IoT sensing as a tool for determining the resilience of buildings to forest fire generated $PM_{2.5}$

Jovan Pantelic, Megan Dawe
CBE

Dusan Licina

EPFL

CBE
CENTER FOR THE BUILT ENVIRONMENT

Overview

Objective

- Demonstrate how low-cost IoT environmental sensing network can be used to understand building resiliency to urban pollution (episodic pollution events)

Approach

- PM2.5 IoT sensors measurement
  - Naturally ventilated (NV) building
  - Mechanically ventilated (MV) building
- Survey of occupants
- Chico Camp Fire event (8/11 to 21/11)

Funding

- CITRIS
- CBE match funding

Sacramento 9/11/18

Sacramento 11/14/18 Courtesy of Abdel K Darwich

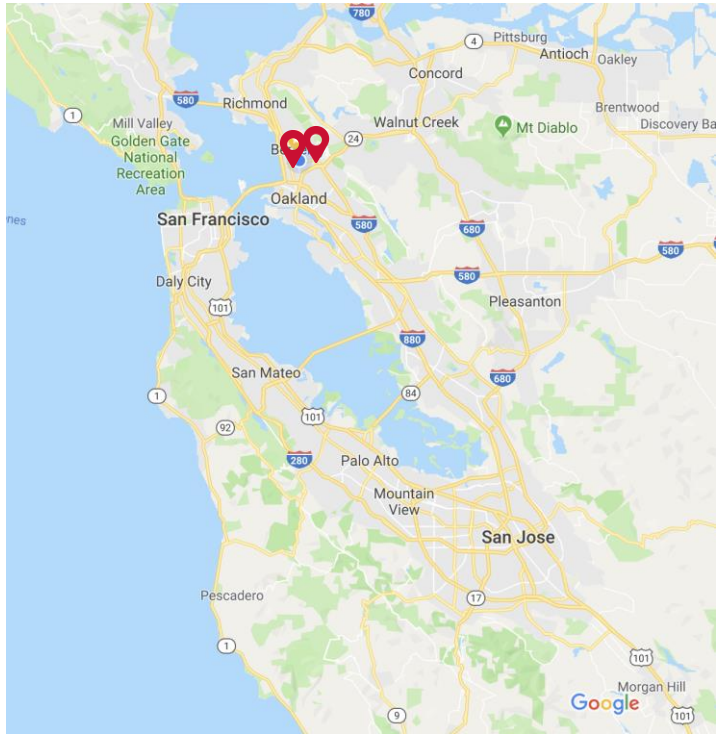
Study sites in Berkeley, CA

1608 4th Street

- Mechanical ventilation system
- No operable windows
- High grade filter
- Low infiltration
- Occupants: University staff

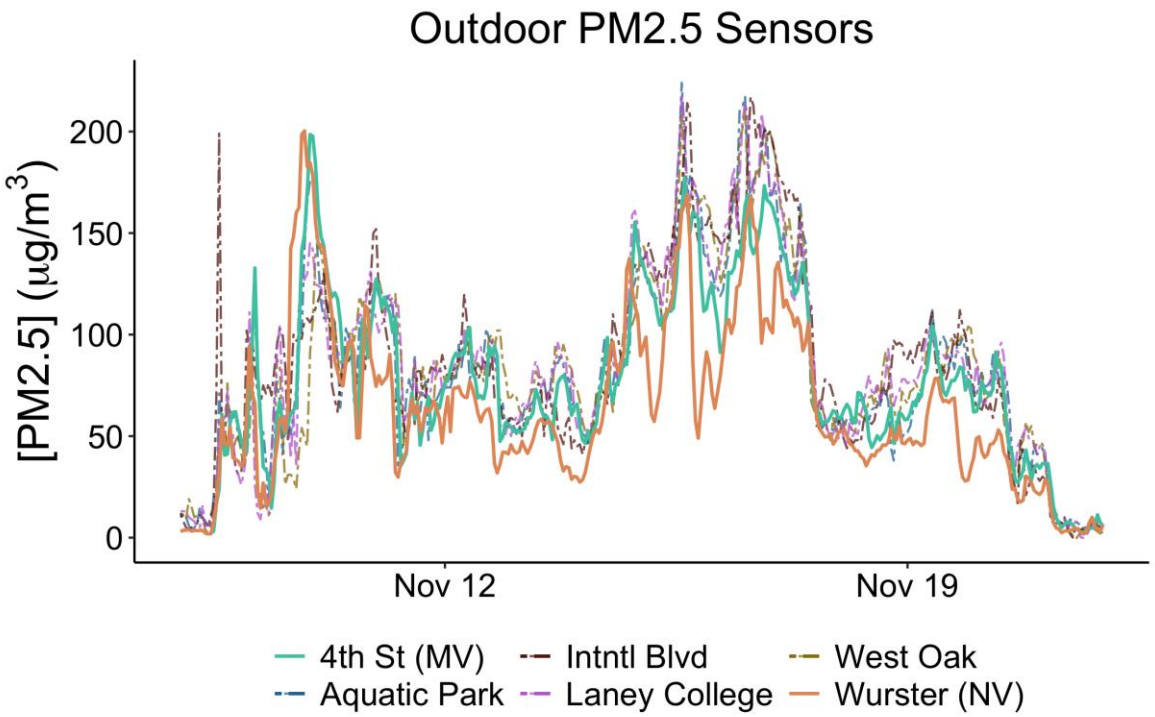
Wurster Hall – Berkeley campus

- Naturally ventilated (summer)
- Mechanical ventilation (winter)
- Occupants: Faculty, staff, graduate students



