Development of novel point of care methods for allergen and mold detection

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Associate Professor

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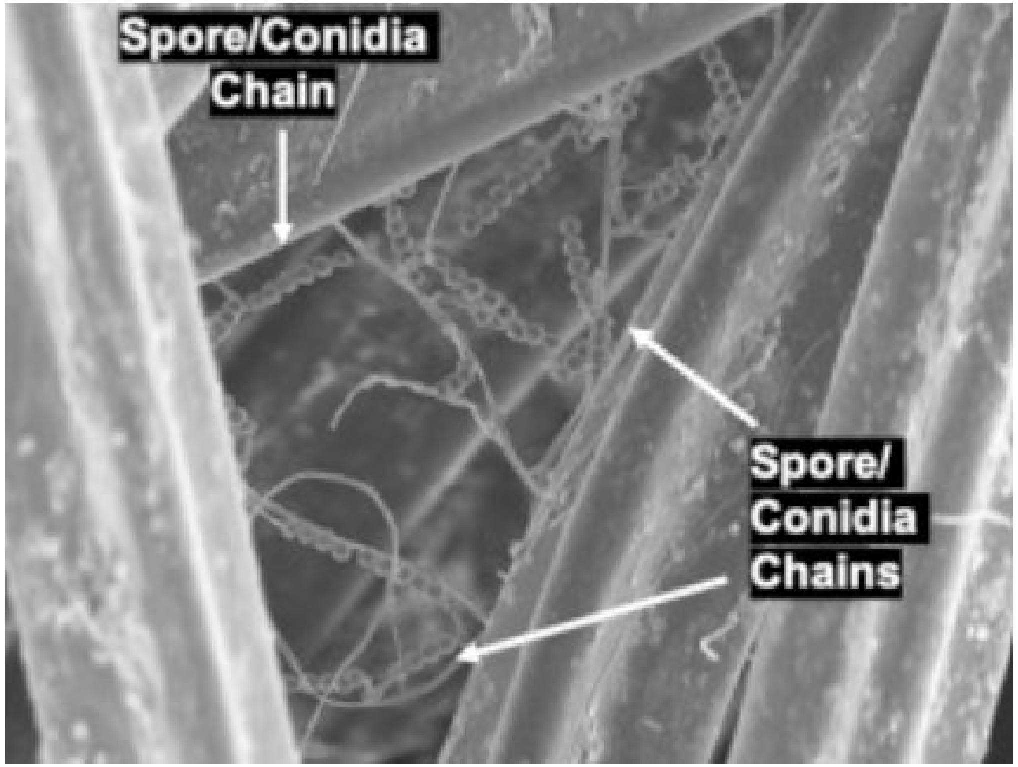
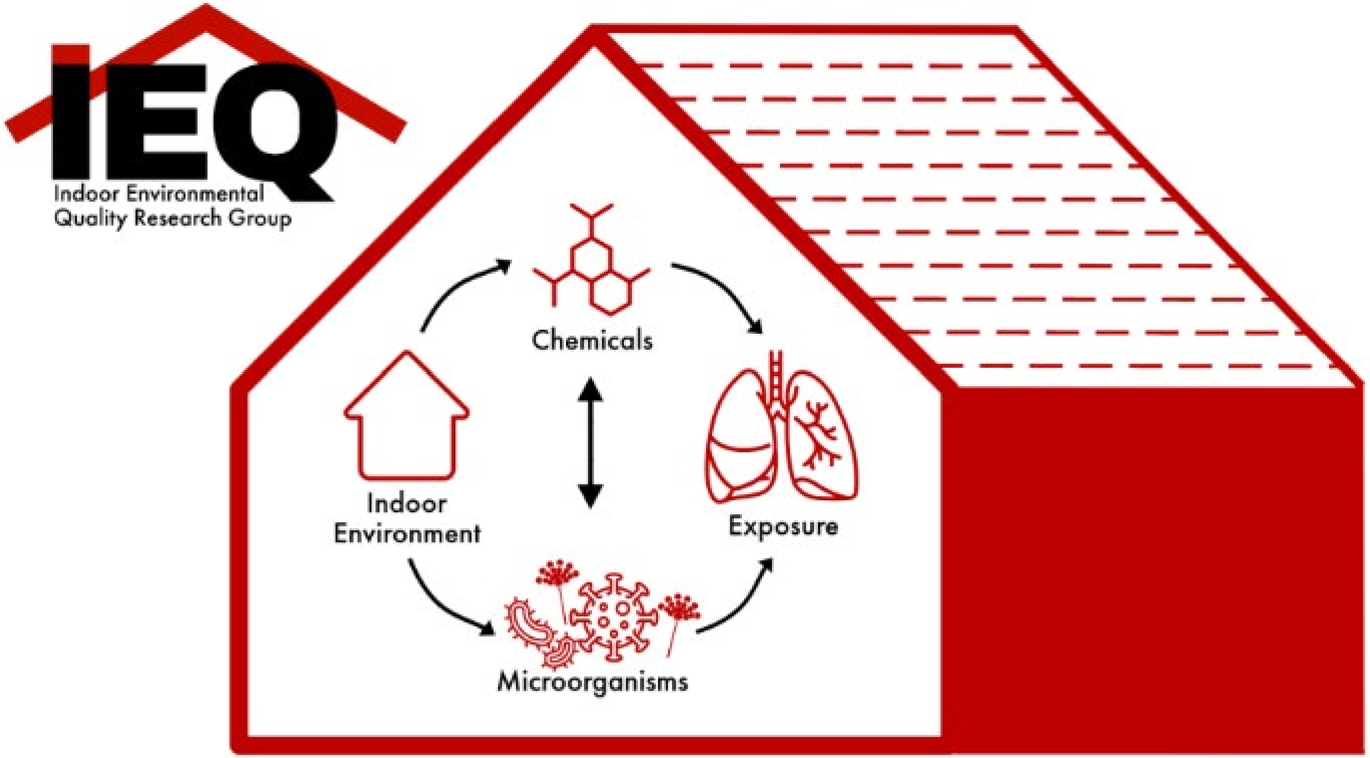


OHHN

May 1, 2026

THE OHIO STATE UNIVERSITY

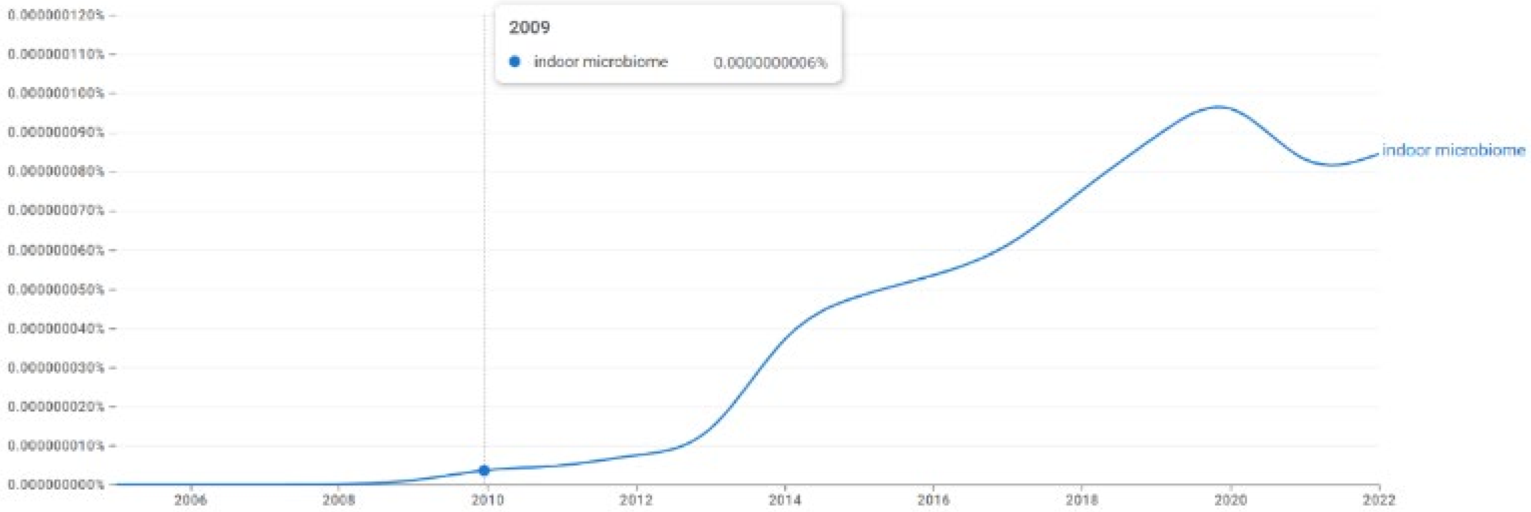
Our homes contain a complex indoor microbiome



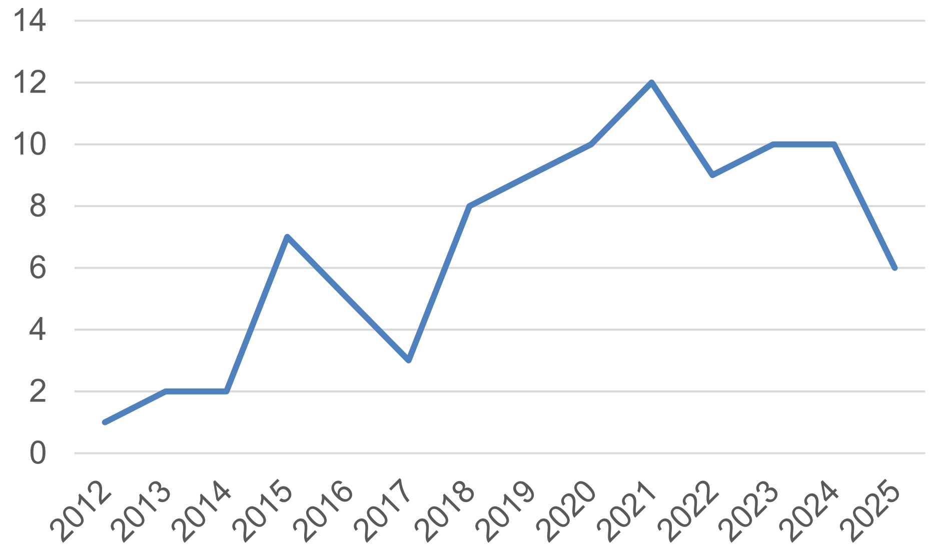
The Indoor Microbiome is a nascent field

“Indoor Microbiome” mentions on

Google Scholar



Web of Science



Born out of a need for Biosecurity

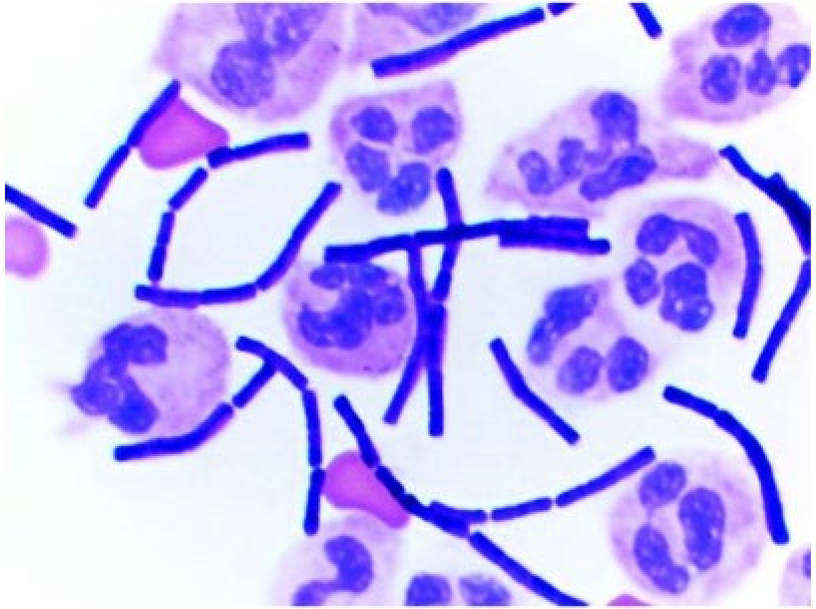


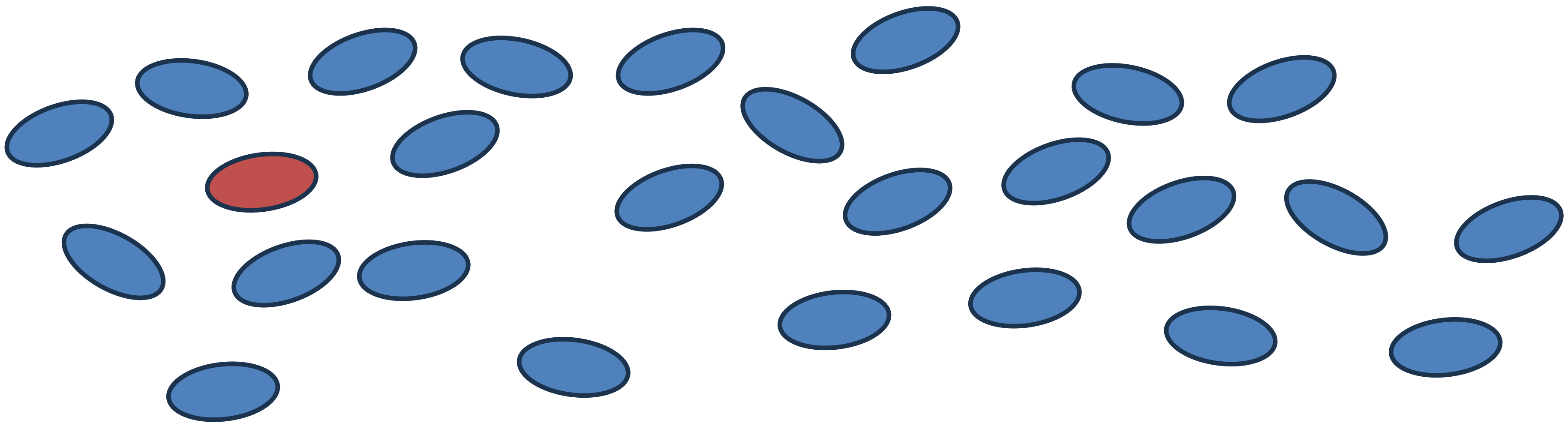
Figure. Cerebrospinal fluid of the first documented anthrax case in 2001.

Large, boxcar-shaped, gram-positive bacilli and polymorphonuclear leukocytes (Gram stain; original magnification, ×400).

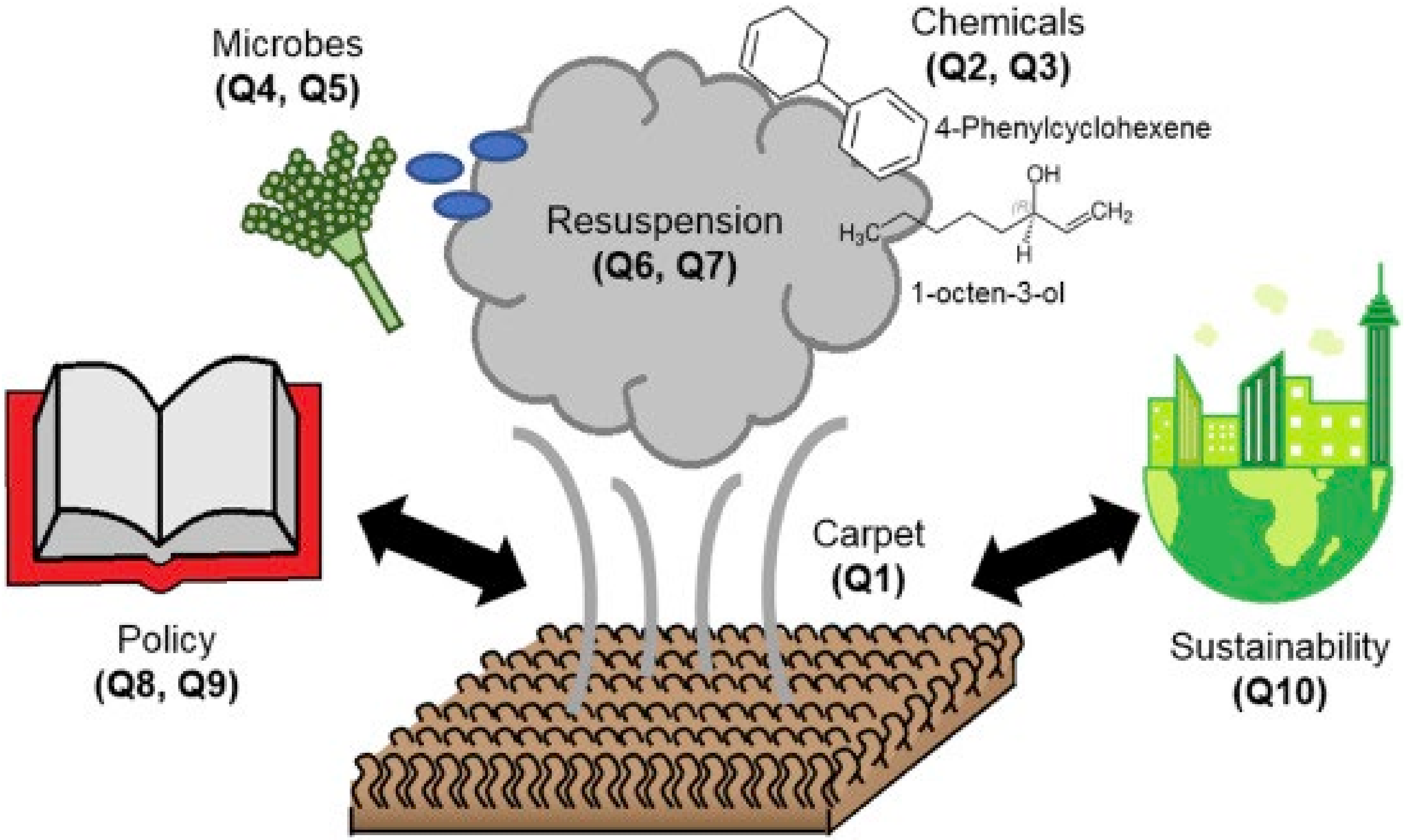
Bush et al, 2012. https://doi.org/10.7326/0003-4819-155-12-201112200-00373

Born out of a need for Biosecurity

We want to detect a threat, but we don't know what is normal



We have spent a decade on characterization



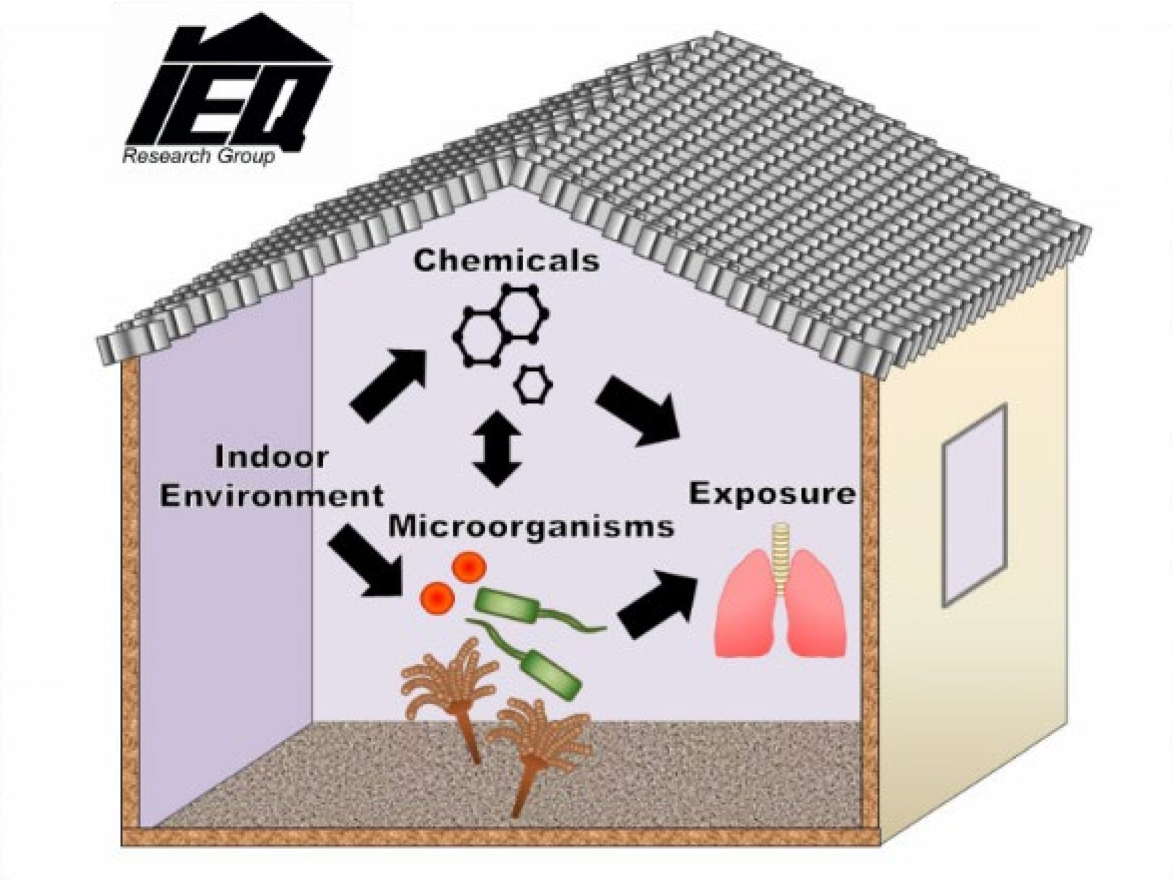
Haines et al., Building and Environment, 170, 2020, 106589

Now it's time to move to application!

- Viral pathogen surveillance
- Mold
- Asthma prevention
- Biosecurity

- And more!

Talk Outline
Healthy Indoor Microbiome



<u>Part 1:</u> New Mold Indicators

<u>Part 2:</u> Pathogen Surveillance

<u>Part 3:</u> Asthma and Sensors

Part 1: Today, exposure to mold in homes costs $22.4 billion per year

Artwork by Daniele Del Nero

16% of cost associated with:

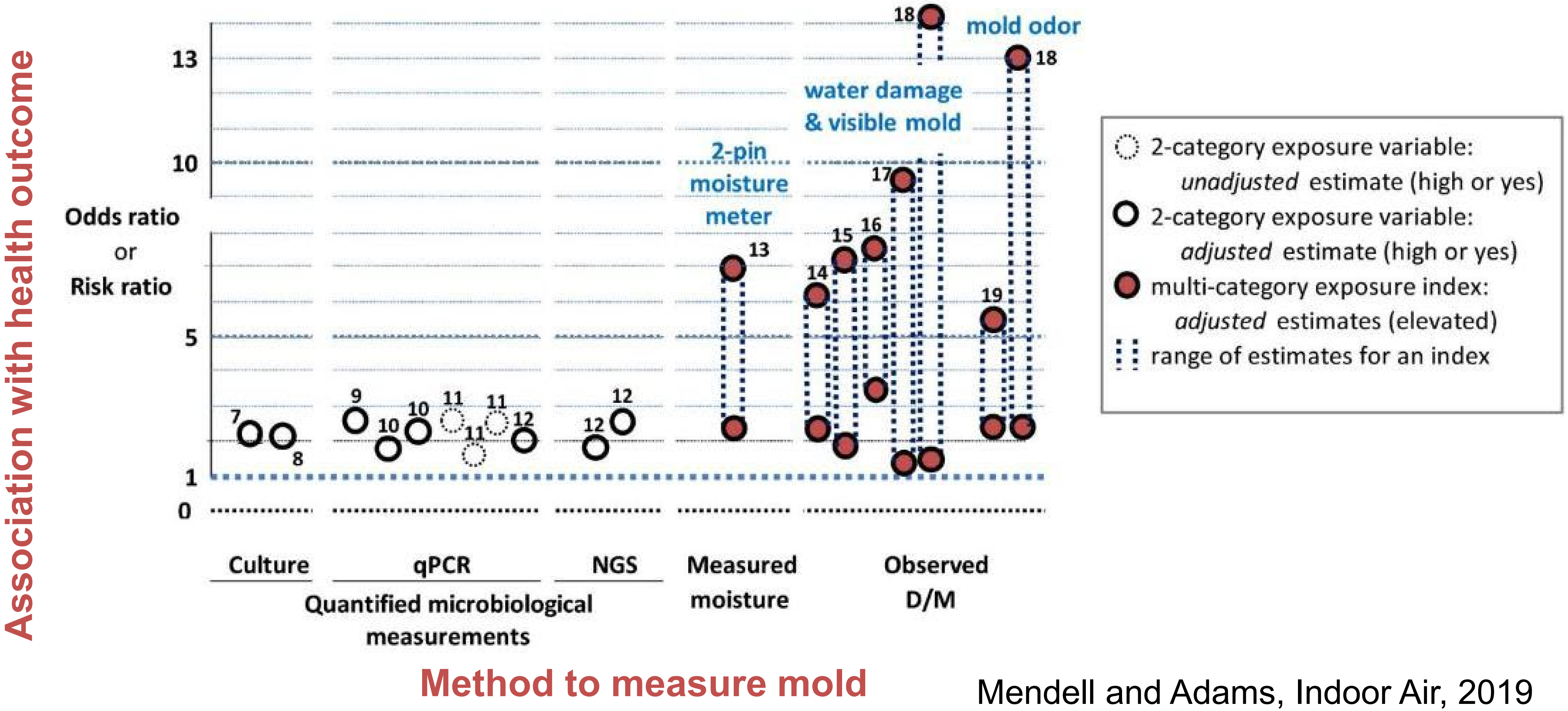
- Allergic Rhinitis
- Acute Bronchitis
- Asthma

Mudarri, D., J Environ Public Health. 2016; 2016: 2386596.

About 1 in 6 cases of asthma attributed to damp buildings, but what is the cause?

Mudarri, D., J Environ Public Health. 2016; 2016: 2386596.

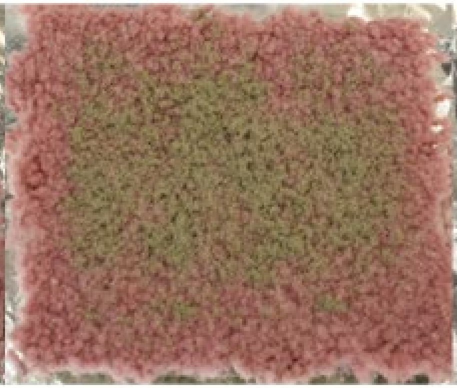
Lack of quantitative measurement method is a scientific failing



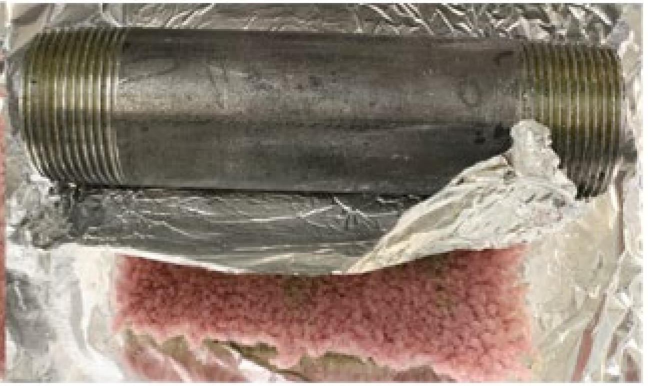
Mendell and Adams, Indoor Air, 2019

Dust is embedded in carpet

10 cm x 10 cm
carpet coupon



Apply dust

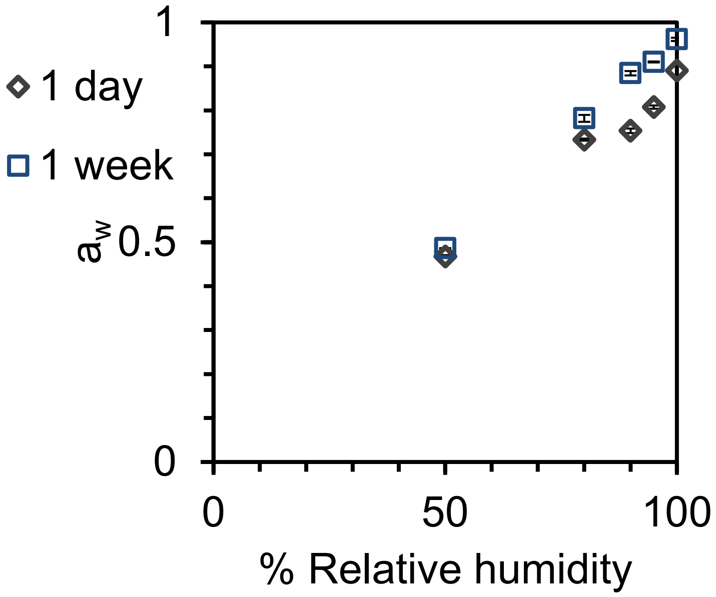


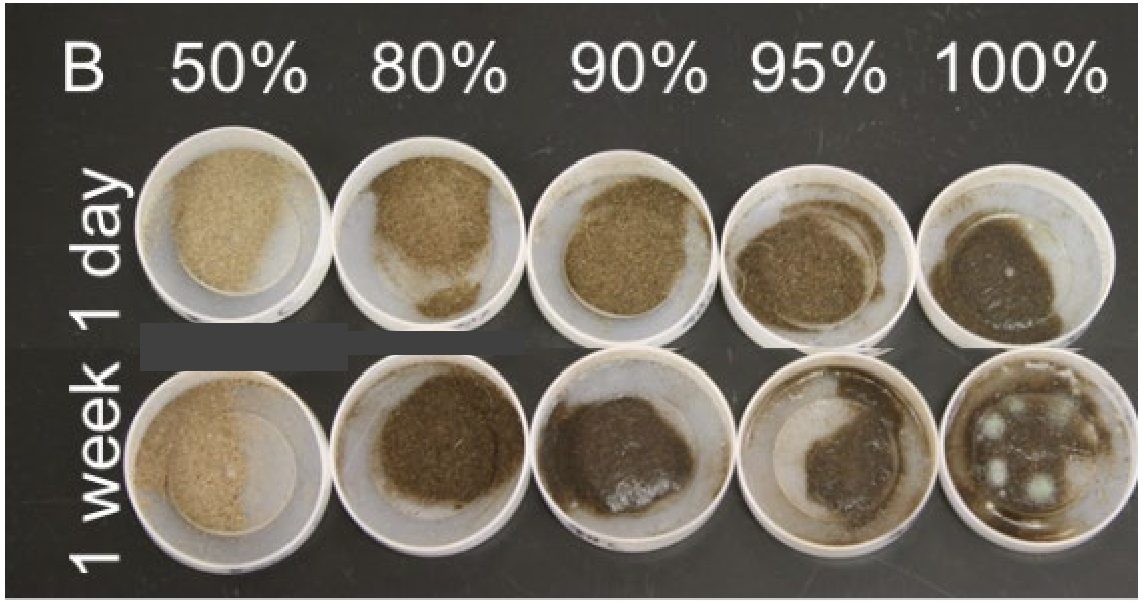
Embed dust with modified ASTM F608−13 method

Dust is embedded

Place carpet coupon in temperature- & relative humidity-controlled chamber

Water activity (a_w) of dust equilibrates quickly with RH

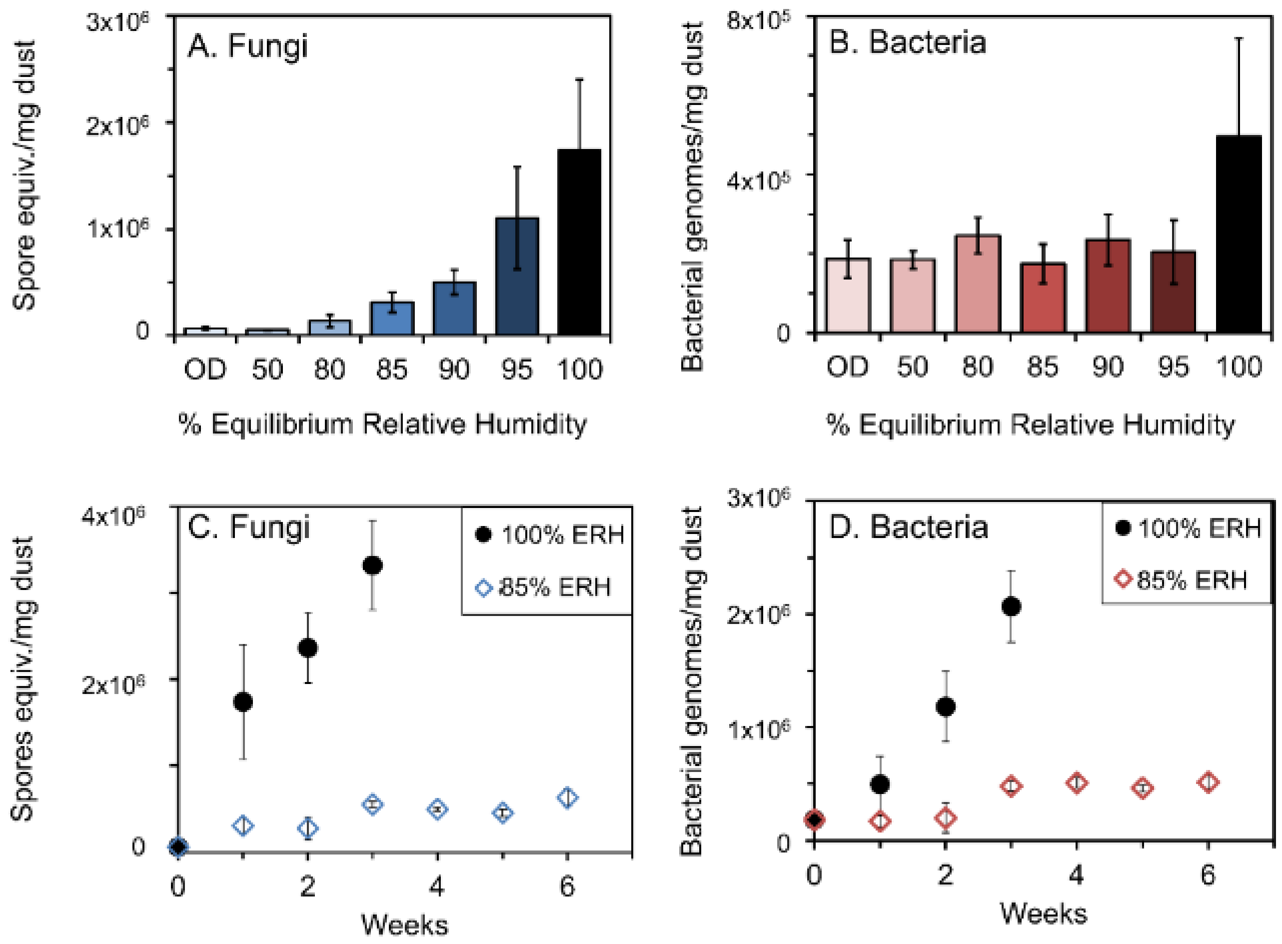




$$a_w = \frac{p_{dust}}{p_{water}}$$

$$Equilibrium\ RH = a_w \times 100\%$$

Microbial growth occurs above 80% relative humidity



Dannemiller, Weschler, and Peccia. *Indoor Air, 2016*

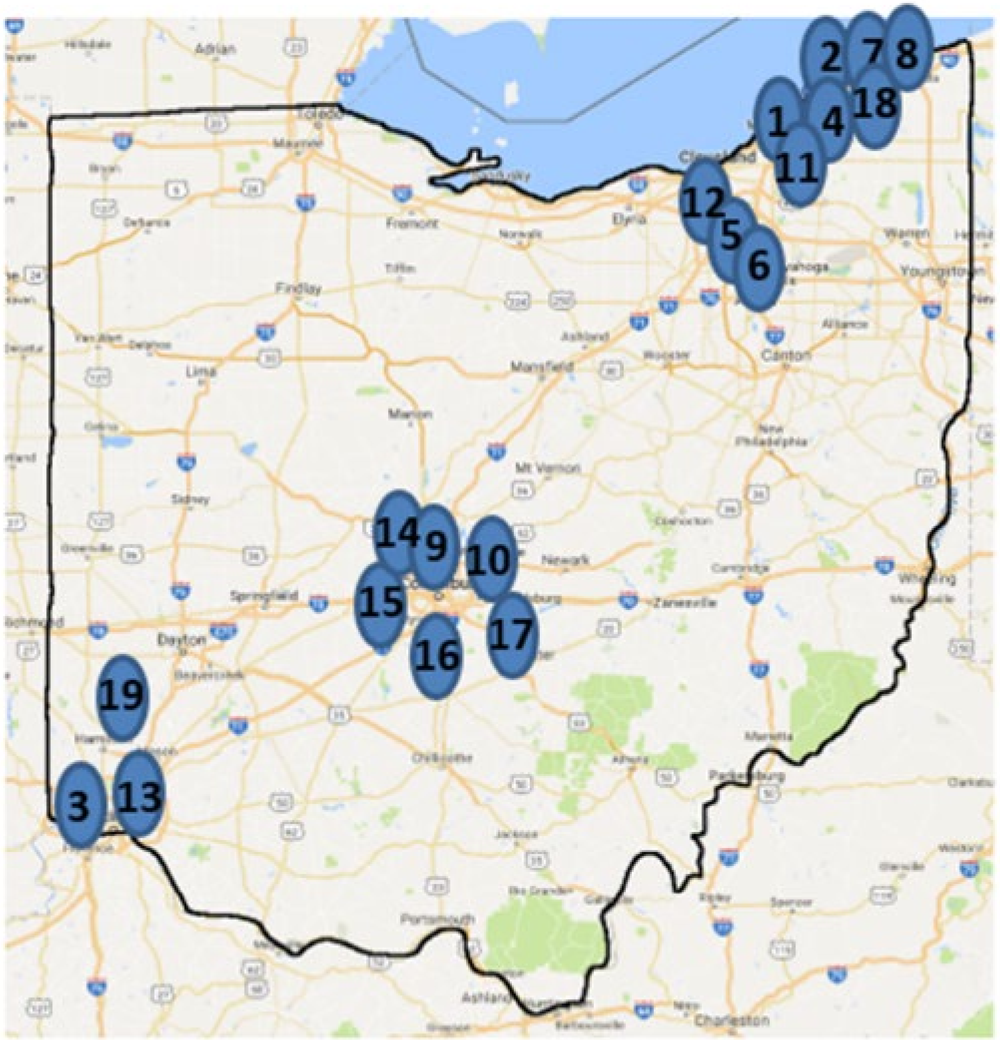
Moisture is the limiting factor for growth

