Spore Migration in the Indoor Environment

AIHCE 2007
Roundtable 202
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Visible & Hidden Mold

- **Visible Mold**
  - Colonized a substrate
  - Formed fungal mycelia
  - Sufficiently developed to be visible to the naked eye
  - May be active, dormant or non-viable

- **Micro-colonies**, need microscope to see colonies.

1. Assessment, Remediation, and Post Remediation Verification of Mold in Buildings; AIHA Guideline 3 - 2004
Visible & Hidden Mold

- **Hidden Mold**
  - Visible mold growth within a building
  - Concealed from view during normal walk thru inspection
  - May be in/on structural, mechanical, or electrical systems or finishes, furnishings, or fixtures
  - May be in HVAC system or building cavities
  - May be active, dormant or non-viable

1. Assessment, Remediation, and Post Remediation Verification of Mold in Buildings; AIHA Guideline 3 - 2004
Mold Exposures

- Primarily inhalation
- Skin contact
- Ingestion
Inhalation Exposure Mechanisms

- **Source** – visible or hidden mold
- **Pathway** – route between source and receptor
- **Driving force** – energies that transport bioaerosols thru the pathway

\[ \text{Source} + \text{Pathway} + \text{Driving force} = \text{Exposure} \ \text{[when receptor is present]} \]
Structural Mold Sources

- Wall cavities
- Wall sheathing
- Attics
- Crawl spaces
- Ceiling interstitial spaces
- Basements
- Other exposed and hidden surfaces
HVAC/Mechanical Systems

- Mold sources
  - Condensate collection areas
  - Cooling coil housing insulation
  - Duct liners
  - Pipe insulation
  - Duct coverings
Air Dispersal

- Mold Spores –
  - Most “Born to Fly”
- Predominant method of spore dissemination in fungal reproduction
Other Dispersal

- Water – leaks and flow can transport spores to new locations
- Insects/animals – contact with mold colony can transport spores
Common Building Pathways

- Chases
- Interstitial spaces
- Conduit & Pipes
- Gaps around plumbing & electrical fixtures
- Cracks and gaps in walls, floors, ceilings
- Unsealed wall penetrations
- Construction joints
- Window frame assemblies (even good windows can leak 0.3 cfm/sq.ft.!)
Building Envelope Pathways

Window

Recessed Ceiling light

Electrical Outlet
Air Movement Pathways
Air Infiltration Rates

- Tightly constructed homes = 0.25 to 0.35 ACH.
- A typically built newer home = about 1.75 ACH.
- Older poorly weather-stripped and sealed homes may be >2.5 ACH.

- A 2500 sq. ft. home with 8 ft ceilings = about 20,000 cu. ft of air.
- Between 5,000 and 50,000 cu. ft. of air per hour would be expected to move through that home due to infiltration.

ACH = Air Changes per Hour
Air Infiltration Pathways

Chart from LSU study

- Soleplate: 25.0%
- Exterior Windows: 12.0%
- Wall Outlets: 20.0%
- Exterior Doors: 5.0%
- Bath Vent: 1.0%
- Recessed Spot Lights: 5.0%
- Exterior Walls: 5.0%
- Range Vent: 5.0%
- Fireplace: 5.0%
- Other: 3.0%
- Duct System: 14.0%
- Dryer Vent: 3.0%
Air Infiltration Pathways
In Unsealed Framed Wall Cavities

ASHRAE research project RP 438, Colliver, D.G.; 1994
Driving Forces

- **Pressure differential causes**
  - Wind/air movement
  - Stack effect
  - Mechanical systems
  - Temperature gradients (stack effect)

- **Gases/vapors move:**
  - From areas of higher concentration to areas of lower concentration
  - From warmer areas to cooler areas

- **Physical Disturbances**
HVAC - Driving Force

- Air Currents
- Pressure Differentials – Unbalanced HVAC
- Exhaust fans
  - Kitchen
  - Bath
  - Whole house
  - Attic
  - Clothes dryer
- Leaking Ducts
  - Pressurize some spaces, depressurize others
Disturbance of a few square feet of vinyl wall covering over moldy drywall increased Asp/Pen in air concentration by 1,000X
Driving Force

- Reduced air pressure = driving force
- Air infiltration from attic = pathway in wall framing
More Pressure Differential Illustrations

- Adjoining closed rooms with unequal supply and return ventilation rates
- Leaking supply ducts in attics or crawlspaces can place occupied space under negative pressure
- “Stack-Effect” can create negative pressure on lower floors and positive pressure on upper floors
Air Pressure Differentials

- A recent study \(^1\) determined that mechanical exhaust in apartment buildings caused negative pressure of 5 – 20 Pa.
- This resulted in transport of 1 – 3 micron spores thru floor cracks from the crawlspace.
- Larger spores were transported thru a 15 mm pipe penetration.

