ASHRAE Position Document on Limiting Indoor Mold and Dampness in Buildings

Approved by ASHRAE Board of Directors
June 27, 2012

Reaffirmed by ASHRAE Technology Council
January 27, 2016

Expires
January 27, 2019

ASHRAE
1791 Tullie Circle, NE • Atlanta, Georgia 30329-2305
404-636-8400 • fax: 404-321-5478 • www.ashrae.org

COMMITTEE ROSTER

The ASHRAE Position Document on Limiting Indoor Mold and Dampness in Buildings was developed by the Society's Limiting Indoor Mold and Dampness in Buildings Position Document Committee formed on December 14, 2010.

Lewis G. Harriman III, *Chair*
Mason-Grant
Portsmouth, NH

Carl Grimes, CIE
Healthy Habitats LLC
Denver, CO

K. Quinn Hart, PE
U.S. Air Force
Panama City, FL

Michael Hodgson, PhD, MD
Veterans Health Administration
Washington, D.C.

Lan Chi Nguyen Thi, PEng.
InAIR Environmental Ltd.
Ottawa, ON, Canada

Francis (Bud) Offermann, PE, CIH
Indoor Environmental Engineering
San Francisco, CA

William Rose, RA
University of Illinois at Urbana-Champaign
Champaign, IL

COGNIZANT COMMITTEE

The chairperson(s) of ASHRAE's Technical Committee 1.12 and Environmental Health Committee served as ex-officio members.

Lewis G. Harriman III
ASHRAE Technical Committee 1.12, *Chair*
Mason-Grant
Portsmouth, NH

Jianshun (Jensen) Zhang
Environmental Health Committee, *Chair*
Syracuse University
Syracuse, NY

ABSTRACT

Credible research and cognizant health authorities have established an association between health problems and indoor dampness. A building's mechanical systems, its exterior enclosure, and its occupant activities all affect the amount of wetting and drying indoors. Therefore, ASHRAE takes the position that all policymakers, regulatory authorities, building professionals, and building occupants should be aware that indoor dampness, mold, and microbial growth are warnings of potential problems. All concerned should make decisions and take actions that help buildings, their contents, and their systems stay as dry as possible, given their functions. This position document provides help in understanding some of the complex interactions and decisions that lead to indoor dampness. However, professionals and the public need to know, with greater certainty than at present, when a building is "dry enough" to avoid dampness-related health risks. ASHRAE recommends further health-related building research to develop and publish a practical, quantitative, and effective definition and measurement technique for whole-building dampness.

HISTORY OF REVISION/REAFFIRMATION/WITHDRAWAL DATES

The following summarizes the revision, reaffirmation, or withdrawal dates: 2/6/2005—

BOD approves Position Document titled *Minimizing Indoor Mold Problems through Management of Moisture in Building Systems*

10/22/2010—BOD approves revised Position Document titled *Limiting Indoor Mold Growth and Managing Moisture in Building Systems*

6/27/2012—BOD approves revised Position Document titled *Limiting Indoor Mold and Dampness in Buildings*

1/29/2013—Technology Council approves reaffirmation (with minor editorial updates) of Position Document titled *Limiting Indoor Mold and Dampness in Buildings*

Note: ASHRAE's Technology Council and the cognizant committee recommend revision, reaffirmation, or withdrawal every 30 months.

Note: ASHRAE position documents are approved by the Board of Directors and express the views of the Society on a specific issue. The purpose of these documents is to provide objective, authoritative background information to persons interested in issues within ASHRAE's expertise, particularly in areas where such information will be helpful in drafting sound public policy. A related purpose is also to serve as an educational tool clarifying ASHRAE's position for its members and professionals, in general, advancing the arts and sciences of HVAC&R.

CONTENTS

ASHRAE Position Document on Limiting Indoor Mold and Dampness in Buildings

EXECUTIVE SUMMARY

In many parts of the world, moisture damage and microbial growth including mold have caused billions of dollars in repair costs and interruption of building operations. Further, in both North America and Europe, building dampness and mold have been documented to be associated with adverse health outcomes related to asthma and upper respiratory problems.

As moisture levels increase, so does the possibility of microbial growth and with it the potential for adverse effects on the building and its occupants. The buildup of moisture indoors can be controlled through the building's design, construction, and operation and the actions of its occupants.

ASHRAE is a cognizant technical authority in the field of HVAC system design, installation, and operation, as well as building energy conservation. All of these factors can influence the amount of moisture in buildings. Consequently, those who develop and enforce public policy within the building industry often rely upon ASHRAE standards and guidance. Therefore, it is appropriate for ASHRAE to make clear the Society's positions with respect to managing moisture, avoiding persistent dampness, and reducing the risks associated with indoor microbial growth.

ASHRAE currently takes the following positions:

1. When humidity and moisture are not effectively controlled, persistent dampness can lead to material damage, corrosion, structural decay, and microbial growth, including mold. Cognizant health authorities have established an association between damp buildings and the increased potential for adverse health effects (IOM 2004, WHO 2009, New York State 2010, Mudarri and Fisk 2007, Fisk et al. 2007, Mendell 2011). ASHRAE believes that the potential for these problems can and should be reduced by limiting the buildup of indoor moisture through the decisions and actions taken by designers, contractors, owners, and occupants of buildings.
2. Small amounts of wetting and drying in buildings and in HVAC systems are normal and represent no long-term risk for durability, increased energy consumption, or mold growth. Occasional wetting is not usually a problem provided that wetting is followed promptly by drying. Problems occur when the dampness becomes persistent. To limit the potential for problems, professionals and the general public should be aware there are risks associated with prolonged dampness and should take action to prevent and correct such conditions.
3. Currently, no quantitative, health-based exposure guideline or thresholds can be recommended for acceptable levels of contamination by microorganisms (IOM 2004). While associations between persistent dampness and adverse health effects have been observed, relationships between persistent dampness, microbial exposure, and health effects cannot be quantified precisely at this time (WHO 2009, Mendell 2011). In light of this information, ASHRAE believes the most effective course is to limit the potential for microbial growth indoors by reducing the causes of persistent dampness.

1. ISSUES

The six issues addressed by this position document are summarized below. The inherent complexities of these issues are described in more depth in the appendix.

