Exposure Disparities within the Indoor Environment: Understanding Critical Pathways and Implications for Policy Responses

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Abstract

Background and Objectives Disparities in indoor environmental quality have not been fully incorporated into the dialog on environmental justice. Studies of the residential environment frequently ignore fundamental physical and chemical processes that drive exposure in these spaces, limiting efficient mitigation. This study explores these proximate (i.e., causal) determinants of environmental exposures and their relationships to observed disparities.

Methods A review of the peer-reviewed literature on exposure disparities within indoor environments and potential driving forces was conducted. This evidence is placed in the context of physical and chemical models of indoor exposure dynamics to provide insight on the development of mitigation strategies.

Results Exposure to lead, secondhand smoke and asthma triggers continue to disproportionately affect low SES populations. Recent evidence highlights additional determinants of disparities in indoor environmental exposures, including: age of household furnishings, history of pesticide usage, product usage profiles, lack of mechanical ventilation in kitchens and bathrooms, and air infiltration pathways (multifamily setting). Physical models of emissions, dynamic partitioning, deposition, re-suspension and other critical processes can aid in the evaluation of risk-reduction strategies. Shared pathways (i.e., root causes) and disparities in susceptibility may also contribute to disproportionate cumulative risks.

Conclusion Understanding specific physical and chemical pathways aids in the development of residential interventions that may reduce disparities. The persistence of some chemical residues may contribute to a 'legacy' effect within older housing stock. These linkages will become increasingly relevant in buildings where energy-saving retrofits or weatherization efforts, motivated by climate change benefits, may reduce air exchange rates.

Background

Housing, Health and Disparities The physical home environment has long been known as a determinant of health, but the connections between indoor environmental exposures and specific health effects have become more clear and varied in recent years. Indoor air pollution and other residential exposures have been linked to acute and chronic diseases, including asthma, neurodevelopment disorders and cancer. Relevant exposures include: insect and pet allergens; chemicals in flooring and furnishings; penetrating outdoor toxics; pesticides; chemicals from consumer products; environmental tobacco smoke (ETS) and fungi. Due to the amount of time spent indoors, personal exposures to many of these agents are primarily a function of indoor concentrations.

Motivation for this work

- Environmental exposures originating in the indoor environment can be substantial determinants of poor health for low SES communities.
- Studies of the residential environment frequently ignore known physical and chemical pathways that drive human exposure in these spaces – this limits efficient mitigation.
- Exposure disparities may be driven by these proximate (i.e., causal) determinants, such as those shown below in Figure 1
- In addition, low-SES populations may have heightened vulnerability and/or background exposures, so the risk for the same indoor concentration could be greater.

Figure 1: Key Determinants of Indoor Environmental Quality

Sources	Structure	Behavior
Indoor Sources • Cooking appliances • Tobacco smoke • Cleaning products • Air fresheners • Personal care products • Furnishings • Pesticides • Pollutant reservoirs • Water sources	**Physical Structure** • Size and design of structure • Age • Size of living space • Single family vs. multifamily • Leakage and/or air exchange • Heating systems • Mechanical ventilation	**Source use patterns** • Cooking appliance usage • Cooking practices • Smoking behavior • Consumer product usage • Personal care product usage
Outdoor Sources • Traffic • Industrial Activity • Residential Activity • Contaminated soil		**Activity Patterns** • Time spent at home • Interaction with sources • Influence on air exchange

Insight from Modeling

Physical models of pollutant emission and dynamics can be used to understand the interrelationships between home characteristics, resident behaviors and exposures. As a first step, we will explore these processes in a model of a non-reactive gas-phase pollutant emitted at a constant rate indoors, with no outdoor sources. In this case, the principal contributors to indoor concentrations are: **source strength**, **residence volume**, and the **air exchange rate**. We can represent the steady state concentration of the pollutant as a function of these variables through the following simplified relationship:

$$C_{in} = \frac{S}{(a+k)\cdot V}$$

where C_{in} is the indoor steady state concentration (mg/m^3)
S is the source emission rate (mg/hr)
a is the air exchange rate of the home (1/h)
k represents loss terms, such as deposition or reaction (1/h)
V is the volume of the home (m^3)