Nutrient/ Salt	Dissolvable amount in dust (mg/kg dust)	Estimated amount needed to support growth (mg/kg dust)
C	35000	7.2
N	5.7	1.3
P	7.9	0.22
S	9.1	0.058
Na	6300	-
K	2100	-
Ca	1600	-
Mg	220	-
NH_4	160	-
Cl	2400	-

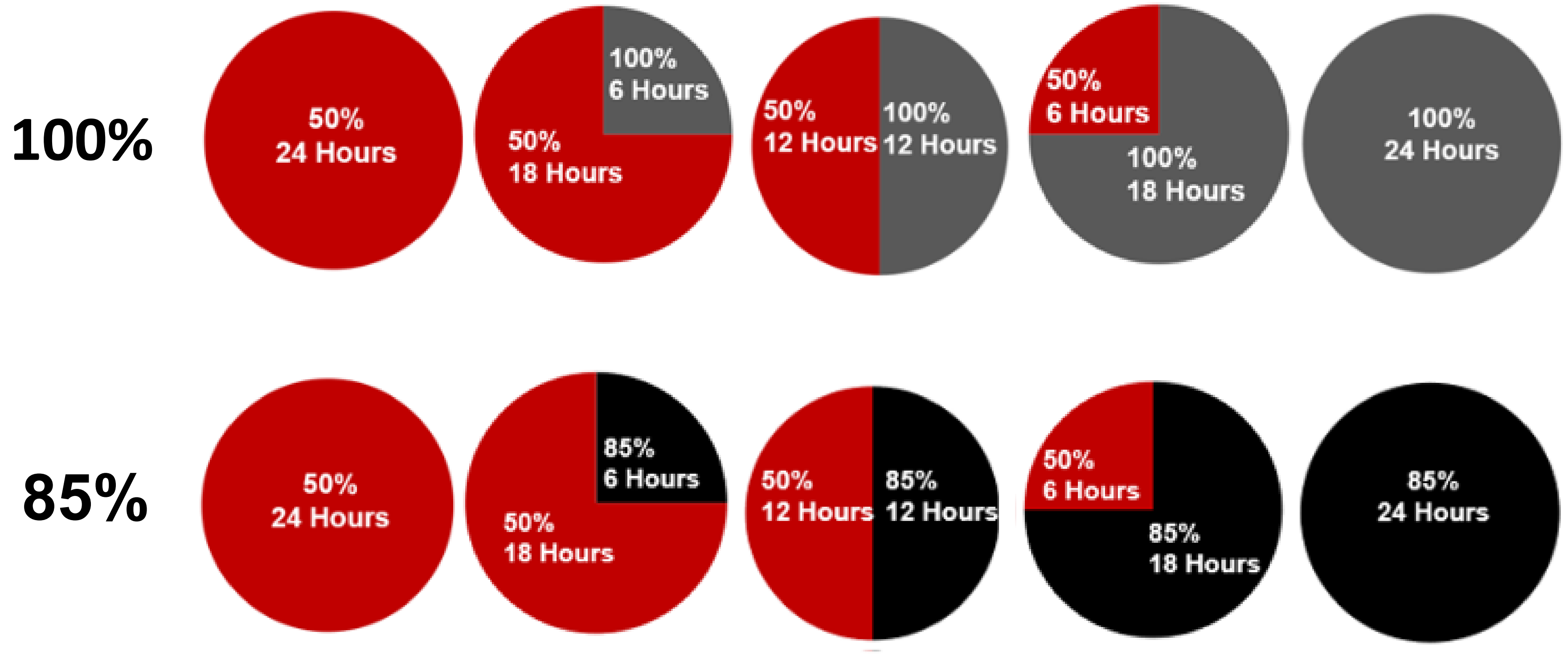
Dannemiller, Weschler, and Peccia. *Indoor Air, 2016*

Next Goal: Determine how variations in RH affect fungal growth in carpet

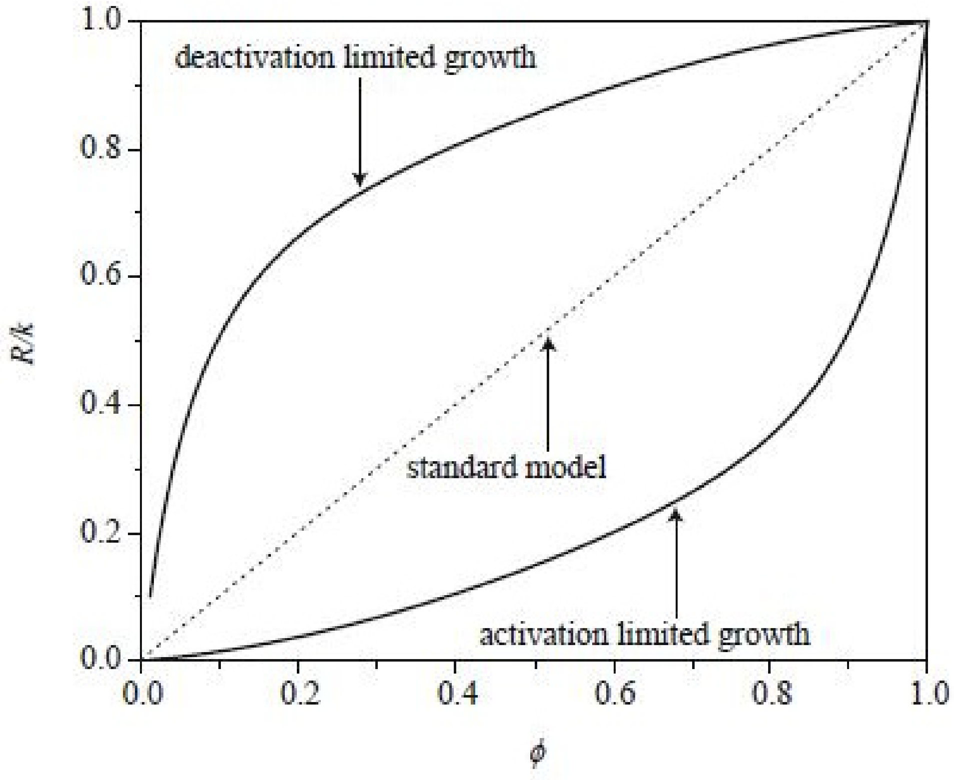
Sarah Haines



Goal: Determine how variations in RH affect fungal growth in carpet



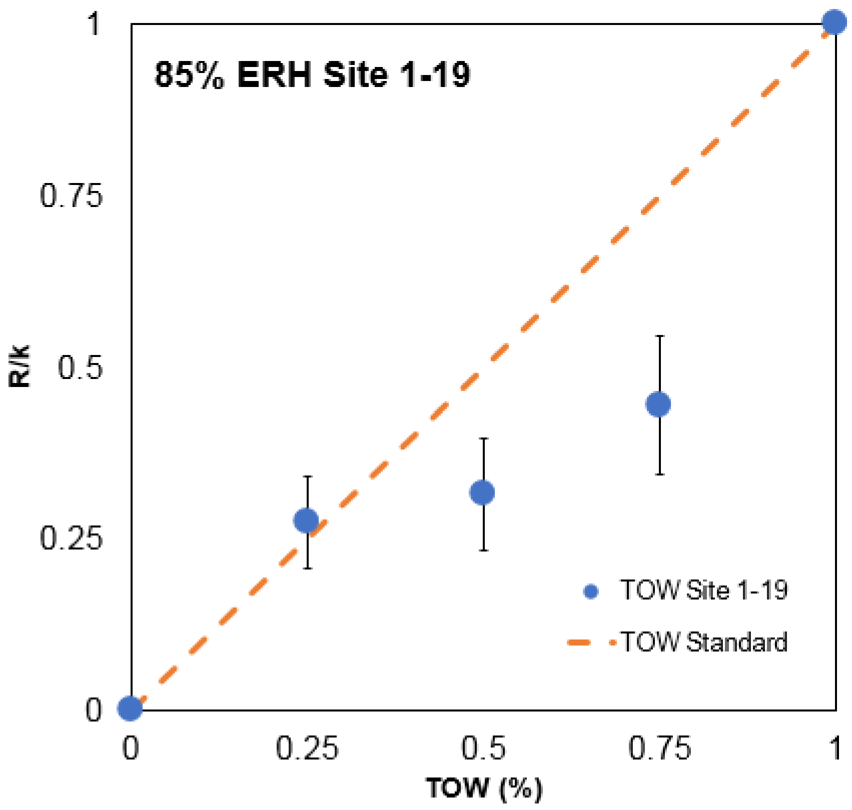
Apply Time of Wetness model

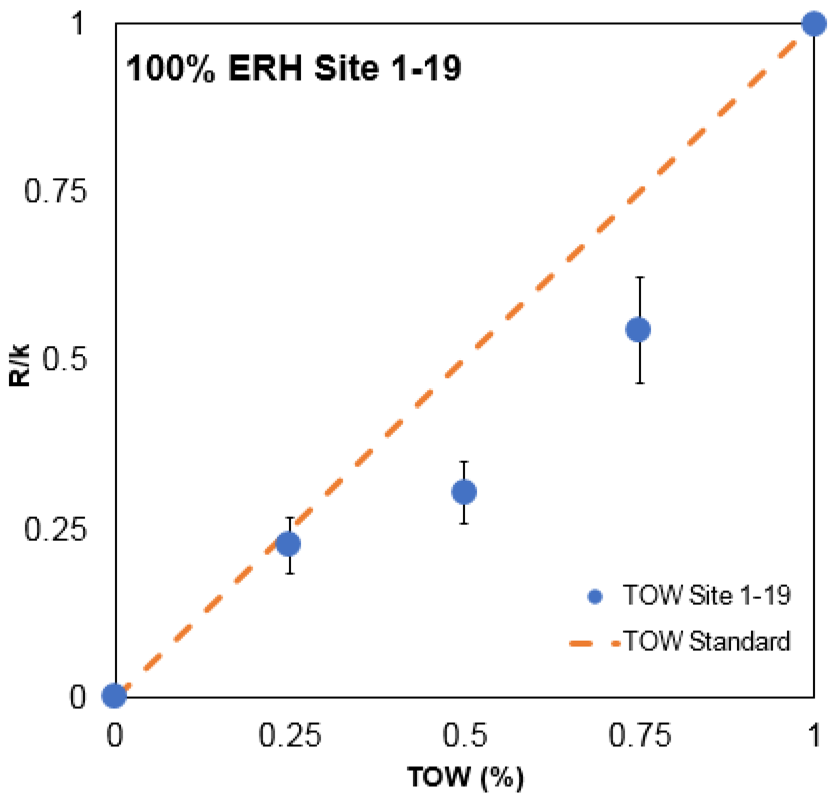


Adan, O., Huinink, H. "Fungal Growth & Humidity Fluctuations: A Toy Model. *Fundamentals of Mold Growth in Indoor Environments and Strategies for Healthy Living*. 2011

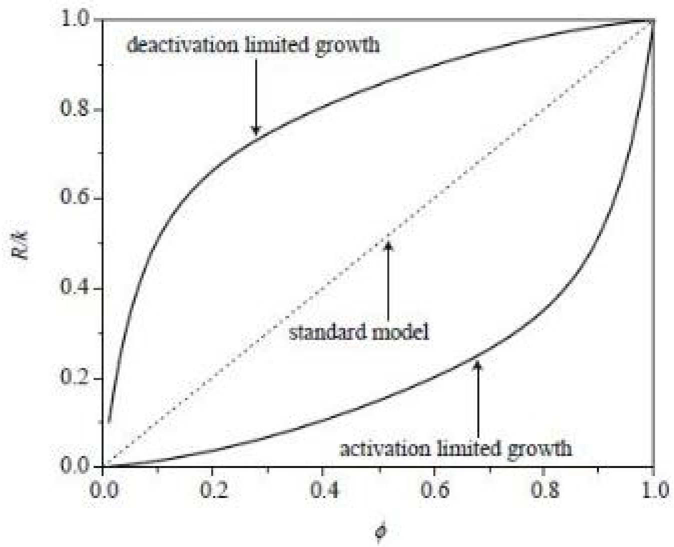
We can model fungal growth in carpet and dust based on moisture availability

Carpet TOW data





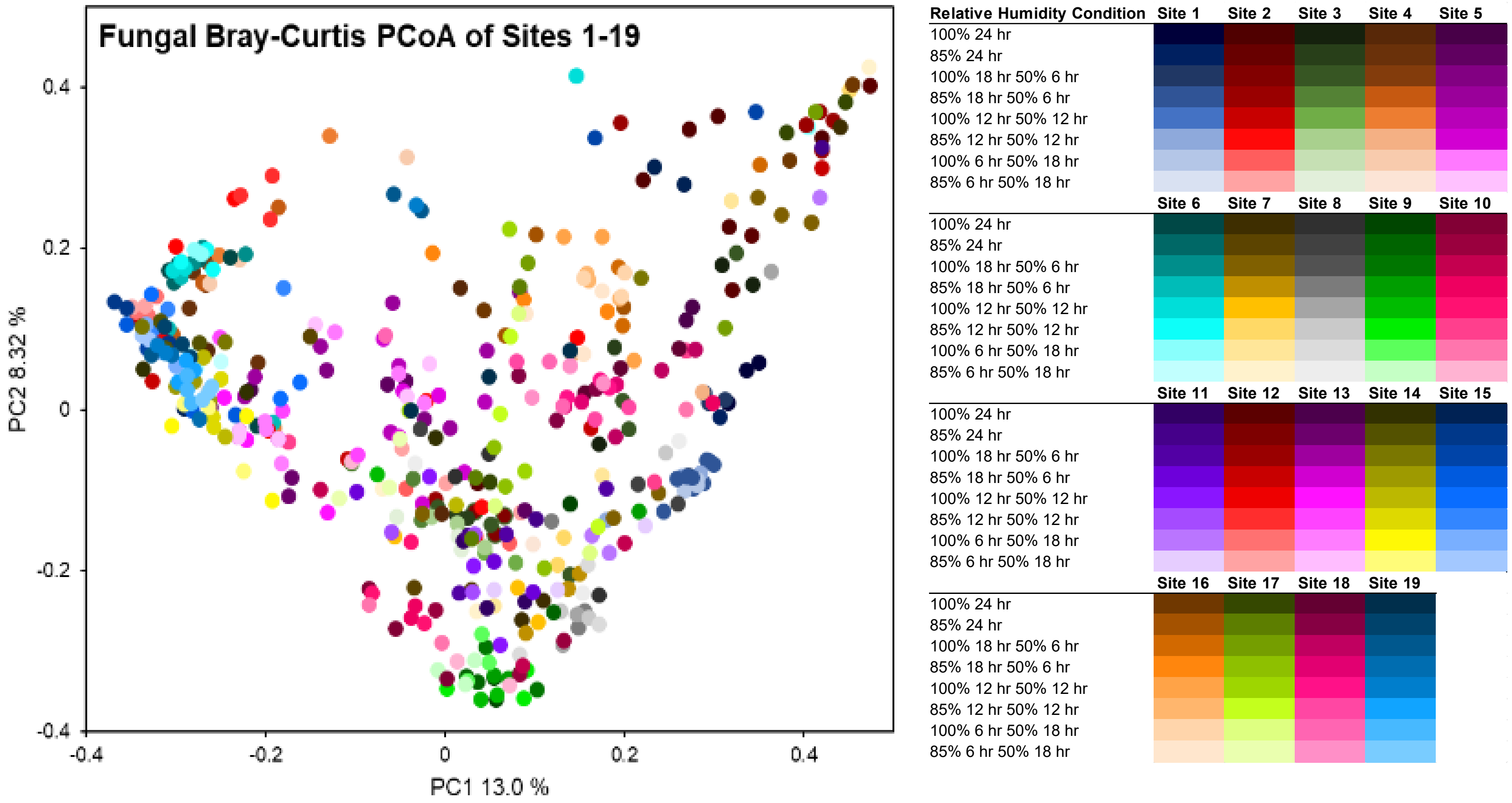
Standard TOW Model



Adan, Olaf C. G., and Robert A. Samson. (2011) "Fundamentals of Mold Growth in Indoor Environments and Strategies for Healthy Living", *Wageningen: Wageningen Academic*

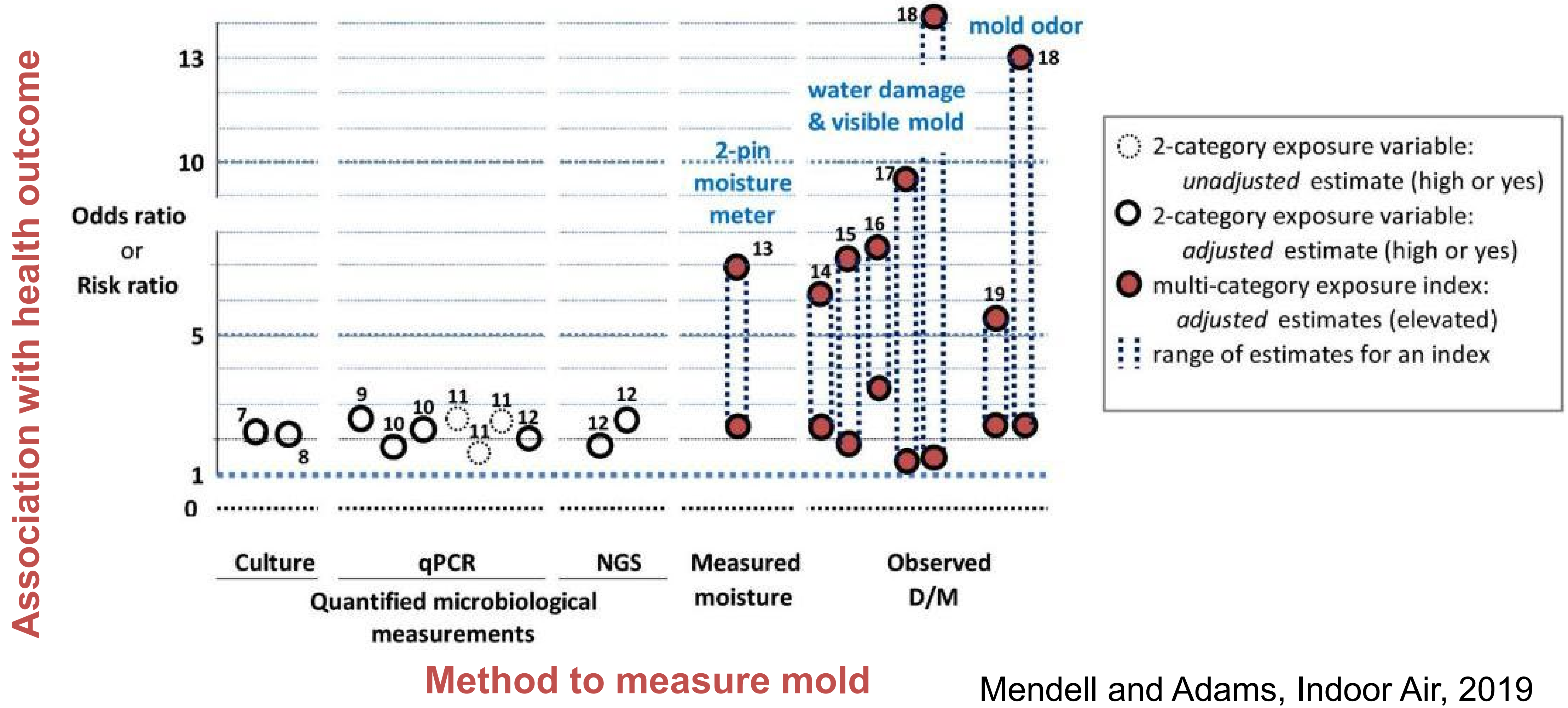
Haines, Siegel, Dannemiller. *Indoor Air.* 2020.

Prior quantitative mold tests are based on an incorrect assumption



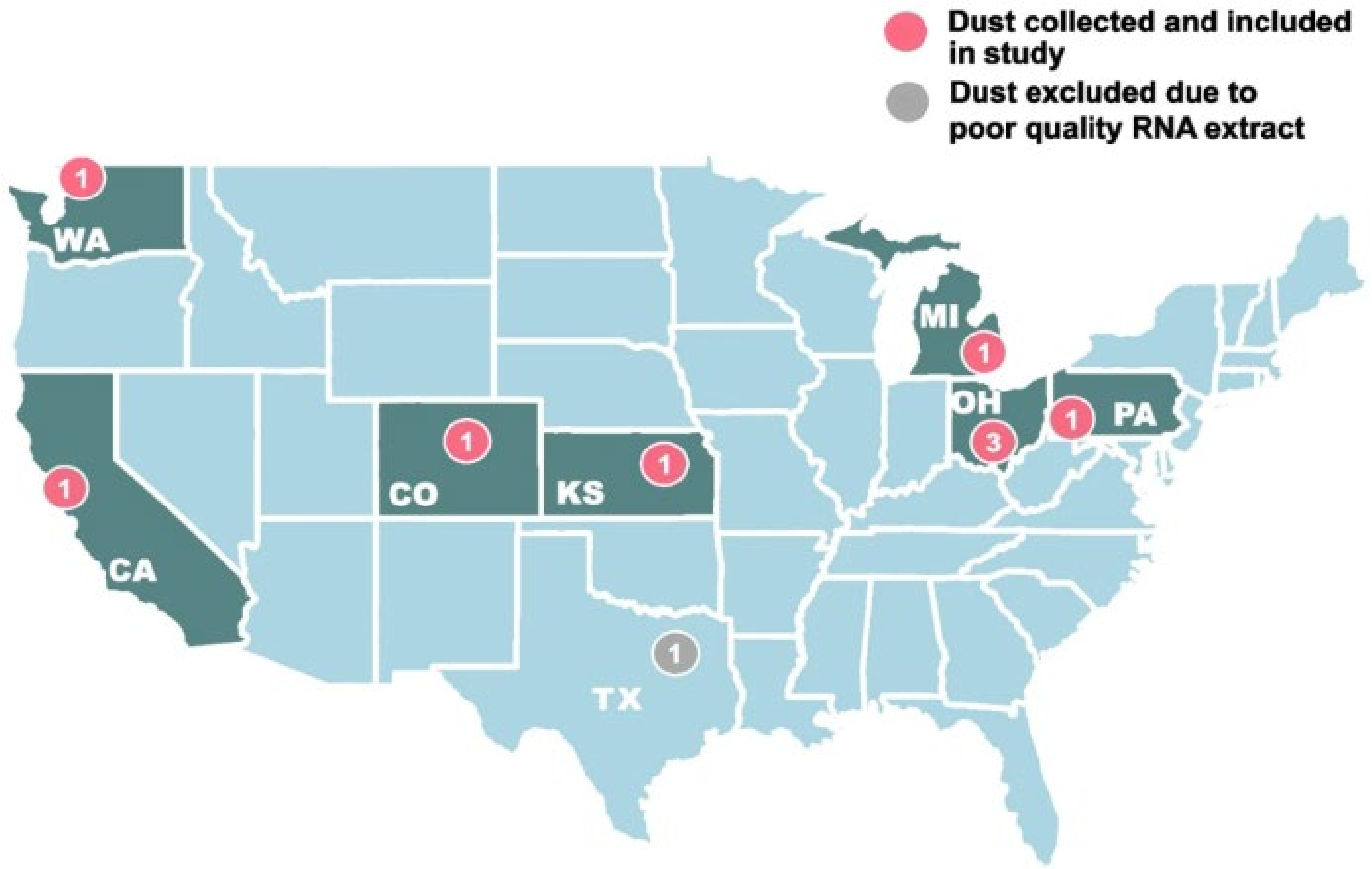
Haines, Siegel, Dannemiller. *Indoor Air.* 2020.

Many prior mold sampling tests are based on taxa



Mendell and Adams, Indoor Air, 2019

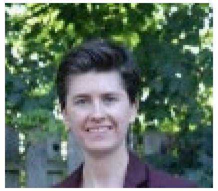
So let's look at fungal function



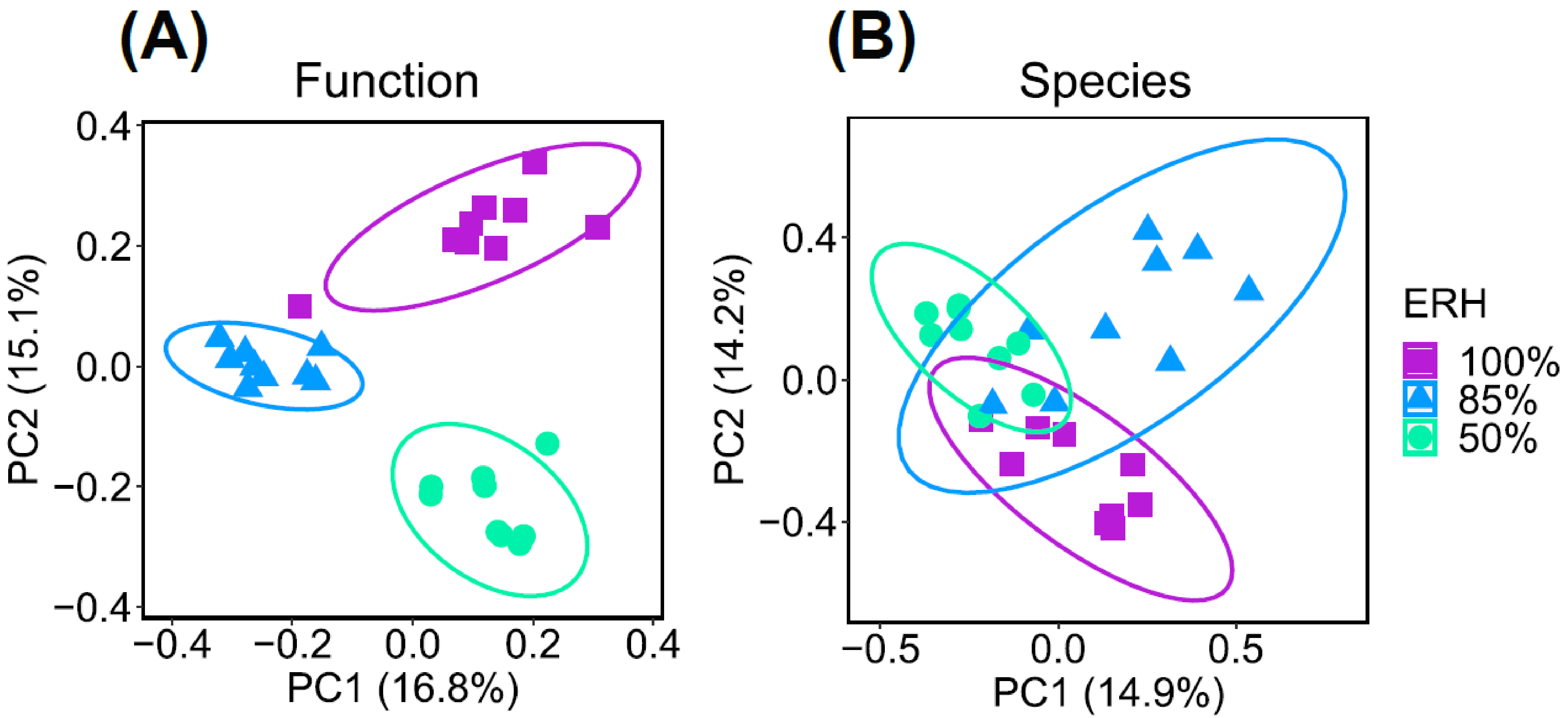
It’s so clear when we look at function

Neeraja Balasubrahmaniam

Jon King

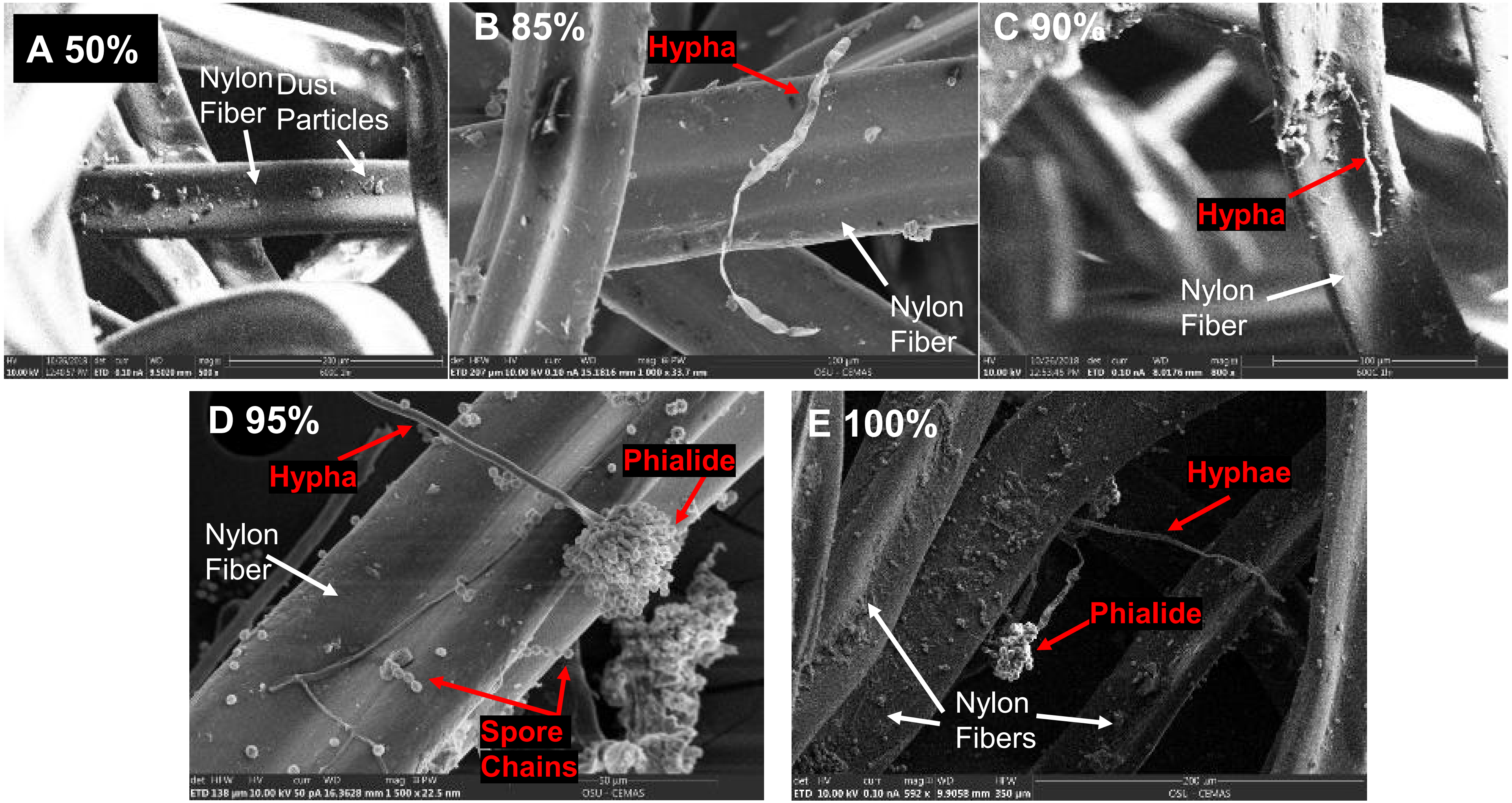


Collaborator Bridget Hegarty



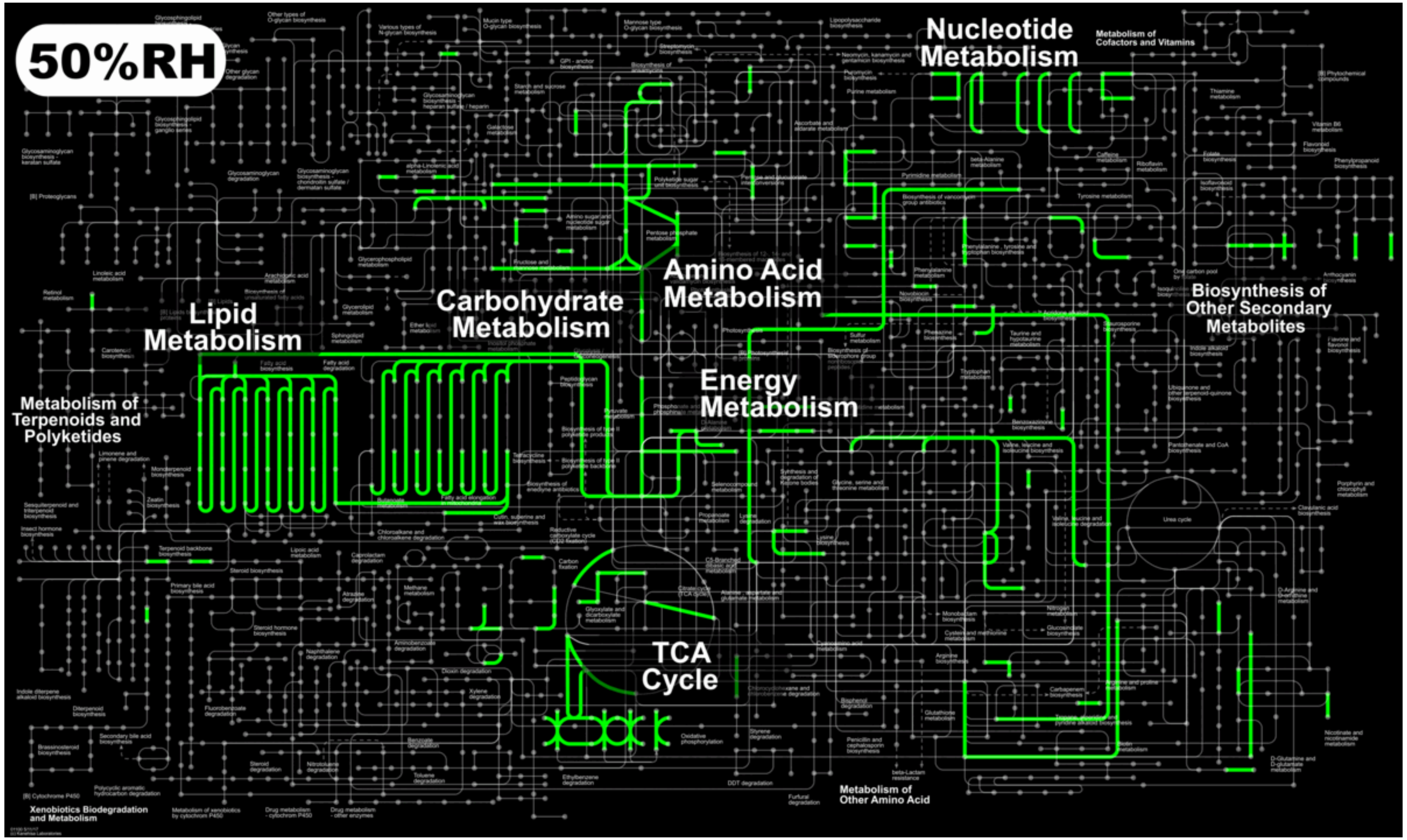
Balasubrahmaniam, King, Hegarty, and Dannemiller. *Microbiome.* 2024.

You can see the difference
Low → High RH



Nastasi et al. *Building and Environment*, 2020

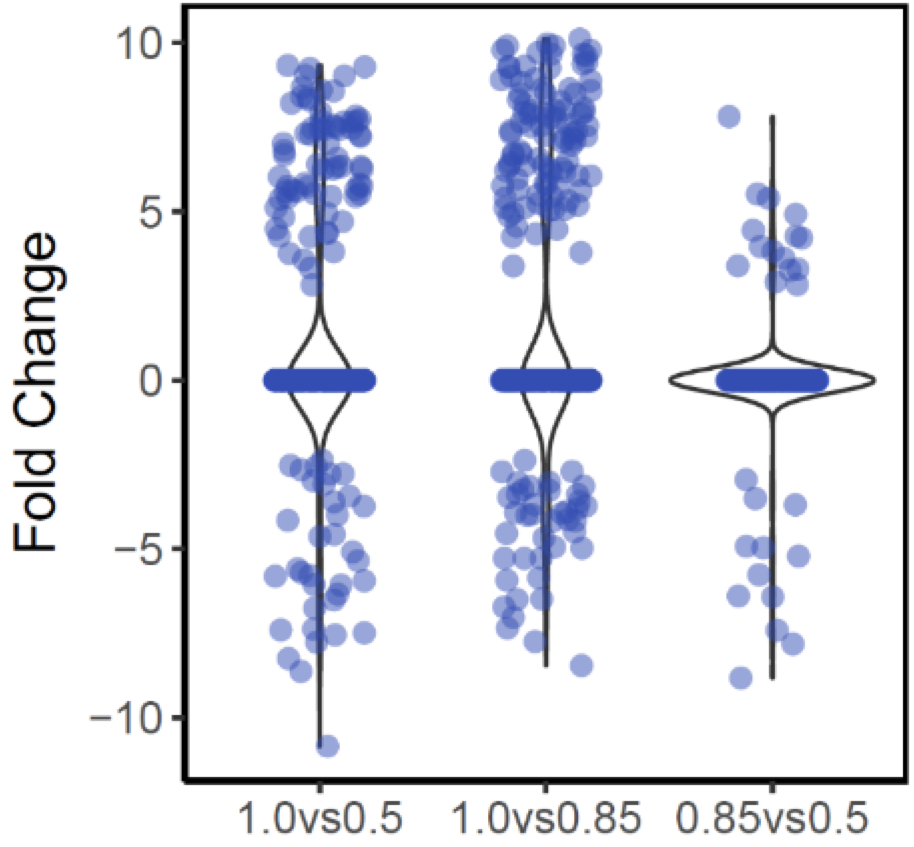
More secondary metabolic gene expression at higher moisture conditions



Balasubrahmaniam, King, Hegarty, and Dannemiller. *Microbiome.* 2024.

