Clearing the Air: The Impact and Cause of Microbial Growth in HVAC Systems
Introduction

Simple Truths about HVAC and Microbial Growth

• Microbial growth is a normal attribute of all HVAC systems
• Only limited microbial taxa are suited to grow inside an HVAC system

Oxygen

- Approximately 21%

Nutrients

- Fructose
- Glucose
- Sucrose
- Mannitol
- Arabitol

Moisture

- Water Activity Between 0.60-0.98 for Most Fungal Taxa

Viable Spores
- Requires Incubation
- Potato Dextrose Agar
- Corn Meal Agar
- Malt Extract Agar

Suitable Temperature
- Between 0-40°C (32-104°F)
Agenda

• Understanding HVAC Systems
• Characteristics of Microbial Growth
• Relationship between HVAC System and Microbial Growth
• Condensation inside HVAC Air Handlers
• Test Procedures
• How to Mitigate Microbial Growth
• Can We Control the Microbial Growth
Understanding HVAC Systems

Vapor-Compression Refrigeration Cycle Commonly known as HVAC (Heating, Ventilation and Air Conditioning)

1) Fundamental Operation and Components
2) Conditions at Areas Where Microbial Growth Occurs
3) How The Right Conditions are Achieved on HVAC Surfaces

IAQA

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Understanding HVAC Systems
Fundamental Operation and Components

- Compressor
- Condenser Coil
- **Evaporator Coil**
- Thermostatic Expansion Valve
- Blower
- Electrical (Motors, Capacitors, Wires, Switches, etc.)
- Thermostat/Humidistat
- Duct Work
- Registers
Understanding HVAC Systems

Ideal Vapor-Compression Cycle

Common Residential Split System
Understanding HVAC Systems

Determining the Conditions at Microbial Growth Locations

The Science of Psychrometrics

Growth Surfaces

• Ducting
• Metal Components
• Registers
• Wires
• Paper Labels
Understanding HVAC Systems

Conditions for Microbial Growth in an HVAC System

• Standard Operation
• 100% Relative Humidity After Evaporator Coils
• Dry Bulb Temp At or Below Dew Point Temperature
• HVAC Inefficiencies Decrease Moisture Removal
Characteristics of Microbial Growth

Microbial Growth on HVAC Components

- **Cladosporium**
- Yeasts
- **Phoma**
- **Rhizopus**

- **Acremonium**
- **Penicillium**
- Asp/Pen-like
## Characteristics of Microbial Growth

### Microbial Growth on HVAC Components

#### Lab Results (n=37)

<table>
<thead>
<tr>
<th>Microbial Growth</th>
<th>Fiberglass Duct</th>
<th>Evaporator Coil</th>
<th>AHU Metal Interior</th>
<th>Supply Vent</th>
<th>Duct Face Interior/Exterior</th>
<th>AHU Wires</th>
<th>AHU Paper</th>
<th>Drain Pan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladosporium</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Yeasts</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Phoma</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Rhizopus</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Acremonium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Penicillium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Asp/Pen-like</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Low 1-3, Medium 4-6, High >7
# Characteristics of Microbial Growth

## Water Activity for Microbial Growth

<table>
<thead>
<tr>
<th>Range of $a_w$</th>
<th>Microorganisms Generally Inhibited by Lowest $a_w$ in This Range</th>
<th>Foods Generally within This Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00–0.95</td>
<td>Pseudomonas, Escherichia, Proteus, Shigella, Klebsiella, Bacillus, Clostridium perfringens, some yeasts</td>
<td>Highly perishable (fresh) foods and canned fruits, vegetables, meat, fish, milk, and beverages</td>
</tr>
<tr>
<td>0.95–0.91</td>
<td>Salmonella, Vibrio parahaemolyticus, C. botulinum, Serratia, Lactobacillus, Pediococcus, some molds, yeasts (Rhodotorula, Pichia)</td>
<td>Some cheeses (Cheddar, Swiss, Muenster, Provolone), cured meat (ham), bread, tortillas</td>
</tr>
<tr>
<td>0.91–0.87</td>
<td>Many yeasts (Candida, Torulopsis, Hansenula), Micrococcus</td>
<td>Fermented sausage (salami), sponge cakes, dry cheeses, margarine</td>
</tr>
<tr>
<td>0.87–0.80</td>
<td>Most molds (mycotoxigenic penicillia), Staphylococcus aureus, most Saccharomyces (bailii) spp., Debaryomyces</td>
<td>Most fruit juice concentrates, sweetened condensed milk, syrups, jams, jellies, soft pet food</td>
</tr>
<tr>
<td>0.80–0.75</td>
<td>Most halophilic bacteria, mycotoxigenic aspergilli</td>
<td>Marmalade, marzipan, glace fruits, beef jerky</td>
</tr>
</tbody>
</table>

