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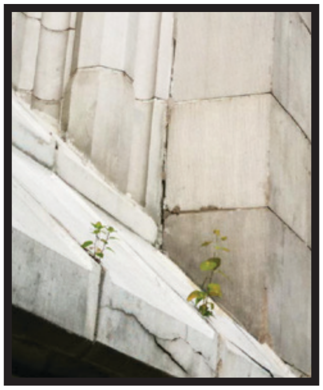

Moisture Control Guidance for Building Design, Construction and Maintenance

Indoor Air Quality (IAQ)

Moisture Control Guidance for Building Design, Construction and Maintenance
U.S. Environmental Protection Agency
December 2013

www.epa.gov/iaq/moisture

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Foreword: How to Use this Guidance

This document was developed by the U.S. Environmental Protection Agency, Indoor Environments Division. It provides practical guidance on how to control moisture in buildings.[1] It is not a textbook, code or standard.

Chapter 1 focuses on principles of moisture control: how water moves into and within a building and why the movement of water should be controlled or managed. Chapters 2, 3 and 4 provide profession-specific guidance for the design, construction and maintenance phases of a building's life. To illustrate how core concepts and principles relate to each stage of a building's life, each guidance chapter contains hyperlinks to relevant principles described in Chapter 1 and other related material throughout the text. Each guidance chapter also includes methods for verifying the appropriate implementation of the moisture control recommendations and a reference section that identifies additional related resources for readers interested in more detailed information.

Who Should Read this Guide

This guide can be used by anyone who designs, builds, operates or maintains buildings and heating, ventilating and air conditioning (HVAC) equipment. It was developed specifically for:

- Professionals who design buildings and produce drawings, specifications and contracts for construction or renovation.
- Professionals who erect buildings from the construction documents.
- Professionals who operate and maintain buildings, conducting preventive maintenance, inspecting the landscape, building interior and exterior equipment and finishes and performing maintenance and repairs.

[1]NOTE: This document does not address flood water control. For information about managing flood water, see http://www.epa.gov/naturalevents/flooding.html or http://www.epa.gov/naturalevents/hurricanes/. Accessed on November 6, 2013.

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The figures in this document came from several sources:

- Terry Brennan provided the photographs used in Figures 1-1 to 1-14.
- Christopher Patkowski created Figures 1-15, 1-16 and 2-14 based on illustrations in the *Whole Building Design Guide* (www.wbdg.org), a program of the National Institute of Building Sciences.
- Terry Brennan drew Figure 1-17 and provided the spreadsheets used to create Figures 1-18 and 1-19. He also provided the photograph for Figure 1-20.
- Christopher Patkowski created Figure 2-1. He also created Figures 2-2 to 2-4, Figures 2-6 and 2-7, and Figures 2-9 to 2-12 based on illustrations provided by Joe Lstiburek of Building Science Corporation.
- The U.S. Department of Energy provided the map in Figure 2-5.
- Christopher Patkowski drew Figure 2-8 based on an illustration in a publication of the Canadian Mortgage and Housing Corporation. He also drew Figure 2-13.
- Terry Brennan drew Figures 2-15 and 2-16.
- Lew Harriman provided Figure 2-17.
- Terry Brennan provided Figure 4-1 and drew Figures A-1 to A-3.
- Christopher Patkowski drew Figures D-1 to D-3 based on drawings by Terry Brennan.
- Figure G-1 was provided by the National Institute of Occupational Safety and Health (NIOSH).

Chapter 1: Moisture Control in Buildings

Introduction

Moisture control is fundamental to the proper functioning of any building. Controlling moisture is important to protect occupants from adverse health effects and to protect the building, its mechanical systems and its contents from physical or chemical damage. Yet, moisture problems are so common in buildings, many people consider them inevitable.

Excessive moisture accumulation plagues buildings throughout the United States, from tropical Hawaii to arctic Alaska and from the hot, humid Gulf Coast to the hot, dry Sonoran Desert. Between 1994 and 1998, the U.S. Environmental Protection Agency (EPA) Building Assessment Survey and Evaluation (BASE) study collected information about the indoor air quality of 100 randomly selected public and private office buildings in the 10 U.S. climatic regions. The BASE study found that 85 percent of the buildings had been damaged by water at some time and 45 percent had leaks at the time the data were collected.[2]

Moisture causes problems for building owners, maintenance personnel and occupants. Many common moisture problems can be traced to poor decisions in design, construction or maintenance. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) notes that, more often than not, the more serious problems are caused by decisions made by members of any of a number of different professions.[3] However, such problems can be avoided with techniques that are based on a solid understanding of how water behaves in buildings.

Moisture control consists of:

- Preventing water intrusion and condensation in areas of a building that must remain dry.
- Limiting the areas of a building that are routinely wet because of their use (e.g., bathrooms, spas, kitchens and janitorial closets) and drying them out when they do get wet.

To be successful, moisture control does not require everything be kept completely dry. Moisture control is adequate as long as vulnerable materials are kept *dry enough* to avoid problems. That means the building must be designed, constructed and operated so that vulnerable materials do not get wet. It also means that when materials do get wet, the building needs to be managed in such a way that the damp materials dry out quickly.

Health Implications of Dampness in Buildings

At the request of the U.S. Centers for Disease Control and Prevention (CDC), the Institute of Medicine (IOM) of the National Academy of Sciences convened a committee of experts to conduct a comprehensive review of the scientific literature concerning the relationship between damp or moldy indoor environments and the appearance of adverse health effects in exposed populations. Based on their review, the members of the Committee on Damp Indoor Spaces and Health concluded that the epidemiologic evidence shows an association between exposure to damp indoor environments and adverse health effects, including:

- Upper respiratory (nasal and throat) symptoms.
- Cough.
- Wheeze.
- Asthma symptoms in sensitized persons with asthma.

The committee also determined that there is limited or suggestive evidence of an association between exposure to damp indoor environments and:

- Dyspnea (shortness of breath).
- Lower respiratory illness in otherwise healthy children.
- Asthma development.

[2] http://www.epa.gov/iaq/base/. Accessed November 6, 2013.

[3] Limiting Indoor Mold and Dampness in Buildings. 2013 (PDF) at https://www.ashrae.org/about-ashrae/position-documents. Accessed November 6, 2013.

Details of the results of this review were published in a 2004 report, *Damp Indoor Spaces and Health.*[4] It is also important to note that immuno-compromised individuals, such as some categories of hospital patients, are at increased risk for fungal colonization and opportunistic infections.[5]

After the publication of the IOM report, a study by Lawrence Berkeley National Laboratory concluded that building dampness and mold raise the risk of a variety of respiratory and asthma-related health effects by 30 to 50 percent.[6] A companion study by EPA and Berkeley Lab estimated that 4.6 million cases of asthma, 21 percent of the 21.8 million cases of asthma in the U.S. at that time, could be attributed to exposure to dampness and mold in homes.[7]

Moisture Damage in Buildings

In addition to causing health problems, moisture can damage building materials and components. For example:

- Prolonged damp conditions can lead to the colonization of building materials and HVAC systems by molds, bacteria, wood-decaying molds and insect pests (e.g., termites and carpenter ants).
- Chemical reactions with building materials and components can cause, for example, structural fasteners, wiring, metal roofing and conditioning coils to corrode and flooring or roofing adhesives to fail.
- Water-soluble building materials (e.g., gypsum board) can return to solution.
- Wooden materials can warp, swell or rot.
- Brick or concrete can be damaged during freeze-thaw cycles and by sub-surface salt deposition.
- Paints and varnishes can be damaged.
- The insulating value (R-value) of thermal insulation can be reduced.

The following photos show some of the damage that can result from moisture problems in buildings.

Figure 1-1 Mold growing on the surface of painted gypsum board and trim. Long-term high humidity is the source of the moisture that allowed the mold growth. All of the walls experienced similar near-condensation conditions. Consequently, the mold growth is widespread rather than concentrated in a single damp area.

[4] Institute of Medicine (2004) *Damp Indoor Spaces and Health*. http://www.iom.edu/Reports/2004/Damp-Indoor-Spaces-and-Health.aspx. Accessed November 6, 2013.

[5] Institute of Medicine (2004) *Damp Indoor Spaces and Health.* http://www.iom.edu/Reports/2004/Damp-Indoor-Spaces-and-Health.aspx. Accessed November 6, 2013.

[6] W. J. Fisk, Q. Lei-Gomez, M. J. Mendell (2007) Meta-analyses of the associations of respiratory health effects with dampness and mold in homes. *Indoor Air* 17(4), 284-295. doi:10.1111 /j.1600-0668.2007.00475.x

[7] D. Mudarri, W. J. Fisk (2007) Public health and economic impact of dampness and mold. *Indoor Air* 17 (3), 226–235. doi:10.1111 /j.1600-0668.2007.00474.x

Figure 1-2 Mold growth on painted concrete masonry. The cool masonry wall separates a classroom from an ice rink. Humid air in the classroom provides moisture that condenses on the painted surface of the masonry. That moisture allows mold to grow on the paint film.

Figure 1-3 Mold growth on vinyl floor tile. Long-term high humidity provided moisture that was absorbed into the cool vinyl tile and supported mold growth. Also note that the high humidity caused the adhesive attaching the tile to the floor to fail, allowing the tile to become loose.

Figure 1-4 Corrosion of galvanized fluted steel floor deck. The floor is at grade level. The source of the water is rainwater seepage.

Figure 1-5 Corrosion of structural steel in a ceiling cavity in a cold climate. The steel extends into the exterior wall assembly. During cold weather, the steel near the wall is chilled by cold outdoor air. The building is humidified, and condensation from high indoor humidity provides the moisture that rusts the cold steel.

Figure 1-6 Blistering paint on split face concrete block. Wind-driven rain is the source of moisture contributing to the damage. Water wicks into the concrete masonry unit (CMU) through pin holes in the paint. The sun drives water vapor through the CMU. The assembly cannot dry to the interior because low-vapor-permeability foam board, taped at the joints, insulates the interior surface of the wall. The wall remains saturated throughout the spring, summer and fall. The same paint on areas of the wall sheltered from sun and rain shows no damage.

Figure 1-7 Condensation behind vinyl wallpaper in a warm, humid climate. Condensation and mold growth occurs behind the vinyl wallpaper on both exterior and interior walls. Air leaks in the return plenum of the air handler depressurizes the interior and exterior wall cavities. Warm, humid exterior air is drawn from outside through air leaks in a heavy masonry wall.

Figure 1-8 Rainwater leaks in a rooftop parapet wall result in damaged plaster and peeling paint. Rainwater is drawn into this brick assembly by capillary action, and the moisture is aided in its downward migration by gravity. The peeling paint contains lead and results in an environmental hazard as well as physical damage to the plaster.

Figure 1-9 Interior plaster damaged by rain seeping around a window in a brick building. The inside of the exterior wall is insulated with closed-cell spray foam. Consequently, the wall cannot dry to the interior, so it retains excessive amounts of moisture. At the point where the plaster on the window return meets the brick wall, rainwater wicks into the plaster causing the damage seen in this photo.

Figure 1-10 Further rain damage to interior plaster. At another location on an office window in the building shown in Figure 1-8, rain seepage turns gypsum board joint compound to a fluid, causing the gypsum to bubble and lift.

Figure 1-11 Gypsum board on the lower edge of a basement wall dissolved by seasonal flood waters. The water table is just below the basement floor during dry weather and rises several inches above the floor during heavy spring rains.

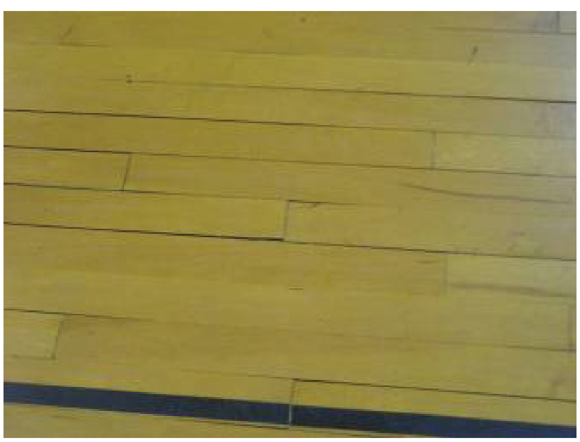


Figure 1-12 Hardwood gymnasium floor warped by moisture in the cavity below it. Water rises through the concrete sub-floor. The source of the moisture is rainwater that has not been drained away from the foundation of the building.

Figure 1-13 Tile adhesive that failed to cure because of water in the concrete and high pH. The tile can be removed by hand. The floor is a concrete slab-on-grade. The water visible in the photo evaporates into the room after several minutes. Its source may be liquid water wicking up from the sub-slab fill or water vapor migrating through the slab.

Figure 1-14 Damage to bricks caused by the migration of soluble salt through them. Salts in the brick or mortar dissolve in rainwater that wicks through the brick. The water evaporates in the building's interior, and the salt left behind crystalizes and splits the surface layer off the brick, exposing its interior. This process is called sub-fluorescence.

Moisture Problems are Expensive

Health problems and building damage due to moisture can be extremely expensive. Berkeley Lab estimates that the annual asthma-related medical costs attributable to exposures to dampness and mold total approximately $3.5 billion in the U.S.[8] But many more adverse health outcomes due to damp buildings have been reported, each with associated costs of its own. And damage to the building itself is also costly. Building owners and tenants bear a significant proportion of these costs, including:

- Absenteeism due to illnesses such as asthma.
- Reduced productivity due to moisture-related health and comfort problems.
- Increased insurance risk, repair and replacement costs associated with corroded structural fasteners, wiring and damaged moisture-sensitive materials.
- Repair and replacement costs associated with damaged furniture, products and supplies.
- Loss of use of building spaces after damage and during repairs.
- Increased insurance and litigation costs related to moisture damage claims.

How Water Causes Problems in Buildings

Mention water damage and the first image that comes to mind for most people is liquid water in the form of rain, plumbing leaks or floods. Many water leaks are easy to detect. When it rains, water may drip around skylights, or a crawl space may fill with water. If a toilet supply line breaks, the floor will likely be flooded.

On the other hand, many water-related problems are less obvious and can be difficult to detect or diagnose. For example, the adhesive that secures flooring to a concrete slab may not cure properly if the slab is damp, resulting in loose flooring and microbial growth in the adhesive. Or, humid indoor air may condense on the cool backside of vinyl wallpaper that covers an exterior wall, providing ideal conditions for mold to grow. These problems are less obvious than a leak because water is not running across the floor, and the real damage is being done out of sight under flooring or behind wallpaper.

Moisture problems are preventable. They do not happen until water moves from a source into some part of a building that should be dry. The actual

[8] D. Mudarri, W. J. Fisk (2007) Public health and economic impact of dampness and mold. *Indoor Air* 17 (3), 226–235. doi:10.1111 /j.1600-0668.2007.00474.x

damage begins after enough moisture accumulates to exceed the safe moisture content limit of moisture-sensitive materials.

To diagnose or prevent a moisture problem, keep in mind **four key elements** of moisture behavior in buildings:

1. **Typical symptoms of moisture problems.** They include corrosion of metals, the growth of surface mold or wood-decaying molds, insect infestations, spalling exterior brick or concrete, peeling paint, failing floor adhesives, stained finishes and health symptoms.
2. **Sources of moisture.** Among them are rainwater, surface water, ground water, plumbing water, indoor and outdoor sources of humidity and sewer water.
3. **Transport mechanisms.** They include liquid water leaking through holes, wicking through porous materials, or running along the top or bottom of building assemblies and water vapor carried by warm, humid air leaking through assemblies and by diffusion through vapor-permeable materials.
4. **Common failures of moisture control elements and systems.** Moisture controls include site drainage, gutter systems, above- and below-grade drainage planes, effective flashing, condensate drainage and humidity controls. Failures can occur during any phase of a building's life and may include poor site selection or design, poor material or equipment selection, improper installation or sequence of building materials and equipment, insufficient coordination between trades during construction and insufficient or improper maintenance of materials or equipment.

Moisture Control Principles for Design

To control moisture for long building life and good indoor air quality, follow these three principles:

1. Control liquid water.
2. Prevent excessive indoor humidity and water vapor migration by air flow and diffusion in order to limit condensation and moisture absorption into cool materials and surfaces.
3. Select moisture-resistant materials for unavoidably wet locations.

Armed with an elementary understanding of these principles, readers will be prepared to control moisture and prevent the vast majority of moisture problems that are common in buildings.

Moisture Control Principle #1: Control Liquid Water

The first principle of moisture control is to keep liquid water out of the building. Sheltering occupants from water is a primary purpose of building assemblies including roofs, walls and foundations. Among the sources of water from outside a building are:

- Rain and melting snow, ice or frost.
- Groundwater and surface runoff.
- Water brought into the building by plumbing.
- Wet materials enclosed in building assemblies during construction.

Problem: Building Assemblies and Materials Get Wet

Moisture problems are common. By their very nature, buildings and the construction process are almost certain to encounter moisture problems that could lead to poor indoor air quality and other negative impacts. The most common liquid water problems include:

- **Rain and snow get inside.** Rainwater, surface water and ground water, including snowmelt, may enter a building through leaks in roofs, walls, windows, doors or foundations. In most climates, rain is the largest source of water in buildings. Rainwater intrusion can cause great damage to the building itself and to its contents.
- **Plumbing leaks.** We intentionally bring water into buildings for cleaning, bathing and cooking, and we intentionally drain wastewater out of buildings. Any water brought in and drained out is contained in pipes, vessels and fixtures that can tolerate being wet all or most of the time. However, leaks in plumbing supply lines, drain lines, sinks, showers and tubs may cause problems. Although model plumbing codes require both the supply side and drain/vent side of plumbing systems to be tested for leaks, these tests are sometimes performed poorly or not at all. Large plumbing leaks are immediately obvious, but small leaks inside walls and ceiling cavities may continue unnoticed for some time.
- **Water during construction causes problems.** Some materials are installed wet because they were exposed to rain or plumbing leaks during construction. Wet concrete masonry units (CMUs), poured or pre-cast concrete, lumber and the exposed earth of a crawl space floor have all been sources of problems in new buildings.

- **Some materials are installed wet because water is part of the process.** Poured concrete, floor levelers, wet-spray insulation and water-based finishes all contain water. Porous materials that appear dry may contain enough water to cause problems if they come in contact with moisture-sensitive materials or if they humidify a cavity after they are enclosed. Flooring, wall coverings and coatings will fail if they are applied before surfaces are dry enough. Water from these materials may indirectly cause problems by raising the humidity indoors during a building's first year of use, leading to condensation problems.

Solution: Control Liquid Water Movement

Effectively controlling liquid water intrusion requires all of the following:

- **Drain rain, irrigation water and snowmelt away from the building.** The first step in water control is to locate the building in dry or well-drained soil and use or change the landscape to divert water away from the structure. In other words, drain the site. This includes sloping the grade away from the building to divert surface water and keep subsurface water away from the foundation below grade. After the site is prepared to effectively drain water away from the building, the building needs a storm water runoff system to divert rain from the roof into the site drainage system.
- **Keep rain and irrigation water from leaking into the walls and roof.** Leaking rainwater can cause great damage to a building and to the materials inside. In successful systems, rainwater that falls on the building is controlled by:
  - Exterior cladding, roofing and storm-water management systems to intercept most of the rain and drain it away from the building.
  - Capillary breaks, which keep rainwater from wicking through porous building materials or through cracks between materials. A capillary break is either an air gap between adjacent layers or a material such as rubber sheeting that does not absorb or pass liquid water. A few rain control systems consist of a single moisture-impermeable material, sealed at the seams, that both intercepts rainwater and provides a capillary break. Membrane roofing and some glass panel claddings for walls work in this way.
- **Keep water from wicking into the building** by using capillary breaks in the building enclosure. Moisture migration by capillary action can be interrupted using an air space or water-impermeable material.
- **Prevent plumbing leaks** by locating plumbing lines and components where they are easy to inspect and repair, are unlikely to freeze, and are not in contact with porous cavity insulation.
- **Avoid enclosing wet materials in new construction** by protecting moisture-sensitive and porous materials during transport and on-site storage and by drying wet materials before they are enclosed inside building assemblies or covered by finish materials.

Drained Roofing and Wall Cladding

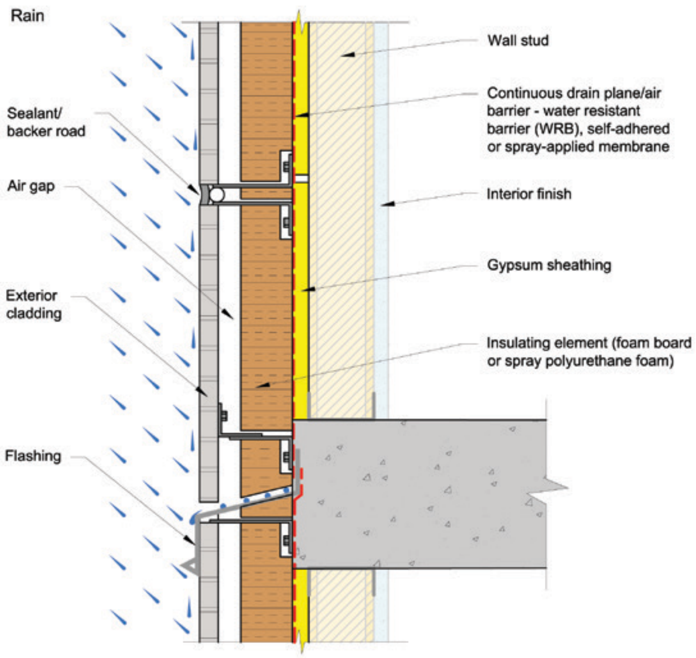
Roofing and cladding systems are frequently backed by an air gap and a moisture-resistant material that forms the drainage plane. Most of the water that seeps, wicks or is blown past the cladding will drain out of the assembly. The drainage plane prevents any water that might bridge the air gap from wetting the inner portions of the assembly. Some examples are:

- **Roofs.** Asphalt or wooden shingles, metal panels and elastomeric membranes are common outer layers for roofs.
- **Walls.** Wooden and vinyl siding, stucco, concrete panels, brick, concrete masonry units and stone veneers are common outer layers for walls.
- **Drainage planes.** Building felt, tar paper and water-resistant barriers are commonly used as drainage planes beneath roofing and wall cladding systems. Single- and multi-ply roofing combine the drainage plane with the outer layers of the roof—there is no inner drainage plane material.

Figure 1-15 illustrates the concept of a drained wall assembly. Although the cladding intercepts most of the rainwater, some liquid will seep inward. The air gap acts as a capillary break, and seepage cannot jump that gap. Instead, seepage runs down the back of the cladding until it is drained out by the flashing. Some of the seepage may run to the drainage plane along materials that bridge the gap, for example, mortar droppings or cladding fasteners. The impermeable surface of the drainage plane keeps water out of the backup sheathing, CMU or concrete, protecting the inner wall. Water flows down the drainage plane and over the flashing, which diverts it back outside.

Some roofing or siding materials absorb water (e.g., wooden shingles or siding, fiber cement siding, traditional stucco and masonry veneers), while others do not (e.g., roofing membranes, vinyl siding and metal or glass panels). Historically, the porous

Figure 1-15 Drained Wall Assembly



materials were backed by an air gap. Examples include wooden shingles on skip sheathing, masonry veneers and heavy masonry walls with 1- to 2-inch cavities separating brick walls and beveled siding installed shingle style. The air gap between the siding and the interior of the wall enables wet porous materials to dry out to either the outdoor air or into the air gap.

In either case, the drainage plane must be watertight at all joints and penetrations. Table 1-1 lists penetrations commonly found in roofs and walls and presents ways to maintain the watertight integrity of the drainage plane. This list is not comprehensive. Any and all penetrations through roofing and exterior cladding must be detailed to prevent rainwater intrusion.

Windows, curtain walls and storefronts are all used in wall assemblies and are among the more complex penetrations to detail. Typically, standard details for window head, jamb and sill flashing are provided by the manufacturers of these components. Figure 1-16 illustrates a method of providing pan sill and jamb flashings for walls constructed with an exterior insulation and finish system (EIFS). Note that the sill flashing protects the wall assembly from seepage at the corners of windows and at the joints between windows. Dams on the sides and back of the sill pan flashing stop any seepage from running into the building or into the wall beneath the window.

Foundations

The building foundation must be detailed to protect the building from rainwater. The above-grade portions of a foundation are often masonry or concrete. Much of the rainwater that wets the above-grade wall simply drains off the surface to the soil below. Masonry walls are often protected below grade using Portland cement-based capillary breaks (e.g., traditional parging or proprietary coatings). Concrete walls may be treated with additives that provide an integral capillary break or may be so massive that absorbed water is more likely to be safely stored in the wall—drying out between storms—than to wick through to the interior.

Landscape surfaces immediately surrounding the foundation perform the same function for the walls below grade as the roofing and cladding in the walls above grade: they intercept rain and drain it away from the building.

The damp-proof or waterproof coatings on below-grade walls serve the same purpose as the drainage plane in the above-grade walls. These coatings provide a capillary break that excludes the rainwater that saturates the surrounding fill. An additional capillary break is formed by free-draining gravel or geotechnical drainage mats placed against the below-grade walls. These materials provide an air gap that allows water to drain freely down the foundation wall.

At the bottom of the below-grade wall, a footing drain system carries rainwater and ground water away from the footing and the floor slab. Paint formulated for use on concrete can be applied to the topside of the footing to provide a capillary break between the damp footing and the foundation wall. A layer of clean coarse gravel, with no fines, can provide an air-gap-style capillary break between the earth and the concrete floor slab. Plastic film beneath the floor slab provides a vapor barrier as well as a capillary break beneath the slab. These drainage layers and the vapor barriers beneath foundation slabs are often required by building codes.

Table 1-1 Maintaining Drainage Plane Water-Tightness in Roofs and Walls

Penetrations Commonly Found in Roofs	How to Maintain Drainage Plane Water-Tightness
Joints between pieces of roofing	Shingling or sealing provides continuity
Roof edges	Overhangs, copings and drip edges provide capillary breaks
Roof intersections with adjoining, taller walls	Through-flashing provides continuity where a lower story roof intersects the wall of the higher level and where any roof meets a dormer wall. Flashing and counter-flashing of veneers and low-slope roof membranes keep water out of joints between materials
Skylights and roof hatches	Flashing, curbs and counter-flashing provide continuity
Chimneys	Flashing, crickets and counter-flashing provide continuity
Air handlers and exhaust fans	Flashing, curbs and counter-flashing provide continuity
Plumbing vents	Flashing and counter-flashing provide continuity
Penetrations Commonly Found in Walls	**How to Maintain Drainage Plane Water-Tightness**
Windows	Head flashing, jamb flashing and panned sill flashing provide continuity
Doors	Head flashing, jamb flashing and panned sill flashing provide continuity
Outdoor air intakes	Head flashing, jamb flashing and panned sill flashing provide continuity
Exhaust outlets and fans	Head flashing, jamb flashing and panned sill flashing provide continuity
Fasteners	Sealants provide continuity
Utility entrances	Sealants provide continuity

The "Pen Test"

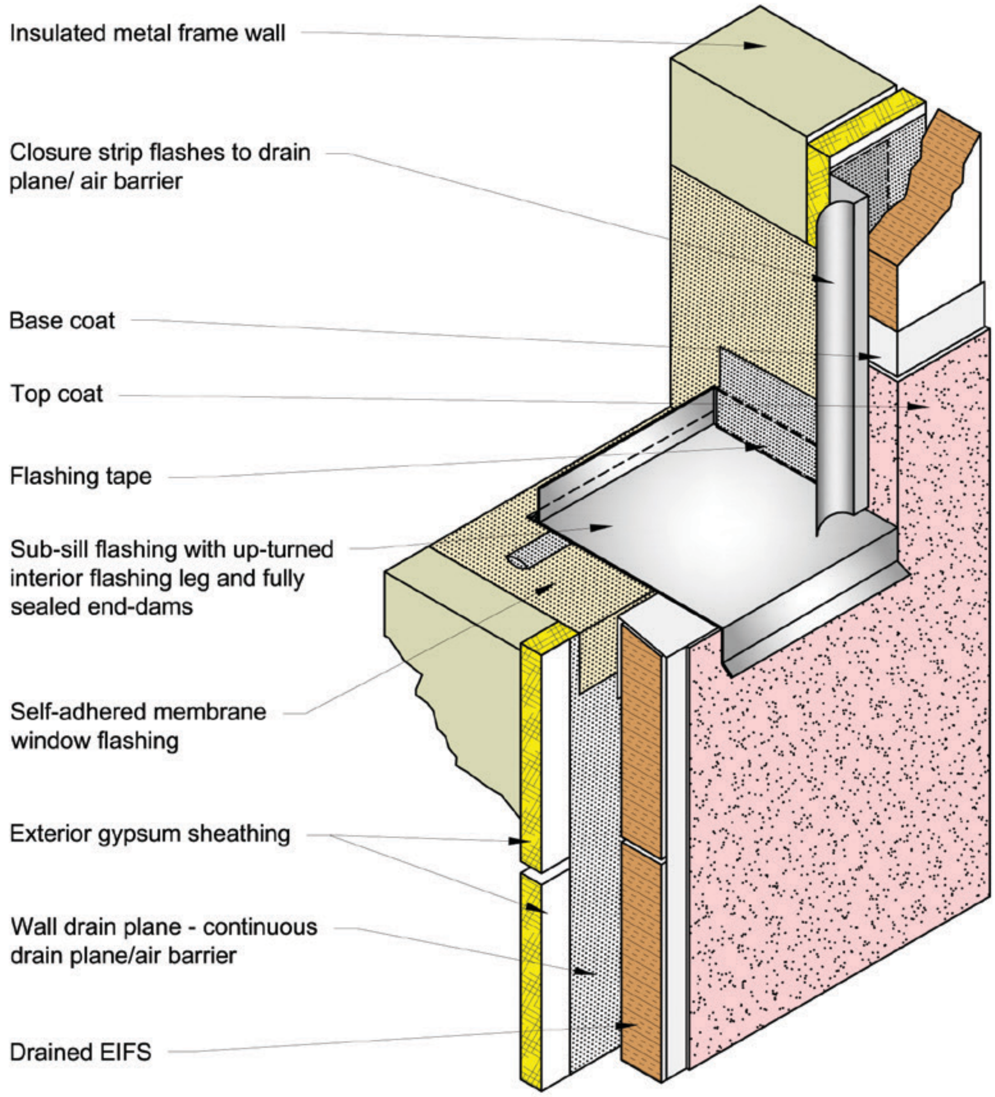
The waterproof layers of the walls, roof and foundation must form a continuous, six-sided box with no gaps, no cracks and no holes. It is difficult to achieve this degree of integrity, especially at the long edges where the walls meet the roof and the foundation. The pen test is used before the architectural design is complete to help make sure these continuous water barriers, when installed according to the design, will not leak.

When rainwater control has been well designed, it should be possible to trace the waterproof layers that form a capillary break around a sectional view of the building without lifting pen from paper. This simple test can be performed not only for the rainwater control, but also for the thermal insulation layer and the air barrier. The methods for all three are outlined in Appendix A and are part of the requirements for documenting compliance with the guidance in Chapters 2, 3 and 4.

Figure 1-17 illustrates tracing the capillary break in a sample section. Starting at the center of the roof:

- The roofing membrane is the first line of defense, protecting the water-sensitive inner materials from rain and snowmelt.
- Tracing the roofing membrane from the center of the roof to the edge of the roof, the roofing membrane rises up the parapet wall where it flashes beneath a metal coping, which also forms a metal fascia.
- The fascia forms a drip edge, channeling water away from the cladding.
- An air gap between the drip edge and the brick veneer forms a capillary break, protecting the materials beneath the coping from rainwater.

