AIHA members receive discounts and free shipping on all Bookstore orders.  
JOIN NOW AND SAVE!

Recognition, Evaluation, and Control of Indoor Mold, 2nd edition

2020 Bestseller!

Book
Member $145  
Non-Member $205  
Student $145

PDF
Member $145  
Non-Member $205  
Student $145

KIT
Member $217.50  
Non-Member $307.50  
Student $217.50

ORDER the BOOK  
ORDER the PDF  
ORDER the KIT
AIHA’s mold reference provides the most current and comprehensive discussion on the basic practice of identifying mold damage, the evaluation of the samples that are collected and the process of remediation.

Edited by
Ling-Ling Hung, PhD
Steven M. Caulfield, PE, CIH, LEED® AP
and J. David Miller, PhD, FAIHA®
Table of Contents

Preface ......................................................................................................................................... xiii
Section Editors and Contributing Authors ................................................................................. xvii

Section 1: Underlying Principles and Background for Evaluation and Control

Chapter 1: Indoor Mold: Basis for Health Concerns ................................................................. 1
  1.1 Dampness, Mold, and Health .............................................................................................. 3
    1.1.1 Background .............................................................................................................3
    1.1.2 Current Knowledge about Dampness-Related Health Effects .............................. 3
    1.1.3 Assessing Health-Relevant Dampness/Mold: Epidemiologic Evidence ............. 5
    1.1.4 Summary: Dampness-Related Health Risks ........................................................... 6
  1.2 Exposure Considerations ..................................................................................................... 6
    1.2.1 Introduction ............................................................................................................6
    1.2.2 Exposure Difficulties ............................................................................................6
    1.2.3 Toxins Associated with Mold Particles ................................................................. 7
    1.2.4 Risk Management Role of the Industrial Hygienist ............................................... 7
  1.3 Clinical Issues Regarding Moisture, Mold, and Disease .................................................... 8
    1.3.1 Specific Diseases and Conditions ........................................................................... 9
    1.3.2 Asthma .................................................................................................................... 9
    1.3.3 Allergic Bronchopulmonary Mycosis (ABPM) ..................................................... 10
    1.3.4 Allergic Fungal Sinusitis (AFS) ........................................................................... 10
    1.3.5 Hypersensitivity Pneumonitis (HP) ...................................................................... 10
    1.3.6 Diagnosing and Treating Fungal Allergy .............................................................. 10
  1.4 References ......................................................................................................................... 10

Chapter 2: Guidance for Assessment and Remediation of Indoor Microbial Growth ............ 17
  2.1 Documents Published Prior to 2019 .................................................................................. 17
    2.1.1 Voluntary Guidance ............................................................................................... 17
  2.2 Enforceable Regulations .................................................................................................. 18
# Reference List

## Chapter 3: Accountability of the Industrial Hygienist: Constituencies and Co-Investigators

- **3.1 Assessment**
  - 3.1.1 Physical Site

- **3.2 Occupants**
  - 3.2.1 Contractor

- **3.3 Role of Public Health Agencies**
  - 3.3.1 Federal
  - 3.3.2 State and Local

- **3.4 References**

## Chapter 4: Mold Ecology: Recovery of Fungi from Certain Moldy Building Materials

- **4.1 Factors that Determine the Occurrence of Biodeteriogenic Fungi**
- **4.2 Fungi on Insulation**
- **4.3 Fungi on Gypsum Wallboard**
- **4.4 Cellulose-Based Materials**
- **4.5 Summary**
- **4.5 References**

## Section 2: Building Evaluation

### Chapter 5: Science and Buildings

- **5.1 Understanding Moisture in Buildings**
- **5.2 Moisture Dynamics**
- **5.3 Prevention of Water Problems in Buildings**
- **5.4 Rain and Groundwater**
- **5.5 Plumbing**
- **5.6 Condensation**
- **5.7 Water Vapor Sources**
- **5.8 Built-in Water**
- **5.9 References**

### Chapter 6: On-Site Considerations

- **6.1 Public and Occupant Relations**
  - 6.1.1 Building Occupants
  - 6.1.2 Interacting with Health Professionals
  - 6.1.3 The Larger Community

- **6.2 Safety and Health Considerations**
  - 6.2.1 Health and Safety of Investigators during Mold Investigations
  - 6.2.2 Precautions during Inspection
  - 6.2.3 Disturbance of Hazardous Materials and Potential Release into the Air

---

*Copyright AIHA® For personal use only. Do not distribute.*
### Chapter 9: Documentation

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.1</td>
<td>Reasons for Documentation</td>
<td>105</td>
</tr>
<tr>
<td>9.2</td>
<td>Photography</td>
<td>106</td>
</tr>
<tr>
<td>9.2.1</td>
<td>Still Photography</td>
<td>106</td>
</tr>
<tr>
<td>9.2.2</td>
<td>Video Photography</td>
<td>106</td>
</tr>
<tr>
<td>9.3</td>
<td>Documenting Extent and Density of Visible Mold</td>
<td>106</td>
</tr>
<tr>
<td>9.3.1</td>
<td>Field Notes</td>
<td>107</td>
</tr>
<tr>
<td>9.3.2</td>
<td>Drawings</td>
<td>107</td>
</tr>
<tr>
<td>9.3.3</td>
<td>Moisture Measurement</td>
<td>107</td>
</tr>
<tr>
<td>9.3.4</td>
<td>‘Hidden’ Mold</td>
<td>108</td>
</tr>
<tr>
<td>9.4</td>
<td>Occupant Locations</td>
<td>108</td>
</tr>
<tr>
<td>9.5</td>
<td>Duration of Growth: Active Growth / Dry Condition</td>
<td>108</td>
</tr>
<tr>
<td>9.6</td>
<td>Documentation for Forensic Purposes</td>
<td>108</td>
</tr>
<tr>
<td>9.7</td>
<td>Example Documentation (Forms and Checklist, Non-medical)</td>
<td>108</td>
</tr>
<tr>
<td>9.7.1</td>
<td>Systematic Collection of Consistent Data</td>
<td>108</td>
</tr>
<tr>
<td>9.7.2</td>
<td>Environmental Sample Data Forms</td>
<td>109</td>
</tr>
<tr>
<td>9.7.3</td>
<td>Visual Inspection Forms</td>
<td>110</td>
</tr>
<tr>
<td>9.8</td>
<td>References</td>
<td>110</td>
</tr>
</tbody>
</table>

### Section 3: Evaluation and Interpretation of Data Collected Prior to Developing a Remediation Strategy

#### Chapter 10: Sampling Design Strategy

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.1</td>
<td>Hypothesis Formulation and Testing</td>
<td>127</td>
</tr>
<tr>
<td>10.2</td>
<td>Sampling in Building Assessments</td>
<td>128</td>
</tr>
<tr>
<td>10.2.1</td>
<td>Use of Air Sampling in Building Assessment</td>
<td>128</td>
</tr>
<tr>
<td>10.2.2</td>
<td>Contribution of Surface Sampling to Building Assessments</td>
<td>129</td>
</tr>
<tr>
<td>10.2.3</td>
<td>Structural Testing and Wall Cavity Inspections</td>
<td>129</td>
</tr>
<tr>
<td>10.3</td>
<td>Contents Sampling</td>
<td>129</td>
</tr>
<tr>
<td>10.4</td>
<td>Sampling During and Following Remediation</td>
<td>130</td>
</tr>
<tr>
<td>10.4.1</td>
<td>Sampling During Mold Remediation Surveillance</td>
<td>130</td>
</tr>
<tr>
<td>10.4.2</td>
<td>Post Remediation Sampling</td>
<td>130</td>
</tr>
<tr>
<td>10.5</td>
<td>Sampling Protocols and Techniques</td>
<td>130</td>
</tr>
<tr>
<td>10.5.1</td>
<td>Occupant Notification</td>
<td>130</td>
</tr>
<tr>
<td>10.5.2</td>
<td>Isolation of the Area of Interest</td>
<td>131</td>
</tr>
<tr>
<td>10.5.3</td>
<td>Indoor Sample Location</td>
<td>131</td>
</tr>
<tr>
<td>10.5.4</td>
<td>Numbers of Samples</td>
<td>131</td>
</tr>
<tr>
<td>10.5.5</td>
<td>Outdoor Air Samples</td>
<td>131</td>
</tr>
<tr>
<td>10.5.6</td>
<td>Quality Control Samples</td>
<td>131</td>
</tr>
<tr>
<td>10.5.7</td>
<td>Sample Numbering</td>
<td>132</td>
</tr>
<tr>
<td>10.5.8</td>
<td>Turnaround Time</td>
<td>132</td>
</tr>
<tr>
<td>10.5.9</td>
<td>Species Identification</td>
<td>132</td>
</tr>
<tr>
<td>10.5.10</td>
<td>Calibration of Sampling Devices</td>
<td>132</td>
</tr>
<tr>
<td>10.5.11</td>
<td>Decontamination of Samplers</td>
<td>132</td>
</tr>
</tbody>
</table>
10.6 Handling of Samples after Collection ................................................................. 132
10.7 Considerations of the Microbiology Laboratory .................................................. 133
  10.7.1 Need for Written Standard Operating Procedures ........................................ 133
  10.7.2 QA/QC ........................................................................................................ 134
  10.7.3 Analyst Certification ..................................................................................... 135
10.8 References .......................................................................................................... 136

Chapter 11: Sampling Methods ............................................................ 137
  11.1 Sampling of Ambient Air .................................................................................. 137
  11.1.1 Air Sampling Methods Using Culture-Based Analysis ................................. 137
  11.1.2 Air Sampling Methods Using Non-culture-Based Analyses (Spore Traps) ...... 138
  11.1.3 Sampling Methods Using Both Culture-Based and Non-culture-Based Analyses ........................................................................................................... 140
  11.1.4 Sampling Methods Using Chemical Analysis .............................................. 142
  11.2 Sampling within Wall Cavities ......................................................................... 143
  11.3 Surface Sampling ............................................................................................ 143
  11.3.1 Swab ........................................................................................................... 144
  11.3.2 Settled Dust ................................................................................................ 144
  11.3.3 Bulk Material ............................................................................................. 145
  11.3.4 Surface Contact Plating ............................................................................. 146
  11.3.5 Tape Lifts ................................................................................................... 146
11.4 References .......................................................................................................... 147

Chapter 12: Laboratory Analytical Methods ........................................ 151
  12.1 Direct Microscopy ............................................................................................ 151
  12.1.1 Source Samples .......................................................................................... 151
  12.1.2 Spore Counting ......................................................................................... 153
  12.2 Culture Assay .................................................................................................. 155
  12.2.1 Dilution Culture versus Direct Plating ....................................................... 155
  12.2.2 Controls .................................................................................................... 156
  12.2.3 Interpreting Results from Culture Analysis .............................................. 156
  12.2.4 Units for Reporting Culture-Based Results .............................................. 157
  12.3 DNA Diagnostics ............................................................................................ 157
  12.3.1 Background .............................................................................................. 157
  12.3.2 MSQPCR .................................................................................................. 157
  12.3.3 High-Throughput DNA Sequencing ......................................................... 158
  12.3.4 Advantages and Disadvantages ............................................................... 159
  12.3.5 Quantitative Uncertainties ....................................................................... 159
  12.3.6 Qualitative Uncertainties ........................................................................ 159
  12.4 Mycotoxins ...................................................................................................... 161
  12.5 Microbial Volatile Organic Compounds ......................................................... 161
    12.5.1 MVOC Sample Analysis ............................................................ 161
    12.5.2 Data Analysis ......................................................................................... 162
    12.5.3 Data Interpretation ............................................................................... 162
  12.6 (1→3)-β-D-glucan ......................................................................................... 162
    12.6.1 Analysis of (1→3)-β-D-glucan ............................................................. 162
    12.6.2 Interpretation of Results ....................................................................... 163
  12.7 Immunochemical Methods ............................................................................ 163
    12.7.1 Advantages and Limitations ................................................................. 164
12.8 References .......................................................................................................... 165

