Environmental Conditions within Low-income Urban Housing: Understanding clustering and associations with self-reported health

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Health in Common Study

- 4-year study funded by National Cancer Institute (PI: Glorian Sorensen)
- OVERALL GOALS OF STUDY
  - To study social and physical determinants of cancer risk-related behavior among residents of low-income housing
  - Develop intervention to be tested in future study

Health in Common Study

- THIS ANALYSIS
  - To understand the prevalence of key environmental hazards within low-income housing in the Boston area
  - To understand the extent of clustering of these hazards
  - To examine associations with self-reported health among residents of these housing units

Housing Development Characteristics

- Cambridge, Chelsea, Somerville
- 15 public & 5 privately managed
- Family units
- Approx. 40 households per development
- Primary languages spoken at sites: English, Spanish, & Haitian-Creole

Health in Common

Typical Housing Styles

Participant Eligibility

- Adults 18 years of age and older
- Resident of development
- Speaks English, Spanish, or Haitian-Creole
- Randomly Selected Household Member

Assessment Tools

- **Resident Survey (N= 828)**
- **Visual Inspection (N= 828)**
- Manager Interview & Survey (N=20)
- Development Visual Inspection (N=20)
- Neighborhood Assessment (N=479)

Participant Characteristics

Characteristic	n (%)
Age - n (%)	
18-29	153 (19%)
30-39	218 (26%)
40-49	169 (21%)
50-59	145 (18%)
60+	140 (17%)
Gender - n (%)	
Male	169 (20%)
Female	659 (80%)
Race/ethnicity - n (%)	
Hispanic	341 (41%)
Non-Hispanic White	93 (11%)
Non-Hispanic Black	316 (38%)
Other	74 (9%)
Income below poverty - n (%)	
Yes	445 (58%)
No	327 (42%)

Characteristic	n (%)
Survey language - n (%)	
English	445 (54%)
Spanish	221 (27%)
Creole	162 (20%)
Education - n (%)	
Grade school or below (<8 yrs)	152 (21%)
Some HS (9-11.5 yrs)	123 (17%)
High School (12 yrs)	200 (27%)
More than high school (13+ yrs)	261 (35%)
Years living in development - n (%)	
0-5 years	382 (48%)
5-10 years	184 (23%)
More than 10 years	226 (29%)
Number of people in apartment	
Mean (SD) [Range]	3.0 (1.5) [1-13]

Environmental Exposures

Characteristic	n (%)
Smoking status (participant) - n (%)	
Never	534 (64%)
Former	117 (14%)
Current	177 (21%)
Pests observed in-unit by participant during the past year - n (%)	
Cockroaches	389 (47%)
Mice	351 (42%)
Rats	42 (5%)
Bedbugs	63 (8%)
Mold in the past year reported by participant - n (%)	
Yes	276 (34%)
No	545 (66%)
Mold seen during inspection - n (%)	
Yes	125 (15%)
No	696 (85%)
Used stove to heat apartment in past 12 months - n (%)	
Yes	107 (13%)
No	719 (87%)

Analysis

- **Created indices for key hazards / risk factors**
  - chemical exposure, mold, ETS, pests, combustion by-products, poor ventilation
- **Created summed index**
- **Examined correlations**
- **Built model for each index and summed index**
- **Built model for self-reported health**

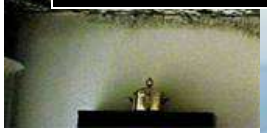

Raid
Ant & Roach


Xpelair

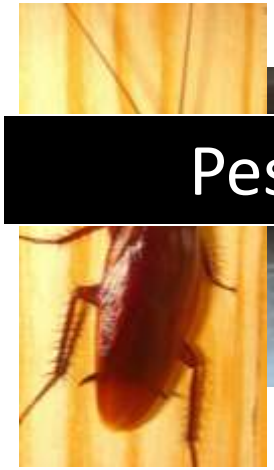
ETS

Combustion by-products

Chemicals



Mold



Pests

Inadequate ventilation

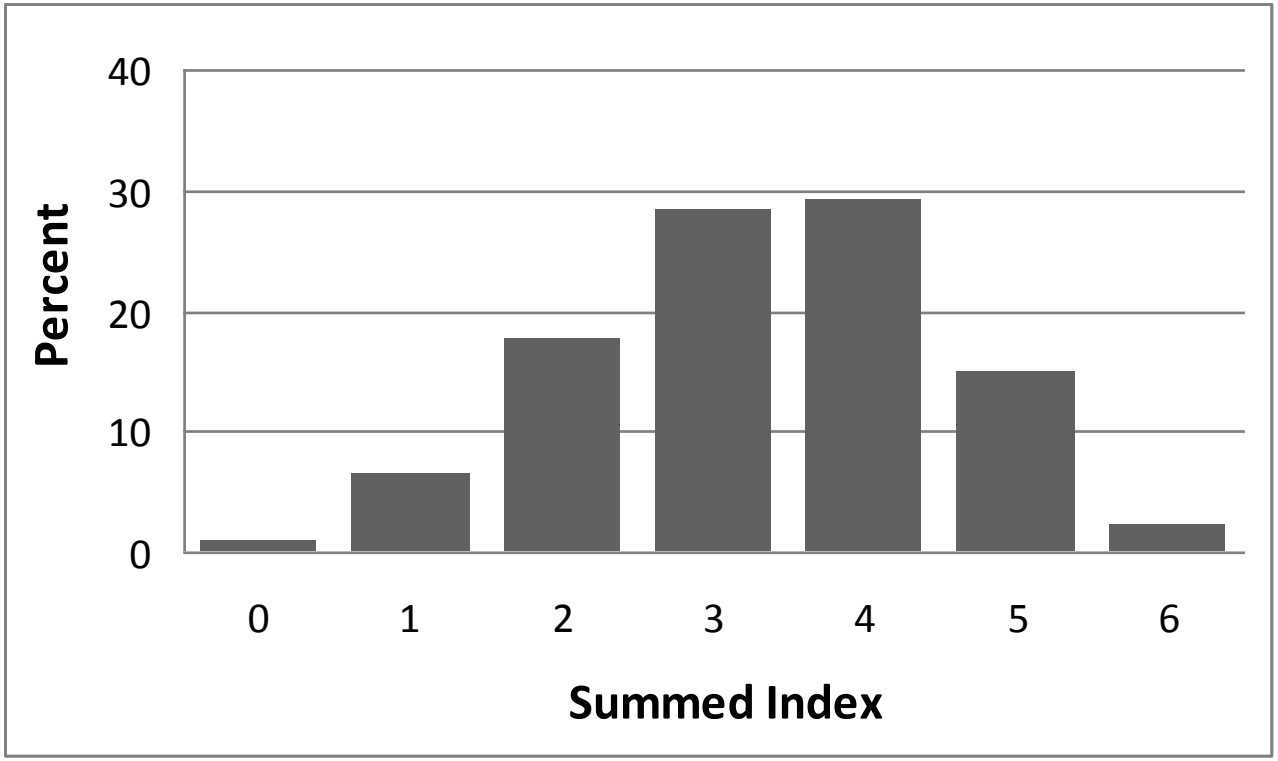
Results

Environmental Indicators

Characteristic	n (%)
Environmental indices [n with problem (%)]	
CHEMICAL	663 (81%)
Frequent use of pesticides or air fresheners in the homes	
MOLD	358 (43%)
Visible mold or mold treatment reported by resident or visible mold noted during inspection	
SECONDHAND SMOKE	172 (22%)
Any reported smoking within the home	
PESTS	443 (54%)
Frequent sightings of mice, cockroaches or rats	
COMBUSTION BY-PRODUCTS	415 (52%)
Gas stove without mechanical kitchen exhaust or reported use of gas stove to heat apartment	
INADEQUATE VENTILATION	368 (48%)
Inadequate kitchen or bathroom mechanical ventilation	
Summed index	
Mean (SD) [Range]	2.9 (1.3) [0-6]

What are the relationships between these indicators/exposures ??

Summed Index Distribution

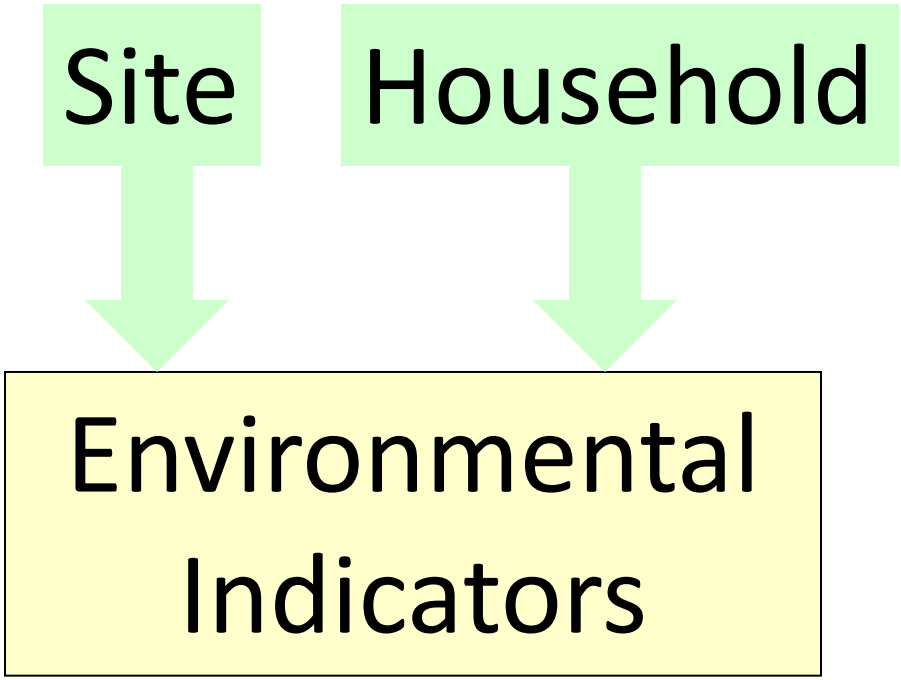


Correlations

	Chemical	Mold	SHS	Pests	Combustion	Ventilation
Chemical		0.50	**0.035**	**0.0008**	0.69	0.66
Mold			0.51	**0.0002**	0.067	**0.03**
SHS				0.96	0.44	0.21
Pests					0.19	0.14
Combustion						**<0.0001**
Ventilation						

