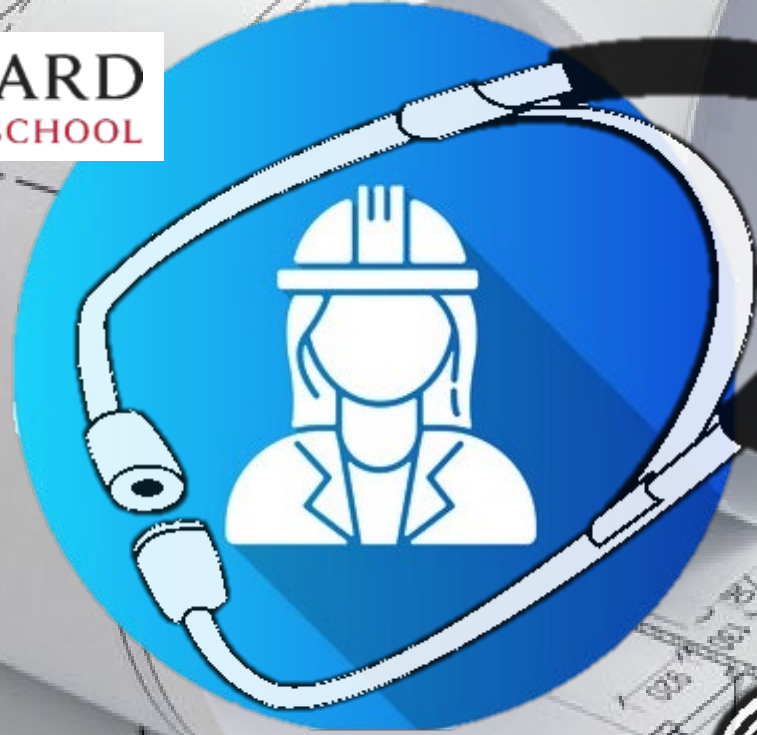


# Engineers Are The Physicians of the Future



# WELCOME AND HELLO



Stephanie Taylor, MD, M Arch



ASHRAE Distinguished Lecturer  
Epidemic Task Force  
Environmental Health Committee

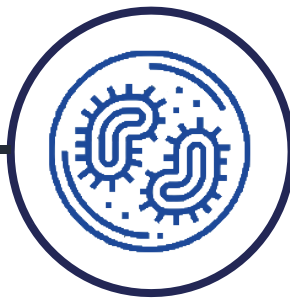


**Building4Health**  
President and Founder



# Learning Objectives

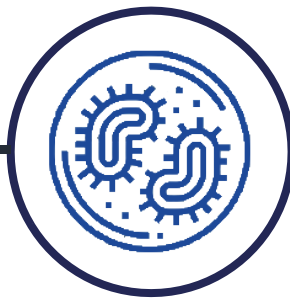
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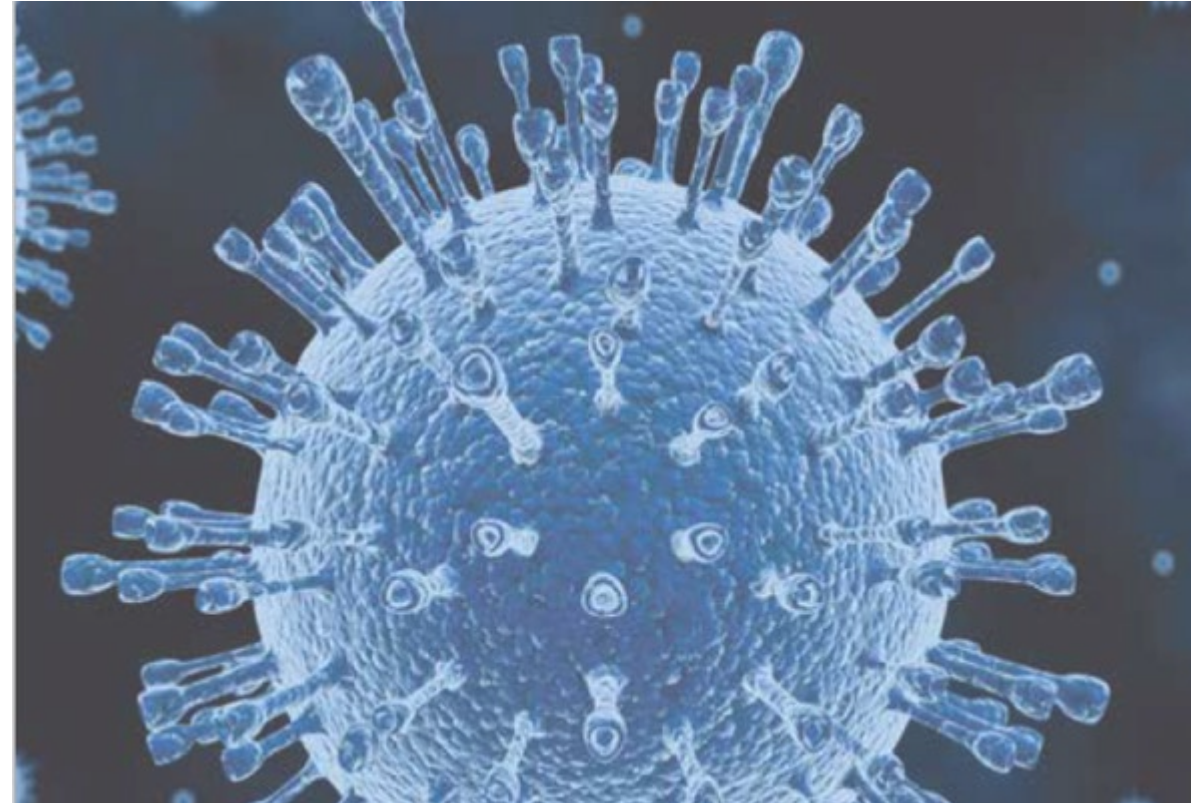
- 1.Explain the value of utilizing human physiological data as a metric for overall building health and operation
- 2.Describe the impacts of indoor air quality on the human body, the microbiome of the built environment, and the transmission of disease-causing microbes
- 3.List new research supporting the health benefits of indoor air quality
- 4.Participate in ASHRAE and FGI discussions on best-practice indoor management for occupied buildings

# IS THIS QUESTION ON YOUR MIND?

---



**How can we restore  
safety and confidence  
in re-occupying  
buildings?**



# PRESENTATION OVERVIEW

---

## **A. Medicine and Buildings**

- Travelling Across Silos

## **B. Studies on Life Indoors**

- Indoor Environments and Health

## **C. Scaling Health Visibility**

- COVID and Beyond

# PRESENTATION OVERVIEW

---

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# MY JOURNEY WITH BUILDINGS AND HEALTH



# MY EARLY FOCUS ON INFECTIOUS DISEASE



Harvard Medical School  
Chief-of-Surgery, Judah  
Folkman, M.D.  
working with medical student  
S. Taylor, 1986

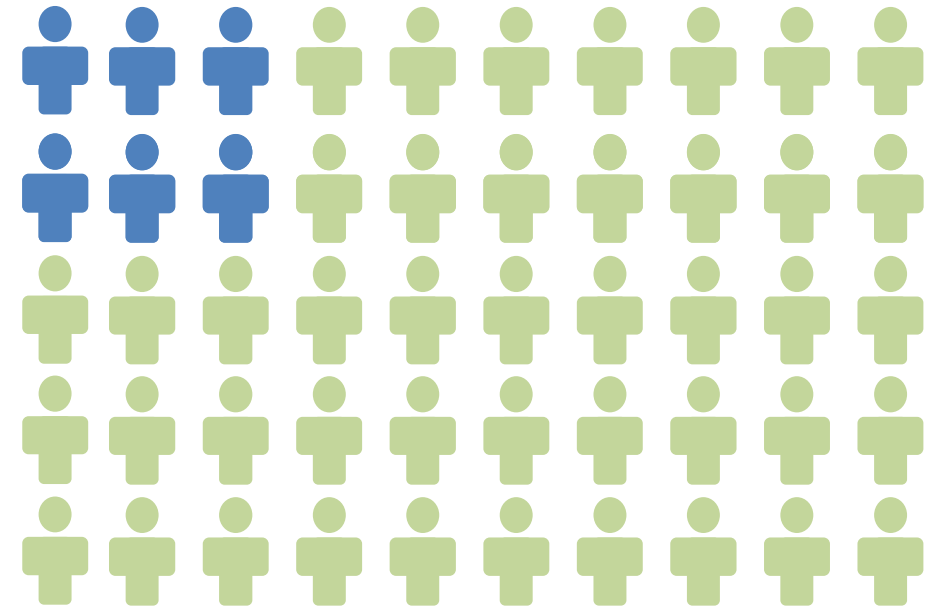


Wewack General Hospital,  
Papua New Guinea 1983





# WHY DO 1,700,000 PATIENTS/YEAR GET A HEALTHCARE-ASSOCIATED INFECTION IN USA?



# OUR INDOOR ENVIROMENT HAS EVOLVED



Timeline:	10,000 BC	800 BC - 500 AC	1900 AC	2021
Housing:	primitive housing, no sanitation systems	simple sanitation, in rural villages	industrial revolution: central sewage & water systems, heating, electricity	post-industrial cities, tighter buildings, dryer and warmer indoor air



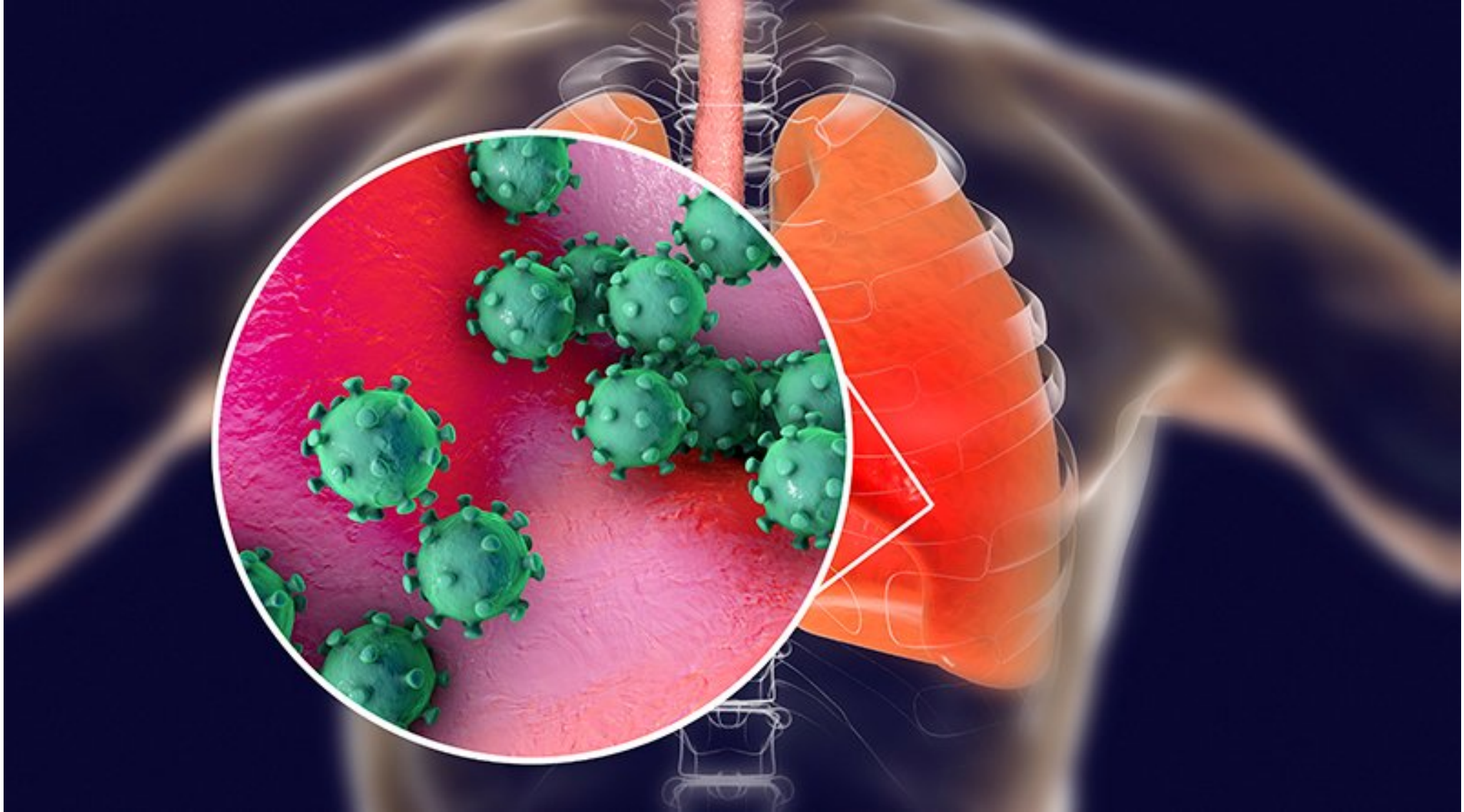
# YET, AS WE MOVE INDOORS – DISEASES ESCALATE

Timeline:	10,000 BC	800 BC - 500 AC	1900 AC	2021
<b>Housing:</b>	primitive housing, no sanitation systems	simple sanitation, in rural villages	industrial revolution: central sewage & water systems, heating, electricity	post-industrial cities, tighter buildings, dryer and warmer indoor air
<b>Infectious diseases:</b>	parasites, zoonosis	1 <sup>st</sup> epidemics: small pox, measles, influenza, plague	1 <sup>st</sup> pandemic “Spanish flu” introduction of antibiotics & vaccines	Increasing infections, ABX-resistant bacteria, COVID-19

