THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

Evaluation of Low-Cost Particle Sensors for Use in Indoor Air Quality Monitoring and Smart Building Systems

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Acknowledgements

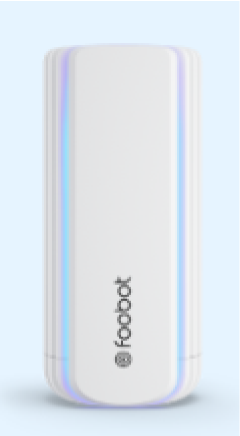
- Dr. Jordan Clark
- Dr.* Yangyang Zou, Mr. Matt Young

- Dr. Brent Stephens, Dr. R. Vijayakumar, Dr. Paolo Tronville, Dr. Liping Wang, Mr. Glenn Remington

- **Disclaimer**: the use of commercial names does *<u>not</u>* imply ASHRAE endorsement, approval, or certification

The marketplace for indoor air quality monitors is rapidly expanding

www.iqair.com



www.foobot.io

www.getawair.com

www.airqualityegg.com

www.getuhoo.com

How well do they perform in buildings?

- Can they reliably detect indoor particle sources?
- Can they communicate with building automation systems?
- What are their upper and lower limits of quantification?
- How do the size and composition of the particles affect their performance?
- Do temperature or relative humidity bias the results?

What sensors did we test?

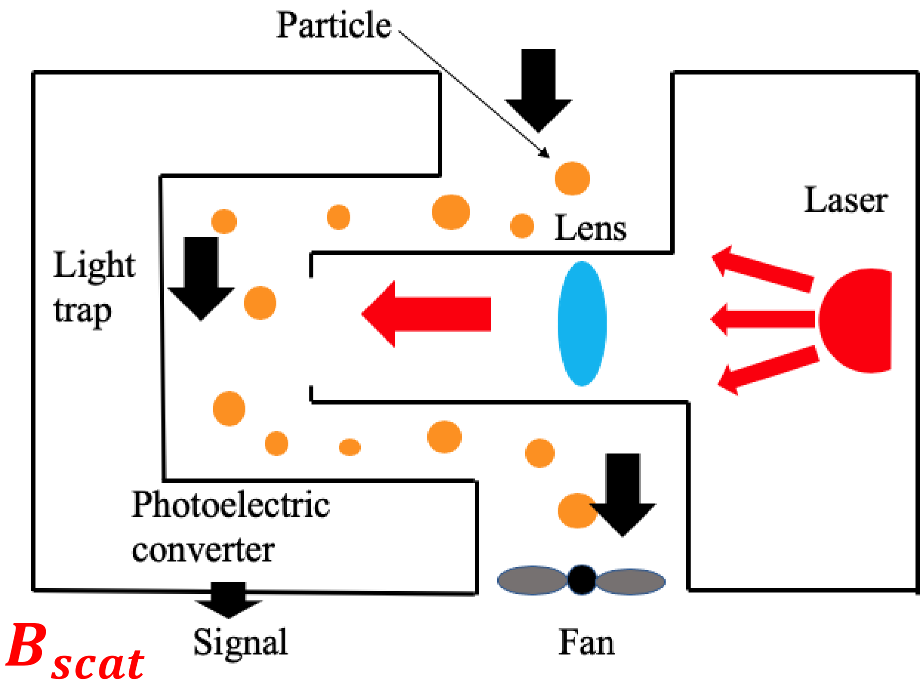
Bare Sensors

- Honeywell HPM
- Sharp GP2Y
- Plantower PMS5003

Integrated Devices

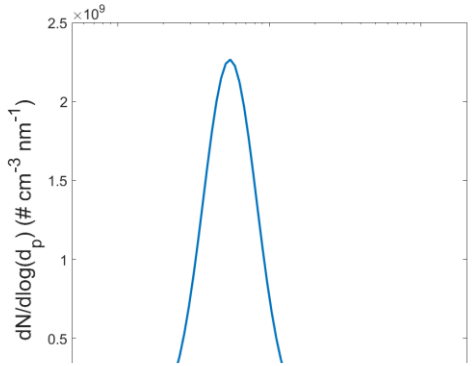
- AirThinx IAQ
- Taking Space AirBeam2
- Dylos DC1100 Pro
- TSI BlueSky
- PurpleAir II

