Building Envelopes for Healthy & Resilient Buildings in a Post-COVID-19 Pandemic World

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Applied Building Technology Group (ABTG) is committed to using sound science and generally accepted engineering practice to develop research supporting the reliable design and installation of foam sheathing. ABTG's educational program work with respect to foam sheathing is supported by the Foam Sheathing Committee (FSC) of the American Chemistry Council.

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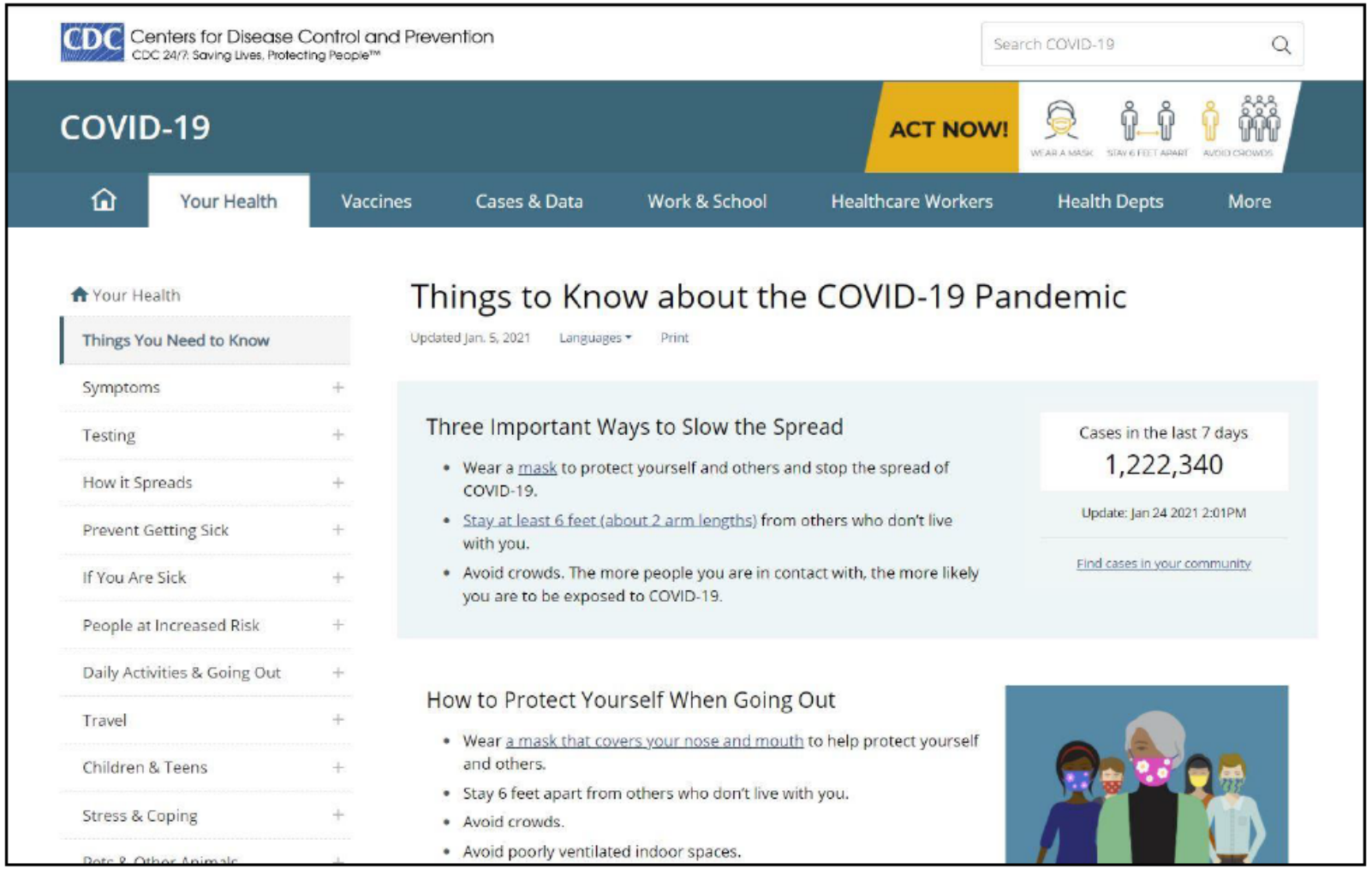
Foam Plastic Applications for Better Building

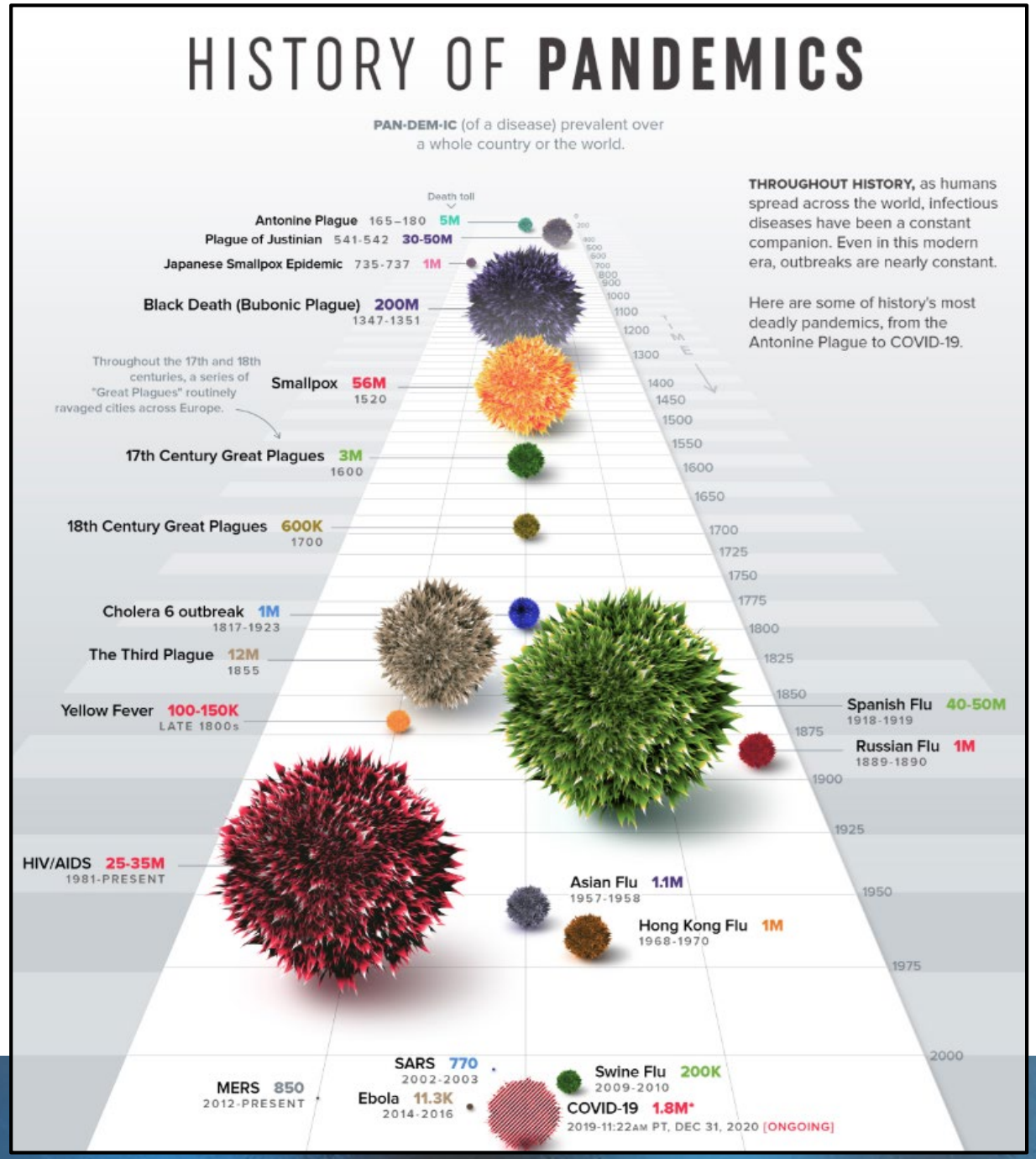
Outline

- Introduction
- History Repeats Itself
- What can we do?
- The Role of Building Science for Healthy Buildings
- HVAC Actions
- Building Envelope Actions
- Conclusions
- Questions

COVID-19 Has Us Concerned About Protecting Ourselves and Others



Pandemics are nothing new



Source:
https://www.visualcapitalist.com/history-of-pandemics-deadliest/

We've Been Here Before

Figure 2. Red Cross volunteers assembling flu masks and a Rochester Department of Health poster in response to the 1918 Spanish flu pandemic.
(Source: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2862330/)