Chapter 13: Documentation and Reporting ........................................... 169
  13.1 Field Notes ...................................................................................................... 169
    13.1.1 Documentation of Real-Time Measurements ....................................... 170
    13.1.2 Fungal Sample Collection Notes ........................................................... 170
    13.1.3 Laboratory Submittal and Chain-of-Custody Forms .............................. 170

Copyright AIHA® For personal use only. Do not distribute.
Section 4: Remediation and Control

Chapter 14: Remediation: Scope, Roles, and Risk Communication............ 177

14.1 Justification, Definition, Goals and Quality Assurance/Quality Control ........ 177
  14.1.1 Management of Materials Based on Porosity ........................................ 178
  14.1.2 Importance of Minimizing Aerosolization of Mold Particulate during Remediation ........................................ 178
  14.1.3 Quality Control during Remediation ...................................................... 178

14.2 Scopes of Work, Work Plans, and Project Specifications .......................... 179
  14.2.1 Scope of Work ..................................................................................... 179
  14.2.2 Work Plan ......................................................................................... 180
  14.2.3 Project Specifications .......................................................................... 180
  14.2.4 Example Content of Project Specifications ........................................ 180
  14.2.5 Types of Specifications ....................................................................... 181

14.3 Roles in Remediation ............................................................................ 181
  14.3.1 Building Owner or Manager (Owner/Manager) ........................................ 182
  14.3.2 Remediation Company ......................................................................... 182
  14.3.3 Industrial Hygienist (Competent Professional, Independent Environmental Professional) ........................................ 183

14.4 Risk Communication ............................................................................ 184
  14.4.1 Risk Communication in Public and Commercial Office Buildings ....... 185
  14.4.2 Risk Communication in Schools .......................................................... 185
  14.4.3 Risk Communication in Health Care Facilities ...................................... 186

14.5 Communication Principles ................................................................... 187
14.6 References .............................................................................................. 188

Chapter 15: Remediation of Moisture Resulting from Sudden and Intrusive Water Entry................................................................. 189

15.1 Rapid Response ...................................................................................... 190
15.2 Assessment of Extent and Degree of Water Intrusion .............................. 190
15.3 Removal of Bulk Water .......................................................................... 190
15.4 Development of Drying and / or Material Removal Plan ........................... 190
15.5 Isolation and Environmental Control ...................................................... 190
15.6 Dehumidification and Progress Control .................................................. 191
15.7 Air Movement and Evaporation ............................................................. 191
15.8 Documentation ....................................................................................... 191
15.9 IICRC Categorization of Water ............................................................... 191
15.10 Time ..................................................................................................... 192
15.11 Drying Systems and Equipment ............................................................. 192
15.12 Training and Certification ...................................................................... 192
15.13 References ........................................................................................... 192
Chapter 16: Selecting Remediation Strategies for Moisture and Mold

16.1 Problems Associated with Using Quantity of Mold as a Remediation Metric
16.2 Assessment of Dampness / Moisture Damage
16.3 Assessment of Mold Severity as a Remediation Metric
16.3.1 Location
16.3.2 Extent
16.3.3 Material
16.4 Additional Consideration in Using the Mold Cleanup Matrix
16.4.1 Occupant Susceptibility Considerations
16.4.2 HVAC System Remediation Considerations
16.5 References

Chapter 17: Remediation: Procedural Considerations

17.1 Review of Current Guidance on Containment Based on Extent of Visible Contamination
17.1.1 Institute of Medicine
17.1.2 New York City Department of Health
17.1.3 U.S. Occupational Safety and Health Administration
17.1.4 Canadian Construction Association
17.1.5 Institute of Inspection, Cleaning, and Restoration Certification
17.2 Biocides and Antimicrobials
17.2.1 Antimicrobial Applications
17.2.2 Should Antimicrobials be used during or after Remediation?
17.2.3 What are Appropriate Uses?
17.2.4 Precautions during Biocide Application
17.2.5 PPE and Antimicrobials
17.2.6 Other Related Issues
17.3 Worker Safety and Health during Remediation Activities
17.3.1 Regulatory Considerations
17.3.2 Hazards Created by the Use of PPE
17.3.3 Other Hazards Encountered During Demolition
17.3.4 Selection of Respiratory Protection
17.4 Disposal of Mold-Contaminated Materials
17.5 Remediation of Hidden Mold
17.5.1 Definition
17.5.2 The Need to Remediate Hidden Mold
17.5.3 Use of Building Pressurization to Control Hidden Growth
17.5.4 Property Damage Resulting from Hidden Mold Growth
17.5.5 Hidden Mold Growth in the HVAC Systems
17.6 Recommendation to Remediate all Visible Growth
17.7 Remediation of Hidden Mold Based on Viability and Taxa
17.7.1 Re-inspection during Remediation
17.7.2 When to Leave Concealed Growth in Place
17.8 References

Chapter 18: Judging the Effectiveness of Remediation

18.1 Performance Criteria
18.2 The White Glove Test
18.3 Measurement of Settled Dust
18.4 Species Determination of Settled Dust
18.5 Final “Clearance”
18.5.1 Project Overview
18.5.2 Microbial Sampling
18.5.3 Microbial Air Sampling
18.6 References
Chapter 19: Mold Prevention Programs ........................................................ 219

19.1 Program Elements .................................................................................. 219
19.2 Program Description ............................................................................... 220

Chapter 20: Different Building Types: Issues to Consider ......................... 223

20.1 Introduction ............................................................................................ 223
20.1.1 Systems Approach to Moisture and Mold in the Health Care Environments... 223
20.2 Schools .................................................................................................... 224
20.2.1 Unique Characteristics/Considerations Related to this Building Type ........ 224
20.2.2 Investigation/Remediation Considerations Based on Building Type/Occupancy ... 225
20.2.3 Difference in Approach without Occupants Present .............................. 225
20.2.4 Hidden Mold Considerations ............................................................... 225
20.2.5 Financial Constraint Considerations .................................................... 225
20.2.6 Re-occupancy Considerations ............................................................. 225
20.3 Residential ............................................................................................ 225
20.3.1 Single Family Homes ........................................................................... 225
20.3.2 Multifamily Residential ....................................................................... 226
20.4 Commercial Office Buildings ................................................................. 227
20.4.1 Unique Characteristics/Considerations Applied to this Building Type ...... 227
20.4.2 Investigation/Remediation Considerations Based on Building Type/Occupancy ... 227
20.4.3 Difference in Approach without Occupants Present .............................. 227
20.4.4 Hidden Mold Considerations ............................................................... 227
20.4.5 Financial Constraint Considerations .................................................... 227
20.5 Hotel/Seasonal Buildings ....................................................................... 228
20.5.1 Unique Characteristics/Considerations to this Building Type ................ 228
20.5.2 Investigation/Remediation Considerations Based on Building Type/Occupancy ... 228
20.5.3 Difference in Approach without Occupants Present .............................. 228
20.5.4 Hidden Mold Considerations ............................................................... 228
20.5.5 Financial Constraint Considerations .................................................... 228
20.5.6 Re-occupancy Considerations ............................................................. 228
20.6 Health Care Facilities ............................................................................ 228
20.6.1 Unique Characteristics/Considerations Based on Building Type/Occupancy ... 228
20.6.2 Investigation/Remediation Considerations Based on Building Type/Occupancy ... 228
20.6.3 Difference in Approach without Occupants Present .............................. 229
20.6.4 Hidden Mold Considerations ............................................................... 229
20.6.5 Financial Constraints .......................................................................... 229
20.6.6 Re-occupancy Considerations ............................................................. 229
20.7 References ............................................................................................ 229

Appendix: Mold in Buildings – Exterior and Interior Images ....................... 231

Index ........................................................................................................... 237
Preface

Industrial hygienists are trained to understand how indoor environments may affect health in the workplace. Chemical agents such as pesticides, lead, or asbestos; physical agents such as radon or excessive heat; and biological agents such as bacteria, mold, or infectious agents; all must be managed in a responsible manner by trained practitioners. This involves the recognition of the potential of a threat to occupant health, evaluation of the threat, including measurements, when appropriate, and the design and implementation of efficient and effective strategies for mitigating or eliminating the risk. These actions comprise the public health contribution of the industrial hygienist, which are grounded in good science and engineering, effective risk communication skills, and skilled management of the investigation. These words formed the first paragraph of my preface to the first edition of the American Industrial Hygiene Association (AIHA®) ‘Green Book’ and this vision was the lens through which all changes in the present text was viewed.

A relationship between damp indoor environments and poor occupant health has been documented for centuries. Sir John Floyer was regarded as differentiating asthma from general respiratory disease. In 1726, he wrote that "There is a remarkable instance in Bonetus (1620–1680) of an asthmatic who fell into a violent fit because by going into a wine cellar where the must was fermenting"(1), that is, an indoor exposure to mold and dampness. Dr. Samuel Feinberg, the author of the influential textbook, “Allergy in Practice” (1946) wrote that “When, in 1935, I proposed the idea that sensitivity to fungus spores constituted a common cause of allergic disease, there was almost universal opposition to its acceptance.”(2)

From the mid-1970s building materials changed and ventilation rates of homes and public buildings were lowered in response to the energy crisis of the 1970s. After 1940, installations of water-cooled air conditioning for public buildings were increasing at 10% per year such that by 1965, nearly 2 billion gallons of water per day were used for this purpose.(3) An unanticipated consequence was that the first cases of what came to be called as Legionnaires Disease from building air conditioning were recorded in 1968.(4) Post war buildings were air leaky but by the mid-1990s, about a quarter of houses in the USA and Canada from the mid-1990s had less ventilation than recommended.(5,6) Indoor temperatures increased during the same period. In the UK, winter indoor living room temperatures increased from 15° to 21°C from 1960–2010. In the United States, winter indoor temperatures when someone was sleeping at home increased from the 1970s, followed by a pause in the early 1980s. Overall nighttime temperatures increased from 17°C to 21°C.(7) In 1950, air conditioning in homes was exceptional. In 1960, national prevalence in the United States was 13%, 1970, 36% and by 1980 59% ranging to 80% in some areas.(8)
There were consequences to these changes in materials and ventilation rates. House dust mites were only detected homes in the US and Canada and in low prevalence in samples from the late 1960s.\textsuperscript{9,10} Whereas mold does not grow very well on traditional lime plaster, wetted paper-faced gypsum wallboard is comparatively prone to fungal damage.\textsuperscript{11} Taken together, the use of generally more susceptible building materials\textsuperscript{12}, combined changes of building materials, increased risk of condensation failures and designs and construction details\textsuperscript{13} conspired to make an unacceptable prevalence of our homes and non-industrial buildings with mold damage.

