Safe Indoor Air: Top Experts Offer Advice For Future Pandemics

Table of Contents

I. Presentation Slides: Buildings Are Our Best Medicine

II. Presentation Slides: Ventilation in Buildings: To reduce exposure to infectious aerosols

III. Presentation Slides: Hospital-grade air quality solutions
Buildings Are Our Best Medicine

Stephanie Taylor, M.D., M Arch.
Hello! I am honored to speak with you.

Research

- Massachusetts General Hospital Infection Control
- Harvard Medical InCite Health Fellow

ASHRAE

- Distinguished Lecturer
- Epidemic Task Force
- Environmental Health Committee
- Presidential Award Winner

Building4Health

- CEO and Founder

Stephanie Taylor, M.D., M Arch.
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• **John Levy, PhD**: Boston University School of Public Health, Department of Environmental Health

• **Building4Health**: Peter Taylor, Olivia Saber, Yaron Yaniv, Francis Caruccio, Gene Lochart, Oliver Zimmermann
Presentation: Why we are all here today

Past: Protective structure

Present: Energy efficiency

Future: Optimize occupant health

A building's purpose
I was not [that] surprised by this pandemic! Were you?
Airborne viruses that can easily mutate to survive cause pandemics

Spanish Influenza 1918

COVID-19

We must manage our buildings to both decrease pathogen infectivity *and* support human immunity.
We need to unite indoor environmental management and medicine

**Building Management**
- Reduce energy use
- Avoid disasters
- Follow best practices and coc

**Occupant Health is key to building management**

**Medical Care**
- Heal patients
- Follow clinical protocols
- Avoid lawsuits
There are three components to diseases

IAQ influences all three components of infectious (and most) diseases!!

1. The agent (pathogen, particle, gas, etc.) that causes the disease:
   - abundance
   - virulence
   - resistance to treatment

2. The human host:
   - immune system function
   - genetic stability
   - tissue repair capacity

3. The environment where the agent interacts with the host:
   - exposure to the agent(s)
   - transmission route
   - influence on penetration
We now have tools to take a closer look at humans and microbes
Humans indoors
We send our microbes into buildings
(37 million microbes per person per hour)

The indoor environment selects communities of bacterial, viral and fungal microbes through “survival of the fittest”
Managing indoor spaces for occupant health needs combined medical and “traditional” IAQ data

**Optimize occupant health**

- Immunity
- Inflammation
- Cognition
- Metabolism

- IAQ effect on human physiology
- Airborne bio-aerosols
- Surface pathogens and biofilms
- Balance between "good" and "bad" bacteria

**Optimize energy savings**

- Particle and gas concentrations
- Temperature
- Humidity (hopefully)
- Room air changes
- Pressurization

**Metrics for Human Health**
Step 1: Identify essential IAQ components that impact health

11 indoor metrics that alone and in combination have quantifiable physiological impacts on occupant health within a short time:

- Brain function and productivity
- Infections and inflammation
- Heart function and blood clotting
- Metabolism and hormones
IAQ and human health

NO$_2$, SO$_2$, CO$_2$, carbon monoxide, particles, ozone, VOCs, etc. can penetrate cell membranes

Affecting the brain, respiratory and cardiac system, skin and covering membranes

These biological effects then need to be quantified, reported and remediated
Steps to quantify the occupant health risk from indoor exposures

1. Measure human exposure to indoor compounds with sensors
2. Quantify capacity of compounds to penetrate membranes, damage cells through oxidative stress, and disrupt DNA/RNA replication
3. Predict health impact from pathway interruptions
4. Determine the dose response for the mix of indoor constituents
The road-map from detection to reporting

HIDDEN LAYERS & INTERRELATIONSHIPS

- RH
- TEMP
- PM 1.0
- PM 2.5
- PM 10
- TVOCs
- O₃
- CO
- CO₂
- NO₂
- SO₂

HEALTH CONSEQUENCES

- Changes to Immune System
- Tissue penetration
- Genetic disruption
- Infectivity of microbes

B4H.Dx
Video-microscopy of muco-ciliary clearance in mice trachea

After exposure to aerosolized Influenza viruses, all mice kept in low relative humidity died within 5-10 days.
"Antibiotic Resistance Can Spread Through The Air, Scientists Warn, And Yes - You Should Be Terrified"

*July 26, 2018*

Poor air quality increases the **airborne** transfer of antibiotic resistance genes.
Scoring was based on quantification of:

• Penetration into respiratory, central nervous system, circulatory and skin structures

• Alteration of immune function

• Inhibition or stimulation of immunological or inflammatory mediators through DNA &/or RNA methylation

• Degree of oxidase activity and resulting reactive oxidation species production

• Environmental selection of bacterial, viral, fungal species
The process

1. Sensors give precise, real-time measurement of 11 key variables necessary to understand the impact of the indoor environment on occupant health.

