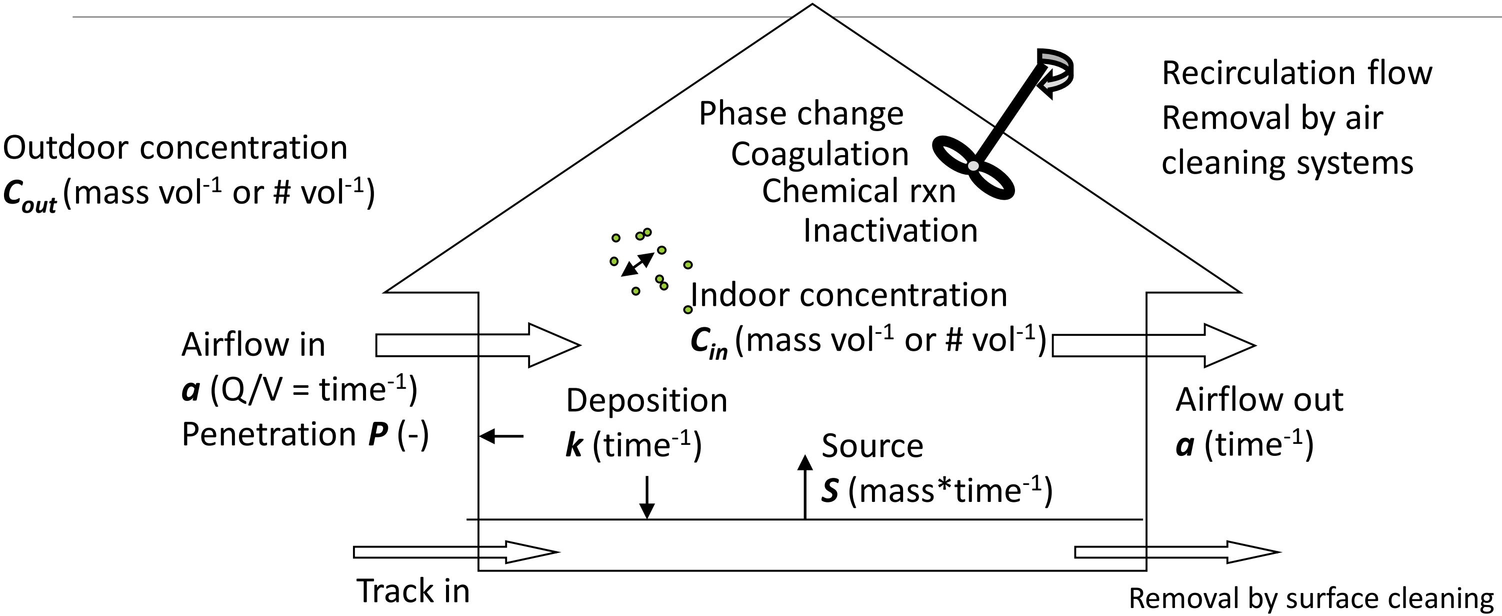
FIGURE 1 The formation, dynamics, and functions of microbiomes in built environments are shaped by complex interactions of factors related to the characteristics of a building, its human occupants, and the microbial communities associated with both.

NASEM, 2017



Shang et al., 2019 *Env. Pollution*, $PM_{2.5}$ personal exposure of two cohorts living in urban and suburban Beijing

Material balance approach using well-mixed assumption for indoor $PM_{2.5}$ is often reasonable

