NMHC National Multi Housing Council®

National Apartment Association

Best Practices for Reducing Moisture Intrusion and Excessive Mold Growth during Construction and Renovation

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- This guidance document offers baseline best practices to address moisture intrusion issues and excessive mold growth in low-rise, wood-framed construction. These suggestions are meant to highlight and optimize conditions in the built environment that will discourage dampness and ultimately limit the growth of mold. The threat of moisture intrusion and excessive mold growth does not end with completion of the construction and renovation process; operations and maintenance will continue to be key aspects in addressing these issues.

- NMHC/NAA's *Operations and Maintenance Plan for Mold & Moisture Control* (O&M Plan) identifies best practices and concrete steps apartment owners and managers can use to manage moisture intrusion and mold on their properties.

- Recommended Distribution:
  - Developers
  - Owners
  - Risk Managers
  - General Counsels
  - Construction Supervisors
  - On-Site Personnel

About the National Multi Housing Council and National Apartment Association

The National Multi Housing Council (NMHC) and the National Apartment Association (NAA) represent the nation's leading firms participating in the multifamily rental housing industry.

Based in Washington, DC, **NMHC** represents the interests of the nation's largest and most prominent firms in the apartment industry. NMHC members are engaged in all aspects of developing and operating apartments, including ownership, construction, management, and financing. The Council was established in 1978 as a national association to advocate for rental housing and to provide a source of vital information for the leadership of the multifamily industry. Since then, NMHC has evolved into the industry's leading national voice. The association concentrates on public policies that are of strategic importance to participants in multifamily housing, including finance, tax, property management, environmental and building codes. NMHC benefits from a focused agenda and a membership that includes the principal officers of the most distinguished real estate organizations in the United States. For more information on joining NMHC, contact the Council at 202/974-2300 or www.nmhc.org.

NAA, based in Alexandria, VA, is a federation of 168 state and local affiliated associations representing more than 32,000 members responsible for more than 5 million apartment homes nationwide. It is the largest broad-based organization dedicated solely to rental housing. NAA members include apartment owners, management executives, developers, builders, investors, property managers, leasing consultants, maintenance personnel, suppliers and related business professionals throughout the United States and Canada. NAA strives to provide a wealth of information through advocacy, research, technology, education and strategic partnerships. For more information, call 703/518-6141, e-mail information@naahq.org or visit www.naahq.org.

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FOREWORD

Mold is an all too familiar problem for anyone who owns, manages or develops real estate. It is well-established that the natural presence of mold in the environment makes absolute prevention impossible, but eliminating moisture sources and choosing appropriate materials can effectively minimize mold growth in buildings.

To that end, the National Multi Housing Council (NMHC) has authored this "best practices" guide for reducing moisture and mold intrusion during the building design and construction process. Readers should note that this guidance is not meant to serve as a how-to manual. Nor is it expected, or even appropriate, for an owner or builder to uniformly implement the recommendations herein. Each project is unique, and moisture-management policies should reflect individual needs, site considerations and the building's future use. This document is intended to inform property owners and development decision-makers of the prevalent issues relating to moisture intrusion in residential construction. It is designed as a tool to promote understanding of these issues and facilitate communication between owners and their design and construction teams.

These best practices solely address the mitigation of moisture intrusion and mold damage. As such, they may be at odds with other construction and durability concerns. Therefore, this guidance is not intended as a substitution for individualized design assessment and construction expertise. Further, the recommendations made herein are principally drawn from sources directed toward single-family and low-rise multifamily construction. Information about high-rise construction is available from the Associated General Contractors of America.

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INTRODUCTION

Molds are naturally-occurring organisms, ever-present and in fact essential to biological processes in the environment. Most human contact with mold is non-hazardous and poses no threat to public health. Nevertheless, heightened public awareness and a virtual explosion of mold-related litigation have intensified concerns over mold infestation and subsequent liability. As a result, it is important to adopt practices that effectively minimize and control moisture intrusion and mold growth. Readers should note, however, that no building can be made "mold-proof." Even the strictest adherence to any mitigation guidelines can not absolutely prevent mold growth.

National Academies-Institute of Medicine Report

In 2004, the National Academies-Institute of Medicine (IOM) issued a long-awaited report on mold and human health. Commissioned by the Centers for Disease Control, *Damp Indoor Spaces and Health* (cited hereinafter as "the report"), examined "the relationship between damp or moldy indoor environments and the manifestation of adverse health effects."[1] Although the report found that "[t]he relationship between dampness or [mold] and health effects is sometimes unclear and in many cases indirect," it did note that "excessive indoor dampness is a public-health problem."[2] Although the report emphasized that further research is needed,[3] it recommended that "[h]omes and other buildings should be designed, operated, and maintained to prevent water intrusion and excessive moisture accumulation when possible." According to the authors, "[w]hen water intrusion or moisture accumulation is discovered, the sources should be identified and eliminated as soon as practicable …."[4]

Implications of the Report

The majority of mold-related lawsuits to date have alleged that exposure to mold growth has caused adverse health effects. However, the aforementioned report echoes the findings of courts nationwide; stating that lawsuits premised on personal injury lack the causal link between presence of mold and health problems to be successful. As personal injury-based lawsuits become harder to pursue, it is likely that a growing number of mold lawsuits will be brought as conventional construction and design defect actions. State legislatures are further compelling this shift by passing limitation of liability statutes. For instance, the state of Louisiana recently enacted a law exempting contractors, architects and engineers from personal injury and property damage claims resulting from mold infestation, unless the damage stems from workmanship or design defects.[5]

Typically, construction defect suits allege that moisture intrusion and mold damage stem from a building's initial construction or renovation, due to improper design, construction, installation or material choice. These defects can relate to any number of building components, including wall systems; roof systems; foundations; windows and doors; plumbing; and HVAC units. These suits are brought under a host of legal theories, such as negligence; strict liability; breach of implied or express warranties; nuisance; fraudulent or negligent misrepresentation; breach of contract; unfair trade practices or violation of consumer protection laws; and real estate disclosure laws.[6]

Plaintiffs generally cast a wide net when targeting defendants, often including apartment property owners, managers and developers; construction managers; architects; design professionals; engineers; contractors and subcontractors; HVAC and plumbing manufacturers; real estate agents and brokers; home inspectors; insurers; environmental consultants; remediation contractors; and lenders.[7]

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[1] INSTITUTE OF MEDICINE, DAMP INDOOR SPACES AND HEALTH, 1 (May 2004), National Academies Press.
[2] *Id.* at 11.
[3] *Id*. at 5.
[4] *Id.* at 253.
[5] *See* LA. REV. STAT. § 9:2800.15 (2004).
[6] Susan Hickman & Jason G. Werhle, *Mold and Construction Defect Litigation*, 2 MEALEY'S LITIG. REP.: MOLD 9 (Sept. 2002).
[7] *See id.*

Therefore, actions to control moisture and mold must be part of the initial building planning and design phase.

Among its many recommendations, the IOM report suggests that "private entities with building design, construction, and management interests should provide new or continuing support for research and demonstration projects that develop education and training for building professionals (architects, home builders, facility managers and maintenance staff, code officials, and insurers) on how and why dampness problems occur and how to prevent them."[8] This focuses attention on the fundamental problem inherent in building with an eye to moisture and mold prevention: lack of information.

Advances in technology and building practices and improved materials can greatly minimize the risk of moisture and mold intrusion. Yet, these innovations are largely underutilized and unfamiliar, with many owners and design professionals continuing to rely on conventional construction techniques and traditional materials. On the other hand, some well-established construction practices use proven moisture-retardant characteristics. However, these bedrock principles are sometimes neglected or overlooked, such as the importance of proper flashing.

This document addresses this need for education and understanding. It provides a discussion of industry practices for project design and construction procedure, product use and materials selection that may reduce the incidence of moisture intrusion issues during new residential construction and property renovation. It is meant as an overview of industry-recommended practices, innovative or emerging products and technologies, and areas of unsettled opinion.

PRE-CONSTRUCTION CONSIDERATIONS

Communication and Education

Effective communication is the foundation of a successful building project. This is especially true when an owner has specific project objectives or concerns. Therefore, an owner's goal regarding moisture management and mold deterrence needs to be communicated to every member of the building and design team, including design professionals, architects, engineers, project managers, contractors, subcontractors, landscapers and interior designers. This is important because moisture and mold control decisions begin during the earliest stages of the design and construction process, and affect fundamental choices such as material selection, delivery, storage, site selection, and the need for specialized contractors or consultants.

Similarly, all contractors and work crews should be educated about the importance of minimizing moisture intrusion and mold growth. All construction supervisors and site managers should learn how to: (1) identify water-damaged or mold-infested materials; (2) properly store and protect building materials; and (3) clean or dispose of wet or moldy materials.[9] Likewise, workers need to understand the importance of reporting materials with damage or mold growth to their supervisor.

Appropriate worker supervision and site inspections are also advantageous, especially when coupled with a thorough risk management plan. Such a plan should identify who is responsible for specific duties (e.g., the design team, the general contractor, an individual subcontractor or a special inspector), oversight or supervision, and repair or correction of on-site construction failures. It should also address the interactions between the parties involved in a building project relating to financial obligations, legal

[8] INSTITUTE OF MEDICINE, *supra* note 1, at 273.
[9] Although not specifically directed to residential construction concerns, the U.S. Environmental Protection Agency (EPA) has two publications available that provide useful information about mold in general, proper remediation and material cleaning recommendations, and mold prevention. *See* U.S. EPA's, "A Brief Guide to Mold, Moisture, and Your Home." *See also* U.S. EPA's, "Mold Remediation in Schools and Commercial Buildings."

relationships, and day-to-day operations. Finally, these relationships and policy decisions should be included in all appropriate contract documents.[10]

Building Codes and the Danger of General Design Plans
It is well-recognized within the building industry that design principles and construction practices are not "one-size-fits-all." Although it is a common practice to replicate a standard community design, one set of architectural or design plans should not be used for multiple projects without careful consideration. Different climatic conditions and individual land characteristics necessitate site-specific design and construction.[11]

Many building components are designed and manufactured with environmental considerations in mind, including wall systems; roofing material; HVAC systems; windows; exterior finishes; moisture barriers; and foundations. Using any of them in a marginal climate can directly affect the overall performance and durability of these materials and systems. Therefore, be cautious of generalized practices or design features that may conflict with particular site characteristics or moisture management goals. This warning extends to general practices imposed by building codes and over-reliance on codes in the design process.

Building codes exist to regulate and ensure the quality, performance and safety of structures and construction materials. However, even conscientious adherence to all applicable building codes may not prevent moisture and mold problems. First, building codes often reflect only the *minimum* standard of conduct that is required, not necessarily the *best* standard. That means that complying with the applicable building codes will not always shield a builder from liability if a legal dispute should arise.[12]

Moreover, it is important to recognize that some local building code requirements may conflict with moisture control and mold prevention best practices. In the 1970s, building codes were tailored to address energy consumption. Most of these changes focused on "tightening up" building envelopes.[13] In essence, these code changes promoted energy efficiency without proper consideration of the impact on air movement, ventilation, humidity and condensation control, and drainage mechanisms. Therefore, to prevent moisture and mold, builders must often take additional action not mandated by codes.

Third-Party Evaluation

Peer Review
Owners and designers should consider using peer reviews to identify building pitfalls related to mold and moisture during the design process. According to the American Society of Civil Engineers (ASCE), "peer review is a separate, important step in the design process…to provide an evaluation of design concepts and management to meet performance objectives."[14] In these reviews, independent individuals not associated with the original design team provide an objective assessment of potential moisture and mold problems in the building design. Although peer reviews have not been widely used to address water intrusion issues, they can be a cost-effective and proactive tool. On average, peer

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[10] Examples include the decision to use specific mold-resistant materials; that moldy or water-damaged materials will not be used; that mold identified during the construction process will be properly remediated; etc.
[11] "[D]ifferent climates present different problems, and buildings should be designed and operated accordingly. Although this is an obvious requirement, it is often not met." J. DAVID ODOM, CH2M HILL, INC., PREVENTING MOISTURE AND MOLD PROBLEMS IN HOT, HUMID CLIMATES: DESIGN AND CONSTRUCTION GUIDELINES 1-13 (2003) (citing ASHRAE, FUNDAMENTALS (1989)).
[12] *See* Patrick J. Perrone et. al, *The Standard of Care for a Property Owner in a Mold Case*, 1-11 MEALEY'S LITIG. REP. MOLD 15 (Nov. 2001) (citing Glynos v. Jagoda, 249 Kan. 473, 485 (1991) (holding that compliance with a building code standard, although evidence of due care, did not preclude a finding of negligence where a reasonable person would have taken precautions under the circumstances)).
[13] Allen Seale, *Mold, Building Science and Interior Air Quality*, (2005), *at* www.starlink2000.com/ARTICLESpagesSITE/MOLDquestions.htm.
[14] American Society of Civil Engineers, *at* www.asce.org/pressroom/news/policy_details. cfm?hdlid=117 (last visited August 16, 2005).

reviews do not exceed 5 percent of the total building design budget and constitute about 0.3 percent of the total construction cost.[15]

Commissioning

Where peer review identifies potential performance and quality problems during the design process, commissioning is used to ensure that a building operates as the original design intended and that the building systems perform as effectively and efficiently as possible. Although the goal of commissioning is to provide an owner with a fully operational building at the end of construction, the Building Commissioning Association recommends that the commissioning process begin prior to design and extend through all phases of construction.[16]

Ideally, a commissioning plan should help an owner evaluate a building's operational needs (e.g., energy use, indoor environment, staff training and maintenance) before design begins. Then, it should review all design and construction plans for issues regarding compliance with the design plans; bidding problems; construction sequencing and installation; performance; and operations, maintenance, and training.[17] Once construction is complete, the system start-up plan should be reviewed and a preventative maintenance plan developed.[18]

Commissioning costs vary according to the size and complexity of the proposed construction and the extent of the commissioning plan. On average, commissioning costs 0.5 to 1.5 percent of the total construction cost.[19] On the other hand, the operational costs of a commissioned building are estimated to be 8 to 20 percent less than that of a non-commissioned building.[20] Further, from a risk management standpoint, commissioning allows builders and property owners to identify and proactively address potential moisture and mold problems. Also, if litigation later arises concerning the building's indoor air quality (e.g., "sick building syndrome"), commissioning can provide an owner some liability protections.[21] It can provide an owner with objective documentation attesting to the building's performance and operation. Additionally, if any problems were discovered during commissioning, the commissioning records can verify that appropriate repairs were made.

Third-Party Consultants, Contract Issues and Insurance Concerns

The construction superintendent bears primary responsibility for ensuring that building components have been correctly installed, and that employees and subcontractors have been properly handling their on-site duties and responsibilities. However, consider employing a third-party contractor or consultant with specialized expertise when designing and installing key components of the building structure such as the roof, doors, windows, HVAC systems, etc. This expert input into the design and installation of these systems can prevent problems relating to moisture intrusion and mold growth.

All contractors, subcontractors and anyone involved in the design and construction process should carry appropriate insurance coverage, in case any workmanship or related litigation issues arise. This coverage should include insurance for errors and omissions or professional liability insurance. Whenever possible, owners should be listed as an additional insured party on insurance policies.

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[15] J. DAVID ODOM, *supra* note 11, at 1-17.