1.1 Health

Negative health effects have been credibly established as being associated with dampness in buildings. But to date the exact causes and the exact extent of such problems has not been defined. As an engineering society rather than a cognizant health authority, ASHRAE expects and follows guidance from health professionals with respect to the health effects of indoor dampness, mold, and microbial growth.

1.2 Damp Building Definition and the Need for Its Improvement

According to public health researchers, problems in the past have been associated with the occurrence of visible water damage or stains, visible mold, and/or odors from microbial growth (WHO 2009; Mendell et al. 2011). The presence of these factors—alone or in combination—is therefore useful as a warning and as a call for action to remediate the source of the water accumulation. However, the presence of these three factors, even in combination, allows neither certainty nor practical quantification concerning health-relevant dampness.

Consequently, ASHRAE recommends further health-related building research. The goal should be to develop and publish a quantitative definition of a "damp building," together with an economically practical measurement technique. To be useful in the real world of building design, construction and operation, such a definition and measurement technique must allow determination (with reasonable and repeatable certainty) of a building that is "dry enough" to avoid dampness-related health risks.

1.3 Negative Effects of Moisture Other than Microbial Growth

Quite apart from health effects, there are other important reasons to avoid excessive indoor moisture accumulation. The appendix to this position document outlines some of the non-health-related negative effects of moisture on buildings.

1.4 Complex Causation

Based on past observation of problem buildings, dampness sufficient to cause problems seldom has a single cause. More often, a series of events, including decisions in many areas of professional and personal responsibility, combine in complex ways to cause a problem. Therefore, it is not appropriate to assign responsibility for building dryness to any one group, because it is not likely that any one group can prevent a problematic level of dampness, mold, and microbial growth by their actions alone.

1.5 Decisions and Actions that Avoid Problems

There are known and avoidable contributors to moisture, mold, and microbial growth problems in all areas of professional and personal responsibility (HVAC, architectural design and construction, building operation and maintenance, building occupant's actions, and the actions of policymakers and regulatory authorities). The appendix provides useful detail about decisions and actions that have increased or reduced risks.

1.6 Investigation and Remediation of Mold and Microbial Growth Problems

ASHRAE provides neither guidance nor professional certification in this area but notes that other cognizant authorities have established useful guidelines for mold investigations and remediation. Some cautions for investigators and building owners about investigations are included in the appendix to this document.

2. BACKGROUND

Well-designed, well-constructed, well-maintained building envelopes are critical to the prevention and control of excess moisture and microbial growth, because they limit thermal bridges and the entry of liquid water, humid air, or water vapor diffusion. Management of moisture also requires control of temperature and ventilation to avoid excess humidity, condensation on surfaces, or excess moisture in materials.

Building owners are responsible for providing a healthy workplace or living environment without excess moisture and mold by ensuring proper building design, construction, and maintenance. To the extent that they are allowed control, building occupants are responsible for managing the use of water, heating, air conditioning, ventilation, and appliances in a manner that does not contribute to dampness and mold growth.

To help reduce the potential for problems, ASHRAE provides the observations, suggestions, and resources described in the appendix to this position document and makes the following recommendations.

3. RECOMMENDATIONS

a. All building professionals, building occupants, public policymakers, and regulators should understand that persistent indoor dampness is neither normal nor desirable and can lead to problems for both the occupants and the building itself. All concerned should take action to design, construct, and keep buildings and their systems as dry as possible, given their normal functions.

b. To more effectively inform the professions and the public, ASHRAE technical committees should generate a new chapter for the ASHRAE Handbook consolidating known problems and describing known techniques for managing and measuring moisture in buildings and for avoiding problems associated with indoor dampness. In addition, ASHRAE technical committees should strengthen guidance provided in other chapters of the ASHRAE Handbook with respect to minimizing the risk of excessive moisture accumulation in buildings and HVAC systems.

c. ASHRAE should establish a joint research project in cooperation with cognizant health authorities, related professional societies, and building owners to develop and publish a practical, quantitative, and certain definition and inspection protocol for whole-building dampness. Both the professions and the public need to know when a building is "dry enough" to reduce dampness-related health risks.

d. ASHRAE should remain committed to continue updating the more than 3000 pages of ASHRAE resources described in the reference sections of this document on a regular basis, through volunteer and partner-supported efforts.

4. REFERENCES

Fisk, W., Q. Lei-Gomez, and M. Mendell. 2007. Meta analysis of the associations of respiratory health effects with dampness and mold in homes. *Indoor Air* 17:284–96.

IOM. 2004. *Damp Indoor Spaces and Health*. Washington, D.C.: Institute of Medicine of the National Academies, The National Academies Press.

Mendell, M., A. Mirer, K. Chung, et al. 2011. Respiratory and allergenic heath effects of dampness, mold and dampness-related agents: A review of the epidemiologic evidence. *Environmental Health Perspectives* 119(6). National Institute of Environmental Health Sciences. www.niehs.nih.gov/health/topics/index.cfm.

Mudarri, D., and W. Fisk. 2007. Public Health and economic impact of dampness and mold. *Indoor Air* 17:226–35.

New York State. 2010. New York State Toxic Mold Task Force: Final Report to the Governor and Legislature, New York State Department of Health. www.health.state.ny.us/environmental/indoors/air/mold/task_force/.

WHO. 2009. Guidelines for indoor air quality: Dampness and mould. Copenhagen: World Health Organization. http://bit.ly/xNKFEk.