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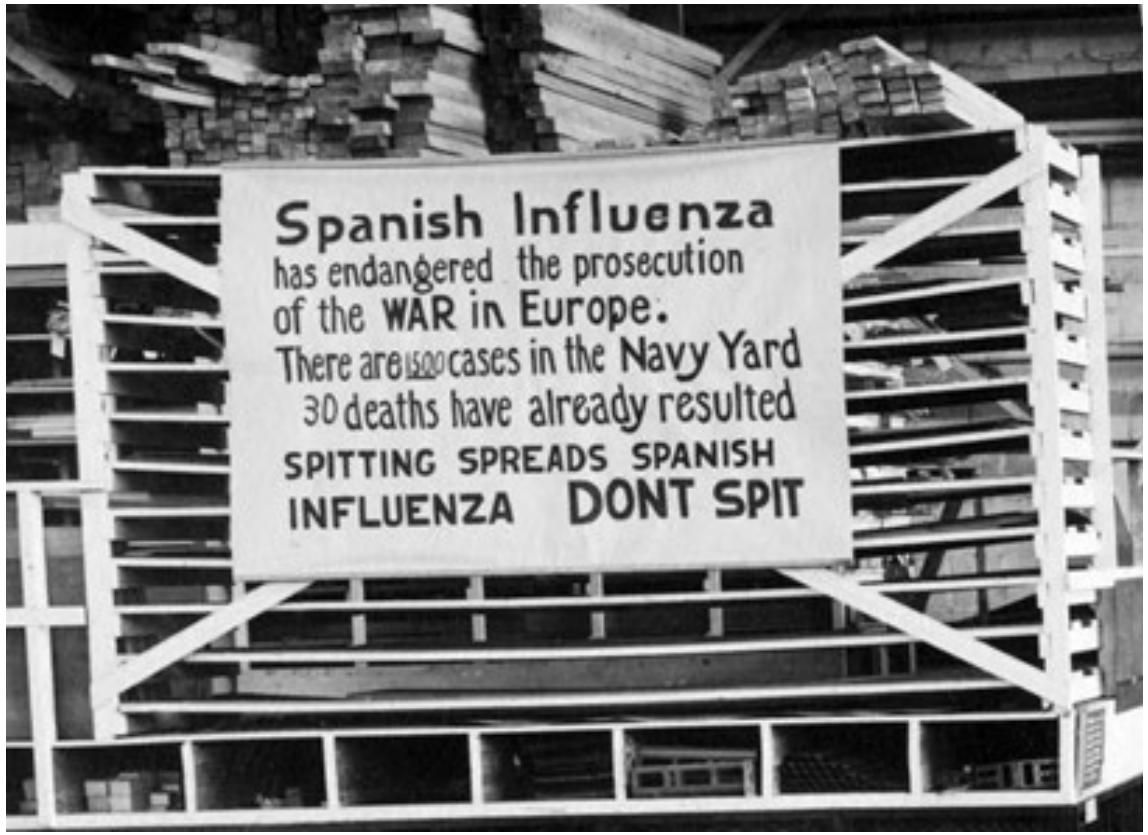
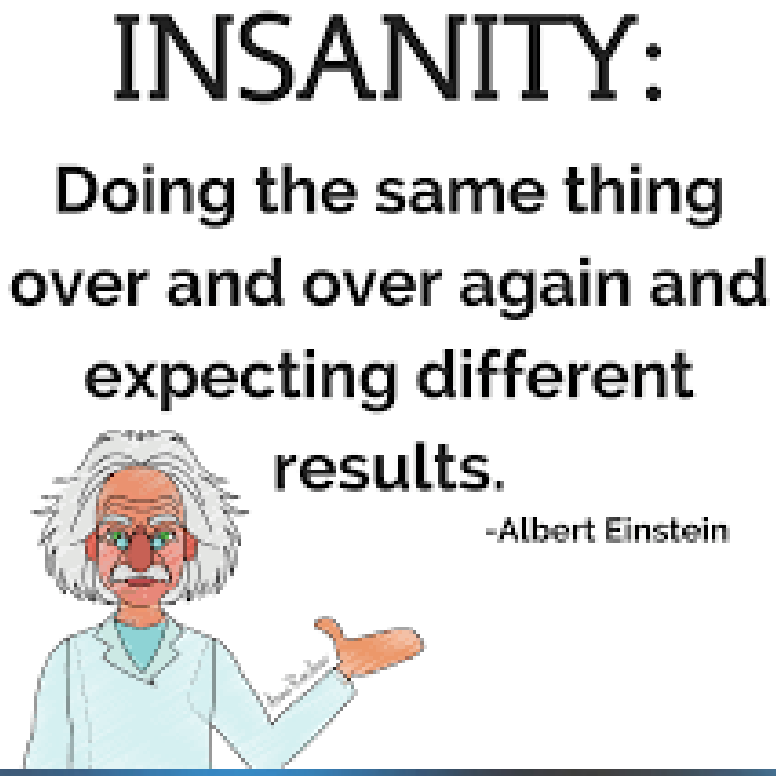
And we will be here again

History repeats itself

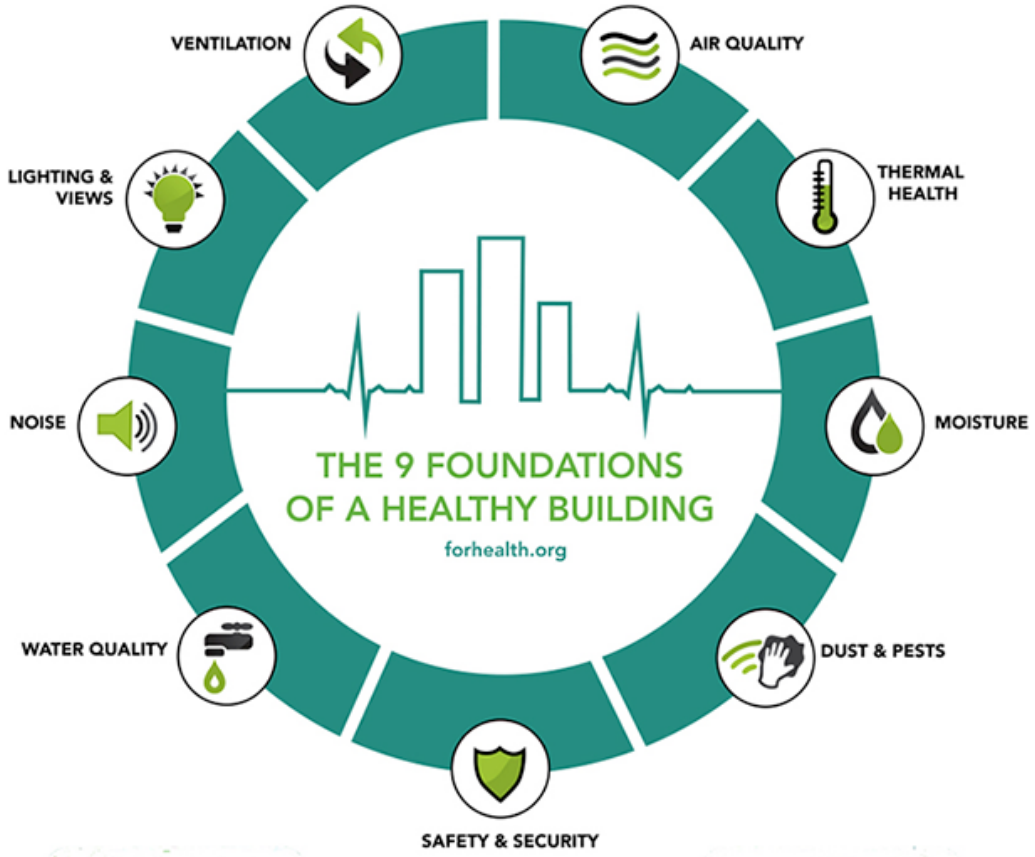


The similarities are striking

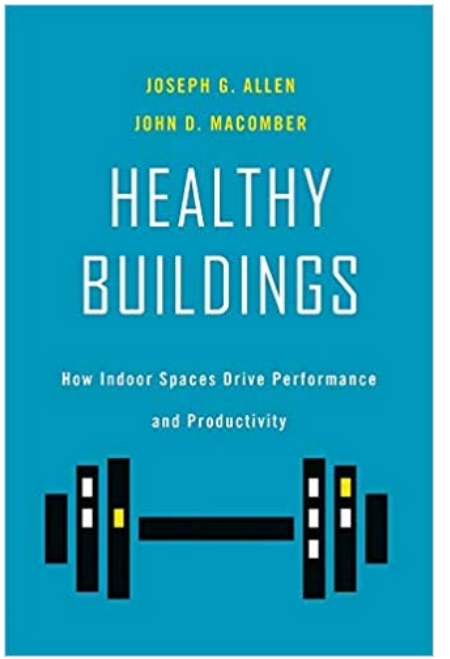
The pandemics will come but our preparation can be different. We can be more resilient.



Building design needs to play a role



Building envelopes play a direct and indirect role in all of these foundations of healthy buildings.



Source: https://hbswk.hbs.edu/item/why-covid-19-raises-the-stakes-for-building-health

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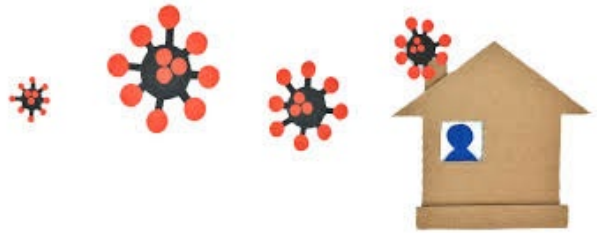
Buildings also Play an Important Role in Protecting Ourselves and Others



"Think of the **building envelope** as the protective skin or PPE of the building and the **HVAC system** as the internal lymphatic system to maintain internal health and help suppress pathogen propagation and survival within the buildings body."