[16] Building Commissioning Association, *Attributes*, *at* www.bcxa.org/about/attributes.shtm (last modified June 28, 2004). For more information about the use and design of commissioning plans, *see* ASHRAE / National Institute of Building Sciences Guideline 0-2005, "The Commissioning Process."

[17] *Id.*

[18] *Id.*

[19] Oregon Department of Energy, *Commissioning Costs*, *at* www.energy.state.or.us/bus/comm/ commcost.htm (last updated June 2, 2004).

[20] Oregon Department of Energy, *Building Commissioning Power Point Presentation*, *at* www.energy.state.or.us/bus/ comm/Cxppt_files/frame.htm (last visited August 16, 2005). *See also* Oregon Dept of Energy, *Commissioning for Better Buildings in Oregon*, *at* www.energy.state.or.us/bus/comm/bldgcx.htm (explaining that these lower operation costs stem from: the early detection of potential problems; precise operation of HVAC system; properly trained building operators; shortened occupancy transition periods; lower maintenance costs; energy savings; and improved indoor air quality, occupant comfort, and productivity) (last updated June 2, 2004).

[21] Oregon Department of Energy, *Building Commissioning Savings*, *at* www.energy.state.or.us/bus/ comm/commsave.htm (last updated June 2, 2004).

Further, if possible, insurance policies should contain coverage for water intrusion problems created by, or resulting from, any services rendered.

Since most new insurance policies specifically exclude coverage for mold damage, indemnity agreements should be established whenever appropriate. These agreements would require contractors and materials suppliers to indemnify the builder/owner from mold problems arising from the work or product.[22] In lieu of an indemnity agreement, alternative contract agreements may be possible between owners, builders, subcontractors, and suppliers that compensate owners for mold remediation costs or other costs associated with moisture intrusion and mold growth.[23]

Contract Considerations

When negotiating construction contracts, it is important to bear in mind that some commonly proposed elements can greatly alter the allocation of risks and liabilities among the contract parties. Some points to consider include:

- Architects, engineers and other design professionals often contractually limit their liability for errors and omissions. Owners should understand the nature of damages that can arise from improper design performance and allocate those risks in the contract documents.[24]
- Legal claims arising from actions by design professionals may be first asserted against the property owner, forcing the owner to bring a third-party claim against the responsible design professional.[25] To help avoid the most common of these claims, owners can require design professionals to provide complete construction drawings, respond to contractor questions in a timely manner and provide the builder with accurate site descriptions.[26]
- Owners should carefully consider the implications of contractually waiving consequential damages due to design or construction problems.[27] While construction contracts often contain these provisions, they preclude recovery for damages such as lost profits, business interruption, loss of financing, etc. An alternative is to limit any recovery to the proceeds of professional liability insurance.[28]
- Statutes of limitations vary among the states, but many laws dictate that the limitations period does not begin to run until latent construction defects are discovered by the owner.[29] Therefore, owners should be cautious of contractually regulating the limitations period.[30]

Cost Considerations

Cost is always a driving force in building design choices and construction decisions. Nevertheless, owners should keep some important factors in mind. First, many mistakenly associate mold problems with low-cost construction. On the contrary, high-cost construction can also suffer from the same moisture-related problems as any other structure, as evidenced by the many lawsuits against luxury condominium, apartment and hotel owners and builders. For example, one suit alleged that multi-million-dollar, celebrity-owned condominiums in Washington, D.C., were overwhelmed with mold within

[22] *See* Holland & Knight, LLP., *Minimize Liability for Mold Crisis During Construction*, 2 INDOOR AIR QUALITY, Issue 1 (April 2004). But, specific state law may prevent the enforcement of such indemnity agreements.
[23] *See id*.
[24] William H. Hughes, Jr. and Brian K. Fielden, *Blueprint For Success: The Key Provisions In Every Design Contract*, Presented at Avoiding Construction Claims: Practical Advice for Construction Owners and Their Counsel (Nov. 13, 2003), p. 1.
[25] *Id*. at 4.
[26] *See id*. at 3-4.
[27] *Id*. at 15.
[28] *Id*. at 18.
[29] Robert L. Crewdson, *The Ten Most Important Provisions In Every Construction Contract*, Presented at Avoiding Construction Claims: Practical Advice for Construction Owners and Their Counsel (Nov. 13, 2003), p. 17.
[30] *Id*.

weeks of opening. Another $2 billion mold suit involved New York City Park Avenue residences billed as "the world's most expensive residential building."[31]

While cost is not the determining factor in whether a building has moisture and mold problems, some marginal, upfront construction expenditures can substantially reduce the risk of future moisture and mold intrusion. Altering building practices to address moisture and mold may increase construction and materials costs, but these higher costs must be balanced against the long-term benefits of good construction practices and moisture prevention. Many of the construction practices that owners can undertake to prevent mold growth can also substantially reduce maintenance and repair expenses, increase energy-efficiency and promote building durability. Likewise, by incorporating new, improved or industry-recommended products and construction practices into the building and design processes, owners can save untold sums in future remediation or litigation costs.

Finally, building design and materials selection is a delicate process that must balance long-term building goals with cost and labor abilities. For instance, a perfect, moisture-minimizing design is of no use if it cannot be constructed properly. Therefore, complicated or intricate design and building plans should be simplified if time constraints, insufficient resources or the skill and number of workers will not allow for full attention to, or understanding of, the plans.[32]

Similarly, be cautious of choosing materials or designs based on their "ideal" moisture-resistant qualities. Many factors contribute to the effectiveness of moisture-prevention products and techniques, including proper installation, maintenance needs, ease of repair and intended use. For instance, some exterior finishing materials that advertise high water-resistant properties also require diligent maintenance and skilled repair. So, if the building's maintenance staff or occupants cannot provide this level of care, a more forgiving finish should be considered. Likewise, a finish that is difficult to install would not be recommended for inexperienced work crews.

Condominium Conversions

The conversion of apartments into condominiums (condos) has regained popularity after several years of lackluster interest. While there are numerous advantages of condo conversion, builders and investors often mistakenly include a reduced risk of liability among them. "[M]any condominium converters incorrectly believe their liability exposure is less than [that of] a builder of new condominiums, reasoning that since they did not perform the original construction, they cannot be held liable for construction defects."[33] On the contrary, it is generally believed that condo converters may be held liable for subsequent construction-related failures.[34] Converters face liability for such claims under several legal theories, including traditional construction defect claims due to the converter's alterations or improvements to the property; negligent conversion; strict liability; violation of specific conversion statutes; nondisclosure; fraud; and breach of fiduciary duty.[35]

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[31] *See* Alex Williams*, Spore War*, NEW YORK MAGAZINE, March 8, 2004, *available at* www.newyorkmetro.com/nymetro/realestate/ features/realestate2004/n_9985/index.html. *See also* Annie Groer, *At Ritz Complex, Mold Came to Call on Condo Owners*, WASHINGTON POST, May 5, 2003, at A1.

[32] For instance, "[m]any of today's homes require complex flashing details that are easily executed by a master craftsman but that can lead to disaster when out in the hands of the average framing crew." Therefore, a design that does not require complex flashing can reduce the risk of moisture intrusion. Charles Wardell, *Designing to Avoid Mold,* BUILDER MAGAZINE, May 1, 2005, *available at* www.builderonline.com/industry-news-print.asp?sectionID=28&articleID=127525.

[33] Roger C. Haerr, *Apartment to Condominium Conversion Liability Exposure and Methods to Minimize the Risks*, 3 REAL ESTATE LITIGATION E-UPDATE, No.2 (May 17, 2004), at eupdate.luce.com/ realestatelit/0302.pdf.

[34] *See* Lori Weisberg, *Yesterday's Standards Haunt Brand-new Condo Conversions*, THE SAN DIEGO UNION-TRIBUNE, April 17, 2005, www.signonsandiego.com/uniontrib/20050417/ news_1h17condo.html.

[35] Roger C. Haerr, *supra* note 33.

SOURCES OF BUILDING MOISTURE

Moisture issues are problematic for property owners and builders partly because there are many ways for water to enter and accumulate within an occupied building. Further, each moisture source has different causes, effects and prevention techniques. These are the main pathways of moisture into a building.

- *Bulk Moisture.* Water penetration or buildup in the building envelope due to: (1) climatic conditions (i.e., precipitation); (2) ground water; (3) internal sources (e.g., plumbing leaks); and (4) improper landscaping.
- *Capillary Action.* Moisture is sucked through porous building materials (e.g., masonry, cement).
- *Vapor Diffusion.* Moisture is driven through the building envelope by vapor pressure differences.
- *Air Flow.* Water vapor is driven through the building envelope by air pressure differentials via leaks.
- *Built-In Moisture.* Moisture enclosed within the building interior due to use of building materials with a high moisture content, either by design (cement or green lumber) or due to wetting during construction.
- *Occupant-Generated Moisture.* Daily activities, like respiration, bathing and cooking, produce moisture within the building environment. The use of certain appliances, such as air conditioners, humidifiers and clothes dryers, also generates moisture.
- *Condensation.* When warm air comes in contact with a cold surface, it condenses into a liquid form.

Owners and their representatives should also understand two other terms that are commonly used in discussions of building moisture.

- *Humidity* refers to the amount of moisture or water vapor in the air. In the building context, humidity is often discussed in terms of "relative humidity" (RH). "RH is the amount of water vapor actually present in the air compared to the greatest amount of water vapor the air can hold at that temperature."[36] Appropriate indoor RH levels range between 30 and 50 percent, depending on the climate, season and building materials.

- *Permeance*, or the rate at which water vapor travels through materials (known as the perm rate), commonly plays a role in the selection of building materials. A high perm rate allows greater moisture movement through materials than a low perm rate.

SITE CONSIDERATIONS

Site Selection

Selection of an appropriate building location is the first step in minimizing the risk of moisture intrusion. Fundamental problems relating to poor site drainage or a high water table can significantly contribute to eventual moisture problems.[37] Even when a change of building site is not an option, an awareness of the site's characteristics is essential in the design process. The

[36] Energy Star, *Dehumidifier Basics*, *at* www.energystar.gov/index.cfm?c=dehumid.pr_basics_ dehumidifiers (last visited August 16, 2005).

[37] NAHB RESEARCH CENTER, Prepared for U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, DURABILITY BY DESIGN: A GUIDE FOR RESIDENTIAL BUILDERS AND DESIGNERS (May 2002), at 11 [hereinafter DURABILITY BY DESIGN].

following preliminary practices may be useful in determining a site's potential moisture problems:[38]

- Survey surface appearance and vegetation for signs of high ground water levels.

- Examine the lay of the land and surface water flow onto and off of the property to make sure appropriate water drainage is possible.

- Reference USDA Natural Resources Conservation Service's soil maps or bore test holes at the building site. If local experience suggests deeper subsurface problems, the assistance of a geotechnical engineer and specialized drilling equipment may be necessary.

- Test the soil for bearing capacity using a simple handheld penetrometer.

- Consider consulting a design professional and experienced foundation contractor where questionable soil conditions (e.g., steep slope, high water table) are present.

Site Drainage

"Controlling surface water drainage is universally recognized as the first line of defense against foundation moisture problems."[39] Therefore, site drainage plans must take into account the natural water flow and divert the water flow away from the building foundation. This can be accomplished by grading the site to allow for natural water run-off and/or by constructing underground drainage systems.

Natural grading is achieved by sloping the ground around the foundation away from the structure. However, building and design experts do not uniformly agree on what constitutes appropriate grading. For instance, many codes require ground to be sloped at least 4 percent for a minimum of 6 feet from the building foundation. However, many experts state that effective grading slopes away from the foundation at a minimum of 10 percent for 8 to 12 feet.[40] Other effective, natural drainage techniques include creating swales (channels cut into the slope); terracing the site; and creating a "ground roof" (placing an impervious layer of clay or bentonite under the top soil around the foundation).[41] Note that natural grading is often costly and may be ineffective or impossible due to the natural site conditions.

Unfortunately, artificial drain systems, which are designed to intercept and redirect the flow of water, can also be cost-preclusive depending on the size of the drains required.[42] Alternatively, the proper placement and use of gutters and downspouts can effectively direct water away from the building foundation for a minimal expenses.

Roof Overhangs, Gutters, and Downspouts

Appropriately placed roof gutters and downspouts can greatly reduce moisture intrusion problems through the building envelope, especially the foundation system. Yet it is not uncommon for building codes to be silent on the subject.[43] Some general guidelines for the design and use of gutters and downspouts include:[44]

- Design downspouts to discharge at least 2 feet away from the structure.

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[38] *Id*. at 11-12.
[39] NEWPORT PARTNERS, Prepared FOR U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, BUILDING MOISTURE AND DURABILITY (Oct. 2004), at 65 [hereinafter BUILDING MOISTURE AND DURABILITY].
[40] STEVEN WINTER ASSOCIATES, Prepared for U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, VOLUME 1 OF THE REHAB GUIDE: FOUNDATIONS (June 1997), at 14 [hereinafter THE REHAB GUIDE: FOUNDATIONS].
[41] *Id*. at 15.
[42] *See id.*
[43] *See* BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 16.
[44] DURABILITY BY DESIGN, *supra* note 37, at 18.

- Design downspouts discharging below grade using non-perforated corrugated or smooth plastic pipe, which run underground to a suitable outfall.
- Gutters and downspouts should be constructed using corrosion- and abrasion-resistant material, including aluminum, vinyl, plastic, copper and coated metal.
- Use gutter splash shields where water may overshoot the gutter.
- Properly maintain gutters and downspouts to prevent blockages.

Similarly, the use and size of a roof overhang can directly affect the frequency and magnitude of moisture penetration problems through exterior building walls and foundations.[45] To provide maximum building protection, an overhang should be used in all but arid climates. Its width should be designed according to local climatic conditions and the building's individual characteristics, such as the construction budget, the wall type below, the number of windows and doors exposed and the height of the building.[46] From a practical standpoint, "roof overhangs also provide durability and energy benefits in terms of solar radiation."[47] However, some large overhangs (typically those exceeding 12 inches) require costly framing methods and may not be consistent with the architecture of the building. Therefore, the style and design of overhangs is dependent on cost and aesthetic considerations.[48]

THE BUILDING ENVELOPE

Foundations

A potential route for bulk water entry into a building is through its foundation. The foremost way to prevent foundation-related moisture intrusion is through the selection of an appropriate foundation design (such as basement, concrete slab-on-grade and crawlspace). This decision should be made with an eye to geographic location, specific site conditions and local experience. For example, knowledge of high ground water conditions or a history of flooding would indicate that neither a basement nor a crawlspace with lower interior grade should be used.

Note that a multitude of design and construction features interact to protect the foundation from excessive moisture intrusion, including use of gutters and downspouts; proper surface grading; vapor barrier installation; foundation drainage systems; appropriate material choice; and dampproofing/waterproofing of foundation walls.[49]

Foundation Drainage

Properly designed and installed drainage systems are an important tool for minimizing moisture and standing water problems in and around the building substructure. In addition to a code-required drainage system, there are optional drainage devices that can provide additional foundation drainage, if situations warrant.

1. Install a perimeter baseboard drainage system. A perimeter gutter picks up water draining from wall cracks, concrete blocks, and floor/wall juncture, and directs it to a sump pump. The significant disadvantage of this system is that it collects unwanted water, but does not address the source (e.g., wall dampness or drainage problems). Since the walls remain moist, it will not prevent mold from forming on the wet walls or in the gutter itself.