Mold and dampness and health came into the public health agenda in the late 1980s, many organizations adopted strong positions on either side: mold explained all building associated disease or, alternatively, mold in buildings explained all manner of diseases. In contrast, AIHA\textsuperscript{a} has been a leader in recognizing that, as noted in the AIHA\textsuperscript{a} position paper on mold, investigations of apparent or suspected mold-related health complaints must consider all possibilities. While mold damage comprises a large percentage of problem situations, studies of occupant complaints find that a high percentage have an outdoor air make up below the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard, inappropriate and inadequate temperature and humidity levels, inadequate control of contaminants from outdoor air, contaminants arising from equipment or activities within the building or house and poor air distribution."

The challenge was and remains to apply existing techniques and knowledge in a prudent and reasonable manner to manage damage and prevent disease. Unfortunately, instrument readings alone may never be able to locate hidden damage and help define safe levels of exposure. However, the basic practice for identifying mold damage and the process of remediation has been stable since the appearance of the New York City Department of Health guidelines in 1993, and all cognizant authorities since then have endorsed those approaches. As a public health issue, mold has been treated in a regulatory sense as an avoidable contaminant that should be reduced to as low as reasonably achievable levels. Protection of public health demands a rational approach to managing issues, which means balancing risks as we understand them within an environment of imperfect knowledge.

This second edition of the AIHA Green Book remains unique amongst those that address the topic of mold in the built environment. First, it is comprehensive, and, second, this guidance publication was written by a diverse mix of qualified and experienced practitioners, academics and government officials and scientists. Much of the text is new. The text that remains from the first edition was updated as appropriate particularly with updated references.

The major change in this second edition reflects the convergence in thinking between public health\textsuperscript{12,13} occupational medicine\textsuperscript{14} and engineering communities\textsuperscript{15} with respect to the health implications of mold and dampness on public health. The health sections of this edition reflects those changes. The strong voice of the practitioner in its development is something I regard as critical for public health. It remains important that innovation in methods and approaches be encouraged while each situation is assessed and managed in way that the industrial hygienist can defend to his peers, and to the occupants and owners of the building affected.

In 1675, Sir Isaac Newton wrote “If I have seen further it is by standing on the shoulders of Giants.” The contributions of the contributors and reviewers to the first edition have stood the test of time. It is hard to single out one individual, but I will: the late Dr. Phil Morey. All of us who have worked in this field whether you knew him or not continue to benefit from his wisdom accumulated over a long and diverse career. I certainly did. Finally, it has been a privilege for me to work with my co-editors, Ling-Ling Hung and Steve Caulfield. We were extremely fortunate to have the skills of Katie Robert as style/grammar editor.

J. David Miller
Carleton University
Ottawa


Underlying Principles and Background for Evaluation and Control

Section 1

2nd Edition Section Editors
J. David Miller, PhD, FAIHA®
Carleton University
Ottawa, Ontario, Canada

Ling-Ling Hung, PhD
Federal Occupational Health
Philadelphia, PA

1st Edition Section Editors
Harriet Ammann, PhD, DABT
Bradley Prezant, MSPH, CIH, CPE

Contributing Authors
Christopher P. D’Andrea, CIH
New York City Department of Health and Mental Hygiene
New York, NY

Ling-Ling Hung, PhD
Federal Occupational Health
Philadelphia, PA

Laura Kolb, MPH
U.S. EPA
Washington, D.C.

Heather McGregor
Paracel Laboratories
Ottawa, Ontario, Canada

Mark J. Mendell, PhD
California Department of Public Health
Richmond, CA

J. David Miller, PhD, FAIHA®
Carleton University
Ottawa, Ontario, Canada

Jay Portnoy, MD
Children’s Mercy Hospitals & Clinics
Kansas City, MO

James A. Scott, PhD, ARMCCM
Dalla Lana School of Public Health
University of Toronto
Toronto, Ontario, Canada

Jonathan Solomon
Building Science Investigations, Inc.
Niagara Falls, NY

John P. Springston, CIH, CSP, MS, FAIHA®
ATC Group Services
New York, NY

Tom Rand, PhD
St. Mary’s University (retired)
Halifax, Nova Scotia, Canada

Bradley Prezant, MSPH, CIH, CPE
VA Sciences Pty. Ltd.
Melbourne, Australia
1.1 Dampness, Mold, and Health

1.1.1 Background

Over 30 years ago, researchers first showed that observed dampness and mold (D/M) in homes were associated with an increase in childhood wheeze and cough. Today, the accumulated evidence links observed D/M even more strongly to a variety of adverse respiratory health effects. In fact, a large body of research associates observed indicators of indoor D/M – including visible mold, moldy or musty odor, water damage, and dampness/moisture – with increased risk of asthma development, asthma exacerbation, allergic rhinitis, respiratory infections, upper and lower respiratory tract symptoms, and other effects. Among these four D/M indicators, mold odor, despite its subjectivity, has shown the strongest associations with adverse respiratory effects.

However, measured indicators of D/M – for example, relative humidity or culturable airborne fungi – have not been linked consistently with respiratory health outcomes. The dampness-related agents of disease (i.e., specific microorganisms or microbial compounds) are still unidentified. Some approaches to microbiological measurement have yielded initially promising relationships with health effects, but these are still not refined or validated enough to recommend their use.

While in theory, chemical emissions from damp materials may also be involved, little evidence is available to link such emissions to the health effects associated with dampness.

Indoor D/M are common worldwide, occurring in up to 47% of U.S. homes, 35% of New Zealand homes, and 40% of Japanese homes. An important proportion of human respiratory and allergic illness in the U.S. (e.g., 10–20% of current asthma, respiratory infections, and respiratory symptoms) is estimated to be attributable to residential D/M and thus potentially preventable.

1.1.2 Current Knowledge about Dampness-Related Health Effects

A series of comprehensive reviews of the scientific literature, reported by organizations considered as cognizant authorities or in later updates by epidemiologic researchers, document our increasing knowledge about the links between building D/M and adverse human health effects. The strength of evidence linking indoor D/M with specific human health effects is summarized below, based on the most recent conclusions that use criteria from the International Agency for Research on Cancer (IARC). Indoor D/M in these reviews has generally been defined as the presence of one or more observable, subjective indicators, including presence of visible mold, water damage,
moisture, or mold odor. The categories for strength of evidence include: **sufficient** evidence of a causal relationship, **sufficient** evidence of an association, **limited or suggestive** evidence of an association, **inadequate or insufficient** evidence to determine whether an association exists, and **limited or suggestive** evidence of no association.**

- Sufficient evidence of a causal relationship with D/M: exacerbation of existing asthma in children**; note: the most recent review by a cognizant authority, in 2009, had concluded that the evidence was sufficient to support only an association with D/M.**
- Sufficient evidence of an association with D/M: exacerbation of existing asthma, asthma development, current asthma, ever-diagnosed asthma, bronchitis, respiratory infections, allergic rhinitis, dyspnea, wheeze, cough, upper respiratory tract symptoms, eczema.
- Limited or suggestive evidence of an association: common cold, allergy/atopy.
- Inadequate or insufficient evidence to determine whether an association exists with D/M: altered lung function, allergy/atopy, any other health effect not listed above.
- Limited or suggestive evidence of no association with D/M: no health effect identified.

Other reviews and large studies using different approaches to summarize their findings have reached similar conclusions.**

Damp and moldy organic materials are recognized as causing several additional illnesses, based on clinical experience rather than epidemiologic findings. These diagnostically challenging outcomes, occurring mostly but not always in occupational settings, include hypersensitivity pneumonitis (HP, also called extrinsic allergic alveolitis)** and organic toxic dust syndrome (ODTS, which includes numerous types of inhalation fevers, such as wood trimmer’s disease, silo-unloader’s disease, mushroom worker’s disease, grain fever, mill fever, and swine fever).**

Because very strong evidence is needed to document a causal link with disease, most health effects linked to D/M have only a documented association, not documented causation. However, a lack of evidence for causation may indicate only a lack of research, and is quite different from finding sufficient evidence for a lack of association or causation. Policies and actions to protect the public health often proceed based on sufficiently persuasive evidence of association, even before full demonstration of causality.

Regarding the available evidence to link microbiological measurements to health effects, the earliest reviews reported no associations, but provided little description of the evidence.** A later review evaluated the evidence more explicitly, and found only suggestive evidence associating fungal ergosterol with current asthma, as well as suggestive but contradictory evidence on bacterial endotoxin and 1→3-β-D-glucans, which had both adverse and protective associations with wheeze.** A more recent review focused on indoor risks for asthma exacerbation found only suggestive evidence of an association with measured airborne fungi indoors.** Recent work, not considered in these reviews, shows potential promise for identification of fungi in house dust by quantitative polymerase chain reaction (qPCR).** However, research using different metrics to summarize the fungal qPCR data has shown inconsistencies.** It thus seems premature to recommend use of any specific microbial metric for fungal qPCR to assess health risks. More recently developed methods using “next generation” sequencing to identify microbial species or characterize microbial communities, included till now in limited reported research related to dampness, has not yet been useful in identifying dampness-related microbial risk factors.

Relationships between indoor D/M and health effects also have a paradoxical aspect. In environmental health research, usually the more quantitative the measurements of an adverse exposure, the stronger the demonstrated links to the adverse health effects. However, no microbiological measurement has shown links to respiratory or allergic effects as strong as some of the subjective, more qualitative indicators of D/M.** For instance, the strongest reported associations between indoor microbiological measurements and health effects to date include adjusted odds ratios (ORs) of 1.8–2.6 for summary metrics of fungi in dust by qPCR in two reports on one study** and a hazard ratio (similar to a relative risk but from a prospective study) of 3.3 for specific fungal genera in dust by culture in one study.** Paradoxically, multiple studies have also found measured fungi linked to protection from health effects.** In contrast, at least eight different semi-quantitative metrics of observed D/M from eight studies, involving the area or severity of observed mold, water damage, or the severity of mold odor, have shown substantially stronger associations with respiratory health effects, often with dose-related increases. For these D/M metrics, the highest levels of the metric have adjusted ORs for respiratory effects ranging up to 13.0, with many between 4.0 and 8.0.** No reported studies have found metrics of observed D/M to have protective associations.**

The difficulty in finding consistent links between microbiological measurements and health effects is still unexplained. One likely explanation is that current approaches have not yet successfully measured exposures to the true dampness-related causal agents, or even factors sufficiently correlated with these agents. Research results have shown microbial exposures to be associated, in different studies, with either adverse or protective health effects. For instance, indoor *Penicillium* species have been suggested to be a risk factor for asthma exacerbation**, but also to have protective associations with asthma**; endotoxin has associations with increased asthma severity** and chronic bronchitis**, yet also clearly protective associations with allergy and asthma**; and for 1→3-β-D-glucans, high-level exposures have been linked to less risk than medium-level exposures.** Additionally, certain microbiologically rich environments and occupations, such as farming, have been repeatedly documented to confer strong protective effects against later allergy and asthma, through mechanisms not yet fully understood.** Identification and disentanglement of the microbial exposures responsible for the protective effects
of farming environments versus those responsible for the adverse effects of damp environments has not yet been possible.