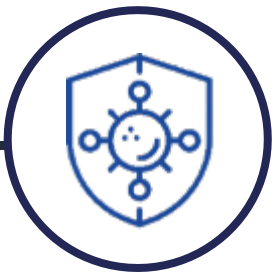


**INFECTIOUS AND INFLAMMATORY DISEASES**

# NOW WE ARE FACED WITH COVID-19 DUE TO A MUTATED CORONAVIRUS



# IN FACT, ALL PANDEMICS ARE CAUSED BY MICROBES THAT EASILY ADAPT TO NEW CONDITIONS



**Bubonic Plague**  
**1347**



**Spanish Influenza**  
**1918**



**COVID-19**  
**2020**

# NEW TOOLS REVEAL THE INFLUENCE OF IAQ ON BUILDING MICROBES



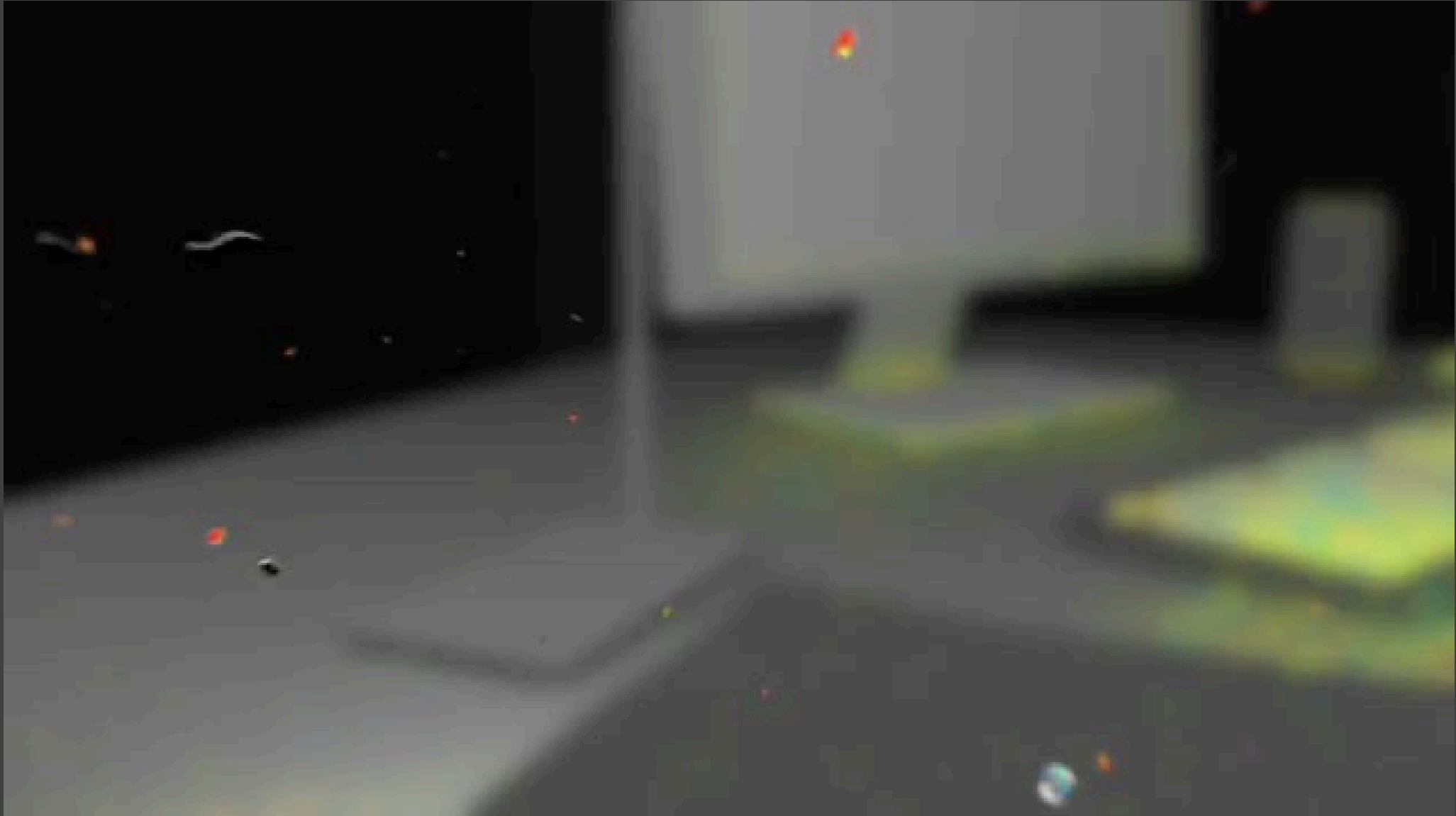
Tissue Culture



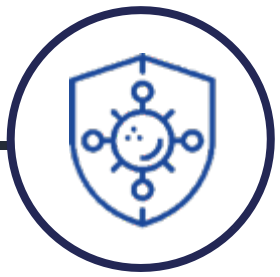
Metagenomics 2018

# MANY GOOD MICROBES COHABITATE WITH US

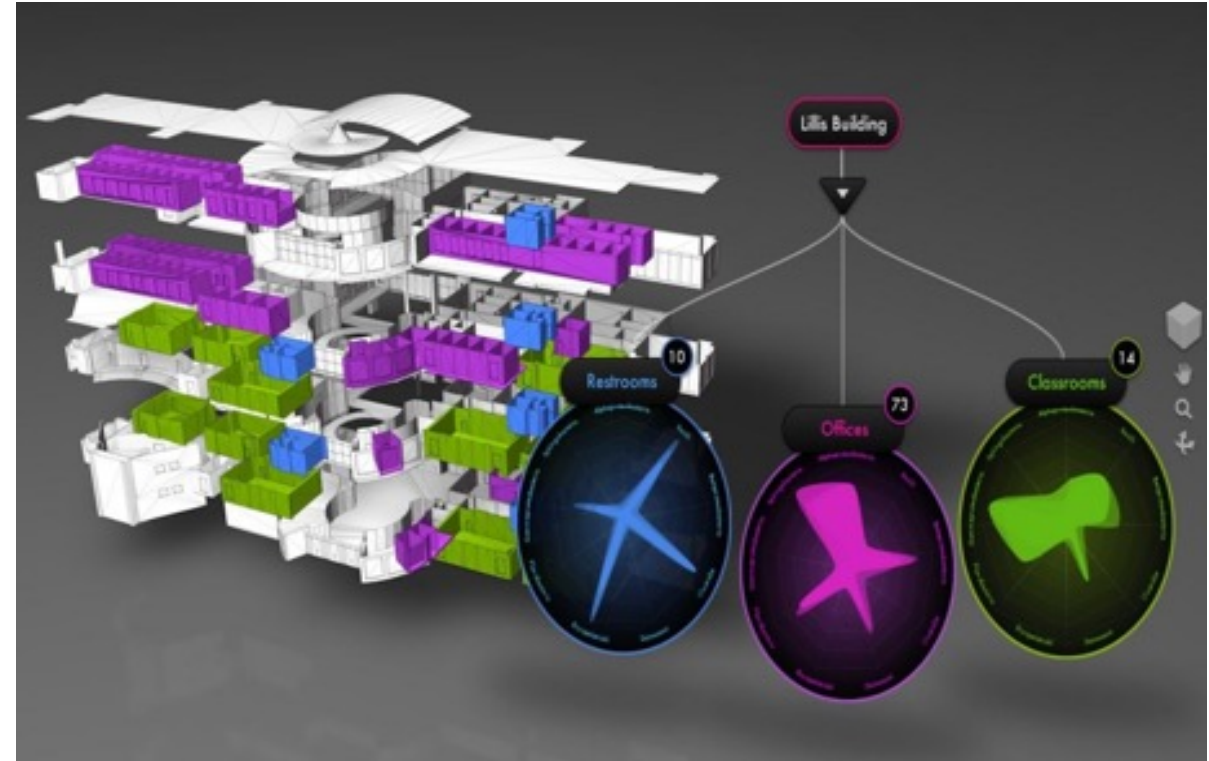
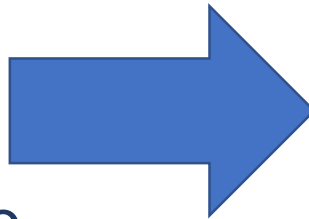
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# THE INDOOR ENVIRONMENT SHAPES BUILDING MICROBIAL COMMUNITIES (MICROBIOMES)



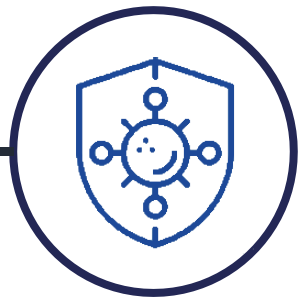
A person sheds approximately **37 million microbes per hour** into the surrounding air and onto surfaces



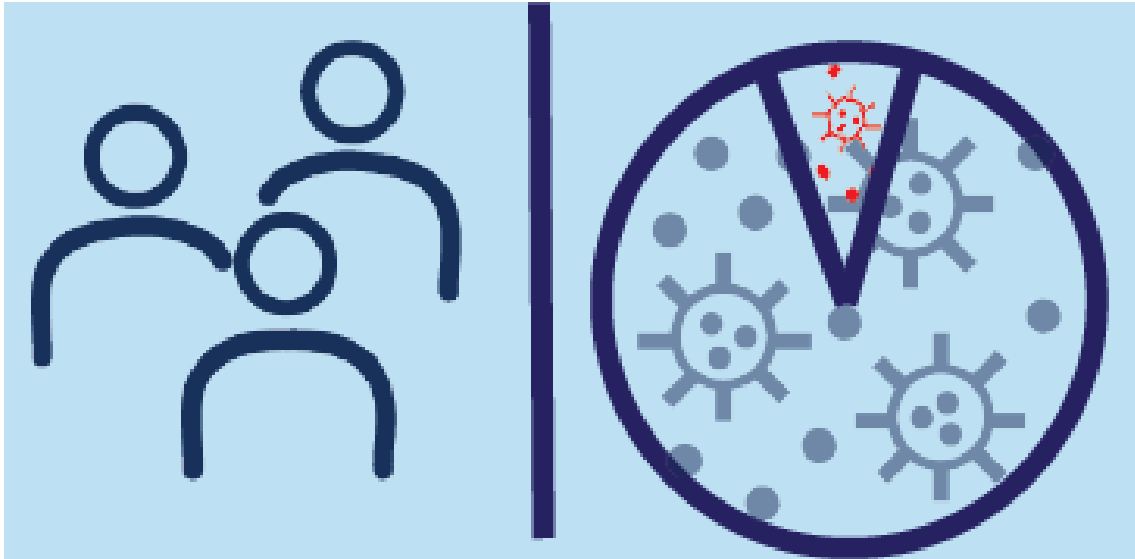
The indoor environment determines which microbes will survive



# CORRECTING MISCONCEPTIONS



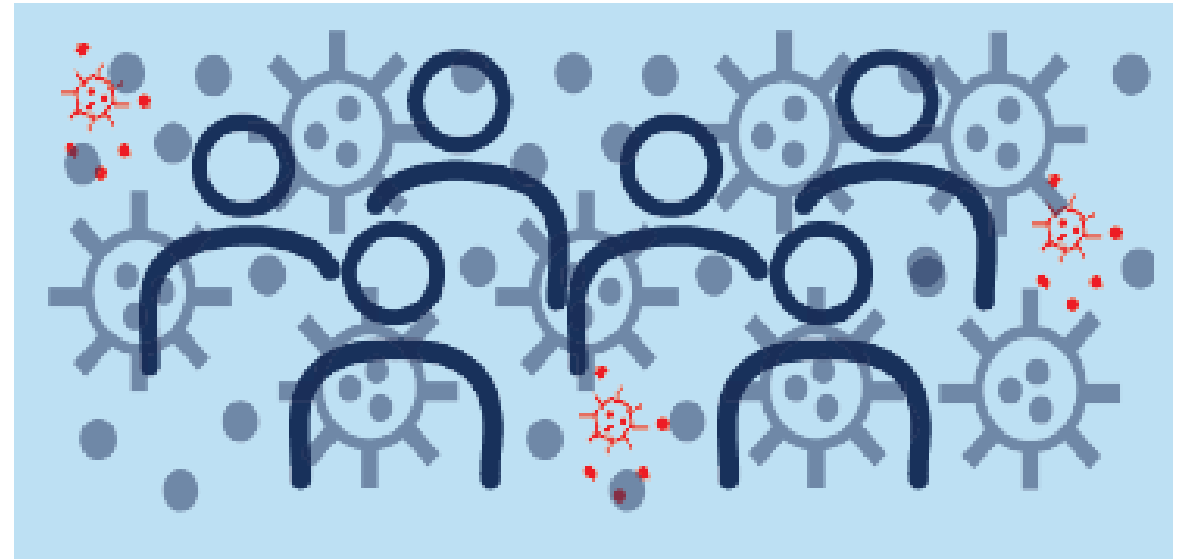
## Historical (and Incorrect) Approach to Hygiene



“All microbes are bad germs that require total eradication.”

In fact, only a small percentage of microbes are disease causing pathogens.

## Modern (and Correct) Approach to Hygiene



“Good microbes are essential to our health.”

Overzealous disinfection can result in takeover by pathogens.

# PRESENTATION OVERVIEW

---

## A. Medicine and Buildings

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# HOW CAN WE STUDY IAQ AND HEALTH?