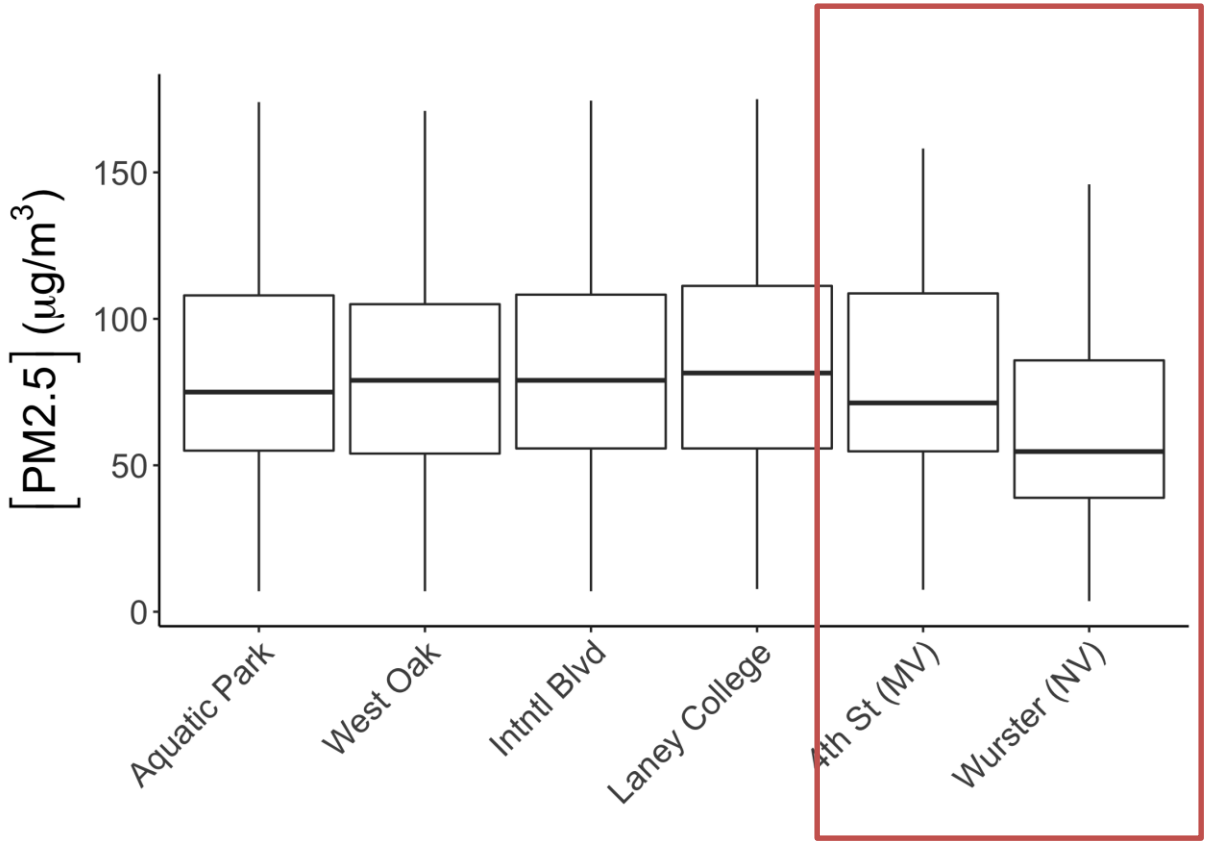
PM2.5 sensors and measurements

- 1 outdoor sensor on the roof (Clarity)
- 11 indoor sensors (Clarity and Senseware)
- Window contact closures – Wurster only (Senseware)