APPENDIX

COMMITTEE OBSERVATIONS CONCERNING MOLD AND MOISTURE PROBLEMSIN BUILDINGS

HEALTH

ASHRAE's expertise lies in the areas of design, installation, operation, and maintenance of mechanical systems and in the hygrothermal performance of building enclosures. These systems do not guarantee human health, which is a result of complex interactions between building systems; outdoor air change rates; air contaminant concentrations; emissions of air contaminants from building materials, furnishings, and equipment; as well as occupant activities and individual susceptibilities. Consequently, for all opinions related to the health impacts of exposure to microbial contaminants (including mold), ASHRAE relies on the expertise of the medical community. ASHRAE's review and analyses of the literature has led to the following observations:

a. When buildings get wet or damp and stay damp for a long enough period of time, microbial growth on building materials and furnishings can occur, including growth of molds, other fungi, and bacteria. This microbial growth can result in significant increases of indoor concentrations of airborne microbial contaminants, including mold spores and mycelia fragments, bacterial spores and cell fragments, mycotoxins, and microbial volatile organic compounds (Park et al. 2008, Cox-Ganser et al. 2005).
b. The medical community has long recognized that in agricultural occupational settings, worker exposures to very high concentrations of microbial air contaminants, including mold spores and bacteria, can cause adverse health effects, including asthma, bronchitis, rhinitis, mucous membrane irritation, allergic alveolitis (hypersensitivity pneumonitis), and inhalation fever (Hodgson and Flannigan 2001, Sorenson 2001).
c. The medical community has also long recognized that in health care settings, especially in immuno-compromised patients, exposure to even relatively low levels of pathogenic fungi such as *Aspergillus fumigatus* can cause severe invasive respiratory disease and death. In these settings, the buildings' HVAC systems must be carefully designed, installed, and operated to significantly reduce exposure (ASHRAE 2008).
d. The precise nature of health effects in buildings with moisture problems and their relationships to types and levels of microbial air and surface contaminants, including mold spores, is not fully understood. However, in the U.S., the Institute of Medicine (2004) concluded in *Damp Indoor Spaces and Health* that while there was not at that time sufficient evidence of a causal relationship between health outcomes and exposure to mold or other agents in damp buildings, there was sufficient evidence of an association between damp buildings and upper respiratory tract symptoms, asthma symptoms in sensitized asthmatic persons, hypersensitivity pneumonitis in susceptible persons, wheezing, and coughing. In the years since that report, other credible sources have reached similar conclusions (WHO 2009, New York State 2010, Mendell et al. 2011).
e. According to public health researchers, problems in the past have been associated with the occurrence of any of three factors: visible water damage or stains, visible mold, and odors from microbial growth (WHO 2009; Mendell et al. 2011). The absence of any of these three factors does not rule out the potential for a problem, nor does their presence

indicate the certainty of one. But when any of these three factors are present, the research suggests that building owners and occupants should be aware of the potential for health-related problems and take steps to investigate and eliminate the causes of excessive moisture accumulation.

The implication of these observations by cognizant health authorities and public health researchers is that the prudent course for owners, designers, builders, installers, and operators of all buildings and HVAC systems is to make decisions and take actions that limit the potential for long-term accumulation of excess moisture in building materials and systems.

DAMP BUILDING DEFINITION AND THE NEED FOR ITS IMPROVEMENT

For many years, public health researchers have observed that health problems are more common in "damp buildings" (IOM 2004, WHO 2005, Cox-Ganser 2005, etc.).

Further, for decades the mechanisms of mold growth in buildings have been clear, and computerized mold growth models have been well correlated with laboratory experimental results (ASHRAE 2009a, Viitanen 1997, Rowan et al. 1999, Pasenen et al. 2000, and Sedlbauer et al. 2001). Recently, public health researchers (WHO 2009; Mendell et al. 2011) have noted that negative health effects among occupants have been more commonly reported when a building exhibits evidence of excessive moisture, such as:

- Visual evidence of water damage or water stains
- Visible mold growth
- Moldy or earthy odors

While these research results are helpful, they are not sufficient. They provide no actionable definition of a "damp building." And they provide no quantitative definition of how many water stains, how much visible mold growth, or what strength of musty odors are sufficient to suggest that action is required to avoid negative health effects. Many buildings have one or more of these problems, in small amounts, in different parts of the building, without any recognized negative health effects. It is only by aggregating many buildings that health studies have documented the consistent, significant associations of these problems with respiratory and allergic effects. However, the studies have not identified threshold amounts of one or more of these problems that merit action.

To be useful for those who intend to prevent problems in buildings and investigate them when they do occur, a definition of a damp building likely to produce negative health effects needs to include:

a. Discreet threshold levels of concern for the moisture content of building materials that have been frequently observed to be either sensitive to mold growth and/or that serve as reservoirs of moisture that transfers to nearby sensitive materials.
b. A material moisture content measurement technology, sampling procedure, and inspection methodology that is sufficient (in the real world of large buildings and complex building assemblies) to repeatably and economically identify at least three levels of health concern for the general population: low, medium, and high probability of negative health effects among a randomly-selected population.
c. Health concern adjustment factors for important segments of the general population that are known to have elevated sensitivity to health effects of damp buildings including (at

least) infants and the elderly, asthmatics, and individuals with compromised immune systems.

d. An empirical foundation for the definition and protocol that includes a correlation of the protocol results with observed negative health effects in real-world buildings and real-world populations.
e. Documented tests using a random selection of building owners and building investigators that demonstrate that the protocol is relevant, repeatable, and economical enough for general use.

ASHRAE does not have the expertise to lead such a research effort, but our technical and standing committees can and must be a part of the research to help ensure that the resulting protocol is relevant, repeatable, and economical enough for everyday use by both building investigators and building owners.

NEGATIVE EFFECTS OF MOISTURE OTHER THAN MICROBIAL GROWTH

Long-term moisture accumulation has documented negative consequences quite apart from mold growth or any potential health risks of damp buildings. Measurable effects of excess moisture accumulation and/or episodic water damage include the following:

a. Shortening the life of materials, structural fasteners, and building assemblies, which increases structural risk and leads to excess maintenance, repair, and renovation costs (Harriman et al. 2006).
b. Reducing the effectiveness of insulation, leading to increased energy consumption.
c. Reducing the perceived value of a property and increasing the cost of its insurance coverage.
d. Reducing occupant satisfaction because of unpleasant odors and musty smells.

Based on these observations, ASHRAE believes that the prudent course for designers, installers, builders, owners, operators, and occupants of buildings and building systems is to make decisions and take actions that limit the potential for long-term accumulation of excess indoor moisture. Keeping buildings dry reduces the risk of problems with respect to their value, durability, sustainability, indoor air quality, occupant comfort, and energy efficiency.