Current evidence also suggests that adverse health effects of microbial exposures involve physiologic mechanisms beyond those previously attributed to these exposures. The most common and long-recognized effect of microbial exposures has been to cause allergic responses in those specifically sensitized to particular fungal antigens. Rarer effects have also long been recognized through broad clinical experience: pulmonary inflammation from HP, in a small proportion of persons exposed to high levels of bioaerosols, and frank fungal infections among those immunocompromised or otherwise susceptible. More recently, epidemiologic studies have shown D/M-related respiratory effects that, although sharing many symptoms characteristic of allergic responses, occur in persons not sensitized to fungi (i.e., without IgE-mediated mold allergy). In addition, non-allergic health effects such as viral respiratory infections have now been linked to D/M exposures. Evidence from animal, in vitro, and epidemiologic studies have documented that pro-inflammatory and other non-allergic mechanisms are part of the response to dampness-related microbial exposures. Together, these observations indicate that, in addition to well-documented allergic response among specifically mold-sensitized persons, previously unrecognized non-allergic responses to microbial exposures are likely.

Other non-respiratory and non-allergic health effects of D/M have received little rigorous research attention. Limited available research shows associations of D/M with depression, sleep disturbances, and symptoms such as fatigue and eye irritation.

### 1.1.3 Assessing Health-Relevant Dampness/Mold: Epidemiologic Evidence

The goals of D/M investigations in buildings generally include identifying the presence, location, severity, and sources of any moisture, in order to guide remediation. Often, key objective is to determine if the D/M is at an unhealthy level that merits remediation. Unfortunately, D/M assessment methods that identify the exposures causing dampness-related health effects are not yet available, as the specific causal agents are still unknown. What we want, but do not yet have, is one or more well-defined measurement metrics for which increasing levels indicate increasing risks of adverse health effects for occupants, and with some defined threshold of maximum acceptable levels. Meanwhile, buildings with moisture problems still require investigations and decisions. Currently, three general approaches are available for assessing D/M in buildings to determine the level of risks to health: observed indicators of D/M, moisture measurements, and microbiological measurements.

- Among observed indicators of building D/M, those that have shown consistent associations to increased risks of adverse respiratory effects include visible mold, water damage, moisture, and (especially) mold odor. While a single best approach to assess and summarize these has not been determined, it seems clear that the more of these indicators that are present, and the more of any specific indicator that is present, the greater the risk of health effects. The strongest summary metrics identified so far include the total area of visible mold plus water damage, the severity of mold and water damage, or the strength of the mold odor. Multi-level indices of size, severity, or strength, based on visual and olfactory observations, have shown associations with health effects much stronger than have any specific type of microbiological measurement in air or dust. However, the use of these specific metrics in epidemiologic studies does not yet validate them for decision making in individual buildings. Evidence-based public health advice currently recommends remediating any indoor D/M that can be seen or smelled, without specification of a threshold.

- Building investigators often use moisture measurements in walls and other building surfaces to identify the location, severity, and pathway of moisture, generally either by identifying indoor locations relatively wetter than others, or by using specific thresholds for moisture meter readings to indicate excessive dampness. These readings can be very useful, but they do not provide direct information on the risks for microbial growth, or of health risks. The limited available scientific evidence suggests that higher levels of measured wall moisture can be linked to elevated health risks, but the findings are too limited to suggest specific thresholds for maximum acceptable moisture levels in buildings. Significant challenges to developing these thresholds include the lack of standardization across makes and types of meters and, most importantly, the fact that moisture meters do not measure moisture in relevant for microbial growth. Water activity (a_w) is the measurement of chemically available moisture that is the key determinant for microbial growth. Yet different materials at the same a_w levels can have very different measured moisture contents when assessed by moisture meters. Unfortunately, it is not yet practical to measure a_w in the field.

- Traditional microbiological measurements in buildings have generally not been useful related to health risks. The limitations of culture-based air samples for accurately characterizing microbial presence and concentrations are well known. Newer methods of microbial identification, such as qPCR, have shown promise in research studies, but are not yet sufficiently validated in health studies to recommend wide use. Next generation sequencing approaches have demonstrated limited utility in identifying microbial signatures of D/M. Some measurements of indoor microbial levels may prove useful in indicating hidden mold growth, although scientific evidence is currently very limited. Measurements of microbial compounds such as endotoxin, 1→3-β-D-glucans, ergosterol, extracellular polysaccharides, and muramic acid also do not yet have sufficient convincing evidence for use in assessing microbial health risks. Regarding fungal mycotoxins, sufficient evidence currently is not available to support...
measuring them to determine health risks in homes, offices, or other indoor non-occupational settings. Microbial volatile organic compounds (MVOCs) are theoretically of interest, because of the strong association of mold odor with adverse health effects, and the presumption that mold odor is mediated by MVOCs. Still, there is little convincing evidence that these compounds either cause health effects themselves, or would be sufficiently present and specific to serve even as reliable indicators of excess D/M.

Thus, based on current evidence, it seems inappropriate to use quantitative microbiological measurements to estimate health-relevant exposures or assess the risk of dampness-related health effects. Observed indicators of D/M, including mold odor, have substantially more evidence available to support their use in guiding decisions about remediating D/M to protect the health of building occupants. Still, microbiological measurements, as an optional supplement to an informed inspection in buildings where mold is suspected but not visible, may be useful in hypothesis-based investigations for hidden microbial growth.

1.1.4 Summary: Dampness-Related Health Risks
Dampness and mold (D/M) are common in buildings worldwide. Substantial scientific evidence links observed D/M to multiple respiratory health effects, including new asthma, asthma exacerbation, respiratory infections, and both upper and lower respiratory tract symptoms. However, the specific dampness-related agents of disease are still unknown. Building investigations are often triggered by concerns about health, mold, or moisture. At this time, the best-documented approach to determining the presence of health-relevant D/M is careful inspection to evaluate observable indicators of D/M, including the presence of one or more of the following: visible mold, water damage, moisture, or (especially) mold odor. The more of these indicators observed, or the greater quantity or severity of specific indicators, the larger the risks of adverse health effects. Still, no specific ideal assessment protocol using these indicators has yet been agreed upon, nor has a standardized threshold been determined that would be universally considered to indicate maximum acceptable levels of indoor D/M. Evidence-based public health advice currently recommends remediating any indoor D/M that can be seen or smelled, without specification of a threshold. Microbiological measurements as currently used have not been validated to be useful for assessing health risks; although microbiological measurements may help identify hidden moisture or mold, proper interpretation for these purposes is still uncertain and current approaches are not standardized or validated.

1.2 Exposure Considerations
1.2.1 Introduction
To determine whether moisture-related microbial and other growth impacts the health of occupants, exposure to a known agent or agents of interest must be determined either qualitatively or quantitatively. The complexity, variety, and imperfect means of assessing agents and determining the effects of the mixture of human occupants breathe is a very large task, in which we have made limited progress. Environmental assessment is not the same as exposure assessment. Exposure assessment must become possible if relationships to health outcome are to be determined. Currently, we have identified allergens as some of the active ingredients associated with mold spores and/or mold fragments but have not found means to quantify them or the other potential adverse agents associated with damp buildings that affect health. The full picture cannot emerge until we identify and measure the right agents and determine their roles in health complaints and symptoms observed in epidemiologic and clinical studies.

1.2.2 Exposure Difficulties
Although ecological considerations can help us to count particle and gaseous materials found in the indoor air of damp spaces, enumeration does not constitute an analysis of exposure to such agents. Measurement of any of the components, let alone their mixture in air, is fraught with many difficulties, because concentrations change with distance from sources, and air moves turbulently due to ventilation, movement, and the activities of occupants. Activity of buildings, their ventilation systems, and the activities of occupants can, through disturbance of the building ecosystem, change the behavior, concentration, and flow patterns of the particles and gases that enter the occupied space. Additionally, changes in the biological activity of the building ecosystem — episodes and rate of mold sporation, competitive and noncompetitive interactions among microbes, dust mites and other arthropods in producing fecal pellets that contain allergen — can also influence what is in the air at any given moment.

Fungal spores and fragments can enter the living space of a building from the outside air through intentional openings in the building envelope such as open windows and doors, as well as fresh air intakes of forced air ventilation systems on commercial buildings. Spores can be transported inside on the clothing, skin, and on hair of people and pet fur. Thus, in a well-maintained and dry building, fungi in indoor air mirror the adjacent outdoor air except are attenuated where air filtration is part of the HVAC system.

Although an appreciable percentage of the population is allergic to the dominant fungi in outdoor air, mainly phytoplane species, crop diseases and mushroom spores according to the season, this is the normal baseline. The foundation for the guidance on airborne fungi in the built environment was articulated by a Federal Provincial working group in Canada and by ACGIH. Both groups said that fungal contamination in buildings — intended to mean growth and accumulation in dusts — should be minimized and a measure of this was that the indoor mycobiome should mirror that of outdoor air above grade.

Three decades later, it remains that there are no methods to measure personal exposure to fungi that are health relevant. Data on personal exposure and sensitization to fungal allergens are mainly based on the assessment of a few, easily identifiable species.
As noted above, in dry and clean buildings, the indoor mycoflora mirrors that of the adjacent outdoor air. The more fungal growth in a building, the greater the proportion of spore- and mycelial fragments in the air compared to intact spores.\(^{(70)}\) When settled dusts in a home were disturbed, as much fungal biomass in the air was present as particles less than 0.18 μm as was also present from the fraction >18 μm.\(^{(71,72)}\) Very high airborne concentrations of fungal fragments have been found in flood-damaged homes contaminated with mold.\(^{(73)}\) The large majority of intact spores travel no further down the lung than the naso-oro-pharyngo-laryngeal region. In contrast, 30–60% of particles between 0.1 and 1 μm reach the tracheobronchial and pulmonary regions.\(^{(74)}\) Fragments contain fungal glucan, allergens and species-specific low molecular weight metabolites.\(^{(75)}\) For fungal glucan, exposures in murine models that are comparable to those that might be experienced in a moldy building in murine models result in a variety of immunomodulatory and inflammatory consequences.\(^{(76)}\)

Some fungal allergens are homologues of human proteins that signal or cause tissue disruptions.\(^{(77)}\) Inhaled spore- and mycelial fragments also contain a number of so-called pathogen associated molecular patterns (PAMPs).\(^{(77)}\) These include the form of β-1,3-D-glucan found in fungi such as *Penicillium* and *Aspergillus*. This glucan interacts with human and rodent dectin receptors that result in inflammation.\(^{(78)}\) Together with glucan, fungal chitin is present in spore- and mycelial fragments, and also recognized by receptors in lung epithelial cells.\(^{(79,80)}\)

### 1.2.3 Mycotoxins Associated with Mold Particles

The IOM 2004 report titled *Damp Indoor Spaces and Health* \(^{(81)}\) stated that there was biological plausibility for considering more epidemiologic research regarding mycotoxin-induced toxicity from indoor exposure.