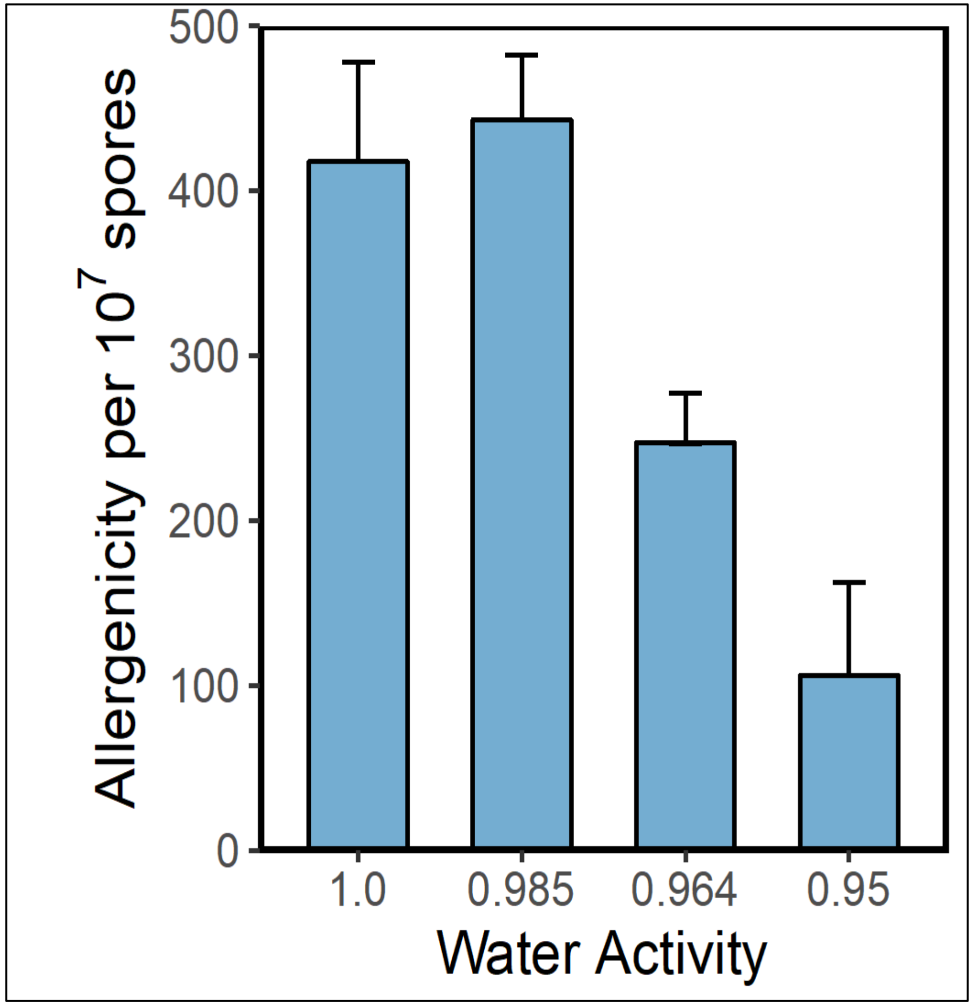
Growth at increased water activity increases allergen potency

Gene Expression



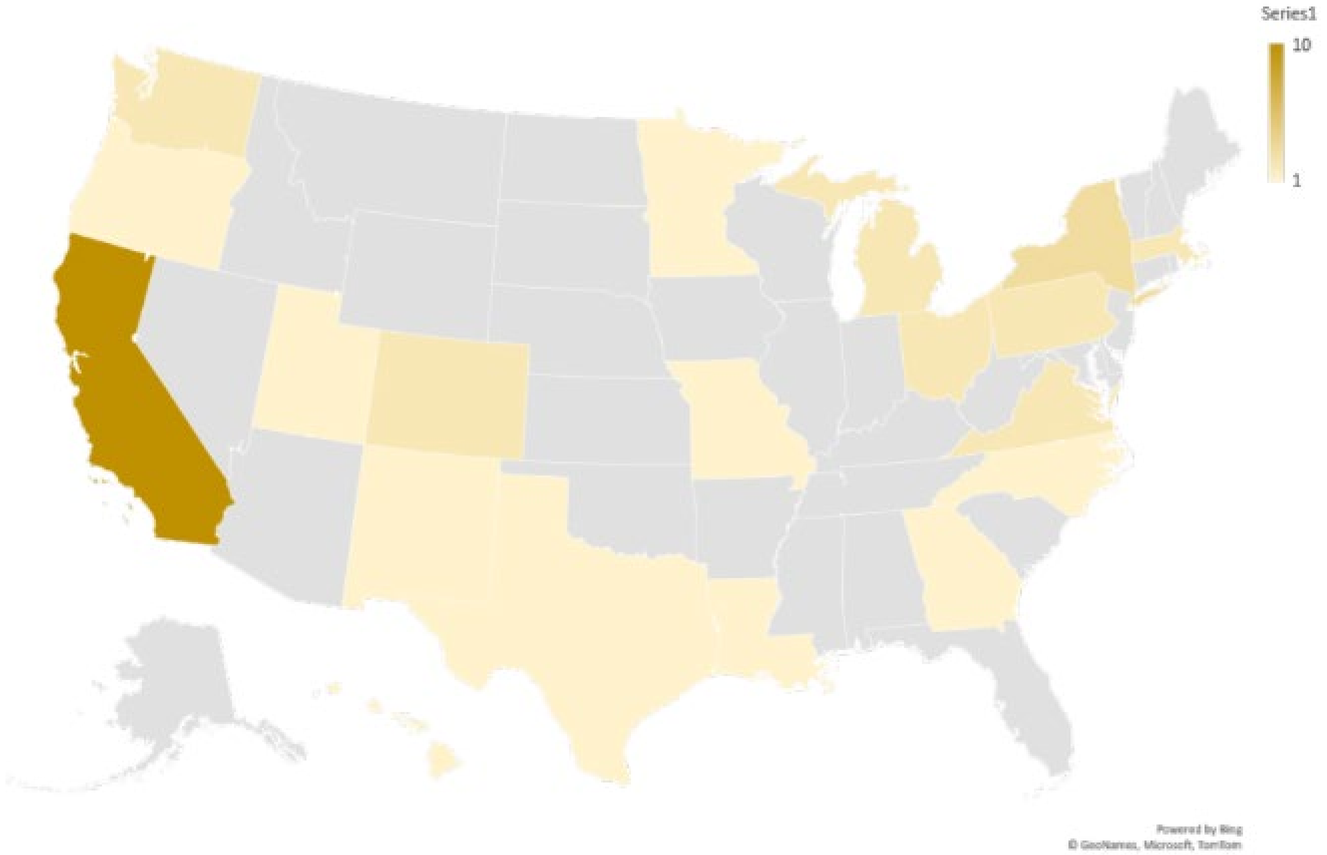
Hegarty, Dannemiller, & Peccia. *Indoor Air*

Allergen Potency

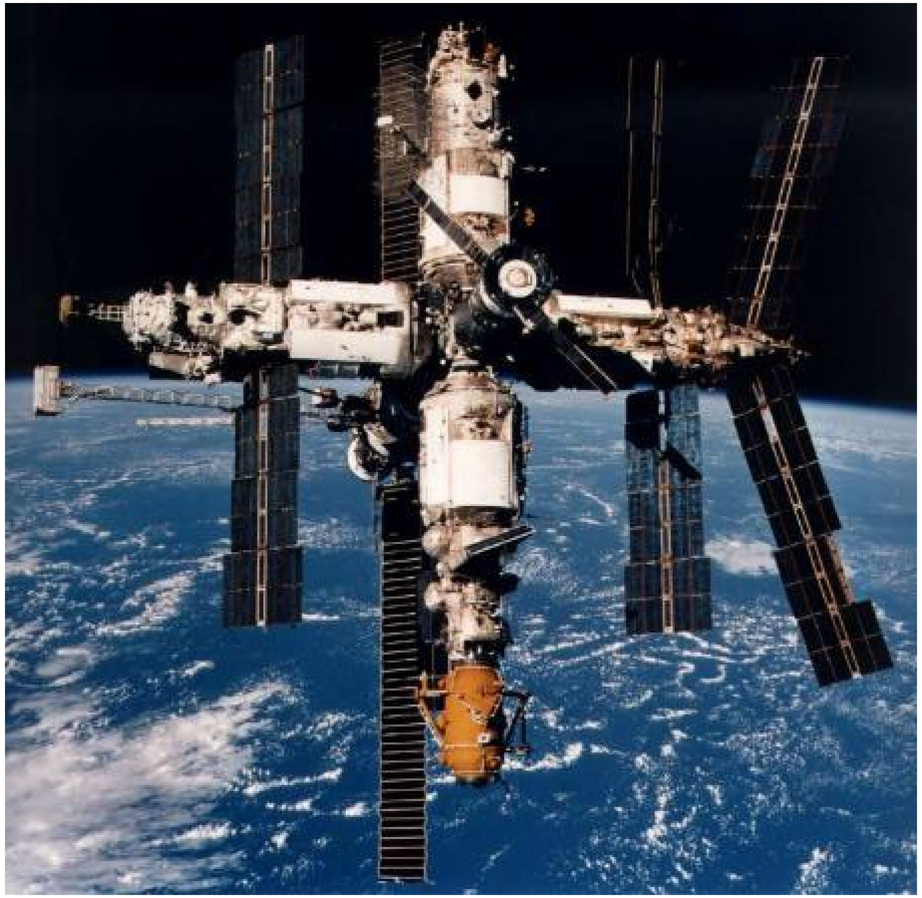


From these terms

- We can identify potential protein targets that will be consistently associated with mold growth in homes
- Now developing tests for top targets
- Four RNA targets are being validated in 35 homes



Microbial growth is problematic on Earth and in space



Mir suffered from microbial growth

Mold growth on fabric panels on ISS from wet hanging towels

Microb. Ecol., vol. 47, no. 2, pp. 133–136, 2004

Res. Microbiol., vol. 159, no. 6, pp. 432–435, 2008

Photo credit: NASA.

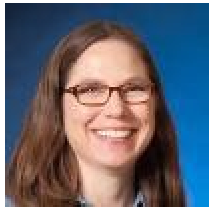
Relative humidity is very important to control on spacecraft

Nick Nastasi

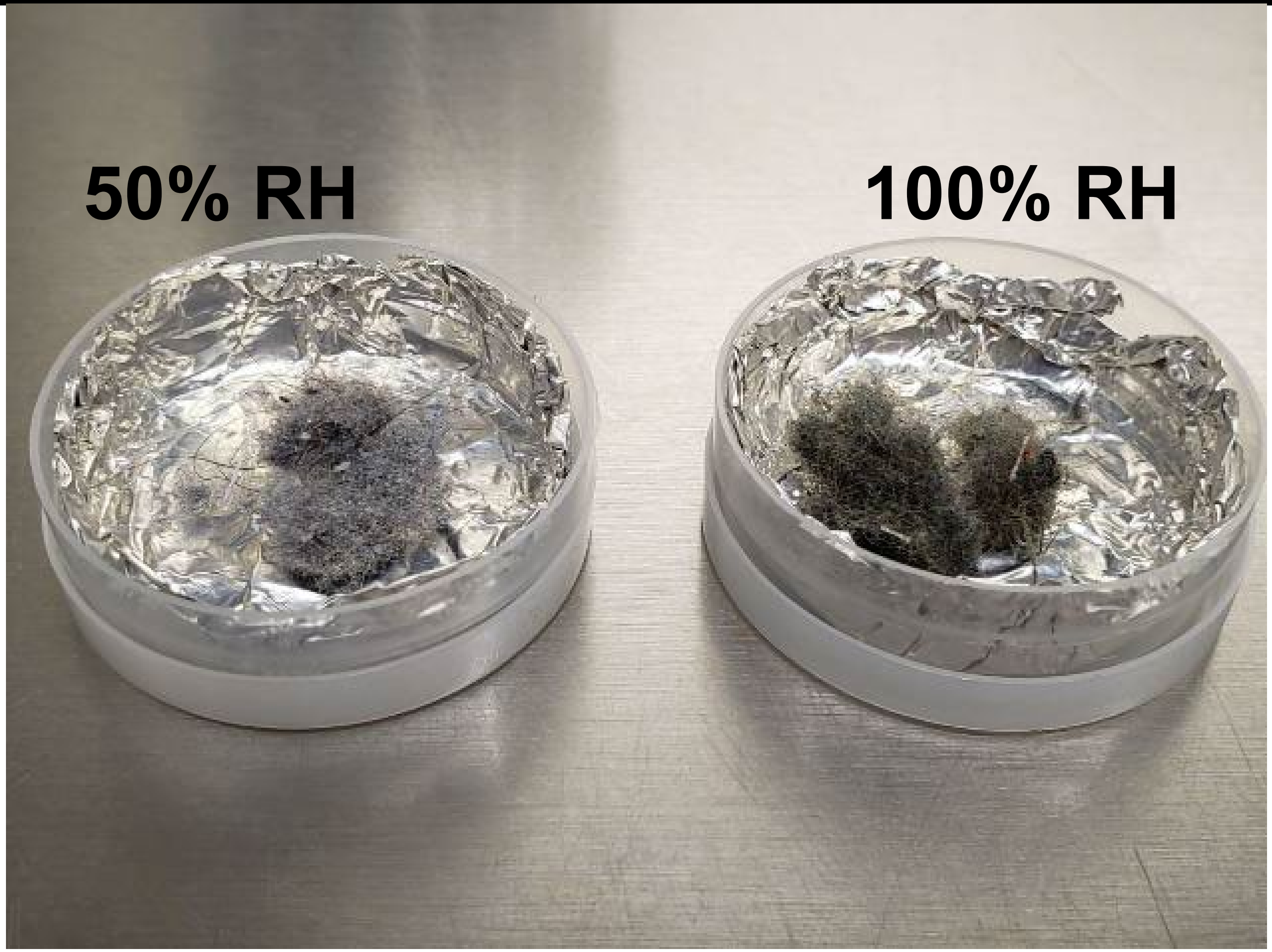
Neeraja Balasubrahmaniam

Ashleigh Bope

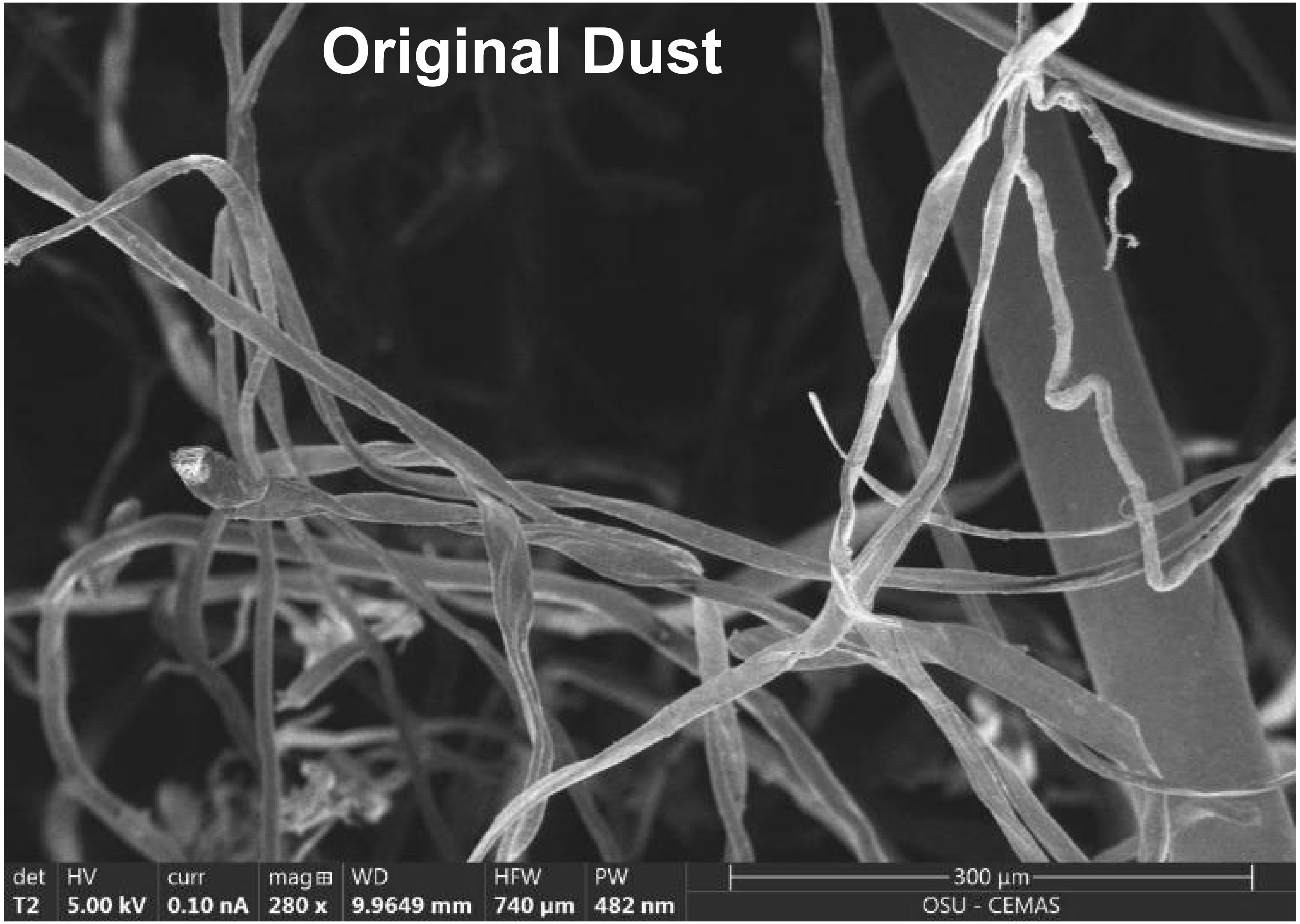
John Horack



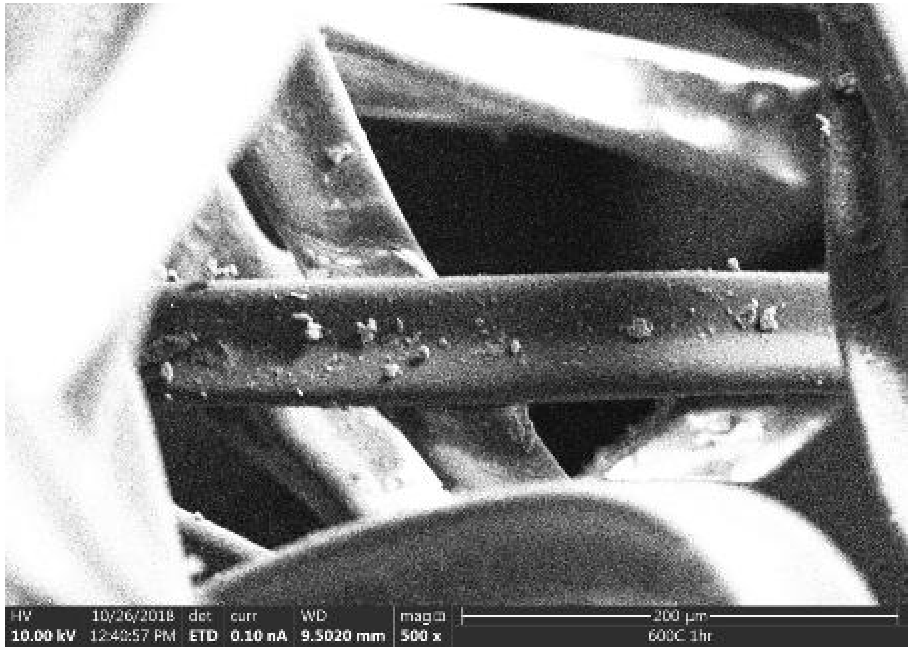
Marit Meyer (NASA)



Original dust has few microbes; Looks similar to carpet

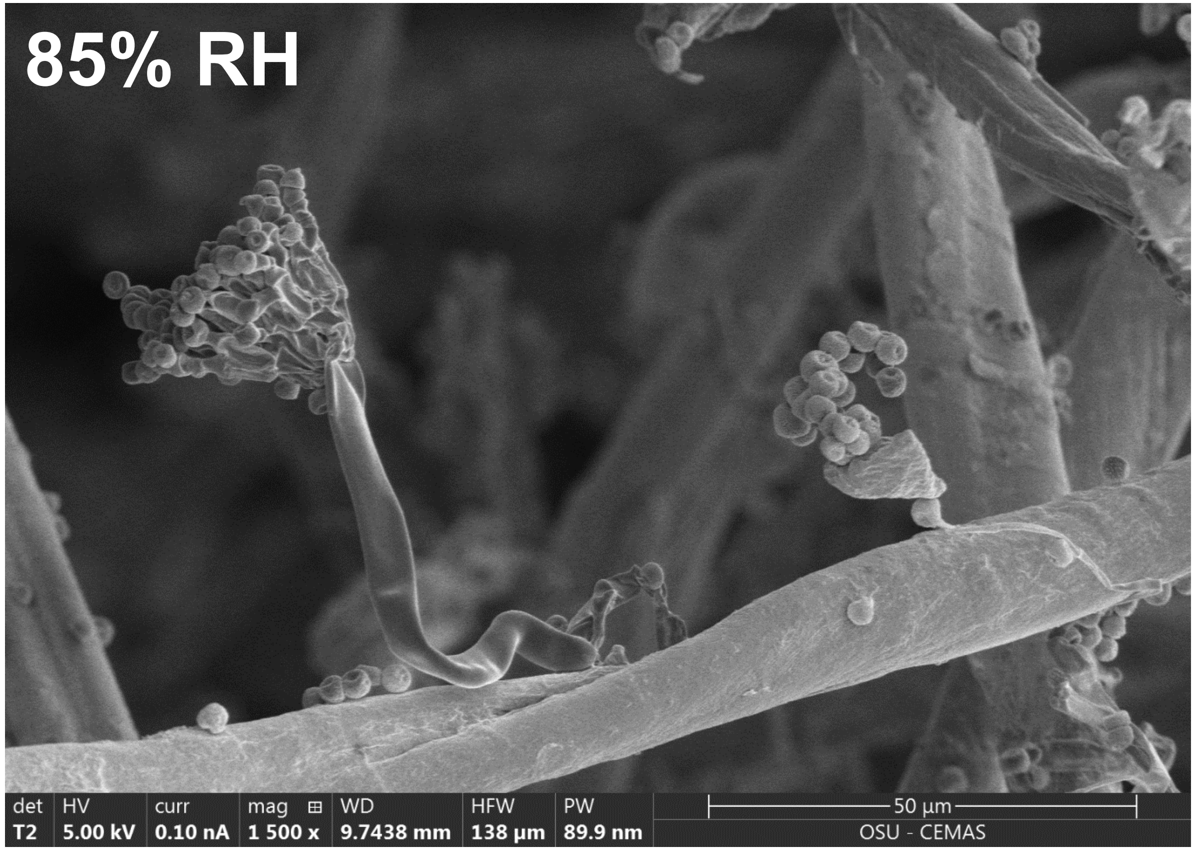


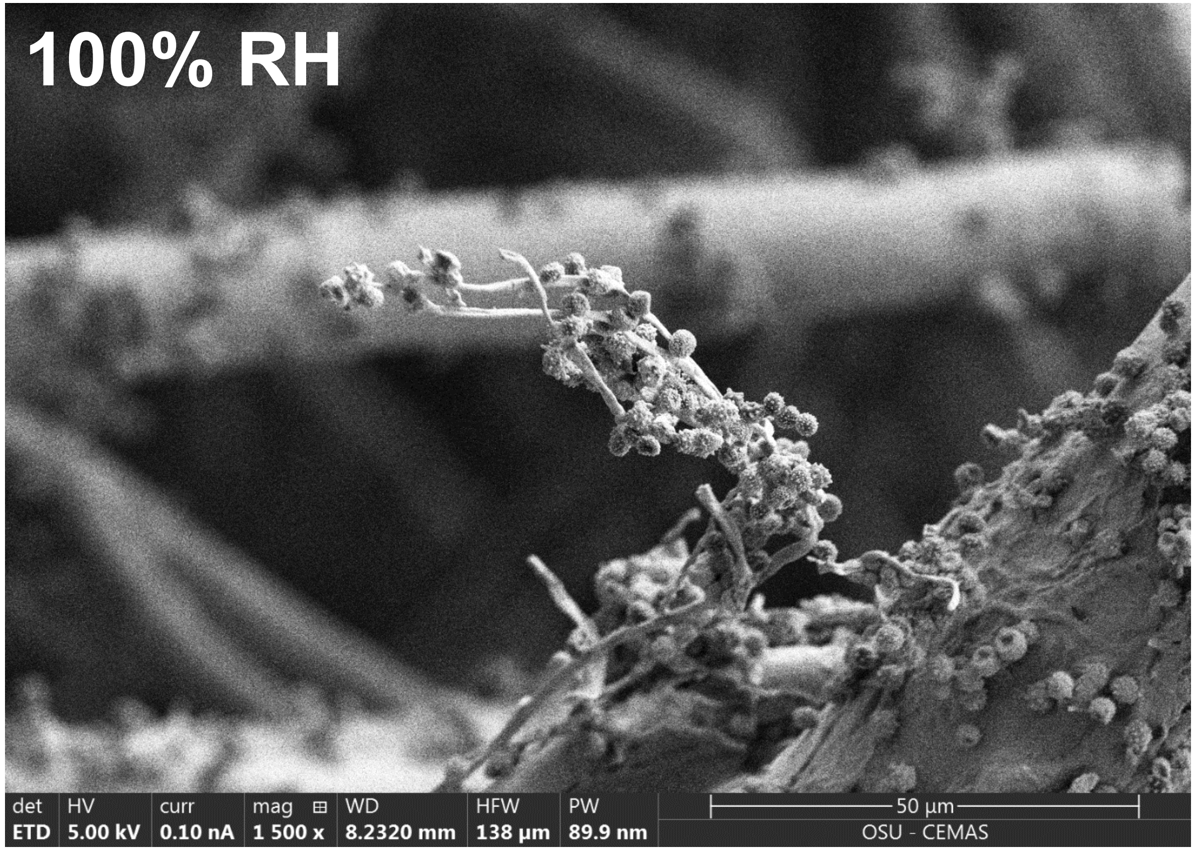
Carpet from Earth



Nastasi et al. *Microbiome.* 2024.

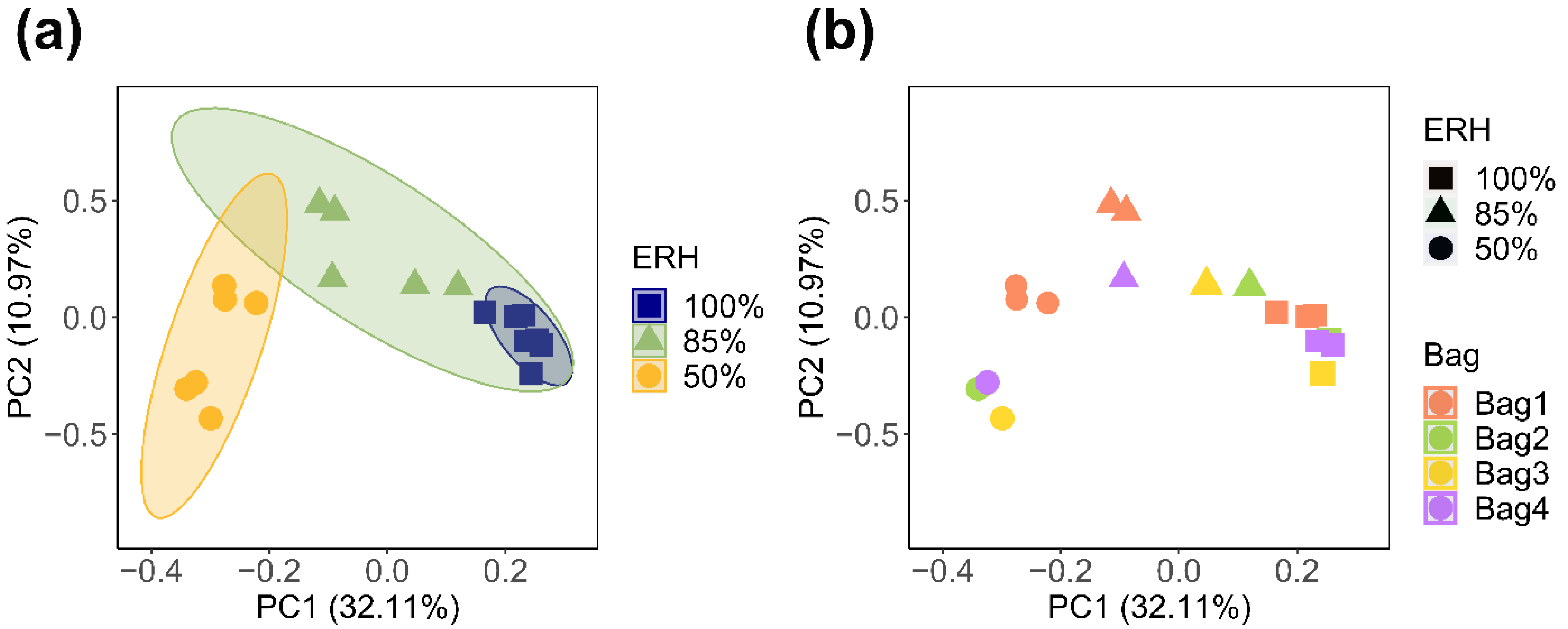
Dust incubated at higher RH has growth; Models a ventilation system failure scenario





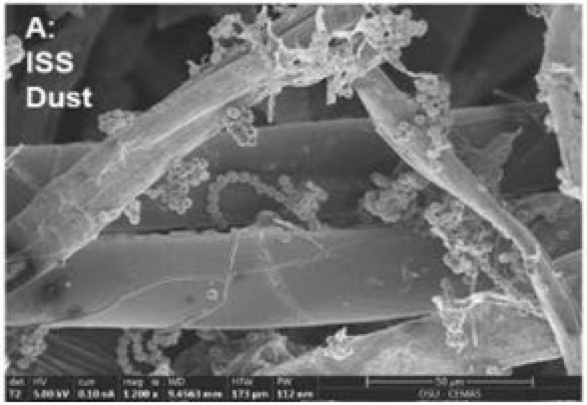
Nastasi et al. *Microbiome.* 2024.

Moisture is also an important driver of microbial function in spacecraft

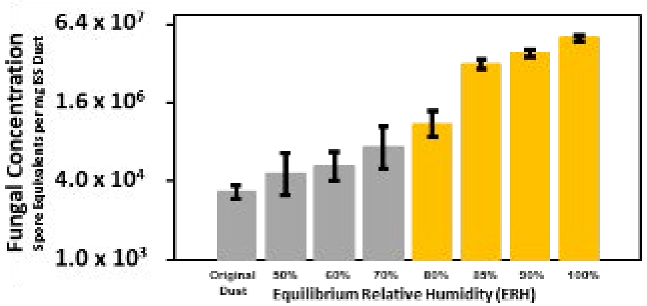


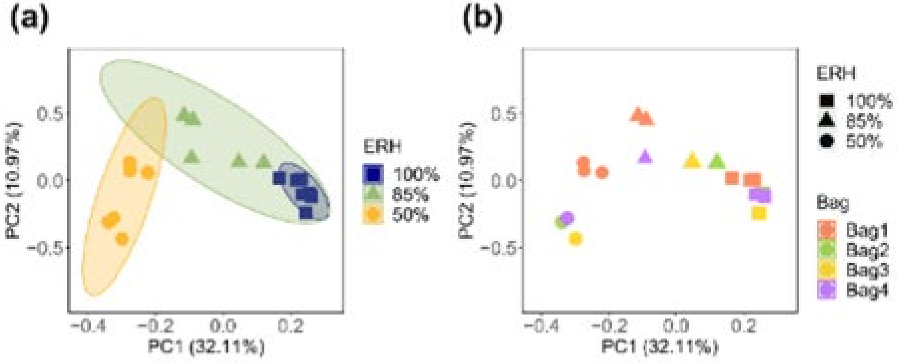
Balasubrahmaniam, et al. *Scientific Reports.*

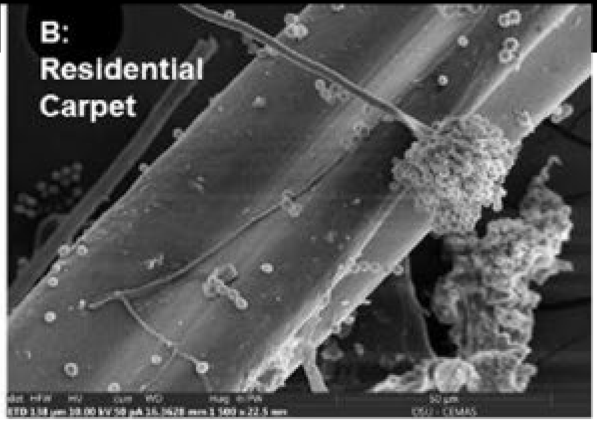
This work can improve environments on Earth and in space



ISS DUST

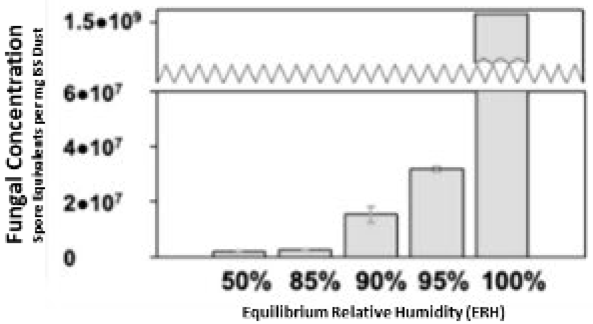


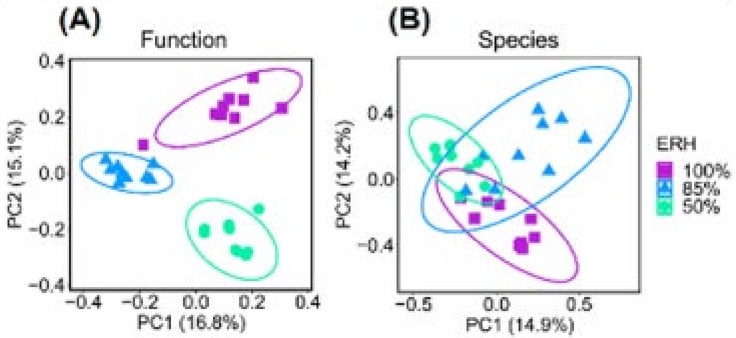




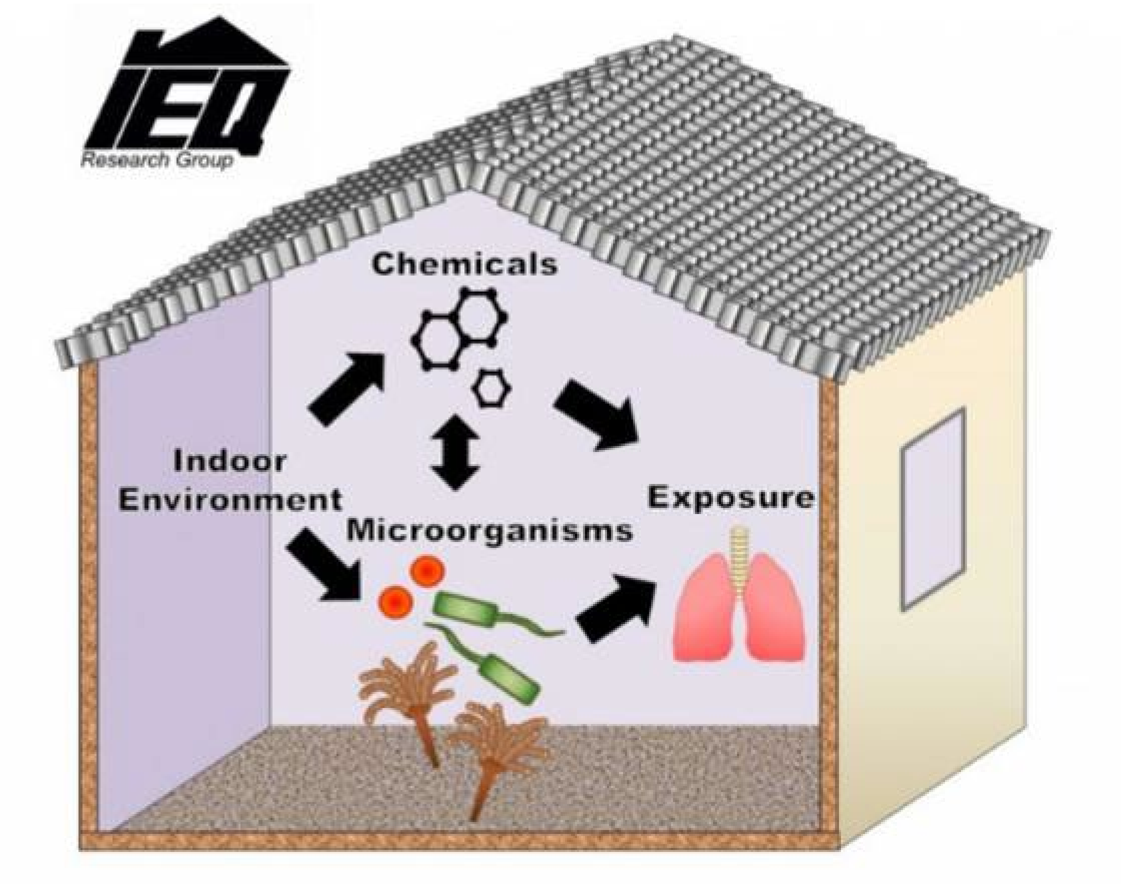
Earth-based Dust and Carpet

Nastasi et al., Building and Environment, 2020
https://doi.org/10.1016/j.buildenv.2020.106774