All tested sensors are nephelometers



Operationally, nephelometers output a single value

$B_{scat} = \int$



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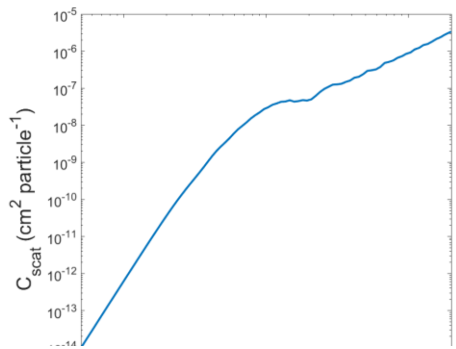


dd_p

This means that nephelometers cannot truly distinguish between PM_1, $PM_{2.5}$, and PM_{10}

$$M_{PM} \propto B_{scat}$$

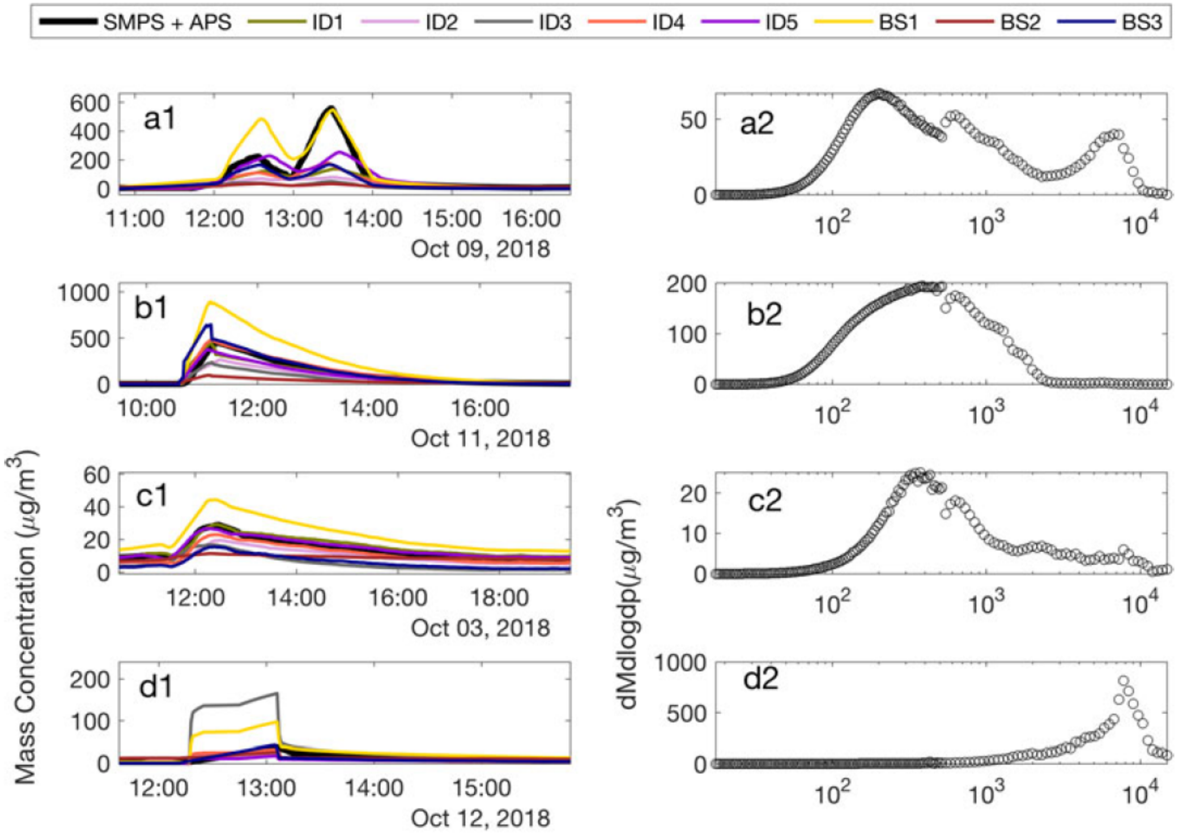
Low-cost sensors generally respond to particle source events