Figure 1-16 Pan Sill and Jamb Flashings for EIFS Walls

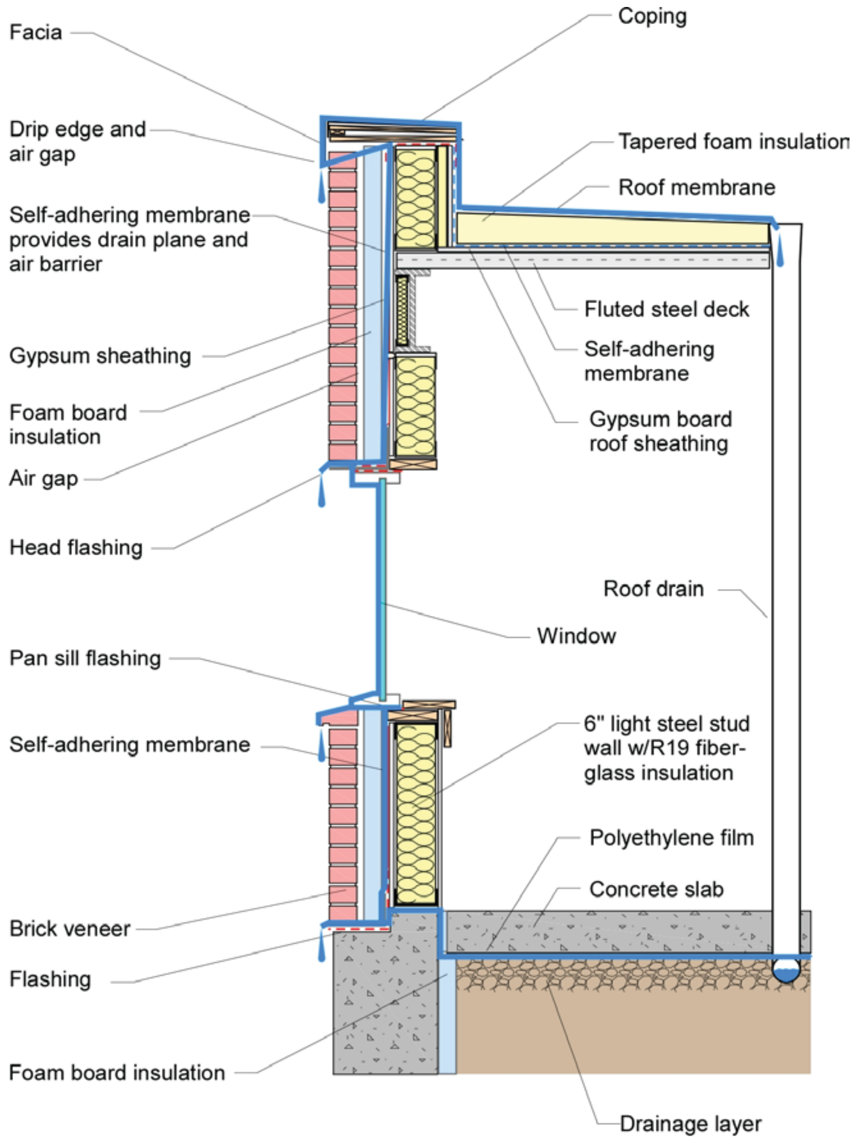


- Behind the brick veneer, air gap and foam board, a self-adhering water-resistant barrier (WRB) applied to the gypsum sheathing forms a capillary break between the damp brick and the inner wall assembly.
- The WRB laps over the vertical leg of a head flashing, protecting the window from rainwater with a drip edge and an air gap. Weep holes allow water to drain from behind the brick cladding.
- The window frame, sash and glazing form a capillary break system that sits in a pan sill flashing at the bottom of the window.
- The pan sill flashing forms a capillary break protecting the wall beneath from seepage through the window system.
- The pan sill flashing shingles over the WRB in the wall beneath, which shingles over a flashing that protects the bottom of the wall system.
- A polyethylene foam sill seal makes a capillary break between the foundation and the bottom of the framed wall, connecting with an inch of extruded polystyrene insulation that makes a capillary break between the top of the foundation wall and the edge of the floor slab. Polyethylene film immediately beneath the slab provides the code-required water vapor retarder and forms a capillary break between the bottom of the slab and the fill below. NOTE: If the bed of fill beneath the slab consists of crushed stone greater than ¼ inch in diameter (and if it contains no fines), the bed also forms a capillary break between the soil and the slab.

Note the critical role of flashing in excluding water and in diverting water out of the building if it leaks in. Applying the pen test to the building design shows

Figure 1-17 Tracing the Capillary Break in a Sample Section[9]

The blue line traces the elements of the capillary break in the rainwater control system for a section through a building.



the importance of flashing that is both well-designed and well-installed. There are no certification programs for the proper installation of flashing; however, the following trade associations offer educational materials and training programs for flashing design and installation:

- Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), http://www.smacna.org.
- National Roofing Contractors Association, http://www.nrca.net/.
- National Concrete Masonry Association, http://www.ncma.org.
- Brick Industry Association, http://www.bia.org.
- Spray Polyurethane Foam Alliance, http://www.sprayfoam.org.

Prevent Plumbing Leaks

To avoid plumbing leaks, new plumbing systems must be pressure tested at a stage of construction when the plumbing lines are easily inspected and leaks can be readily repaired. This is a code requirement in many jurisdictions.

Supply lines must be pressurized to design values, and drain lines must hold standing water. Plumbing must be designed not only to prevent initial problems, but also to permit easy maintenance to avoid future problems.

[9] Figure 1-17 was updated in April, 2014.

Further, plumbing should be located where:

- Leaks will be noticed quickly.
- Leaking water will not wet easily damaged materials.
- Water inside the plumbing will not freeze in cold weather.

Plumbing access panels allow critical maintenance over the life of the building. They should be located anywhere concealed valves or traps will need to be inspected for leaks or accessed for adjustment, maintenance or replacement.

No matter the climate, avoid placing plumbing lines, valves and drain lines in exterior walls and ceilings that have porous insulation. If the plumbing leaks, insulation in those walls or ceilings will get wet. Once wet, porous insulation takes a long time to dry (or may never dry). This situation can lead to mold growth, corrosion of structural fasteners and needless energy consumption. Also, in climates with cold winters, any plumbing located in exterior walls or above ceiling insulation is more prone to freezing and bursting.

Avoid Enclosing Wet Materials in Building Assemblies

Moisture-sensitive materials and equipment should be kept dry during construction. In particular, gypsum board, finished woodwork, cabinets and virtually all mechanical equipment should be stored in a weather-protected shelter or installed in their final, weather-protected locations immediately upon delivery to the site.

If moisture-sensitive or porous materials get wet, dry them quickly before mold grows or physical damage occurs. Masonry walls and concrete floor slabs, for example, are very porous and can hold a great deal of water. Masonry block and concrete must be thoroughly dry before being coated or covered by water-sensitive materials such as floor tile, carpeting, paint or paper-faced gypsum board.

Water is added to some materials during installation (e.g., concrete, water-based coatings, wet-spray fire-proofing and wet-spray insulation). These materials must be allowed to dry naturally, or force-dried using specialized equipment before being enclosed in building assemblies. These intentionally wet materials may not suffer from long exposure to moisture, but as they dry, they will transfer their moisture to nearby materials that can support mold growth or change dimension.

Moisture Control Principle #2: Manage Condensation

Limit indoor condensation and make sure condensation dries out when and where it occurs.

Problem: Condensation Happens—Keep Track of the Dew Point

Both indoor air and outdoor air contains water vapor. Wherever air goes, water vapor goes. When humid air contacts a surface that is cold enough, the water vapor in the air will condense onto that cold surface. The concept of the air dew-point temperature is very useful in understanding when, why and how much condensation will occur—and how to avoid it.

The dew point is the temperature of the air at which condensation occurs. The higher the dew point, the greater the risk of condensation on cold surfaces. The dew point depends on how much water vapor the air contains. If the air is very dry and has few water molecules, the dew point is low and surfaces must be much cooler than the air for condensation to occur. If the air is very humid and contains many water molecules, the dew point is high and condensation can occur on surfaces that are only a few degrees cooler than the air.[10]

Consider hot weather condensation inside a building. Condensation can be prevented as long as the indoor air dew point is *below* the temperature of surfaces that are likely to be cold. If the dew point rises, moisture will begin to condense on cold surfaces. For example, humid outdoor air leaking into a building in Miami will have a dew point above 70°F throughout most of a typical year. During normal operation of an air-conditioned building, there are *many* surfaces that have a temperature below 70°F. For example, a supply air duct carrying air at 55°F will have a surface temperature near 55°F. If the infiltrating outdoor air has a dew point of 70°F, its moisture will condense on the outside of that cold duct, and possibly on the supply air diffuser.

Dew Point vs. Relative Humidity

When most people think of humidity, they think of relative humidity (RH) rather than dew point. But

[10] Dew point can be measured by cooling a mirrored surface until condensation just begins to appear. Monitors that measure dew point directly in this way are called chilled mirror devices.

relative humidity is just that, a relative measurement and not one that expresses the absolute amount of water vapor in the air. In simple terms, RH is the amount of water vapor in the air compared to the maximum amount the air can hold at its current temperature.[11] Change the air temperature and the relative humidity also changes, even if the absolute amount of water vapor in the air stays the same. So knowing only the RH of the air is not much help in predicting condensation.

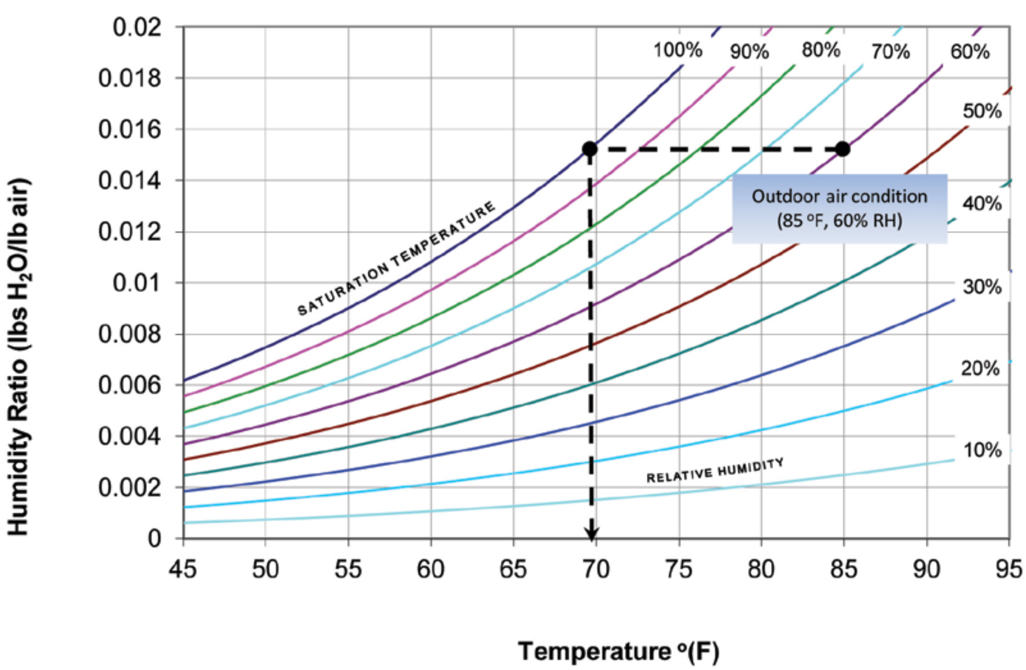
Unlike RH, the dew point does not change with air temperature. In that sense it is an "absolute" measurement of the amount of water vapor in the air. When you know the dew point of the air and the temperature of a surface, you can predict condensation. If the dew point is *above* the temperature of the surface, water vapor will condense onto that cold surface. If the dew point is *below* the surface temperature, moisture will not condense. So it is simple to predict condensation, as long as you know the dew point of the air surrounding the surface.

To be sure, knowing the dew point is not always easy because many humidity instruments measure and read only air temperature and relative humidity. So if the instrument you are using does not display the air dew point, you will need a psychrometric chart to find the dew point based on the temperature and RH of the air. A psychrometric chart graphs the physical and thermal properties of moist air.[12] A simplified psychrometric chart relating the air's temperature and RH to its dew point at sea level is shown in Figure 1-18. With this chart and the readings from a low-cost monitor to measure air temperature and RH, one can determine the more useful value of air dew point in a few seconds.

For example, assume an instrument shows the outdoor air is 85°F and its RH is 60 percent. Plot that point on the chart. Then, beginning at that point move horizontally to the left until your line intersects the saturation curve (i.e., the 100 percent RH curve that forms the left edge of the chart). From that intersection, read straight down to the bottom of the chart to determine the dew point. As shown in Figure 1-18, the dew point of air at 85°F and 60 percent RH is 70°F. In other words, air at those conditions will begin to condense moisture when it contacts any surface that has a temperature of 70°F or below.

The psychrometric chart reveals an important dynamic between surface temperature, dew point and RH. Notice that if the RH is 90 percent, a surface only

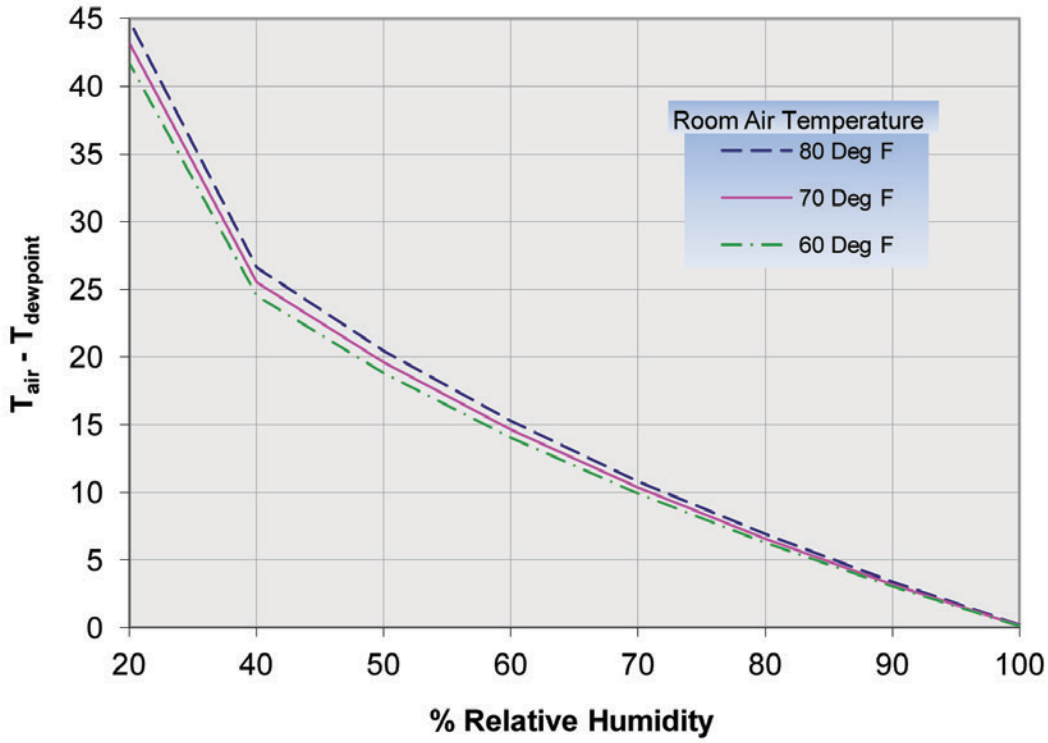
Figure 1-18 A Simplified Psychrometric Chart Relates Air Temperature, RH and Dew Point.



[11] The technically more accurate definition of relative humidity is the ratio of vapor pressure in the air sample compared to the vapor pressure of that air if it were completely saturated at the same temperature, expressed as a percentage. But the definition provided above is sufficiently accurate, easier to understand and useful for managing moisture in buildings.

[12] The psychrometric chart is a powerful tool for understanding the water vapor characteristics of air and the effects of heating and cooling moist air. Its history and use are fully explained in the ASHRAE publication *Understanding Psychrometrics* by Donald Gatley.

Figure 1-19 The Difference Between Room Air Temperature and the Dew Point as a Function of RH



has to be 3°F cooler than the air for condensation to occur. It is very likely that during normal operation in many seasons there will be surfaces in buildings that are 3°F colder than room temperature.

At high temperatures, high RH may also mean there is a strong risk of condensation. Figure 1-19 shows the relationship between RH and the number of degrees cooler a surface must be for condensation to appear when the RH is between 25 percent and 100 percent. This graph provides a way to think about dew point in terms of RH. At 50 percent RH, a surface must be around 20°F cooler than the room air for condensation to occur. Under ordinary circumstances, few surfaces in a building are 20°F cooler than room air.

Causes of Condensation in Buildings

Condensation may be the result of excessively high dew point, unusually cold surfaces, or a combination of the two.

The indoor dew point is a balance between the addition and subtraction of water vapor from the air. A building has both indoor and outdoor sources that add water vapor, and its mechanical systems must have adequate dehumidification capacity to remove it, in order to keep the dew point within reasonable limits.

Inside residential buildings, people and their activities, especially cooking and washing of floors and clothes, are usually the leading sources of humidity.

In humidified commercial and institutional buildings such as hospitals, museums and swimming pool enclosures, indoor humidity is very high by design or necessity.

In low-rise buildings of all types, damp basements or crawlspaces may add as much water vapor to the air in a day as all the other internal sources combined.

During the cooling season, humidity loads from outdoor air are far larger than loads generated inside commercial and institutional buildings. The largest sources of humidity are the ventilation air, the makeup air that compensates for exhaust air, and the air that infiltrates into the building through air leaks in the enclosure. If the ventilation and makeup air is kept dry and the building is tight so that it does not allow much leakage, the contributions from outdoor air will be low.

Water vapor may be removed from indoor air by dehumidification (e.g., air conditioners or dehumidifiers) or by ventilation air when the outdoor air is dry. Ventilating air only dehumidifies the indoors when the outdoor air dew point is lower than the indoor air dew point.

Exhaust air is a special case. When an exhaust fan rids a building of highly humid air, from showers or cooking, for example, the indoor humidity loads are reduced. On the other hand, if the outdoor air that replaces that exhaust air has a dew point above the indoor dew point, the incoming outdoor air represents a humidity load that must be removed by the mechanical system.

Condensation Problems During Cold Weather

In cold weather, condensation is most likely to occur on the inside of exterior walls or roof assemblies. The temperature of sheathing and cladding on the outside of the insulation and air barrier will be near the temperature of the outdoor air. Indoor window surfaces are often cooler than surrounding walls and are typically the first sites of condensation during cold weather. If the surface temperature of an indoor wall is below the indoor dew point at a void in the insulation or at an uninsulated framing member, enough water may accumulate to support mold growth. If there is a hole in the air barrier and the building is under negative pressure at that location, cold infiltrating air may bypass the insulation layer and chill indoor surfaces to temperatures below the dew point.

Condensation may occur within an assembly. For example, a steel beam that passes through an exterior wall will be much colder than the adjoining inner surfaces of the wall because the beam conducts heat from inside to outside hundreds of times faster than an insulated portion of the wall. If the building is under positive pressure, the warmer, more humid indoor air will be forced into the enclosure through holes in the air barrier and condensation within the assembly may result.

Condensation problems within wall or roof assemblies are hidden and may be mistaken for rainwater or plumbing leaks. For example, warm air from a humidified space, such as a swimming pool area, may leak past the air barrier and insulation layers into an attic during freezing weather. The water vapor in the indoor air may form frost on the bottom of the roof deck, accumulating there until a warm day when it melts and leaks back through the ceiling. If it happens to be raining the day the condensation problem is found, it might be mistaken for a rainwater problem.

Figure 1-20 Condensation on Uninsulated Metal Framing in a Cold Climate

Condensation occurs on a C-channel at the top of a parapet wall located in a cold climate. The building is humidified and pressurized with filtered outdoor air to maintain specified interior conditions.

Air pressure can be higher inside a building than outside for two reasons. First, the upper floors of a building are usually under positive pressure during cold weather due to the stack effect. Buoyant warm air rises from the lower to the upper floors and then flows out near the top of the building. As a result, cold outdoor air is pulled into the building at its base. During cold weather, condensation usually occurs on the upper floors. Any gaps, cracks or holes through the upper floors of the enclosure receive a constant flow of warm, humid air exiting the building. Condensation occurs where the warm humid air leaves the cold enclosure.

The second reason air pressure can be higher inside is that, to avoid uncomfortable drafts and freezing pipes, the mechanical ventilation system generally brings in more air from outdoors than is exhausted to the outside. Condensation may occur when warm, humid air is forced out of the building through cold walls. In addition, portions of a building may be pressurized by mechanical system fans if the supply air side of the air distribution system has more air than the return air side. For example, a room that has two supply diffusers but no dedicated return will be under positive pressure when the windows and doors are closed. If the interior surfaces of the exterior walls near that room have gaps, cracks or holes, humid indoor air under positive pressure will be forced into the cold exterior wall.

Condensation Problems During Hot Weather

Condensation can sometimes be a problem in hot weather. Hot weather condensation is more common in buildings equipped with air conditioning (AC) systems that are very large and difficult to control and in buildings located in climates that have thousands of hours of humid weather. Six factors contribute to problems in buildings that have air conditioning systems:

1. Air conditioning chills all the indoor surfaces—some surfaces more than others.
2. When air conditioners do not run long enough to dehumidify, they cool the air in the building without removing moisture from the air, raising the indoor dew point and increasing the chances of condensation on cool surfaces.
3. Supply air ducts, diffusers and refrigerant or chilled water lines are much colder than the room air.
4. When a building's exhaust air exceeds the amount of its makeup air, the building will draw in unconditioned, moisture-laden outdoor air through gaps, cracks and holes in the building enclosure. That outdoor air will come into contact with surfaces chilled by the AC systems.
5. Sun shining on wet masonry, stucco or wood will raise the temperature of that material, evaporating some of the stored water and "driving" a portion of the evaporated water further into the assembly, and sometimes into contact with colder indoor surfaces.
6. Intentional or accidental vapor barriers on the inside surfaces of exterior walls may cause condensation during cooling conditions. For example, water vapor driven in from outdoors may condense when it encounters a vinyl wall covering on the cool, inside surface of an exterior wall.

   A similar dynamic occurs in below-grade walls. Water vapor migrating into a basement from the ground beneath may condense when it encounters a vapor barrier on the inside of a finished basement wall.

Solution: Control Condensation

Effective condensation control requires keeping the dew point below the temperature of surfaces indoors and within building cavities. The dew point can be lowered by designing, installing and maintaining HVAC systems to control indoor humidity in both heating and cooling mode. Building enclosures can be designed and constructed so surface temperatures within the assemblies are above the dew point regardless of season. Neither of these design elements can succeed by itself. They must work together as a system.

Use airtight HVAC systems to keep indoor dew points low. To prevent condensation on indoor surfaces during cooling mode, keep the indoor dew point below 55°F (e.g., maximum 50 percent RH when the indoor air temperature is 75°F). This can be done by designing air conditioning systems that dehumidify even when there is no need for cooling, or by using dedicated dehumidifiers to dry the ventilation air whenever the outdoor dew point is above 55°F. See references below and in Chapter 2 for more details on designing HVAC systems to manage indoor humidity.

The most important job of the air conditioning system is to remove the large and nearly continuous humidity load from the incoming ventilation and makeup air. After that load is removed, the much smaller water vapor loads from indoor sources may be removed by:

- **Exhaust systems** designed to remove water vapor from known sources of humidity such as showers, cooking areas and indoor pools.
- **Ventilation** with outdoor air in non-air-conditioned buildings.
- **Air conditioning systems** equipped with dedicated dehumidification components and controls that activate them when the dew point rises above 55°F.

Design building enclosures to prevent condensation. At minimum the exterior enclosure must:

- Be made airtight by using continuous air barrier systems around the entire enclosure. These systems must greatly reduce leakage of inside air into the exterior enclosure assemblies during cold weather and leakage of outdoor air into the exterior enclosure or interior wall, ceiling and floor cavities during warm weather.[13] Air sealing an enclosure makes it easier to manage indoor-outdoor air pressure relationships with practical airflow rates.

- Meet minimum R-values in accordance with the 2012 International Energy Code.
- Manage the flow of heat and water vapor through all enclosure assemblies to avoid condensation on materials inboard of the drainage plane.

Insulating materials must be used to manage heat flow in order to keep the surface temperature of low-permeability materials inside the enclosure above the expected dew point. A continuous thermal barrier is also necessary to prevent condensation on the interior surfaces of exterior walls and ceilings during heating conditions. The insulation layer must be continuous to prevent condensation in low R-value components of the enclosure (e.g., metal framing, concrete slab edges and angle iron ledgers). The pen test can be conducted to trace the thermal barrier's continuity.

To manage water vapor migration by diffusion, select materials with appropriate water vapor permeability. The materials in the wall or roof assembly must be layered to keep low-perm materials above the dew point during the heating and cooling seasons and to allow the assembly to dry out if it gets wet. This protection must be provided in all above- and below-grade walls, floors, ceilings, plaza and roof assemblies, including opaque walls and roofs, glazed fenestration and skylights, curtain wall systems and exterior doors.

Condensation control must be provided for typical sections and at thermal bridges. Many standard designs in published work detail assemblies that provide condensation control for various assemblies in many climates. For example, the International Building Code covers condensation control for a variety of wall types and all North American climates. Straube (2011) includes systematic guidance for four fundamental wall and roof assemblies in all North American climates, plus a discussion of underlying moisture dynamics. (See references below and in Chapter 2. For designs and climates not covered in published guidance, and for buildings with high humidity levels indoors [e.g., swimming pools, hospitals, knitting mills and museums], analyses should be performed by a knowledgeable person using one of several computer simulations such as WUFI or hygIRC. For more information on managing condensation in the enclosure and hygrothermal modeling, see references in Chapter 2).

It is important to note that a layer of porous material which can safely store moisture may be used as a buffer to improve the condensation resistance of an assembly. For example, a fibrous cover board beneath a fully adhered low-slope roofing membrane reduces the risk of condensation that can damage the adhesive layer. A concrete masonry backup wall behind a fluid-applied drainage plane can safely store moisture in the event of minor seepage.

Design HVAC systems to manage air flow and control condensation. HVAC system pressurization may be used to manage the direction in which air flows through an enclosure. Controlling pressure in air-conditioned buildings in hot, humid climates is crucial to controlling condensation in the enclosure. Buildings in those climates must be positively pressurized to prevent warm, humid outdoor air from entering building cavities and the building itself.

In climates with a significant cold season, humidified buildings—such as swimming pools, hospitals and museums—must not be positively pressurized, otherwise humid air will be forced into cold building cavities. In cold climates, slight depressurization is a better strategy for humidified buildings.

Moisture Control Principle #3: Use Moisture-Tolerent Materials

The final moisture control principle is to use building materials that can withstand repeated wetting in areas that are expected to get wet. Adequate control can be achieved by using moisture-tolerant materials and by designing assemblies that dry quickly. Moisture-tolerant materials should be used in areas that:

- Will get wet by design.
- Are likely to get wet by accident.

Areas that Get Wet by Design

Some locations and materials in buildings are designed specifically to be wet from time to time.

[13] The U.S. Army Corps of Engineers (USACE), for example, has chosen a maximum allowable air leakage rate of 0.25 cubic feet per minute per square foot of total enclosure area at a pressure difference of 75 Pascals when tested in accordance with the USACE test protocol. *U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes Version 3* May 11, 2012.

They include custodial closets, laundry rooms, kitchens, baths, indoor pools, spas, locker rooms, entryway floors and floors that are regularly mopped or hosed down.

Areas Likely to Get Wet by Accident

Some areas are likely to experience water leaks over the course of time. For example, spaces that contain plumbing equipment, such as laundry, lavatory, bath and utility rooms, are prone to water leaks and spills. Below-grade wall and floor assemblies are at the bottom of the building. Water from leaks below grade, on the surface, or above grade is likely to end up on the lowest floor. In these areas, use moisture tolerant materials and assemblies that dry quickly.

Many materials can safely get wet as long as they dry quickly enough. Stainless steel, copper, some stones, china and porcelain tile contain no nutrients to support the growth of molds or bacteria, do not absorb water and are stable when wet. These characteristics are why these materials have long been used in bathrooms, kitchens and entryways.

In areas that may get wet from time to time, it is best to avoid building materials that have proven to be vulnerable to moisture damage. Among these moisture-sensitive materials are untreated paper-faced gypsum board, medium density fiberboard (MDF) and oriented strand board (OSB). Moisture-sensitive materials are vulnerable because they may:

- Contain nutrients that are digestible by molds, bacteria or wood-decaying molds.
- Quickly and easily absorb liquid water and, once wet, take longer to dry than materials that are impermeable to liquid water.
- Have no anti-microbial characteristics.
- Delaminate, crumble, dissolve or deform when wet or while drying.

Substitutes for vulnerable materials are now commonly available at only a modest increase in cost. For example, mold- and moisture-resistant gypsum board, fiber cement board tile backers and sub-floors are available in home improvement stores in addition to builders' supply yards.

If in doubt, the moisture-resistant properties of a building material can be determined by testing according to ASTM D3273-00 (2005) *Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber*. Designers can ask the manufacturer for the results of these tests.

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The Basics of Water Behavior

Water occurs at temperatures often found in buildings as a liquid, a gas (water vapor) and in an in-between state (adsorbed on solid surfaces).

Liquid water moves from one place to another in several ways:

- **Water runs through pipes and vessels.** Water moves from higher pressure to lower pressure in pipes and fixtures. A leak in a pressurized pipe or tank can release much more water than a similar leak on the drain side of the plumbing system.
- **Water runs downhill.** Rainwater, surface water, spilled water, water on the drain side of plumbing fixtures and water in condensate pans are all affected by gravity.
- **Water wicks upwards.** Water wicks up through tiny cracks and holes. To see wicking in action, stand two plates of glass on edge in ¼ inch of water. Push them together and as they get closer the water wicks up between them. The closer together the plates, the higher water wicks. This happens because water molecules are attracted to the glass and to other water molecules. What works for cracks works for pores in materials. Stand a porous material like paper, wood, concrete, a sponge or gypsum board on edge in ¼ inch of water and the water wicks up into the material. How high it goes depends on pore size and how quickly the water can dry out the sides to the air. Water wicks through materials in a process called "capillary action." When water is in tiny pores, gravity is not the most important force acting on it.
- **Water runs along the bottom or sides of materials.** For the same reasons that water wicks up through porous materials, water can cling to the sides and bottoms of materials. Water is attracted to many materials and to itself. Water from rain or a plumbing leak may travel many feet along the bottom of a floor joist or roof truss before collecting in a drop big enough to fall. When water first condenses on a mirror or a cooling coil, it clings to the vertical surfaces. Water does not run down until the droplets become large enough for gravity to overcome the intermolecular forces.

Water vapor migrates from one place to another in several ways:

- **Water vapor in the air goes where the air goes.** This is, by far, the fastest and largest mechanism of water vapor transport. All air, whether inside or outside of buildings, is constantly moving from areas of higher pressure to areas of lower pressure. If dry air is pulled into the building from outdoors, it will dehumidify the indoor air. If humid air is pulled in, it will add to the humidity load that must be removed by the mechanical system.
- **Water vapor migrates through materials by diffusion.** Liquid water may not be present and nothing may appear to be wet, but water vapor can still slowly migrate through what appears to be solid materials. Vapor molecules will slowly bump their way through the spaces between molecules of the material. The molecules are moving from an area of higher water vapor concentration to lower water vapor concentration. The more porous a material is, the easier it is for water vapor to diffuse through it. The rate water vapor diffuses through a material is measured in "perms." Higher perms mean higher water vapor flow rates.

Water changes from liquid to gas (evaporation) and from gas to liquid (condensation).

- **Water evaporates from liquid water on surfaces, becoming water vapor.** Most of the water vapor that originates inside buildings is the result of evaporation from open containers, sprays or damp porous materials. Showers, fountains, pools, sinks, pots on stoves, dishwashers and wash water on floors are all sources of indoor humidity, as are the building occupants themselves. People, plants and animals release water vapor. In typical office spaces, the occupants are probably the main source of water vapor. Wet materials such as wet concrete or exposed earth in crawl spaces or basements are also sources of indoor humidity. The evaporation rate depends on many factors including the temperature of the water and the relative humidity of the air. The warmer the water, the drier the air next to the wet surface. The faster air blows across a wet surface, and the larger the exposed surface area, the greater the evaporation rate. It takes more energy to evaporate water from porous materials than from impermeable materials because the water molecules are more tightly bound by capillary forces and it is difficult to blow dry, ventilating air through many porous building materials.

- **Water vapor condenses on a surface, becoming liquid.** If surface temperatures are below the dew point of the air next to them, water molecules in the surrounding air will condense on the cool surfaces. Cold water pipes, air conditioning ducts and cold roof decks experience condensation, just like a cold drink sweats in the humid summer air.
- **Water vapor is adsorbed onto surfaces.** Water as a gas moves around very freely. Water adsorbed onto a solid surface is far less free to move around than water vapor. In this state, it takes more energy to break the water free than if it is a liquid or a gas. Water molecules clinging to a solid surface are less available for chemical or biological activity than is liquid water.

Chapter 2: Designing for Moisture Control

Introduction

The most common participants in the process of designing a building are architects, engineers, landscape architects and the clients. The design team can also include:

- **The owner of the building,** if the building is being designed and built for a specific person or entity. The owner can help identify how and by whom the building will be used.
- **The future occupants of the building,** if they are known at the time the building is designed. They can help set goals for durability, maintainability and moisture protection.
- **Building and grounds personnel representing the owner,** who can provide years of building operation and maintenance (O&M) experience.
- **The contractor that will construct the building,** if the contractor has been selected when the design work begins.[14] Experienced contractors and subcontractors can bring the realities of managing moisture during construction to the design of the building.

Where there is a shortage of real estate for sale or rent, buildings are often designed and built on speculation. In such cases, the occupants, programs and processes that eventually will reside in the building are known only in general terms. For example, when planning an office building, the design team can assume the occupants will be ordinary office workers and the building will have no special sources of liquid water or humidity. However, the resulting design will not have the benefit of input from the owner, the actual occupants or the building and grounds staff that will have to make the building work over the years.

Designing Effective Moisture Controls

Providing good moisture control in the design of a building is largely the responsibility of the design team. Third parties that provide construction management or commissioning services may play critical roles in the design and implementation of moisture controls. A construction management service may participate in the management of the project at varying levels from inception, design and construction to turnover and occupancy. The goal of construction management ordinarily is to manage the schedule, cost and quality to the owner's satisfaction, but if a construction manager is part of the design team, it is crucial that the manager take on responsibility for implementing the team's moisture control objectives.