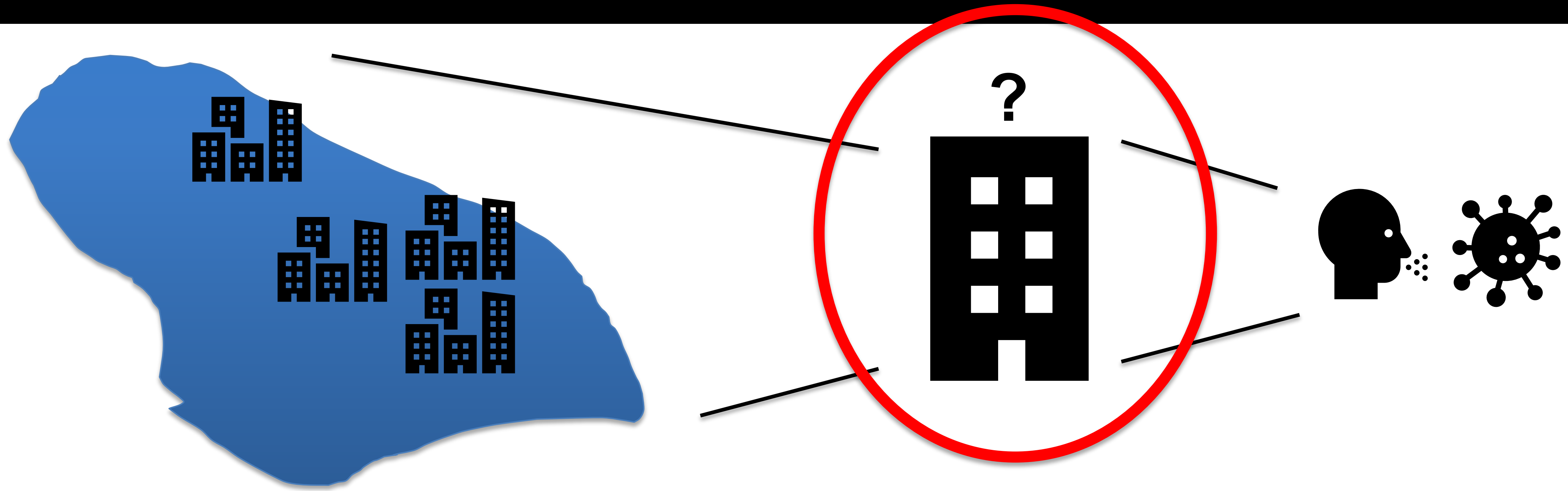
Part 1 Summary



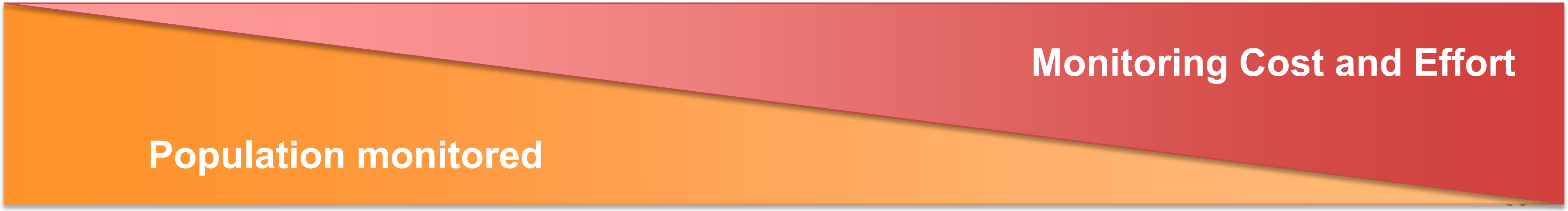
- Elevated moisture is sufficient to support microbial growth and function in dust
- We can use this information to develop a better mold indicator

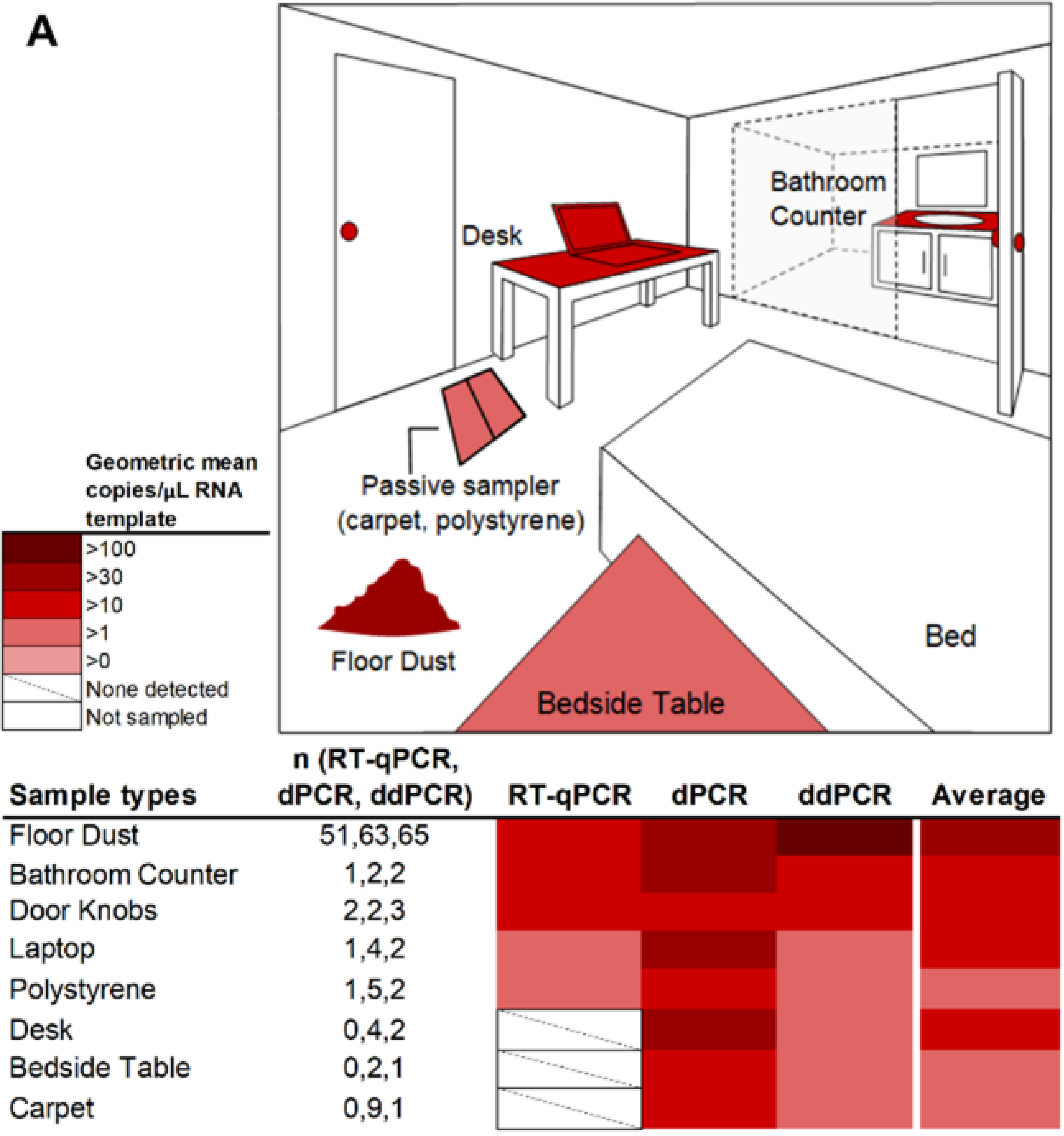
Part 2: Viral Disease Monitoring

Goal: Dust as a matrix for outbreak surveillance

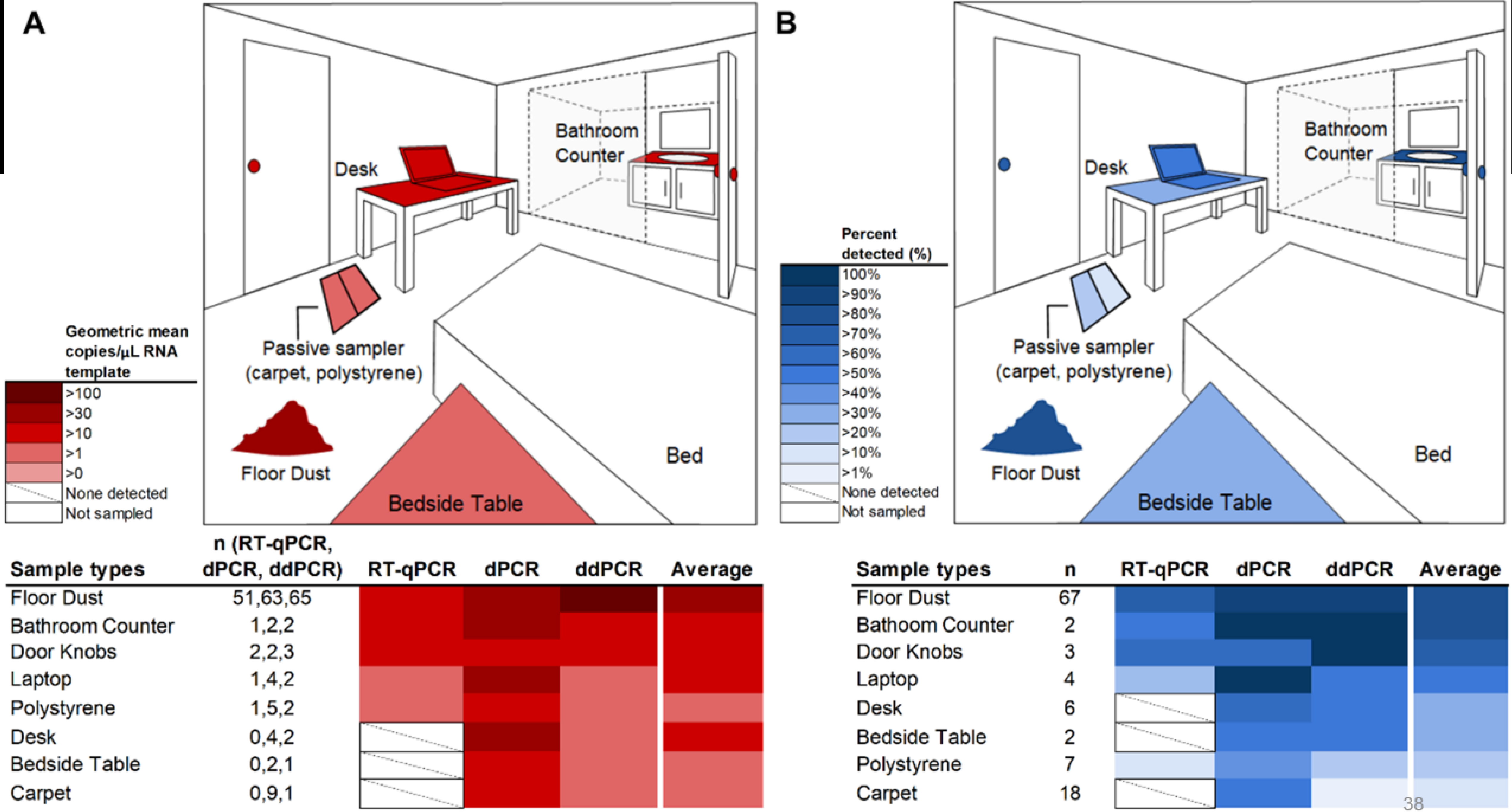


Solutions: Wastewater Monitoring   Building Monitoring????   Individual Testing



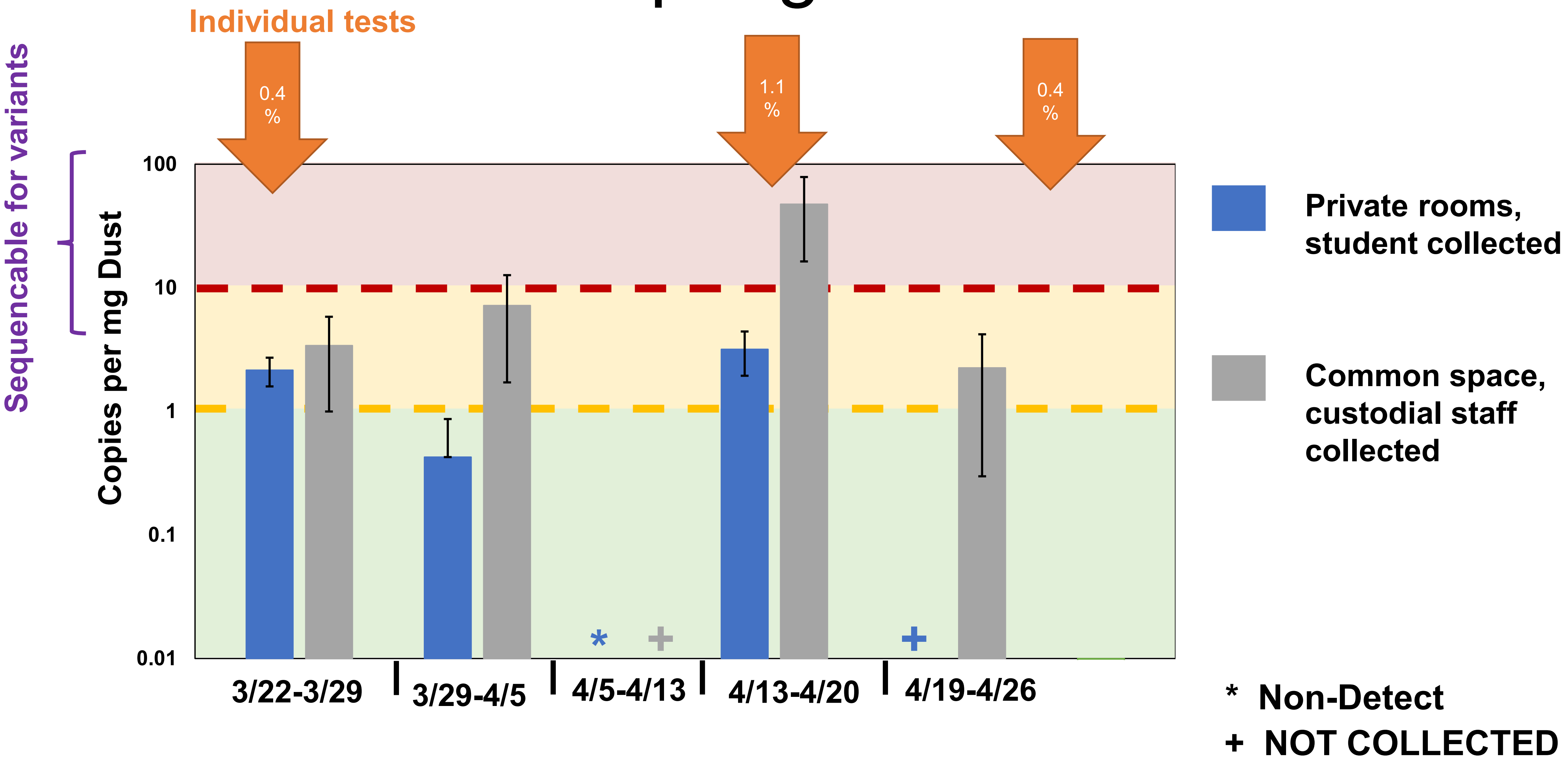


- Samples collected from rooms of students in isolation with positive test
- Bulk dust, surface swabs, passive sampler

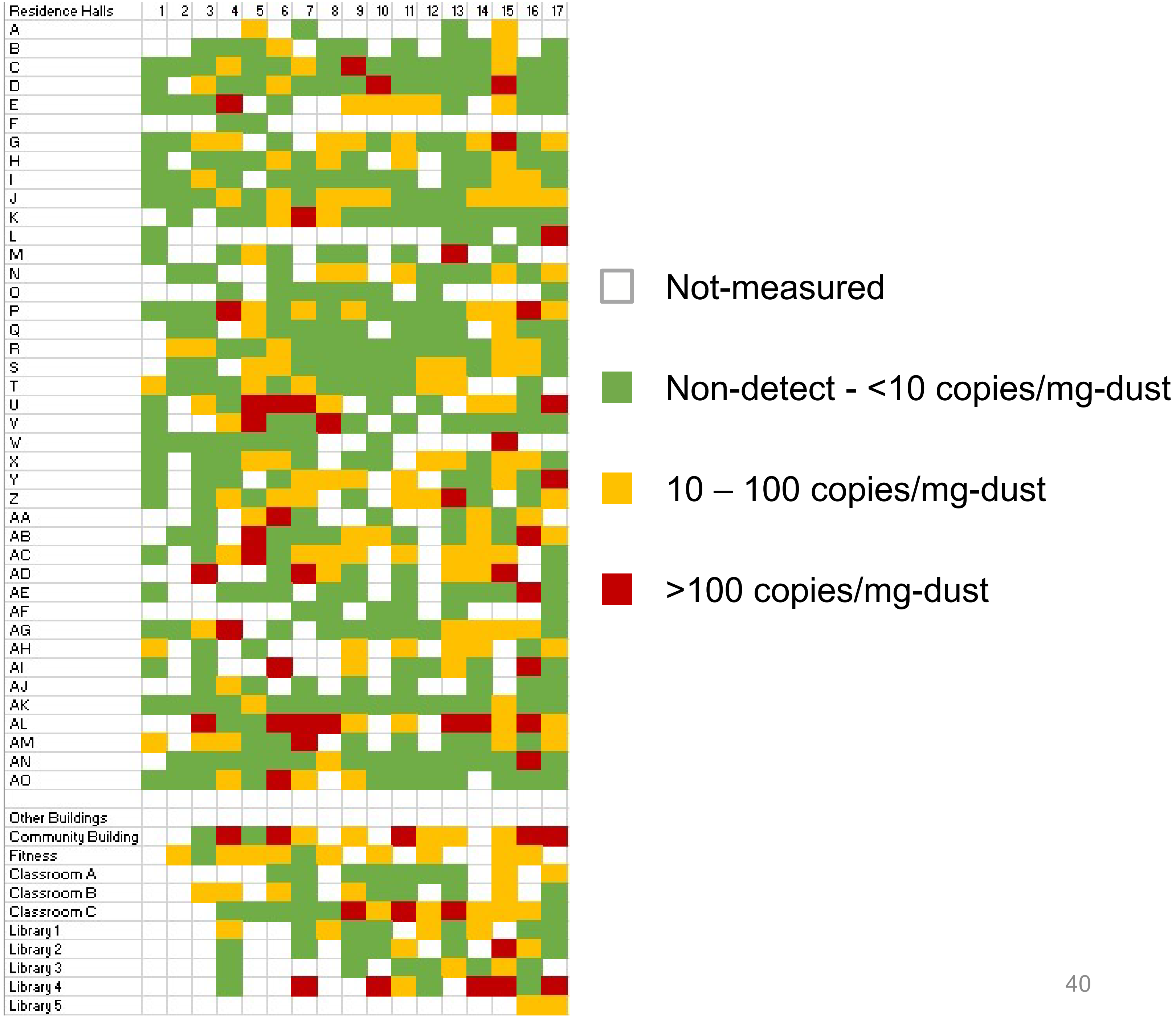


Renninger et al. *mSystems*, 2021

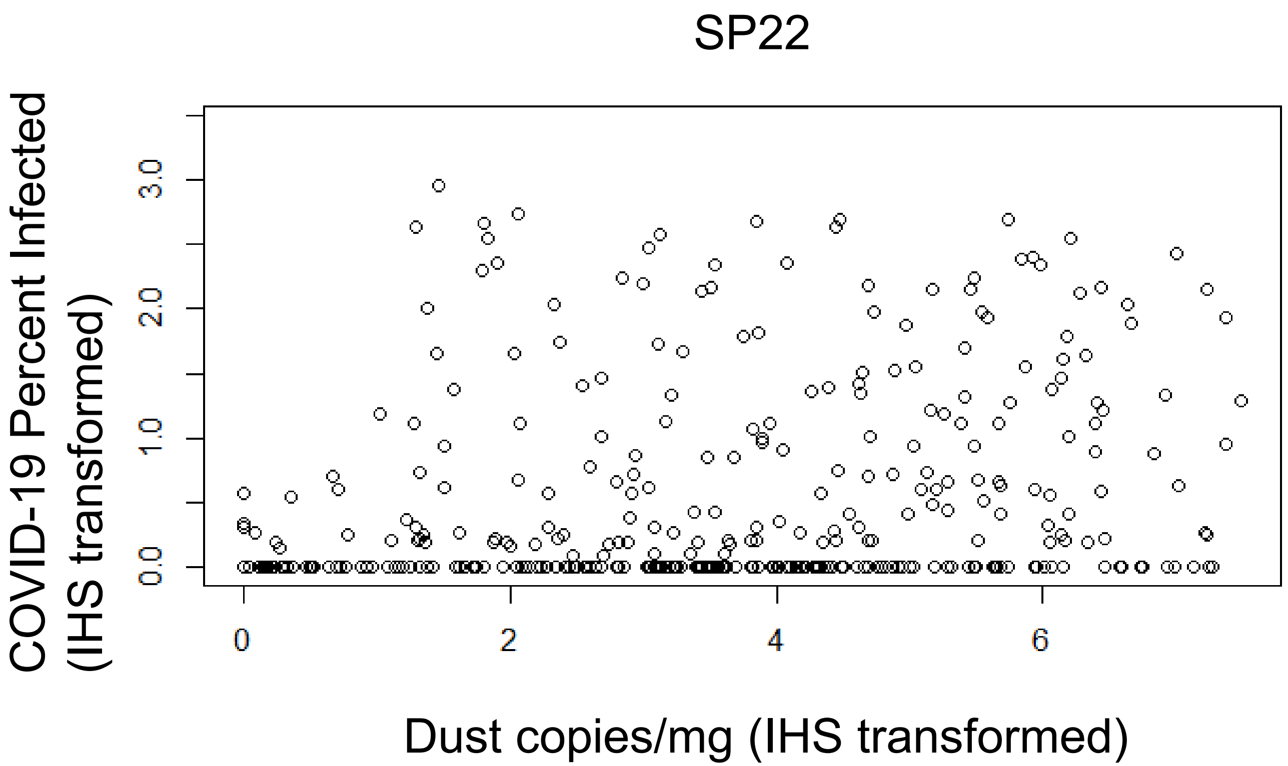
Pilot data from spring – Residence Hall



Can identify patterns across multiple residence halls and public buildings

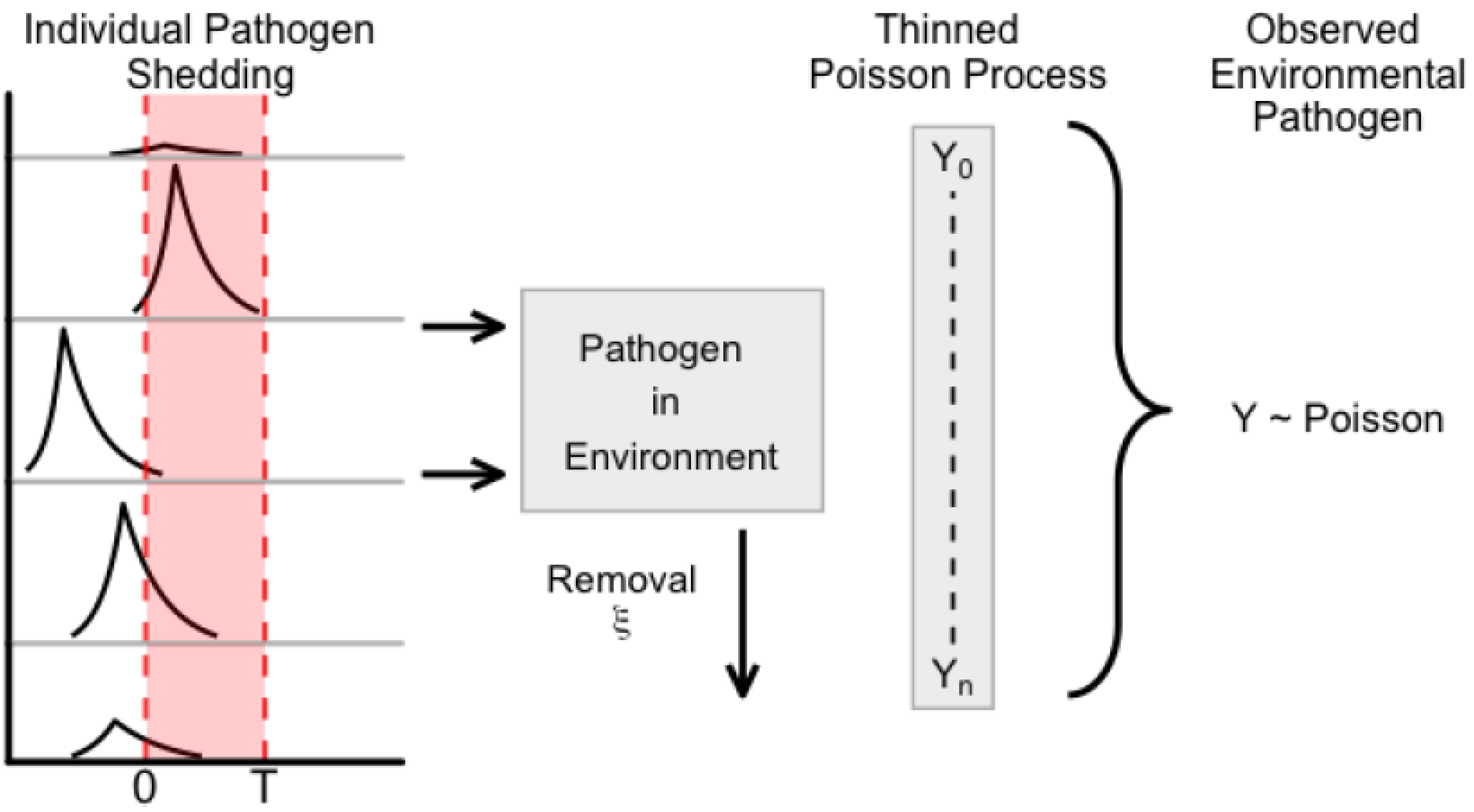


Correlations exist but data is messy



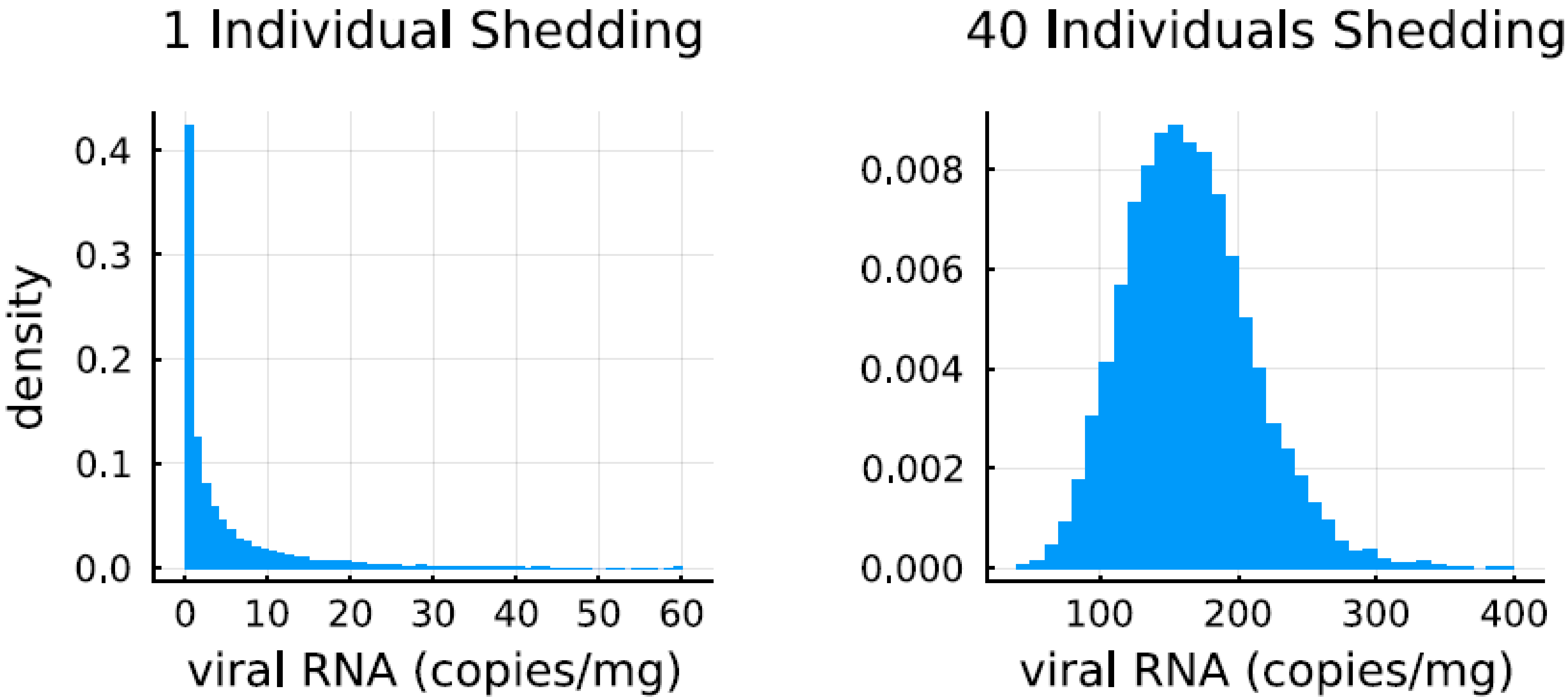
SARS-CoV-2 concentrations in dust vs. cases in the same building from spring 2022 ($R=0.22$, $p=0.00004$)

Statistical modeling helps



Wascher et al., 2024

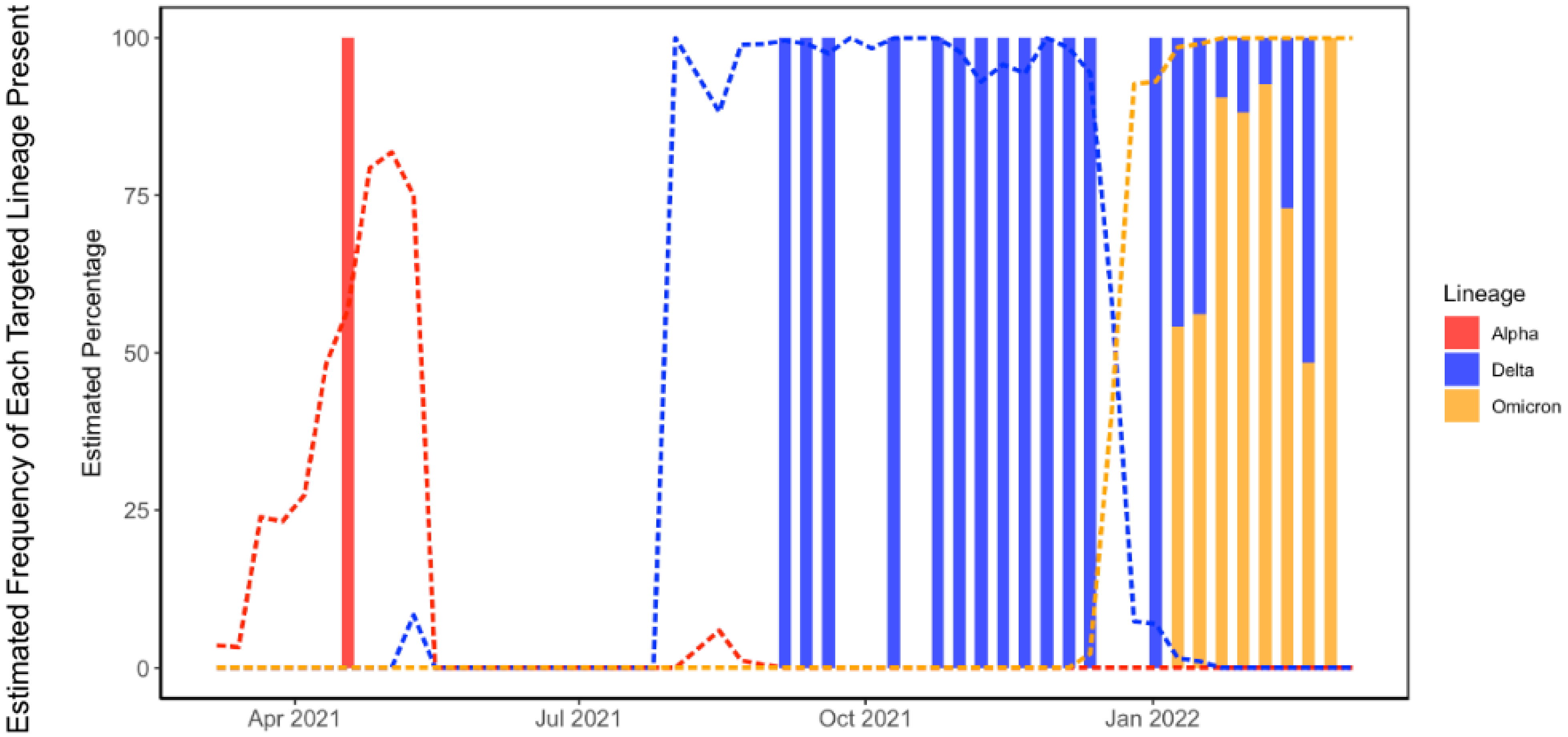
We can estimate disease prevalence



Wascher et al., 2024

Viral RNA values are based on Alpha variant

We can track variants across many buildings



Van Dusen et al., *PLOS One,* 2024

This can be applied to other viruses

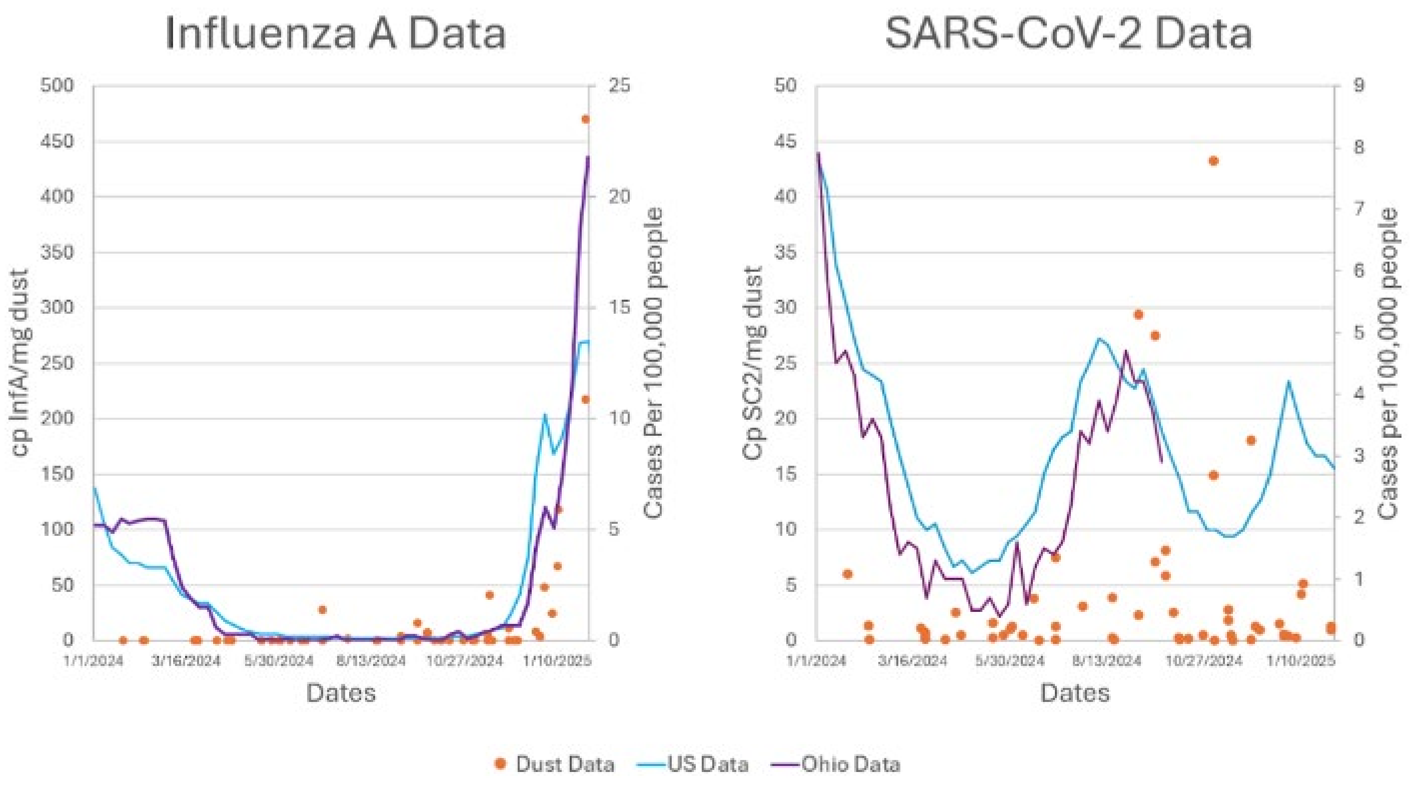
- 27 samples
- 54 viruses

Shamblin et al., *In Revision*

Distro A: Cleared for Public Release, AFRL/PA, AFRL-2025-5627, 11 Dec 25.

