



The Essential Role of Indoor Air Quality in Patient Outcomes

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HARVARD
MEDICAL SCHOOL

How I got here



Stephanie Taylor, MD,
M Arch, FACHE, FRSPH(UK), MCABE

- Medical doctor since 1984
- Pediatric oncologist at the Dana Farber Cancer Institute, Boston, Massachusetts
- Too many of my patients were dying from being in the hospital
- Masters in Architecture & Engineering
- Started focusing on decreasing infections
- Now studying impact of enclosures on all occupants

Thank you for this opportunity to meet!

Presentation summary

Let's talk about evolution

- Public health trends
- Survival of the fittest, change or face extinction
- Who is in the room with us?

The roommates we are selecting

- New tools and understanding
- The new tree of life
- Microbes and indoor air (diversity and pathogenicity)

Research

- Microbiome study
- Other studies
- Mechanisms

“To change, or not to change?”

- No: (legionella, building envelopes, energy consumption)
- Yes: health, savings
- Next steps

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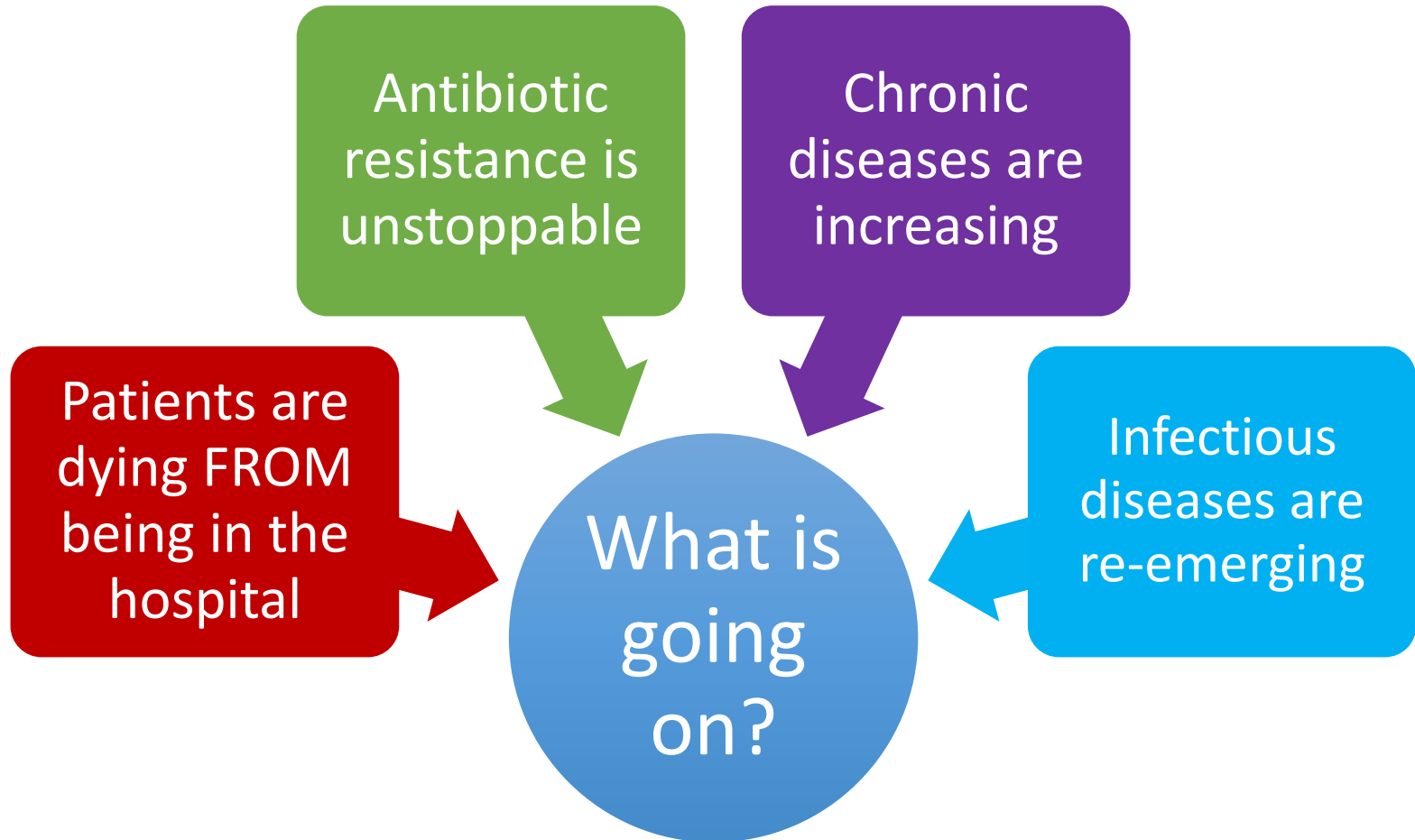
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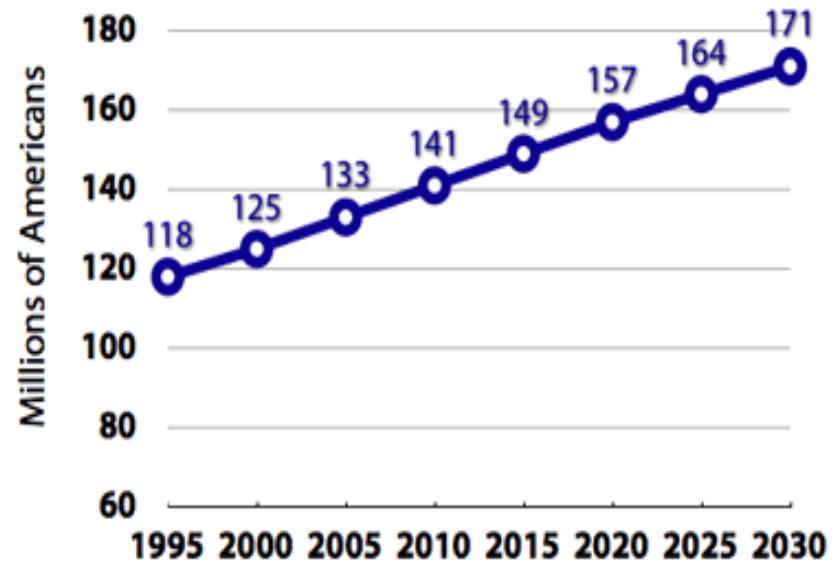
This is confusing.....



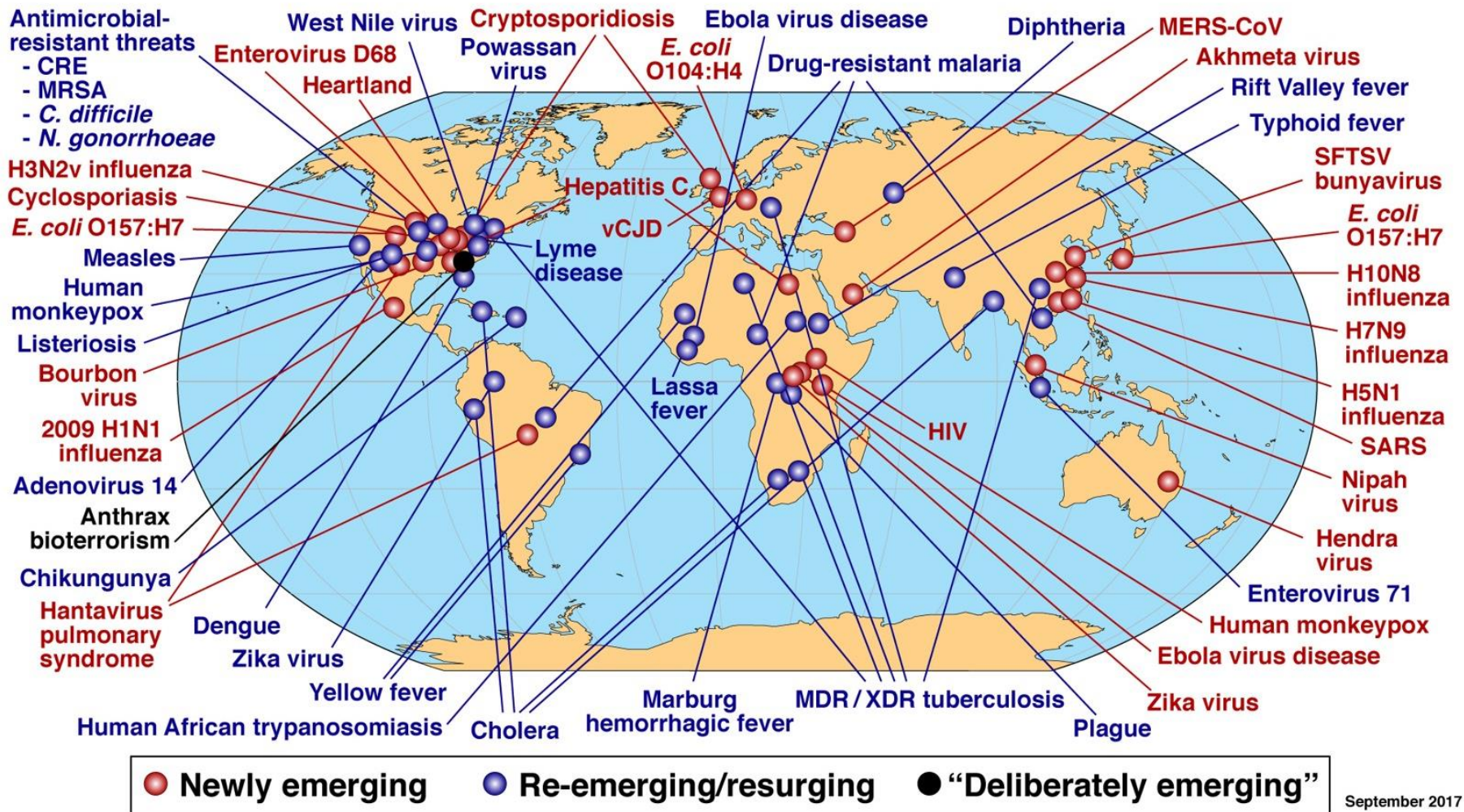
Chronic diseases are affecting more and more people

- Autoimmune diseases have increased
- Learning disabilities have risen 50 % in the past 10 years
- Endocrine disorders such as diabetes have increased 30% since 1985
- Asthma has reached epidemic proportions, now the No. 1 cause of school absenteeism
- Birth defects are the leading cause of infant mortality in the US

