63rd annual Yankee Conference:
Hands -On Environmental Health

Fresher Air - Smarter Schools Novel Methods to Monitor Indoor Air Quality in Boston Public Schools

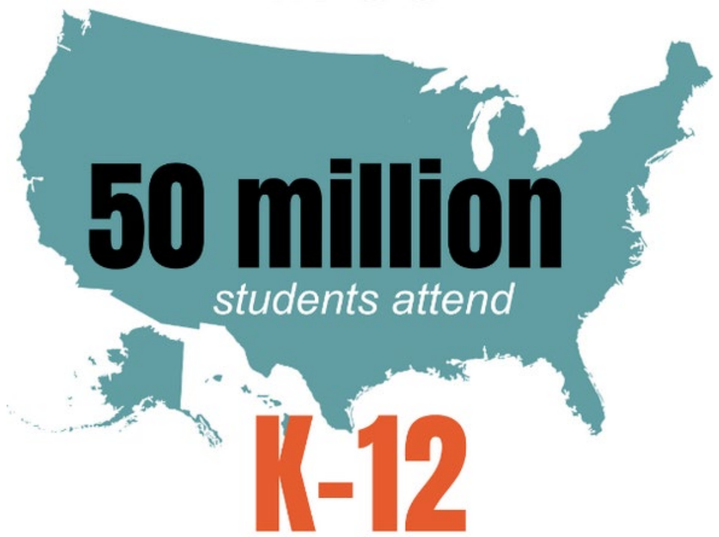
M. Patricia Fabian
Associate Professor of Environmental Health
Associate Director for the Institute for Global Sustainability
Boston University

September 11, 2025

BOSTON UNIVERSITY

If you know a school-age child in the US…

In US



School students spend

6-10

hours a day

inside schools

about 3 years

of a student life...

"School age is a vulnerable time for students.
It is a unique period of rapid growth and development "

https://arcg.is/1rG58m1

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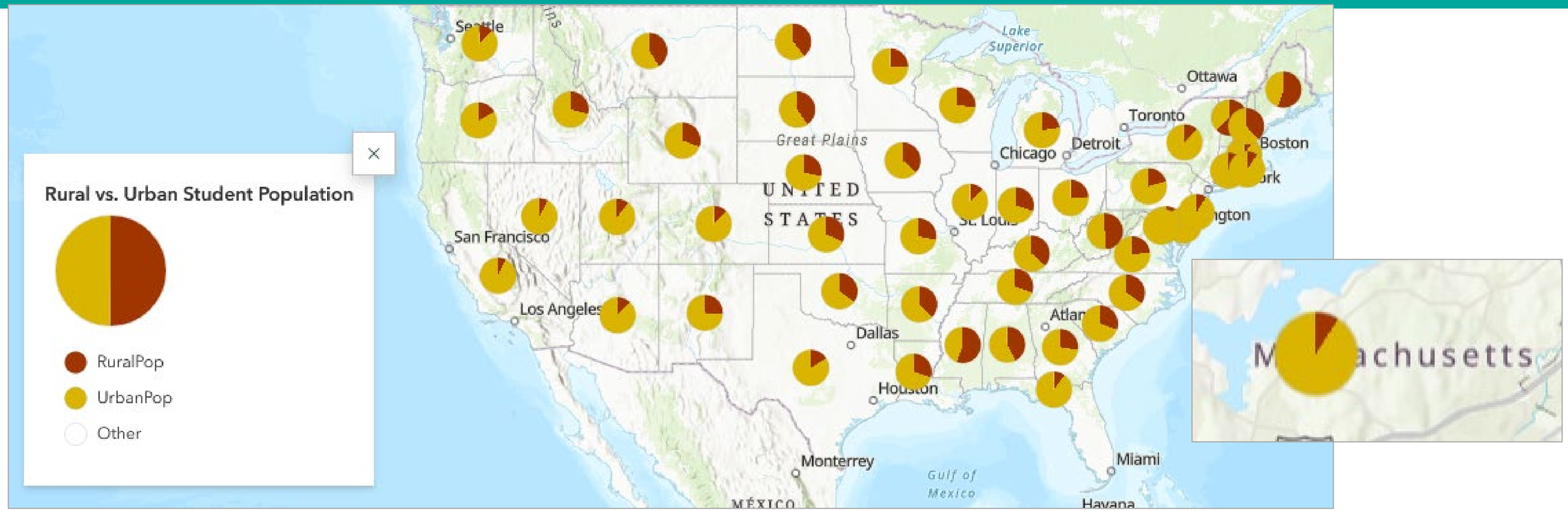
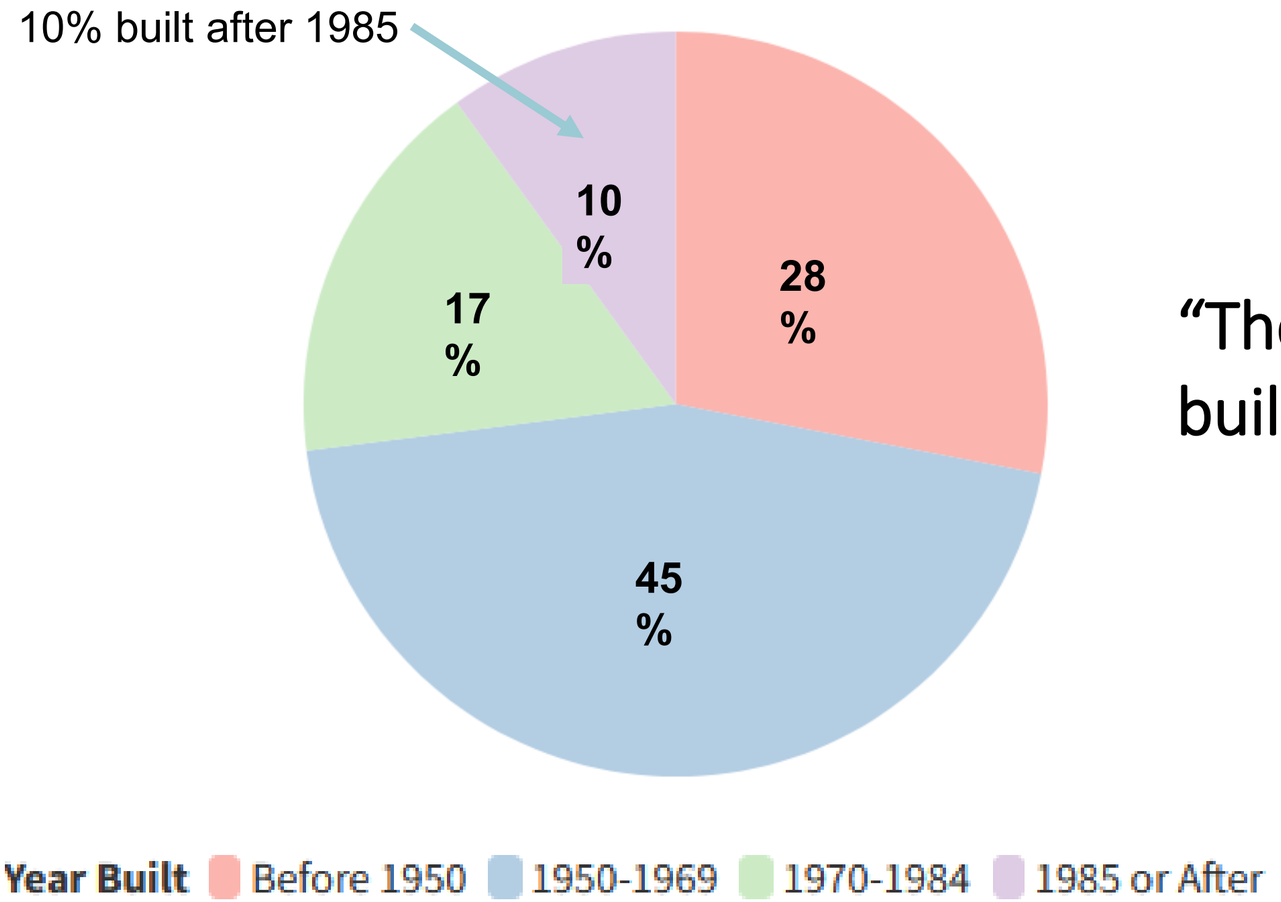
Most likely the child attends an urban school



https://arcg.is/1rG58m1

…and are most likely learning in an old building



"The mean age of US school buildings is 65 years"

https://arcg.is/1rG58m1

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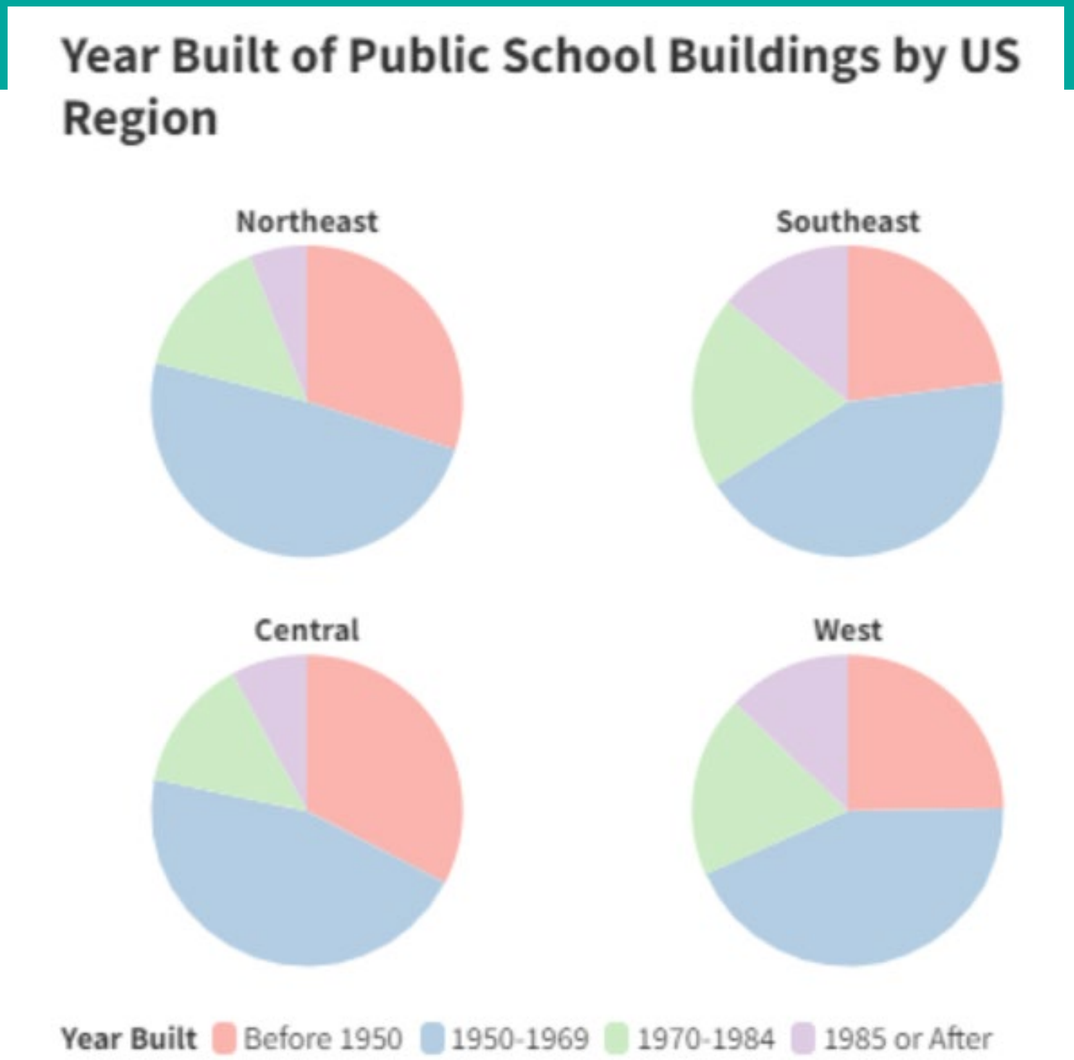
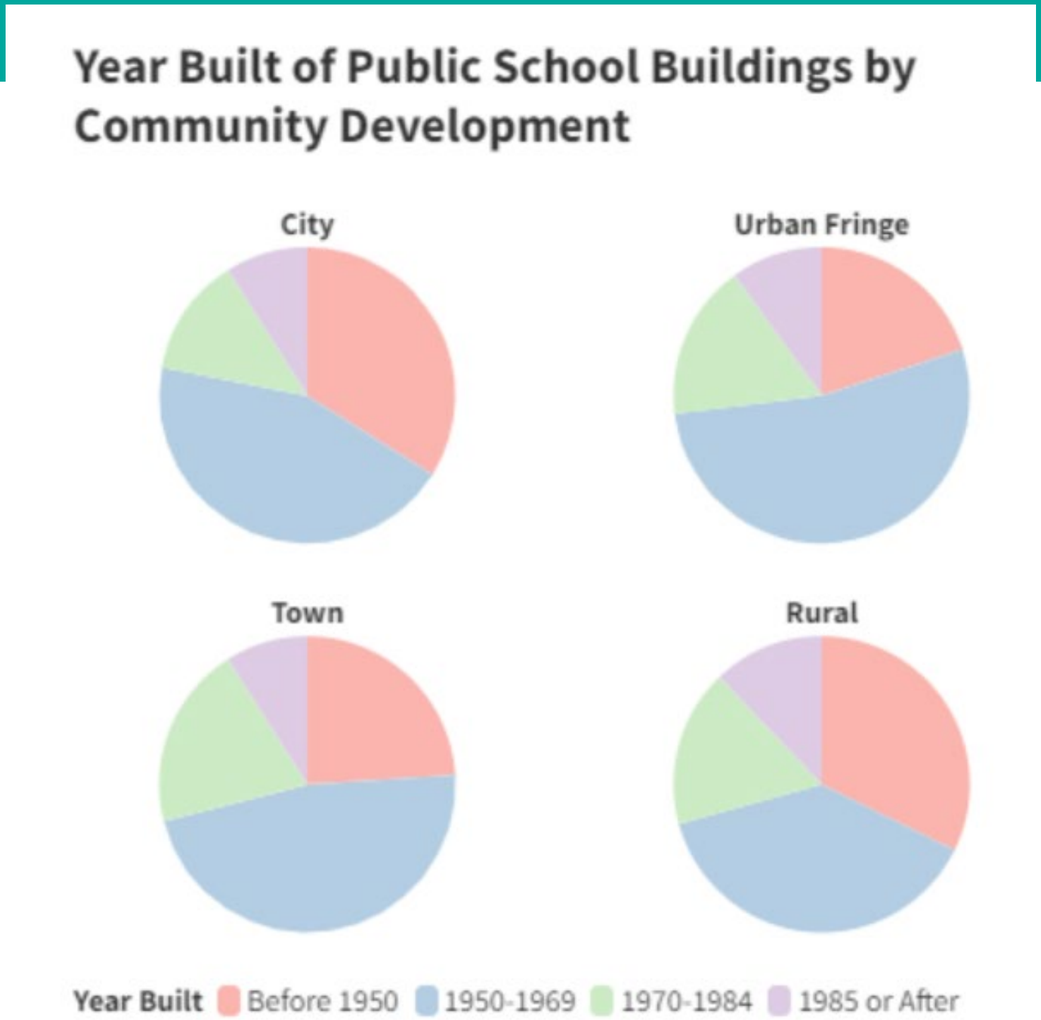
…and are most likely learning in an old building



