

The Effect of Humidity on the Chemistry and Biology of Indoor Air



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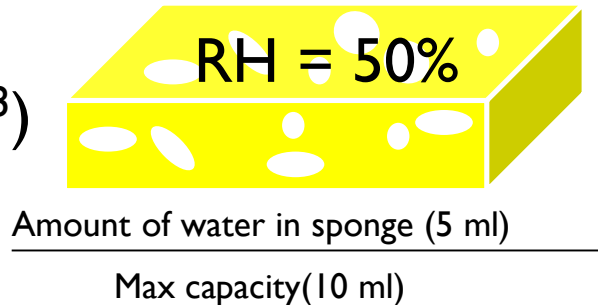
Overview

1. Humidifiers as sources of PM
2. Microbiology: bacteria, viruses, fungi
3. pH and chemistry

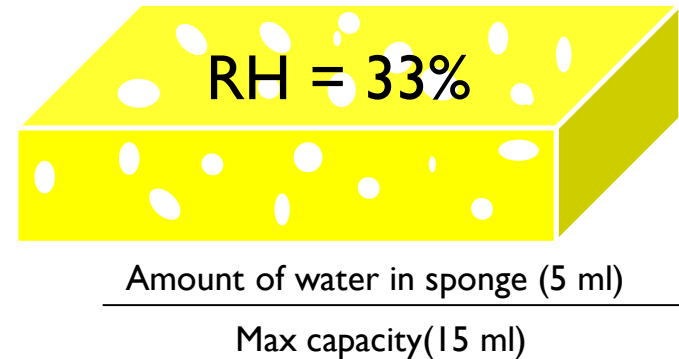


Absolute vs. Relative Humidity

same AH
(up to 40 g/m³)



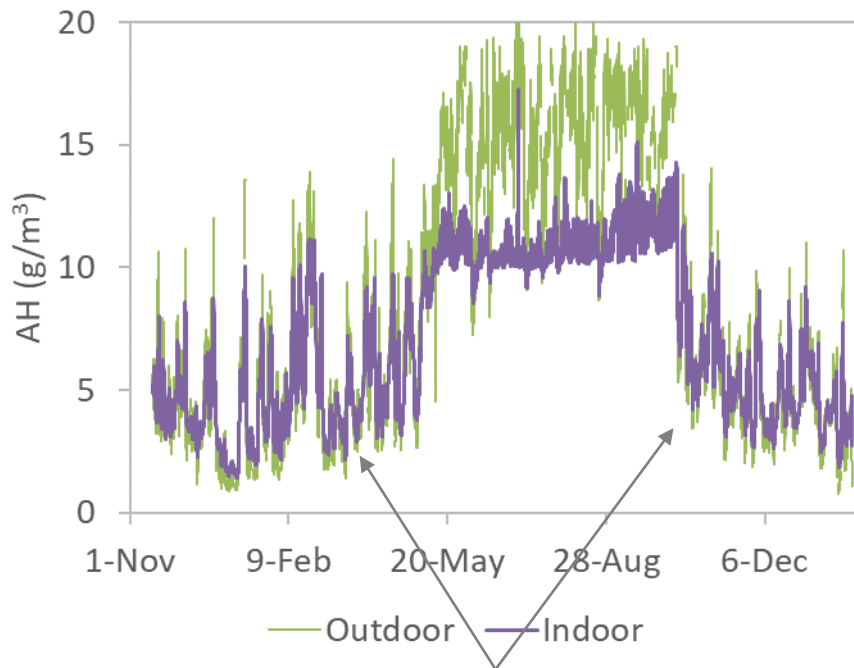
Higher temperature $\Rightarrow$
bigger sponge



AH and RH are strongly correlated indoors because the temperature falls in a narrow range.