(p-values for Chi-square tests)

Models



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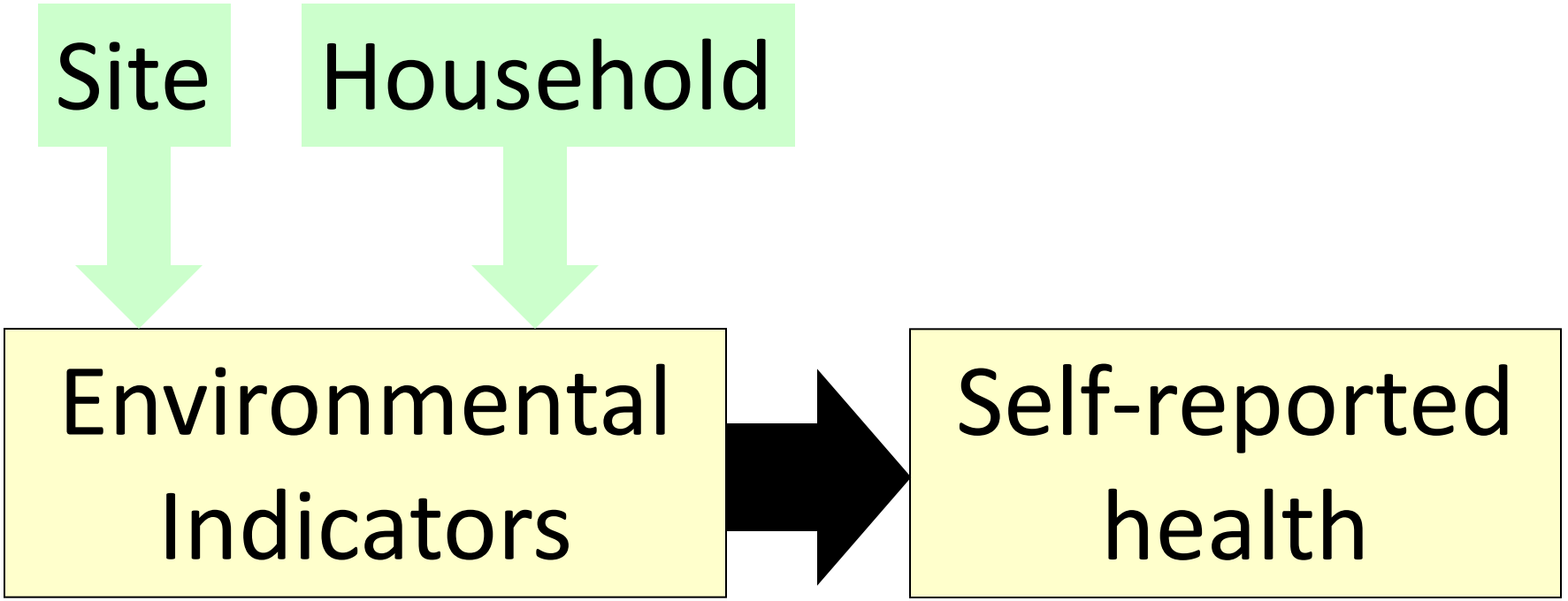
Site
Household
Environmental Indicators
Self-reported health

Environmental Indicators

Index	*Significant Fixed Effect for 'Site'?*	*p value*	*Other significant predictors†*
Chemical index	No	NS	-
Mold index	**Yes**	<0.0001	Years in complex (+) Occupancy (+)
ETS index	No	NS	Race/ethnicity (↑White) Survey language (↑English) Education (-) Gender (↑Male)
Pest index	**Yes**	<0.0001	Age (-)
Combustion byproducts	**Yes**	<0.0001	Adult over 65 in household (-)
Inadequate ventilation	**Yes**	0.0087	Adult over 65 in household (-)
Summed index	**Yes**	<0.0001	Years in complex (+)

*All associations are adjusted for site, age, race/ethnicity, poverty status, survey language, education, having a child under 5 in the household, having an adult over 65 in household, tenure in apartment, and gender. Full models presented as supplemental information.

†$p<0.05$ for variables listed in this column

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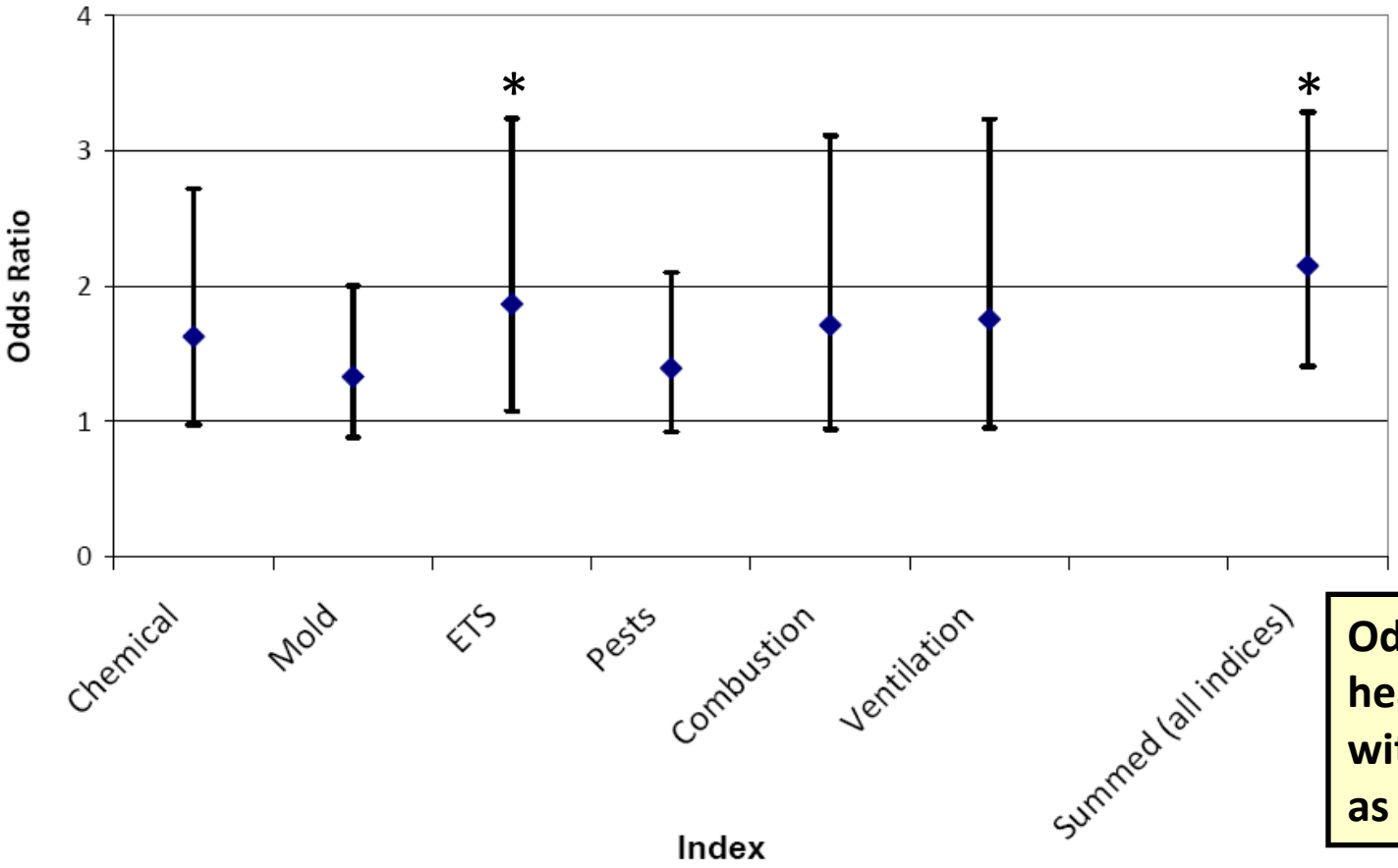
Associations with Self-reported Health

