The Essential Role of Indoor Air Quality in Patient Outcomes

Stephanie Taylor, MD, M Arch, RSPH(UK), MCABE
How I got here

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

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

Thank you for this opportunity to meet!
Presentation summary

Let’s talk about evolution
- Public health trends
- Survival of the fittest, change or face extinction
- Who is in the room with us?

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

Research
- Microbiome study
- Other studies
- Mechanisms

“To change, or not to change?”
- No: (legionella, building envelopes, energy consumption)
- Yes: health, savings
- Next steps
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What is going on?

Antibiotic resistance is unstoppable

Chronic diseases are increasing

Patients are dying FROM being in the hospital

Infectious diseases are re-emerging

This is confusing.....
Autoimmune diseases have increased

Learning disabilities have risen 50% in the past 10 years

Endocrine disorders such as diabetes have increased 30% since 1985

Asthma has reached epidemic proportions, now the No. 1 cause of school absenteeism

Birth defects are the leading cause of infant mortality in the US
Global Examples of Emerging and Re-Emerging Infectious Diseases

- Antimicrobial-resistant threats
  - CRE
  - MRSA
  - C. difficile
  - N. gonorrhoeae
- H3N2 influenza
- Cyclosporiasis
- E. coli O157:H7
- Measles
- Human monkeypox
- Listeriosis
- Bourbon virus
- 2009 H1N1 influenza
- Adenovirus 14
- Anthrax bioterrorism
- Chikungunya
- Hantavirus pulmonary syndrome
- Dengue
- Zika virus
- Yellow fever
- Human African trypanosomiasis
- West Nile virus
- Enterovirus D68
- Heartland virus
- Cryptosporidiosis
- Powassan virus
- E. coli O104:H4
- Ebola virus disease
- Drug-resistant malaria
- Diphtheria
- MERS-CoV
- Akhmeta virus
- Rift Valley fever
- Typhoid fever
- SFTSV bunyavirus
- E. coli O157:H7
- H10N8 influenza
- H7N9 influenza
- H5N1 influenza
- SARS
- Hendra virus
- Nipah virus
- Human monkeypox
- Ebola virus disease
- Lassa fever
- HIV
- Marburg hemorrhagic fever
- MDR/XDR tuberculosis
- Plague
- Zika virus

Legend:
- Newly emerging
- Re-emerging/resurging
- “Deliberately emerging”

September 2017
Humans spend 95% of our indoors!
Are our buildings really protecting our health?

“We shape our buildings, then they kill us!”
Kenneth Dickerman, AIA 2011

Is this true ??
Survival of the fittest
We have many invisible “roommates”
How much do we know about these “roommates”? 

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New tools have revealed a whole new understanding

“Old school” tissue culture sampling

Genetic analysis tools
We are more microbial than human!

Each of us is an ecosystem with ~ 100 trillion other microscopic organisms living in and on us.
The expanded tree of life

Genetic analysis has revealed diverse microbial populations that were unknown before cultivation-independent approaches.
Our microbes interact with the indoor environment

We send our microbes into buildings

Buildings send their microbes to us

Humans emit approx. $10^7$ genome copies of bacteria, and $10^6$ fungi into the air per person-hour
The indoor microbiome has less variation than outdoors.
Loss of biodiversity is bad for ecosystems

Invasion of one species

Invasion of a few species
Microbes in mechanically ventilated buildings are closely related to pathogens

Kembel et al. (2014)
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Let’s talk about evolution
- Survival of the fittest, change or face extinction
- Our “new” environment
- Who is in the room with us?

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One year study on patient room IAQ and new infections

10 patient rooms, 2 nurse stations
Patient room measurements

8 million data points!!
Results?
Low indoor air RH was found to be the biggest driver of patient infections (HAIs)
Statistically significant correlation

Findings:

as RH

patient infections

Significance:

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Constant)</td>
<td>Beta</td>
<td>-2.348</td>
<td>.023</td>
<td></td>
</tr>
</tbody>
</table>

Multivariable regression analysis: Statistical analysis that tests the relationship between multiple predictor variables and one outcome
The universe strives for equilibrium

Dry, thirsty air steals moisture from wherever it can
– a law of physics
Dry weather brings meningitis outbreaks

- Bacteria spread through the air when the outdoor humidity is low
- “Once the humidity exceeds 40%, the epidemic ends”
Dry seasons promote many bacterial epidemics
Dry air is a greater factor than cold temperatures