Where there are very high exposures resulting, for example, from remediation activities without appropriate PPE, the toxins present in spores can contribute to health outcomes.\(^{(82)}\)

The weight of evidence today is that low molecular weight compounds produced by damp buildings play only a modest role compared to the factors illuminated above in clinical symptoms.\(^{(83,84)}\) Most reports of fungal toxins in buildings use methods that have not been validated for this purpose\(^{(85)}\) and many report fungal toxins that are not produced by fungi associated with damp building materials.\(^{(85,86)}\)

This has been the subject of considerable investigation. Damp building strains of the two species of *Stachybotrys* that occur on damp buildings in the U.S. and Canada make many biologically active compounds.\(^{(82)}\) The *Stachybotrys* toxins satratoxin H and G, as well as atranone C, have been reported on building materials contaminated with *S. chartarum sensu lato*.\(^{(87)}\) Roridin E, along with a number of spirocyclic dimanes, have been detected in settled dust collected from a water-damaged building.\(^{(88)}\)

The most common species of *Penicillium* found on damp materials in the U.S. and Canada is the Fleming clade of *P. chrysogenum* now called *P. rubrum*. Indoor strains of this fungus make penicillin G, roquefortine C, and meleagrin.\(^{(89,90)}\) Toxins from damp buildings strains of another common species, *P. brevicompactum* include brevianamide, mycophenolic acid\(^{(91)}\) and tanzawaic acid. The latter two have been reported on moldy building materials.\(^{(92,93)}\) Metabolites of damp building strains of *P. corylophilum* include phenomone, citreohydrinol and andrastin A, koninginin A, E and G.\(^{(94)}\)

Damp building strains of *Aspergillus versicolor* produce sterigmatocystin. This has been detected on water-damaged building materials and in dusts collected from carpets and floors.\(^{(95)}\) The isoquinoline alkaloids TMC-120 A-C and derivatives are produced by damp building strains of *A. insuetus* and *A. calidoustus* (formerly *A. ustus*).\(^{(96)}\) TMC-120A has been detected on building materials (Nielsen, personal communication). Echinulin and the related compounds neoechinulin A and B are produced by several species of *Eurotium*. In North American buildings, the dominant species are *E. amstelodomi* and *E. helibactiourum* (Chapter 4). Strains from the built environment in the U.S. and Canada accumulate a number of compounds including echinulin which was produced in greatest quantity.\(^{(96)}\) Echinulin has been detected on building materials.\(^{(91)}\)

*Chaetomium globosum* is one of the most common fungi isolated from damp building materials but often overlooked. Strains of this fungus from damp buildings in the U.S. and Canada produce chaetoglobosin A, C and F, chaetomuignil D, and chaetoviridin A.\(^{(97)}\) Chaetoglobosins A, C, E, F, chaetomuignil F and chetomin all have been reported from moldy materials collected in damp buildings.\(^{(92,93,99,100)}\)

Strains of another common damp building genus, *Trichoderma*, produce a variety of compounds, *T. atroviride*, *T. koningiopsis*, *T. cirrvinoviride*, and *T. harzianum*. These produce peptaibols, which have potent membrane-disrupting potentials.\(^{(101)}\)

*W. sebi* is a xerophilic fungus separated into four species: *W. sebi sensu stricto* and three new species described as *W. mellicola*, *W. canadensis*, and *W. tropicalis*. These are very common in house dust, with dominate species depending on geographic location.\(^{(102)}\) New world strains of *W. sebi* (now *W. canadensis*) make wallernemone and wallimidione.\(^{(103)}\)

At realistic doses, some of these compounds that are possible in the lung from exposure in damp buildings (nM), many of these (pure) compounds modulate a variety of genes. The genes involved are associated with asthma pathways in vivo, in primary lung cells as well as relevant immortalized cell lines.\(^{(104-108)}\) Nonetheless, their impact is less than glucans, some allergens and other components of the fungi that occur in damp buildings.\(^{(77)}\)

### 1.2.4 Risk Management Role of the Industrial Hygienist

It is important to consider what practical measures the industrial hygienist should recommend when encountering moldy environments. In 2013, the AIHA released its position statement on mold and dampness.\(^{(109)}\)

Two elements of this position should be noted:

“IHs and other IEQ practitioners should approach mold, water intrusion, and IEQ investigations with the same mindset they use when they approach all investigations. The process includes three of the five...
key industrial hygiene elements: anticipation, recognition, and evaluation. While the IH can reasonably anticipate that there will be mold exposures associated with water intrusion, mold may or may not be the primary cause of any health effect(s) that may be experienced by the occupants. The IH should ensure that, while investigating mold-related complaints, whether apparent or reported, active consideration of other possibilities affecting IEQ in the space is an essential part of the investigation.

If mold is discovered, “the position of AIHA® is that persistent dampness and mold damage in the non-industrial workplace, including schools and residential housing, requires prevention, management and effective remediation. If visible mold is present, it should be remediated, regardless of what species are present. Such actions are likely to reduce new onset asthma, lead to savings in health care costs, and improve public health.”

Because a building owner or manager is responsible for the health and well-being of building occupants, this individual will likely request and appreciate guidance on whether a building with indoor mold can continue operating normally or occupants need to be isolated from the mold. If isolation is appropriate, an opinion on the degree of isolation will be requested of the industrial hygienist. The degree of isolation may range from locking a door to completely evacuating the building. If remediation is to take place, the industrial hygienist will likely be asked if it needs to be done quickly or how far into the future would be reasonable.

To make these recommendations, an estimate of the degree of dispersion of mold particles and possibilities for exposure and an evaluation of the number and vulnerability of individuals in the building is necessary. For example, recommendations for a normally unoccupied building with a modest amount of contamination would differ from a situation in which there was a significant amount of mold damage in a school. Occupants with particular susceptibility would be handled differently from a healthy working population. The process of making these recommendations is defined as risk management, and the decision is referred to as a risk management decision.

The AIHA® Field Guide offers some specific guidelines on particular fungi indicating that risk management decisions are required of the industrial hygienist in the following conditions:

- The confirmed presence of facultative pathogens (fungi capable of inducing pulmonary infections in humans) such as Aspergillus fumigatus and A. flavus; and
- The confirmed presence of fungi in air samples known to be commonly associated with water damaged building materials such as Stachybotrys chartarum (or Chaetomium, Trichoderma) and those listed above (among others) requires that the location of the mold growth be determined and the extent of the contamination assessed.

The justification for the first condition is that in an open population there is a low prevalence (~1%) of people who have preexisting medical conditions that might increase their risk from exposures to facultative pathogens. Such pre-existing conditions include cystic fibrosis and illnesses such as AIDS that compromise the ability of the body to prevent pulmonary colonization by opportunistic fungi.

Because S. chartarum requires water-saturated conditions and is often difficult to recover by sampling methods such as agar-impaction, “some contamination” might mean much more is actually present in the air. In such circumstances the duty of care of industrial hygienists might be challenged should S. chartarum not be treated with special care.

Implementing the risk management guidelines as described necessarily implies that each situation is unique, and the skills and experience of the industrial hygienist are necessary to tailor the recommendations to the specific situation.

1.3 Clinical Issues Regarding Moisture, Mold, and Disease

The relationship between adverse health effects and exposure to fungi has been evaluated extensively during the last 10 years. In 2009, the World Health Organization (WHO) report on damp buildings and fungi, based on a systematic review of the literature at the time, concluded that the presence of dampness or fungal contamination can contribute to health problems. Dampness can be defined as sufficient moisture on or in a substrate to support microbial growth. Indicators of dampness as defined by the WHO include the presence of condensation or other moisture on surfaces or in structures, visible fungi, perceived moldy odor, and a history of water damage, leakage or intrusion.

Several systematic reviews subsequently evaluated the relationship between fungal exposure and respiratory diseases such as asthma. These reviews provided evidence that exposure to fungi at a young age increases the risk of developing asthma, that continued exposure once asthma has developed increases the likelihood of having symptoms and that reducing fungal exposure can decrease and possibly prevent respiratory tract symptoms associated with asthma. Armed with this information, it is increasingly clear that indoor fungal exposure can pose a health risk and that reducing exposure can mitigate that risk.

In their 2012 alert on mold and dampness, NIOSH noted “Occupants of damp office buildings, schools, and other non-industrial buildings report a broad range of building-related symptoms and illnesses, including headache; fatigue; irritation of eyes, nose, and throat; lack of concentration; rhinitis and sinusitis (or rhinosinusitis); lower respiratory symptoms; exacerbation and onset of asthma; hypersensitivity pneumonitis and respiratory infections.” The Health Canada mold guideline states that “exposure to indoor mold is associated with an increased prevalence of asthma-related symptoms such as chronic wheezing, irritation symptoms, and non-specific symptoms.”
1.3.1 Specific Diseases and Conditions

Health conditions associated with fungal exposure primarily involve the respiratory tract since exposure to spores and other fungal emanations tends to occur by inhalation. For that reason, exposure to airborne fungi is associated with morbidity including rhinitis and asthma. Other conditions, such as atopic dermatitis, can be exacerbated by cutaneous fungi such as Malassezia species but these generally are not airborne and have a different mechanism of disease. Other diseases including allergic bronchopulmonary mycosis, allergic fungal sinusitis, and hypersensitivity pneumonitis also are known to be triggered by exposure to fungi. Candida hypersensitivity is controversial because the syndrome is poorly defined and the association between exposure to Candida and the condition has not been convincingly demonstrated.

Exposure to fungal products also can occur from ingestion of contaminated food, however, the resulting illnesses have mechanisms that can be directly attributed to the ingestion and not to indoor air exposure. A CDC report described the misuse of urine toxin assays to support claims that exposure to airborne fungi causes illness. They noted that ingestion is the most common reason why toxins might be detectable in urine. A review by Hurras et al. representing the German Society of Hygiene, Environmental Medicine and Preventative Medicine indicated that none of these purported tests for mycotoxins in clinical samples had medical relevance.

1.3.2 Asthma

Dampness and the Risk of Developing Asthma

The relationship between exposure to a damp environment and subsequent sensitization and development of asthma has been studied extensively in a series of studies. Damp indoor environments are associated with dusty odor, water intrusion, high indoor humidity, limited ventilation and increased indoor fungal growth. An early study of dampness with 900 children from Edinburgh found that dampness and mold were associated with increased wheeze, school absences and night time cough. A follow-up questionnaire found that bronchial reactivity was present more often when the parents reported visible mold in the home.

Another study of 4600 children from the Harvard Six Cities Study evaluated 10 year old children with a questionnaire adapted from the Harvard Six Cities questionnaire with additional questions related to mold and dampness indicators. In this study, wheeze and cough were significantly associated with molds and dampness indicators.

A comprehensive review of the literature in 2011 found sufficient evidence to conclude that there is an association between indoor dampness or fungal exposure and an increased risk of developing asthma in allergic and nonallergic individuals. At the same time, The Cincinnati Childhood Asthma and Air Pollution Study provided additional evidence for an association between fungal exposure and development of childhood asthma. In this study, investigators found a significant relationship between fungal exposure during infancy and development of recurrent wheeze and asthma at 1, 3, and 7 years of age.