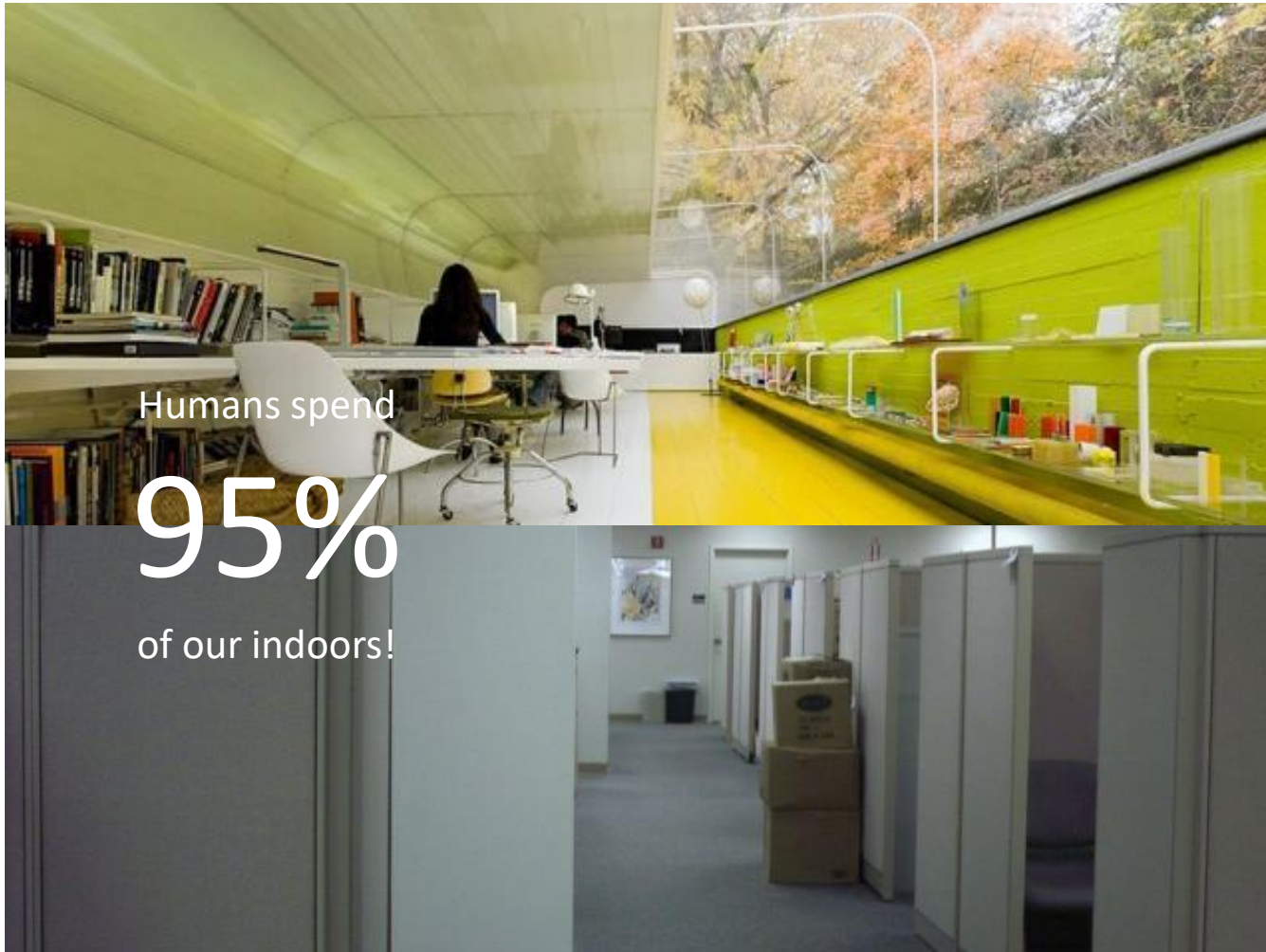
Prevalence of Chronic Disease in the U.S.



Global Examples of Emerging and Re-Emerging Infectious



Our “new” environment



Are our buildings really protecting our health?



“We shape our buildings, then they kill us!”

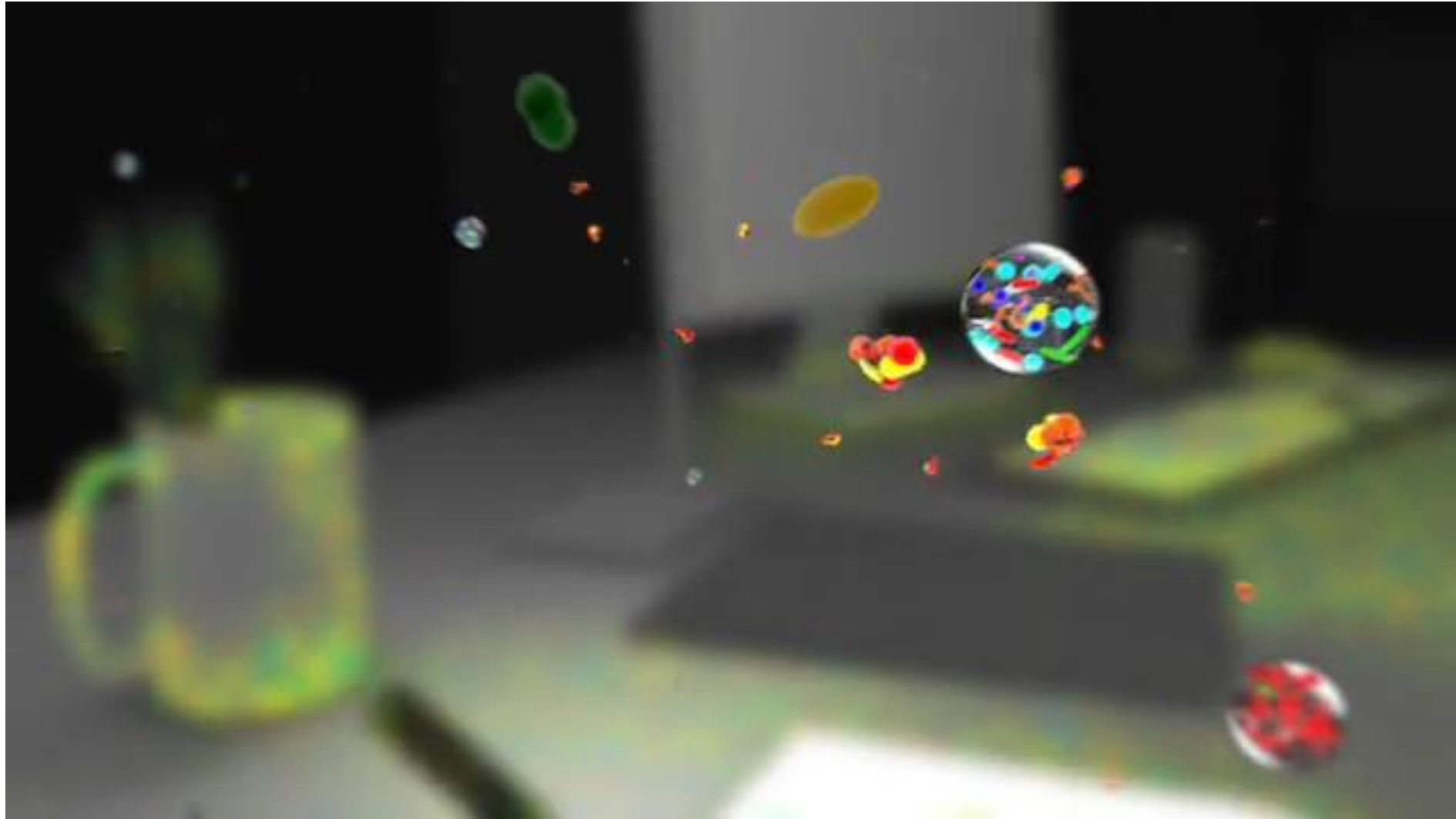
Kenneth Dickerman, AIA 2011

Is this true ??

Survival of the fittest



We have many invisible “roommates”



How much do we know about these “roommates” ?



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New tools have revealed a whole new understanding



“Old school” tissue culture sampling

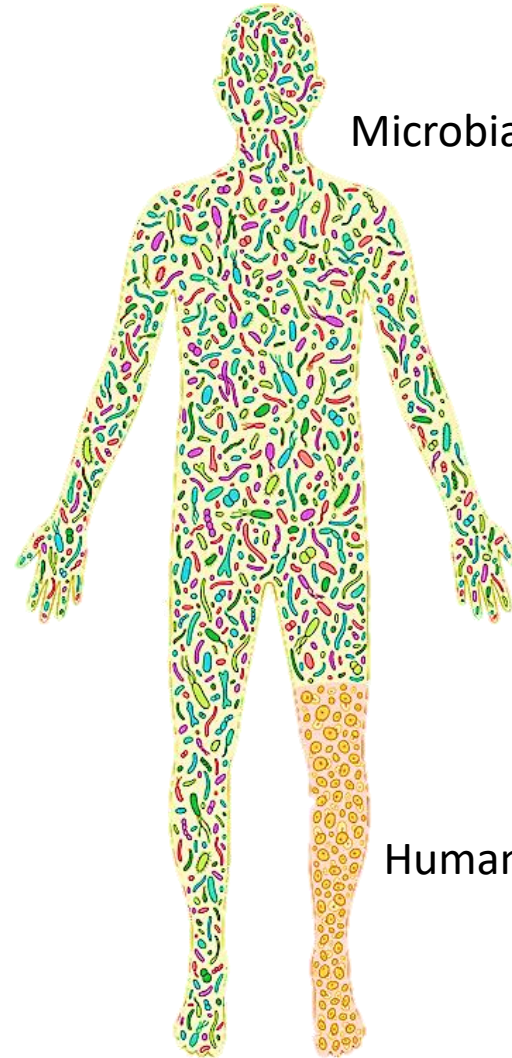


Genetic analysis tools



We are more microbial than human!

Each of us is an ecosystem with ~ 100 trillion other microscopic organisms living in and on us

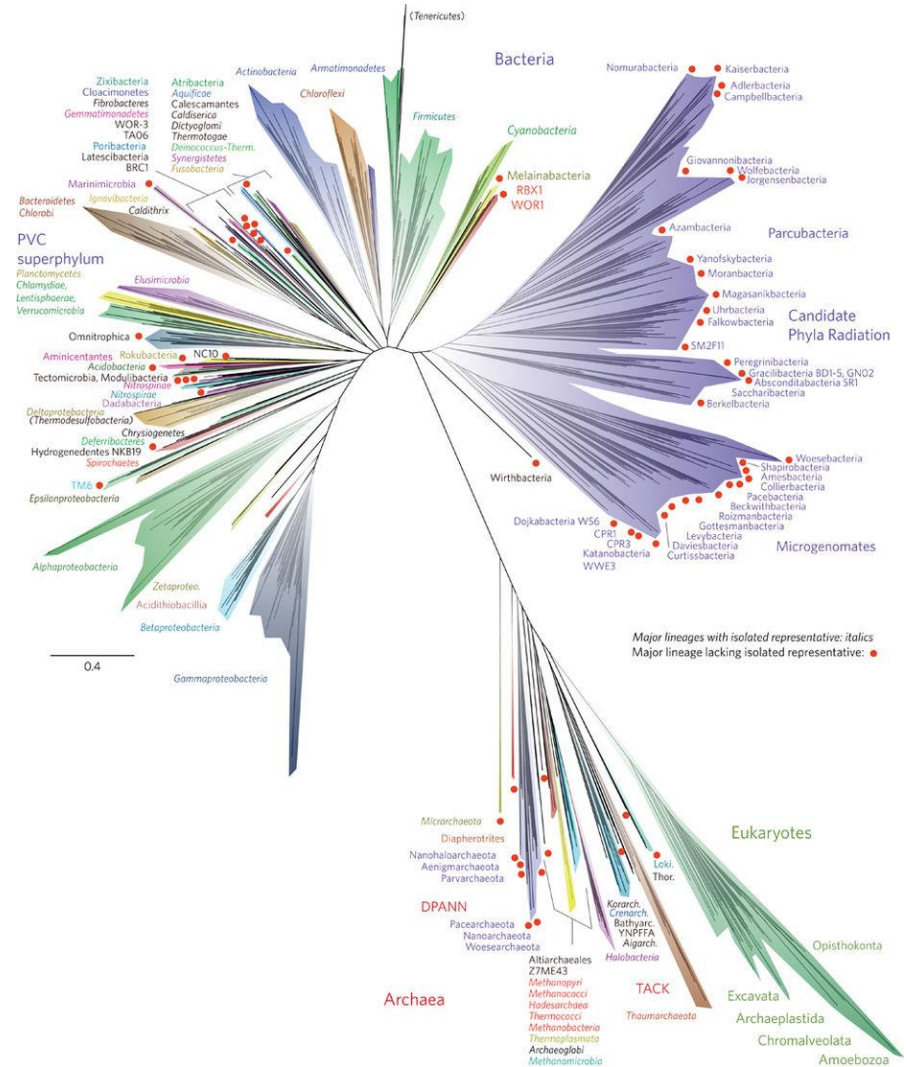


Microbial cells ~ 100 trillion

Human cells ~ 30 trillion

The expanded tree of life

Genetic analysis has revealed diverse microbial populations that were unknown before cultivation-independent approaches