True for all regions

https://arcg.is/1rG58m1

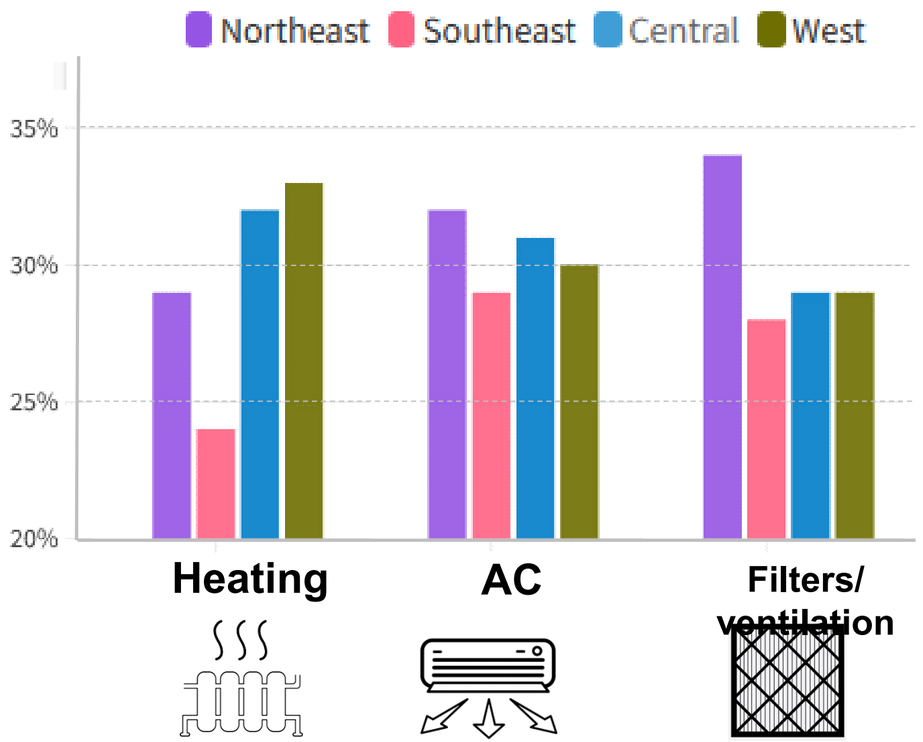
…and are most likely learning in an old building



True for all types of neighborhoods

https://arcg.is/1rG58m1

… with aging building systems in fair or poor condition



Percent of systems in fair or poor condition

Nationally, “41% of districts need to update or replace heating, ventilation, and air conditioning (HVAC) systems in at least half of their schools”

2020 GAO-Report

“$85 billion funding gap needed to maintain school buildings and equipment”

2021 State of our Schools Report

“K-12 school districts spend nearly $8 billion annually on energy costs, the second largest expense after teacher salaries.”

US DOE

https://arcg.is/1rG58m1

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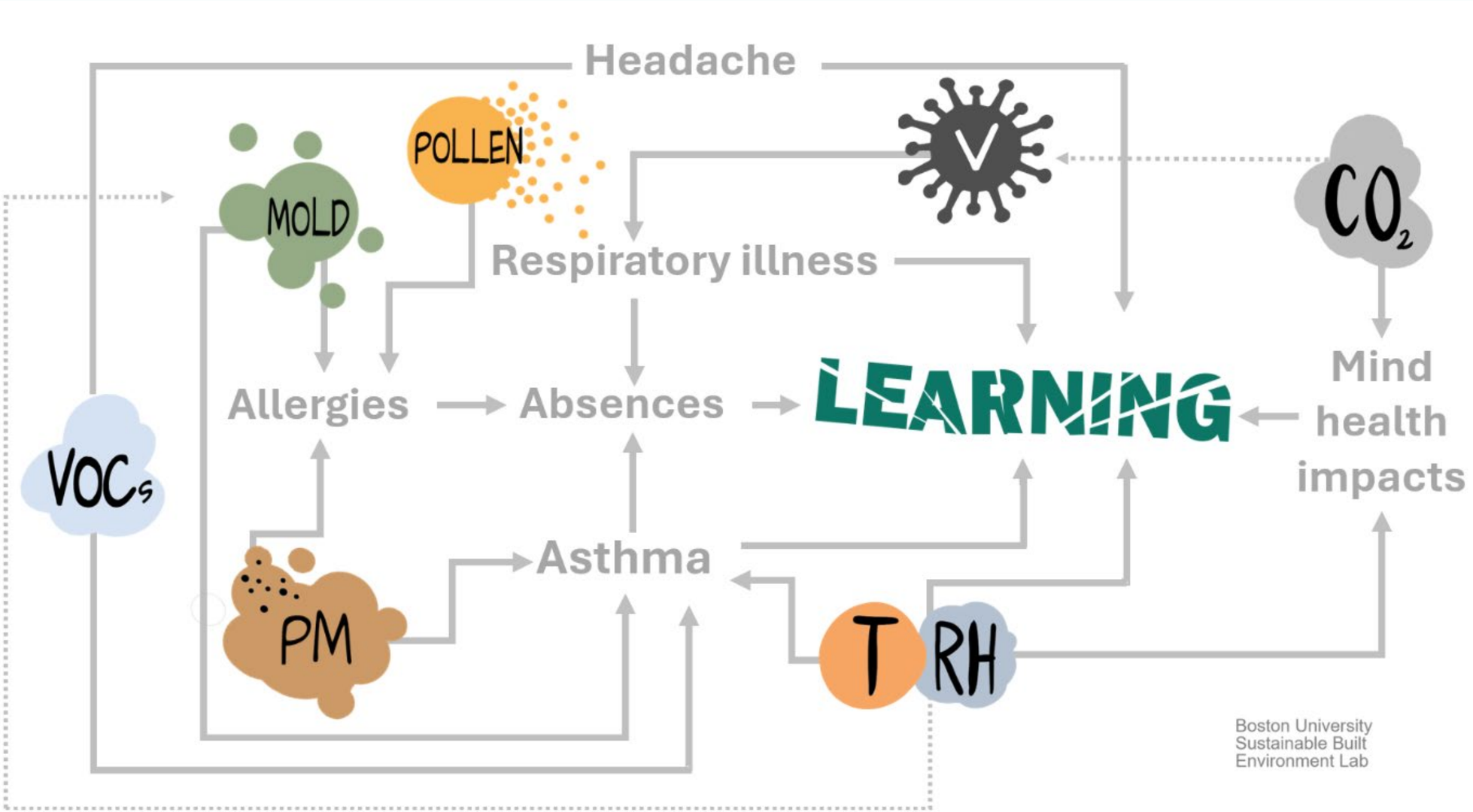
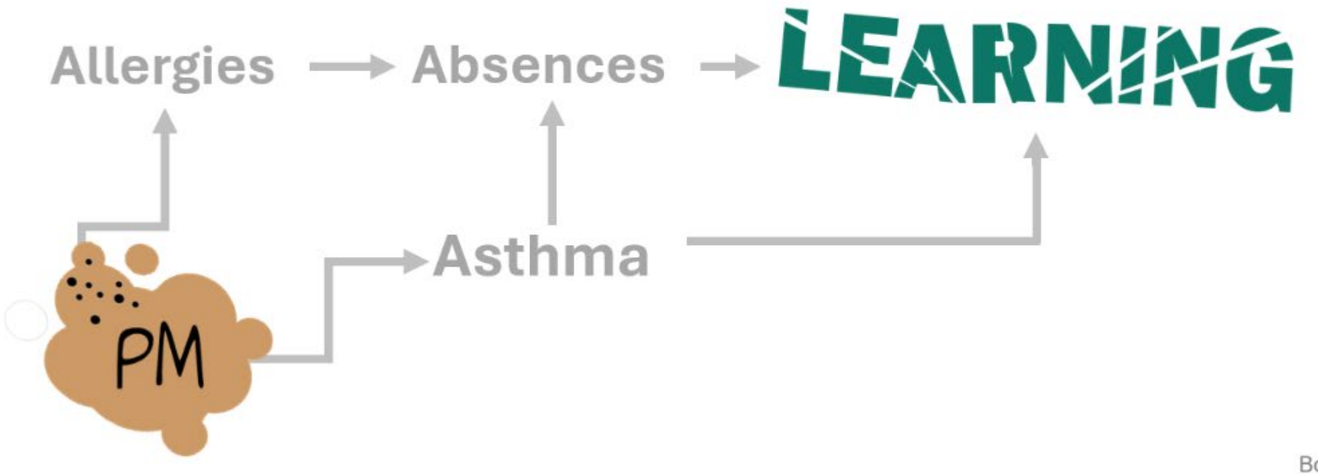
… which can result in exposure to indoor contaminants



https://arcg.is/1rG58m1

… and can be exposed to many indoor contaminants



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https://arcg.is/1rG58m1

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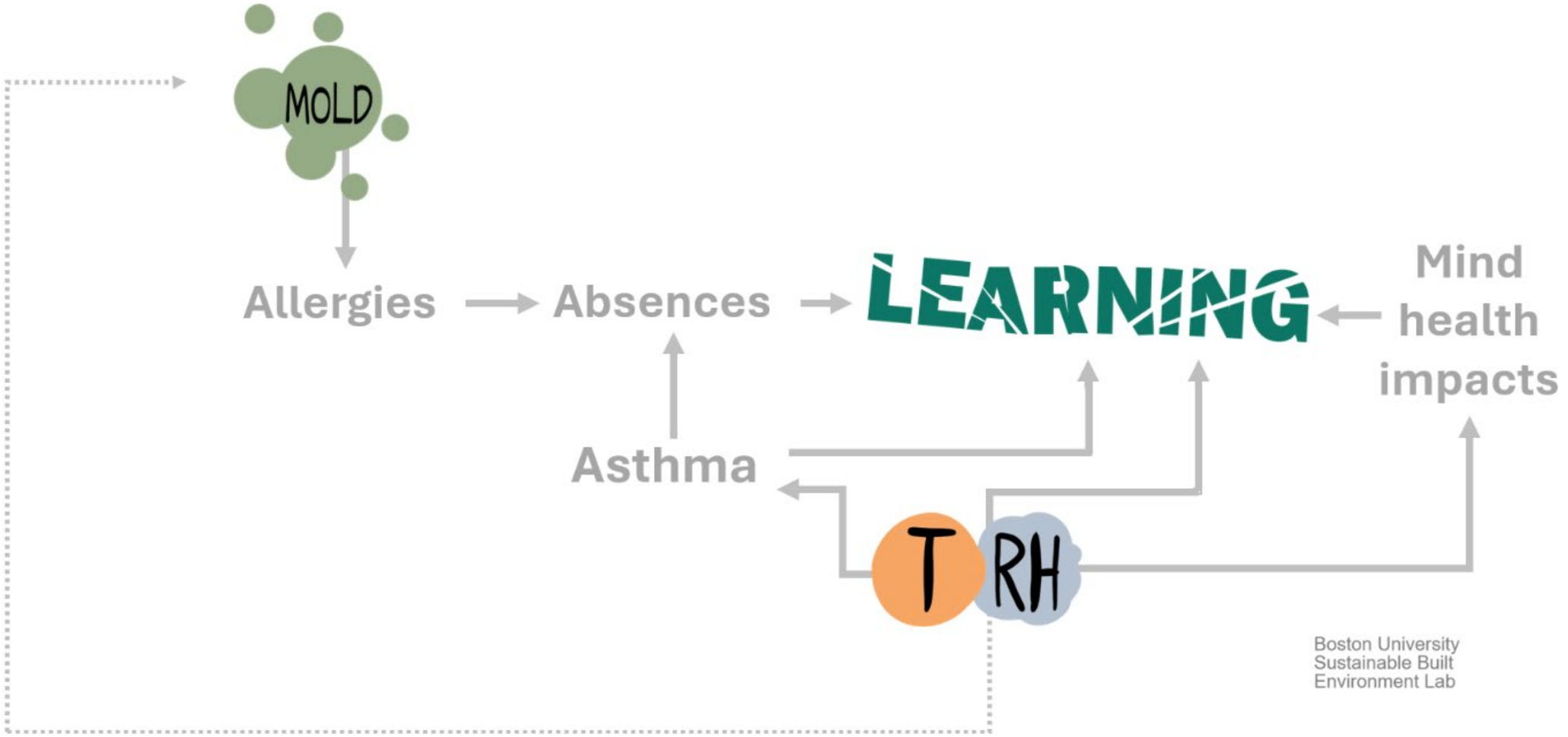

