40 is the new 20, balanced air-hydration for health!

Updating Scientific Evidence about the Effects of Low Humidity on People
Learning Objectives

• Understand the effects of humidity on health, comfort and IAQ

• Understand the relationship between low indoor relative humidity and increased healthcare-associated infections in the hospital setting

• Understand the human physiological reactions to low humidity

• Understand the effects of low humidity on human performance

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Outline

1. Overlap between engineering and medicine
2. A new study to test the impact of the building on occupant health
3. Dry building syndrome
4. Conclusions and best practices
Outline

1. Overlap between engineering and medicine
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Engineers and physicians have much in common

- Many years of school!!!
- Technical vocabulary that excludes outsiders
- Budgets control our jobs
- We both promote human health

“ASHRAE is a global society advancing human well-being through sustainable technology for the built environment”
How does the building impact occupant health?

Hospitals are a perfect setting to study this

Patients are vulnerable

Pathogens are virulent
Outline

1. Overlap between engineering and medicine
2. Our study to test the impact of the building on occupant health
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Monitor indoor conditions in 10 patient rooms

Map bacterial communities in these spaces

Track patient infections acquired while in the hospital

a 12 month study
The hospital building

- Built 2013, LEED Silver
- 1.2 million sq. feet (111,484 sq. meters)
- 100,000 sq. feet per floor (9,290 sq. meters)
- 240 single-occupancy inpatient rooms
- Green roof
Data collected from the patient room

- Staff hand hygiene
- Traffic (beam breaks)
- RH, absolute humidity
- Outdoor air fractions
- Room pressurization

- Temperature
- Lux
- CO₂
- RAC
# Examples of new patient infections

<table>
<thead>
<tr>
<th>Patient</th>
<th>Room</th>
<th>Clinical symptoms</th>
<th>HAI Organisms (if indicated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>xx</td>
<td>xx</td>
<td>pneumonia, viremia</td>
<td>Pseudomonas, Epstein-Barr virus (EBV)</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>pneumonia</td>
<td>Staphylococcus aureus</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>open wound of head, neck, and trunk</td>
<td>Citrobacter infection</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>bacteremia, organism unspecified</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>infection due to vascular device</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>cellulitis</td>
<td>Staphylococcus aureus</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>sepsis, cellulitis, abscess</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>bacteremia, organism unspecified</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>pneumonia, organism unspecified</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>fever; bacteremia, organism unspecified</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>viremia</td>
<td>Cytomegalovirus (CMV)</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>wound infection after surgery</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>urosepsis, organism unspecified</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>sepsis following cardiac surgery</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>pneumonia, organism unspecified</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>infection of skin and subcutaneous tissue</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>colitis and diarrhea</td>
<td>Clostridium difficile</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>wound infection after surgery</td>
<td></td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>urosepsis, organism unspecified</td>
<td>salmonella enteritis</td>
</tr>
<tr>
<td>xx</td>
<td>xx</td>
<td>diarrhea</td>
<td>salmonella enteritis</td>
</tr>
</tbody>
</table>
As indoor RH went down, the patient infection rate went up

Avg RH for all 10 patient rooms

Healthcare-Associated Infections in 10 monitored patient rooms
SPSS analysis of relationships between indoor conditions and infections

<table>
<thead>
<tr>
<th>Model</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Constant)</td>
<td>-2.348</td>
<td>-2.348</td>
<td>.023</td>
</tr>
<tr>
<td>Avg RH</td>
<td>-9.060</td>
<td>-2.396</td>
<td>.020</td>
</tr>
</tbody>
</table>
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The invisible world
Things in the air that affect our health

<table>
<thead>
<tr>
<th>VOC</th>
<th>Mycotoxin</th>
<th>Allergen</th>
<th>Virus</th>
<th>Mold fragment</th>
<th>Bacteria</th>
<th>Mold spore</th>
<th>Pollen</th>
<th>Mite feces</th>
<th>Mite</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="image" /></td>
<td><img src="image2.png" alt="image" /></td>
<td><img src="image3.png" alt="image" /></td>
<td><img src="image4.png" alt="image" /></td>
<td><img src="image5.png" alt="image" /></td>
<td><img src="image6.png" alt="image" /></td>
<td><img src="image7.png" alt="image" /></td>
<td><img src="image8.png" alt="image" /></td>
<td><img src="image9.png" alt="image" /></td>
<td><img src="image10.png" alt="image" /></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Diameter (um)</th>
<th>0.0001</th>
<th>0.001</th>
<th>0.01</th>
<th>0.1</th>
<th>1</th>
<th>10</th>
<th>100</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERV rating</td>
<td>15</td>
<td>13</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>blood</th>
<th>alveolus</th>
<th>bronchial tube</th>
<th>sinus</th>
<th>skin</th>
<th>Landing site</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>gaseous</td>
<td>particles or droplets (large and small)</td>
<td></td>
<td></td>
<td></td>
<td>skin contact</td>
<td></td>
</tr>
</tbody>
</table>
In air with 20% RH, an inactive 50 kg person loses 1 - 2% body weight in 8 hrs, becoming clinically dehydrated before thirst begins.

