CANADIAN CENTRE FOR BUILDING EXCELLENCE

Engineering Health and Efficiency

Buildings, Microbiology, and Moisture

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Moisture in buildings is very complicated.

Microbially-relevant moisture is even more complicated.

Roadmap

- Microbiology
- Moisture measurement
- Impact of building (office surfaces)
- Impact of wetting

When/why/how does the building matter?

A brief history of indoor microbiology from a building science perspective

- >200 years ago-present: culturing
  - Advantages: long history, “easy” to do, quantitative
  - Disadvantages: Presents a skewed picture
- ~2000-present: DNA sequencing
  - Advantages: Much richer and more complete view
  - Disadvantages: Generally non-quantitative, viability, more of challenge to identify species, huge **bioinformatics** challenges

Example of Challenge

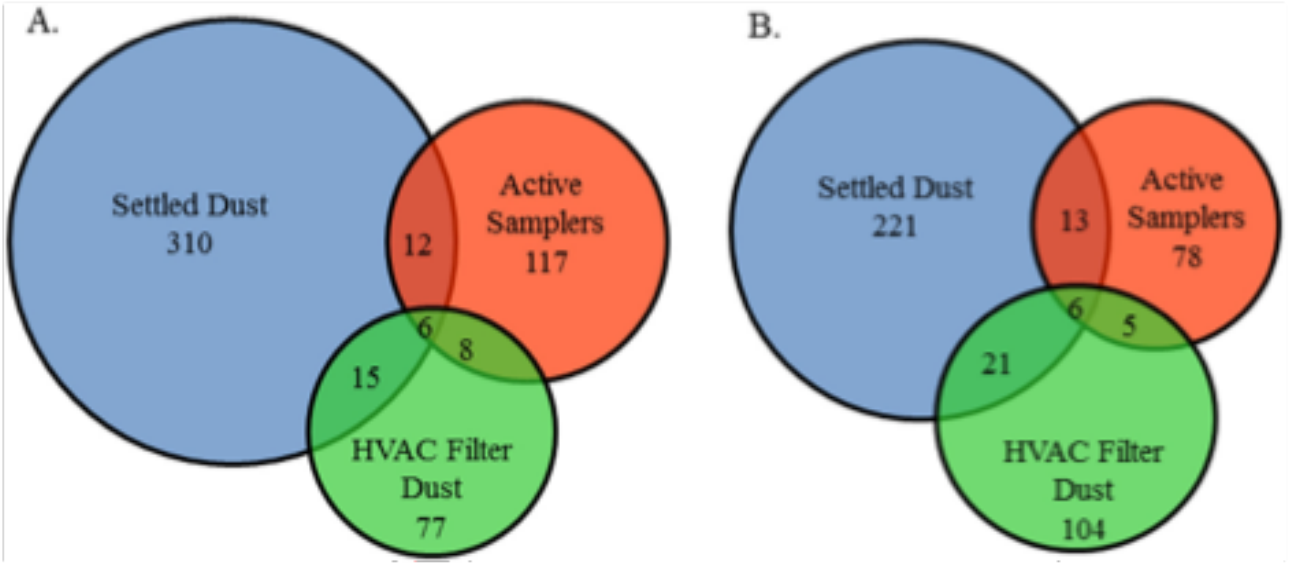


Fig. 6. Shared bacterial OTUs for settled dust, HVAC filter dust, and bioaerosol samplers (combined) for Week 1 (A) and Week 2 (B).

Hoisington et al. (2014) *Building and Environment*

Microorganisms are Everywhere

- Every surface, every breath, etc.
- In general, this is neither good nor bad, with some exceptions

Next-generation DNA sequencing reveals that low fungal diversity in house dust is associated with childhood asthma development

Influence of housing characteristics on bacterial and fungal communities in homes of asthmatic children

"Increased microbial richness was associated with the presence of pets…"

Dannemiller et al. (2014,2015) *Indoor Air*

People add microorganisms to their homes

"Homebiotic is a spray and leave on treatment that lasts 6 months. Bacterial cultures take up residence and prevent mold growth."

Benefits:

- Maintains a healthy balance of microbes in your home
- 1 application covers 1000 square feet
- Non-toxic, GMO-free, **Gluten-free**
- Pleasant citrus smell from organic botanical oils

Reviewed by:Tatortodd Verified Reviewer

Posted:12/15/15

TOOK AWAY MOLDY SMELL OUT OF OUR HOUSE

We had some roof leak/flooding and could always smell it. Used this item and it has taken away the smell when we walk into our kitchen. What a relief!!

http://www.bulletproof.com/homebiotic-concentrate-4oz

Even By Scientists

An Innovative Approach to Hospital Sanitization Using Probiotics: In Vitro and Field Trials

La Fauci et al. (2015) *J Microb Biochem Technol*

Methods: The study included survival tests and *in vitro* and field trials. The *in vitro* trials tested three surfaces (washbasin, floor and desk) in the absence of recontamination. Field trials were carried out in order to evaluate the efficacy of probiotics in the presence of contaminants and to study whether probiotics are able to contain pathogens over time. Samples were taken from the floor in a corridor and an inpatient room and the dispensary washbasin twice daily (pre-sanitization and post-sanitization).

The probiotic-based solution contained 1% of spores (30×10^6 CFU/ml) of *Bacillus subtilis*, *Bacillus pumilus* and *Bacillus megaterium*, in addition to ionic surfactants (0.6%), anionic surfactants (0.8%) and enzymes (amylases 0.02%) [18].

One more thing

- Why do we care about mold?
  - It smells
  - It looks ugly

Connection to Moisture and Health

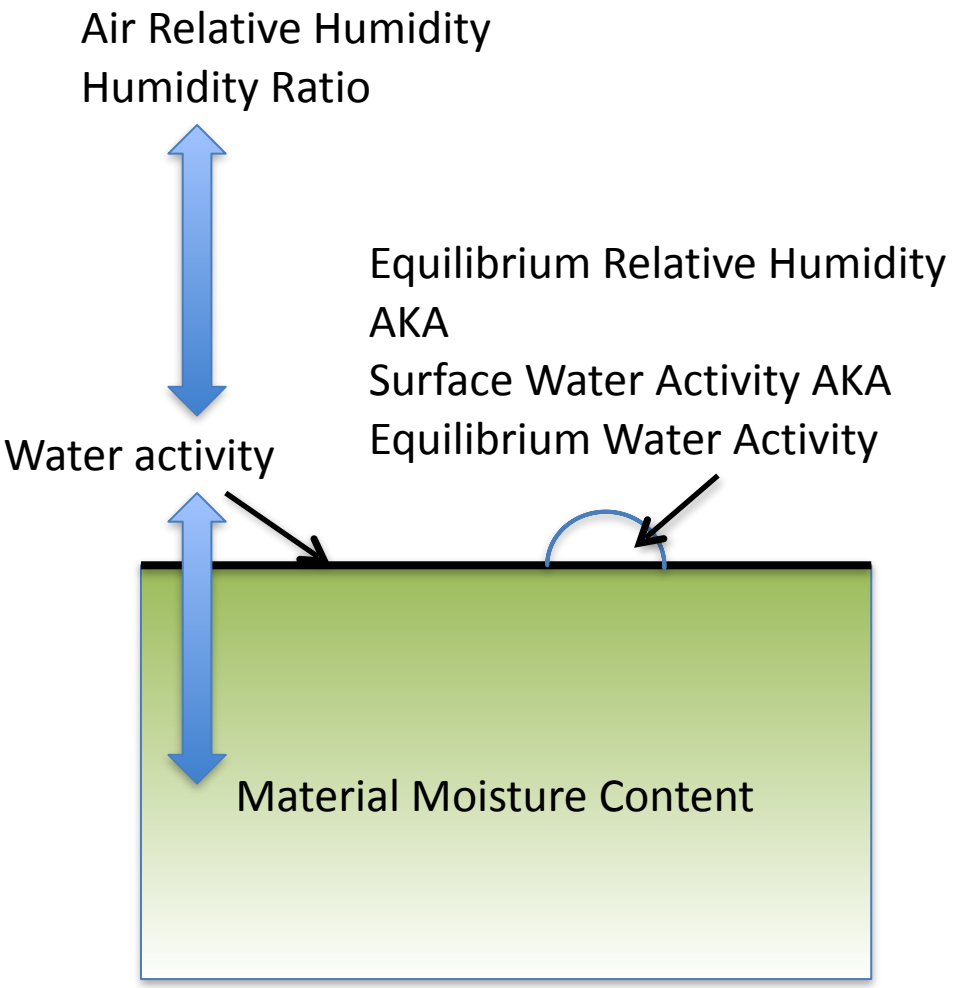
- Moisture damage has a negative impact on health
  - e.g., Mendell et al. (2011) *Environ. Health Persp.*
  - *We don't know if this microbiological or not….*
- Paradox:
  - "Increased microbial richness was associated with the presence of pets, [illegible] ition

Dannemiller et al. (2015) *Indoor Air*

Quest for Microbial Relevance

- What matters for microorganisms?
- Environmental conditions
  - Small ranges of temperature, light on indoor surfaces
  - Insufficient data (generally)
- Food
  - Plentiful (building materials, soiling, building contents)
- Water

Moisture Measurements



- All communicate
- Different measurements
  - Different relevance
  - Different challenges
  - Different temperature interactions
- **Water activity can not be measured in-situ**