Our microbes interact with the indoor environment

We send our microbes into buildings



Buildings send their microbes to us

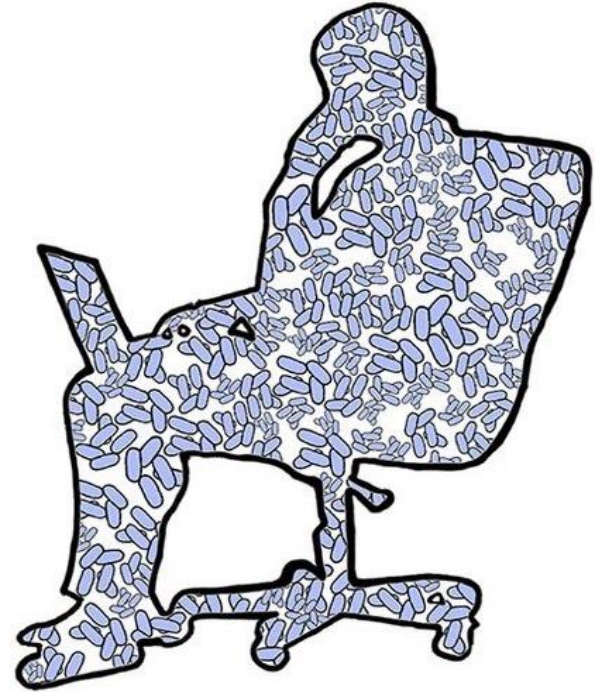


Humans emit approx. 10^7 genome copies of bacteria, and 10^6 fungi into the air per person-hour

The indoor microbiome has less variation than outdoors



outdoors

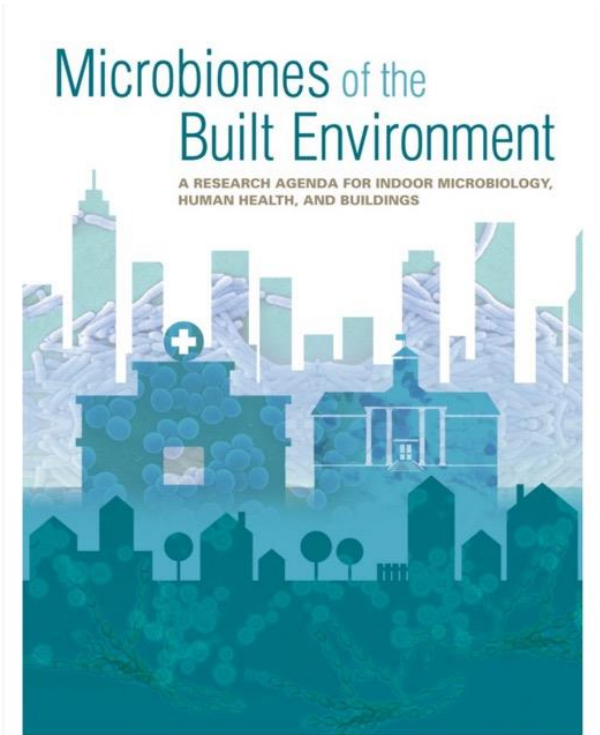


indoors

Loss of biodiversity is bad for ecosystems

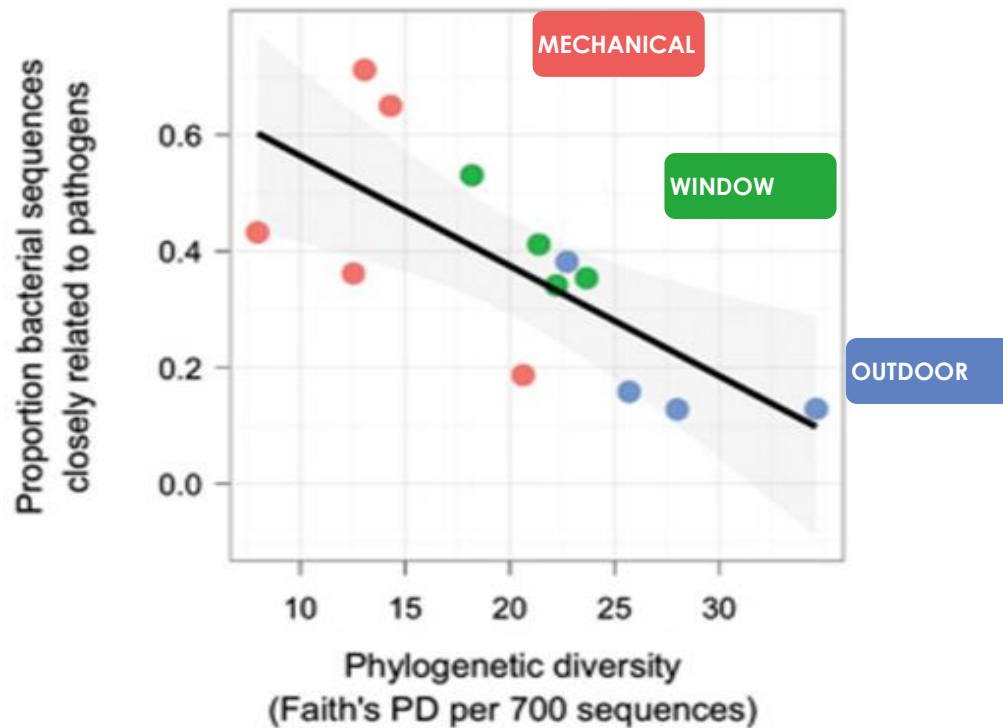


Invasion of one species



Invasion of a few species

Microbes in mechanically ventilated buildings are closely related to pathogens



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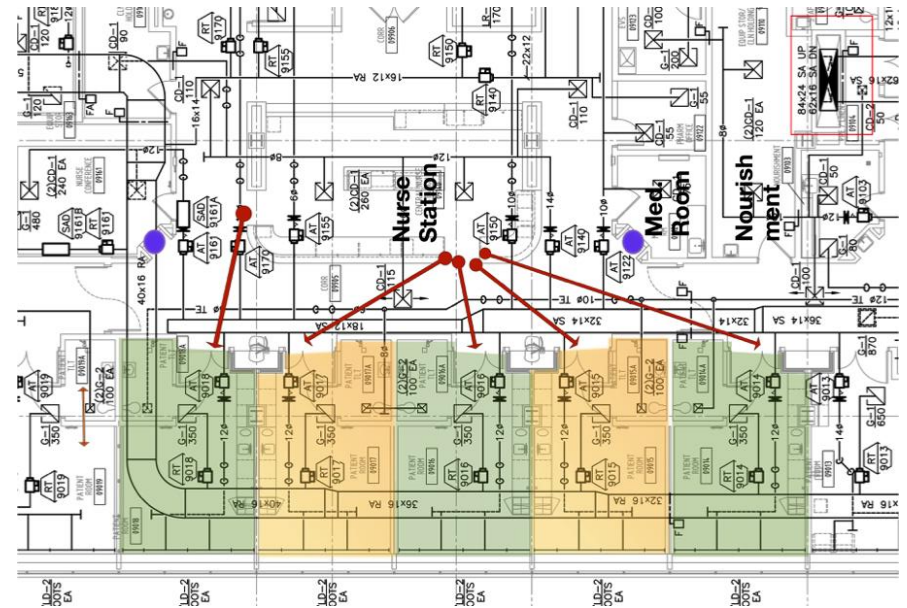
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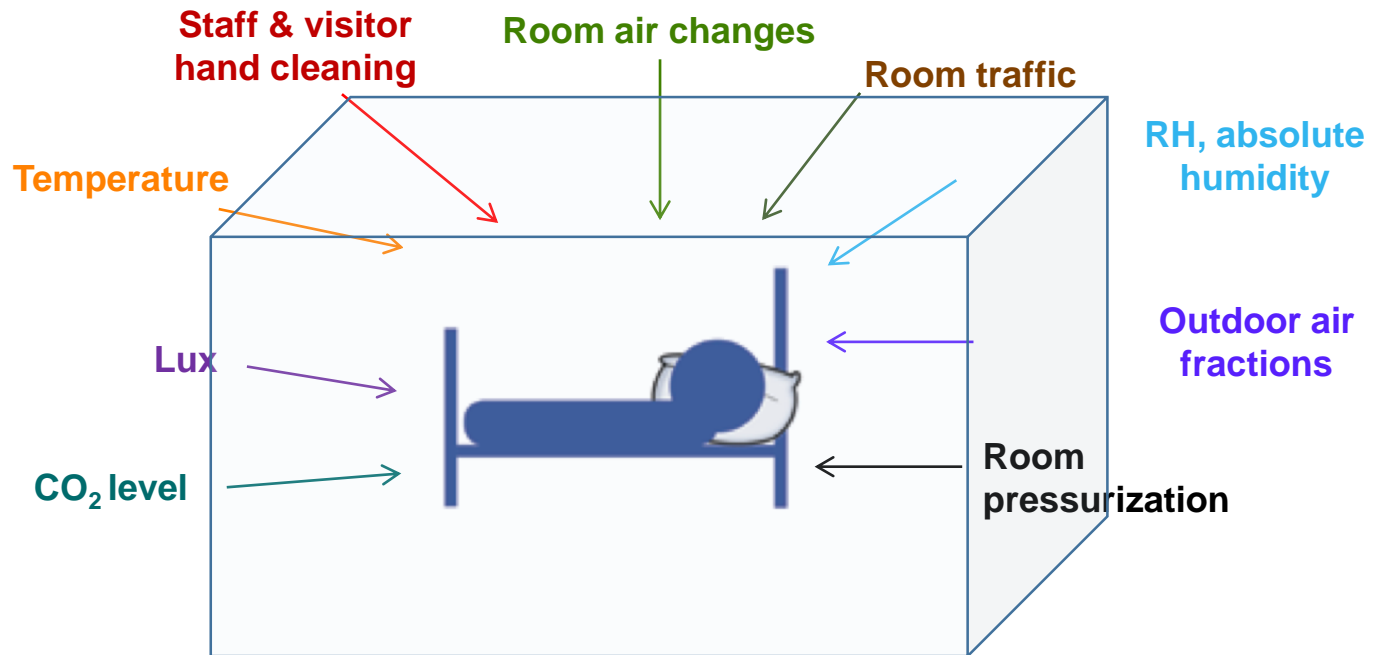
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One year study on patient room IAQ and new infections