This mild dehydration results in:

- Impaired immunity, increased infections
- Breached skin barrier & delayed wound healing
- Diminished brain function & performance
Dry Building Syndrome increases infections
Will this cough infect others?
Low indoor RH shrinks aerosolized droplets, promoting greater pathogen spread.
Thermodynamic and kinetic changes in infectious droplets

**HUMAN AIR**

- 34-36 °C (93 – 99 °F)
- ≈ 95% RH

**HUMIDIFIED ROOM AIR**

- 20-24 °C (68- 75 °F)
- 50% RH

**H₂O ENERGY AND MASS TRANSFER**

- Evaporation/condensation
- Heat transfer

**KINETIC MOVEMENT**

- 3 thermal buoyancy
- 5 resultant trajectory
- 4 force of gravity

1. expulsion
2. natural or forced convection
Thermodynamic and kinetic changes in infectious droplets

**HUMAN AIR**
- 34-36 °C (93 – 99 °F)
- ≈ 95% RH

**DRY ROOM AIR**
- 20-24 °C (68-75 °F)
- 20% RH

**H₂O ENERGY AND MASS TRANSFER**
- Evaporation/condensation
- Heat transfer

**KINETIC MOVEMENT**
- Thermal buoyancy
- Resultant trajectory
- Force of gravity

1. Expulsion
2. Natural or forced convection

- 34-36 °C (93 – 99 °F) ≈ 95% RH

- 20-24 °C (68-75 °F) 20% RH
Indoor air with RH < 40% promotes pathogen transmission in tiny aerosolized droplets.

Droplets carrying bacteria or virus are expelled into the hospital environment and dried rapidly.

Pathogens circulate through the ventilation system.

Recirculate in turbulent flow.

Re-contaminate hands and surfaces.

Infectious droplets spread disease to in-patients (HAIs).
With RH of 40%–60%, infectious droplets settle out of the air within a short distance of the source.

- Bedrails and other frequently touched surfaces are more effectively cleaned
- Hand hygiene is maintained
- Settled infectious droplets are not re-suspended

1 – 2 meters (3-6 feet)
Viability of many pathogens is reduced in air with RH 40%–60%
Appropriate humidity supports cell hydration needed for respiratory defense mechanisms.

**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
Children and seniors are especially vulnerable to the ill-health effects of low RH

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

**Seniors**
- Sense of thirst is reduced and thus unreliable in preventing dehydration
- Bedridden people have little autonomy
- Seniors often limit drinking in order to reduce toilet visits
- Non-active people often forget to drink
Dry Building Syndrome affects our brain
Dry Building Syndrome harms our skin

Skin functions are impaired:
- wound healing
- immune system training
- protection from injury
- protection from infections
- preserving internal water
Dry Building Syndrome harms our skin

Dry air harms skin

- Desquamation
  - 1000 cells/cm²/hour
  - 5 x 10⁹ cells/day

- Stratum Corneum Thickness
  - 15-20 cell layers

- Transit Time
  - ~14 days

- Well hydrated
- Dehydrated
Dry weather reliably predicts meningitis outbreaks
Dry weather reliably predicts meningitis outbreaks

- Bacteria spread when the outdoor humidity is low
- Once the humidity exceeds 40%, the epidemic ends
Outline

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The optimum indoor air RH: 40 is the new 20!

Buildings don’t care about humidity
- Facility managers often think, “the drier the better”
- Improve the envelope construction
- Test and validate insulation

Occupants need RH 40% – 60% RH for optimal health
- Decreased infections
- Fewer allergies
- Improved hydration
- Improved wound healing
- Increased work performance
We need to maintain maximum AND minimum RH!
They care about water activity!

Fungi don’t care about humidity!

They care about water activity!
### Good Insulation Properties

<table>
<thead>
<tr>
<th>Outside Shell</th>
<th>Boundary Layer</th>
<th>Room Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 °C (14 °F)</td>
<td>20°C (68°F)</td>
<td>22 °C (72 °F)</td>
</tr>
</tbody>
</table>

\[ \text{R-value} = 2.0 \text{ W/m}^2\text{K} \]

### Bad Insulation Properties

<table>
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<tr>
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<th>Room Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10 °C (14 °F)</td>
<td>6°C (43°F)</td>
<td>22 °C (72 °F)</td>
</tr>
</tbody>
</table>

\[ a_w = 0.8 \quad 80\% \quad 35\% \]

With a relative humidity of 35 percent, the surface temperature of the wall reaches dew point temperature.

### Identical Outside and Inside Air Temperatures

- The different results in the inner surface temperature of the wall.

### Condensation on the Wall

- Condensation on the wall starts with a relative humidity of >95 percent.
- Condensation on the wall starts with a relative humidity of 35 percent. With 6 °C (43 °F), the surface temperature of the wall reaches dew point temperature.
Conclusions:

• New data correlates low indoor RH with occupant illness and decreased productivity

• Building codes should enforce both minimum and maximum indoor RH levels
Bibliography


QUESTIONS?

Stephanie Taylor, MD, M Arch, FRSPH(UK), MCABE
MD@taylorcx.com