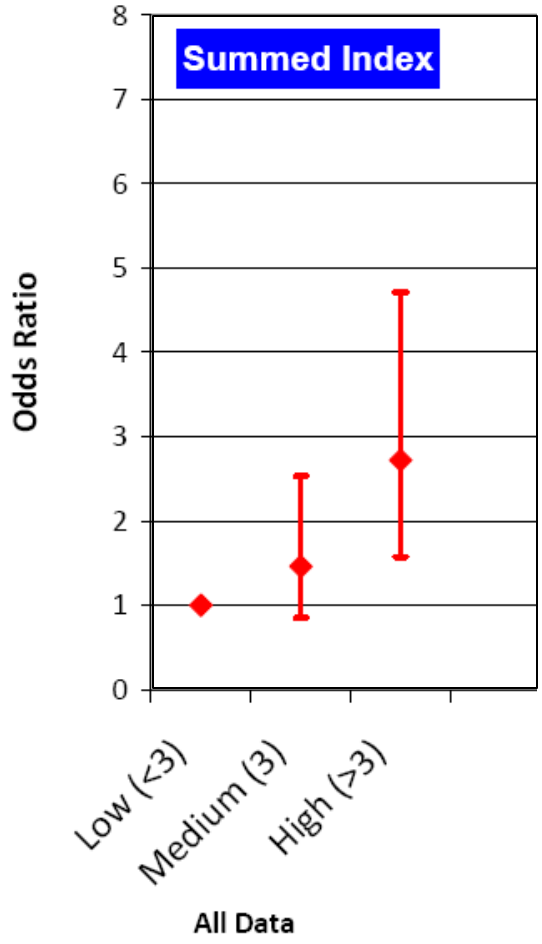


Odds Ratio = 2.15 (1.4,3.3) p<0.001

Odds of self-reporting health as poor to fair, with good to excellent as control

All associations are adjusted for site, age, race/ethnicity, poverty status, survey language, education, having a child under 5 in the household, having an adult over 65 in household, tenure in apartment, gender and 'ever smoked. *p<0.05

Associations with Self-reported Health



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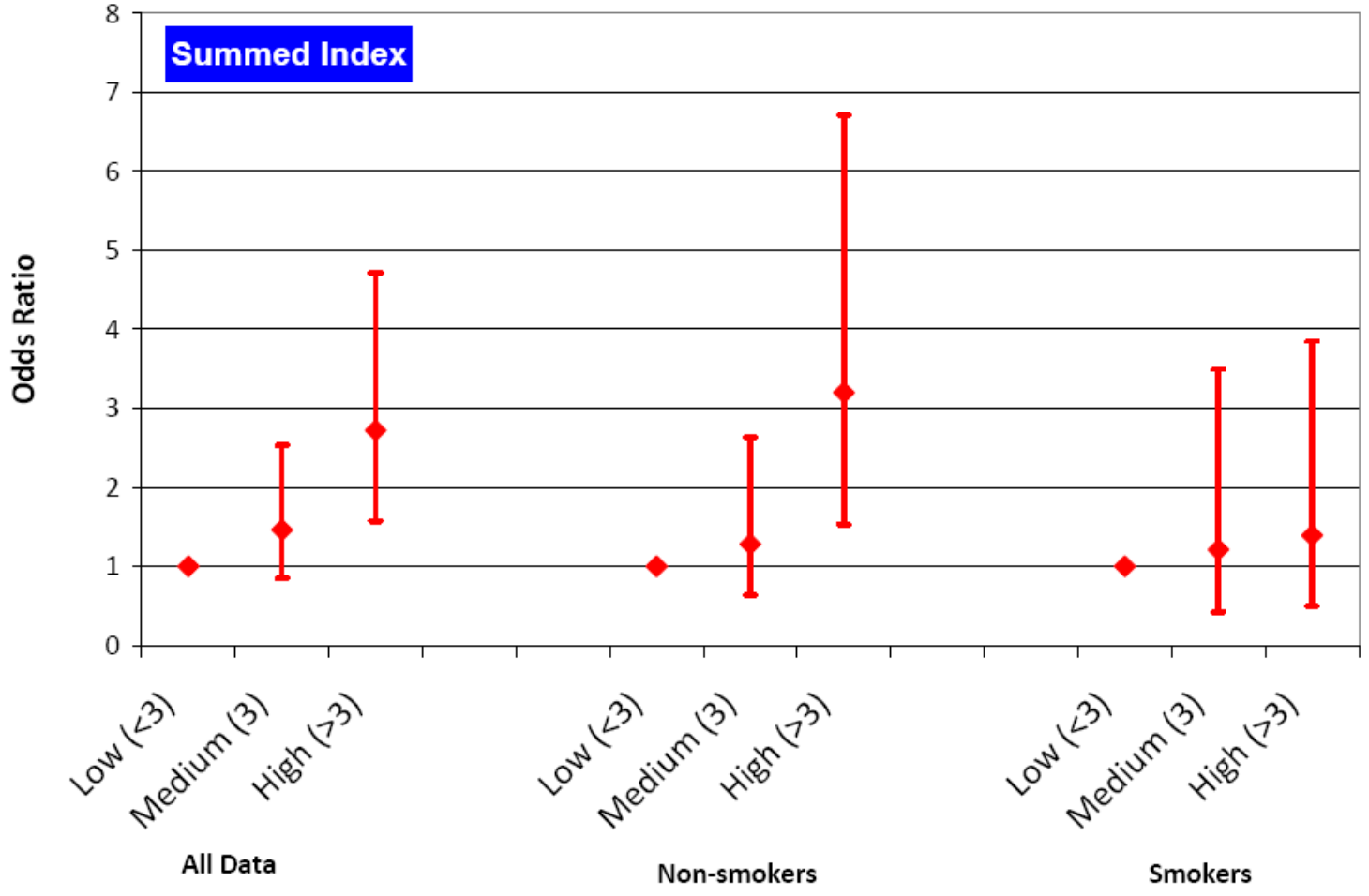


Conclusions

- Environmental **hazards are common** in low-income housing
- Strong evidence for **clustering by site** for hazards with clear ties to structure or operations at the building/development level
- **Associations with self reported health** are significant for ETS and for a summed measure of environmental hazards

Acknowledgements

- Administrative and field staff at:
  - Harvard School of Public Health
  - Dana Farber Cancer Institute
- Project team:
  - Reggie Tucker-Seeley
  - Brittany Bricen
  - Lorraine Wallace
  - Ruth Lederman
  - Mike Massagli
- **Funding:** This research was supported by the National Cancer Institute (R01 CA111310-01A1). Principal investigator: Glorian Sorensen.

Health Hazards in the Residential Environment

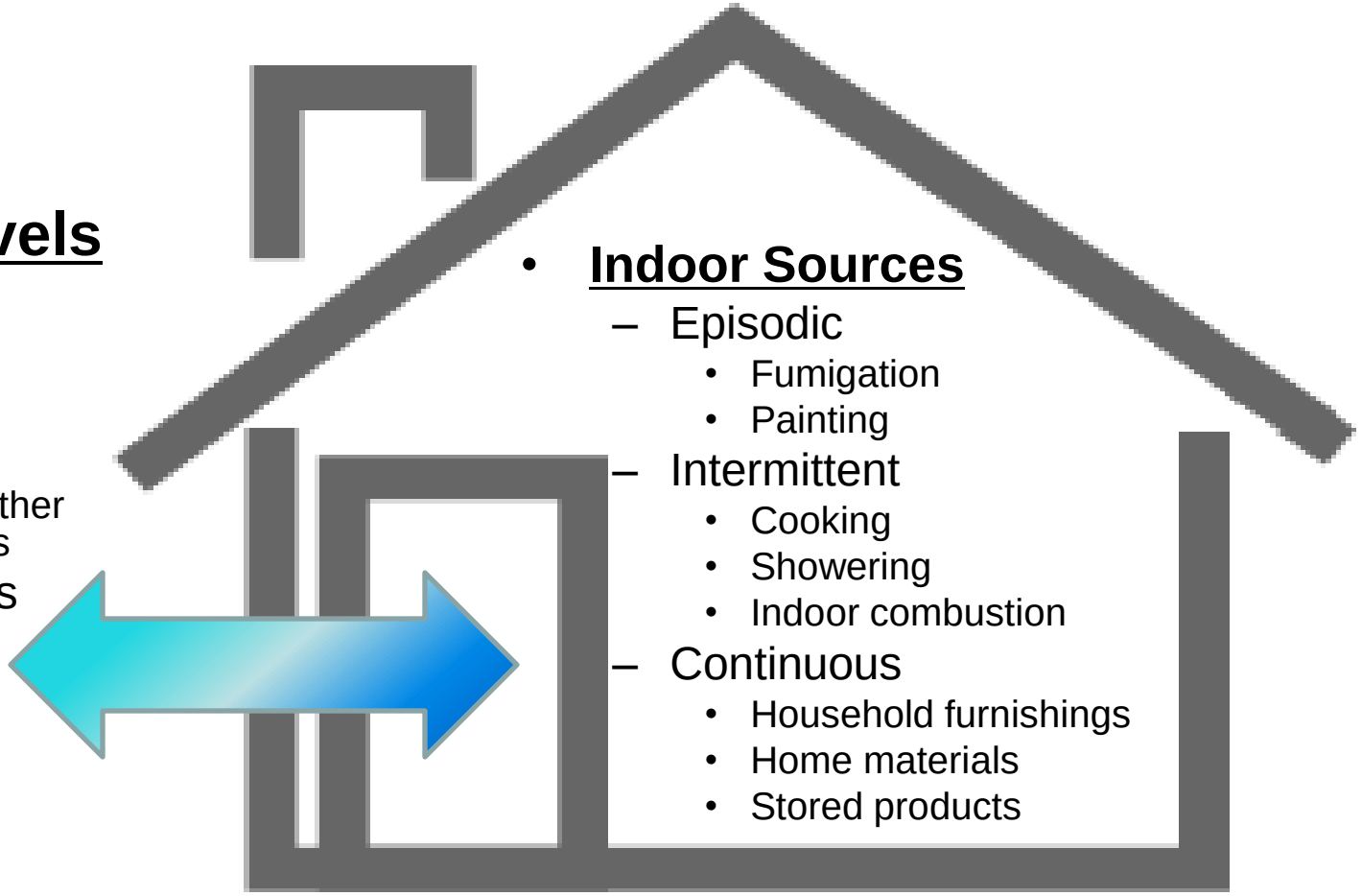
Jennifer Logue

Brett Singer

Determinants of Indoor Pollutant Concentrations

- **Outdoor Pollutant levels**

- **Air flow**
  - Infiltration
    - Function of weather and air tightness
  - Windows & doors
  - Mechanical Ventilation
    - Kitchen & bath
    - Whole house



- **Indoor Sources**
  - Episodic
    - Fumigation
    - Painting
  - Intermittent
    - Cooking
    - Showering
    - Indoor combustion
  - Continuous
    - Household furnishings
    - Home materials
    - Stored products

But what are pollutants of concern?