Viral concentrations in dust differ by virus

Figure 4a: Figure 4b:

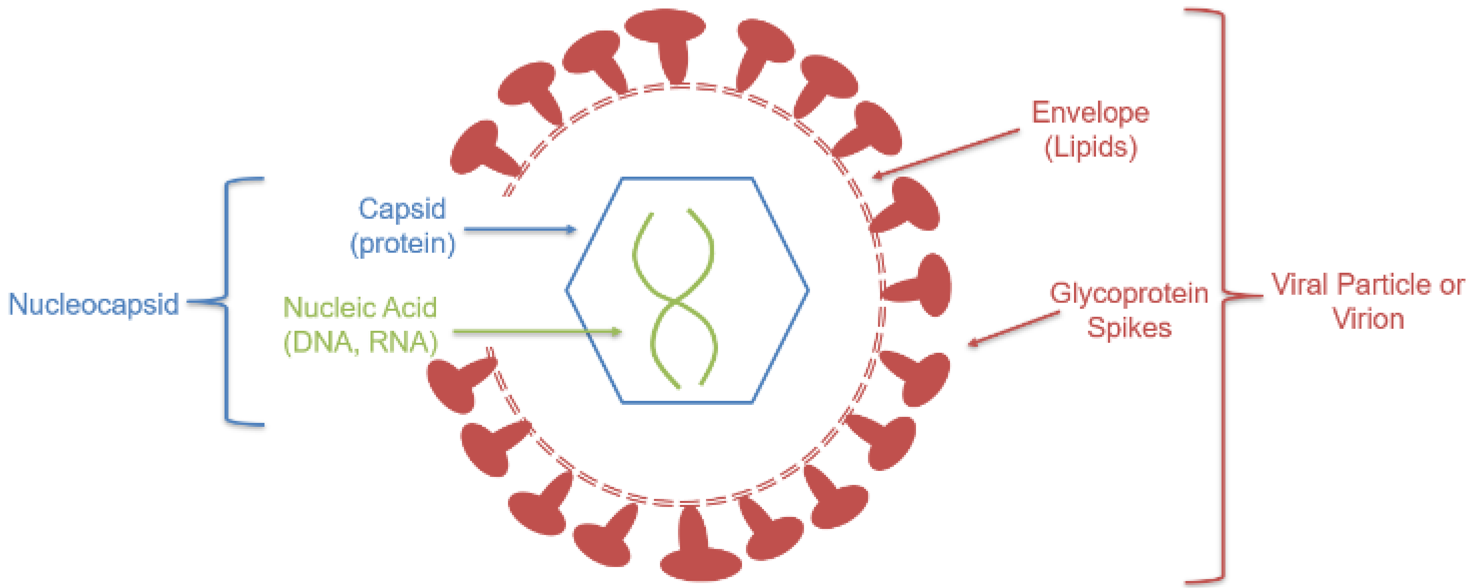


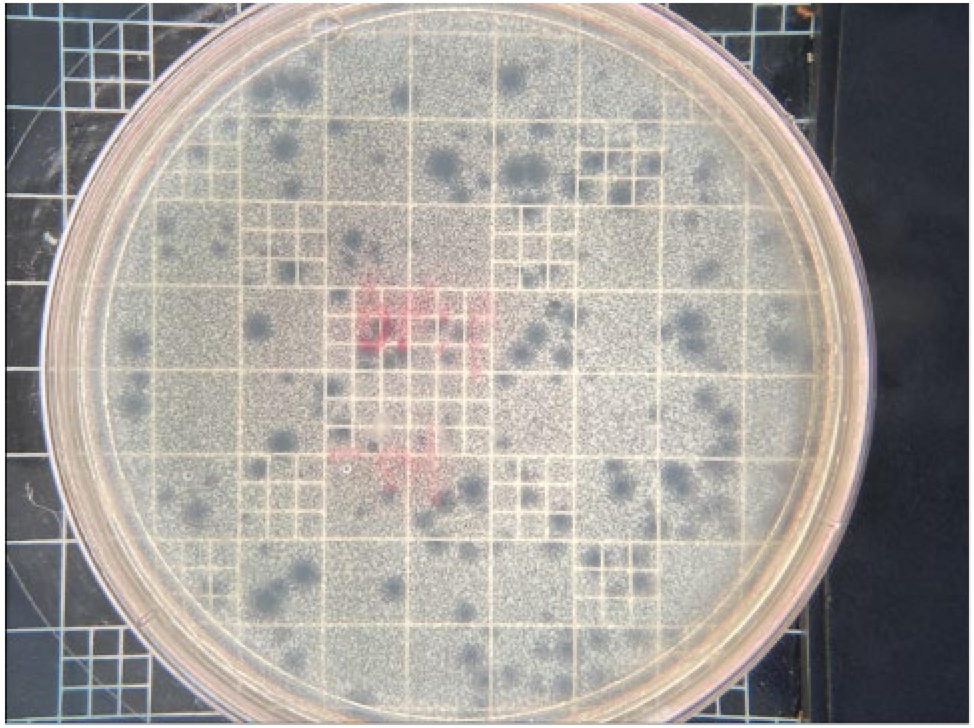
Shamblin et al., *In Revision*

Distro A: Cleared for Public Release, AFRL/PA, AFRL-2025-5627, 11 Dec 25.

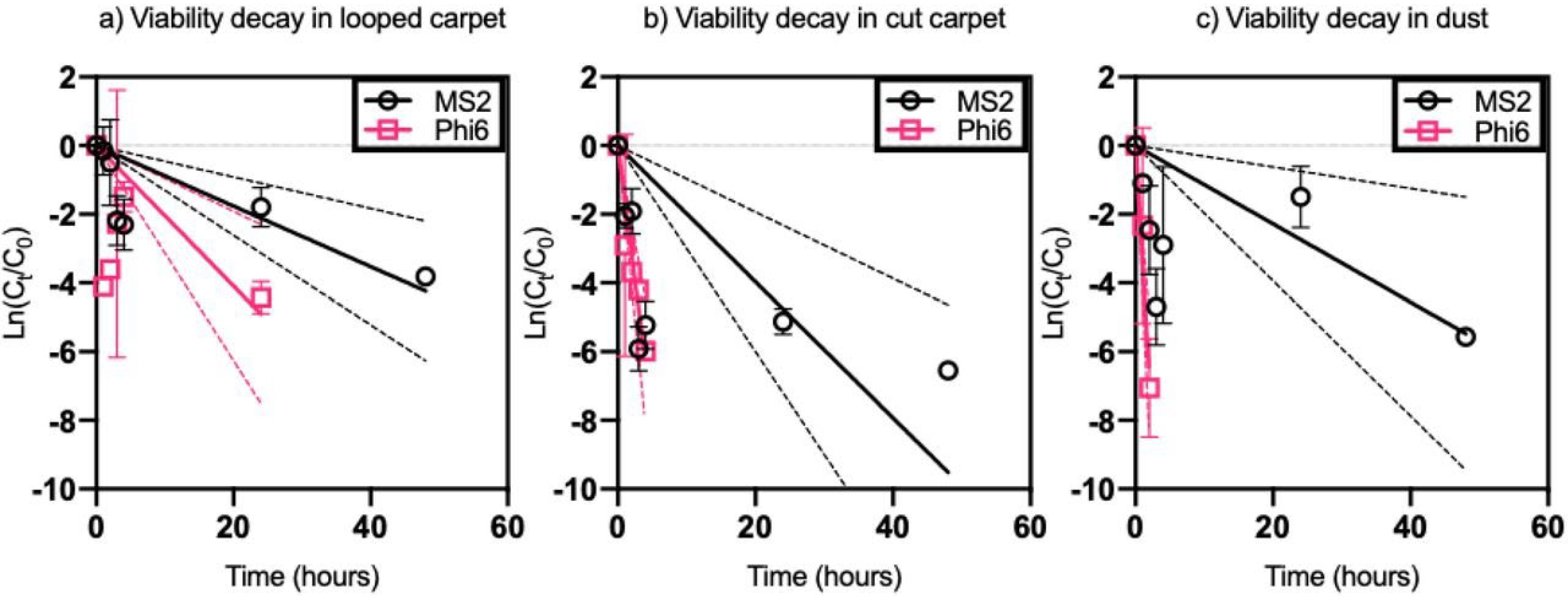
So what does this mean about viability in dust and on surfaces?

Essentially Nothing.



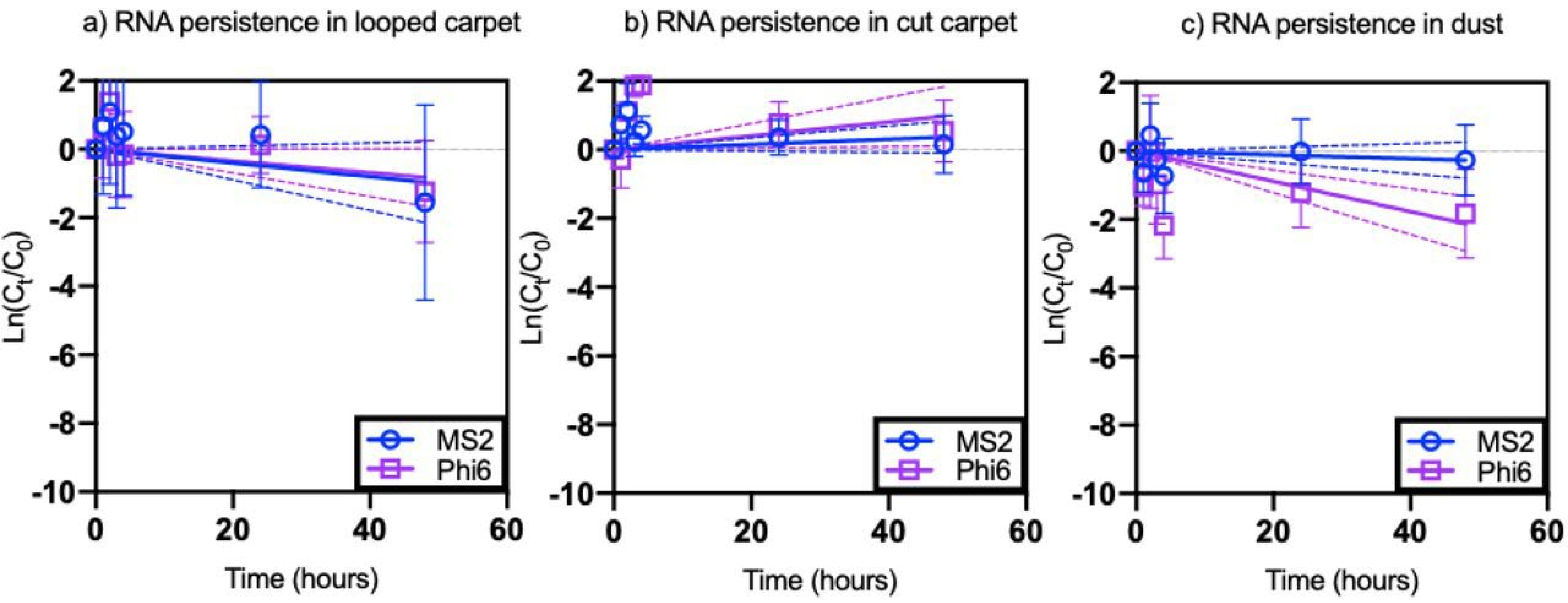


Enveloped viruses decay more quickly than non-enveloped



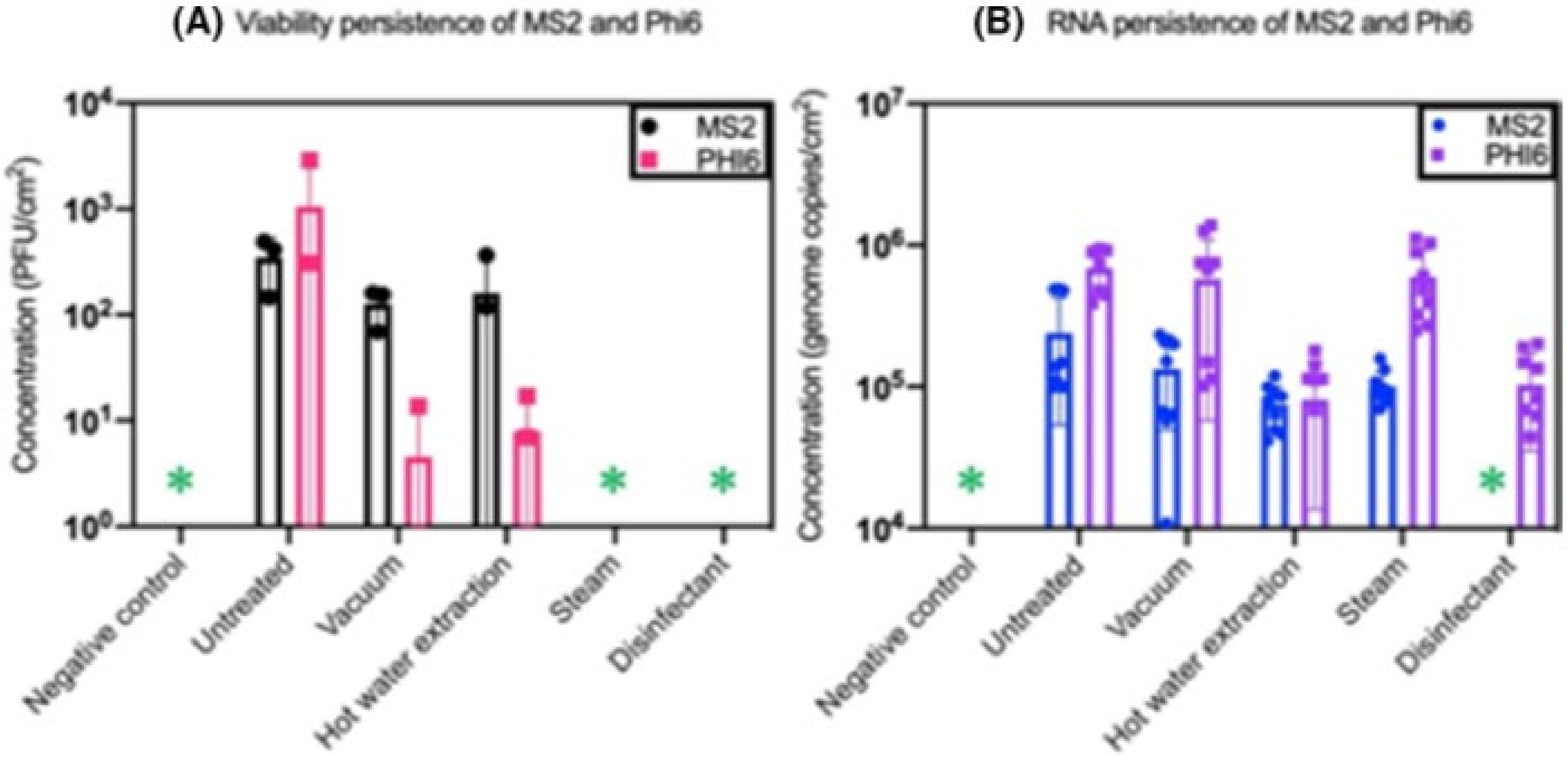
Nastasi et al., *Indoor Air,* 2022

RNA persists



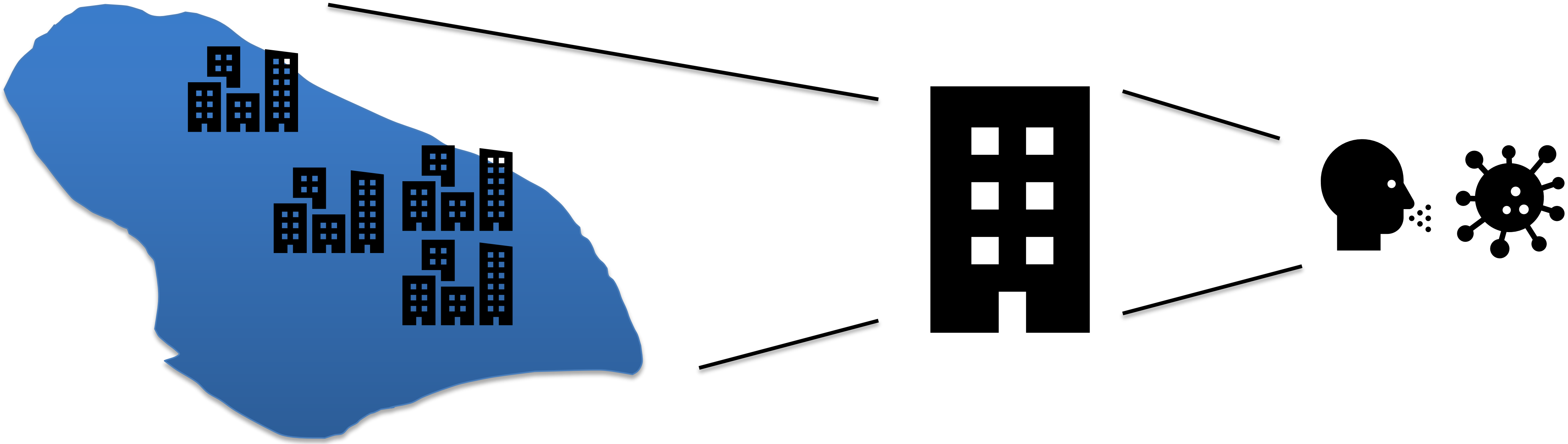
Nastasi et al., *Indoor Air,* 2022

Removal by cleaning methods vary

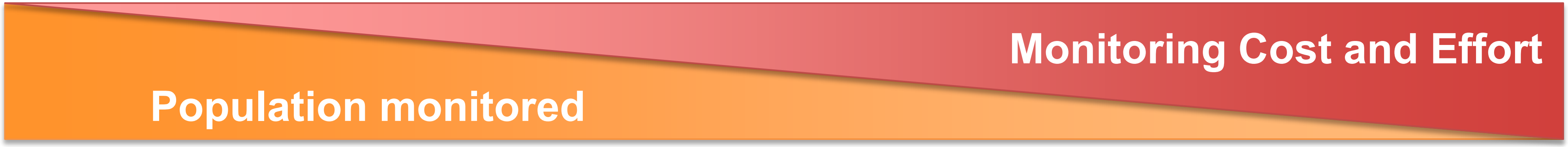


Nastasi et al., *Indoor Air,* 2022

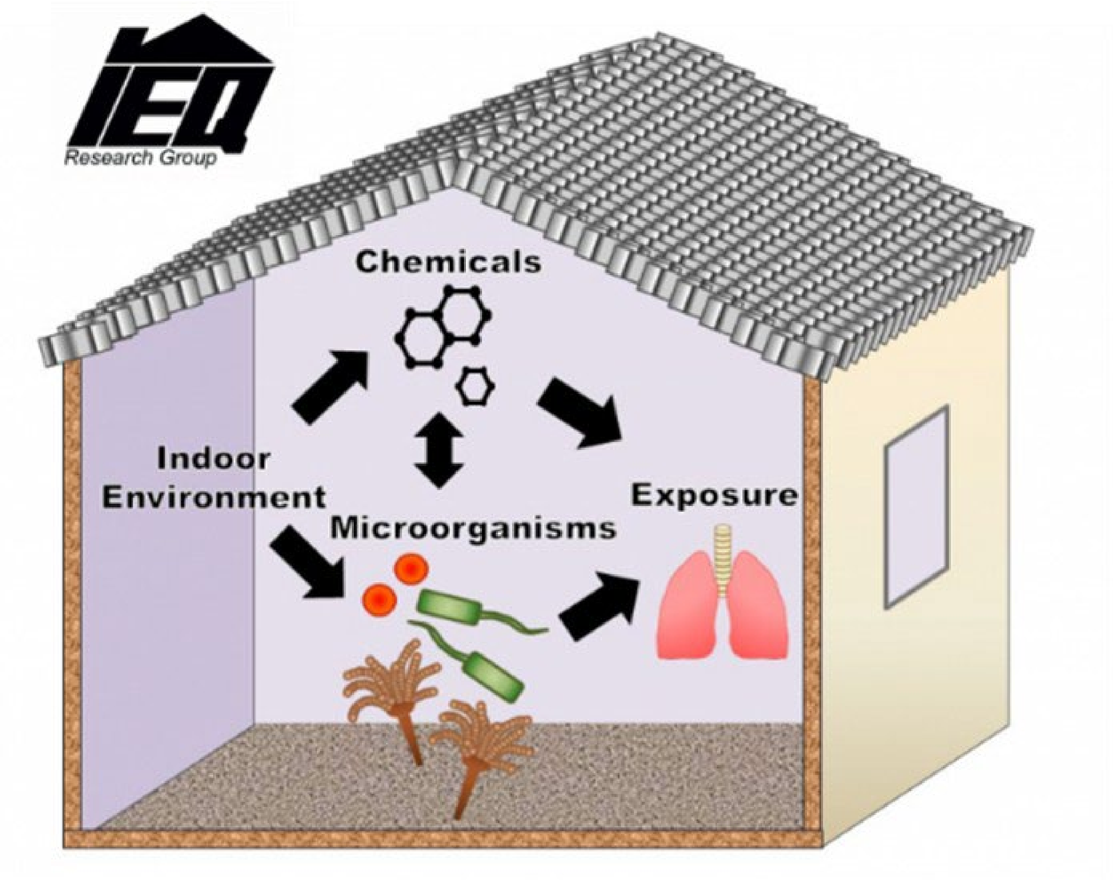
Dust monitoring: A new long-term viral monitoring tool



Solutions: Wastewater Monitoring | Building Dust Monitoring | Individual Testing

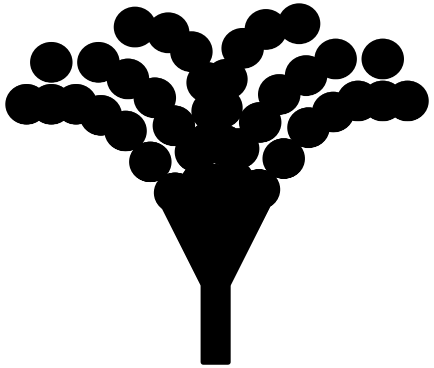


Part 2 Summary

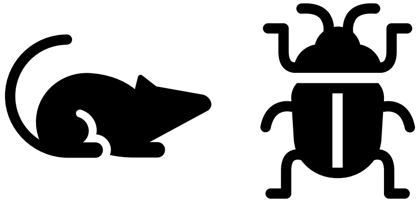


- We can look for pathogens in indoor spaces now that we know where to look

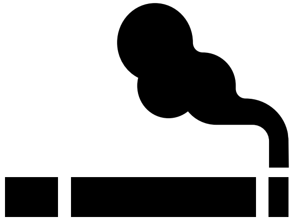
Part 3: Detection. Multifactorial interventions are necessary to address housing quality



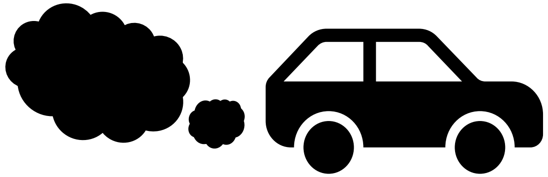
Mold/Dampness



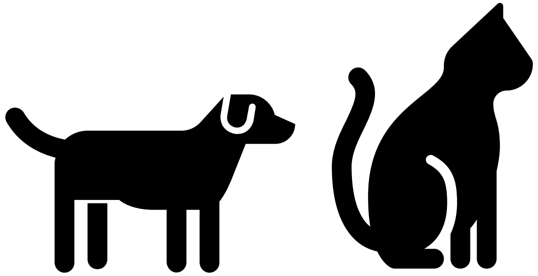
Pests



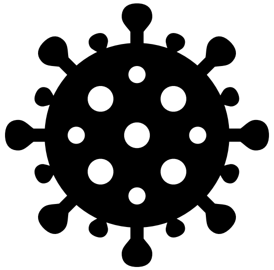
Environmental Tobacco Smoke



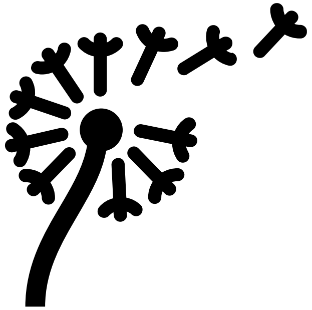
Pollution



Pets



Pathogens

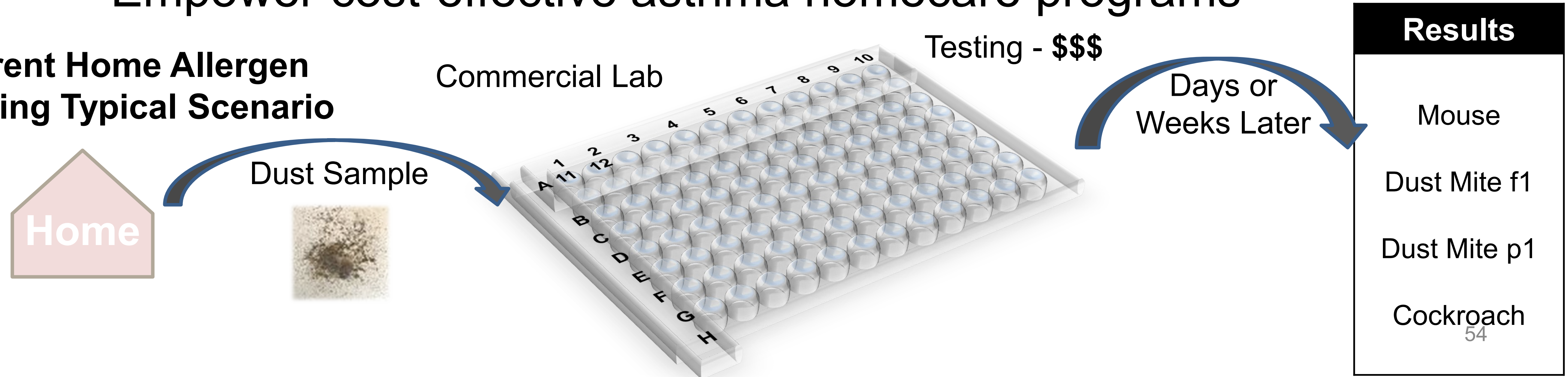


Pollen

We need improved identification of the hazards in each home for efficient resource allocation

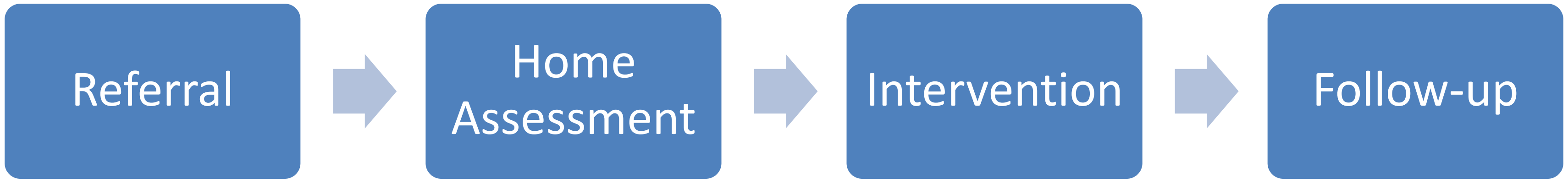
- Children sensitized and exposed to allergens have worse outcomes
- Need to be able to measure allergens in homes
  - Current methods are difficult and results are delayed
  - Empower cost-effective asthma homecare programs

Current Home Allergen Testing Typical Scenario

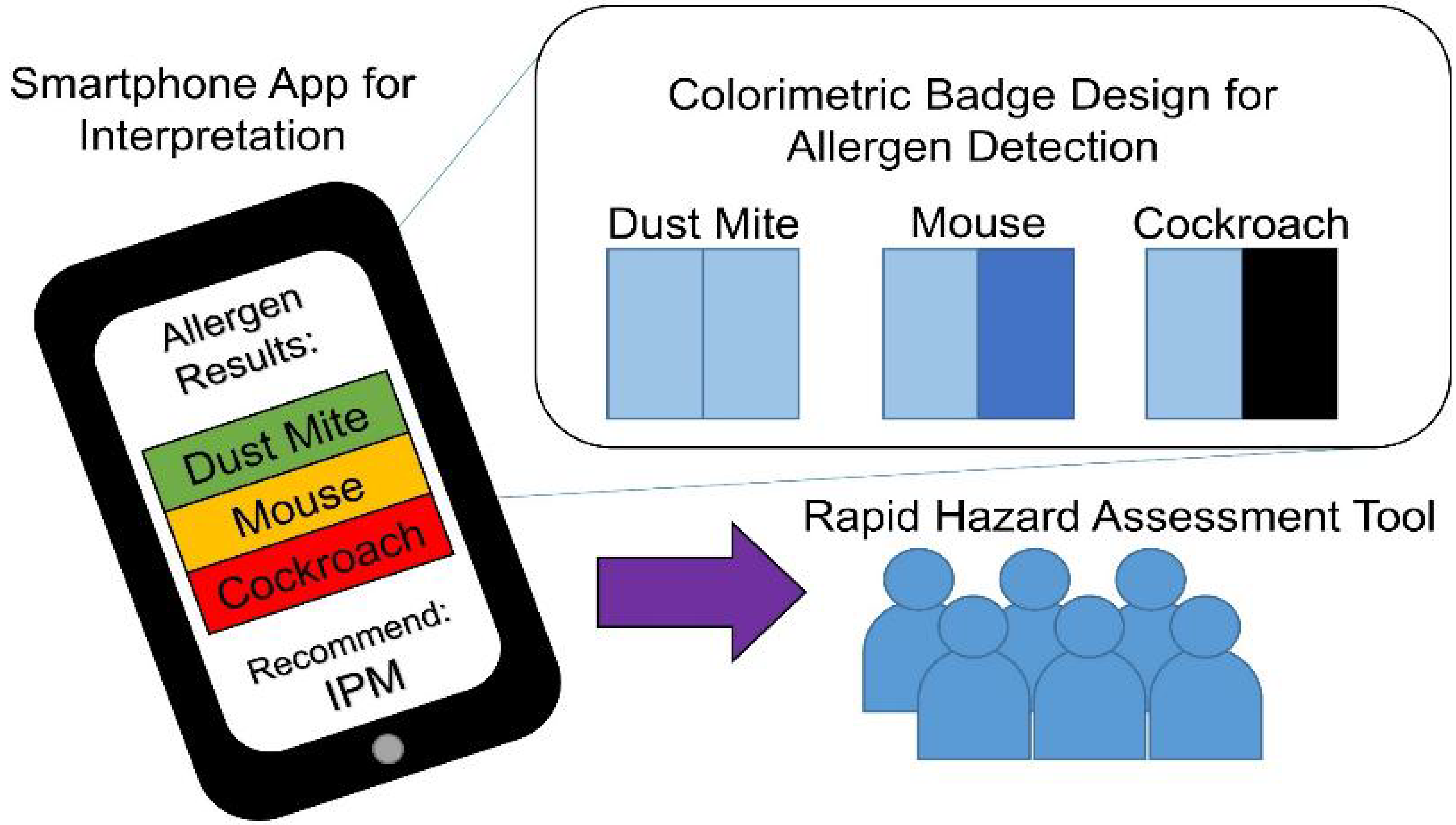


NCH Asthma Express Program Components

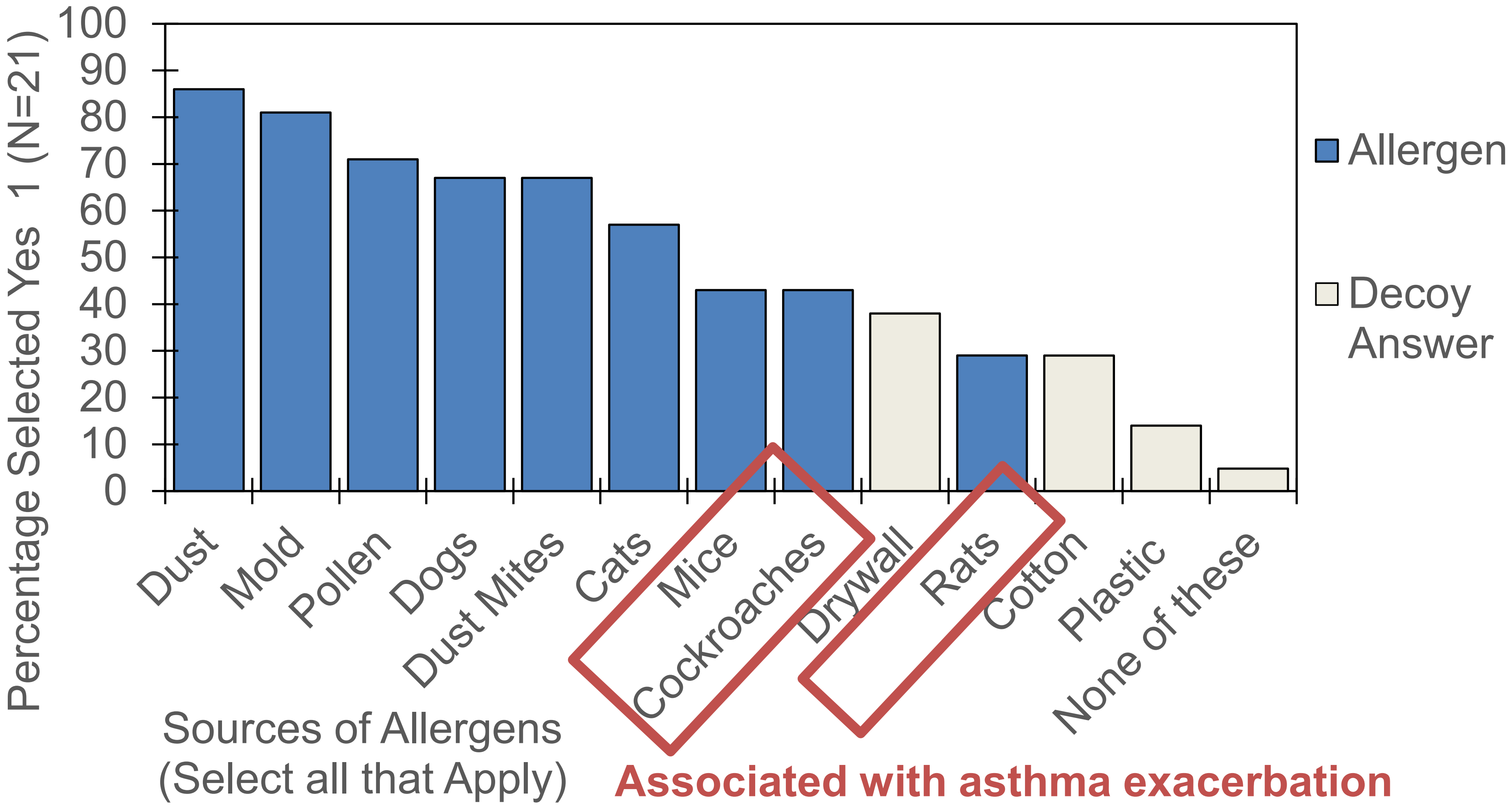
- Home assessments by nurses
- Environmental trigger identification (mold, dust, allergens)
- Education for patients and caregivers on asthma management
- Support for adherence to medication plans



Goal: Develop smartphone-based system for point-of-care allergen detection



Use of these system highlights need for education

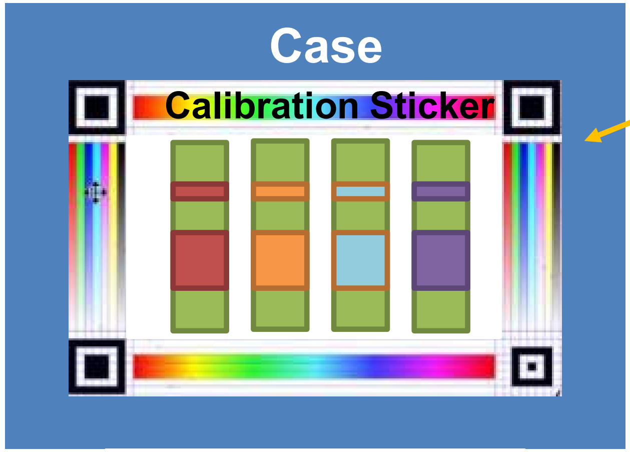


- 23% can define "allergen"
- 69% can list examples

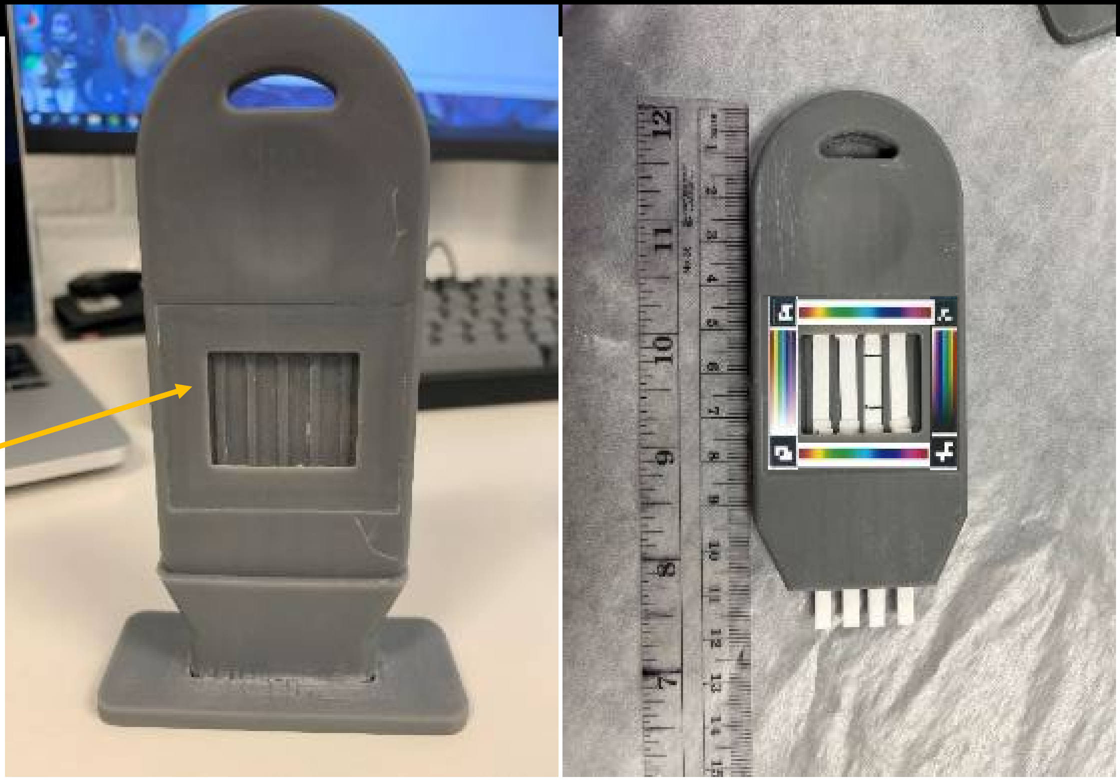
Young et al., *Pediatric Allergy, Immunology, and Pulmonology, 2024*