https://arcg.is/1rG58m1

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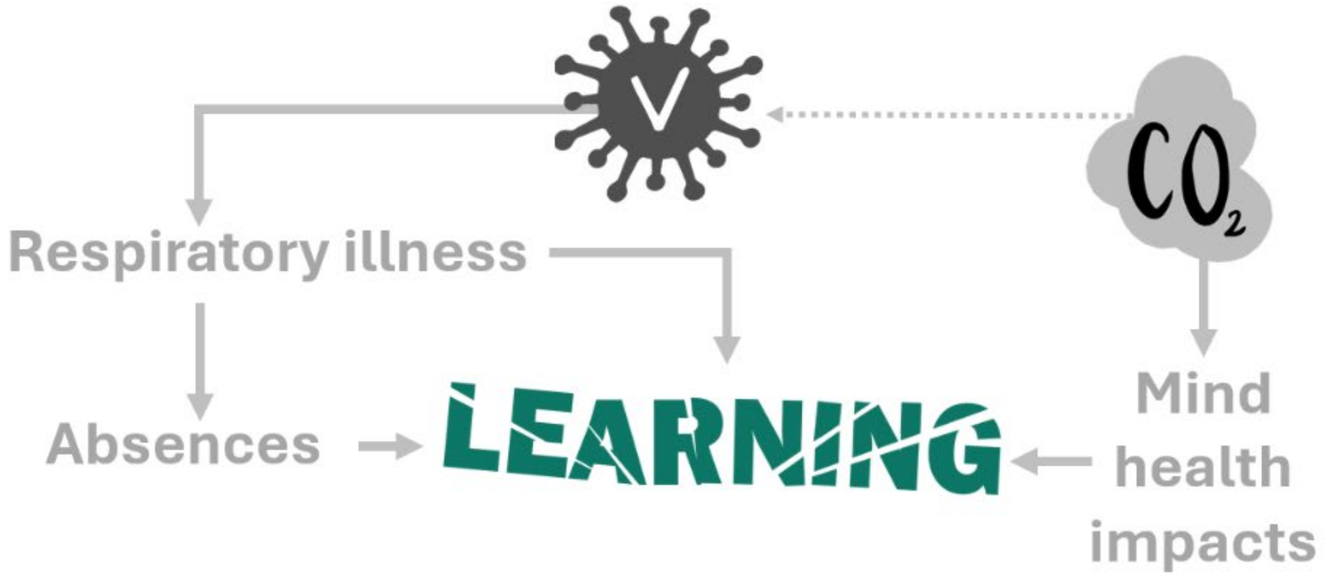

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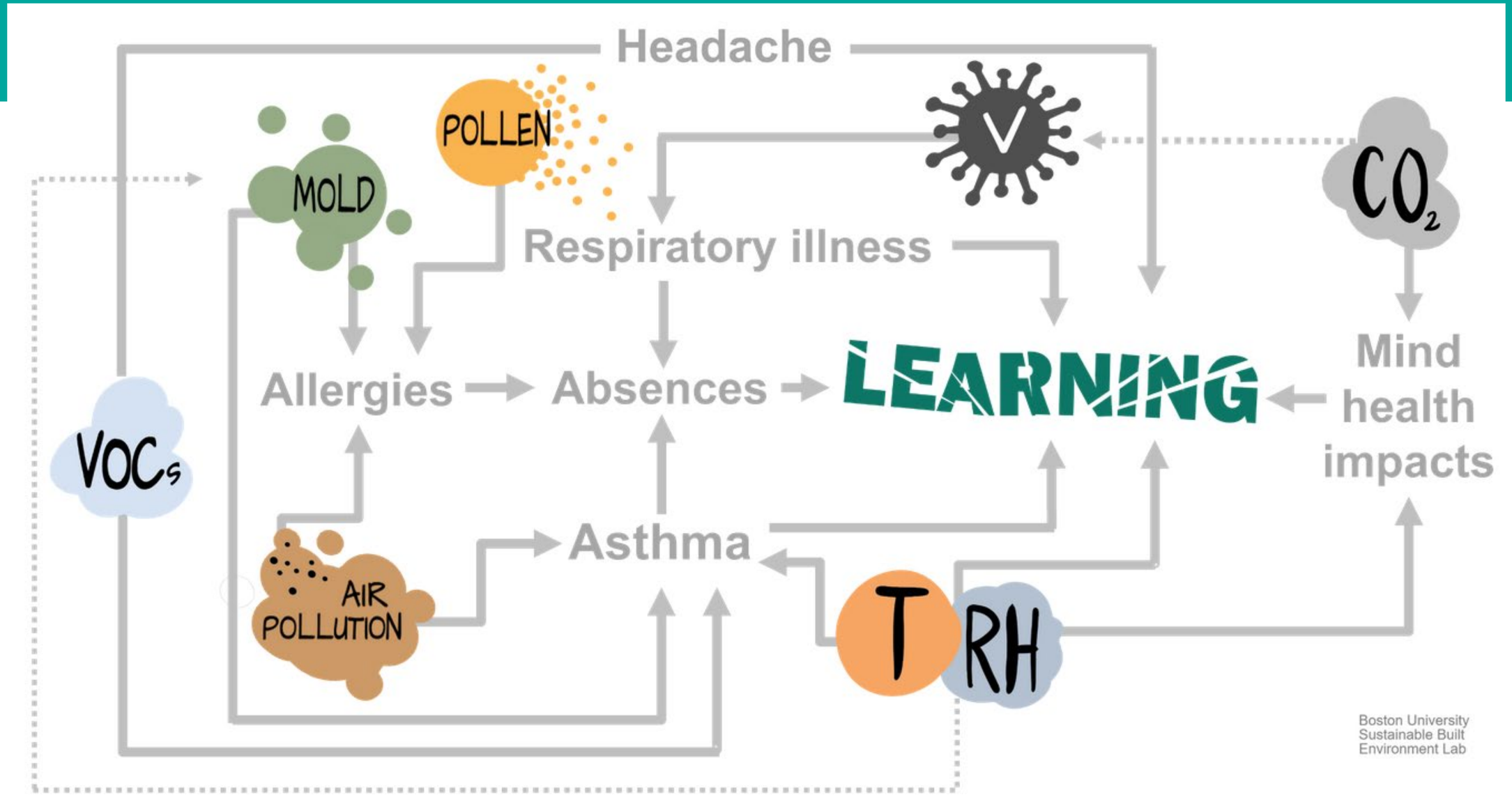
https://arcg.is/1rG58m1

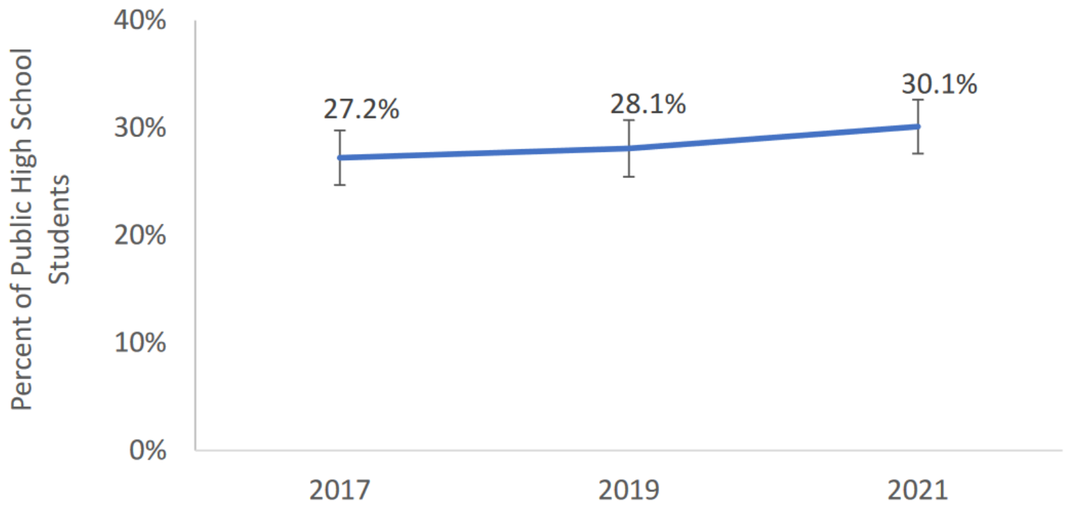
… and can be exposed to many indoor contaminants



https://arcg.is/1rG58m1

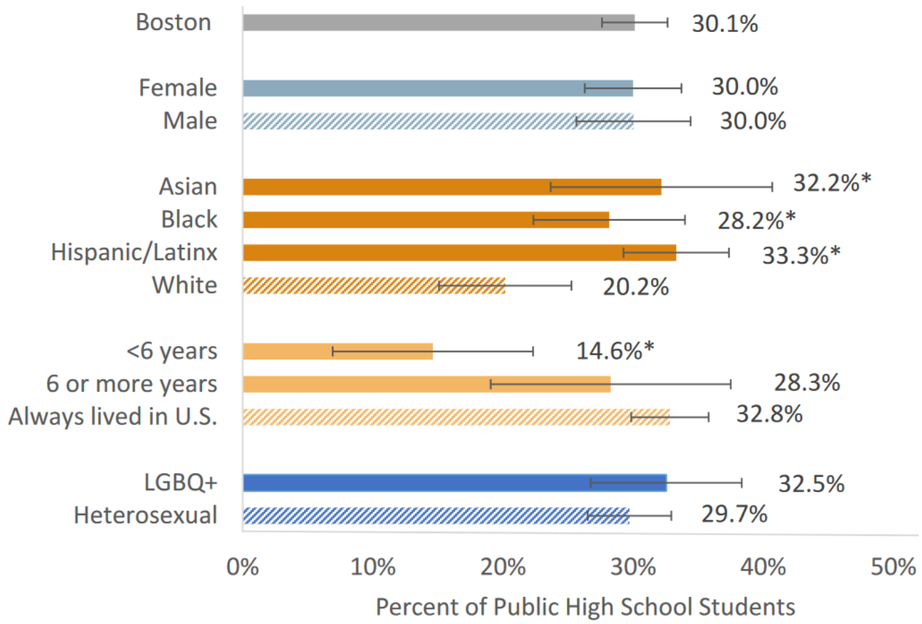
Asthma in Boston Public Schools

Figure 1. Asthma Among Public High School Students by Year, 2017, 2019, 2021



DATA SOURCE: Youth Risk Behavior Survey (2017, 2019, 2021), Centers for Disease Control and Prevention and Boston Public Schools

Figure 2. Asthma Among Public High School Students by Selected Demographics, 2021



https://www.boston.gov/sites/default/files/file/2023/05/HOB_Asthma_2023_FINAL_May11.pdf

Solutions through collaboration & research

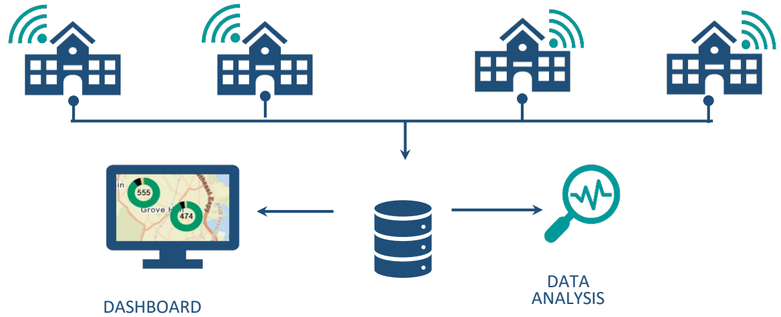
Patricia Fabian (left) poses with Katherine Wash (right) in a classroom at the Dr. Catherine Ellison/Rosa Parks Early Education School in Mattapan, Massachusetts where a sensor located on the wall behind Fabian continuously monitors indoor air quality.

https://www.bu.edu/sph/news/articles/2024/professor-partners-with-boston-public-schools-to-study-classroom-air-quality/