COMPLEX CAUSATION

Mold spores and mycelial fragments can be found in the air and on surfaces of nearly all buildings, but prolific mold growth is not. Airborne mold contaminants, including mold spores and hyphal fragments, are constantly present in outdoor air in concentrations that vary widely by season, location, and even time of day. In all buildings, airborne mold contaminants in outdoor air enter the building through the ventilation system, through open windows, and through air leaks in the building envelope. In clean, dry buildings, the indoor concentration of airborne mold contaminants is typically less than the outdoor concentration. In contrast, in buildings that become damp enough to support mold growth, the indoor concentrations of airborne mold contaminants can become much higher than the outdoor concentrations. In addition to differing concentrations, the types of microbial contaminants in buildings that become damp may be different from those typically present outdoors and in dry buildings.

ASHRAE observes that microbial growth, including mold and bacteria, does not occur without an accumulation of excessive amounts of moisture for a sufficient amount of time, within an adequate temperature range and in a material or surface coating that is microbially digestible (ASHRAE 2009a).

Factors that allow all of these preconditions to persist for long enough to create a microbial growth problem are highly complex. Surface treatments, moisture content, duration of excessive moisture, and material temperature can vary widely over a distance of a few inches or centimeters, leading to microbial growth in one small portion of a given material and the absence of microbial growth in nearby parts of the same material (Harriman and Lstiburek 2009).

Also, a material that is not microbially digestible, such as concrete or masonry, may act as a reservoir for excess moisture. That moisture can then transfer over time to more digestible materials nearby, such as paint layers or untreated paper-faced gypsum board. In addition, dust, dirt, and oils commonly accumulate on materials, creating an organic layer that can support microbial growth if the near-surface air layer is sufficiently humid for long periods. For example, the residual soap film on floors, bathtubs, and showers is an organic layer that can support microbial growth when it is damp, even though the ceramic tile surface itself does not support mold growth.

Further, the interactions that lead to the necessary amount and duration of moisture accumulation are similarly complex. One example of the interactions between different building elements that combine to result in moisture accumulation includes vinyl wallpaper on the indoor surfaces of exterior walls in combination with an air-conditioned space in a hot, humid climate. Outdoor air with a high dew point infiltrates the wall and condenses on the cavity side of the cool interior gypsum wallboard. Because the vinyl wallpaper is relatively impervious to water vapor transport, moisture accumulates in the wall cavity, resulting in microbial growth, including mold, and eventually decay and rot.

Note that the growth in this situation requires high outdoor dew point for many days or weeks, extensive air leakage through the enclosure, chilled indoor surfaces, vinyl wallpaper, and untreated paper-faced gypsum board. If any one of those elements is absent, it is quite possible that little or no mold growth would occur (Harriman et al. 2006). This example includes the following elements:

a. The owner or interior designer made a decision to install vinyl wall covering rather than a more permeable wall covering.
b. The architectural designer apparently designed and/or the contractor built a building that allows extensive inward humid air infiltration and also selected untreated gypsum wallboard for a location likely to experience high humidity in a climate where that high humidity will continue for many months.
c. The HVAC system is apparently designed and/or installed such that it overcools wall surfaces, and it is designed and installed (or operated) such that it encourages humid air infiltration and a high surface relative humidity (RH) inside the wall for extended periods.

As the example illustrates, risks from not one but several decisions made by many different professionals can act in combination to produce enough moisture accumulation in the wall cavities for a long enough period to create a microbial growth problem. Rarely can one profession, acting in isolation, take all the actions that either produce or prevent a moisture problem. Preventing moisture problems requires attention from the owner as well as all of the building professions.

Further, the risk of excess moisture accumulation can be either increased or reduced by the building occupants themselves as they use the building for their daily activities. For instance, if the occupants of an apartment generate a significant amount of moisture from cooking and cleaning activities without opening windows or using exhaust fans, excess moisture accumulation and mold growth may occur. A building is a complex and dynamic system, and its occupants are an integral and constantly changing component of that system.

Finally, individuals in the same building may be quite different with respect to their particular sensitivities to airborne microbial contaminants. A low level of contamination that causes adverse health effects for one sensitive individual often causes no health effects for others. Because of the complexity of these interactions, from a public policy perspective it would be ineffective and inappropriate to assign sole responsibility for microbial growth avoidance to any single group.

The prudent course of action is to keep all of the materials that make up a building and its HVAC systems as dry as possible, consistent with their normal functions. More specifics are discussed in Section A5. In general terms, all building professionals and occupants should be advised to do the following:

a. Remain aware that the factors that lead to microbial contamination, including mold, are catastrophic water damage, repeated wetting, or excessive long-term moisture accumulation in materials.
b. Make decisions and take actions that will keep the building and its systems, furnishings, and finishes as dry as possible, given the function of the component in question and the available resources.
c. Be aware that, if adequate resources are not made available to keep the building, its systems, and contents dry, then the risk of microbial contamination, including mold, will increase.
d. Keep the above facts in mind whenever one observes persistent dampness inside a building or when one constantly observes stagnant water in condensate drain pans or constantly damp insulation, filters, or sound lining of HVAC systems.

KNOWN FACTORS THAT INCREASE OR REDUCE THE RISK OF MOLD AND MOISTURE PROBLEMS

In each area of professional and occupant activity, there are decisions and actions that can either increase or reduce the risk of problems related to moisture, mold, and other microbial growth. In most cases, the individuals involved are not aware they are making fateful decisions. The factors described below come from the broad array of building professionals' experiences, many of which have been collected in ASHRAE publications and in the publications of allied professional societies.

When reviewing these factors, it is important to keep in mind that moisture and mold problems can develop for different reasons in cold and hot climates and can also occur through mechanisms caused by regionally specific building designs, material selections, and construction practices in different parts of the world. Therefore, recommendations based on local conditions are often needed to avoid dampness-related problems.

Note also that these factors have seldom been responsible, in isolation, for moisture and microbial growth problems. More commonly, the risk of microbial growth has increased when more than one of these factors are present or when an architectural risk factor is combined with risk factors associated with either HVAC systems or occupant activities.

a. HVAC factors that have been observed to ***reduce*** the risks of moisture accumulation, mold, and microbial growth include the following:
   1. Ensuring that all ventilation air is dried to a dew point below the dew point maintained inside the building when the building is being mechanically cooled (Harriman and Lstiburek 2009, Harriman et al. 2006).
   2. Ensuring that all condensation inside HVAC components and air distribution ductwork is drained to an appropriate sanitary drain or condensate collection system (Harriman et al. 2006).
   3. Ensuring that indoor surfaces of both occupied and unoccupied spaces are not cooled to temperatures so low as to create an average surface RH of over 80% that lasts for more than 30 days or surfaces cold enough to allow visible condensation (ASHRAE 2009a).