Building Commissioning

HVAC systems have been commissioned for many years by testing, adjusting and balancing (TAB). However, commissioning entire buildings is a relatively recent innovation in construction. In 1996, ASHRAE published *The HVAC Commissioning Process Guideline 1-1996,* which extended the scope of traditional TAB to include point-to-point testing of digital controls and functional performance testing to assess the performance of electrical and mechanical systems that work together. Since then this process has been extended to the electrical systems; potable, sanitary, drainage and irrigation systems; power production and cogeneration systems; the building enclosure; sustainable aspects of the project; and the entire building design process itself. In 2005, the U.S. General Services Administration (GSA) published *The Building Commissioning Guide*. The guide provides a process for including building commissioning in the planning, design, construction and post-construction phases of a project. A table in the guide summarizes commissioning activities and recommends the commissioning agent review the design for, among other things, the enclosure's thermal and moisture integrity and its moisture vapor

[14] Whether or not the contractor is on board during the design process, the contractor will have the important role of clarifying the design team's intentions regarding moisture control, planning measures to control water during construction, and preparing response plans for accidental water events that occur during construction. This role is explored in detail in Chapter 3.

control. If a commissioning agent is involved in the design and construction of a building, many of the quality assurance procedures related to moisture control and associated measures could easily fall within the agent's scope. A general process for building commissioning is presented in *ASHRAE Guideline 0-2005: The Commissioning Process*—the industry-accepted commissioning guideline. The National Institute of Building Science (NIBS) published *Guideline 3-2006: Exterior Enclosure Technical Requirements for the Commissioning Process,* which presents a process for building enclosure commissioning and contains many annexes to illustrate the steps in the process. In 2012, ASTM published *E2813-12 Standard Practice for Building Enclosure Commissioning.* This standard practice follows Guideline 3 procedures and includes functional testing required for fundamental and enhanced enclosure commissioning.

Who Should Read this Chapter

This chapter is for the design team members who produce the design, bid and construction documents. It includes a list of design elements that will protect a building from moisture-related problems. The design team must understand the problems that water causes in buildings and the dynamics of moisture sources, moisture migration and moisture control. This knowledge must be reflected in the design documents, building drawings and specifications.

Good design is a prerequisite for a building that resists moisture problems; however, good design alone is not enough. The design must be implemented correctly during construction and maintained during the building's operation by the owner or manager. To that end, the design team in cooperation with the owner, contractor and third parties:

- Documents overall moisture control goals.
- Plans water controls and water event responses to be implemented during construction.
- Identifies inspection, testing, commissioning and quality-assurance activities to ensure the intended moisture-control measures are implemented as designed.
- Establishes requirements of and responsibility for providing, reviewing and accepting submittals, shop drawings, proposed substitutions and scheduled inspections.
- Documents the O&M procedures required to keep the intended moisture control measures working throughout the building's life.

This chapter has six subsections:

1. Site Drainage.
2. Foundations.
3. Walls.
4. Roof and Ceiling Assemblies
5. Plumbing Systems.
6. HVAC Systems.

Each subsection discusses techniques to provide protection from moisture problems and specifies:

- The issue that is being addressed.
- The moisture-control goals for the issue.
- Guidance on implementing techniques to achieve each moisture-control goal.
- Ways to verify that the moisture-control techniques have been included in the building design and have been properly installed or constructed.

Site Drainage

Issue

Water from rain, snowmelt and irrigation systems can infiltrate a building, damaging the structure and its contents. Properly designed site drainage avoids building damage and the need for potentially costly remediation.[15]

Goal

Design the site so that water from rain, snowmelt and landscape irrigation is prevented from entering the building.

Guidance

Guidance 1: The site drainage design creates a controlled condition to help move water away from the building. To the extent possible, the design maintains the rate of water-soil infiltration (i.e., the downward entry of water into the surface of the soil) at the site before the site was disturbed. Runoff (i.e., water that does not infiltrate into the soil) must be managed by other drainage methods.

Guidance 2: Avoid unnecessary impervious surfaces. Avoiding unnecessary or large impermeable surfaces—or using alternative, relatively permeable paving materials—will allow more water to infiltrate, thus reducing the size and cost of systems managing runoff. Placing facilities on a site changes the site's drainage characteristics by increasing the impervious area, which, in turn, increases the volume of runoff that must be managed. Where large expanses of impervious surface are unavoidable, such as parking lots, breaking the expanse into smaller areas or using alternative permeable pavement techniques can help reduce runoff.

Alternative paving materials such as pervious pavement, modular porous paver systems or other surfaces can be used to reduce runoff.

- Porous pavement is a permeable surface often built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil. Porous pavements may be made using asphalt or concrete. Medium-traffic areas are the ideal application for porous pavement. Porous pavement may be inappropriate in areas such as truck loading docks and areas where there is a great deal of commercial traffic.
- Modular porous pavers are permeable surfaces that can replace asphalt and concrete; they can be used for driveways, parking lots and walkways. Alternative pavers can replace impervious surfaces, resulting in less storm water runoff.
- The two broad categories of alternative pavers are paving blocks and other surfaces, including gravel, cobbles, wood, mulch, brick and natural stone.

Guidance 3: Use grading to slow down runoff and achieve a more balanced infiltration rate. Topography helps determine the amount, direction and rate of runoff. To the extent possible, retain existing contours so that the existing drainage patterns can be maintained. Grading also can be used to correct drainage problems. Where steep slopes contribute to rapid runoff, re-grading to more moderate slopes can reduce runoff velocity.

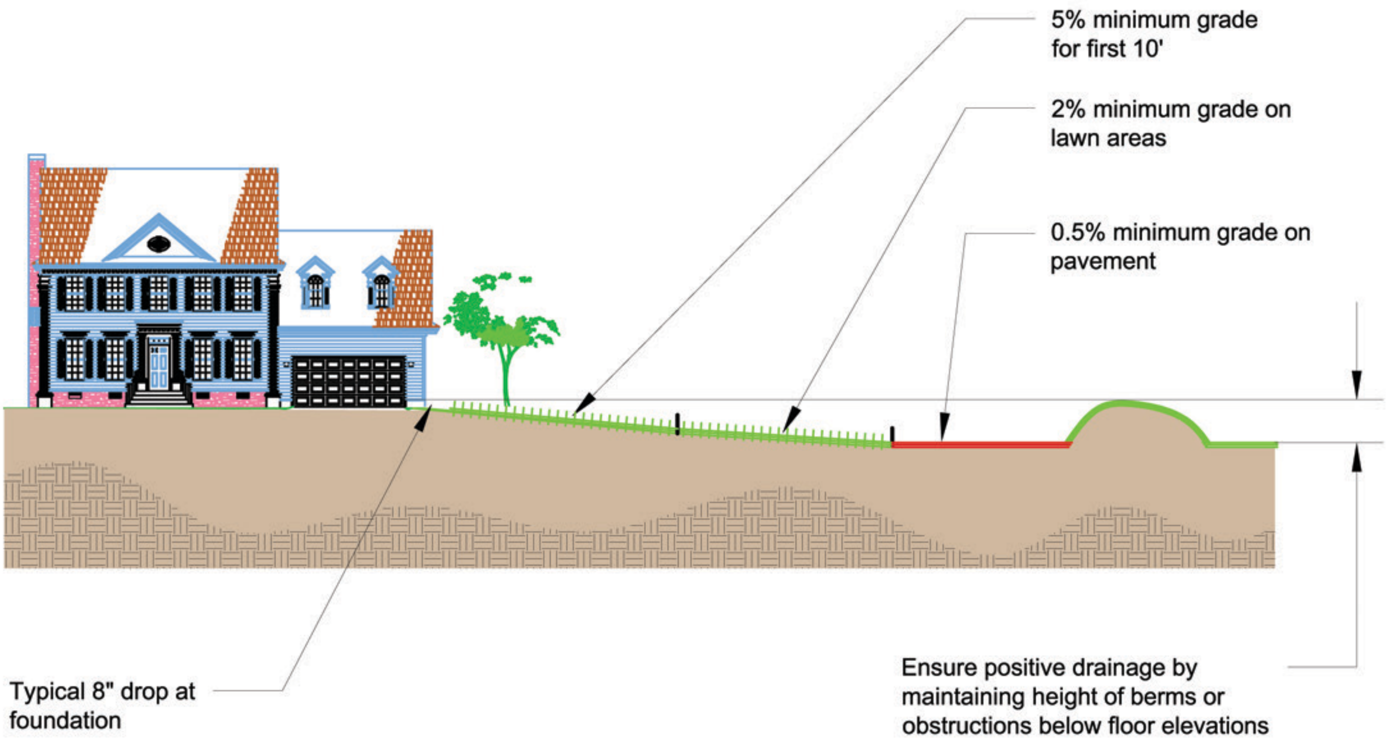
Guidance 4: Ensure positive site drainage principles are met, including:

- Making certain water is moved away from the building.
- Ensuring water is not allowed to accidentally pond in low areas.
- Making sure the finished floor is elevated enough so that water will not back up into the building if the drainage systems are blocked.

Figure 2-1 illustrates positive drainage principles.

[15] This document does not address flood waters from rivers or lakes, the sea or from other extreme weather events.

Figure 2-1 Positive Drainage Principles



Guidance 5: When runoff must be controlled and redirected away from the building, identify and design water runoff management approaches appropriate for the site's characteristics. Potential approaches to use include:

- Infiltration control methods such as swales or infiltration trenches.
  - A swale (i.e., a grassed channel, dry swale, wet swale, biofilter or bioswale) is a vegetated, open-channel management practice designed specifically to treat and attenuate runoff for specified water quality and volume. As water flows along these channels, vegetation slows it to allow sedimentation; the water filters through a subsoil matrix or infiltrates the underlying soils or both.
  - An infiltration trench (i.e., infiltration galley) is a rock-filled trench with no outlet that receives runoff. The runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. Runoff is stored in the spaces between the stones in the trench and from there infiltrates through the trench bottom and into the soil. The primary pollutant removal mechanism of this practice is filtering through the soil.
- Retention or detention control methods such as wet or dry ponds.
  - Wet ponds—storm water ponds, wet retention ponds and wet extended-detention ponds—are constructed basins that contain a permanent pool of water throughout the year or at least throughout the wet season. Ponds treat incoming runoff by allowing particles to settle and algae to take up nutrients. The primary removal mechanism is settling, which occurs as runoff resides in the pond. Pollutant uptake, particularly of nutrients, occurs through biological activity. Wet ponds traditionally have been widely used as a storm water best management practice.
  - Dry detention ponds—dry ponds, extended detention basins, detention ponds and extended detention ponds—hold runoff for some minimum time to allow particles and associated pollutants to settle. Unlike wet ponds, these facilities do not have a large permanent pool of water; however, they are often designed with small pools at the basin's inlet and outlet. Dry detention ponds also can contribute to flood control by providing additional flood water storage.

For detailed information including applicability, design criteria, limitations and maintenance requirements on these and many other site drainage methods, visit EPA's storm water management website.[16]

Guidance 6: Landscape irrigation systems must be designed so that they do not spray the building or soak the soil next to the foundation. Consider hiring a qualified irrigation designer or irrigation consultant to design the system, keeping in mind these considerations:

- Spray heads and rotor heads spray water into the air. When designing spray systems consider wind conditions. Wind can carry airborne water beyond the area intended to be covered, and the sprinklers may spray the building or the soil around the foundation.
- Drip irrigation is a slow, even application of water through plastic tubing that delivers water directly to plants. Drip irrigation systems use less water than spray systems; however, they still can soak the ground around the foundation and cause moisture problems in a building.
- All irrigation systems, regardless of type, should be properly controlled and monitored. Timers should be installed to ensure the system shuts off. Water flow meters should be installed to measure the volume of water moving through the system. Regularly monitored meters can be a source of information about excessive water use due to timer problems or system leaks. Consider installing devices such as tensiometers or soil blocks to measure soil moisture.

Guidance 7: Ensure water draining from one building or site does not violate the good drainage of an adjacent building or site. This can happen when a building is constructed close to an existing building and dumps drainage water (e.g., roof, surface, etc.) onto or at the existing building, overwhelming its drainage features.

Guidance 8: Consider green building practices that minimize the need for irrigation or that capture rainwater for use in irrigation.

- Select trees, shrubs, ground cover and other landscaping elements based on their ability to grow well with little or no additional water. Such plants will minimize the use of water for irrigation.
- Explore the potential for capturing, diverting and storing rainwater for landscape irrigation, drinking and other uses. This approach can be used in all climates. For more information, see the Texas Water Development Board reference *The Texas Manual on Rainwater Harvesting*.

Guidance 9: Develop a construction-phase storm-water-management plan. The plan should address at a minimum:

- Methods for minimizing the potential for storm water runoff during construction.
- Methods to drain storm water from the site and away from the structure during construction.
- Methods for preventing building materials from getting wet.
- Methods for keeping the building or portions of the building dry during construction.[17]
- Policies and methods for drying materials and the building if they become wet.
- Construction-phase storm water management supervisory roles and responsibilities.

For detailed information on construction-phase storm water management, visit EPA's storm water best management practices website.[18]

Guidance 10: Develop guides covering the O&M of the storm water management system. The guides should include:

- The theory of operation of storm-water-management systems.
- Inspection procedures.
- Maintenance procedures and requirements.

For detailed information on post-construction storm water management, visit EPA's storm water best management practices website.[19]

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[16] http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm. Accessed November 6, 2013.

[17] For some large projects, interior work may begin before the upper floors have been completed. Special rainwater-control measures are needed to protect the lower floors. See Chapter 3 on the construction phase for more details.

[18] http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm. Accessed November 6, 2013.

[19] http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm. Accessed November 6, 2013.

Verification of Site Drainage

- If storm water from the site is to be conveyed to a municipal separate storm sewer system (MS4), get a list of MS4 operator's requirements for the municipality. Give the list to the construction manager before construction begins.
- Provide the construction manager with a list of construction-phase critical details and an inspection schedule of the site drainage system, identifying the sequence of inspections, parties responsible for the inspections, and required documentation of the inspection results.
- Provide the construction manager and the building owner with a list of post-construction inspection and maintenance requirements for the site drainage systems.

Foundations

Issue

Building foundations are vulnerable to moisture problems for a number of reasons, including:

- Water from rain and from plumbing leaks is drawn by gravity to foundations, which are exposed to surface water, rain-soaked soil and, possibly, high water tables.
- Water may condense on foundation materials during warm weather because the materials are cooler than the outdoor air.
- Crawl spaces and basements are holes in the ground and have more extensive contact with soil than slab-on-grade foundations.
- Many moisture problems can be avoided by properly designing the foundation. Moisture problems associated with improperly designed foundations can be difficult and expensive to identify and fix, can create the potential for health problems resulting from mold growth, and can be a liability for building owners.

Goals

Foundation Design Goal 1: Design the foundation to prevent rainwater and groundwater incursions.

Foundation Design Goal 2: Avoid condensation on slab-on-grade foundations, in crawl spaces and in basement foundations.

Guidance

Foundation Design Goal 1: Design the foundation to prevent rainwater and groundwater incursions.

Guidance 1: Plan the surrounding slope to divert water away from the building. This guidance applies to slab-on-grade foundations, crawl spaces and basements.

- Specify a 5 percent—6 inches per 10 feet—slope to the finish grade away from the foundation to control the surface flow of water, or meet a more stringent local building code requirement. Applying this slope to a distance of 6 to 10 feet from the foundation generally is acceptable.
- Reduce water infiltration into the soil surrounding the building using a barrier at or slightly beneath the surface (e.g., a cap of silty-clay soil or subsurface drainage landscape membrane). Care must be taken to prevent the roots of plants in this zone from penetrating the barrier.
- Design the foundation and surrounding grade so there is a minimum of 8 inches of exposed foundation after the final grading.

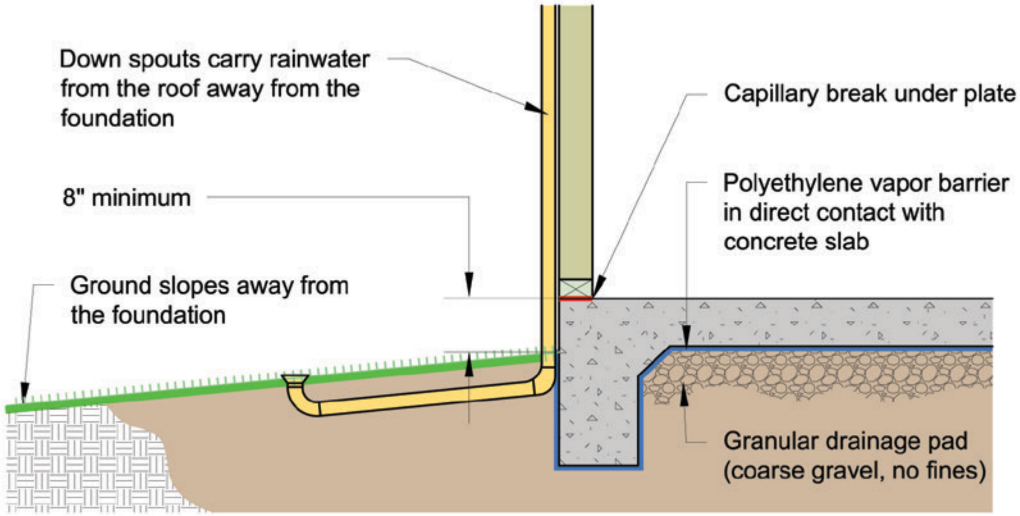
Guidance 2: Design below-grade drainage systems to divert water away from the foundation and specify capillary breaks to keep water from wicking through the foundation to moisture-sensitive materials (e.g., wooden framing and paper-covered gypsum board).

Slab-On-Grade Liquid Water Control (See Figure 2-2)

Below-grade perimeter drainage is not required for concrete slab-on-grade foundations when the surrounding finish grade is sloped as specified in Guidance 1, the slab is elevated at least 8 inches above finished grade, and the design includes appropriate capillary breaks. Incorporate a capillary break between:

- The foundation and the above-grade wall (e.g., a layer of polyethylene foam sill seal, metal or rubber flashing, or a damp-proof masonry course between the concrete foundation and the wood or steel framed walls or the concrete or masonry walls).
- The earth and the floor slab (e.g., a layer of coarse aggregate with no fines, a plastic or rubber membrane, or a layer of plastic foam insulation placed beneath the slab). NOTE: While coarse stone will provide a capillary break, a vapor barrier directly beneath the slab is required to manage water vapor migration.
- The earth and below-grade portion of the perimeter stem wall or thickened edge slab (e.g., damp-proof coating or a water-proof membrane placed on the thickened edge slab or stem wall).

Figure 2-2 Illustration of Ground Water Control for Slab Foundations



- Keep rain water away from the foundation perimeter
- Do not place sand layer over polyethylene vapor barrier under concrete slab
- Where vinyl flooring is installed over slabs, a low water-to-cement (w/c) ratio (= 0.45 or less is recommended) to reduce water content in the concrete; alternatively, the slab should be allowed to dry (less than 0.3 grams/24hrs/ft²) prior to flooring installation

If there is a joint between the slab's perimeter edge and a stem wall, a capillary break may be needed between the edge of the slab and the perimeter wall to prevent water wicking from the perimeter wall into the slab.

If the roof slopes to eaves without gutters, protect the bottom of the above-grade portion of the wall against rain splash (e.g., raise the foundation wall and slab out of the ground 18 inches or more, or construct the wall with robust drainage and drain plane protection).

Crawl Space and Basement Liquid Water Control (See Figures 2-3 and 2-4)

- Design the basement or crawlspace so that the interior floor grade is above the 100-year flood level and the local water table.
- Specify a curtain of free-draining material (e.g., sand and gravel, coarse aggregate with no fines, or a synthetic drainage mat) around the outside of the foundation between the unexcavated earth and the basement wall.
- Specify a drainage collection and disposal system to be located below the top of the footing or the bottom of the slab floor (e.g., perforated exterior footing drain pipe surrounded by coarse aggregate with no fines and filter fabric, drained to a preferred disposal option such as daylight or a sump pump).
- Locate the top of the pipe at or below the bottom of the finished slab regardless of the location of the pipe with respect to the footing.
- Specify filter fabric to prevent fine soils from clogging the curtain drain and the footing drain system.
- Incorporate a capillary break between:
  - The top of the foundation wall and the first-floor framing system (e.g., a layer of polystyrene sill seal, metal or rubber flashing, or a masonry damp-proof course between the concrete foundation and the wood, steel, or concrete floor structure).
  - The earth and the basement floor slab (e.g., a layer of coarse aggregate with no fines, a plastic or rubber membrane, or a layer of styrene foam insulation placed beneath the slab).
  - The free-draining perimeter fill and the below-grade portion of the basement wall (e.g., a damp-proof coating or a water-proof membrane placed on the outside of the basement wall).

NOTE: A plastic or elastomeric membrane can be used in place of a concrete slab to form a capillary break and prevent evaporation from the soil into the crawl space. A concrete slab has the advantages of being more durable and of blocking the entry of burrowing rodents. Membranes are less expensive and easier to install.

- Design a capillary break between the top of the footings and foundation walls (e.g., painted-on coating).
- Specify a drain in the foundation floor that leads to an approved disposal site.
- Include in the plan:
  - Assumptions about maximum rainfall or snowmelt.
  - Drainage surface areas including shapes, slopes, superstructures or other obstructions.
  - Estimated water flows.
  - The location and capacities of all sub-grade drainage features (e.g., drain lines, discharge locations, man-holes, access pits).

Foundation Design Goal 2: Avoid condensation on slab-on-grade foundations, in crawl spaces or in basement foundations.

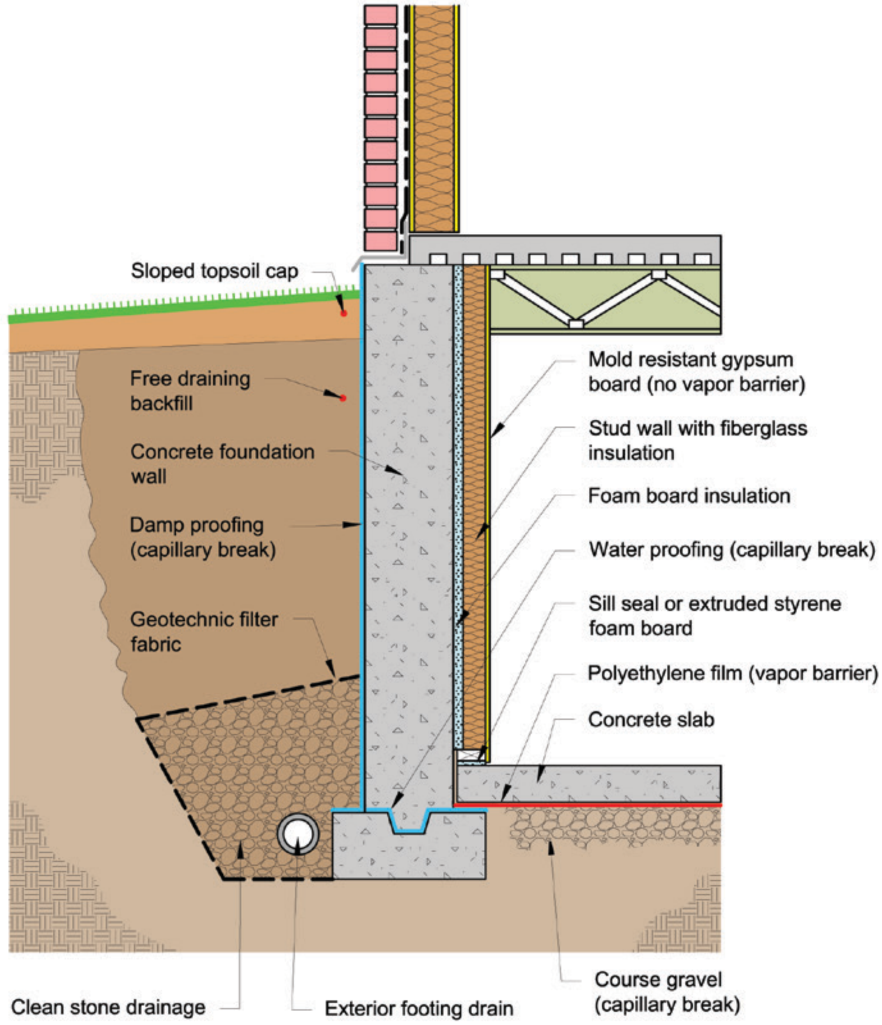
Slab-on-Grade Condensation

- Insulate slab-on-grade foundations (e.g., install extruded styrene foam board beneath the slab) to keep the floor from sweating during warm, humid weather.
- Provide perimeter and sub-slab insulation to meet the International Energy Conservation Code.
- Provide a vapor retarder sheet directly under the concrete floor slab to prevent water vapor from infiltrating the floor system. Vapor retarders should meet the requirements of ASTM specification E 1745 Class A, B or C.

Basement Condensation Control (See Figure 2-3)

- Specify insulation for the above- and below-grade basement walls to meet the ASHRAE Standard 90.1 requirements. NOTE: Do not insulate basement ceilings.
- Provide a vapor retarder sheet directly under the concrete floor slab to prevent water vapor infiltration through the floor system. Vapor retarders should meet requirements of ASTM specification E 1745 Class A, B or C.
- Mechanical equipment can be located in basements that have insulated walls. Specify air-sealing details to provide a continuous air barrier from the above-grade wall down the foundation wall and ending in the center of the basement floor. Use the pen test (See Appendix A) to trace the continuity of the air barrier. NOTE: The air barrier for the foundation is a part of the whole building air barrier system.
- Specify a whole building air leakage rate when tested at 75 Pascal pressure difference in accordance with ASTM E779-10 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* or ASTM E1827-96(2007) *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door.* For example, the U.S. Army Corps of Engineers now requires a maximum air leakage rate of 0.25 cubic feet per minute at 75 Pascal pressure difference.
- When insulating on the outside of foundation walls:
  - Specify insulating materials that can tolerate exposure to the earth. Extruded styrene and high-density expanded styrene foam boards, closed-cell spray polyurethane foam insulation, and fiberglass or mineral wool insulating drainage panels have been successfully used to insulate outside surfaces of foundation walls.
  - Extend the insulation from the top of the footing to the top of the sub-floor.
  - Specify protective covering for the above-grade portions of exterior insulation (e.g., stucco on stainless steel lath).
- When insulating on the inside of foundation walls:
  - Specify a layer of foam board or closed-cell spray polyurethane foam insulation against the interior side of the basement wall to keep warm humid air away from the cool foundation.
  - Specify an insulating value for the foam layer high enough to meet the ASHRAE Standard 90.1 requirements, or specify a combination of foam insulation and, on the foundation wall, moisture-tolerant insulation in the wall cavity (e.g., fiberglass or mineral wool). The combination of foam and fiberglass insulation meets the required R-value, prevents condensation and allows the assembly to dry to the interior (See Figure 2-3).

Figure 2-3 Illustration of Basement Foundation Showing Drainage and Damp Proofing Only



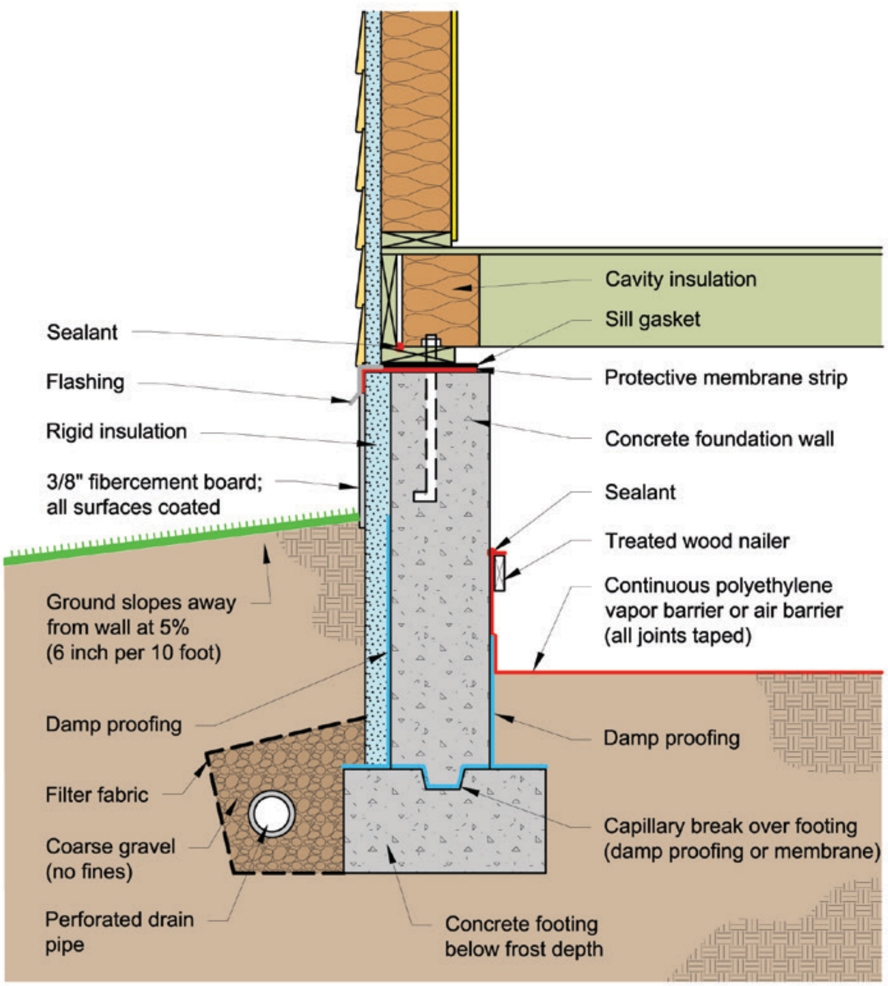
- Specify appropriate fire protection for the interior insulation system (e.g., fire-rated gypsum board).
- Design the entire system so that wooden and paper-based materials do not touch concrete (e.g., isolate them with a spacer, such as closed-cell foam board, spray polyurethane foam or polyethylene foam, which provides a capillary break).
- Do not use any materials inboard of the insulating layer that have a permeability rating of less than two perms. Materials that have a perm value of one by the dry cup method and a perm value higher than two by the wet cup method may be used. For example, do not use vapor-impermeable vinyl wallpaper on insulated basement walls.
- Provide details showing how the insulation layer on the inside of the foundation provides continuity with the upper floor wall insulation.
- Use air conditioning or dehumidifiers to reduce basement humidity during warm, humid seasons.

Crawl Space Condensation Control

- Crawl space foundations may be vented to the outdoors or air sealed.
- The specifications for non-vented crawl spaces are the same as for basements, with one exception: a plastic or elastomeric membrane can be used instead of a concrete slab to form a capillary break and prevent evaporation from the soil into the crawl space. Concrete slabs are more durable, provide a solid floor for the contractor to work from, and block the entry of burrowing rodents; however, membranes are less expensive and easier to install. Sealed crawlspaces must be ventilated in accordance with International Building Code 1203.3.22012 (See Figure 2-4).

- For vented crawl spaces:
  - Specify one or more layers of insulation in the floor system between the crawl space and the first floor to achieve the insulation levels required by ASHRAE Standard 90.1. NOTE: Mechanical equipment cannot be located in vented crawlspaces. Specify air-sealing details to provide a continuous air barrier from the above-grade wall across the floor between the crawl space and the first floor. Use the pen test (See Appendix A) to trace the continuity of the air barrier. NOTE: The air barrier for the foundation is part of the whole building air barrier system.
  - Specify a whole building air leakage rate when tested at 75 Pascal pressure difference in accordance with ASTM E779-10 Standard Test Methods for Determining Air Leakage Rate by Fan Pressurization or ASTM E1827-96(2007) Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door. For example, the U.S. Army Corps of Engineers requires a maximum air leakage rate of 0.25 cubic feet per minute at 75 Pascal pressure difference.
  - A plastic or elastomeric membrane can be used instead of a concrete slab to form a capillary break and prevent evaporation from the soil into the crawl space. Concrete slabs are more durable, provide a solid floor for the contractor to work from, and block the entry of burrowing rodents; however, membranes are less expensive and easier to install.
  - Provide screened vents to meet the International Building Code requirements for ventilated crawl spaces (Section 1203.3.1).

Figure 2-4 Components of an Unvented Crawl Space Foundation



Source: Conditioned Crawlspace Performance, Construction and Codes, Building Science Corporation (http://www.buildingscience.com/documents/bareports/ba-0401-conditioned-crawlspace-construction-performance-and-codes). Accessed November 6, 2013.