*Adapted from L.R. Beuchat, Cereal Foods World, 26:345 (1981)*
# Characteristics of Microbial Growth

## Water Activity for Microbial Growth

<table>
<thead>
<tr>
<th>Water Activity</th>
<th>Characteristics</th>
<th>Foods and Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.75–0.65</td>
<td>Xerophilic molds (Aspergillus chevalieri, A. candidus, Wallemia sebi), Saccharomyces bisporus</td>
<td>Molasses, raw cane sugar, some dried fruits, nuts, snack bars, snack cakes</td>
</tr>
<tr>
<td>0.65–0.60</td>
<td>Osmophilic yeasts (Saccharomyces rouxii), few molds (Aspergillus echinulatus, Monascus bisporus)</td>
<td>Dried fruits containing 15-20% moisture; some toffees and caramels; honey, candies</td>
</tr>
<tr>
<td>0.60–0.50</td>
<td>No microbial proliferation</td>
<td>Dry pasta, spices, rice, confections, wheat</td>
</tr>
<tr>
<td>0.50–0.40</td>
<td>No microbial proliferation</td>
<td>Whole egg powder, chewing gum, flour, beans</td>
</tr>
<tr>
<td>0.40–0.30</td>
<td>No microbial proliferation</td>
<td>Cookies, crackers, bread crusts, breakfast cereals, dry pet food, peanut butter</td>
</tr>
<tr>
<td>0.30–0.20</td>
<td>No microbial proliferation</td>
<td>Whole milk powder, dried vegetables, freeze dried, corn starch, potato chips, corn chips</td>
</tr>
</tbody>
</table>
Characteristics of Microbial Growth

Nutrient Sources for Microbial Growth Indoors

- Cellulose Fibers
- Plants
- Decayed Organic Matter
- Fruits
- Flowers
- Fabric (Organic)
Characteristics of Microbial Growth

Composition of Dust

- Skin Cells
- Hair
- Clothing Fibers
- Bacteria
- Dust Mites
- Dead Bug Fragments
- Soil Particles
- Pollen
- Plastic

Pelley, J., Tracing the chemistry of household dust, Chemical & Engineering News, American Chemical Society, 2018
Characteristics of Microbial Growth

Ideal Temperature Ranges

- Commonly Between 50-100°F for Microbial Growth
- Ideal Temperatures Vary Greatly Between Taxa
- Similar to Human Ideal Temperatures

<table>
<thead>
<tr>
<th>Microbial</th>
<th>Temperature Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cladosporium</strong></td>
<td>0-28C (32-82F)</td>
</tr>
<tr>
<td><strong>Curvularia</strong></td>
<td>10-40C (50-104F)</td>
</tr>
<tr>
<td><strong>Yeast</strong></td>
<td>27-38C (80-100F)</td>
</tr>
<tr>
<td><strong>Phoma</strong></td>
<td>10-35C (50-95F)</td>
</tr>
<tr>
<td><strong>Rhizopus</strong></td>
<td>No Data</td>
</tr>
<tr>
<td><strong>Acremonium</strong></td>
<td>&gt;30C (&gt;86F)</td>
</tr>
<tr>
<td><strong>Penicillium</strong></td>
<td>8-35C (46-95F)</td>
</tr>
</tbody>
</table>
Relationships Between HVAC Systems and Microbial Growth

Nutrient Accumulation

- Deposition (Fan Blade, Duct Work)
- Adsorption (Sticking of Particles on Surfaces)
- Electro Static Precipitation (All Interior Surfaces)
- Absorption (Evaporator Coil, Paper Label)
- Gravity
- Increased Surface Area with Age

Simple Truth: An HVAC System is a Nutrient Sink
Relationships Between HVAC Systems and Microbial Growth

Moisture Sources

- HVAC Systems Create Conditions for Microbial Growth
- Occupant Created Moisture (Cooking, Bathing, Unconditioned Outside Air, Deferred Maintenance, Irregular Thermostat Controls)
Relationships Between HVAC Systems and Microbial Growth

Temperature Comparison between Air Handler Unit (AHU) Supply and Microbial Growth