      Note that the relative humidity of air measured in the occupied space or return air does not indicate the RH in the thin boundary layer of air in contact with cool surfaces. Monitoring and controlling indoor dew point compared to indoor surface temperatures is the more useful metric for humidity control decisions.

      For example, in buildings that are being mechanically cooled during hot or humid weather, keeping the indoor air dew point below 55°F (12.8°C) nearly always ensures that surface RH will stay below 80% even on cool surfaces. In contrast, if the indoor air RH is 55% at 78°F (25.6°C), any surface cooled below 66°F (18.9°C) will have an RH above 80% (Harriman and Lstiburek 2009).
   4. Keeping the indoor dew point low enough to ensure that there is no condensation on the exposed surfaces of cool HVAC components or on sensitive building materials or furnishings. Nor should the indoor dew point be high enough to allow any surface RH over 80% when averaged over 30 days. The caution against condensation and long-term average surface RH above 80% applies not only to visible surfaces in occupied spaces but also to surfaces inside hidden building cavities and unconditioned spaces (Harriman et al. 2006).
   5. Ensuring that humidifiers are sized, installed, and controlled so they do not overload the air with humidity, which increases the risk of condensation inside air distribution systems and exterior walls and roofing assemblies (Harriman et al. 2006).
   6. Ensuring that cold HVAC and plumbing components and systems such as chilled-water pipes and valves, supply air ducts, cold domestic water lines, and cold condensate drain piping are sufficiently insulated to keep the temperature of all of their surfaces at least 10°F (4°C) above the dew point of the surrounding air. Note that pipes often pass through unconditioned spaces such as basements, crawlspaces, and attics. Insulation must be continuous and complete to limit high surface RH on a cold pipe as it passes through such high-dew-point locations (Harriman and Lstiburek 2009).
b. HVAC factors that have been observed to ***increase*** the risks of moisture accumulation include:
   1. Failing to keep the indoor dew point low enough to prevent condensation indoors or failing to keep surface RH below 80% in occupied spaces or inside hidden building assemblies (Harriman and Lstiburek 2009).

2. Overchilling a building's surfaces during humid weather (Harriman and Lstiburek 2009).
3. Redistributing microbial air contaminants, including mold, from a contaminated space into occupied areas. Examples of contaminated spaces sometimes include parts of the building under construction or renovation, hidden building assemblies such as damp crawlspaces or attics, or spaces above dropped ceilings or below raised floors (Harriman and Lstiburek 2009).
4. Failing to make air distribution components and joints in return plenums and supply and exhaust ducts sufficiently airtight. Joints and connections must be tight enough to prevent suction that otherwise pulls humid outdoor air into the building and/or leakage that allows cold supply air to chill surfaces inside humid building cavities (Harriman and Lstiburek 2009, Harriman et al. 2006).
5. Failing to keep the long-term average indoor air pressure positive with respect to the outdoors when the outdoor dew point is higher than indoor surface temperatures (Harriman et al. 2006).
6. Failing to prevent dirt and dust accumulation on cooling coils and on duct surfaces and sound lining downstream of cooling coils. This can lead to microbial growth in the damp layer of dust that collects inside the cooling system. Installing access panels that allow for the inspection and cleaning of the condensate pans and areas upstream and downstream of cooling coils is an important requirement for ensuring the condensate pan is not ponding water, the coils are clean, and the upstream and downstream surfaces are clean and dry. Regular cleaning and ultraviolet lamps can reduce the impact of occasional lapses in filtration. But over time, effective filtration is the most important factor in preventing microbial growth in those parts of the system that can be expected to accumulate moisture during normal operation.
7. Failing to keep the air velocity through cooling coils low enough to prevent droplet carryover into downstream ductwork and filters, leading to microbial growth in those locations (Harriman and Lstiburek 2009).
8. Failing to install condensate drain traps deep enough to allow free-flowing drainage of normal cooling coil condensate and failing to install traps and condensate drain lines with a diameter large enough to allow maintenance personnel to both observe clogs and clean out anything that obstructs free-flowing drainage (Harriman et al. 2006).
9. Failing to install accessible cleanouts in condensate drain lines to allow periodic removal of algae and the particulate, feathers, sticks, and leaves that typically wash off the coil. Note that copper piping has been effective in limiting accumulation in condensate drain lines (Harriman et al. 2006).
10. Failing to measure and limit the volume of ventilation and makeup air to the amount required for the application and that will in fact be dried effectively by the system's dehumidification components (Harriman and Lstiburek 2009). (Note that ventilation without dehumidification has been responsible for major mold growth problems in hot and humid climates. Whenever any building in any climate is being mechanically ventilated, the indoor dew point must remain low enough to keep the indoor surface RH below 80%, even on hidden cool surfaces.)
11. Failing to ensure that system operation during unoccupied periods keeps the indoor dew point low enough to prevent a 30-day average surface RH above 80% on cool surfaces, 100% RH for 24 consecutive hours, or visible condensation. Mold and microbial

growth accelerates when the indoor dew point stays high while surfaces are intermittently chilled by cooling systems. Moisture accumulation caused by intermittent chilling of surfaces often occurs in unoccupied schools and health care clinics overnight or during vacations if dew points are uncontrolled when cooling systems are reset to higher indoor temperature setpoints (Harriman and Lstiburek 2009).