BU School of Public Health

BPS IEQ system

BOSTON Public Schools



125 Schools

~4,400 IAQ sensors

= billions of data points

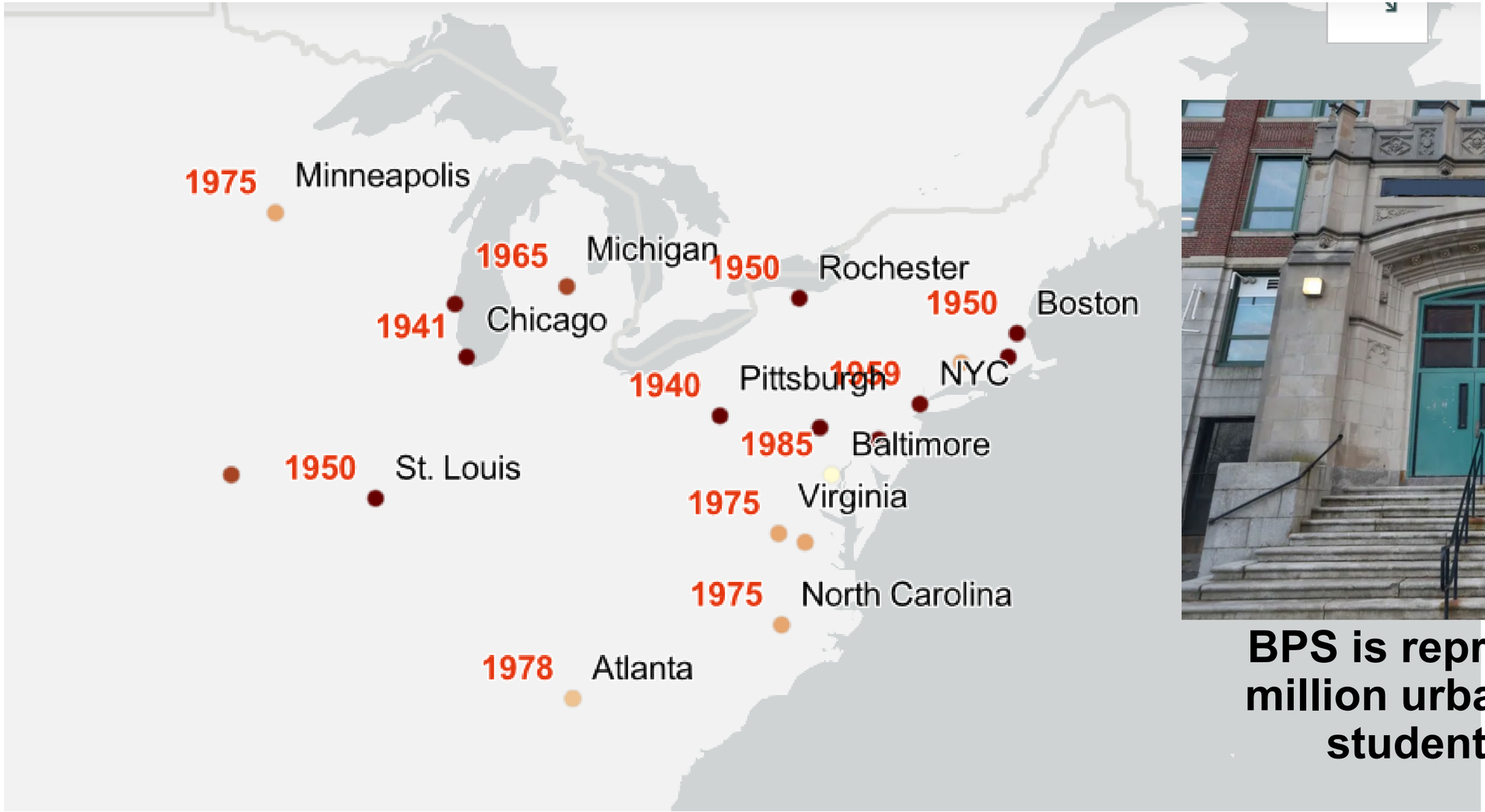
You can't fix what you don't measure – Katherine Walsh, BPS

Boston Public Schools

- Oldest public school system in the U.S.
- Serves ~48,000 students and ~11,700 staff in 119 schools from pre-kindergarten to 12th grade
- Student demographics:
  - 43% Latinx, 29% African American/Black, 15% not Hispanic White, 9% Asian, 3.5% multi-race and 0.5% Native American or Native Hawaiian/Pacific Islander
  - 71% low-income
  - 48% first language not English
- 11.6 million sq. ft, 132 Buildings:
  - 50% built before 1950, and 73% built before 1970
  - 30% percent of the school buildings use HVAC for heating and cooling; 70% use steam heat with limited or no ventilation or cooling

Boston Arts Academy

Similar to many school districts across the US…



BPS is representative of 15 million urban public school students in the U.S.

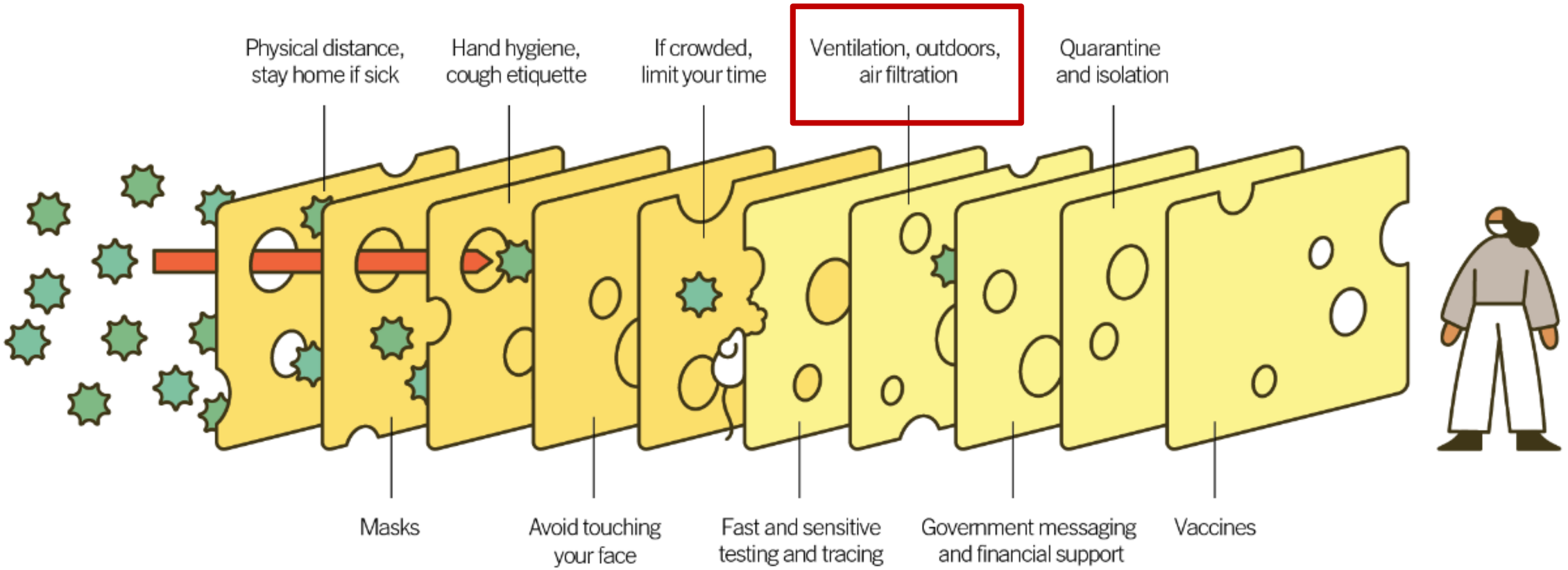
Average age of school buildings in cities in the US

https://arcg.is/1rG58m1

BOSTON PUBLIC SCHOOLS

07.30.21 - ESSER II Submission to DESE

Why Monitor IAQ?



New York Times, December 2020

https://www.nytimes.com/2020/12/05/health/coronavirus-swiss-cheese-infection-mackay.html

BPS IAQ Monitoring System

~4,500 IAQ sensors launched Fall 2021

- PM_{10} Air Particulate
- CO_2 Carbon Dioxide
- T Temperature
- $PM_{2.5}$ Air Particulate
- CO Carbon Monoxide
- RH Relative Humidity

Indoor

Outdoor

BOSTON Public Schools

BPS IAQ MONITORING SYSTEM

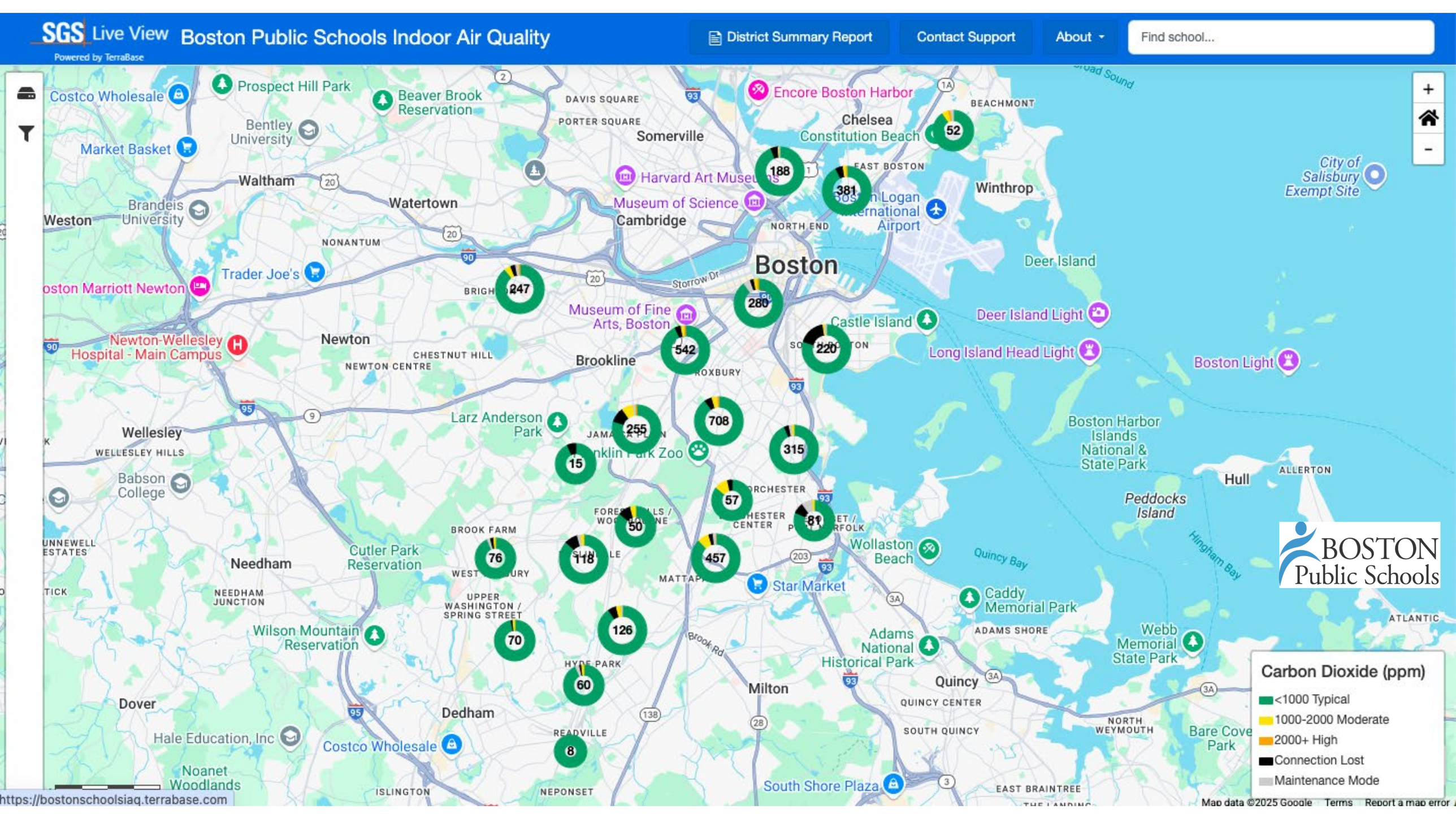
Why did BPS install Indoor Air Quality Sensors?

Monitoring & Reporting Risk Reduction Layer

Collect, monitor, measure, and evaluate IAQ data in order to:

- Prioritize decision-making.
- Take appropriate action, such as implementing IAQ interventions or adjusting ventilation rates.
- Develop IAQ standards and secure investments that improve IAQ and ventilation.
- Communicate and educate about IAQ.
- Develop community agency, collaboration, and trust around BPS schools' indoor environmental quality.

BOSTON Public Schools


SGS Live View
Powered by TerraBase
Boston Public Schools Indoor Air Quality
District Summary Report
Contact Support
About
Find school...
Boston
Cambridge
Somerville
Chelsea
Winthrop
Brookline
Newton
Waltham
Watertown
Weston
Wellesley
Needham
Dedham
Milton
Quincy
Dover
Hull
Encore Boston Harbor
Harvard Art Museums
Museum of Science
Museum of Fine Arts, Boston
Logan International Airport
Deer Island
Deer Island Light
Long Island Head Light
Boston Light
Castle Island
Boston Harbor Islands National & State Park
Peddocks Island
Wollaston Beach
Quincy Bay
Hingham Bay
Star Market
Caddy Memorial Park
Adams National Historical Park
Webb Memorial State Park
Bare Cove Park
South Shore Plaza
Costco Wholesale
Prospect Hill Park
Beaver Brook Reservation
Bentley University
Market Basket
Brandeis University
Trader Joe's
Newton-Wellesley Hospital - Main Campus
Babson College
Larz Anderson Park
Franklin Park Zoo
Cutler Park Reservation
Wilson Mountain Reservation
Hale Education, Inc
Noanet Woodlands
Constitution Beach
City of Salisbury Exempt Site
52
188
381
247
280
542
220
255
708
315
15
57
81
50
76
118
457
70
126
60
8
Carbon Dioxide (ppm)
<1000 Typical
1000-2000 Moderate
2000+ High
Connection Lost
Maintenance Mode
BOSTON Public Schools
Map data ©2025 Google
Terms
Report a map error
https://bostonschoolsiaq.terrabase.com

SGS Live View Powered by TerraBase

Boston Public Schools Indoor Air Quality

District Summary Report | Contact Support | About | Adams Elementary School

Adams Elementary School

Overview | Latest Sensor Results | 30 Day Report

Carbon Monoxide (ppm)

Min: 0.423
Avg: 0.9665
Max: 2.275
Devices: 24

Carbon Dioxide (ppm)

Min: 675.5
Avg: 868.8
Max: 1496
Devices: 24

Relative Humidity (%)

Min: 25.64
Avg: 42.48
Max: 54.56
Devices: 24

Particulate Pollution 10 (ug/m3)

Min: 0
Avg: 9.083
Max: 25.66
Devices: 24

Particulate Pollution 2.5 (ug/m3)