Verification of Foundation Design

- Write a description detailing how the foundation system manages rain and surface and sub-surface water. This typically would be located in the basis-of-design document.
- Provide details of sub-surface drainage systems in construction documents.
- Use the pen test (See Appendix A) to verify elements of the drainage system and the continuity of the capillary break from the intersection of the foundation with the first floor walls, around the foundation wall footing, to the center of the foundation.
- Provide two-dimensional sectional drawings where two materials that form the rainwater control come together and three-dimensional drawings where three or more elements of the rain protection system come together.
- Provide a list of critical details and an inspection schedule for the drainage and capillary break elements of the foundation that identifies the sequence of inspections, the parties responsible for the inspections, and the required documentation of the inspection results.
- Provide a list of inspection and maintenance requirements for the foundation drainage system.
- Write a description detailing how the foundation system manages water vapor during cooling and heating modes, as applicable. Prepare drawings and specifications that detail water vapor migration control and the permeability and insulating values for all materials.
- Provide two-dimensional sections where two materials that form the air barrier, insulation layer and water vapor control intersect. Provide three-dimensional drawings where three or more elements of the air barrier, insulation layer and water vapor control intersect.
- Specify a fan pressurization test in design specification documents to assess the entire building enclosure using ASTM E779-10 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. Or ASTM E1827-96(2007) *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door.*
    - Specify when the test should be conducted in relation to the completeness of the air barrier system.
    - Identify the appropriate testing party.
    - Specify how the results should be documented, judged and accepted or rejected.
    - Specify the remedies if the building fails the test.
- Specify quality assurance programs for the installation of the hygrothermal control elements of the enclosure. Provide a list of critical details and an inspection schedule for the air barrier, insulation layer and water-vapor-control elements of the foundation. Specify the sequence of inspections, the parties responsible for the inspections and the required documentation of the inspection results.
- Provide a list of inspection and maintenance requirements for the interior finishes if they are critical to water vapor control. For example, if water vapor control depends on a vapor-permeable interior finish, low-perm vinyl wall coverings and paints should be avoided during renovations. Pictures, blackboards and mirrors should be spaced off the wall.
- Specify, in the control guide for the building operators, the maximum dew point levels allowed in the interior of basements and crawlspaces.

Walls

Issue

Moisture control is an important aspect of designing an integrated building enclosure. Failing to properly design walls to manage moisture and failing to integrate moisture management system features with those of other building enclosure components, such as the roof and foundation, can lead to serious moisture-related damage. Correcting problems resulting from poorly designed walls can necessitate the replacement of multiple building components leading to high repair costs.

Goals

Wall Design Goal 1: Design exterior walls to manage rainwater.

Wall Design Goal 2: Design exterior walls to prevent condensation of water vapor on cool surfaces within the dry portion of the exterior wall assembly, on the inner surface of the exterior walls or within the interior wall, floor or ceiling cavities.

Guidance

Wall Design Goal 1: Design exterior walls to manage rainwater.

Guidance 1: Design walls to protect their inner portions from direct rain and seepage through the cladding.

- Design walls that have rainwater protection behind the cladding in the form of air gaps and barrier materials (i.e., the drain plane) to keep water from wicking further into the wall.
- Specify in the design drawings and specifications the flashing of penetrations—including windows, doors and roof-wall intersections—to a designated drain plane.
- Provide sections and specifications detailing flashing for all wall penetrations. Flashing for larger penetrations (e.g., windows, doors and exhaust and intake grilles) must be carefully designed and detailed. At the top, flashing must extend from beneath the drain plane material, across the top of the trim, and out past the siding and trim (See Figures 2-6 and 2-7). The bottom must have a pan flashing with end dams and a back dam. Side flashing must cover the rough opening and extend beneath the drain plane on the wall and flash down over the end dams on the sill flashing.
- Among the most common problem areas for flashings in walls are:
    - Windows.
    - Doors and trim.
    - Outdoor air intakes, exhaust outlets and fans.
    - Ducts, pipes and electric conduit entries and exits.
    - Through-wall flashings where a horizontal element (e.g., roof) intersects the wall of a taller portion of the building. Similar locations include exterior stairway-wall intersections as well as relieving angles, awning decks, and balcony and plaza intersections with the wall of a taller section of building (See Figure 2-8.)

Wall Design Goal 2: Design exterior walls to prevent condensation of water vapor on cool surfaces within the dry portion of the exterior wall assembly, on the inner surface of the exterior walls or within the interior wall, floor or ceiling cavities.

Guidance 1: Design walls to be sufficiently airtight to limit water vapor migration by air flow.

Specify air-sealing details to provide a continuous air barrier from the roof-wall intersection to the above-grade wall-foundation intersection. Use the pen test (See Appendix A) to trace the continuity of the air barrier. NOTE: The air barrier for the walls is part of the whole building air barrier system. Specify a whole building air leakage rate when tested at 75 Pascal pressure difference in accordance with ASTM E779-10 *Standard Test Methods for Determining Air Leakage Rate by Fan Pressurization* or ASTM E1827-96(2007) *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door.* For example, the U.S. Army Corps of Engineers requires a maximum air leakage rate of 0.25 cubic feet per minute per square foot of air barrier surface when measured at a pressure difference of 75 Pascals between indoors and outdoors. The air barrier surface area includes all six surfaces of the barrier: top, bottom and all four sides.

- Select a layer of material in the wall assembly to form the basis of the air barrier systems. Interior gypsum board, foam board or spray foam insulation, concrete, and oriented strand board (OSB) or plywood deck are good choices for the basis of air barrier systems in wall assemblies. Include specifications for all accessory materials required to provide durable continuity of the air barrier.
- Provide sections and specifications detailing methods for providing air barrier continuity, especially at penetrations, corners and edges:
  - At penetrations through the air barrier layer (e.g., rough openings for windows, doors, pipes, shafts and conduits).
  - At transitions between one air barrier material and another (e.g., wall-ceiling intersections and wall-floor intersections).
  - Where the air barrier must pass around structural elements (e.g., heavy steel construction must be carefully detailed where the exterior walls encounter vertical steel posts or horizontal beams).
- Provide sections highlighting the air barrier and connecting materials and methods from the center of the roof to the center of the foundation for each section.

Guidance 2: Meet or exceed the R-value for walls as described in the 2012 International Energy Conservation Code.

- Provide two-dimensional sections detailing methods for providing insulation layer continuity:
  - At windows, doors, columns, conduits and other penetrations through the air barrier layer.
  - At transitions between one insulating material and another (e.g., where roof insulation meets wall insulation).
  - At thermal bridges in the insulation layer (e.g., where steel members penetrate the insulation layers).

Guidance 3: Design walls to manage heat flow and vapor diffusion to avoid condensation in the wall assembly and to dry toward the interior, exterior or both. Designers may provide details about the continuity of the air barrier and the insulating layers at penetrations and intersections.

Option 1: Follow published regulation or guidance on combining insulation, air barriers and the permeability of materials for walls to control condensation (See references Chapter 2). Examples include:

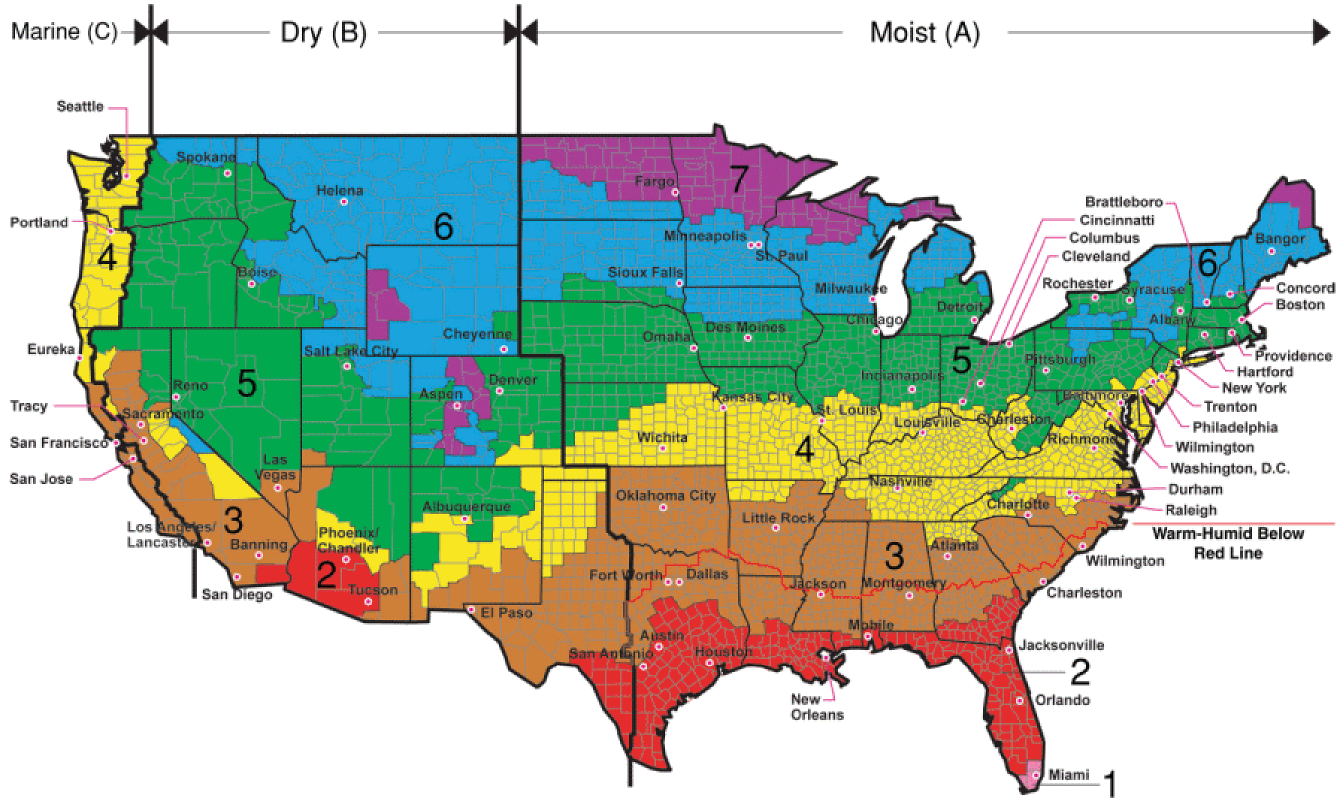
- The 2012 International Building Code and International Residential Code.
- *High Performance Building Enclosures* by Straube (2011) provides systematic guidance for condensation control in four types of roof and wall assemblies for all North American climates.
- *Understanding Vapor Barriers* by Lstiburek (ASHRAE August 2004) applies to all climate zones (See Figures 2-9 through 2-12).
- *The Building Envelope Design Guide* on the Whole Building Design Guide website includes brick and stone veneer and curtain wall systems.
- The Canadian Mortgage and Housing Corporation *Best Practice Guides* apply to climate zones 6 and 7.

Option 2: Model the performance of proposed wall assemblies using a hygrothermal software program (e.g., WUFI or hygIRC). Use design conditions from ASHRAE Standard 160P for modeling. Note, however, that the results of computer simulations should be interpreted cautiously and in light of real-world construction practices. For example, most computer models assume that walls are airtight and that no water vapor is transported through them by airflow. Therefore, for the model to be valid, the assembly must be designed, installed and tested to meet air tightness standards. Also, the performance of any assembly depends on its orientation in regard to solar load and wind direction during heavy rains. Some of the programs can model the dynamic of rainwater absorbed by porous claddings and vaporized into the assembly by the sun, but others cannot.

Guidance 4: Design brick and masonry-clad walls to prevent the rain-sun-driven water vapor dynamic.

- If the cladding is brick or concrete masonry units and the wall is insulated with high-permeability (perm >10) porous insulation and located in climate zones 1, 2, 3, 4 or 5 (See Figure 2-5):
  - Back-vent the cladding.
  - Use low-permeability (perm <1) insulating sheathing and interior finishes with perm >2.
  - In climate zones 1, 2 and 3, design the building to operate at positive pressure.

Figure 2-5 The International Energy Code Climate Zone Map Developed by the U.S. Department of Energy



All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

Verification of Wall Design

- Write a description detailing how the wall system manages rain. Include this description in the basis-of-design document.
- Use the pen test (See Appendix A) to verify the continuity of the drain plane from the intersection with the roof, through flashings, and around penetrations to the foundation.
- Provide two-dimensional sections where two materials that form the rainwater control come together and three-dimensional drawings where three or more elements of the rain protection come together. Sections must show continuity of capillary breaks and flashing around penetrations and interface with air barrier and insulation systems (See Figure 2-8).
- Specify a quality assurance (QA) program for installation of the rainwater protection systems. At a minimum, provide a list of critical details, an inspection schedule and quality assurance tests of the drainage and capillary break elements of the wall systems. Specify the sequence of inspections and tests, the parties responsible for them and the required documentation of the results. Parties involved in QA may include subcontractors, general contractors, commissioning agents and independent third-party inspection or testing providers. Provide a list of inspection and maintenance requirements for the exterior cladding, flashings and drain plane.
- Use wall assemblies detailed in guidance or journals that have been designed to manage water vapor and condensation for the climate of interest. Perform hygrothermal modeling when no documentation through previous testing or modeling of a wall assembly in a particular climate is available.
- Write a description detailing how the wall system manages water vapor during cooling and heating modes, as applicable. Prepare drawings and specifications that detail water vapor migration control and the permeability and insulating values of all materials.
- Use the pen test (See Appendix A) to verify the continuity of the insulation layers and air barriers from the intersection with the roof,

through flashings, and around penetrations to the foundation.

- Provide two-dimensional sections where two materials that form the insulation layers and air barrier come together and three-dimensional drawings where three or more elements of the insulation and air barrier come together.
- Specify in the design specification documents a fan pressurization test to assess the entire building enclosure in accordance with ASTM E779-10 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, ASTM E1827-96(2007)*Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door* or the U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes.
  - Specify the target airtightness level.
  - Specify when the test should be conducted in relation to the completeness of the air barrier system.
  - Identify the appropriate testing party.
  - Specify how the results should be documented, judged and accepted or rejected.
  - Specify the remedies if the building fails the test.
- Provide a list of critical details, an inspection schedule and QA tests for the air barrier, insulation and vapor control elements of the walls. Specify the sequence of inspections and tests, the parties responsible for them, and required documentation of the results.
- Specify QA programs for the installation of the hygrothermal control elements of the enclosure. Provide a list of inspection and maintenance requirements for the interior finishes if they are critical to water vapor control (e.g., if water vapor control depends on a vapor-permeable interior finish, then low-perm vinyl wall-coverings and paints should be avoided during renovations; pictures, blackboards and mirrors should be spaced off the wall).
- Specify maximum dew points to be maintained in conditioned spaces during the heating and cooling seasons.

Figure 2-6 Section Illustrating Window Flashing and Jamb Flashing for Stone Veneer Wall

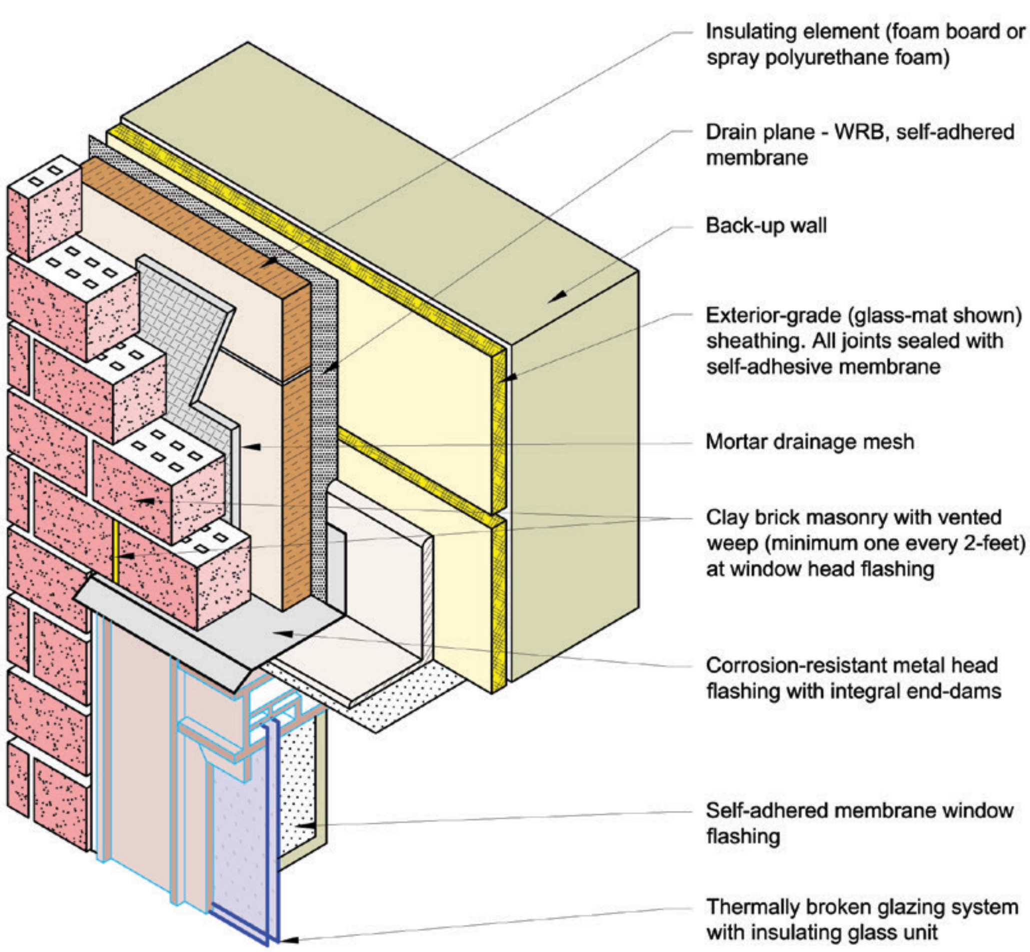


Figure 2-7 Section Illustrating Pan Sill Flashing and Jamb Flashing For Brick Veneer Wall

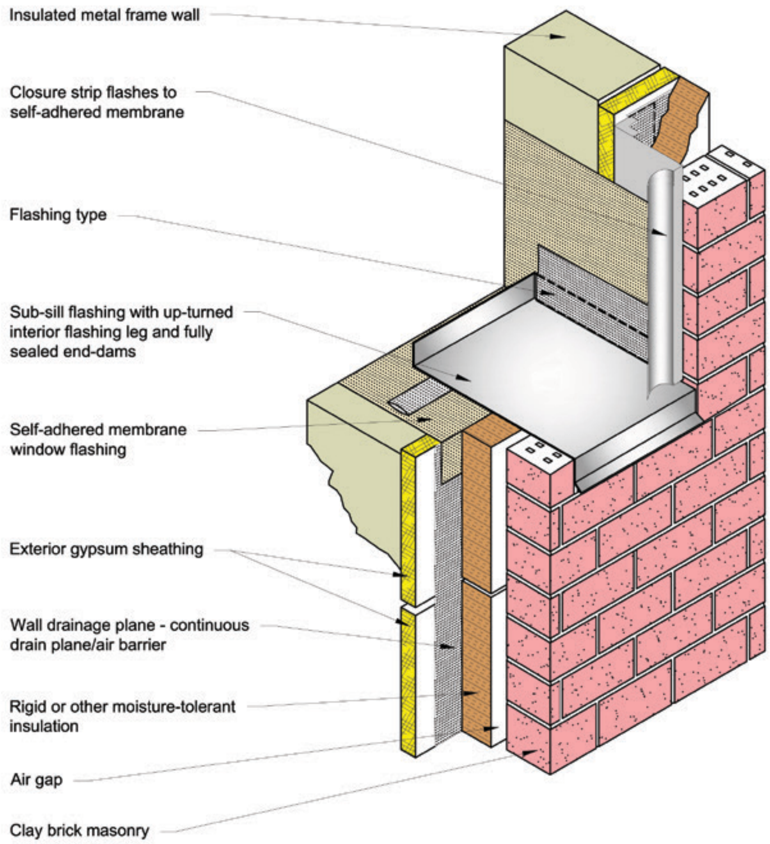


Figure 2-8 Detail Illustrating Through Flashing Where a Lower Roof Intersects a Wall

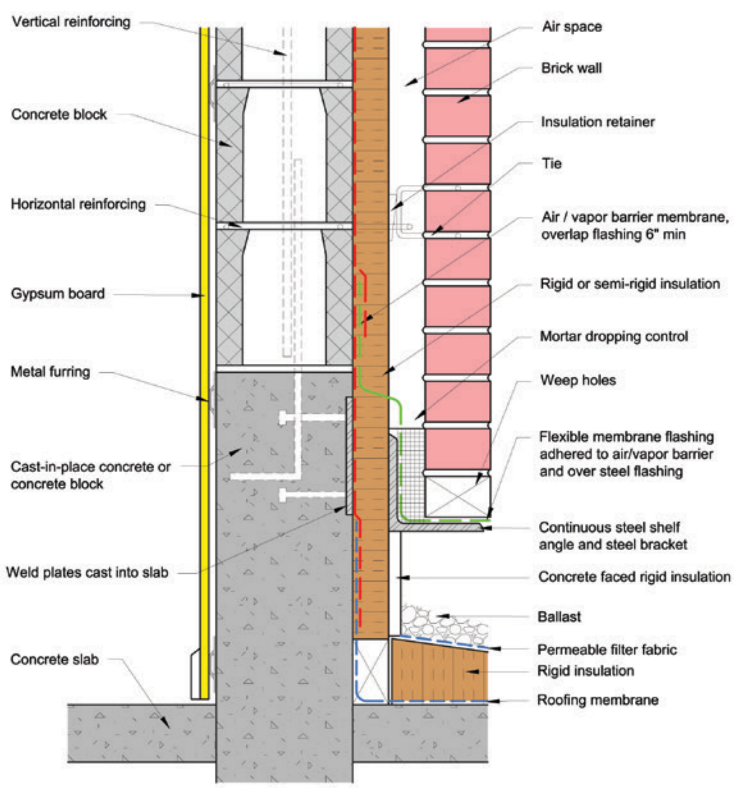


Figure 2-9 Concrete Block with Interior Rigid Insulation and Stucco

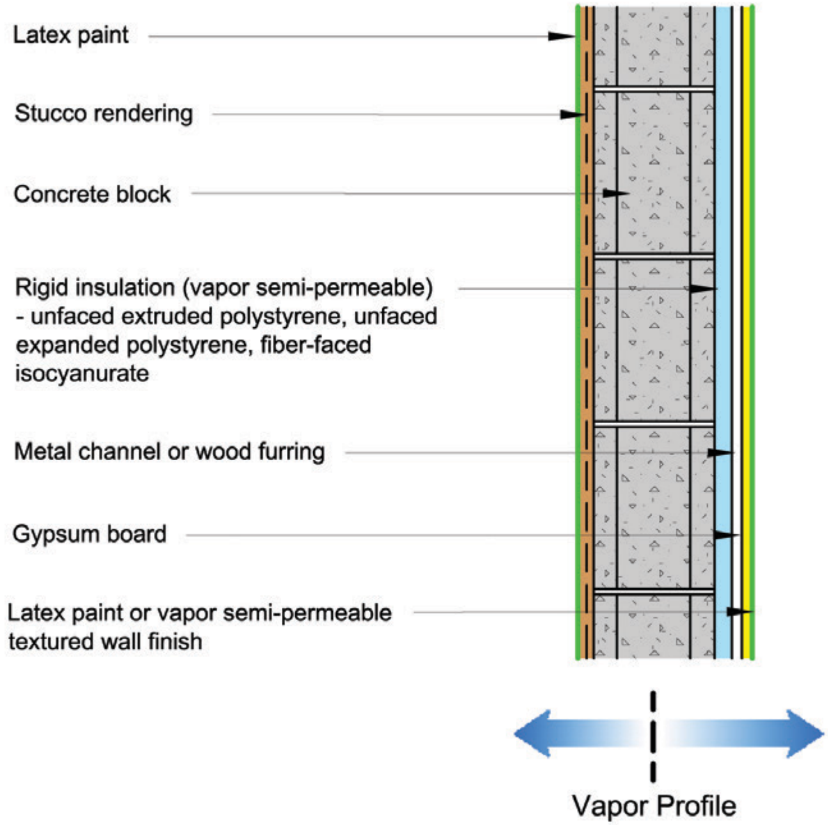


Figure 2-10 Concrete Block with Interior Rigid Insulation Frame Wall with Cavity Insulation and Stucco

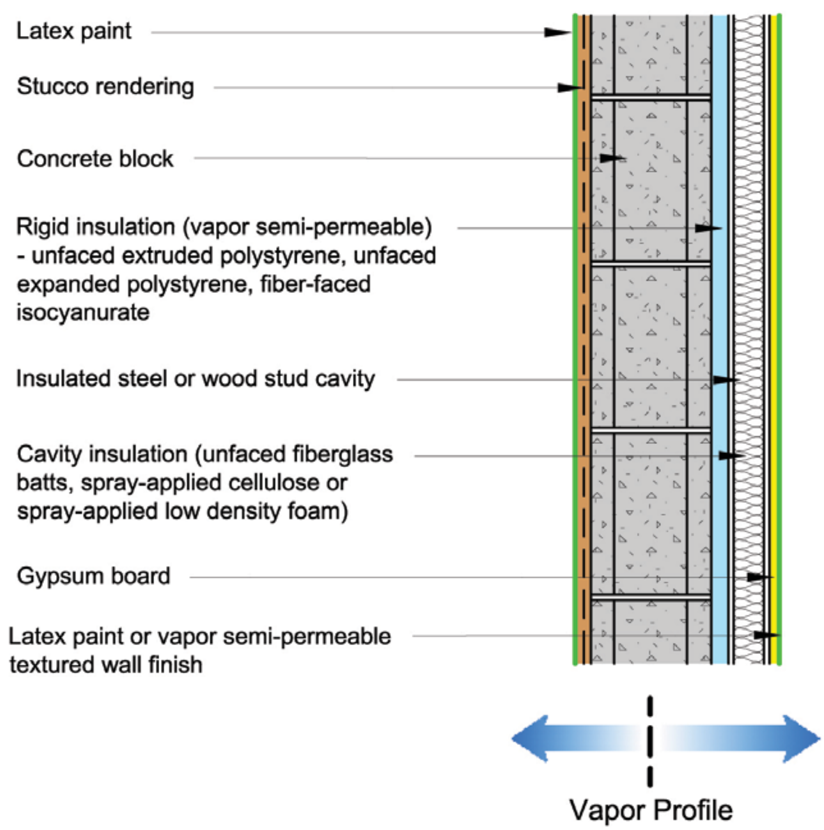


Figure 2-11 Frame Wall with Exterior Rigid Insulation with Cavity Insulation and Brick or Stone Veneer

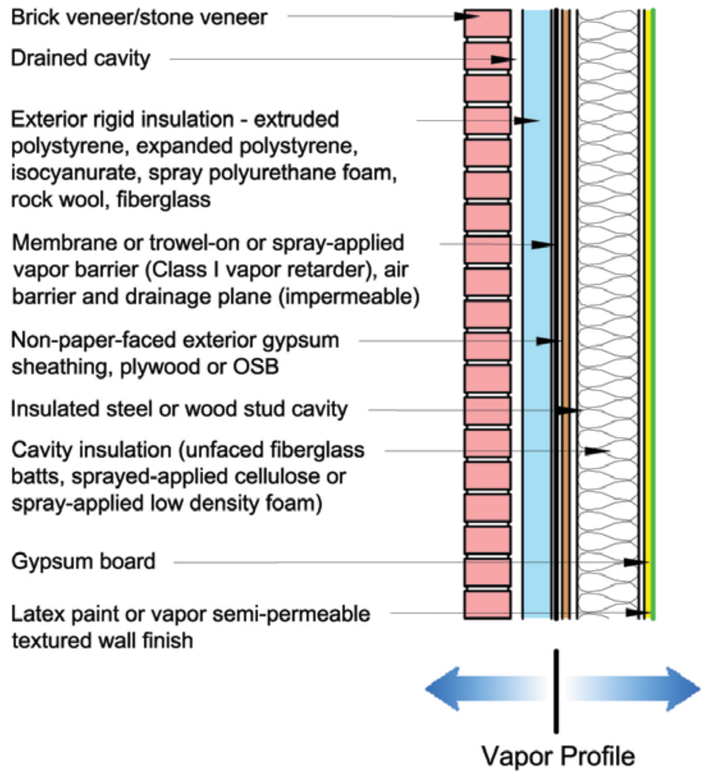
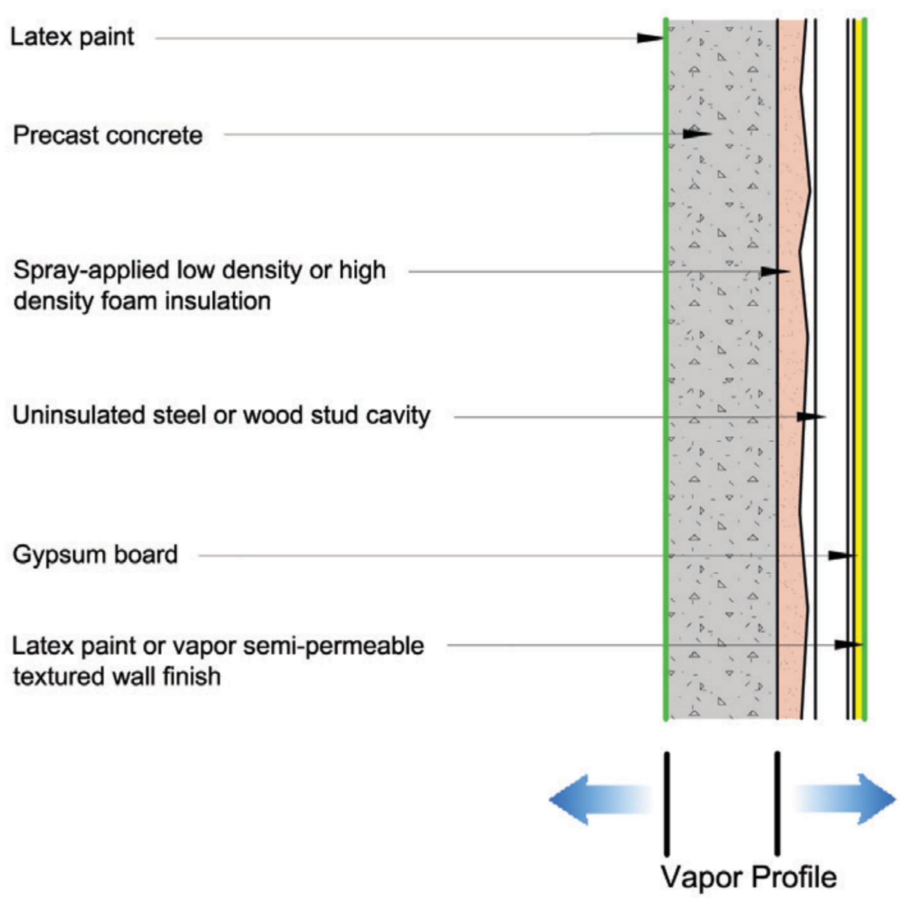


Figure 2-12 Precast Concrete with Interior Spray-Applied Foam Insulation



Roof and Ceiling Assemblies

Issue

Improper detailing of the roof and ceiling assemblies may result in unwanted water intrusions or condensation problems that can lead to damage to the building and its contents. Failure to properly design the roof can result in more frequent and costly roof maintenance or repairs and a shorter building lifespan. In roof-and-ceiling assemblies, the rain water control portion of the roofing system may be separated from insulation and air barrier layers by a vented attic space. In this case, rainwater control continuity is traced through the roofing system, while air barrier and insulation continuity may be traced at ceiling level. In this section, the term roof assembly refers to the entire assembly that provides rain protection, thermal insulation, air barriers and condensation control.

Goals

Roof and Ceiling Assembly Design Goal 1: The roof collects and disposes of rainwater.

Roof and Ceiling Assembly Design Goal 2: Roof assemblies are designed to prevent condensation of water vapor on cool surfaces within the dry portion of the roof assembly, on the interior surface of the exterior roof assembly or within the interior wall, floor or ceiling cavities.

Roof and Ceiling Assembly Design Goal 3: The roof design considers maintenance for moisture control.

Guidance

Roof and Ceiling Assembly Design Goal 1: The roof collects and disposes of rainwater.

Guidance 1: Slope the roof to drain rainwater toward collection and disposal sites.

Determine roof slope, or pitch, based on ordinary use and design requirements. For example, for safety purposes a roof that serves as a plaza, garden area, or other social space must have a slope low enough to be safe. Slightly higher slopes can be tolerated for limited-access roofs where mechanical equipment that requires routine inspection and servicing is located, but the slope of these roofs still must be low enough to allow safe walking. Higher roof pitch may be selected for visual appeal, consistency with surrounding buildings or for the ability to shed snow or rain. Roofing materials selected for appearance or performance may have minimum slope requirements. For example, slate roofs should not be less than or equal to a 3-in-12 pitch (3:12), while some low-slope roof membranes have been used on essentially flat roofs. For these materials, this guidance requires at least a ¼-in-12 pitch (¼:12) to promote positive drainage in the face of deflection and construction tolerances. Even "flat" roofs should be sloped.

Slopes and Typical Roof Coverings

- Low-slope roof coverings:
  - Built-up roofs.
  - Modified bitumen.
  - Single-ply.
  - Sprayed polyurethane foam.
  - Metal panels.
- Steep-slope roof coverings:
  - Metal panels and shingles.
  - Asphalt shingles.
  - Slate.
  - Tile.