2. A patented algorithm integrates building measurements and medical research to produce an actionable score.

3. The dashboard displays a real time indoor health index and provides reports, alerts, and remediation recommendations to improve your score if necessary.
The resulting **B4H.Dx** Score is a single score from 0 to 100

- A score of 50 and above indicates an environment that supports human health. Components of the score have been correlated with reduced risks of viral infection, respiratory and other diseases, and impaired cognition. **Consequently, a high score reflects short and long-term health benefits**
How can we resolve this tug-of-war?

Protect the environment

Protect the occupants

Keep energy consumption low

• Energy is expensive
• Outdoor air pollution is already bad
• We are mandated to decrease our carbon footprint

Manage indoor air for occupant health

• Decrease infections
• Reduce allergies
• Improve wound healing
• Increase work performance

Health Impact Rating:

0 10 20 30 40 50 60 70 80 90 100
An actionable IAQ Health Standard can guide HVAC operations according to real-time conditions.
Remediation for health incorporates flexible interventions

These inter-relations allow for both flexibility and precision in where and when remediation is needed. This means a clearer idea of what is needed, and fewer expensive and high-energy fixes.
We must manage IAQ for occupant health!

NEW & EXISTING PANDEMICS
Decrease infectivity of SARS-CoV-2, Polio, Monkeypox, Tuberculosis, Antibiotic resistant mutations.

TECHNOLOGY
The technology to create healthier indoor environments and better occupant health exists, and should be used.

HEALTH EQUITY
Prioritizing health equity requires action to protect underserved and vulnerable populations.

THE CLIMATE CRISIS
Addressing the climate crisis requires using all available tools to decrease our carbon footprint and energy use.
The cost/benefit of managing buildings for healthy occupants

<table>
<thead>
<tr>
<th>Sickness and disease create immeasurable direct and indirect costs including:</th>
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<tr>
<td>• Loss of productivity</td>
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<td>• Absenteeism</td>
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<td>• Higher healthcare costs</td>
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<tr>
<th>Buildings managed for health create confidence in occupants.</th>
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<td>Increase in occupancy = increase in profits</td>
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<th>Safely reduce energy use without causing harmful health impacts to building occupants.</th>
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<th>Comply with ESG goals proactively and tangibly.</th>
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<th>Use real-time data to manage expensive and potentially unnecessary building modifications.</th>
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<td>Test before you invest!</td>
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Summary

• By giving visibility to the health impact of the indoor environment, we have a scientific basis for managing IAQ to support occupant health, productivity and learning

• By knowing the interactive chemistry, attainable remediation can diminish the harm of interacting indoor pollutants

• Humidification to RH 40%–60% is a foundational step in supporting health

• Healthy people increase the profitability of businesses and the success of our species
Please contact me if you:

✓ Have questions?
✓ Want to monitor your building with the B4H platform
✓ Would like help setting up a cost/benefit study for buildings managed for occupant health

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Ventilation in Buildings:
To reduce exposure to infectious aerosols

Kenneth R. Mead, PhD, PE
Division of Field Studies and Engineering
National Institute for Occupational Safety and Health (NIOSH)
Do not get distracted by terminology

- Different professions (clinicians, aerosol scientists, engineers, industrial hygienists, microbiologists) do not always use consistent terminology.
- Regardless of the name, if it is small enough to float in air, then ventilation interventions can help prevent its distribution and reduce individual exposure.