12. Failing to ensure that the temperatures of chilled-water systems stays low enough and the flow rates through the coils stay high enough to effectively dry the air (when such a chilled-water system is the only means of removing excess humidity from the building) (Harriman and Lstiburek 2009).

c. Architectural features that have been observed to ***reduce*** the risks of moisture accumulation and microbial growth include:
   1. Roof overhangs of at least 24 in. (600 mm) or more (CMHC 1996).
   2. Pan flashing under windows and doors that forces any water leakage outward onto an effective water barrier and then out of the building wall (Harriman and Lstiburek 2009, ASTM 2006, ASTM 2009, JLC 2007).
   3. Crawlspaces that are sufficiently lined and sealed to prevent infiltration into the building from surface water, moisture from the soil, and humid air (DOE 2005).

d. Architectural features that have been observed to ***increase*** the risks of moisture accumulation and microbial growth include:
   1. Vinyl wall covering on exterior and demising walls of buildings in hot and humid climates. Problems have frequently occurred behind vinyl wall covering when, as is quite common, the building lacks a continuous, sealed air barrier that effectively keeps humid outdoor air out of the cavities inside the exterior and demising walls (Harriman and Lstiburek 2009).
   2. Damp crawlspaces (DOE 2005).
   3. Water accumulating next to or under the building's foundation (Rose 2005, ASTM 2009).
   4. Rain leaks through joints around windows, doors, or other wall penetrations such as through-wall AC units, electrical fixtures, exhaust ducts, or structural fasteners or leakage through joints where different types of exterior cladding come together (Harriman and Lstiburek 2009).
   5. Absence of effective flashing around windows, doors, skylights, and other penetrations of the building's walls or roof (ASTM 2009).
   6. Absence of an effective, continuously sealed air barrier covering all six sides of the building envelope, allowing leakage of humid air from either indoors or outdoors into cool exterior walls, crawlspaces, roof assemblies, or attics (ASHRAE 2011a, ASHRAE 2010b).
   7. Absorptive exterior cladding such as brick veneer, stucco, or masonry that retains rain water but is not backed by a free-draining and vented air gap followed by an impermeable water and vapor barrier and flashing to exclude moisture (ASHRAE 2009b).
   8. Failing to install effective flashing around wall penetrations and terminations of external insulation and finish systems, along with a protective and continuously sealed waterproof drainage layer integrated with that flashing behind the insulation (Harriman and Lstiburek 2009).

e. Building operational decisions that have ***reduced*** the risks of moisture accumulation and microbial growth include:

1. Mopping and drying up spilled liquids or wash water promptly, limiting the amount of water that soaks into walls, carpeting, or flooring materials through the development of spill protocols and standard operating procedures.
2. Repairing plumbing leaks quickly and drying up any water leakage that resulted from the leaks within 24 to 48 hours.
3. Keeping irrigation spray heads aimed carefully, preventing the frequent soaking of exterior walls and foundation.
4. Maintaining the slope of exterior landscaping so that rainwater and irrigation spray flows away from the foundation rather than accumulating there.
5. Keeping rainwater runoff from the roof at least 3 ft away from the foundation.
6. Removing mold and other microbial contaminants promptly with appropriate engineering controls (e.g., HEPA air filtration, negative pressure containments) to keep contaminants from becoming airborne and distributed throughout the building, in accordance with procedures established by cognizant authorities (EPA 2001, AIHA 2008, ACGIH 1999, IICRC 2008).

f. Building operational decisions that have ***increased*** the risks of moisture accumulation have included:
   1. Failing to effectively exhaust humid air from showers, spas, decorative water fountains, indoor landscaping irrigation, and swimming pools. (When the weather is hot and humid, a related problem is the failure to dry the air that is brought into the building as makeup for exhausted air.)
   2. In cold weather, humidifying the indoor air to dew points high enough to create conditions where there are entire days or weeks of condensation or surface RH above 80% inside cooled walls and attics.
   3. Failing to ensure that the temperatures of chilled-water systems stay low enough and the flow rates through the coils stay high enough to effectively dry the air when such chilled-water systems are the only means of removing excess humidity from the building. (The problem often occurs when chilled-water temperatures are reset in an effort to save energy when the building is unoccupied during hot and humid weather. When chilled-water temperatures must be reset to save energy, or when flow rates through coils are too slow to dry the air, a separate dehumidification system may be necessary to prevent problems associated with persistent dampness.) (Harriman et al. 2006)

g. Home dwellers' decisions that have been observed to ***reduce*** the risks of moisture accumulation and microbial growth include:
   1. Keeping shower or tub splash within the tub enclosure, limiting the amount of water that can soak the floor or walls of the bathroom.
   2. Mopping and drying spilled liquids or wash water promptly, limiting the amount of water that soaks into walls, carpets, or flooring materials during cleaning operations, and drying the water that remains within 24 to 48 hours.
   3. Repairing plumbing leaks quickly and drying any water leakage that resulted from the leaks within 24 to 48 hours.
   4. Keeping irrigation spray heads aimed carefully, preventing the soaking of exterior walls and foundation.
   5. Maintaining the slope of the landscaping so that rainwater and irrigation runoff flows away from the foundation rather than accumulating there.
   6. Keeping rainwater runoff from the roof at least 3 ft away from the foundation.

7. Removing mold and other microbial contaminants promptly with appropriate engineering controls (e.g., HEPA air filtration, negative pressure containments) to keep contaminants from becoming airborne and distributed throughout the building, in accordance with procedures established by cognizant authorities (EPA 2001, AIHA 2008, ACGIH 1999, IICRC 2008).

h. Home dwellers' decisions that have ***increased*** risks of moisture accumulation and microbial growth include:
   1. Failing to use either fans or window openings to effectively exhaust humid air from cooking or from baths and showers, especially in small homes or apartments with many people or long cooking operations that lead to a large percentage of hours per week or month at a high indoor dew point.
   2. Failing to effectively exhaust (or dehumidify) humid air from clothes driers or drying racks. The problems associated with this error are especially severe during cold weather.
   3. Growing an unusually large number of live plants indoors without exhausting or otherwise removing the humidity they produce. The problems created by this oversight are especially severe in cold climates.
   4. In cold weather, humidifying the indoor air to dew points high enough to create conditions where there are entire days or weeks of condensation or surface RH above 80% inside cooled walls and attics.
   5. Storing large amounts of documents, furniture, or cardboard boxes in damp basements or crawlspaces or in contact with cold exterior walls or foundations.

i. Public policy and building code decisions that have ***reduced*** the risks of moisture accumulation and microbial growth include:
   1. Water barrier requirements. A requirement for a continuous, sealed water barrier in the outer layers of exterior walls and foundation can be very helpful in keeping rainwater from leaking inward into more moisture-sensitive components of the building. This is particularly helpful behind brick veneer, masonry, and stucco cladding, which can all retain a great deal of rainwater. When retained and driven by solar heat, water can move into the building unless there is a vented air gap and a continuous, well-sealed water barrier to protect the inner layers of the exterior wall (ASHRAE 2009a).
   2. Air barrier requirements. Air barrier requirements (in particular, the mid-construction measurement of the air leakage rate of a building against some allowable code-required maximums) is a proven means of reducing both energy consumption and reducing risk of moisture accumulation caused by humid air infiltration (ASHRAE 2010b, ASHRAE 2009a, ASHRAE 2011b, Harriman and Lstiburek 2009).

j. Public policy and building code decisions that have ***increased*** the risks of moisture accumulation and microbial growth include:
   1. Unwise or overly restrictive vapor retarder requirements. Wholesale adoption of prescriptive vapor barrier requirements generated for cold climates have proven to be destructive for buildings in hot and humid climates.