# HOW DO WE PROTECT OURSELVES FROM THE BAD MICROBES?

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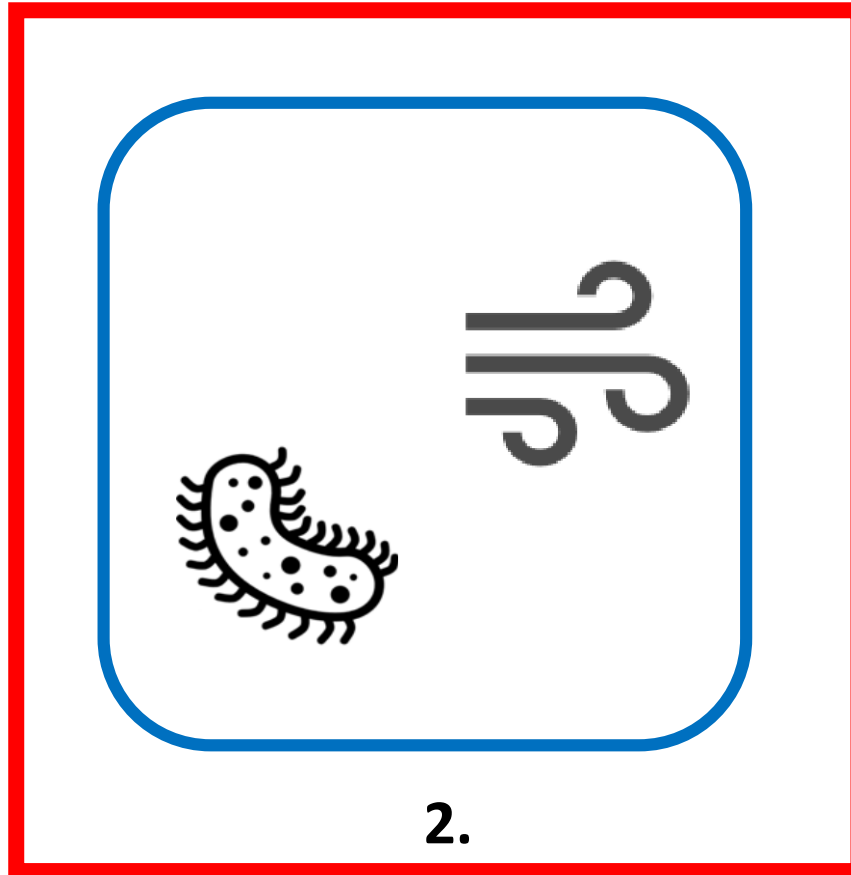


# THERE ARE 3 WAYS TO REDUCE COVID-19 INFECTIONS



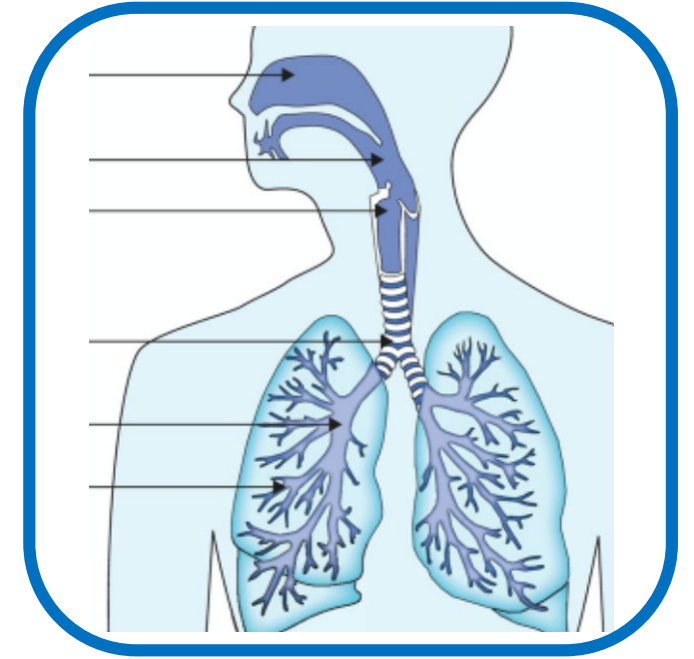
1.

Restrict your viral exposure



2.

Manage the indoor environment



3.

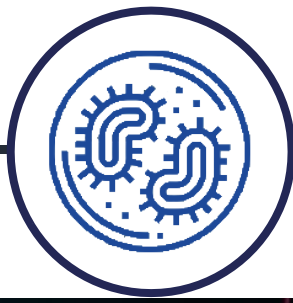
Take care of your health and immunity

# FLYING CANARIES WERE USED TO ASSESS IAQ IN MINES

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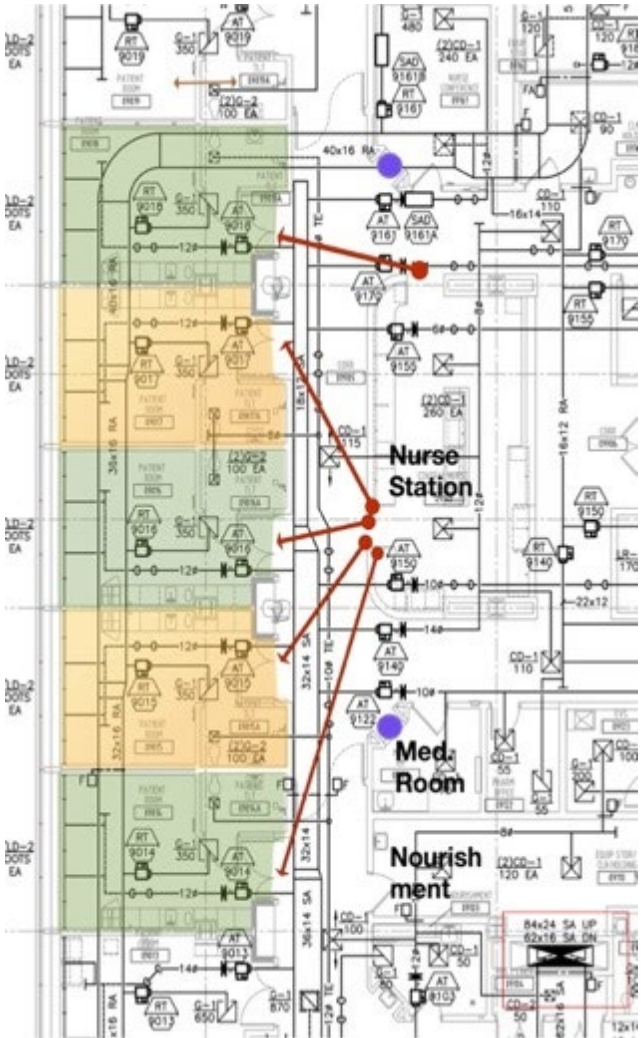


# MONITORING IAQ FOR OCCUPANT HEALTH

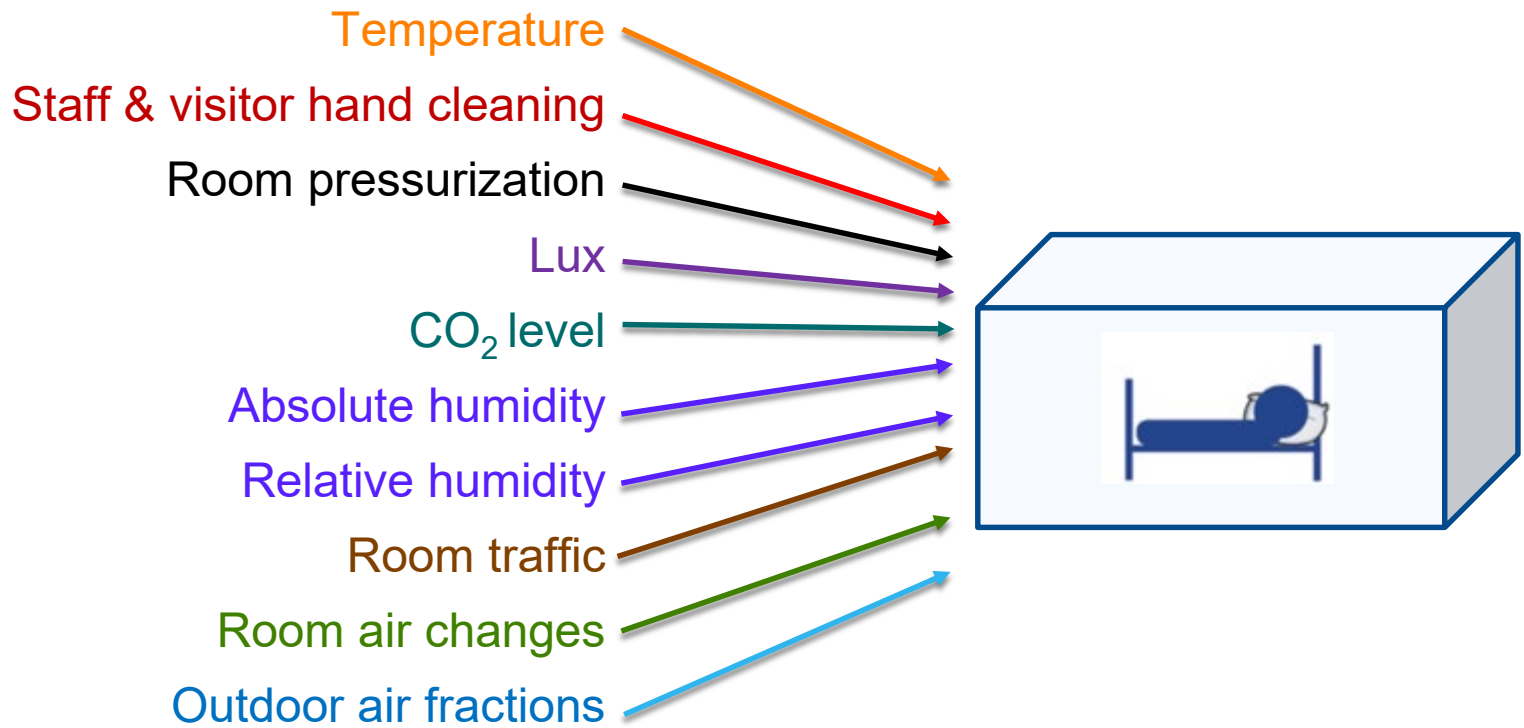


What is your building's ***Health Impact Rating***?

# NEW PATIENT INFECTIONS AND THE INDOOR ENVIRONMENT



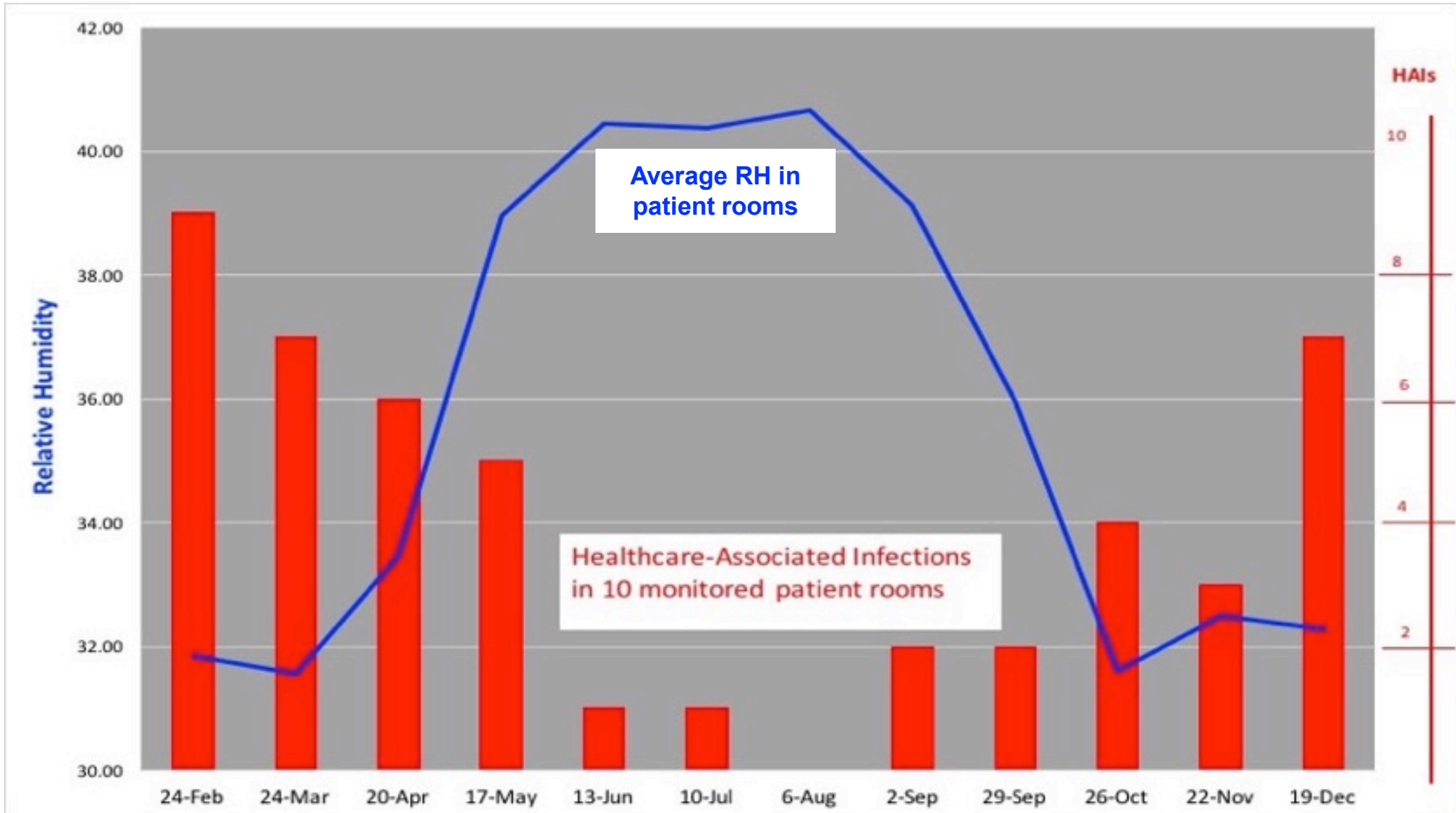
**Study design**  
Compared patient room data to hospital associated infections to determine key drivers



