

BUILDINGENERGY BOSTON

Indoor Air Quality in Affordable Housing: Issues, Occupant Perceptions and Solutions

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**Northeast Sustainable Energy Association (NESEA)
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PRESENTERS



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Areas of Interest: Urban air pollution, highway and aviation emissions, ambient and indoor characterization, exposure assessment, mobile monitoring, mitigation strategies.

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Areas of Interest: Health equity, racial justice, the built environment, and community-engaged research

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OBJECTIVES

1. Describe how near-highway pollution impacts indoor air quality (IAQ) and health of residents in near-highway housing.
2. Describe health benefits of installing and maintaining ventilation systems that improve indoor air quality.
3. Explain the difference between IAQ impacts of whole-building ventilation strategies versus individual-level behaviors.
4. Engage in discussions to identify opportunities, challenges, and solutions for improving IAQ in affordable residential buildings.

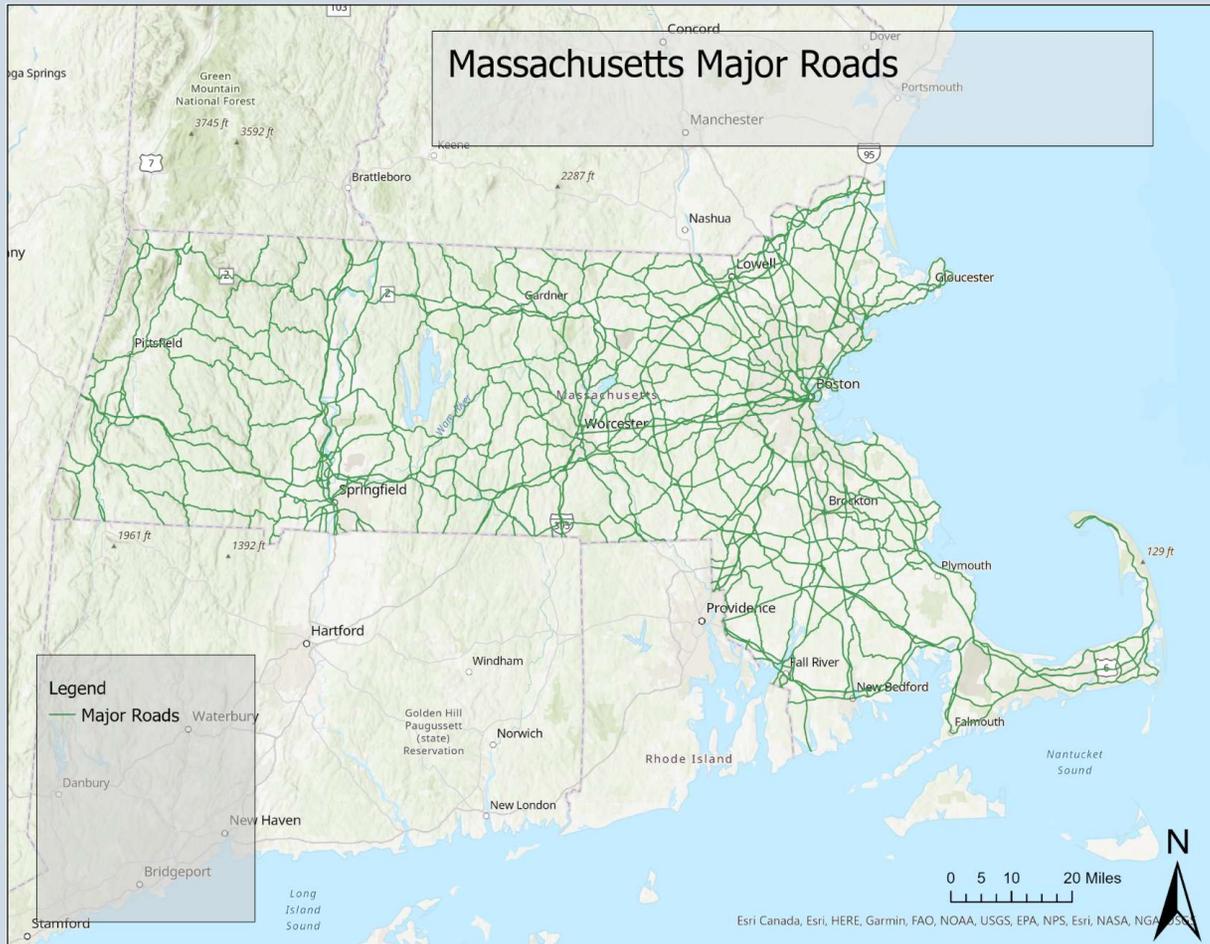
SESSION OUTLINE

- **Part I:** Presentation (45 minutes)
- **Part II:** Questions and Answers (20 minutes)
- **Part III:** Break-out Groups (25 minutes)

PART I: THE PRESENTATION

- **Issues**
 - Affordable housing near busy roadways
 - Transportation-related air pollution and health effects near busy roadways
 - Indoor pollution of outdoor origin
- **Sustainable Air Quality in Affordable Housing (SAQIAH)**
 - Air quality monitoring results
 - **Occupant perceptions**
- **Solutions** (our suggestions)

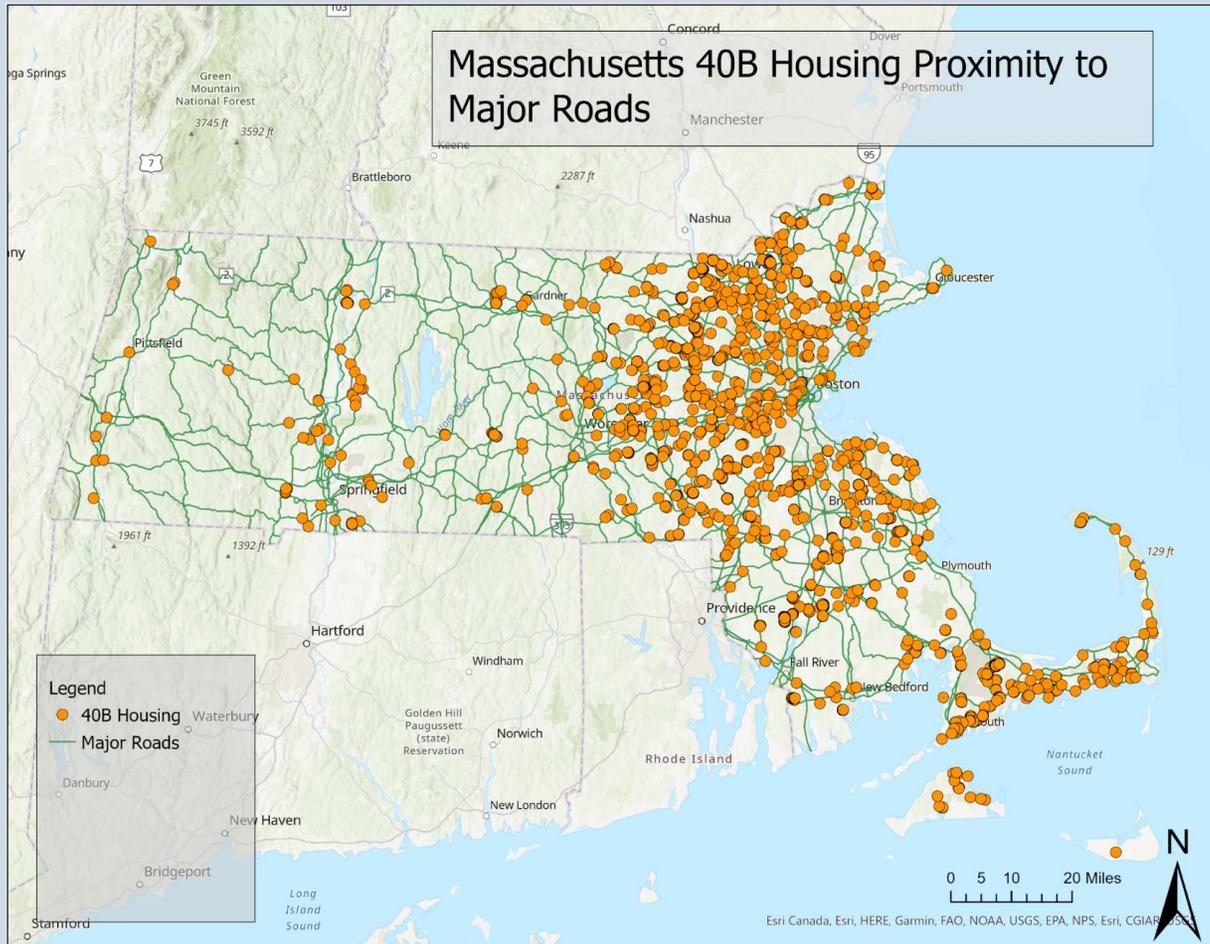
AFFORDABLE HOUSING NEAR BUSY ROADS



Major roads include the following classes:

- 1 - Limited access highway**
- 2 - Multi-lane highway, not limited access.**
- 3 - Other numbered route.**

AFFORDABLE HOUSING NEAR BUSY ROADS



- 52% of all units are within 200 m of busy roads
- ~500 buildings are within 100 m of major roads

Data Credits: Noémie Sportiche, Tim Reardon and Jessie Patridge, **MAPC**;
Mapping Credits: Grace Anderson, Tufts

TRANSPORTATION-RELATED AIR POLLUTION (TRAP)



- Cars, buses, trucks, trains, and airplanes produce a wide range of pollutants including

Gases

- Carbon monoxide (CO)
- Nitrogen oxides (NO_x)
- Volatile organic compounds (VOC)
- Carbon dioxide (CO₂)

Particles

- Ultrafine particles (<100 nanometers)
- Particle-bound metals and semi-volatile organic compounds
- Black carbon (soot)

TRANSPORTATION-RELATED AIR POLLUTION (TRAP)

- TRAP accounts for a significant fraction of annual emissions in the US



Pollutant Emissions (million tons/year)

Vehicle type	CO	VOC	NOx
Cars + motorcycles	20.4	1.7	1.7
Pick-ups + SUVs	13.5	1.2	1.1
Gasoline trucks	4.7	0.4	0.3
Diesel trucks + buses	0.3	0.1	2.1
Total On-Road Vehicles	38.9	3.4	5.2
Aircraft	1	0.2	0.2
Railroads	0.1	0	0.7
Marine Vessels	0.1	0	0.8
Other Non-Road	18	2.6	4.2
Total Mobile Sources	58.1	6.2	11.1
Total All Sources	77.7	15.9	16.3
% Mobile Sources	75%	39%	68%