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[45] *Id*. at 15.
[46] *Id*. at 16.
[47] *Id.*
[48] *See id*. at 16-17, comparing eave and rake overhangs, and their sizing recommendations.
[49] *See* BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 66.

2. Install a system of interior foundation drains and a sump pump. A sump pump may be used alone to lower the ground water table below the basement slab, or it can be coupled with the installation of additional drains that direct water to the sump pump.

Landscaping

Appropriate landscaping can help minimize foundation drainage problems and unnecessary wetting of the foundation. Sprinkler systems should be designed to avoid wetting the foundation or the building envelope. Ideally, watering should be conducted so that excess water flows away from the building foundation. Mulch or any organic filler should not be piled against the foundation and should not exceed the surface grade. Similarly, shrubbery should not be planted directly against the building exterior. It is particularly important that mulch and other landscaping not block weep holes, drain pipes, and gutters or redirect water run-off back towards the building envelope.

Finally, trees should be planted far enough from the building to minimize underground damage to the foundation from extensive root systems and damage to the building envelope from limbs.[50] However, appropriately placed trees can effectively shield the building envelope and roof system from wind-driven rain, thereby reducing bulk water penetration of the building exterior.[51] Certain trees can also shade the building in a way that promotes energy efficiency.[52] An experienced landscaper can provide information about the benefits and limitations of various landscaping choices.

Permanent Wood Foundations

A Permanent Wood Foundation (PWF) (sometimes referred to as an "All Weather Wood Foundation") is an alternative to traditional concrete and masonry foundations. It is a load-bearing foundation system constructed entirely of lumber and sheathed with plywood. Many believe that PWFs are more resilient to mold growth and moisture problems than are other foundation systems. All the wood products are pressure-treated, which provides permanent protection from moisture and termites. Water intrusion is minimized because "PWF walls are designed to resist and distribute earth, wind, seismic loads and stresses that may crack other types of foundations."[53] And, according to the Southern Pine Council, PWFs provide the warm, dry conditions of above-ground living, because they "incorporate superior drainage features that prevent the moisture problems typical of ordinary foundations."[54]

PWFs also have the advantage of simplifying the construction process. Unlike masonry foundations, a PWF can be installed by the same carpentry crew framing the structure, in an abbreviated time period, thereby saving on labor costs. Further, wet or freezing weather will not postpone or inhibit installation. They are versatile and suitable for both single-family and multifamily structures. And, although PWFs are not well-known, they have been used for over 40 years; accelerated aging studies attest to their long-term strength and durability.[55] Finally, PWFs have been accepted by major model building codes, federal agencies and lending and insurance firms.

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[50] DURABILITY BY DESIGN, *supra* note 37, at 42.
[51] *Id.*
[52] An experienced landscaper can provide information about the benefits and limitations of various landscaping choices. To achieve the most cost-effective and beneficial results, incorporate landscape design decisions into the early planning stages of the project. *See* Cheryl Kollin, *Building Greener, Building Smarter*, AMERICAN FORESTS (Spring 2005).
[53] SOUTHERN PINE COUNCIL, PERMANENT WOOD FOUNDATIONS DESIGN AND CONSTRUCTION GUIDE (2000), at 2, newstore.southernpine.com/images/ref400.pdf.
[54] *Id*. at 5.
[55] Toolbase Services, *Wood Foundations*, *a*t www.toolbase.org/tertiaryT.asp?TrackID=&Category ID=1286&DocumentID=2067 (last visited August 16, 2005).

Wall System Design

A key element of moisture-conscious construction is the selection of the exterior wall-system design. Since the wall system plays an important role in keeping the building interior secure and dry, it is designed using four main strategies to prevent water intrusion.[56]

- *Barrier system*. These systems are designed to repel all water that tries to penetrate the exterior. However, if no drainage system is incorporated, any moisture that does pass the exterior surface can be trapped in the wall assembly. For example, early versions of exterior insulation and finish systems (EIFS) were barrier systems, which resulted in significant mold-related litigation. (*See* "EIFS" discussion under "Wall Components" below.)

- *Mass system*. Under a mass system, some moisture will be allowed to penetrate the exterior, but thick materials are used to help prevent the moisture from reaching the interior (e.g., concrete and masonry walls). This design assumes that once the source of moisture subsides, the absorbed water can evaporate through the exterior surface.

- *Drainage system*. These systems anticipate that liquid water will penetrate the exterior surface. Materials like building paper and flashing are used to create a drainage plane behind the exterior surface to facilitate water's movement out of the wall system.

- *Rain screen system*. This design is similar to a drainage system, but an air cavity is included behind the exterior cladding, which allows water to drain and facilitates air pressure equalization (e.g., brick veneer cavity walls and drainage EIFS). These systems also utilize a drainage plane and an air- and watertight support wall.

The choice of a wall system is a highly individualized decision, and each system has benefits and limitations based on climate, cost considerations, maintenance abilities and numerous other construction concerns. However, any system used should incorporate a wall system design philosophy known as the 4 Ds. Accordingly, walls should:

1. *Deflect*. "Deflect rain from penetrating past the outermost surface (e.g., siding) of the wall envelope;"

2. *Drain.* "Provide a means for draining water that penetrates the outermost wall surface without harming internal wall components;"[57]

3. *Dry.* "Select combinations of materials and configure them in a way to promote wall drying after wetting episodes;" and be

4. *Durable.* "Use adequately durable materials that are resistant to moisture damage in parts of the wall that are intended to be frequently exposed to moisture."[58]

There are some important practices that can help facilitate this approach. First, the proper design and use of roof and drainage systems (i.e., gutters and overhangs) can help deflect bulk water away from the exterior walls. Second, proper flashing and sealing allows moisture within the wall assembly to effectively drain. Finally, all components of the wall system must be compatible. Before using any building material, the manufacturer's guidelines should be consulted to ensure that the product is

[56] Toolbase Services, *Rain Screen Exterior Walls*, *at* www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2140&CategoryID=1017 (last visited June 10, 2005). *See also* David A. Deress*, Preventing Water Woes* (June 2004), *available at* www.facilitiesnet.com/ms/Jun04/Jun04envelope.shtml.

[57] *See* DURABILITY BY DESIGN, *supra* note 37, at 22, table 4.4 "Recommended Drainage Plane Characteristics For Exterior Walls in Various Climate Conditions."

[58] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 58 (citing D.T. Damery and P. Fisette, *Decision Making in the Purchase of Siding: A Survey of Architects, Contractors, and Homeowners in the U.S. Northeast*, FOREST PRODUCTS JOURNAL (July 2001)).

appropriate for the intended use. If possible, select a manufacturer that provides a complete system of compatible materials.[59]

Wall Components

Exterior Wall Finishes

The exterior wall system is the building envelope's foremost barrier to moisture intrusion. Typical exterior wall finishes include stucco, wood siding, vinyl and aluminum siding, concrete or masonry, stone and synthetic stucco (known as EIFS). In general, a building's exterior finish is selected based on cost considerations, aesthetics, durability, labor requirements and anticipated maintenance needs.[60] Notably, "[r]elatively little quantitative information is available to predict or document actual performance differences between these many [finishes]."[61] Therefore, the most effective means of preventing moisture problems is to select building materials that are compatible with the chosen finish and to use proper design and installation techniques.[62]

- *EIFS (Exterior Insulation and Finish System)*
  Considerable attention has been focused on the performance failures of the EIFS in recent years, but it is important to recognize that there are two forms of EIFS: barrier systems and drainable systems. While the inability of water to exit barrier systems can create significant mold growth problems, drainable systems remain a viable choice for exterior wall finishing.

  Drainage EIFSs incorporate various drainage mechanisms into their design, which allow water within the wall assembly to escape the system. However, drainage EIFSs can experience moisture-retention problems similar to those of the barrier systems if they are not designed or installed correctly. Therefore, careful attention to manufacturers' recommendations, compatibility with other building components and installation by experienced work crews are necessary. Nevertheless, a stigma surrounds all EIFSs due to the problems with barrier EIFSs, which may cause difficulties for builders and deter the use of drainage EIFSs. For instance, some builders' insurers refuse to insure homes with any kind of EIFS.[63]

- *Fiber-Cement Siding*
  Fiber-cement siding is an alternative exterior finishing material comprised of cement, sand and cellulose fiber. Although first introduced in the late 1980s, it is now gaining recognition for its durability and performance in hot and humid climates. Manufacturers emphasize that it is rot- and mold-resistant, termite resistant, non-combustible and has excellent impact resistance.[64] And, while fiber-cement requires periodic maintenance such as painting and caulking, it exhibits good overall weathering characteristics. Additionally, fiber-cement siding reportedly costs less than traditional masonry or synthetic stucco finishes and is equal to or less than hardboard siding, but more expensive than vinyl siding.[65]

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[59] Dave Olson, *Moisture Management in Exterior Wall Assemblies*, WALLS & CEILINGS (Oct. 10, 2002), *at* www.wconline.com/CDA/ArticleInformation/coverstory/BNPCoverStoryItem/0,3296,85808,00.html.
[60] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 58 (citing Damery and Fisette, *supra* note 58).
[61] *Id.* Although, performance research that is widely available has been conducted on some of these finishes, along with studies of different installation methods (e.g., with or without caulking). Additionally, after selecting a type of exterior finish, individual brands and manufactures can have widely divergent performance and durability characteristics.
[62] On the other hand, some finishing products have promised comparably greater durability, moisture-resistant qualities, and lower maintenance needs than some traditional finishing materials. These products include: vinyl siding and vinyl trim; plastic trim; fiberglass trim; plastic lumber; and fiber-cement siding and trim. *See* DURABILITY BY DESIGN, *supra* note 37, at 56.
[63] Toolbase Services, *EIFS-Drainable Systems*, *at* www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1017&DocumentID=2043 (last visited August 16, 2005).
[64] Toolbase Services, *Fiber-Cement Siding*, *at* www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1299&DocumentID=2042 (last visited August 16, 2005).
[65] *Id.*

Interior Wall Finishes

Interior wall finishes are well-documented sources of severe moisture and mold problems in buildings.[66] This results from the installation of impermeable interior finishes without proper consideration of infiltration, outdoor dew point temperatures and condensation.[67] "In general, the permeance of the interior finish material should be significantly higher [meaning that it allows more water vapor movement] than the permeance of the other components in the wall system."[68] This prevents moisture that has entered the wall system from becoming trapped and unable to dry.

Vinyl wallpaper is a typical interior wall finish, but it has a very high resistance to water vapor. This means that when outside air enters the wall cavity and reaches a cooler interior surface, it condenses but cannot dry. The condensation can degrade the finish substrate, like gypsum board, which provides excellent conditions for mold growth.[69] As such, vinyl wallpaper or any impermeable finish should be restricted to a building's interior walls and should not be used on the interior surfaces of exterior walls.[70]

Vapor Retarders

Water vapor in the air is transported by vapor diffusion and bulk air movement.[71] Vapor retarders are used to minimize the diffusion of water vapor into the wall and roof systems, where subsequent condensation can cause moisture damage and mold growth. This moisture is driven through building materials by pressure differentials between the outdoor and interior environments. For instance, high outdoor humidity levels will force water vapor through the building envelope by diffusion to an indoor environment with lower humidity levels.

While vapor retarders play an important role in control of this moisture, improperly selected, designed or installed retarders can be at odds with moisture management goals. Unfortunately, the question of where to place the vapor retarder remains open to debate. And, contrary to conventional wisdom, vapor retarders are not necessary in all situations.[72]

Local climatic conditions have dictated the proper placement of vapor retarders. Traditionally, vapor retarders are placed on the "warm side" of the wall. So, in cold climates, the vapor retarder is installed on the interior side of the wall system, while in hot, humid climates, the vapor retarder is installed on the exterior side of the wall system. However, new technologies, namely computerized moisture modeling, illustrate that adherence to this design technique can result in catastrophic moisture problems, particularly in mixed climates (e.g., North Carolina, Virginia) (*See* "Computer Moisture Modeling" section below).

Recognizing the need to re-examine proper vapor retarder design, some updated building codes no longer require the use of a vapor retarder in certain climatic conditions.[73] In these regions, the use and placement of a vapor retarder will be an individual design consideration based on environmental conditions, material selections and expected interior living conditions.

If a vapor retarder is used, it is important to ensure that the opposite wall surface is permeable.[74] This minimizes the chance that moisture within the wall assembly will become trapped and allows for proper drying. As an example, if the vapor retarder is installed on the exterior wall, the interior wall surface should not be finished with vinyl wall paper or a vapor retarder paint. Similarly, vapor retarders should never be installed on both sides of a wall.[75]

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[66] J. DAVID ODOM, CH2M HILL, INC., PREVENTING MOISTURE AND MOLD PROBLEMS IN HOT, HUMID CLIMATES: DESIGN AND CONSTRUCTION GUIDELINES 2-12 (2003).
[67] *Id.*
[68] *Id.* at 2-13.
[69] *Id.* at 2-12.
[70] *See id*. at 2-12 and 2-13.
[71] DURABILITY BY DESIGN, *supra* note 37, at 21.
[72] Odom, *supra* note 66, at 2-9. But note, vapor retarders are required by most building codes.
[73] *See* 2006 International Building Code and International Energy Conservation Code.
[74] STEVEN WINTER ASSOCIATES, Prepared for U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, VOLUME 2 OF THE REHAB GUIDE: EXTERIOR WALLS (Aug. 1999), at 32 [hereinafter THE REHAB GUIDE: EXTERIOR WALLS].
[75] *Id*.

To be effective, a vapor retarder must have a water vapor permeability not exceeding 1.0 perms.[76] Therefore, materials commonly used as vapor retarders include vapor retarder paint; treated kraft paper and foil-faced batt insulation; and clear, black, and fiber-reinforced polyethylene sheeting.[77] Be aware that certain vapor retarder materials are not appropriate for all applications, and different kinds of vapor retarders are recommended for different uses. Also, it is important to recognize that many materials that are not classified as vapor retarders (e.g., vinyl wallpaper, housewrap) will nonetheless affect water vapor movement.[78] Therefore, careful consideration must go into the selection of materials for each element of the wall system, to ensure compatibility and prevent any unwanted restrictions of air flow and drying ability.

Smart Vapor Retarders

Although not yet widely available for commercial uses, smart vapor retarders can alleviate some of the problems associated with traditional vapor retarders.[79] Vapor retarders continually prevent vapor transmission, even when the inner-wall conditions require moisture movement. However, smart retarders respond to changing humidity levels within the wall system, like those caused by seasonal climatic changes.

In low-humidity conditions, the smart retarders' plastic membrane forms a tight, impermeable barrier, but as humidity increases, the pores of the smart retarder swell. This increases permeability and facilitates drying within the wall cavity. However, a smart retarder is estimated to cost $0.15 to $0.20 more per square foot than a traditional polyethylene retarder, and it is not recommended for use in all climates or for all applications.[80]

Air Infiltration Barriers

Compared to moisture penetration through diffusion, approximately 10 to 100 times more water vapor is transported through bulk air movement (air leakage containing water vapor).[81] So, an air infiltration barrier (like housewrap) is installed over the exterior wall sheathing to restrict air movement through the wall assembly. However, these materials are not impervious to water vapor diffusion, so moisture vapor within the wall system can freely escape through the building exterior. There is a wide selection of housewrap products available, with varying performance characteristics. Therefore, selection of a housewrap should focus on the strength of the housewrap, local climatic conditions and compatibility with other building materials.