Source: ABTG RR No 2006-01, p.8, https://www.continuousinsulation.org/topical-library/healthy-buildings

The Role of Building Science

- **Building Science** – the application of science as it relates to the physical behavior of buildings as systems with many interactions

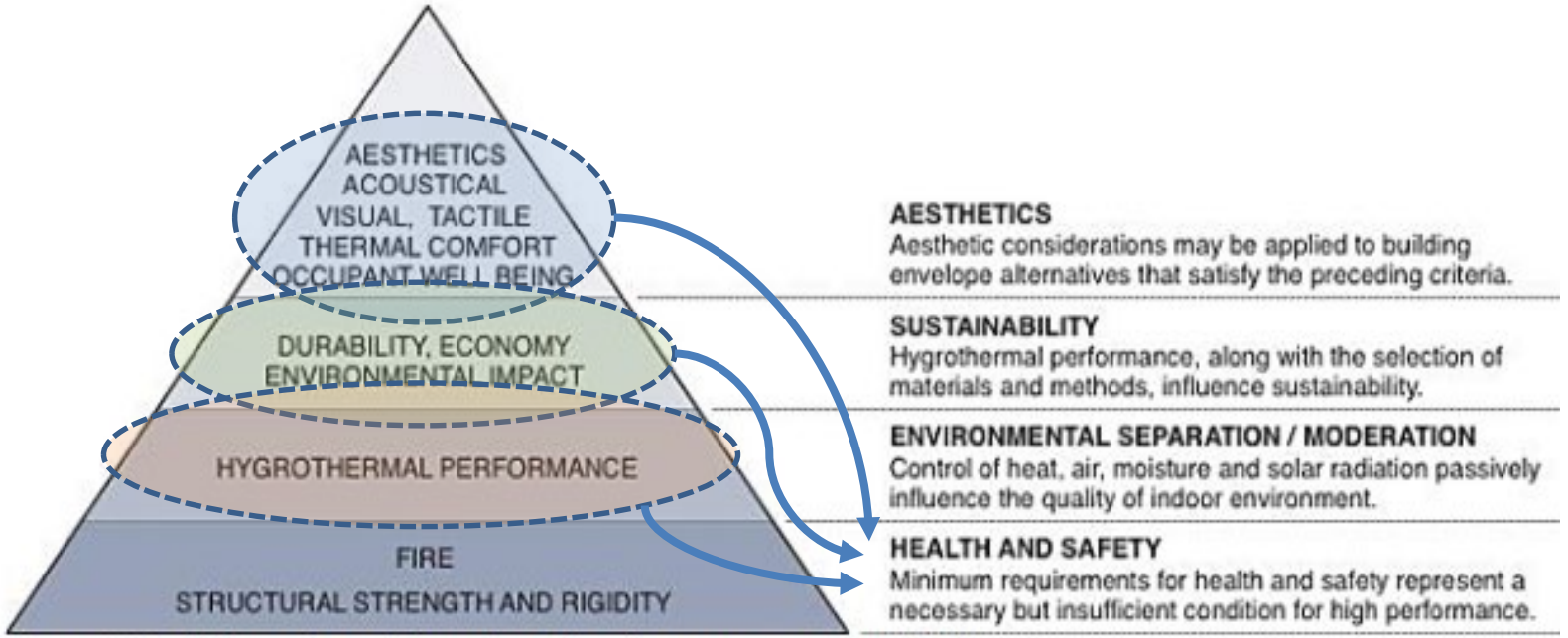


Figure 3. Building science hierarchy of performance requirements.

Source: https://www.wbdg.org/resources/building-science-concepts

Relevant Science for Healthy Buildings

- **Sociology** – the study of human behavior
- **Biology** – the study of life and living organisms
- **Economics** – the study of how society uses its limited resources

Sociology

- People in the U.S. spend about 87% of their time indoors.
- Over 2,000 COVID-19 superspreader events (SSEs) worldwide
  - Nearly all SSEs occurred indoors
  - Most involved confinement for extended time
  - Higher frequency during flu season
- Indoor environment is important to health and safety.

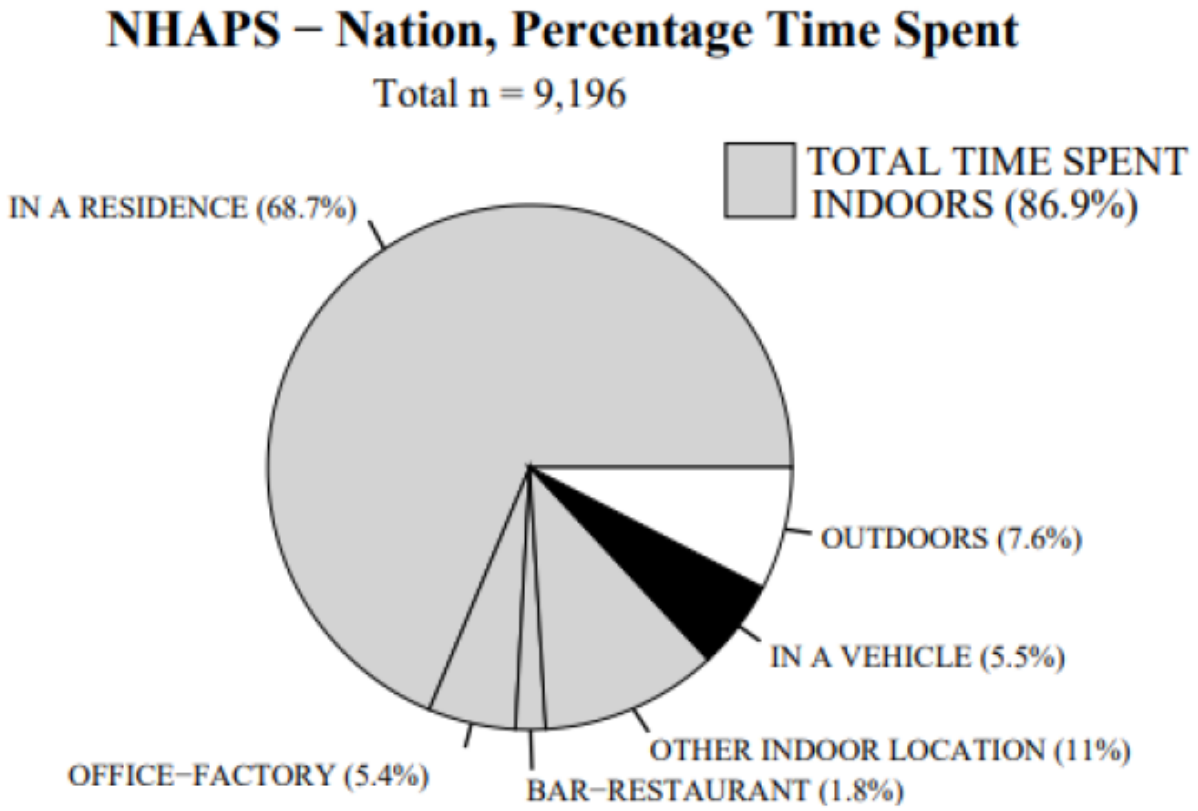


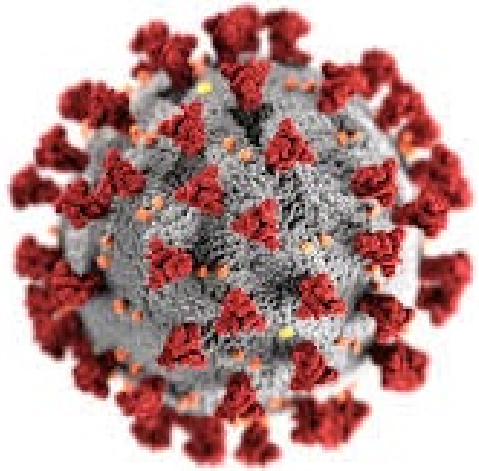
Figure 3. Survey of time spent in various locations. (Source: https://indoor.lbl.gov/sites/all/files/lbnl-47713.pdf)

Biology

- People and other organisms need the following things to live:
  - Oxygen (O_2)
  - Water (H_2O)
  - Food (energy and nutrition)
  - Protection (extreme temperature, solar UV radiation, **pathogens**, natural and man-made hazards, etc.)

Biology

- Pathogens
  - Molds
  - Bacteria
  - Viruses

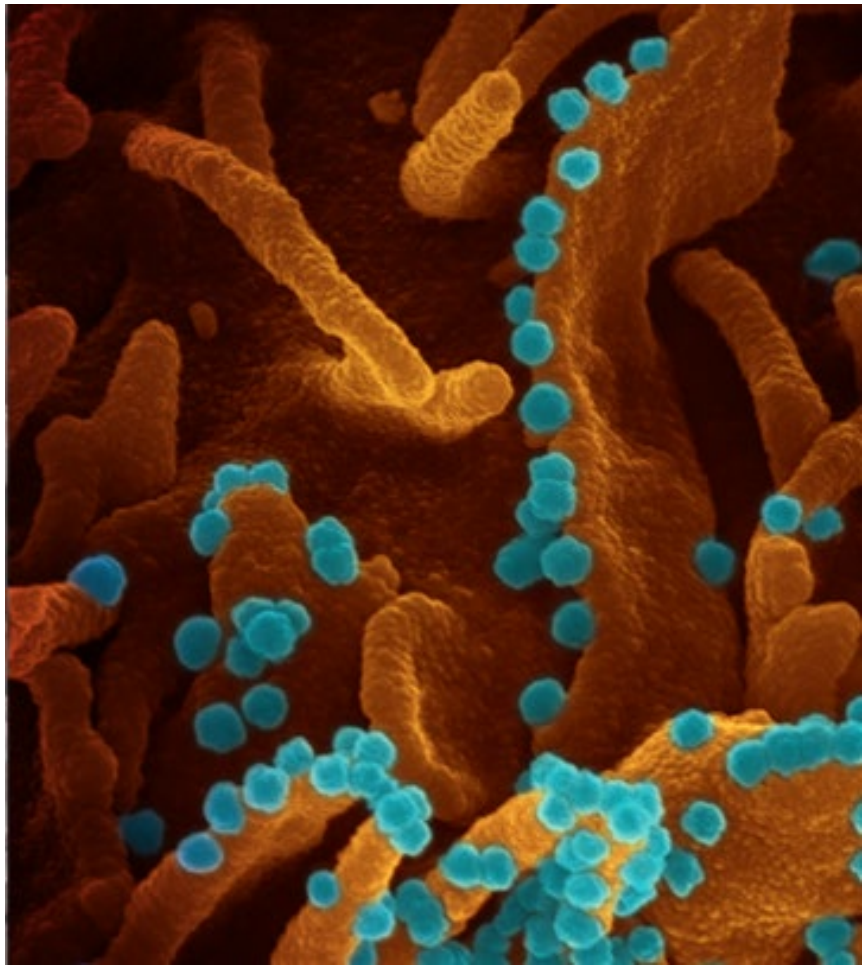


Biology

- Molds and bacteria are prolific and thrive in buildings when conditions are conducive.
  - Temperature
  - Humidity/water
  - Food source
- Molds and bacteria tend to have optimal temperature and moisture conditions for survivability.