Practicality of Moisture Measurement in Buildings

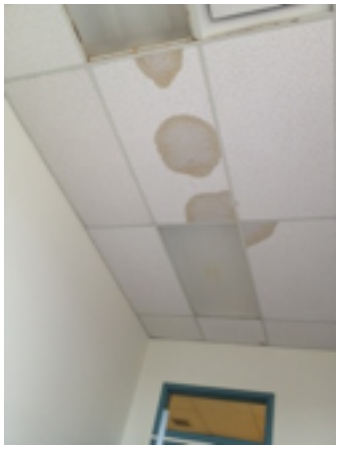
Presence of moisture damage

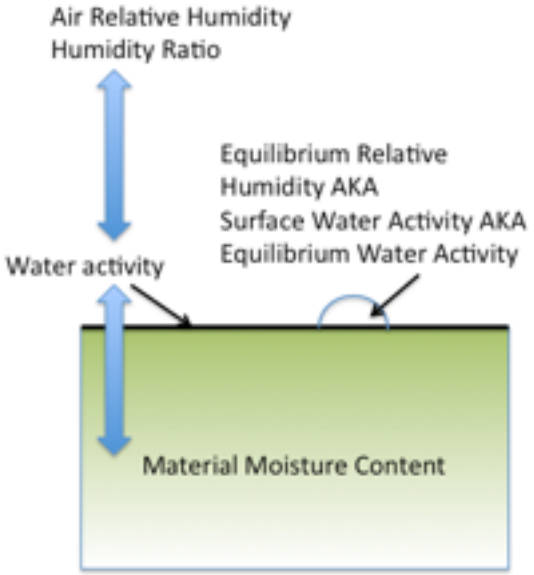
Moisture content

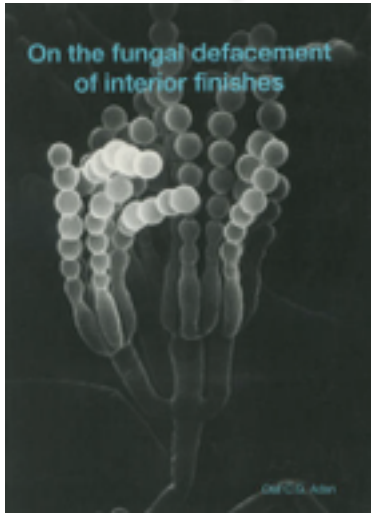
Relative humidity, RH

Equilibrium relative humidity, ERH

Water activity, a_w



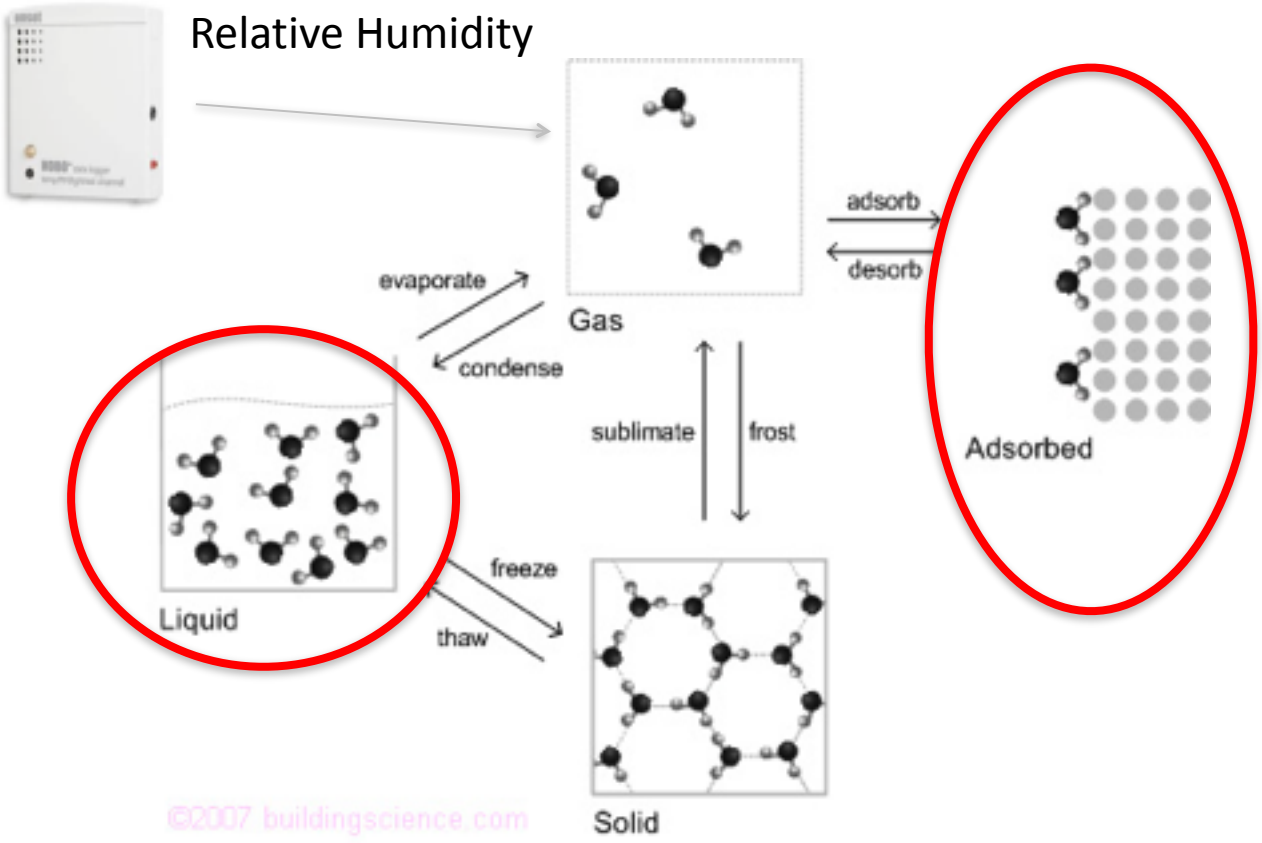




Moisture damage = health problem
Mendell et al. (2011) *EHP*

Moisture transport with NMR
Adan et al.

Phases of Water



Ref: http://buildingscience.com/documents/digests/bsd-138-moisture-and-materials

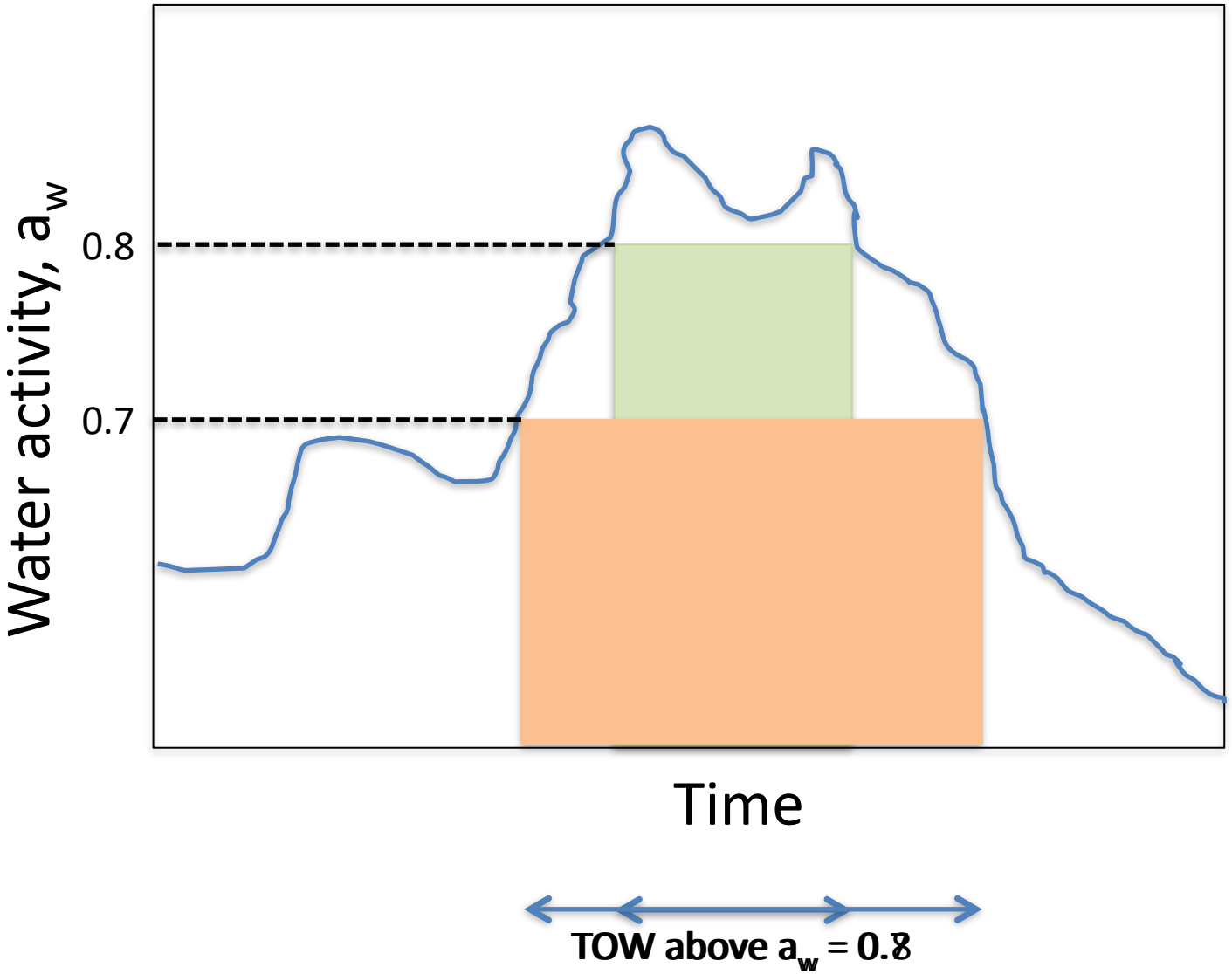
Practical Measurement Issues

- **Relative humidity** – not very meaningful
- **Water activity** – can't be measured in-situ at non-equilibrium conditions
- **Equilibrium relative humidity** – sensor interferes with exchange of moisture between material and air

- **Moisture content** – doesn't correlate with water available to the microorganism

Dedesko and Siegel (2015) *Microbiome*

Another Complexity - Time



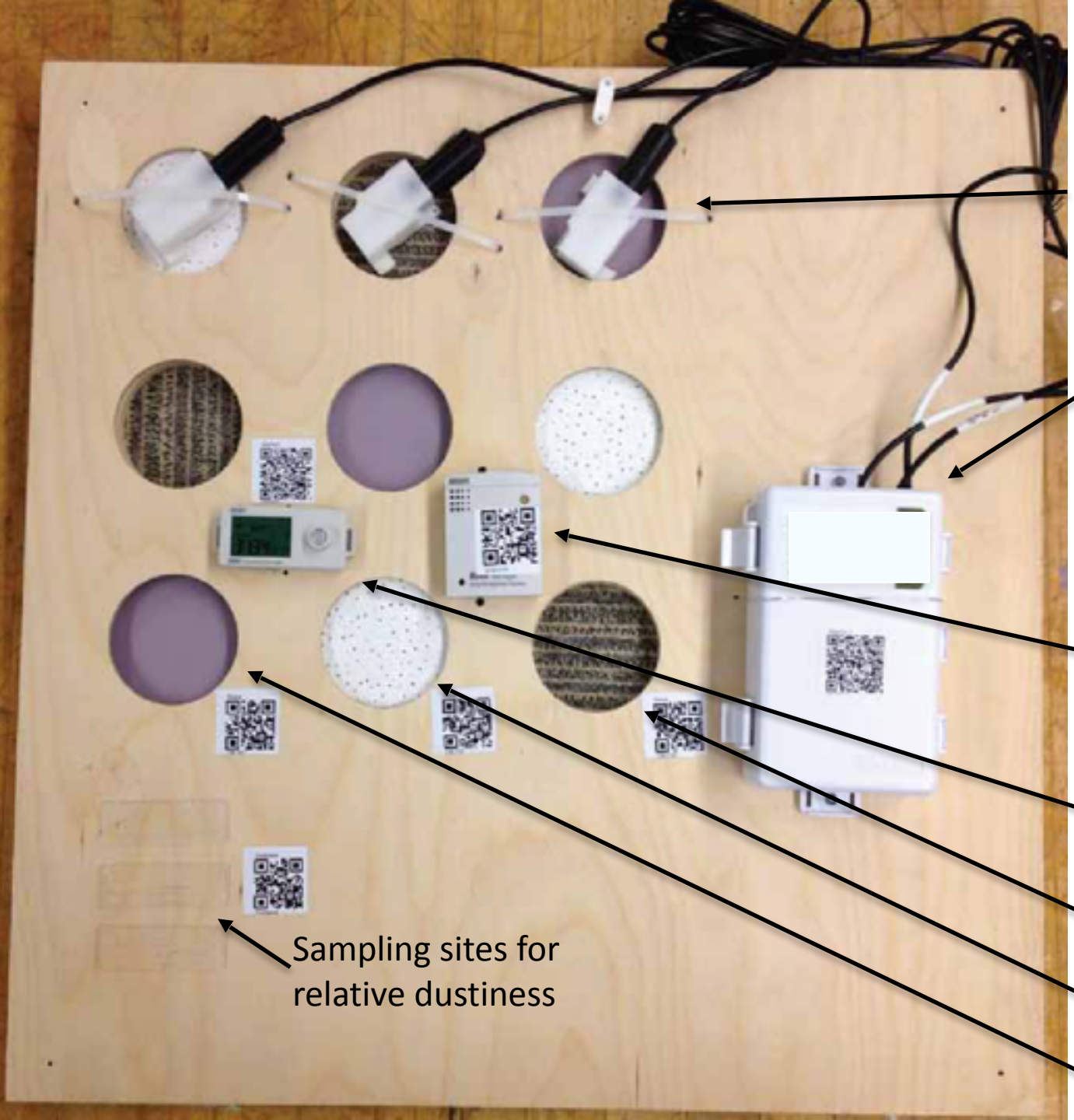
Our goal: Characterize offices from many perspectives

