Putting People First!
Managing IAQ for Health

Stephanie Taylor, M.D., M. Arch
We are *Homo-indooris*

New understanding

- Medicine is failing us
- Are buildings still shelters?

Please explain!

- New tools and new data
- Hospitals, offices, schools

New directions

- Microbes indoors
- Humans indoors

- What should we do?
- Conclusions
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We are trying hard to decrease HAI rates, but these infections are still too common.
Autoimmune, inflammatory and many infectious diseases are on the rise.
Domesticated dogs are now carriers of the quickly evolving influenza virus

We are NOT the problem!!
350,000 years ago humans lived and worked 100% outdoors

2,000 years ago humans lived in buildings, still spending 100% of lifetime outdoors

200 years ago working in factories and offices, living 90% indoors

50 years ago live and work in centrally heated and ventilated buildings

Last 20 years ago live and work in airtight, mechanically ventilated buildings

Industrial revolution
Homo Indooris - we are now inside 85% of our time

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

- Open dwellings
- Outdoor air exchange
- Tight building envelopes
- Mechanical air ventilation systems
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Thankfully, we can now see if this is true
Microbial cells ~ 100 trillion

Human cells ~ 30 trillion

Don't worry, most of these microbes are good for us, helping our:

- digestion and metabolism
- mental health
- immune system

Microbial imbalances, however, are associated with:

- inflammatory diseases
- obesity
- neurological disorders

Genetic analysis has shown us that each of us is an entire ecosystem!
Buildings have their own microbiome

by naked eye we see nothing!

by microscopy we can detect thousands of microbes

gene sequencing has uncovered trillions of microbes that inhabit our buildings

Buildings have their own microbiome
A closer look at our surroundings
The indoor environment now drives natural selection

Occupants send microbes into buildings

Building design, use and ventilation “select” microbes which survive and interact with occupants
Microbes in mechanically ventilated buildings are more closely related to pathogens

Mechanically ventilated
- **Low** bacterial diversity
- **High** average pathogenicity

Outdoor Air
- **High** bacterial diversity
- **Low** average pathogenicity
A study to examine the impact of a building on occupant health
One year-long study to evaluate the patient room environment and HAIs

Correlate indoor conditions in 10 patient rooms and 2 nurse stations

With new patient infections
One year-long study to evaluate the patient room environment and HAIs

**Patient room data** vs. **Patient HAIs**

- Staff & visitor hand cleaning
- Temperature
- Room pressurization
- Lux
- CO₂ level
- Relative humidity, Absolute humidity
- Room traffic
- Room air changes
- Outdoor air fractions

- Room HAIs
  - Pneumonia, viremia
  - Pseudomonas, Epstein-Barr virus
  - Pneumonia
  - Staphylococcus aureus
  - Open wound of head, neck, and trunk
  - Citrobacter infection
  - Bacteremia, organism unspecified
  - Citrobacter infection
  - Infection due to vascular device
  - Cellulitis
  - Staphylococcus aureus
  - Sepsis, cellulitis, abscess
  - Staphylococcus aureus
  - Pneumonia, organism unspecified
  - Cytomegalovirus (CMV)
  - Fever, bacteremia, organism unspecified
  - Wound infection after surgery
  - Urosepsis, organism unspecified
  - Sepsis following cardiac surgery
  - Pneumonia, organism unspecified
  - Infection of skin and subcutaneous tissue
  - Clostridium difficile
  - Colitis and diarrhea
  - Wound infection after surgery
  - Urosepsis, organism unspecified
  - Diarrhea
  - Salmonella enteritidis

8 million room data points ~ 300 patient outcomes
As patient room RH went down, HAIs went up!