- What pollutants should we be controlling for?
- What is the most effective way to control them?
- Need to narrow down the immense list of existing chemicals to a manageable number for further analysis
- Our Approach: Hazard Analysis - a binary identification of pollutants that may cause harm

Types of Indoor Pollutants

- SVOCs
- ETS
- Radon
- CO
- Mold / allergens
- Microbes
- Biological
- VOCs
- Outdoor origin

Types of Indoor Pollutants

Chemical Pollutants

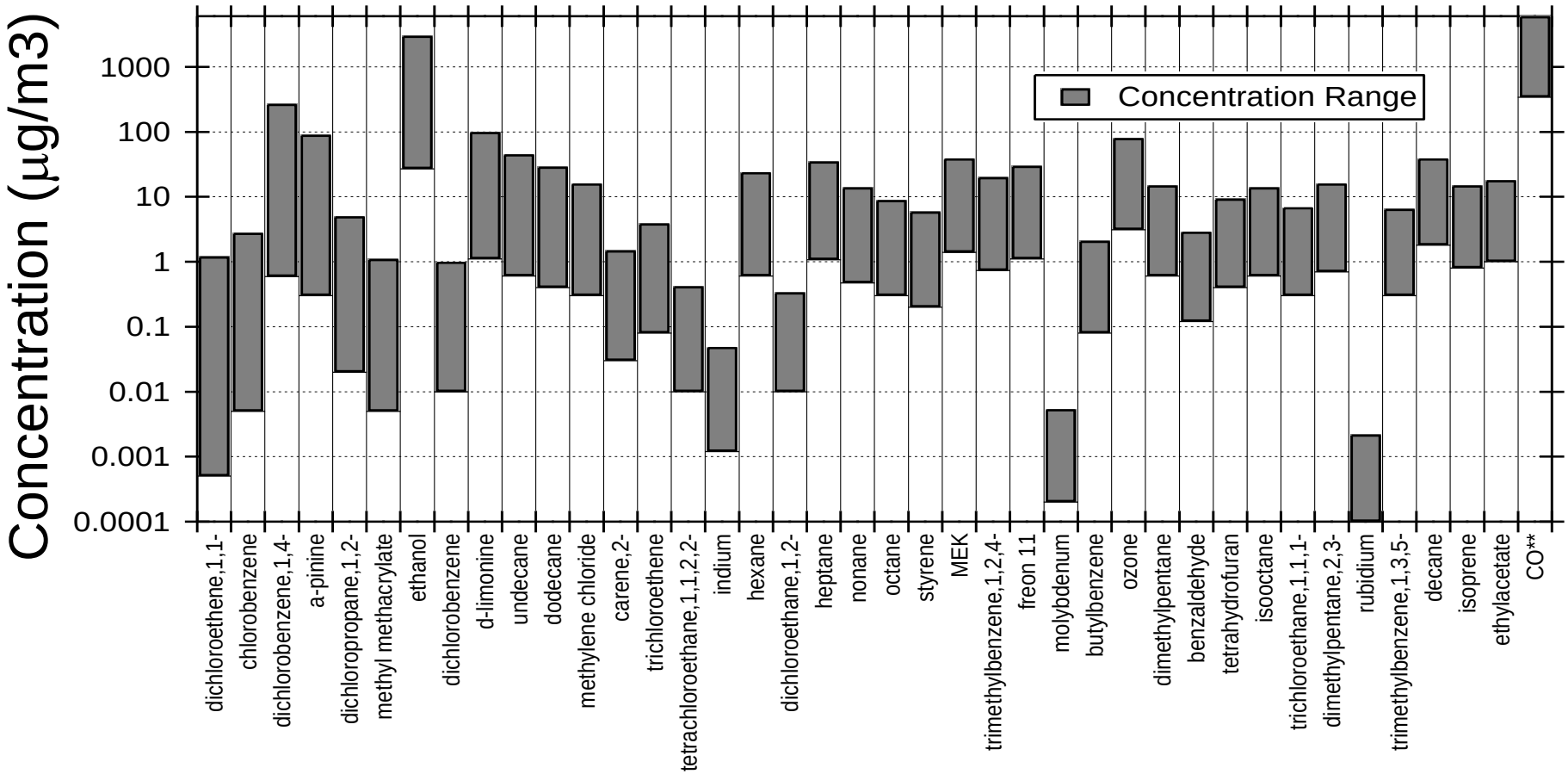
Overview of Study

- Compiled available data on measured concentrations
- Compared median and 95th to available health based standards
- Identified chronic hazards in
  - Most (>50%),
  - Many (5-50%),
  - Few (<5%) homes
- Identified potential acute hazards indoors
- Noted suspected hazards without health standards

What are concentrations in homes?

- Compiled 80 studies of measured concentrations
- Calculated weighted summary statistics for long-term concentrations
  - 321 pollutants
- Compiles short term peak concentrations
  - Cooking, cleaning, etc.
  - 5 pollutants

Typical Home Concentrations



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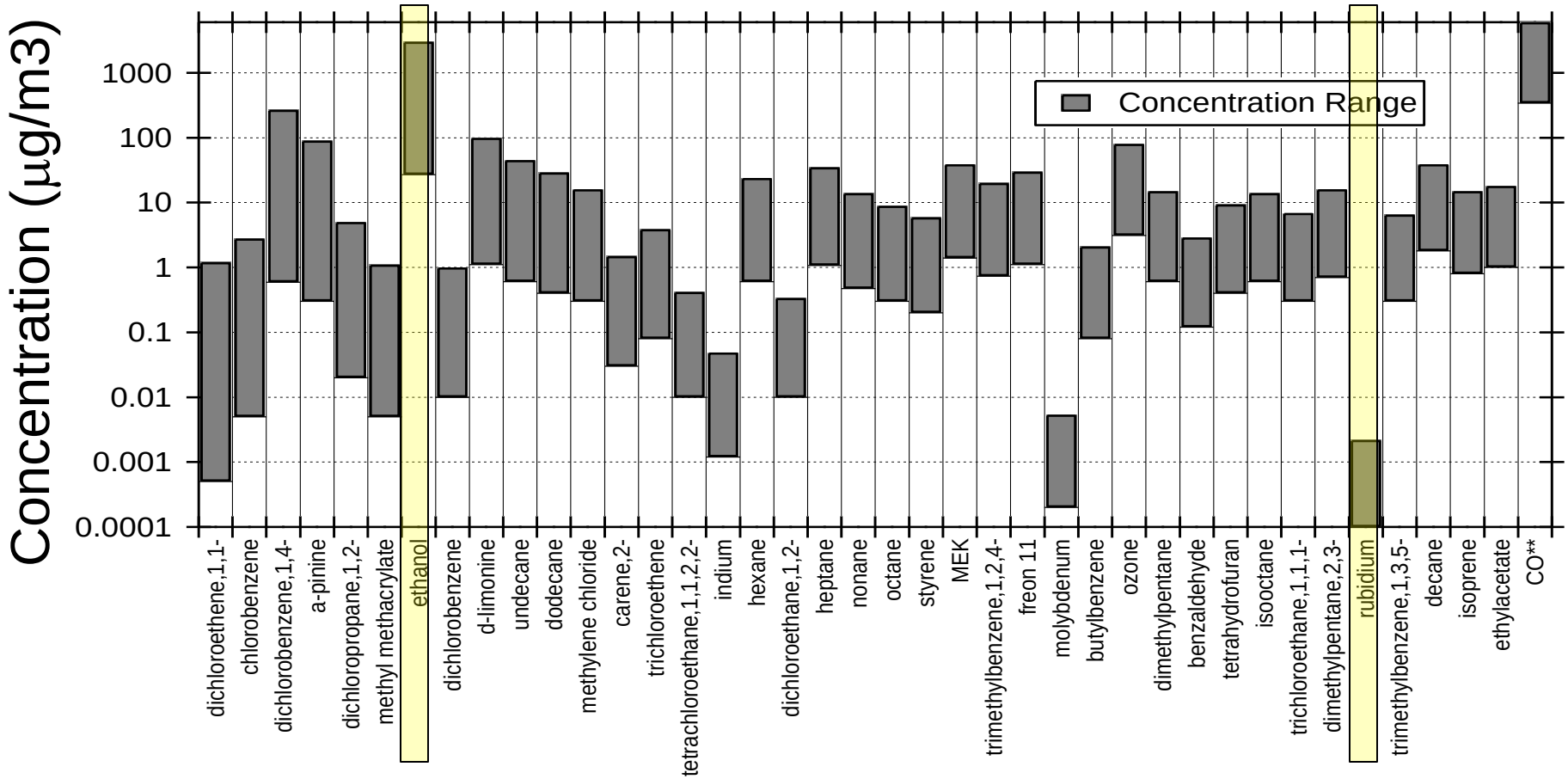