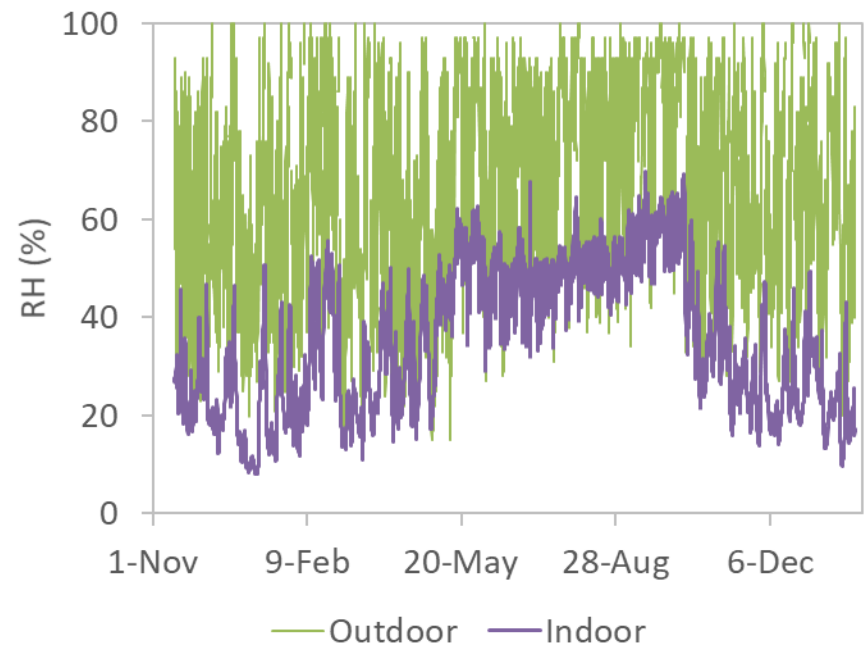
Indoor vs. Outdoor Humidity

Absolute Humidity



Indoor AH and outdoor AH are correlated during non-AC season

Relative Humidity

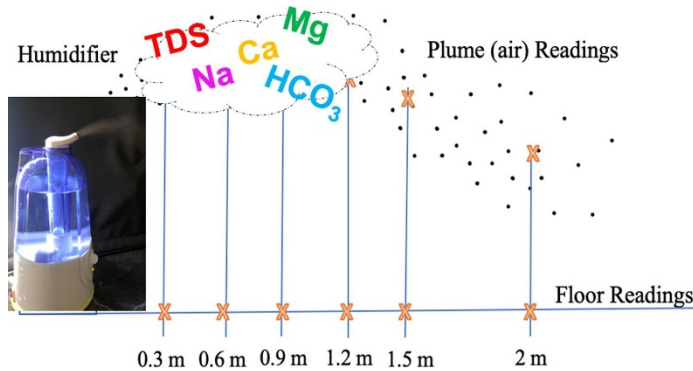


Indoor RH is better correlated with outdoor AH than outdoor RH

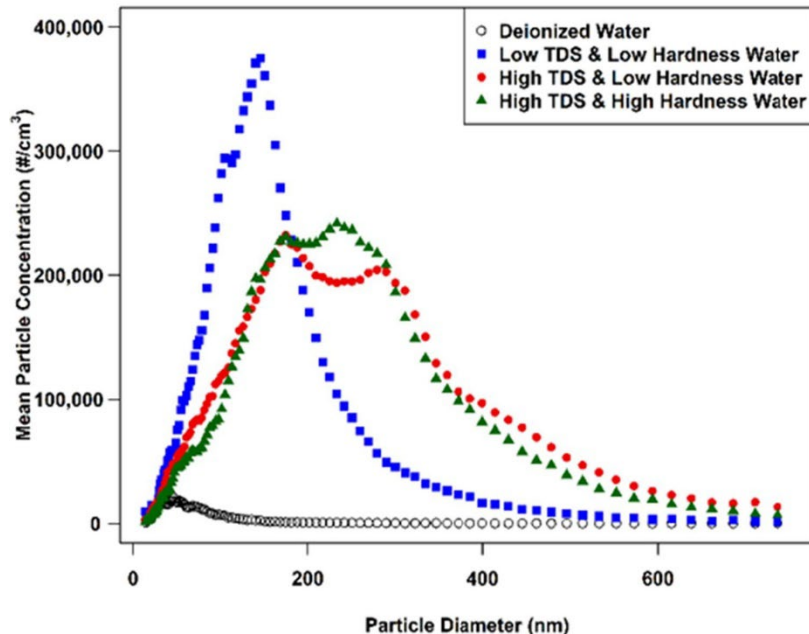
This is for temperate regions. The pattern differs in tropical regions.

(1) Nguyen et al., 2014, [The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity](#), *Indoor Air*; (2) Nguyen et al., 2016, [Daily indoor-to-outdoor temperature and humidity relationships: a sample across seasons and diverse climatic regions](#), *Int J Biometeorol*; (3) Pan et al., Correlating Indoor and Outdoor Temperature and Humidity in a Sample of Buildings in Tropical Climates for Understanding the Seasonality of Respiratory Viruses, *Indoor Air*, submitted