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Healthcare-Associated Infections in 10 monitored patient rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-Feb</td>
<td>34.00</td>
</tr>
<tr>
<td>24-Mar</td>
<td>37.00</td>
</tr>
<tr>
<td>20-Apr</td>
<td>36.00</td>
</tr>
<tr>
<td>17-May</td>
<td>41.00</td>
</tr>
<tr>
<td>13-Jun</td>
<td>32.00</td>
</tr>
<tr>
<td>10-Jul</td>
<td>30.00</td>
</tr>
<tr>
<td>6-Aug</td>
<td>30.00</td>
</tr>
<tr>
<td>2-Sep</td>
<td>30.00</td>
</tr>
<tr>
<td>29-Sep</td>
<td>30.00</td>
</tr>
<tr>
<td>26-Oct</td>
<td>30.00</td>
</tr>
<tr>
<td>22-Nov</td>
<td>30.00</td>
</tr>
<tr>
<td>19-Dec</td>
<td>30.00</td>
</tr>
</tbody>
</table>

Average RH for all patient rooms

Coefficient Table:

<table>
<thead>
<tr>
<th>Beta</th>
<th>t</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.348</td>
<td>-2.396</td>
<td>.020</td>
</tr>
</tbody>
</table>

Note: Coefficients follow the t-test and significance levels.
As patient room RH went up, HAIs went down!
2018 Study: Indoor-air RH and health outcomes in residents in a long-term care facility (over 4 yrs)

Patient infections VS Environmental data

Infections
- respiratory (viral & bacterial)
- GI (Noro. & Notovirus, C. diff)
- urinary tract
- conjunctivitis
- cellulitis

Indoor conditions
- temperature
- relative humidity
- visitors
- staff absenteeism

Outdoor climate
- temperature
- relative humidity
- flu outbreaks
Respiratory & GI infection rates were lowest when indoor RH = 40-60%
2018 study: Humidity decreased Influenza A illness in a pre-school

January 25 – March 11 (32 days)

Half of the classrooms were humidified, the other half were not

<table>
<thead>
<tr>
<th>RH of classrooms</th>
<th>% Airborne particles carrying virus (PCR)</th>
<th>Virulence of airborne virus (% cells infected)</th>
<th># children absent due to influenza illness</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>49%</td>
<td>75%</td>
<td>22</td>
</tr>
<tr>
<td>45%</td>
<td>19%</td>
<td>35%</td>
<td>9</td>
</tr>
</tbody>
</table>
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Why is dry air so powerful?

Dry, thirsty air steals moisture from wherever it can – a law of physics
What determines if this cough will infect others?
When RH < 40%, pathogen infectivity is high

- Greater airborne transmission
- Evasion from surface cleaning through resuspension
- Increased survival and infectivity
Infectious droplets shrink, travel far and evade surface cleaning when the air is dry.

**Droplet diameter in microns (um)**

- 0.5: 41 hours – 21 days
- 1: 1.5 hours
- 3: 6 seconds
- 10: Distance travelled: 1m
- 100: Distance travelled: 10m+
Does recontamination from infectious droplet nuclei settling out of the air explain this?

Contact precautions have not been shown to effectively reduce transmission in most patients with MRSA and VRE.

When full contact precautions were stopped:

- No significant increase in transmission rates
- The health system saved approx. $643,776 and 45,277 hours per year in healthcare worker time previously spent on donning and doffing personal protective equipment.
C. diff can travel in infectious aerosols

December 2018 – American Journal of Infection Control.

- C-Diff seeded in a toilet
- Water samples, settle plates, and air samples
- Spores present after 24 flushes
- Droplet nuclei spore bioaerosol produced over at least 12 flushes
Transmission of bacteria in the OR is **higher** in low RH

The sterile field was less contaminated in OR with RH 35% vs 20%
Influenza A virus is more infectious when RH is below 40%
Did the very low RH in the airplane cabin contribute to this?

“Yes, she was vaccinated!

“Flight attendant in Hospital After Deadly Infection Spreads Onboard” April 7, 2019

✓ Yes, she was vaccinated!
Pathogens Requiring Airborne Infection Isolation

- Anthrax
- Avian influenza
- Varicella disease (chickenpox, shingles)
- Measles (rubeola)
- Severe acute respiratory syndrome (SARS)
- Smallpox (variola)/Varioloa virus
- Tuberculosis (TB)