Durability of the housewrap is important because handling and installation can damage the material. Even small tears and punctures can negatively affect the product's overall performance.[82] Additionally, the characteristics of some housewrap products are more conducive to individual climatic conditions than others. For instance, "[i]n northern heating climates, where interior vapor barriers are the norm, a highly moisture permeable housewrap may be required. In hot, humid, cooling climates, where an interior barrier is not required, a housewrap with a low air leakage rate may be preferred. In low-wind environments, a low-strength material may be selected."[83]

Importantly, housewrap serves dual roles—as an air barrier and a drainage plane. Accordingly, housewrap will collect and channel moisture that penetrates the exterior finish whether it was intended

[76] *Id.*
[77] *See* DURABILITY BY DESIGN, *supra* note 37, at 23, Table 4.5 "Drainage Plane and Vapor Retarder Materials Properties."
[78] *Id*. at 22-25.
[79] At the time of publication, the only smart retarder commercially available in the United States was the nylon-based MemBrain™ by CertainTeed.
[80] Currently available smart retarders are only recommended for cold or mixed climates. Further, they should not be used in buildings with high, constant humidity levels (such as pools and spas). CertainTeed, *Smart Vapor Retarders: A Technology Primer*, *at* www.certainteed.com (last visited August 16, 2005).
[81] DURABILITY BY DESIGN, *supra* note 37, at 22.
[82] THE REHAB GUIDE: EXTERIOR WALLS, *supra* note 74, at 36.
[83] *Id.*

to or not.[84] Therefore, the wall design and housewrap installation must be such that accumulated water can effectively drain from the wall assembly. Lapping of the housewrap edges, in conjunction with proper taping and sealing, will provide this necessary drainage pathway for water.[85] Ideally, housewrap should be installed prior to the window and door installation.[86]

Insulation

Wall insulation is installed to provide comfortable indoor living conditions and improve energy consumption. Insulation also plays a role in reducing air leakage and improving moisture control within the wall system. However, improper installation can render insulation ineffective for these purposes and can actually increase moisture problems. For example, if insulation does not completely fill the wall cavity, air leakage can bypass the insulation and cause condensation within the wall assembly.[87]

As such, proper insulating is especially important around common sites of air leakage such as the sill, the wall plates, vertical corners, around openings, and at electrical outlets.[88] Ensuring the completeness of insulation can be difficult, but today's builders have access to a high-technology solution. After insulating, an infrared scan of the wall system can reveal cavities that have not been fully insulated.[89] (*See* "Infrared Thermography" in the "New Technologies" section below.)

Sheathing

Sheathing is installed on the exterior of the framing for several purposes, including increased structural integrity; insulation; to aide installation of the exterior finishing system; and as part of the building's moisture barrier system.[90] The sheathing should remain dry, but water damage to sheathing can be caused by improper flashing and caulking around doors and windows, inadequate flashing at the wall/roof juncture, wind-driven rain, moisture intrusion through mortar joints in brick veneer walls, and the lack of or poorly installed moisture barriers like housewrap.[91] Since some significant moisture-related sheathing problems have resulted from moisture penetrating the exterior finish and becoming trapped (particularly in EIFS), a drain system should be installed between the finishing system and the sheathing using furring strips, drainage channels and housewrap, plastic matting or similar methods.[92]

Sheathing is made from numerous materials, with plywood, oriented strand board (OSB) and gypsum being the most commonly used. However, some sheathing materials are highly susceptible to moisture damage, notably paper-faced gypsum sheathing. Glass mat-faced gypsum, other non-paper faced gypsum or fiber-cement sheathing are moisture-conscious alternatives. All of these materials possess good moisture-resistant qualities and can be installed and left unfinished for longer periods than traditional sheathing materials.[93]

Roof Systems

Proper roof design and installation are critical to preventing moisture in a building. Roof systems are generally classified into two major types: water-shedding (steep-slope roofs) or waterproof (low-slope or flat roofs). Since water-shedding roof systems rely on the force of gravity to drain water off the roof, carefully installed roofing materials and proper flashing are important to direct the water flow.[94] Low-slope or flat roofs, on the other hand, rely on a waterproof barrier system to keep water from penetrating the building below and are particularly vulnerable to water intrusion problems. "Instead of providing the redirecting force to channel water away from the inside of the building envelope, the force of gravity

[84] DURABILITY BY DESIGN, *supra* note 37, at 23.
[85] *Id*. at 25.
[86] *Id*.
[87] THE REHAB GUIDE: EXTERIOR WALLS, *supra* note 74, at 39.
[88] *Id*.
[89] *Id*.
[90] *Id*. at 28. *See also* DURABILITY BY DESIGN, *supra* note 38, at 19-20, explaining that drainage planes should be considered in all but the most arid climates with insignificant rainfall.
[91] THE REHAB GUIDE: EXTERIOR WALLS, *supra* note 74, at 28.
[92] *Id*.
[93] *Id.* at 29-31.
[94] THE ENGINEERED WOOD ASSOCIATION, BUILD A BETTER HOME: DESIGNING ROOFS TO PREVENT MOISTURE INFILTRATION (Revised Jan. 2003), at 2, *available at* www.apawood.org/bbh_roofs.cfm.

drives the water into every imperfection in the waterproofing system. [And, commonplace weather events can prevent water from draining properly.] Once standing water is present, even minor defects can cause major water leaks."[95]

Roof systems depend on the interaction and performance of many components to provide appropriate moisture protection, including sheathing; flashing; moisture barriers and underlayment; insulation; finishing material; and ventilation. Therefore, it is crucial that all materials used in the roof system are compatible.

Roof Sheathing
Roof sheathing is installed over the roof framing and is typically made from plywood or oriented strand board. This material should not degrade, although leaks from improper flashing, condensation from inadequate ventilation, and insufficient protection from the elements during construction can result in water damage and mold growth.[96]

Underlayment
Underlayment acts as an important secondary water barrier installed beneath the finishing material. Conventional underlayment has been made of asphalt-impregnated felt, and is installed from the bottom up with each upper layer overlapping the lower to ensure that water does not penetrate the lower sheets. However, numerous manufacturers are now offering reinforced underlayment materials and ice and water barriers that boast greater strength, durability, water resistance and overall leak protection than traditional roofing felt. While some of these products have been used for many years, exercise caution before using these products. In general, reinforced underlayment materials act as vapor barriers that can trap moisture and cause condensation problems if used without proper roof or attic ventilation.[97]

Flashing
Flashing is a critical component of moisture-resistant building, yet it is also an often neglected element of construction.[98] It is used to prevent water penetration through seams, joints and various openings in the building exterior, and to direct water to an appropriate drainage path. For example, flashing is commonly used at the roof/wall juncture, around chimneys, skylights, vents, windows and doors.

Flashing products can be made of various materials, as long as they are durable, low maintenance, weather-resistant and compatible with other building materials.[99] However, the quality of the flashing material is irrelevant if it is improperly installed. The following points should be kept in mind when designing and installing flashing:[100]

- All breaches of the exterior walls or roof system should be flashed.
- Flashing details and installation instructions should be explicitly included in the architectural plans and construction drawings.
- Generally, do not substitute caulks or sealants for proper flashing. (*See* "Caulks and Sealants" below.)
- Remember that gravity pulls water downward, but wind can force water upward, so flashing must be layered and overlap according to manufacturer or industry recommendations.[101]

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[95] *Id*.
[96] STEVEN WINTER ASSOCIATES, Prepared for U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, VOLUME 3 OF THE REHAB GUIDE: ROOFS (March 1999), at 14 [hereinafter THE REHAB GUIDE: ROOFS].
[97] *Id*. at 22-23.
[98] *See* BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 13, 67; *see also* DURABILITY BY DESIGN, *supra* note 37, at 26.
[99] THE REHAB GUIDE: ROOFS, *supra* note 96, at 16.
[100] DURABILITY BY DESIGN, *supra* note 37, at 26.
[101] For illustrations of proper flashing techniques *see* DURABILITY BY DESIGN, *supra* note 37, at 26-34, or THE ENGINEERED WOOD ASS'N, BUILD A BETTER HOME: DESIGNING ROOFS TO PREVENT MOISTURE INFILTRATION, *supra* note 94.

- Minimize roof penetrations with ventless plumbing techniques like air admittance valves, side wall vents and direct vented appliances if local building code allows.
- Utilize gutters and overhangs to direct water away from wall openings like windows and doors.

Ventilation

The decision of whether or not a building should be designed with roof/attic ventilation is becoming increasingly controversial. The purposes of ventilation are to promote drying of roofing materials after wetting, to control interior condensation and moisture damage, and to reduce the roof and attic temperatures. Building codes commonly require one square foot of ventilation for every 300 square feet of insulated attic space, and double that amount in the case of low-slope roofs. Ventilation relies on natural air flow through various openings or proprietary vent devices to draw moisture upward and out of the attic and roof system. Therefore, improper roof ventilation has been blamed for many attic and ceiling moisture problems and material degradation.

However, some experts have concluded that roof ventilation is actually a major source of indoor moisture, and is therefore a problematic design element.[102] These criticisms are generally directed toward buildings in cool and wet or hot and humid regions. Ultimately, however, roof ventilation may still be recommended or required for reasons other than moisture control.[103]

Nevertheless, roof ventilation cannot prevent attic and ceiling moisture by itself, and it can even cause significant moisture problems in any environment if other good construction practices are not followed. Therefore, design decisions for roof ventilation systems must be made in consideration of other roof, attic and ceiling characteristics. Design issues concerning vapor retarder placement, insulation, indoor humidity levels, mechanical ventilation systems and proper sealing are intertwined with the roof ventilation design. The following practices are particularly important to ensure the effectiveness of roof ventilation:[104]

- All exhaust fans (like those in bathrooms and kitchens) should vent directly to the outdoors, not to the attic or any indoor space.
- Indoor humidity must be kept within recommended limits. Indoor sources of moisture should be properly controlled and HVAC systems should be properly sized, functional and operated appropriately. (*See* "HVAC System" below.)
- Ceiling moisture barriers should be compatible with the moisture/vapor retarder qualities of the roofing materials.
- Insulation placement and installation must be carefully considered and executed.
- Ceiling air leakage should be minimized through proper air barriers, sealing and insulation.

Caulks and Sealants

Caulking or sealing is commonly required or recommended in the installation of various building components including exterior finishes, roof systems, windows, doors and the wall assembly. However, most caulk and sealants have a limited life span and a high potential for failure after two to three years.[105] Although some long-lasting products (like silicon-based and polyurethane caulks) promise considerably longer life spans (20+ years), they are not suitable for all materials or applications, and

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[102] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 79.
[103] *Id*. (citing W. Rose and A. TenWolde, Venting of Attics and Cathedral Ceilings, ASHRAE JOURNAL (Oct. 2002)). Some considerations important for non-vented roof designs can be found at DURABILITY BY DESIGN, *supra* note 37, at 25.
[104] *See* DURABILITY BY DESIGN, *supra* note 37, at 35.
[105] *Id*. This estimate assumes the use of normal quality products, with typical surface preparation, and typical shrinkage and swelling of building components.

can cost up to two-thirds more than the average product. Further, the life span of even high-quality, long-life products is dependent on proper application and compatibility with other building materials.[106]

As such, do not rely on these products to provide a continuous watertight seal or long-term moisture penetration protection. One expert illustrated this problem by saying that although sealants comprise less than 1 percent of the building cost, they can represent "90 percent of the problem" if the building develops leaks.[107] Instead, ensure that flashing is properly installed and drainage planes are carefully designed and maintained.

Nevertheless, caulk and sealants are essential in many applications, though the quality of the product, installation technique and maintenance will affect their usefulness. Further, it is important to follow manufacturers' instructions concerning surface preparation, installation conditions and proper storage. Additionally, it should be noted that different varieties of caulk are recommended for different surfaces and applications. The proper selection of caulk and sealant materials increases effectiveness and minimizes the risk of product failure due to incompatibility with other building materials.[108]

It should be noted that over-sealing or caulking can also be problematic. For instance, any blockage of weep holes or other intended drainage paths by careless or excessive caulking can trap or redirect moisture within the building envelope.[109]

Windows, Doors and Skylights

As noted above, poorly installed, improperly sealed and inadequately flashed windows, doors and skylights are a source of bulk water entry into a building, which can cause significant moisture and mold damage. The common problem of window condensation can be similarly damaging, however, and can indicate greater indoor moisture problems.

Window condensation is formed when moisture in the air touches a cold window surface. It is particularly problematic during the winter months. Continuous or excessive condensation may result in mold growth and deterioration of the window and surrounding wall assembly. Sometimes this condensation is caused by air leakage around the window, which can often be prevented and remedied with proper caulking and weather stripping.

If cost permits, inefficient, single-pane windows should be replaced with storm windows or high-performance glass (windows with a low emittance or "low E" coating that restrict heat flow through the glass). These windows have greater insulation abilities, which keeps the glass surface warmer and reduces condensation.[110] Additionally, it is important to choose windows that are appropriate for local climatic conditions. For example, EPA's Energy Star program recommends different low E coatings for different weather conditions.[111] A low-cost option is to apply shrink film or polyethylene sheet insulation to the window surfaces.

On the other hand, condensation on interior window surfaces is often a sign of excessive indoor humidity and inadequate ventilation.[112] Steps should be taken to identify the source of humidity and to

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[106] For instance, while polyurethane caulk is long-lasting, it can be difficult to use and install properly. Further, it is more unforgiving when mistakes are made, since polyurethane caulk cannot be cleaned up with water.

[107] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 68 (citing T.F. O'Connor, *The One Percent of Cost That Can Become 90 Percent of Trouble*, STANDARDIZATION NEWS (June 2003)).

[108] A chart providing suggestions for the proper selection of caulk can be found in DURABILITY BY DESIGN, *supra* note 37, at 36. *See also* THE REHAB GUIDE: EXTERIOR WALLS, *supra* note 74, at 80, discussing the product characteristics important to consider during any selection of these products including elasticity; elongation; adhesion; durability; paintability; compatibility with adjacent materials; and weatherability.

[109] *See* CHARLES CARLL, U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE FOREST PRODUCTS LABORATORY, THE INS AND OUTS OF CAULKING (Revised April 1998).

[110] Energy Star labeled windows serve well in this capacity.

[111] Energy Star, *Anatomy of an Energy Efficient Window*, www.energystar.gov/index.cfm?c= windows_doors.pr_anat_window (last visited August 16, 2005).

[112] Energy Star, *Moisture on Windows*, www.energystar.gov/index.cfm?c=home_solutions.hm_ improvement_moistureonwin (last visited August 16, 2005).

reduce the household humidity level. Although there are many potential reasons for high indoor humidity, Energy Star recommends:

(1) examining any humidifiers and dehumidifiers to ensure they are operating properly;
(2) using ventilation fans in kitchens and bathrooms; and
(3) ensuring that all exhaust fans and clothes dryers vent directly and without obstruction to the outside.

Balconies and Decks

It is particularly important to properly design and maintain balconies and decks because even relatively minor construction defects can provide a pathway for bulk water intrusion into a building. Appropriate drainage is of primary importance in preventing damaging moisture accumulation and penetration. First, balconies and decks must be sloped away from the building to minimize the pooling of water on their surfaces or against the wall seams. They should also drain water away from the building's interior, foundation, lower walls, and other balconies or decks to the extent possible. Finally, all drains should be properly installed, sealed and designed to minimize blockages.