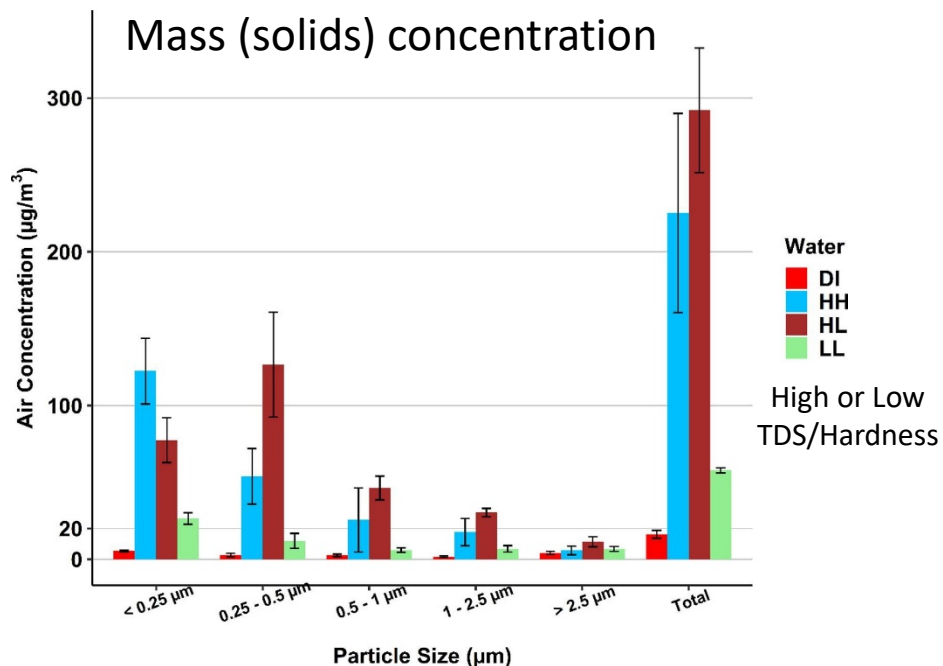
Humidifiers



(A) 0.3m In Plume



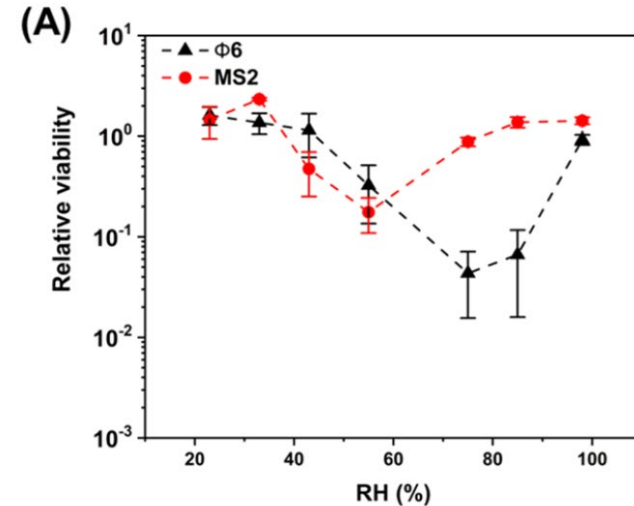
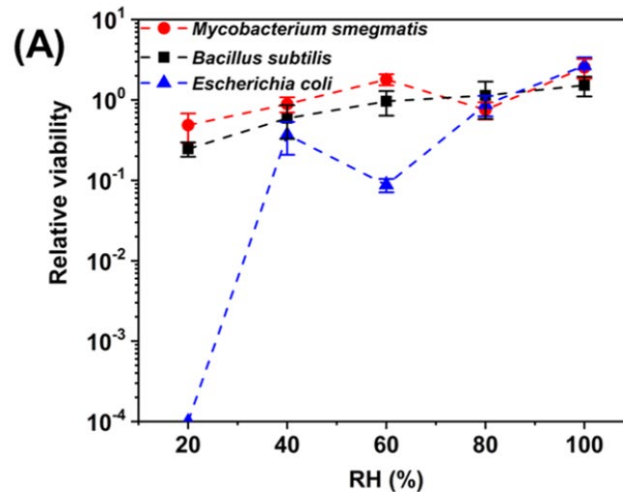
Ultrasonic humidifiers generate non-volatile aerosols from impurities in water



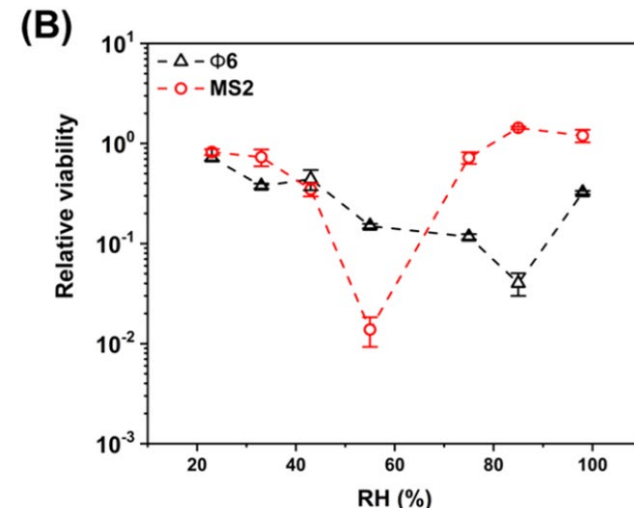
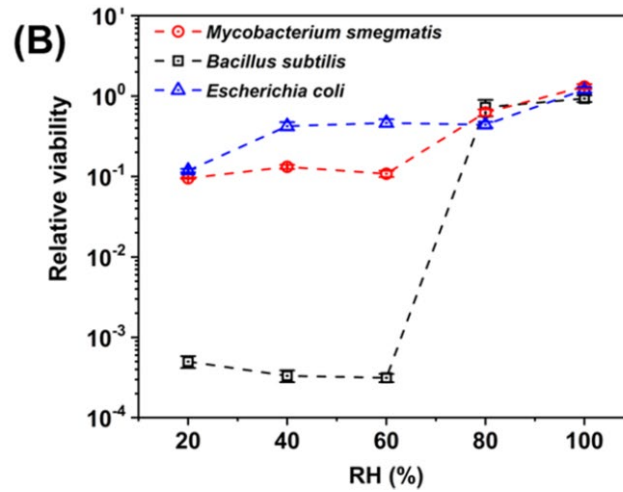
(1) Yao et al., 2020, [Human exposure to particles at the air-water interface: Influence of water quality on indoor air quality from use of ultrasonic humidifiers](#), *Environ Internat* (2) Yao et al., 2019, [Emission of iron and aluminum oxide particles from ultrasonic humidifiers and potential for inhalation](#), *Water Res*