Graphic: [https://www.cdc.gov/niosh/topics/aerosols/pdfs/Aerosol_101.pdf](https://www.cdc.gov/niosh/topics/aerosols/pdfs/Aerosol_101.pdf)
Ventilation in Buildings

CDC recommends a layered approach to reduce exposures to SARS-CoV-2

The Swiss Cheese Respiratory Virus Pandemic Defence

Recognising that no single intervention is perfect at preventing spread.

Note: The interventions shown are not all-inclusive and are not depicted in any meaningful order.

Graphic Credit: Ian W. McKay, virologydownunder.com
SARS-CoV-2 viral particles are more readily spread between people indoors than outdoors

- Outdoors: Even a light 1 mph [88 feet per minute (fpm)] wind can rapidly reduce airborne contaminant concentration.

- Indoors: Protective ventilation practices and interventions can reduce the airborne concentration of the virus and reduce the overall viral dose to occupants.

Graphic: Getty Images
Are you Code Compliant?

- Code compliant = aligns with year building constructed or most recently renovated/upgraded
- Applies to outdoor air % of HVAC delivery only (per person & per sq-ft approach by room type)
- At a minimum, encourage consideration of upgrading existing systems to current code.
  - Establishes a strong baseline from which to consider future improvements
Steps beyond code-compliant minimums

- Ventilation system upgrades or improvements can increase the delivery of “clean” air and dilute potential contaminants.
  - Consult experienced heating, ventilation, and air conditioning (HVAC) professionals.
  - CDC guidance presents a list of ventilation interventions, “tools in the mitigation toolbox,” that can help reduce the concentration of viral particles in the air.
    - Each tool can contribute towards a reduction in risk.
    - Implementing multiple tools at the same time is consistent with CDC’s layered approach and will increase overall effectiveness.
Steps beyond code-compliant minimums (cont.)

- Using these tools can reduce the risk of exposure to the virus and the spread of disease but will not eliminate risk completely.
- Tools can be universally applied across indoor environments but choosing which tools to apply can be challenging.
- The specific combination of tools used at any point in time can change.
- The building owner or operator (with expert consultation as needed) should identify which exposure reduction tools are appropriate for each building throughout the year.

- In addition to buildings, ventilation improvements can be applied to vehicles, including public transportation.
Tools to Improve Ventilation
Tools to improve ventilation

- Some interventions are based on COVID-19 Technical Resources published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).
- Not all interventions will work in all scenarios.
- Local conditions may drive adoption preferences for specific tools.

ASHRAE Technical Resources: https://www.ashrae.org/technical-resources/resources
Increase the natural introduction of outdoor air

Open Windows and Doors:
- When the weather allows.
- Increases outdoor air flow.
- Even slightly opened windows can introduce beneficial outdoor air.
- Do not open if it poses a safety or health risk (e.g., risk of falling or triggering asthma).
Use fans to supplement open windows and doors

- Increases efficiency of outdoor air delivery.
- Placement is important; will vary with room configuration.
  - Avoid directing potentially contaminated air from one person to another.
  - Place fans safely and securely in windows or doors to exhaust air outdoors.
- Similar results can be achieved in larger spaces with gable fans, roof ventilators, etc.
Increase the HVAC system’s supply of outdoor air

- Open HVAC outdoor air dampers beyond minimum settings.
- Eliminate or reduce HVAC air recirculation.
- Will not affect thermal comfort during mild weather; may be more difficult in cold, hot, or humid weather.
- May require consultation with an experienced HVAC professional.
Improve central air filtration

- Increase air filtration to as high as possible without significantly reducing design airflow.
- Increased filtration efficiency is especially helpful when enhanced outdoor air delivery options are limited.
- Make sure air filters are properly sized and within their recommended service life.
- Inspect filter housing and racks to ensure appropriate filter fit and minimize air that flows around, instead of through, the filters.
HVAC system recommendations

- Ensure ventilation systems are operating properly and provide acceptable indoor air quality for occupants.
- Rebalance or adjust systems to increase total air flow to occupied spaces.
- During occupied hours, turn off demand-controlled ventilation (DCV) controls that are designed to:
  - Reduce the air supply based on occupancy levels or temperature.
  - Save energy.

For systems controlled by a simple thermostat, set the fan to “ON” instead of “AUTO”, which will operate the fan continuously.
Operate exhaust fans during building occupancy

- Ensure restroom exhaust fans are functional, operating continuously, and at full capacity when the building is occupied.