Biology / Virology

- Viruses require a host to replicate and propagate.
  - Example: just one infected kidney cell can shed thousands of SARS Cov2 virions that then infect other cells of the host (see electron microscope image)



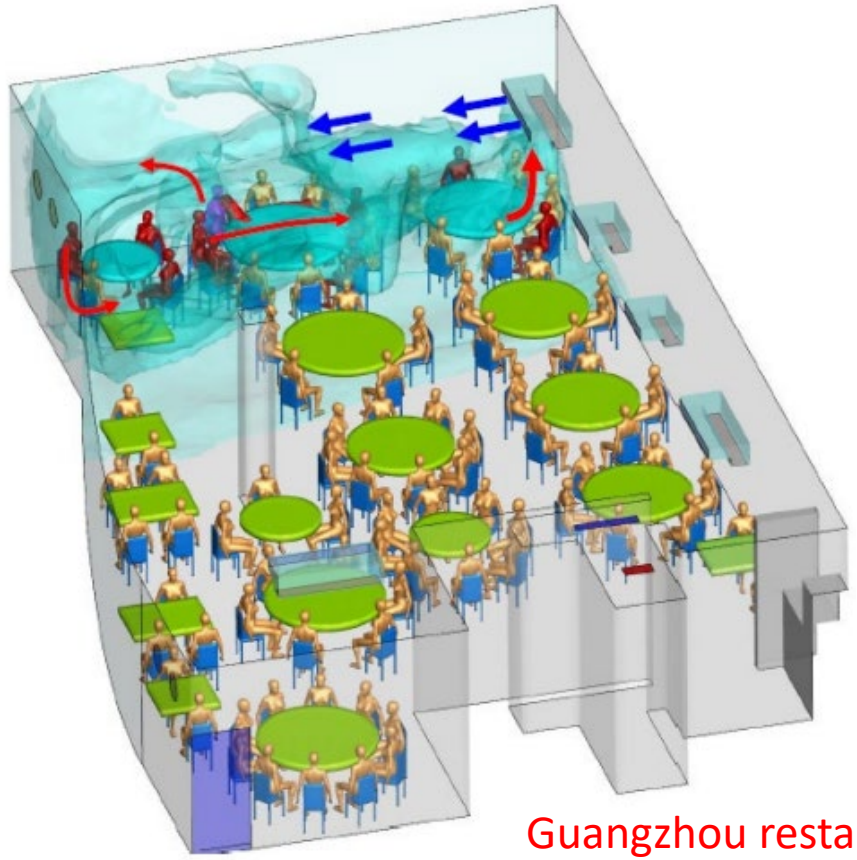
Source: https://directorsblog.nih.gov/2020/04/28/capturing-viral-shedding-in-action/

Biology / Virology

- Viruses become part of the building biome by “shedding” of body fluids from a host
  - Coughing
  - Talking & Breathing & Touching
  - Urine and Feces

Biology / Virology

- Viruses exist and are transferred to others in the building environment by:
  - Infectious droplets on building surfaces (fomite transmission)
  - Infectious aerosols suspended in the air (air-borne transmission)
- Dose/Exposure and vulnerability are important factors determining risk
- When exposed to the building environment (i.e., shed from a host), virions tend to have optimal conditions for survivability.



Guangzhou restaurant superspreader event

Source: Jay C. Butler, MD, Center for Disease Control, "Importance of Understanding the Role of Airborne Transmission in COVID-19" (image attributed to Li Y, et al. MedRxIV preprint) https://doi.org/10.1101/2020.04.16.20067728

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The “Health Window” for Indoor Humidity

- 40% to 60% indoor relative humidity favors human respiratory defenses against air-borne disease (REDUCED VULNERABILITY)
- It also tends to disfavor survival of many types of pathogens (REDUCED HAZARD, VIRAL BURDEN)
  - These trends are representative and have much variation (e.g., SARS Cov-2 survivability considered to be mildly influenced by RH).
- Why does this chart show a “Healthy Zone” of 30% to 60% RH if the optimal “Health Window” is 40% to 60% RH?
  - ANSWER: Building envelopes must be designed more robustly to withstand 40% RH during winter in cold climates.

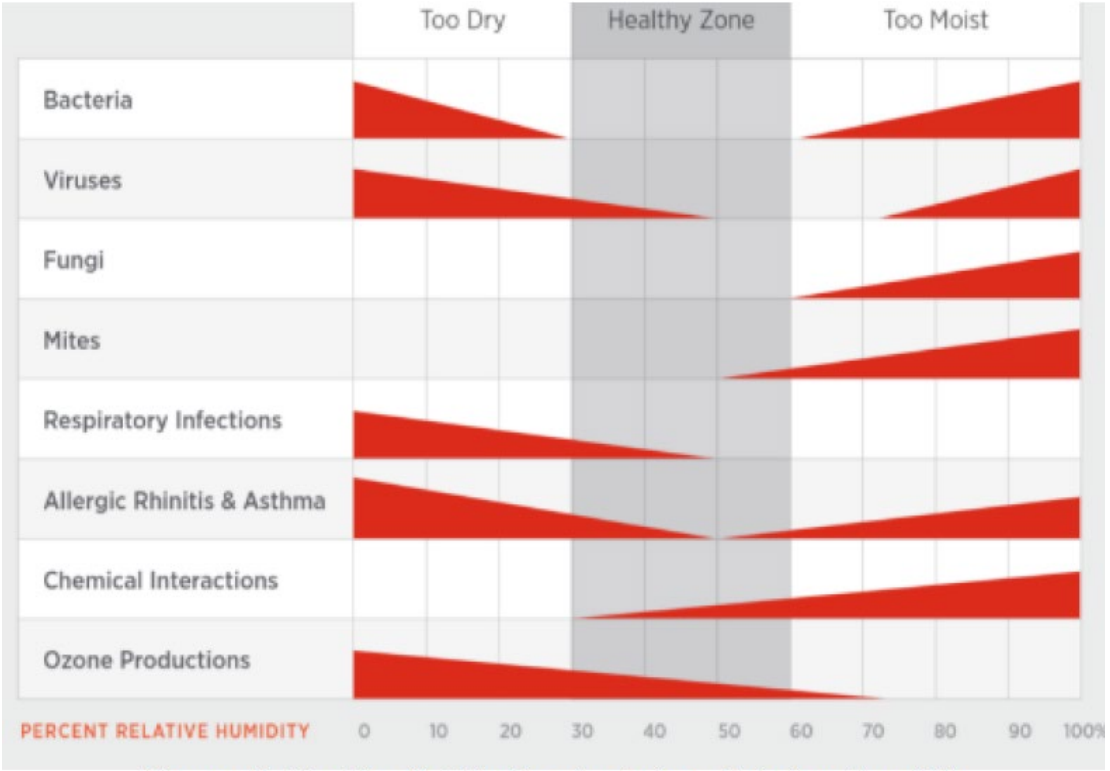
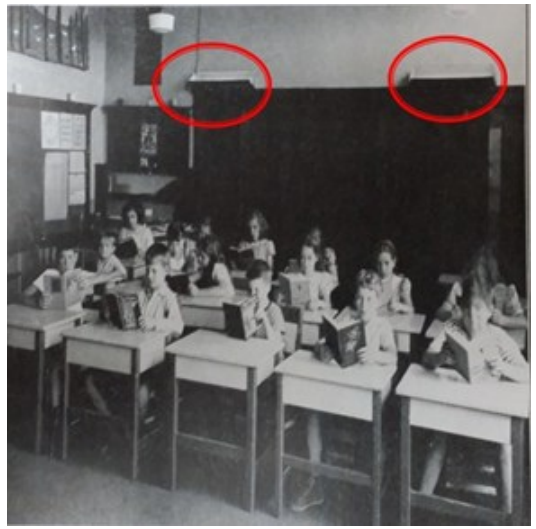


Figure 4. The Health Window for Indoor Relative Humidity
(Source: https://www.eeba.org/the-health-window)

UVGI – Ultra-Violet Germicidal Irradiation (aka, killing germs with UV light)

- Not healthy for humans (sunburn, skin cancer, eye damage, etc.)
- But, also not healthy for pathogens
  - ~260 nm most effective U/V wavelength to disable many types of pathogens
  - Dose is important
- Effectiveness known since 1800s
- Measles outbreak in 1930s during U/V upper room air treatment experiment:
  - 50% measles transmission in school rooms without U/V treatment
  - Only 15% in rooms with U/V treatment