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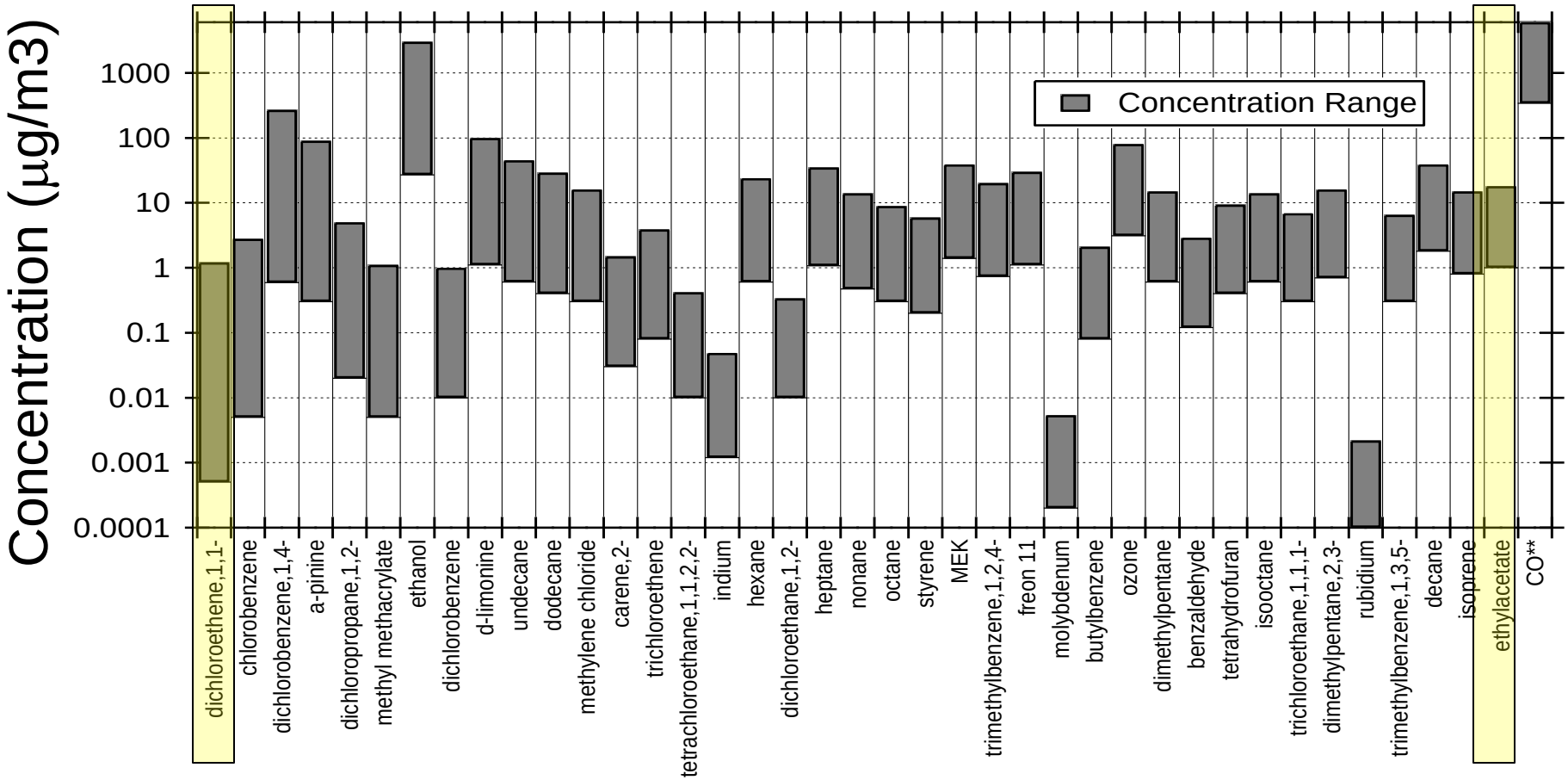


Not all pollutants are created equal!

- Level of toxicity varies widely between pollutants
- Measurements like TVOC are relatively useless
- Several state, federal, and international agencies have set standards or guidelines for exposure

Acute vs. Chronic Exposure

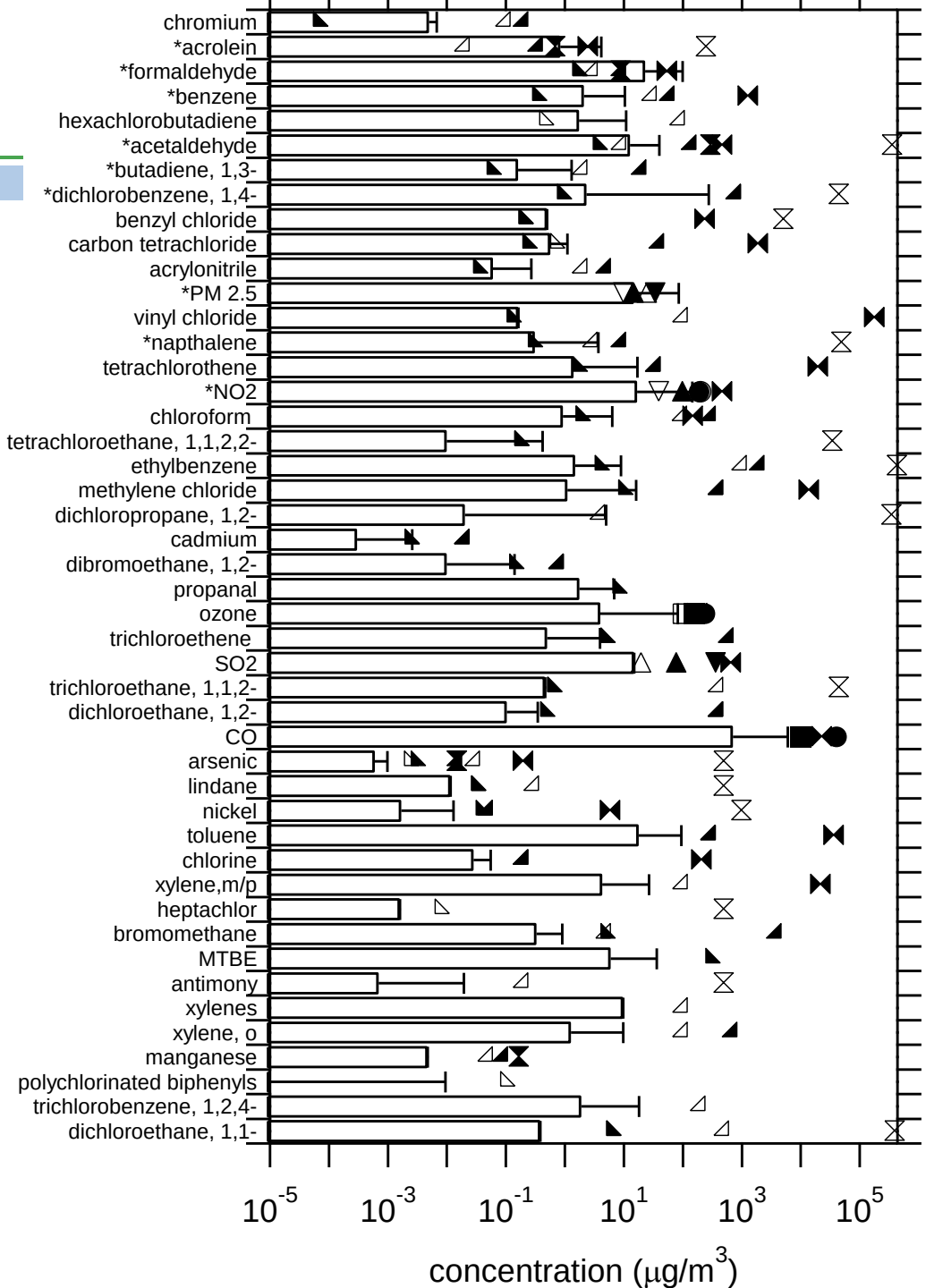
- Chronic Exposure
  - Life-time of exposure
  - Effects are cumulative
  - Exposure time frame is 1year
  - Ex. SHS, furniture emissions

- Acute Exposure
  - Instant effect
  - Exposure period is considered 1hr or less
  - Effects can clear up or be permanent
  - EX: Carbon monoxide in homes

Standards Organizations

- Environmental Protection Agency
- World Health Organization (WHO)
- California Environmental Protection Agency (CalEPA)
- Occupational Safety & Health Administration (OSHA)

Identifying Chronic Health Hazards



Benchmark

- CalEPA 8hr
- CalEPA REL
- CalEPA Cancer
- CalEPA Acute
- WHO Annual
- WHO 24hr
- WHO 8hr
- WHO 1hr
- OSHA 8hr
- EPA RfC
- EPA Cancer
- NAAQS Annual
- NAAQS 24hr
- NAAQS 8hr
- NAAQS 1hr

Hazards in most homes	*# of studies (# of data points, midpoint, upper bound)*	*Level of certainty*
acetaldehyde**	**12 (1578, 965)**	**high**
acrolein**	**5 (1241,965)**	**high**
benzene**	**21 (6897, 3240)**	**high**
butadiene, 1,3-**	**8 (328, 7)**	**high**
dichlorobenzene, 1,4-**	**12 (1691, 1626)**	**high**
formaldehyde**	**18 (1916, 965)**	**high**
naphthalene**	**9 (2043, 1544)**	**high**
NO2**	**19 (7797, 1642)**	**high**
PM2.5**	**18 (2822, 1141)**	**high**
carbon tetrachloride	5 (861, 554)	high
acrylonitrile	1 (75, 75)	medium
chromium	4 (284, 334)	medium
hexachlorobutadiene	1 (443,400)	low
benzyl chloride	1 (39, --)	low
vinyl chloride	1 (447, 447)	low
Hazards in some homes		
chloroform	12 (1217, 1107)	high
ETS	not applicable	high
ethyl benzene	18 (5689, 2640)	high
methylene chloride	8 (1538, 1130)	high
radon	not applicable	high
tetrachlorothene	13 (3648, 3158)	high
cadmium	3 (275, 372)	medium
dichloropropane,1,2-	2 (75, 538)	medium
Hazards in few homes		
bromomethane	1 (439,400)	high
chlorine	4 (342,499)	high
CO	8(1077,770)	high
dichloroethane,1,2-	3(292,75)	high
trichloroethene	11(3118,3145)	high
propanal	4(343,398)	low