10 patient rooms, 2 nurse stations

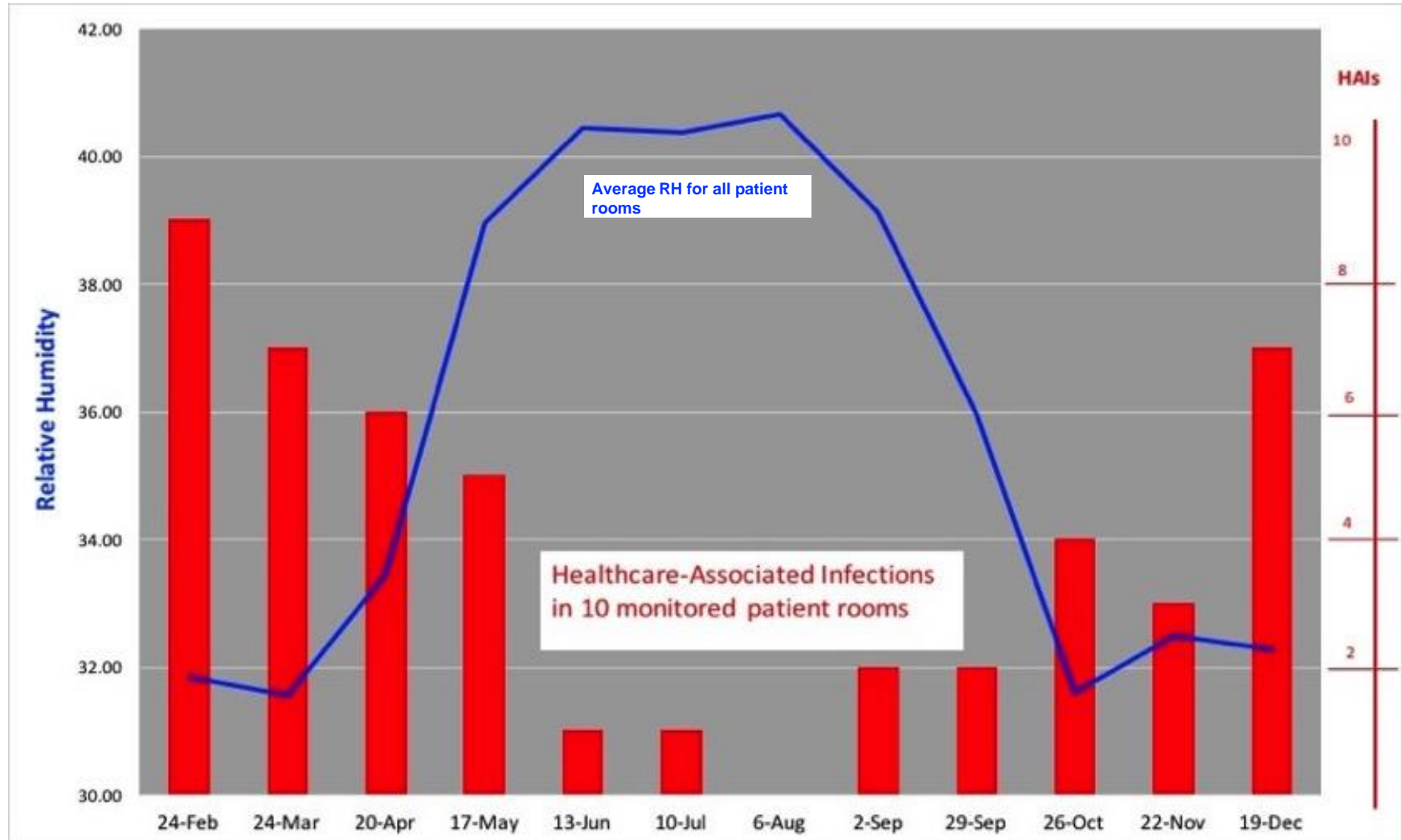
Patient room measurements



8 million data points!!

Results?

Low indoor air RH was found to be the biggest driver of patient infections (HAIs)



Statistically significant correlation

Findings:

as RH



patient
infections



Significance:

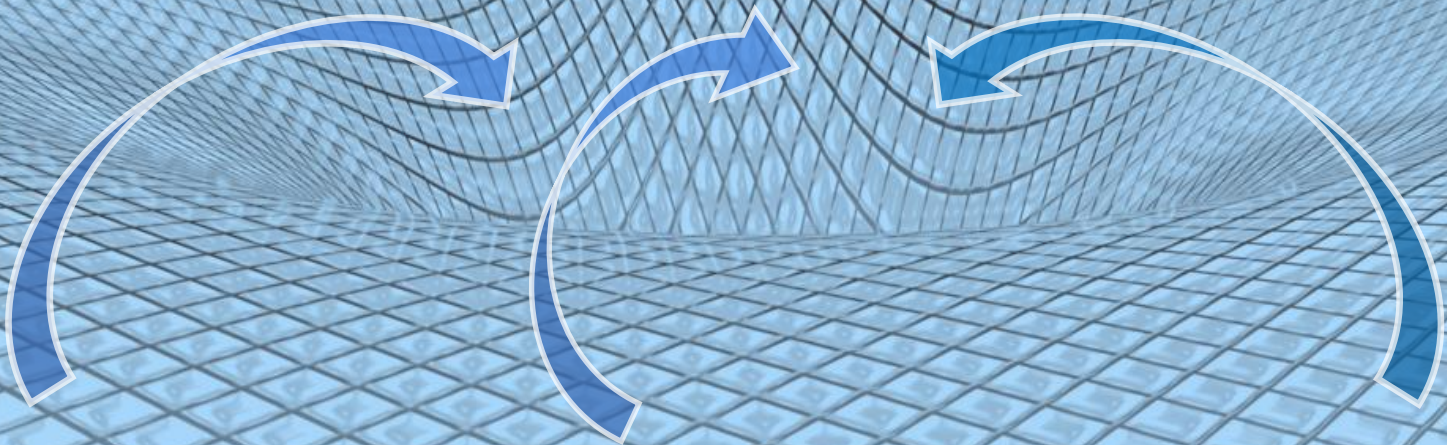
Model	Coefficients ^a		
	Standardized Coefficients Beta	t	Sig.
1 (Constant)		-2.348	.023
Avg RH	-9.060	-2.396	.020

Multivariable
regression analysis:

Statistical analysis that tests the relationship between multiple predictor variables and one outcome

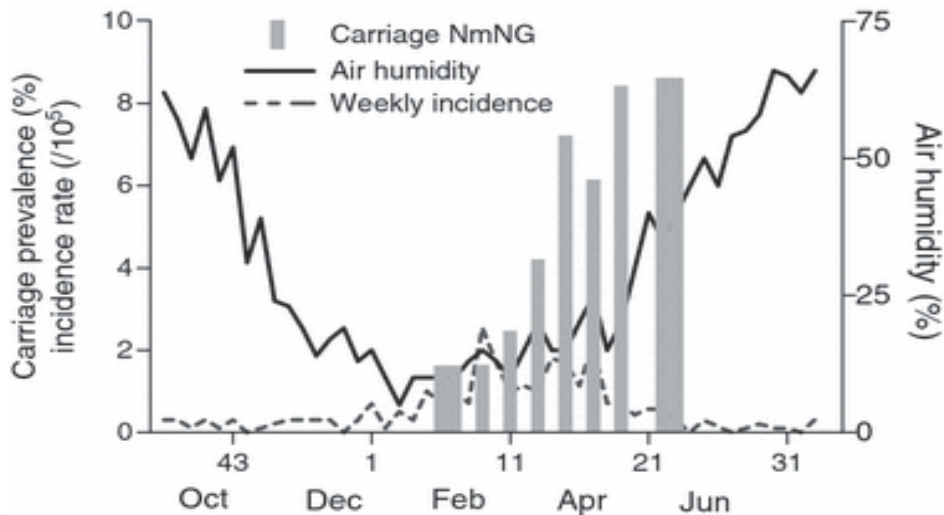
The universe strives for equilibrium

**Dry, thirsty air steals
moisture from wherever
it can
– a law of physics**

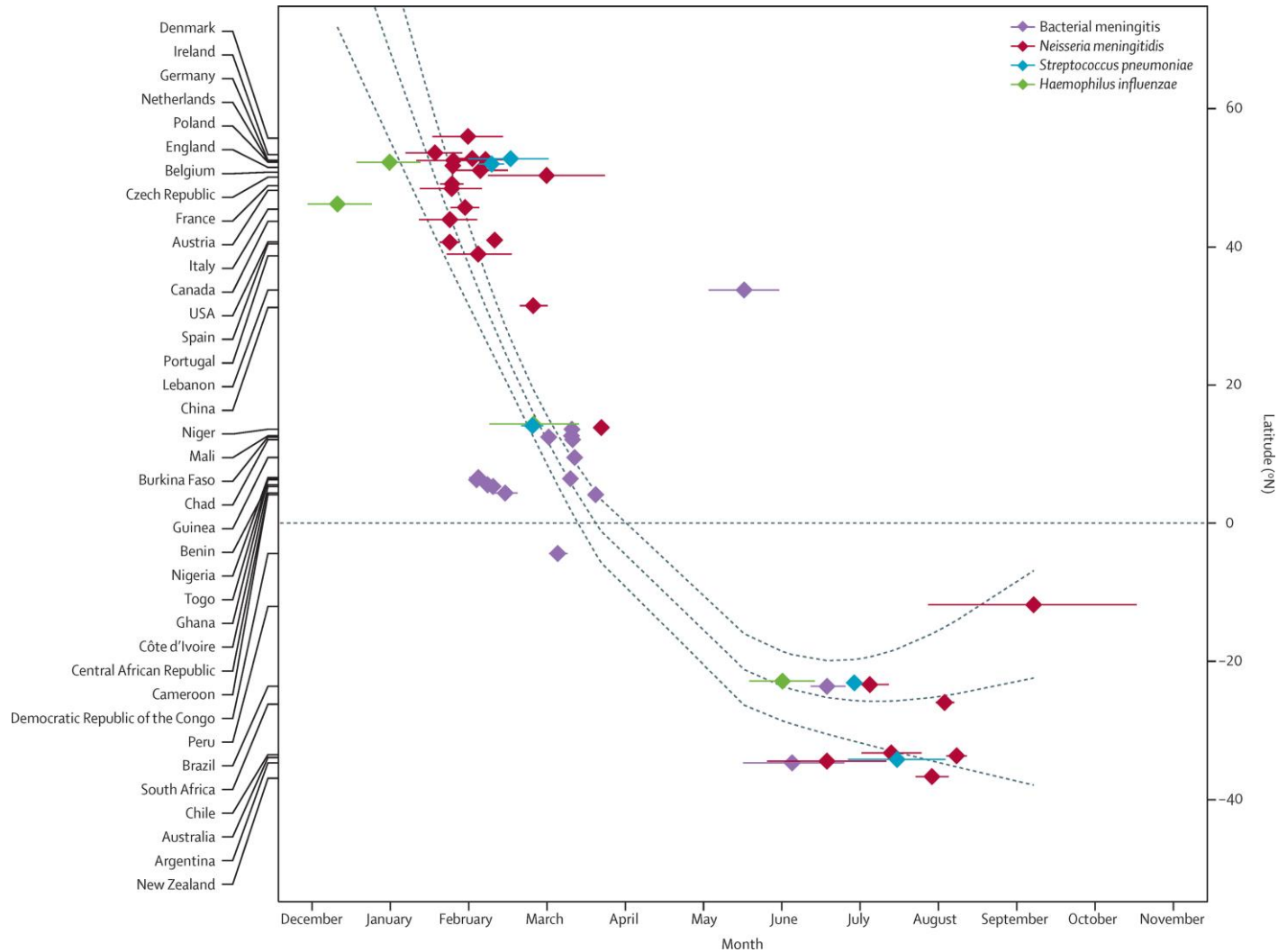


Dry weather brings meningitis outbreaks

- Bacteria spread through the air when the outdoor humidity is low
- “Once the humidity exceeds 40%, the epidemic ends”

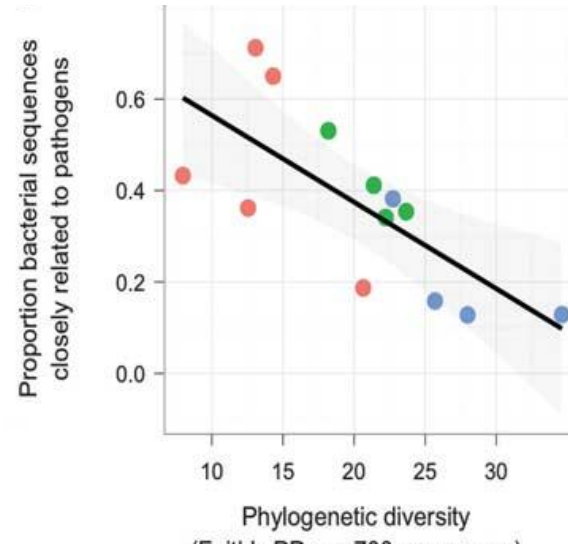


Dry seasons promote many bacterial epidemics



Dry air is a greater factor than cold temperatures

Low RH was associated with higher pathogenicity



This connection was more significant than humidity ratio or temperature

Variance explained (total)

	R^2	P-value
<i>(B) Indoor samples only (mechanical and window-ventilated rooms)</i>		
Ventilation method	0.66	< 0.01
Relative humidity	0.38	0.01
Humidity ratio	0.07	0.31
Temperature	0.14	0.08
Air changes per hour	0.38	0.02
Air flow velocity at bed	0.10	0.13
Air flow velocity at supply	0.37	0.03
Time of sampling	0.06	0.22
Room	0.12	0.27