Source: US EPA

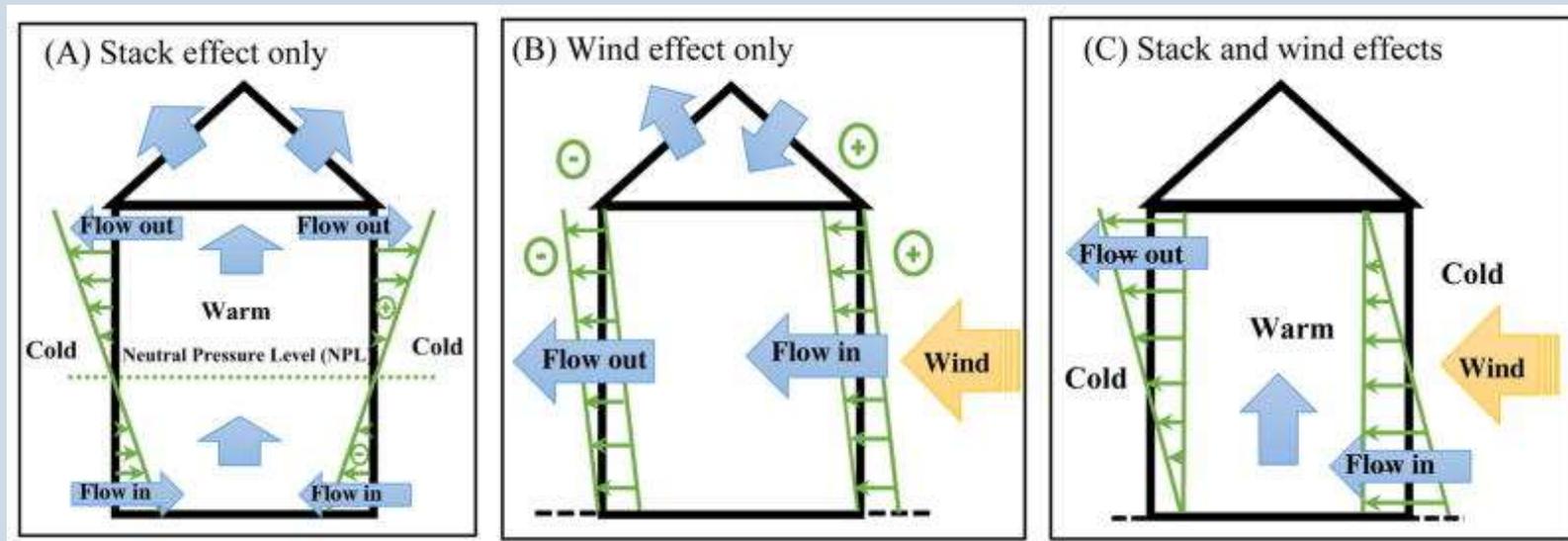
HEALTH EFFECTS

- Proximity to roadways and exposure to traffic-related air pollution is associated with adverse cardiovascular, respiratory, and neurological health impacts

	Health effects	Example study	Study
Cardiovascular	<ul style="list-style-type: none"> Increased heart rate, blood pressure Increased rates of heart attacks 	Living within ~150 m of highways or ~50 m of major roads is associated with higher risk of coronary mortality than living farther from high-traffic roadways.	Gan et al., 2010
Respiratory	<ul style="list-style-type: none"> Decreased lung function Increased rates of atherosclerosis, COPD 	Causal relationship between exposure to TRAP within 300-500 m of a highway or major road and asthma in children and reduced lung function in adults	HEI, 2010
Neurological	<ul style="list-style-type: none"> Degenerative diseases Memory loss 	Living within ~150 m of a highway or ~50 m of a major road is associated with incidence of non-Alzheimer's dementia, Parkinson's disease, Alzheimer's disease and multiple sclerosis	Yuchi et al., 2020

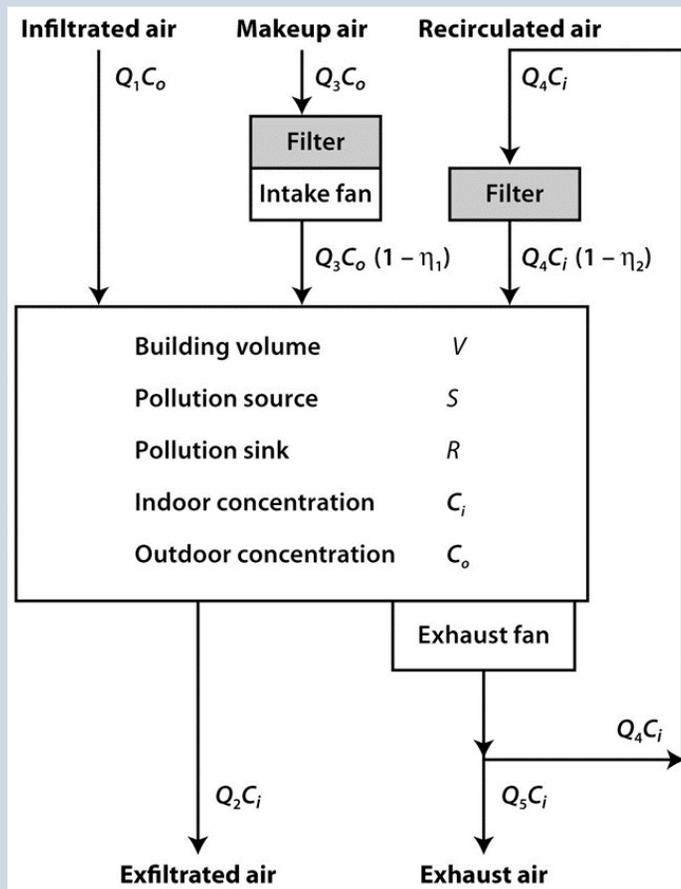
INFILTRATION

- Air pollutants of outdoor origin can infiltrate into buildings, particularly leaky buildings and buildings with poor ventilation systems.



VENTILATION

Forced ventilation



Natural ventilation



A multi-family residential building near a highway in a city

- As a result of both infiltration and ventilation, **pollutants of outdoor origin can account for over 50% of indoor air pollution levels in buildings**

FACTORS THAT GOVERN INDOOR AIR QUALITY

- **Categories of factors affecting pollutant concentrations indoors:**

1. **Pollutant attributes**

- a. Outdoor concentration
- b. Whether the pollutants are gases or particles
- c. Pollutant dynamic properties (reactivity for gases, size of particles)

2. **Building attributes**

- a. Air-exchange rates
- b. Effectiveness of air cleaning systems (if present)
- c. Types of materials used in the building and the furnishings

3. **Occupant behavior**

- a. Amount of time spent indoors
- b. Occupant density
- c. Activities that influence pollutant emissions and exposure

SUSTAINABLE AIR QUALITY IN AFFORDABLE HOUSING (SAQIAH), A HUD-FUNDED STUDY IN SOMERVILLE, MA

Study goal:

- Develop a data-driven framework for **ventilation considerations** for multi-family housing near highways that accounts for **air quality benefits, indoor comfort, and sustainability.**

Study objectives:

- (1) Measure indoor air quality in buildings with different ventilations systems
- (2) Quantify benefits derived from use of varying degrees of filtration (no filtration to MERV10)
- (3) Hold a stakeholder workshop to generate guidance that can be used to inform and improve air quality in multi-family housing near highways

INDOOR AIR QUALITY



Bedroom



Bedroom

A bedroom often contains carpets, blankets, and vacuum regularly.

Dust

Dust mites can trigger allergies. Vacuum regularly, wash blankets, carpets, upholstery, and bedding, and use allergen-reducing products.

- [Learn more about dust mites](#)

Bathroom



Bathroom

A bathroom is often the dampest area of a home. It is important to ventilate and dry damp surfaces.

Mold

Bathrooms are a common source of mold. Humidity from showers can cause moisture problems, which will lead to mold growth. Mold can cause allergic reactions, asthma and other respiratory ailments. Installing and using a ventilation fan will help to control moisture and inhibit mold growth.

- [Learn more about mold](#)

<https://www.epa.gov/indoor-air-quality-iaq/interactive-tour-indoor-air-quality-demo-house>

INDOOR AIR QUALITY

The screenshot shows the Mass.gov website interface. At the top left is the Mass.gov logo. To its right is a search bar with the placeholder text "Search Mass.gov". Below the logo, it says "PART OF Sources of Indoor Air Pollution". A red rectangular box highlights the search results section. The first result is "What you need to know" with a sub-link "For Sources of Indoor Air Pollution". Below this, under the heading "SHOWING RESULTS", are several other search results: "Improper chemical storage or usage", "Bird waste and related diseases", "Indoor ozone", and "Radon". To the right of the search results, there is a list of related topics with arrows pointing to the right: "Construction and renovation generated pollutants in occupied buildings", "Ventilation systems", "PCBs (Polychlorinated Biphenyls) in building materials", "Pressure-treated wood use in playground equipment", and "Trichloroethylene (TCE) in indoor air".

Mass.gov

PART OF [Sources of Indoor Air Pollution](#)

What you need to know
For [Sources of Indoor Air Pollution](#)

SHOWING RESULTS

[Improper chemical storage or usage](#) →
A list of examples of improper storage of chemicals in schools' science laboratory. These could create indoor environmental pollutants as well as potential safety hazards.

[Bird waste and related diseases](#) →
Learn about the risk factors bird waste in the air, and cleanup procedures.

[Indoor ozone](#) →

[Radon](#) →

[Construction and renovation generated pollutants in occupied buildings](#) →
Learn what methods can be used to reduce and/or prevent exposure to pollutants from construction or renovation of occupied buildings.

[Ventilation systems](#) →

[PCBs \(Polychlorinated Biphenyls\) in building materials](#) →
Information about PCB-containing materials in the indoor environment of schools and other public buildings.