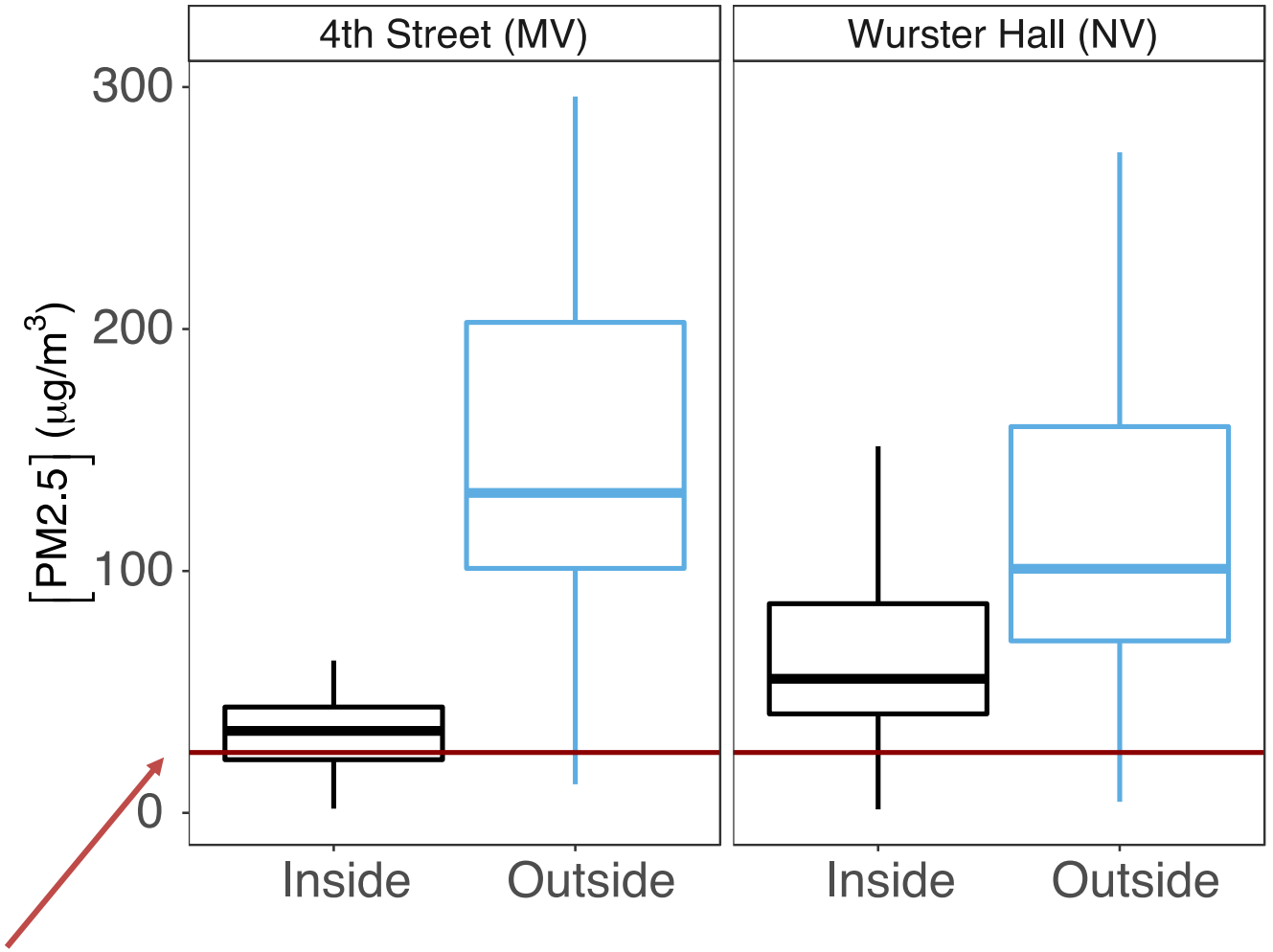
PM2.5 sensors and measurements

- 1 outdoor sensor on the roof (Clarity)
- 11 indoor sensors (Clarity and Senseware)
- Window contact closures – Wurster only (Senseware)



PM2.5 sensors and measurements

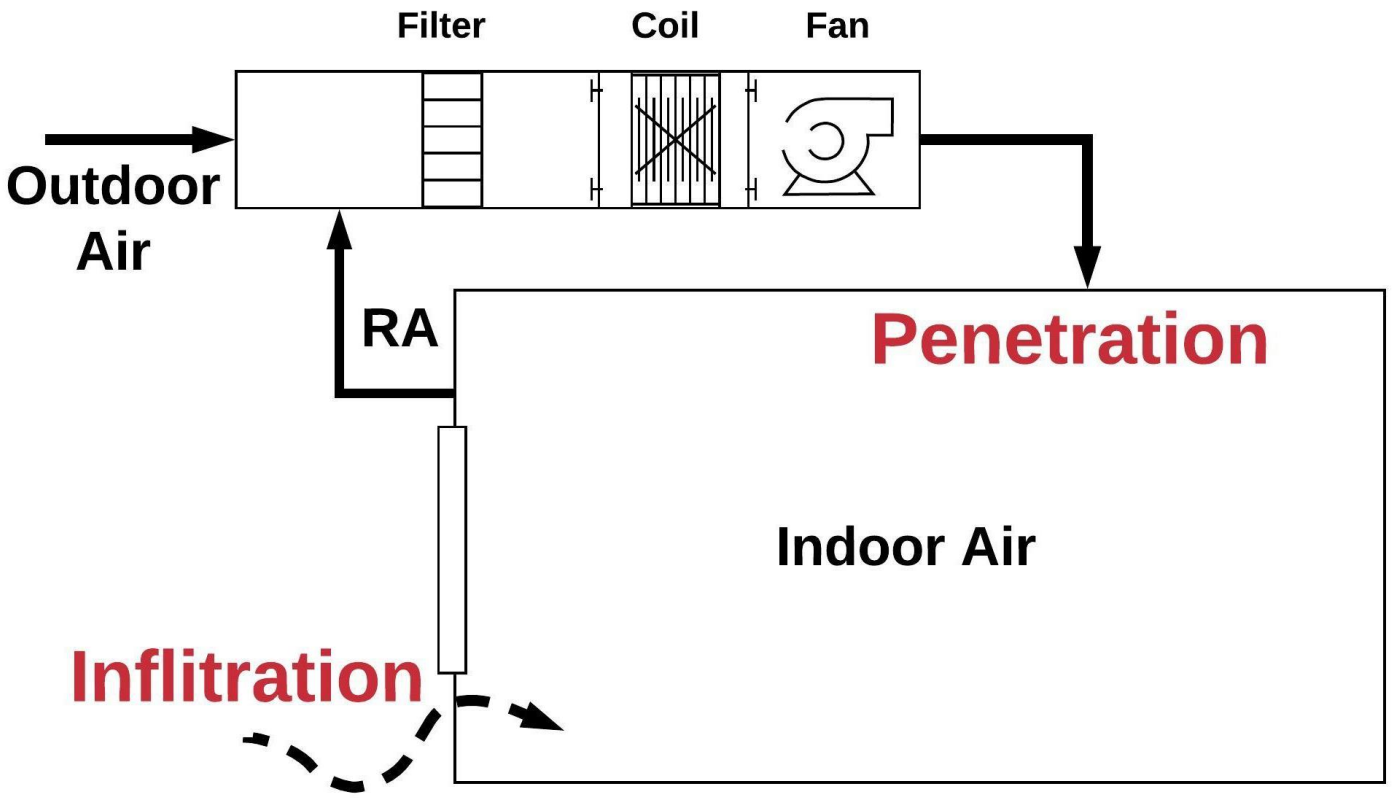
- 1 outdoor sensor on the roof (Clarity)
- 11 indoor sensors (Clarity and Senseware)
- Window contact closures – Wurster only (Senseware)