Low RH was associated with higher pathogenicity

This connection was more significant than humidity ratio or temperature

<table>
<thead>
<tr>
<th>(B) Indoor samples only (mechanical and window-ventilated rooms)</th>
<th>R²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation method</td>
<td>0.66</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>0.38</td>
<td>0.01</td>
</tr>
<tr>
<td>Humidity ratio</td>
<td>0.07</td>
<td>0.31</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.14</td>
<td>0.08</td>
</tr>
<tr>
<td>Air changes per hour</td>
<td>0.38</td>
<td>0.02</td>
</tr>
<tr>
<td>Air flow velocity at bed</td>
<td>0.10</td>
<td>0.13</td>
</tr>
<tr>
<td>Air flow velocity at supply</td>
<td>0.37</td>
<td>0.03</td>
</tr>
<tr>
<td>Time of sampling</td>
<td>0.06</td>
<td>0.22</td>
</tr>
<tr>
<td>Room</td>
<td>0.12</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Bacteria from spaceships reveal robust survival tactics

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

(i) spore-forming ability
(ii) resistance against radiation, pressure, desiccation
(iii) the increased expression of antibiotic resistant genes
Humans are harmed by dry air
With RH of 20%, dehydration occurs in 8 hours

- dry eyes & blurry vision
- skin cracking & decreased wound healing
- impaired brain function
- more infections & asthma
- dangerous blood clotting
- With RH of 20%, dehydration occurs in 8 hours

- dry eyes & blurry vision
- skin cracking & decreased wound healing
- impaired brain function
- more infections & asthma
- dangerous blood clotting
Dry air harms our skin
Children and seniors are especially vulnerable to the ill-health effects of low RH

Children

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

Seniors

- Sense of thirst is reduced
- Bedridden people have less autonomy
- Seniors often limit drinking to reduce toilet visits
Proper air hydration is essential for our respiratory system defenses

Key functions of respiratory cells:
• Cilia wash particles away from delicate lung tissue
• Mucus layer allows healthy immune modulation to reduce allergic reactions
• Mucous from goblet cells trap pathogens

Dry inhaled air causes:
• Increased susceptibility to infections
• Increased wheezing from allergic disease
Dehydration affects our brain
Responses of the Human Brain to Mild (1%) Dehydration

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

Explored in vivo by 1H-MR imaging and spectroscopy
Dry air impairs vision

take off 20-20

six hours later 20-60

landing
Dry air damages our corneas

Figure 1.
A. Mean relative humidity (%) and temperature (°C) recordings in the Low humidity room (LH) and vivarium throughout the experiment.
B. Representative H&E staining of corneas cryosections of C57BL/6 mice subjected to low humidity stress for 15 and 30 days (LH15D and 30D, respectively). Note desquamation of apical corneal epithelial cells at LH15D and 30D while control eye (nonstressed, NS) showed normal corneal architecture. Original magnification 10X. Insets indicate high magnification of left area immediately adjacent to inset.
Opposite to humans, pathogens thrive in dry air!

- Farther spread
- Many are more infectious
- Re-suspension & deposition onto previously cleaned surfaces
Will this cough infect others?
Infectious droplets shrink and travel in dry air

**Droplet diameter in microns (um)**
- 0.5
- 1
- 3
- 10
- 100

**Float time**
- 41 hours – 21 days
- 1.5 hours
- 6 seconds

**Distance travelled:**
- 1m
- 10m+
Infectivity of many viruses is greater in dry air

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

High Humidity Leads to Loss of Infectious Virus from Simulated Coughs. U. Illinois, 2013
J Noit, et al.
Nearly 100% humidity

Humidity over 45%

Humidity below 45%

aerosol containing pathogens before evaporation

super-saturated salt solution inactivates pathogens

salts crystallize, pathogens remain active
Infectious droplets are expelled into the hospital environment. Pathogens circulate through the ventilation system and recirculate in turbulent flow. Infectious droplets spread disease to in-patients (HAIs). Dry indoor air increases infectious droplets spread.
With RH of 40%–60%, infectious droplets settle out of the airborne environment.

**Particle behavior with increased air hydration**

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

Ventilation Duct

Bedrails and other frequently touched surfaces are more effectively cleaned

Hand hygiene is maintained

Settled infectious droplets are not re-suspended due to the adhesive from water’s dipole forces.
Sterling diagram published in 1985, with optimal RH level for health of 40%–60%
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“To change, or not to change?”
The great indoor air RH debate!

Buildings *don’t care* about humidity

Facility managers often incorrectly think:
- The drier the air the better
- Easier to dry the air than fix the envelope construction

Occupants *need* RH between 40% and 60% for health
- Decreased infections
- Fewer allergies
- Improved hydration
- Improved wound healing
- Increased work performance
Hello, hello, hello!
<table>
<thead>
<tr>
<th>Infection Type</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>2,592.0</td>
</tr>
<tr>
<td>Surgical Wound Infections</td>
<td>365</td>
<td>$7,042,464</td>
<td>4,378.0</td>
</tr>
<tr>
<td>CRBSI</td>
<td>148</td>
<td>$4,990,636</td>
<td>2,509.0</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><strong>2,066</strong></td>
<td><strong>$15,297,799</strong></td>
<td><strong>11,028.0</strong></td>
</tr>
</tbody>
</table>
Projected financial benefits of indoor humidification in a 250-bed hospital