- Inspect and maintain exhaust ventilation systems in kitchens, cooking areas, etc.
  - Operate these systems any time these spaces are occupied.
  - Consider operating them even when the specific space is not occupied, to increase overall ventilation within the occupied building.

Graphic: Getty Images
Consider portable HEPA* fan/filtration systems

- These systems provide additional air cleaning.
- Especially useful in higher risk areas.
  - Workplace medical clinics.
  - Areas frequently occupied by people with a higher likelihood of having COVID-19 and/or an increased risk of getting COVID-19.
- Note: Portable air cleaners that use filters less efficient than HEPA filters can contribute to room air cleaning.
  - Units should be clearly labeled as non-HEPA.
  - Effect on overall air cleaning needs to be understood.

* HEPA = High Efficiency Particulate Air
Generate clean-to-less-clean air movement

- Can be achieved using central HVAC system or portable HEPA units.
  - For central HVAC systems:
    - As necessary, reposition the supply air louvers, exhaust air grilles, and adjust damper settings.
    - Easier with ceiling grid systems.
  - For portable HEPA units:
    - Easier with flexible ductwork connections.
    - Can be done with temporary partitions.

Graphic: CDC
Consider ultraviolet germicidal irradiation (UVGI) [a.k.a. Germicidal Ultraviolet (GUV)]

- Should not be used alone, but as a supplemental treatment to inactivate SARS-CoV-2.
- Especially useful if options for increasing room ventilation and filtration are limited.
- Three types:
  - Upper-room UVGI systems provide air cleaning within occupied spaces.
  - In-duct UVGI systems can enhance air cleaning inside central HVAC systems. More powerful than typical coil cleaning systems.
  - Far UV systems (emerging technology).

Photo: CDC.gov

Flushing with air

- Consider running the HVAC system to flush the building air after the building is occupied.

- Not applicable to residential buildings.

Graphic: cdc.gov
Costs

- Tools come with a range of initial costs and operating costs, which along with risk assessment factors, may affect the selection of tools.
  - No cost: opening windows; inspecting and maintaining dedicated exhaust ventilation; disabling Demand-Controlled Ventilation (DCV) controls; repositioning outdoor air dampers.
  - Less than $100: using fans to increase effectiveness of open windows; repositioning supply/exhaust diffusers to create directional airflow.
  - $500 (approximately): portable HEPA systems.
  - $1500 to $2500 (approximately): upper room UVGI.
Ventilation in Buildings

Stephen B. Martin, PhD, PE
Respiratory Health Division
National Institute for Occupational Safety and Health (NIOSH)
Opening windows, using portable air cleaners, and improving building-wide filtration are ways you can increase ventilation in your school or childcare program.

Interactive School Ventilation Tool:

[Image of a classroom with a dial indicating 95% particle reduction achieved in classroom by using ventilation.]

How can I decrease the level of particles during the school day?

Select the options to see how particle levels change as you adjust ventilation settings. (To see the effects of these ventilation settings on different room sizes and HVAC system types, see this report from the National Institute of Standards and Technology.)

### Interactive Home Ventilation Tool:

**End of 4-hour visit**

82% particle reduction achieved in your home by using ventilation.

**1 Hour Later**

97% particle reduction achieved in your home by using ventilation. You can decrease particles even more by continuing to ventilate for an extra hour.

Ventilation FAQs
Ventilation FAQs

1. Can COVID-19 be transmitted through HVAC (ventilation) systems?

2. How long will it take to dilute the concentration of infectious particles in a room once they are generated?

3. Can ventilation filters effectively capture SARS-CoV-2 viral particles?

4. What is meant by “directional airflow?” How and where should it be used?

5. What is a HEPA filter and why use a portable HEPA air cleaner?

6. Does ultraviolet germicidal irradiation (UVGI) kill SARS-CoV-2?

7. What types of ultraviolet germicidal irradiation (UVGI) devices are available for cleaning and disinfection in the workplace?

8. Many new air disinfection devices are marketed for their ability to inactivate SARS-CoV-2. How can I tell if they work as advertised?