Bacteria and Virus Viability

Aerosols

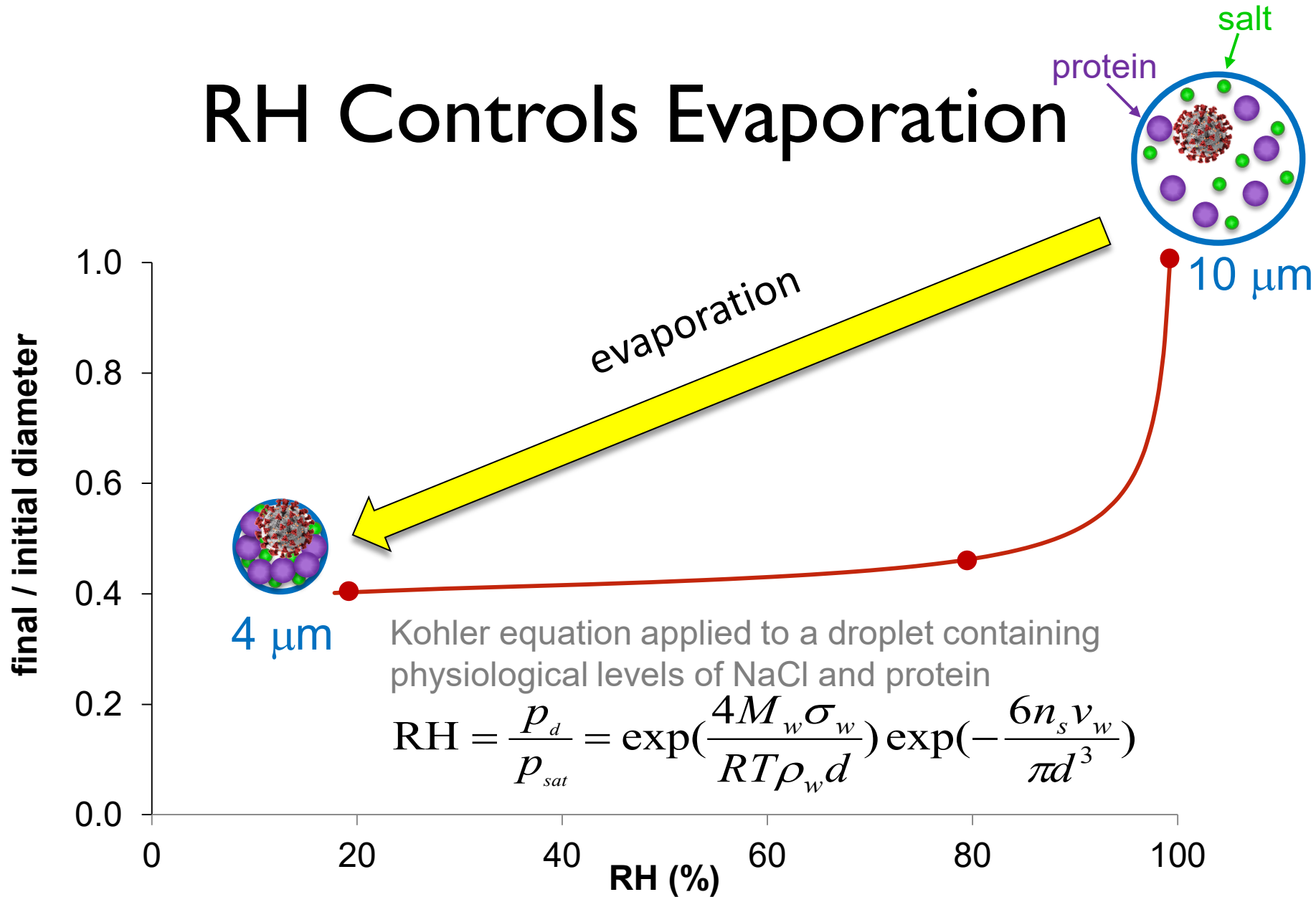


Droplets
on plastic