- **Cladosporium**
  - <35°F

- Temperature Range for AHU Interior
  - ≈ 35°F

- Microbial Temperature Range
  - ≈ 50°F

- 50-55°F Common Temperature of HVAC Supply Air
  - ≈ 60°F

- ≈ 100°F
Condensation Inside HVAC Air Handlers

Psychrometrics Inside HVAC System

\[
Q_{in} \frac{4}{m} = h_1 - h_4
\]
Condensation Inside HVAC Air Handlers

HVAC Issues that Result In Excess Condensation

- Increased Latent Heat Load
- Refrigerant Low/High
- Introduction of Non-conditioned Air
- Clogged Filter
- Fan Always “on”
- Obstructed Evaporator Coils/Low Fan Speed (Super Cooled Air)
- Series Wiring Configuration in a Humid Environment
- Continuously Full Primary Drain Pan
Test Procedures

Sample Surfaces & Observations
<table>
<thead>
<tr>
<th>Prestige #</th>
<th>Fungal ID</th>
<th>Fungal structures observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client sample ID</td>
<td>Location</td>
<td></td>
</tr>
<tr>
<td>180309-03-046</td>
<td>TL-1LR AHU Cabinet Wall</td>
<td>Cladosporium Phoma, spores, conidiophores, hyphae, pycnidia, hyphae</td>
</tr>
<tr>
<td>180309-03-047</td>
<td>TL-2LR AHU Evaporator Coil</td>
<td>Cladosporium Phoma, spores, conidiophores, hyphae, pycnidia, hyphae</td>
</tr>
<tr>
<td>180309-03-048</td>
<td>TL-3LR Bedroom 3 Ceiling @ SAG</td>
<td>Cladosporium Phoma, spores, conidiophores, hyphae, pycnidia, hyphae</td>
</tr>
</tbody>
</table>
Test Procedures

Determine Conditions at Sample Location

Supply Registers/Ducts
- Visible Condensation
- Temperatures

HVAC Air Handler
- Visible Condensation on Interior/Exterior Surfaces
- Supply and Return Temperature (ΔT)
- Relative Humidity (Return Duct Only)
Test Procedures
Comparison of Old and New HVAC Systems

Old System
• Historic Condensate Issues
• $\Delta T$
• Examine Evaporator Coil
• Mold on Duct Work
• Dust Precipitation/Air Leaks
• Thermostat and Humidistat Settings
• Wiring Configuration
• Approximate Cooling Capacity per Living Area (tons/sq ft)
• Effective Filter Fitting
Test Procedures
Comparison of Old and New HVAC Systems

New System
• Evidence of Condensate Issues
• $\Delta T$
• Thermostat Settings
• Approximate Cooling Capacity per Living Area (tons/sq ft)
• Excess Filtering
How to Mitigate Microbial Growth

Duct Cleaning

- Removes Bacterial and Fungal Mass
- Temporary Solution
- Increases Air Flow/Reduces Friction
- Reduces Nutrient Sources
How to Mitigate Microbial Growth

Coil Cleaning

- Removes Bacterial and Fungal Mass
- Temporary Solution
- Increases Air Flow
- Reduces Nutrient Sources
- Increases HVAC Efficiency

BEFORE

AFTER
How to Mitigate Microbial Growth

Register Cleaning

• Temporary Solution
• Indicator of Bigger Issue (Elevated RH%, Excess Latent Heat, Super-cooled Air)
How to Mitigate Microbial Growth

Application of Chemicals (i.e., biocides)

- Temporary Solution
- Toxic to Humans
- Remove Moisture to Avoid Use
- Manual Removal of Visible Growth is Recommended
Can We Control Microbial Growth?

How Many Spores Pass Through an Air Handler?

<table>
<thead>
<tr>
<th>Microorganism</th>
<th>Count</th>
<th>Spores per Cubic Meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ascospores</td>
<td>6</td>
<td>320</td>
</tr>
<tr>
<td>basidiospores</td>
<td>1</td>
<td>53</td>
</tr>
<tr>
<td>Cercospora</td>
<td>1</td>
<td>53</td>
</tr>
<tr>
<td>Cladosporium</td>
<td>4</td>
<td>210</td>
</tr>
<tr>
<td>Curvularia</td>
<td>1</td>
<td>53</td>
</tr>
<tr>
<td>Ganoderma</td>
<td>1</td>
<td>53</td>
</tr>
<tr>
<td>hyphal fragments</td>
<td>1</td>
<td>53</td>
</tr>
<tr>
<td>Pen/Asp-like</td>
<td>8</td>
<td>420</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>1,200</strong></td>
</tr>
</tbody>
</table>

- Assuming a 1 air change per hour (ACH) rate
- ≈63% mix of outside air after 1 hour at 1 ACH
- 1,200 spores per cubic meter
- Over 15 years
- Assuming 3,400 cubic meters per hour through air handler

\[
\frac{3400\text{ m}^3/\text{hr}}{1\text{ hr}} \times \frac{1200\text{ spores/m}^3}{\text{m}^3} = 4 \times 10^6\text{ spores/hr}
\]

\[
4 \times 10^6\text{ spores/hr} \times \frac{8760\text{ hr}}{1\text{ yr}} = 3.5 \times 10^{10}\text{ spores/yr}
\]
Can We Control Microbial Growth?