      Placement of vapor barriers does not easily lend itself to simple or global prescriptive requirements. In place of prescriptive requirements, ASHRAE recommends adoption of ASHRAE Standard 160 (ASHRAE 2009a) guidelines for envelope design decisions regarding the need for or the lack of need for vapor barriers and vapor retarders in a specific building assembly in a specific climate and for a specific building use.

When code authorities decide that adoption of Standard 160 guidelines by themselves will not be sufficiently specific and that prescriptive requirements for vapor barriers are useful and necessary, ASHRAE recommends that requirements be specific to the local climate, the type of building, and the magnitude of the building's internal humidity loads. Narrowing the scope of any prescriptive vapor barrier requirement helps limit its potential for creating more problems than it solves (Harriman and Lstiburek 2009).

2. Energy-saving operational practices and regulations can inadvertently increase risks of moisture accumulation and mold growth. Any energy-saving regulations or recommendations should take into account the fact that when excessive moisture and high humidity are present indoors, the risk of mold growth and moisture-related problems is also high.

   For example, if local regulations for public buildings require resetting a chilled-water temperature to a higher level when the building is unoccupied, and if that system is responsible for dehumidification in addition to cooling, the indoor dew point can rise to excessive, even risky levels. And if regulations require that parts of a building be uncooled when other parts of the same building are cooled, as in the case of health care facilities in many parts of the world, the dew point in uncooled parts of the building can rise high enough to create high surface RH and microbial growth on (or inside) walls separating cooled and uncooled spaces.

   Consequently, ASHRAE suggests that regulations that govern cooling not overlook the need to keep the indoor dew point low enough to reduce the risk of high surface RH in cooled parts of a building, especially when other parts of a building are not cooled or are intermittently cooled.

INVESTIGATION AND REMEDIATION OF MOLD AND MICROBIAL GROWTH PROBLEMS

Although many ASHRAE members may be qualified by training and/or experience to investigate and remediate microbial problems including mold, these skills are not overseen, collected, or codified by ASHRAE technical committees. Consequently, ASHRAE takes no position on the question of certification or accreditation of technical competence in these areas.

As technical professionals, however, ASHRAE members and technical committees have observed the following:

1. In the U.S., no cognizant health authority has yet established microbial exposure limits for residential or commercial buildings. In other countries, such exposure limits have been established (Brandys and Brandys 2011), but there is little agreement between different countries concerning what the limits should be to ensure acceptable levels of health risk.
2. Other organizations have published detailed guidance on the assessment of fungal growth in buildings (ASTM 2010), on the appropriate assessment of the presence of or exposure to bioaerosols (ACGIH 1999), and on appropriate investigation and remediation of moisture and mold problems in buildings (AIHA 2008). These references provide useful guidance to those who need to investigate, assess, and deal with any consequences of mold and other microbial growth in buildings and residences.
3. Sampling for airborne mold spores is often utilized to assess the degree of contamination of the indoor air, especially following mitigation of a mold problem. However, cognizant authorities for these techniques advise that air sampling for mold spores should only be

conducted with a hypotheses-driven sampling plan that provides a sufficient number of sample locations and air samples to provide a statistically relevant interpretation. Furthermore, spores are not the only component of microbial growth that is of concern. While presence of an unusual number of mold spores may be a relatively reliable indicator of "a microbial problem," the absence of spores is not a reliable indicator of absence of "a microbial problem" (ACGIH 1999).

4. The moisture content of materials is a key aspect of assessing the risk of microbial growth on their surfaces. However, ASHRAE advises caution when taking moisture content readings and interpreting their significance. There is nearly always extreme spatial variation in the moisture content of materials over short distances (a few inches or centimeters). Also there are many different materials in a building, each with different wetting and drying characteristics and different susceptibility to moisture problems over both short and long periods.

   These factors, combined with normal daily temperature cycles that affect wetting and drying, suggest that any single-point or single-event moisture content measurement is not likely to be useful in assessing the presence or absence of excessive moisture accumulation or mold risk. As a further complication, different moisture meters are calibrated to different scales. The readings from one type of meter—or even different models of the same type of moisture meter—may have no definable or consistent correlation with readings from a different type of meter (Harriman and Lstiburek 2009).

   Mapping the moisture measurements, taking measurements in the exact same location over time with the same meter, and using thermal cameras to help locate areas of potential concern can reduce (but not eliminate) the high level of uncertainty associated with conclusions based on current moisture measurement technology.

5. Wetting events associated with rainwater leakage, wind-driven rain, and condensation indoors are common sources of moisture accumulation and microbial problems, including mold. Investigations that occur only on dry days, or on days without wind-driven rain, may fail to identify and locate such leakage. The same is true for periodic HVAC malfunctions such as shortcomings in the control systems during shutdown or lightly occupied periods. Consequently, multiple site visits during different weather conditions and different HVAC operational modes may sometimes be necessary to reach robust conclusions.

REFERENCES FOR THE APPENDIX

AIHA. 2008. *Recognition, Evaluation and Control of Indoor Mold*. Prezant, Weekes and Miller, Eds. Fairfax: American Industrial Hygiene Association.

ACGIH. 1999. *Bioaerosols: Assessment and Control*. Cincinnati: American Conference of Governmental and Industrial Hygienists.

ASHRAE. 2007. ASHRAE/ANSI Standard 62.1-2007, *Ventilation for Acceptable Indoor Air Quality*. Atlanta: ASHRAE.

ASHRAE. 2008. ASHRAE/ANSI/ASHE Standard 170-2008, *Standard for Ventilation of Health Care Facilities*. Atlanta: ASHRAE.