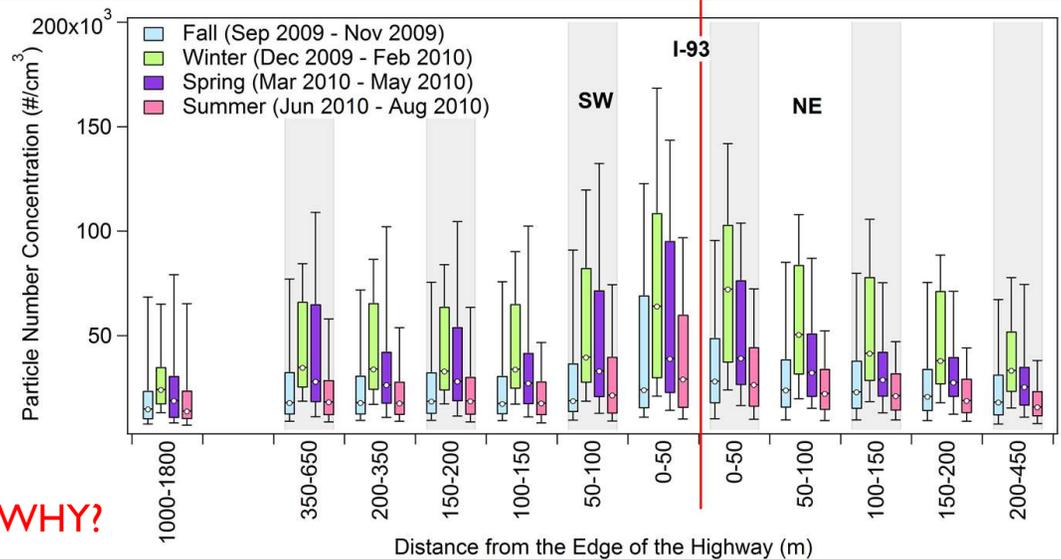
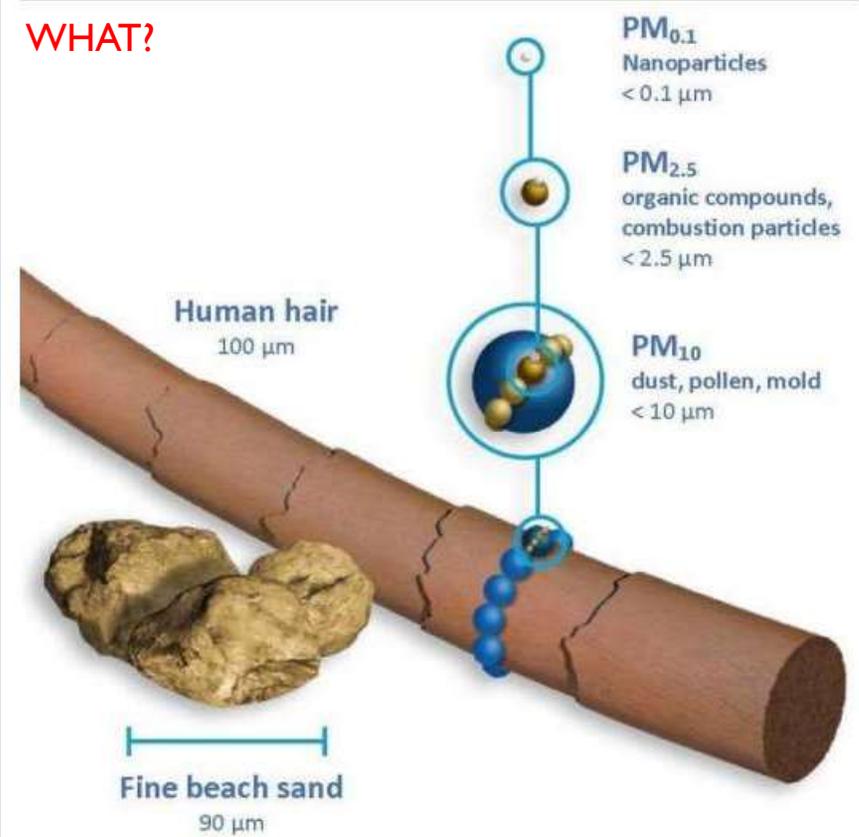
[Pressure-treated wood use in playground equipment](#) →
Learn about precautions, types, health effects of exposure, and regulations.

[Trichloroethylene \(TCE\) in indoor air](#) →
Learn about TCE exposure, risks, and more.

<https://www.mass.gov/sources-of-indoor-air-pollution/need-to-know>

POLLUTANT OF INTEREST: ULTRAFINE PARTICLES

WHAT?



WHY?

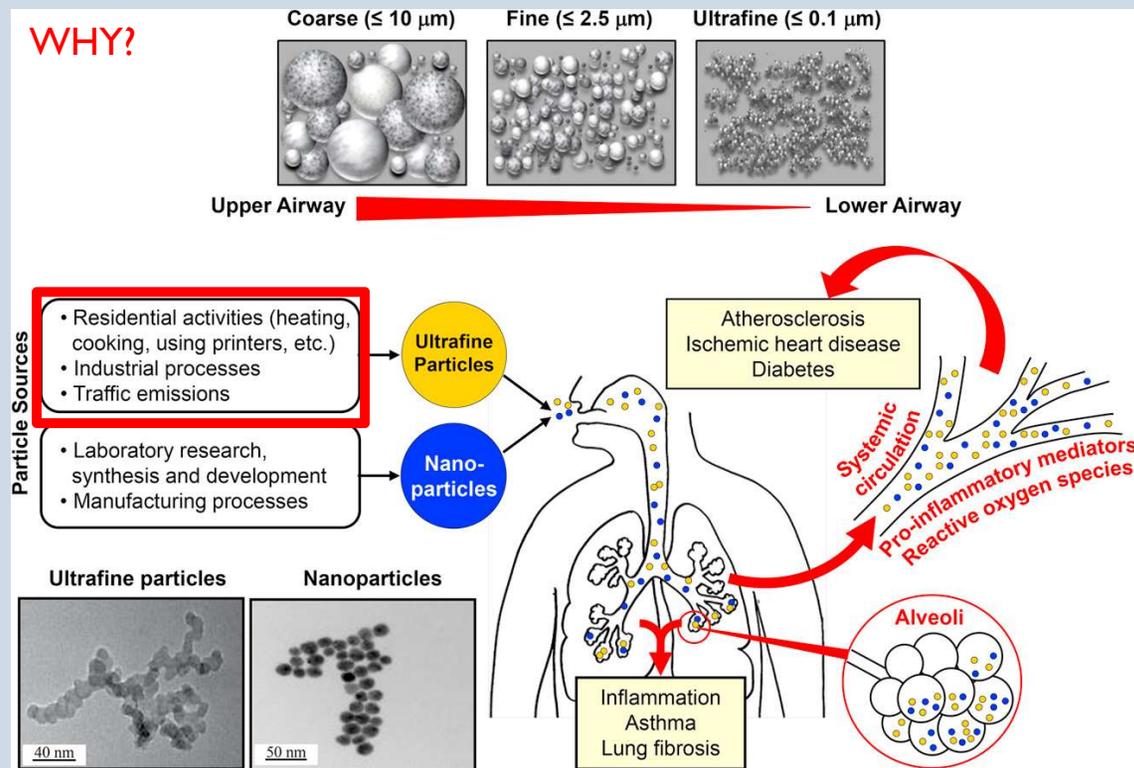
Ultrafine particle number concentration (count/cm³) vs. distance from I-93 in Somerville, MA

Ultrafine particles are produced during fuel combustion and are present at high concentrations near busy roadways

Particles smaller than 10 and 2.5 microns are regulated by EPA, but not ultrafine particles that are smaller than 0.1 micron.

ULTRAFINE PARTICLES & HEALTH

WHY?



A work group report on ultrafine particles (American Academy of Allergy, Asthma & Immunology): Why ambient ultrafine and engineered nanoparticles should receive special attention for possible adverse health outcomes in human subjects. Li et al. 2016

Ultrafine particles

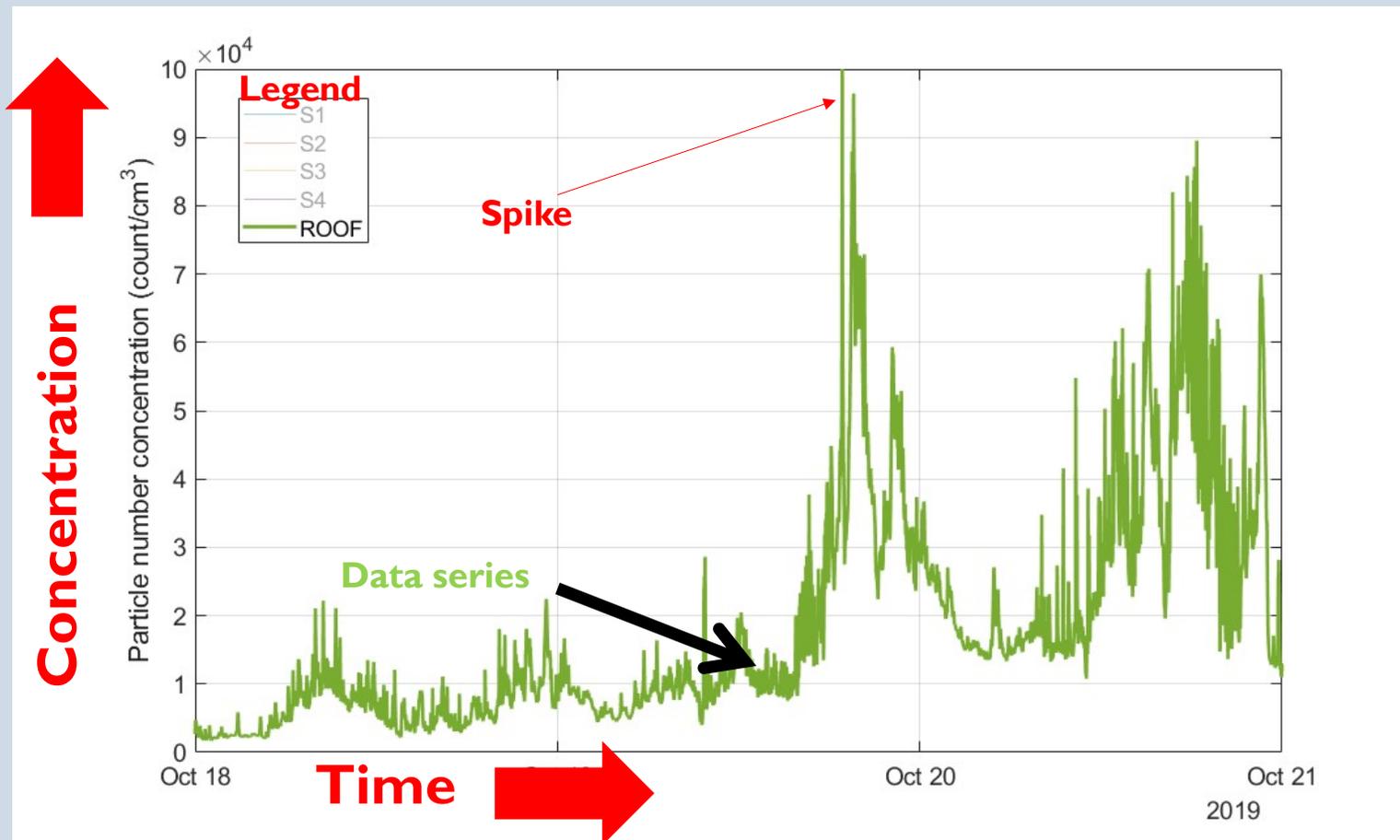
- are readily inhaled
- are deposited in different locations in the respiratory tract, and depending on their size,) can penetrate deep into the lungs
- can diffuse into the blood stream and become widely distributed in the body
- and can adversely impact different organs

SAQIAH: STUDY DESIGN

- Two groups of participants:
 1. **Survey only**
 - Survey a larger set of participants than air quality monitoring participants in a building
 2. **Air quality monitoring + survey**
 - Monitoring in both warm and cold seasons
 - Simultaneous monitoring indoors in multiple homes and outdoors/roof
 - Also unoccupied apartments and lately common areas
- Purposeful selection of buildings:
 - Varying degree of filtration (no filtration, MERV8, MERV10)
 - Variation in HVAC design
 - Located near-highways (>20,000 vehicles per day)