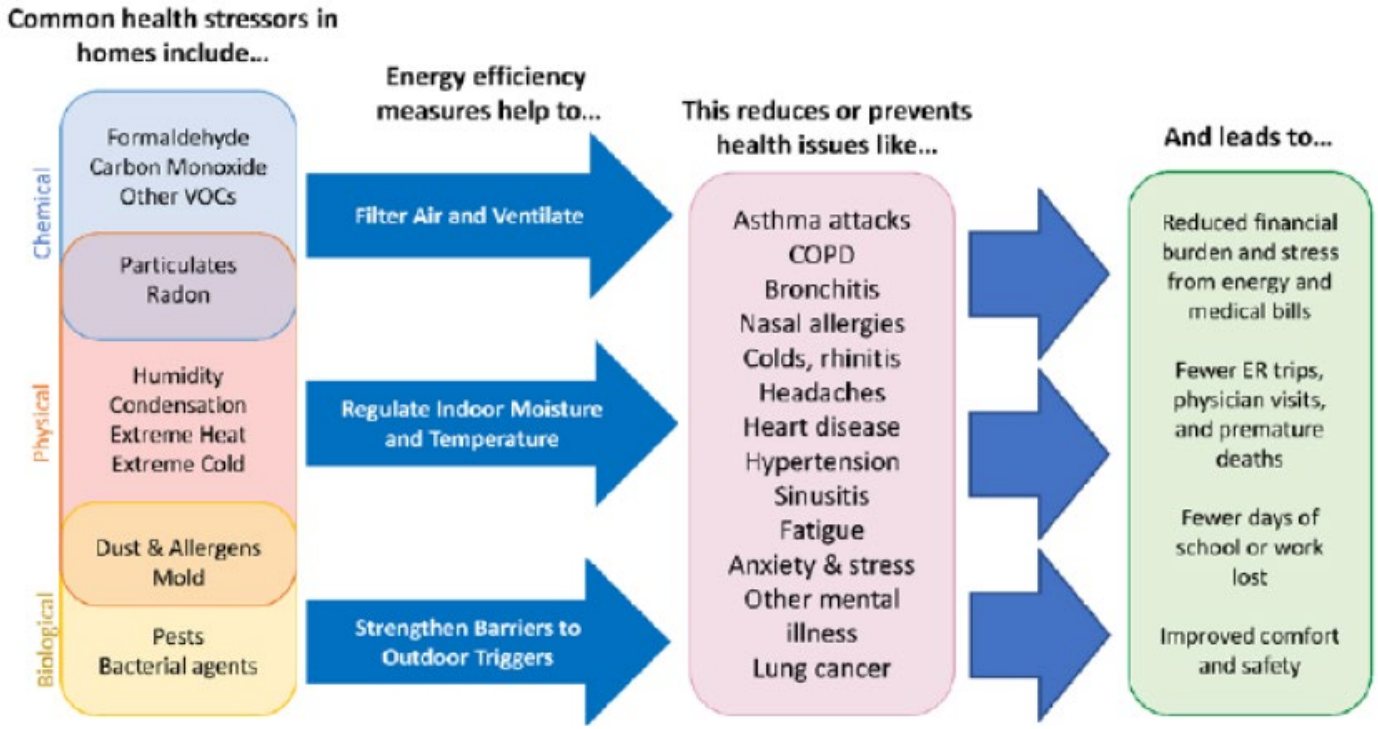
Source:
http://www.uvresources.com/blog/uv-c-lamps-a-short-wave-history/

Economics

- Cost of COVID-19:
  $3,000,000,000,000+
  - ~$9,000+ per capita every ~100 years
- Annual Cost of Colds/Flu:
  $130,000,000,000
  - ~$400 per capita every year!
- Value of healthy building improvements estimated to be **$25 to $150 billion per year**
  - Doesn't include energy savings benefits

Economics

- Retrofitting/weatherizing 200,000 homes could save an estimated $600 million over 10 years in consideration of several health benefits.
- Generally, estimated $3 dollar benefit for every $1 invested.



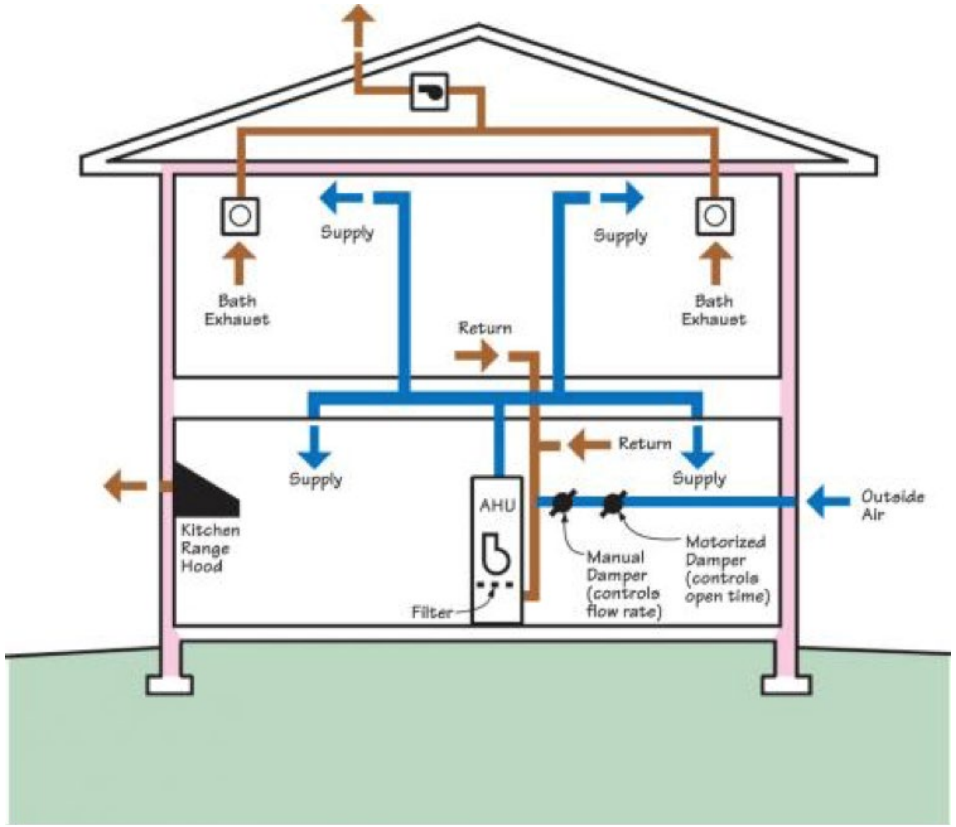
Source: ACEEE

Economics

- Difficult to precisely quantify and monetize these benefits, but a clear potential for health and economic benefits exists.
- Health risks must be balanced with cost-effective measures to implement in new and existing buildings

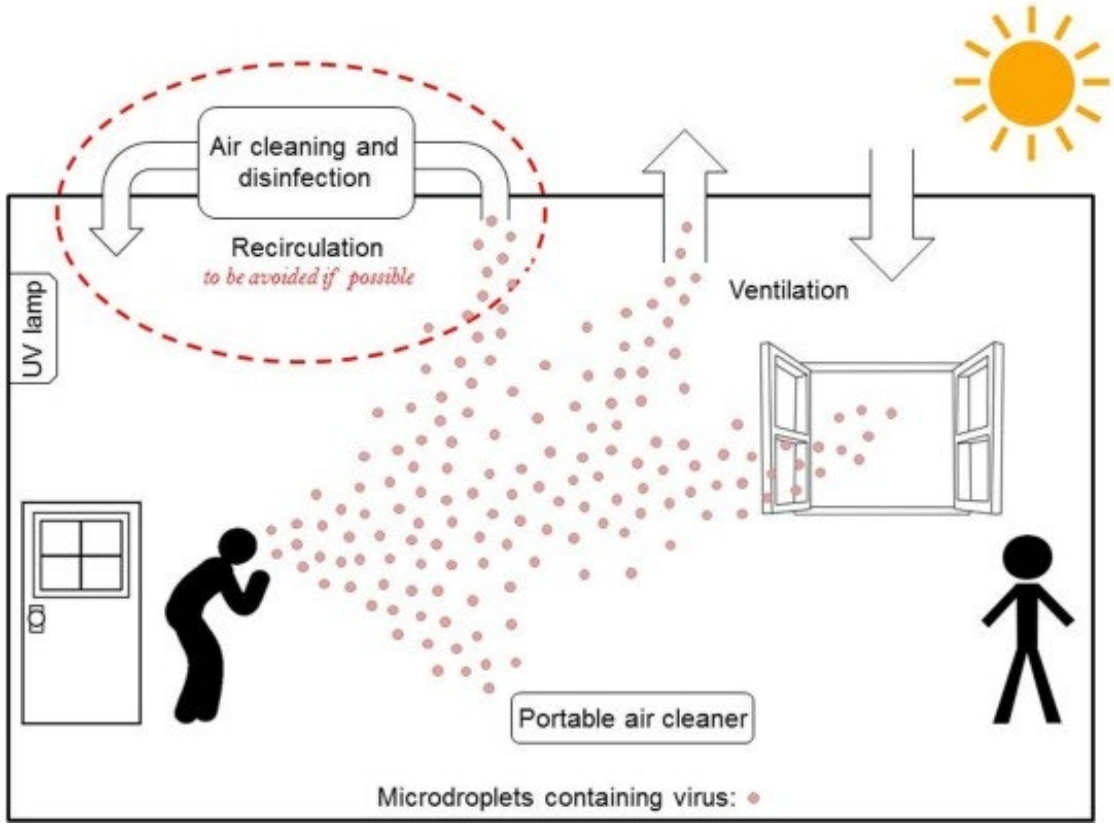
Building Science Applications – The Role of HVAC Systems

- **Objective:** Control the indoor air quality
- Air Quality Measures:
  - Temperature (set points)
    - Heating – 68°F
    - Cooling – 75°F
  - Mechanical ventilation (Outdoor air + indoor air recirculation)
  - Indoor air hygiene (particulate burden)
  - Indoor air humidity
- Controlling these measures is not a substitute for other interventions during periods of high risk (PPE, social distancing, disinfecting surfaces, etc.)