ASHRAE. 2009a. ASHRAE/ANSI Standard 160-2009, *Criteria for Moisture-Control Design Analysis in Buildings*. Atlanta: ASHRAE.

ASHRAE. 2009b. The nature, significance, and control of solar driven moisture diffusion in wall systems. Research Project 1235. Atlanta: ASHRAE.

ASHRAE. 2010a. ASHRAE/ANSI Standard 62.2-2010, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. Atlanta: ASHRAE.

ASHRAE. 2010b. ASHRAE/ANSI/IES Standard 90.1-2010, *Energy Standard for Buildings except Low-Rise Residential Buildings*. Atlanta: ASHRAE.

ASHRAE. 2011a. *ASHRAE Handbook—HVAC Applications*, Chapter 44: Building Envelopes. Atlanta: ASHRAE.

ASHRAE. 2011b. *Indoor Air Quality Guide: The Best Practices for Design, Construction and Commissioning.* Atlanta: ASHRAE.

ASTM. 2006. *Performance and Durability of the Window-Wall Interface: STP 1484*. Hardman, Wagus and Weston, Eds. West Conshohocken, PA: ASTM International.

ASTM. 2009. *Moisture Control in Buildings: The Key Factor in Mold Prevention*, Second Edition. Treschel and Bomberg, Eds. West Conshohocken, PA: ASTM International.

ASTM. 2010. *Standard Guide for Assessment Of Fungal Growth in Buildings (D7338-10)*. West Conshohocken, PA: ASTM International.

Brandys, R. C., and G. M. Brandys. 2010. *Worldwide Exposure Standards for Mold and Bacteria-with Assessment Guidelines for Air, Water, Dust, Ductwork, Carpet and Insulation*, 8th Edition. Hinsdale, IL: OEHCS Publications.

CMHC 1996. *Survey of Building Envelope Failures in the Coastal Climate of British Columbia*. Report by Morrison-Hershfeld. Ottawa, Canada: Canadian Mortgage and Housing Corporation.

Cox-Ganser, J., S. White, R. Jones, et al. 2005. Respiratory morbidity in office workers in a water-damaged building. *Environmental Health Perspectives* 113(4). National Institute of Environmental Health Sciences. www.niehs.nih.gov/health/topics/index.cfm.

DOE 2005. *Closed Crawl Spaces: An Introduction to Design, Construction, and Performance Advanced Energy*. Report to the U.S. Department of Energy under Contract No. DE-FC26-00NT40995. www.advancedenergy.org.

EPA 2001. *Mold Remediation in Schools and Commercial Buildings*. U.S. Environmental Protection Agency. www.epa.gov/mold/mold_remediation.html.

Harriman, L., G. Brundrett, and R. Kittler. 2006. *Humidity Control Design Guide.* Atlanta: ASHRAE.

Harriman, L., and J. Lstiburek. 2009. *The ASHRAE Guide for Buildings in Hot & Humid Climates*. Atlanta: ASHRAE.

Hodgson, M.J., and Flannigan B. 2001. *Occupational Respiratory Disease: Hypersensitivity Pneumonitis*, Chapter 3.2, Microorganisms in Home and Indoor Work Environment. B. Flannigan, R.A. Samson, and J.D. Miller, Eds. New York: Taylor & Francis.

IICRC. 2008. IICRC/ANSI S520-2008, *Standard and Reference Guide for Professional Mold Remediation*, Second Edition. Vancouver, Canada: Institute of Inspection, Cleaning, and Restoration.

IOM 2004. *Damp Indoor Spaces and Health*. Washington, D.C.: Institute of Medicine of the National Academies.

JLC. 2007. *The JLC Guide to Moisture Control: Practical Details for Durable Buildings*. Washington, D.C.: Hanley Wood LLC.

Mendell, M., A. Mirer, K. Chung, et al. 2011. Respiratory and allergenic heath effects of dampness, mold and dampness-related agents: A review of the epidemiologic evidence. *Environmental Health Perspectives* 119(6). National Institute of Environmental Health Sciences. www.niehs.nih.gov/health/topics/index.cfm.

Nielsen, K.F. G. Holm, et al. 2004. Mould growth on building materials under low water activities; Influence of humidity and temperature on fungal growth and secondary metabolism. *International Biodeterioration and Biodegradation* 54:325–36.

New York State. 2010. *New York State Toxic Mold Task Force: Final Report to the Governor and Legislature*. New York State Department of Health. www.health.state.ny.us/environmental/indoors/air/mold/task_force/.

Park, J.H., J. Cox-Ganser, K. Kreiss, et al. 2008. Hydrophilic fungi and egosterol associated with respiratory illness in a water-damaged building. *Environmental Health Perspectives* 116(1). National Institute of Environmental Health Sciences. www.niehs.nih.gov/health/topics/index.cfm.

Pasenen, A.L., Rautiala, S., et al. 2000. The relationship between measured moisture conditions and fungal concentrations in water-damaged building materials. Indoor Air 2000 Conference 11:111–20.

Rose, W.B. 2005. *Water in Buildings: An Architect's Guide to Moisture and Mold*. Hoboken, NJ: John Wiley & Sons.

Rowan, N., J. Johnstone, C.M. McLean, et al. 1999. Prediction of toxigenic fungal growth in buildings by using a novel modeling system. *Applied and Environmental Microbiology* 65(11):4814–21. American Society for Microbiology.

Sorenson, W.G. 2001. *Occupational Respiratory Disease: Organic Dust Syndrome*, Chapter 3.3, Microorganisms in Home and Indoor Work Environment. B. Flannigan, R.A. Samson, and J.D. Miller, Eds. New York: Taylor & Francis.

Sedlbauer, K., M. Krus, W. Zillig, and H.M. Kunzel. 2001. Mold growth prediction by computational simulation. IAQ 2001 Conference. Atlanta: ASHRAE.

Viitanen, H.A. 1997. Modelling the time factor in the development of brown rot decay in pine and spruce sapwood; The effect of critical humidity and temperature conditions. *Holzforschung* 51(2). New York: Walter de Gruyter.

WHO 2009. Guidelines for indoor air quality: Dampness and mould. Copenhagen: World Health Organization. www.euro.who.int/en/what-we-publish.