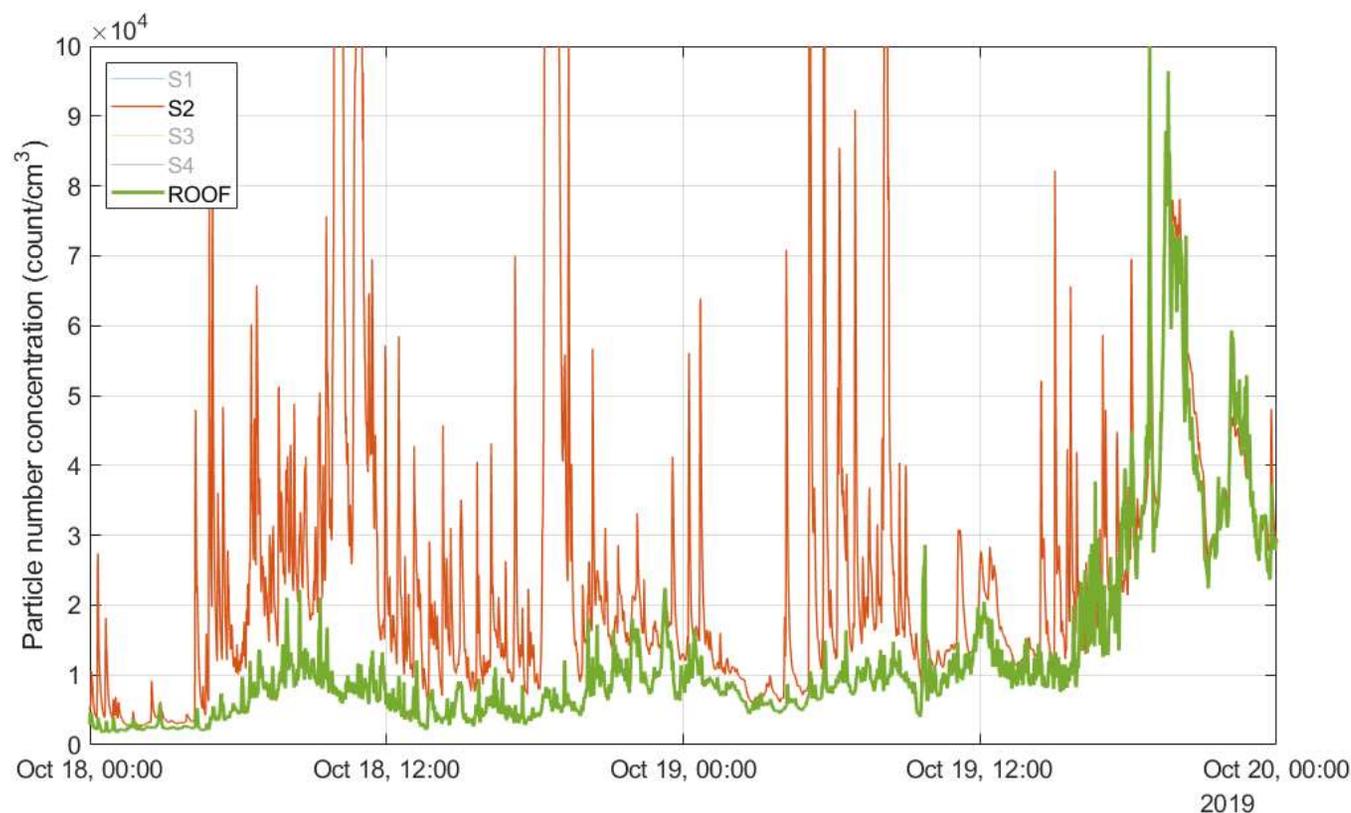


DATA WILL BE SHOWN IN A TIME SERIES FORMAT



Takeaway message:

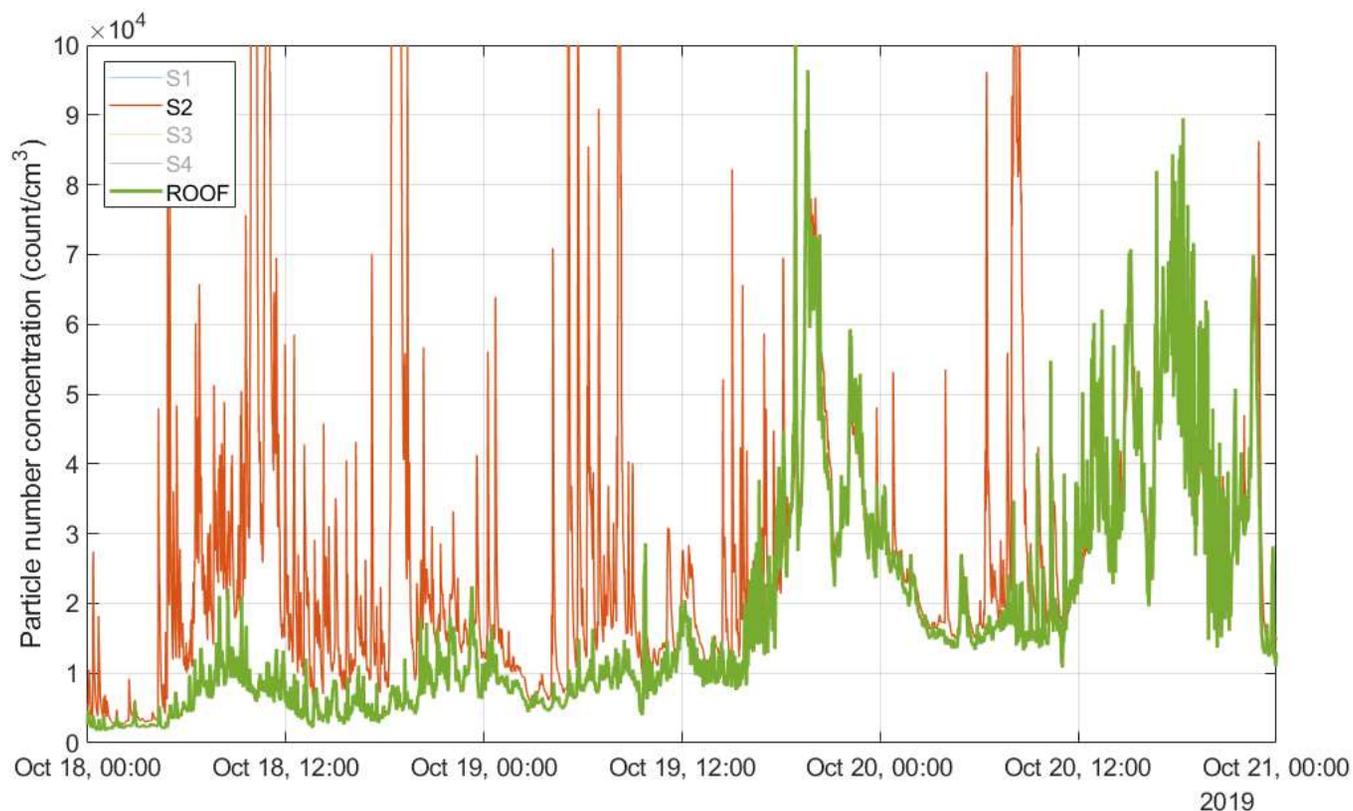
OUTDOOR-ORIGIN POLLUTION IS OBSERVED INDOORS



- Same temporal patterns observed in the baseline concentrations
- Indoor at least as high as outdoors + additional influence of indoor sources

Takeaway message:

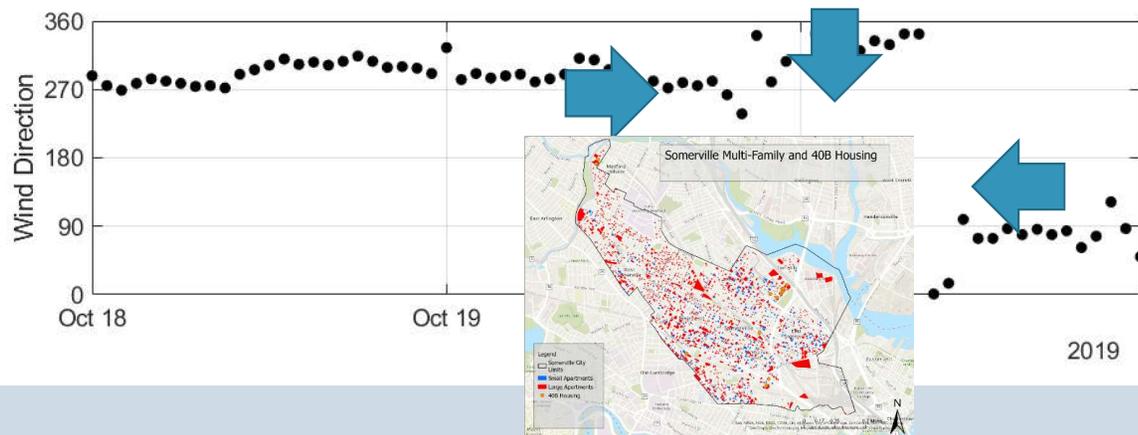
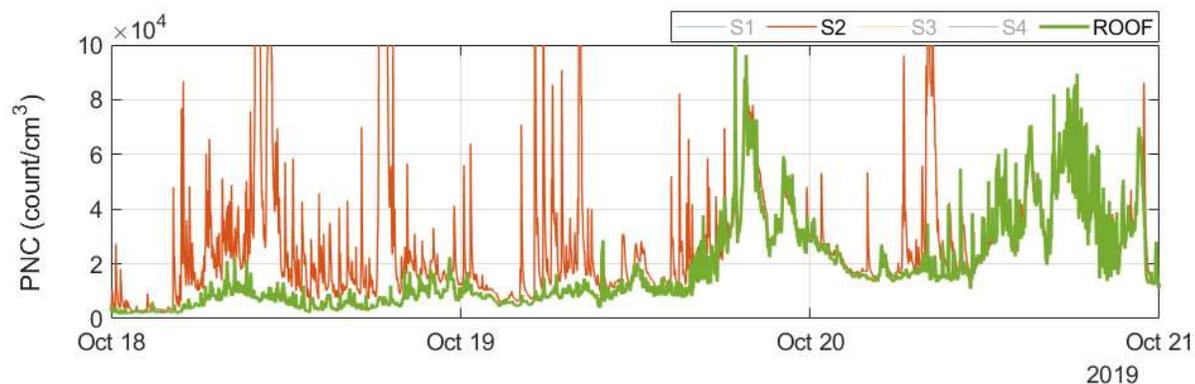
INDOOR RESPONDS TO OUTDOOR CHANGES



- Outdoor varies f(meteorology, distance to highway, season, etc.)
- Indoors in response to the changes outdoors.