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Identifying Acute Hazards

Pollutant	Activity	Conc. (μg/m3)
Chloroform	12min shower	157
Formaldehyde	oven cleaning	417
	cooking fish (electric and gas)	129
NO2	unvented fireplace use	2422
	oven cleaning	1435
	cooking french fries (gas)	772
	unvented fireplace use	677
	cooking	355
	maxiumum in kitchen	243
	maxiumum in kitchen	209
CO	unvented fireplace use	114000
	unvented fireplace use	20486
PM2.5	oven cleaning	6381
	constantly sooting candle	1400
	cooking	745
	cleaning product	215
	candle vapor eucalypt oil	132

Controlling IAQ

Pollutant Source Type	Source Control	Windows & Task Vent.	Kitchen and Bath Vent.	Programmed Mech. Vent.
Episodic Events (painting, fumigation)	Most efficient	Helpful but costly	Helpful but costly	Helpful
Intermittent Local (cooking, showering)	Somewhat effective	Most efficient	Most efficient	Helpful
Intermittent Distributed Cleaning, Product use	Potentially effective	Generally effective	Effective for kitchen & bath	Helpful
Continuous Distributed Finishing materials, Furnishings, Products	Most robust and efficient for new stuff	Not suitable	Not suitable	Effective and robust; energy trade-offs

Reducing Indoor Airborne Concentrations

		Mitigation Methods		
Priority Pollutants	**Indoor Sources**	**Removing/ Reducing Sources**	**Task Ventilation**	**Whole House Ventilation**
acetaldehyde	combustion,products, materials, infiltration	X	X	X
acrolein	combustion, materials		**X**	X
benzene	combustion, infiltration, products	**X**	X	
butadiene, 1,3	combustion, infiltration		**X**	
dichlorobenzene, 1,4-	products	**X**		
formaldehyde	combustion, materials		X	X
naphthalene	products	**X**		X
NO2	combustions, products		**X**	X
PM2.5	combustion, secondary reactions, infiltration	X	**X**	

Potential Hazards Not Covered by Standards

- 54% of the compounds measured had no available standards
- Significant health impacts, no standards
  - Bio-accumulating SVOCs
  - Ultrafine particulates
  - Mold/Moisture
- Large material loading, but little available toxicology information

Questions?


LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES

Pollutant	Effect of Ventilation	Effective Mitigation Methods
Mold/ Moisture	Depends on climate	Fixing leaks, effective use of task ventilation
SVOCs	Limited effect based on volatility	Removal of source/ potentially cleaning the area
Dirty Ducts/ Filters	Increases potential issues	Routine maintenance of HVAC system
Radon	Depends on pressurization of home	EPA approved mitigation techniques
ETS	Reduces concentration of volatiles	Don’t smoke indoors

- The next contaminant of concern?

Additional Issues of Concern

- Mold and moisture
- Bio-accumulating SVOCs
- Endocrine disruptors
- Biological contaminants
- Ultrafine particles
- Dirty ducts?
- The next contaminant of concern


LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES


LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES


LEADING THE NATION TO HEALTHY
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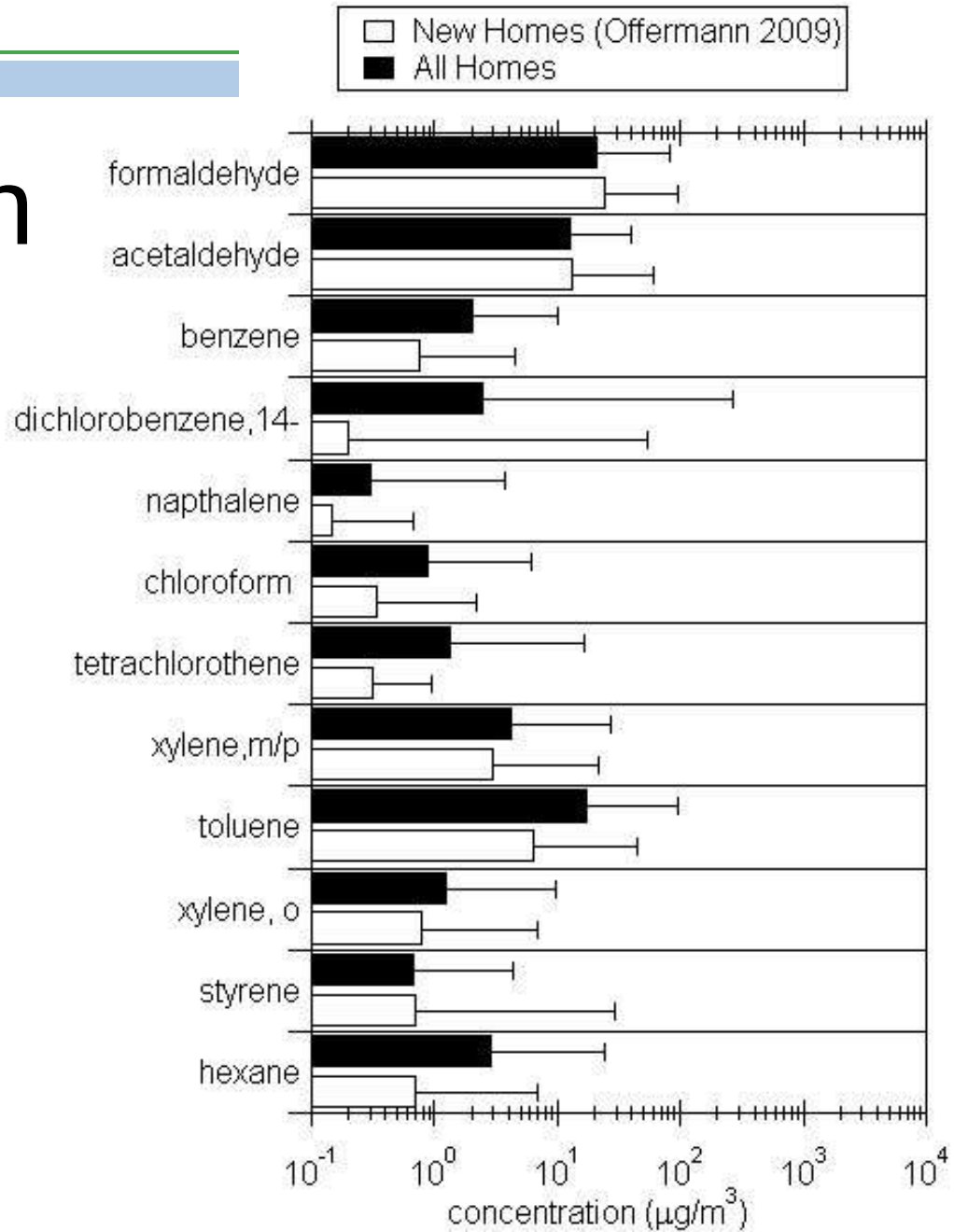
LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES

Concentrations in New Homes

- Lower concentrations of compounds associated with product use indoors
- Brown et al.(1994): study new home concentrations appear to be going down




LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES


LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES


LEADING THE NATION TO HEALTHY
HOMES, FAMILIES, AND COMMUNITIES

Modeling contributions of pollution sources to indoor concentrations of NO_2 and $PM_{2.5}$ in multi-family housing using CONTAM

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Boston University School of Public Health
Harvard University School of Public Health

June 21, 2011

BOSTON UNIVERSITY

Outline

- Justification
- Project overview
- Discrete event simulation
- CONTAM simulations
- Results & other work

Justification

- Pediatric asthma prevalence and the frequency of severe attacks have been shown to be elevated in low-income urban populations

- Residents of low-income multi-family housing can have elevated exposures to multiple environmental pollutants known to influence asthma.