Subsequently, a population-based case-control study of 121 children 12 to 84 months of age found that the risk of developing asthma correlated with the amount of moisture and the presence of visible fungi in the main living areas of the house regardless of the patient’s atopic status.

More recently, a systematic review of 11 cohort and 5 incident case control studies by Quansah concluded that the presence of a damp environment, visible mold and moldy odor, is associated with increased risk of developing asthma. Since these are all observational studies, they cannot be used to determine whether reducing fungal exposure would decrease that risk.

Exposure to Fungi and Respiratory Symptoms

In addition to a link with increased risk of developing asthma, fungal exposure has been linked with triggering of respiratory symptoms in patients who already have asthma. A Canadian study of indoor dampness, and exposure to fungi in 15,000 homes found that the prevalence of respiratory symptoms was higher in homes with fungal contamination or dampness. The National Asthma Survey found a positive association between current asthma both in children and adults and reported mold.

A quantitative meta-analysis of the 33 studies that had been reviewed by the Institute of Medicine found a statistically significant correlation between the presence of mold and dampness and development of upper respiratory tract symptoms, cough, wheeze, current asthma, and ever diagnosed as having asthma. In addition, the presence of building dampness and mold were associated with increases of 30% to 50% in cough, wheeze, and asthma.

Intervention Studies to Demonstrate the Link between Fungal Exposure and Symptoms

To prove that exposure to fungi causes symptoms, it is necessary to perform randomized, controlled interventional studies. A Cochrane systematic review of such studies was performed by Sauni et al. The investigators identified 12 studies with 8028 total participants that met their inclusion criteria. The meta-analysis included 3 randomized trials and 9 controlled before and after studies. The authors found moderate to very low-quality evidence that repairing fungus-contaminated houses and offices reduced asthma-related symptoms and respiratory infections in adults. In addition, reducing fungal exposure in schools decreased student visits to physicians due to respiratory infections. When looked at alone, most of the studies failed to demonstrate a significant improvement in symptoms. It was only when they were combined into a larger meta-analysis that significant results were demonstrated.

A study by Kercsmar did find a decrease in asthma symptom days and a lower rate of exacerbations in the intervention group following extensive home remediation. In addition, fungal allergen exposure decreased in the intervention group while other allergen exposures (cockroach, rodent, dust
mite) did not suggest that it was the fungal exposure that was causing the symptoms.

### 1.3.3 Allergic Bronchopulmonary Mycosis (ABPM)

ABPM is an inflammatory disease characterized by a constellation of criteria that include asthma, pulmonary opacities, proximal bronchiectasis, eosinophilia, and elevated total IgE in addition to elevated specific IgE and precipitating IgG to certain fungi. It often occurs in individuals with asthma or cystic fibrosis. The most common fungus associated with this disorder is Aspergillus. More recently it has been described with other genera of fungi leading to the generic term bronchopulmonary mycosis. This disorder is exacerbated by exposure to fungal allergens to which the patient is sensitive, making avoidance an important component of management. Since it is not caused by fungal infection, antifungal agents are generally not effective. Extensive reviews of this condition have been published recently.

### 1.3.4 Allergic Fungal Sinusitis (AFS)

Allergic fungal sinusitis is a distinct non-invasive fungal sinusitis. The offending organisms typically include taxa such as Alternaria, Epicoccum, Ulocladium, Botritis and Bipolaris. AFS is associated with the presence of nasal polyps and with elevated fungus-specific IgE levels. It is characterized by an intense allergic response against fungi giving rise to formation of allergic (eosinophilic) mucin, mucostasis, and sinus opacification. Several potential deficits in the innate and acquired immunity of patients with fungal sinusitis appear to alter host ability to respond to fungi. It is also possible that fungi have a disease modifying role in the development of this condition. Since AFS involves a hypersensitivity reaction to fungal allergens, it is important for the patient to avoid exposure to the offending fungus. Several reviews of AFS have been published recently.

### 1.3.5 Hypersensitivity Pneumonitis (HP)

Hypersensitivity pneumonitis is an inflammatory lung disease caused by an exaggerated immune response to inhalation of a variety of organic particles. The most frequent causal antigens are bird proteins and bacteria such as thermophilic actinomycetes. Fungi also have been implicated in both occupational and non-occupational outbreaks. When fungi are involved, it is characterized by the presence of precipitating IgG antibodies directed at the specific fungus such as Aspergillus. The clinical course of the disease is variable and its diagnosis difficult since no specific test or biomarker provides a consistent diagnosis. The histopathology usually consists of a granulomatous interstitial bronchiolocentric pneumonitis characterized by the presence of poorly formed granulomas and a prominent interstitial infiltrate composed of lymphocytes, plasma cells, and macrophages.

In a German study, 23 children with confirmed HP were identified in 2005/2006 and fungal sensitivity was second in addition, the report of symptoms relies on recall which can be flawed. This is where a report from an industrial hygienist can be critical in the further evaluation of a patient.

### 1.3.6 Diagnosing and Treating Fungal Allergy

Clinically, a diagnosis of fungal allergy requires both the demonstration of fungus-specific IgE antibodies and development of symptoms with exposure to those same fungal allergens. Demonstration of fungus-specific IgE can be done either with appropriate skin tests using fungal extracts or in-vitro tests with fungal allergens in solid phase. Demonstration that symptoms occur with exposure to fungi is more difficult outside of controlled exposure chambers because such exposure rarely occurs in isolation.

A clinical history is used in practice to determine whether a patient has increased symptoms when exposed to environments that are likely to have increased fungal exposure. Such environments include damp or musty buildings, basements, barns, cut grass (outside of grass pollen season), and rainy weather.

Larenas-Linnemann et al. proposed a series of questions that would be useful for a clinician to identify an association between fungal exposure and increased symptoms.

These include:

1. Do your symptoms get worse when you are in an environment with visible mold?
2. Do your symptoms get worse when you enter a basement or other damp environment?
3. Do your symptoms get worse when you are in buildings with a moldy or musty smell?

It is important to note that ‘reported symptoms’ tend to be nonspecific and are therefore likely to be attributed to the exposure that the allergist is asking about when they could easily be due to a different cause. In general, a negative history is probably more useful than a positive history since exposure without symptoms is relatively specific. A patient who does not have symptoms when in an environment likely to have high fungal exposure is unlikely to be allergic to fungi with the caveat that the actual fungal exposure may be small. In addition, the report of symptoms relies on recall which can be flawed. This is where a report from an industrial hygienist can be critical in the further evaluation of a patient.

### 1.4 References

Both abiotic (nonliving) and biotic (living) factors affect fungal growth and reproduction. The relative importance of each of these factors in fungal growth is discussed in detail in the chapter on fungal ecology and in the *Field Guide for the Determination of Biological Contaminants in Environmental Samples*, 2nd edition. The primary factors contributing to fungal proliferation in the building context are water, temperature, and nutrient availability. These factors also impact the types of species found and the fungal community structure. Because water availability is the most important factor (and the easiest to control) in preventing fungal growth, this chapter focuses on understanding and detection of moisture in buildings.

### 5.1 Understanding Moisture in Buildings

Buildings use plumbing systems for the transport of both potable water and wastewater. When these systems develop leaks, water is released into the structure. More subtle, but no less significant, is the role of moist air which under appropriate environmental conditions, will release that moisture onto surrounding building materials. To adequately understand the nature of moisture in buildings, it is useful to have an understanding of factors such as relative humidity, condensation, dew point, water activity and moisture content, active or chronic moisture, periodic moisture, and seasonal moisture.

Relative humidity is the ratio of the actual amount of moisture in the air at a specific temperature to the amount of moisture that the air could hold if saturated at that same temperature. This ratio is typically represented as a percentage value. At warmer temperatures the air is capable of holding more moisture than at lower temperatures. Therefore, if warm saturated air is cooled, visible moisture can collect on surfaces. This moisture is called *condensation*. The optimum range of relative humidity for health purposes for the general population is believed to be between 40 and 60%. However, this range may result in concealed condensation that can adversely affect structural components. Or it can result in visible condensation that can damage windows and support mold growth on surfaces where room air circulation is poor, where thermal bridges occur due to framing, or where convection occurs in cavities.

The temperature at which air with a specific moisture load begins to release its moisture is called the *dew point*. Cooling of moist warm air is a common cause of water deposition on surfaces, including ventilation surfaces, of a building. In some cases, moisture deposits in areas concealed from the investigator.
Water activity in a material is analogous to relative humidity in the atmosphere and is expressed in a similar ratio as a decimal fraction. For example, if a piece of wood is in equilibrium with air having a relative humidity of 85%, the water activity (aw) in the wood is 0.85. High levels of water activity, greater than 0.85, allow fungi to obtain moisture from the wood for growth, resulting in potential damage to the wood. At levels of water activity below 0.80 to 0.85, the fungi cannot use the moisture within the wood for growth, and colonization will not occur. The water activity of many materials is dynamic and varies between different environmental conditions and locations within the country.

Moisture content (MC) is determined by weighing a material at environmental equilibrium and then weighing it again when it is completely dry. It is expressed as a percentage ([wet mass – dry mass] × 100 / dry mass). Water activity can be correlated with MC but varies with each material. For example, an aw of 0.80 corresponds with an MC of 0.7% in gypsum board, 1% in cement, 11.3% in wallpaper, and 17% in soft wood.

Moisture can also be categorized into active/chronic, periodic, and seasonal events. Active or chronic moisture is ongoing, for example a leaking water or wastewater pipe. Periodic moisture events are intermittent and not affected by season, such as a leaking roof or sink drain. Seasonal moisture is affected by the time of year. Examples of seasonal moisture are condensation occurring during the summer time on poorly insulated cooling coil refrigerant lines or condensation on windows during the winter months.

Active moisture is frequently the easiest to identify because it is ongoing during any investigation. Periodic and seasonal sources of moisture, however, may be more difficult to identify and require an investigator to consider conditions that may not exist at the time of a site visit.

5.2 Moisture Dynamics

To control water and moisture in building, it is important to understand their transport mechanisms, some of the most important of which are:

- liquid flow by gravity or pressure difference;
- capillary suction of liquid water in porous building materials;
- movement of water vapor by air movement; and
- water vapor diffusion by vapor pressure differences.

The first two mechanisms can move greater amounts of moisture than the last two, although many strategies have focused on the control of vapor diffusion. For instance, a plumbing leak on an upper building floor illustrates a liquid flow by gravity and/or pressure differences. The water damages not only materials near the leak, but also can move down several floors, wetting materials in its path. Frequently, wet ceiling tiles, walls with water stain, and wet carpets are associated with this type of water infiltration.

Capillary action into porous materials may be associated with the flow of water within a building. Frequently, a pipe break results in drywall wicking up the water, thus increasing the affected area. This is also true when a basement is flooded. Although the flood might only wet the bottom inch of the drywall, capillary action could prompt fungal growth up to several feet higher.

The movement of moist air is commonly observed in attics where stack effect results in air currents entering the attic from the lower floors. This may be of great importance if the warm, humid air from the house contacts the cold roofing material and condenses. When this happens, moisture collects on the cold side of the roof and/or roof components (e.g., protruding ends of fasteners) and provides conditions suitable for mold growth. Fungal growth on the north side of a roof area (where sun warming is less than on the south side) is a common result from this type of moisture transport.