Source: https://basc.pnnl.gov/resource-guides/outdoor-air-intake-damper-controlled

Outdoor Air Ventilation



- Dilution with outdoor air
  - Mechanical Ventilation (HVAC System)
  - Natural Ventilation (operable windows)
- Must consider trade-off in control of indoor air humidity, temperature, and energy penalty
- Many recommend code-minimum ventilation is sufficient with good filtration
- Consider higher outdoor air ventilation rate during high occupancy and for “flushing” before and after events (weather permitting)

Filtration

- The HVAC filter is like your mask
- If the ventilation fan is not running, it will not filter/clean the indoor air
- Run fan “on” (instead of auto) during high occupancy
- Avoid high velocity room airflows from supply registers

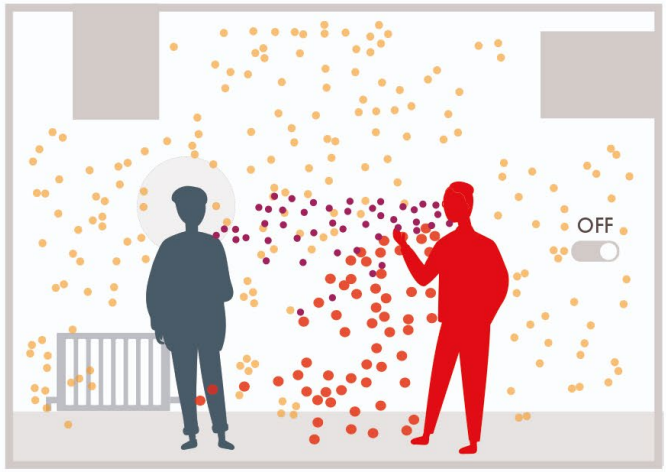


Fig 1. Infected person talking with non-infected person with ventilation system switched off

Fig 2. Infected person talking with non-infected person with ventilation system switched on

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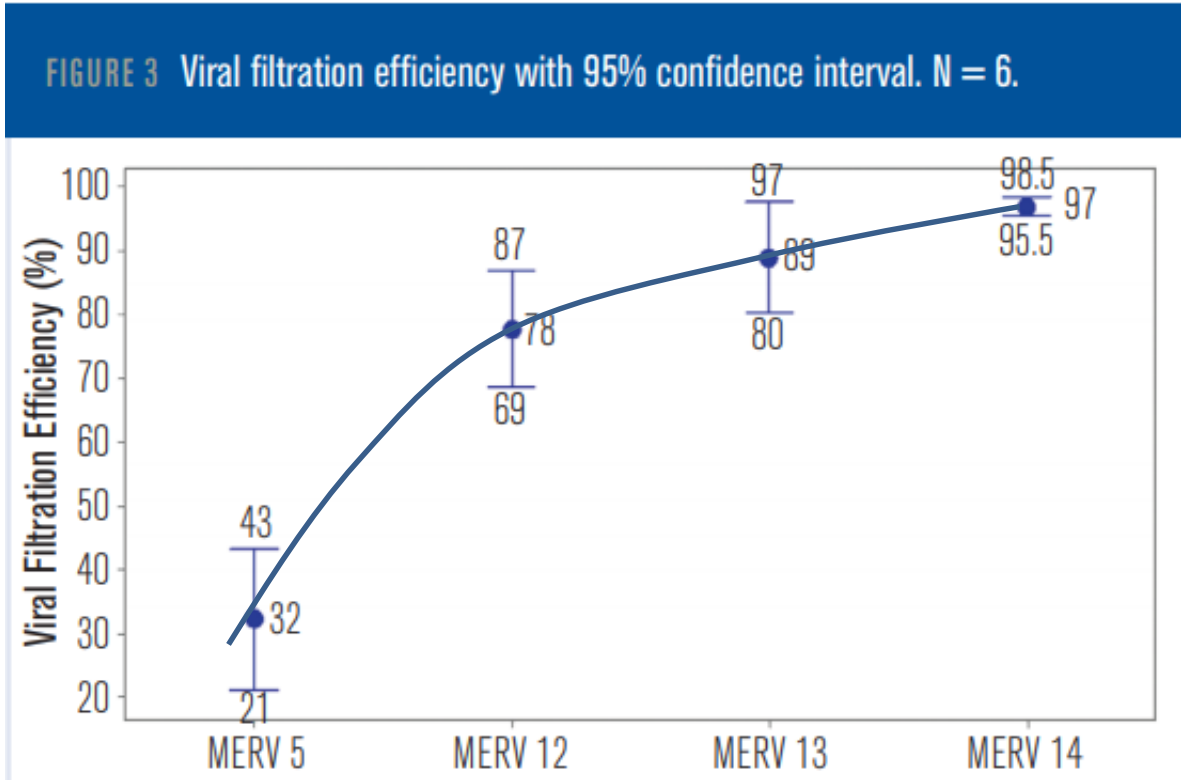
Filtration Efficiency Ratings

- Use the most efficient filter that your HVAC system and budget will allow:
  - MERV 13 (~FPR 10) often recommended
  - MERV 11 (~FPR 7) is better than MERV 8 (~FPR 5)
  - Generally, less than MERV 8 is not recommend (very low capture efficiency for “viral-sized” particles < 1 micron or 0.00004”)
- Filter “blow-by” (poor fitting) will decrease filtration effectiveness

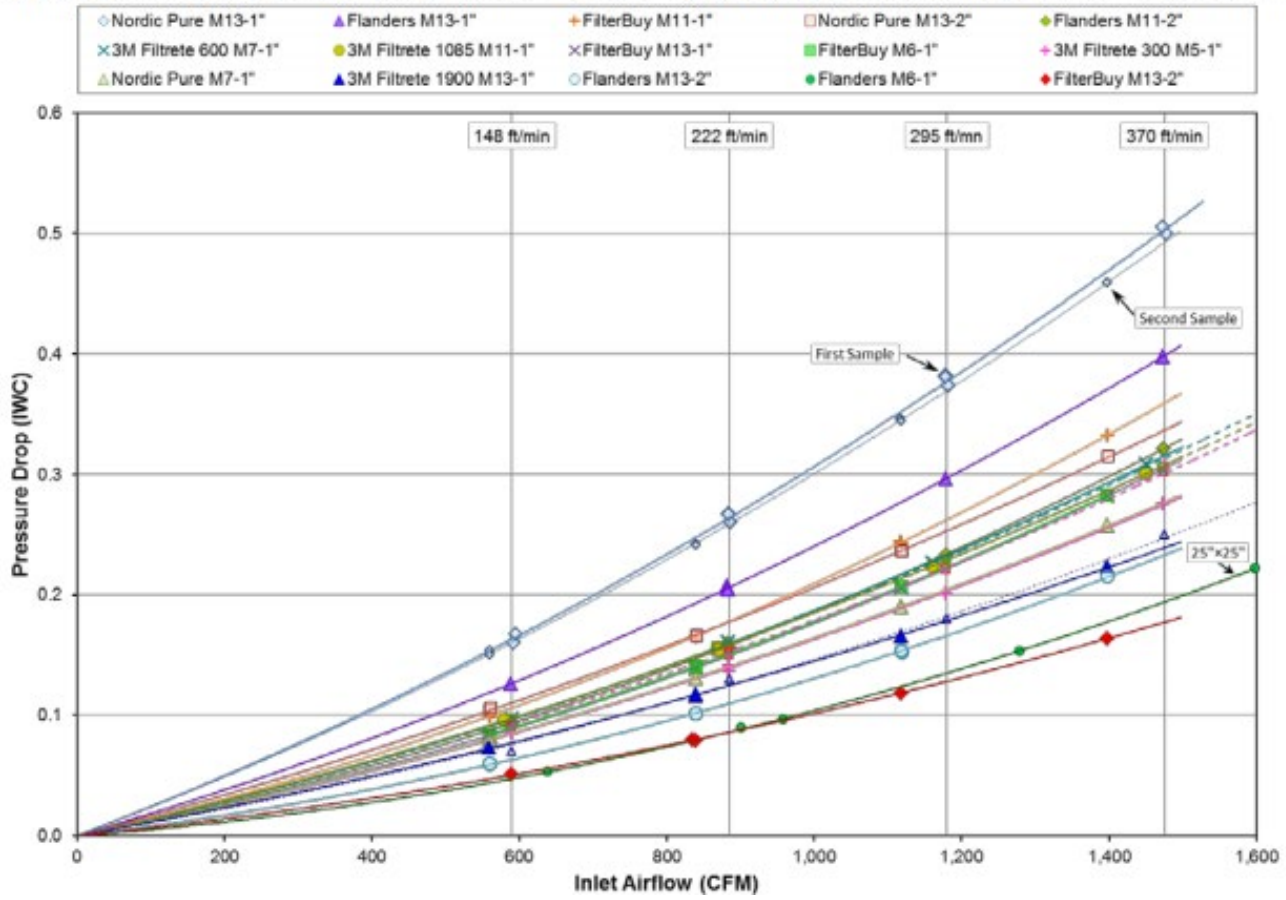


Source: Zhang, et al., Study of Viral Filtration Performance of Residential HVAC Filters, ASHRAE Journal, August 2020

Filtration Pressure Drop

- Getting the “best” filter is not always the best for the HVAC system
  - Filter resistance to air flow (pressure drop) also is important
  - Must match the capability of the HVAC system and fan, including energy penalty for higher pressure drop
- Not all filters are equal
  - Significantly higher or lower pressure drops for different filter brands with the same MERV rating

Figure 3. Pressure Drop Measurements – MERV 6, 7, 11, 13 Filters with 24” x 24” Face Area



Source: CEC, Staff Supplement to Case Report #2019-RES-IAQ-F

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Room Filtration

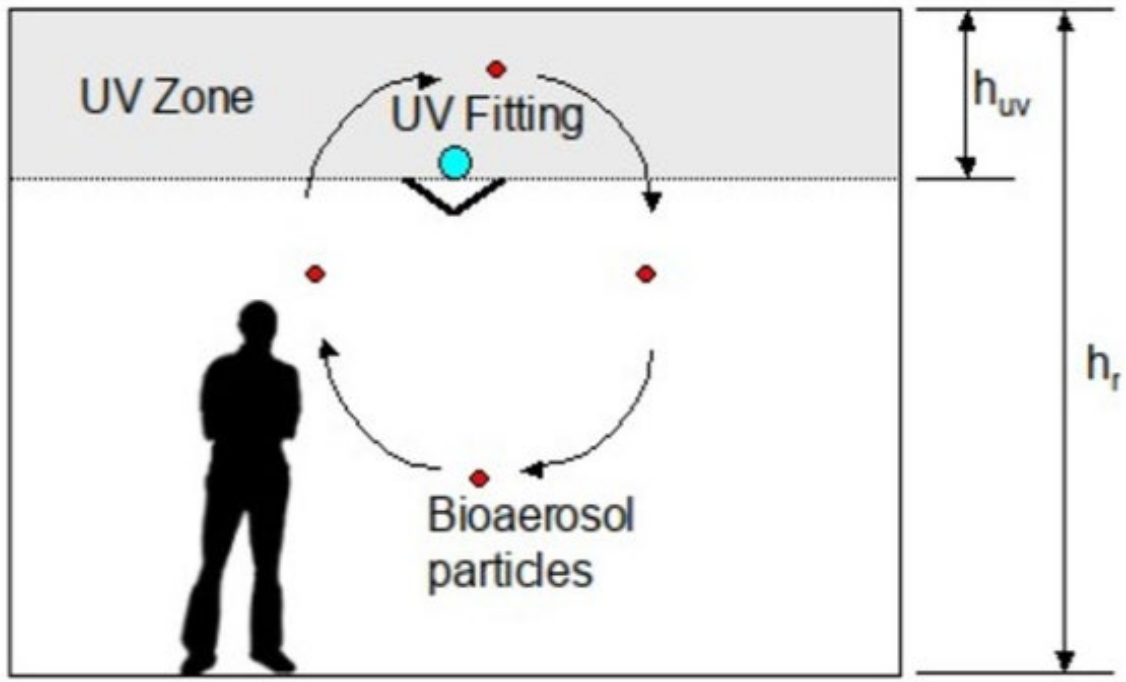
- When all else fails?
  - Consider a portable room air cleaner
  - The only option where the HVAC system does not use forced air
  - Also useful in “quarantine rooms”