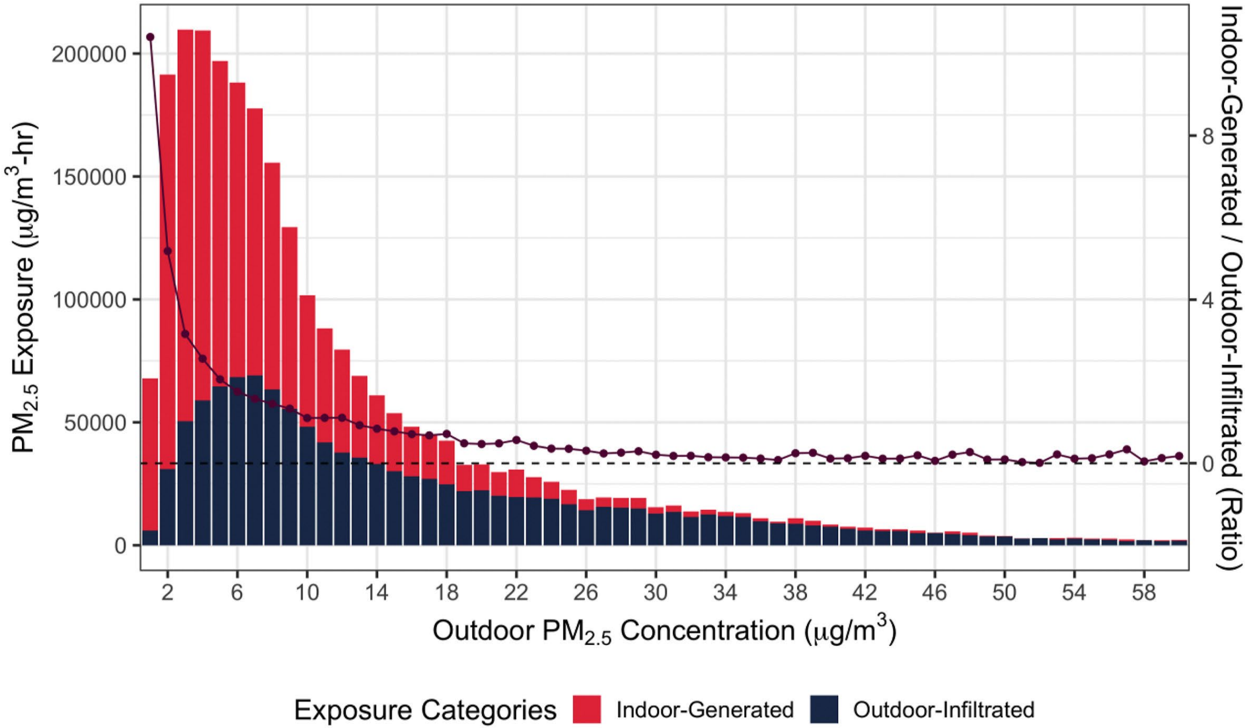


Exposure to Indoor Generated and Outdoor-Infiltrated PM

Used citizen-based PurpleAir monitors used to obtain I/O $PM_{2.5}$ at 41 residential houses and 50 public/commercial buildings

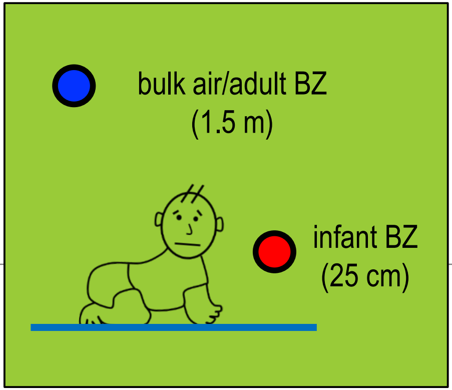
Estimated mean site-specific $\mathbf{F_{inf} = 0.26 \pm 0.04}$ (low end of range reported by Chen and Zhao, 2011 *Atmos Environ*)

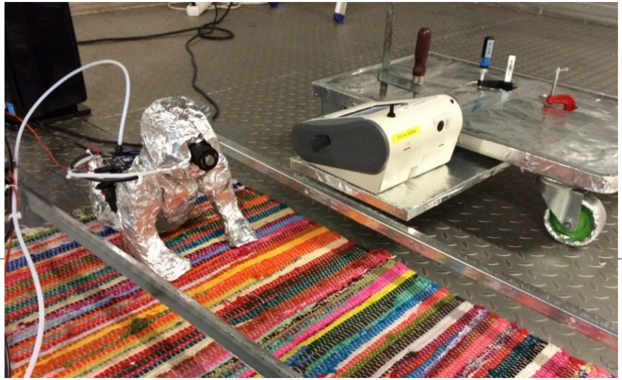
Below $PM_{2.5}$ ~30 µg/m³ indoor sources contributed substantially to personal exposures