Min: 0
Avg: 2.444
Max: 4.546
Devices: 24

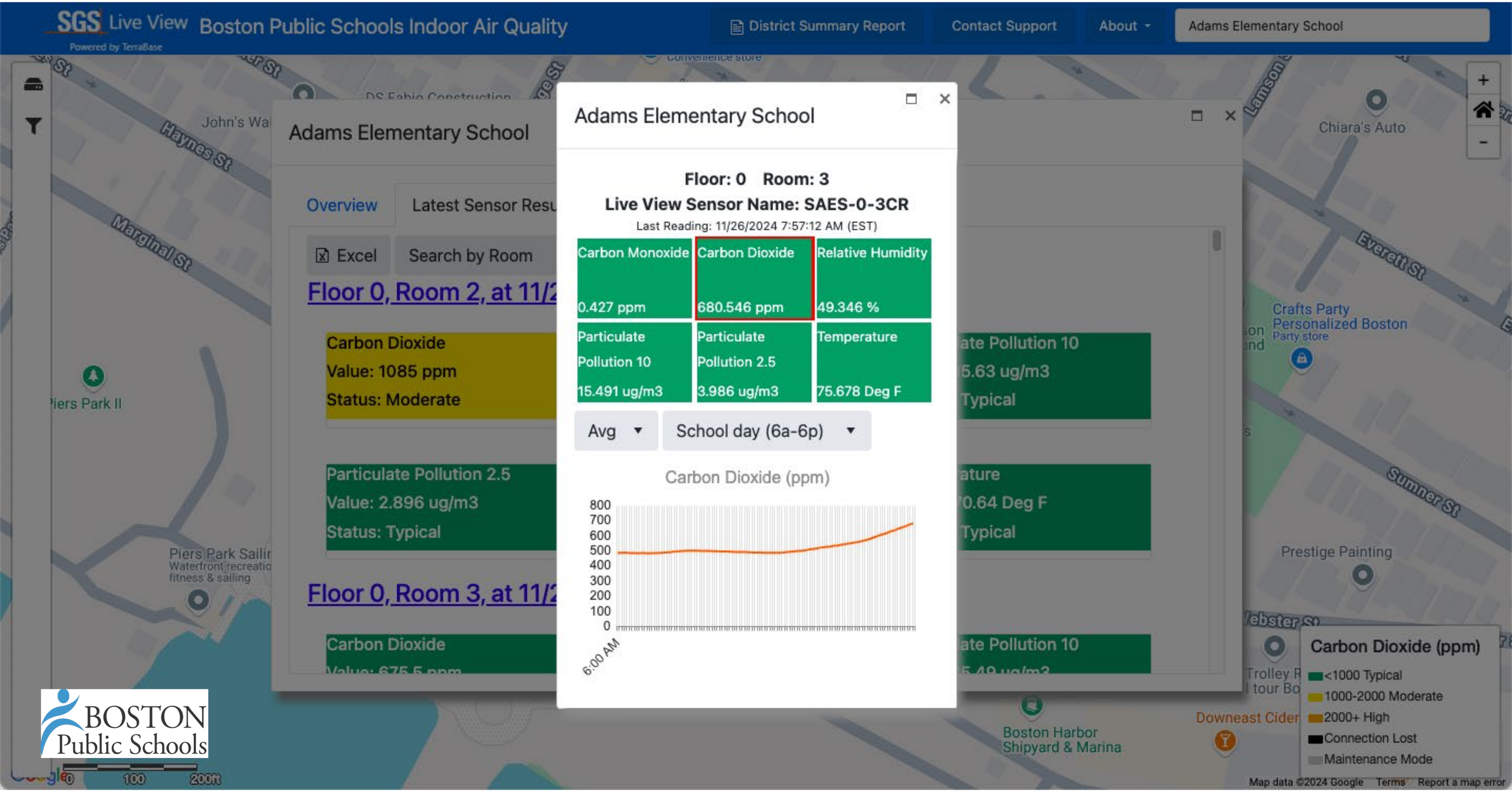
Temperature (Deg F)

Min: 65.99
Avg: 73.53
Max: 83.36
Devices: 24

Carbon Dioxide (ppm)
<1000 Typical
1000-2000 Moderate
2000+ High
Connection Lost
Maintenance Mode

BOSTON Public Schools

https://bostonschoolsiaq.terrabase.com


SGS Live View
Powered by TerraBase
Boston Public Schools Indoor Air Quality
District Summary Report
Contact Support
About
Adams Elementary School
Adams Elementary School
Overview
Latest Sensor Resu
Excel
Search by Room
Floor 0, Room 2, at 11/2
Carbon Dioxide
Value: 1085 ppm
Status: Moderate
Particulate Pollution 2.5
Value: 2.896 ug/m3
Status: Typical
Floor 0, Room 3, at 11/2
Carbon Dioxide
ate Pollution 10
5.63 ug/m3
Typical
ature
0.64 Deg F
Typical
ate Pollution 10
Adams Elementary School
Floor: 0 Room: 3
Live View Sensor Name: SAES-0-3CR
Last Reading: 11/26/2024 7:57:12 AM (EST)
Carbon Monoxide
0.427 ppm
Carbon Dioxide
680.546 ppm
Relative Humidity
49.346 %
Particulate Pollution 10
15.491 ug/m3
Particulate Pollution 2.5
3.986 ug/m3
Temperature
75.678 Deg F
Avg
School day (6a-6p)
Carbon Dioxide (ppm)
800
700
600
500
400
300
200
100
0
6:00 AM
Chiara's Auto
Crafts Party Personalized Boston
Party store
Prestige Painting
Piers Park II
Piers Park Sailir
Waterfront recreatio
fitness & sailing
Boston Harbor Shipyard & Marina
Downeast Cider
Carbon Dioxide (ppm)
<1000 Typical
1000-2000 Moderate
2000+ High
Connection Lost
Maintenance Mode
Map data ©2024 Google
Terms
Report a map error
BOSTON Public Schools

Using IAQ data in BPS operations

- Monitor and make timely temperature and ventilation adjustments in classrooms. Identify and make repairs with existing HVAC systems.
- Monitor and respond to issues of concern like re-entrainment of CO from co-gen, elevated PM from nearby construction or house fire, elevated CO2 due to poor ventilation.
- Make decisions about school and program closures during extreme heat and cold events.
- Update policies and practices within the BPS IAQ Management Plan and HVAC Maintenance Protocols.
- Enforce district anti-idling and green cleaner policies.
- Educate BPS community about IAQ in their schools.

BOSTON Public Schools

BPS IAQ Monitoring System

~4,500 IAQ sensors launched Fall 2021

= billions of data points

- PM_{10} Air Particulate
- CO_2 Carbon Dioxide
- T Temperature
- $PM_{2.5}$ Air Particulate
- CO Carbon Monoxide
- RH Relative Humidity

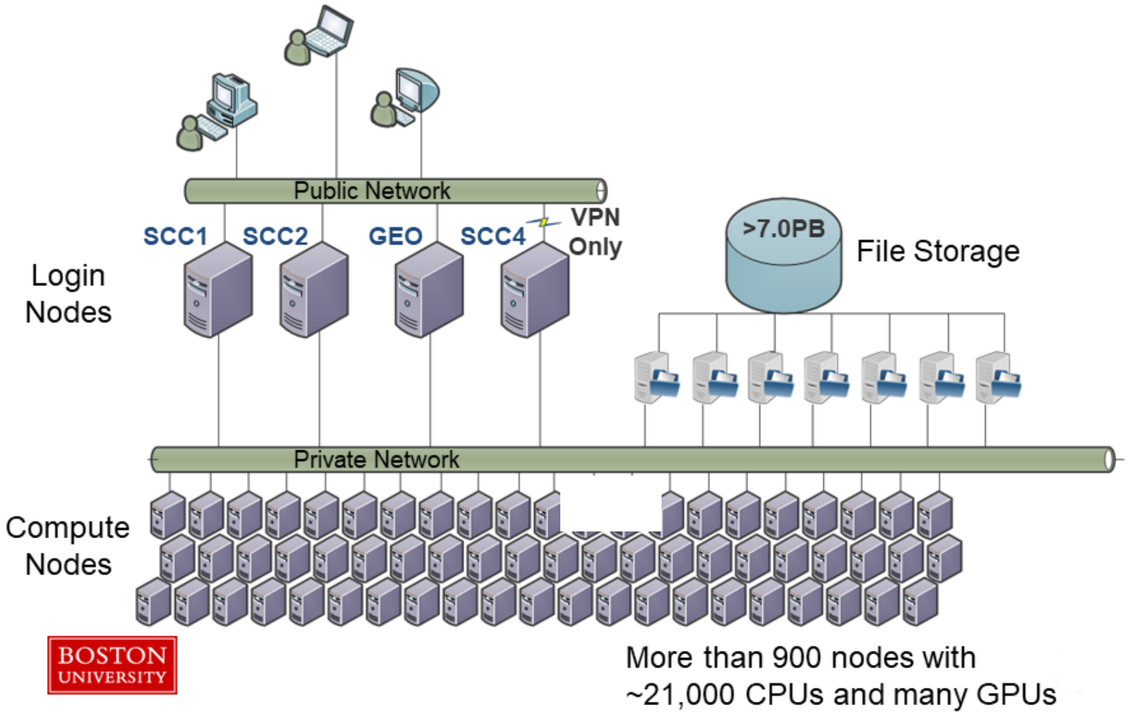
Indoor

Outdoor

BOSTON Public Schools

Storage and handling billions of data points

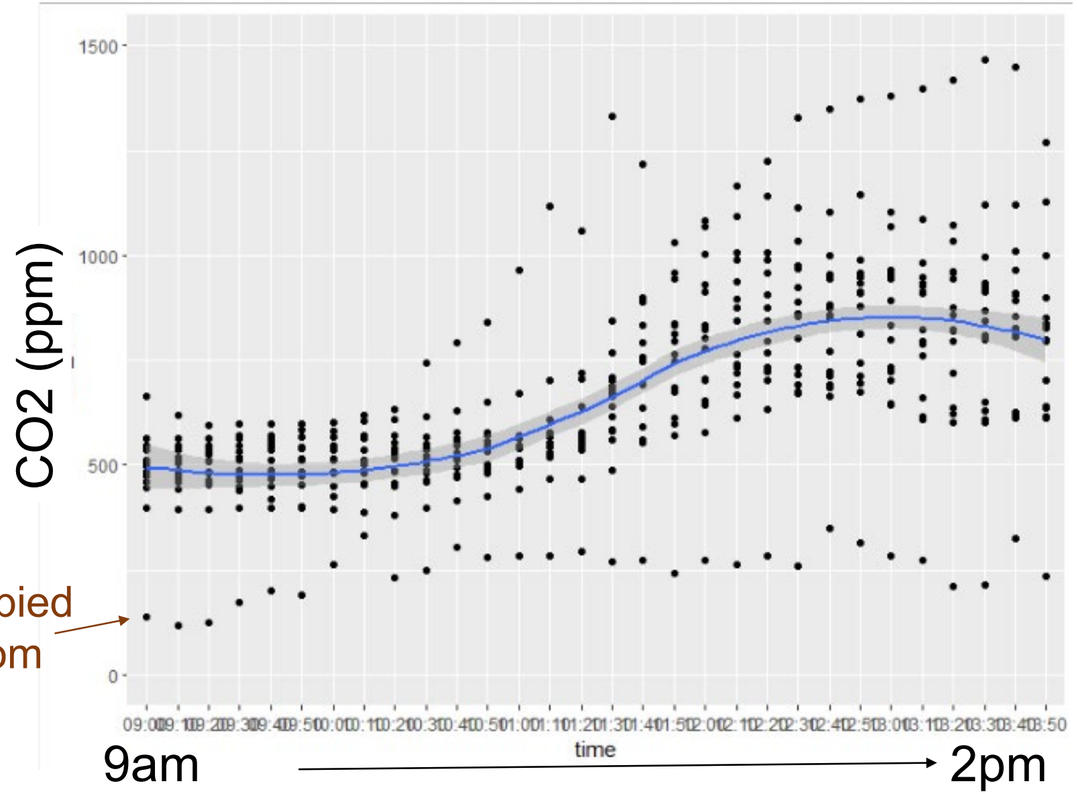
- Raw data
  - 1 minute capture
  - Calibrated
  - Year (08/202x-08/202x)
    - ~2.4 billion data points
    - ~1.2 million csv files
- Storage & processing
  - Amazon S3
  - BU's Shared Computing Cluster
- Flags
  - School, classroom/roof, level
  - Time stamps: weekday, school hours
  - Occupancy status
- Create analytical datasets



https://www.bu.edu/tech/files/2021/07/scclayout.png

Quality control – is this real?