Bacteria from spaceships reveal robust survival tactics

Microbes in dust from the Russian ISS modules survived desiccation, ultraviolet radiation and heat shock through developing “extremo-tolerant” characteristics such as:

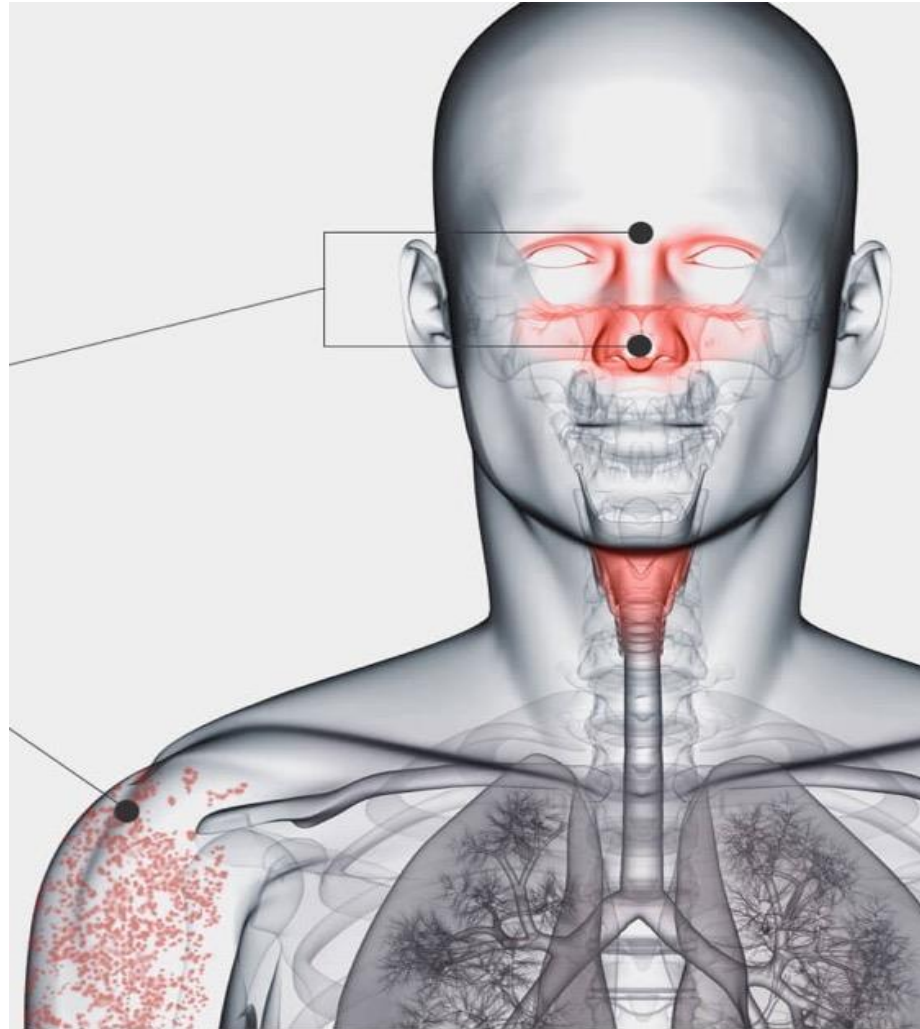
- (i) spore-forming ability
- (ii) resistance against radiation, pressure, desiccation
- (iii) the increased expression of antibiotic resistant genes



Humans are harmed by dry air



With RH of 20%, dehydration occurs in 8 hours



dry eyes & blurry vision

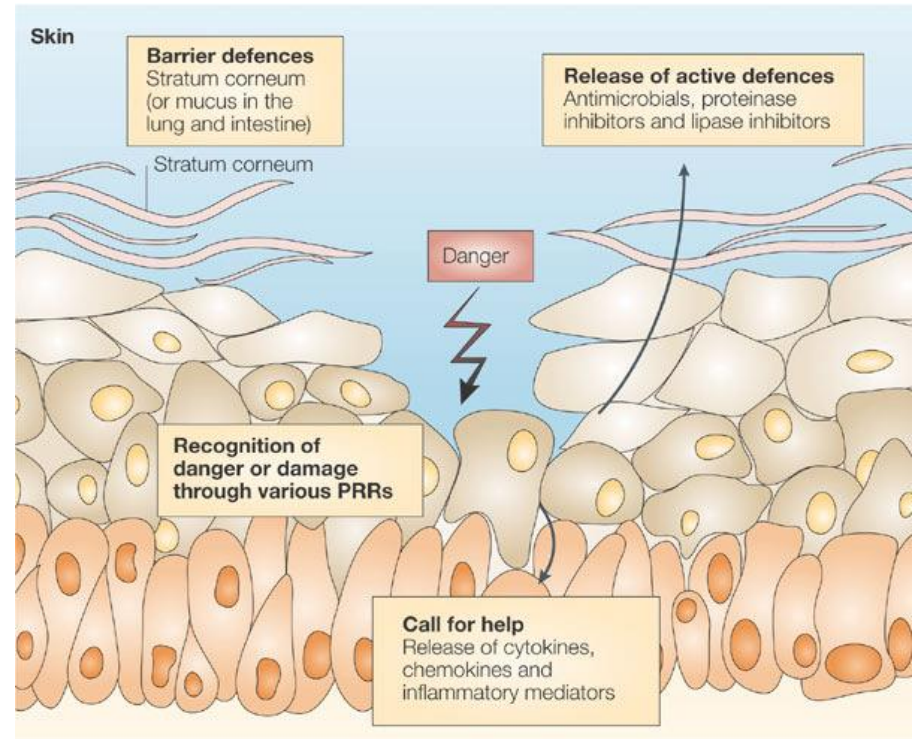
skin cracking &
decreased wound
healing

impaired brain
function

more infections
& asthma

dangerous blood
clotting

Dry air harms our skin



Children and seniors are especially vulnerable to the ill-health effects of low RH



Children

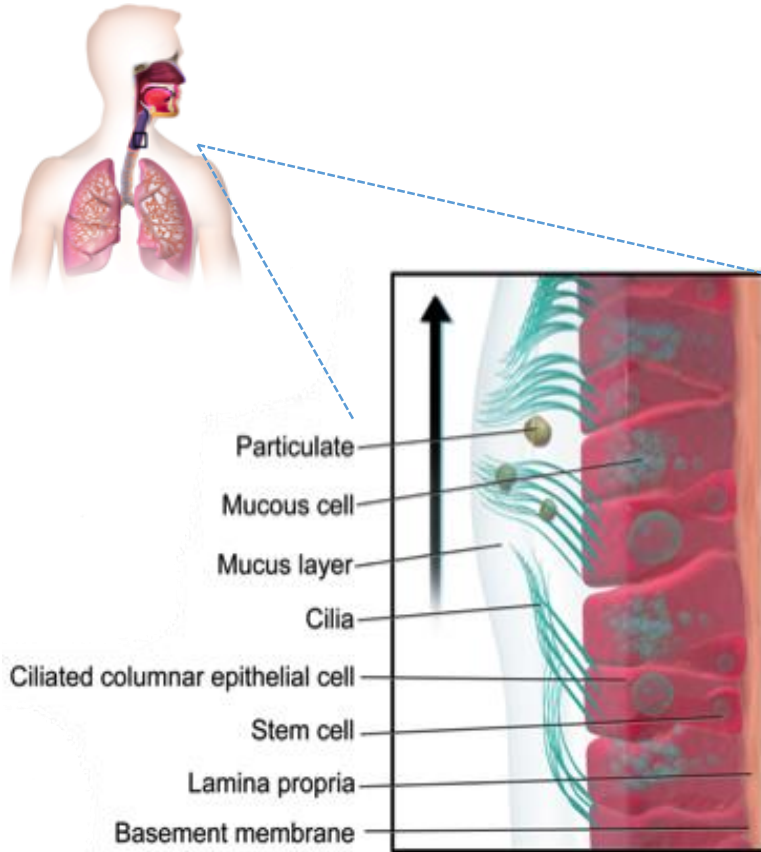
- Delicate fluid balance
- Higher water loss through skin
- No control over fluid input
- No control of clothing



Seniors

- Sense of thirst is reduced
- Bedridden people have less autonomy
- Seniors often limit drinking to reduce toilet visits

Proper air hydration is essential for our respiratory system defenses



Key functions of respiratory cells:

- Cilia wash particles away from delicate lung tissue
- Mucus layer allows healthy immune modulation to reduce allergic reactions
- Mucous from goblet cells trap pathogens

Dry inhaled air causes:

- Increased susceptibility to infections
- Increased wheezing from allergic disease

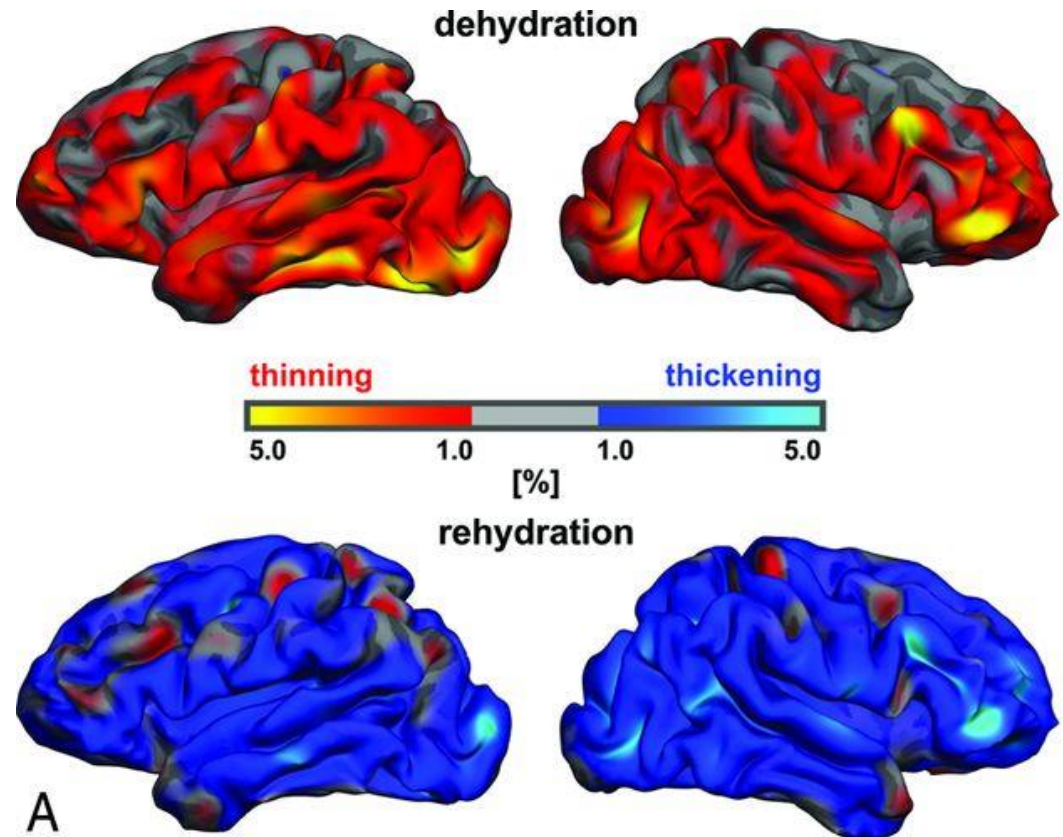
Dehydration affects our brain



Responses of the Human Brain to Mild (1%) Dehydration

Diminishes our:

- ability to think
- short-term memory
- concentration
- reaction times
- visual-motor tracking