Academic Hospital: 10 rooms, 13 months, 8M datapoints



# AS PATIENT ROOM RH WHEN DOWN, INFECTIONS WENT UP!



# INDOOR-AIR RH AND HEALTH OUTCOMES

## A LONG-TERM SENIOR CARE FACILITY

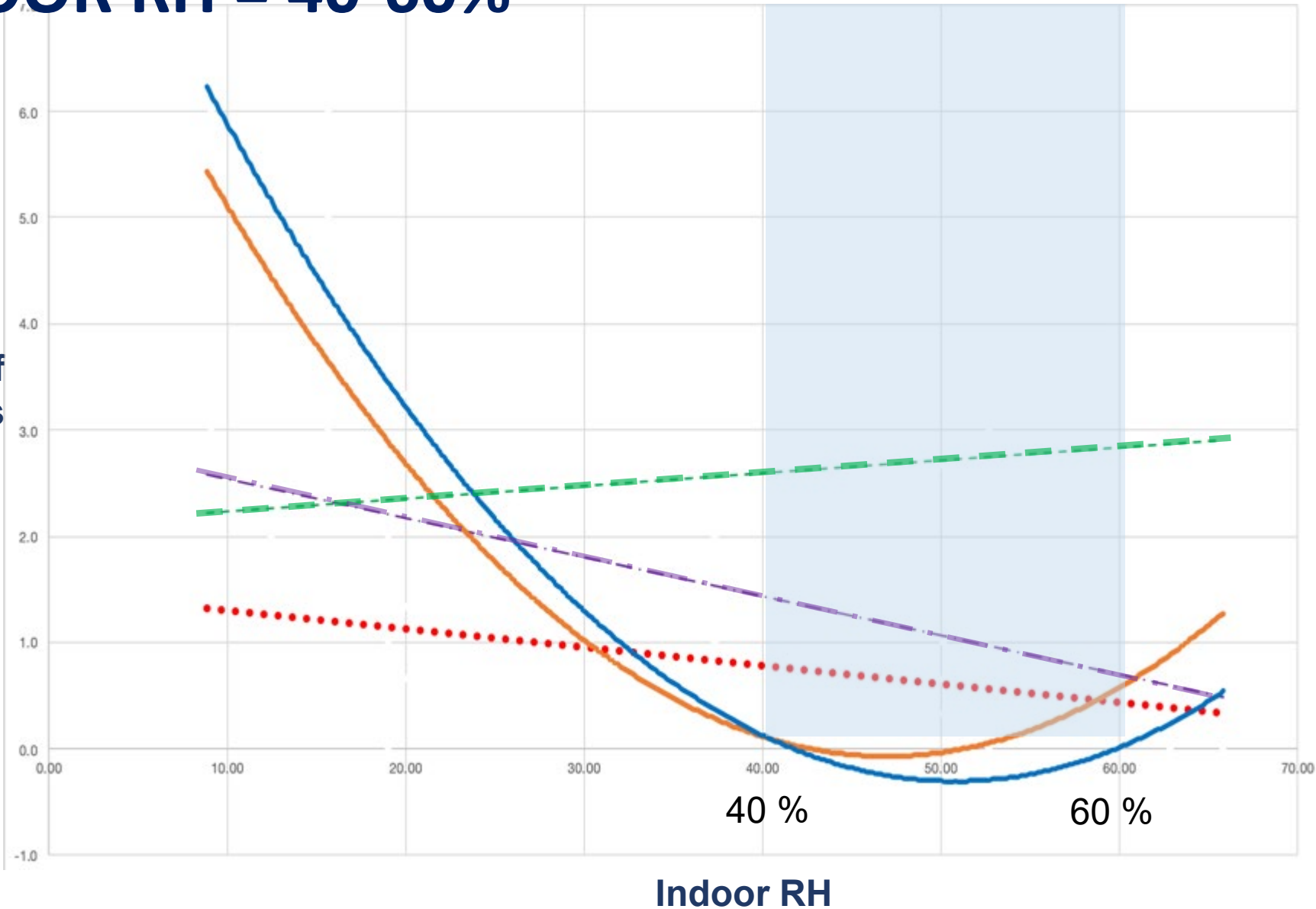


**74 bed residential care for elderly patients, in northern Vermont**

# INFECTION RATES WERE LOWEST WHEN INDOOR RH = 40-60%

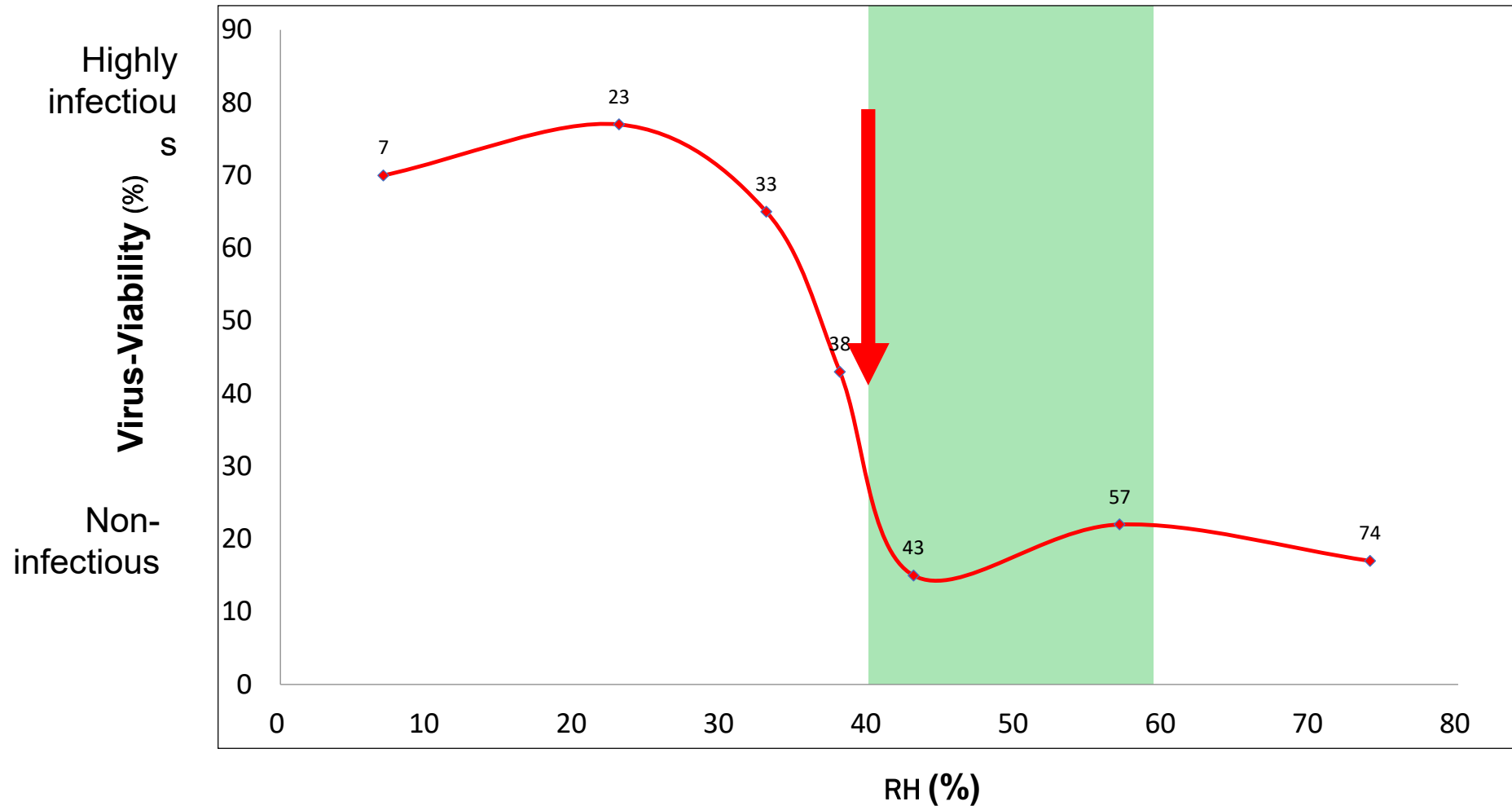


Avg # of infections



- Respiratory (bacterial & viral)
- Gastrointestinal (Noro-virus, C diff)
- Urinary tract infections
- Cellulitis
- Eye infections

# IN THE LAB, RH 40% INACTIVATED INFLUENZA A VIRUS IN 1% MINUTES



# CASE CONTROLLED STUDY IN A PRE-SCHOOL



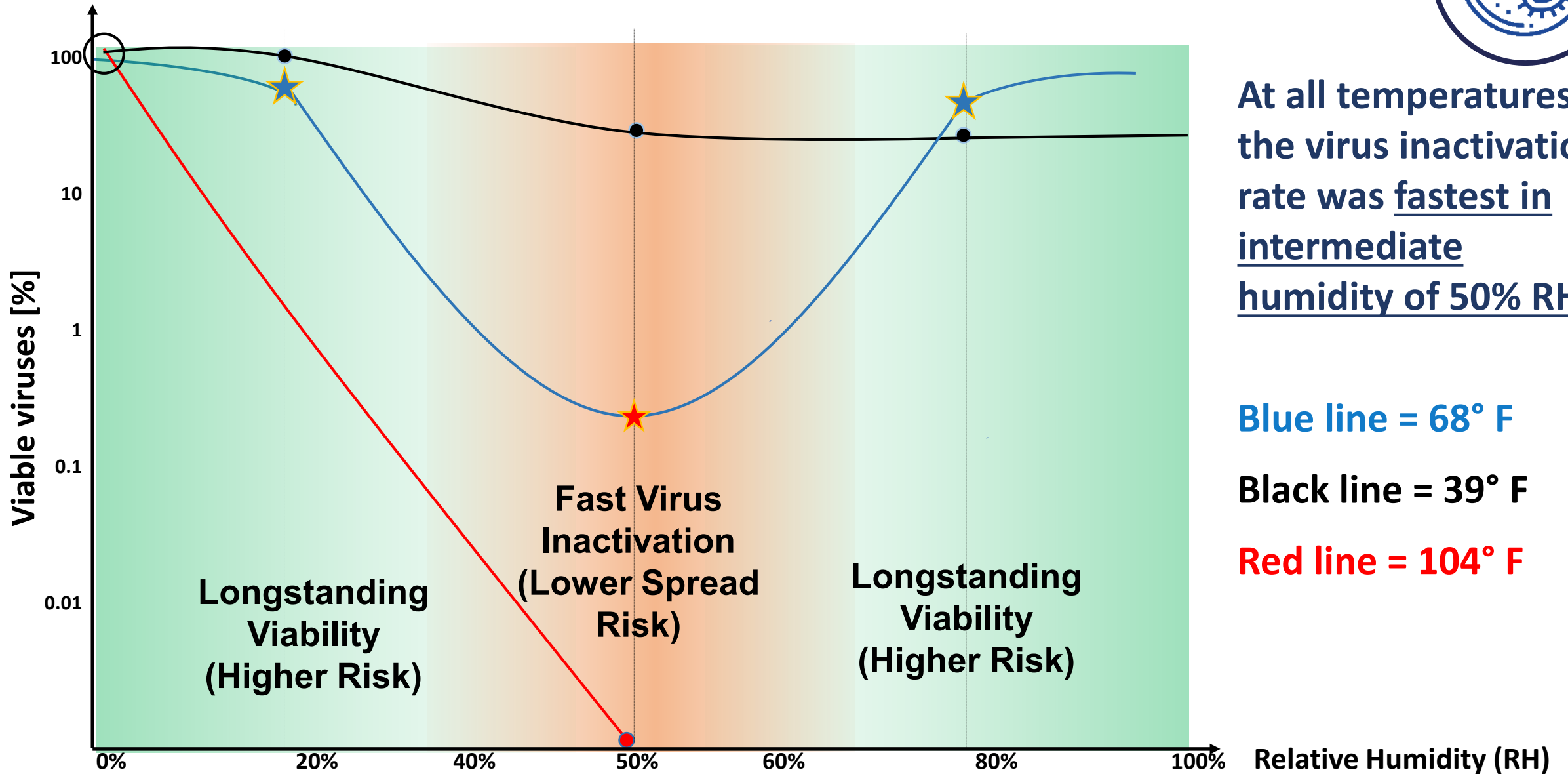
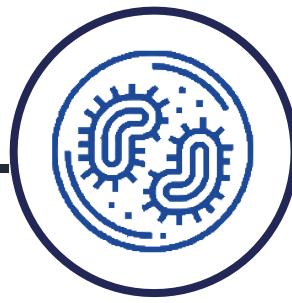
## Humidification Decreased Influenza A Illness in Children

- January 25 – March 11 (32 days)
- Half of the classrooms were humidified, the other half were not

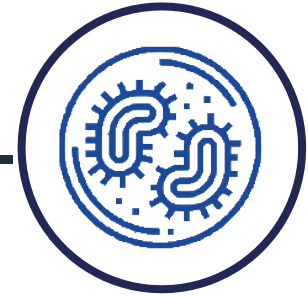


RH of Classrooms	% Airborne Particles Carrying Virus (PCR)	Virulence of Airborne Virus	# Children Absent Due to Influenza Illness
20%	49%	75%	22
45%	19%	35%	9

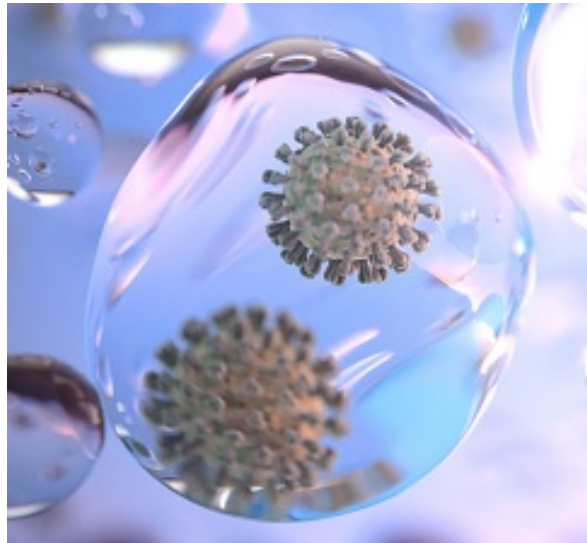
# RH: SPEED OF INACTIVATION OF SARS CORONAVIRUS



# WHAT HAPPENS INSIDE DROPLETS AT DIFFERENT AMBIENT HUMIDITY LEVELS?



Exiting airways  
with RH 100%



100  $\mu\text{m}$

Indoor RH  
over 40%



50  $\mu\text{m}$

Pathogens are inactivated  
by mid-range salt  
concentrations (reducing  
risk for transmission)

Indoor RH  
below 40%



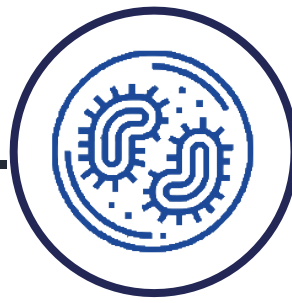
3.9  $\mu\text{m}$

Pathogens are  
preserved by high salt  
concentrations  
(creating higher risk for  
transmission)

RESEARCH AT A GLOBAL SCALE

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**BREAKING NEWS**



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EXPLORING THE POTENTIAL ROLE OF INDOOR CLIMATE IN  
GLOBAL COVID-19 OUTCOMES