Air Purifier Ratings by Consumer Reports

Source: https://www.consumerreports.org/cro/air-purifiers/buying-guide/index.htm

UV Treatment of Indoor Air

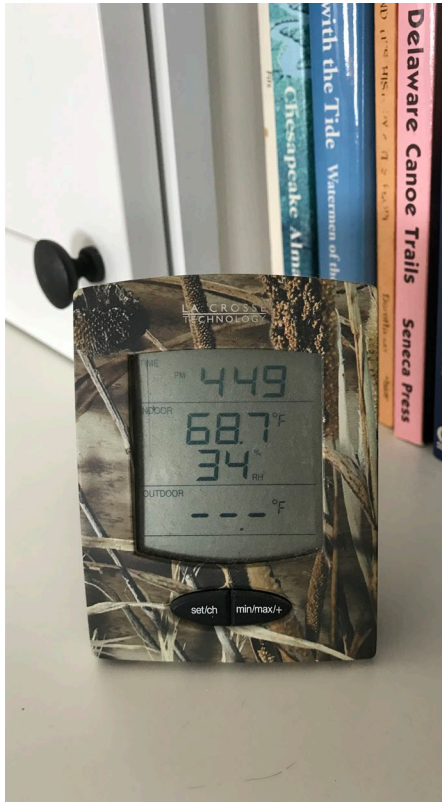
- In-duct systems
- Room upper air systems
- Portable treatment systems
- Must be designed to get the desired treatment level
- Generally considered for uses where risk and consequences of disease transmission are high



Source: https://peerj.com/articles/10196/

Indoor Relative Humidity

- Health Window (target): 40% to 60% RH
- Difficult to maintain 100% of the time.
  - Summer: max 65% for short periods probably OK
  - Winter: min 35% for short periods probably OK
- Ability to control RH also depends on:
  - Occupancy conditions (moisture load)
  - Tightness of building envelope
  - Outdoor air ventilation rate
- Control methods:
  - Manually controlled equipment/sensors (retrofit)
  - Automated equipment/sensors (built-in)
  - Maintenance is important



ASHRAE Indoor Air Quality Guide

By the time a building's schematic design is complete, many opportunities to achieve good IAQ have been foreclosed, which can easily result in unintended consequences or expensive and inadequate "force fitting" of solutions. When IAQ, energy efficiency, and other project objectives are considered together at the initial design phases, design elements for each objective can be mutually reinforcing rather than at odds with one another.

- **EXAMPLE:** Unless designed for it, many building envelopes meeting minimum code compliance are unable to endure a prolonged exposure to 40% indoor RH during the winter in cold climates.

Building Science Applications – The Role of the Building Envelope

- The primary function of a building envelope is to separate the indoor from the outdoor environment.

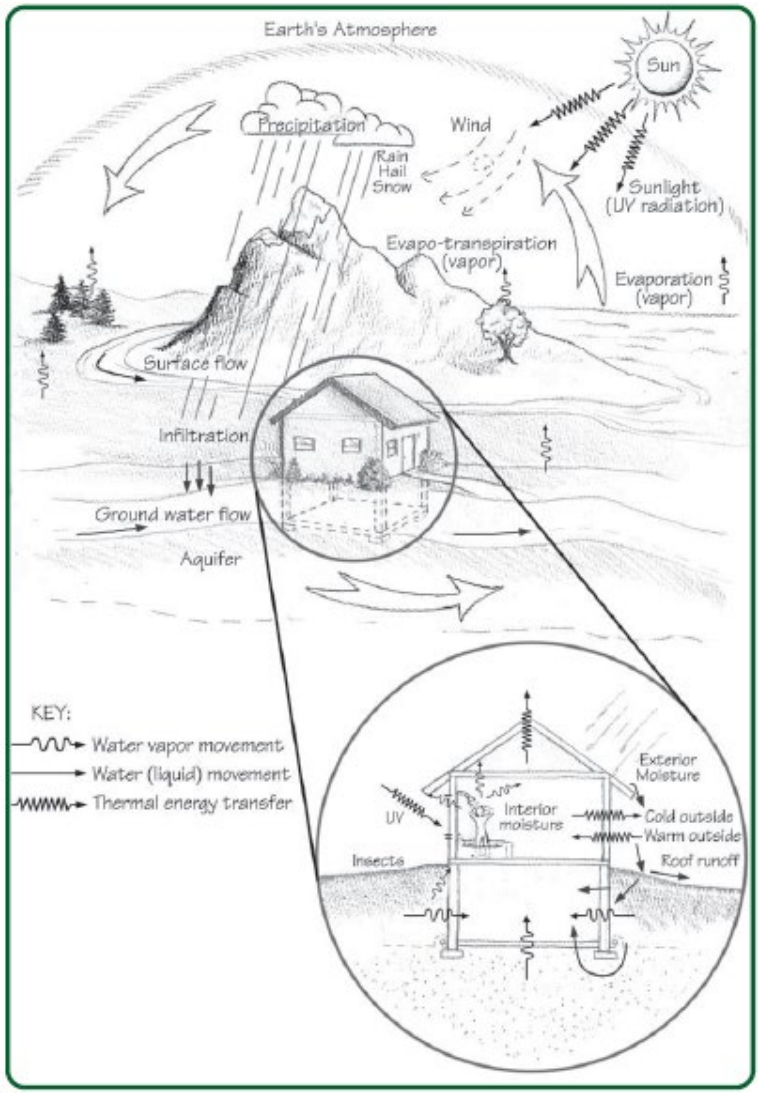
"Without a good building envelope,

the previous HVAC system and design

actions become more difficult and costly,

and uncertain in their effectiveness."

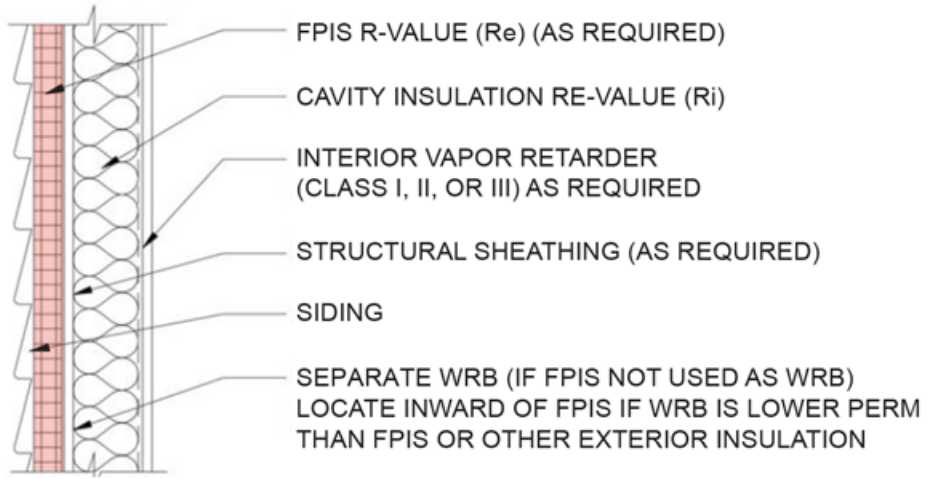
Source: ABTG RR No. 2006-01, p10,
https://www.continuousinsulation.org/topical-library/healthy-buildings



Source: HUD, Durability by Design

Applications – Building Envelope

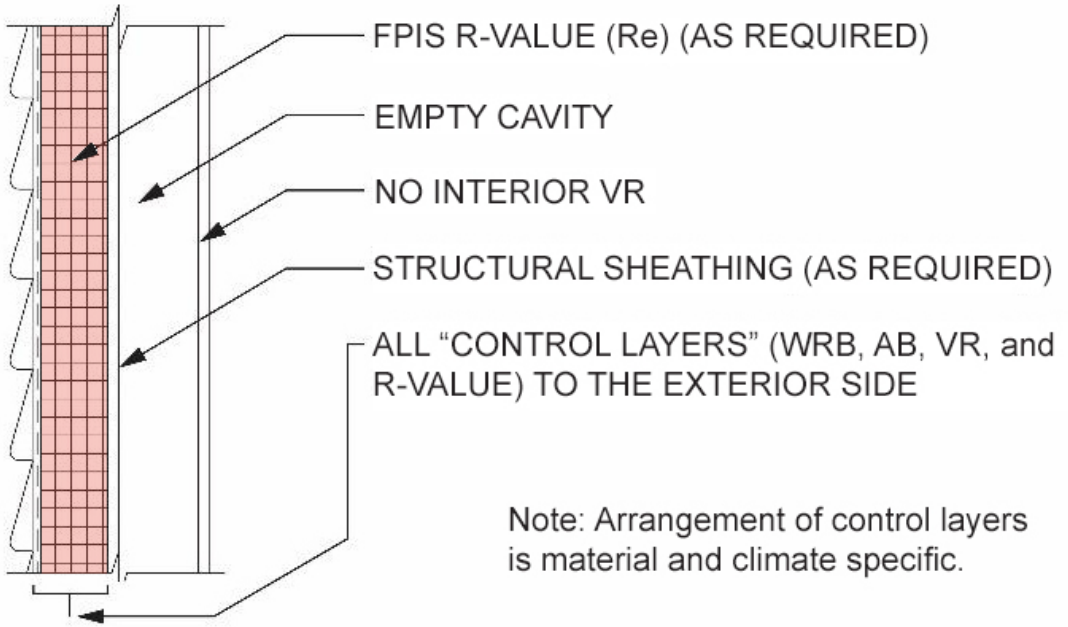
- Benefits of a Good Building Envelope:
  - Better energy efficiency, less costly to operate as a healthy building
  - Better moderate indoor temperature and humidity
  - Better moderate temperature and humidity within the envelope assembly itself
  - Minimize thermal bridging to avoid “cold” or “hot-spots” with can promote condensation, mold-growth, corrosion, etc.
  - Provide sustained protection to occupants during power outages.
- Control layers in a building envelope support all of these benefits