World Health Organization prescribed 24 hr average concentration: 25 $\mu g/m^3$

Indicators of performance

- Infiltration
- Penetration
- E-index = $C_{IN}/25$ [µg/m^3]
- Indoor/Outdoor (I/O) ratio = C_{IN}/C_{OA}



Analysis cumulative performance

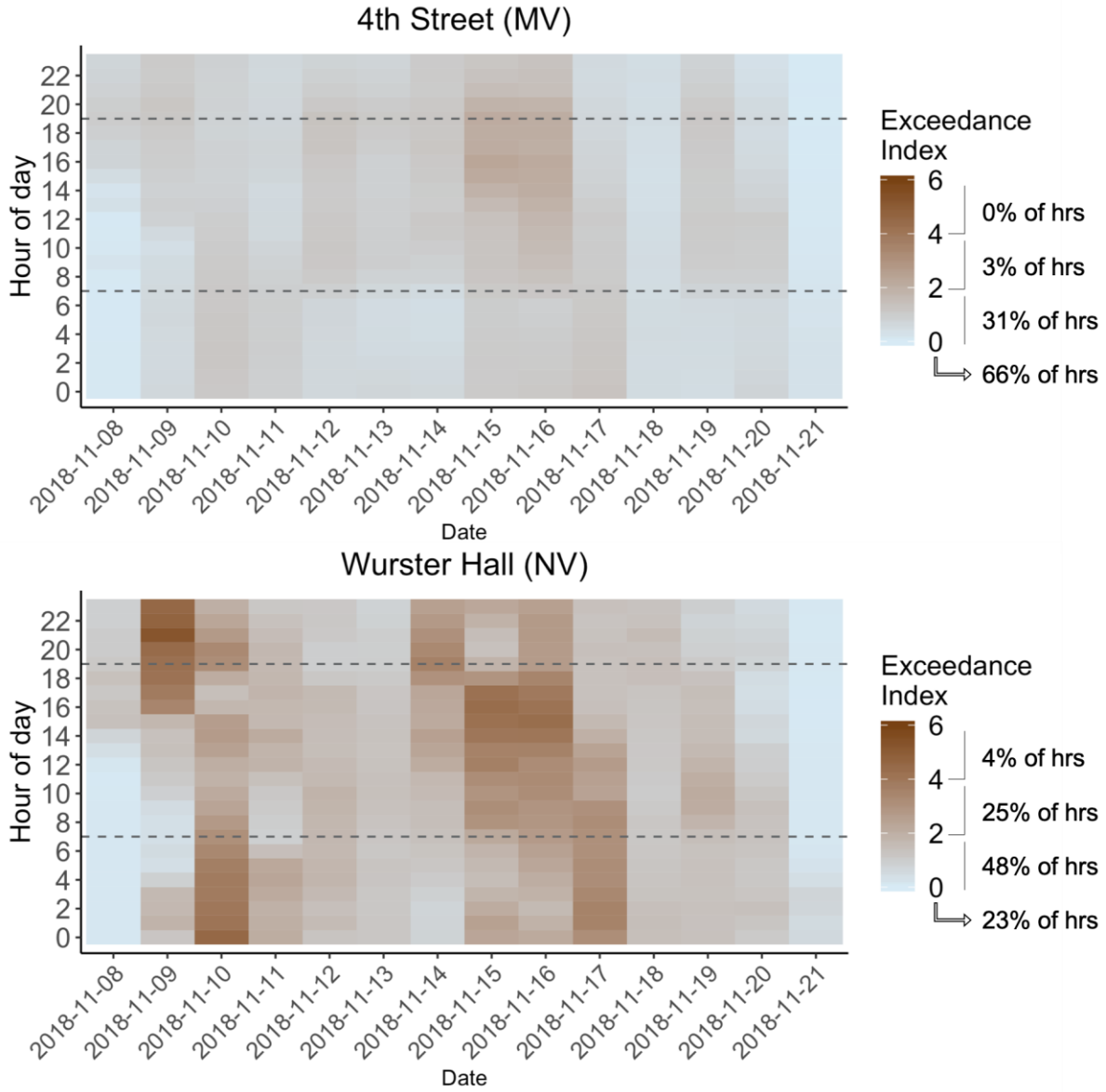
IoT sensing enables deeper understanding building performance

1608 4th Street (mechanically ventilated)

- E-index average 0.82
- E-index was up to 4
- PM2.5 penetrated building through HVAC system
- Filtration has to be improved

Wurster Hall (naturally ventilated)

- E-index average 1.69
- E-index was up to 6
- I/O ratio was higher during the non-occupied hours
- Portable filters are necessary to reduce indoor exposure