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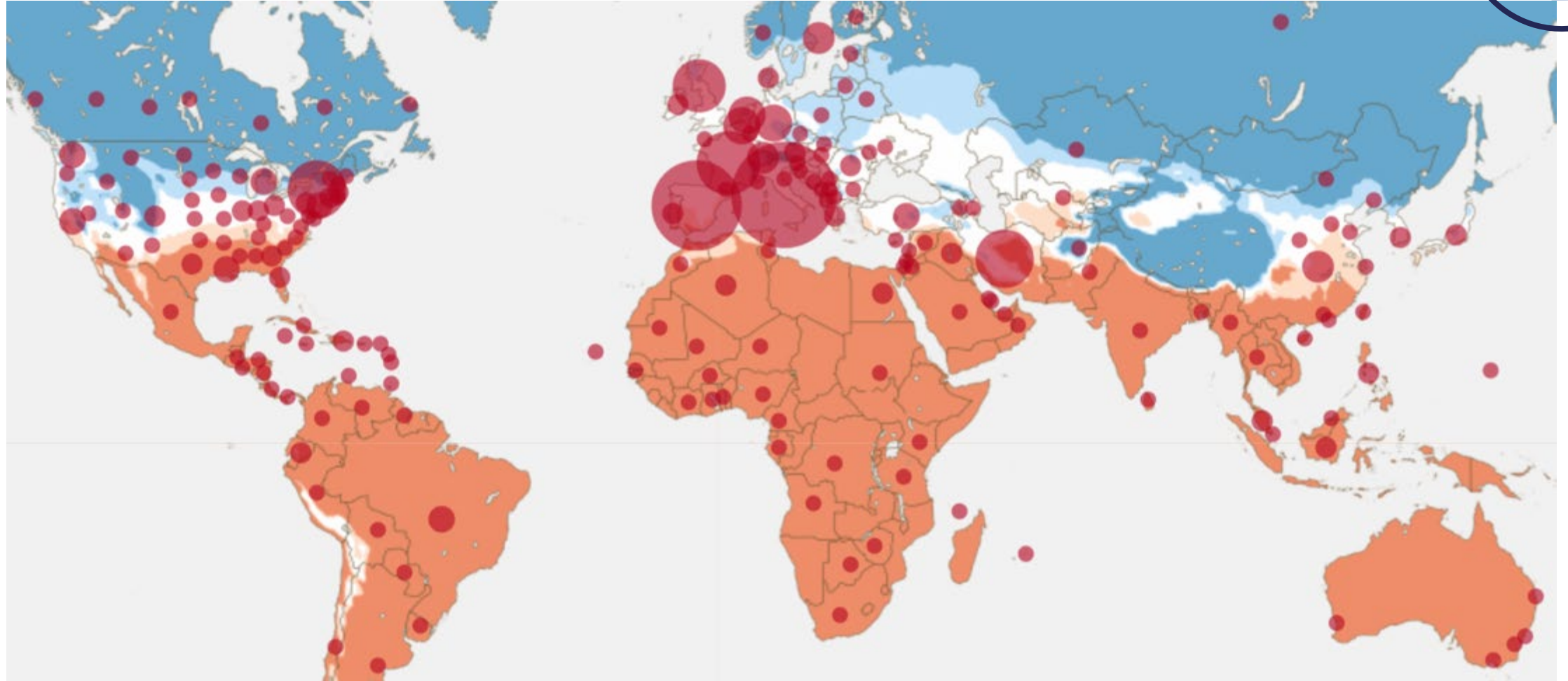
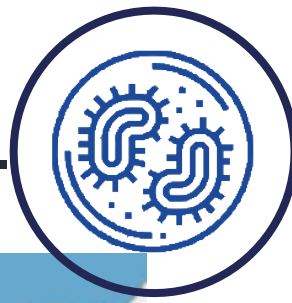
Harvard-MIT Health Sciences and Technology  
Boston, MA 02139

Stephanie Taylor  
Connor Verheyen  
Lydia Bourouiba

Submitted to Nature

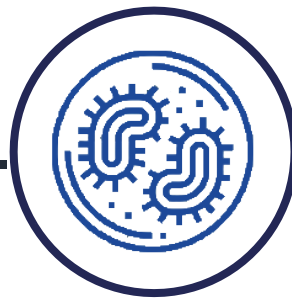


# WHY ARE COVID-19 OUTBREAKS REGIONAL?



Number of deaths in March 2020  
Copernicus COVID-19 climate viewer

# THE CATEGORIES OF DATA THAT WE ANALYZED



## Government Policies and Public Health Measures

School closing, workplace closing, cancel public events, restrictions on gatherings, close public transport, stay at home requirements, restrictions on internal movement, international travel controls, income support, debt/contract relief, fiscal measures, international support, public information campaigns, testing policy, contact tracing, emergency investment in healthcare, investment in vaccines

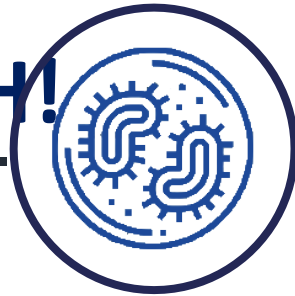
## Ambient Environmental Variables

Daily outdoor temperature, daily UV, daily surface pressure, daily precipitation rate, daily wind speed, daily dewpoint, daily outdoor relative humidity, daily outdoor absolute humidity, standard human thermal comfort zone, daily extrapolated indoor relative humidity

## Demographics, Socioeconomics, and Testing

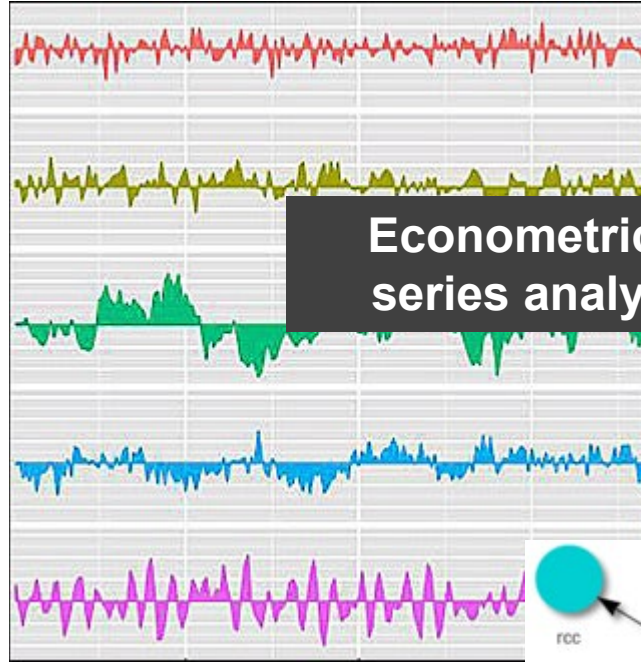
Population, population density, median age, aged 65 and older, aged 70 and older, life expectancy, cardiovascular disease death rate, diabetes prevalence, GDP per capita, extreme poverty, handwashing facilities, hospital beds per thousand, total tests, new tests, total tests per thousand, new tests per thousand

# OUR STATISTICAL ANALYSIS WAS INSANELY THOROUGH!



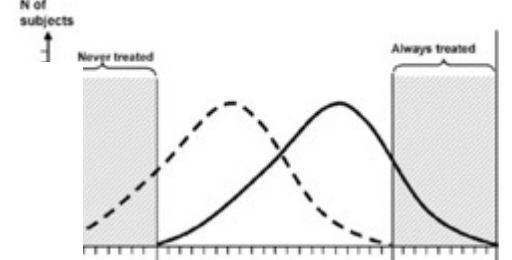
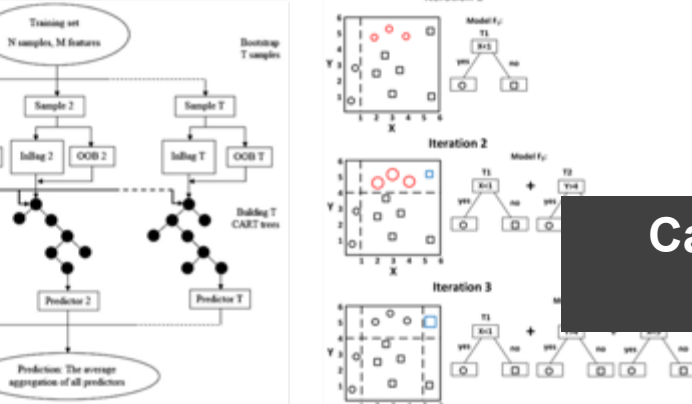
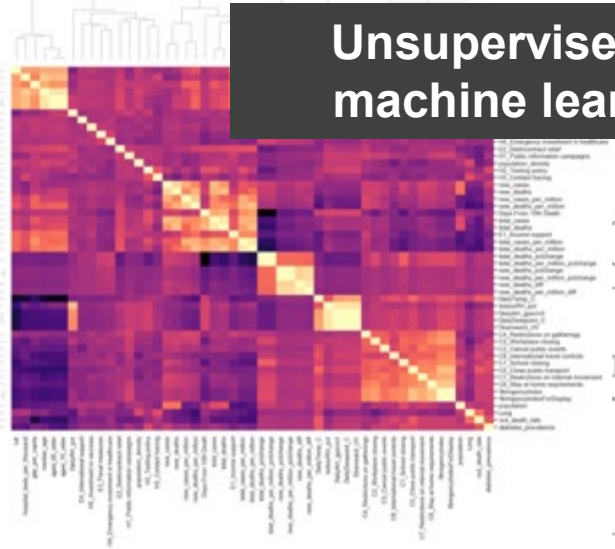
Quartile Val	Deaths	from 100k	Lat	Long	School closure	public on	home	on intel	lational tra	home sub	contradical	med	national	formation	Testing p	contact tr	investment	in	Medic	Agency	indoor	Farm	Temp	Develop	bal	hy	AI	door	RM				
0	39.0675	16.5125	4.68801	1.90284	1.941176	2.771429	1.532941	1.663871	1.709244	1.672269	0.702944	0.991597	3.68E-08	1.941176	1.171429	0.902521	235142	0	709.0876	78.63272	78.63272	24.9816	6.62278	48.25896	10.27364	40.52632							
1	77.54048	17.1875	27.77047	23.05602	2.444643	1.9375	1.146429	1.994643	1.876786	1.739286	3.408929	0.637514	0.955357	1.89E+09	1.944643	1.435714	1.2625	6662028	5880.027	1702.469	81.99618	81.99618	17.501	8.099417	56.93456	4.90243	42.50555						
2	131.5679	17	24.72997	17.77683	2.919643	2.483929	1.9375	2.482414	1.338929	1.591071	1.792857	3.578571	0.964286	0.905357	5.46E+08	181568.8	1.9375	1.621429	1.408929	6433239	2482143	3755.666	82.00025	82.00025	18.16351	10.98712	65.36729	12.12018	53.29083				
3	211.5911	17	31.66911	17.95828	2.728571	2.107143	1.75	3.25387	0.985714	1.7125	1.532143	3.439286	0.914286	1.201786	4.35E+08	961501.3	1.9125	1.6375	1.482143	7478526	339950	7953.691	76.19564	76.19564	9.405832	3.161391	61.35928	6.39211	32.70074				
4	173.0141	17	42.23895	1.38571	2.789286	2.358929	1.932143	2.975	0.73214	1.676786	1.571429	2.976786	1.223214	1.194643	1.58E+08	1208940	1.891071	1.566071	0.982143	6.95E+08	344864	31227.39	71.00661	71.00661	9.928322	2.161391	61.35928	6.39211	32.70074				
0	43.10714	17	15.55273	17.6791	1	2	3	2	1.771429	2	4	0.542857	1	0	0	0	2	1.428571	1.257143	4659.371	0	1673.029	82.21686	82.21686	17.0372	4.256694	61.15277	6.398449	34.81694				
1	60.6514	17	32.39585	20.6638	3	2.657143	2	3.957143	1.742857	2	1.9	3.914286	0.942857	0.942857	4295.972	0	2	1.428571	1.257143	4659.371	0	1673.029	82.21686	82.21686	17.0372	4.256694	61.15277	6.398449	34.81694				
2	105.7429	17	21.21023	23.95215	3	2.7	2	3.128571	1.342857	1.785714	2	4	0.942857	0.957143	13771429	0	2	1.628571	1.3	0	3618.714	85.35886	85.35886	19.4691	11.70764	62.56906	11.03985	48.48741					
3	126.9143	17	30.68765	23.54925	2	2.271429	2	3.728571	1	1.971429	1.8	4	0.971429	1	1.43E+08	0	2	1.7	1.914286	0.000429	8210.143	83.65143	83.65143	16.95343	5.649093	49.45537	7.024952	28.29936					
4	1109.514	17	46.5229	4.64565	2.985714	2.697143	2	2.985714	2.697143	2	2	2.985714	2.697143	2	2.985714	2.697143	2	2.985714	2.697143	2	2.985714	2.697143	2	2.985714	2.697143	2	2.985714	2.697143	2	2.985714	2.697143	2	2.985714