Source:
https://www.continuousinsulation.org/content/2021-ibc-irc-adopt-improved-vapor-retarder-requirements

Applications – Building Envelope

- Building Envelope Control Layers:
  - **Water** control layers (cladding + continuous water-resistive barrier to prevent water intrusion)
  - **Air** control layer (continuous air barrier to prevent air leakage)
  - **Thermal** control layer (continuity of thermal insulation to prevent heat loss/gain and control surface temperatures)
  - **Water vapor** control layer (use of vapor retarders in coordination with insulation strategy)



Example Wall Assembly for Maximal Compatibility with and Support of a Healthy Indoor Environment in Any Climate Zone

Applications – Building Envelope

- Water vapor control is perhaps the most tricky due to many inter-dependencies
- Resources:
  - Wood Wall Calculator
  - Water Vapor Control
  - Basis of newer vapor retarder provisions in 2021 IRC and IBC

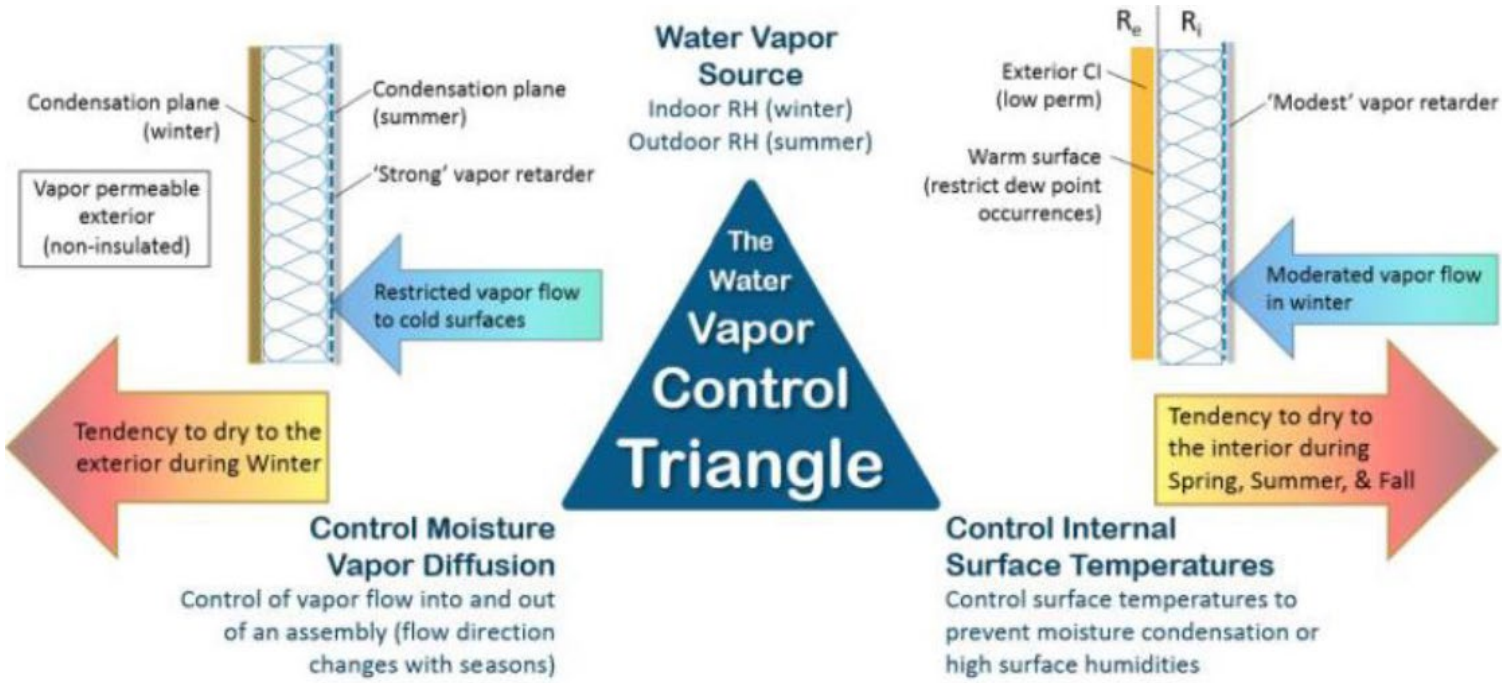
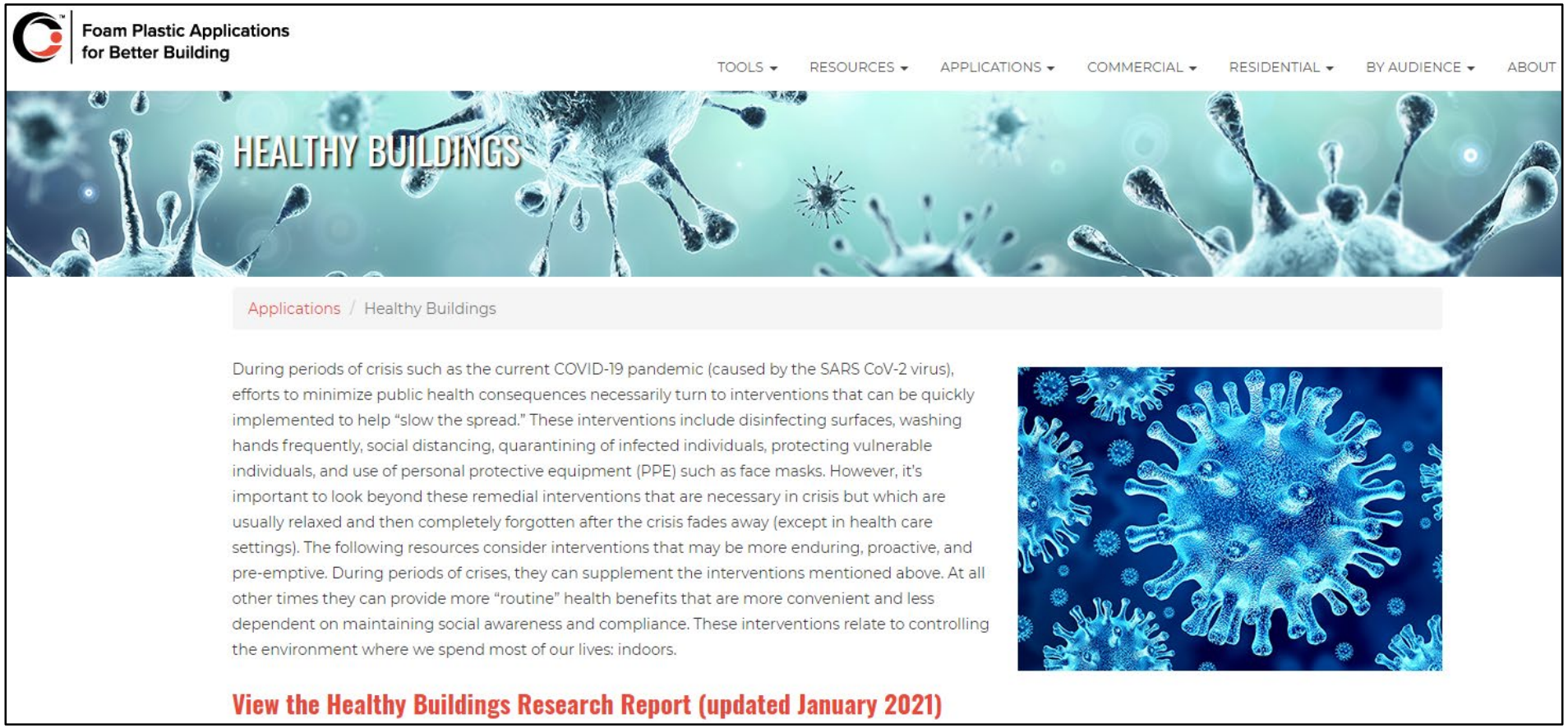


Figure 7. Illustration of two accepted water vapor control design approaches for building envelopes. (Sources: ABTG[32], ASTM[37])

Find Helpful Resources at Ci.org



continuousinsulation.org/healthybuildings

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Conclusions

- History repeats itself:
  - Pandemics will come again
  - Routine health threats will persist
- We can be more prepared and resilient if we design buildings to better mitigate these threats
- Various branches of science intersect to build a strong case for reasonable actions
- Building science integrates related science to guide optimal design for occupant health and protection, energy efficiency, and durability through coordinated:
  - HVAC System Design and Operational Practices
  - Building Envelope Design and Construction Practices

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Questions?

- Thank you!
- Please submit any questions through the Continuous Insulation website at continuousinsulation.org/contact.