Analysis cumulative performance

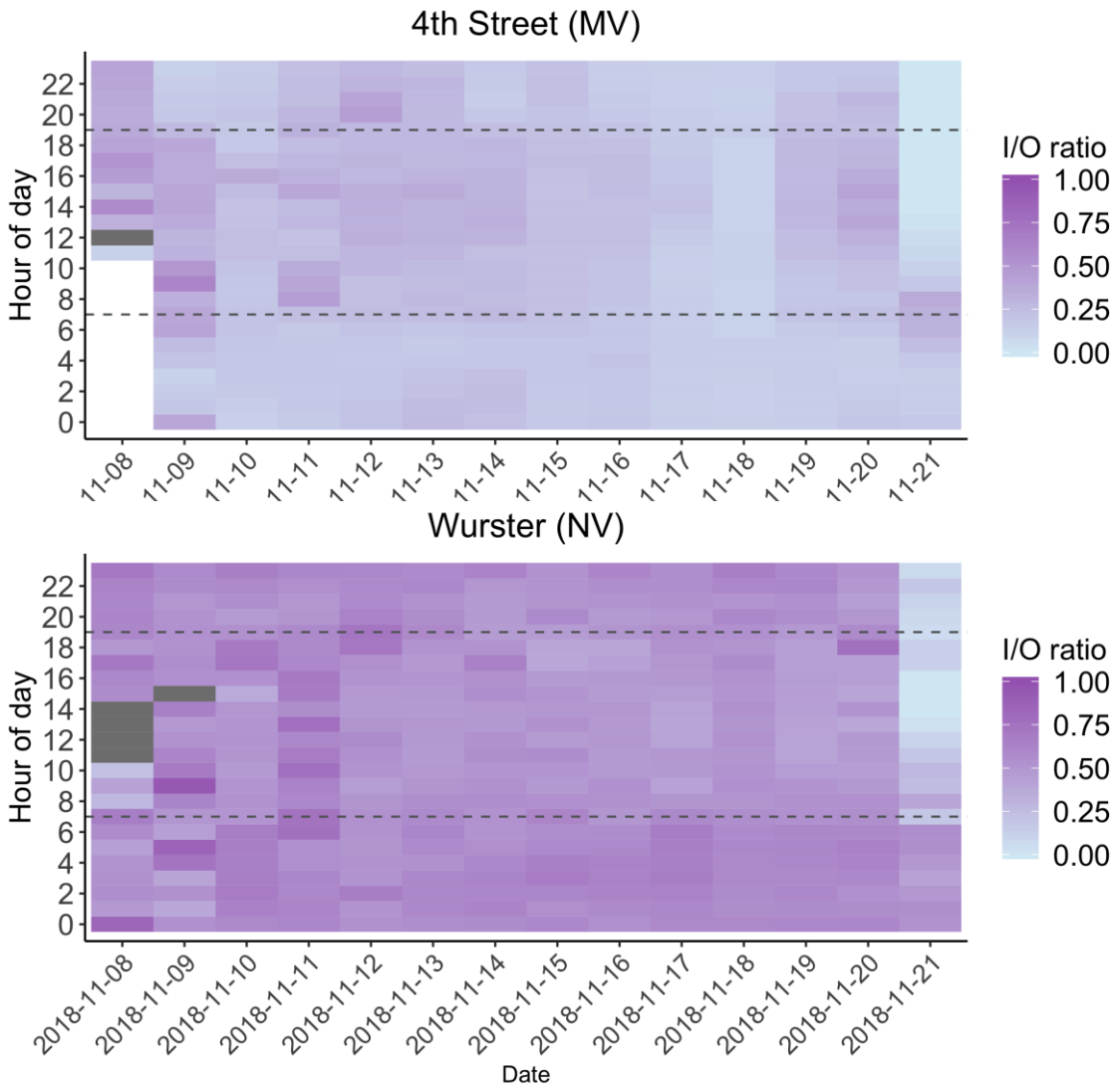
IoT sensing enables deeper understanding building performance

1608 4th Street (mechanically ventilated)

- I/O ratio is 0.3
- I/O ratio increases during HVAC operating hours
- PM2.5 penetrated building through HVAC system
- Filtration has to be improved

Wurster Hall (naturally ventilated)

- I/O ratio is 0.5
- /O ratio was higher during the non-occupied hours
- Infiltration was higher during the non-occupied hours
- Portable filters are necessary



Analysis instantaneous performance

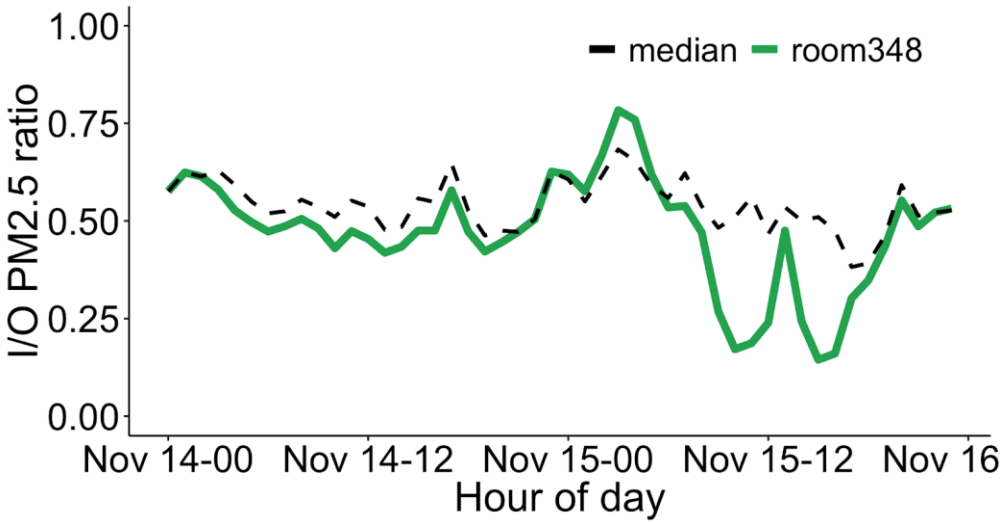
IoT sensing enables deeper understanding building performance