Incense

Toast

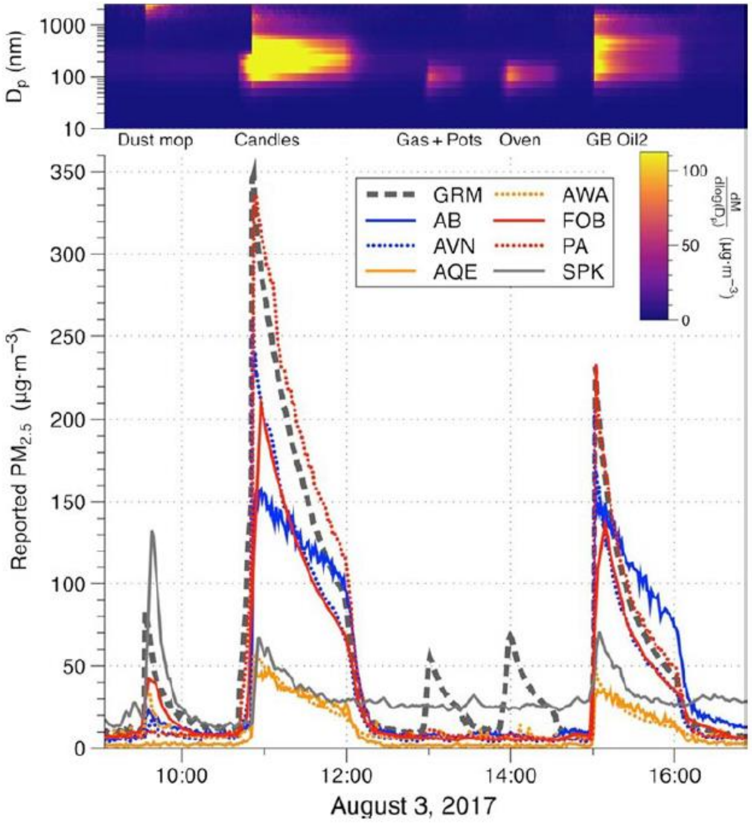
Window

Spray



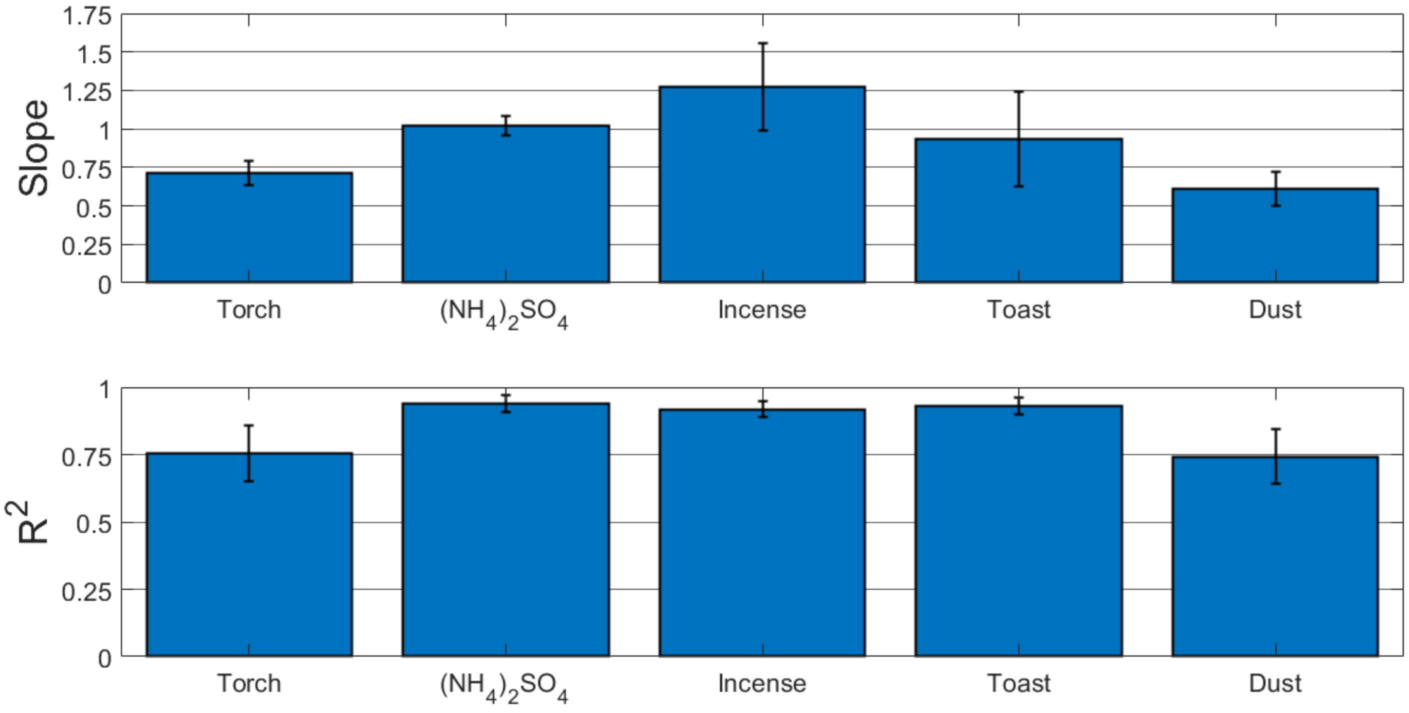
Zou et al. (*Sci. Technol. Built Environ.*, 2020)

Low-cost sensors generally respond to particle source events



Singer and Delp (*Indoor Air*, 2018)

"Event exposure" is variable based on the sensor and the source



Zou et al. (*Aerosol Sci. Technol.*, under review)

Can the sensors communicate with buildings?

- The short answer is "Yes, they all can"
- Some use building communication protocols
  - Awair (BACnet, Zigbee, LONtalk, MODbus, MSTP)
  - Dylos DC-1700 (custom units for MODbus, Zigbee, etc.)
  - TSI AeroTrak (BACnet with complementary room pressure sensor)

Can the sensors communicate with buildings?