BREATHE-Smart Test Unit under development

- Case prototype printed
  - Produced by the Center for Design and Manufacturing Excellence (CDME) at OSU
  - Will house the sensor

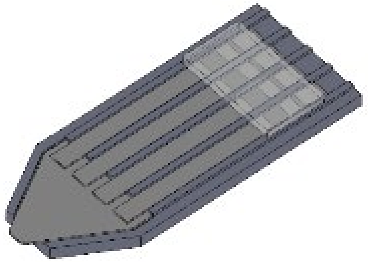


Results window



Complete sensor unit with case. Left: case only (3D-printed from synthetic resin), Right: the complete sensor inside the case

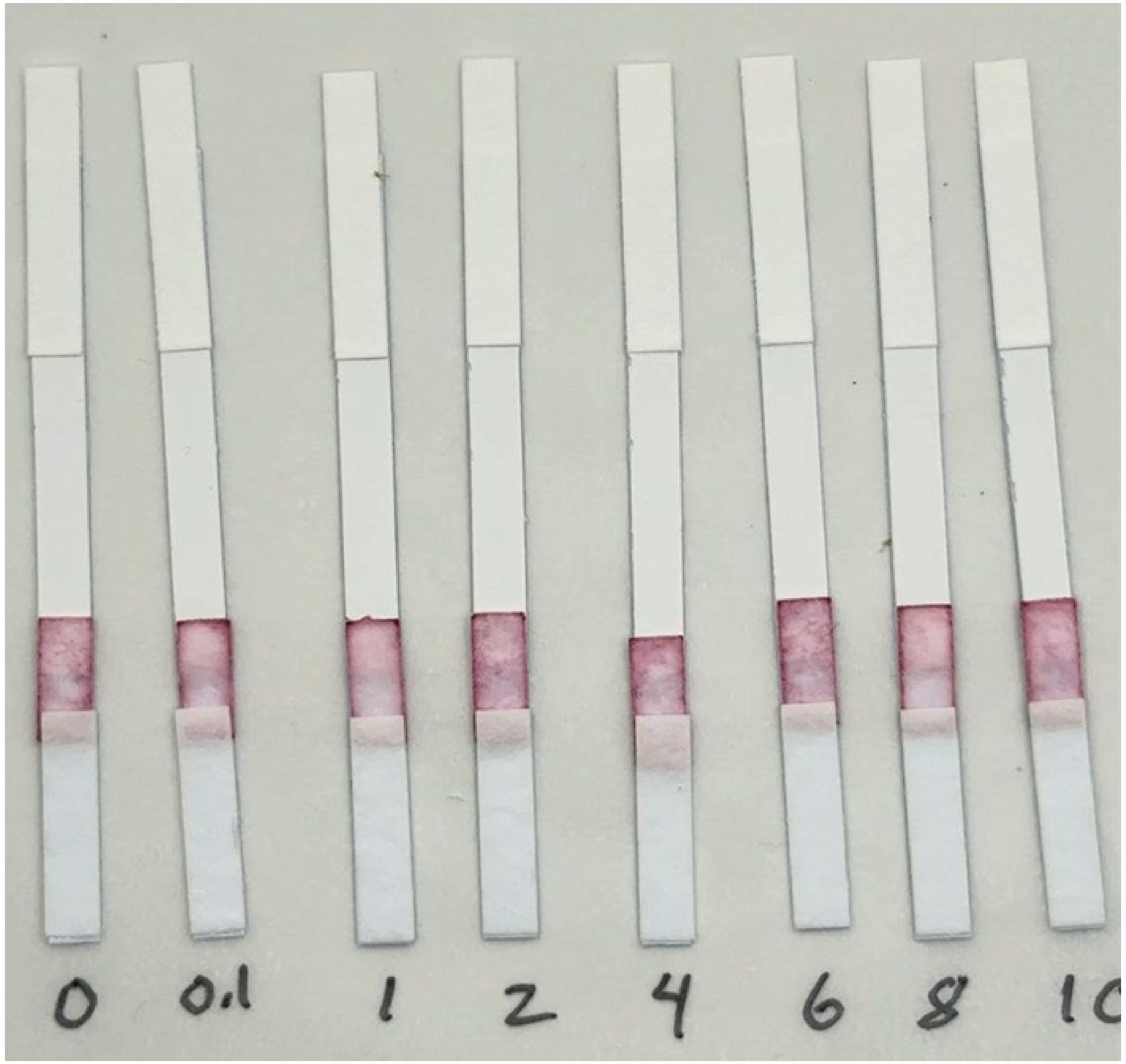
interior of the test unit (drawing)



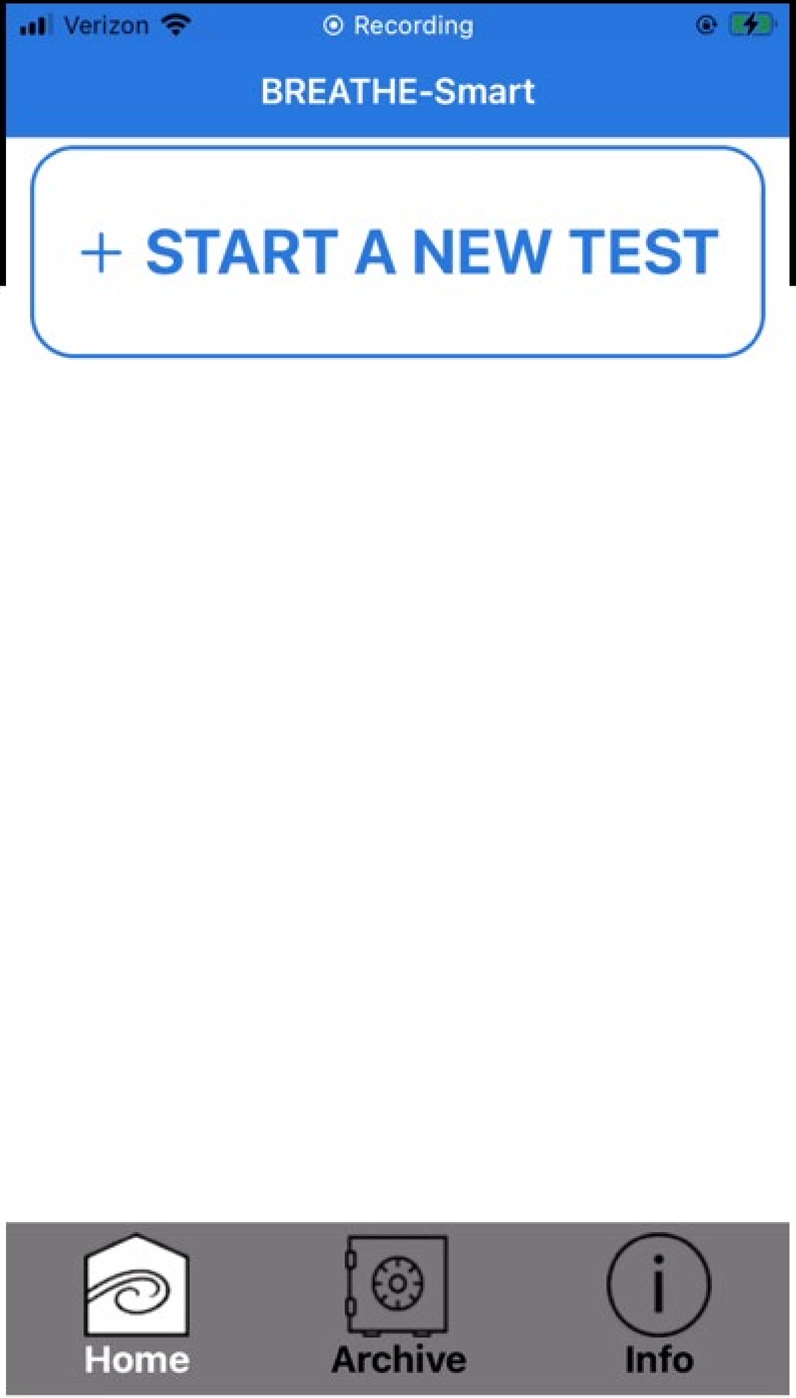
Walt VanCleave, CDME, 2021
Dannemiller and Panescu, 2021

Line dispenser Test Video (Cockroach Bla g 2)

NOTE
Video will not be active in handout



User-friendly App Development



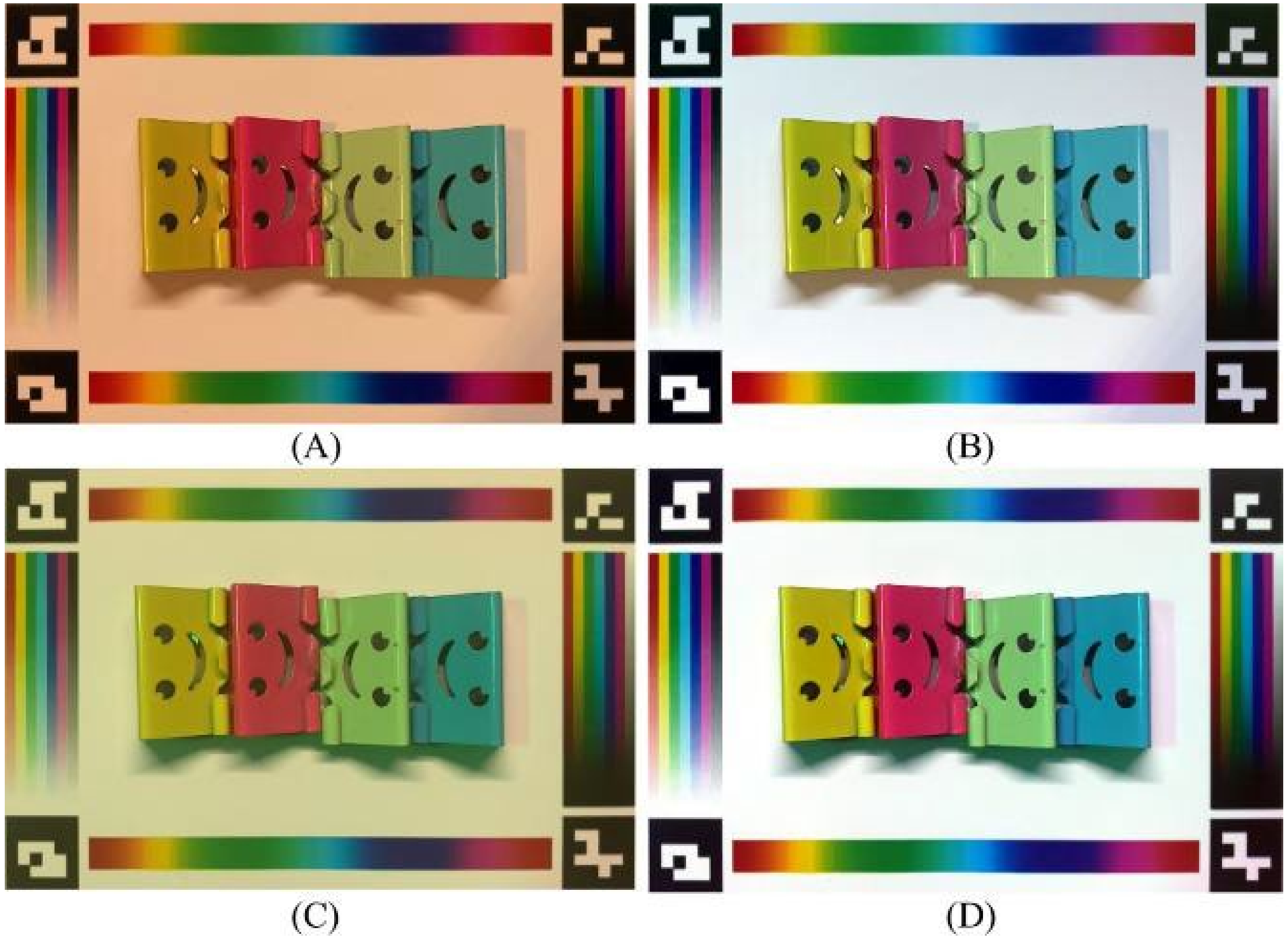
The app for the iPhone platform is completed

- Refinements
- Accessibility
- Will be tested with the sensor once it is completed

NOTE
Video will not be active in handout

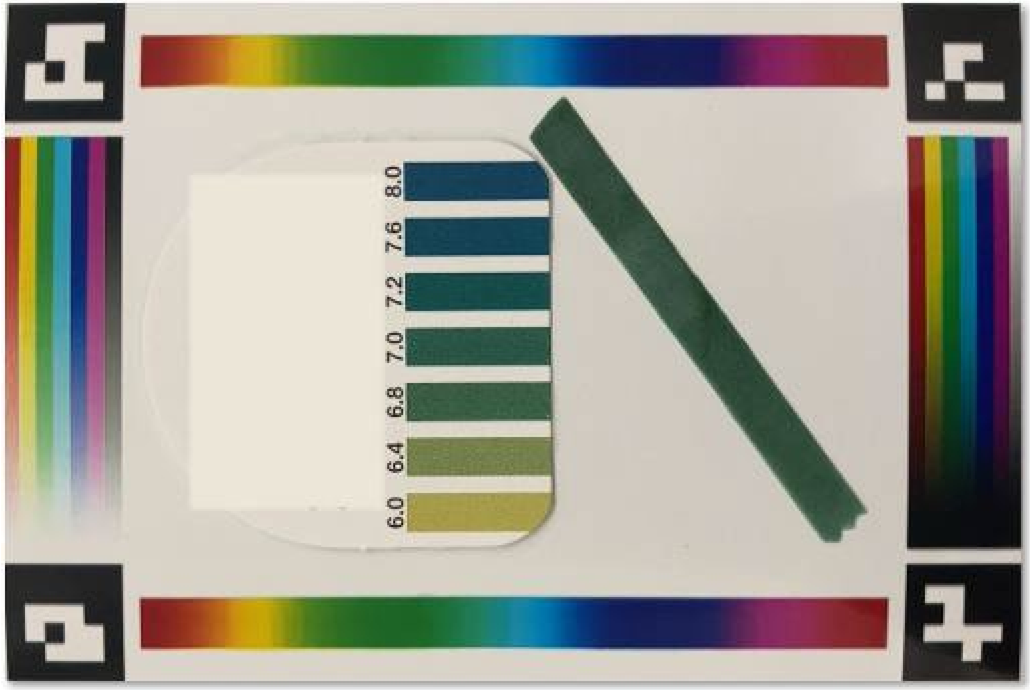
Song, Zhang and Qin, unpublished research, 2023

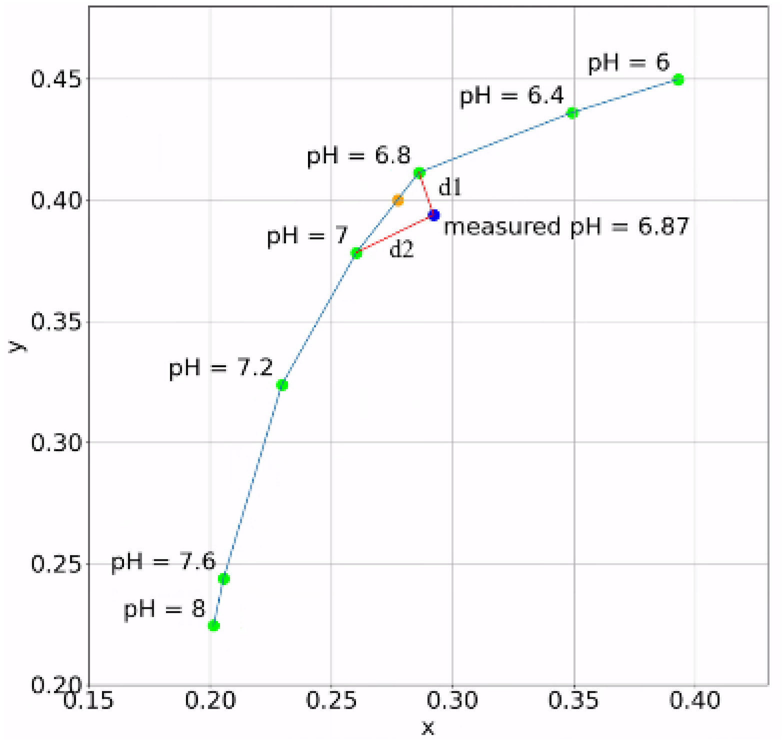
Correction of poor lighting conditions



Zhang et al., *PLOS ONE*, 2023

Improved color determination: pH strip demo



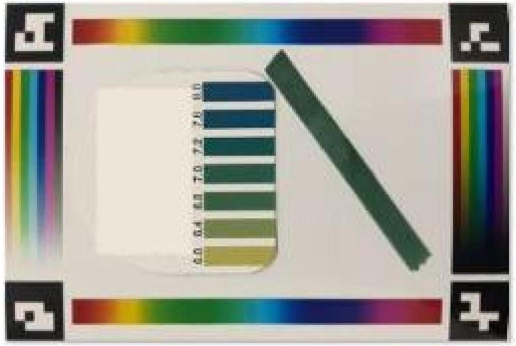


Zhang et al., *PLOS ONE*, 2023

Smartphone measurements were 3x better than human eye

	Reference–pH test paper and color chart co-located (color chart and pH test paper under the same illumination)			Color chart free pH reading (color chart and pH test paper under different illumination)	
Ref. pH value	w/o correction	w/ correction	avg. human readings	w/o correction	w/ correction
3.00	+0.16 (3.16)	+0.15 (3.15)	**-0.07** (2.93)	+0.16 (3.16)	**+0.13** (3.13)
6.86	-0.17 (6.69)	-0.20 (6.66)	**-0.06** (6.80)	-0.24 (6.62)	**-0.20** (6.66)
7.00	-0.10 (6.90)	-0.13 (6.87)	**-0.08** (6.92)	-0.10 (6.90)	**-0.09** (6.91)
7.80	**+0.05** (7.85)	+0.07 (7.87)	+0.17 (7.97)	+0.09 (7.89)	**+0.06** (7.86)
9.00	**+0.13** (9.13)	-0.15 (8.85)	+0.45 (9.45)	-0.22 (8.78)	**-0.20** (8.80)
9.18	+0.12 (9.30)	**0.00** (9.18)	+0.67 (9.85)	-0.06 (9.12)	**-0.04** (9.14)
MAE	**0.12**	**0.12**	0.37	0.15	**0.12**

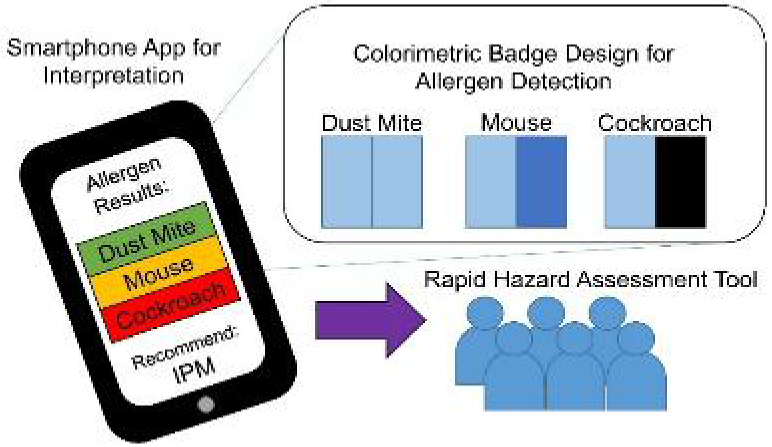
https://doi.org/10.1371/journal.pone.0287099.t002



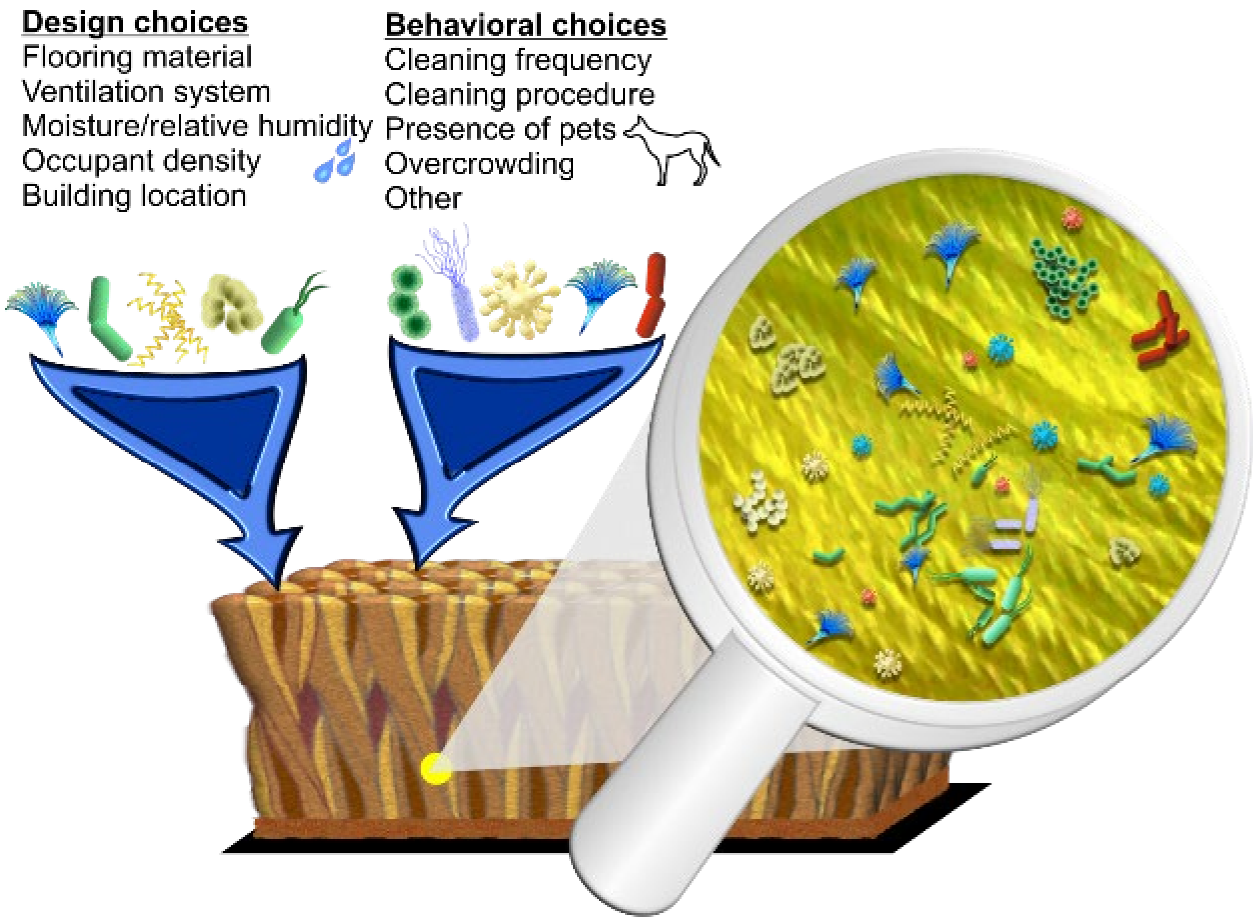
Zhang et al., *PLOS ONE*, 2023

Part 3 summary: A new tool for asthma homecare programs

- Patient education: Many common allergens associated with asthma exacerbations are underrecognized
- Lateral flow assays offer opportunity for point-of-care allergen testing
- Smartphone technology can improve measurement accuracy



Summary: Time for application to support a Healthy Indoor Microbiome



Dannemiller, *mSystems*, 2019

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The Ohio State University

Colleagues
Students
Study participants
Custodial Staff

Collaborators: Matt Perzanowski, Adnan Dijvan, Luis Acosta, Seth Faith, Mike Sovic, Austin Shamblin, Joe Tien, Matt Wascher, Justin Greaves, Aaron Bivins, Mikkel Quam, and others

Questions?

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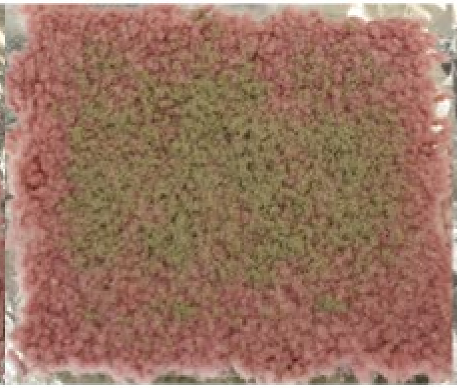
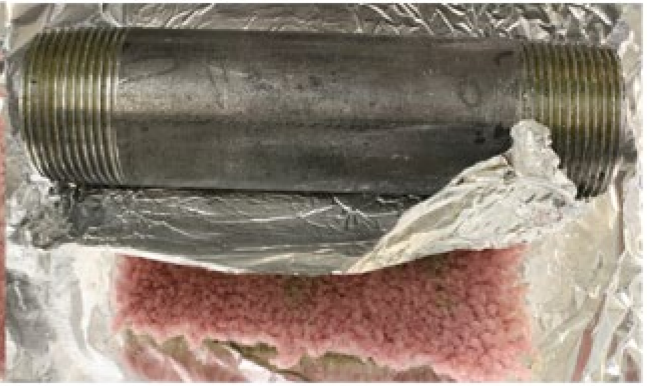
@KarenCDannemill

Dust is embedded in carpet

10 cm x 10 cm
carpet coupon



Apply dust

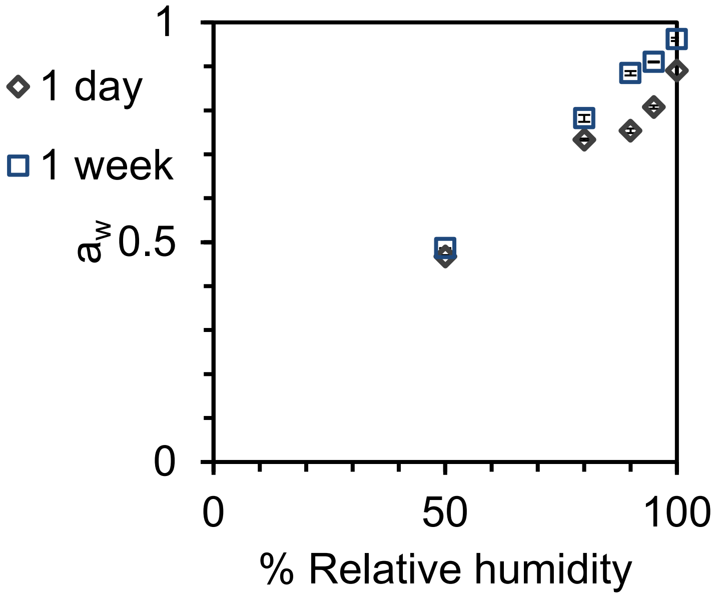


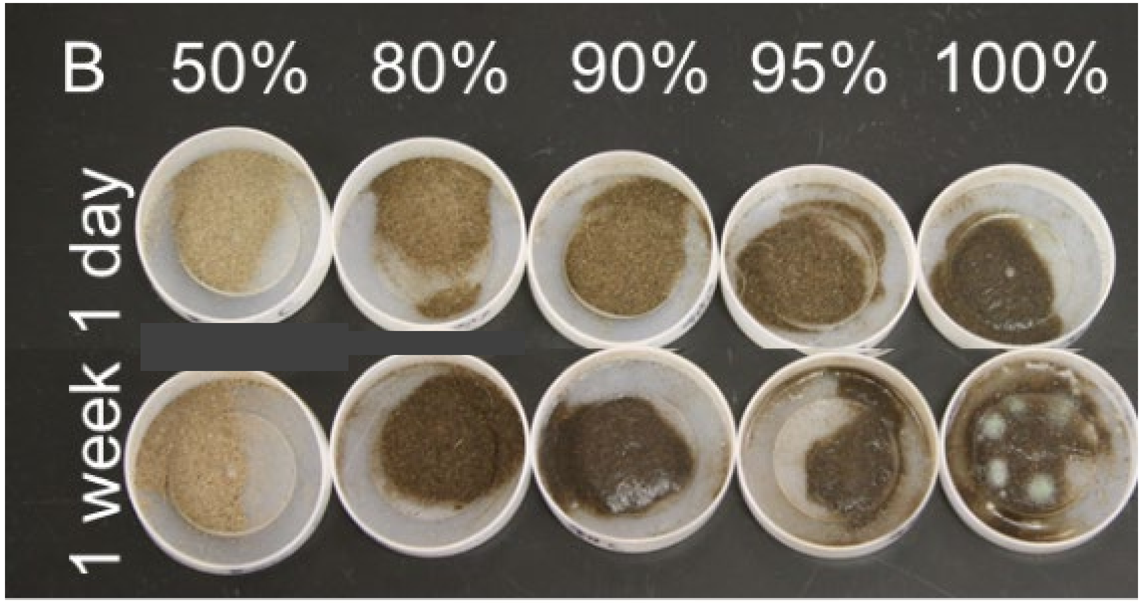
Embed dust with modified ASTM
F608−13 method

Dust is embedded

Place carpet coupon in temperature- &
relative humidity-controlled chamber

Water activity (a_w) of dust equilibrates quickly with RH

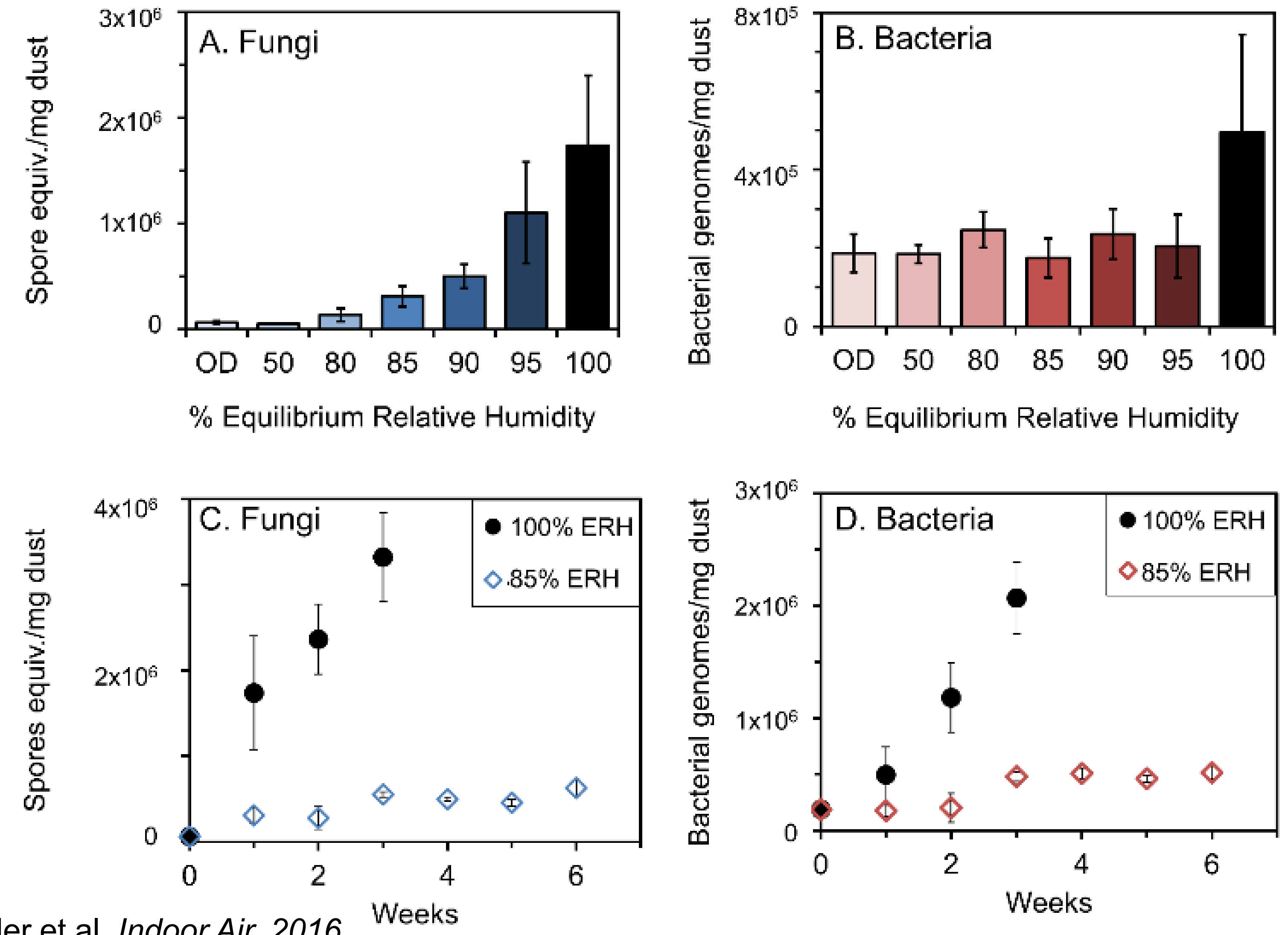




$$a_w = \frac{p_{dust}}{p_{water}}$$

$$Equilibrium\ RH = a_w \times 100\%$$

Microbial growth occurs above 80% relative humidity

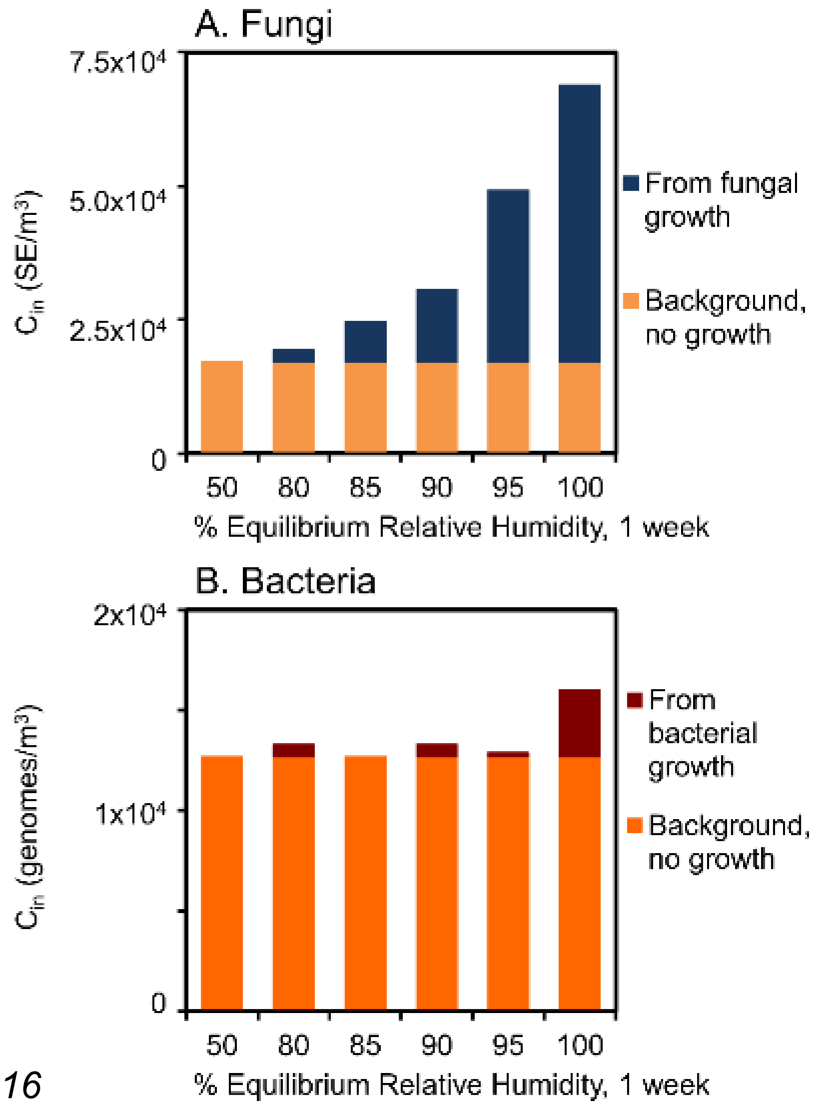


Dannemiller et al. *Indoor Air, 2016*

Moisture is the limiting factor for growth

Nutrient/ Salt	Dissolvable amount in dust (mg/kg dust)	Estimated amount needed to support growth (mg/kg dust)
C	35000	7.2
N	5.7	1.3
P	7.9	0.22
S	9.1	0.058
Na	6300	-
K	2100	-
Ca	1600	-
Mg	220	-
NH_4	160	-
Cl	2400	-