Experimental Matrix

- Building Type: **Office**
- **Cities**
  - Flagstaff: Semiarid
  - San Diego: Mediterranean/Arid Mediterranean
  - Toronto: Humid Continental
- **Surfaces**
  - Ceiling
  - Floor
  - Wall

- **Materials**
  - Carpet tile
  - Ceiling tile
  - Painted drywall
- **Three offices in each city**

Microbial Sampling
- Four 6-week seasonal sampling campaigns
- Sampling period every other day

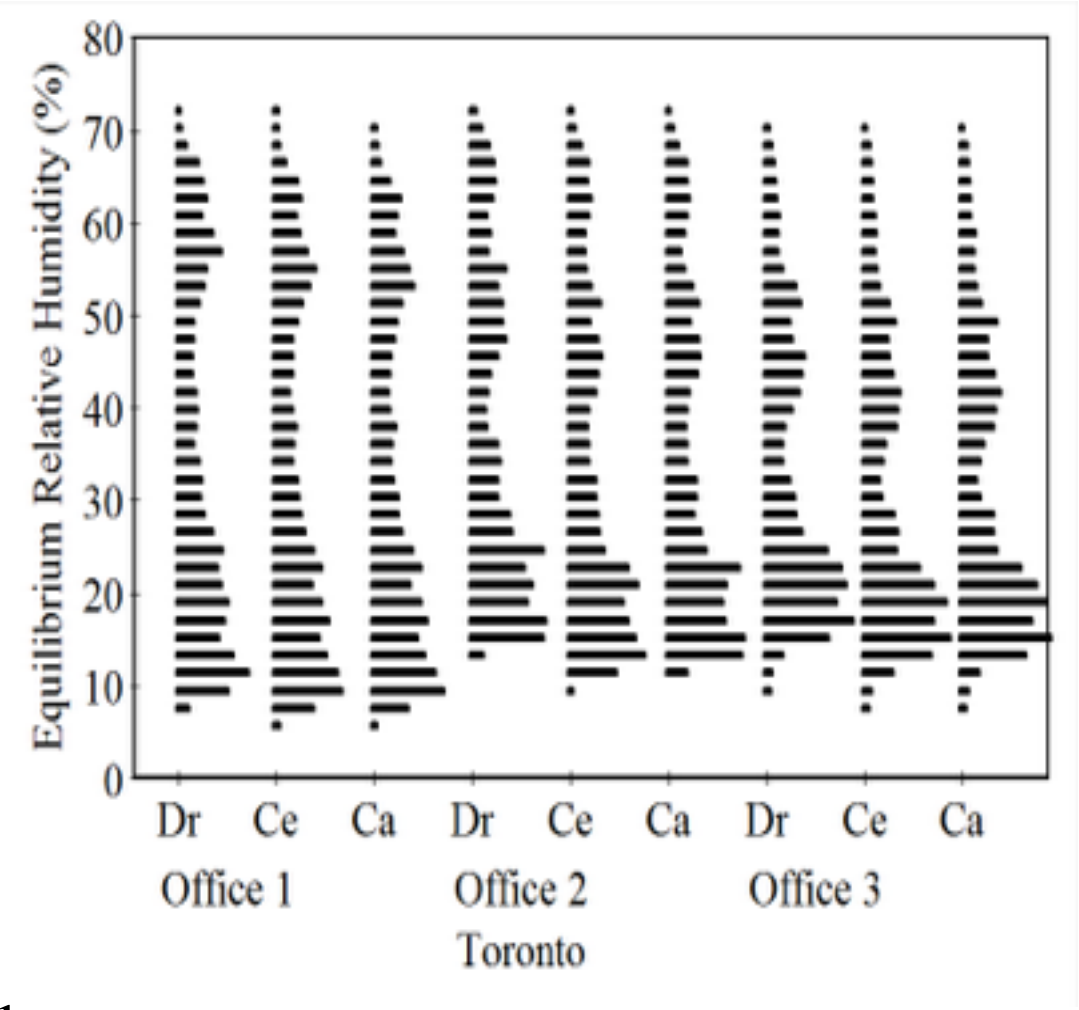

Equilibrium relative humidity sensors and data logger
Temperature, relative humidity, and illumination sensor
Occupancy sensor
Carpet tile
Ceiling tile
Painted dry wall
Sampling sites for relative dustiness

Time-Scale of Sampling

- All parameters measured every 5 minutes for a year in each office

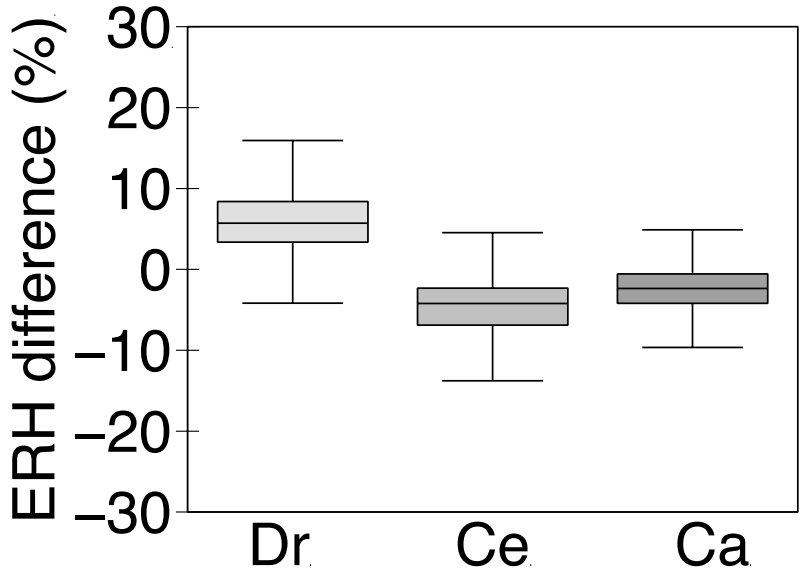
- Coincidental microbial (swab) samples every other day for 4 six-week seasonal sampling periods
  - Sequenced for bacterial and fungal communities