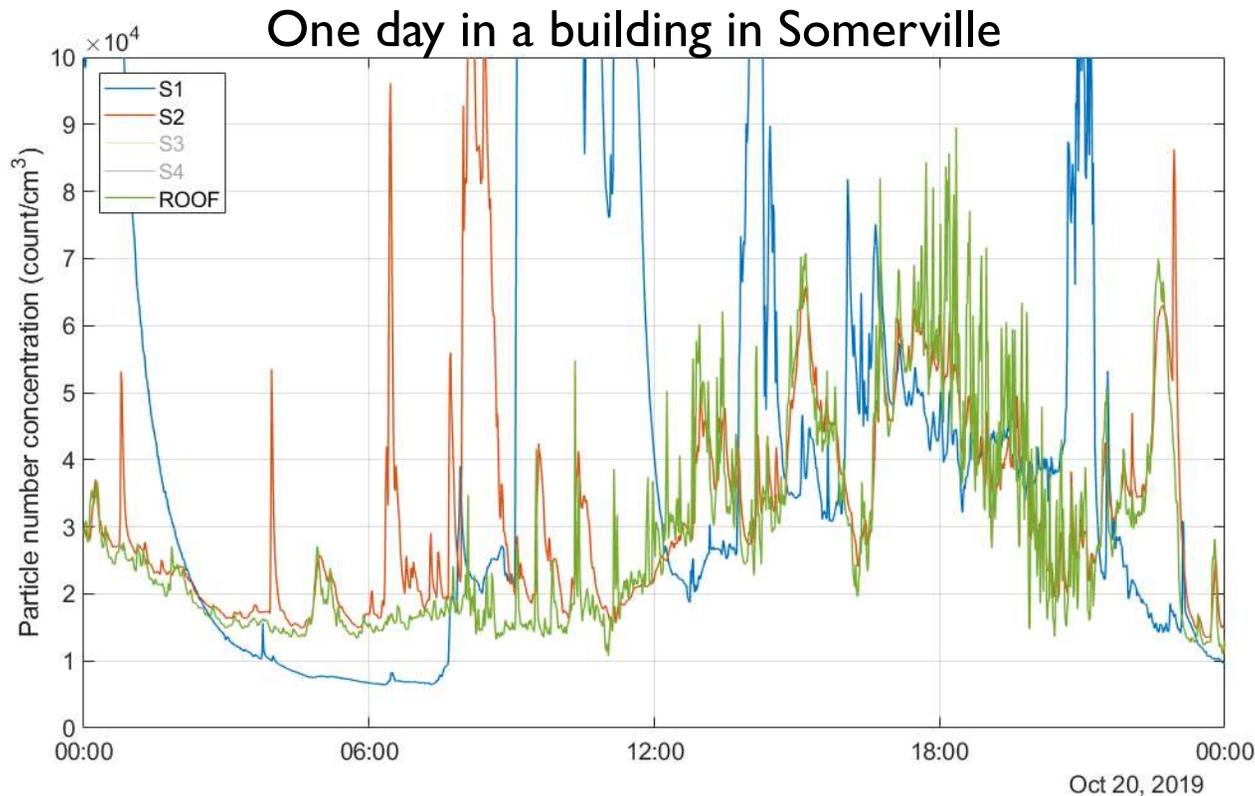
Takeaway message:

INDOOR AND OUTDOOR POLLUTION LEVELS INCREASE WHEN BUILDING IS DOWNWIND OF HIGHWAY



Takeaway message:

OUTDOOR AND INDOOR POLLUTION PATTERNS ARE SIMILAR IN MULTIPLE APARTMENTS – A BUILDING WIDE IMPACT

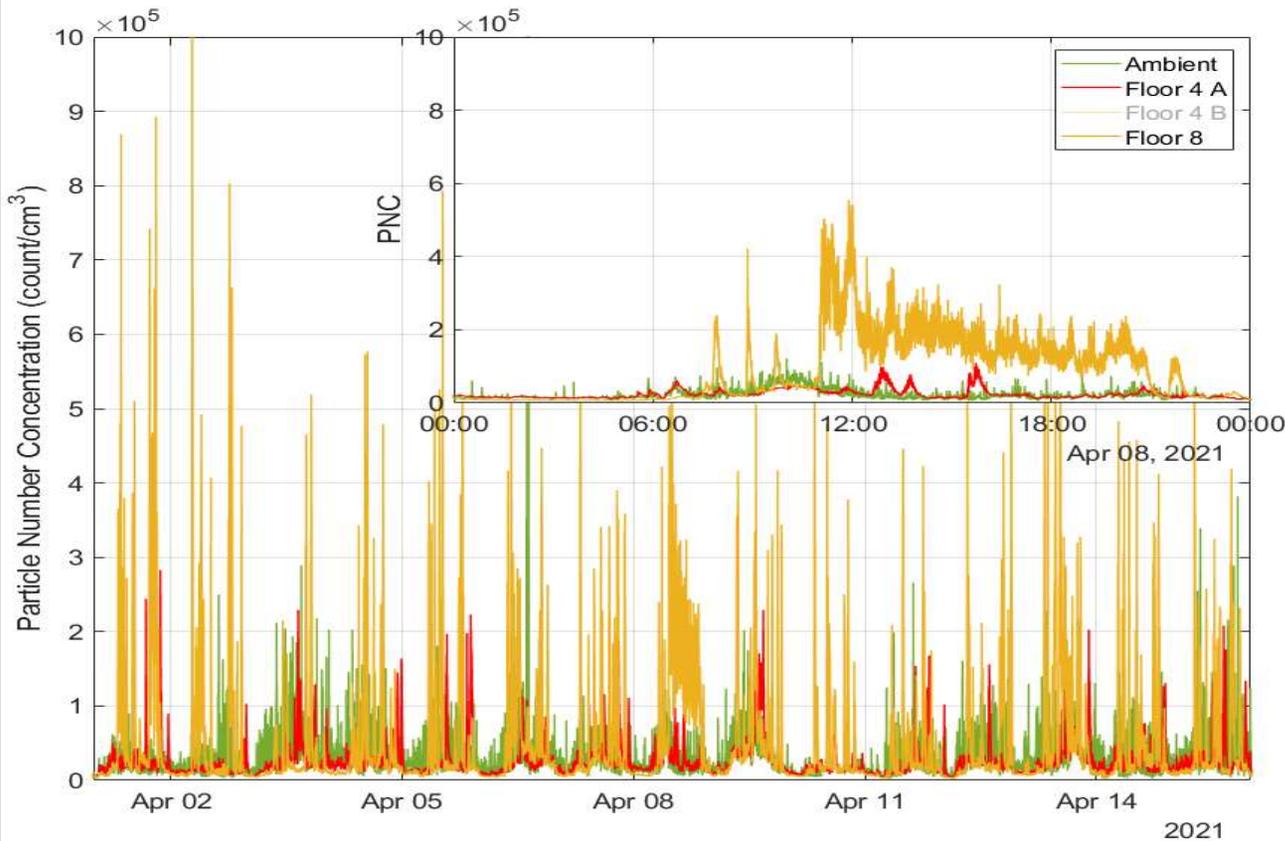


- Simultaneous increase in concentrations on a fall evening and night.
- Similar pattern observed on roof and in two apartments on the building (and additional indoor influence)

Building has LEED Certification (Platinum Level) & ENERGY STAR
Mechanical ventilation system has a MERV8 filter

Takeaway message:

OUTDOOR AND INDOOR POLLUTION PATTERNS ARE SIMILAR IN MULTIPLE APARTMENTS – A BUILDING WIDE IMPACT

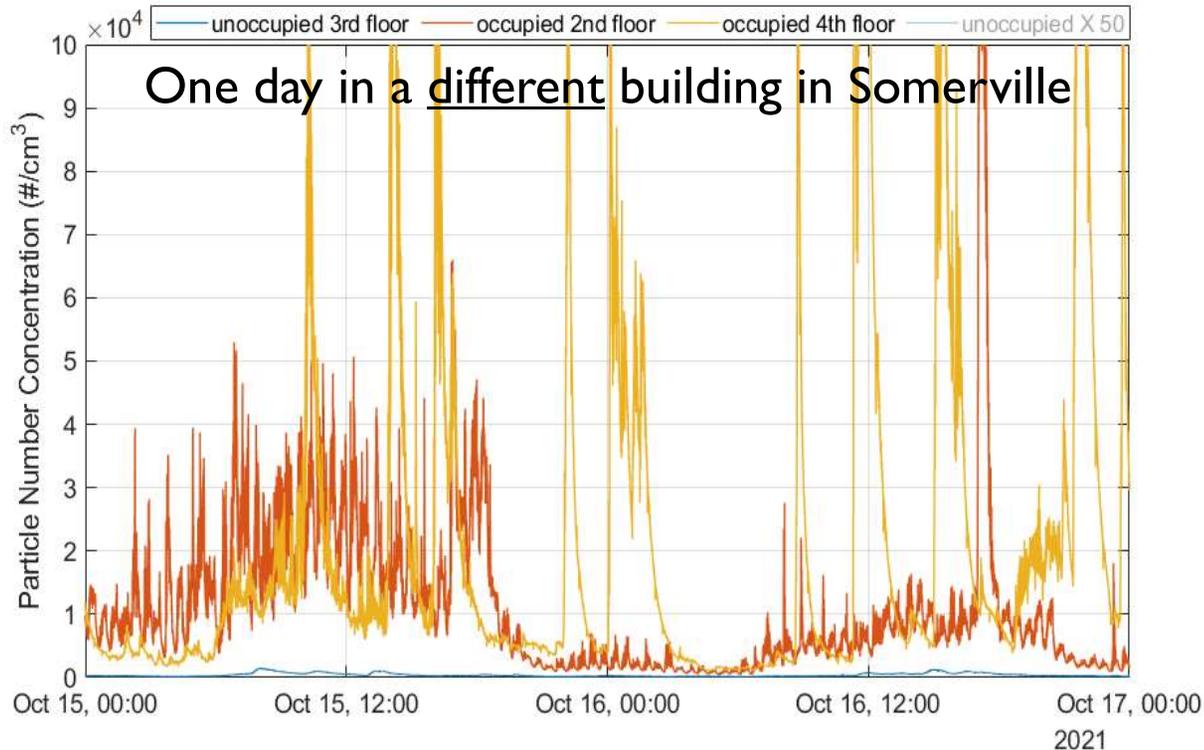


- Two weeks in a high-rise building in downtown Boston

Fresh air + heat supply to common areas; kitchen and bathroom exhaust; window AC and baseboard heating in apartments

Takeaway message:

OUTDOOR AND INDOOR PATTERNS ARE THE SAME IN MULTIPLE APARTMENTS – A BUILDING WIDE IMPACT

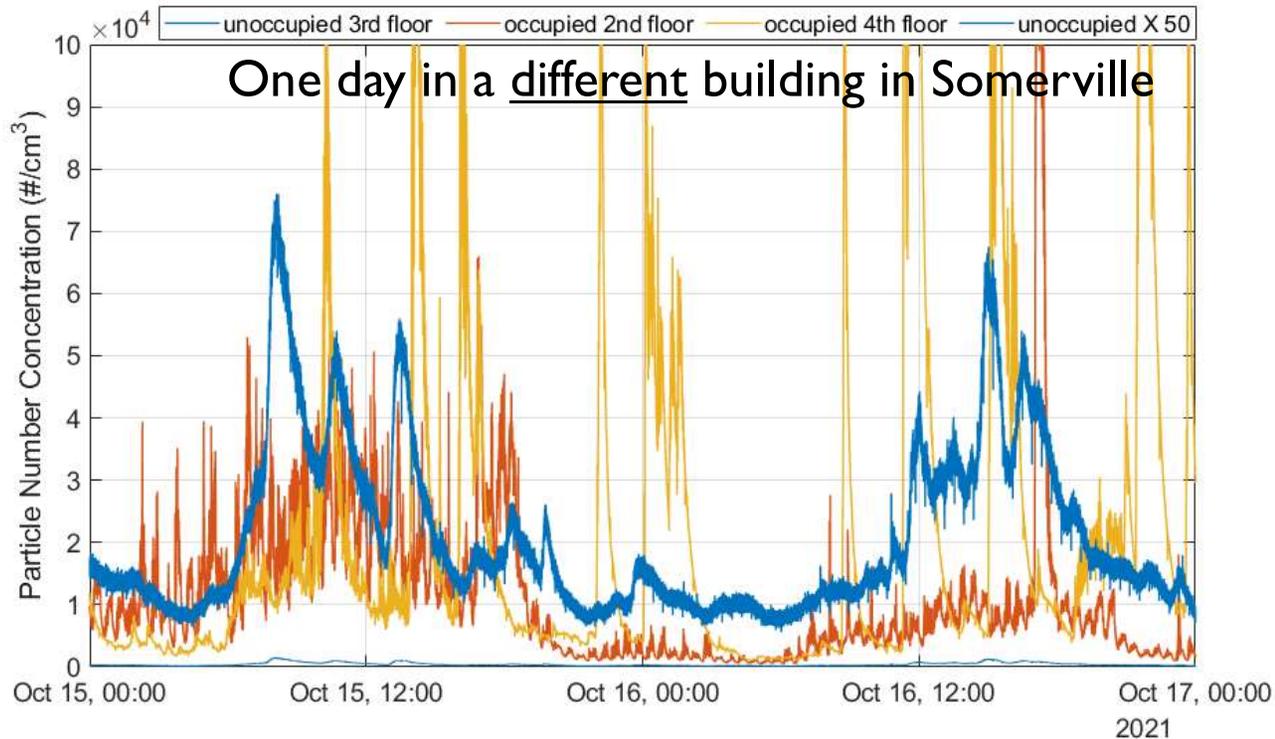


- Data is shown for two occupied apartments on different floors and one unoccupied apartment
- Unoccupied apartment same pattern but much lower concentration.

The building has LEED Certification (Silver) and MERV8 filtration

Takeaway message:

SAME PATTERN AS OUTDOORS IS OBSERVED INDOORS IN MULTIPLE APARTMENTS – A BUILDING WIDE IMPACT

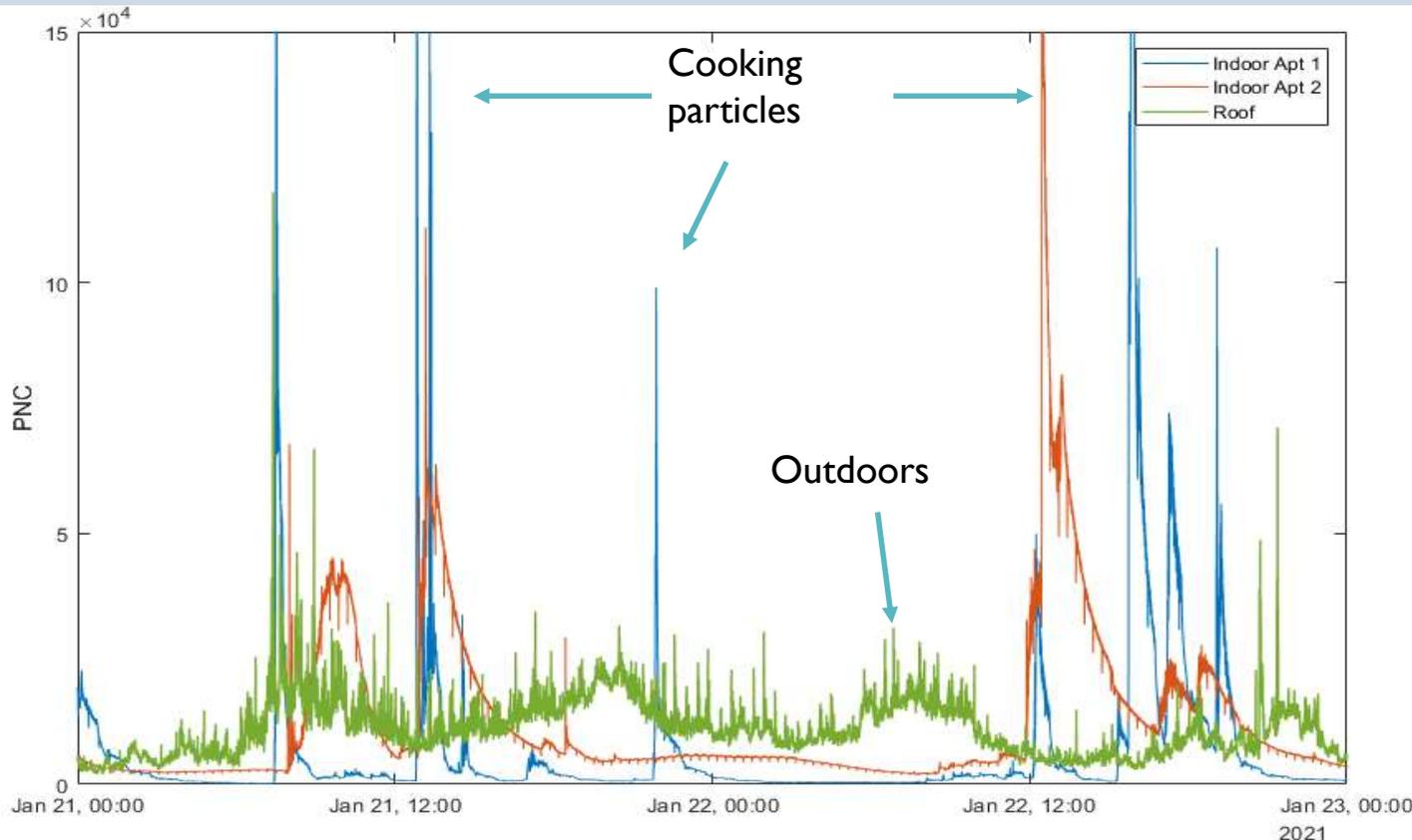


Unoccupied apartment data X 50 times (same pattern that is more visible now) but much lower concentration.

What role is mechanical ventilation playing in moderating outdoor pollution from entering indoors?

Takeaway message:

SAME PATTERN AS OUTDOORS IS **NOT OBSERVED
INDOORS IN MULTIPLE APARTMENTS – NO
EVIDENCE OF A BUILDING WIDE IMPACT**



- No simultaneous increase in outdoor and indoor particle concentrations.
- Evidence of indoor generation of particles due to cooking (not smoking)

Energy Star 3; LEED Platinum;
MERV10 in units and each
apartment has its own AHU

KEY OBSERVATIONS AND TRENDS FROM OUR DATASET

1. **Outdoor and indoor concentrations increase when buildings are downwind of the highways and busy roadways.**
 - The patterns are the same indoors in multiple apartments (i.e., building wide) and outdoors.
2. **Building envelope and ventilation system offer little to no protection from ambient ultrafine pollution – a proxy of traffic-related air pollution.**
 - Indoor concentrations frequently at least as high as outdoors in a building with no filtration and in another building with a centralized air handling (MERV8).
 - Indoor concentrations in a building with individual AHU for each apartment did not show concurrent patterns.
3. **Indoor concentrations are also highly impacted by indoor activities, particularly cooking.**
 - Highly dependent on occupant's ventilation practices (range hood operation, window opening) and indoor-origin pollution >> outdoor-origin pollution observed indoors.

OCCUPANT PERCEPTIONS

- Survey
- Occupant demographics
- Survey results
 1. Satisfaction with indoor air quality
 2. Reasons why people were dissatisfied with their air quality
 3. Reasons for opening windows
 4. Cooking
 5. Knowledge of ventilation systems
- Key takeaways

INDOOR AIR QUALITY AND VENTILATION PRACTICES SURVEY

The survey has the following modules:

1. Demographics
1. Indoor Air Quality Satisfaction
2. Kitchen and Cooking
3. Bathroom Ventilation
4. Bedroom Ventilation
5. Living Room and Other Room Ventilation
6. Window Operation (Motivation for opening/closing windows or doors)
7. Ventilation System

Confidential

Sustainable Air Quality in Affordable Housing-copyjuly25
Page 1

Investigator Data Collection Module 1

Date of data collection _____

Name of the Investigator _____

Participant Name _____

Participant Address

Address
Street _____

Address
Apartment number _____

Address
City _____

Address
Zipcode _____

What aspect of the study are they participating in? Air quality monitoring and survey
 Survey only

Is this the first phase of monitoring or the only survey for the unit? Yes
 No

What phase of air quality monitoring is this form being completed in? Warmer weather
 Cooler weather

Does anyone in your household smoke? Yes
 No

Unit Characteristics

1. What floor is your unit located on? _____

2. How many rooms are in your unit? Bedroom = 1
 Bedroom = 2
 Bedroom = 2+
 Bathroom = 1
 Bathroom = 2
 Kitchen
 Kitchen in the living area
 Other rooms