Hidden Mold Impact

- **Case 1** – new home – midwest locale
  - Odor complaint
  - A few small patches of visible mold in basement ($< 1 \text{ ft}^2$ – floor joists & subflooring)
  - Otherwise, no visible mold or water staining
  - Home was immaculate
### Case 1 Air Testing

<table>
<thead>
<tr>
<th>Location</th>
<th>Viable Mold cfu/m³</th>
<th>Dominant Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor</td>
<td>483 (ave.)</td>
<td>Cladosporium</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; fl lv rm</td>
<td>940 (ave.)</td>
<td>89% Asp/Pen</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; fl kit</td>
<td>995 (ave.)</td>
<td>94% Asp/Pen</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; fl fam rm</td>
<td>1068 (ave.)</td>
<td>90% Asp/Pen</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; fl rms</td>
<td>446 (ave.)</td>
<td>87% Asp/Pen</td>
</tr>
<tr>
<td>Basement</td>
<td>822 (ave.)</td>
<td>93% Asp/Pen</td>
</tr>
</tbody>
</table>
Case 1 Investigation

- Surface samples of small areas of visible mold on basement lumber showed Penicillium and various Phylloplanes.
- No current moisture found.
- Insulation samples pulled from some 1st floor wall cavities showed a range of non-detect to significant amounts of A. Versicolor, A. glaucus or Aureobasidium pullulans.
Case 1 Outcome

- Owners were allergic to mold
- Owners moved out
- Builder was sued
- Suspected that construction delay in installation of exterior brick cladding allowed water infiltration of insulated wall cavities
- Air movement in wall cavities believed to deliver mold spores into living space
- Final resolution unknown
Hidden Mold Impact

- Case 2 – Southern Climate Home
  - Musty odor throughout house
  - No significant visible mold on interior surfaces
  - Hidden mold growth found in attic and wall cavities
## Case 2 Air Testing

<table>
<thead>
<tr>
<th>Location</th>
<th>Spore Trap Mold S/m³</th>
<th>Dominant Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoors</td>
<td>5994 (ave.)</td>
<td>50% Asp/Pen</td>
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<tr>
<td></td>
<td></td>
<td>50% Basidios</td>
</tr>
<tr>
<td>Fam Rm 1st fl</td>
<td>849 (ave.)</td>
<td>42% Asp/Pen</td>
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<tr>
<td></td>
<td></td>
<td>15% Stachy</td>
</tr>
<tr>
<td>Attic</td>
<td>29,470 (ave.)</td>
<td>97% Asp/Pen</td>
</tr>
<tr>
<td>Bedrooms – 2nd fl</td>
<td>21,263 (ave.)</td>
<td>87% Asp/Pen</td>
</tr>
</tbody>
</table>
Case 2 Surface Sampling

- Surface samples/bulks from attic, wall and ceiling cavities showed:
  - Asp/Pen species dominated
  - Stachybotrys present in significant % in some samples
Case 2 Outcome

- AC supply ducts in attic leaked air
  - AC air leaks caused condensation to form on attic ducts
  - Air leaks also caused interior of home to be under negative pressure (-3 to -10 Pa)
  - Numerous unsealed ceiling and wall penetrations found
  - Infiltration of warm humid outdoor air thru walls (est. 200-400 cfm) = condensation = mold growth
  - Infiltrating air carried spores into living spaces
Hidden Mold Impact

- **Case 3 - West Coast Climate**
  - Apartment building
  - History of leaks in some units due to wind driven rain
  - No visible mold on exposed interior surfaces
  - Hidden mold growth found in wall cavities
## Case 3 - Air Testing

<table>
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<tr>
<th>Location</th>
<th>Viable Mold cfu/m³</th>
<th>Dominant Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoors</td>
<td>320 (ave.)</td>
<td>74% Clad sp. + Alternaria</td>
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<tr>
<td></td>
<td></td>
<td>19% Asp/Pen</td>
</tr>
<tr>
<td>Leaky Apts.</td>
<td>646 (ave.)</td>
<td>15% Clad sp. + Alternaria</td>
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<tr>
<td></td>
<td></td>
<td>76% Asp/Pen</td>
</tr>
<tr>
<td>Non-Leaky Apts.</td>
<td>493 (ave.)</td>
<td>66% Clad sp. + Alternaria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11% Asp/Pen</td>
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</tbody>
</table>
Case 3 Leaking Apartment

Typical exterior wall – no visible mold (atypical air test)

Interior cavity with hidden visible mold
Case 3 - Outcome

- Defects in building envelope allowed wind driven rain to infiltrate wall cavities of some apartments.
- Hidden mold growth developed in those wall cavities.
- Air infiltration carried spores from the wall cavities into the living space of those apartments.
- Profile of airborne mold taxa significantly different in affected apartments.
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