9. Can carbon dioxide (CO₂) monitors be used to indicate when there is good ventilation?

10. Should indoor temperature and humidity be used to help reduce the risk of COVID-19 transmission?

11. Can fans be used to decrease the risk of COVID-19 transmission indoors?

12. Will using protective barriers interfere with improved ventilation?

DIY Air Cleaners

Do-it-yourself (DIY) air cleaners are indoor air cleaners that can be assembled from box fans and square HVAC (or furnace) filters. They are sometimes used during wildfire events when air quality is poor and other filtration options are unavailable. There have been questions about whether DIY air filters can be effective in reducing virus particles in indoor environments. DIY air cleaners may provide some benefits for reducing concentrations of viruses and other indoor air pollutants, but research is limited and there are several important considerations explained below.

EPA does not recommend the routine use of DIY air cleaners as a permanent alternative to products of known performance (such as commercially available portable air cleaners). The performance of different DIY air cleaners will vary and cannot be reliably assessed without specialized instruments. Commercial devices have been tested for performance and can be chosen to match the size of a room.

EPA and Underwriter Laboratories evaluated the use of DIY air cleaners and the risk of fire. Fans that were built since 2012 and met UL standard 507 did not pose a fire hazard under the conditions tested in the study. (See Research on DIY Air Cleaners to Reduce Wildfire Smoke Indoors for more information.)

New Opportunities

Clean Air In Buildings Challenge

1. Create a clean indoor air action plan that assesses indoor air quality, plans for upgrades and improvements, and includes HVAC inspections and maintenance.

2. Optimize fresh air ventilation by bringing in and circulating clean outdoor air indoors.

3. Enhance air filtration and cleaning using the central HVAC system and in-room air cleaning devices.

4. Engage the building community by communicating with building occupants to increase awareness, commitment, and participation.

Hospital-grade air quality solutions

rensair.com
- WHY INDOOR AIR QUALITY (IAQ) MATTERS

“We expect to have clean water from the taps.

We expect to have clean and safe food when we buy it in the supermarket.

In the same way, we should expect clean air in our buildings and any shared space.”

People spend more than 90% of their time indoors

Indoor air quality can be 2 to 5 x worse than outdoor quality

Indoor air pollution is ranked as one of the top 5 environmental risks to public health

50% of illnesses are caused by aggravated indoor air pollution

Source: US Environmental Protection Agency
The size of a particle determines its capacity to penetrate into the body.

**Particulate Matter** damage to the lungs will impact their ability to properly oxygenate blood.

Poor blood oxygenation impacts the performance of vital organs in the human body.

Airborne **Pathogens** (Viruses and Bacteria) cause illnesses and transmit diseases between people.

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**POLLEN**
10-100 µm
A fine powder from plants that aggravates allergies and makes it hard to breathe indoors.

**MOLD**
3-100 µm
A fungus that reproduces by forming airborne spores that settle onto other organic material and form into new clusters.

**DUST**
0.03-1000 µm
Particles that result from the disintegration of earth, sand and other matter.

**PET DANDER**
0.1-5 µm
Microscopic flecks of skin shed by pets and other animals with fur and feathers.

**PM2.5**
Up to 2.5 µm
Particulate matter up to 2.5 micrometers in size, such as fine dust, bacteria, viruses and mite feces. Major sources are traffic, candles, cooking and smoking.

**SMOKE**
0.01-1 µm
Particles containing a mixture of harmful substances that result from burning wood, tobacco or candles. Can be found indoors or outdoors, but produced on a massive scale in wildfires.

**VIRUSES**
0.005-0.1 µm
A small infectious agent that can infect all types of life form.

**GASES**
0.0003-0.001 µm
Toxic gases such as nitrogen dioxide, ozone and VOCs.
Higher particulate matter (PM) levels means lower productivity

Poor indoor air quality doesn’t just make us unhealthy. It makes us less productive

A major new study from Harvard University shows that there is a direct relationship between the amount of fine particulate matter in the air and how people perform in mental tests. The more polluted the air, the worse people perform.

Each interquartile increase in fine particulate matter of just 8.8 micrograms per cubic metre was associated with a:

- 0.82% increase in Stroop response time
- 6.18% increase in Stroop interference time
- 0.7% decrease in Stroop throughput
- 1.51% decrease in ADD throughput

More on the Harvard study can be found here
WHO: has defined ventilation and purification standards to prevent airborne disease transmission: 10 litres per person per second for non-residential (offices, schools etc) and residential settings, 60 l/p/s for healthcare settings (but 160 l/p/s where AGPs are performed).