Water leakage through the balcony/deck seam with the wall assembly poses another significant problem. Flashing and sealing around the balcony/deck connection with the wall and around any doors leading out of the building should be carefully installed. Also, the balcony or deck itself should be properly waterproofed and constructed of appropriate, weather-resistant materials.

Thermally-Broken Balconies

Thermally-broken balconies have been used successfully to reduce energy costs and prevent moisture and mold problems. However, the additional construction costs and design efforts have limited their application.[113] Unlike traditional balconies that wick heat outdoors and bring cool air indoors, these balconies are "separated" from the building structure and allow the building's thermal, moisture, air and vapor barrier systems to be maintained and continuous through the building/balcony connection. Thermally-broken balconies are supported by exterior columns and footings, and include insulation between the balcony and the interior floor slab. This purports to prevent thermal bridging, thereby reducing cold interior surfaces and related condensation and mold problems while promoting energy efficiency.

Crawlspaces

Crawlspaces consistently pose challenges to designers and builders intent on minimizing moisture problems. Moisture within a crawlspace can lead to two main problems: (1) condensation on the crawlspace surfaces themselves can cause mold or degradation of building materials; and (2) if air leaks between the crawlspace and the building interior, the elevated humidity level can increase indoor humidity.[114]

The natural release of ground moisture is often the source of unwanted water, although site drainage and other construction details can contribute to the problem. Many experts now agree that a polyethylene ground cover should be used to inhibit the evaporation of ground moisture into the crawlspace.[115] One estimate indicated that a crawlspace without ground cover can release 40 to 50 liters (approximately 10 to 13 gallons) of moisture into thermally conditioned space every day.[116]

[113] Advanced Buildings*, Thermally-broken Balconies*, www.advancedbuildings.org/main_t_ building_therm_balconies.htm (last visited June 14, 2005).
[114] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 81.
[115] *Id.*
[116] *Id*. (citing M.X. Rousseau, *Sources of Moisture and Its Migration through the Building Enclosure*, STANDARDIZATION NEWS (Nov. 1984)).

Another crawlspace design detail that is not so easily resolved involves the question of whether the crawlspace should be vented or unvented. Crawlspace vents have traditionally been required by building codes to facilitate air flow and moisture removal within the crawlspace. As a result, standard practice dictates that insulation be installed under the floor over a vented, unconditioned crawlspace. Yet many professionals now argue that ventilated crawlspaces can introduce wet outdoor air into the cooler crawlspace environment, thereby causing condensation and mold growth, especially in humid or mixed climates.[117]

The alternative is to treat the crawlspace like a basement and design an airtight, unvented space by sealing and insulating the foundation walls. Many believe that unvented designs increase occupant comfort, promote energy savings and provide better moisture control.[118] Unvented crawlspaces also help protect piping and ductwork from freezing, since they are within the conditioned space of the building and air sealing between the building interior and crawlspace is less critical.[119] However, the design of unvented crawlspaces should also include careful attention to site grading and drainage, air sealing between the outdoors and the crawlspace to keep humid air out, properly insulating the perimeter walls (not the floor), a polyethylene ground cover and dampproof walls.[120]

HVAC System

Improperly designed or installed heating, ventilation, and air conditioning (HVAC) systems can greatly contribute to indoor moisture problems, specifically condensation. During the design phase, the following HVAC issues should be considered:

- *Duct Design.* Ineffective ductwork can introduce unwanted moisture into the indoor environment. To minimize this, duct length and the number of bends should be kept to a minimum. Also, consider installing the HVAC equipment and ducts within the building's conditioned space, as opposed to traditional locations like crawlspaces and garages. Conditioned-space installation prevents moisture and outdoor pollutants from being pulled into the building through leaky ducts. This can also reduce energy costs by an estimated 20 to 35 percent. Further, the equipment costs for a conditioned-space system can be at least 20 percent less than that for an unconditioned-space system, since the system heating and cooling capacity and the ducts can be downsized.[121]

- *Duct Leakage*. Leaky ducts[122] can create an indoor depressurization problem, which "causes humid outdoor air to flow in through exterior walls and other building assemblies."[123] This results in condensation on cool surfaces, like the back side of gypsum board. This can easily be prevented by simply building tightly sealed duct systems and conducting leakage testing.[124]

  Duct testing can determine the amount of leakage and energy loss within a duct system and verify the quality of the system installation. The most common testing method utilizes a calibrated fan to pressurize the duct system after sealing off all supply registers and return grilles. The rate of airflow into the ducts is then used to determine the duct tightness. Sometimes fog, like that used in theatres, is used to determine the exact location of leaks.

[117] DURABILITY BY DESIGN, *supra* note 37, at 37.
[118] *Id*.; *see also* SOUTHFACE ENERGY INSTITUTE, Prepared for U.S. DEPARTMENT OF ENERGY, CRAWLSPACE INSULATION (Dec. 2000).
[119] U.S. DEP'T OF ENERGY, CRAWLSPACE INSULATION, *supra* note 118.
[120] DURABILITY BY DESIGN, *supra* note 37, at 37.
[121] Toolbase Services, *Ducts in Conditioned Space vs. Ducts in Unconditioned Space* (Feb. 2002), www.toolbase.org/tertiary T.asp?TrackID=&DocumentID=1906&CategoryID=1092.
[122] Note: "An estimated 15 to 30 percent of a home's total heating and cooling energy is lost through leaky ductwork, costing consumers about $5 billion dollars per year." Toolbase Services, *Aerosol Duct Sealing*, www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2083&CategoryID=65 (last visited June 14, 2005).
[123] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 86.
[124] DURABILITY BY DESIGN, *supra* note 37, at 65; *see also* Toolbase Services, *Duct Leakage Testing* (Reviewed April 2005), www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2027& CategoryID=208.

Overall, these tests are inexpensive, easy to conduct and accurate. Studies show that fixing leaky ductwork can save up to 25 percent in energy costs.[125]

Aerosol Duct Sealing

New and reportedly more effective techniques for sealing ducts are becoming available. Lawrence Berkley National Laboratory had developed one method for internally sealing HVAC ducts using a pressurized aerosol sealant. The system forces vinyl adhesive particles into the duct system. As the particles naturally try to exit the system, the adhesive builds up on any openings encountered and seals the leak. It is estimated that when aerosol sealing is used in combination with other approved sealing materials (traditionally mastic or aluminum tape), the ductwork is five to eight times more airtight, and the energy savings can be as much as 30 percent.[126] The process is relatively inexpensive ($300 to $600 for a single-family home), and accelerated aging tests indicate it will not degrade over time. However, aerosol duct sealing is currently commercially available only in limited geographic areas.[127]

- *Equipment Size.* HVAC systems are not one-size-fits-all, and should be designed with regard to the actual heating and cooling loads of the building.[128] Installing oversized HVAC systems can create a significant moisture problem. When the system's cooling capacity greatly exceeds the building's heating and cooling loads, the system cools the building too quickly and does not run long enough to adequately remove moisture from the air.[129] This results in a cool home with high humidity.

- *Central Returns.* Be cautious when designing a system with central returns (i.e., a system where supply air is ducted into individual rooms, but that air is drawn back to the system handler through a centralized return grille located outside of the rooms), since they can result in indoor pressure imbalances.[130] Depressurization results in the buildup of humidity and condensation.

- *Drainage*. Ensure that the condensation collected by the air conditioning cooling coil is properly collected and drained to an appropriate location, not an improper place such as a crawlspace or under the foundation slab.[131]

- *Humidifiers*. Where humidifiers are in use, it is important to install the system properly, ensure that the controls are accurate, and educate occupants about appropriate operation.[132]

Dehumidification

Dehumidification is typically accomplished by cooling the air, which reduces air's ability to hold moisture and causes moisture to condense out of the air.[133] Air conditioning can effectively dehumidify indoor air if the unit runs for the proper length of time, at an appropriate temperature. However, even if the unit is properly sized (*See* "Equipment Size" above) this is often not accomplished, because (1) the necessary temperature/run-time may not create comfortable conditions for building occupants, and (2) most air

[125] Toolbase Services, *Duct Leakage Testing* (Reviewed April 2005), www.toolbase.org/tertiaryT.asp?TrackID=&DocumentID=2027&CategoryID=208.
[126] Toolbase Services, *Aerosol Duct Sealing*, www.toolbase.org/tertiaryT.asp?TrackID=& DocumentID=2083&CategoryID=65 (last visited June 14, 2005).
[127] Aerosol duct sealing is available through Aeroseal, Inc. Aeroseal certifies local contractors and has established franchises nationwide to perform aerosol duct sealing (although not yet available in every state). For more information, *see* www.aeroseal.com.
[128] Traditional, rule-of-thumb calculation methods should not be used. Instead, an HVAC contractor should calculate heating and cooling loads using an approved method, such as the Air Conditioning Contractor of America's Manual J.
[129] DURABILITY BY DESIGN, *supra* note 37, at 66.
[130] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 87 (citing Brennan, Cummings and Lstiburek, *Unplanned Airflows and Moisture Problems*, ASHRAE JOURNAL (Nov. 2002)).
[131] BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 89-90.
[132] *See id*. at 89.
[133] *Id*. at 88.

conditioning systems are activated by temperature (using a thermostat) rather than humidity levels (using a humidistat). This can be remedied by installing a dehumidification system. Dehumidifiers are available as stand-alone units, although some systems can be integrated with an air conditioning system. Note: the most practical dehumidification systems will include a built-in humidistat. Humidistats are used to maintain a set level of humidity, so that when a room reaches the programmed humidity level, the dehumidifier automatically cycles off.

Mechanical Ventilation Systems

Mechanical ventilation systems that claim to effectively improve indoor air quality and reduce moisture problems are gaining popularity in residential construction. These systems offer a combination of services, including ventilation (where outdoor air is admitted into the indoor environment); filtration (the system filters the air supply and re-introduces the air back into the interior); and dehumidification (see above). However, some experts believe that "while ventilation systems can dilute indoor moisture levels under some conditions, they can also have the opposite effect, creating or worsening moisture problems."[134] These systems have the potential to develop into important moisture control tools; however, more research is needed concerning proper system selection, design, installation and operation.[135] Therefore, if a mechanical ventilation system is used, give special attention to its design and interaction with the heating and cooling system.

Interior Moisture Sources

Although proper building design and construction practices can substantially reduce the moisture level in a home's indoor environment, many acts of everyday living introduce large amounts of moisture into the building's interior. The use of clothes dryers, combustion heaters, fireplaces, bathroom facilities and the like greatly affect indoor humidity levels and condensation. By addressing indoor moisture sources during the design and construction process, the likelihood of future moisture accumulation problems is minimized.

Because kitchens and bathrooms are subject to high humidity and wetting from splashes, condensation and leaks, special attention should be given to the materials used. For instance, commonly used materials, such as paper-faced gypsum board, are highly moisture-sensitive. Alternative products, like gypsum covered with fiberglass fabric, foam insulating sheets and fiber-cement boards are designed to resist moisture damage.[136]

Although not always required by building codes, all rooms with moisture-generating appliances or daily activities should generally be designed with ventilation fans to exhaust indoor moisture. Further, code-required ventilation rates are often too low to be effective. Therefore, the minimum ventilation rate recommended is 80 to 100 cubic feet per minute (cfm) for bathrooms and 150 cfm for kitchens.[137] However, these ventilation systems are useless if occupants are reluctant to use them or do not operate them for a sufficient period of time. As such, consider installing low-noise fans (generally 2 sones or less), or fans that operate automatically for a timed period.[138]

The operation of some household appliances releases water vapor into the indoor environment that can substantially increase indoor relative humidity levels. Proper venting is necessary to prevent moisture and condensation problems. Beyond venting exhaust outdoors, the design of exhaust ducts should be considered. A professional engineer can make specific recommendations about the design of duct systems.[139]

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[134] *Id*. at 19.
[135] *See id*. at 90-91.
[136] BUILDING MOISTURE AND DURABILITY, *supra* note 40, at 84 (citing Brennan, *supra* note 130).
[137] D.M. Brook, Oregon State University Extension Service, *Home Moisture Problems* (Reprinted Feb. 1995), at 7.
[138] *Id.*
[139] BUILDING MOISTURE AND DURABILITY, *supra* note 40, at 84 (recommended by the Texas Association of Builders, *Recommendations for the Prevention of Water Intrusion and Mold Infestation in Residential Construction*, BUILDING STANDARDS INITIATIVES (Dec. 2002)).

Finally, a distinction should be made between moisture-generating appliances and moisture-using appliances. For example, air conditioners, gas appliances and clothes dryers are moisture-generating devices because they either cool air and collect moisture or release water vapor into the indoor environment. Since moisture problems related to these appliances stem from improper collection and disposal of moisture, appropriate ventilation and exhaust systems are necessary. On the other hand, many household appliances and fixtures use water as part of their operation, like washers, sinks and toilets. For these appliances, plumbing and drain systems must be sufficient to minimize leakage and bulk overflow.

THE CONSTRUCTION PROCESS: MATERIALS, STORAGE AND SEQUENCING

Even a carefully designed building can experience mold and moisture problems as a result of unorganized construction practices, beginning with the delivery of materials, storage and construction sequencing.

Delivery Issues

Builders and contractors should be conscientious in ensuring the quality of their construction materials. Since mold can readily grow on many building materials, especially wood and drywall, special attention should be given to the condition of building materials when delivered. Upon delivery, materials should be inspected for mold growth and moisture damage. Mold-infested or significantly damaged materials should not be used, and those shipments should be rejected if possible.[140] Traditional and state contract law, the Uniform Commercial Code (UCC) and individual business agreements establish the procedures and time frame allowed for rejection of unfit, mold-damaged materials.[141]

On-Site Mold Remediation

If there is only minimal mold growth, or if mold growth occurs after delivery, builders may consider treating the mold-affected materials. Most cleaning protocols involve the use of detergent, a bleach solution, or a commercial mold remover. However, some manufacturers and associations have made specific mold treatment and cleaning suggestions available for their products.[142] Alternatively, the EPA provides general remediation guidelines for problematic mold growth.[143]

It is also important to consider the timing of material shipments. Scheduling material deliveries close to their time of installation will reduce their environmental exposure on the construction site, which in turn can reduce wetting and opportunities for mold and moisture damage.[144] Recognizing that it may not be possible to precisely schedule shipments in correlation with their installation, on-site storage of materials is important.

Storage

All building materials on-site should be properly stored prior to use. Ideally, moisture vulnerable materials should be stored under a roof. However, since this is often not possible, the following are some suggestions to keep building materials mold-free:[145]

- Do not store materials in wet areas or places with a high moisture load (e.g., basements).

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140 Toolbase Services, *Helping Your Buyers Understand Mold During the Building Process* (April 2002), www.toolbase.org/tertiary_printT.asp?TrackID=&CategoryID=1554&DocumentID=3465 (last visited March 21, 2005).
141 *See id.*
142 *Id.*
143 U.S. ENVIRONMENTAL PROTECTION AGENCY, A BRIEF GUIDE TO MOLD, MOISTURE, AND YOUR HOME, Pub. No. 402-K-02-003, *available at* www.epa.gov/mold/images/moldguide.pdf (last visited June 14, 2005). *See also*, U.S. ENVIRONMENTAL PROTECTION AGENCY, MOLD REMEDIATION IN SCHOOLS AND COMMERCIAL BUILDINGS, Pub. No. 402-K-01-001 (March 2001), www.epa.gov/mold/images/ moldremediation.pdf.
144 Toolbase Services,*Helping Your Buyers Understand Mold During the Building Process*, *supra* note 140.
145 *Id.*

- Store materials off the ground to facilitate air flow around the materials.
- Cover materials with a tarp, plastic sheeting, etc. Secure this covering, but do not tighten around materials or completely enclose materials. This could trap any moisture that penetrates or collects within the covering, restrict air circulation and promote mold growth.