Old news
Pathogens Requiring Airborne Infection Isolation

- Clostridium difficile
- Diphtheria
- Epiglottitis, due to Haemophilus influenzae type b
- Haemophilus influenzae Serotype b (Hib) disease
- Influenza, human (typical seasonal variations)
- Meningitis & Meningococcal disease sepsis, pneumonia
- Mumps (infectious parotitis)/Mumps virus
- Mycoplasmal pneumonia
- Parvovirus B19 infection (erythema infectiosum)
- Pertussis (whooping cough)
- Pharyngitis from Adenovirus, Orthomyxoviridae, Epstein-Barr virus, Herpes simplex virus
- Pneumonia (Adenovirus, Haemophilus influenzae Serotype b, Meningococcal Mycoplasma)
- Streptococcus Group A
- Pneumonic plague/Yersinia pestis
- Rubella virus infection (German measles)/Rubella virus
- Severe acute respiratory syndrome (SARS)
- Streptococcal disease (group A streptococcus)
- Viral hemorrhagic fevers due to Lassa, Ebola, Marburg, Crimean-Congo fever viruses

New news
Dry conditions increase **horizontal** transfer of antibiotic resistance genes
Enough about microbes. How do humans do in dry air?
Sitting in room air with 20% RH, the average person becomes clinically dehydrated in 8 hours.

When RH<40%, humans suffer!

- More infections & asthma attacks
- Impaired brain function
- Skin cracking, decreased wound healing
- Dry eyes, excessive tearing
Dry air impairs our respiratory system defenses

Dry inhaled air causes:
• Increased susceptibility to infections
• Increased wheezing from allergic disease
A key study just published in PNAS

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

*Proceedings of the National Academy of Sciences, USA. May 19, 2019*

Eriko Kudo, Eric Song, Laura Yockey, Tasfia Rakib, Patrick Wong, Robert Homer, Akiko Iwasaki
Question investigated: Why do these differences exist?

- RH 50% gets rid of the virus
- RH 50% gets a little sick
- RH 20% gets VERY sick
Study setup

**Chamber conditions**
- Temp = 20°C
- 20%RH 3g/m³ AH
- or
- 50%RH 9g/m³ AH

**MX1** mice have functional Type I IFN responses

**Cabinet**

**Precondition:** 5 days

**Post-infection:** 7 days

* Intranasal Influenza Challenge

* Remove from chamber
Summary: Innate respiratory protective mechanisms are optimal at 50% RH, and impaired at RH 20%
Summary: Innate respiratory protective mechanisms are optimal at 50% RH

- Increased Epithelial Repair
- Decreased cytokine production, cell damage
- Increased clearance of virus by protective alveolar macrophages ("big-eaters")
- Decreased infection of distal airway epithelium
ASHRAE 1985: “Optimal RH Level For Health” = 40%–60%
35 years later….. Taylor Chart 2019

Infectivity of Pathogens

- **High Infectivity**
  - Influenza, coronavirus, RSV, parainfl.
  - Measles, rubella, herpes
- **Low Infectivity**

**Human Illness from Infections**

- Adult in-patients (acute care)
- Elderly patients in long-term care
- Pre-school children
- Employee productivity
- Employee sleep quality
- Student learning

**Healthiest Humans**

**Poor Human Functioning**

**Relative Humidity (%)**

10, 20, 30, 40, 50, 60, 70, 80, 90
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Why do we still keep our indoor environment so dry?
The great indoor air RH debate!

**Protect the building**

Buildings *don’t care about humidity*

- The drier the air the better
- Easier to dry the air than fix the envelope construction
- Humidification will cost more

**Protect the occupants**

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

- Decreased infections
- Fewer allergies
- Improved hydration
- Improved wound healing
- Increased work performance
What motivates people to listen?
Humidification is used when the financial impact is quantifiable.

- **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?
These humans are worthy of humidification

“Arrrgghh, Why didn’t we humidify our air sooner?!?”
HAIs are costly for a 250 bed hospital

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

*2015 volume of a selected 250-bed hospital, APIC calculated costs*
The majority of bacteria causing HAI's are resistant to dryness and survive in the air.

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Persistence</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acinetobacter spp.</td>
<td>3 d up to 5 months</td>
<td>6 references</td>
</tr>
<tr>
<td>Clostridium difficile (spores)</td>
<td>5 months</td>
<td>3 references</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>1.5 h up to 16 months</td>
<td>10 references</td>
</tr>
<tr>
<td>Enterokokkus supp. inkl. VRE und VSE</td>
<td>5 d up to 4 months</td>
<td>4 references</td>
</tr>
<tr>
<td>Klebsiella supp.</td>
<td>2 h up to &gt;30 months</td>
<td>5 references</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>6 h up to 16 months</td>
<td>7 references</td>
</tr>
<tr>
<td>Staphylococcus aureus, inkl. MRSA</td>
<td>7 d up to 7 month</td>
<td>6 references</td>
</tr>
</tbody>
</table>

reaction to hospital’s dry environment → increased infectivity

Hospital surfaces are dry and non-porous.