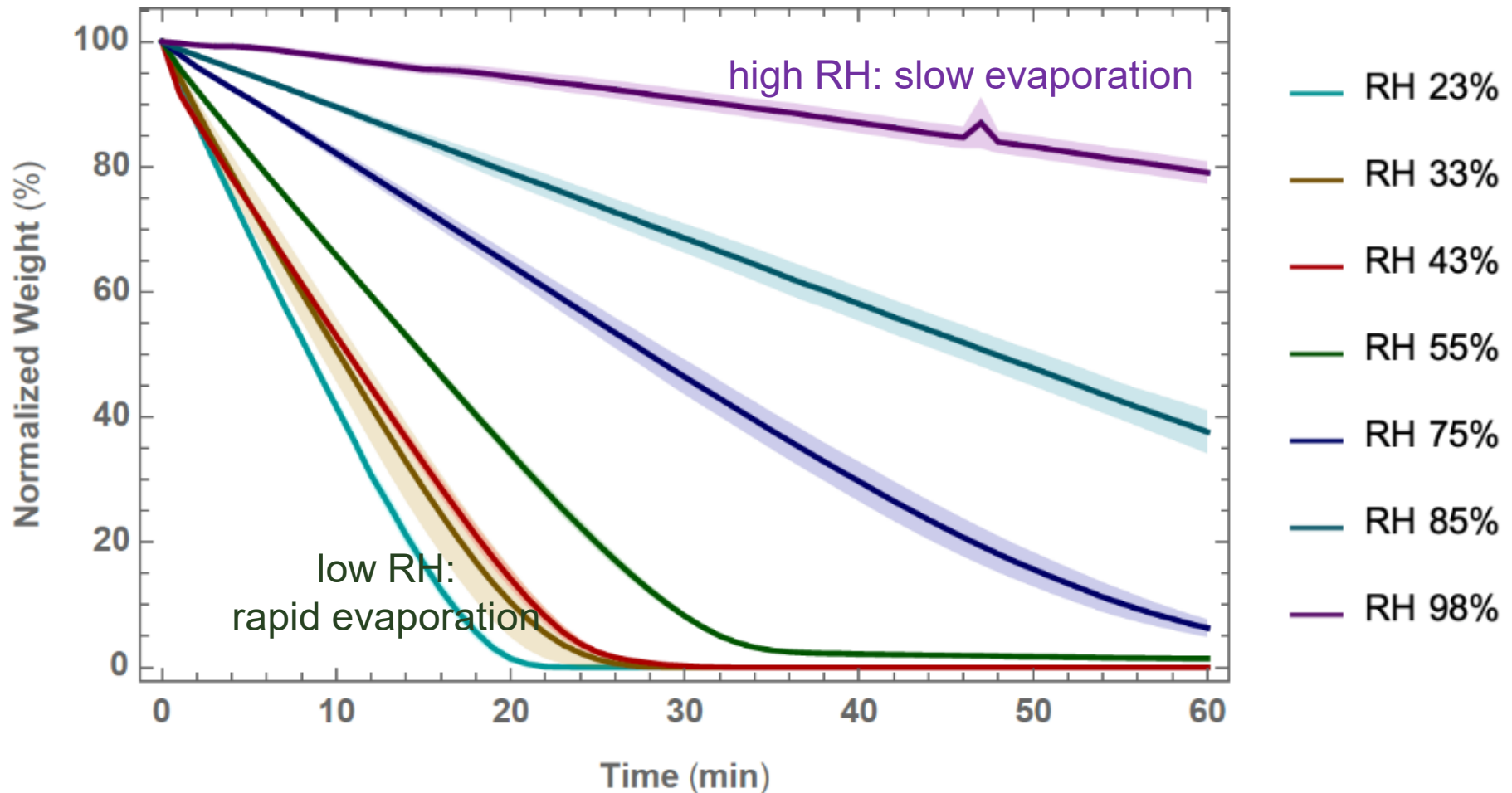
Bacteria survive worst at low RH, viruses at mid-range RH.