- Use roofing materials that are appropriate for the pitch. Select roofing material in accordance with the requirements of the *Whole Building Design Guide* for low-sloped and steep-sloped roofs. NOTE: Low-sloped roofs are defined as roofs with a slope less than or equal to 3:12 (25 percent). However, with the exception of metal roofs, most low-slope roofs must have a minimum slope of ¼:12 (2 percent). Steep-slope roofs are defined as roofs whose slope is greater than 25 percent. Some materials can be used on both low and steep slopes, while others are limited to either low or steep slopes.

- Design site water collection and disposal systems to provide positive roof drainage where:
  - All loading deflections of the roof deck are considered.
  - Local rainfall rates are considered.
  - The roofing manufacturer's drain placement requirements are followed.
  - Roof drainage within a maximum of 48 hours after precipitation is ensured.

Guidance 2: Design the roof drainage system with sufficient runoff-handling capacity.

The amount of water to be handled depends on the area and slope of the roof and the intensity of rainfall at the building site. Chapter 11 of the 2003 International Plumbing Code (IPC), Storm Drainage, requires that the size of vertical conductors and leaders, building storm drains, building storm sewers, and any horizontal branches of such drains or sewers be based on the 100-year hourly rainfall rate. Use figures presented in that chapter or rainfall rates derived from approved local weather data.

The building's design, appearance and location influence the type of roof drainage system. Designers may opt to use external drainage systems, internal drainage systems or both.

External Gutter and Downspout Drainage Systems

Design external gutter and downspout roof drainage systems in accordance with Chapter 1 (Roof Drainage Systems) of the Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA) *Architectural Sheet Metal Manual*. The SMACNA manual provides guidance for sizing drainage systems for 10-year and 100-year storms. Compare net drainage capacity of design with local code requirements.

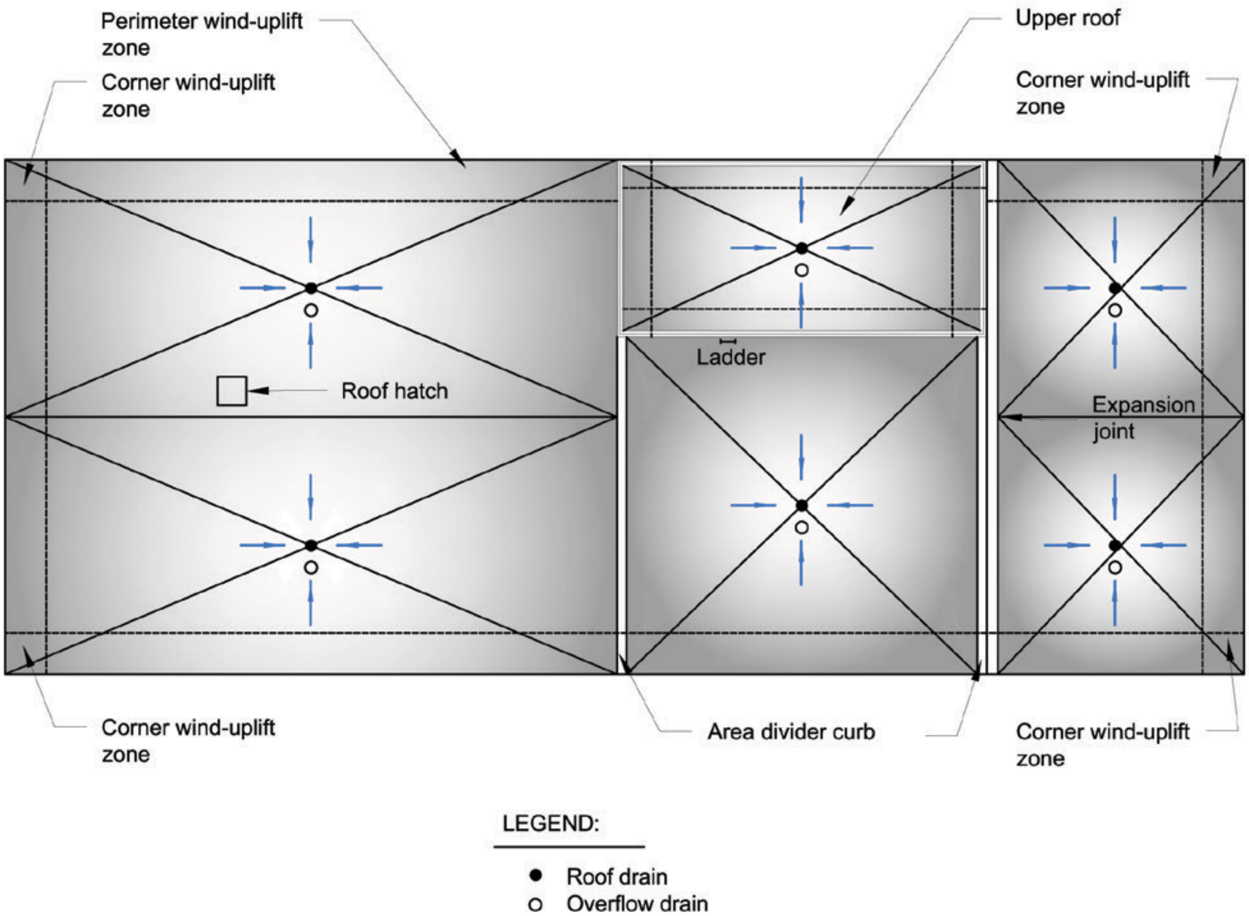
- Size gutters and downspouts to effectively drain maximum runoff by determining the amount of water the drainage system must handle given the area of the roof to be drained, its pitch, and the rainfall intensity. For specific information, see the SMACNA Architectural Sheet Metal Manual or the IPC requirements referenced in this section.
- Connect all downspouts to sloped leaders, with a 5 percent—6 inches per 10 feet—minimum slope that extends at least 10 feet from the foundation or that meets more stringent local code requirements. Leaders may be placed either above or below ground.
- For below-ground or above-ground leaders, use materials conforming to the standards listed in the IPC. Ensure that seams and joints in leaders are watertight to prevent water from escaping next to the foundation. In order to prevent root growth within below-ground leaders, ensure that the leaders are not perforated.
- If above-grade leaders are used, provide protection from accidental damage or encroachment.
- Direct all leaders to code-approved disposal, typically daylight, drywells, swales or ponds. But in buildings making efforts to reduce rainwater runoff, rainwater may be collected for use in building operations. Proper disposal prevents potentially contaminated storm water from adversely affecting water quality.
- In climates with significant snowfall, design the roof assembly to avoid ice dams on roofs that drain to external gutter systems. See Roof and Ceiling Assembly Design Goal 4 guidance.

Internal Roof Drainage Systems

Internal roof drainage systems consist of drains on the roof surface connected to down pipes running through the building's interior and leading to storm sewers or other discharge points. Internal roof drainage systems are the most practical solution for large, low-slope roofs. They are resistant to ice dam problems on low-slope roofs in areas of significant snowfall because the drains are warmed by the down pipes passing through the building. Internal drainage systems are seldom used on high-slope roofs (greater than 3:12). Figure 2-13 illustrates interior drain placement for a low-slope roofing system.

- Size and locate drains to remove maximum rainwater and snowmelt flows effectively. Refer to IPC Chapter 11, Storm Drainage.
- Ensure that features such as superstructures and roof-mounted HVAC units do not obstruct the flow of water from the roof to the drain.
- Equip roof drains with strainers or other devices to prevent leaves and other debris from clogging the drain or the down pipe.
- Locate drains at the center of bays between columns so that any structural deflection will produce slopes to the drain. Provide allowance in the leader connection for any vertical movement resulting from the structural deflection.

Figure 2-13 Plan Drawing Illustrating Interior Drain Location and Roofing Slope for a Low-Slope System



- Design all roofs with at least a ¼:12 pitch to overcome low spots caused by expected roof member deflection or construction within tolerances.
- Locate down pipes in interior chases. Down pipes in chases along exterior walls are more vulnerable to condensation.
- Allow easy access to down pipes for periodic inspection and repair by providing access panels or utility closets.
- For parapets or other architectural protrusions above the roofline, provide a secondary method for draining rainwater if the primary roof drainage system does not function. Two methods are often used:
  - The installation of scuppers through the parapet.
  - The installation of an additional system of roof drains and down pipes.

Guidance 3: Design penetrations parapets and roof and wall intersections to prevent the entry of rainwater. Figures 2-14, 2-15 and 2-16 illustrate rainwater control details for a gooseneck vent penetrating a low-slope roof and for a low-slope roof intersecting a parapet wall.

Drainage layers must maintain integrity at joints and penetrations, where the enclosure is the most susceptible to moisture problems. See Table 2-1 for a list of penetrations commonly found in roofs and for guidance on how to maintain integrity at those penetrations.

Figure 2-14 Three-Dimensional Drawing Detailing Rainwater Control Continuity at Intersection of Goose Neck Vent, Flashing and Roofing Membrane

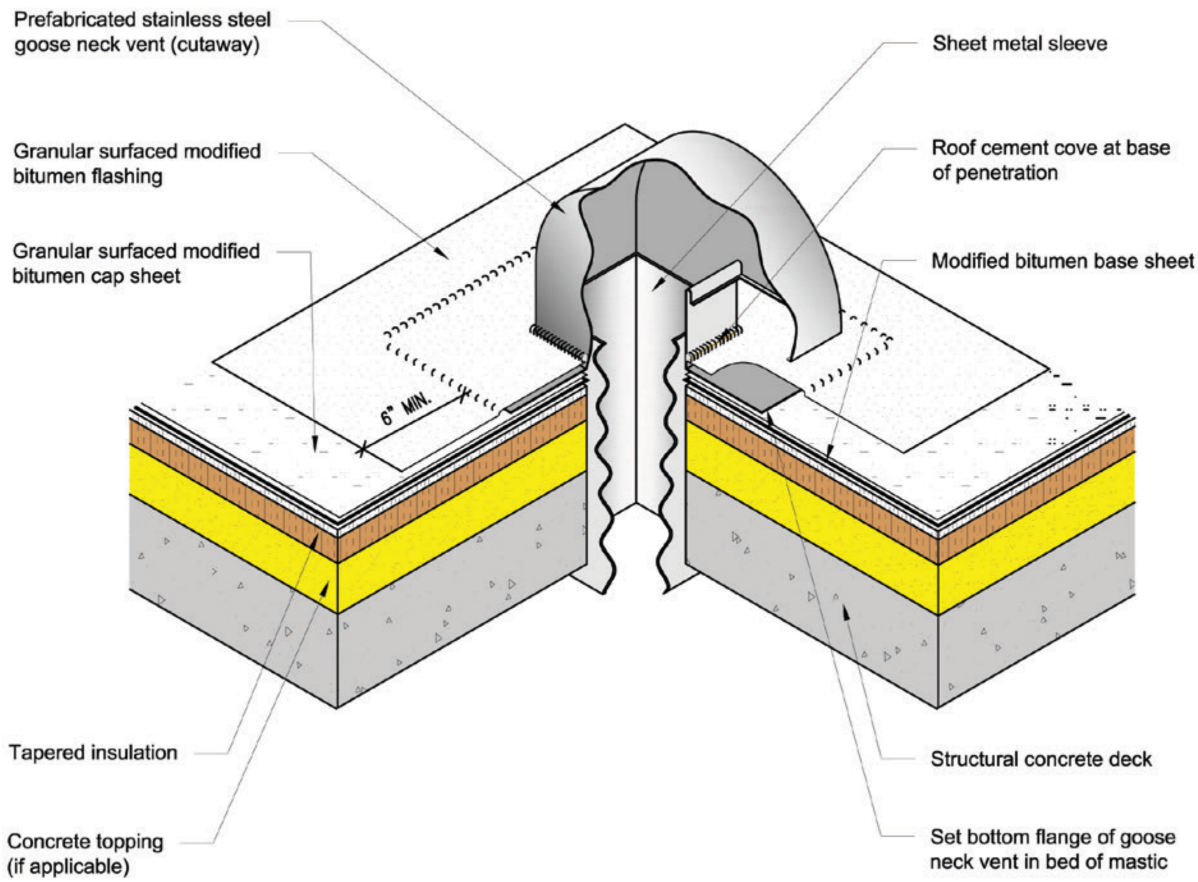


Table 2-1 Maintaining the Integrity of Drainage Layers at Joints and Penetrations
NOTE: Continuity of the air barrier and insulation layer must also be maintained at these locations.

Common Roof Penetrations	Ways to Maintain Integrity of Rainwater Protection
Joints between roofing materials	Provide continuity by shingling or sealing
Roof edges	Provide capillary breaks by using overhangs, copings and drip edges
Joints between the intersection of walls and roofs	Provide continuity by using flashing where a lower story roof intersects a wall of a higher level and where the roof meets the wall of a dormer
Skylights and roof hatches	Provide continuity by using flashing, curbs and counter-flashing
Chimneys	Provide continuity by using flashing, crickets and counter-flashing
Air handlers and exhaust fans	Provide continuity by using flashing, curbs and counter-flashing
Outdoor air intakes and passive relief vents	Provide continuity by using flashing and counter-flashing
Plumbing vents	Provide continuity by using flashing and counter-flashing

Roof and Ceiling Assembly Design Goal 2: Design roof assemblies to prevent condensation of water vapor on cool surfaces within the dry portion of the roof assembly, on the interior surface of the exterior roof assembly or within interior wall, floor or ceiling cavities.

Guidance 1: Design the roof and ceiling assembly to be sufficiently airtight to limit water vapor migration and heat transfer by air flow.

- Specify air-sealing details to provide a continuous air barrier from the center of the roof-and-ceiling assembly to the roof-wall intersection. Use the pen test (See Appendix A) to trace the continuity of the air barrier. NOTE: The air barrier for the roof is part of the whole building air barrier system.
- Specify a whole building air leakage rate when tested at 75 Pascal pressure difference in accordance with ASTM E779-10 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* or ASTM E1827-96(2007) *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door* or the U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes. For example, the U.S. Army Corps of Engineers requires a maximum air leakage rate of 0.25 cubic feet per minute per square foot of air barrier surface (6 sides) at a pressure difference of 75 Pascals.
- Use a layer of material in the roof or ceiling assembly as the basis of the air barrier systems:
    - Interior gypsum board, foam board or spray foam insulation, concrete, and OSB or plywood deck are good selections to form the basis of air barrier systems in roof assemblies. Include specifications for all accessory materials required to provide durable continuity of the air barrier.
    - Fully adhered roofing membranes can be used to make the air barrier in non-vented low-slope roof systems.
    - Fluted steel deck is difficult to use as the basis of an air barrier. (The flutes are difficult to air-seal at the perimeter and joints.)
    - A suspended T-bar ceiling—clipped or not—cannot be used as an air barrier system.
- Provide two-dimensional sections detailing methods for providing air barrier continuity at pipes, shafts, skylight vaults, light fixtures, conduits and other penetrations through the air barrier layer (See Table 2-1).
- Provide two-dimensional sections highlighting the air barrier and connecting materials and methods for each section.

Guidance 2: Select the overall insulation R-value to meet or exceed ASHRAE 90.1 or International Energy Conservation Code requirements.

- Provide two-dimensional sections detailing methods for providing insulation layer continuity:
    - At pipes, shafts, skylight vaults, light fixtures, conduits and other penetrations through the air barrier layer (See Table 2-1).
    - At transitions between one insulating material and another (e.g., where roof insulation meets wall insulation).
    - At thermal bridges in the insulation layer (e.g., where steel members penetrate the insulation layers).

Guidance 3: Collect the air barrier, the insulation layer and the materials with the lowest water vapor permeability (<2 perms) into an assembly of consecutive, touching layers. NOTE: This does not include the roofing or roof sheathing. Roofing and sheathing may be in contact with these layers—non-vented roof assembly—or separated by a space that vents to the outdoors—vented roof assembly. Figures 2-17 and 2-18 illustrate condensation control in two non-vented low-slope roof systems.

Step 1: Determine whether to use a vented or non-vented roofing system based on climatic and space-use considerations.

- Do not place mechanical equipment in vented attic space.
- Condensation on roof bottom sheathings that results from night sky radiation is most easily avoided by using unvented roof assemblies.
- Non-vented roofing is more resistant to fire caused by wildfire embers.

Step 2: Collect all the materials with low water vapor permeability (< 2 perms) together on one side of any vapor open cavity insulation layer. NOTE: Vented roof and ceiling assemblies separate low-permeability materials in the roofing-sheathing layer from low-permeability materials in the ceiling, air barrier and insulation layers by a vented space between them. Both the roof and ceiling assemblies can dry to this space. Apply either Step 3A or Step 3B.

Step 3A: Follow published guidance on combining insulation, an air barrier, and materials of appropriate permeablility for vented and non-vented roofing systems in the relevant climate zone.[20] Depending on the insulation systems selected, apply the following specific guidance.

If using insulation composed entirely of low-permeability foam insulation (e.g., closed-cell spray polyurethane foam or foam board insulation), note that:

- Spray foam provides an inherent air barrier, insulation layer, and vapor control for all climates. It still requires specific detailing at transitions between the spray foam and adjoining assemblies.
- Foam board provides insulation and vapor permeability control but requires air-sealing details at the joints, penetrations and roof-wall intersection. This can be achieved using a separate air barrier system (e.g., wood panel or gypsum board roof deck sealed to provide the air barrier) or using the foam board as the basis of the air barrier.

Caution: In special high-moisture areas (e.g., indoor swimming pools) using closed-cell spray polyurethane or foam board insulation, non-vented low-slope roofs may need a vapor retarder with a lower perm rating than that of the roofing membrane. Special analysis is needed for high internal moisture load uses (See Step 3B). If using all open-cell spray foam (½ lb./cu. ft. spray):

- Foam provides an inherent air barrier.
- Separate interior vapor control is required in climate zones 5, 6 and 7.
  - Put materials (except roofing materials) with perm <2 and the air barrier on the interior side of the insulation layer.
  - Use interior class II or III vapor barrier.
- Applies to vented and non-vented roofs.

If using all high-perm porous insulation (e.g., fiberglass, cellulose) for non-vented roofs:

- Use only in hot, dry climates.
- A separate air barrier system is required.

If using all high-perm porous insulation (e.g., fiberglass, cellulose) for vented roofs:

- A separate air barrier system is required.
- Separate water vapor control is required in climate zones 5, 6 and 7.
  - Put materials with perm <2 (except roofing materials) and the air barrier on the interior side of the insulation layer.
  - Use interior class I or II vapor barrier in climate zones 6 and 7.
  - Use interior class III vapor barrier in climate zone 5.
  - In all milder climate zones, put the air barrier on the inside or outside of the insulation layer. Use no materials less than 2 perms in the assembly —excluding roofing.

If using a layer of high-perm insulation and a layer of low-perm insulation together for non-vented roofs:

- All the low-perm materials (<2 perms) including the foam insulation should be collected on the exterior side of the high-perm insulation layer.
- Closed-cell spray polyurethane foam insulation provides an inherent air barrier.
- Foam board insulation must have a separate air barrier (e.g., roof sheathing or roofing membrane or air-sealing details at the joints, penetrations and roof-wall intersection).
- The temperature of the condensing surface should be controlled using a ratio of low-perm R-value to high-perm R-value. For ordinary indoor humidity conditions, at least one-third of the overall R-value should be provided by the foam insulation.

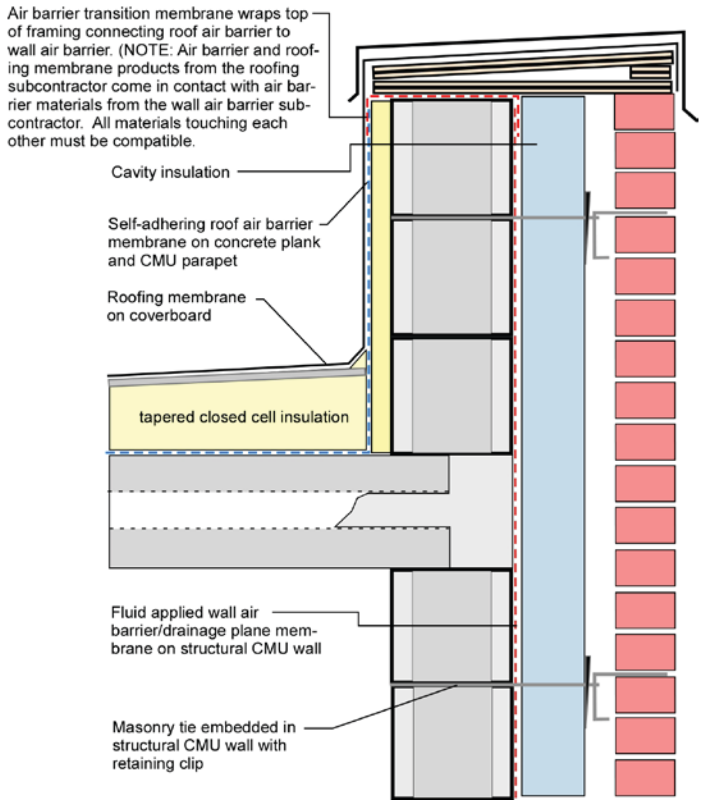
If using a layer of high-perm insulation and a layer of low-perm insulation together for vented roofs:

- All the low-perm materials (<2 perms) including the foam insulation should be collected on the interior side of the high-perm insulation layer.
- Closed-cell spray polyurethane foam insulation provides an inherent air barrier.
- Foam board insulation must have air-sealing details at the joints, penetrations and roof-wall intersection or a separate air barrier (e.g., roof sheathing or roofing membrane).

Step 3B: Model the performance of proposed roof assemblies using a hygrothermal software program (e.g., WUFI or hygIRC). Use design conditions from ASHRAE Standard 160-2009 for modeling. Note, however, that the results of computer simulations should be interpreted cautiously and in light of

[20] See Straube (2011) for all climate zones, Lstiburek (ASHRAE April 2006) for all climate zones and CMHC Best Practice Guides for climate zones 6 and 7.

Figure 2-15 Moisture Control in an Unvented Low-Slope Roof Assembly with Structural CMU Walls



real-world construction practices. For example, most computer models assume that walls are airtight and that no water vapor is transported through them by airflow. Therefore, for the model to be valid, the assembly must be designed, installed and tested to meet air tightness standards. Also, the performance of any assembly depends on its orientation in regard to solar load and wind direction during heavy rains. Some, but not all, of the programs can model the dynamic of rainwater absorbed by porous claddings and vaporized into the assembly by the sun.

Guidance 4: Control ice dams in climate zones 5, 6 and 7.

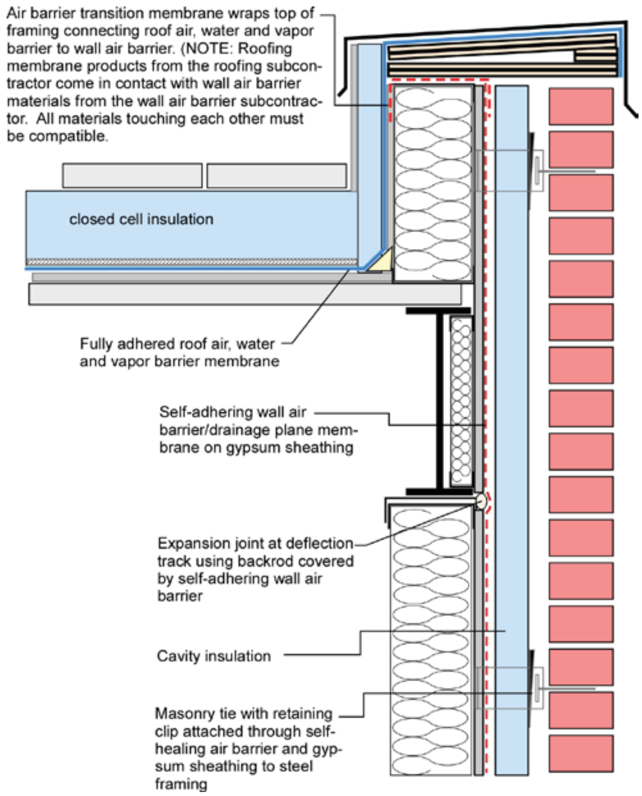
- Provide a carefully detailed, tested air barrier in the roof system (See Guidance 2). Locate the air barrier in the same plane as or adjacent to the insulation layer for all assemblies.
- Drain non-vented, low-slope roofs to interior drains or use spray or board foam to insulate non-vented roofs that slope to eave drainage. The required total R-value can be met using foam insulation alone or by a combination of foam insulation and high-perm porous insulation materials (e.g., fiberglass, cellulose or mineral wool). The foam insulation must be located in contact with, but outside of, the porous insulation.
  - Or use vented roofs that slope to eave drainage and avoid sources of heat in vented attics and vented roof sheathing systems.

Roof and Ceiling Assembly Design Goal 3: Roof design considers maintenance for moisture control.

Guidance 1: Ensure that systems are easily maintained and that maintenance plans are reviewed with the owner.

- Materials in the roof and ceiling assembly that will be difficult or expensive to remove and replace must have an expected service life at least as long as the materials enclosing them.
- Design assemblies to shed rainwater by use of flashings and lapping materials to drain. Do not depend on sealants alone to control rainwater entry in areas that will be difficult or hazardous to inspect and repair.
- Develop or require the contractor to develop maintenance documents for the roofing systems including warranty requirements, scheduled inspections and maintenance, and appropriate repair processes.
- Develop a plan for both surface and subsurface drainage that specifies:

Figure 2-16 Moisture Control in an Inverted Membrane Roof with Heavy Steel Frame and Light Steel In-Fill



- Maximum rainfall or snowmelt assumptions.
- Drainage surface areas including shapes, slopes, superstructures or other obstructions.
- Estimated water flows.
- The location and capacities of all conduits.

- Provide drainage system maintenance plan requirements.

Verification of Roof and Ceiling Assemblies

- Write a description detailing how the roof system manages rain. Include this description in the basis-of-design document.
- Use the pen test (See Appendix A) to verify the continuity of drainage surfaces, capillary breaks and flashing around penetrations from the center of the roof to the intersection with the exterior walls.
- Provide two-dimensional sections where two materials that form the rainwater control come together and three-dimensional drawings where three or more elements of the rain protection come together. Sections must show continuity of capillary breaks and flashing around penetrations and interface with air barrier and insulation systems.
- Provide a list of critical details, an inspection schedule and quality assurance tests of the roofing, inner capillary break (e.g., roofing felt, self-adhering bituthene membrane), flashing and drainage elements of the roof systems; identify the sequence of inspections and tests, the parties responsible for them and the required documentation of the results.
- Provide a list of inspection and maintenance requirements for the roofing, coping and flashing.
- Reference published roof assemblies designed to manage water vapor and condensation within the appropriate climate. Perform hygrothermal modeling when documentation through previous testing or modeling of a roof assembly in a particular climate or for unusual space humidity levels is not available.
- Write a description detailing how the roof system manages water vapor during cooling and heating modes, as applicable. Drawings and specifications must identify vapor migration control details and the permeability and insulating values of all materials.
- Use the pen test (See Appendix A) to verify the continuity of the insulation layers and air barriers from the center of the roof to the intersection with the walls.

- Provide two-dimensional sections where two materials that form the insulation layers and air barrier come together and three-dimensional drawings where three or more elements of the insulation and air barrier come together.
- Specify a fan pressurization test in design specification documents to assess the entire building enclosure in accordance with ASTM E779-10 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, ASTM E1827-96(2007) *Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door* or the U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes.
  - Specify the target airtightness level.
  - Specify when the test should be conducted in relation to the completeness of the air barrier system.
  - Identify the appropriate testing party.
  - Specify how the results should be documented, judged and accepted or rejected.
  - Specify the remedies if the building fails the test.
- Specify quality assurance programs for the installation of the hygrothermal control elements of the enclosure. Provide a list of critical details and a schedule for inspecting the air barrier, insulation and vapor control elements of the roof assembly. Specify the sequence of inspections, the parties responsible for the inspections, and the required documentation of the inspection results.
- Provide a list of inspection and maintenance requirements for the interior finishes if they are critical to water vapor control.

Plumbing Systems

Issue

Moisture problems associated with plumbing equipment include:

- Leaks in pressurized pipes and vessels, in appliances that use water and in pipes that drain wastewater.
- Condensation on cold-water lines, chilled water lines and toilets. The colder these surfaces are, the more likely condensation will form.
- Mold growth on partitions, ceilings and floors enclosing spaces that are subject to repeated wetting.

Once installed, plumbing is difficult and expensive to replace and relocate, so good design is very important. Moisture problems associated with poorly designed plumbing can cause damage that can affect almost any location in the building, including places that are not often seen or inspected or are difficult to access. Unnoticed mold growth can result from leaks, posing a health risk to building occupants. Gaining access to poorly designed plumbing for repair or replacement can necessitate demolishing obstructions, which leads to higher repair costs.

Goals

Plumbing System Design Goal 1: Design supply lines, drain lines, and fixtures to prevent water leaks and facilitate leak detection and repair.

Plumbing System Design Goal 2: Design plumbing systems to prevent condensation on cold water lines and fixtures.

Plumbing System Design Goal 3: Select materials to minimize mold growth in areas that are unavoidably wet.

Guidance

Plumbing System Design Goal 1: Design supply lines, drain lines and fixtures to prevent water leaks and to facilitate leak detection and repair.

Guidance 1: Reduce initial leaks by specifying testing of supply lines, drain lines and fixtures.

Determine specifications for pressure tests of supply and drain lines and fixtures to identify leaks in plumbing.

- Design specifications should require, at a minimum, the testing of supply lines in accordance with section 312.5 of the International Plumbing Code, or relevant sections of other applicable local codes, but they may require testing at higher pressures depending on the requirements of the equipment and plumbing system and the intent of the design.
- Design specifications should require, at a minimum, testing the drain and vent side of the plumbing system as required by the relevant building code. For example, designs should specify a gravity test of the drain and vent side of the system according to sections 312.2, 312.3, and 312.4 of the International Plumbing Code, or relevant sections of applicable local codes. If all or a portion of the drain side of the system will be pressurized during operation, appropriate pressure testing must be specified.
- Identify the test method and the design test pressure.
- Specify when the tests should be conducted in relation to the completeness of the plumbing system and the closing of the cavities (e.g., while lines are exposed for inspection, but before enclosing).
- Identify the appropriate testing party. Depending on the scale of the project and the parties involved, the appropriate testing party may be a commissioning agent; a testing, adjusting, balancing (TAB) contractor; a subcontractor to the general contractor; or a plumbing contractor.
- Specify how the results should be documented, judged and accepted or rejected.
- Specify the remedies if any portion of the plumbing system fails the test.

Guidance 2: Design the plumbing system for easy inspection and repair of components (e.g., pipes, valves, traps, grease traps, tanks, controls, heaters, filters and connections to appliances).

Place pipes and valves where they can be easily inspected and repaired, where leaks will be seen quickly, and where even a small leak will not wet a cavity made from moisture-sensitive materials. Avoid locating water lines and other plumbing components in exterior wall or ceiling cavities insulated with porous insulation. NOTE**:** If pipes must be located in an exterior wall or ceiling, they must be protected so that outdoor temperatures do not affect them and outdoor air cannot leak in to them. In addition to any required pipe insulation, place a layer of closed-cell board or spray-foam insulation between the pipe and the exterior sheathing or curtain wall. If board foam is used, it must be air sealed at the joints and edges and connected in an airtight way to the air barrier system at all perimeter edges. The object is to surround the pipe with warm interior air when it is cold outdoors and with cool, dry, conditioned air in air conditioning mode.

Plumbing System Design Goal 2: Design plumbing systems to prevent condensation on cold water lines and fixtures.

Guidance 1: Design the plumbing system's insulation and water vapor controls so the pipes, tanks and other equipment that convey or contain water cooler than the dew point of the outdoor air—or cooler than the expected dew point of the air in the enclosure where the equipment will be located—are free of condensation.

- Specify the design temperature and humidity conditions for the spaces that contain plumbing components conveying cool or cold water (e.g., chilled water lines, cold water lines, toilets, cold water storage tanks or water treatment tanks) and the expected surface temperatures of these items during the design condition.
- Specify the required R-value of the insulation and the permeability and location of the water vapor control element to prevent condensation on the surface of the insulation or on the surface of the pipe or plumbing component.
- Specify air-sealing methods and materials at joints and seams in the insulation and water vapor control elements.
- Provide details showing the continuity of the insulation and water vapor control where pipes pass through walls, ceilings or floors and where pipes join other plumbing components such as valves, gauges, pumps and tanks.
- Require the inspection of condensation controls for components that convey cool or cold water and specify when in the construction sequence the inspections must take place, the party responsible for performing the inspections, the methods that should be used to document the results of the inspections and any remedies for failed inspections.

Plumbing System Design Goal 3: Select materials to minimize mold growth in areas that are unavoidably wet.

Guidance 1: In unavoidably wet areas, use materials that tolerate repeated wetting and drying.

- Identify areas in the building that will get wet because of their use (e.g., entryway floors, bathroom floors, tub surrounds, showers, locker rooms, pool and spa rooms, and kitchens). Specify materials that are highly resistant to the growth of mold. Among these materials are ceramic tile, glass, plastic resins, metals and cement-based products.
- For materials known to be vulnerable to mold growth (e.g., untreated paper-faced gypsum board and OSB), use products and paints that are resistant to mold growth. Specify mold-resistance testing criteria that are appropriate for these materials (e.g., a score of 10 when tested using ASTM D3273 *Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber).*
- Avoid specifying materials that provide nutrients and sustain mold growth. Such materials include untreated paper-based products and composite wood materials.