Kramer A et al, How long do nosocomial pathogens persist on inanimate surfaces? a systematic review, BMC Infectious Diseases 2006, 6:130
Value analysis of humidification in 250-bed hospital

<table>
<thead>
<tr>
<th>BENEFITS - Year One</th>
<th>Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Increased Revenue</strong></td>
<td></td>
</tr>
<tr>
<td>Maximize per day bed value by decreasing LOS</td>
<td>$1,310,126</td>
</tr>
<tr>
<td>Decrease non-reimbursable HAI costs</td>
<td>$764,890</td>
</tr>
<tr>
<td><strong>Cost Avoidance</strong></td>
<td></td>
</tr>
<tr>
<td>3% CMS penalty for readmissions</td>
<td>$91,787</td>
</tr>
<tr>
<td>CMS Quality Index penalty</td>
<td>TBD</td>
</tr>
<tr>
<td>Joint Commission citations</td>
<td>TBD</td>
</tr>
<tr>
<td>Employee absenteeism</td>
<td>TBD</td>
</tr>
<tr>
<td>HAI litigation by patients</td>
<td>TBD</td>
</tr>
<tr>
<td><strong>Quarterly total</strong></td>
<td>$2,166,803</td>
</tr>
<tr>
<td><strong>Cumulative value</strong></td>
<td>$2,166,803</td>
</tr>
</tbody>
</table>

**INVESTMENTS**

<table>
<thead>
<tr>
<th></th>
<th>Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td></td>
</tr>
<tr>
<td>Installation &amp; Integration of New System</td>
<td>$(1,198,500)</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$(23,850)</td>
</tr>
<tr>
<td>Operating Cost</td>
<td>$(34,573)</td>
</tr>
<tr>
<td>OR &amp; PT Room Down Time</td>
<td>$(10,000)</td>
</tr>
<tr>
<td><strong>Quarterly total</strong></td>
<td>$(1,266,923)</td>
</tr>
<tr>
<td><strong>Cumulative investment</strong></td>
<td>$(1,266,923)</td>
</tr>
</tbody>
</table>

**Summary**

$899,880

**1st Quarter**

500.97%

$7,225,018
Change is hard! We resist and often do not even listen.
Do we really want to keep doing the same old thing?
Clinicians working alone in their silo of delivering medical and surgical treatments cannot solve problems caused by the indoor environment.

If clinicians, facility managers and regulators work together, we can soar!
Uniting our goals would benefit everyone

**Medical professionals**
- Heal patients
- Follow clinical protocols
- Avoid lawsuits

**Building professionals**
- Reduce energy use
- Stay within budget
- Follow building codes

**IMPROVE OCCUPANT HEALTH**
- Better health
- Decrease acute and chronic diseases
- Decrease financial losses from illness
Evolution and RH

skull of the grassland Saiga antelope
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
Conclusions

- The indoor environment is critical for our health
- Humans need water vapor
- Humidification can present significant challenges
- We cannot ignore this!
Thank you!

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M Arch, FRSPH(UK), M CABE

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(860) 501-8950


• Tropical Medicine & International Health. 2008., Volume 13, Issue 12, pages 1543-1552, 6 Oct.


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

Eriko Kudo, Eric Song, Laura Yockey, Tasfia Rakib, Patrick Wong, Robert Homer, Akiko Iwasaki

*Proceedings of the National Academy of Sciences, USA. May 19, 2019*
Findings: 1

Low humidity of RH = 10% decreased muco-ciliary clearance of influenza virus.
Findings:

Mice in RH 10% were less able to clear the virus from their lungs, and therefore viral growth was ongoing. Mice in RH 50% were more resistant to the virus and had milder infections.
Findings:

- Low humidity of RH = 10% diminished repair of airways damaged by infection.

- Active airway repair (dark dots) at RH = 50%.