Air with high moisture content also can diffuse throughout a structure due to improper ventilation. Air leaks transport more moisture than the last two, although, when compared to all of the other avenues of moisture transport, diffusion may only transport small quantities of moisture. For example, air leaks transport more moisture than the diffusion of water vapor through a material or assembly of combined materials (e.g., a wall or roof assembly).

5.3 Prevention of Water Problems in Buildings

Sources of moisture problems can be divided into five categories.

1. Rain water or groundwater
2. Plumbing water
3. Condensation
4. Water vapor sources
5. Built-in water (construction materials installed wet during initial assembly)

Each category is discussed in following paragraphs.
5.4 Rain and Groundwater

Intercepting falling or wind-driven rain and diverting it to safe on-site or off-site disposal prevents rainwater intrusion into buildings. The roofs, walls, windows, doors, foundations, and surrounding landscape must be constructed so as to drain rainwater away from the building. Roof areas should be provided with gutters to prevent rainwater from draining within 3 ft of the foundation of the structure.

Exterior building materials must withstand periodic wetting and drying. Many of them, such as rubber or plastic roofing membranes, vinyl siding, glass, and corrosion protected metals (copper, aluminum, galvanized steel, stainless steel), are impermeable to water and cannot absorb much water. Others, such as wooden siding or shingles, fiber-cement siding, brick or concrete masonry units, traditional stucco, or external insulation and finish systems (EIFS), absorb water and must be installed so they can dry.

Rainwater must be managed at joints and where exterior materials are penetrated by windows, doors, pipes, wires, and ducts. Historically this has been done by shingling and flashing, which provide waterproof barriers between the penetration and the side of the structure. Sufficient flashing overlap prevents water from entering these areas as a result of wind-driven pressure differential, during snowfall, or after the accumulation of debris on the siding or shingles.

Roofs can be either flat (low slope) or pitched. Impermeable materials that are sealed at joints and penetrations typically cover low-slope roofs. The seals should be waterproof and typically consist of rubber, plastic, or modified bituminous membranes. In some cases, sheet metal roofing is used to cover low slope roofs, which really should not be flat but should pitch to roof drains or eaves to avoid standing water. Low-slope roofs most frequently fail at the edges, at penetrations, or at seams. Penetrations include chimneys, railings, skylights, roof drains, rooftop air handlers, air intake or relief fixtures, roof vents, water pipes, and plumbing vents. Parapet walls and other changes in elevation also tend to be weak areas in the design of low-slope roofs. Some low-slope roof membranes are covered by stone pebbles, foam insulation, or rooftop plantings.

Pitched roofs drain rainwater to eaves. They are usually covered by materials that are not intended to be watertight but shingled so that water has to run uphill to penetrate them. A backup layer of moisture protection (e.g., shingled felt paper or bituminous membrane) beneath the shingles prevents leaks and seepage at penetrations, joints, overlaps, valleys, and walls such as dormers and cupolas. Penetrations, including chimneys, roof and plumbing vents, and exhaust fan terminations must be protected using flashing material. If the edge of an eave is not provided with at least one drip edge, it is possible for rainwater to bridge back onto the wall below the overhang, causing intrusion into the building assemblies. The drip edge extends from the end of the roof to assure that all water flows down and away instead of entering the space between the shingles and the roof.

In locations that receive significant snowfall, ice dams may allow water intrusion through the roofing system. Ice dams form when snow accumulates on roofs that drain to cold locations such as eaves or exterior drains. Snow insulates the roofing from the cold outdoor air. If there is heat gain from below, the temperature of the roof can reach 32°F (0°C) or higher, and the snow begins to melt. The melt water runs down the roof beneath the snow until it reaches a surface that is below freezing (usually the eave, where there is no heat gain from below and less snow to insulate the surface from the cold air). Here it freezes into icicles and ice dams. As the ice builds up, it causes water to back up beneath the shingle and leak into the building below. Typical sources of heat that warm the roof system include:

- warm air leaking from inside the building into the vent space beneath the roof sheathing (usually either attic space or ventilation channels when the insulation follows the roof slope);
- recessed lighting fixtures;
- air-handling equipment or ductwork in an unconditioned attic; and
- chimneys passing through the attic.

Ice dam problems are more likely at the bottom of valleys present in the roof, because a valley greatly increases the watershed area that drains to a single point on the eave. A small amount of melting over a large area delivers a lot of water to a small area.

To fix or prevent ice dams, the sources of heat must be removed. Air leaks from the conditioned parts of the building must be sealed. Recessed lights can be replaced with airtight fixtures. Mechanical equipment must be air sealed and insulated or removed. Another approach is to apply foam insulation to the bottom side of the entire roof deck and gable ends. In this case the ceiling air leaks, thermal bypasses, mechanical equipment, and recessed lights can be left in place. Valleys may still be troublesome. In new construction the roof deck can be covered with an impermeable membrane as added protection.

Walls may be solid materials (e.g., solid brick, stone, concrete, or logs) or may be covered with claddings. Some examples of claddings are:

- horizontal siding ( clapboards, cove, log cabin siding);
- vertical boards (board and batten, channel-lock, reverse board and batt);
- sheets (textured plywood, fiber-cement board, textured composites);
- panels (glass, metals, metal or glass clad composites);
- masonry (brick, concrete blocks, stone veneers), and
- stucco (traditional, EIFS).

Rainwater protection in massive walls ( masonry, concrete, logs) is provided by the capacity of the walls to absorb, disperse, and dry without damage. Some amount of the rainwater that strikes claddings leaks past them at joints, windows, and doors. Historically this relatively small amount of seepage has been accommodated with a capillary break behind the cladding. An air gap and/or a membrane that is impervious to
liquid water is the most common way of protecting inboard materials. For example, clapboards installed over asphalt-impregnated building felt provide a fair amount of air gap and a membrane that sheds liquid water. The building paper provides something that can easily be shingled over and under flashing around windows and doors. If the cladding is stucco, it is applied over heavy building paper, providing a capillary break. Brick veneer walls managed moisture by having an air gap between them and the inboard wall. In the past, the inboard wall was frequently made of brick with air gaps between. Later technology utilized hollow-core concrete masonry units. Both of these methodologies have air gaps, are composed of materials that are resistant to mold growth, and provide significant storage and dispersion for seepage past the brick veneer. These details are shown in Architectural Graphic Standards.\(^7\)

In recent times, walls covered by cladding systems often have material inboard that must be kept drier than brick, concrete block, or even diagonal wooden sheathing boards. Oriented strand board (OSB), gypsum board, and plywood are not only more vulnerable to mold growth, but they also are used in walls that take longer to dry out. If these materials are used, more attention must be paid to detailing walls and penetrations. Cladding systems require an air gap and a drainage plane that can protect the inboard materials. Plastic house wraps, asphalt impregnated building paper, and extruded styrene foam boards have been used successfully as drain planes.

Windows and doors have always caused problems in moist climates. For many years, rainwater infiltration has been managed around windows and doors using building paper shingled overhead flashing, drip edges, sills that slope to the exterior, or sculpted stone and concrete sills that collect rainwater that has leaked through windows. Pan flashing also has been installed beneath doors. When wall sections were more mold resistant, some of these details were considered an upgrade, the earmark of superior construction. Now they are required to protect walls from moisture problems. Of course, sculpted stone pan flashing beneath windows has been replaced by metal flashing, building paper, and peel and stick products. In modern walls windows must be flashed on all four sides with the flashing shingled into the drain plane.

Many buildings have damp foundations. Although in some locations damp foundations are caused by a high water table, many are also the result of poorly managed rainwater. For the purposes of this book, foundation types are divided into basements, crawlspaces, and slab-on-grade. What distinguishes a basement from a pond is that the basement has a drain, and hopefully the surface surrounding it drains water away from it. A crawlspace is the area between the bottom floor of a house and the ground under the house. Crawlspaces frequently are used where soil type excludes the use of a slab, but they also are used in place of a basement. Crawlspaces sometimes house the heating and plumbing for the building. Slab-on-grade foundations are the easiest to deal with because the bottom of the foundation floor is above (or ought to be) the surrounding grade. All that is needed is to slope the grade away from the building and provide capillary breaks beneath the slab and between the walls and the slab edge. Capillary breaks beneath the slab can be provided by polyethylene film, plastic foam board, or stone pebbles larger than peas.

### 5.5 Plumbing

Water is intentionally brought into buildings for drinking, cooking, washing, bathing, toilet uses, and for some commercial and industrial processes (e.g., chilled water air-conditioning, ice making, humidification, lubrication). This water is delivered by the supply side of the plumbing system. While in use, some of it evaporates into the building air (covered under condensation issues), some of it is absorbed by materials in the building, and most of it goes down the drain lines to the sewer system.

Moisture problems can occur on the supply side, the drain side, and in wet rooms where water is used. On the supply side, poorly made joints, leaking valves, pipes with nails or screws through them, leaks in flexible pipes, leaks from internal plumbing associated with washing and ice machines, and burst-frozen pipes are common problems. On the drain side of the system, poorly made joints are probably the most common leaks found (e.g., traps and drain baskets under sinks). A plumbing leak causes more damage if it goes unnoticed for a long time, if it leaks into a porous material that takes a long time to dry, or if the water is wicked a distance from the leak by porous building materials. For instance, water leaks in insulated walls or ceilings wetting porous insulations may hold water in place for a long time and make it less likely that it will be noticed. A slow drip onto a bare concrete floor in a utility closet may wick water for a great distance beneath nearby vinyl floor tile or carpet, where it may not be noticed until it begins smelling musty. Lastly, rooms that will be unavoidably wet, such as bathrooms, laundry rooms, custodial closets, and spa and pool rooms, must be constructed using materials and systems that can get wet daily without damage. Many moisture problems in buildings occur when these systems are poorly designed (e.g., ceramic tile attached to paper covered gypsum board) or have failed (e.g., a leak in a custom shower pan). Following are some recommendations for plumbing.

- Avoid using insulated walls or ceilings for plumbing supply or return lines when alternatives exist.
- Make it easy to access and inspect vulnerable fittings (e.g., drain traps, valves, faucets, tub and sink plumbing).
- Pressure test plumbing before closing it in.
- Put drain pans beneath hot water tanks and washers.

### 5.6 Condensation

Condensation problems are the result of chilled surfaces and humidity and are caused by a combination of ordinary surface temperatures and unusually high humidity or of unusually low surface temperatures and ordinary humidity. Many are the result of surface temperatures that are a bit too cold and humidity that is a bit too high. When problem-solving it is crucial to
understand which of these is happening, because the solutions are different. If the humidity is too high, then sources (e.g., bath exhaust fans, foundation drainage) must be controlled or dehumidification accomplished. If the surfaces are too cold then they must be warmed (e.g., by adding insulation and vapor control to present a warmer surface to the water molecules in the air or by heating the surface) until they are above design dew point temperature.