Data aggregation

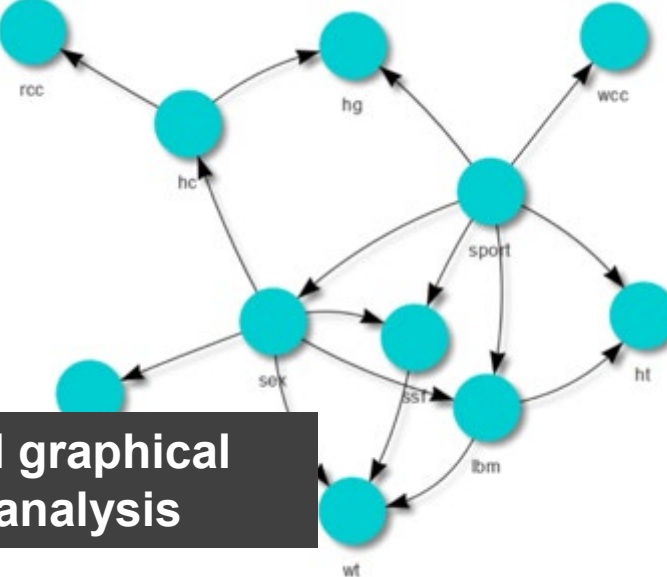


Econometrics methods for time series analysis and forecasting

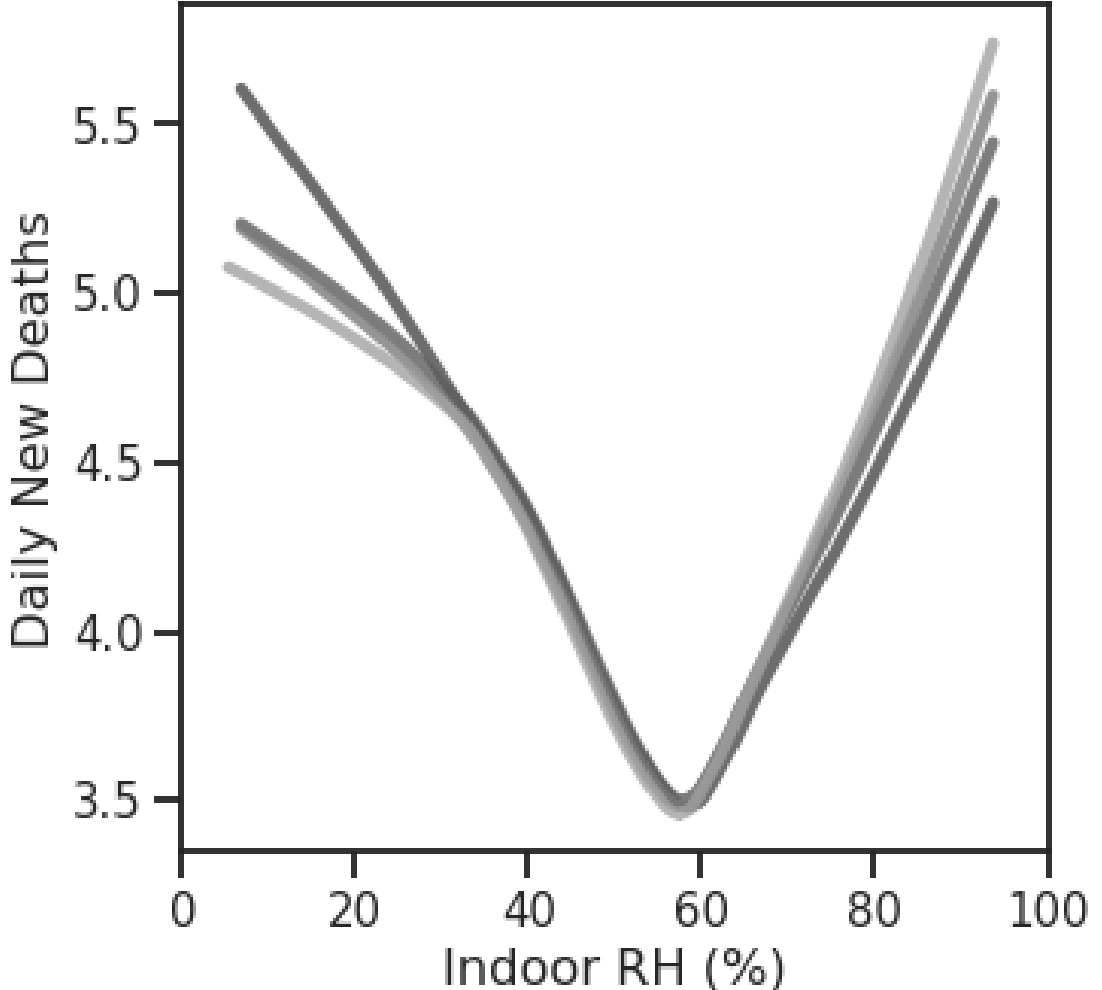
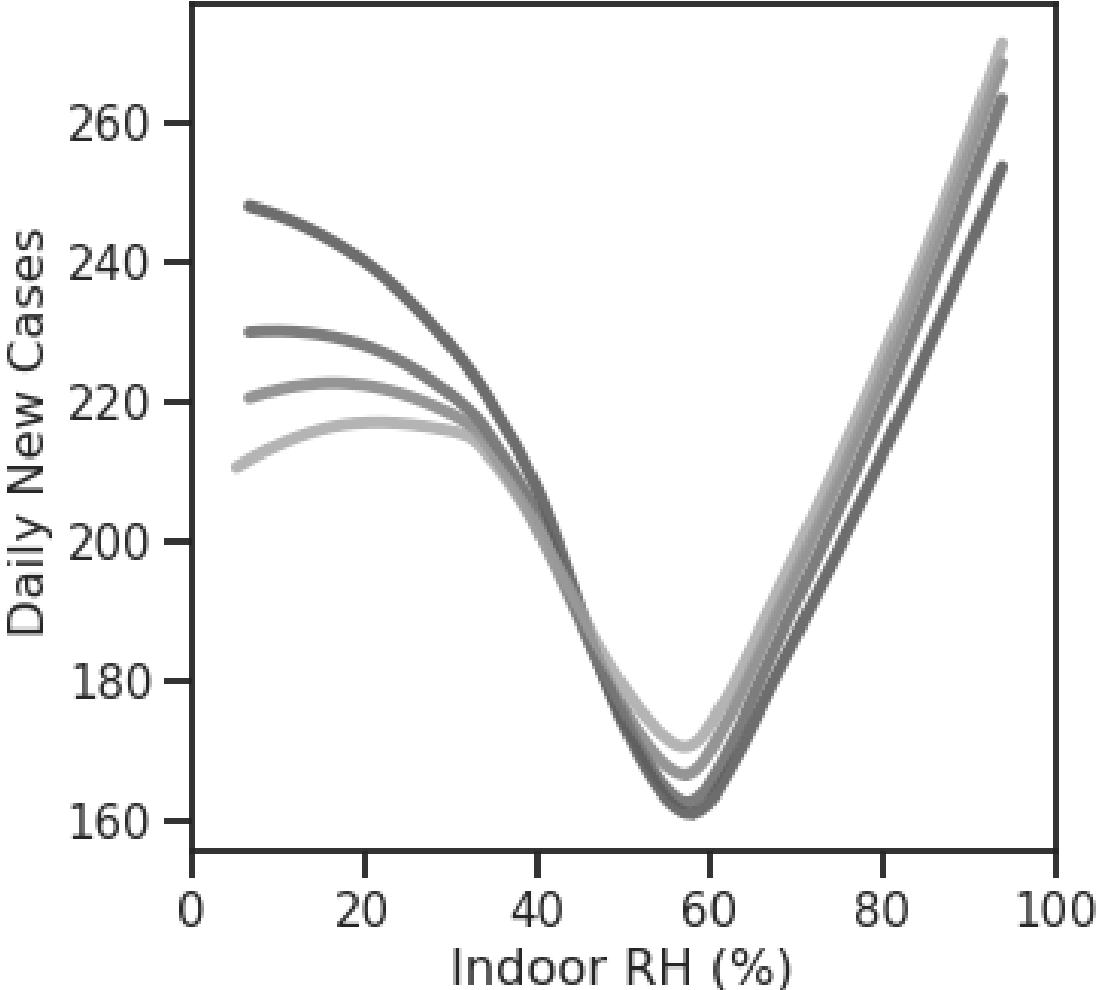
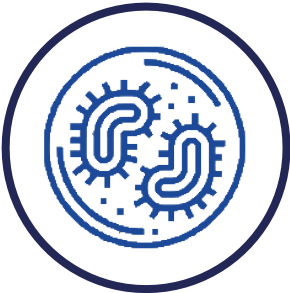
Unsupervised and supervised machine learning approaches



Causal inference and graphical Bayesian network analysis



# CASES AND DEATHS WERE LOWEST WHEN INDOOR RH WAS 40–60%



# THERE ARE 3 WAYS TO PROTECT PEOPLE



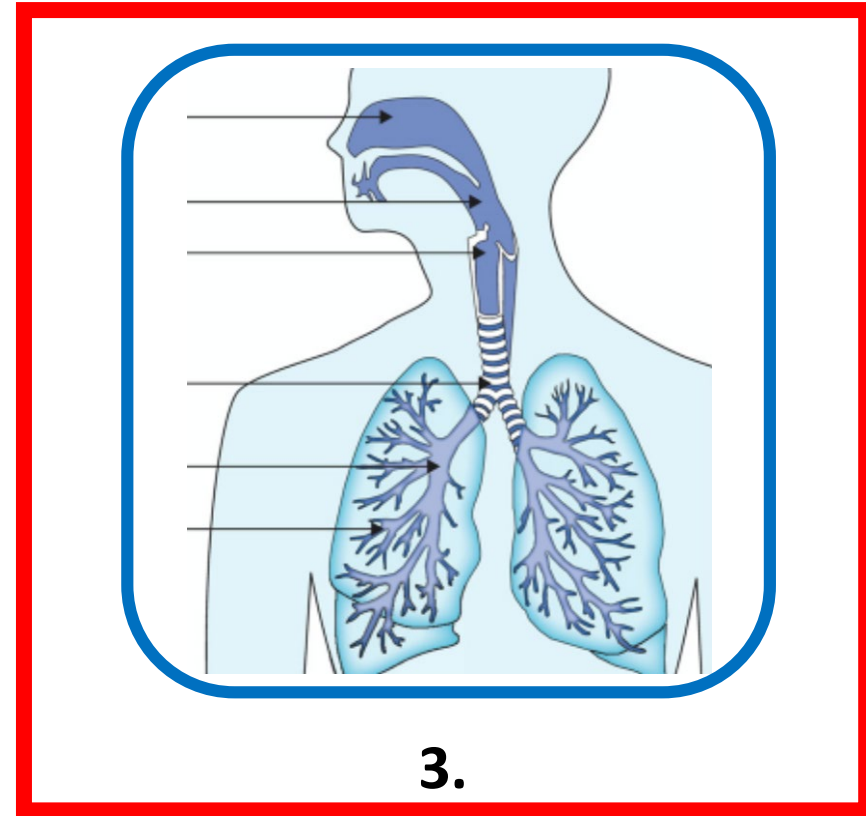
1.

Restrict your viral exposure



2.

Manage the indoor environment



3.

Take care of your health and immunity

**A KEY STUDY PUBLISHED IN 2019**



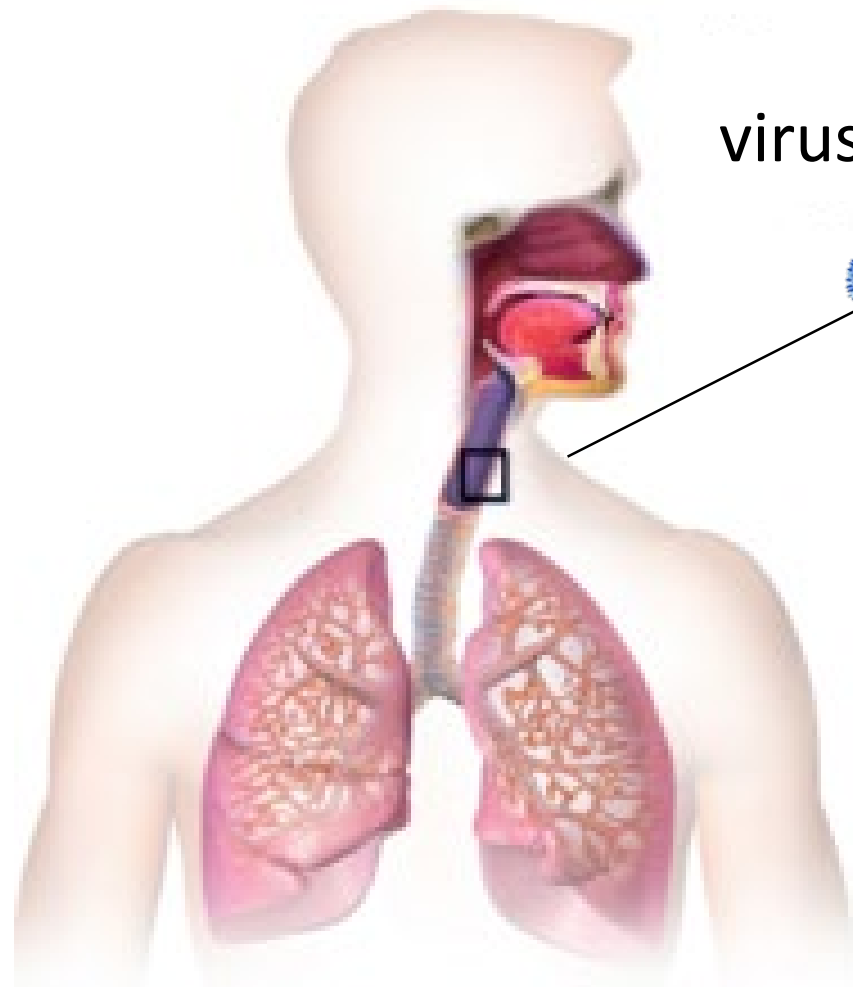
**“Low ambient humidity impairs barrier function and innate resistance against influenza infection”**

*Proceedings of the National Academy of Sciences, USA. May 2019*

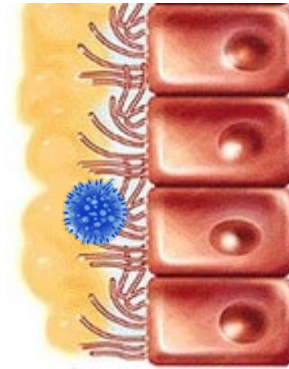
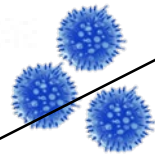
E Kudo, E Song, L Yockey,  
T Rakib, P Wong, R Homer,  
A Iwasaki