RH Controls Evaporation

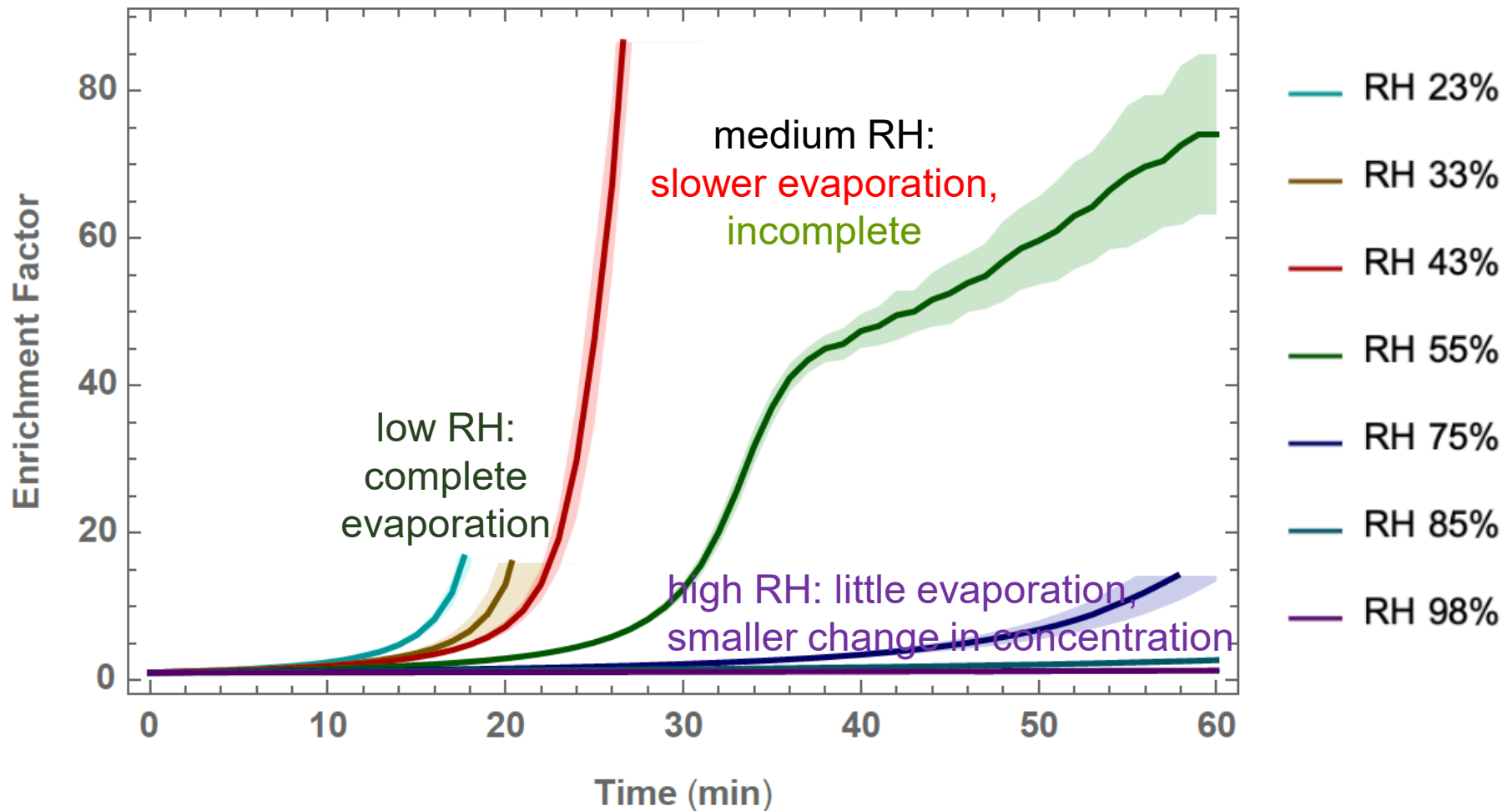


(1) Mikhailov et al., 2004, [Interaction of aerosol particles composed of protein and salts with water vapor: hygroscopic growth and microstructural rearrangement](#), *Atmos Chem Phys* (2) Marr et al., 2019, [Mechanistic insights into the effect of humidity on airborne influenza virus survival, transmission and incidence](#), *J Roy Soc Interface*

Weight of Evaporating Droplets

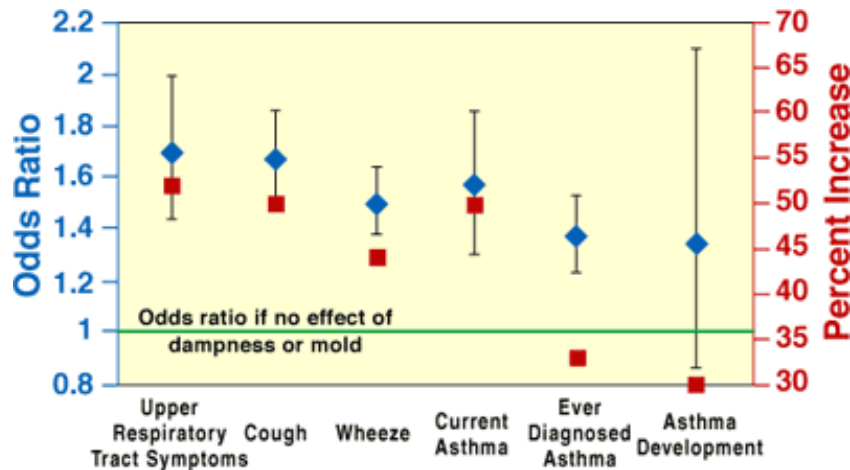


Change in Solute Concentration



Mold is Underappreciated

18-50% of buildings



Spores are 2-100 μm

“Emissions” of spores?
Chemistry of mVOCs?

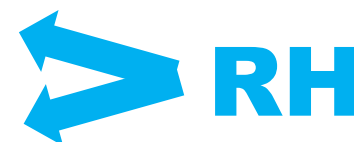
Measuring pH of Droplets



50 μm

Important for

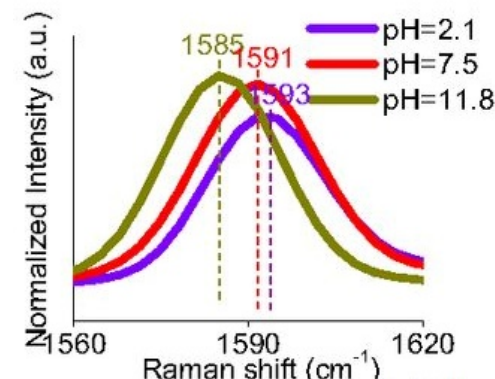
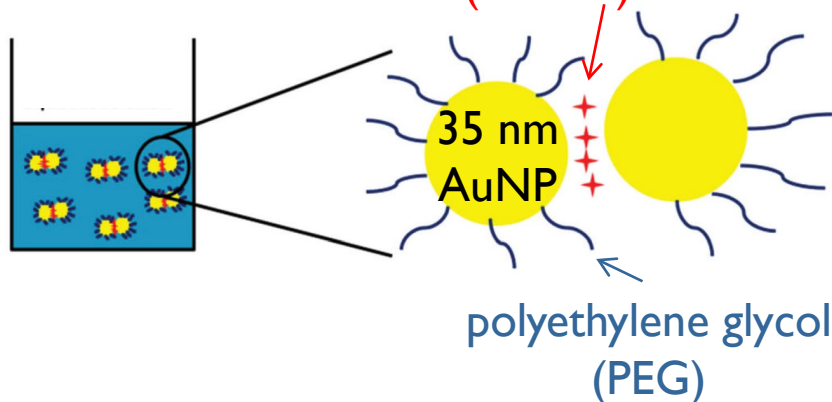
- reactions
- phase-separation
- microbe survival