UV Light

- Minimizes Bacteria and Fungal Growth
- Closed Circuit Most Efficient
- Diminished Effectiveness with Increased Distance from Source
- Certain Taxa Affected
- Debris on UV Light

Can We Control Microbial Growth?

**AHU HEPA Filter**

- Normally Independent System
- Minimum Efficiency Reporting Value (MERV) Rating
- True HEPA is >14
- Reduces Air Flow Through AHU

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>General Surgery</th>
<th>Hospital Inpatient Care</th>
<th>Smoking Lounges</th>
<th>Superior Commercial Buildings</th>
<th>Superior Residential</th>
<th>Legionella</th>
<th>Humidifier Dust</th>
<th>Milled Flour</th>
<th>Auto Emissions</th>
<th>Welding Fumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 0.30-1.0 pm</td>
<td>General Surgery</td>
<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
</tr>
<tr>
<td>15 All Bacteria</td>
<td>General Surgery</td>
<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
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<tr>
<td>14 Most Tobacco Smoke</td>
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<td>Smoking Lounges</td>
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<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
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<tr>
<td>13 Proplet Nuceli</td>
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<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
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<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
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<tr>
<td>12 1.0-3.0 pm</td>
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<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
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<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
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<tr>
<td>11 Humidifier Dust</td>
<td>General Surgery</td>
<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
</tr>
<tr>
<td>10 Milled Flour</td>
<td>General Surgery</td>
<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
</tr>
<tr>
<td>9 Welding Fumes</td>
<td>General Surgery</td>
<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
</tr>
<tr>
<td>8 3.0-10.0 pm</td>
<td>General Surgery</td>
<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
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<td>Humidifier Dust</td>
<td>Milled Flour</td>
<td>Auto Emissions</td>
<td>Welding Fumes</td>
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<td>7 Hair Spray</td>
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<td>Hospital Inpatient Care</td>
<td>Smoking Lounges</td>
<td>Superior Commercial Buildings</td>
<td>Superior Residential</td>
<td>Legionella</td>
<td>Humidifier Dust</td>
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<td>Auto Emissions</td>
<td>Welding Fumes</td>
</tr>
</tbody>
</table>

- Dusting Aids
- Cement Dust
- Pudding Mix
- >10.0 pm Particle Size
- Pollen
- Dust Mites
- Sanding Dust
- Spray Paint Dust
- Textile Fibers
- Carpet Fibers
- Industrial Workplace
- Paint Booth Inlet
- Minimal Filtration
- Residential
- Window A/C Units

*2019 IAQA Annual Meeting*
Can We Control Microbial Growth?

Air Scrubbers w/ HEPA Filters

- Three Stage Filters Used
- True HEPA Filters are Costly
- Bulky Equipment
- Excess Power Requirements
- Very Efficient (Particle Removal)
Can We Control Microbial Growth?

Moisture Control

• Indication of HVAC Issues
• Reduced Moisture=Reduced Microbial Growth
• Bulky Equipment in Some Cases
• Excess Power Requirements
• Odor Reduction
Can We Control Microbial Growth?

Remove Nutrient Sources

- Reduces Microbial Growth
- Most Effective on Non-porous Surfaces
- Replace Carpet with Non-porous Flooring
- Temporary Solution
- Complete Nutrient Removal is Impossible
Conclusions

Simple Truths

HVAC Systems . . .
• produce moisture
• are intrinsically dirty
• encourage growth of a selected group of microbial taxa

Maintenance and Proper Operation are Critical for Peak Efficiency
Bibliography


Almaguer, M., Amador, V., Batista, A. Effect of temperature on growth and germination of conidia in Curvularia and Bipolaris species isolated from the air, Aerobiologia, 2012

Aldred, D., Magan, N., Lane, B., Influence of water activity and nutrients on growth and production of squalestatin S1 by a Phoma sp., Journal of Applied Microbiology
Questions?

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