*Explored in vivo by 1H-MR
imaging and spectroscopy*

Dry air impairs vision



take off 20-20

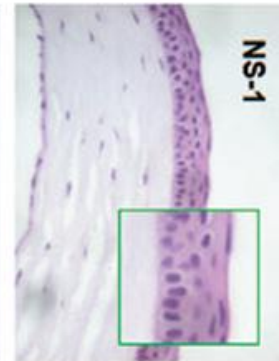
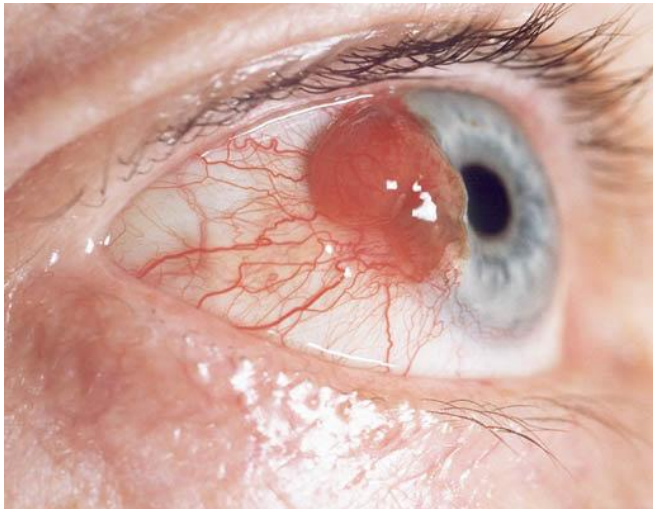


six hours later
20-60

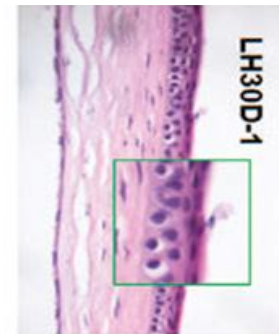


landing

Dry air damages our corneas

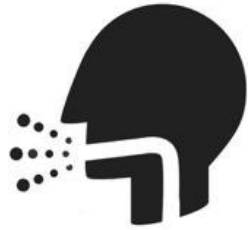


normal cornea



dry cornea
after 30 days
at 20% RH

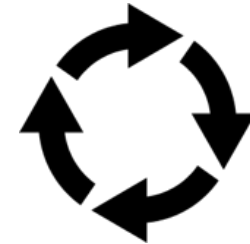
Opposite to humans, pathogens thrive in dry air!



farther spread



many are more
infectious



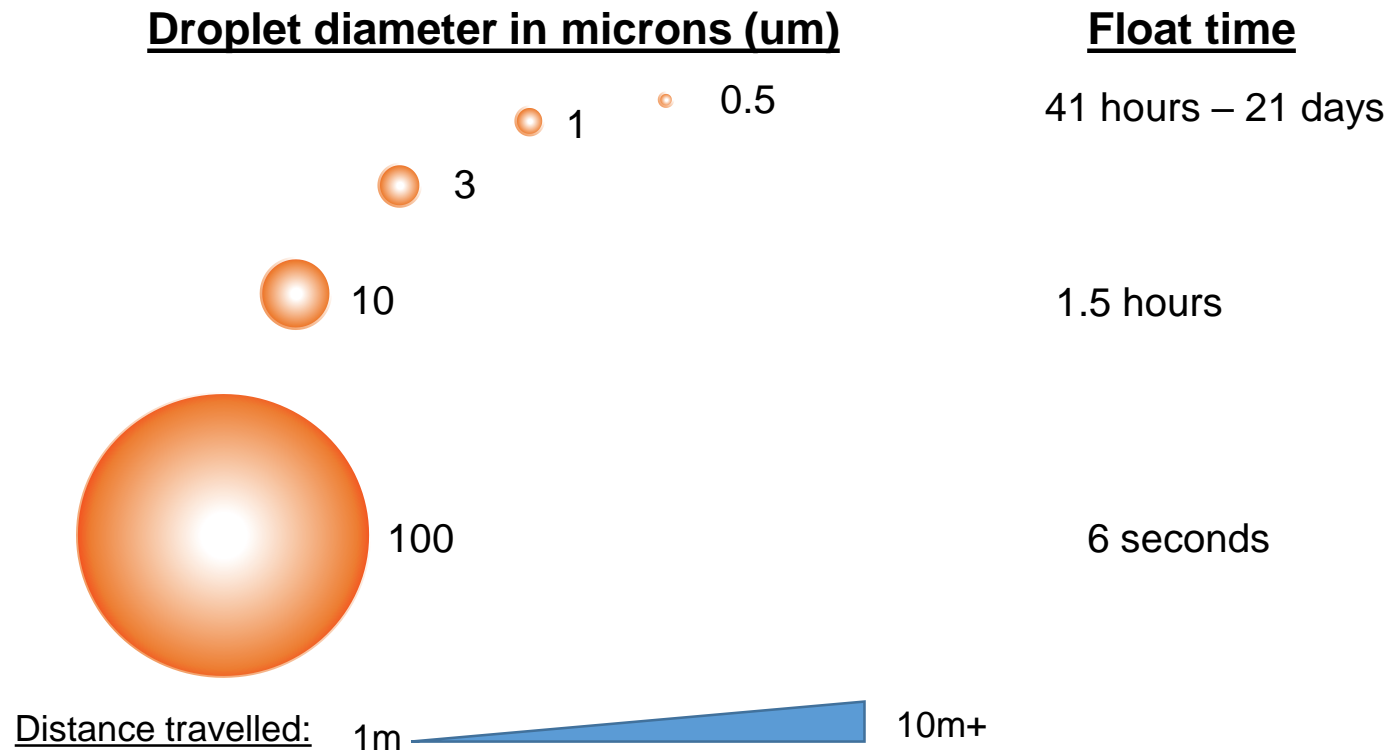
re-suspension & deposition
onto previously cleaned
surfaces

Will this cough infect others?



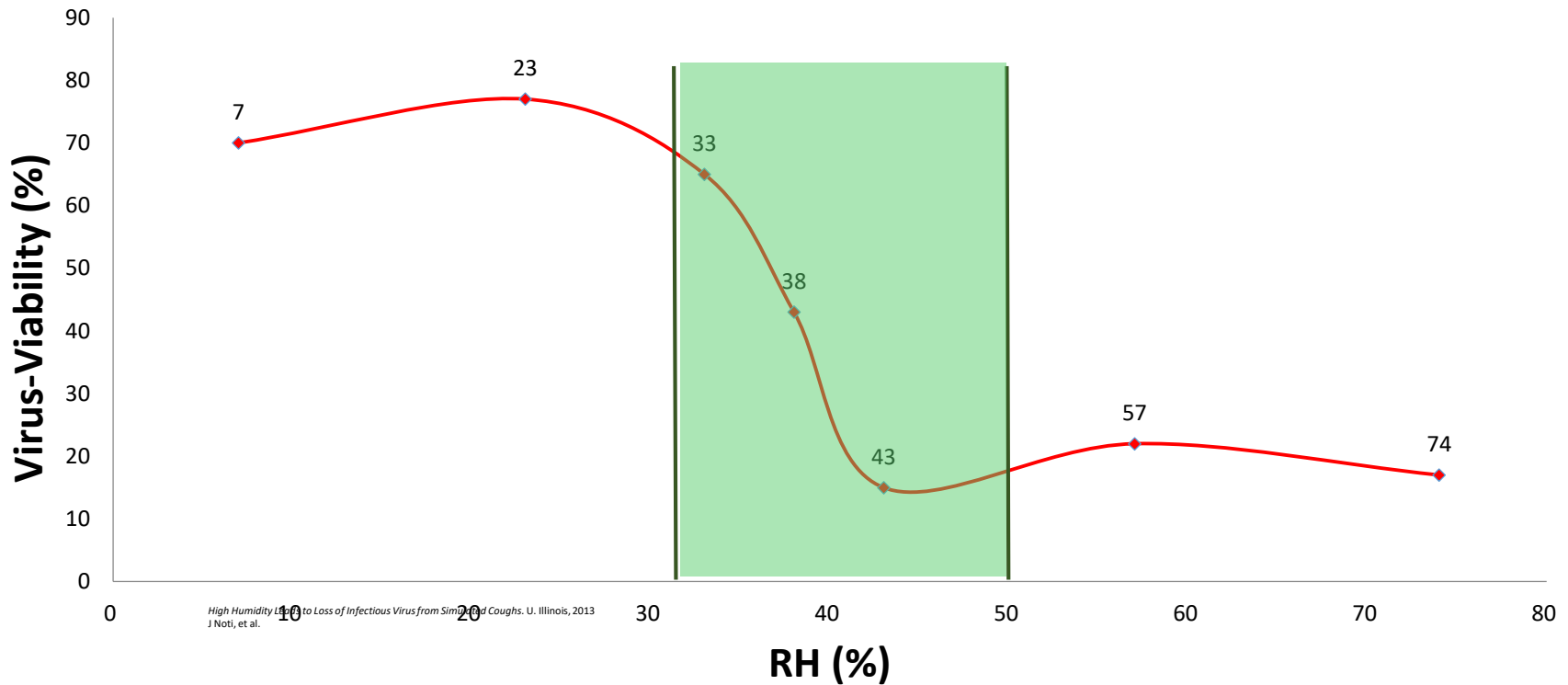
Bourouiba and Bush (2014)

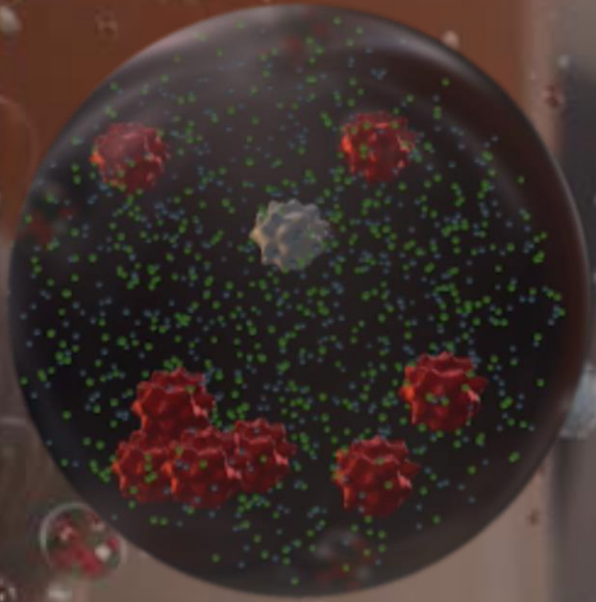
Infectious droplets shrink and travel in dry air



Infectivity of many viruses is greater in dry air

RH of 40% inactivates approx 80% of influenza viruses within 15 minutes

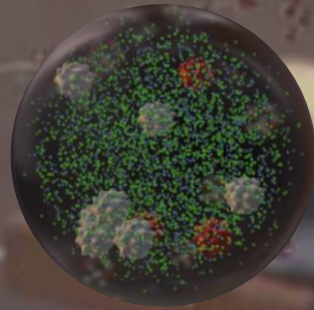




8 μm

Nearly 100 % humidity

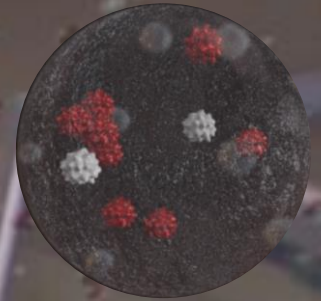
aerosol containing
pathogens before
evaporation