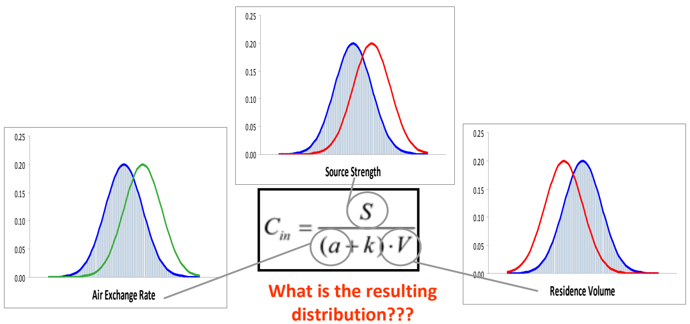
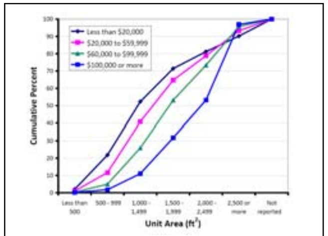
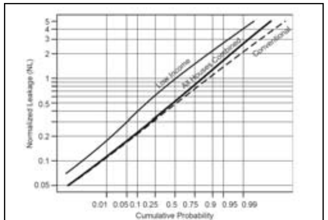


Figure 2: Simplified indoor pollutant model and idealized distributions of key determinants

Examples of Determinant Variability Associated with SES



Dwelling Area by Income - Single Family
(American Housing Survey 2008)



Estimated US nationwide
distributions of normalized leakage
(from Chan et al. 2005)

Implications: → Smaller volumes will increase concentrations;
→ Leakier homes will decrease concentrations

Basic models

Table 1: Idealized Pollutant Modeling Under Various Determinant Scenarios

	Reference Case	Low-income 'Normal' Emission High AER	Low-income High Emission High AER	Low-income Normal Emission 'Normal' AER	Low-income High Emission 'Normal' AER
Volume (m^3)	335*	225*	225*	225*	225*
Source strength (mg/hr)	50	50	100	50	100
Air exchange rate (hr^{-1})	0.6**	1.2**	1.2**	0.6	0.6
Concentration (mg/m^3)	0.25	0.19	0.37	0.37	0.74
Relative to conventional	**1.00**	**0.74**	**1.49**	**1.49**	**2.98**
Percent change	-	**↓26%**	**↑49%**	**↑49%**	**↑198%**

*Median estimated from Chan et al. 2005
**Estimated median from Chan et al. 2005

What does modeling tell us?

As you see in this simplified example:
- predicted steady state concentrations vary considerably due to shifts in the underlying parameters, which may be independently tied to SES; and
- perturbations in more than one determinant can contribute collectively to large changes in exposure.

Given the importance of air exchange as a direct determinant of indoor pollutant (and moisture) levels, SES-related differences in this measure should be noted in the design of energy improvements that reduce air exchange. Settings where higher source emissions and smaller homes volumes have been offset by increased air exchange may be vulnerable to the increased exposure associated with these improvements. Indoor exposures are also influenced by outdoor concentrations (ignored in this example), which may offset some benefits of increased air exchange. (Semi-volatile organic compounds such as flame retardants, pesticides, plasticizers, etc. provide additional challenges due to their persistence indoors.)

Reported Exposure Determinant Disparities

Table 2: Representative studies that inform the links between disparities and determinants in indoor environments

Pollutant	Measure: Environmental Media	Measure: Body Burden	Hypothesized Determinant: Source	Hypothesized Determinant: Source Use	Hypothesized Determinant: Physical Structure (incl. AER)	Hypothesized Determinant: Activity Pattern	Hypothesized Determinant: Other	Reference
VOCS								
1,4-dichlorobenzene	X		X	X				(Wang et al. 2009)
tetrachloroethene	X		X	X			X	(Wang et al. 2009)
BTEX	X		X	X			X	(Wang et al. 2009)
Chloroform	X		X					(Wang et al. 2009)
1,4-dichlorobenzene	X		X	X	X			(Hun et al. 2009)
Chloroform	X		X					(Hun et al. 2009)
Metals								
Lead	X		X		X	X		(Gaitens et al. 2009)
Lead		X	X					(Levin et al. 2008)
SVOCs								
PBDEs		X	X				X	(Zota et al. 2009)
Pesticides		X	X	X			X	(Julien et al. 2008)
Other								
Nitrogen dioxide	X		X	X	X			(Zota et al. 2005)
ETS	X		X		X			(Kraev at al., 2009)
Asthma triggers	X		X	X	X			(Simons et al. 2007)

Benefits of this Framework

Framing the indoor disparity discussion around 'root' causes and key determinants can help:

Design targeted interventions - Individual determinants may be more amenable to intervention or cost effective; and

Identify dominant determinants - Key determinants may contribute to many indoor environmental risks (e.g. air exchange) and thus may be effective 'levers' for intervention.

Challenges/Data Needs

Significant methodological and data needs still exist, including: data on determinants that may serve as intervention targets; comprehensive exposure studies focused on 'new' pollutants (e.g., consumer product use/SVOC exposure); and the identification of existing data sources that can inform intervention design (e.g., American Housing Survey)