Construction Sequence Concerns

Some degree of wetting is likely to occur during the construction process. For instance, rainfall and other wetting is typical during framing. However, this wetting will usually not present a problem if work is properly sequenced and appropriate drying time is allowed before closing in wet materials.[146]

> "For instance, a building may be exposed to several days of rain during the framing stage, resulting in moisture uptake of wood members like wall studs. However, as a typical construction sequence would progress, the house would be put under roof, sheathed, sided, and roughed-in (mechanicals) before the studs would be covered up with insulation and drywall (i.e., closed in). This would permit at least a few weeks to dry. What's more, the studs would not be exposed to further wetting from rain once the house was under roof, sheathed, and sided. At this stage, the interiors of homes are protected from bulk water, and moisture-sensitive components like drywall, insulation, and finish products can be installed."[147]

In addition, as long as any mold growth that did result from construction wetting is properly cleaned, it should not create future mold problems. However, all parties should be aware of any mold growth during, and soon after, the building is closed in. This can signify design or installation problems that should be addressed.

Some sequencing issues should be addressed during the building design phase. Since some materials are more susceptible to damage from exposure and intermittent wetting than others, a decision to use more resilient products may be prudent in anticipation of construction delays or installation problems. For instance, non-paper faced gypsum or fiber-cement sheathing can be installed and left unfinished for longer periods than traditional sheathing products. Likewise, when a sensitive sheathing product is selected, exercise caution when choosing finishing materials. You may want to avoid products that are difficult or time-consuming to install.

Drying Time

As previously discussed, closing in a building prematurely can lead to damaging moisture and mold problems. Wet building materials and unfavorable closing-in conditions can result from wetting during construction, moisture absorption during storage or transport, using materials with high latent moisture loads (e.g., green lumber and concrete) and high outdoor humidity levels. Owners and contractors alike should be sure that in their efforts to meet building schedules they are not rushing construction and failing to allow sufficient drying time. It is important that all materials reach their manufacturer-recommended or code-required moisture content level before closing in a building, applying finishes and other interior details and installing flooring.

Do not run the building's permanent HVAC system to dry out the building at this stage. "The moisture load from wet materials is simply too large and the drying task too complex for systems that are intended for comfort air conditioning."[148] If the HVAC system is used while construction is ongoing, construction debris can contaminate the system and serve as a later food source for mold. Likewise, the relatively common use of combustion heating units to dry out the building interior is also discouraged, since these heaters have been proven to add moisture to the environment. Instead, dehumidification equipment specifically designed for construction drying should be used.

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[146] *Id.*
[147] *Id.*
[148] Lewis G. Harriman III, Donald Schnell, and Mark Fowler, *Preventing Mold by Keeping New Construction Dry*, ASHRAE JOURNAL (Sept. 2002).

Dehumidification systems can speed construction drying time without increasing interior moisture levels. They can remove up to 300 gallons of moisture from the building interior per day, and they can be less costly and labor-intensive than combustion drying systems.[149]

The Use of Moisture Meters During Construction

Moisture in building materials must be controlled to prevent the growth of mold. One option is to use moisture meters to measure the relative moisture content of various construction materials as a routine part of the construction and renovation process. Moisture meters can detect excessive moisture content in construction materials, including wood, gypsum board, plaster, concrete, brick, roofing, and insulation. They can also be used to monitor the progress of drying damaged buildings or materials.

Moisture meter prices range from $100 to $1,450, depending on quality, features and accessories, but good meters may typically be found in the $250-$400 range.[150] Consider using moisture meters to inspect delivered materials when excessive moisture is suspected, and at other appropriate occasions during the construction process. If it has been properly calibrated, a moisture meter may be valuable in detecting "wet" conditions. Meter readings will vary by geography and climate region. To promote accuracy, baseline meter readings should be taken on a clear day, with humidity levels that are typical for a particular geography and climate.

There are several types of moisture meters. "Electric moisture meters" use known relationships between electrical properties and moisture levels in materials that are hygroscopic (able to absorb water from the environment).[151] "Conductance meters" have two to four metal probes, or pins, that are physically inserted into the building material and read the moisture content of the material through electrical conductance between electrodes.[152] "Dielectric-type moisture meters" are non-invasive and do not typically puncture the material; instead, they generate an electrical field through flat platens located on the bottom of the meter.[153]

Moisture meters and visual inspections are useful in determining whether materials are wet. According to IICRC S520 (Standard and Reference Guide for Professional Mold Remediation), "[p]roperly calibrated moisture meters, used according to manufacturer specifications, are highly recommended to determine the potential for mold amplification in structural material."

Concrete Drying

Concrete needs water to properly set and to gain strength for a certain period of time after it is poured. However, since every yard of concrete contains nearly 50 gallons of water in excess of what is necessary for curing, this excess water must be removed.[154] As such, moisture-laden concrete can present a significant liability if it is not properly addressed.[155] In general, there are four choices available for handling concrete with excess moisture:

(1) ignore it and install flooring, finishing and drywall;

[149] Combustion drying systems, such as propane heaters, can cost much more than dehumidification systems because they use a large amount of fuel and must be monitored 24 hours per day for refueling and fire safety purposes. Ragan Willis, *Creating a little desert indoors*, SEATTLE DAILY JOURNAL OF COMMERCE ONLINE EDITION (June 2000), www.djc.com/const/cis.html?id=11008359.

[150] Toolbase Services, *Electric Moisture Meters*, www.toolbase.org/tertiary_printT.asp?TrackID=&CategoryID=1292&DocumentID=2120 (last visited June 14, 2005).

[151] *Id.*

[152] *Id.*

[153] *Id.*

[154] Lewis G. Harriman III, Donald Schnell, and Mark Fowler, *Preventing Mold by Keeping New Construction Dry*, ASHRAE JOURNAL (Sept. 2002).

[155] Since elevated moisture levels in concrete can result in substantial building failures, accurate testing of concrete moisture levels is essential. Therefore, neither moisture meters nor a sheet of plastic are appropriate testing methods in this context. Rather, an anhydrous calcium chloride test or tests using in situ probes should be used. These test methods have been standardized in ASTM F 1869 and F 2170. *See* Christopher Capobianco, *How ASTM Standards Help the Floor Covering Industry*, STANDARDIZATION NEWS (May 2005), at 27.

(2) allow the concrete to dry naturally;
(3) seal the surface so the excess moisture remains in the concrete; or
(4) use a dehumidification system.[156]

It is an unacceptable construction practice to continue with interior installation and closing in without properly drying out the concrete. In addition to promoting mold growth, this residual moisture can void warranties, like those for flooring.[157] However, simply waiting for the concrete to dry naturally can be time-consuming and result in costly construction delays. Therefore, sealing and dehumidification are the most practical drying options. Sealing can be very effective, but it can cost considerably more than using drying equipment. For instance, floor-sealing costs are typically between $1 and $8 per square foot, whereas mechanical drying costs range between $0.15 and $1 per square foot.[158]

Lumber and Wood Finishes

Wood is especially susceptible to wetting, moisture damage and mold growth, so special care should be taken to see that it is adequately stored, installed and treated. "[I]t is generally recommended that untreated wood be maintained in conditions where the moisture content does not exceed 20 percent."[159] There are three primary methods for preventing moisture and mold damage to wood products:

(1) Use naturally decay- and moisture-resistant wood.
(2) Protect or create a barrier from sources of moisture.
(3) Use preservative-treated wood.[160]

Some species of wood, such as bald cypress, cedar, black locust, redwood, and black walnut, naturally resist decay that could lead to moisture damage and mold growth.[161] Of course, appropriate wood choice will vary according to local climate, cost considerations, aesthetics and intended use. And, since many of the most moisture-resistant wood species cannot feasibly be used in construction because they are cost-preclusive or scarce, use of preservative-treated wood is an attractive alternative.

It is important to note the difference between preservative pressure-treated wood and protective wood finishes. The former is produced by using a high-pressure process to saturate the wood with preservative chemicals. The most popular and consistently used wood preservative has been Chromated Copper Arsenate (CCA). Although highly effective, concerns over potential adverse health effects related to CCA resulted in a voluntary agreement between the EPA and industry to discontinue the use of CCA in most residential applications.[162] Alternative treatments are now commercially available. Detailed information concerning the properties, recommended uses and effectiveness of various wood preservatives is available through the USDA Forest Service Forest Products Laboratory.[163]

Wood can also be protected from moisture damage by applying a finish (such as paints, stains, and water repellents) to its exterior. The selection of a protective finish and its subsequent effectiveness depends on the species and type of wood involved, its surface condition and treatment history, cost, aesthetics and climate.[164]

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[156] Harriman, Schnell, and Fowler, *supra* note 154.
[157] *Id.*
[158] *Id*.
[159] DURABILITY BY DESIGN, *supra* note 37, at 51.
[160] *Id.*
[161] For more information on the decay-resistant qualities of wood species see the U.S. Department of Agriculture, Forest Service Forest Products Laboratory, *at* www.fpl.fs.fed.us/rwu4723/ preservation_faqs/durable.html.
[162] For more information about the phase-out of CCA-treated wood, *see* NMHC's guidance document discussing the science, problems, and recent developments concerning CCA-treated wood. *Available at* www.nmhc.org/Content/ServeContent.cfm?IssueID=461&ContentItemID=3520.
[163] *Available at* www.fpl.fs.fed.us/research-areas/rwu/rwu4723/preservation_faqs/faqs.html.
[164] *See* DURABILITY BY DESIGN, *supra* note 37, at 52.
[165] *Id*. at 53.

Ultimately, to ensure the long-term integrity of wood products and building materials, the most important factors are: "Choosing the most appropriate and cost-effective wood material; Matching the selected wood material with a compatible finish; Applying the finish properly; and Educating the owner [or occupant] on the need for periodic maintenance."[165]

Masonry

Masonry refers to construction materials such as stone, concrete blocks, bricks and tile that are held together by mortar. Masonry can be an attractive material choice for anyone concerned with moisture damage and mold. However, masonry is also susceptible to the same wetting and mold growth (due to organic matter collecting on the masonry) as wood or other building materials. Typical masonry problems involve cracking and subsequent leakage; and, since masonry is porous, moisture due to capillary action, vapor diffusion, air movement, and condensation can be an issue. Therefore, the usual practices must be observed to minimize moisture intrusion into the wall assembly, foundation and other building systems. The following best practices specifically apply to masonry:

- Like all building materials, masonry should be inspected upon delivery. Cracked or otherwise damaged bricks or concrete blocks should not be used, since this can provide a passage for moisture intrusion and result in interior water leaks.

- An appropriate drainage system is necessary for moisture that penetrates the wall exterior. Weep holes should be designed at regular intervals to allow moisture to escape from behind the wall exterior. Clogged or blocked weep holes can result in moisture accumulation, cracking and mold growth, so some care should be taken to ensure that weeps remain functional. To that end, plastic mesh products are available that suspend mortar droppings above weep holes, thereby minimizing the possibility of blocking weeps with debris.[166] A similar product involves a vertical insert between bricks that serves as a continuous weep.[167]

- Various coatings can be applied to masonry to promote water resistance, preserve the finish, and keep the masonry clean and graffiti-free. However, exercise caution when using any of these coatings since they can alter the vapor permeability of the wall as designed. These products come in two varieties: clear film coatings and penetrating coatings. Although film sealants can help keep surfaces clean and bridge hairline cracks, they can inhibit evaporation of water through the masonry surface causing breakage in some conditions.[168] Penetrating coatings, on the other hand, allow the masonry to breathe and have been proven to decrease moisture absorption and increase water repellence. However, they too have drawbacks. They can react with other building materials, may emit harmful vapors, cannot be applied over existing film coatings, and may have a limited life span.[169] And, in general, penetrating coatings are not necessary for new masonry or brick veneer walls with drainage cavities.[170]

- Cracking can occur in concrete masonry walls due to stresses caused by temperature fluctuation, moisture change and settlement of the foundation. The use of steel reinforcement, as well as weakened joints in the wall at controlled locations or spacings ("control joints"), can relieve some of the stresses that cause cracking.[171] While most building codes do not require

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[166] THE REHAB GUIDE: EXTERIOR WALLS, *supra* note 74, at 25. Companies include Mortar Net™ and Heckman Building Products.
[167] Available through Mortar Net™.
[168] THE REHAB GUIDE: EXTERIOR WALLS, *supra* note 74, at 23.
[169] *Id.*
[170] *Id.* But *see also*, NAHB RESEARCH CENTER, Prepared for U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, BUILDING CONCRETE MASONRY HOMES: DESIGN AND CONSTRUCTION (Aug. 1998), at 10 [hereinafter BUILDING CONCRETE MASONRY HOMES] (saying "If concrete masonry is chosen as the exterior finish, a water repellent should be used to effectively control water penetration." Either a surface treatment (like the film coatings discussed above) or an integral treatment (where a water repellent is added to both the concrete mix during manufacturing and to the mortar at the jobsite) is suggested.) Therefore, the decision to use a masonry sealant or water repellent should be based on individual building characteristics, climate concerns, manufacturer recommendations, and compatibility with other building components.
[171] BUILDING CONCRETE MASONRY HOMES, *supra* note 171, at 8.
[172] *Id.* Where these practices are required by building codes, they are usually incorporated to ensure structural integrity in high wind and high seismic zones, not to prevent cracking. BUILDING CONCRETE MASONRY HOMES, *supra* note 171, at 8.

these practices for low-rise construction, they are recommended by the concrete masonry industry.[172] Note: steel is increasingly being incorporated into residential wall systems (whether as a replacement for wood-framed construction or as structural support for masonry walls) and substituted for other building components. However, the use of an inorganic building material like steel does not render moisture-minimizing design unnecessary. Although steel does not provide a food source for mold, moisture will cause steel to rust and expand. This can compromise the structural integrity of the steel and cause damage and cracking to adjacent building materials (thereby providing a pathway for bulk moisture intrusion).

Plumbing and Pipe Materials

Plumbing leaks are continually cited as a major cause of mold infestations. Unfortunately, designing to prevent plumbing leaks is difficult since many leaks are unexpected and unavoidable. However, there are some things that designers and builders can do to help deter, or at least contain, plumbing problems. First, quality piping material, fittings and fixtures should be used to promote durability and to prevent cracking and breakage. Second, to the extent possible, avoid installing piping in inaccessible locations (like in concrete slabs) where leak detection is impaired. Instead, the building design should include numerous access panels that allow for easy repair, inspection and upkeep of plumbing lines and fixtures. Water shut-off valves should be located in easy-to-reach locations. Finally, piping should be properly insulated and installed within the building's conditioned space to minimize the risk of rupture due to freezing. Insulation can prevent problematic condensation on cold piping that can foster mold growth and can also reduce heat loss on hot pipes.