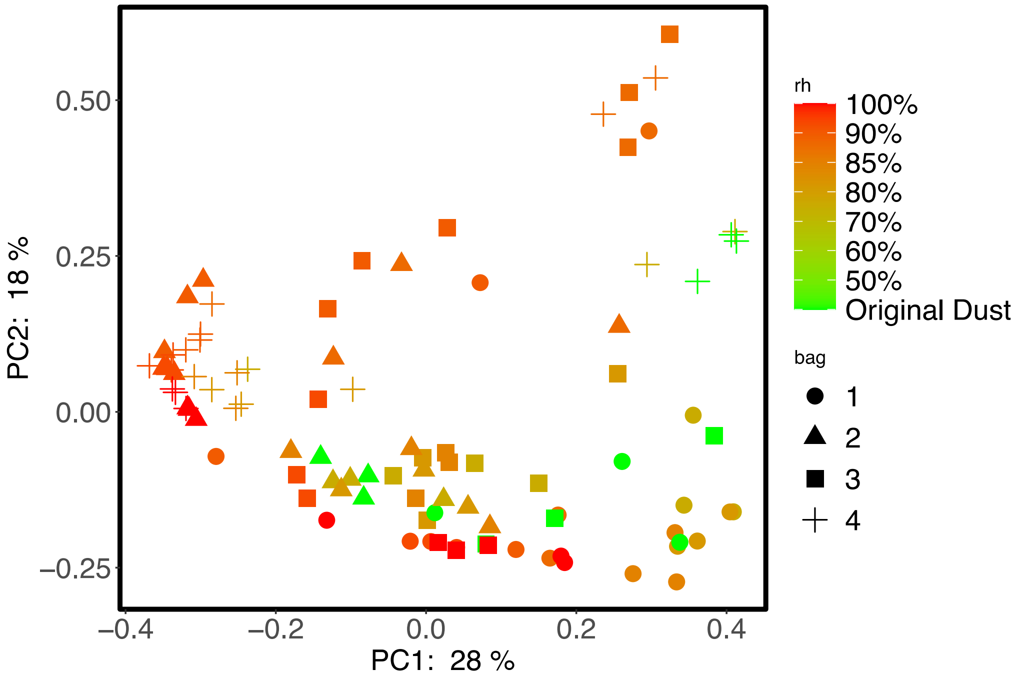
Growth in dust contributes to human aerosol exposure



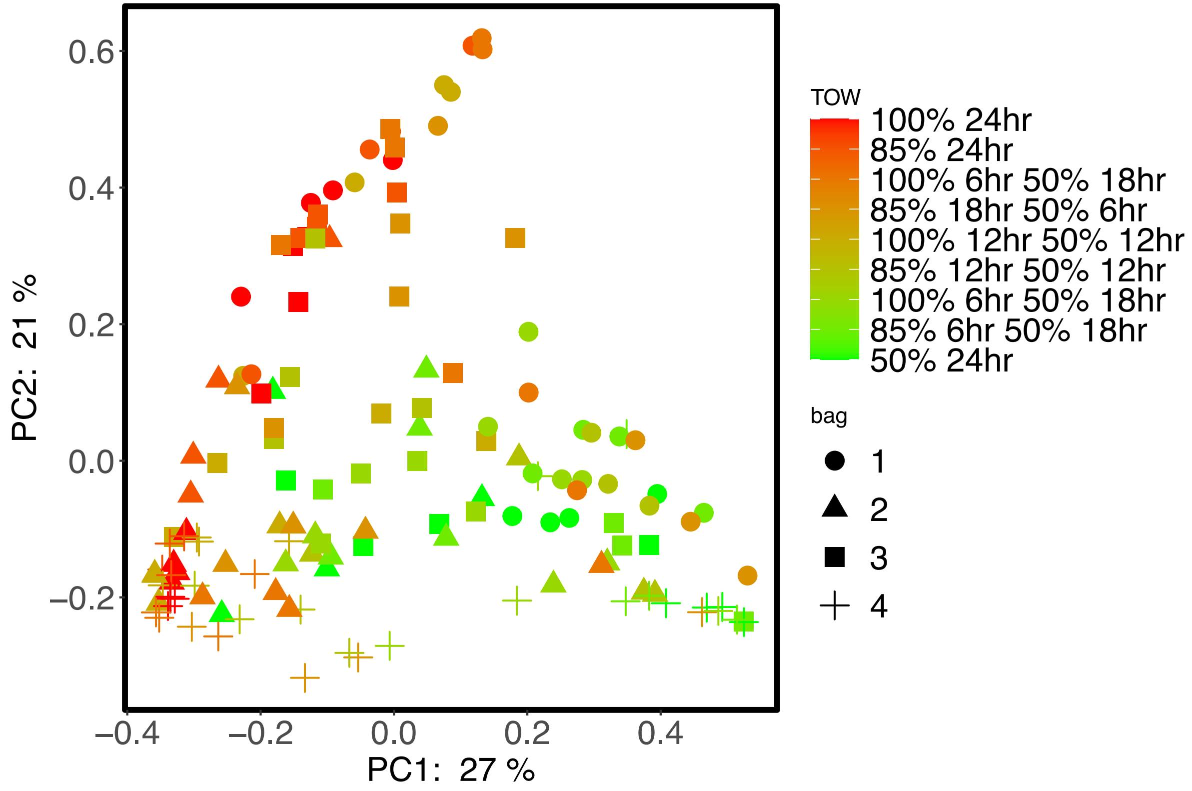
Dannemiller et al. *Indoor Air, 2016*

Species do change in a specific environment

(A) 2-Week Incubation Samples



(B) Time-of-Wetness Samples

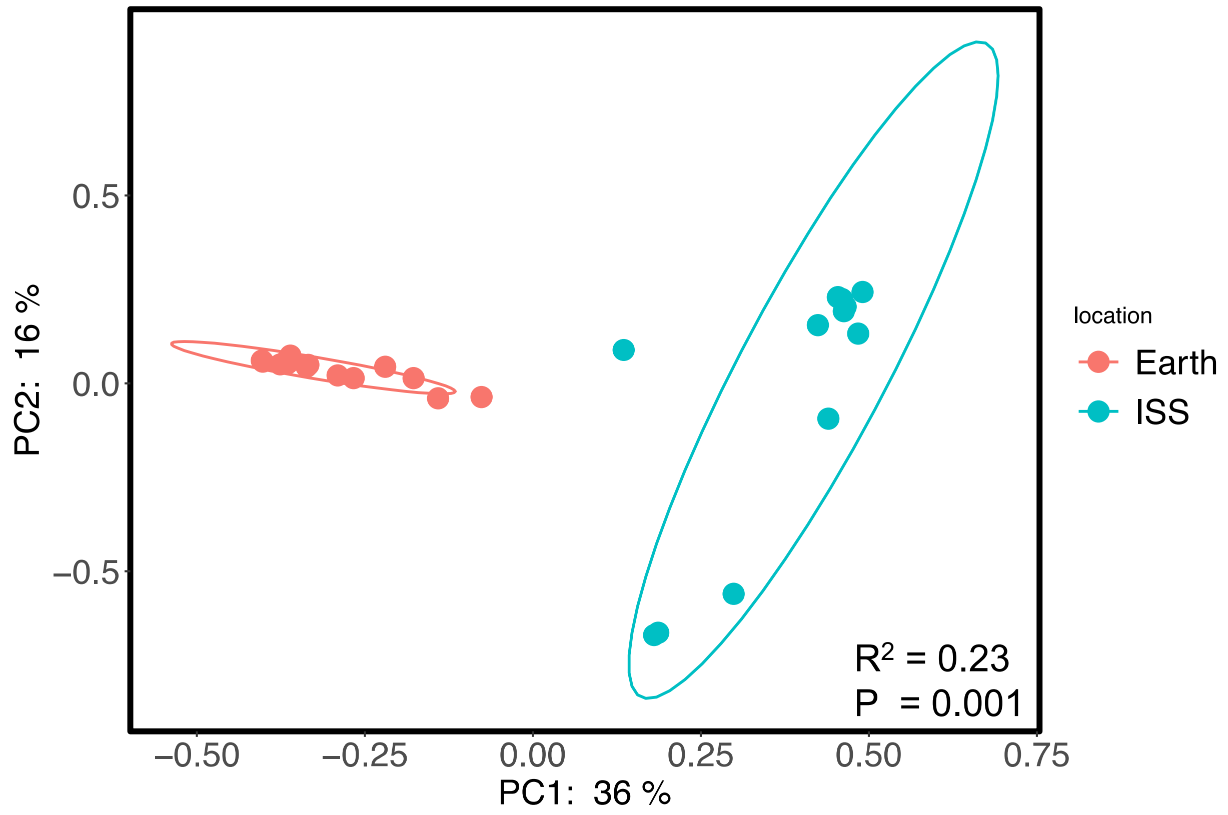


Nastasi et al. *Scientific Reports.* 2024.

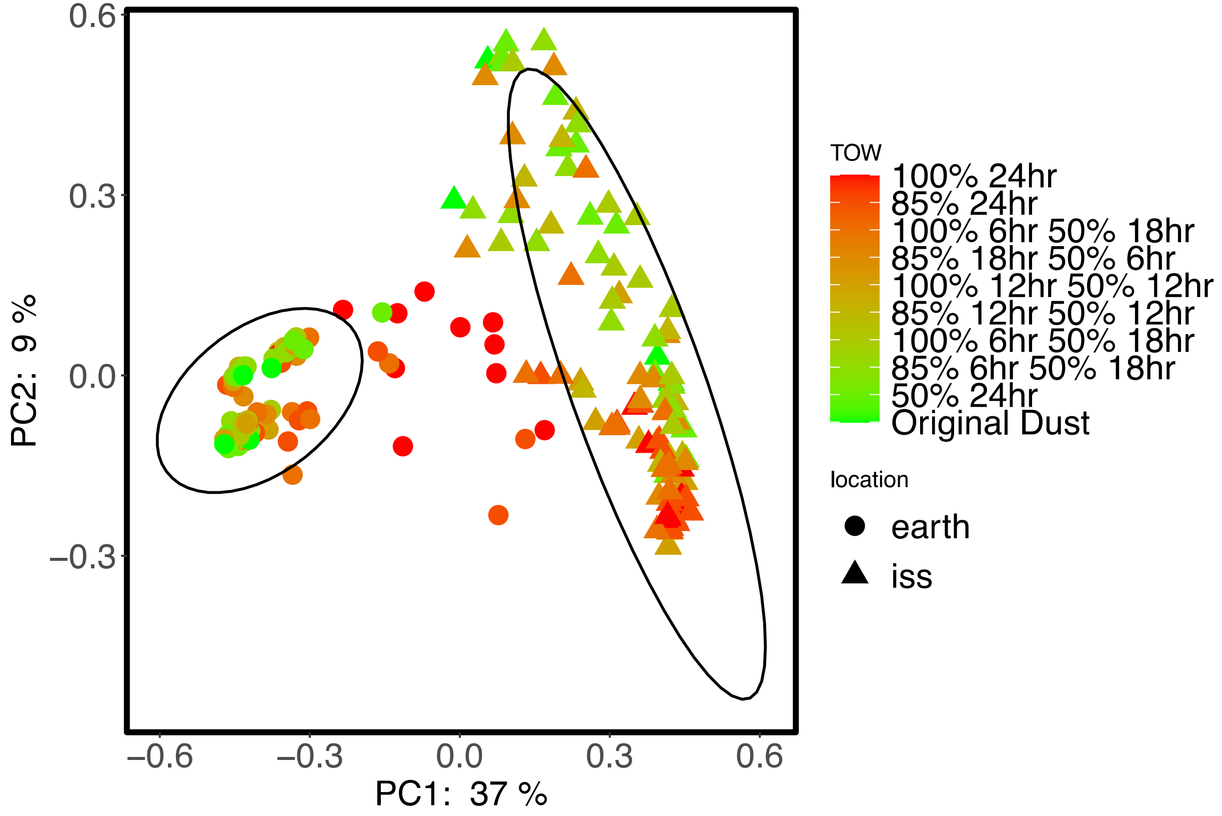
Comparison to Earth

Earth-ISS Fungal Community Comparisons

(A) Original Dust Samples

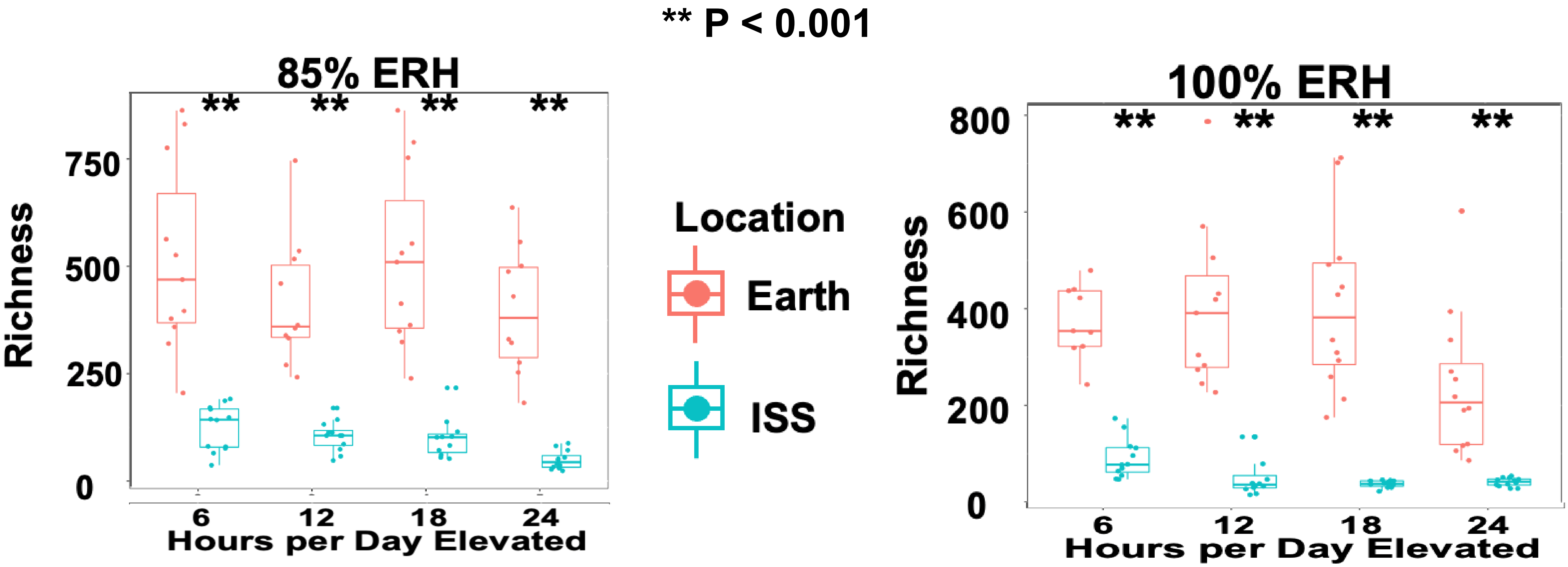


(B) Time of Wetness Samples



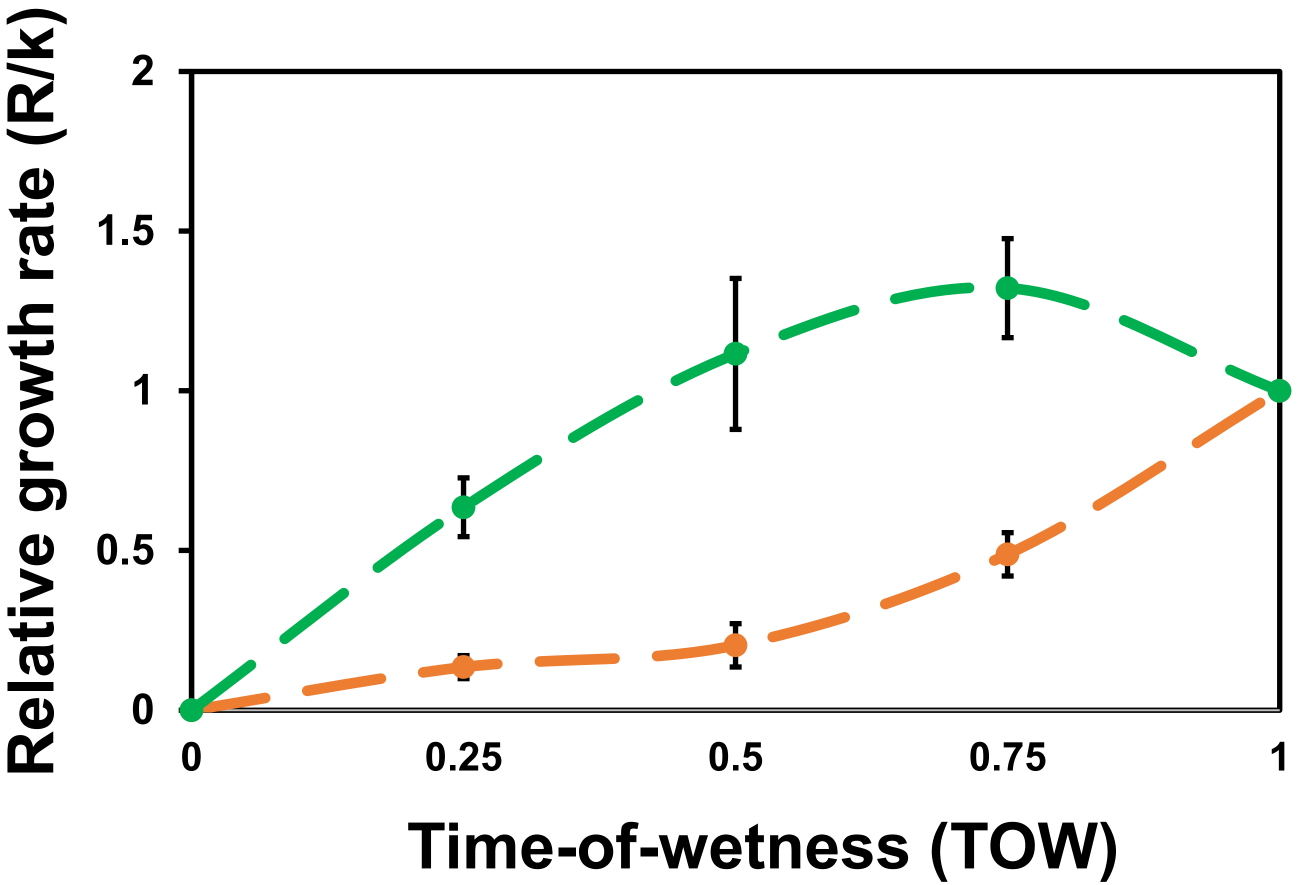
Nastasi et al. *Scientific Reports.* 2024.

Fungal alpha diversity is significantly lower in ISS dust compared to Earth dust at all ERH conditions and times



Nastasi et al. *Scientific Reports.* 2024.

Growth can be modeled using the time-of-wetness framework, even if RH fluctuates



85% ERH

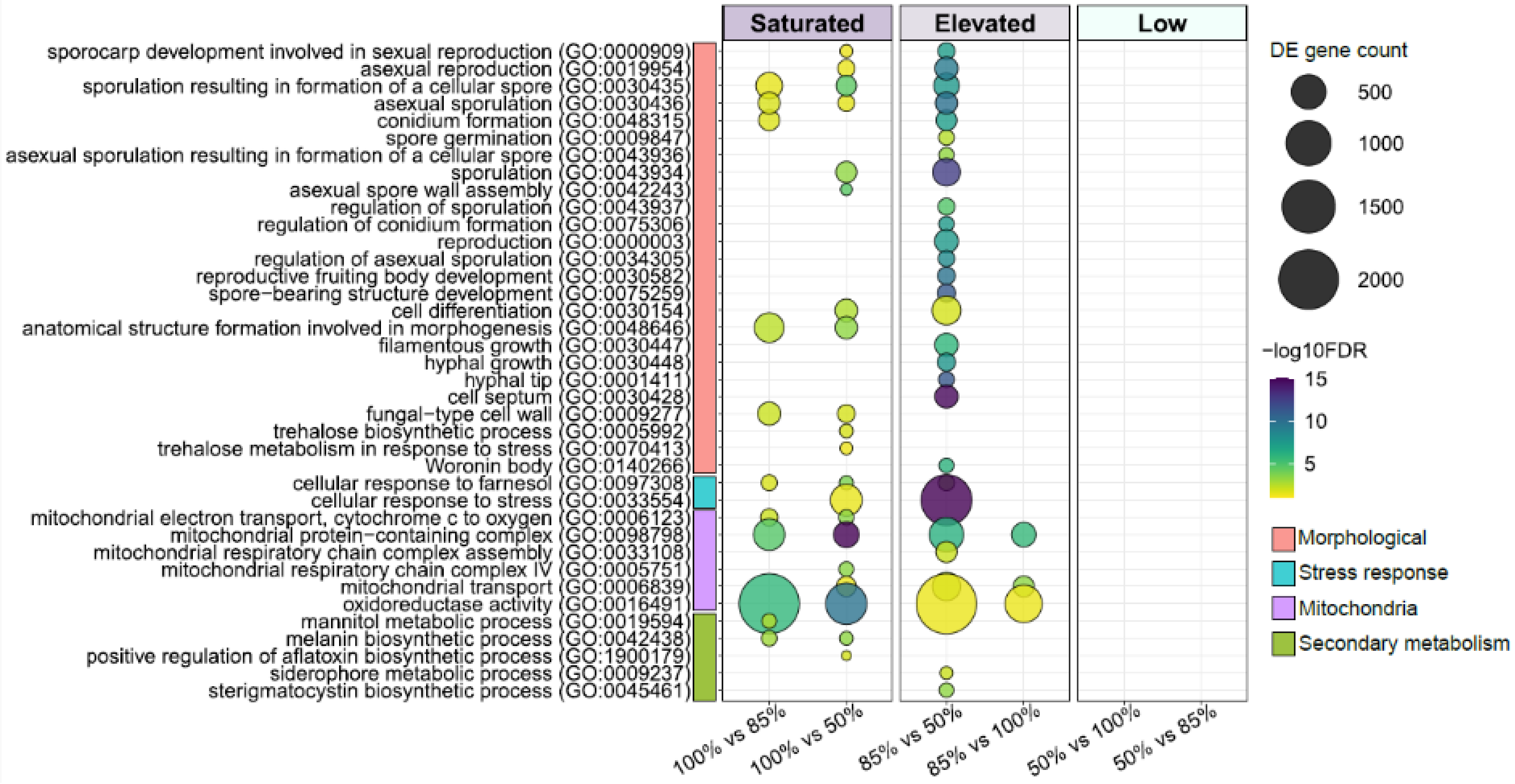
Activation Limited Growth

100% ERH

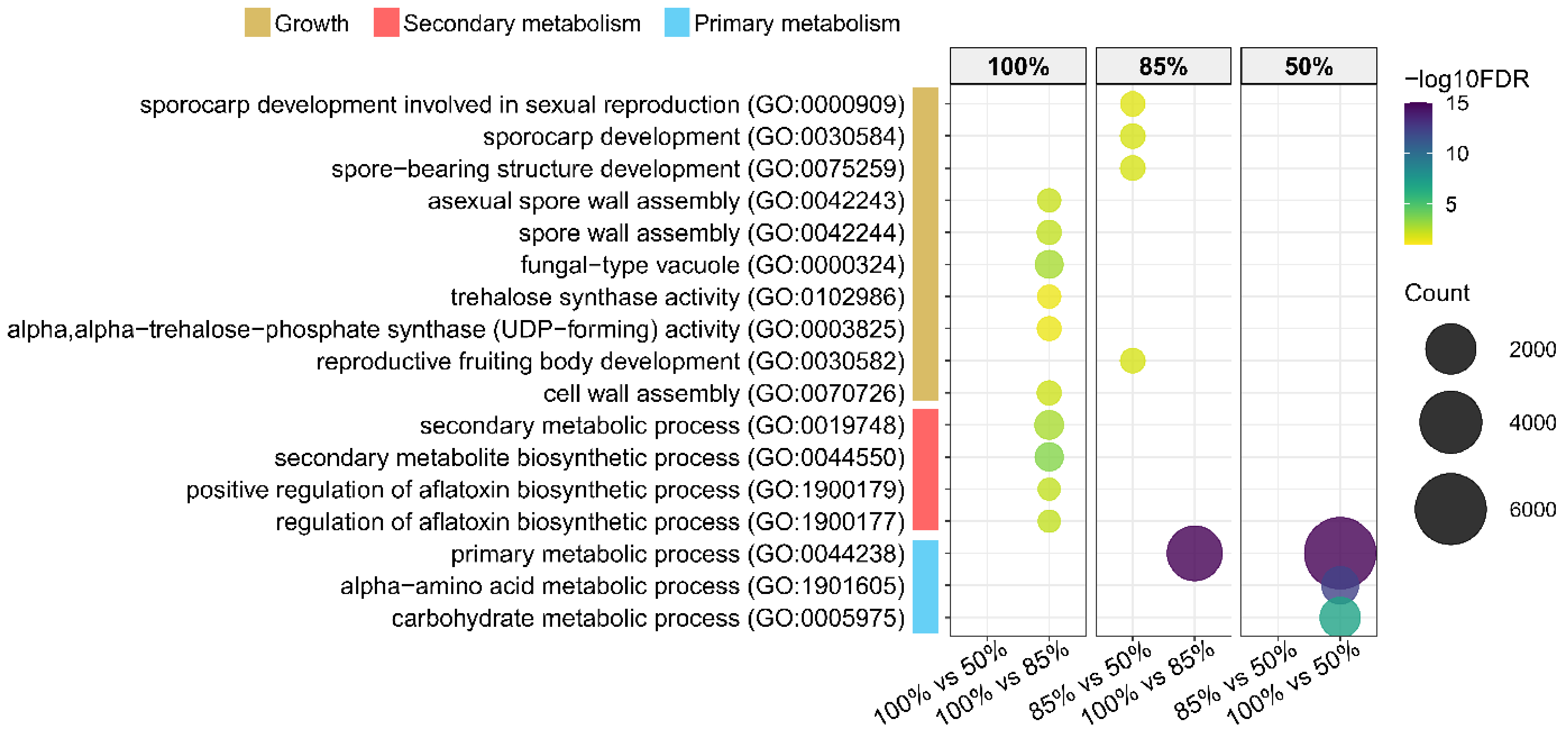
Deactivation Limited Growth

Nastasi et al. *Microbiome.* 2024.

Growth-associated genes are upregulated at high RH



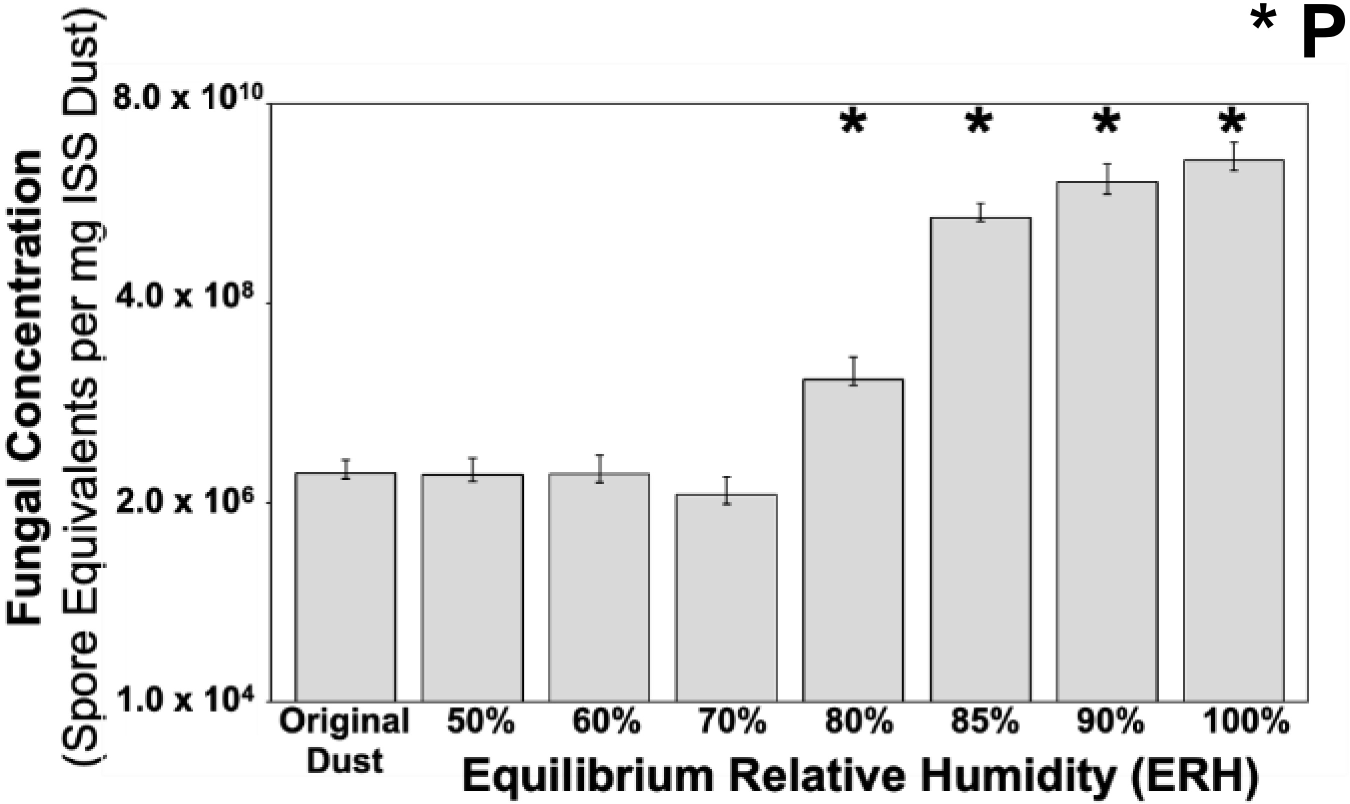
Growth-associated genes are upregulated at high RH

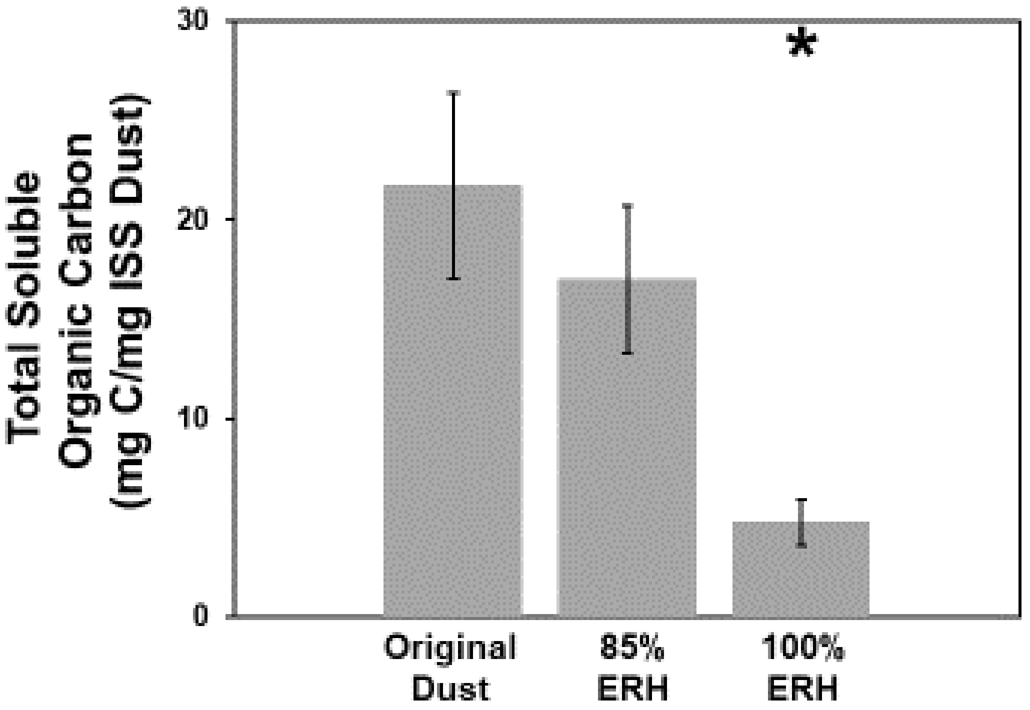


Constant equilibrium relative humidity (ERH) conditions significantly more fungal growth starting at 80%

2-week incubations at each ERH condition

*** P < 0.05**





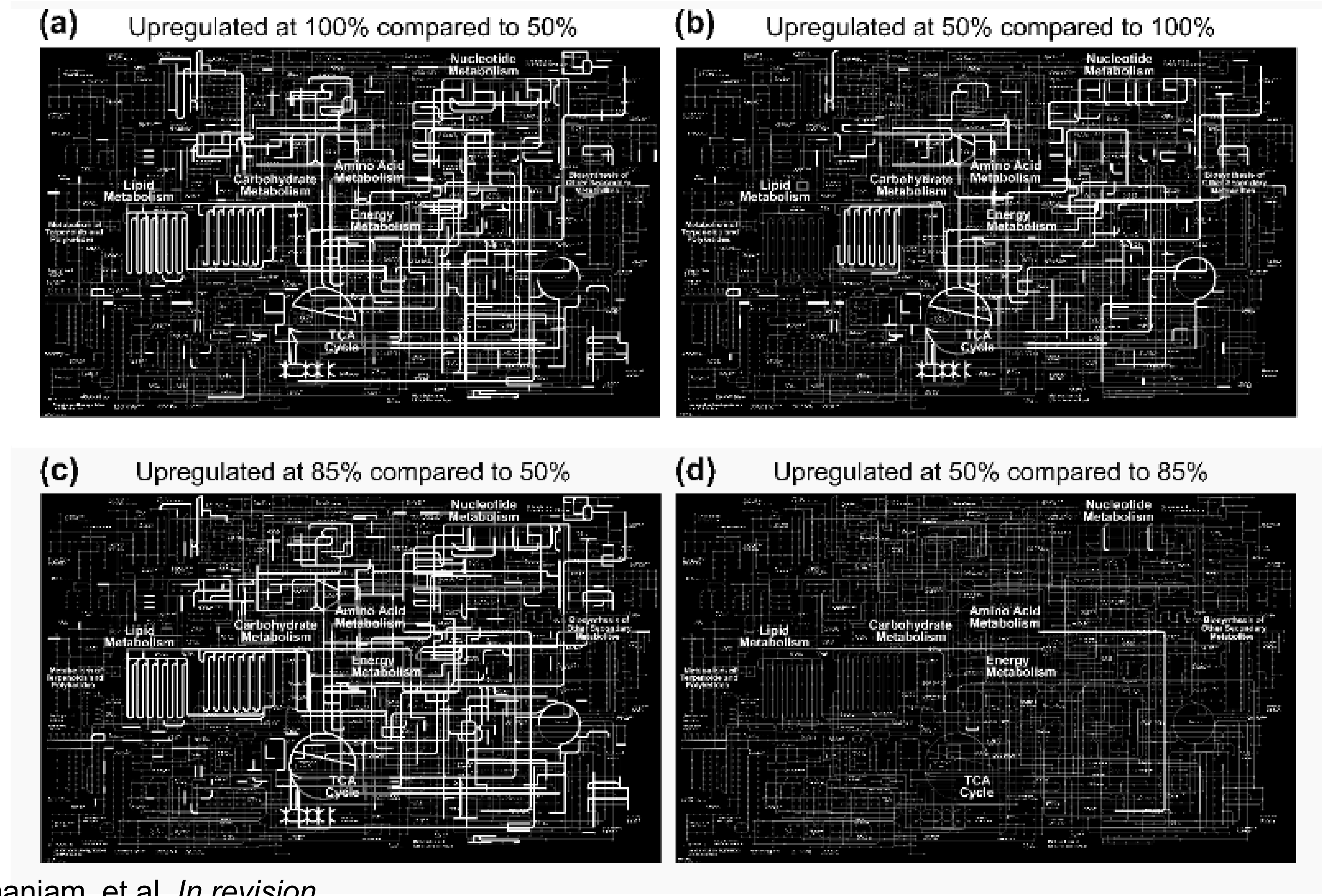
Fungal Carbon Utilization with Increased ERH

Nastasi et al. *Microbiome.* 2024.