Bi et al., 2021

Vertical Variability





10 min. bkg

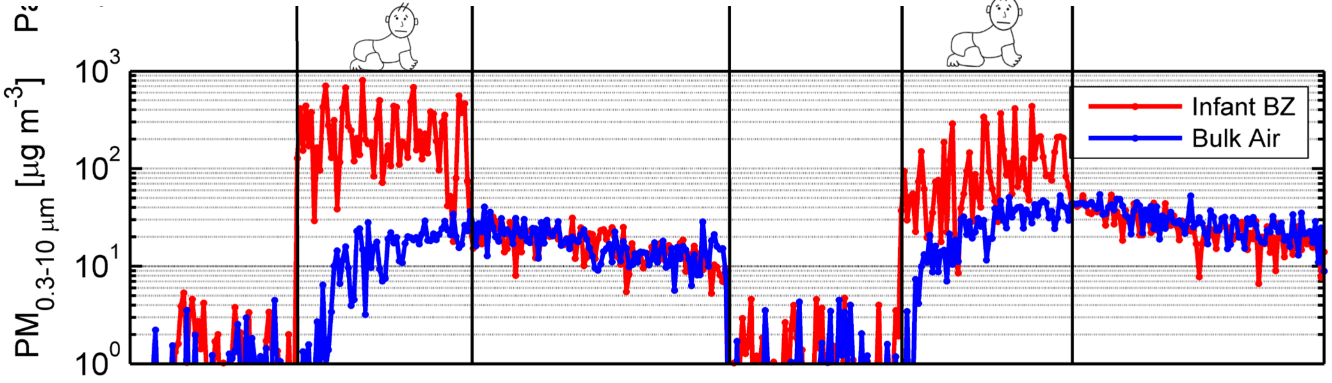
10 min. crawl

15 min. decay

10 min. bkg.

10 min. crawl

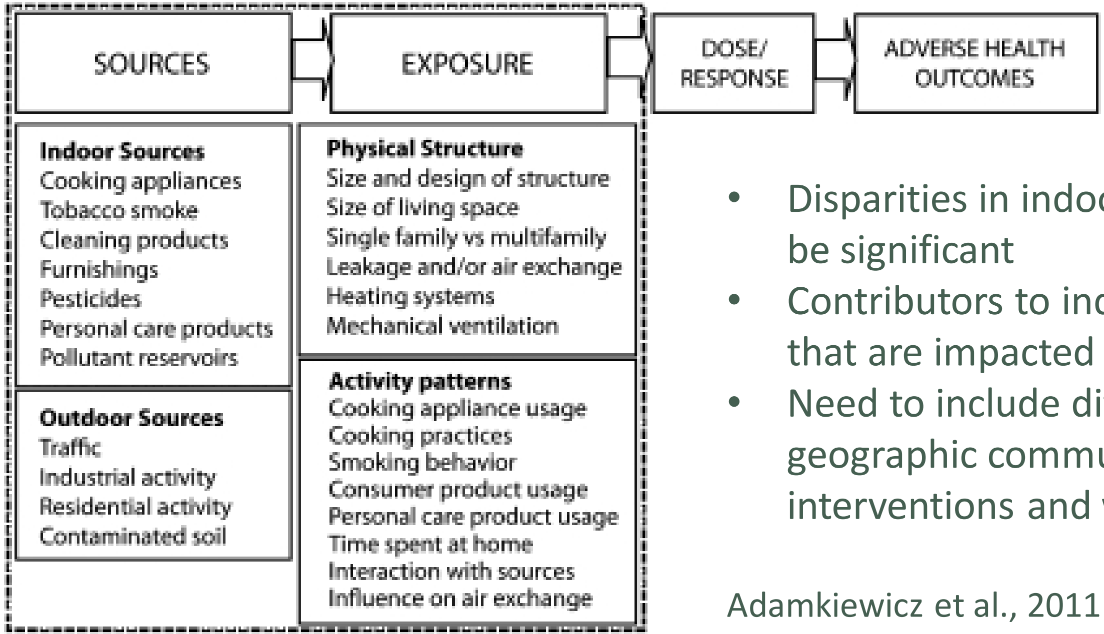
15 min. decay



gravimetric calibration of OPS, $\rho \sim 1.4\ g/cm^3$

Boor, 2017; Hyytiainen, 2018

Contributors to indoor exposure disparities



- Disparities in indoor environmental exposures can be significant
- Contributors to indoor exposure include factors that are impacted by socioeconomic status
- Need to include different socioeconomic and geographic communities in assessments and interventions and work directly with communities

Adamkiewicz et al., 2011

Can ambient air quality standards be used to assess indoor air pollutants?