RH

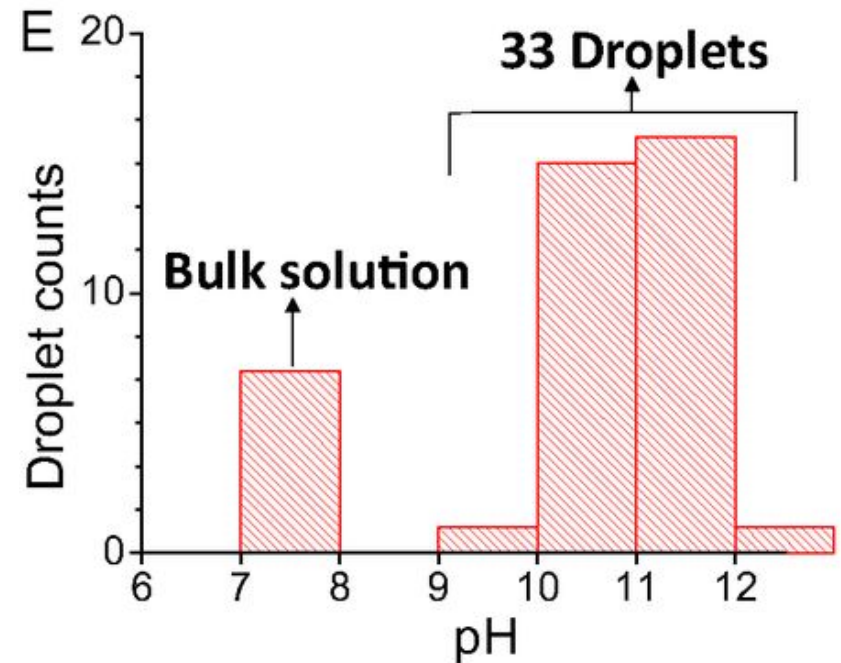
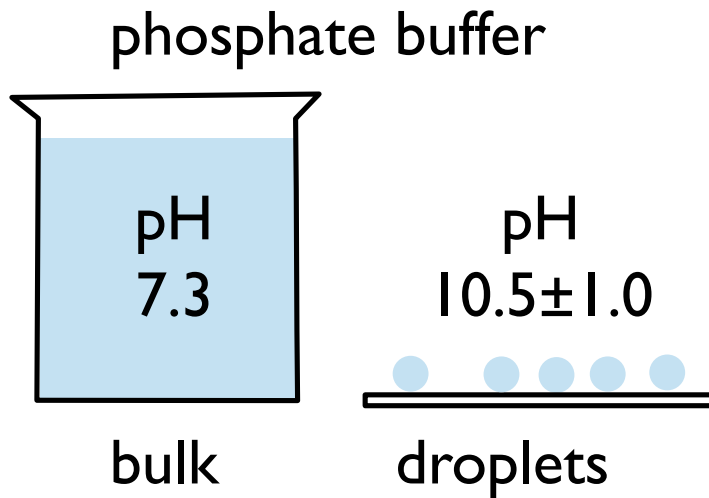
Surface-enhanced Raman spectroscopy (SERS)

4-mercapto-benzoic acid
(4-MBA)

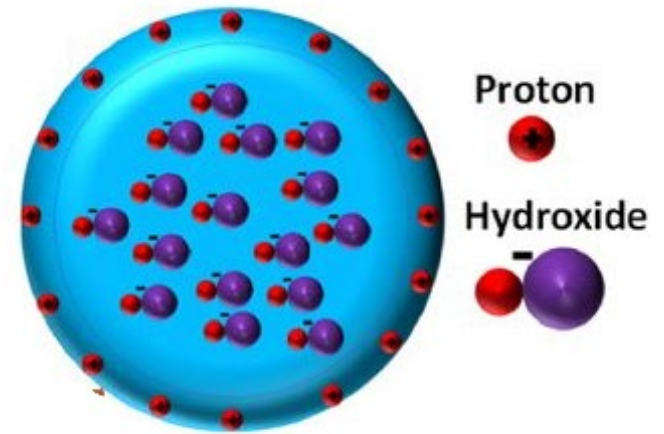
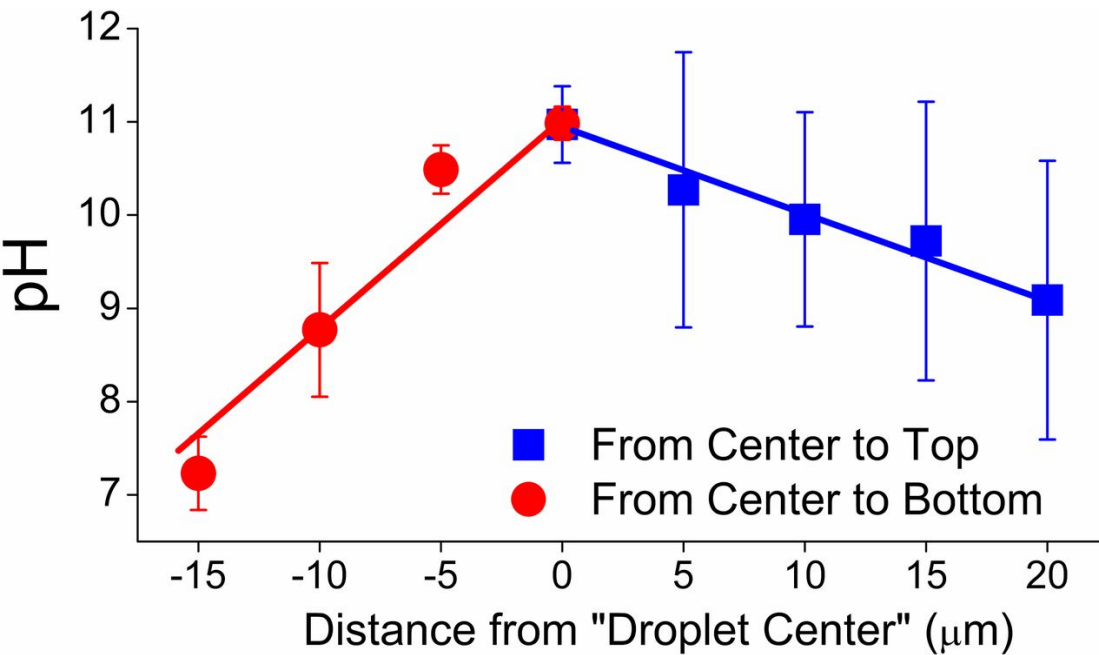