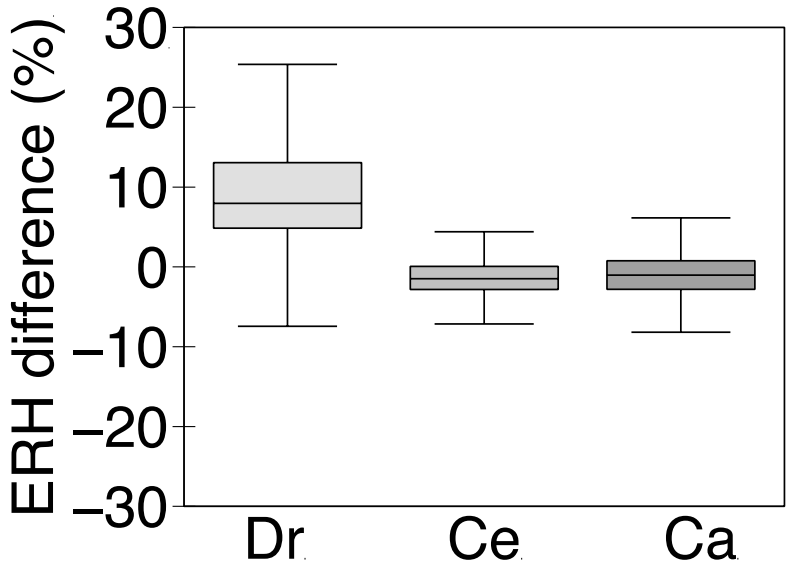
Equilibrium Relative Humidity Range

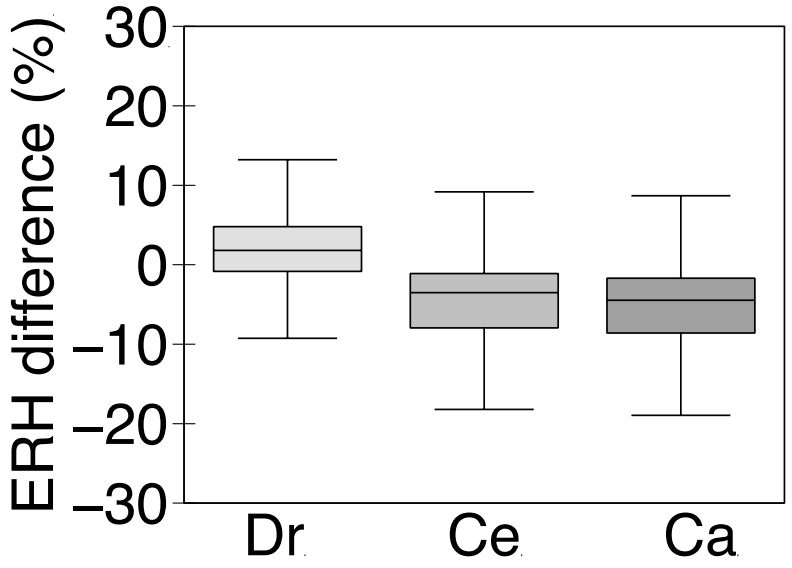


Dr=Drywall
Ca=Carpet
Ce=Ceiling tile

Difference Between ERH and RH

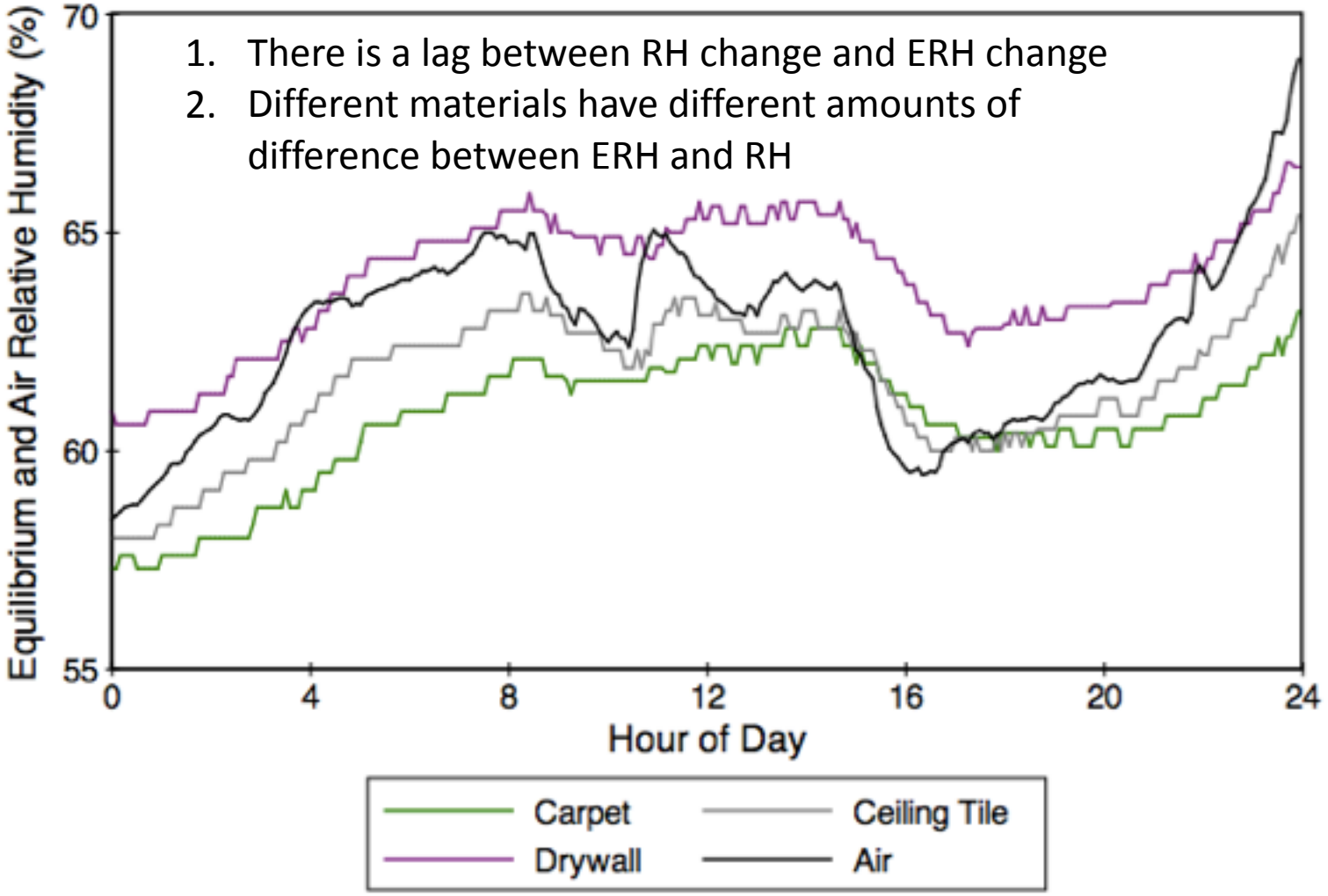




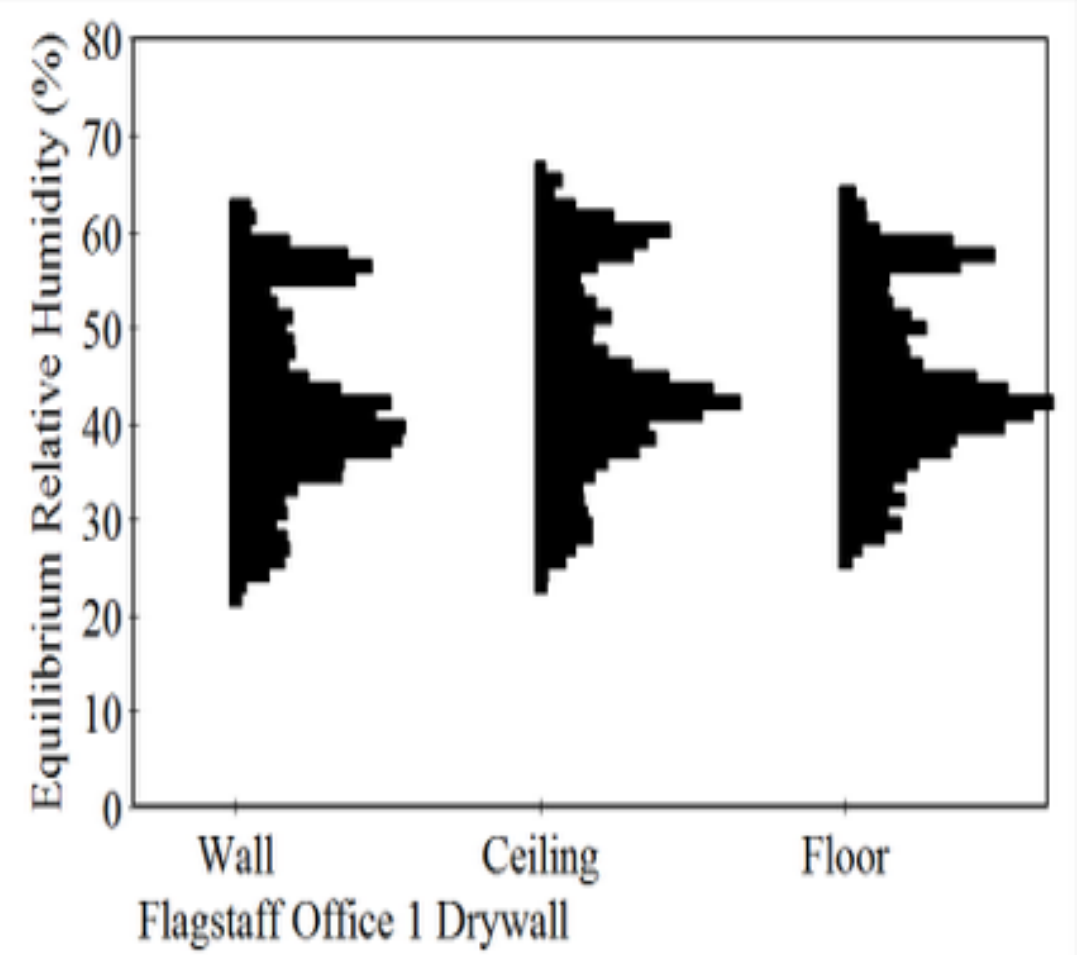


Dr=Drywall
Ca=Carpet
Ce=Ceiling tile

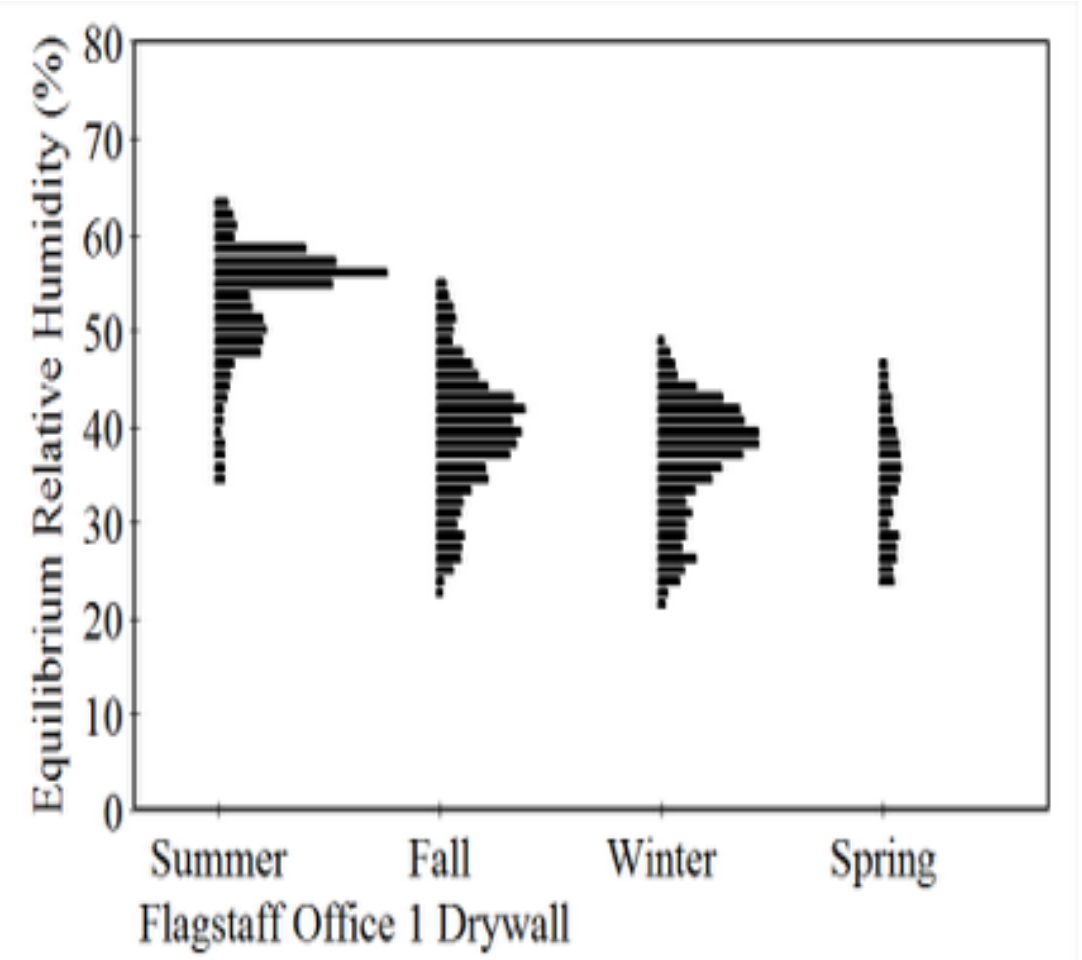
Humidity Time Series



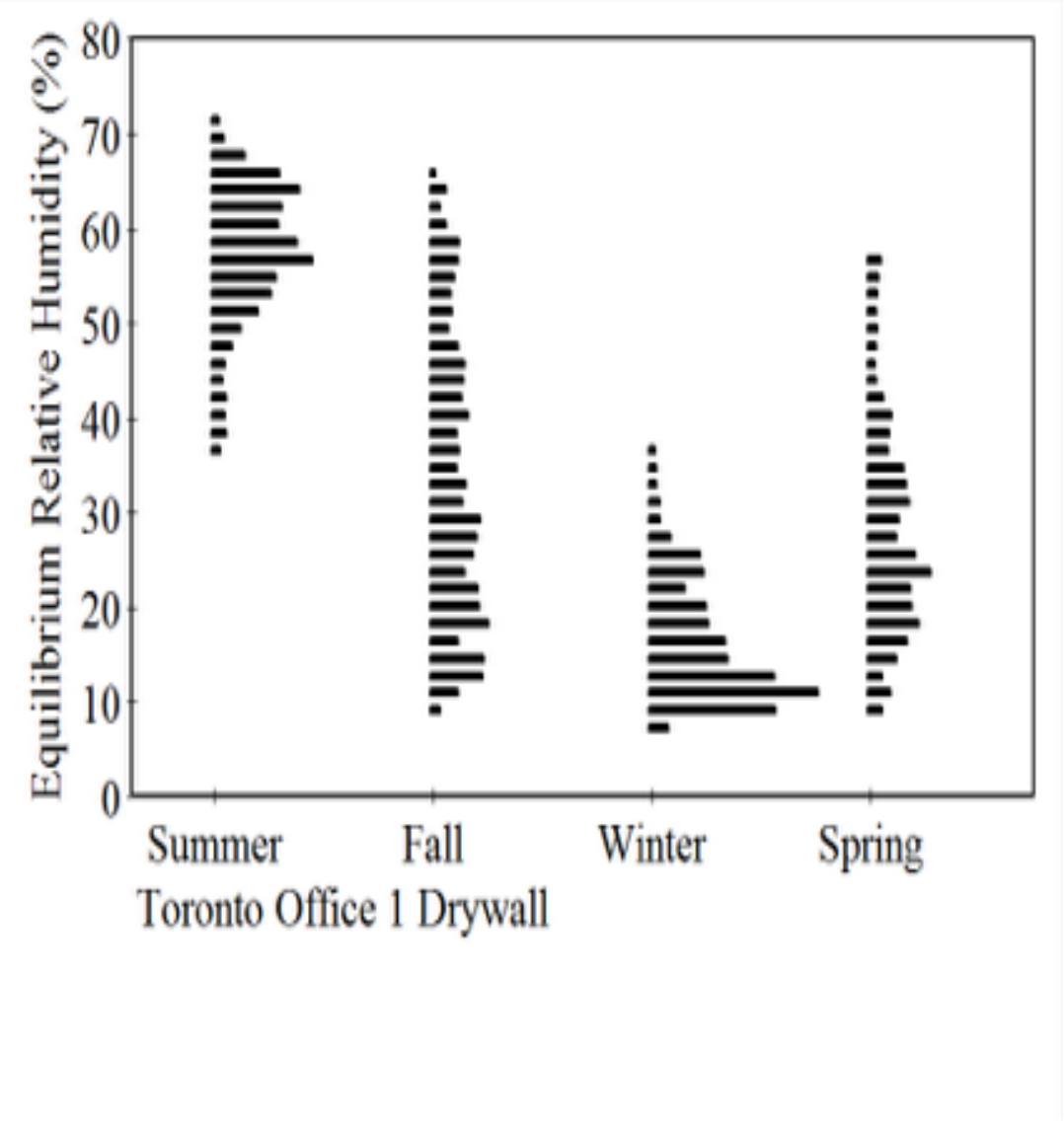
Variation Among Surfaces, Flagstaff



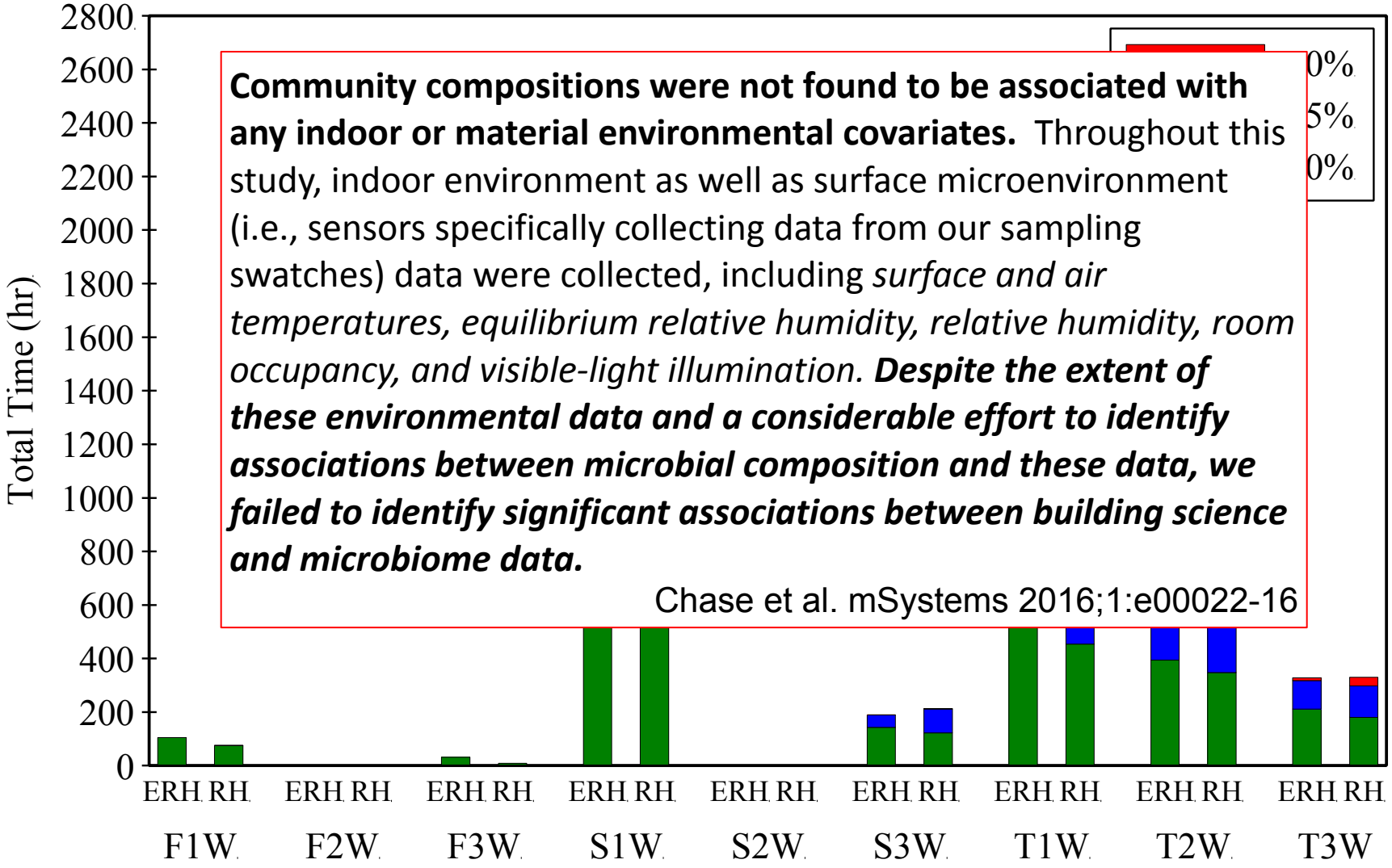
Seasonality of ERH, Flagstaff



Seasonality of ERH, Toronto



Time of Wetness



Community compositions were not found to be associated with any indoor or material environmental covariates. Throughout this study, indoor environment as well as surface microenvironment (i.e., sensors specifically collecting data from our sampling swatches) data were collected, including *surface and air temperatures, equilibrium relative humidity, relative humidity, room occupancy, and visible-light illumination.* ***Despite the extent of these environmental data and a considerable effort to identify associations between microbial composition and these data, we failed to identify significant associations between building science and microbiome data.***

Chase et al. mSystems 2016;1:e00022-16

Study: Cities Have Unique 'Bacterial Fingerprints'

AMERICAN VOICES
April 25, 2016
VOL 52 ISSUE 16
Opinion

A study that swabbed office buildings in major cities found that the bacterial profile of the swabs corresponded to their location, suggesting that cities each have their own "bacterial fingerprint." What do you think?

"Man, is there anything swabbing can't illuminate for us?"

Robert Larson • SALAD VISIONARY

"I don't need some fancy microbiome to tell me someone is from Boise."

Sam Balducci • BAND NAMER

"Amazing. If I ever want to know what city I'm in, all I need is a microscope!"

Phoebe McNamara • REBATE COORDINATOR

Buildings as Deserts

- James Scott: "…few places on earth get as hot as a rooftop or as dry as the corner of a heated living room." *Wired* 2011
- Chase et al: "BE surface microbial communities may behave similarly to those found in the soils of the Atacama Desert, waiting for liquid water to become active."