Justification

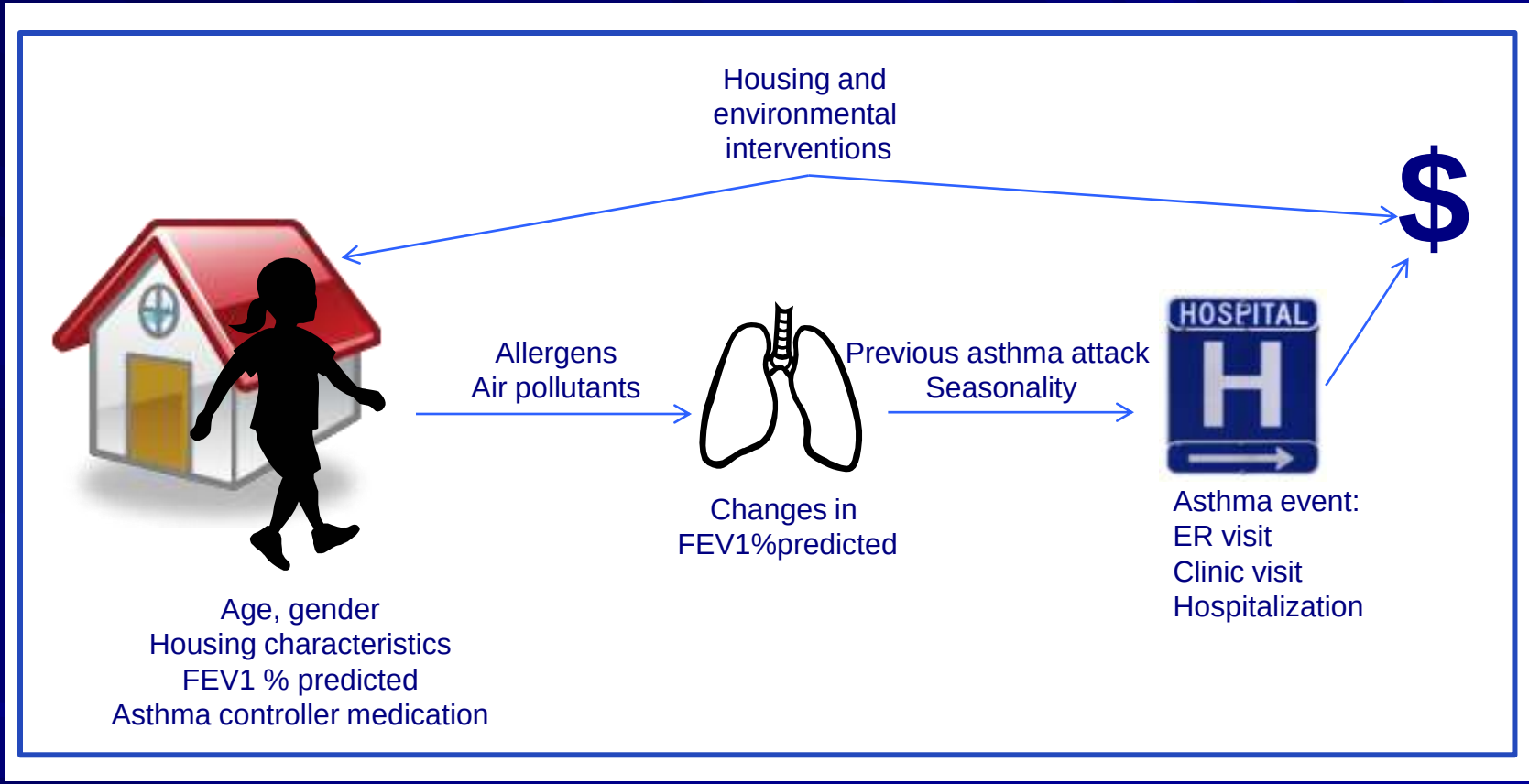
- Difficult to disentangle the various contributing factors and to quantify the tradeoffs between indoor and outdoor sources given changes in ventilation or other household characteristics.

- Simulation models can characterize the health implications of changing indoor concentrations, but quantifying the influence of interventions in multi-family housing on concentrations is challenging given complex airflow and source characteristics.

Discrete Event Simulation (DES)

- A systems science approach involving modeling of a complex system that evolves over time given changes in state variables that occur at defined points in time (Law, 2000)

Pediatric asthma DES in Boston Public housing



DES of pediatric asthma: project overview

Boston Public Housing
- Housing characteristics
- Occupant behavior
- Meteorological conditions
- Outdoor pollutant concentrations

Outdoor pollutants

Meteorological conditions

CONTAM

Detailed output database

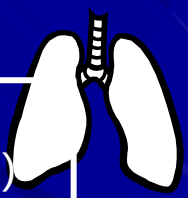
Regression models
- NO_2
- $PM_{2.5}$

Allergens & other pollutants

History of asthma attacks

Asthma medication

Lung function (FEV1% predicted)



Asthma attack
Healthcare utilization
- ER visits
- Hospital stays
- Clinic visits

DES of pediatric asthma: project overview

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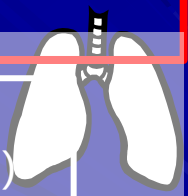

Asthma attack Healthcare utilization
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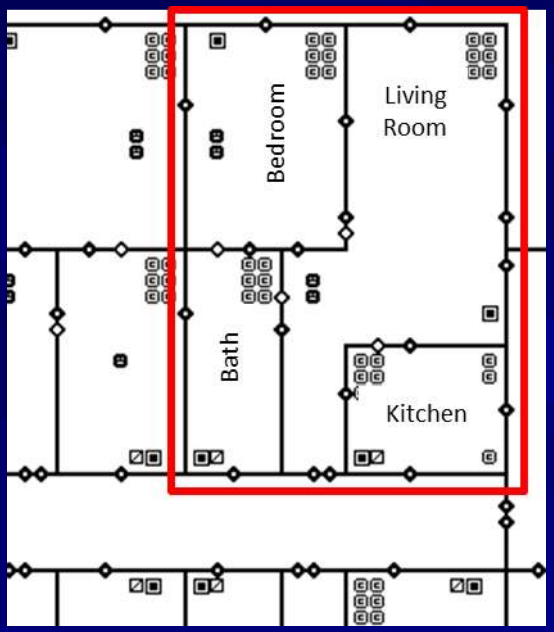
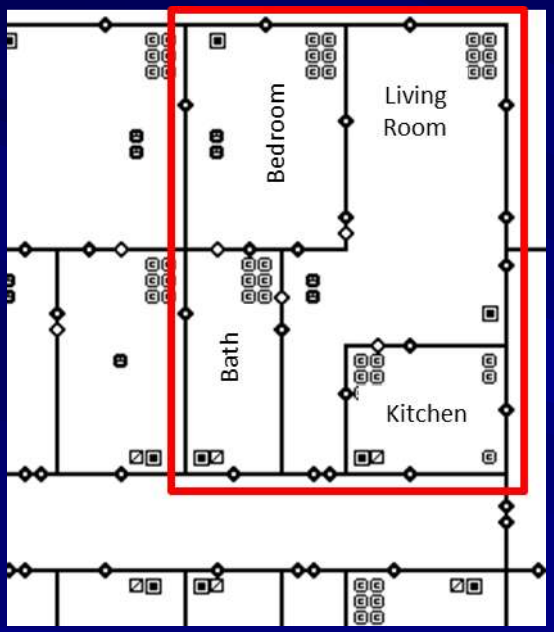
- Clinic visits

Methods: CONTAM



- NIST multi-zone simulation program used to model:
  - Effect of indoor environmental interventions on concentrations of multiple contaminants in inner-city housing (Emmerich, 2005).
  - Effect of air cleaning systems on indoor concentrations of $PM_{2.5}$ (Myatt, 2008, Macintosh 2010).
- Outputs for individual units within a building, time resolved
  - Ventilation rates
  - Pollutant concentrations
  - Thermal conditions (temperature and humidity)
- 209 housing templates already developed

Methods: CONTAM



- Population: Boston Public Housing
- Multi-family apartment building #26
  - 4 stories
  - 1940-1969 construction
  - Naturally ventilated
  - Square footage: 703 sf
- Selected 1st and 4th floor apartments

Methods: CONTAM Pollutants

- NO_2 sources: gas stove use, use of gas oven for supplemental heating in winter, outdoors
- $PM_{2.5}$ sources: cooking, environmental tobacco smoke (ETS), outdoors
- Humidity sources: cooking, breathing, showering, dishwasher

Methods: CONTAM Factors

- House leakiness
  - 4 categories
  - Assigned by wall leakage (0.0177, 0.0530, 0.0722, 0.1878 in^2/ft^2)
- Kitchen and bathroom fan operability (ON/OFF)
- # of times stove was used daily (2X/3X)
- Seasons
- 2 weeks per season,
- Output every 30 min.

CONTAM Results

- Generated a database of 896 24-h average NO_2 and $PM_{2.5}$ concentrations
- Developed regression models with database
- Regression model objectives
  - Determine if simple box model parameters described pollutant behavior
  - Build more comprehensive models to predict pollutant concentrations

DES of pediatric asthma: project overview

Boston Public Housing
- Housing characteristics
- Occupant behavior
- Meteorological conditions
- Outdoor pollutant concentrations

Outdoor pollutants

Meteorological conditions

CONTAM

Detailed output database

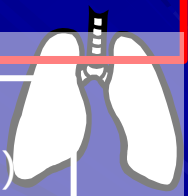
Regression models
- NO_2
- $PM_{2.5}$

Allergens & other pollutants

History of asthma attacks

Asthma medication

Lung function (FEV1% predicted)



Asthma attack Healthcare utilization
- ER visits
- Hospital stays
- Clinic visits

Results: Regression models

- Box model term

$$C_{in} = \frac{Pa}{a+k} C_{out} + \frac{Q/V}{a+k}$$

Outdoors Indoors

P= penetration efficiency (dimensionless)

a = air exchange rate (1/h)

k = decay rate (1/h)

Q = source strength

V = unit volume

Results: Regression models

- Box model term

$$C_{in} = \underbrace{\frac{Pa}{a+k} C_{out}}_{\text{Outdoors}} + \underbrace{\frac{Q/V}{a+k}}_{\text{Indoors}}$$

Example: NO_2 from gas stove

Box model term = $\frac{\text{Stove use (2x/3x per day)}}{a + k}$

Results: Regression Models

- Individual regression models per source
  - NO_2 = outdoors, stove used for cooking & heating
  - $PM_{2.5}$ = outdoors, stove used for cooking & ETS
- Model R^2 ranged between 0.89 to 0.98
  - Box model term explained 29-92% of variability, depending on model