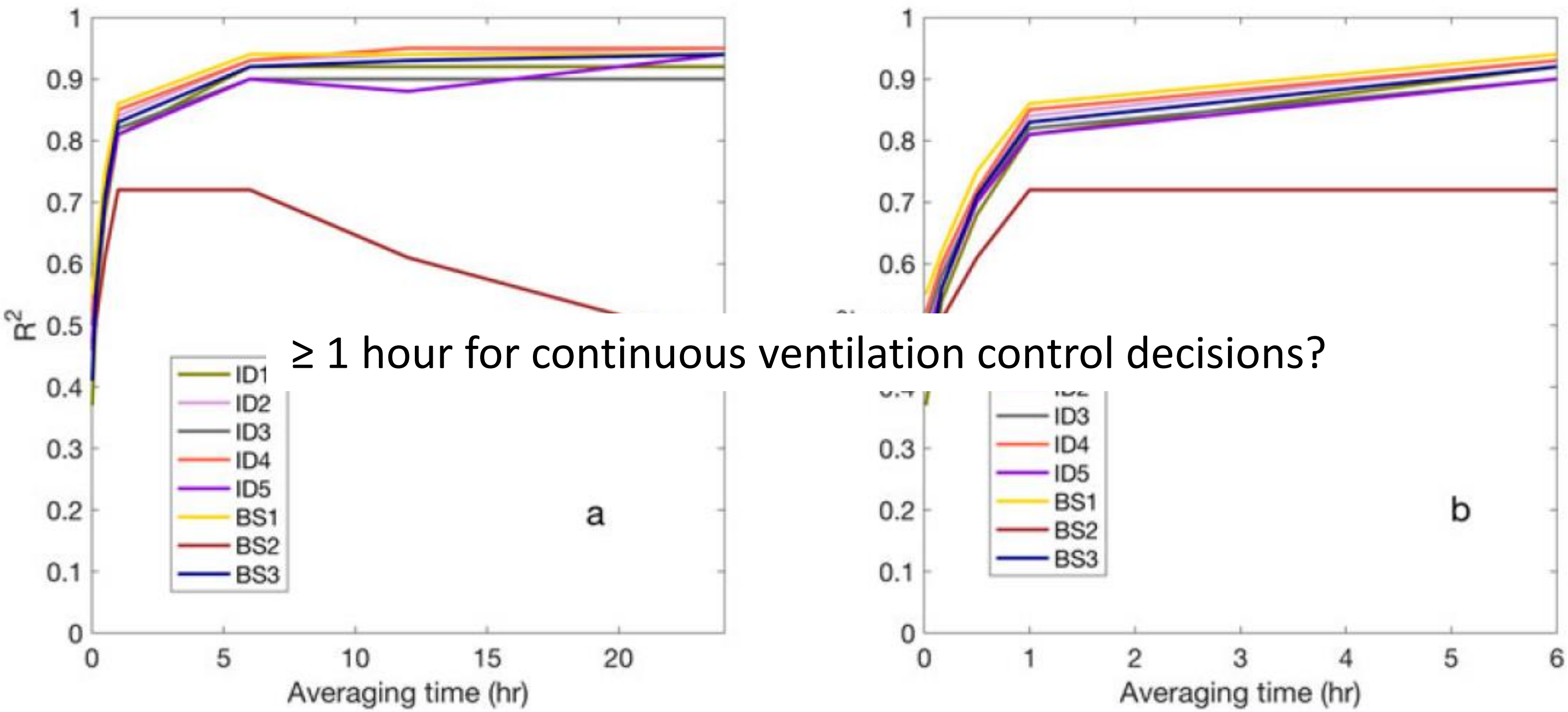
- Some can communicate via Wi-Fi and API
    - AirThinx IAQ
    - Airviz Speck
    - Air Quality Egg (subscription)
    - PurpleAir PA-II
    - IQAir Air Visual Pro (also IFTTT)
    - uHoo (business account)
    - foobot

What else is important with respect to smart building systems?

- All of the bare sensors output an electrical signal
  - If you have the software and hardware know-how, you can make it work

- Some Wi-Fi networks may pose challenges
  - Zikova et al. (*J. Aerosol Sci.*, 2017): “strong Wi-Fi signals are necessary”
  - OSU Wireless could not support Wi-Fi connectivity due to its security settings