Verification of Plumbing Design

Piping, Valves, and Controls

- Confirm that drawings and specifications document the location of pipes, valves and other plumbing system components and the location, size and type of access panels for inspection and repair.
- Confirm that the pressure test requirements of supply and drain lines, the specific responses to success or failure, the testing schedule, the responsible testing party and the required documentation have all been specified.
- Provide a list of critical details and a schedule for inspecting the plumbing system including supply

lines, drain lines, air vents, plumbing fixtures, appliances that use water, tanks and vessels. Specify the inspection sequence, the parties responsible for the inspections and the required documentation of the inspection results.

Insulation and Vapor Retarders

- Confirm that drawings and specifications include the design conditions, condensation control elements, inspection procedures, responsible parties and documentation as required.
- Provide a list of critical details and a schedule for inspecting the plumbing system insulation and vapor retarders, including supply lines and drain lines. Specify the inspection sequence, the parties responsible for the inspections and the required documentation of the inspection results.

Wet Spaces

- Confirm that the drawings and specifications identify appropriate moisture-resistant materials for use in wet locations including bathrooms, showers, locker rooms, pool and spa rooms, and kitchens.
- Provide a list of inspection and maintenance requirements for the moisture-resistant materials used in the unavoidably wet areas.
- Provide a list of critical details and a schedule for inspecting the moisture-resistant materials and associated liquid-water-control elements specified for use in unavoidably wet areas. Specify the inspection sequence, the parties responsible for the inspections and the required documentation of the inspection results.
- Provide a list of inspection and maintenance requirements for the moisture-resistant materials used in the unavoidably wet areas.

HVAC Systems

Issues

Some of the moisture problems in buildings can be caused or accelerated—or reduced or avoided altogether—through the design and installation of the HVAC system. The HVAC components that dehumidify the ventilation air deserve careful attention because **outdoor air constitutes most of the annual humidity load for nearly all buildings.**

Common HVAC-related contributors to moisture problems include:

- **Inadequate dehumidification by the HVAC system during humid weather.** The resulting high indoor air dew point can lead to condensation, near-condensation and mold growth. Comfort problems also are common when the indoor dew point is high because the relative humidity is also high. Occupants often demand lower thermostat settings in an attempt to be more comfortable. This is counterproductive. Lowering the thermostat overcools the building, which increases the risks of condensation, excess moisture absorption and subsequent mold growth. Cold temperatures also further reduce comfort and increase energy costs.
- **Leaking return and exhaust air duct connections, leaking indoor air handler compartments operating under suction, and leaking return air plenums.** These leaks create suction in building cavities, pulling humid outdoor air into the building where it can condense moisture onto cool surfaces and support mold growth.
- **Leaking supply air duct connections and leaking indoor air handler compartments operating under positive pressure.** When the weather is hot or humid, these cold air leaks chill surfaces behind walls and above ceilings, creating condensation and supporting mold growth. During cold weather these same leaks can force warm, humid indoor air into cold cavities where it can condense and support mold growth and corrode structural fasteners.
- **Oversized cooling systems.** When cooling systems, rather than dedicated dehumidification components, are expected to control humidity, the traditional inclination of designers is to increase the cooling tonnage to remove the combined sensible and latent loads. But overpowered cooling systems have exactly the opposite effect. A large cooling system removes the normal sensible load very quickly. Then, to avoid over-chilling the space, compressors are shut off or chilled water flow rate is reduced before the coils can condense enough moisture to control humidity. In nearly all cases, oversized cooling systems do not solve humidity control problems—instead, they cause them.
- **Ineffective drainage of condensate collected inside the HVAC system or condensation on the outside of the system's cold and uninsulated surfaces.** Undrained and uncollected condensate leads to water leaks, drips and subsequent moisture damage and mold risk.
- **Failure to exhaust indoor humidity sources such as showers, bathrooms, spas, pools and kitchens, especially in residential buildings and sports facilities.** Humid air can migrate from these sources to cold surfaces, leading to condensation or near-condensation and subsequent mold growth and structural deterioration.

Goals

HVAC System Design Goal 1: Keep the indoor air dew point low enough to reduce the risk of condensation on cool surfaces and the risk of moisture absorption by organic materials.

HVAC System Design Goal 2: Seal all duct connections to prevent hot, humid outdoor air from being pulled into the building by leaking return air duct connections, leaking return air plenums and unbalanced exhaust. Sealed connections also prevent condensation caused by supply air escaping through duct connections into unconditioned spaces.

HVAC System Design Goal 3: Prevent condensate from cooling coils from overflowing into drain pans and prevent condensation on the external surface of cold pipes, valves, ducts, diffusers and indoor air handler cabinets.

HVAC System Design Goal 4: Limit indoor humidity loads through effective exhaust ventilation—via duct work with sealed connections—from showers, tubs, kitchens, pools, spas and other significant sources of moisture. Balance the exhaust air with dry makeup air to prevent the exhaust from pulling unconditioned outdoor air through the building enclosure.

Guidance

Building owners and HVAC designers will note that this guidance is a necessarily brief summary of several complex tasks. More detailed design methods to achieve these goals are presented in the ASHRAE *Humidity Control Design Guide for Commercial and Institutional Buildings.*

HVAC System Design Goal 1: Keep the indoor air dew point low enough to reduce the risks from condensation on cool surfaces and from moisture absorption by organic materials.

Guidance 1: For an air-conditioned building, design the HVAC systems to include dehumidification components and a control system that will keep the indoor air below a 55°F dew point during humid weather.

Indoor air held below a 55°F dew point cannot condense moisture onto cool ducts carrying supply air at 55°F. Nor will moisture condense on surfaces chilled by that supply air as it leaves the supply air diffusers. And only very small amounts of condensation, if any, will form on incompletely insulated chilled-water piping. A maximum 55°F dew point control level provides an appropriate safety margin to reduce the impact of minor shortcomings in the building enclosure design and construction, and it minimizes the risk of condensation from the inevitable minor air leakage through duct connections.

Among the effective dehumidification techniques are:

- Drying all the ventilation air in a separate, dedicated outdoor air system (DOAS) to a dew point low enough to remove the internally generated humidity loads. DOAS can also be designed to have other significant risk-reduction benefits. They can reduce ventilation air in response to reduced occupancy, which greatly lowers annual humidity loads, energy use and the risks associated with moisture accumulation. During occupied hours, dedicated outdoor air units can be used to provide a slight excess of dry ventilation air, so most of the air leaks in the building enclosure involve dry air moving outward, rather than humid air moving into the building. By providing a return air connection with a damper, the system can keep the building dry during unoccupied periods by recirculation, without the need to either ventilate or to operate the central cooling system.
- Arranging the main cooling system so it can sufficiently dry ventilation and return air to remove all of the humidity loads even when thermostats are not calling for cooling. This drying can be accomplished by using a separate dehumidification coil, or by a variable air volume cooling system. In both cases, the cooling coil must stay constantly cold and not re-set to a higher temperature during periods of low sensible heat load. In a variable volume system, keeping the coil constantly cold will require reheating the supply air to some zones. To comply with energy codes and ASHRAE Standard 90.1, reheat energy should come from heat otherwise wasted, such as rejected heat from refrigeration condensers or heat from exhaust air. Also note that to avoid losing dehumidification capacity, reheat coils should be located well downstream from dehumidification coils. Otherwise, the energy radiating from a closely coupled reheat coil will re-evaporate some of the condensed water as it drips from the dehumidification coil.
- Drying a portion of the blended return and ventilation air with a secondary cooling coil or a desiccant dehumidifier that operates in response to a rise in the indoor dew point. In this alternate arrangement, the air will follow a dual path: part of it will be dried by the secondary coil or desiccant dehumidifier and the rest will bypass the main cooling coils unless there is a need for cooling. Reheat or post-cooling usually is not required for this arrangement. After the dry air blends back into the supply, the blended mixture is generally warm or cool enough for occupant comfort.

Guidance 2: Use the peak outdoor dew point design conditions—not the peak sensible heat design values—to estimate humidity loads when sizing dehumidification components and systems.

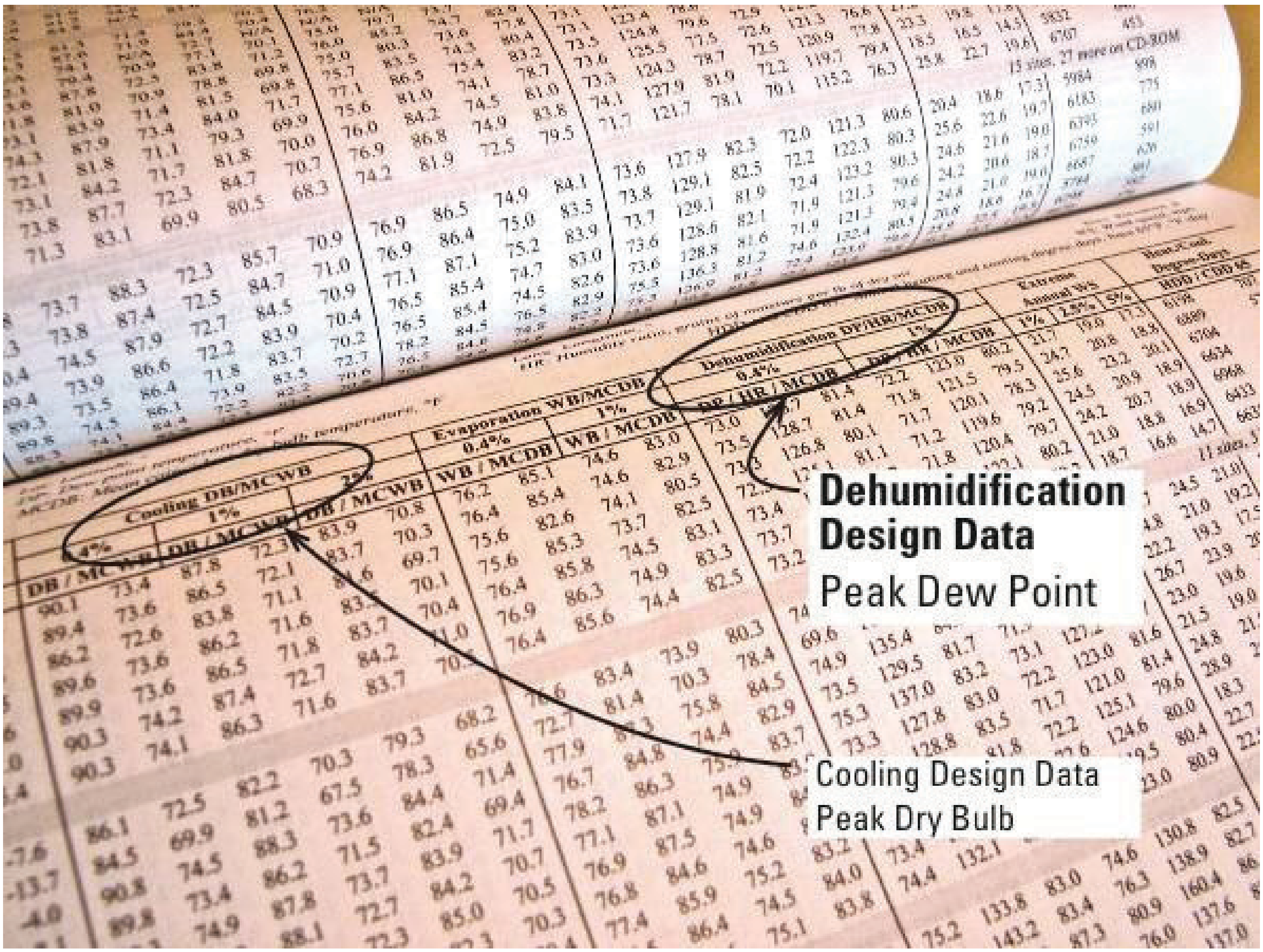
- The largest sources of humidity load are nearly always the ventilation air, the exhaust makeup air and air infiltrating through the building enclosure. These loads are at their peak when the outdoor air is at a moderate temperature but a very high humidity. At this peak outdoor dew point design condition, the humidity loads are 30 percent to 100 percent greater than the humidity loads at the hottest outdoor dry bulb conditions. So for sizing dehumidification loads and determining component performance, it is very important to use the ASHRAE peak dew point design conditions and not the peak cooling design conditions.

- Peak dew points along with their corresponding humidity ratio values for major North American and international locations are available in the ASHRAE *Humidity Control Design Guide*. Those data and values for many additional locations also now appear in Chapter 14 of both the print and electronic editions of the ASHRAE *Handbook 2009—Fundamentals*, as shown in Figure 2-17.

Guidance 3: Limit the operation of any air-side economizer to only when the outdoor air dew point is below 55°F.

- Air-side economizers have been responsible for significant problems related to moisture in buildings, especially schools and libraries that require only moderate cooling during lengthy unoccupied periods—a task well suited to cooling with outdoor air. However, unless that outdoor air is dry as well as cool, the flood of air brought in during the economizer cycle adds a tremendous amount of moisture to the building and its contents. Controlling the economizer with an enthalpy control does not solve the problem because the outdoor

Figure 2-17 Peak Dew Point Data are Available in the Climatic Design Information Chapter of the ASHRAE *Handbook—Fundamentals*



NOTE: The print edition of the ASHRAE Fundamentals volume for 2005 did not contain these values, but they are available on the accompanying compact disk. The printed edition of the 2001 Fundamentals contains peak dew point values for a more limited set of locations, as does the 1997 edition. Be aware, however, that the ASHRAE Fundamentals volumes from 1993 and earlier do not contain values for peak dew point—only for the sensible cooling design extremes, which have much lower absolute humidity levels than the peak dew point conditions.

humidity can still be too high even when its enthalpy is lower than indoors.

- An air-side economizer is still a useful energy-saving feature in less-humid climates. But the decision to bring in outdoor air for cooling should be made based on the outdoor air dew point as well as the outdoor dry bulb temperature. A maximum 55°F dew point is a good rule of thumb. If the outdoor dew point is above 55°F, do not bring in extra outdoor air for cooling, even if its dry bulb temperature or its enthalpy is below the indoor value.

Guidance 4: Design the system to keep the indoor dew point near or below 35°F when the outdoor temperature falls below freezing.

- To limit the risk of damage from moisture and mold, the basic requirement for humidity control in the winter is to avoid condensation inside the cold exterior wall. The most appropriate maximum indoor dew point in the winter depends on the annual duration and severity of cold weather at the site, and on the design and construction of the building enclosure and its glazing.
- Higher indoor dew points provide more comfort during the winter, but lower dew points are better for avoiding condensation on cold surfaces on and inside exterior walls. A 35°F dew point maximum during winter weather is a prudent compromise between these two competing goals for most commercial and institutional buildings. That level is at the lower boundary of the winter thermal comfort zone as traditionally defined by ASHRAE Standard 55. And as noted in the ASHRAE *Humidity Control Design Guide,* a 35°F dew point is still high enough to help limit uncomfortable electrostatic discharges and eye irritation for the general population.
- Museums, swimming pool enclosures and hospitals are exceptions; they all have much higher winter indoor dew points for important reasons. Their building enclosures demand very careful attention to interior-side air tightness and vapor retarders on the inside surface of the exterior walls in order to limit their high risk of moisture problems due to wintertime condensation.
- For any type of building in an extremely cold climate; the more hours below freezing, the more important it will be to carefully analyze the condensation potential of the exterior wall and glazing designs and to install continuous air and vapor barriers inboard of the buildings' insulation. Better insulated and more air-tight building enclosures can tolerate higher indoor dew points to improve comfort for occupants.
- Most buildings are not mechanically humidified during the winter, but in some cases such humidification is useful and necessary. When the building is humidified, the designer should remember the advice of humidifier manufacturers, which is repeated in the ASHRAE *Humidity Control Design Guide.* Namely, consider splitting the required humidification capacity between several units in stages, rather than install one single, large unit. Humidifier manufacturers warn that building moisture problems are sometimes caused by humidifiers that are so large they cannot be controlled at the lower end of their capacity. These units can overload the supply air with water vapor, causing condensation, moisture accumulation and water leaks from ducts.

HVAC System Design Goal 2: Prevent hot, humid outdoor air from being pulled into the building by leaking return air duct connections, leaking return air plenums and unbalanced exhaust. Prevent condensation caused by supply air escaping through duct connections.

Guidance 1: Specify that all duct connections on the supply and return air sides be sealed with mastic to the standards established by SMACNA's *HVAC Duct Systems Inspection Guide* for high-pressure duct work (Seal Class A).

- Ducts and their connections need not be built to resist high pressures if they are not operating under high pressure. However, all duct connections, especially where ducts meet air handlers, must be sealed tight with mastic. NOTE: Recent energy code changes in several states have made this guidance a requirement. The requirement is based on the considerable energy cost savings and equipment size reductions made possible by preventing air leaks into and out of duct work.

Guidance 2: Specify that all joints and penetrations of all return air plenums be sealed with fire or smoke sealant so that the plenum is open to air flow only from the inside of the occupied space it serves—and especially not open to inward leakage from exterior walls, crawl spaces or basements.

- One classic problem area is an exterior wall where the gypsum wallboard does not extend all the way up to seal against the bottom of the floor or roof above. Such openings to the inside of the exterior wall must be plugged with backing material such as glass fiber insulation and then sealed with liquid-applied conformal film such as fire or smoke sealant.

- In commercial buildings, roof-mounted air conditioning units are often mounted on curbs above return air plenums. The joint between the curb and the unit must be sealed tight because it is effectively part of the duct system.
- Fire codes sometimes allow vertical plumbing chases to be used as return air ducts, a situation that can be found in low-cost construction. The volume of air that leaks into such chases is likely to be extreme, however, and likely to come from undesirable locations such as basements and crawl spaces, loading the return air with humidity, particulates and microbiological contaminants. To avoid problems, the designer should insist that all spaces used as air ducts be sealed and tested for air tightness.
- In low-rise school, office and retail strip mall construction, the joint between the exterior walls and roof often includes an open soffit under the eaves. A return air plenum that can draw air through that soffit becomes, by accident, an all-outside air system. Any building that has a soffit requires special attention from the HVAC designer to ensure that return air is pulled from the occupied space and not from outdoors.

Guidance 3: Design the systems to manage indoor-outdoor air pressure relationships. If a building enclosure has been designed and constructed with an effective air barrier, continuous insulation layers, and rainwater control as required by this guide, then for ordinary occupancies enclosure-related problems are not very sensitive to indoor-outdoor pressure relationships. In warm, humid climates (See Climate Zone map, Figure 2-5) maintaining a slight positive pressure during cooling conditions adds extra protection against condensation in the building enclosure.

To create a slight positive pressure, add up all the exhaust air volumes from all zones served by a single system. Design the air conditioning system for those zones so that the total of the dry makeup/ventilation air exceeds the total exhaust from those areas by 5 to 10 percent. Balance the exhaust and ventilation air flows during humid weather so that the building stays, on average, under slightly positive air pressure (5 Pa or 0.02" WC). Use dry ventilation air to accomplish this slight positive pressure.

Maintaining an average positive air pressure can also be accomplished more explicitly and automatically by sensing the pressure difference between indoors and outdoors and using that signal to control a relief damper on small buildings and one or more relief air fans on larger buildings. Such a pressure control system makes it easier for the building operations staff to reverse the direction of the pressure difference for winter operation.

- When outdoor air temperatures are below freezing and indoor relative humidity must be maintained above 35 percent, there are advantages to operating under neutral or slightly negative air pressure so humid indoor air is not forced into cold exterior wall cavities, where it could condense moisture.
- Note that some buildings such as hospitals, museums, and high-rise buildings, as well as areas such as walk-in freezers and indoor swimming pools, require special care with respect to air balance. Their unique and sometimes critical needs for specific pressure differences between spaces necessitates consultation with industry-specific references for more detailed and appropriate guidance.

HVAC System Design Goal 3: Prevent normal condensate from cooling coils from overflowing drain pans and prevent condensation on the outside of cold pipes, valves, ducts, diffusers and indoor air handler cabinets, as recommended by ASHRAE Standard 62.1-2007.

Guidance 1: Specify that all cooling coils be equipped with condensate drain pans that have these characteristics:

- The pan is long enough in the direction of air flow to catch any condensate blown off the coil during heavy condensing conditions.
- The pan drains from its lowest point and slopes towards that lowest point from two directions to ensure there is never any standing water in the pan.
- Any drain pan that does not have a condensate pump is equipped with a trap on the condensate drain line deep enough to ensure no water remains in the pan drain when the fan is operating.
- The trap is vented on the outlet side to ensure that plug flow in the downstream condensate piping does not siphon water out of the bottom of the trap.
- The condensate drain line and trap are accessible and detachable to allow cleanout with a brush.
- Clearances around the duct work and duct access doors allow for regular inspections and cleaning of the condensate drain pan.

Guidance 2: Specify that all interior faces of duct work or plenums located immediately downstream from cooling coils be lined with smooth, washable, water-impermeable material to prevent accumulation of moisture and dirt on those surfaces. It is a prudent rule of thumb to have an impermeable and washable surface for at least the first 10 feet downstream of dehumidification coils. Also specify that:

- Any joints in the moisture-impermeable lining are sealed watertight.
- The outlet duct work or plenum is equipped with a gasketed door large enough to ensure access adequate for inspecting and cleaning downstream duct surfaces.

Guidance 3: Design the component layout so that filters are located either upstream of cooling coils or far enough downstream so they do not collect droplets of moisture stripped from the coil during periods of heavy condensation. For coils intended principally as dehumidification components, specify:

- Coil fin height no greater than 4 feet above the bottom of the drain pan, face velocity below 400 feet per minute, and spacing of eight fins per inch or wider to minimize water accumulation on the fins and subsequent droplet carryover into the supply air under heavy condensing conditions.
- Maintenance access upstream of the coil through one or more gasketed doors that are sufficiently large to allow the full width and height of the coil surface to be cleaned.

HVAC System Design Goal 4: Limit indoor humidity loads through effective exhaust ventilation—through duct work with sealed connections—from showers, tubs, kitchens, pools, spas and any similar significant sources of indoor humidity.

Guidance 1: Provide exhaust ventilation of strong humidity sources (e.g., showers and bathtubs, spas, cooking ranges, commercial dishwashers and combustion devices), as recommended by ASHRAE 62.1-2007 and ASHRAE 62.2-2004. In addition:

- Specify sealing of all exhaust air duct work connections to SMACNA seal class A using mastic. Pay special attention to the joint where the ducts connect to the exhaust grille collars and to the inlets and outlets of fan compartments. This sealing is important for all exhaust ducts in all buildings, but it is especially important for ducts that have continuously operating exhaust fans, such as those in the bathrooms of hotels and eldercare buildings. Many of these buildings have suffered frequent mold problems as a direct result of leaking exhaust duct connections. Such leaks create suction that pulls humid air into the building, where its moisture condenses or is absorbed into cool wall board and onto ceiling tile and furnishings where the moisture supports mold growth.
- For exhaust ducts from commercial kitchens, spas, pools, athletic building showers and other hot, high-humidity spaces, require duct insulation in order to avoid internal condensation. Specify similar insulation for exhaust ducts from residential bathrooms and kitchens in cold climates, because the dew point in the exhaust air is likely to be above the cool indoor air temperatures in the unheated cavities and attics that the ducts pass through on their way to the outdoors.
- Design exhaust ducts to terminate outdoors and not in unconditioned indoor areas such as attics or crawl spaces.
- Do not terminate the exhaust duct by directing exhaust air through the ventilated soffit under eaves. The hot and humid air will quickly rise and re-enter the attic space through nearby vents in the same soffit, leading to mold growth in the attic and on the roof's inside surface.

Verification of HVAC System Design

Cooling Season Dew Point Control

- Explain in the design specifications the operation of the air conditioning and dehumidification equipment at design dew point conditions and the expected humidity removal under those conditions, expressed in pounds of water vapor removed per hour.
- Require that the supplier of the dehumidification component or system provide written documentation of the equipment's performance—including pounds of water vapor removed per hour, total air flow, and the temperature of air as it leaves the device—when the system is operating under peak outdoor dew point conditions. These conditions will always be of reduced sensible heat loads, so the suppliers' submittals for the peak dew point conditions will provide very useful snapshots of the behavior of the entire system's operation under part-sensible-load conditions—temperature conditions that occur for thousands, rather than dozens, of hours every year.

- Require that the dehumidification system be tested, adjusted and balanced and that reports from that process verify and document the system's performance after the system is running. At a minimum, measure and document the design versus actual air flow through the device and the temperature and humidity ratios of the air as it enters and exits the device, then calculate the equipment's performance in pounds of water vapor removed per hour.
- Require that the economizer air-flow and damper operation be tested, adjusted and balanced and require reports from that process that will verify and document the economizer air flow rate. The Test, Adjust and Balance (TAB) report should also confirm that the economizer damper has been seen to open correctly and that the dampers and control set points allow the economizer to operate only when the outdoor air dew point is below 55°F.

Winter Condensation Control

- Design the installation surrounding any humidifier in strict accordance with the manufacturer's recommendations for exterior insulation and for unobstructed lengths of straight duct downstream for complete vapor absorption. Also ensure that the controls allow smooth modulation of humidity production down to 20 percent of the equipment's peak design capacity.
- Require that any humidifier and its control system be tested, adjusted and balanced and that the ductwork downstream be checked for condensation during operation of the humidifier. Require reports that measure and verify total air flow and the temperatures and humidity ratios of entering and leaving air.

Air Distribution

- **Minimal requirement:** Require the general contractor to inspect all sides of all joints between ducts and air handlers and to provide a written report that all sides of joints to and from air handlers are sealed with mastic. Also require the installer to certify that all other joints in the system have been sealed with mastic.
- **Robust requirement:** Require that the completed system, including air handlers, be tested for air tightness in accordance with SMACNA requirements for commercial buildings or with the Air Conditioning Contractors Association (ACCA) recommendations for residential buildings. Require a written report of measured air leakage values in accordance with the recommendations of those organizations.
- Require the HVAC contractor to inspect all sides of return air plenums and provide a written report, including photographs, that documents all joints and penetrations are effectively sealed.
- Require that the written TAB report provide assurance that all exhaust duct joints, and especially their connections to exhaust grilles and exhaust fans, have been inspected to confirm they have been sealed with mastic.
- Require that the air conditioning and exhaust systems be tested, adjusted and balanced.
- Include in the TAB process a pressure map of the building during air conditioning and heating modes documenting indoor-outdoor pressure differences over the course of daily sequences.
- Require reports from the TAB process that will verify and document system air flows after the system is running.

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Chapter 3: Constructing to Prevent Moisture Problems

Introduction

This chapter is for the people who turn design documents into buildings. More attention is being paid to moisture control during construction now than ever before because of increased concern about mold growth in buildings. In this chapter moisture control issues are divided into two major topics:

1. Control of water during the construction of the building.
2. Effective implementation of the moisture control requirements specified by the designers in the construction documents and associated contracts.

Erecting a building often involves several companies providing services from multiple trades. The general contractor has the primary responsibility and contractual obligation for the building's construction. The physical work often is carried out by specialized subcontractors such as landscapers, roofers, glazers, concrete and masonry contractors, steel fabricators, electrical contractors, insulation and waterproofing contractors and mechanical contractors. Providing moisture control during construction is largely the responsibility of the general contractor and the subcontractors. However, firms specializing in construction management or building commissioning may have responsibilities for moisture control.

The concept of commissioning traditionally has been applied to heating, ventilation, and air conditioning (HVAC) systems. Commissioning has been very effective in reducing problems and increasing energy efficiency and comfort. Over the past decade, this process has been extended to entire electrical systems; potable water, sanitary, drainage and irrigation systems; power production and cogeneration systems; the building enclosure; sustainable aspects of the project; and the entire building design process (ASHRAE Guideline 0: *The Building Commissioning Process*, GSA *The Building Commissioning Guide,* and the National Institute of Building Science [NIBS] *Total Building Commissioning Program*).

If a commissioning agent is involved in the design and construction of a building, many of the quality assurance procedures for moisture control and associated measures could easily fall within the commissioning agent's scope.

During the initial meetings, the contractor can develop a plan to:

- Protect the building from, and respond to, moisture problems during construction.
- Implement the moisture control elements, verification activities and commissioning activities detailed in the drawings and specifications.

Moisture control policies to protect the building during construction and to ensure the design has been effectively implemented should be in place before construction begins. After agreement on moisture control issues has been reached, the contractor must implement and verify the moisture controls required during construction and those required for the successful operation of the building.

Control of Moisture During Building Construction

Construction companies have always had to deal with moisture problems at the construction site. Materials and equipment get wet from:

- Rain.
- Water used in materials that are installed wet.
- Leaks in temporarily or permanently installed plumbing.
- Condensation in the building before it is enclosed.
- Poor humidity control after the building is enclosed, but before the HVAC system is operational.

As the site work begins and before the building is enclosed, contractors may use temporary site drainage, pumps, and dunnage and tarps to keep the site and materials relatively dry. Many of the materials used in the early phases of a project will not be damaged if they get wet, although some will have to be dried before they can be used. For example, foundation materials need to be dry before some coatings and flooring can be applied.

The sequence of activities plays an important role in preventing moisture problems during construction

- Moisture-sensitive and moisture-absorbing material and equipment should be scheduled for delivery when dry, protected storage is available.
- Wet, porous materials should be dry before moisture-sensitive materials are installed or moisture-sensitive coatings are applied.
- Moisture-sensitive materials need to be protected from the weather as they arrive on site. Measures to keep rain away from the materials may also protect them from damage by dust and wind.
- It is preferable to enclose the building so it is weather-tight before the moisture-sensitive materials arrive. While this situation can be planned for smaller projects, it may not be possible for larger ones. In these instances, contractors may provide temporary shelter for materials and equipment stored on site. They may protect partially completed work with tarps, temporary enclosures, or temporary bulkheads at floor penetrations. For example, gypsum board, brick, concrete block and wooden materials can be wrapped in plastic, covered by tarps or plastic and stacked on pallets in well-drained areas. Some materials that need to be protected, such as brick and concrete masonry units, can be delivered wrapped in plastic.
- The lower stories of high-rise buildings are often being finished while the upper floors are still open to the weather. This situation requires using upper floors as temporary protection by making temporary bulkheads at floor penetrations and draining floors to the perimeter. Increasingly, contractors also use dehumidification equipment to dry out buildings that are enclosed, but not yet air conditioned.
- In spite of the best efforts to keep material and equipment dry, accidents still happen and things do get wet. Brick and concrete block may have absorbed water before they were delivered or while they were stored at the site. Heavy wooden timbers may have been milled and installed while still green. The earthen floor of a crawlspace foundation is a large area of soil exposed to the weather right up until the overhead floor deck is installed. Some materials get wet accidentally because of rain or for other reasons. It is important to dry out any moisture-sensitive materials as quickly as possible.

Implementing the moisture control features of the design consists of two essential actions

1. Understanding the moisture control design features in detail and ensuring their constructability.
2. Ensuring the moisture control features are effectively installed.

Coordination between construction companies who are obligated to control moisture in buildings as specified in the construction documents and building designers (architects and engineers) will enhance moisture control in the building. The contractor should review the moisture-control elements of the enclosure and mechanical system designs and discuss them with the designer(s) at the start of the project. However, contractors, subcontractors, construction management personnel, commissioning agents, and owners frequently propose alternative details, materials, or equipment. It is important to note that these changes can lead to changes in the moisture control requirements of the building and must be included in moisture planning. This includes proposals made during the bid process; during the development and review of submittals; at initial meetings between the contractor, designer, owner, and construction management service; or during meetings to review submittals, construction progress, difficulties, and responses to problems that have arisen. The contractor is urged to read Chapter 2 of this document to become familiar with the moisture control guidance for designers. The construction documents can be compared with the design recommendations of Chapter 2.

Scheduling is an ever-changing target that requires juggling the schedules of numerous suppliers, sub-contractors, supervisors and inspectors. This already daunting task can be further complicated by larger issues, such as changes in markets or disasters in other parts of the world, that might affect the price and availability of supplies. It is crucial that the materials required to control moisture in the enclosure and the equipment required to control humidity in the building arrive so they can be installed in the correct sequence. For example, the drain plane or air barrier within a wall must be installed before the wall is closed in; otherwise, proper installation becomes a matter of demolition and reconstruction.

Whether the general contractor is coordinating the installation of moisture control systems or a subcontractor is installing them, it is crucial to have a quality assurance program in place to inspect, test and document the correct installation and functioning of the moisture control elements. This may mean the difference between avoiding or having a moisture problem. Some examples of moisture problems resulting from poor or no quality assurance practices are:

- Missing flashing.
- Flashing installed with laps reversed.
- Flashing that stops short of becoming a through flashing.
- Missing insulation.
- Missing sealant.
- Unsealed holes in the return plenum that cause depressurization of wall cavities.
- Condensate pan drain lines, internal roof drains, or basement sump crocks installed at the highest point rather than the lowest.
- Impermeable flooring or moisture-sensitive flooring installed on a concrete slab that is releasing too much water vapor.