NEW PRODUCTS

Mold- and Moisture-Resistant Products

Incorporating materials that do not support mold growth into a moisture-conscious building design can be a powerful tool against mold- and moisture-related damage. Construction material manufacturers have responded to the rising tide of mold litigation by introducing new moisture- and mold-resistant products.[173]

- *Interior Wallboard*. Georgia-Pacific recently began marketing lines of paperless, mold-resistant interior wallboard, as a substitute for traditional gypsum wallboard. DensArmor™ Plus provides "a glass mat surface facing the wall cavity that resists possible mold growth" with a moisture-resistant core.[174] A similar product, DensShield® Tile Backer, was designed for use in wet areas such as bathrooms and has an additional acrylic coating that serves as a vapor barrier to prevent moisture penetration into the product and wall. Georgia-Pacific claims that these products provide a long-term solution to moisture and mold damage compared to traditional gypsum treated with a mold-resistant surface coating which could diminish over time. These products make no guarantees, however, and do not warrant against mold growth.

[173] Please note the disclaimer appearing in this document's "Foreward," page 1.
[174] *See* Georgia-Pacific, *Building Products-FAQ*, www.gp.com/build/faq.aspx?k=daplus (last visited June 14, 2005).
[175] The brewing controversy over the potential hazards and public health concerns of antimicrobial overuse should not be ignored. Many in the scientific and medical communities believe that the preemptive use of antimicrobial products in problem-free households contributes to the development of resistant microbial strains. In fact, the introduction of antimicrobial agents into healthy households has increased from a few dozen products in the mid-1990s to more than 700 in 2001. *See* Stuart B. Levy, *Antibacterial Household Products: Cause for Concern*, 7 EMERGING INFECTIOUS DISEASES 3 Supplement, 512 (2001). "If we go overboard and try to establish a sterile environment, we will find ourselves cohabitating with bacteria that are highly resistant to antibacterials and, possibly, to antibiotics." Stuart B. Levy, *The Challenge of Antibiotic Resistant*, SCIENTIFIC AMERICAN (March 1998), at 34. Further, "[i]ndustrial application of chemicals…and antimicrobial agents in caulking, fabrics, construction/building materials, paint, etc. may contaminate air, soil, and water, contributing to the development of [antimicrobial resistance] in organisms present in the environment." THE INTERDEPARTMENTAL ANTIMICROBIAL RESISTANCE POLICY AND SCIENCE COMMITTEES, HEALTH CANADA, ANTIMICROBIAL RESISTANCE: DEVELOPING A COMMON UNDERSTANDING (Updated Dec. 2002), at 9, *available at* www.hc-sc.gc.ca/vetdrugs-medsvet/amr_issue_id_paper_e.pdf.

- *Exterior Sheathing*. BPB GlasRoc® Brand Sheathing is a line of paperless, gypsum-based sheathing for exterior uses. It advertises superior water, mold and mildew resistance qualities and offers long-term protection from weather exposure.

- *Tile*. Glass tile has been gaining popularity over ceramic tile for aesthetic reasons, but now glass tile is increasingly used to resist mold and mildew growth. Unlike ceramic tile, glass tile is non-porous, thereby avoiding the moisture absorption and penetration problems that lead to mold growth. Additionally, epoxy grouts are commonly used in the installation of glass tile. Since these grouts are non-porous, non-absorbent and can be mixed with antimicrobial products, they provide increased protection against mold growth when compared to traditional cement grout.

- *Antimicrobial Treatments*. A wide range of antimicrobial treatments intended to eliminate or inhibit mold growth has been developed for use in building construction. These products were previously used only for remediation and after-the-fact infestation control situations, but they are now being used for proactive mold control. Many building materials are now available with optional antimicrobial treatments incorporated or applied directly by the manufacturer. Some basic treatments involve mold-resistant coatings or additives for construction materials, while the newest technologies entail on-site application by professional contractors. These antimicrobials require a graduated process of surface treatments. For instance, American MoldGuard applies a silicon-based, EPA-registered anti-mold product to new construction in three stages:

  (1) first, all "raw" interior structural surfaces, such as the drywall, floors, wall framing and concrete blocks, are treated;
  (2) then, all surfaces are treated a second time following the drywall installation; and
  (3) finally, all interior surfaces, including carpets, walls, sinks, tile, cabinets and closets, are treated after they are finished.

  Other comparable treatment systems use alkaline and silver-based products, and some offer treatment warranties that reimburse the cost of remediation and restoration in the event of a mold infestation.

  Caution is recommended against the over-reliance on, or even the outright use of, antimicrobial treatments. The long-term effects[175] or potential toxic interactions of these treatments with other building, finishing or household cleaning products are largely unknown.[176] Ultimately, there is no substitute for proper building design, construction best practices, and careful maintenance.

- *Plastic Lumber*. Wood products are naturally susceptible to moisture damage and mold growth. Plastic lumber, made from recycled plastic and fill, may be used instead of wood for certain purposes. Today, plastic lumber is mainly used for decking, landscaping, outdoor equipment and roofing. It has limited structural applications; however, it is increasingly popular and may soon gain acceptance for indoor and construction applications. Plastic lumber is typically marketed as a replacement for pressure-treated lumber, with its major advantages being that it is similar looking to wood, but denser, chemical-free, waterproof and extremely low-maintenance. It requires no sanding, painting or finishing of any kind and is sold with warranties ranging from 50 years to lifetime.[177]

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[176] Nigel F. Maynard, *Products That Help Fight Mold*, BUILDER Magazine (Sept. 2003), *at* www2.residentialarchitect.com/guide/resources/product-news.asp?ID=10992&catCode=14.

[177] Information about plastic lumber, as well as manufacturers and distributors, can be accessed through the U.S. EPA's supplier database *at* www2.ergweb.com/cpg/user/cpg_search.cfm.

[178] Stephani L. Miller, *On Board: Gypsum Manufacturers Step Up Efforts To Provide Mold- and Abuse-Resistant Drywall Solutions*, PROSALES (April 2004), *at* www.findarticles.com/p/articles/ mi_m0NTC/is_4_16/ai_115498327.

- *Ceiling Panels.* EuroStone™, produced by Chicago Metallic®, is a line of sustainable, mold-resistant ceiling panels. They are made from 100 percent volcanic rock and inorganic binder, and are allegedly impervious to all humidity and water damage and do not support mold growth. Moreover, their natural alkalinity inhibits and remediates mold growth. Finally, they contain no chemical coatings, emit zero volatile organic compounds (VOCs), are fireproof, and have a life expectancy of 40 years (compared to an estimated 4-10 years for mineral fiber ceiling panels).

- *HVAC Mold Control.* Steril-Aire's UVC Emitters™ use ultraviolet (UV) light to kill mold and bacteria within the HVAC system. A device is installed in the air conditioning unit that floods the cooling coil, drain pans, and the air with UV light, thereby destroying mold spores before they can circulate throughout the HVAC system or grow within the unit itself.

When considering emergent products and materials that claim to be "mold-resistant," it is important to bear in mind a number of truths. First, "mold-resistant" is not "mold-proof." There is no way to completely prevent mold growth, and most of these products do not carry warranties against eventual mold growth. Second, mold-resistant product alternatives are generally more costly than their traditional counterparts, and their use will likely increase construction costs. For instance, mold-resistant gypsum board can cost 20 to 60 percent more than conventional wallboard, though the installation costs remain the same.[178] Of course, the additional cost of these materials may be offset by avoided downstream expenses of repair and remediation. Third, these products have not been subjected to long-term efficacy tests in the multifamily housing context. Finally, the use of these products does not guarantee that moisture problems will be avoided. For example, moisture generated by a leak could be trapped behind a moisture-resistant product, thereby creating a situation where mold growth is not readily detectable.

NEW TECHNOLOGIES

Computer Moisture Modeling Design and Analysis Tools

Technological advances afford designers, engineers and builders ever-increasing opportunities to predict and prevent moisture and mold intrusion accurately and cost-effectively. Moisture modeling and design techniques are proving to be an indispensable way to avoid short- and long-term moisture-related damage, as well as unnecessary heat loss.[179] These models can be used to develop and test general design guidelines or requirements, assess the moisture vulnerabilities of specific designs and determine ideal material properties.[180] Although moisture modeling is not new to the industry, each generation of analysis tools is more precise, individualized and user-friendly.

The earliest moisture modeling approaches focused on vapor pressure-driven diffusion through building materials.[181] While they were easy to perform, these conventional practices could illustrate only one-dimensional, steady-state performance, and they could not predict moisture transportation by capillary action, convection flow and unintended water penetration.[182]

More recent approaches, known as Heat, Air, and Moisture (HAM) Models, address hygrothermal activity and have been incorporated into readily accessible computer software.[183] This computerized modeling allows for highly individualized results. Instead of assuming steady-state environmental

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179 A.N. Karagiozis, Advanced Hygrothermal Models and Design Models, eSim 2001-The Canadian conference on building energy simulation, June 13th-14th, Ottawa, Canada, (2001), www.esim.ca/2001/documents/proceedings/Session3-4.pdf.
180 BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 5.
181 *Id*. at 92.
182 *Id*.
183 *Id.*
184 Available at www.ornl.gov/sci/btc/apps/moisture/. (A professional version is available with advanced features and an expanded materials database. Commercial licensing fees for WUFI-pro start at $2,000.)

conditions or extreme climatic conditions, users may customize the analysis to their specific location and building circumstances.

One example is WUFI® ORNL/IBP for North America (WUFI), which generates a computer-based model for hygrothermal analysis of building enclosures over time. Originally available only in Europe, its success led to the development of a North American version that is now available. It can be downloaded at no charge from the Web.[184]

To create a moisture model using WUFI, the user must input three fields of data: the building's physical characteristics (i.e., building materials and the order in which they are installed); the time period of calculation (usually one year); and the interior and exterior climatic conditions.

For user convenience, WUFI provides menus and databases to guide the input of information, including a materials database with a wide range of materials commonly used in North America, and meteorological data spanning 30 years for over 50 locations in the U.S. and Canada. Additionally, this model incorporates the effects of night sky radiation and cloud cover, which accounts for surface wetting overnight, and wind-driven rain (that alone can account for more than 80 percent of the total moisture load of building enclosures).[185] The result is a "real time" display of the computed thermal and moisture profiles as conditions change throughout the simulation period. This output shows likely sites of moisture buildup, which can be used to guide the installation of vapor barriers and insulation.

Additional Models:

- MOIST 3
  Predicts the one-dimensional transfer of heat and moisture, but does not account for transfer by air movement. Performs much like WUFI, in that the user builds a model based on the input of specific building materials, their relative structural placement, and climatic conditions. MOIST 3 is available at no cost at www.bfrl.nist.gov/863/moist.html.

- MOISTURE-EXPERT
  Elaborates on the capabilities of WUFI and MOIST 3 by allowing for the two-dimensional analysis of heat, air, and moisture transport, and making durability predictions.[186] However, the advanced MOISTURE-EXPERT model is not available as a publicly accessible software program.

Infrared Thermography

Investigating moisture intrusion problems and locating the source of mold infestation has traditionally involved a combination of inexact or invasive methods, including visual inspection, use of contact devices like moisture meters and sampling of materials (e.g., removing sections of wall, flooring, etc.). Infrared thermography is a cost-efficient, accurate, and non-destructive alternative capable of detecting problematic moisture accumulation within a building.

This technology uses an infrared camera that can produce a visual image of the electromagnetic radiation (i.e., heat or temperature) given off by objects. Because water possesses unique thermal qualities when compared to other construction materials, infrared thermography can identify potential

[185] A.N. Karagiozis, H.M. Kunzel, and A. Holm, WUFI ORNL/IBP Hygrothermal Model (March 2002), *at* www.osti.gov/bridge/product.biblio.jsp?osti_id=788530.
[186] *See* Karagiozis, *supra* note 178; *see also* BUILDING MOISTURE AND DURABILITY, *supra* note 39, at 97.
[187] The use of a Mold Dog™ may provide another non-invasive method of identifying moisture and mold problems within an existing structure. "Scent discrimination enables the mold dog to differentiate between normal product materials found in the home and alert only [when mold is discovered]." *See* www.stopmold. com/training.php. Instead of taking random samples of building materials looking for mold growth, samples are only taken from the sites marked by the mold dog. Mold dogs are purportedly reliable, time-efficient, and comparatively inexpensive (about $500 per visit), although their use is limited by building accessibility.

moisture sources hidden within wall, roof and foundation systems. This process does not require any contact with, or removal of, building materials.[187]

Infrared technology has numerous applications, including:[188]

- Inspecting roofs and building exteriors, especially flat roofs and EIFS, which rarely provide visual indicators of leaks or water retention.
- Locating moisture buildup, condensation problems, infiltration and leakage in wall and floor assemblies.
- Identifying moisture buildup in non-accessible foundation space.
- Determining the adequacy and the proper placement of insulation.
- Surveying new construction for defects and moisture problems before occupancy and before warranty expirations.

CONCLUSION

Moisture and mold continue to pose challenges for the design, construction and renovation of residential buildings. While there is no way to completely guard against mold growth, moisture-conscious design and construction is a proven mold-prevention tool. The use of emerging moisture detection and design tools and careful material selection provide additional protections against problematic moisture intrusion and mold growth. Ultimately, the acceptance and utilization of today's moisture management practices as well as future innovations are integral to providing durable, secure and comfortable homes.

[188] Zalma, Infrared Detection of Water Damage (Oct. 2004), *at* www.irmi.com/Expert/Articles/ 2004/Zalma10.aspx.

APPENDIX I: DISCUSSION CHECKLIST

1. **Pre-Construction Considerations**
   - ☐ Have moisture-management goals been discussed with design and construction team?
   - ☐ Do construction personnel know how to identify and address on-site mold problems?
   - ☐ Has a risk management plan been developed and documented?
   - ☐ Are peer reviews being used?
   - ☐ Will commissioning be used?
   - ☐ Will independent experts be consulted during the design and installation of key building components?
   - ☐ Do all parties carry appropriate insurance coverage?
   - ☐ Do the contract documents accurately reflect the risks and liabilities assumed by all parties?

2. **Sources of Building Moisture**
   - ☐ Have all feasible sources of moisture intrusion been addressed?

3. **Site Considerations**
   - ☐ Have you assessed the water characteristics of the site? Are there signs of high ground water? What is the direction of the water flow?
   - ☐ Is there proper site drainage and grading?
   - ☐ Is an artificial drain system needed?
   - ☐ Does the design include roof overhangs, gutters, and downspouts? Are they properly sized and designed to drain away from the building envelope?

4. **Foundation**
   - ☐ Has an appropriate foundation design been selected?
   - ☐ Does the foundation require drainage in addition to the code-required drainage system?
   - ☐ Does the landscape design minimize wetting of and damage to the building envelope?

5. **Wall Systems**
   - ☐ Does the wall system design include appropriate drainage pathways?
   - ☐ Are all wall component materials compatible?
   - ☐ Has the effect of an impermeable interior finish been considered?
   - ☐ Have vapor retarders been properly installed, in the appropriate wall location? Has a computer moisture model been used?
   - ☐ Is there an air infiltration barrier?
   - ☐ Have the walls been properly insulated?
   - ☐ Has moisture-resistant sheathing been considered?

6. **Roof Systems**
   - ☐ What kind of underlayment is being used?
   - ☐ Has flashing been properly designed and installed?
   - ☐ Has roof/attic ventilation been properly designed and incorporated into the overall building design?