Parts of buildings and things inside buildings may be chilled in several ways, such as:

- contact with outdoor air in cold climates (usually walls, ceilings, attics);
- contact with air-conditioned air or supply air in warm climates (walls, ceilings, furniture, supply ducts, supply diffusers);
- contact with cold water or refrigerants (cold water pipes, chilled water lines, refrigerant lines, refrigerators/freezers);
- contact with the cool earth (e.g., foundation walls and floors), or
- radiant loss to the night sky (dew on roofs, attic sheathing).

In cold climates wall and roof sheathings and claddings are in direct contact with outdoor air and may be cooler than other materials in the structure. The greater the insulating value of the residence, the colder the outer surface becomes and the warmer the inner surface becomes. Poorly insulated portions of the enclosure can result in warmer exterior surfaces and cooler interior surfaces. If an inner surface is chilled when cold outdoor air is accidentally drawn across it, water may condense out of the warm indoor air. For example, the stack effect may draw cold outdoor air through cracks in the exterior finish and porous insulation beneath the sill of a bay window, chilling the sill from below. This explains the mystery puddle of water that sometimes appears. If an unplanned airflow brings warm indoor air in contact with cool outer surfaces, there is a risk of condensation. The solution is to warm the surface by intervening in the airflow or using the heating system (e.g., blow warm air at it or put a radiator beneath it). An unplanned airflow may cause warm indoor air to come in contact with exterior portions of the building. Common areas for this kind of condensation problem are roof and wall sheathing.

In hot climates, the cold air is inside and the warm air is outside. Traditionally, the way to dry a building has been to ventilate. With the advent of air-conditioning the indoor materials may be below the outdoor dew point temperature, and air-conditioning may result in condensation. Local humidification by outdoor air may happen even if the air-conditioning is drying out the building. When warm, humid, outdoor air is drawn into a wall cavity, it might condense on the back of the gypsum board because the gypsum is chilled by the air-conditioned air. The cavity could also be a sink cabinet with air drawn in from outdoors around the penetration for the water lines or drain. Again, air sealing is the solution, but in this case air sealing does not warm the condensing surface, it controls water vapor migration. It is a source control method. The supply air from an air conditioner is likely to be fairly cool; 55°F (13°C) is not uncommon. The dew point at 75°F (24°C) and 50% relative humidity (RH) is around 55°F (13°C). Supply ducts, diffuser boots, and air-conditioning cabinets are common sites for condensation. Insulation and vapor control prevent condensation by keeping warm water vapor in the air away from the cool surfaces. Condensation may occur on objects in contact with supply air if the room relative humidity is too high – supply diffusers and furnishings may sweat.

Cold or chilled water lines, toilets, interior roof drain lines, and refrigerant lines may all sweat. The colder the fluid the more prone it is to condensation and the greater the insulation needs to be. Vapor control may also be necessary to keep the warm room air away from the cold pipes. Pipes are even more vulnerable to condensation when located in unconditioned space such as attics, crawlspace, and trenches.

In some climates, condensation on the walls or floors of foundations occurs. The earth chills the foundation materials below the dew point of the outdoor air. In this case, as in air-conditioned buildings, the ventilating air is wetting the building, not drying it. This is why crawlspace foundations and finished basements may be vulnerable to mold growth (compounding poorly managed rainwater issues and remaining after rainwater issues have been solved). Solutions for this issue include:

- active dehumidification (dehumidifier or air-conditioning),
- insulating foundations on the outside to warm the interior surfaces, or
- insulating foundations on the inside using systems that also manage vapor migration, so the water molecules are kept from the chilled surfaces.

For crawlspace foundations this would require including the crawlspace within the thermal, rainwater, airflow, and vapor control systems and omitting foundation vents to the outside.

In some climates roof sheathings can be chilled below the nighttime outdoor air dew point by radiation to the night sky. Air is condensed onto the sheathing from the ventilating air entering the attic through the softfit vents or from interior spaces through building assemblies.

### 5.7 Water Vapor Sources

Water vapor in buildings either is released inside the building or comes in as part of the intentional or unintentional ventilating air. Inside sources of water vapor include the following:

- Exhaled breath
- Bathing
- Mopping/washing/cooking
- Drying dishes and clothing
- Damp foundations
- Damp crawlspaces
- Special sources – spas, pools, aquariums
- Intentional humidification systems
Respiration and activities for a typical family of four releases around 20 pounds (5 L) of water vapor a day into the indoor air. Controlling these sources has traditionally been accomplished with exhaust ventilation of the source, dilution ventilation with outdoor air, and, more recently, with active dehumidification using air conditioners or dehumidifiers. Bathroom, kitchen range, and clothes dryer exhaust are effective ways of reducing indoor humidity loads. Ventilating with outdoor air only dehumidifies when the building is not air-conditioned. Ventilating to cool works best when the outdoor air dew point is less than 55°F (13°C).

Air conditioners can dehumidify the indoor air by condensing water out of the air and draining it away. There is a wide variation in the ability of air conditioners to dehumidify. Things that increase an air-conditioner’s ability to dehumidify include coil temperatures in the range of 55°F (13°C) or less (but not cool enough to freeze or cause condensation on the outside of equipment or pipes) and longer runtimes (air conditioners do not dehumidify well until they run 40% of each hour).

There are a number of strategies for improving air conditioner dehumidification.

- Two stage-split coil systems allow long runtimes and cooler coils.
- Reheat allows cooler coils (reheat can be provided by using waste heat, as in run-around loops, hot gas bypass, and heat recovery).
- Separate dehumidification capacity can be added.
- Desiccant technologies can be used.

A damp foundation, even one that does not appear to have liquid water in it, may release as much water vapor into the indoor air as all other ordinary sources combined. Rainwater and groundwater control is the first required step in prevention. Second, a barrier over the soil in the form of a concrete slab or wrap-around plastic sheeting with ventilation at grade will help. Special sources such as spas, pools, and aquariums can easily be the major source of water vapor in buildings. Enclosures and humidity control must be specially designed for them.

Active humidification should be included in a building only when there is a specific overriding need such as providing adequate environmental conditions for a painting collection. As with pools and spas, the mechanical systems and the enclosure must be specially designed to accommodate constant indoor humidity levels year round.

### 5.8 Built-In Water

As buildings are assembled, some materials are intentionally or unintentionally installed wet — concrete, wet-spray insulation, lumber, wallboard joint compound, and water-based finishes. The lumber in an average two-story house with a gross inside volume of 16,000 cubic feet (460 m³) will dry from approximately 19% (typical moisture in installed lumber) to 9% moisture content. This results in a release of about 200 L (423 pints) of moisture for about 4600 lbs (2100 kg) of lumber used for joists and framing. Concrete releases about 90 L/m³ (146 pints/yard³) over the first 2 years after construction. Basement floors or slabs on grade may release thousands of liters of water during the curing process. During the first year and a half after construction, moisture input from construction sources in a new house may average 8–10 pints/day (4 to 5 L per day), and diminish to 0 in successive years.(8)

Other materials, such as exposed earth floors in crawlspaces and concrete blocks, may absorb rain water during construction and release it into the building as they dry. For the first few months after enclosure buildings may experience higher humidity levels than they will in ordinary operation. The most damaging moisture source is likely the combination of damp earth in a crawlspace with an OSB or plywood subfloor on the joists. OSB covers with mold quicker than other building materials at humidity levels greater than 95% RH.(5)

The entire subfloor may become colonized with fungi, because the temperature and humidity conditions are nearly the same for the entire surface. Sometimes builders lay plastic sheeting in the crawlspace to prevent moisture problems. This is wasted effort unless the sheeting is so well sealed that moisture cannot enter the crawlspace. Small ventilation fans set to keep humidity below a specific level also are frequently used to reduce moisture. However, unless the fan is relatively large, moisture will still be present within the crawlspace. The best method of preventing crawlspace mold is by keeping water out by using adequate exterior drainage and a French drain around the crawlspace to exclude groundwater. Well-sealed plastic sheeting with ventilation underneath may also help.

### 5.9 References

Mold in Buildings — Exterior and Interior Images

All photos courtesy of Kyle B. Dotson, CIH, CSP, DEE

This section is intended to act as a supplement to the text, providing readers with images of conditions they might encounter when performing building evaluations.

**Exterior Images**

**Figure 1** — A water leak inside may be most apparent outside.

**Figure 2** — Incorrect gutters increase the risk of water intrusion.
Figure 3 — An interior plumbing leak can be indicated on exterior brick.

Figure 4 — Leaf-clogged gutters increase the risk of water intrusion.

Figure 5 — Mold from a pipe leak in an exterior wall.

Figure 6 — A water leak below a toilet.

Figure 7 — Bowls under PVC union, suggestive of a previous leak.
Figure 8 — Consistent pattern of mold that is consistent with an area of high humidity.

Figure 9 — Heavy Growth on an HVAC register may indicate pan overflow.

Figure 10 — A leak below an improperly flashed window.

Figure 11 — Leakage behind a bath mixing valve.

Figure 12 — A long-term leak associated with water heater plumbing.

Figure 13 — Long-term overflow of catch pan below an HVAC system.

Figure 14 — Mold behind a baseboard, due to flooding of a room.

Figure 15 — Mold between two layers of linoleum sheet flooring.
Figure 16 — Consistent pattern of mold that is consistent with an area of high humidity.

Figure 17 — Heavy Growth on an HVAC register may indicate pan overflow.

Figure 18 — A leak below an improperly flashed window.

Figure 19 — Leakage behind a bath mixing valve.

Figure 20 — A long-term leak associated with water heater plumbing.

Figure 21 — Long-term overflow of catch pan below an HVAC system.

Figure 22 — Mold behind a baseboard, due to flooding of a room.

Figure 23 — Mold between two layers of linoleum sheet flooring.
Figure 24 — Mold under adhesive vinyl tile applied to plywood decking.

Figure 25 — Mold under bath tile that wasn’t installed on greenboard.

Figure 26 — Mold under linoleum.

Figure 27 — Normal growth on an HVAC grill due to condensation.

Figure 28 — Note the importance of moving contents to inspect under vinyl shelf liner.

Figure 29 — A pipe leak in the bathroom above is apparent from the staining on the ceiling below.

Figure 30 — Rust stains on the back of carpet from the tack strip holding it down is indicative of moisture.

Figure 31 — Warped wood is a key indicator of moisture.
Section 4: Remediation and Control

Figure 32 — Washer drain overflow into the wall.

Figure 33 — Water ponding on the ceiling.

Figure 34 — Water stains on the walls near the ceiling line.
Recognition, Evaluation, and Control of Indoor Mold
2nd edition
Edited by Ling-Ling Hung, PhD, Steven M. Caulfield, PE, CIH, LEED® AP,
and J. David Miller, PhD, FAIHA®

Recognition, Evaluation, and Control of Indoor Mold, 2nd edition provides the most current and comprehensive discussion on the basic practice of identifying mold damage, the evaluation of the samples that are collected, and the process of remediation. Its 20 chapters cover the underlying principles and background of evaluation and control, building evaluation, data interpretation, remediation and control. Images of mold found in building exterior and interior are provided in the Appendix.

This mold resource was written by industrial hygiene practitioners, academics, government officials, and scientists, and has been scrutinized by external peer review. Innovative methods and approaches for each assessed situation are provided.

STOCK NUMBER: IMOM19-679