Inspecting moisture control elements as they are installed is the most important aspect of supervision—especially in the areas where inspections may be most difficult. In addition to QA officers who are employees of the general contractor or subcontractor, inspections may be made by third parties such as construction management or commissioning firms.

The inspector must check that the specified materials are on site and being installed so they will perform their function. Sequence is often important in effective installation. The following items must be frequently and carefully inspected during installation:

- The air barrier.
  - Air barrier materials should be installed so they can be easily sealed at the joints and penetrations.
  - Sealants that complete the air barrier should be installed before access to the air barrier is blocked.
- Rainwater control.
  - The shingling of the drain plane and the flashing for roof, walls, windows, doors and other penetrations should be correctly installed.
- Insulation.
  - Insulation should be installed so that it makes as complete a layer as possible (i.e., no voids in cavity insulation, no uninsulated cavities).
- Plumbing.
  - The location of plumbing lines should be checked.
  - Cold water lines, chilled water lines and internal roof drains should be insulated; pressure tests should have been completed prior to installation of insulation and enclosing finishes.
  - Access to valves should be available.
  - Wet rooms should be assembled using only moisture- and mold-resistant materials.
- HVAC.
  - Condensate pans should be sloped and plumbed correctly.
  - Access panels should be installed downstream of the coils so the coils and ductwork can be inspected and cleaned.
  - Ductwork and return plenums should be air sealed and tested.
  - Duct insulation should be installed and the ductwork sealed.
  - Chilled water and refrigerant lines should be insulated and sealed.
- Wet materials.
  - Materials that need to be installed wet or that became wet accidentally must be dry before cavities are enclosed (e.g., concrete, concrete masonry units or porous insulation must be dry before they are enclosed by gypsum board walls; crawlspaces must be drained and ground covering installed before OSB floor decking is installed) or flooring (e.g., vinyl flooring on concrete slabs) is installed on them.

A number of tests may need to be performed to demonstrate that a moisture control element is working properly. Some of the tests are required by code; some may be specified by the designers in the construction documents; some may be required to maintain a manufacturer's warranty and some may be performed by the contractor for its own assurance. The tests include:

- Air tightness of the enclosure test (ASTM E779-10, ASTM E1827-96 [2002] or ACE [2012]).

- Air leakage and rain penetration tests on mockups or in situ portions of the enclosure (ASTM E783, ASTM E1105).
- Water vapor emission test for concrete slabs before installing flooring (ASTM F1869) or ASTM F2170).
- TAB on exhaust airflows (ASHRAE).
- Pressure test of water supply system (International Plumbing Code Section 312.5).
- Testing the drainage and vent air of plumbing systems (International Plumbing Code Section 312.2, 312.3 and 312.4).
- Drainage tests for condensate drain pans in air conditioners. (There are requirements for slope, etc. in ASHRAE 62.1.)
- Air pressure difference tests.
- Duct leakage testing (SMACNA).

Documentation of the inspection and testing results may include the date, location, purpose of inspection, results, deficiencies and proposed corrective actions; all items must all be recorded. Each inspection and test must be documented with log entries, photographs and checklists. The value of photographs in documenting an inspection cannot be overstated. Many industry associations offer quality assurance guidance for building enclosure systems (ABAA, NCRA, NFRC and RCI). Some offer certification for those who provide enclosure consulting and quality assurance services (ABAA, NFRC and RCI).

This chapter has seven subsections:

- Pre-Construction Planning.
- Site Drainage.
- Foundation Construction.
- Wall Construction.
- Roof and Ceiling Assembly Construction.
- Plumbing System Installation.
- HVAC System Installation.

Pre-Construction Planning

To protect a building from moisture problems during construction and to ensure the design's moisture control elements are properly implemented, the contractor needs to incorporate moisture control into the planning, scheduling and sequencing of the project. The contractor also needs to coordinate these activities with the owner and the owner's representatives (e.g., the design team, construction management service or commissioning agent).

Goals

Pre-Construction Planning Goal 1: Develop a moisture control plan to be used while the building is under construction.

Pre-Construction Planning Goal 2: Review the moisture control details in the construction documents with the design team, construction management and subcontractors.

Guidance

Pre-Construction Planning Goal 1: Develop a moisture control plan to follow while the building is under construction.

Guidance 1: Establish with the owner and design team the level of concern for moisture control during construction and after turnover. In developing the moisture control plan, the contractor can be guided by the level of concern the owner and design team express and by the level of concern implicit in the construction drawings and specifications for the design's moisture control elements, third-party inspections, testing and commissioning.

Guidance 2: Plan the construction schedule and the sequence of deliveries to meet the owner's and design team's moisture control objectives. Keeping the building site, building materials and equipment dry during construction requires extra planning, effort, equipment and materials. When the entire site is exposed to the weather and when the building is under construction but not yet closed in, moisture-sensitive materials either must not be on site or must be protected from the elements. Completely enclosing the structure before moisture-sensitive materials and equipment are delivered or are being installed on lower floors may have a significant impact on the schedule. The moisture control plan should address at a minimum:

- Providing construction site drainage: temporary drainage, dewatering.
- Providing protection from construction water and from leaks from hoses and plumbing.
- Making the enclosure or portions of the enclosure weather-tight before the delivery or installation of moisture-sensitive materials.
  - For smaller buildings, the entire enclosure may be made weather-tight before sensitive materials arrive at the site.
  - For larger buildings, a portion of the enclosure may be made weather-tight early enough to store or to begin installing moisture-sensitive materials.
  - Before the top floor in high-rise construction is reached and roofed, lower floor walls may be made weather-tight and floor decks diked or sealed at penetrations (e.g., stairwells, utility chases and elevator shafts) and drained at the perimeter.
- Providing rain protection for work and for stored materials before the building is closed in.
- Preparing a list of materials that must be kept dry, actions planned to protect them during construction, and responses if they get wet.
  - Most finish materials (e.g., paper-covered gypsum board and wooden paneling) and some porous insulating materials (e.g., fiberglass and cellulose insulation) must be kept dry.
- Preparing a plan to store vulnerable materials so they are protected from rain, snow and plumbing leaks during construction (e.g., schedule delivery after the building or a portion of the building is weather tight; provide protection independent of the building, such as pallets and tarps, shrink wrap or a separate storage building).

  - Sequence the installation of these materials when the building or a portion of the building is weather-tight.
- Drying wet materials before finishing or enclosing.
  - Prepare a list of materials that can tolerate wetting, but must be dry before additional materials in the foundation can be installed; the critical points by which they must be dry; actions planned to ensure they are dry at those times; and responses in the event they are wet at a critical time.
  - Impermeable materials (e.g., anodized aluminum, glass and extruded styrene foam board) can tolerate a great deal of wetting, but may need to be dry before sealants or adhesives are applied.
  - Some porous materials (e.g., exterior grade gypsum board sheathing, plywood and oriented strand board) can tolerate short-term wetting, but they must be dry before coatings, tapes, adhesives or interior finish materials are applied. Obtain, read and follow manufacturers' instructions.
  - Some porous materials (e.g., concrete, concrete masonry units and brick) can tolerate a great deal of wetting for extended periods, but must be dry before coatings, tapes, adhesives or interior finish materials are applied. For example, a water-based emulsion used as a spray-applied drain plane may not cure correctly if applied to saturated concrete masonry walls. Installing paper-covered gypsum board next to a wet concrete wall can result in mold growth on the gypsum board.
- Dehumidifying after closing in the building, but before the HVAC system is operational.
- Commissioning and testing the enclosure, plumbing and HVAC systems.
- Responding to moisture and mold problems that happen in spite of these efforts.
  - Surveillance.
  - Emergency response.
  - Drying, clean-up and repair.
  - Clearance.

Guidance 3: Identify the parties responsible for implementing each portion of the moisture control plan.

Pre-Construction Planning Goal 2: Review the moisture control details in the construction documents with the design team, construction management and subcontractors.

Guidance 1: Review moisture control details in the construction documents and discuss them with the design team:

- Review rainwater and subsurface water-control details and specifications for the site with the landscape and excavation contractors.
- Trace rainwater control, air barrier and insulation layer details for continuity; review enclosure testing and commissioning requirements (e.g., air pressure testing the enclosure).
- Examine the water vapor dynamics of sections, considering the design interior temperature and relative humidity and the exterior climate for condensation potential and for drying potential.
- Review ice dam potential in sections and roof plans—air barrier, insulation level, roof venting, drainage of snowmelt—where buildings are prone to ice dams.
- Review the location of plumbing lines and chilled water lines; check cold water and chilled water lines for vapor barrier and insulation details; review plumbing system commissioning and testing requirements (e.g., pressure testing, start-up, owner training).
- Review enclosure commissioning requirements.
- Review mechanical systems for:
  - Indoor humidity control.
  - Pipe and duct insulation and vapor control.
  - Air pressure relationship requirements (e.g., accidental depressurization of air-conditioned buildings, rooms or cavities in hot humid or mixed humid climates; accidental pressurization of buildings in cold climates).
  - Location of air conditioning equipment within thermal and air enclosures, drain pan slope and positive drainage, insulation specifications, adequate room around equipment for proper installation of drains, and access panels.
  - Mold-resistant materials in custodial closets, bathrooms, toilets and other areas that will get wet.
- Review mechanical system commissioning and testing requirements (e.g., test and balance, duct tightness testing, start-up and operator training).

- Review moisture content test procedures before installing or closing in porous materials (e.g., concrete).
- Present concerns, cautions and alternatives to the owner and design team for discussion and final disposition.

Guidance 2: Formalize the results of the discussions and decisions made under Guidance 1 into changes in the construction documents, shop drawings and submittals.

Guidance 3: Schedule required inspection and testing of moisture control elements (who, when, results and remedies) so these activities can be completed while moisture control details are exposed and can be inspected.

Verification of Pre-Construction Planning

Written meeting notes, modified construction documents, plans for controlling moisture problems during construction, planned emergency responses to moisture problems during construction, and lists of the parties responsible for installation, supervision, inspection, and testing of moisture control design elements provide verification of the process followed and the decisions made.

Site Drainage Construction

Issue

Improper site drainage can cause water from rain and snowmelt to damage the building and its components during and after construction. Mistakes made in constructing drainage systems can be difficult and expensive to fix if they are discovered after structures are in place. Repeated flooding caused by poorly constructed drainage systems can lead to moisture damage, high insurance costs and increased liability for building owners.

Goals

Site Drainage Goal 1: Water from rain and snowmelt does not damage the building or its components during construction.

Site Drainage Goal 2: Water from rain and snowmelt does not damage the building or its contents after construction.

Guidance

Site Drainage Goal 1: Water from rain and snowmelt does not damage the building or its components during construction.

Guidance 1: Comply with National Pollutant Discharge Elimination System (NPDES) requirements for construction, as implemented by the relevant authority: U.S. EPA, state government or local government.[21] Determine whether there are applicable state or local erosion, sediment control and storm water management requirements. Obtain local erosion, sediment control and storm water management permits, as necessary, prior to construction.

Guidance 2: Comply with design requirements for maintaining water management during construction. If design requirements are not provided, comply with the following recommended minimum.

Minimize potential for runoff:

- Avoid clearing or grading stream buffers; forest conservation areas; wetlands, springs and seeps; soils highly susceptible to erosion; steep slopes; environmental features; and runoff infiltration areas.
- Group construction activities into phases to limit soil exposure. Limit activities to the current phase to decrease the time soil is exposed.
- Begin immediate efforts to stabilize exposed soils. While the long-term goal is to establish permanently stabilized soils, mulching, hydro-seeding or erosion control matting may provide short-term protection.
- Avoid cuts and grading of steep slopes—greater than 15 percent—wherever possible. If a steep slope exists, diversions or a slope drain should be used so all water flowing onto the slope is directed away from the site to approved disposal areas.
- Train construction staff in storm water management practices.
- Ensure positive drainage principles are met so water drains from the site and away from the structure:
  - Make certain water is moved away from the building.
  - Ensure water is not allowed to pond at low points or in low areas, unless planned for.
  - Make sure obstructions around the building and site (e.g., dirt and gravel stockpiles, silt fencing) do not cause water to back up into the building.
- Institute storm water management supervisory roles and responsibilities by clearly describing each contractor's responsibilities. Specify who will inspect the features and how often.[22]

Site Drainage Goal 2: Water from rain and snowmelt does not damage the building or its contents after construction.

[21] See http://cfpub.epa.gov/npdes/stormwater/authorizationstatus.cfm to determine whether EPA or your state is the relevant authority. See http://cfpub.epa.gov/npdes/stormwater/const.cfm for the federal requirements. Accessed November 6, 2013.

[22] For more information see http://cfpub.epa.gov/npdes/stormwater/menuofbmps/ index.cfm?action=min_measure&min_measure_id=4. Accessed November 6, 2013.

Guidance 1: Identify the water control elements of the site design, such as finish grading and sloping requirements, and the infiltration, retention or detention controls. Work with the design team to interpret and modify the drainage systems if necessary.

Guidance 2: Ensure drainage systems are installed or constructed as specified in the construction document by supervising, inspecting and documenting construction and installation of the site water control elements. Examples include:

- Determining finished grade slope around the building foundation by measuring the change in height over distance.
- Documenting grades and slopes for drainage systems.

Guidance 3: Ensure all temporary water control systems, such as silt fences, have been removed.

Verification of Site Drainage Construction

Create and use inspection checklists to document construction and installation. The material in this chapter can be helpful in identifying items to include in such checklists.

Foundation Construction

Issue

As the interface between a building and the supporting soil, most foundation materials can tolerate wet conditions for long periods of time without deteriorating. However, the foundation must be dry enough to permit the installation of damp-proof coatings and materials used to form the insulation, air barrier, vapor control and finish portions of the foundation walls and floors. Failure to properly construct a foundation can lead to problems that are extremely difficult and expensive to fix once a building is constructed.

Goals

Foundation Construction Goal 1: Keep foundation assembly materials dry during construction.

Foundation Construction Goal 2: Construct foundations to effectively implement the moisture control systems in the design drawings and specifications.

Foundation Construction Goal 3: Prepare operation and maintenance materials regarding continued effective moisture protection for foundations.

Guidance

Foundation Construction Goal 1: Keep foundation assembly materials dry during construction.

Guidance 1: Implement the moisture control plan for the construction phase, which should cover:

- Site drainage to control water in foundations during construction.
- Response strategies for water problems that occur during construction (e.g., have pumps available for emergency response to heavy rains).
- Drying concrete and masonry walls and slabs before installing interior wall insulation, interior gypsum board wall covering and interior slab finishes.
- Preventing high-humidity conditions when crawl spaces are enclosed by the overhead floor deck by:
  - Sloping the earth in the crawl space to direct water to a disposal location; installing a vapor barrier over the earthen floor as soon as possible. NOTE: If the crawl space has a concrete slab, the vapor barrier will be part of the slab detailing.
  - Monitoring the relative humidity to determine whether dehumidification is needed; controlling humidity in the crawl space to less than 65 percent RH using ventilation, if outdoor air dew points are lower than 55˚F, or with dehumidifiers.
- Designate someone to conduct concrete moisture content or water vapor emission tests. Document tests, results and remedies. Appendix C contains an overview of testing the moisture content of materials during construction.

Foundation Construction Goal 2: Construct foundations to effectively implement the moisture control systems in the design drawings and specifications.

Guidance 1: Install foundation rainwater control, insulation, air barrier and water vapor control in accordance with construction documents. Implement quality assurance program for:

- Exterior drainage and foundation wall damp-proof coatings.
- Capillary breaks at footings and at the top of the foundation wall.
- Insulation, air barrier and water vapor control.
- Air barrier and thermal insulation systems.

Foundation Construction Goal 3: Prepare operation and maintenance materials regarding continued effective moisture protection for foundations.

Guidance 1: Provide—or direct contractors, subcontractors or manufacturers to provide—operation and maintenance information required to maintain moisture control elements of the foundations including:

- Signs of foundation drainage or damp-proofing failure.
- Frequency of inspection.
- Method of repairing problems.

Verification of Foundation Construction

- Document quality assurance programs for the installation of the hygrothermal control elements of the enclosure. Document inspection quality assurance testing and functional tests with field log books, test results and photographs. The parties identified in the construction documents or contracts should conduct testing as required by the design or for internal quality assurance. Archive the installation documentation, checklists, photographs, log books and test results. Provide required incidental labor, materials and equipment to support third-party testing.
- Develop written operations and maintenance information, as required by contract.

Wall Construction

Issue

Care must be taken during wall construction to keep moisture-sensitive construction materials dry. Moisture-sensitive wall materials that get wet during construction may grow mold, corrode or deteriorate. Walls must be constructed according to design specifications to incorporate moisture and mold-prevention measures.

Goals

Wall Construction Goal 1: Keep wall materials dry during construction.

Wall Construction Goal 2: Construct walls to effectively implement moisture control systems in the design drawings and specifications.

Wall Construction Goal 3: Prepare operation and maintenance materials regarding continued effective moisture protection for walls.

Guidance

Wall Construction Goal 1: Keep wall materials dry during construction.

Guidance 1: Take the steps developed in the moisture control plan to ensure that materials meant to remain dry, stay dry. Examine and reject materials that arrive contaminated with mold. Store materials in a clean, dry area protected from water (e.g., covered and raised on pallets). Test the moisture content of porous materials (e.g., those that can easily store a great deal of liquid water) before closing them in cavities or applying adhesives or finishes to them.

Guidance 2: Document moisture control efforts undertaken during construction.

Wall Construction Goal 2: Construct walls to effectively implement moisture control systems in the design drawings and specifications.

- **Guidance 1:** Install moisture control elements designed to meet the criteria specified in the construction documents. Implement quality assurance programs for the hygrothermal control systems. Provide required incidental labor, materials and equipment to support third-party testing.

Inspect and verify moisture, air and heat flow control details at these vulnerable locations:

- Cladding.
- Flashing above and below windows, doors and intake and exhaust openings.
- Through-flashing details where a lower story roof, balcony or deck intersects upper story walls.
- Building drain planes: weather-resistant-barriers, felt-paper and spray-applied membranes.
- Insulation layer: Inspect the insulation layer for continuity.
- Air barrier: Air seal and insulate wall and ceiling areas that will be made inaccessible by interior framing or fixtures. These areas include:
  - Staircases, bathtubs, showers and cabinets installed against exterior walls.
  - Soffits beneath insulated ceilings, where interior walls meet exterior walls.
  - Areas around elevator and stair shafts.
  - Air seal and insulate around windows and doors before applying interior finishes.
  - Plan air-sealing activities (e.g., caulking and foaming) so they can be performed and inspected easily and efficiently.
- Sequence delivery and installation of materials so the critical elements of moisture protection can be installed readily. For example, in a wall constructed with a brick veneer/foam board insulation/spray-applied membrane drain plane-air barrier/concrete masonry wall, the membrane must be applied before the foam board, and the foam board applied before the brick veneer is installed. All these materials must be on site and subcontractors must be scheduled, or else a wall or portions of a wall

may end up without the spray-applied membrane or foam insulation behind the brick veneer.

Wall Construction Goal 3: Prepare operation and maintenance materials regarding continued effective moisture protection for walls.

Guidance 1: Provide or direct contractors, subcontractors or manufacturers to provide operation and maintenance information required to maintain moisture control elements of the wall assemblies including:

- Identifying signs of cladding failure.
- Inspection frequency.
- Method of repairing problems.

Verification of Wall Construction

- Document quality assurance programs for the installation of the hygrothermal control elements of the enclosure. Document inspection quality assurance testing and functional tests with field log books, test results and photographs. The parties identified in the construction documents or contracts should conduct testing as required by the design or for internal quality assurance. Archive the installation documentation, checklists, photographs, log books and test results.
- Develop written operations and maintenance information, as required by contract.

Roof and Ceiling Assembly Construction

Issue

Construct roof assemblies according to design specifications that incorporate moisture- and mold-prevention measures. Take care to keep moisture-sensitive materials dry during construction. Moisture-sensitive roof assembly materials that get wet during construction may grow mold, corrode or deteriorate.

Goals

Roof Construction Goal 1: Keep roof assembly materials dry during construction.

Roof Construction Goal 2: Construct roof assemblies to effectively implement the moisture control systems in the design drawings and specifications.

Roof Construction Goal 3: Prepare operation and maintenance materials concerning continued effective moisture protection for roof assemblies.

Guidance

Roof Construction Goal 1: Keep roof assembly materials dry during construction.

Guidance 1: Follow the steps in the moisture control plan to ensure that materials meant to remain dry, stay dry. Examine and reject materials that arrive contaminated with mold. Store materials in a clean, dry area protected from water (e.g., covered and raised on pallets). Test the moisture content of porous materials (e.g., those that can easily store a great deal of liquid water) before closing them in cavities or applying adhesives or finishes to them.

Roof Construction Goal 2: Construct roof assemblies to effectively implement the moisture control systems in the design drawings and specifications.

- **Guidance 1:** Properly install the moisture control elements designed to meet the criteria specified in the construction documents. Implement quality assurance programs for the hygrothermal control systems. Provide required incidental labor, materials and equipment to support third-party testing.

- Inspect and verify details to control moisture, air flow and heat flow at these vulnerable locations:
  - Roofing — slope, installation.
  - Flashing at roof edges, gutters, roof drains, valleys, chimneys, dormers, skylights, equipment curbs, pipe penetrations, structural support for railing, signs, fences and screens.
  - Through-flashing details where a lower story roof intersects upper story walls.
  - Roofing paper, peel-and-stick bituminous membranes.
  - Insulation layer — inspect for continuity.
  - Soffit and roof peak ventilation openings, air sealing and insulation details for vented roofs that pitch to eaves.
  - Air barrier:
    - Air seal the joints between materials that form the air barrier (e.g., foam board, gypsum board thermal barrier and concrete plank or poured concrete roof deck). NOTE: Fluted metal decks are difficult to use as an air barrier and require special detailing in order to be used as one.
    - Air seal between the roof air barrier material and the wall air barrier material.
    - Air seal and insulate the edge of fluted metal decks, parapet wall, equipment curbs, skylights, gaps around elevator shafts and other areas that will be made inaccessible by interior framing, equipment hung from ceilings, pipes, ducts and ceilings.
    - Plan air-sealing activities (e.g., caulking and foaming) so they can be performed and inspected easily and efficiently.
      - Sequence the delivery and installation of materials so the critical elements of moisture protection can be readily installed. For example, if the air barrier in a low-slope roof

system is to be made using two layers of foam board sheets with the joints staggered and taped, it is critical that the correct tape is on hand when the foam board is being placed.

- Plan air-sealing efforts (e.g., caulking, foaming and membrane installation) so they can be accomplished and inspected easily and efficiently.

Roof Construction Goal 3: Prepare operation and maintenance materials concerning continued effective moisture protection for roof assemblies.

Guidance 1: Provide or direct contractors, subcontractors or manufacturers to provide operation and maintenance information required to maintain moisture control elements of the roof assemblies. The builder's responsibilities should be spelled out in the contracts and may include:

- Signs of roofing and roof penetration failure.
- Frequency of inspection.
- Method of repairing problems.

Verification of Roof and Ceiling Assembly Construction

- Document quality assurance programs for the installation of the hygrothermal control elements of the enclosure. Document inspections, quality assurance testing and functional tests with field log books, test results and photographs. The parties identified in the construction documents or contracts should conduct testing as required by the design or for internal quality assurance. Archive the installation documentation, checklists, photographs, log books and test results. Provide required incidental labor, materials and equipment to support third-party testing.
- Develop written operations and maintenance information, as required by contract.

Plumbing System Installation

Issue

Plumbing-related water problems can occur as the result of leaks and other accidental releases of plumbing water from charged systems during construction. Delayed problems can occur because of errors in installing water supply lines, drain lines and appliances.

Goals

Plumbing System Installation Goal 1: Install water supply lines, drain lines and appliances to prevent pre- and post-occupancy leaks and to facilitate the discovery and repair of problems during construction and post-construction occupancy.

Plumbing System Installation Goal 2: Install pipe insulation and water vapor controls on cold water lines and appliances.

Plumbing System Installation Goal 3: Install materials that will minimize mold growth in unavoidably wet areas.

Plumbing System Installation Goal 4: Prepare operation and maintenance materials concerning continued effective moisture protection for plumbing systems.

Guidance

Plumbing System Installation Goal 1: Install water supply lines, drain lines and appliances to prevent pre- and post-occupancy leaks and to facilitate the discovery and repair of problems during construction and post-construction occupancy.

Guidance 1: Review construction documents and prepare shop drawings and submittals that ensure pipes are not located in exterior walls and ceilings that contain porous insulation. NOTE: If pipes must be located in an exterior wall or ceiling, install a continuous, air-sealed layer of closed-cell foam insulation between the pipe and the exterior sheathing, curtain wall or roof deck. Schedule installation so testing can be done before piping and components are closed in. This may require separately testing sub-sections of the plumbing systems.

Guidance 2: Follow construction documents when installing plumbing systems.

Guidance 3: Install plumbing so that it is easy to access and repair. Orient valves, pipes and other key components in locations where leaks will be easily noticed and that are most accessible for inspection and repair. Where appropriate, label key components or affix instructions and diagrams to aid others in accessing and repairing plumbing. These aids may include diagrams of flow directions and valve locations and functions.

Plumbing System Installation Goal 2: Install pipe insulation and water vapor controls on cold water lines and appliances.

Guidance 1: Install plumbing system insulation and water vapor controls in accordance with construction documents. Protect porous insulating and paper-based water-vapor-control materials from rainwater.

Plumbing System Installation Goal 3: Install materials that will minimize mold growth in unavoidably wet areas.

Guidance 1: Install moisture- and mold-resistant materials in unavoidably wet spaces in accordance with design documents.

Plumbing System Installation Goal 4: Prepare operation and maintenance materials concerning continued effective moisture protection for plumbing systems.

Guidance 1: Provide or direct contractors, subcontractors or manufacturers to provide operation and maintenance information required to maintain plumbing systems, appliances, fixtures and moisture-resistant materials used in wet rooms. Among the topics that should be covered are potable water, bathing and wash water, waste water, hydronic heating systems, chilled water cooling systems, spa and pool systems, washrooms, custodial closets and locker rooms. The builder's responsibilities for training materials should be spelled out in the contracts and may include:

- Signs of plumbing system failure and hydronic heating and cooling system failure.
- Frequency of inspection.
- Method of repairing problems.

Verification of Plumbing System Installation

- Inspect installation of plumbing system insulation and water vapor controls. Document inspections with field log books and photographs. Quality assurance is crucial to ensure complete coverage with insulation and water vapor control on joints and seams and where pipes interface with other equipment (e.g., pumps, valves, tanks). Document the inspections with signed checklists, log books and photographs.
- Inspect plumbing for acceptability of installation and materials, for compliance with design documents, and for access to lines before performing tests. Use installation checklists and provide signed documentation of all test results.
- Pressure test water supply lines while they are exposed for inspection (i.e., before they are enclosed or insulated). At a minimum, pressure test water supply lines according to section 312.5 of the International Plumbing Code or the relevant sections of applicable local codes.
- Test the drain and vent side of the plumbing system when all lines are exposed for easy inspection and repair in accordance with design specifications and as required by relevant building codes. At a minimum, gravity test the drain and vent side of the system according to sections 312.2, 312.3 and 312.4 of the International Plumbing Code or relevant sections of other applicable local codes.
- Inspect plumbing and surrounding fixtures located in unavoidably wet areas to ensure the use of moisture- and mold-resistant materials. Document the inspections with signed checklists, log books and photographs.
- Develop written operations and maintenance information, as required by contract.

HVAC System Installation

Issue

Improper installation of HVAC systems can create condensation and moisture-control problems. Examples include:

- Inadequate dehumidification and pressurization performance of the HVAC system, which can lead to occupant discomfort and mold growth.
- Condensation on HVAC equipment components, which can damage components, increase maintenance costs, decrease component and system lifespan and lead to mold growth.
- Inadequate drainage of collected condensate or other water, which can result in moisture damage to the building and its contents and to mold growth.
- Inadequate ventilation of indoor humidity sources (e.g., showers, bathrooms, spas and kitchens), which can lead to mold growth and deterioration.

Goals

HVAC System Installation Goal 1: Keep HVAC equipment and materials dry during construction and provide temperature and humidity control as required during the close-in phase of construction.

HVAC System Installation Goal 2: Install HVAC systems to effectively implement moisture control as specified in the design drawings and specifications.

HVAC System Installation Goal 3: Prepare operation and maintenance materials for continued performance of HVAC system moisture control.

Guidance

HVAC System Installation Goal 1: Keep HVAC equipment and materials dry during construction and provide temperature and humidity control as required during the close-in phase of construction.

Guidance 1: Plan when and how the HVAC equipment will be energized and used during construction. Plan the required inspection and testing—who, when, results and remedies—so these activities can be completed before the plumbing, ductwork and other components are closed in. In addition, plan the installation sequence so testing can be done before system components are closed in.

Guidance 2: Take steps to ensure that equipment and materials meant to remain dry, stay dry. Prepare a list of equipment and materials that must be kept dry, actions planned to protect them during construction, and responses if they get wet.

- Schedule the delivery of HVAC system components so they can be protected immediately from rainwater and plumbing leaks. Uninsulated, galvanized ductwork can tolerate some wetting, but air handlers, insulated components, electronic components, chillers, compressors and controls all need positive protection from weather and moisture.
- Schedule the installation of HVAC components for when the building or a portion of the building has been made weather-tight.
- Inspect insulated ductwork and components for moisture damage and mold growth when they are received and before they are installed.

Guidance 3: Control temperature and humidity during the close-in phase of construction. Plan the transition from unconditioned interior space to conditioned interior space in conjunction with the designers and owners:

- Identify situations and processes that will require humidity control for installation and drying of materials. For example, concrete slabs may need to be dried before finish flooring goes down; below-grade concrete walls may need to be dry before interior insulation and finishes are installed; and temperature and humidity may need to be controlled before painting or varnishing takes place.
- Use the permanent HVAC systems to provide required conditioning, if possible. Follow the guidance in *Duct Cleanliness for New Construction Guidelines* (SMACNA 2010).

- If the permanent HVAC equipment cannot be used, plan for temporary heating, cooling and dehumidification. NOTE: Non-vented combustion devices add a great deal of water vapor as well as heat to a space and cannot be used to dehumidify.

HVAC System Installation Goal 2: Install HVAC systems to effectively implement moisture control systems in the design drawings and specifications. Implement quality assurance programs for the hygrothermal control systems. Provide required incidental labor, materials and equipment to support third-party testing.

Guidance 1: Plan required inspections—who, when, results and remedies—so they can be completed before HVAC components, particularly the distribution systems, are closed in.

Guidance 2: Install HVAC systems, condensation collection and drainage systems, system insulation, air barriers and water vapor controls in accordance with construction documents.

Inspect the installation of:

- Drain pans, drain pan outlets, traps and disposal.
- HVAC ductwork including seams and sealing prior to the installation of duct insulation.
- Insulation and vapor retarders on exposed surfaces that are expected to be below the dew point of ambient air (e.g., chilled water lines, refrigerant lines, air conditioning air handlers and chillers), especially at transitions (e.g., penetrations through walls, floors and ceilings; support clamps; valves; dampers; pumps; blowers; and gauges).
- Access panels to allow inspection and maintenance of HVAC components (e.g., air handlers, filters, coils, drain pans and the supply duct near the air handler).
- Exhaust ventilation systems for duct sealing, insulation and vapor control.

HVAC System Installation Goal 3: Prepare operation and maintenance materials for continued performance of HVAC system moisture control.

Guidance 1: Provide or direct contractors, subcontractors or manufacturers to provide operation and maintenance information required to maintain moisture control elements of the HVAC system components. The builder's responsibilities should be spelled out in the contracts and may include:

- Requirements for filters, coils, condensate drainage systems, ductwork, piping, insulation and vapor barriers, pumps, valves, fans, belts, lubrication and controls.
- Frequency of inspection.
- Methods of repairing problems.

Verification of HVAC System Installation

- Write a plan for moisture control in regard to HVAC equipment and dedicated drying equipment during construction. Use photographs, log books and written reports to document moisture-control activities, water problems and responses to water problems.
- Parties identified in the construction documents or contracts should perform tests as required by the design or for internal quality assurance. These tests include:
  - Creating air pressure difference maps for each mode of operation.
  - Testing for air duct tightness target—before installation of ductwork insulation.
  - Testing drainage of condensate drain pans in air conditioners.
  - Testing, adjusting and balancing the HVAC system as designed.
  - Performing other tests and inspections required by the commissioning plan.
- The tests and inspections should be documented with field log books, moisture content and vapor emission tests, and photographs.
- Develop written operations and maintenance information, as required by contract.

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Chapter 4: Operating and Maintaining Moisture-Controlled Environments

INTRODUCTION

The people who keep buildings working—the HVAC mechanics, carpenters, plumbers, electricians, engineers, custodians and managers—inherit the good points and the bad points of the design and construction.

This chapter consists of the following sections:

- Site Drainage Maintenance.
- Foundation Maintenance.
- Wall Maintenance.
- Roof and Ceiling Assembly Maintenance.
- Plumbing System Operation and Maintenance.
- HVAC System Operation and Maintenance.