The Built Environment Is a Microbial Wasteland

mSystems 2016

Sean M. Gibbons

Department of Biological Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

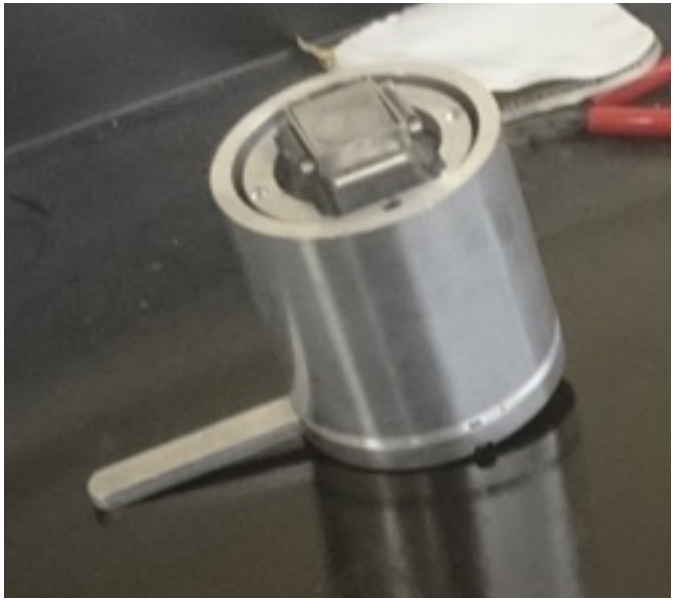
Ongoing Work

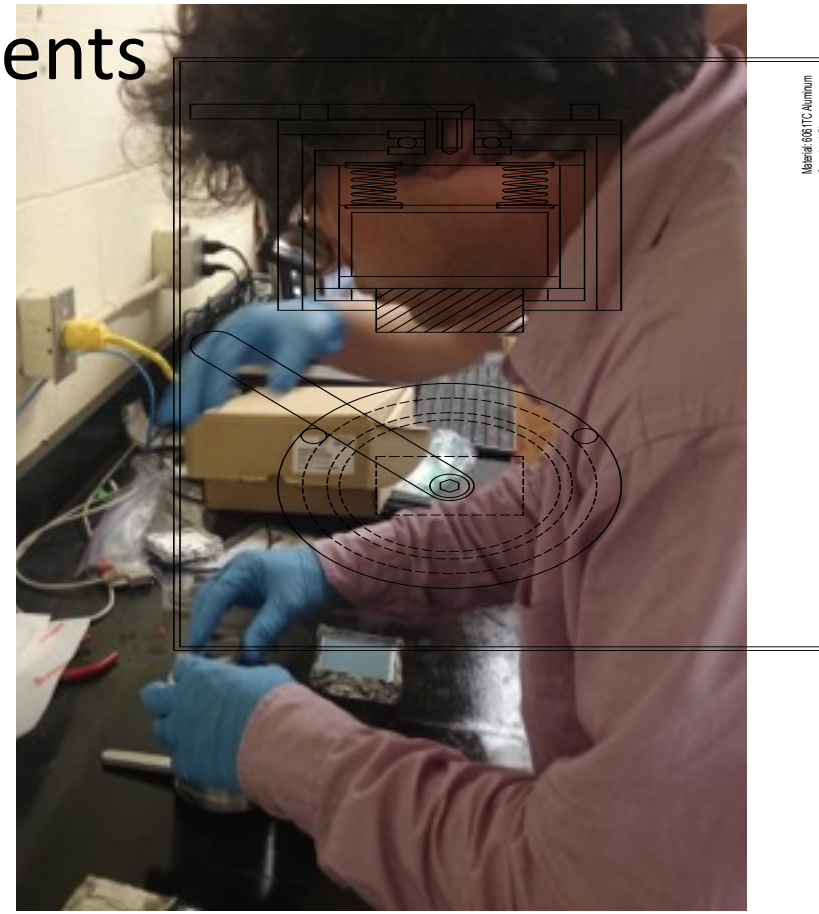
- Non-extreme conditions may not offer a lot of differentiation
- Microorganism quantity matters too
- What moisture parameters should we measure?

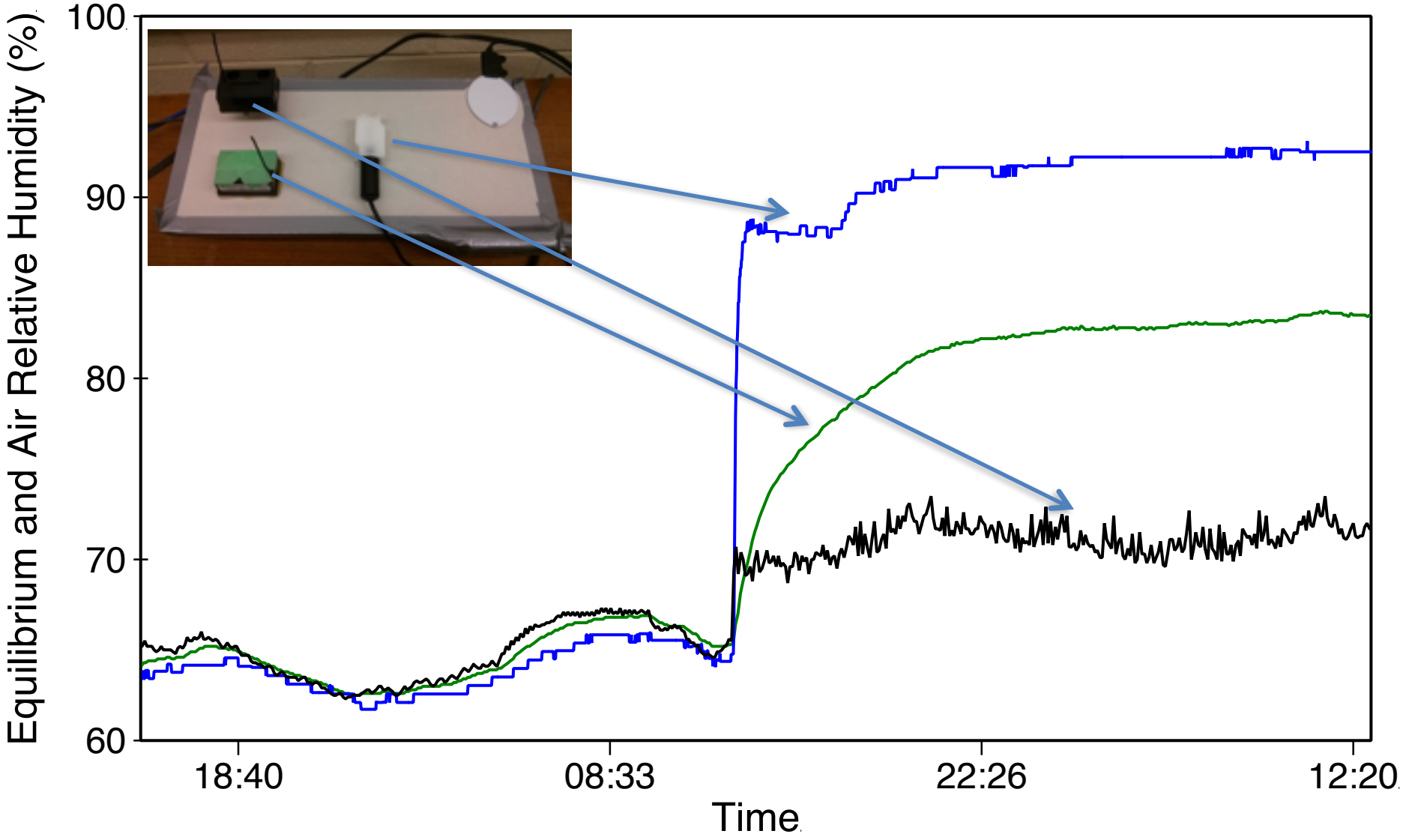
What *in-situ* and *practical* moisture measurement methods correlate with microbial community and microbial biomass on drywall after *wetting*?