Results: Regression Models

- Significant indoor predictors:
  - Box model term
  - AER
  - Level
  - Fan
- Significant outdoor predictors
  - Box model term
  - AER
  - Level
  - Season

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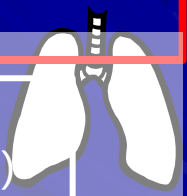

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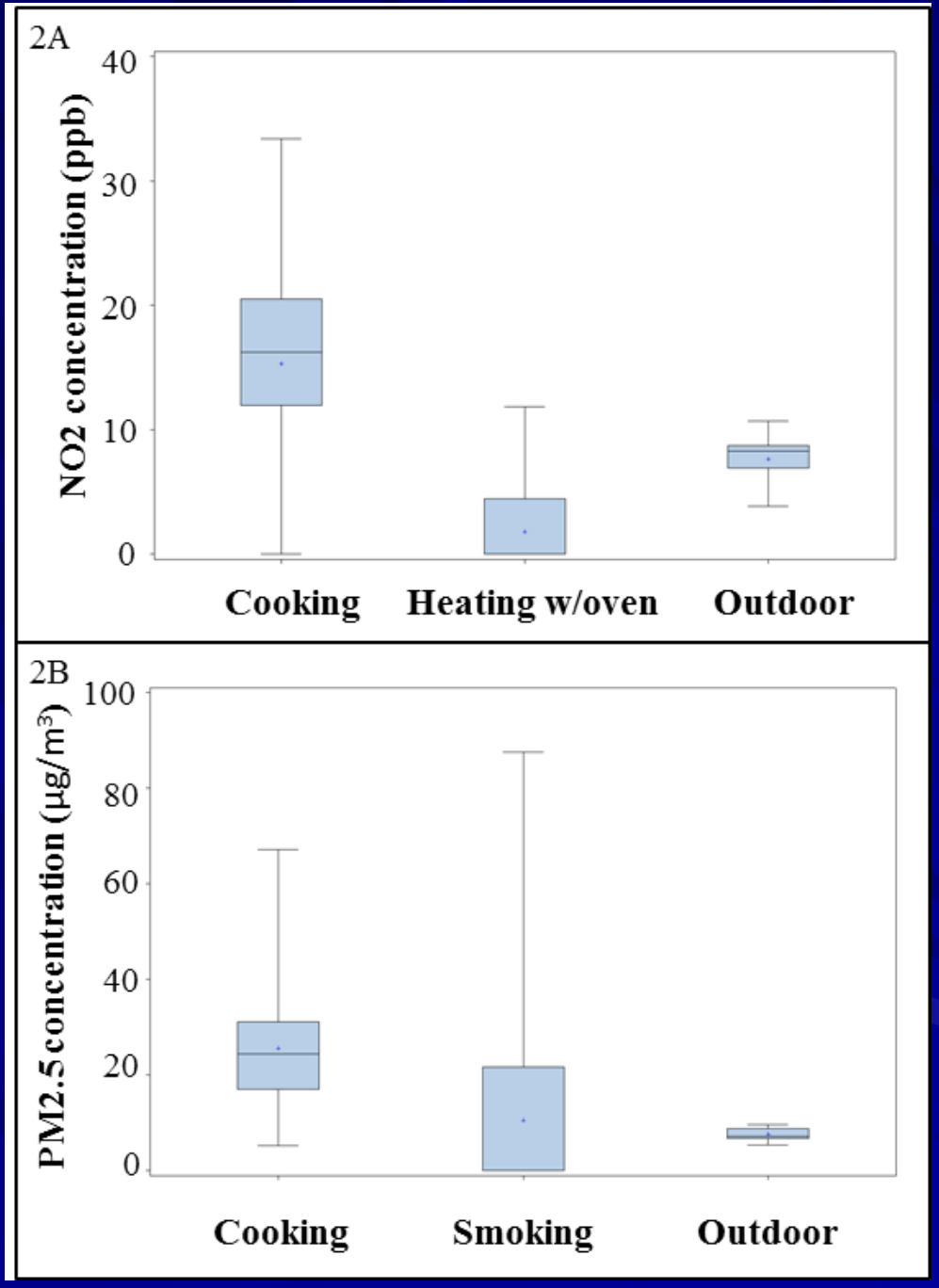
Evaluation

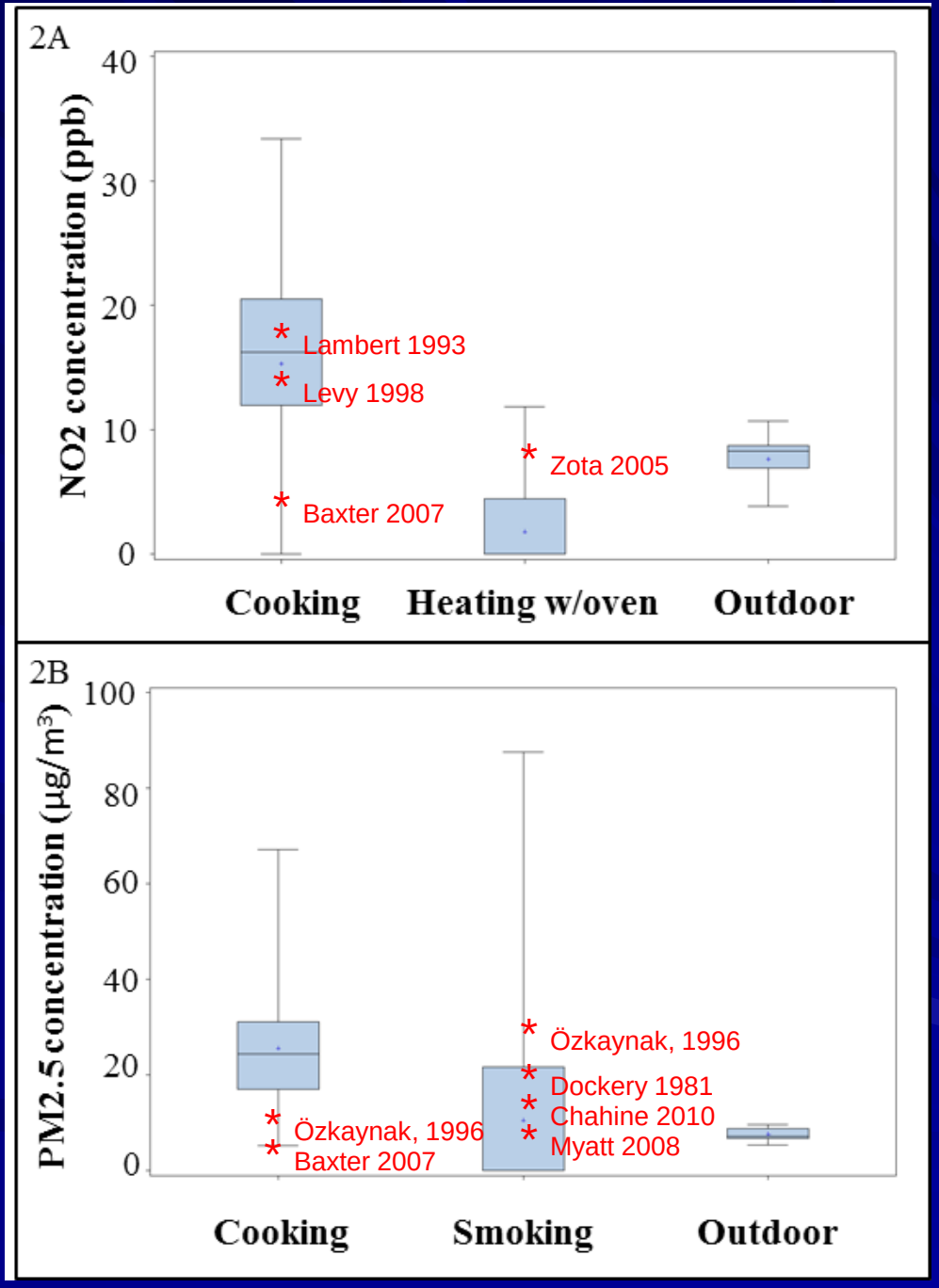
- Predict NO_2 and $PM_{2.5}$ exposure for 1000 households
- Boston Public Housing characteristics
  - In 34% of houses with children at least 1 adult smokes (Digenis-Bury, 2008)
  - 89% of households own a gas stove (Kattan, 1997),
  - 38% use the stove for heating in the winter (Brugge, 2001)
  - 13% have a working exhaust fan in the kitchen (Kattan, 1997),
  - 20%, 50% and 30% of units fall in leak categories 1 through 3 respectively (Zota, 2005)

NO_2 and $PM_{2.5}$ concentrations in 1000 simulated houses with Boston Public Housing characteristics



S o u r c e s

NO_2 and $PM_{2.5}$ concentrations in 1000 simulated houses with Boston Public Housing characteristics



Sources

Conclusions

- Regression models derived from CONTAM simulations:
  - had good predictive power (R^2: 0.89-0.98)
  - were physically interpretable
  - provided information about the added value of more complex IAQ modeling (vs. box model)

- Predicted values of 24 hour average NO_2 and $PM_{2.5}$ concentrations in BPH were comparable to values reported in literature

DES of pediatric asthma: project overview

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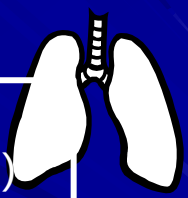

Asthma attack
Healthcare utilization
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Acknowledgements

- Jonathan Levy
- Gary Adamkiewicz
- Amelia Geggel
- Tasha Stout
- Megan Sandel
- Cizao Ren

- National Institute of Environmental Health Sciences award number R21ES017522