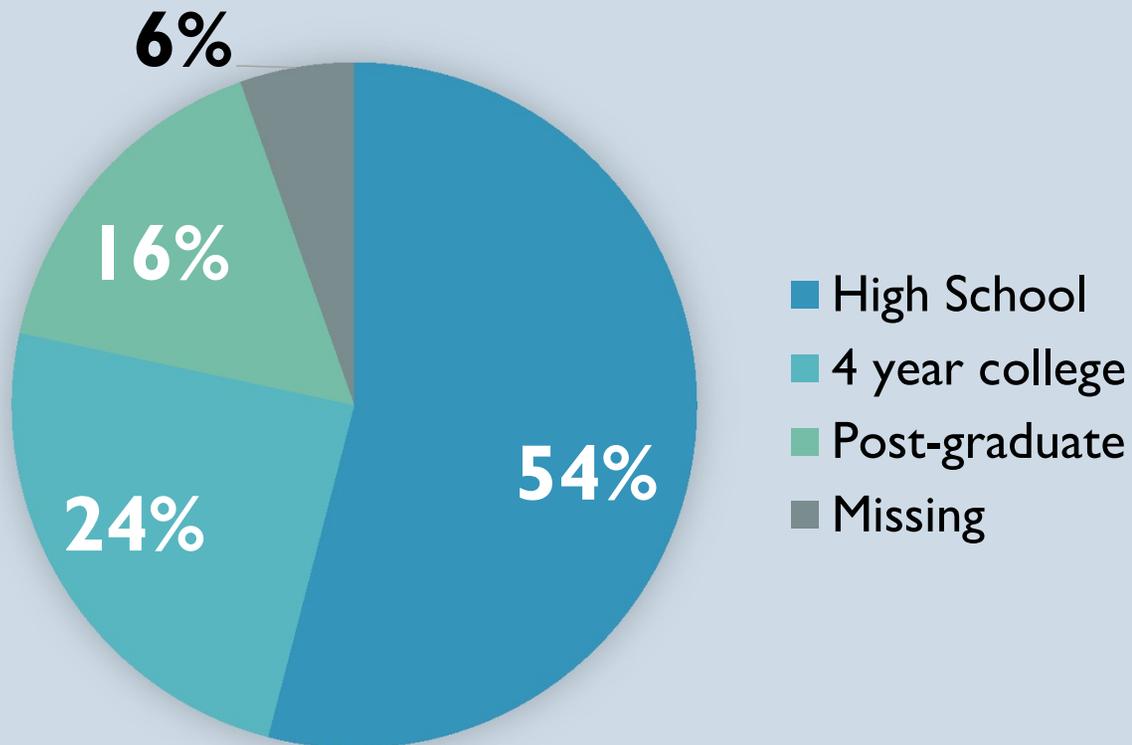
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DEMOGRAPHICS

- 40+ surveys have been collected in multi-family buildings.
- Age of occupants: 18-68 years old (average = 40 years old).
- Length of time in apartment: 19 days-12 years (average = 3.5 years).
- 70% of occupants identified as women.
- 73% of occupants identified as Black/African American, Hispanic or Latinx, or as another racial/ethnic group.
- 65% of occupants worked outside of their homes.

OCCUPANT EDUCATION

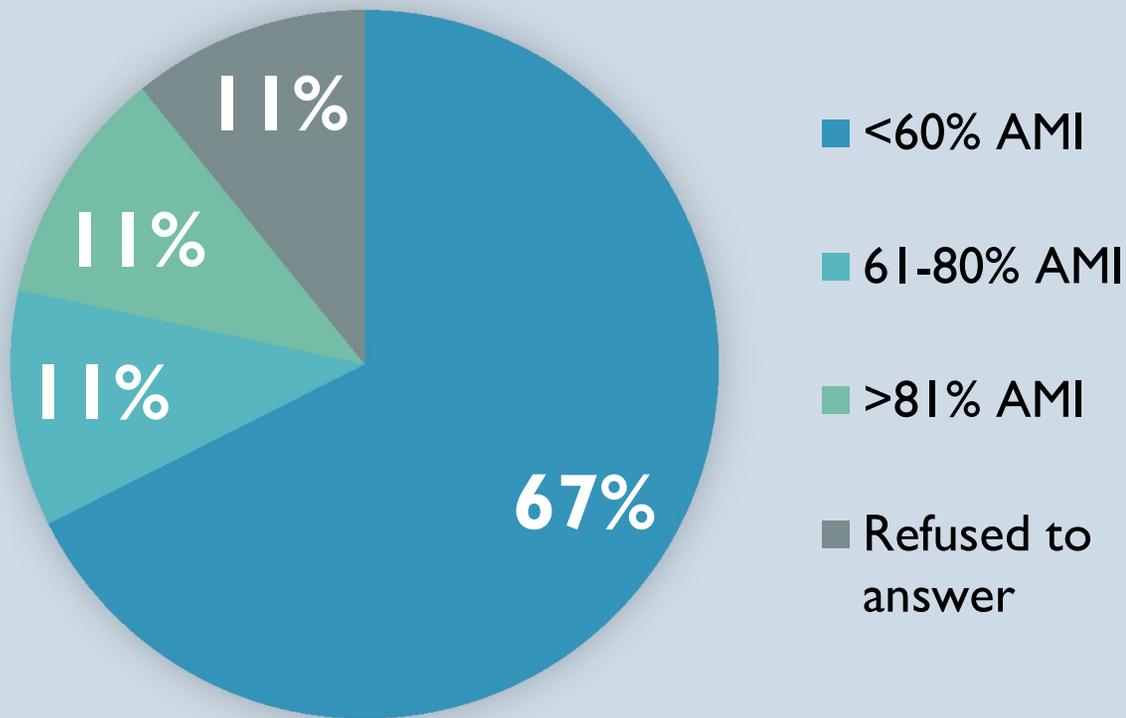
Q: What is the highest grade or year of school you have completed?



- 54% of occupants have a 12th grade education or less.

HOUSEHOLD INCOME

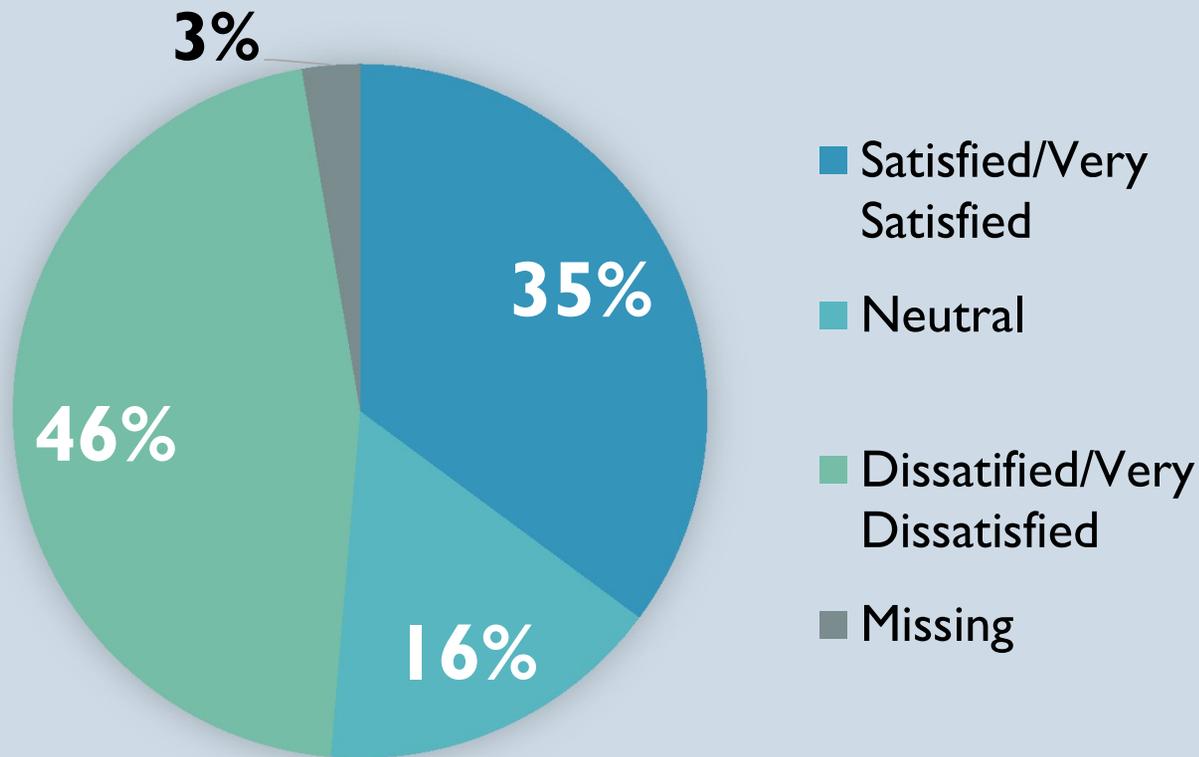
Q: What is your annual household income?



- 67% of occupants earn less than 60% of the Annual Median Income (AMI, \$97,000 for Somerville).

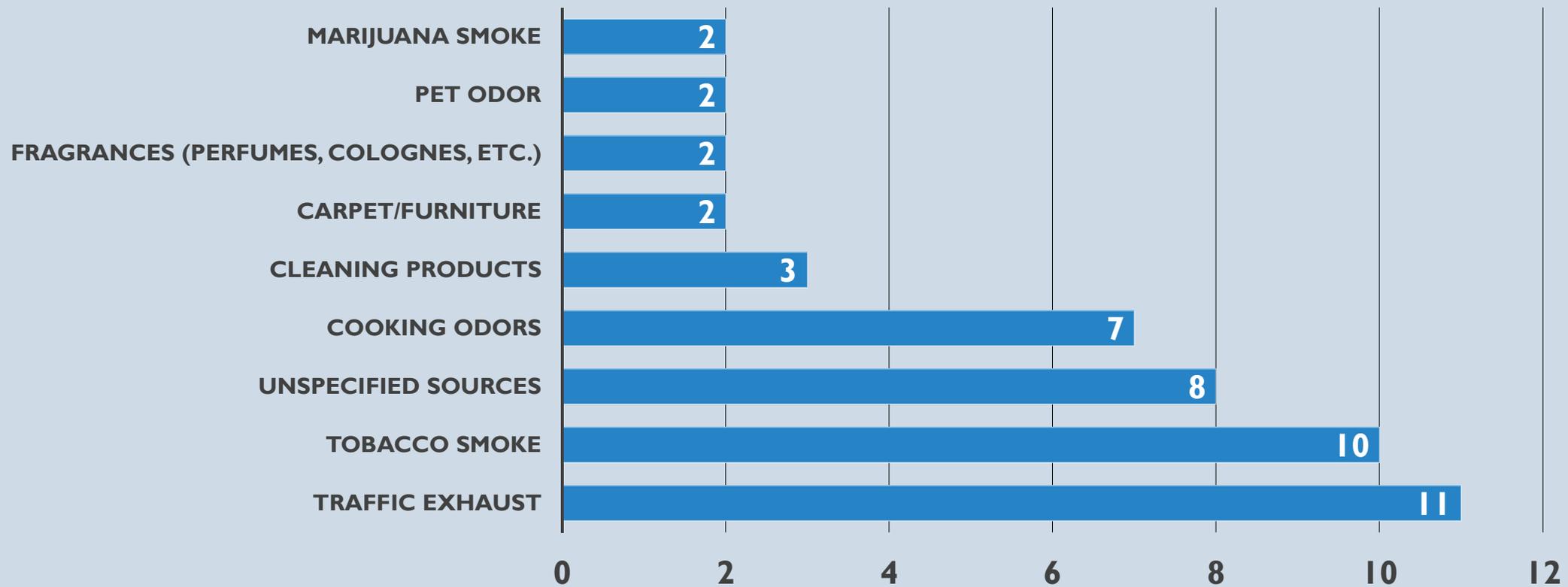
SATISFACTION WITH INDOOR AIR QUALITY

Q: How satisfied are you with the air quality in your unit?