- Ambient $PM_{2.5}$ strongly correlated with health effects
- Most $PM_{2.5}$ exposure occurs indoors
- Since only some of the ambient PM makes it indoors, applying ambient health-based standards assess indoor $PM_{2.5}$ would underestimate risk
- Need to separate indoor-generated vs outdoor-infiltrated $PM_{2.5}$

US National Ambient Air Quality Standards

$PM_{2.5}$	primary	1 year	12.0 μg/m^3
	secondary	1 year	15.0 μg/m^3
	primary and secondary	24 hours	35 μg/m^3

https://www.epa.gov/criteria-air-pollutants/naaqs-table

NEED STANDARDS SPECIFIC TO INDOOR PM

Use of DALYs for evaluation of indoor $PM_{2.5}$

Current GBD Study evaluates ambient $PM_{2.5}$, household air pollution from use of solid fuels for cooking (HAPs) and ambient ozone pollution

Expand to other indoor exposures?

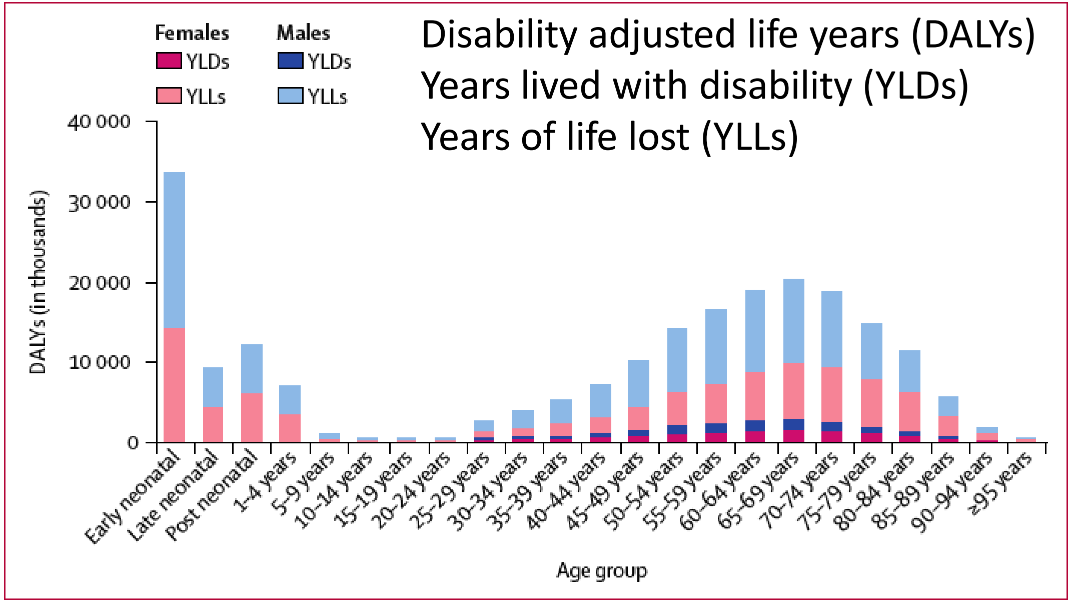


Figure 2: Composition of attributable global DALYs by YLLs and YLDs, age group, and sex, 2019