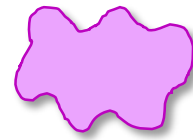
# AT RH 50% OUR BODY PROTECTS US FROM RESPIRATORY INFECTIONS



virus



Interferon



Macrophage

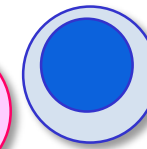


Dendritic cell

Activate



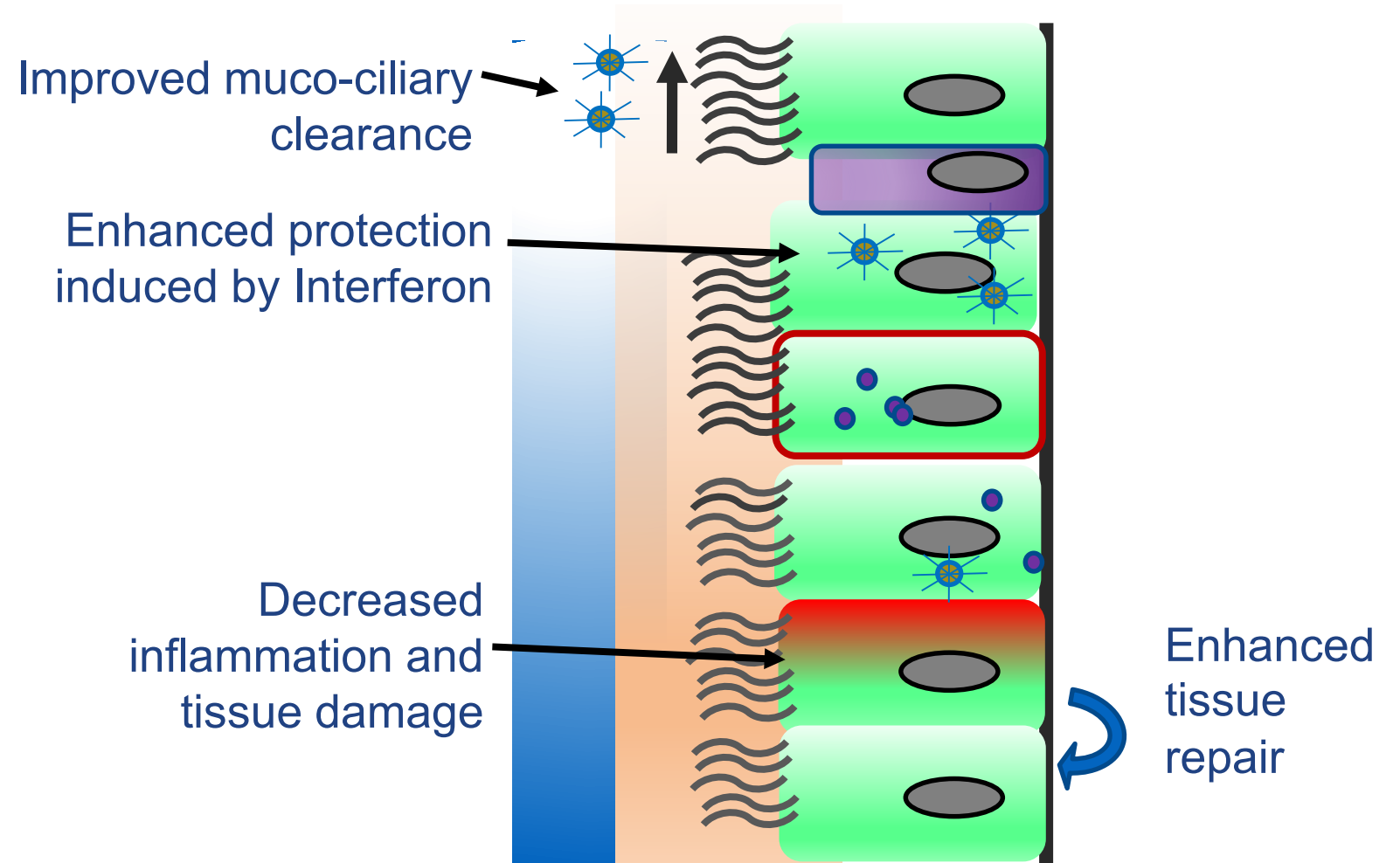
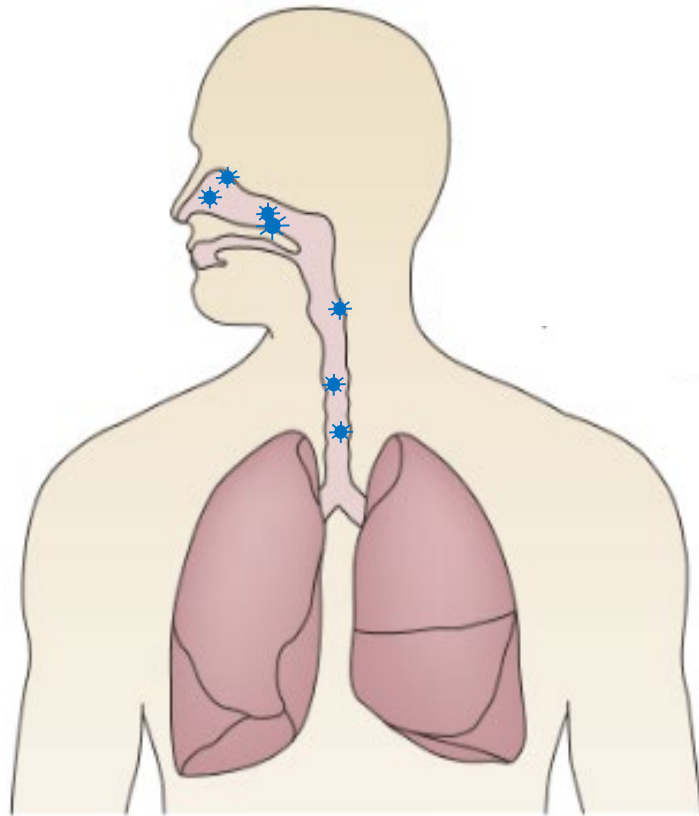
T cell



B cell

1. Physical barrier: Mucus production and ciliary clearance
2. Innate immunity: Type I IFN and Interferon stimulated genes (ISGs)

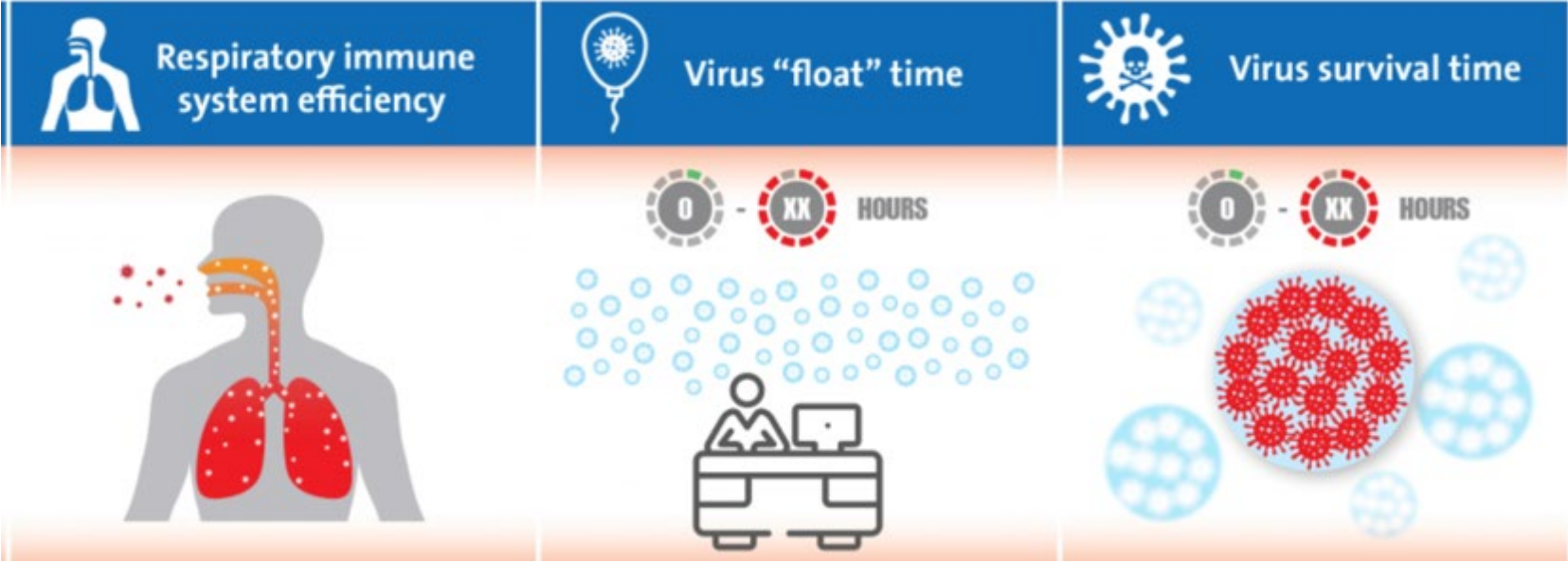
# ALL OF THESE IMMUNE DEFENSE STEPS ARE IMPAIRED AT RH 20% AND ARE OPTIMAL AT 50%





# THREE DIMENSIONS OF RH 40–60% PROTECTION

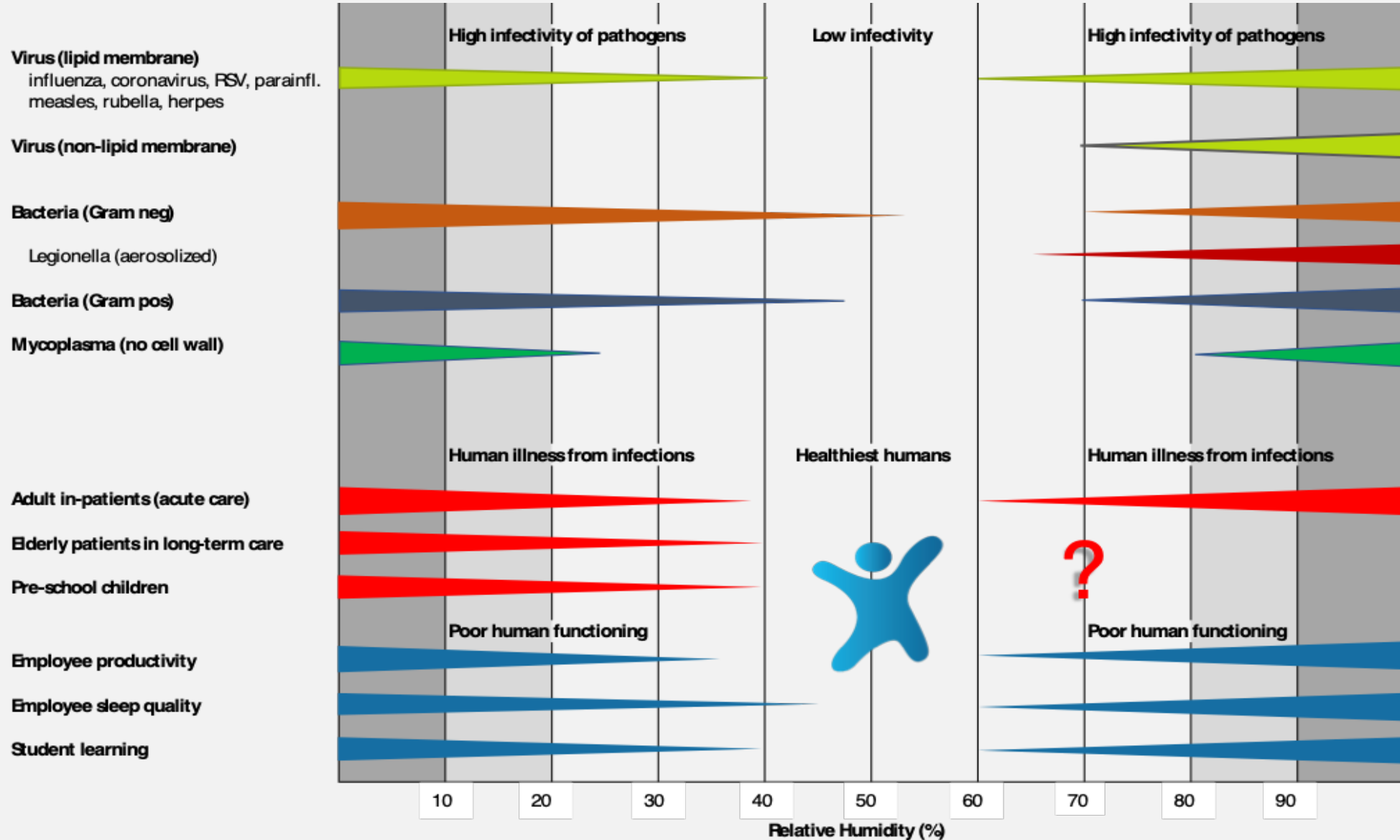
RH < 40%



RH 40% – 60%



# TAYLOR CHART 2019



# THE President of Leapfrog Hospital Safety, Leah Binder



**Forbes blog: Scientists Say This One Move Could Beat Back The Covid-19 Surge, If People Only Knew About It**

A few months before most of us knew the word “coronavirus,” I interviewed a leading cellular biologist at Harvard Medical School, Dr. Stephanie Taylor, on how people can protect themselves from the flu. Her answer was surprising: **properly humidify your indoor spaces, starting with your own house.** This can lower your risk of infection by as much as 60%. Now she has an update: the same advice holds true for the virus that causes Covid-19.



# HUMIDIFICATION IS USED WHEN THE FINANCIAL BENEFITS ARE CLEAR



National Institute of Health animal facility



Replacement cost of a primate:  
\$22,000  
**RH 40%–60%**

NASA spacecraft



Cost to train an astronaut:  
\$50 million (in 2006)  
**RH 40%–60%**

Louvre



Mona Lisa value:  
\$780 million  
**RH 40%–60%**

# DO HUMANS HAVE A DOLLAR VALUE?



# AN EXAMPLE OF HUMIDIFICATION FOR HUMANS!



*“Arrrgghh, Why didn’t we humidify our air sooner?!?”*

# PRESENTATION OVERVIEW

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## A. Medicine and Buildings