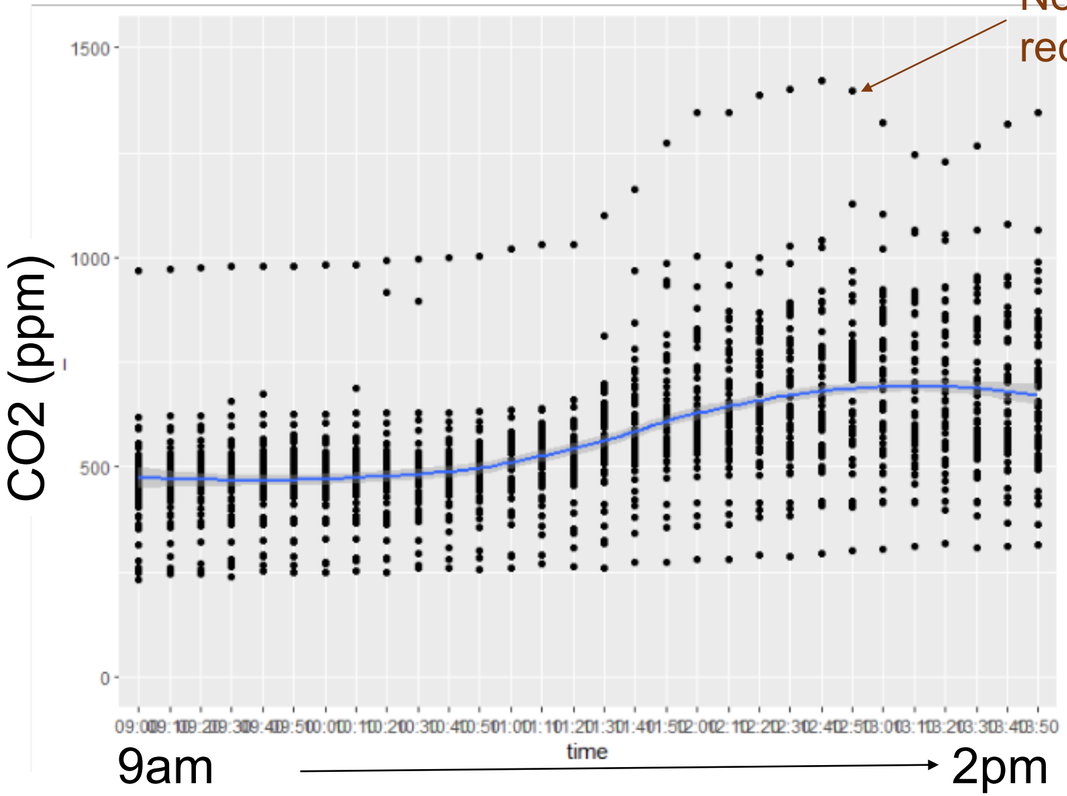
School A 4/13
Smooth of 10-min average CO_2 over the day, all classrooms



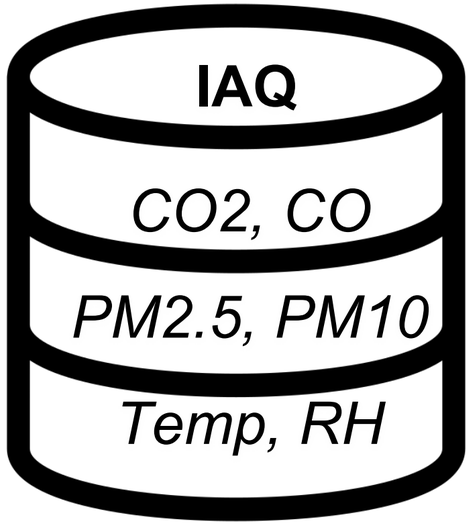
Unoccupied classroom

School B 4/13
Smooth of 10-min average CO_2 over the day, all classrooms

Needs recalibration



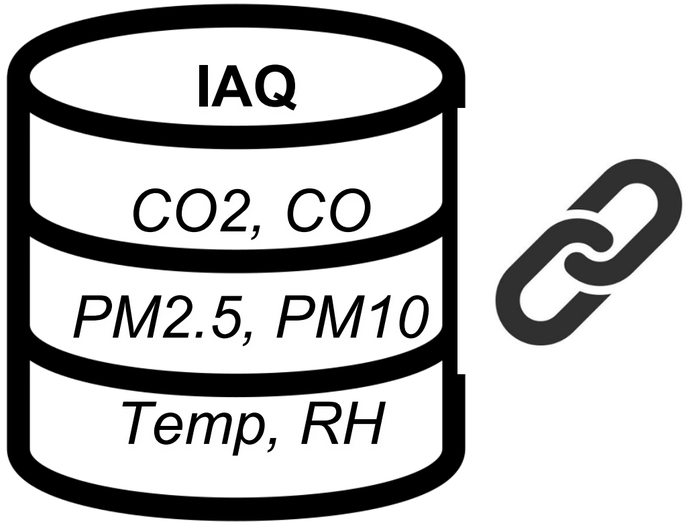
It starts with IAQ data, plus quality control, plus linking more data



It starts with IAQ data, plus quality control, plus linking more data

Researcher tools:

- Computing infrastructure
- Data science
- Geographic Information Systems (GIS)
- Environmental health
- Building science
- Statistics



Schools

Meteorology

HVAC

Energy

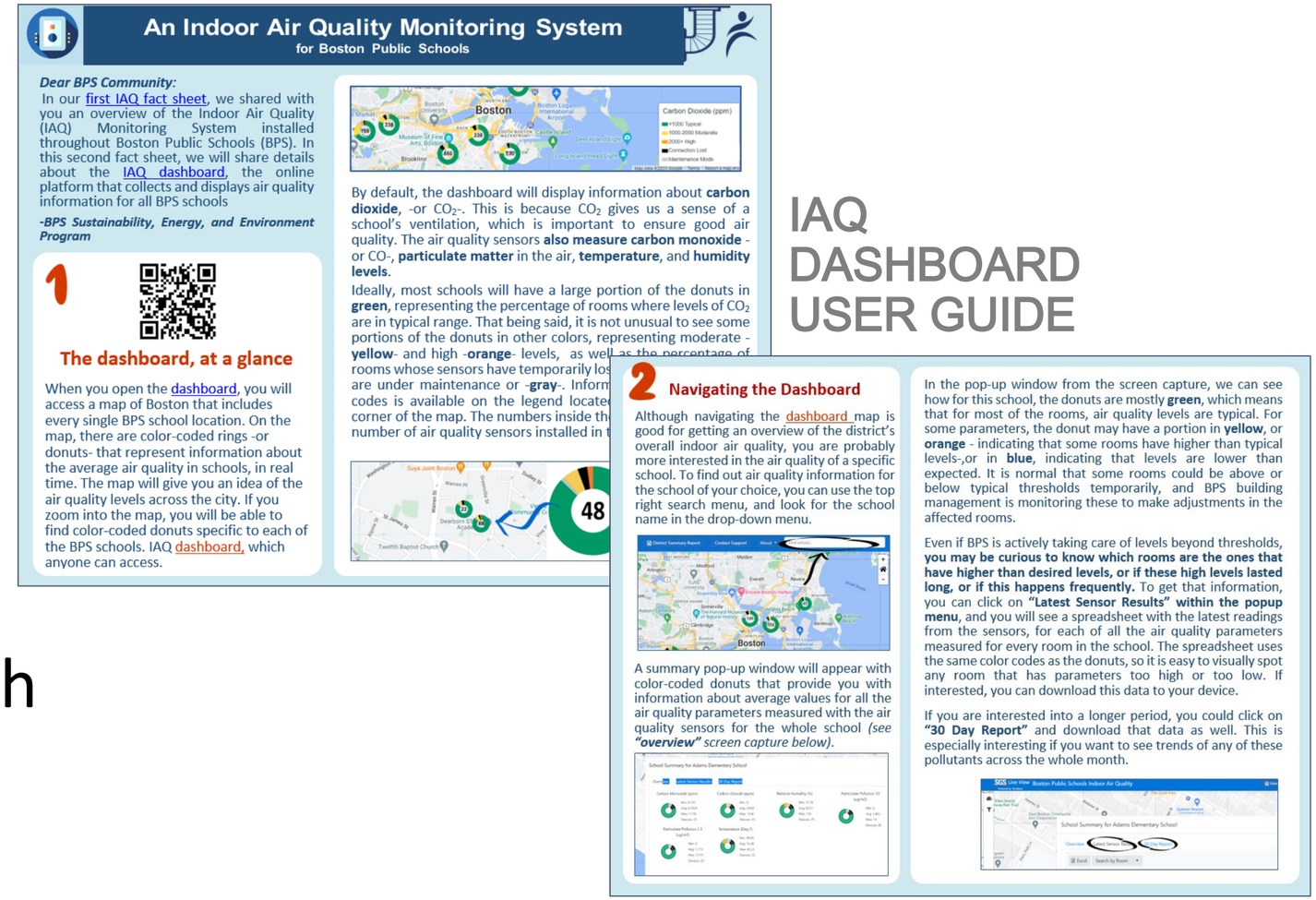
Covid interventions

Neighborhood

- Air pollution
- Greenspace
- Demographics
- …

Boston Public Schools – Boston University collaboration impacts

- Communications
- Workshops
- Presentations
- Grants
- Education
  - School operations
  - Environmental health
- IAQ analysis and research



An Indoor Air Quality Monitoring System
for Boston Public Schools

Dear BPS Community:
In our first IAQ fact sheet, we shared with you an overview of the Indoor Air Quality (IAQ) Monitoring System installed throughout Boston Public Schools (BPS). In this second fact sheet, we will share details about the IAQ dashboard, the online platform that collects and displays air quality information for all BPS schools

-BPS Sustainability, Energy, and Environment Program

1

The dashboard, at a glance

When you open the dashboard, you will access a map of Boston that includes every single BPS school location. On the map, there are color-coded rings -or donuts- that represent information about the average air quality in schools, in real time. The map will give you an idea of the air quality levels across the city. If you zoom into the map, you will be able to find color-coded donuts specific to each of the BPS schools. IAQ dashboard, which anyone can access.

By default, the dashboard will display information about **carbon dioxide**, -or CO_2-. This is because CO_2 gives us a sense of a school's ventilation, which is important to ensure good air quality. The air quality sensors **also measure carbon monoxide** -or CO-, **particulate matter** in the air, **temperature**, and **humidity levels**.

Ideally, most schools will have a large portion of the donuts in **green**, representing the percentage of rooms where levels of CO_2 are in typical range. That being said, it is not unusual to see some portions of the donuts in other colors, representing moderate -**yellow**- and high -**orange**- levels, as well as the percentage of rooms whose sensors have temporarily los are under maintenance or -**gray**-. Inform codes is available on the legend locate corner of the map. The numbers inside th number of air quality sensors installed in t

IAQ DASHBOARD USER GUIDE

2 **Navigating the Dashboard**

Although navigating the dashboard map is good for getting an overview of the district's overall indoor air quality, you are probably more interested in the air quality of a specific school. To find out air quality information for the school of your choice, you can use the top right search menu, and look for the school name in the drop-down menu.

A summary pop-up window will appear with color-coded donuts that provide you with information about average values for all the air quality parameters measured with the air quality sensors for the whole school *(see **"overview"** screen capture below).*

In the pop-up window from the screen capture, we can see how for this school, the donuts are mostly **green**, which means that for most of the rooms, air quality levels are typical. For some parameters, the donut may have a portion in **yellow**, or **orange** - indicating that some rooms have higher than typical levels-,or in **blue**, indicating that levels are lower than expected. It is normal that some rooms could be above or below typical thresholds temporarily, and BPS building management is monitoring these to make adjustments in the affected rooms.

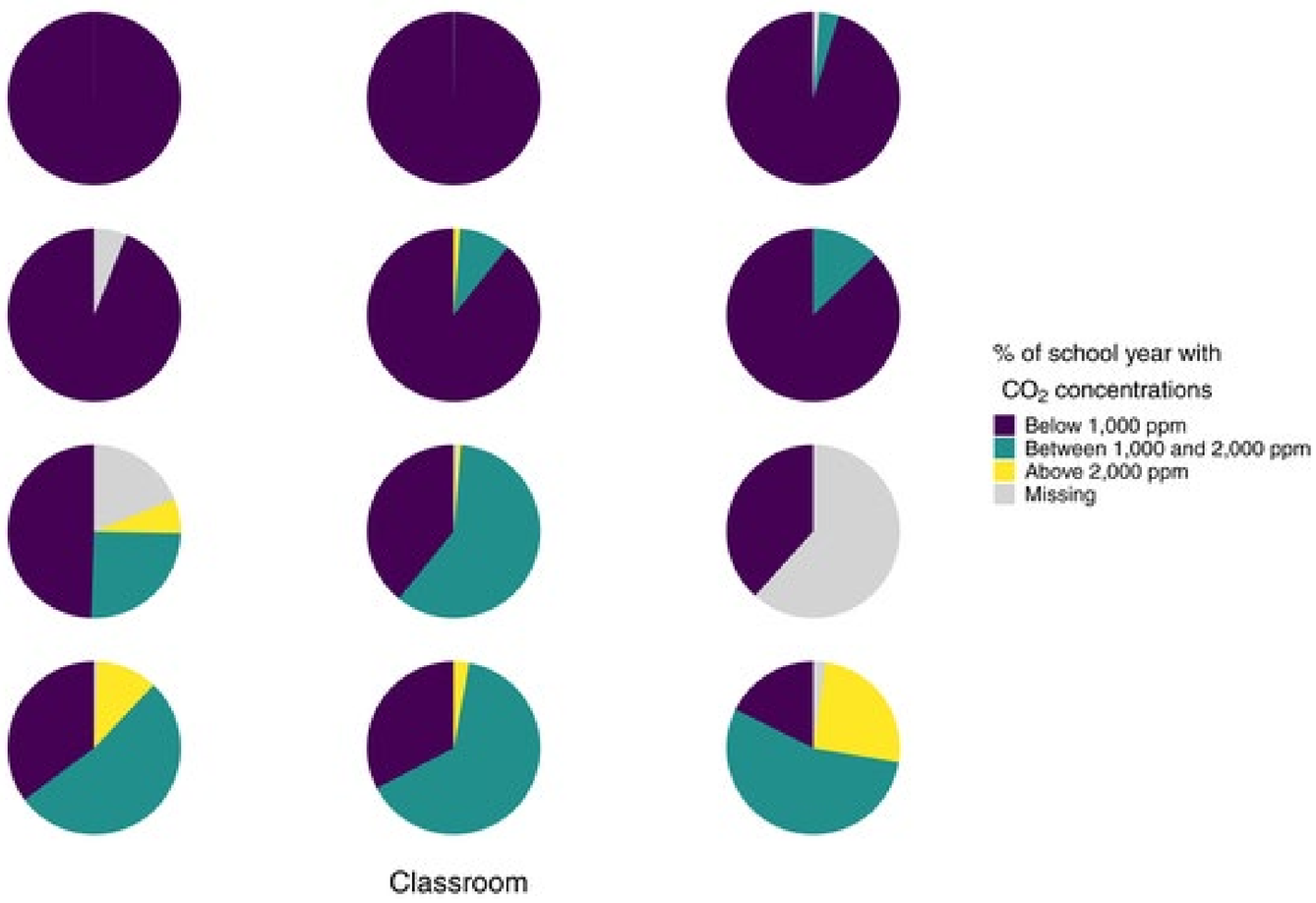
Even if BPS is actively taking care of levels beyond thresholds, **you may be curious to know which rooms are the ones that have higher than desired levels, or if these high levels lasted long, or if this happens frequently.** To get that information, you can click on **"Latest Sensor Results" within the popup menu**, and you will see a spreadsheet with the latest readings from the sensors, for each of all the air quality parameters measured for every room in the school. The spreadsheet uses the same color codes as the donuts, so it is easy to visually spot any room that has parameters too high or too low. If interested, you can download this data to your device.