USA: the EPA “Clean Air in Buildings Challenge” helps fulfill the commitment of the Biden-Harris Administration’s National COVID-19 Preparedness Plan, by providing information and recommendations that can help improve Indoor Air Quality (IAQ).

UK: The Clean Air (Human Rights) Bill, currently going through government, calls for tight IAQ standards that should be regulated. Furthermore, the National Engineering Policy Centre (NEPC) has called for a major reform of ventilation and purification to improve infection resilience across all buildings and public transport. Their recommendations include the establishment of IAQ standards that should be monitored and regulated.

Belgium: the government has introduced a legislative framework to govern indoor air quality in public spaces. Broad in scope, it covers monitoring and risk analysis to action plans, certification and a knowledge platform for sharing insights.
Perspectives from abroad - UK National Health Service

- Different spaces require different levels of ventilation and today’s levels might be insufficient:
  - While Operating Rooms, AGP and ICU are well ventilated, areas such as hospital wards (patient rooms) and A&Es can lack sufficient ventilation
  - Example: Patient with respiratory illness enters A&E
- Convertible spaces need the ability to improve ventilation depending on use
  - Covid (pandemic wards) wards need substantial ventilation
- Older buildings often do not deliver the ventilation rates expected
  - Performance drops off over time due to e.g. leakage
  - Ventilation standards are design standards only, unclear when reviews are made
- NHS focus on upgrading ventilation in AGPs and wards
  - Dentistry and Spirometry particular focus
- New research and studies are being carried out
Study: Improving IAQ in a dentist treatment room

ESI & Birmingham University Hospital
WP2: Dental Treatment Room – Birmingham Hospital

Open volume is 44.7m³

3 occupants and equipment included

Mechanical Ventilation
- Vent air supply @ 5ACH
- Extract exactly balanced

Windows/door closed

Air supply diffuser
- Louver angle 30° from horizontal
WP2: Dental Treatment Room – Birmingham Hospital

CFD MODEL

- Vent air supply @ 5ACpH
- Extract exactly balanced
- Windows/door closed
- Open volume is 44.7m³
- 3 occupants and equipment included

- Air supply diffuser
  - Louver angle 30° from horizontal

- Rensair device in positions
  - **P1**: Max (560m³/h) setting with ventilation ON and OFF
  - Min (300m³/h) setting with ventilation ON
  - **P2**: Max (560m³/h) setting with ventilation ON and OFF
Dental AGP – Deposition and near-patient flow field
All cases, P1/P2 with mechanical ventilation ON/OFF

DATUM: no Rensair + M<sub>ON</sub>

P<sub>1</sub> : 560 + M<sub>ON</sub>

P<sub>1</sub> : 560 + M<sub>OFF</sub>

P<sub>1</sub> : 300 + M<sub>ON</sub>

P<sub>2</sub> : 560 + M<sub>ON</sub>

P<sub>2</sub> : 560 + M<sub>OFF</sub>
In-situ modelling – Dental AGP Log-2 (99%) clearance

Combinations of 220m$^3$/h mechanical and 300/560m$^3$/h enhanced

<table>
<thead>
<tr>
<th></th>
<th>Average Age Of Air (s)</th>
<th>eACH</th>
<th>Log-2 Clearance time (min)</th>
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<tbody>
<tr>
<td>Pos-1-300m3-5ACH</td>
<td>234</td>
<td>11.8</td>
<td>2.37</td>
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<tr>
<td>Pos-2-560m3-0ACH</td>
<td>234</td>
<td>12.6</td>
<td>1.95</td>
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<td>Pos-1-560m3-5ACH</td>
<td>158</td>
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<td>0.84</td>
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How do we translate IAQ regulation/best practices into action?

- Actionable measures can be taken now
  - Review existing ventilation
  - Develop a plan for addressing shortcomings
  - Educate stakeholders
- Let IAQ be a differentiator
  - IAQ can easily be monitored and displayed
  - Upgrade ventilation in patient and staff areas
- Further research and testing
  - Impact of good IAQ in different health settings
  - IAQ technology and innovation
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