- Travelling Across Silos

## B. Studies on Life Indoors

- Indoor Environments and Health

## C. Scaling Health Visibility

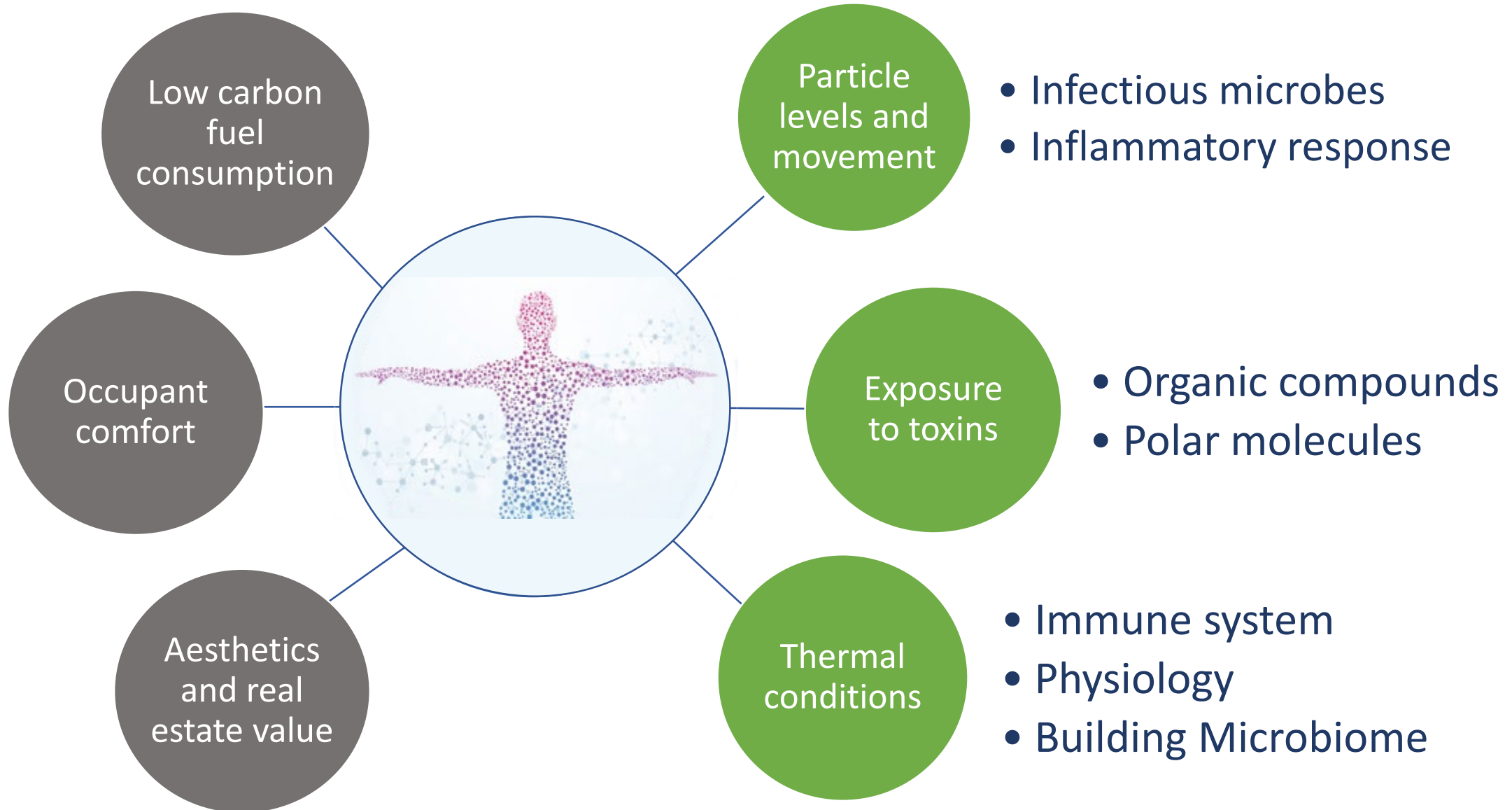
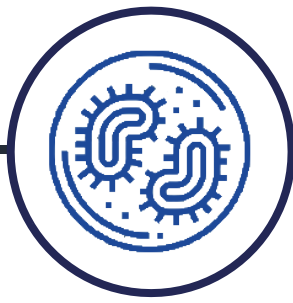
- COVID and Beyond

# HOW CAN WE STUDY IAQ AND HEALTH?





# IMPACT ON OCCUPANT HEALTH



# UNDERSTANDING THE RISKS / BENEFITS



- Increased outdoor air ventilation
- Access to sunlight
- Ultraviolet light irradiation
- Bipolar ionization
- Hydrogen peroxide misting
- HVAC filtration
- Midrange humidity control
- Other



# AN ESSENTIAL NEW APPROACH



## Continuous Indoor Air Monitoring through the Lens of Human Health

- indoor air thermal metrics
- particle counts and densities
- microbial populations
- volatile organic compounds
- relevant gases

# HEALTH AND ENERGY MANAGEMENT CAN WORK TOGETHER



**A S H R A E  
J O U R N A L**

## **Improving IEQ To Reduce Transmission Of Airborne Pathogens In Cold Climates**



Stephanie Taylor, MD, Michael Scofield, ASHRAE Fellow, Patricia Graef, PE, ASHRAE Fellow  
September 2020 issue

# COVID-19 REMINDS US THAT BUILDINGS IMPACT HEALTH



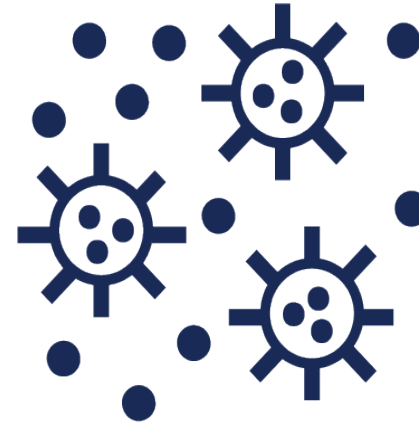
**90%**

of our lives are spent indoors



**11,000**

liters of air are inhaled every day



**80%**

of Influenza viruses are inactivated within 15 minutes of humidity between 40-60%



**9%**

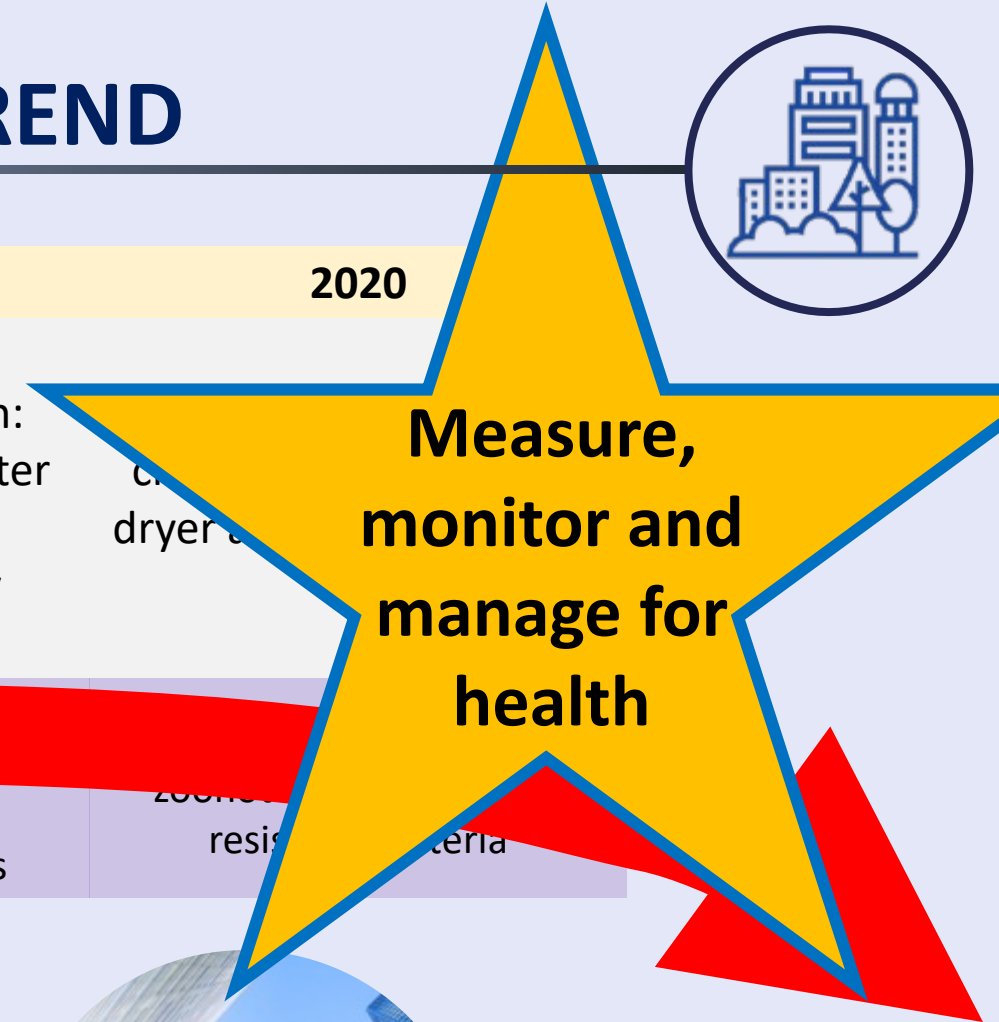
decreased productivity possible due to air quality

# WE CAN (and must) CORRECT THIS TREND



timeline:	10,000 BC	800 BC - 500 AC	1900 AC	2020
housing:	primitive housing, no sanitation systems	simple sanitation, in rural villages	industrial revolution: central sewage & water systems, heating, electricity	central sewage & water systems, heating, electricity, air conditioning, dryers
diseases:	zoonosis	influenza, plague	introduction of antibiotics & vaccines	zoonosis, antibiotic resistance, bacteria

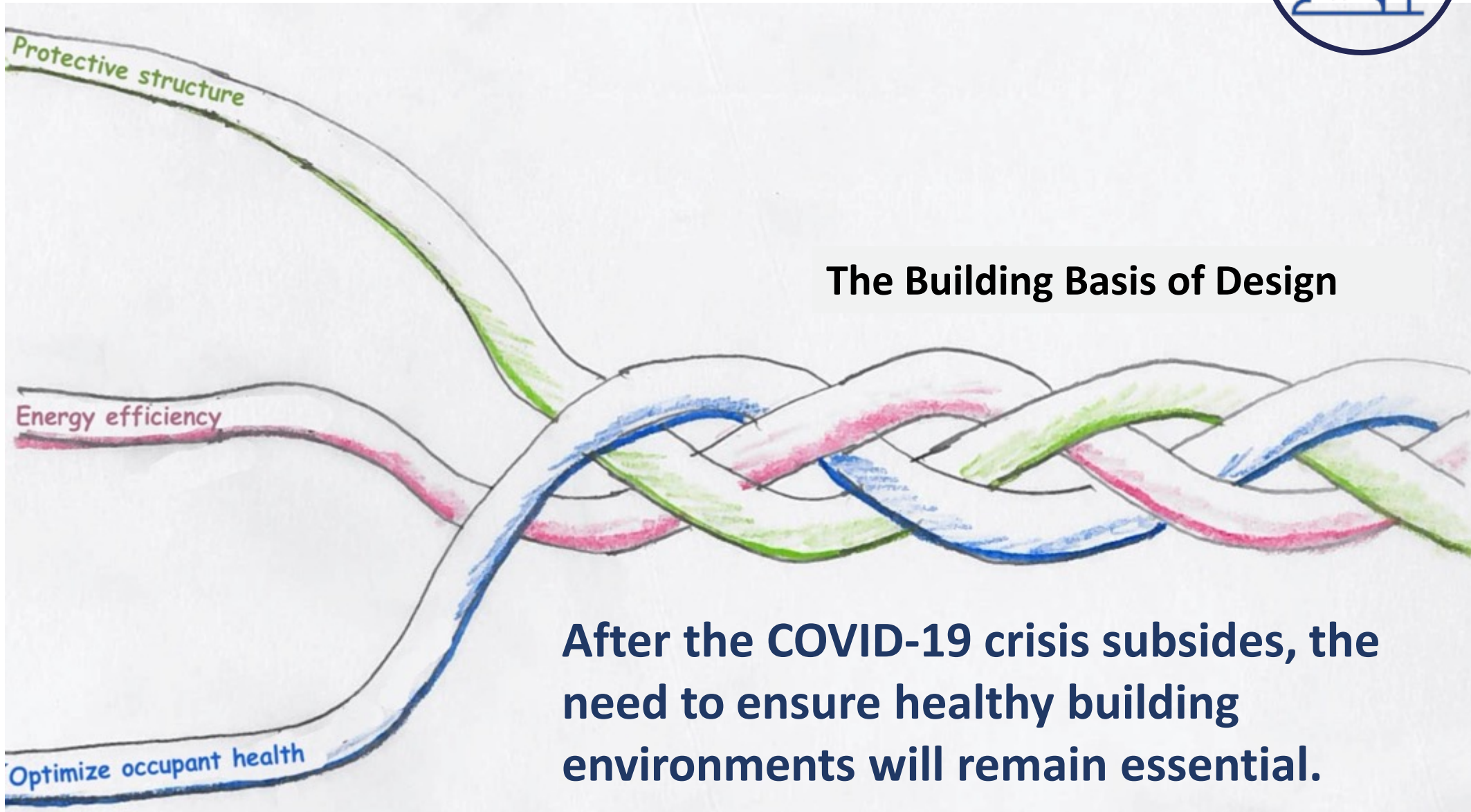
## Infectious and other diseases



# THE FOCUS OF BUILDING DESIGN HAS EVOLVED



Past:  
Shelters



Pre-COVID:  
Sustainability



**NOW:**  
Human Health

**The Building Basis of Design**

**After the COVID-19 crisis subsides, the need to ensure healthy building environments will remain essential.**

# WE PETITIONED THE WORLD HEALTH ORGANIZATION



English (English) ▾

“ Take action and join me in the fight against respiratory infections! Relative humidity of 40-60% in buildings will reduce respiratory infections and save lives. ”

*Steph H. Taylor, MD*



There is now overwhelming scientific evidence that a mid-range air humidity has significant benefits for human health. It is very possible for us to be managing the indoor air quality of our public buildings in line with this evidence. The time has come for regulations on indoor air quality to include a humidity level of 40-60%RH. This is the optimal level for our respiratory immune system, and will reduce the spread of seasonal respiratory illnesses and their burden on society.

I am calling on the World Health Organization to review the scientific evidence on humidity and health, and recommend a minimum lower limit of indoor humidity in public buildings to reduce respiratory infections.

**Dr. Stephanie Taylor**

Infection Control Consultant at Harvard Medical School  
ASHRAE Distinguished Lecturer & Member of the ASHRAE Epidemic Task Group



## Take Action! Sign the Petition

Dear Director General WHO,

I call on the World Health Organization to

- Review the scientific evidence related to indoor humidity and respiratory immune system response, viral transmission and virus inactivation.
- Produce guidelines on the minimum lower limit of indoor humidity in public buildings for health.

First Name \*

Last Name \*

Email \*

City \*

Country \*

ADD ME TO YOUR MAILING LIST

BCC YOURSELF

I'm not a robot



The World Health Organization finally responded to our petition!

Please join us and sign the petition to recommend indoor RH 40–60% to decrease COVID-19 spread.



# NEXT STEPS

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- Remember, healthy people provide a Return–On–Investment.
- Investigate IAQ from the perspective of occupant health
- Make the important indoor components visible by monitoring and analyzing data through the lens of occupant health.
- Maintain indoor RH 40%–60% for starters.
- Sign our WHO petition. [www.rh40to60.com](http://www.rh40to60.com)

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# Thank you!



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**and Luigi!**



# PARTIAL RESOURCE BIBLIOGRAPHY

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