If you are interested into a longer period, you could click on **"30 Day Report"** and download that data as well. This is especially interesting if you want to see trends of any of these pollutants across the whole month.

BOSTON Public Schools

BOSTON UNIVERSITY

The value of installing IAQ sensors in every classroom - CO2



Key data takeaways:

- High CO2 variability at a classroom level within schools, across schools and over the school year (>1X)
- Captured 98% of days per sensor over a school year (5%-100%)
- Processing of CO2 data enhances its value for decisions beyond real-time

Utility:

- Prioritize classrooms and schools needing more ventilation
- Optimize building maintenance resources
- Create baseline metrics to evaluate interventions
- Identify seasonal or recurring patterns

Ge et al (2025) *Lancet Regional Health: Americas*
https://doi.org/10.1016/j.lana.2025.101148

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Environment Lab

The value of installing IAQ sensors in every classroom - CO2

Blue – low CO2
Yellow – high CO2
Gray - missing
White - holiday

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Ge et al (2025) *Lancet Regional Health: Americas*
https://doi.org/10.1016/j.lana.2025.101148

Boston University
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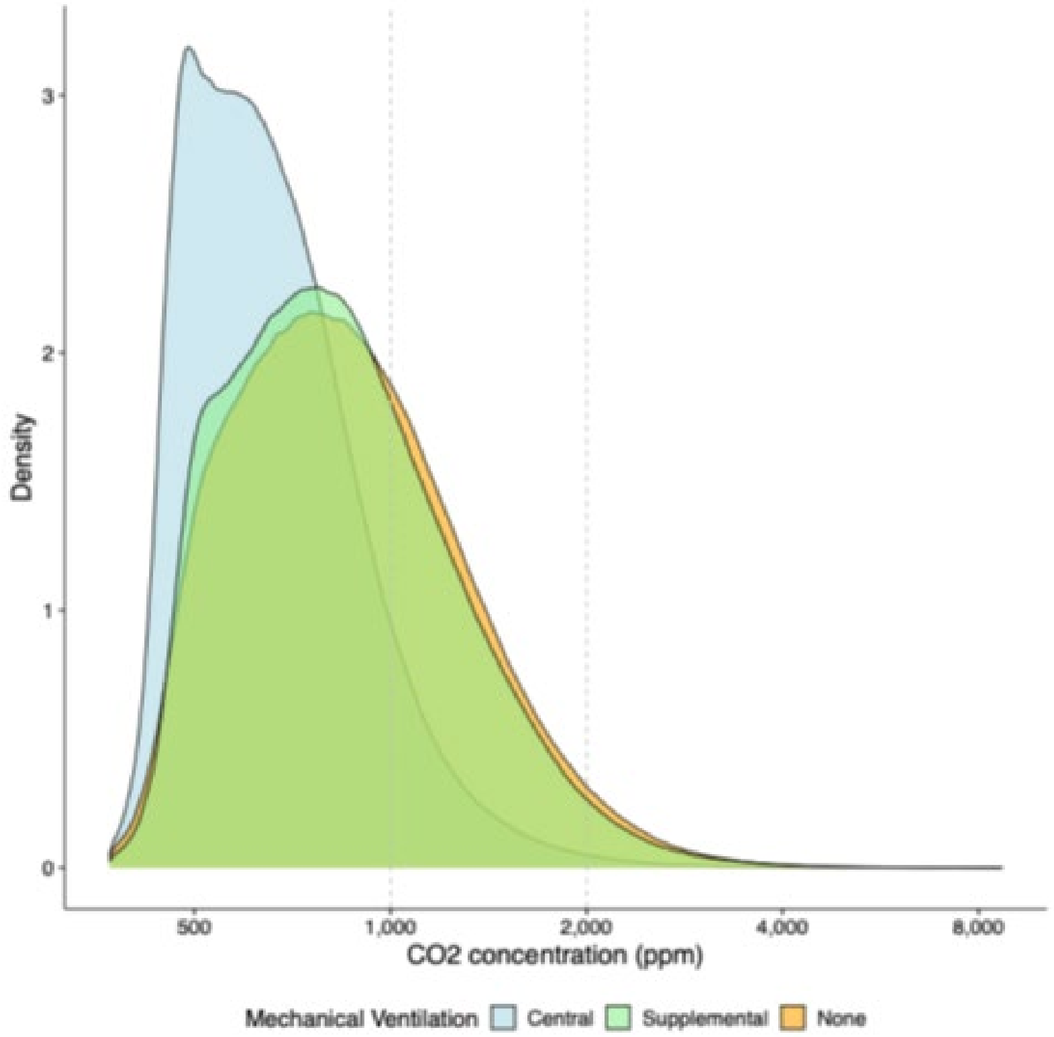
Environment Lab

Does ventilation reduce CO2 in classrooms?



Key data takeaways:

- Lower CO2 in schools with mechanical vs natural ventilation (930 ppm vs 698 ppm on average)
- CO2 elevated at times in all schools
- Demand-control ventilation (DCV) most effective system (99% of CO2 measurements <1000 ppm)

Utility:

- Advocate for system upgrades
- Optimize HVAC system maintenance
- Identify schools to connect to building management systems (BMS)
- Improve vendor accountability

Ge et al (2025) *Lancet Regional Health: Americas*
https://doi.org/10.1016/j.lana.2025.101148

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How many IAQ sensors does a school need?

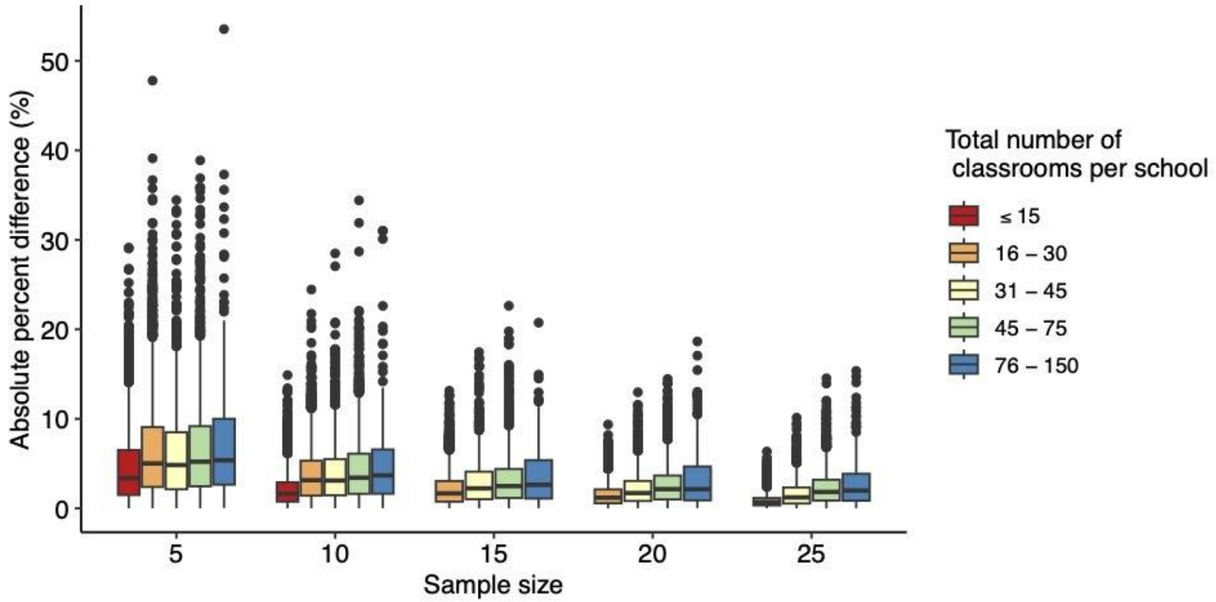

Figure S4. Box plots showing the absolute percent difference between the classroom sensor sample mean and the school building mean for different sizes of sensor samples, stratified by building size.

Key takeaway:

The larger the school the more sensors are needed

- >5 for schools with ≤15 classrooms
- 15 for schools with 16–30 classrooms
- 20 for schools with 31–45 classrooms
- 25 for schools with 46–75 classrooms
- >25 for schools with 76-150 classrooms

Utility:

- Capture the IAQ landscape of a school with limited budget

Ge et al (2025) *Lancet Regional Health: Americas*
https://doi.org/10.1016/j.lana.2025.101148

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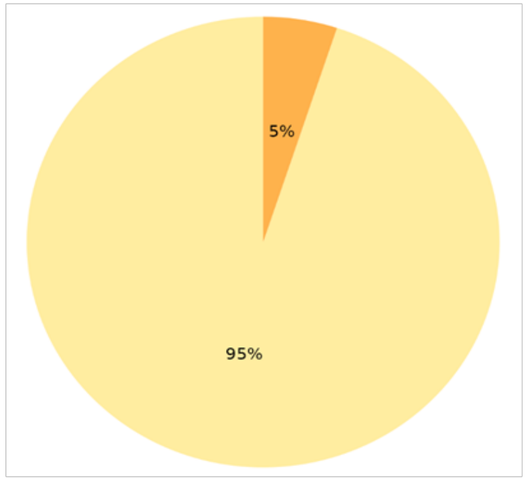
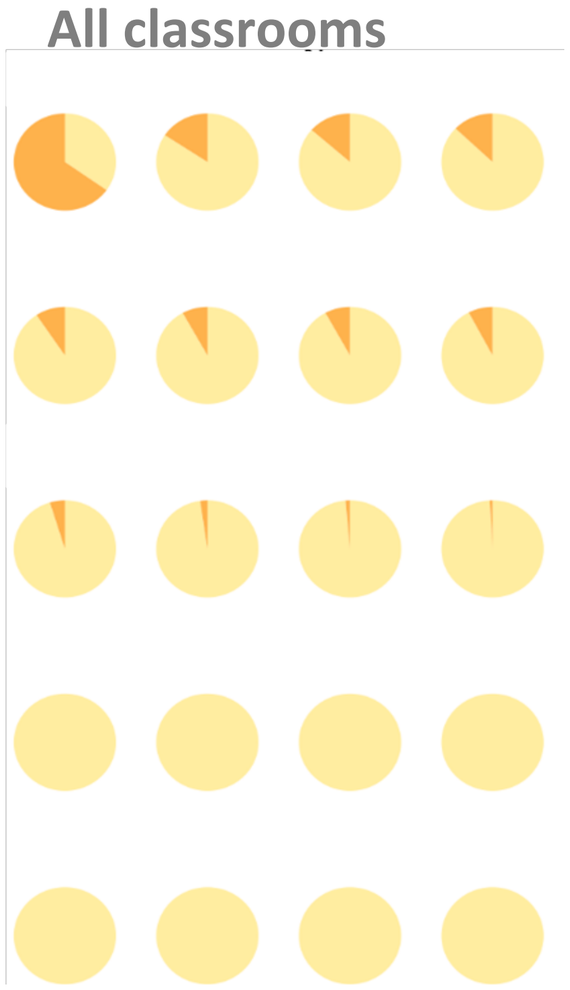
The value of installing IAQ sensors in every classroom - heat





Key takeaways:

- Temperature variability between classrooms in the same building:
  - 2.3°C (3.6F) on average
  - 14.4°C (>20F) max difference in buildings without mechanical cooling
  - 6°C cooler at ground level compared to upper level in buildings without mechanical cooling
- Central and window AC maintained comfortable temperatures compared to buildings without mechanical cooling.
- Novel temperature metrics captured heat frequency, intensity and length - different from maximum temperature

Utility:

- Identify cooling needs and prioritize investments
- Inform heat action plans
- Evaluate interventions
- Identify seasonal or recurring patterns
- Justify mechanical cooling investments in Northeast US

Botana et al (2025) *Indoor Environments*
https://doi.org/10.1016/j.indenv.2025.100105

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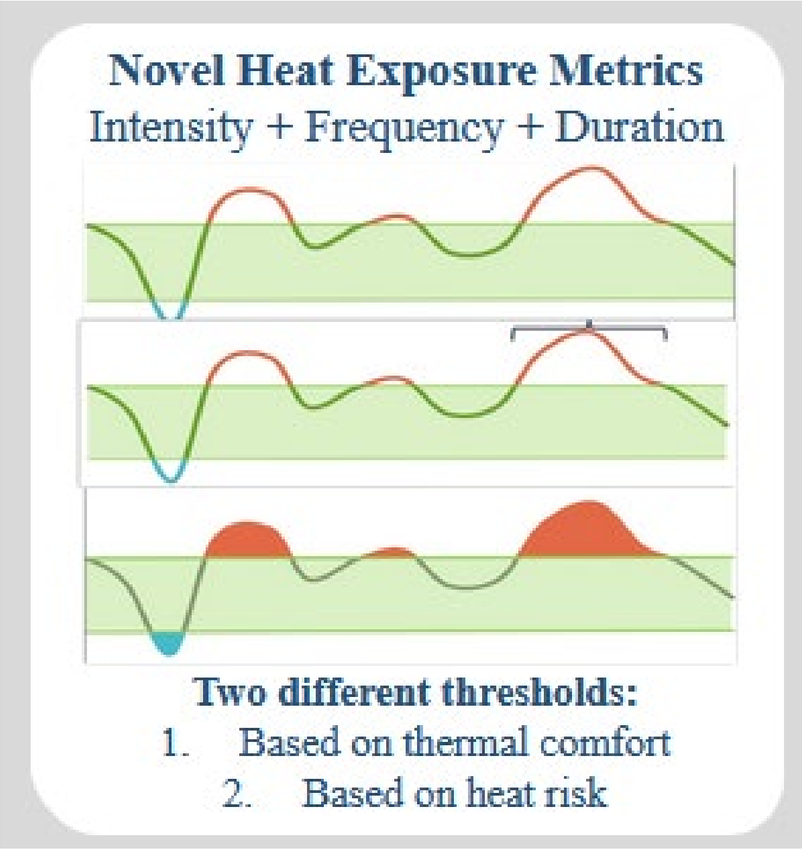
Rethinking Heat Exposure In Classrooms Through Continuous Monitoring: Novel Metrics For Schools