- 46% of occupants are dissatisfied/very dissatisfied with the air quality in their unit

REASONS FOR BEING DISSATISFIED WITH AIR QUALITY



REASONS FOR OPENING AND CLOSING WINDOWS

Motivation for opening windows or doors

How important are each of the following reasons why you and members of your household typically open windows or doors to the outside (outdoors)? Check all that apply. Do not include when you open them for a minute or two, or to enter or exit your home. If you never open them for a given reason, please check the box "Never open for this reason."

Please comment on your reasons for opening windows and doors (at the bottom) if your reasons or motivations weren't adequately addressed in the survey.

	very important	somewhat important	slightly important	not important at all	never open for this reason
To cool the house	<input type="checkbox"/>				
To warm the house	<input type="checkbox"/>				
To provide air movement	<input type="checkbox"/>				
To remove odors	<input type="checkbox"/>				
To remove moisture	<input type="checkbox"/>				
To air out during house cleaning	<input type="checkbox"/>				
To remove smoke, such as from cigarettes or cooking	<input type="checkbox"/>				
To provide draft for cooking appliances or exhaust fan	<input type="checkbox"/>				
To save energy	<input type="checkbox"/>				
To allow pets access	<input type="checkbox"/>				
Other	<input type="checkbox"/>				

Any other reason I may have missed that you can think of?

- 5-point Likert scale
- Motivation for opening windows or doors:
 - Provides 10 potential motivations
 - Opportunity to specify another motivation
- Motivation for closing windows or doors:
 - Provides 16 potential motivations
 - Opportunity to specify another motivation

REASONS FOR OPENING WINDOWS

- 53% of occupants open windows to remove odors.
- 47% of occupants open windows to air out home during cleaning.
- 51% of occupants open windows to provide air movement.
- 44% of occupants open windows to remove cigarette smoke and cooking odors.

Reported percentages include “very important”, “somewhat important” and “slightly important”

REASONS FOR CLOSING WINDOWS

- 81% of occupants closed windows to reduce pollutants or odors from outdoors.
- 68% of occupants closed windows to keep out outdoor air.
- 70% of occupants closed windows to keep out dust.
- 75% of occupants closed window to keep out dust.

Reported percentages include “very important”, “somewhat important” and “slightly important”

COOKING AND VENTILATION PRACTICES

- 92% of occupants have a range hood and exhaust fan over kitchen stove.
 - 48% of occupants said range hood blows air back into the room.
 - 52% of occupants said range hood blows air outdoors.
 - Lack of understanding of ventilation vs. a lived experience
- 60% of occupants reported their unit retained cooking odors.
- For occupants with windows in their kitchen, 66% said it was important to open windows to provide a draft for cooking appliances and exhaust fans.

KNOWLEDGE OF WHOLE-UNIT VENTILATION SYSTEMS

- 76% of occupants indicated that operation of their ventilation system was explained to them when they moved in.
- 62% of occupants believed they understood how their ventilation system works.
- 68% of occupants indicated they knew how to properly control their ventilation system.

KEY TAKEAWAYS FROM THE SURVEYS



Nearly half of occupants surveyed are dissatisfied with air quality in their units.



Odors are the main cause of complaint (cooking, cigarette smoke, and traffic emissions).



Nearly half of occupants surveyed open their windows to improve air circulation and air quality.



Occupants aren't receiving education or materials needed for them to understand their ventilation systems.

SOLUTIONS

FACTORS THAT GOVERN INDOOR AIR QUALITY

- Categories of factors affecting pollutant concentrations indoors:

1. **Pollutant attributes**

- a. Outdoor concentration
- b. Whether the pollutants are gases or particles
- c. Pollutant dynamic properties (reactivity for gases, size of particles)

2. **Building attributes**

- a. Air-exchange rates
- b. Effectiveness of air cleaning systems (if present)
- c. Types of materials used in the building and the furnishings

3. **Occupant behavior**

- a. Amount of time spent indoors
- b. Occupant density
- c. Activities that influence pollutant emissions and exposure

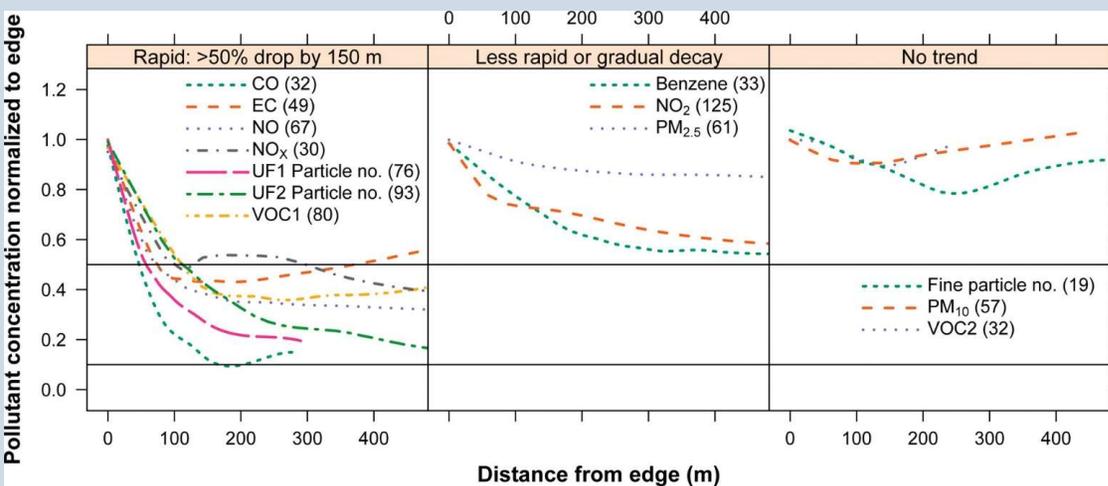
Each factor is also an **opportunity** to improve indoor air quality.

OPPORTUNITIES TO IMPROVE INDOOR AIR QUALITY

I. Pollutant attributes

a. Outdoor concentration

Highway corridors are high pollution zones.



Karner et al., EST 2014

Air intake for a residential building

Solution: Locate buildings and air intakes away from high pollution zones.



OPPORTUNITIES TO IMPROVE INDOOR AIR QUALITY

2. Building attributes

- a. **Effectiveness of air cleaning systems**
- +d. **Effectiveness of air handling systems in hallways**



- We observed that MERV8 filters are ineffective at removing ultrafine particles (MERV8 are designed to remove 3-10 μm particles).
- **Question:** What MERV# is optimal for ultrafine particle removal?
- We observed that hallways, foyers, and stairwells in some buildings contained cooking odors and tobacco and marijuana smoke.
- **Question:** Should common spaces have separate air handling systems and higher air turnover rates?

OPPORTUNITIES TO IMPROVE INDOOR AIR QUALITY

3. Occupant Behavior

- c. **Activities that influence pollutant emissions and exposure**
- +d. **Occupant education on ventilation systems and practices**

Solutions:

- Replace gas ranges with electric ranges
- Vent range hood emissions outdoors
- Regularly replace in-home air filters
- Better educate residents on
 - how to take advantage of existing ventilation features – e.g., HVAC system operation, range hood operation
 - Impacts of window opening on IAQ
 - Impacts of smoking on IAQ



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SCHOOL OF ENGINEERING

Civil and Environmental
Engineering



Boston University School of Social Work

Funding sources: The Healthy Homes Technical Studies Grant Program (MAHHU0044-18), U.S. Dept. of HUD; Department of Civil & Environmental Engineering, Tufts University

PART II: QUESTIONS AND ANSWERS

PART III: INTERACTION (3 BREAKOUT GROUPS)

Solution 1: Optimize location of building & air intake

Solution 2: Optimize filtration and ventilation

Solution 3: Increase resident awareness

Q1. What are the challenges and opportunities?

Q2. What kind of guidance document* would be most helpful to you in your practice of designing/maintaining/promoting better indoor air quality in residential buildings?

*see next slide

PART IV: THE GUIDANCE DOCUMENT

- We are in the process of developing a guidance document to promote improved IAQ in residential housing.
- If you would like to be part of the review panel for the document, then please leave us your email on the signup sheet on your breakout group table.

INDOOR PRESENCE OF TRAP

How does TRAP get indoors?

- ❑ Doors & Windows (Natural ventilation methods)
- ❑ Wind forces the outside air (which carries TRAP) through gaps into homes
- ❑ Outside air also gets pulled in more passively
- ❑ Mechanical ventilation systems that force outdoor air indoors also force what is in the outdoor air indoors

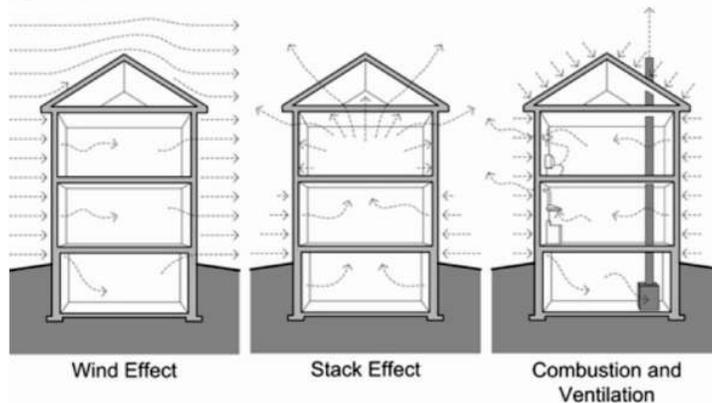


Figure 1: Examples of infiltration. Image courtesy: Building Science Corporation, www.buildingscience.com

How much TRAP get indoors?

- ❑ Varies by pollutant, especially the size of particulate matter pollution under consideration.
 - ❑ Indoor-to-outdoor (I/O) ratios can vary from zero to one, but 0.3-0.7 is common for particulate matter pollution.
- ❑ Also varies by:
 - ❑ Physical characteristics of the house; older leakier homes will have higher I/O ratios.
 - ❑ Ventilation practices
 - ❑ Natural ventilation will lead to I/O of ~ 1
 - ❑ Mechanical ventilation can be very effective in lowering I/O if equipped with filters or can just force outdoor unfiltered polluted air indoors leading to I/O of ~ 1

INDOOR PRESENCE OF TRAP IN GREATER BOSTON AREA

In the following slides we look at data from two studies from the greater Boston area that demonstrate the indoor presence of TRAP

NEAR-HIGHWAY

- The first 0.25 mile is where we observe the most elevation in TRAP near major roadways
- About 3.5% of MA population lives within 1/10th of a mile of a major-highway where concentrations can be elevated by up to an order of magnitude compared to urban background.

NEAR-AIRPORT

- The spatial proximity impacted by an airport is much larger in comparison to that impacted by a highway
- We have detected Logan-related ultrafines in Winthrop, Chelsea, and as far as Roxbury, MA



In addition, conduct a minimum one-hour walkthrough of the home with the occupants. For buildings with building managers, include the building manager. The walkthrough must feature the following:

- identification of all installed equipment;
- instruction in how to use and operate the equipment; and
- information on its maintenance.