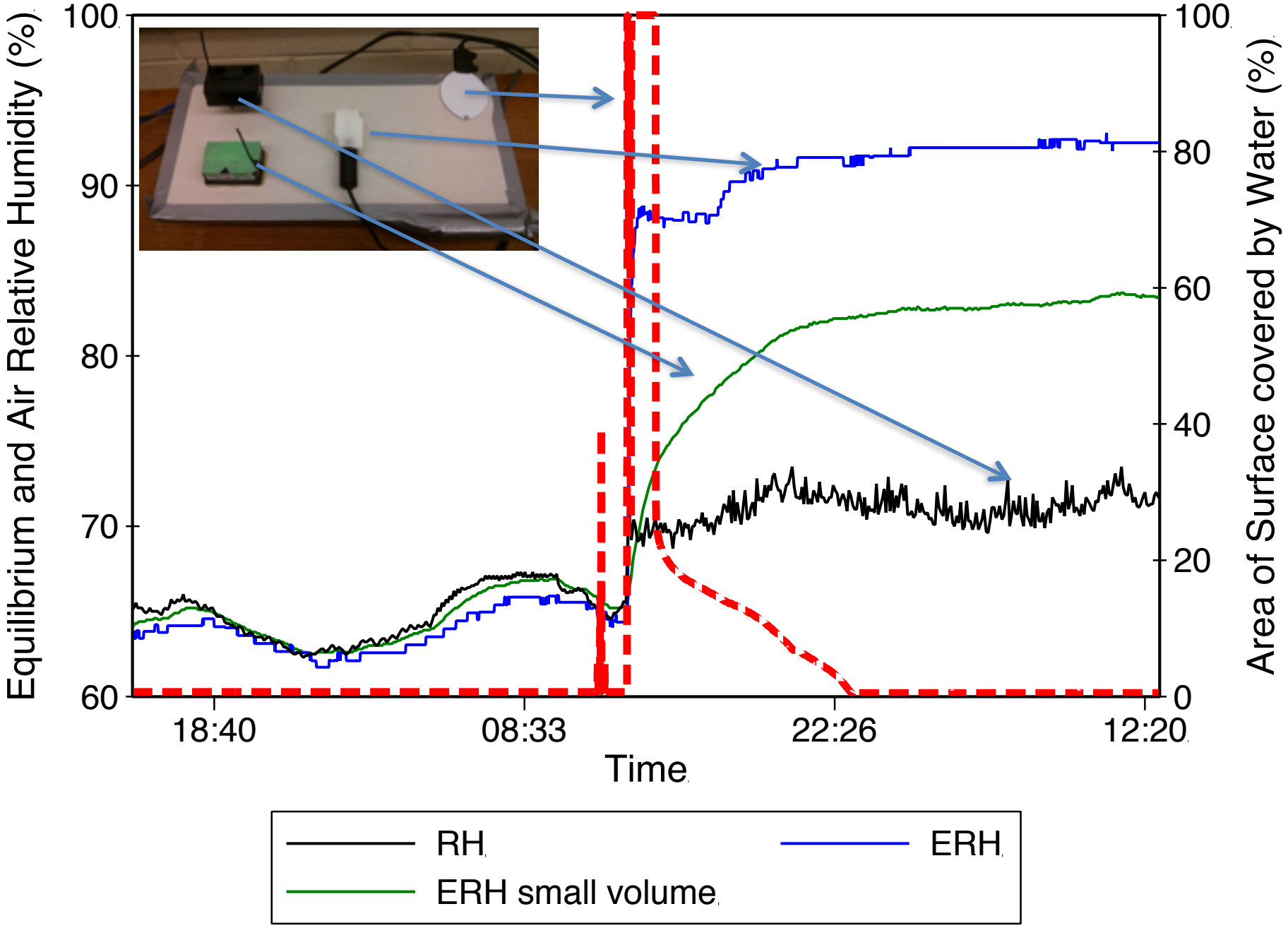
Drywall Wetting Project

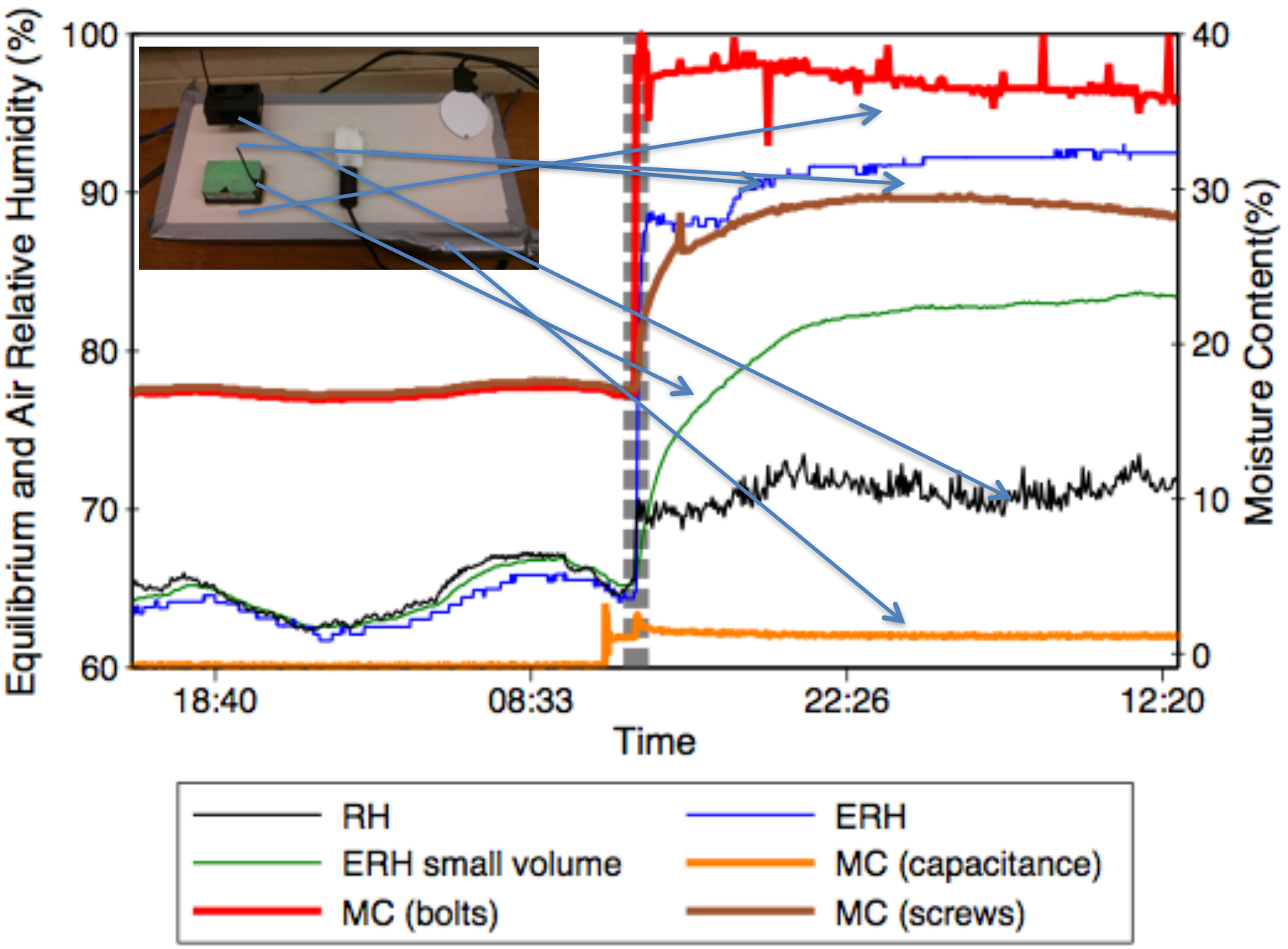
- Three scales (coupons, wall section, in-situ)
- Detailed moisture assessments
- Quantitative microbiology





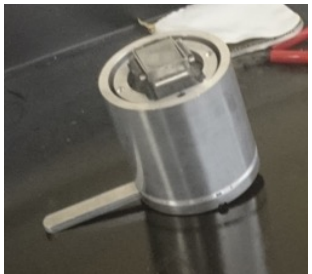

Equilibrium and Air Relative Humidity (%)
100
90
80
70
60
18:40
08:33
22:26
12:20
Time
RH
ERH
ERH small volume


Equilibrium and Air Relative Humidity (%)
Area of Surface covered by Water (%)
100
90
80
70
60
100
80
60
40
20
0
18:40
08:33
22:26
12:20
Time
RH
ERH
ERH small volume


Equilibrium and Air Relative Humidity (%)
100
90
80
70
60
40
30
20
10
0
Moisture Content(%)
18:40
08:33
22:26
12:20
Time
RH
ERH
ERH small volume
MC (capacitance)
MC (bolts)
MC (screws)

Approach

- UV “sterilize” sample
- *Biological sample 1*
- Inoculate sample naturally for 30 days in a well-characterized office
- *Biological sample 2*
- Wet sample in sealed chamber
- *Biological samples 3-7*
  - *After 1,4,7,14,28 days*



Notes: No repeat sampling, no shared biological and moisture measurement (single purpose samples)

Notes: Biological sampling = 16S/ ITS + total fungal and bacterial qPCR + species specific qPCR for ~20 most abundant species

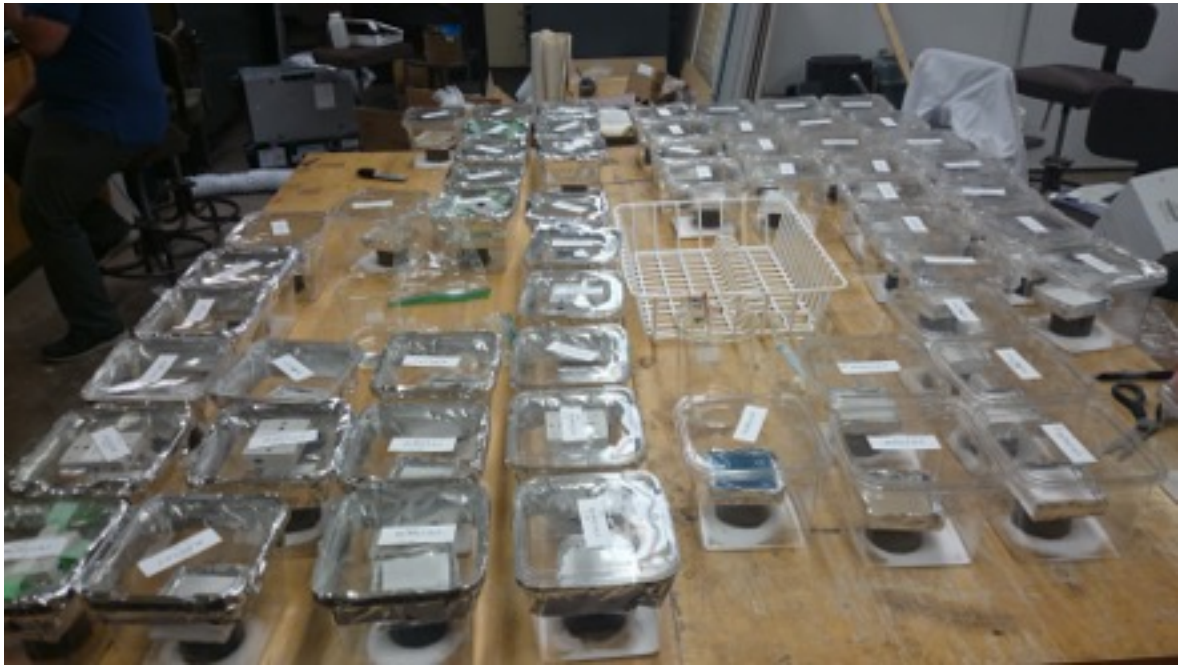
Experimental Matrix

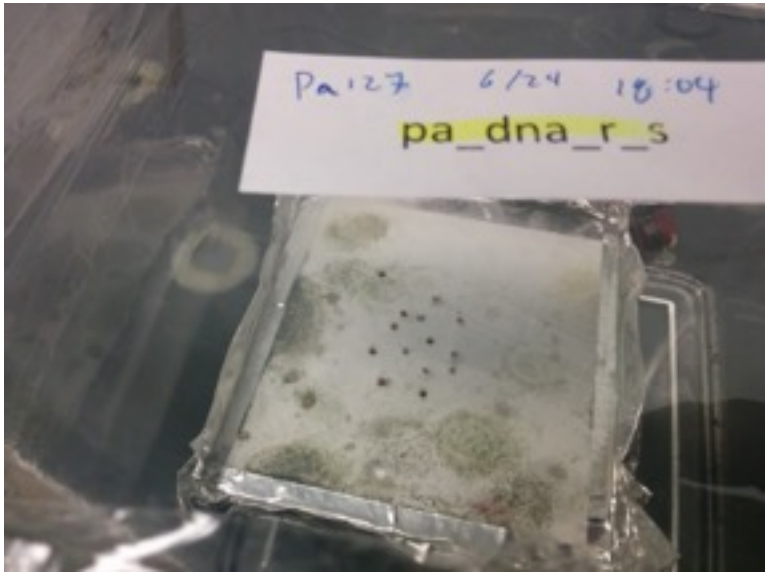
- Three scales (coupons, wall section, in-situ)
- In all cases, characterized natural inoculation
  - Drywall: Unpainted, **painted**, moisture resistant, light weight (high porosity)
  - Water: **DNA-free**, tap, rain
  - Water amount: **Fixed**, doubled, episodic
  - Post-wetting: **Toronto winter**, Toronto summer

- Assessing variance with targeted repetitions
- Different kinds of blanks and controls
- Samples are used only once


STERILIZER D-200


Em50




Pa127 6/24 18:04
pa_dna_r_s

Outcomes

- What is the impact of wetting on different measurements of moisture at different conditions?
- What is the impact of wetting on microbial community and quantity at different conditions?

Parting Thoughts

- As building scientists, we need to do much better at conducting microbially-relevant measurements.
- A big component of this is assembling a highly-spatially resolved measurement of long-term adsorbed and liquid water.
- People will (are) trying to adjust the indoor microbiome – this is going to cause us lots of headaches in the future.

Acknowledgements

- UofT Graduate students: Sandra Dedesko, Mahnaz Zare, Babak Khamsehi, Phil Fan, Amy Li, Masih Alavy
- Undergraduate students: Ryan Williams
- Faculty Collaborators: Greg Caporaso, Scott Kelly, Rob Knight, James Scott, Brent Stephens, Jack Gilbert, Derek Sonderegger
- Student Collaborators: John Chase, Jennifer Fouquier
- Funding: Alfred P. Sloan Foundation

ALFRED P. SLOAN FOUNDATION

Other things we learned

- “The **sequencing run** can be an important confounding factor in long-term temporal studies of bacterial communities.”
- “Across all nine offices, human skin bacterial communities were the largest identifiable source of the office bacterial community samples, with at least 25 to 30% of the office surface microbiome being derived from human skin.”

Challenges

- Unintended consequences
- Building complexity
- Continuous monitoring and maintenance

Unintended Consequences - 1

Next-generation DNA sequencing reveals that low fungal diversity in house dust is associated with childhood asthma development

Influence of housing characteristics on bacterial and fungal communities in homes of asthmatic children

"Increased microbial richness was associated with the presence of pets…"

Dannemiller et al. (2014,2015) *Indoor Air*

Allergens and β-Glucans in Dutch Homes and Schools: Characterizing Airborne Levels

"…pet allergen levels were 13 times higher in schools compared to homes without pets."

Krop et al. (2014) PLoS One

Unintended Consequences -2

Architectural design influences the diversity and structure of the built environment microbiome

The phylogenetic diversity of airborne bacterial communities was lower indoors than outdoors, and mechanically ventilated rooms contained less diverse microbial communities than did window-ventilated rooms.