Botana Martinez et al (2025), *Indoor Environments*, in press

Some findings:

- Access to mechanical cooling critical in Northeast
- Central AC most effective but window AC also works (most of the time)
- On a hot day, classrooms on the ground floor were ~6°C cooler in schools without AC

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Predicting mold growth with temperature and relative humidity

Utility:

- Monitor classrooms during periods of school shut down (i.e., summer)
- Direct resources to prevent larger problems

New methods to measure ventilation using CO2

Old method - spot check with balometer

New method - daily AER estimate with IAQ sensors + machine learning

ENVIRONMENTAL HEALTH

Fresher Air, Smarter Schools: SPH Researchers Share Novel Method for Monitoring Indoor Air Quality

A new study from researchers at the School of Public Health, conducted using data from Boston Public School's extensive network of air quality sensors, showed classroom air quality is often highly variable within school buildings, and even fluctuates greatly within the same classroom over the course of a year.

https://www.bu.edu/sph/news/articles/2025/fresher-air-smarter-schools-sph-researchers-share-novel-method-for-monitoring-indoor-air-quality/

Yuan et al (2025), *Indoor Environments*
10.1016/j.indenv.2025.100083

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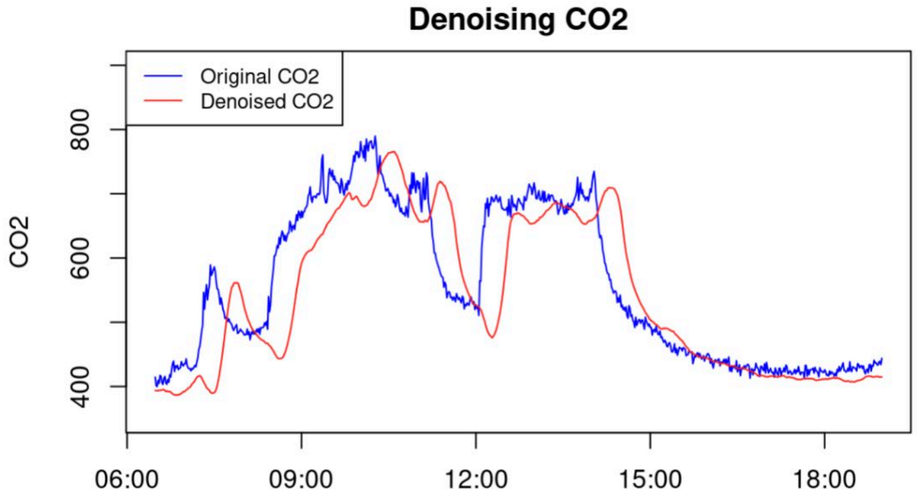
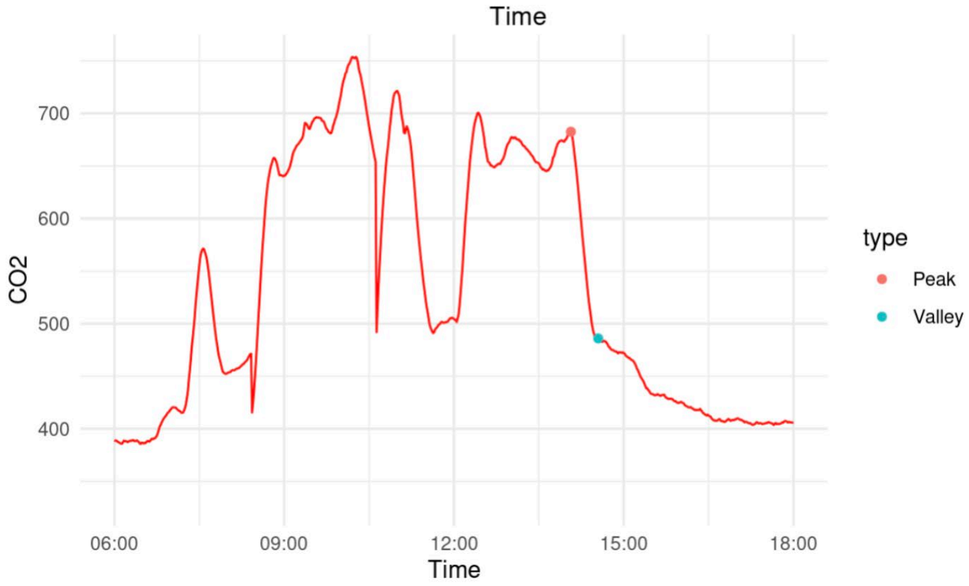
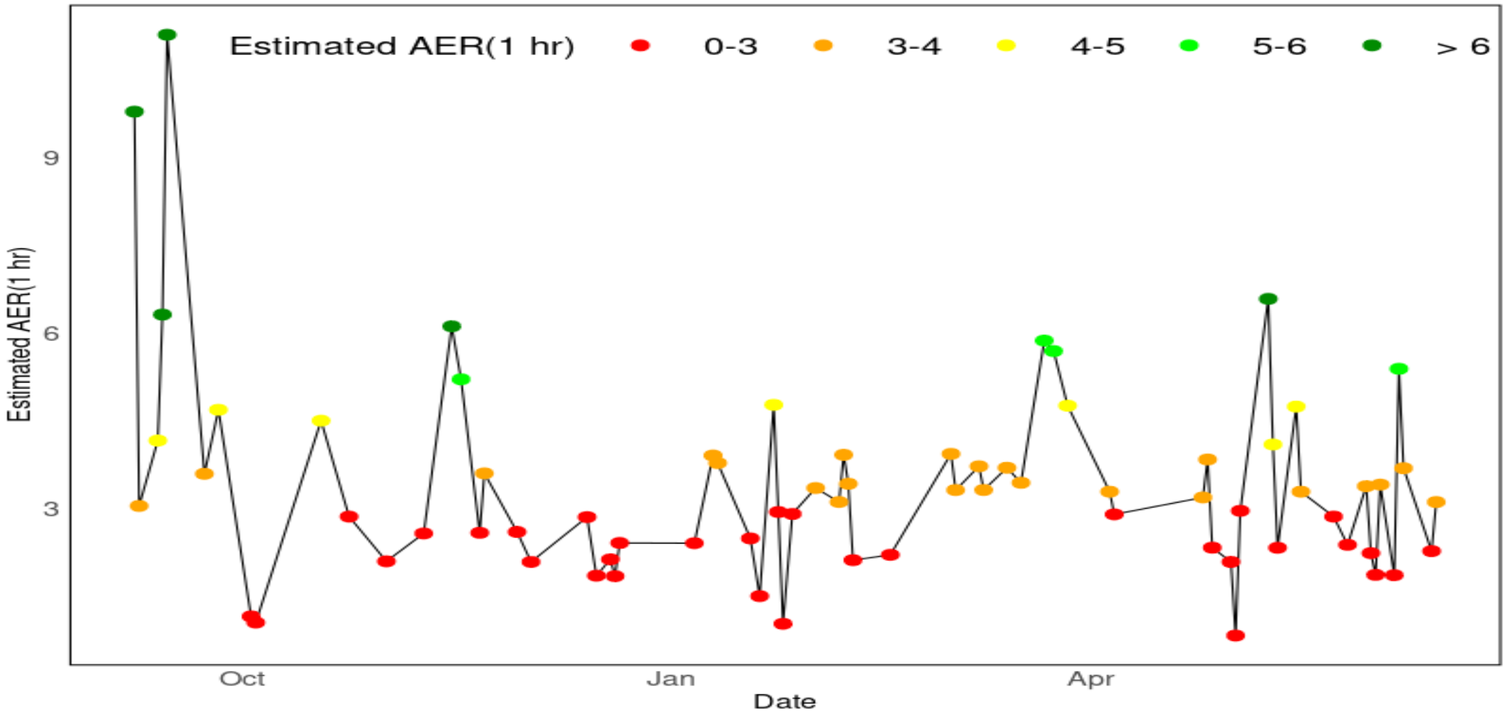
Methods

- Data: 1-minute CO2 recordings over one school year
- Step 1: Smoothing the CO2 curve (i.e. denoising) to better track changes
- Step 2: Identify a peak and valley between 1 and 6 pm
- Step 3: Calculate air exchange rate every day over a school year
- Step 4: evaluate and validate



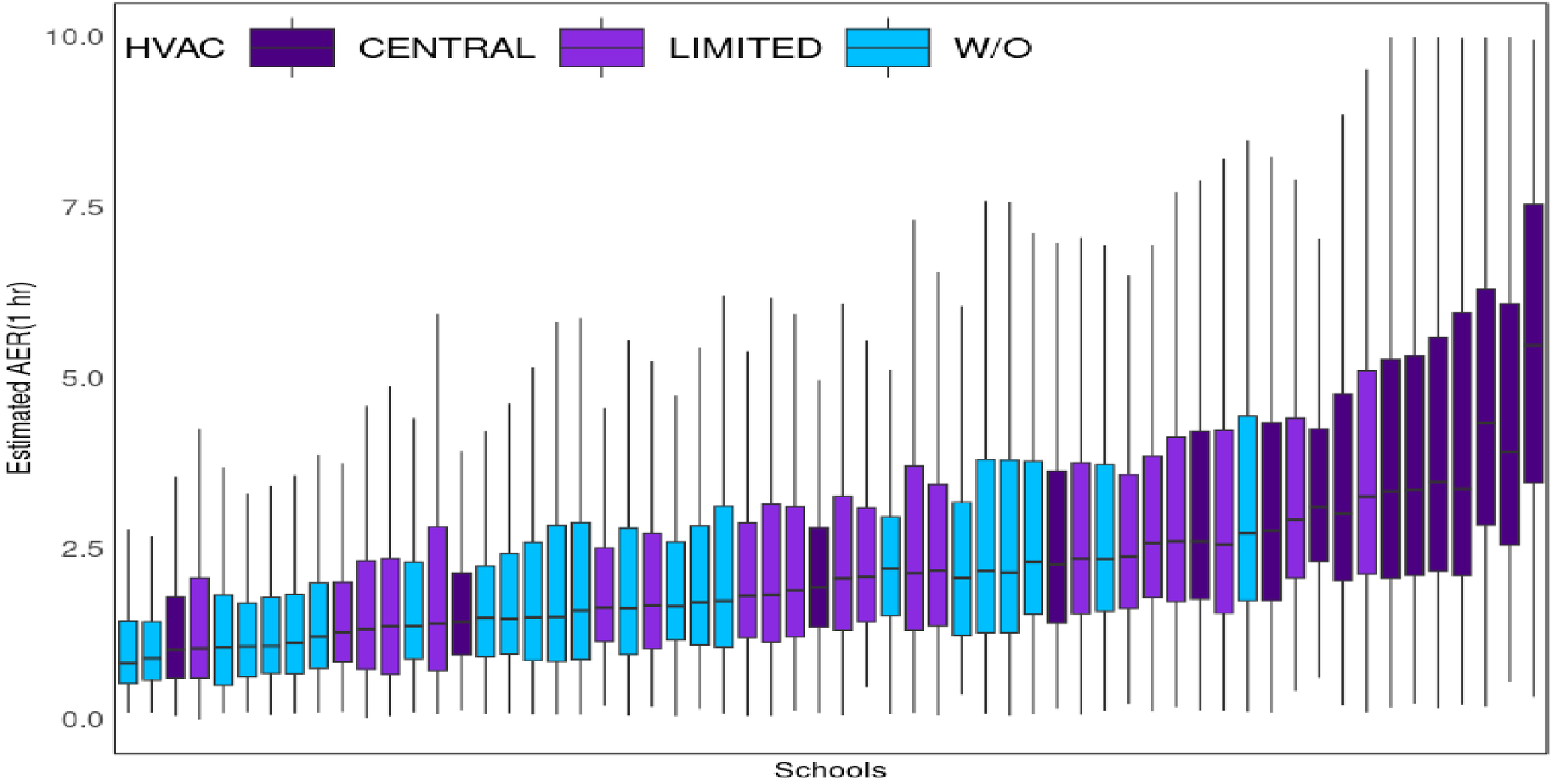


Results: Example of calculated AER over a school year for a random classroom (n= 72 curves).



- ~163 CO_2 preliminary decay curves identified per classroom over 181 school days.
- ~84 final curves included after applying review criteria (15-minute and 200 ppm CO_2 concentration drop criteria)
- Average school district AER was 3.0 h^{-1} (SD = 2.9), ranging from <0.1 to 64 h^{-1}.

Results: Calculated air exchange rate (AER) distribution by mechanical ventilation types for 60 random schools throughout the school year. y-axis maximum limited to 10 1/h.



Key takeaways about comprehensive IAQ monitoring in schools

- Pinpoint specific times, days and locations where there are problems
- Prioritize and optimize resources to improve IAQ
- Inform Action Plans (e.g., heat, mold, wildfire smoke, air pollution, IAQ management)
- Generate local data, sometimes necessary to drive action and investment
- Limitation - needs technical resources to maximize utility (e.g., data science, environmental health, computing, statistics)
    - One solution: school-researcher partnerships

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Questions?

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