4 μm

Humidity over 45 %

super-saturated salt
solution
inactivates pathogens

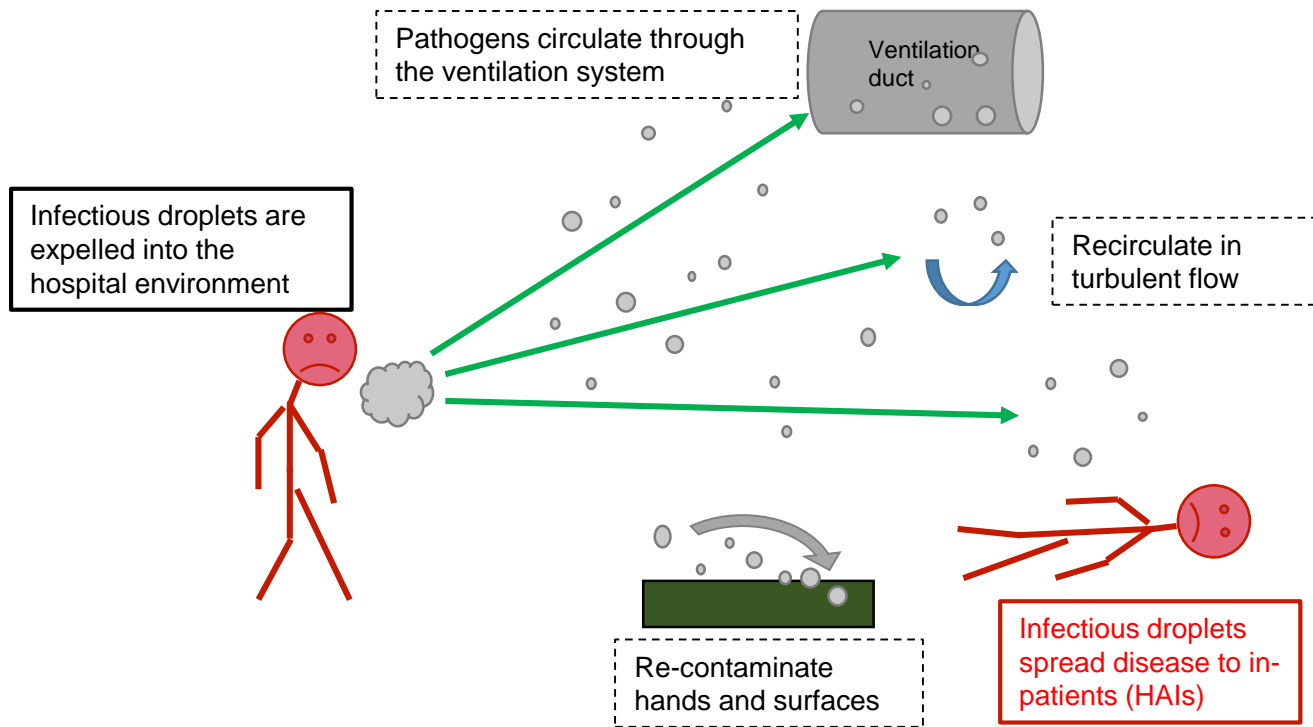


3.9 μm

Humidity below 45 %

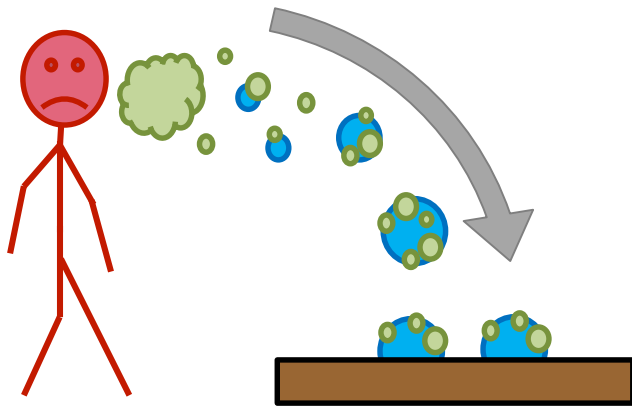
salts crystallize,
pathogens remain
active

Dry indoor air increases infectious droplets spread

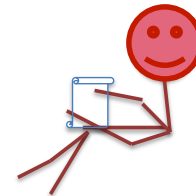


With RH of 40%–60%, infectious droplets settle out of the airborne environment

Particle behavior with increased air hydration



- Bedrails and other frequently touched surfaces are more effectively cleaned
- Hand hygiene is maintained
- Settled infectious droplets are not re-suspended due to the adhesive from water's dipole forces



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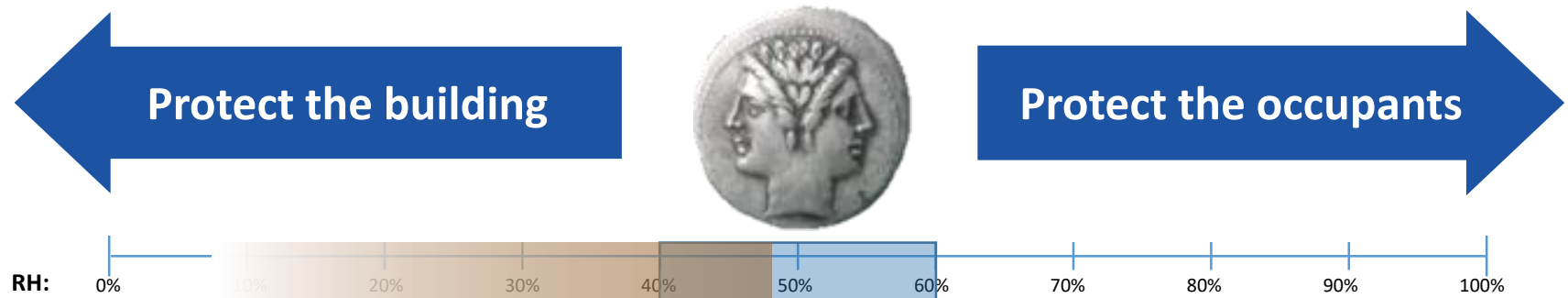
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The great indoor air RH debate!



Buildings **don't care** about humidity

Facility managers often incorrectly think:

- The drier the air the better
- Easier to dry the air than fix the envelope construction

Occupants **need** RH between 40% and 60% for health

- Decreased infections
- Fewer allergies
- Improved hydration
- Improved wound healing
- Increased work performance

Hello, hello, hello!



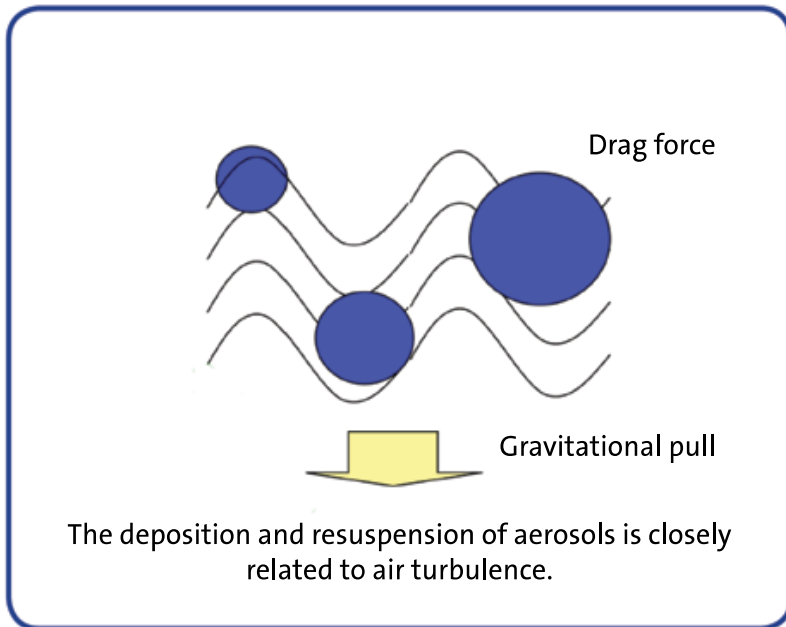
250 bed hospital's excess costs due to preventable patient infections

	Total Infections	Total Excess Costs	Total Excess Hospital Days
Urinary Tract Infections	1,296	\$1,435,968	2592.0
Surgical Wound Infections	365	\$7,042,464	4378.0
CRBSI	148	\$4,990,636	2509.0
VAP	15	\$401,369	170.0
MRSA	120	\$927,162	646.0
CDIFF	122	\$500,200	733.0
TOTAL	2,066	\$15,297,799	11,028.0

Projected financial benefits of indoor humidification in a 250-bed hospital

		Q1	Q2	Q3	Q4
BENEFITS - Year One		Dollars			
Increased Revenue	Maximize per day bed value by decreasing LOS	\$ 1,310,126	1,310,126.00	1,310,126.00	1,310,126.00
	Decrease non-reimbursable HAI costs	\$ 764,890	764,890.00	764,890.00	764,890.00
Cost Avoidance	3% CMS penalty for readmissions	\$ 91,787	91,787.00	91,787.00	91,787.00
	CMS Quality Index penalty	TBD	TBD	TBD	TBD
	Joint Commission citation	TBD	TBD	TBD	TBD
	Employee absenteeism	TBD	TBD	TBD	TBD
	HAI litigation by patients	TBD	TBD	TBD	TBD
	Quarterly total	\$2,166,803	\$2,166,803	\$2,166,803	\$2,166,803
	Cumulative value	\$2,166,803	\$4,333,606	\$6,500,409	\$8,667,212
INVESTMENTS					
	Gas				
	Installation & Integration of New System	\$ (1,198,500)	-	-	-
	Maintenance	\$ (23,850)	(23,850)	(23,850)	(23,850)
	Operating Cost	\$ (34,573)	(34,573)	(34,573)	(34,573)
	OR & PT Room Down Time	\$ (10,000)	-	-	-
	Quarterly total	(\$1,266,923)	(\$58,423)	(\$58,423)	(\$58,423)
	Cumulative investment	(\$1,266,923)	(\$1,325,347)	(\$1,383,770)	(\$1,442,194)
NET VALUE					
	Quarterly total	\$899,880	\$2,108,380	\$2,108,380	\$2,108,380
	Cumulative total	\$899,880	\$3,008,259	\$5,116,639	\$7,225,018
	<i>1st year net return</i>	\$7,225,018			
	<i>Breakeven point</i>	1st Quarter			
	<i>ROI (1st year)</i>	500.97%			

Decrease air changes and building energy use with proper RH



High room air changes with low RH in clinical spaces circulates infectious droplet nuclei



Hospitals can save up to 70% HVAC fan and reheat energy costs by reducing ACH by 10%

Conclusion: dry indoor air is dangerous and costly

Dry indoor air (RH <40%)

Humans:

- Decreased skin barriers
- Decreased respiratory mucous barriers
- Decreased cognitive performance

Microbes:

- Increased transmission
- Decreased diversity
- Increased virility

Hydrated indoor air (RH 40-60%)

Humans:

- Healthy skin barriers
- Functioning respiratory mucous barriers
- Optimal cognitive performance

Microbes:

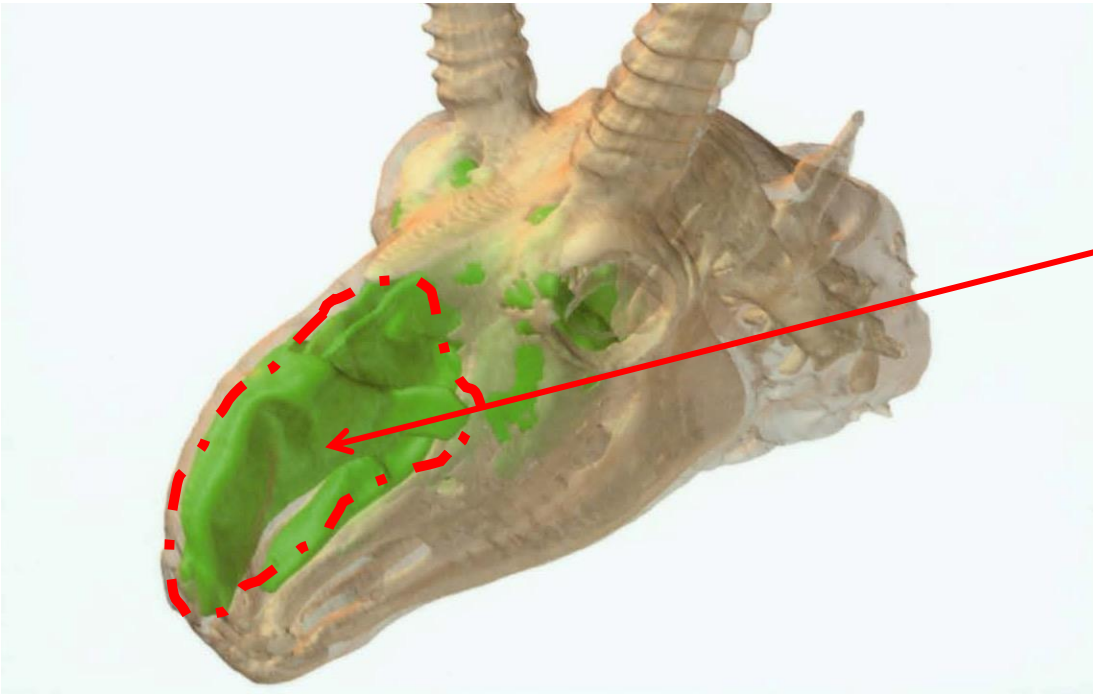
- Settle out of the air
- Healthy diversity
- Pathogens deactivated