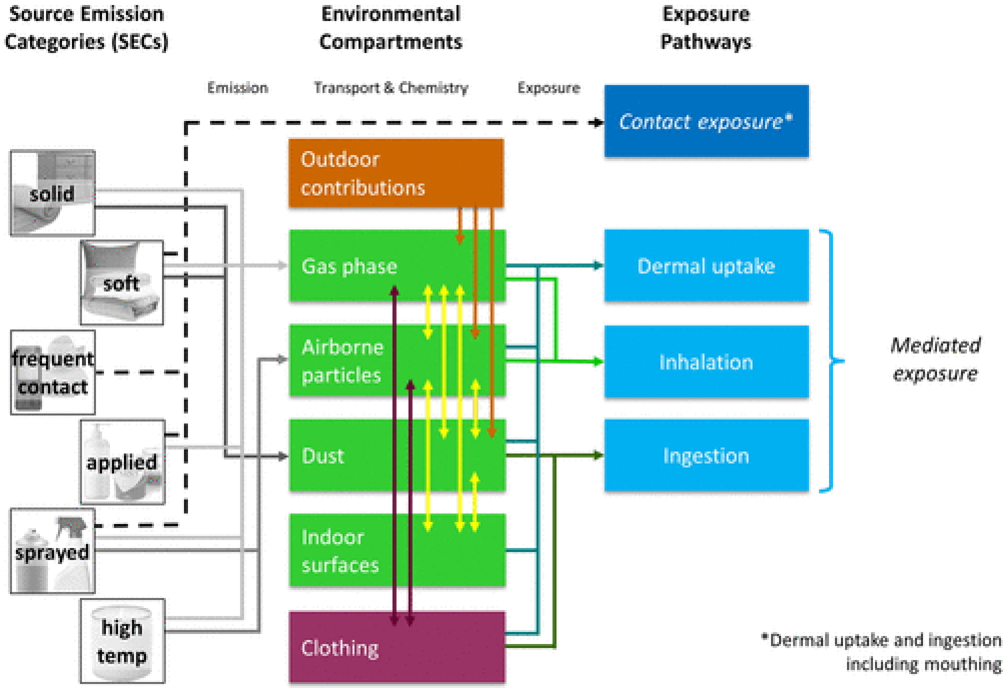
Global Burden of Disease Study 2019: http://ghdx.healthdata.org/gbd-2019

Air pollution—Level 2 risk

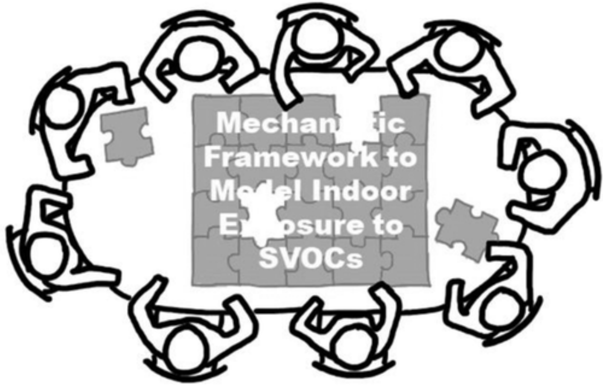
Summary In 2019, air pollution was the leading Level 2 risk factor for DALYs among all environmental and occupational risks. It contributed to 213 million (95% UI 189–240) DALYs and 6·67 million (5·90–7·49) deaths in 2019.

Definition Air pollution includes ambient particulate matter pollution ($PM_{2.5}$), household air pollution from the use of solid fuels for cooking (HAP), and ambient ozone pollution.

Modular mechanistic framework for modeling exposures

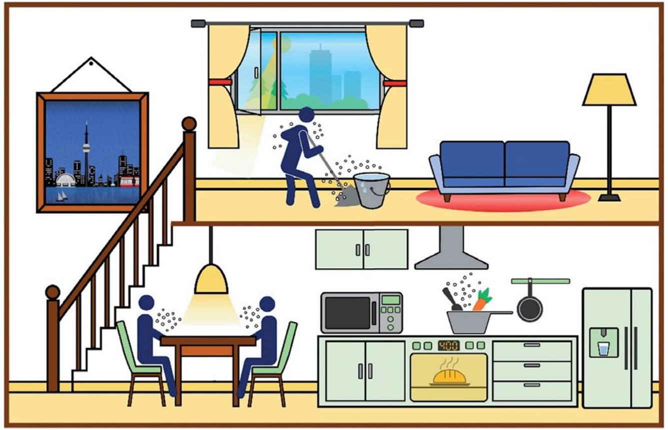


Eichler et al. 2021 *Environ. Sci. Technol.* Assessing Human Exposure to SVOCs in Materials, Products, and Articles: A Modular Mechanistic Framework



Summary & Research Needs

- Indoor $PM_{2.5}$ highly variable, temporally and spatially, and often not strongly correlated with outdoor $PM_{2.5}$
- Composition of indoor $PM_{2.5}$ very different than outdoor $PM_{2.5}$
- Need to separate indoor-generated vs outdoor-infiltrated $PM_{2.5}$ for epidemiological studies
- Update human activity pattern data (e.g., using GPS enabled devices)
- Advance metrics and approach for assessing and communicating indoor $PM_{2.5}$ health impacts
- Increase community-engaged research to understand disparities in $PM_{2.5}$ exposure and develop mitigation strategies



Abbatt and Wang, 2020