<table>
<thead>
<tr>
<th>BENEFITS - Year One</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Revenue</td>
<td>$1,310,126</td>
<td>$1,310,126.00</td>
<td>$1,310,126.00</td>
<td>$1,310,126.00</td>
</tr>
<tr>
<td>Decrease non-reimbursable HAI costs</td>
<td>$764,890</td>
<td>$764,890.00</td>
<td>$764,890.00</td>
<td>$764,890.00</td>
</tr>
<tr>
<td>Cost Avoidance</td>
<td>$91,787</td>
<td>$91,787.00</td>
<td>$91,787.00</td>
<td>$91,787.00</td>
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<tr>
<td>3% CMS penalty for readmissions</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>CMS Quality Index penalty</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Joint Commission citation</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Employee absenteeism</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>HAI litigation by patients</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Quarterly total</td>
<td>$2,166,803</td>
<td>$2,166,803</td>
<td>$2,166,803</td>
<td>$2,166,803</td>
</tr>
<tr>
<td>Cumulative value</td>
<td>$2,166,803</td>
<td>$4,336,066</td>
<td>$6,500,409</td>
<td>$8,667,212</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INVESTMENTS</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation &amp; Integration of New System</td>
<td>$(1,198,500)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$(23,850)</td>
<td>$(23,850)</td>
<td>$(23,850)</td>
<td>$(23,850)</td>
</tr>
<tr>
<td>Operating Cost</td>
<td>$(34,573)</td>
<td>$(34,573)</td>
<td>$(34,573)</td>
<td>$(34,573)</td>
</tr>
<tr>
<td>OR &amp; PT Room Down Time</td>
<td>$(10,000)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Quarterly total</td>
<td>$(1,266,923)</td>
<td>$(58,423)</td>
<td>$(58,423)</td>
<td>$(58,423)</td>
</tr>
<tr>
<td>Cumulative investment</td>
<td>$(1,266,923)</td>
<td>$(1,325,347)</td>
<td>$(1,383,770)</td>
<td>$(1,442,194)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NET VALUE</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative total</td>
<td>$899,880</td>
<td>$3,008,259</td>
<td>$5,116,639</td>
<td>$7,225,018</td>
</tr>
</tbody>
</table>

1st year net return: $7,225,018
Break-even point: 1st Quarter
ROI (1st year): 500.97%
Decrease air changes and building energy use with proper RH

Drag force

Gravitational pull

The deposition and resuspension of aerosols is closely related to air turbulence.

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

Hospitals can save up to 70% HVAC fan and reheat energy costs by reducing ACH by 10%
Energy savings with proper indoor air hydration

A VAV System Heat Recovery
Economizer to Furnish Free
Humidification and Exceed Standard
62.1 Ventilation Requirements in
Winter

Mike Scofield, PE
Fellow ASHRAE

Vijayanand Periannan
Member ASHRAE
**Conclusion: dry indoor air is dangerous and costly**

<table>
<thead>
<tr>
<th>Dry indoor air (RH &lt;40%)</th>
<th>Hydrated indoor air (RH 40-60%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Humans:</strong></td>
<td><strong>Humans:</strong></td>
</tr>
<tr>
<td>• Decreased skin barriers</td>
<td>• Healthy skin barriers</td>
</tr>
<tr>
<td>• Decreased respiratory mucous barriers</td>
<td>• Functioning respiratory mucous barriers</td>
</tr>
<tr>
<td>• Decreased cognitive performance</td>
<td>• Optimal cognitive performance</td>
</tr>
<tr>
<td><strong>Microbes:</strong></td>
<td><strong>Microbes:</strong></td>
</tr>
<tr>
<td>• Increased transmission</td>
<td>• Settle out of the air</td>
</tr>
<tr>
<td>• Decreased diversity</td>
<td>• Healthy diversity</td>
</tr>
<tr>
<td>• Increased virility</td>
<td>• Pathogens deactivated</td>
</tr>
</tbody>
</table>
Skull and nasal cavity of the grassland Saiga antelope
A large cranial air cavity increases ambient RH, preventing dust particles and parasites from entering delicate lung tissue.
Next steps for healthy air-hydration in your building

1. Record occupant health and productivity data
2. Monitor indoor air RH in occupied building spaces
3. Identify weaknesses in the building envelope
4. Run clean and energy efficient humidification systems
5. Continue monitoring indoor air RH and occupant health
Human aging is a battle against dehydration & gravity.
Thank you!

Stephanie Taylor, MD, M Arch, RSPH(UK), MCABE

MD@taylorcx.com

Phone: (860) 501-8950
Mortality rates increased in dry air in US 2009

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


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