10 mm

pH in Droplets is Higher

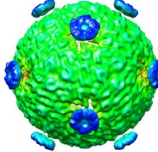


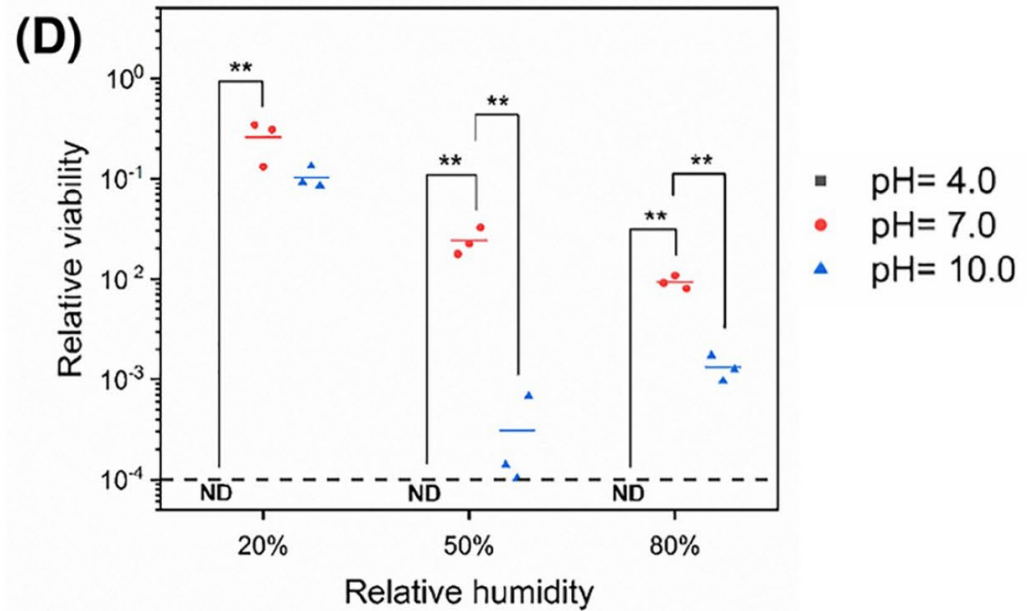
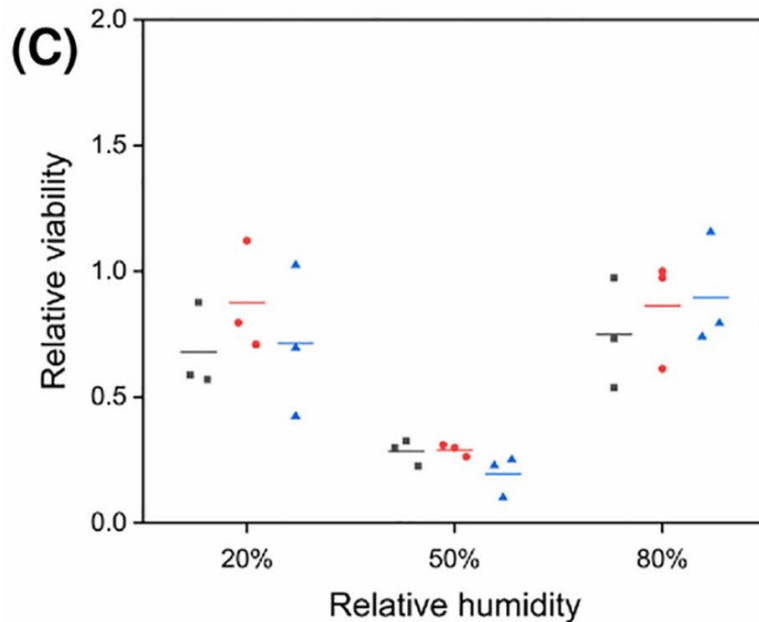
Spatial Gradient in pH



RH and pH Affect Virus Viability

MS2 

$\Phi 6$ 



- MS2 (non-enveloped): lowest viability at mid RH, no effect of pH
- $\Phi 6$ (enveloped): low viability at acidic and basic pH
- Other solutes: protein protects, mixed effects of NaCl and surfactant

Summary

- Humidifiers are a source of non-volatile particulate matter.
- Bacteria survive best at high RH, viruses at low or very high RH.
- RH dynamically controls the water content of particulate matter, affecting its chemistry and biology.