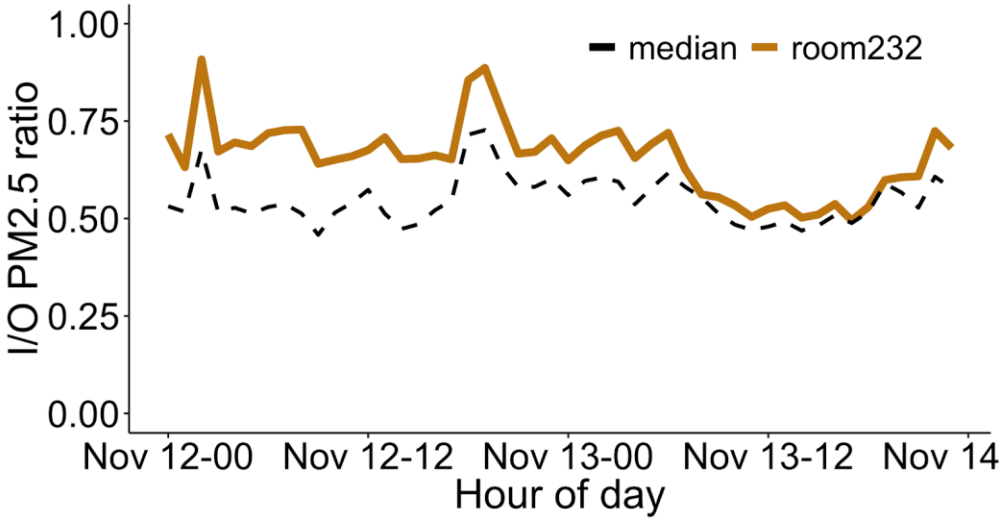
1608 4th Street (mechanically ventilated)

- I/O ratio is 0.3
- E-index was 0.82
- PM2.5 penetrated building through HVAC system
- Filtration has to be improved

Wurster Hall (naturally ventilated)

- I/O ratio is 0.5
- E-index was 1.69
- I/O ratio was higher during the non-occupied hours
- Portable filters are necessary to reduce indoor exposure





	E-index		I/O ratio	
	Instantaneous	Cumulative (entire episode)	Instantaneous	Cumulative (entire episode)
Whole building	Monitor and inform building occupants of air pollutant exposure	Rank or benchmark buildings by occupant exposure relative to guideline exposure limits	Assess whole building interventions (e.g. AHU filter upgrades, changing controls, adjusting outdoor air intake or economizers)	Rank or benchmark buildings by ability to prevent infiltration/ penetration of outdoor pollutants. Predict building's performance under various outdoor air pollution scenarios
By space	Monitor and inform occupants of air pollutant exposure	Identify areas in a building with high potential occupant exposure	Assess zonal or room interventions (e.g. window operation, portable air filters, filter upgrades at the zone)	Rank or benchmark spaces

Survey of occupants post-forest fire period

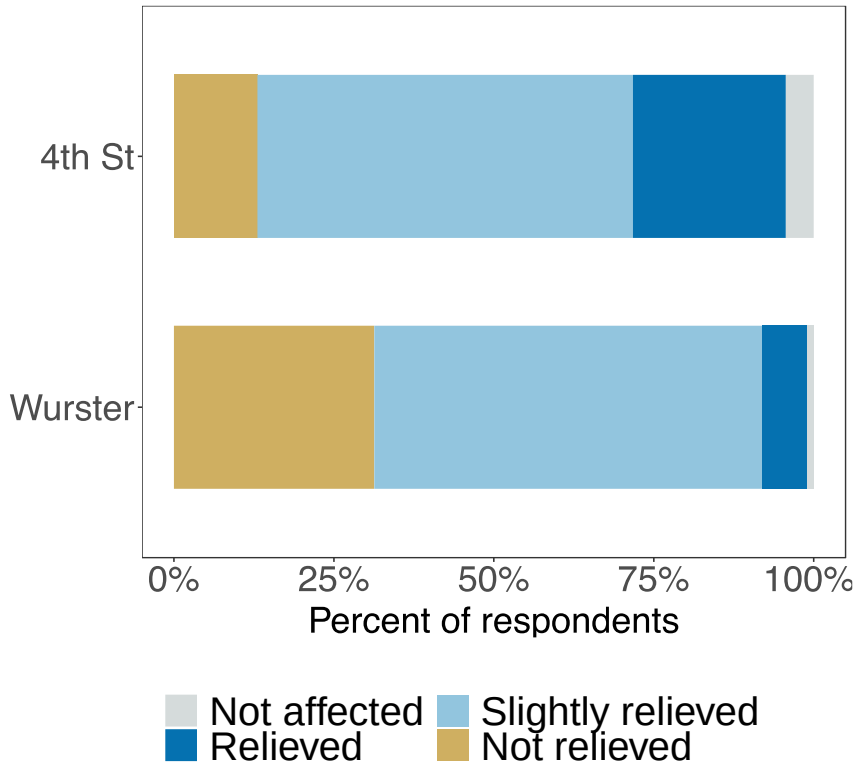
- A retrospective look at occupants' perception and behavior during the forest fire event
- IAQ perception
- Self-reported health symptoms
- Perceived impact on productivity
- Use of personal devices (face masks or air filters)