There is better correlation with longer averaging times

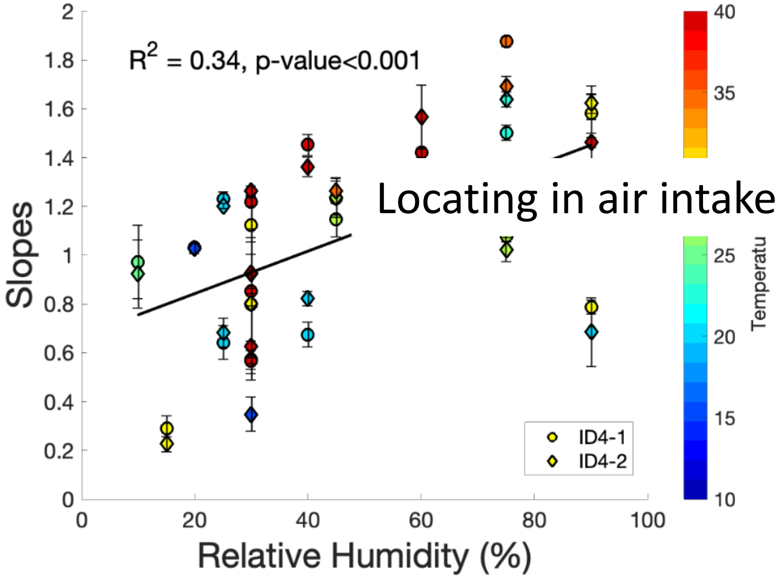


≥ 1 hour for continuous ventilation control decisions?

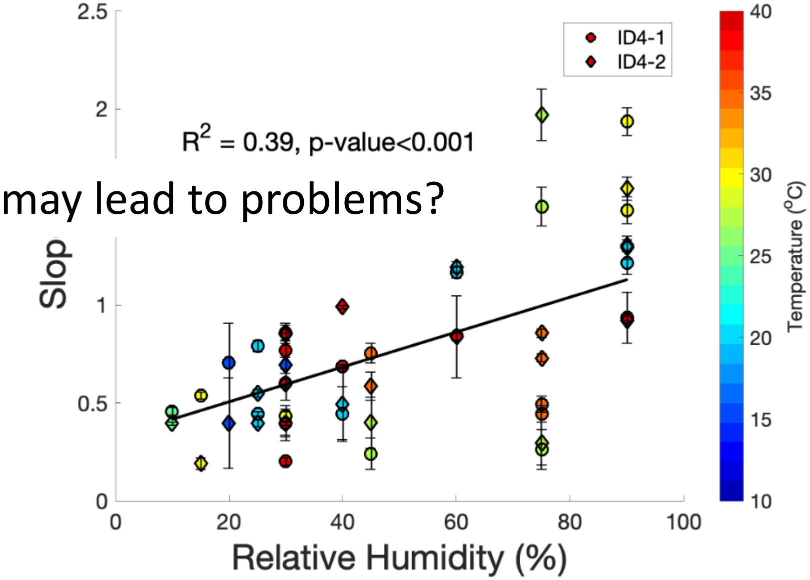
Zou et al. (*Sci. Technol. Built Environ.*, 2020)