Kembel et al. (2012) ISME Journal

Building Complexity-Failures

"In 80% of the houses, signs of current or previous moisture fault were observed." Nevalainen et al. (1988) *Indoor Air*

Why is this an issue for bioinformed design?

- Moisture damage influences indoor microbial communities and quantities
- Negative impact on health
  - e.g., Mendell et al. (2011) *Environ. Health Persp.*
- Paradox:
  - "Increased microbial richness was associated with the presence of pets.

sition

Dannemiller et al. (2015) *Indoor Air*

Building Complexity - Maintenance

- We often make a decision to not maintain or control our buildings appropriately
- Adding microorganisms increases complexity considerably

Maintenance Requires Sampling

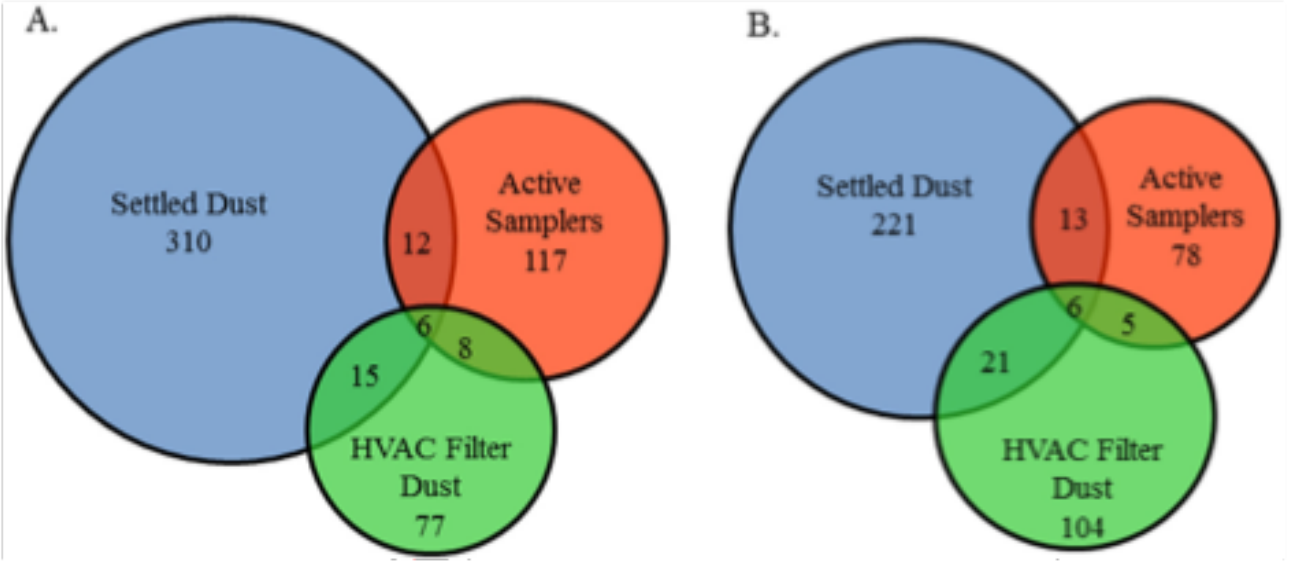


Fig. 6. Shared bacterial OTUs for settled dust, HVAC filter dust, and bioaerosol samplers (combined) for Week 1 (A) and Week 2 (B).

Hoisington et al. (2014) *Building and Environment*

- …..quantitative sampling

Der mentsh trakht un Got lakht

Man plans and god laughs

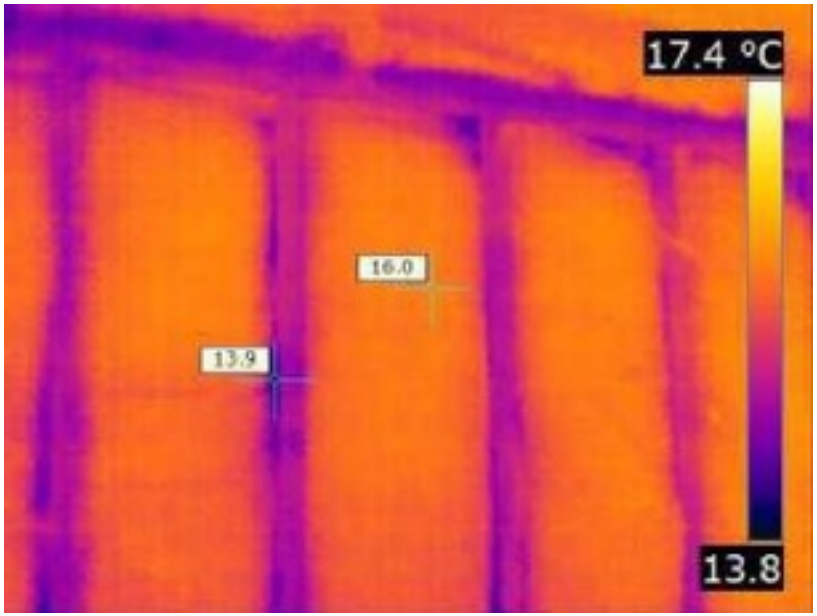
Does this mean we shouldn't do anything?

1. Hypothesis driven research with appropriate controls
2. Specific and targeted
3. Plan for failure
4. Balance with other goals
5. Commission and maintain
6. Plan for monitoring

Lemieux and Totten. (2004). The importance of building envelope commissioning for sustainable structures. *ASHRAE Buildings IX Conference Proceedings* 1-12.

What is (potentially) important to the microorganisms?

- Energy flows



What is the wall structure? Globally and locally?

How much insulation?

What is the temperature on the other side?

Is it connected to other parts of the building?

What is the surface temperature?

Source: http://buildingscience.com, http://quiktherm.com/insulatesmart/wp-content/uploads/2014/10/Thermal-Bridging.jpg

What is (potentially) important to the microorganisms?

- Energy flows (temperature doesn't tell us that)
- Available moisture

What is the surface temperature?

What is the wall structure? Globally and locally?

How much vapour diffusion?

What is the vapour pressure on the other side?

Is it connected to other parts of the building?

Is there condensation?

How much moisture is at the surface/in the material?

What is (potentially) important to the microorganisms?

- Energy flows (temperature doesn't tell us that)
- Available moisture (RH doesn't tell us that)
- Material properties of drywall (all drywall is different)

How many layers of paint?

What kind of paint?

Is there a paper layer?

What kind of adhesive?

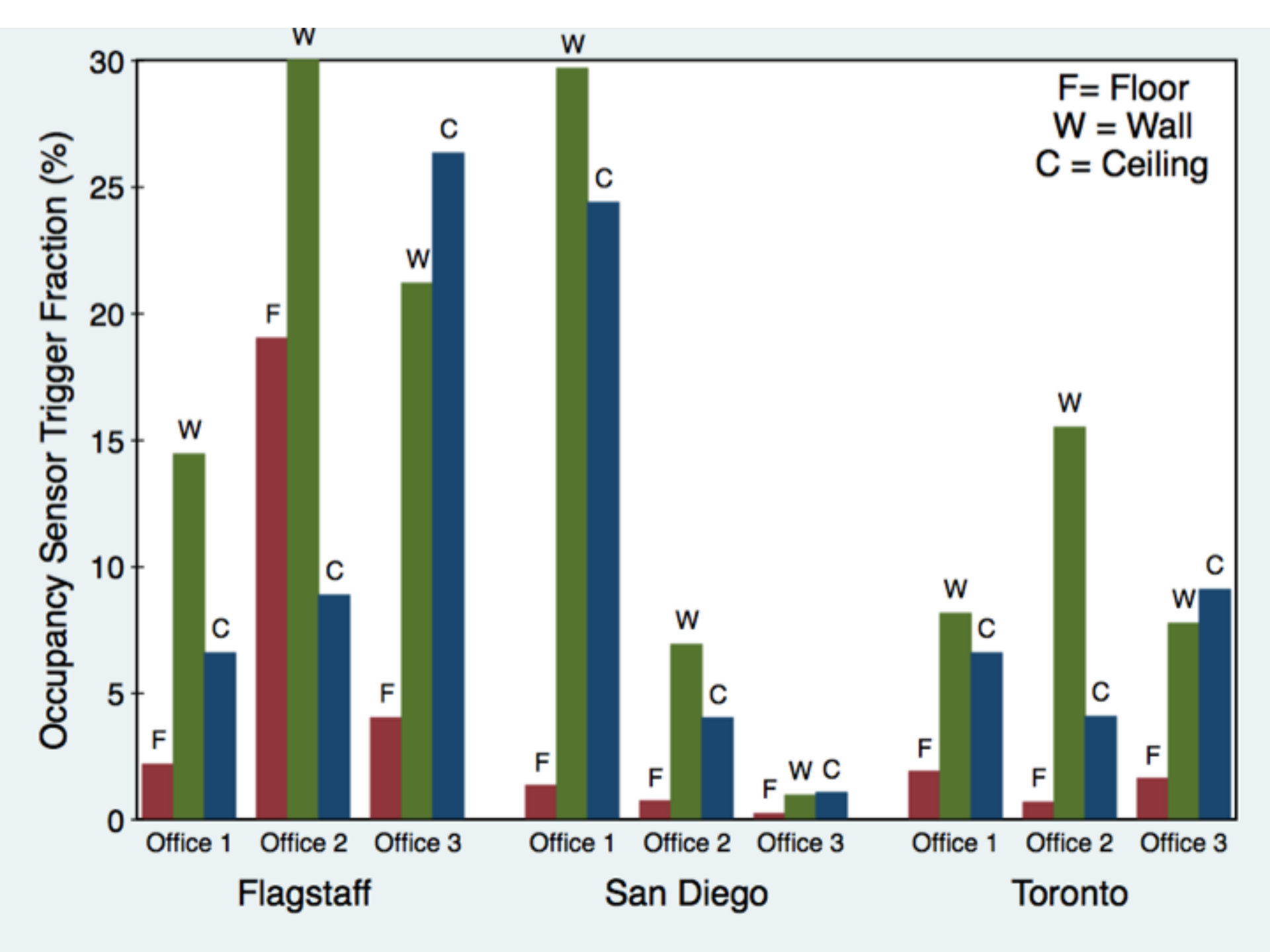
What kind of gypsum?

What other additives?

What are bulk material properties (porosity, density, etc.)?

What I take from this

- We need to do quantitative microbiology
- We need to understand moisture in buildings in a much more sophisticated way


Occupancy Sensor Trigger Fraction (%)
0
5
10
15
20
25
30
F= Floor
W = Wall
C = Ceiling
Office 1
Office 2
Office 3
Flagstaff
San Diego
Toronto

Quest for Functional Relationships

- We often don't have quantitative data
  - Relative abundance
- We often don't have species-level data
- We almost never have time-resolved data
- We often don't have the building characterization done in a microbial-relevant manner