Biology never lies: Evolution and RH



Skull and nasal cavity of the grassland Saiga antelope

Biology never lies: Evolution and RH



A large cranial air cavity increases ambient RH, preventing dust particles and parasites from entering delicate lung tissue

The African desert first cousin

Next steps for healthy air-hydration in your building

1

Record occupant health and productivity data

2

Monitor indoor air RH in occupied building spaces

3

Identify weaknesses in the building envelope

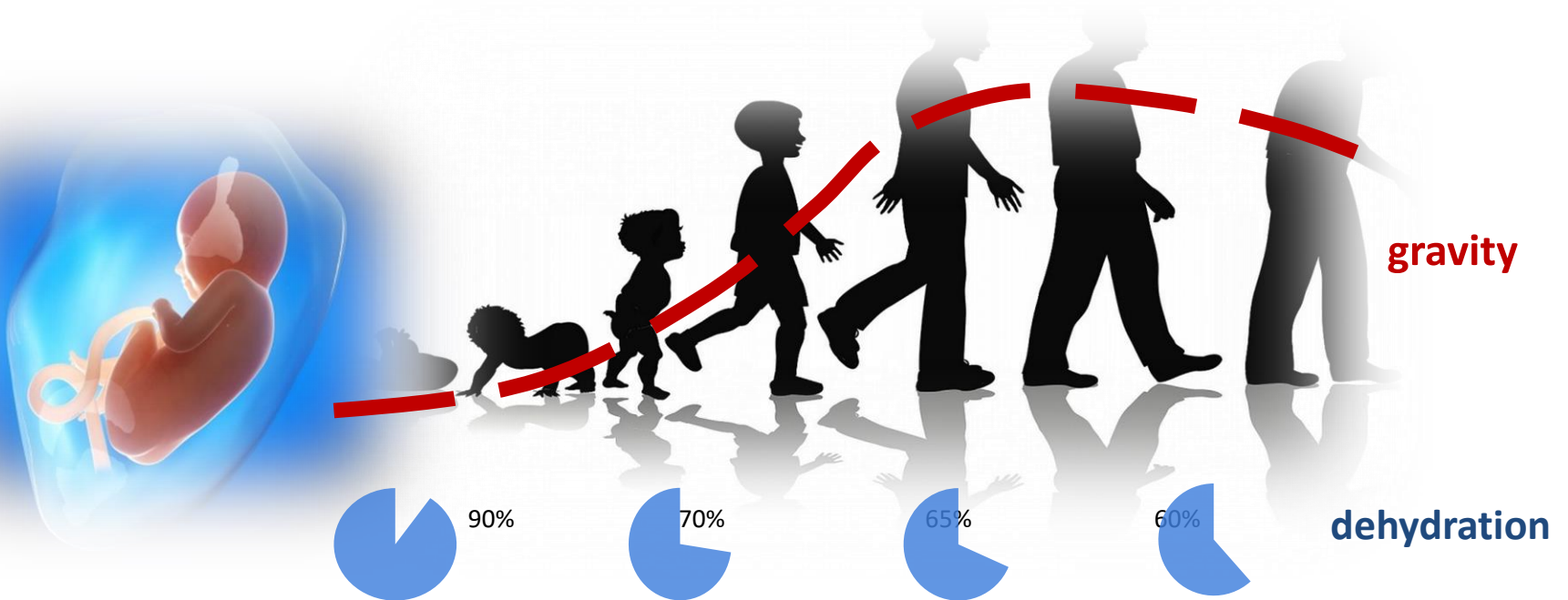
4

Run clean and energy efficient humidification systems

5

Continue monitoring indoor air RH and occupant health

Human aging is a battle against dehydration & gravity



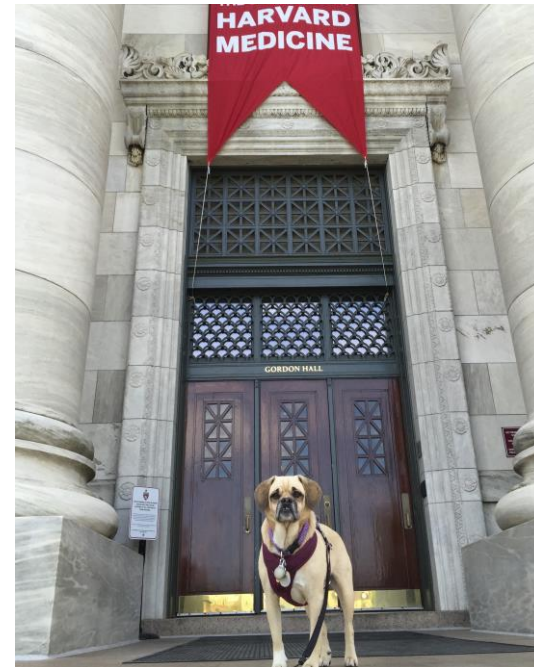
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Questions?

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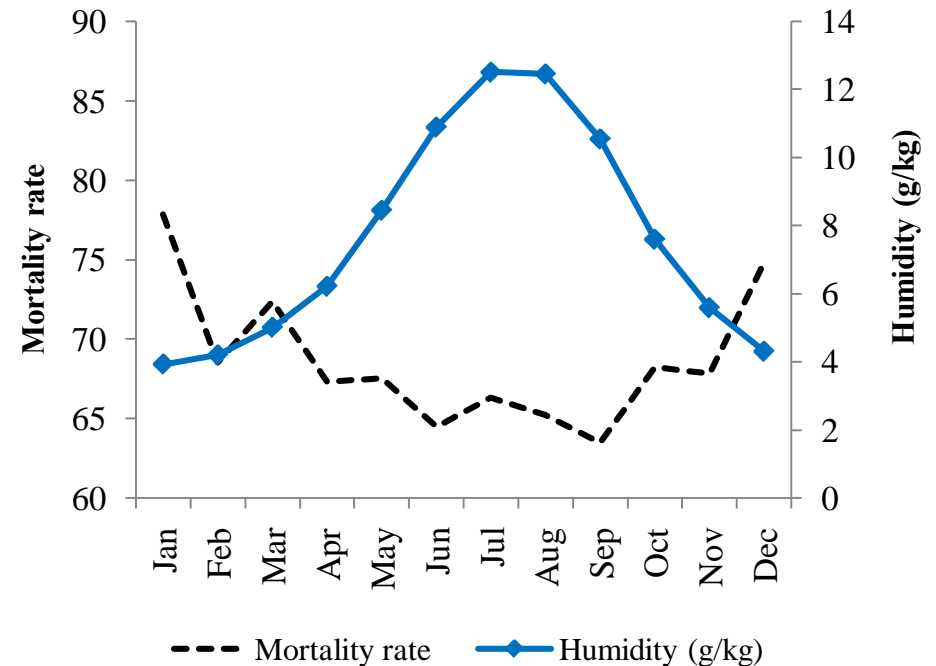
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Phone: (860) 501-8950

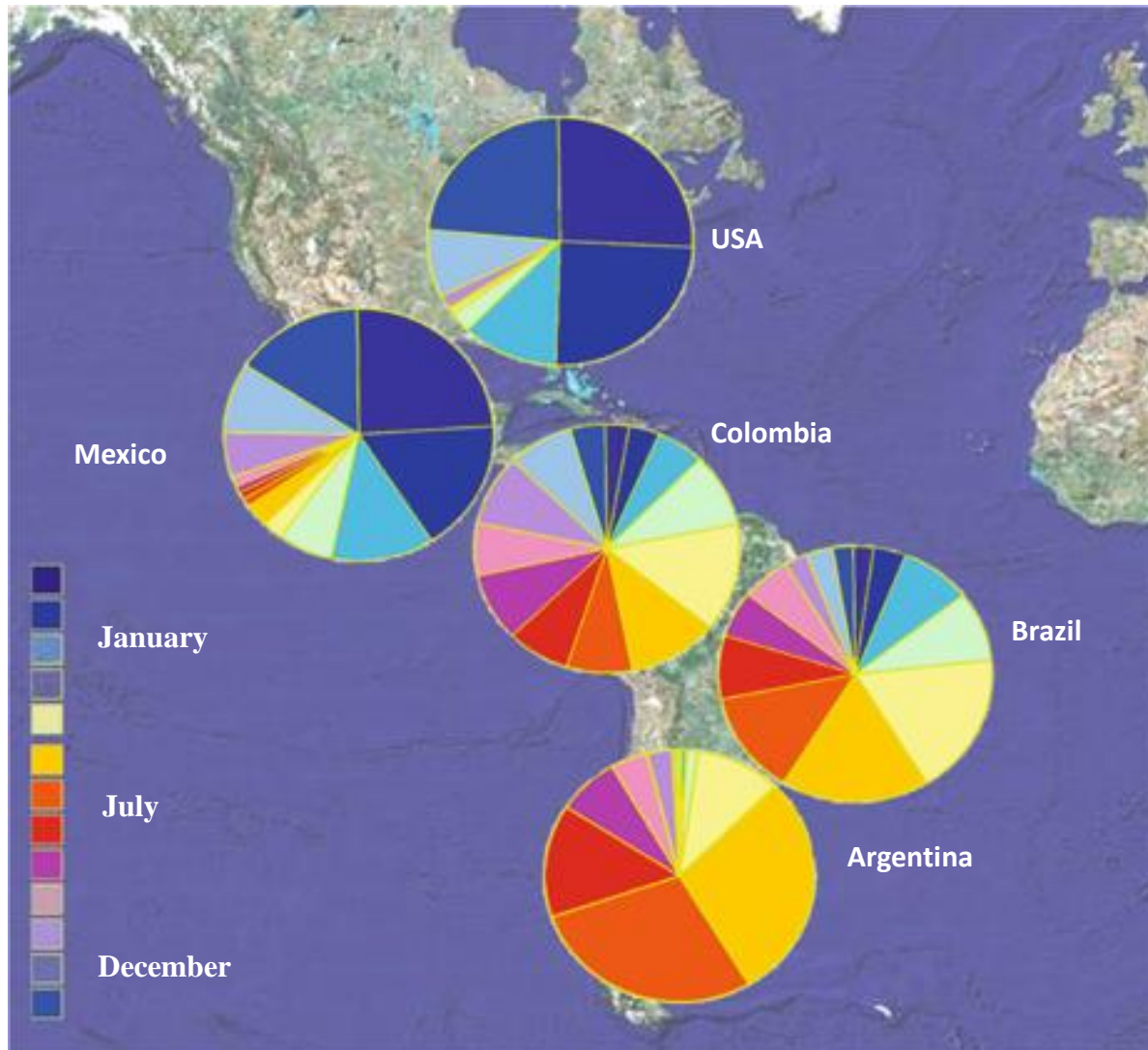


Mortality rates increased in dry air in US 2009

- 35 year period in 350 counties in US
- Mortality from dry air at \$100,000 per life year = \$57,000,000,000 loss by end of 21st century
- This could be decreased by at least .1%



Influenza occurs in dry seasons world-wide



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