More genes are associated with dampness than species

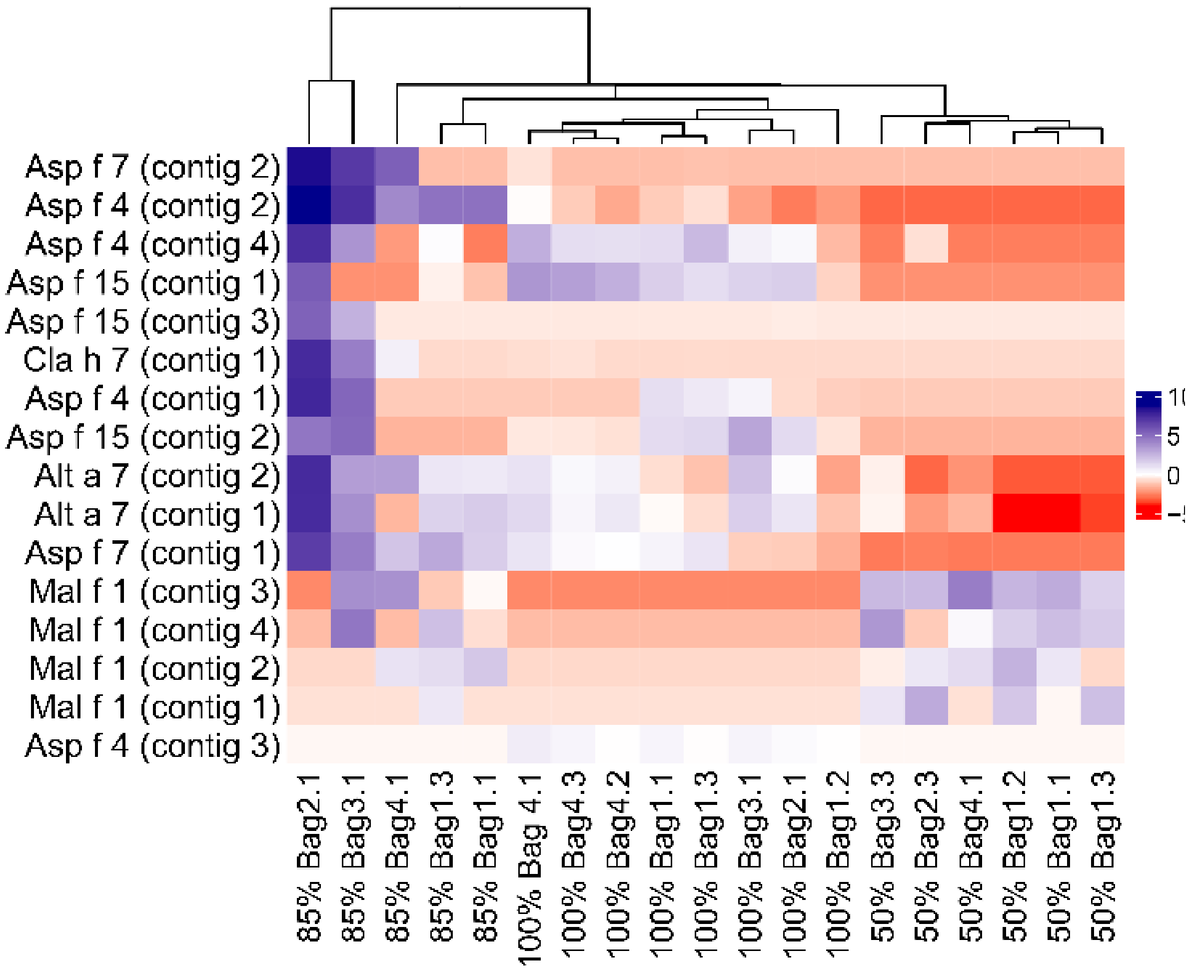
Number of upregulated fungal genes and fungal species that are found to be more abundant at 100% compared to 50% and 85% compared to 50% (FDR-adjusted p < 0.05).		
Gene Expression		
	Upregulated at 100% vs 50%	Upregulated at 85% vs 50%
Number of genes upregulated (FDR-adjusted $p < 0.05$)	**4141**	**12845**
Number of genes upregulated in at least 6/9 sites and not expressed at 50%	**3188**	**5437**
Number of genes upregulated in at least 8/9 sites and not expressed at 50%	**2030**	**2528**
Number of genes upregulated in all sites and not expressed at 50%	**324**	**431**
Taxa (Species)		
	More abundant at 100% vs 50%	More abundant at 85% vs 50%
Number of species differentially abundant (FDR-adjusted $p < 0.05$)	**3**	**2**
Number of species more abundant in at least 6/9 sites and not found at 50%	**1**	**0**
Number of species more abundant in at least 8/9 sites and not found at 50%	**1**	**0**
Number of species more abundant in all sites and not found at 50%	**0**	**0**

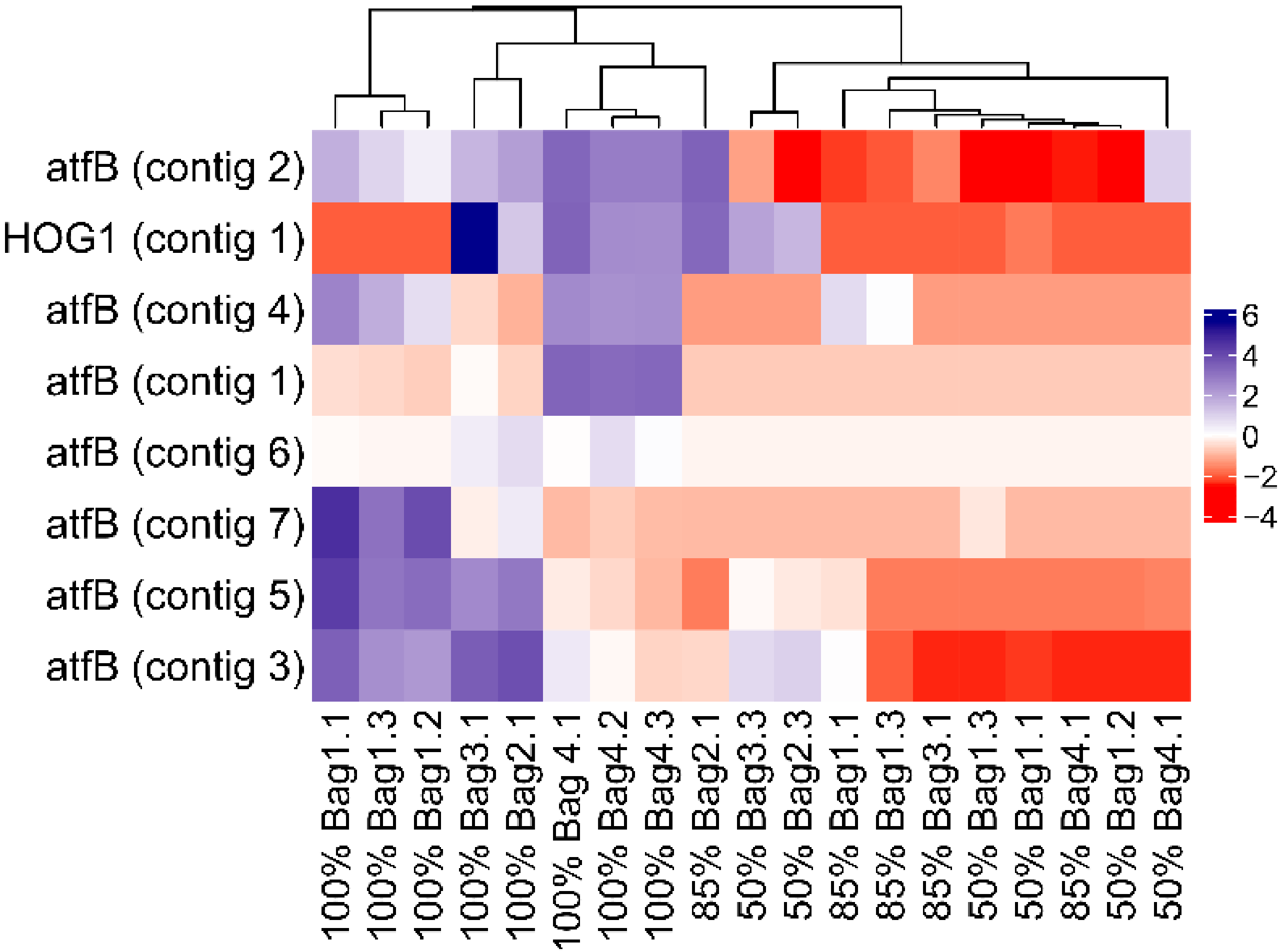
More secondary metabolic gene expression at higher moisture conditions



Balasubrahmaniam, et al. *In revision.*

Moisture results in upregulation of genes associated with allergens and aflatoxin





Balasubrahmaniam, et al. *In revision.*

Collaboration with Asthma Express Program

Phase I (2021- 2023) Needs Assessment – 21 families

- Completed

Phase II (Started 2024) Field Testing – 100 families

- Home visits, sample collection, sensor unit and app testing in the field, allergen detection validation, patient education
- Exploring addition of spirometry for family participants

Home Allergens and Asthma:
Join Our Study

What's the purpose of the study?
Researchers at Nationwide Children's Hospital and The Ohio State University are studying allergens in the home and how they impact those with asthma.

Who can take part in this study?
Patients in the Asthma Express program between 5 and 13 years of age. Participants must be able to read and understand English. If your child has a disability but would like to participate, please contact us to learn more about accommodations and possible enrollment.

Participation is voluntary, and you can leave the study at any time. If you do not want to be in this study, your medical care will not be affected.

What will happen during the study?
Study participants will complete a survey and be interviewed by study staff. Participation will take about 90 minutes.

To participate, visit https://redcap.nchri.org/surveys/ and enter the code 33JL4LJFD, or scan the QR code.

For more information, contact Dr. Chris Timan at (614) 722-4526

Principal Investigator: Dr. Christopher Timan

NATIONWIDE CHILDREN'S
When your child needs a hospital, everything matters.

Needs Assessment: Complete

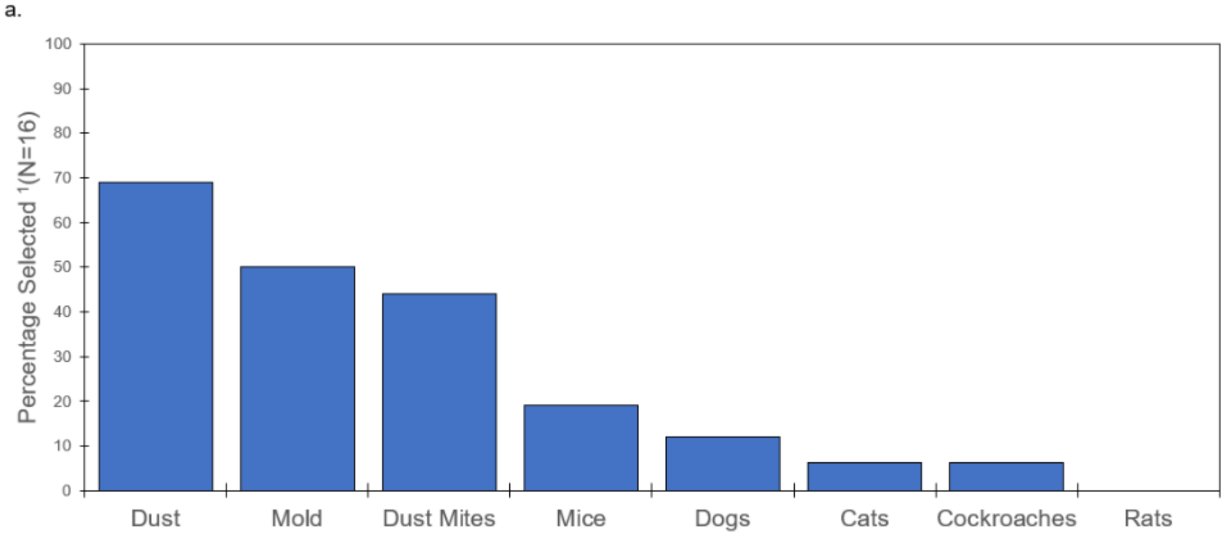
Child Characteristics	N	N=21[1]
Age	20	
5 years old or less		9 (45%)
6 to 10 years old		7 (35%)
11 years old or more		4 (20%)
Sees Asthma or Allergy Specialist	20	
Yes		17 (85%)
No		2 (10%)
Unsure		1 (5%)
Had Allergy Testing	20	
Yes		9 (45%)
No		10 (50%)
Unsure		1 (5%)
Attends Daycare/Preschool Most Days	21	
Yes		17(81%)
No		4 (19%)
Asthma Triggers (Select All That Apply)	21	
Illnesses		11 (52%)
Exercise		7 (33%)
Home Allergies		7 (33%)
Seasonal Allergies		11 (52%)
Smoke		3 (14%)
Weather Changes		12(57%)
Pets		5 (24%)
Strong Odors		2 (9.5%)
Other		3 (14%)

Parental Characteristics	N	N=21[1]
Relationship to Child	21	
Mother		18 (86%)
Father		3 (14%)
Caregiver Age	18	
25-29		6 (33%)
30-34		4 (22%)
35-39		4 (22%)
40-54		4 (22%)
Race/Ethnicity (Select all that Apply)	21	
White		13 (62%)
Black		7 (33%)
Hispanic/Latino		1 (4.8%)
Prefer Not to Answer		1 (4.8%)
Education Level	21	
Did Not Complete High School		3 (14%)
Graduated High School		3 (14%)
Technical/Vocational School or Some College		7 (33%)
Graduated College		6 (29%)
Graduate/Professional School		2 (9.5%)
[1]n (%)		

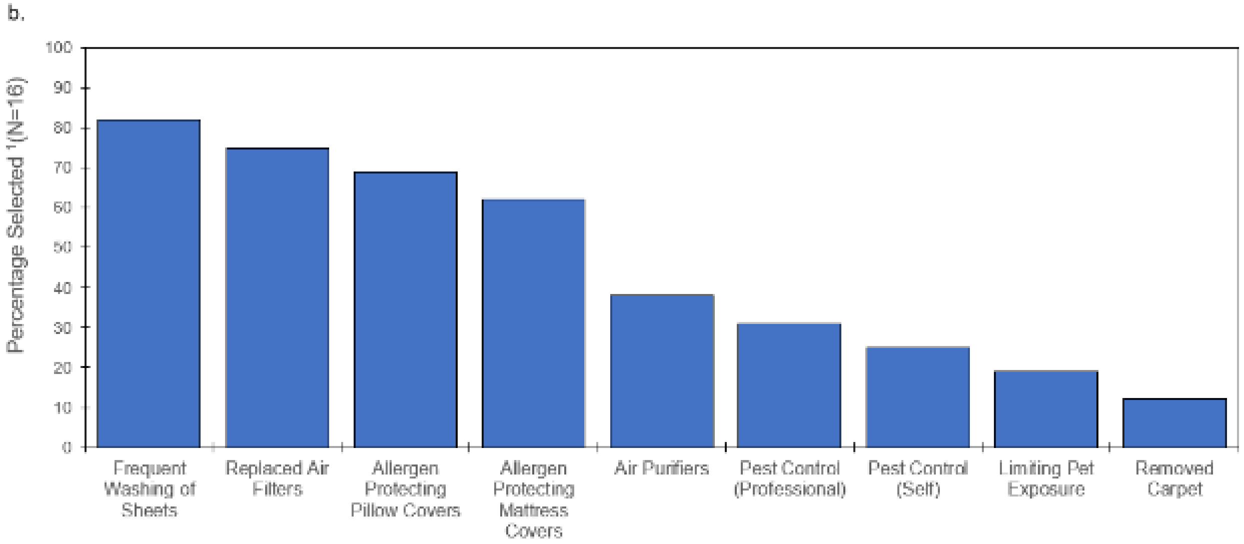
Young et al., *In Review*

The allergens families are focused on removing may not be the most associated with asthma

Allergens tried to remove

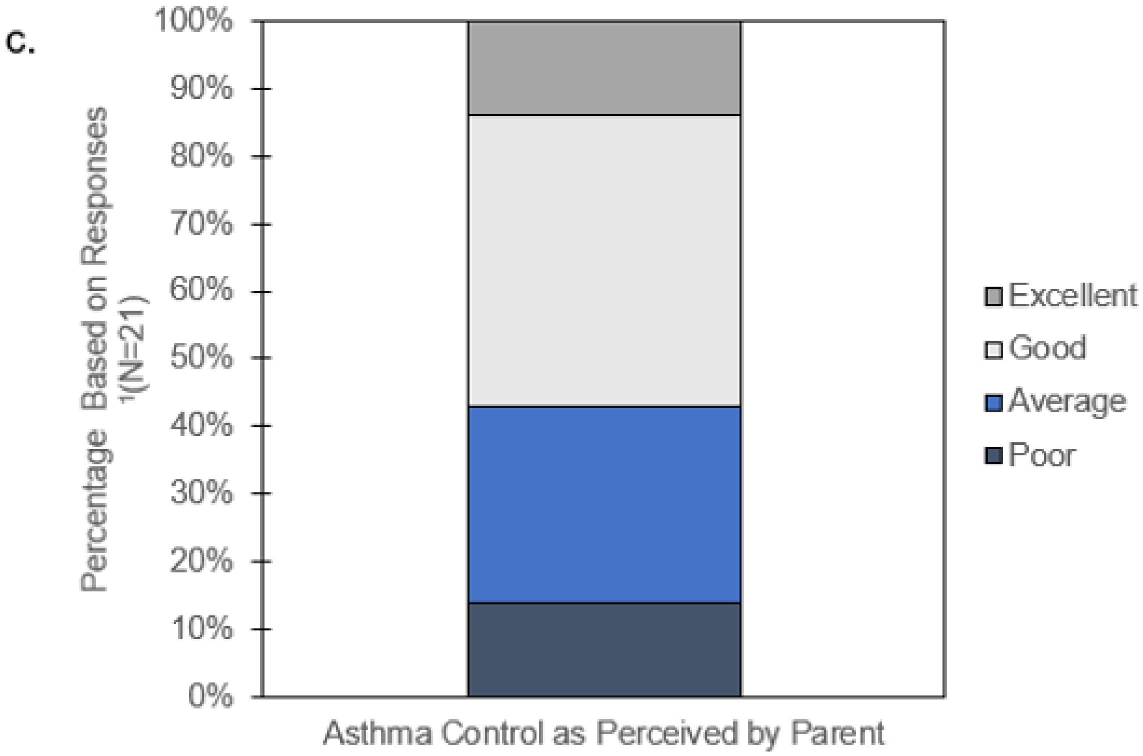


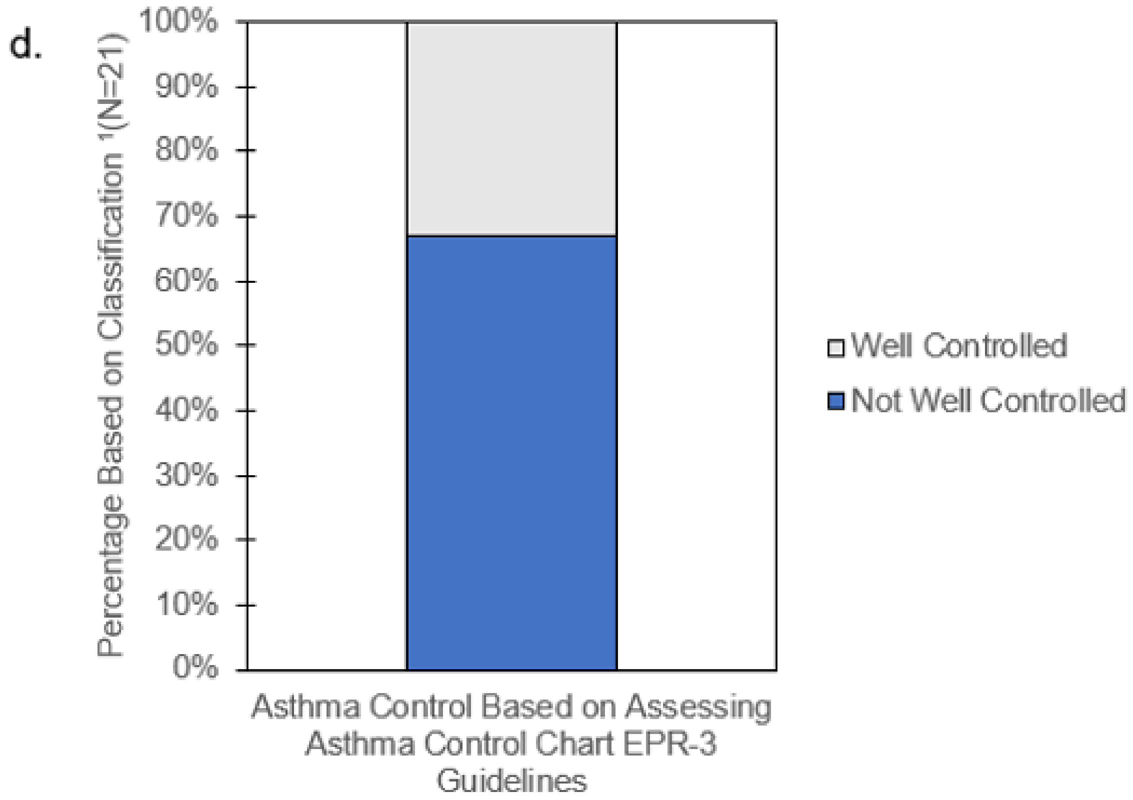
Actions taken



Young et al., *In Review*

Differences in asthma control vs. perception





Young et al., *In Review*

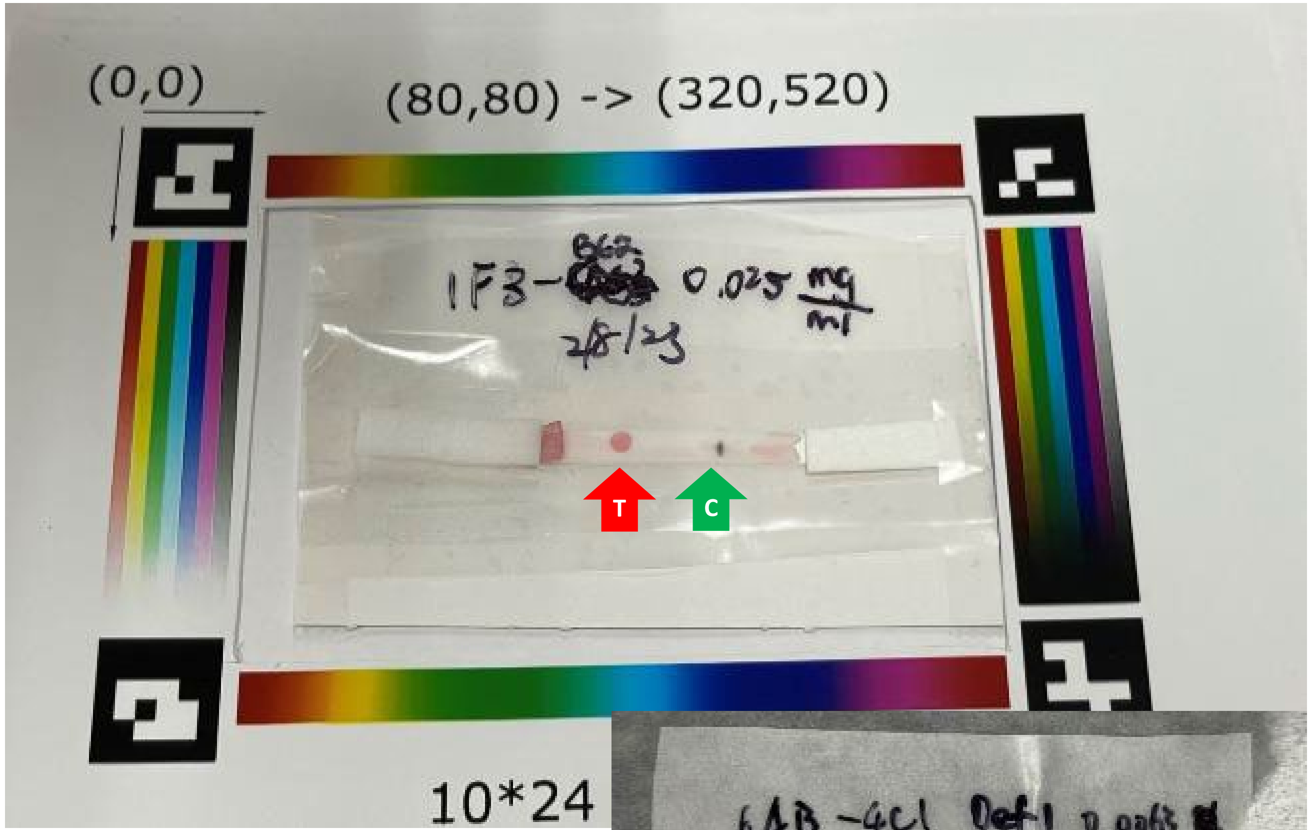
Participants interested in allergen detection

- 71% - "extremely important" to be able to detect allergens
- 52% - allergen education is "extremely important"
- 71% - allergen mitigation is "extremely important"

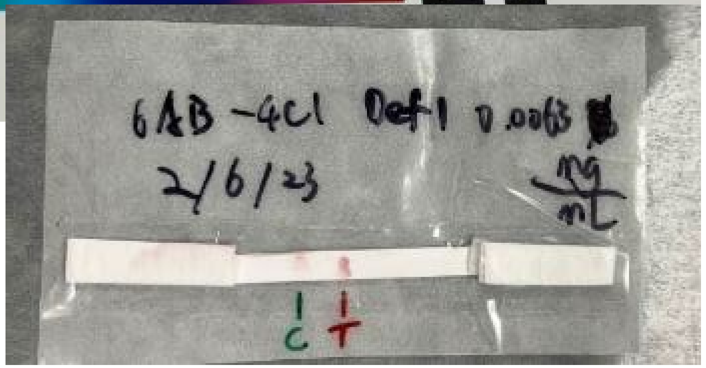
- Participants were especially interested in help resolving landlord/tenant issues

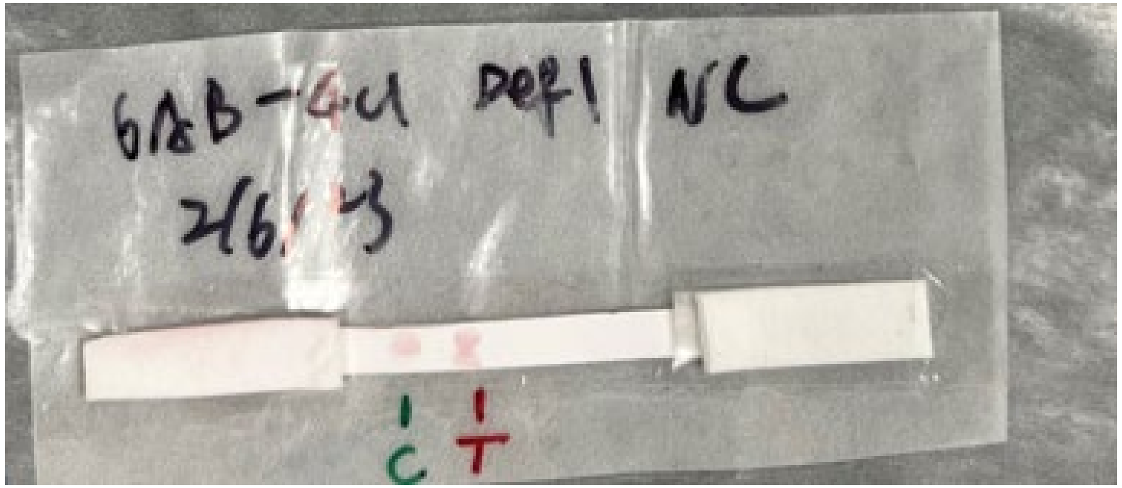
Young et al., *In Review*

Novel Electrospun Sensor



Cockroach sensor

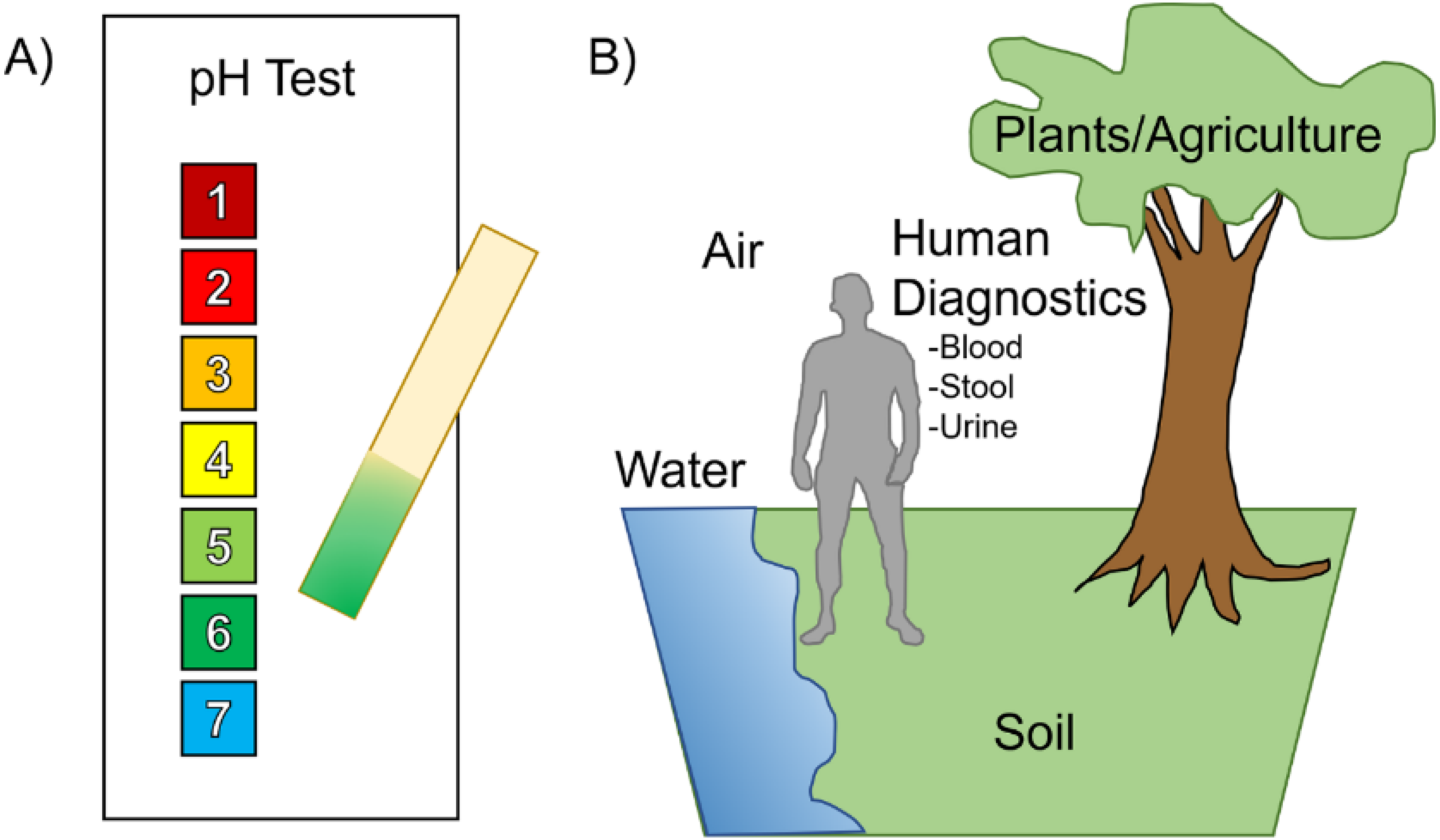




Left: **Cockroach sensor** complementary monoclonal antibody pair

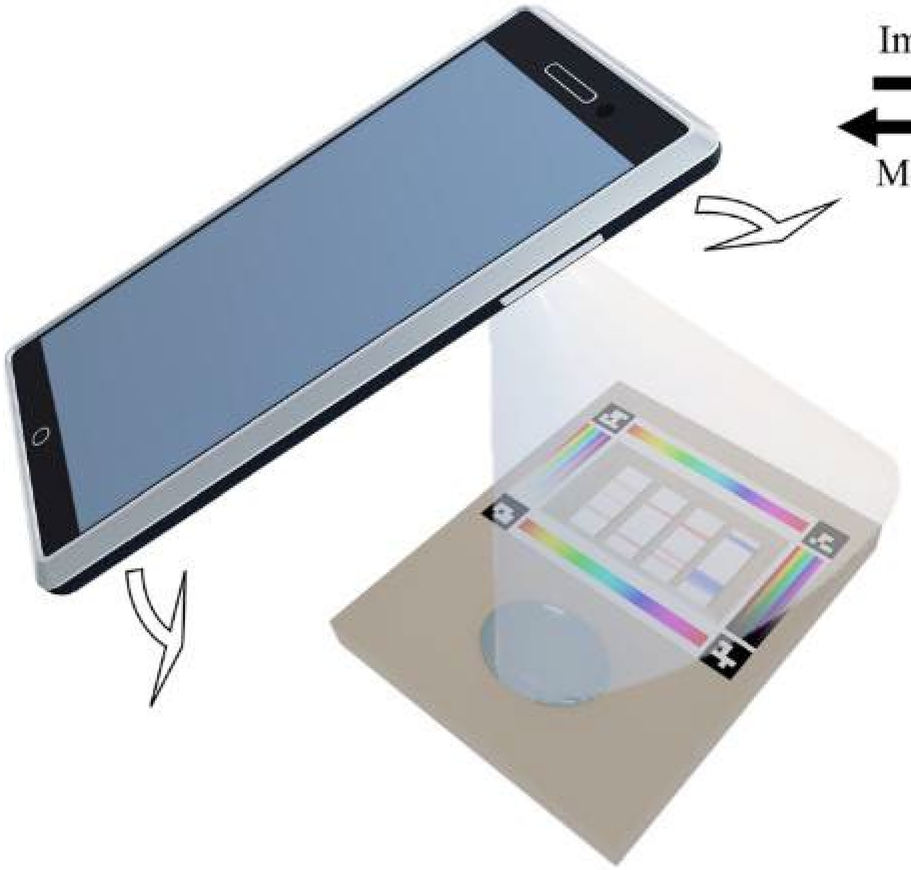
Top: **Dust mite Der f 1** complementary monoclonal antibody pair – false positive result

System dependent on color detection like many other tests

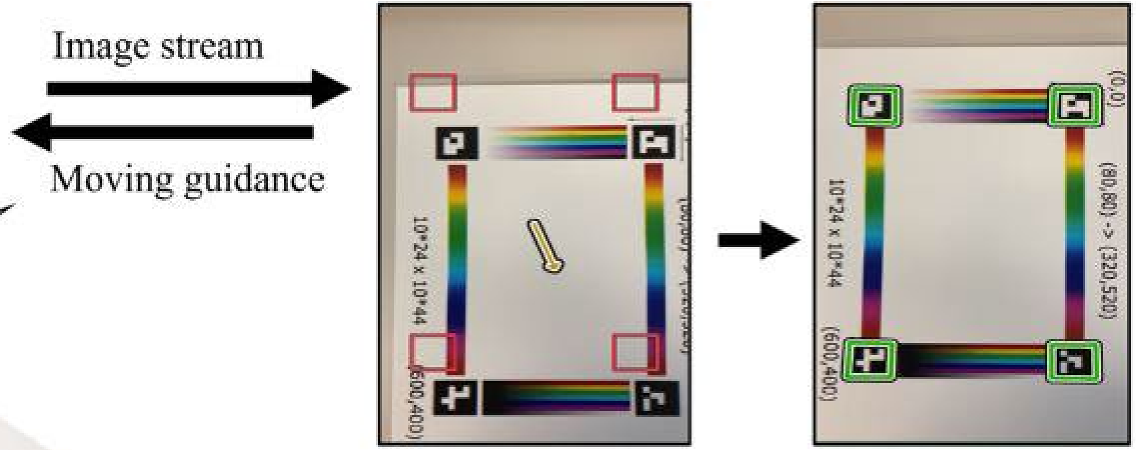


Zhang et al., *PLOS ONE*, 2023

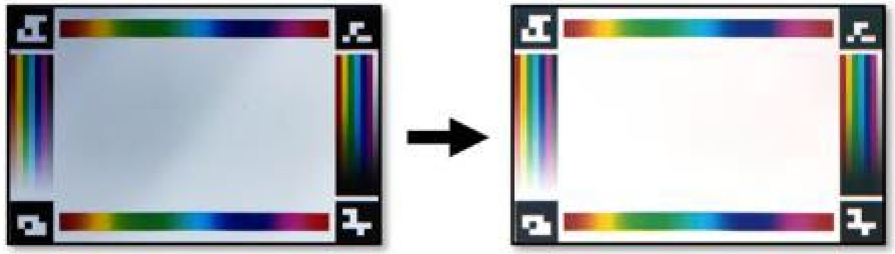
Color detection and quantification enhanced



(A) **Color reference board:** A general-purpose board design can be integrated to test kits.



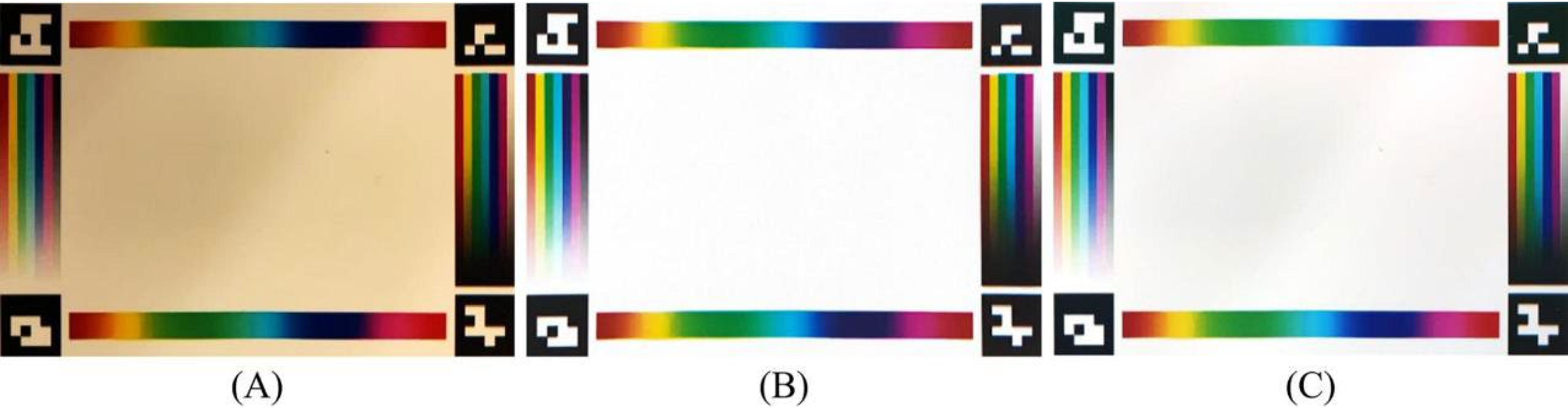
(B) **AR-based image capture module:** Guiding user device movement until optimal position reached.



(C) **Color Correction Algorithm:** Align captured images with the standard color reference board

Zhang et al., *PLOS ONE*, 2023

Integration of warnings and shadow correction



Zhang et al., *PLOS ONE*, 2023