7. **Caulk and Sealant**
   - ☐ Have building components been properly caulked and sealed?

8. **Windows, Doors, and Skylights**
   - ☐ Have all openings in the building envelope been properly flashed and sealed?
   - ☐ Have high-performance windows been considered?

9. **Balconies and Decks**
   - ☐ Do balconies and decks slope away from the building exterior?
   - ☐ Have appropriate drainage features been included to direct water away from the building?

10. Crawlspaces

- ☐ Will a ground cover be installed?
- ☐ Will the crawlspace be vented or unvented?

11. HVAC System

- ☐ Has the ductwork been designed to limit length and bends? Can ductwork be installed within the building's conditioned space?
- ☐ Are ducts properly sealed?
- ☐ Is the HVAC system properly sized?
- ☐ Have issues concerning central returns, drainage, and use of humidifiers been discussed?
- ☐ Will a dehumidification system be installed?
- ☐ Will a mechanical ventilation system be used?

12. Interior Moisture Sources

- ☐ Does the building design include ventilation fans to exhaust indoor moisture? Are the ventilation rates effective?

13. Construction Materials

- ☐ Are building materials inspected for mold upon delivery?
- ☐ Can material shipments be delivered close to their time of installation?
- ☐ Do on-site personnel know how to clean or dispose of mold-affected materials?
- ☐ Are materials being properly stored?
- ☐ Has work been properly sequenced to minimize construction wetting?
- ☐ Has appropriate drying time been allowed before closing in the building? How is drying time being accelerated?
- ☐ Are moisture meters being used?

14. Materials Selection

- ☐ Are wood products naturally moisture-resistant or preservative-treated?
- ☐ Have masonry walls been designed with appropriately spaced and unobstructed weeps?
- ☐ Is it feasible to incorporate mold and moisture-resistant products into the building design?
- ☐ Will piping be insulated, accessible, and located within the building's conditioned space?

15. New Technologies

- ☐ Has a computer moisture modeling tool been used?
- ☐ Has the use of infrared thermography been considered?

APPENDIX II: RESOURCES

General Resources:

- National Academies-Institute of Medicine, *Damp Indoor Spaces and Health* (May 2004). Report commissioned by the Centers for Disease Control and Prevention to review the relationship between mold and adverse health effects.

- PATH (Partnership for Advancing Technology in Housing): www.pathnet.org/.
  PATH is a HUD-supported, public-private partnership that promotes the development and implementation of new building technologies.

- Toolbase Services: www.toolbase.org.
  Funded through the U.S. Department of Housing and Urban Development (HUD) and industry sponsors, Toolbase provides resource information on building materials, new technologies, and general building practice.

- U.S. Dep't of Energy (DOE), Energy Star Program: www.energystar.gov.
  Sponsored by the U.S. EPA and U.S. DOE, Energy Star provides information about energy efficient products and practices, business solutions, and energy management strategies.

- U.S. Dep't of Energy, Office of Energy Efficiency and Renewable Energy (EERE): www.eere.energy.gov.
  Provides information about energy efficient building technologies and design practices, efficient building operation, energy codes, energy audits, renewable energy use, and financing options.

- U.S. Dep't of Housing and Urban Development, *Building Moisture and Durability* (Oct. 2004): www.huduser.org/publications/destech/MoistDurability.html.
  HUD report examining the current problems involving moisture in housing and future research recommendations.

- U.S. Dep't of Housing and Urban Development, *Durability by Design: A Guide for Residential Builders and Designers*, (May 2002): www.huduser.org/publications/destech/durdesign.html.
  HUD report intended to raise the awareness and understanding of building durability as a design consideration in housing.

- U.S. Dep't of Housing and Urban Development, *The Rehab Guide Volumes 1-9:* www.huduser.org/publications/destech/rehabgds.html.
  A series of nine guides from HUD providing information on building technologies, materials, components, and techniques during the building design, construction, and renovation processes.

- U.S. Environmental Protection Agency, Indoor Air Quality – Mold: www.epa.gov/mold/.
  Provides general information about mold growth, adverse effects and remediation.

Lumber and Wood Products:

- American Engineered Wood Association: www.apawood.org/.
- American Wood-Preservers' Association: www.awpa.com/.
- Canadian Wood Council, Publications: www.cwc.ca/publications/PDFs/.
- Southern Pine Council: www.southernpine.com/.
- U.S. Department of Agriculture Forest Service, Forest Products Laboratory: www.fpl.fs.fed.us/.
- U.S. Environmental Protection Agency, Pressure-treated wood: www.epa.gov/oppad001/reregistration/cca/cca_consumer_safety.htm.

- Western Wood Products Association, Mold and Wood Products: www.wwpa.org/index_lumberandmold.htm.

Masonry: Brick Industry Association: www.bia.org/.

- Technical Notes: www.bia.org/html/frmset_thnt.htm
    - 6A: *Colorless Coatings for Brick Masonry* (reissued June 2002)
    - 7: *Water Resistance of Brick Masonry, Design and Detailing Part 1* (April 2001)
    - 7A: Revised *Water Resistance of Brick Masonry, Parts 2 of 3* (Sept. 2004)
    - 7B: *Water Resistance of Brick Masonry – Construction and Workmanship, Part III of III* (Revised Aug. 2002)
    - 7C: *Moisture Control in Brick and Tile Walls – Condensation* (Reissued March 2004)
    - 7D: *Moisture Resistance of Brick Masonry Walls – Condensation Analysis Revised* (Reissued March 2004)
    - 7F: *Moisture Resistance of Brick Masonry – Maintenance* (Reissued October 1998)
    - 27: *Brick Masonry Rain Screen Walls* (August 1994)
    - 28B: Revised *Brick Veneer/Steel Stud Walls* (November 1999)

Computer Moisture Modeling:

- U.S. DOE, Building Technologies Program: www.eere.energy.gov/buildings/tools_directory/subjects.cfm.

Mold Cleanup and Remediation:

- EPA's *A Brief Guide to Mold, Moisture, and Your Home*: www.epa.gov/mold/moldguide.html.
- EPA's *Mold Remediation in Schools and Commercial Buildings* (March 2001): www.epa.gov/mold/mold_remediation.html.
- National Institute of Environmental Health Sciences, *Guidelines for the Protection and Training of Workers Engaged in Maintenance and Remediation Work Associated With Mold* (May 20, 2005): www.wetp.org/wetp/newsbriefs/may05/Final_NIEHS_Mold_Guide_05-20-05.pdf.
- Occupational Safety and Health Administration, *A Brief Guide to Mold in the Workplace* (Oct. 2003), www.osha.gov/dts/shib/shib101003.html.

Commissioning and Peer Review:

- American Society of Civil Engineers: www.asce.org.
- Building Commissioning Association: www.bcxa.org.
- Oregon Department of Energy: www.energy.state.or.us/bus/comm/bldgcx.htm.

Moisture-Resistant Products and Materials:

- Georgia-Pacific Building Products: www.gp.com/build.
- BPB: www.bpb.com.
- American MoldGuard: www.americanmoldguard.com/2004/default.htm.
- AgIon Antimicrobial: www.agion-tech.com.
- Certainteed: www.certainteed.com/certainteed/index.htm.

APPENDIX III: CODE REFERENCE CHART

Following is an alphabetical list of some potential mold and moisture areas, followed by relevant provisions of the model codes published by the International Code Council (ICC).

IBC – International Building Code
IMC – International Mechanical Code
IECC – International Energy Conservation Code
IPC – International Plumbing Code

Air Leakage
Water vapor is carried through the building envelope by air flowing through the building components of a leaky building. The water vapor will condense and become moisture when it is trapped behind a moisture barrier and the temperature at the barrier is below the dew point. Water vapor travels from a high vapor pressure to a low vapor pressure and, in the building envelope, can travel from the inside to the outside or outside to inside, depending on conditions.

Relevant Code Provisions:
IECC § 502.1.1 (Moisture control)
IECC § 502.1.4.1 (Window and door assemblies)

Attic Ventilation
Problems due to frost or moisture accumulation may occur in attics. Particularly in Northern states, improperly installed or the wrong type of attic vents have been associated with moisture problems resulting from wind and snow or rain.

Relevant Code Provisions:
IBC § 1203.2 (Enclosed attics and rafter spaces)
IBC § 1203.2.1 (Openings into attic)

Building Envelope
The building envelope should be appropriately sealed to prevent moisture intrusion.

Relevant Code Provisions:
IBC § 1402.1 (Exterior wall envelope)
IBC § 1403.2 (Weather protection)
IBC § 1807.1 (Dampproofing and waterproofing)
IBC § 1807.2.2. (Walls)
IBC § 1807.2.2.1 (Subsurface preparation of walls)
IBC § 1807.3 (Required waterproofing)

Building Materials/Products
Caution must be exercised when selecting building materials and products, most of which have some degree of moisture storage capacity. It is not necessary for water droplets to appear on a building surface to lead to mold growth. Condensation will lead to higher moisture content in building materials before visible water droplets form. Complete saturation is not required as mold contamination may start to occur when a building material reaches 80 percent of moisture storage capacity.

Relevant Code Provisions:
IBC § 1701.2 (New materials)

Caulking and Sealants
Building materials should be appropriately caulked and sealed to prevent moisture intrusion.

Relevant Code Provisions:
IBC § 1405.17.1 (Panel siding)
IBC § 1405.17.2 (Horizontal lap siding)
IBC § 1405.10.2 (Weather protection for exposed joints and edges)
IBC § 1405.11.7 (Flashing)
IBC § 1405.11.4 (Installation of glass veneer at sidewalk level)
IBC § 1405.17 (Fiber cement siding)
IECC § 502.1.4.2 (Caulk and sealants)

Ceiling Attic Hatches/Light Cans
Moisture may move through these from a humid interior.

Relevant Code Provisions:
IECC § 502.1.4.2 (Attic hatches)
IECC § 502.1.3 (Recessed lighting fixtures)

Concrete Slab
Soil moisture should not wick up through the concrete slab.

Relevant Code Provisions:
IBC § 1911.1 (Thickness of concrete floor slabs)
IBC § F101.6.1.2 (Continuous concrete grade floor slabs)

Crawlspace Vents
Rarely inspected or visited. Crawl spaces may contain many construction defects, including disconnected plumbing, disconnected ducts, rotting structural members, trash, and vermin.

Relevant Code Provisions:
IBC § 1203.1 (General ventilation)
IBC § 1203.3 (Under-floor ventilation)
IBC § 1203.3.1 (Openings for under-floor ventilation)
IBC § 1203.3.2 (Exceptions)
IBC § 1209.1 (Crawl spaces)
IBC § 1807.1.2 (Dampproofing and waterproofing: under-floor spaces)
IMC § 604.11 (Vapor retarders)
IECC § 503.3.3.3 (Duct and plenum insulation)
IECC § 803.2.8 (Duct and plenum insulation and cleaning)

Downspouts/Gutters
The gutter system is an element of building construction that handles a high concentration of water, and is the key to exterior rainwater management. These may need routine maintenance, particularly in areas with many trees and foliage. They also may dislodge or become disconnected due to ice or water loading. In addition, elbow sections may become disconnected. Downspouts terminating near the foundation may lead to water saturating the soil in the area of the downspout, leading to wet basements, crawl spaces, or slabs.

Relevant Code Provisions:
IBC § 1503.4.1 (Gutters and leaders)
IPC § 1101.2 (Where required)

Drainage Channels
Trenches and channels for drainpipes should be properly constructed and designed to divert moisture to the exterior.

Relevant Code Provisions:
IBC § 1405.3 (Flashing)
IBC § 1405.3.2 (Masonry)

Drainage Systems
One of the more common sources of water entry into buildings is site rainwater entering through the base of a building. In general, elevated sites are more suitable for residential construction than low-lying sites. Water from below grade should not be allowed to enter the foundation.

Relevant Code Provisions:
IBC § 1805.3.1 (Buildings below slopes)
IBC § 1805.3.4 (Graded sites)
IBC § 3201.4 (Drainage water collected from a roof)

Exterior Cladding and Sheathing
Moisture may penetrate the cladding, the protective or insulating layer fixed to the outside of a building. This may involve rainwater (and in certain areas, snowmelt) that enters through holes, or damaged and improperly installed flashing in the exterior of the building. Lawn sprinkler systems may cause wetting of exterior cladding. Many exterior claddings, particularly brick, and lapped sidings, permit substantial quantities of water pass through them.

Relevant Code Provisions:
IBC § 1404.2 (Water resistive barrier)
IBC § 703.2 (Weather-resistant sheathing paper)

Flashing
Flashing is a critical component of the building envelope, utilized to direct water to the outside and to limit wetting of the building envelope layers. It is typically located between diverse components of the building envelope to ensure weather tightness of the interface joints.

Relevant Code Provisions:
IBC § 1405.3 (Flashing)
IRC § 703.4 (Approved corrosion resistant flashing)

Foundation
Moisture (typically from rain or snowmelt) enters the foundation of buildings, either into basements, crawl spaces, or through slab-on-grade foundation. Excessive moisture along the foundation may find its way into the basement area in the form of moist walls and elevated basement humidity. In addition, watering a garden adjacent to a basement foundation may cause moisture problems.

Relevant Code Provisions:
IBC § 1805.1 (Footings and foundations)
IBC § 1805.3.1 (Building clearance from ascending slopes)
IBC § 1805.3.4 (Foundation elevation)
IBC § 1807.4.3 (Drainage discharge)

HVAC Systems/Ventilation
Moisture associated with poor ventilation practices and improperly sized equipment.

Relevant Code Provisions:
IBC § 1203.1 (Natural ventilation)
IBC § 1203.2 (Attic spaces)
IBC § 1203.4 (Natural ventilation)
IBC § 1203.3 (Under-floor ventilation)
. IBC § 1204.1 (Interior spaces intended for human occupancy)
IMC § 402 (Natural ventilation)
IMC § 403 (Mechanical ventilation)
IMC § 403, Table 403.3 (Required outdoor ventilation air)
IMC § 504.6 (Domestic clothes dryer ducts)
IMC § 604.11 (Externally insulated)

Moisture Intrusion
Bulk water entry is the unintentional leakage of liquid water into a building. Water entry may be traced from the area of water damage and mold growth back to the source of the leak. Moisture may enter the building through precipitation or ground water sources. Faulty or non-existent flashing, poor site grading, improper or no drainage planes behind exterior claddings are all pathways for bulk moisture intrusion.

Relevant Code Provisions:
IBC § 1402.1 (Exterior wall envelope)

Piping Insulation
Water leaks from faulty piping seep into piping insulation that is slow to dry and breeds mold.

Relevant Code Provisions:
IBC § 2901 et seq. (Plumbing systems)

Plumbing
Mold and moisture occurrence may arise from plumbing problems.

Relevant Code Provisions:
IBC § 2901.1 et seq. (Plumbing systems)

Water Vapor
May come from many sources, such as showering, cooking, human respiration, etc.

Relevant Code Provisions:
IMC § 401.2 (Ventilation of occupied spaces)
IMC § 402.1 (Natural ventilation of occupied spaces)
IMC § 402.2 (Minimum openable area to the outside)
IMC § Table 403.3 (Required outdoor ventilation air)

Window Flashing
Improperly installed, or missing, flashing can be a major contributor to water penetration into the wall cavity.

Relevant Code Provisions:
IBC § 1405.11.7 (Windows and doors)
IRC § 703.4 (Top and sides of all exterior window and door openings)