Increased RH may bias the sensor measurements high

Incense as source



Toast smoke as source

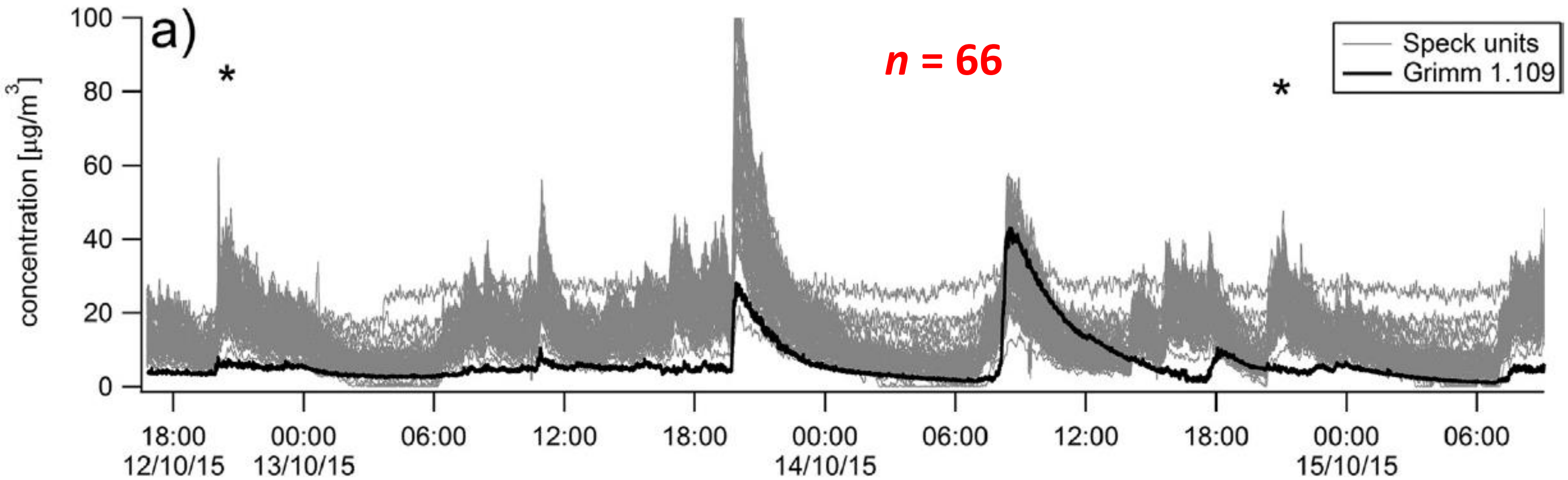


Locating in air intakes may lead to problems?

Reference concentration measured at chamber RH

Zou et al. (*J. Aerosol Sci.*, 2021)

The variability can be large among many sensor “replicates”



Zikova et al. (*J. Aerosol Sci.*, 2017)

In our small sample size, there were some sensors that differed

X Axis sensor	Y Axis sensor	Least square	R^2	Reduced major axis	r
ID2-1	ID2-2	Y = 0.937 x + 0.20	0.97	Y = 0.950x+ 0.142	0.97
ID2-1	ID2-3	Y = 0.974 x+ 0.828	0.96	Y= 0.992x + 0.728	0.95
ID2-2	ID2-3	Y = 1.03x + 0.65	0.99	Y = 1.044x + 0.620	0.98
ID3-1	ID3-2	Y = 0.797x + 1.425	0.64	Y = 1.00x + 0.402	0.62
ID3-1	ID3-3	Y = 0.692x + 0.440	0.80	Y = 0.773x − 0.014	0.81
ID3-2	ID3-3	Y = 0.626x + 0.560	0.65	Y = 0.779x − 0.351	0.62
ID4-1	ID4-2	Y = 1.065x − 0.298	0.99	Y = 1.070x − 0.327	0.99
ID5-1	ID5-2	Y = 1.012x − 0.116	0.99	Y = 1.0144x − 0.1007	0.99
ID5-2	ID5-3	Y = 0.95x − 0.094	0.98	Y = 0.9671 − 0.0317	0.96
ID5-1	ID5-3	Y = 0.981x + 0.075	0.98	Y = 0.9896x − 0.0446	0.99
BS2-1	BS2-2	Y = 0.95x + 11.70	0.77	Y = 1.080x + 11.167	0.75
BS2-1	BS2-3	Y = 1.31x + 11.76	0.36	Y = 2.183x + 7.921	0.34
BS2-2	BS2-3	Y = 1.36x − 3.73	0.45	Y = 2.02x − 13.992	0.45
BS1-1	BS1-2	Y = 0.974x + 0.452	0.93	Y = 1.00x − 0.046	0.93
BS3-1	BS3-2	Y = 0.927x + 0.69	0.91	Y =0.968x − 0.245	0.92

Zou et al. (*Sci. Technol. Built Environ.*, 2020)

Summary

- Low-cost particle sensors can detect many indoor sources → utility for on-demand air cleaning
- Any particle sensor can communicate with a building (with varying degrees of difficulty)
- Some uncertainties remain
  - Accuracy of sensor output mass concentration
  - Reliability and resiliency of the sensors
  - Timescale for building decision making

Thank you!

- Contact: may.561@osu.edu
- Publications:
  - https://doi.org/10.1080/23744731.2019.1676094
  - https://doi.org/10.1111/ina.12621
  - https://doi.org/10.1016/j.jaerosci.2020.105715