	1608 4th Street (MV)	Wurster Hall (NV)
# of occupants	~260	~300
# of complete responses	95	101

Occupant perception aligns with IAQ measurements

I/O ratio: **0.3**

I/O ratio: **0.5**

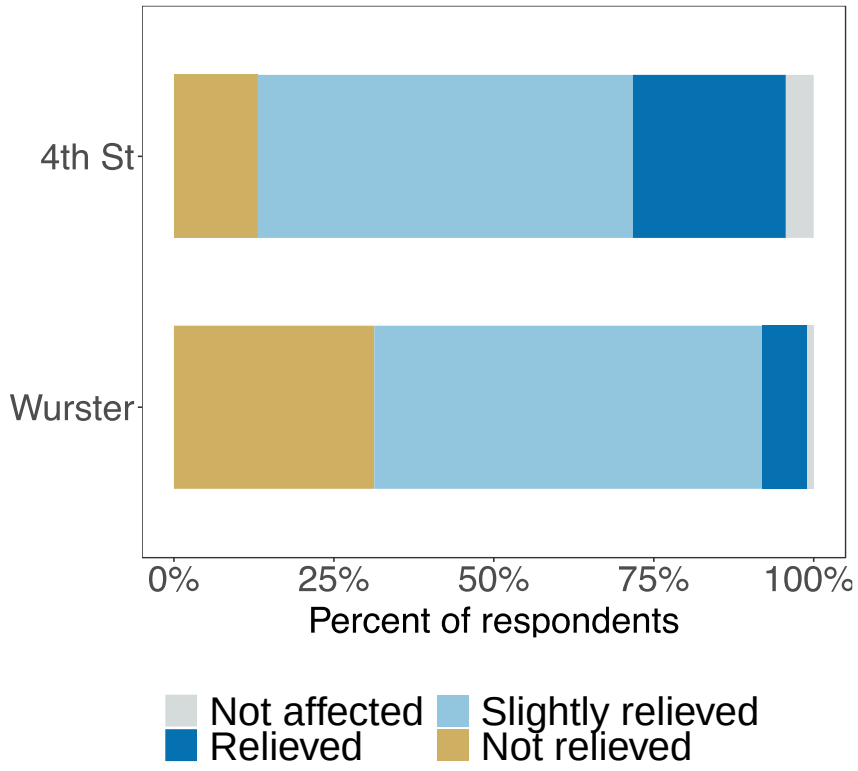


Occupant perception aligns with IAQ measurements

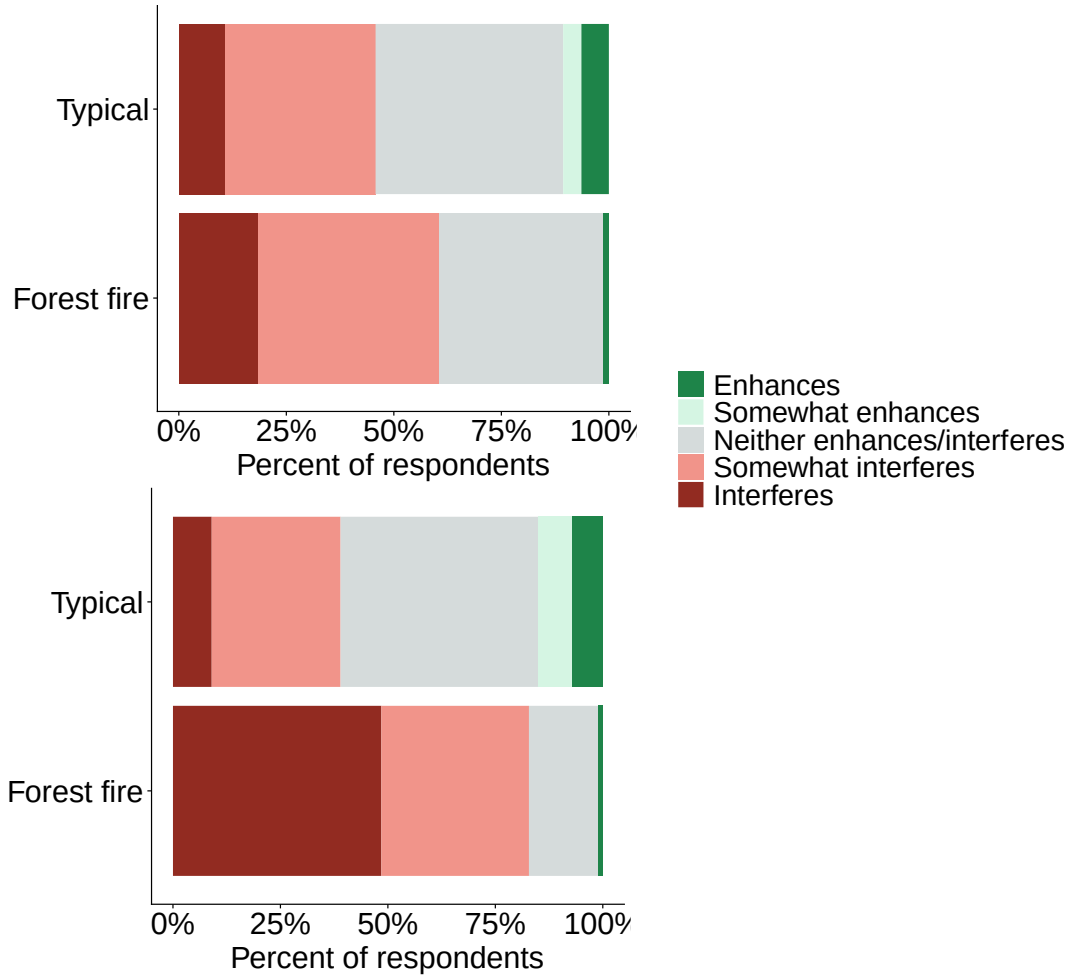
I/O ratio: **0.3**

I/O ratio: **0.5**

Did you feel relief when entering your workspace from the outdoors?

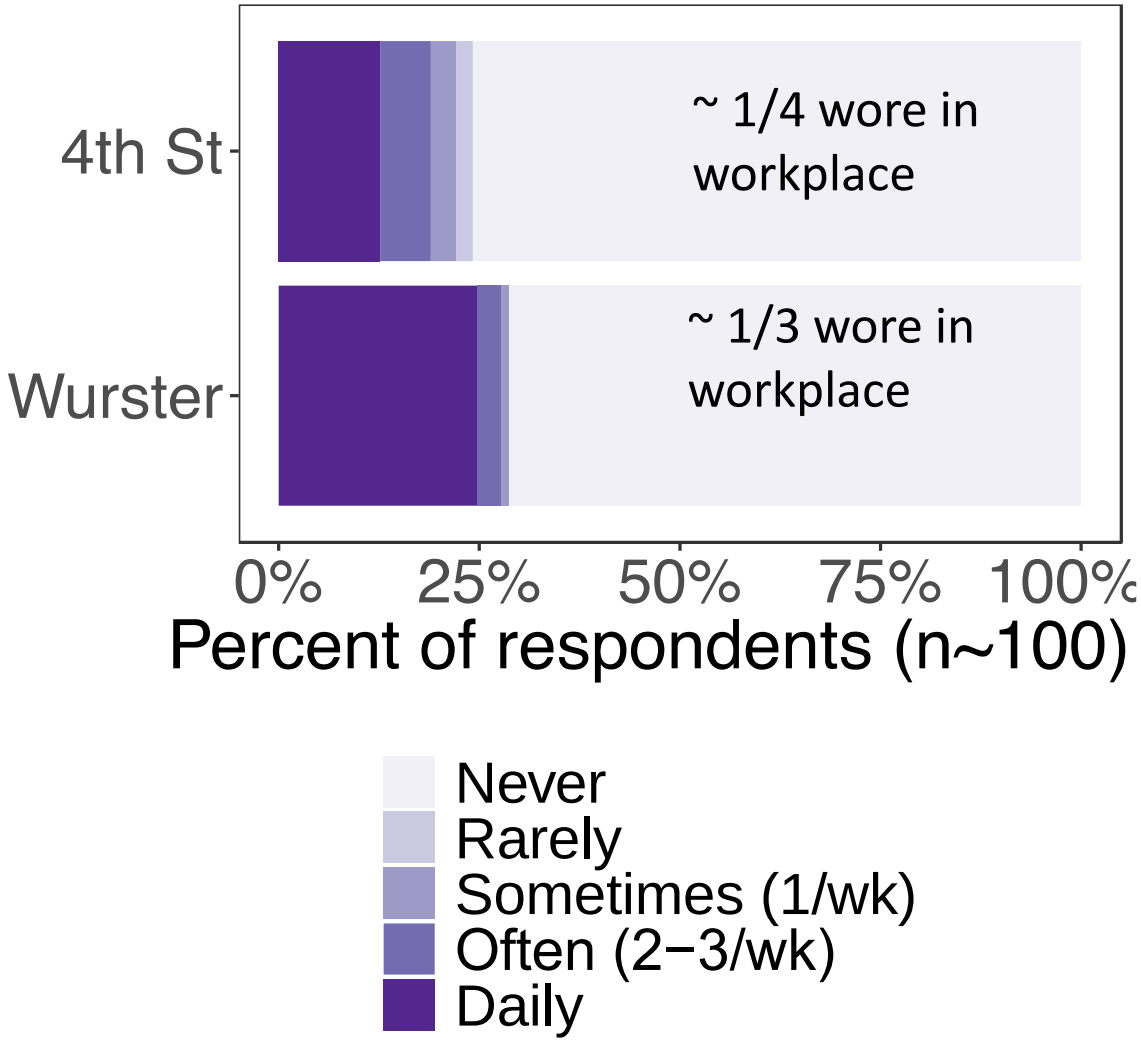


Did the air quality enhance or interfere with your ability to get your job done?



Current occupant solutions

- Wore face masks indoors
- Used portable room air filters (rarely)
- Worked from home, did not work at all, or took PTO



Conclusions

- IoT environmental sensing and analytical tool can help us plan for resiliency during extreme events:
  - Understand building performance
  - Assess successful interventions
  - Develop cost-benefit analysis
- Occupant perception and behavior aligned with PM2.5 measurements
- Occupants need to be informed about the air quality
- Approach described can be used to quantify clean air shelter operation and can be extended to other pollutants

Q&A

Jovan Pantelic
pantelic@berkeley.edu

Megan Dawe
megan.dawe@berkeley.edu