Each section is concerned with regular inspection; the cleaning, lubrication, repair or replacement that may result from the inspection; and the documenting of inspections and responses. Several of these sections require the development of specific operation and maintenance plans. The section-specific plans can be assembled into a master moisture-control plan.

Table 4-1 Troubleshooting Common Indoor Water Problems

SYMPTOMS	MOISTURE PROBLEM	POTENTIAL CAUSES		
		DESIGN	CONSTRUCTION	O&M
Mold growth	Leaks in the building enclosure due to problems with rain and groundwater controls	Missing or poorly designed details	Missing flashing or building wrap Incorrect sloping Damaged sub-grade drainage	Failure to identify and repair settled grading near foundation Damaged flashing on rooftop air handler curb Missing shingles
	Insufficient dehumidification by HVAC system[a]	Air conditioning equipment oversized Air conditioning equipment not designed for sufficient dehumidification at design and part load	Failure to properly wire humidity sensors	Chilled-water temperature set-point too warm Economizer set-point that allows introduction of humid outdoor air Continuously running air handler regardless of cooling demand
	Condensation on dirty surfaces inside HVAC systems	Poor condensate drain design Air handler inside surfaces insulated or hard to clean		Failure to clean HVAC system cooling coils Clogged drain pan
	Wet materials enclosed in building assemblies	Moisture-sensitive materials shown touching porous materials that are likely to get wet No values for moisture content or emission given in the specifications	Flooring placed on slab while it is too damp Vapor emission tests on slab may not have been conducted	Failure to seal penetrations during maintenance, repair or installation of new equipment
Peeling paint **Wood decay** **Corrosion**	Leaks in the building enclosure due to problems with rain and groundwater controls	Missing or poorly designed details	Missing flashing or building wrap Incorrect sloping Damaged sub-grade drainage	Failure to identify and repair settled grading near foundation Damaged flashing on rooftop air handler curb Missing shingles
Plumbing leaks and spills	Improper design Improper installation during construction Improper operations and maintenance practice	Locating water lines in a space that reaches freezing temperatures Poorly designed shower pan	Defective pipe joining Accidental penetration of pipe by one or more drywall screws	Failure to inspect plumbing and repair problems
Water travels to materials that cannot tolerate wetting	Capillary action (water wicks through porous building materials such as concrete or wood)	Moisture barrier omitted from building design Drainage layer beneath slab omitted from building design	Moisture barrier not installed during construction Drainage barrier not installed during construction	

Table 4-1 Continued

SYMPTOMS	MOISTURE PROBLEM	POTENTIAL CAUSES		
		DESIGN	CONSTRUCTION	O&M
Condensation	Warm, moist outside air enters enclosure through cracks and holes during warm, humid weather[b]	Air barrier omitted from building design Building design did not call for positive pressure operation of the building	Controls poorly implemented during construction (e.g., concrete block left out of a soffit area)	
	Warm, moist indoor air leaves enclosure through cracks and holes during cold weather[c]	Air barrier omitted from building design Air barrier detailed for attic assembly is impossible to install Building designed to operate at positive pressure in an extremely cold climate	Air barrier installed poorly Holes cut in well-installed air barrier to permit passage of wire, conduit or ducts	Failure to reseal access holes cut through an assembly Changes in HVAC system operations cause building to run at positive pressurization
	Vapor barriers installed improperly in exterior walls	Vapor barrier specified on both sides of a wall assembly Vapor barrier specified on interior surfaces in hot, humid climates	Unintentional vapor barriers such as vinyl wall covering, mirrors or blackboards installed on inside of exterior walls in hot, humid climate (can create a vapor barrier on the cold side of the wall)	Vinyl wall covering, mirrors or blackboards added on inside of exterior walls in hot, humid climate (can create a vapor barrier on the cold side of the wall)
	Non-vented or poorly vented moisture sources (e.g., swimming pools, spas, aquariums, dishwashers, combustion devices, kitchens and showers)	HVAC system design omitted exhaust ventilation for moisture sources Insufficient exhaust ventilation specified in HVAC system design	Exhaust duct leaks Poor balancing on multiple-inlet exhaust systems Exhaust dampers closed	Broken belt in a fan Clogged exhaust grilles or ducts
Delamination **Improper curing**	Wet materials enclosed in building assemblies	Moisture-sensitive materials shown touching porous materials that are likely to get wet No values for moisture content or emission given in the specifications	Flooring placed on slab while it is too damp Vapor emission tests on slab may not have been conducted	

[a] This problem may also occur during the bidding, contract negotiation or value engineering phases of a project when, for example, different air conditioning equipment is substituted for the equipment called for in the design.

[b] The air leak may be due to holes in the enclosure made by occupants, contractors or maintenance personnel, or it may have been caused by changes in the control sequence of outdoor air and exhaust systems.

[c] The problem of indoor condensation can be greatly aggravated if there are large sources of humidity inside the building.

Site Drainage Maintenance

Issue

Failure to maintain drainage systems can lead to unexpected flooding during events of heavy rain or snowmelt, causing extensive property damage.

Goals

Site Drainage Goal 1: Facility maintenance systems and preventive maintenance plans effectively address site drainage.

Site Drainage Goal 2: All runoff from parking lots, sidewalks and other impermeable or low-permeability surfaces is diverted to a designed drainage system.

Site Drainage Goal 3: Future site development or building modifications or additions do not interfere with existing site drainage systems.

Guidance

Site Drainage Goal 1: Facility maintenance systems and preventive maintenance plans effectively address site drainage.

Guidance 1: Develop and implement a preventive maintenance plan for landscaping and engineered structures. The purpose of the plan is to ensure that all drainage systems serve the purpose for which they were designed. The plan should include:

- An introduction and general information.
  - Name and contact information for persons responsible for operation and maintenance.
  - A narrative overview describing the site and the theory of operation of the drainage systems.
- A definition of the inspection requirements for each drainage feature.
  - Inspection frequency should be specified (See Appendix C).
  - What to look for.
- Definitions of the maintenance activities necessary to keep each drainage feature operating as intended. Examples include:
  - Cleaning debris from diversion systems to prevent water flow from being obstructed.
  - Removing sediment from the bottom of swales (See Appendix F for sample checklists).
- Maintenance agreements and contacts. If contractors are responsible for some or all of the maintenance requirements, list the contractors' names, contact information and responsibilities.

Guidance 2: Develop and implement a preventive maintenance plan to maintain parking lots, sidewalks and other impermeable surfaces.

- Read, understand and comply with the designer's inspection and maintenance requirements or best management practices for impervious surfaces.
- Develop an inspection checklist and logbook (See Appendix F for sample checklists).

Site Drainage Goal 2: All runoff from parking lots, sidewalks and other impermeable or low-permeability surfaces is diverted to a designed drainage system.

Guidance 1: Ensure that actions such as plowing snow from sidewalks and parking lots do not obstruct drainage or pile snow against the building.

Guidance 2: Inform all lawn-care subcontractors and landscapers about drainage systems on the site so their work does not interfere with the drainage. Have them watch for drainage problems as they work.

Site Drainage Goal 3: Future site development or building modifications or additions do not interfere with existing site drainage systems.

Guidance 1: Make sure changes such as additional parking areas (even dirt parking areas) do not overburden existing system capacity or redirect runoff into buildings. Even small projects such as adding planters or walkways can affect infiltration capacity and redirect runoff.

Guidance 2: Persons charged with maintaining drainage systems should participate in the design of any development or building modification.

Verification of Site Drainage Maintenance

Keep and maintain records of all inspections, including completed checklists. Include photographs and test reports so that changes in conditions can be verified.

Foundation Maintenance

Issue

Rainwater and snowmelt can cause unwanted moisture intrusion through the foundation of a building. Foundations are vulnerable to chronic moisture problems from rainwater, ground water, plumbing leaks, and condensation. Regular inspection, particularly of areas not ordinarily occupied, is critical to reduce the risk of serious damage to the foundation and the risk of adverse health effects to the occupants.

Goals

Foundation Drainage Goal 1: Foundation drainage systems divert water away from the structure.

Guidance

Foundation Drainage Goal 1: Foundation drainage systems divert all water away from the structure.

Guidance 1: Inspect the exterior of the foundation and the surrounding landscape.

- Check whether the surrounding landscape diverts water away from the building envelope. Note any soil settlement or pooled rainwater.
- Check the condition of roof drain leaders.
- Inspect the foundation for changes in existing cracks and for new cracks that might indicate water problems.
- Inspect the intersection and slope of sidewalks, patios and pavements with the adjoining building for potential seepage.
- Look for newly sprouted or planted trees near drain lines. Remove or prune as needed.
- Check exterior plumbing fixtures, hoses and irrigation lines for leaks.
- Conduct inspections semi-annually and after heavy rains or rapid melting of snow.

Guidance 2: Inspect the interior of the foundation.

- Inspect the foundation for changes in existing cracks and for new cracks that might indicate water problems.
- Check the condition and operation of the sump crock, drains and pump.
- Look for signs of seepage or wicking (e.g., water stains, damp materials, efflorescence, peeling paint or mold growth) on foundation materials and interior finishes.
- Check for musty odors.
- Look for swollen, warped or moldy wooden materials.
- Determine the temperature and relative humidity. Record the date, time and operation of mechanical systems, the temperature and the relative humidity.
- Look for stained carpet, sheet or vinyl composition tile (VCT) floors with blisters and for bubbles indicating adhesive failures as well as adhesives oozing from joints between tile.
- Look for condensation on pipes, tanks, toilets, pumps, ducts, walls and floors.

Verification of Foundation Maintenance

- Document inspections and responses using a checklist and work order system.

Wall Maintenance

Issue

Failure to properly inspect and maintain interior and exterior walls can result in moisture problems going unnoticed or unrepaired. Unnoticed damage to walls can lead to a need to repair multiple building components at high cost and can create health risks associated with mold growth in the interior of walls.

Goals

Wall Maintenance Goal 1: Create and operate verification and inspection systems to detect potential moisture problems before harm is done.

Wall Maintenance Goal 2: Effectively maintain walls to prevent moisture problems, as intended by the design.

Guidance

Wall Maintenance Goal 1: Create and operate verification and inspection systems to detect potential moisture problems before harm is done.

Guidance 1: Develop inspection checklists and record-keeping systems.

- Develop a wall assembly manual and logbook. Include the type of wall, contractor information, maintenance procedures, a record of inspections and related items.
- Develop a wall assembly inspection checklist. Use it as a guide for evaluating masonry units, flashings and counter flashings, caps and drainage assemblies.
- Develop elevation drawings to map and locate problems found during the inspections.
- Develop and keep inspection and repair records for all exterior walls, including before and after pictures to document results of maintenance and repair activities.

Wall Maintenance Goal 2: Effectively maintain walls to prevent moisture problems, as intended by the design.

Figure 4-1 Interior Wall Showing Water Damage and Mold

Guidance 1: Conduct inspections, record the results and make necessary repairs.

- Inspect walls periodically and after heavy winds and rains. Conducting inspections during each season is recommended.
- Check interior walls and ceilings for signs of water damage or staining (See Figure 4-1).
- Inspect exterior walls and roof overhangs:
  - Look for signs of moisture, cracking or movement.
  - Look for cracked, loose or spalled units on brick masonry walls.
  - Inspect joints for deteriorated mortar.
  - Look for mold or algae growth.
  - Be aware that ivy growing on brick walls can penetrate voids in mortar and may lead to moisture penetration.

  - Open weep holes by probing with a wood dowel or stiff wire. NOTE: Care must be taken to prevent damaging flashing when cleaning weeps.
- Inspect caulking and sealants at junctions of the brickwork and other materials such as windows, doors and expansion joints.
- Inspect flashings and counter flashings. Look for loose flashing or missing fasteners, open ends or lap joints, unsealed corners, and rusted or corroded metal.
- Identify and repair problems before they cause water damage to walls.
- Incorporate the results of each inspection into the user's manual and logbook.

Verification of Wall Maintenance

Incorporate completed inspection forms and completed checklists into the user's manual and logbook.

Roof and Ceiling Assembly Maintenance

ISSUE

Roof and ceiling assemblies can deteriorate due to normal wear, severe weather, building movement, and improper design, construction and maintenance. Failure to correct roof and ceiling problems quickly can cause additional damage to the building envelope and the interior of the building. Uncorrected roof and ceiling problems can also cause loss of occupant productivity, damage to building contents and failure of structural integrity.

GOALS

Roof Maintenance Goal 1: Facility maintenance systems and preventive maintenance plans effectively address moisture control issues for roof and ceiling assemblies.

Roof Maintenance Goal 2: Moisture does not penetrate roof and ceiling assemblies or collect in exterior elements, except as intended by the design.

GUIDANCE

Roof Maintenance Goal 1: Facility maintenance systems and preventive maintenance plans effectively address moisture control issues for roof and ceiling assemblies.

Guidance 1: Read, understand and comply with the manufacturers' or installation contractors' warranty terms and conditions.

Guidance 2: Develop tools for routine inspection and maintenance.

- Develop a roof and ceiling assembly inspection checklist (See Appendix B for a sample). Use it as a guide for observing and evaluating the roof and its systems, equipment mounted on the roof, drainage problems and traffic patterns.
- Develop a roof and ceiling assembly user's manual and logbook. Include such information as:
  - The type of roof, gutter, external downspout system and internal drain and cover.
  - Installation contractor information.
  - Roof, ceiling assembly and drainage system manufacturers.
  - Warranty information.
  - Record of inspections.
- Prepare a map showing all roof and ceiling assembly features such as scuttles, HVAC equipment, drains, gutters, downspouts, scuppers, vents and roof angle changes. Use this map to locate items of interest observed during the inspection. (See Appendix B for a sample map of a roof and ceiling assembly.)

Roof Maintenance Goal 2: Moisture does not penetrate roof and ceiling assemblies or collect in exterior elements, except as intended by the design.

Guidance 1: Inspect the roof and ceiling assemblies to determine whether they are performing their intended functions; to identify signs of weakness, deterioration or hazards; and to identify needed repairs.

Frequency of Inspection

- Inspect semi-annually or in accordance with manufacturer's requirements and as soon as possible after heavy winds or rains.
- Conduct special inspections after events such as construction on the roof or adjacent roofs, rooftop equipment installation, fire or vandalism.

Prepare for Inspections

- Review, learn and follow roof safety procedures.
- Review past inspection reports, construction documents and past maintenance and repair reports before inspecting the roof.

Conduct Inspections

- Use ladders to inspect steep roofs. Ensure all ladders comply with, and are maintained and used in accordance with, the Occupational Safety and Health Administration (OSHA) 29

CFR Occupational Safety and Health Regulation requirements.

- Do not rest ladders against gutters. When on the roof, take care to step on the flat portions of the panels over structural members and not on side-laps or standing seams.
- Inspect interior walls and ceilings for signs of water penetration (i.e., water damage or staining) or structural distress. If possible, check the underside of the roof deck. Look for water or insect damage, deterioration of the deck, rusting, settling or other physical damage. Inspect the interior surface of exterior walls and roof overhangs for signs of moisture, cracking or movement.
- Inspect exterior walls and roof overhangs for signs of moisture, cracking or movement. Inspect exterior grounds around buildings for signs of ponding, which may indicate blockage.
- Inspect the roof covering and edge for continuity. Look for deterioration, damaged or loose laps and seams, loose or missing fasteners, rust or corrosion, physical damage to the roof covering, and the accumulation of debris and vegetation. Look for soft roof insulation and cracked, spalled or discolored walls.
- Inspect for moisture infiltration. Pay attention to areas where walls or parapets intersect roofs, around rooftop HVAC units, and around skylights or other roof penetrations. Check for missing or broken weather seals on equipment housings and cracked or missing caulking.
- Inspect flashings at roof-wall intersections and at curbs. Look for loose flashing or missing fasteners, open ends or lap joints, unsealed corners and rusted or corroded metal. If caulk or roofing tar has been used as a temporary repair, inspect for cracks. Also inspect flashings around curbs, access hatches and rooftop equipment. Where deflection is required, make sure that roof panels and flashings move independently.
- Inspect hips, ridges and valleys. Look for loose or missing fasteners, open ends or open lap joints, damage from foot traffic and corroded metal. In valleys, check to make sure the roof covering is secured at the valley edges and that there are no obstructions blocking water flow.
- Inspect the drainage system. Check gutters and downspouts for loose or missing fasteners, loose joints, corrosion and debris. Make sure sealants and solder are in good condition. Check downspouts, interior roof drains, scuppers and outlets to ensure they are not blocked. If possible, shine a flashlight down each downspout and leader to check for blockage. If blockage is suspected in a downspout running through the interior of the building, snake out the downspout or use a mechanical auger. Do not use water to try to flush out an interior downspout suspected of being blocked. If a roof drain is blocked by ice, do not try to open it by chipping or breaking the ice. Ensure that all joints are properly sealed. Inspect masonry weep holes for signs of dripping.
- Look for ponding or standing water on the roof. Pay particular attention to areas around scuttles, curbs, skylights and other features that may impede roof drainage. Another indication of a failed drainage system is accumulated debris on the roof. Remove all litter and debris from the roof surface. Standing water can damage the gravel and the granule or liquid coatings on roofs. Once these coatings are damaged, sunlight can degrade the roofing membrane. Look in the gutters for mineral granules from shingles, which may indicate that the shingles are worn. A small penetration can allow standing water to seep under the membrane. Deflection may indicate structural problems that must be addressed.
- Include non-destructive tests such as infrared thermography or other appropriate tests if moisture intrusion is suspected.
- Record and report inspection findings.
- Report immediately any unsafe working conditions or potential system failures.

Special Considerations for Membrane Roofs

- Pay particular attention to areas between roof trusses and beams, which are likely spots for roof deflection.
- Inspect the roof membrane for moisture intrusion. Pay particular attention to the joints between two sheets of membrane and to changes in the angle of the roof:
  - Built-up bituminous membrane roofs: Look for blisters caused by the expansion of air or water vapor trapped beneath. Also look for cracks in the membrane, splits, ridges and lifting of the membrane at the seams.
  - Elastomeric membranes**:** Look for open seams, shrinkage and backed-out fasteners. Inspect the roof for damage after windstorms. Pay particular attention to the membrane surface, roof edge metal, flashings, gutters and downspouts.

- Ballasted roof systems: Look for missing or displaced ballast and insulation boards beneath the roof membrane.
- Adhered roof systems: Look for loose areas of the membrane, displaced insulation boards and tented insulation fasteners and plates. On mechanically attached roof systems, look for cuts in the membrane, displaced insulation boards and tented roof fasteners and plates. Inspect for loose flashing. Also inspect rooftop HVAC units for loose or missing sheet metal components.

Special Considerations for Asphalt Shingle Roofs

Pay particular attention to the tops of the vertical slots between tabs. This area is usually the last to dry. Moss and lichen growth on asphalt roofs keeps the roofing materials damp, so use a water hose and nozzle to remove moss and lichen. Spray from the roof facing down the slope to avoid spraying water up under the shingles.

Guidance 2: Repair as needed to meet or exceed warranty requirements.

Develop a maintenance work plan to correct deficient conditions in a timely manner.

Verification of Roof and Ceiling Assembly Maintenance

- Incorporate the completed checklist and map into the user's manual and logbook upon completion of each inspection.
- Keep and maintain records of all inspections, including the checklist. Include photographs and test reports so that changes in roof conditions can be verified.

Plumbing System Operation and Maintenance

Issue

Improperly maintained plumbing systems can cause flooding or condensation build-up. Since plumbing is often located in areas that are not often viewed by occupants, poor maintenance can lead to unnoticed mold growth that can damage the building and its contents, as well as pose health risks to occupants.

Goals

Plumbing Maintenance Goal 1: Plumbing systems are inspected and maintained to prevent flooding or condensation.

Guidance

Plumbing Maintenance Goal 1: Plumbing systems are inspected and maintained to prevent flooding or condensation.

Guidance 1: Develop a plumbing system inspection and maintenance plan. The plan should include:

- The name, address and telephone number of the person or persons responsible for inspection and maintenance of the plumbing systems.
- Specific preventive and corrective maintenance requirements, which can be in the form of checklists. Inspection checklists should be developed for:
  - Water supply and distribution piping, pumps and valves.
  - Water usage equipment such as sinks and drinking fountains.
  - Hot water heaters and storage tanks.
  - Fire sprinkler systems, which should be inspected in accordance with National Fire Protection Association (NFPA) standards or local code requirements.
  - Building drainage systems such as floor drains, sumps and pumps.
  - Other facility plumbing systems and components such as pipe insulation.
- A schedule of regular inspections and routine maintenance tasks.
- Detailed logs of all preventive and corrective maintenance tasks, including all maintenance-related work orders.
- Necessary maintenance equipment, tools and supplies.
- Emergency response actions.
- Procedures and equipment necessary to protect the safety and health of inspectors and maintenance workers.
- System component manufacturers' literature and warranties.
- As-built construction plans.
- Training of maintenance personnel.

Guidance 2: Inspect plumbing systems and components. Make sure:

- Inspections are performed according to the timetable in the plumbing system inspection and maintenance plan.
- Inspection results are logged into the plumbing system inspection and maintenance plan.
- Work orders are prepared for maintenance requirements found during the inspections.

Guidance 3: Maintain plumbing systems and components by performing regularly scheduled preventive maintenance and unscheduled maintenance to correct problems discovered during inspections. Regular maintenance will save money in the long run.

Verification of Plumbing System Operation and Maintenance

- Completed inspection checklists.
- Completed maintenance checklists.

HVAC System Operation and Maintenance

Issue

Failure to adequately maintain HVAC systems can lead to moisture problems including loss of humidity control, condensation and overflowing drain pans. Regularly scheduled inspections and maintenance can prevent unexpected equipment failure and reduce the equipment's life-cycle cost. Properly maintaining HVAC systems helps to ensure occupant comfort and healthy indoor air quality.

Goals

HVAC Operations and Maintenance Goal 1: Facility maintenance management systems and preventive maintenance plans effectively address moisture control in HVAC systems.

HVAC Operations and Maintenance Goal 2: HVAC systems are maintained as intended by manufacturer's specifications and system design to effectively control moisture.

Guidance

HVAC Operations and Maintenance Goal 1: Facility maintenance management systems and preventive maintenance plans effectively address moisture control in HVAC systems.

Guidance 1: Develop and implement facility maintenance management systems and HVAC system preventive maintenance (PM) plans, or review and revise existing systems and plans, to control moisture effectively. Maintenance management systems and PM plans for HVAC systems should:

- Incorporate moisture control into the functional objectives that guide the maintenance program (e.g., as a stand-alone objective, as part of an indoor air quality objective or as part of a reliability or long-term cost-minimization objective).
- Develop a performance objective for moisture control (e.g., number of unanticipated leaks, dollars spent on leak repair, number of hours when indoor relative humidity falls within the specified design range, etc.) and track performance to determine whether that objective is being met.
- Maintain records of all HVAC system installations, inspections and maintenance, along with warranty information and requirements.
- Incorporate best practices for moisture control in the inspection and maintenance of HVAC systems. Particular attention should be paid to coils and drain pans, humidifiers, cooling towers, the introduction of humidity-laden air and the potential for condensation. (See HVAC Operations and Maintenance Goal 2 for more detailed guidance on conducting HVAC maintenance inspections.)
- Ensure that planners and schedulers assign inspectors who are knowledgeable about the HVAC and plumbing systems being inspected.
- Schedule regular inspections at least semi-annually or in accordance with manufacturer's requirements. Additional inspections should be scheduled as soon as possible after heavy winds or rains or after any construction or installations that could affect the integrity of these systems, especially their outdoor components.
- When developing work orders for moisture-related maintenance tasks, include best practices and checklists for detailed inspections and maintenance tasks (See HVAC Operations and Maintenance Goal 2) in the scope of work and instructions.
- Incorporate best practices and checklists (See HVAC Operations and Maintenance Goal 2) into training programs for inspectors and maintenance personnel who deal with these drainage systems.
- Give priority to moisture-control issues in preventive maintenance, major maintenance and repair, and capital renewal planning and budgeting.

HVAC Operations and Maintenance Goal 2: HVAC systems are maintained as intended by the manufacturer's specifications and the system design in order to effectively control moisture.

Guidance 1: Maintain HVAC system components in accordance with the manufacturer's requirements and the moisture control recommendations in this guidance. At a minimum, the following HVAC components should be inspected as part of a PM program:

Thermostats

- Thermostats should be checked in the fall and spring, shortly after switching to or from daylight saving time, or whenever complaints about thermal comfort are received.

Checking Thermostat Operation and Calibration

- If the thermostat is programmable, make sure the time is set correctly and the thermostat is programmed for the hours when the building is occupied.
- Place a calibrated thermometer next to the thermostat. Place a paper towel or other material between the thermometer and the wall to make sure the wall temperature is not influencing the thermometer reading.
- Allow the thermometer to stabilize. How long this takes will depend on the thermometer used.
- Compare the thermostat and thermometer readings. If the thermostat differs by more than 1°F, there is a problem and you should do the following:
  - Remove the faceplate and check whether the thermostat is dirty. Carefully brush or blow away any accumulated dust.
  - If contact points are accessible, clean them with a soft cloth. Do not use sandpaper or other abrasive materials.
  - If the thermostat has a mercury switch, check that it is level. Be very careful not to break the vial that contains the mercury.
  - Check behind the thermostat to make sure the hole for the wires is caulked to prevent air within the wall from influencing the thermostat reading.
  - Allow temperatures to stabilize and compare the thermostat and thermometer readings again. If they still differ by more than 1°F, replace the thermostat.

Control Sequence

- Make sure the clocks on all systems read the correct time and date (if applicable); adjust if necessary.
- Check that equipment is turned off or energized according to the control sequence. (Observe the actual operation of fans, dampers and valves as well as the operation of the control unit.)

Outdoor Air Intakes

- Inspect the area around intakes for potential contaminant sources such as dumpsters, garbage cans, decaying organic matter and automobile idling or parking areas. If there are contaminant sources near the intakes, move them if possible. If contaminant sources are not mobile, other steps may be required to prevent the intake of airborne contaminants. These steps may include relocating intakes or instituting policy changes such as prohibiting vehicle idling.
- Inspect the outdoor air intake louver and the debris screen behind it. Check for signs of rain leaks and clogged screens. If rainwater intrudes into the outdoor air intake, modify as needed to prevent entry. Remove grass clippings, leaves, dust and other materials that obstruct the air intake. Take care when doing this during the warmer months because bees, wasps or other stinging insects may have nested in the intake. NOTE: Do not use a pesticide if insects are found in the outdoor air intake.
- If outdoor air intakes are close to ground level, ensure that all landscape plantings are at least 5 feet from the intake. Require lawns to be mowed in a manner that directs the cut grass away from the building and the intakes.

Outdoor Air Dampers

- Determine the outdoor air damper control sequence, then change the parameters to force the dampers to open and close. Do not rely on observing linkages; watch the outdoor air dampers for movement. Make necessary repairs to ensure dampers open and close in accordance with the control sequence.
- Measure outdoor air volumes on a regularly scheduled basis and whenever indoor air quality problems arise. Either purchase equipment such as balometers, anemometers, manometers and pitot tubes to take these measurements, or hire a qualified contractor.

Cooling Coils, Drain Pans, and Condensate Lines

- Inspect coils, pans and condensate lines regularly for cleanliness and to ensure the drain is operating correctly. Clean or repair faulty drains as necessary.
- Ensure that all traps have water in them. During times of the year when the HVAC system is not used, or when condensate formation is low, the trap can dry out, allowing sewer gases or other gases in the drainage system to be drawn into the HVAC unit and distributed through the building. Fill empty drain traps with water.
- Closely inspect the ducts downstream from the cooling coil for mold growth or signs of condensation being blown off the coil. If mold is found growing on hard-surface ductwork (e.g., sheet metal) or closed-cell insulation, have the ductwork evaluated by a mold remediation specialist or a qualified duct cleaner. If mold is found growing on internal porous duct insulation, remove and replace the insulation because it cannot be effectively cleaned.

Evaporative Cooling Equipment (Common in Dry Climates)

- Inspect the evaporative pad media regularly for cleanliness, and even wetting, across the full face of the pad. Replace clogged media to ensure that supply air is not constricted and forced into high-velocity flow, which could pull water off the media and into the air stream and ductwork downstream. Similarly, make sure the water flow is even across the full face of the pad (for effective cooling) and not excessively high in any one spot, which could also result in water droplets being pulled off the media and into the air stream.
- Ensure the overflow drain is operating correctly. Clean out or repair the drain lines as necessary to ensure that water does not collect in the sump and overflow the edge of the pan. (Overflows can otherwise leak into ductwork or into the building itself.)
- Ensure that the media is not contacting standing water in the sump when the unit is not operating. The sump overflow adjustment must be low enough to prevent water from wicking back up into the media and supporting microbial growth.
- Check the controls to ensure that the evaporative cooler does not operate when it is raining outdoors. Otherwise, the unit could overload the incoming air with humidity at a time when little evaporative cooling needs to be accomplished. Needlessly loading the indoor air with extra humidity can lead to excess moisture accumulation, even in dry climates.
- Closely inspect the ducts downstream from the evaporative cooler coil for mold growth or signs of moisture being blown off the media. If mold is found growing on hard-surface ductwork (e.g., sheet metal) or closed-cell insulation, have the ductwork evaluated by a mold remediation specialist or a qualified duct cleaner. If mold is found growing on internal porous duct insulation, remove and replace the insulation because it cannot be effectively cleaned. Before the equipment is placed back in operation, locate and correct the problem that led to the carryover of water droplets which supported the mold growth.

Air Filters

- Do not rely solely on pressure drop warning equipment to determine the need to replace filters. Clogged filters can be sucked out of their frames and air may bypass the filter, resulting in no noticeable pressure drop. Visually inspect and replace air filters on a regular schedule. Turn unit fans off when changing filters to prevent contamination of the air. Be aware that some filters may need more frequent replacement than others because different areas of a facility may have different airborne particle burdens.
- Record the date of the filter change in the maintenance manual and write the date of the change on the filter, if possible.

Ducts and Supply Diffusers

- Inspect ducts regularly, typically once a year or whenever modifications have been made to the ducts or the areas they serve.
- Information about the potential benefits and possible problems of air duct cleaning is limited. The North American Air Duct Cleaners Association (NADCA) recommends duct cleaning if there is a significant build-up of particles, if the duct is contaminated with mold spores and trace mold growth, or if there is obvious mold growth. If mold is growing in ducts lined with porous insulation, the NADCA guidance recommends removing the insulation. When cleaning ductwork, follow the 2006 NADCA guidance *Assessment, Cleaning and Restoration of HVAC Systems.*

- Inspect ducts for physical damage. Look for crushed or disconnected ducts. Reconnect, repair or replace as necessary.
- Inspect all accessible duct seams and joints for leaks and seal all leaks with appropriate materials. Seal duct leaks with mastic, metal-backed tape or aerosol sealant. Duct tape should not be used because it dries out quickly and fails to hold and because it cannot withstand high temperatures. All sealing materials must comply with Underwriter's Laboratory Standard UL 181A; check the labels.
- Inspect supply diffusers and the ceiling around diffusers for dirt and dust that can indicate dirty ducts or missing, inefficient or bypassed filters. Note that dirt and dust patterns on supply diffusers or ceilings do not necessarily mean the HVAC system is the source of the dirt. The vortexes created as air exits the diffuser can deposit dust from the ambient air onto surfaces.
- Send dirt and dust samples to an environmental laboratory for microscopic examination to determine whether the particles look like soot, lint, mold, sand or something else.
- Look for mold growth on diffusers supplying cooled air to the space. Condensation caused by cooling the diffuser below the dew point can support mold growth. Clean as needed and determine what actions are necessary to prevent condensation.

Return Air Plenums

- Return air plenums are spaces that do not have ducts and typically are found above T-bar ceilings—suspended ceilings—and below the roof or floor deck above. Dust, mold and other contaminants within the space can migrate back to the HVAC unit and be distributed to the occupied areas of the building.
- Periodically inspect buildings that have return air plenums for water-stained ceiling tiles, which may indicate mold growth. If mold growth is found or suspected, consult a qualified professional to determine the extent of the problem and remediation requirements.

Guidance 2: Monitor temperature and humidity while commissioning or recommissioning the HVAC system to ensure humidity control is functioning effectively.

- Penetrations in the return plenum may draw outdoor air into the system. If it is hot and humid outside this can cause condensation on chilled surfaces, in internal building cavities, or in walls or ceilings. Monitoring temperature and relative humidity in the building, supply air, return air, and outdoor air during HVAC commissioning or recommissioning allows tracking of humidity sources. The absolute humidity or humidity ratio can be calculated from these data and mass balance can be made to determine whether there is a source of humidity on the return side of the system.
- The dehumidification performance of the building commissioning or recommissioning should be tested when the building is occupied.

Verification of HVAC System Operation Maintenance

Set inspections and routine maintenance efforts in accordance with equipment warranty requirements. Appendix E contains a sample HVAC inspection checklist. Inspection records should be kept to track the results and any subsequent repairs needed.

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(This website outlines the federal requirements for complying with National Pollutant Discharge Elimination System [NPDES] requirements for construction.)

Appendix A[23] – The "Pen Test"

PURPOSE

By tracing the continuity of all the materials for each control function, the "pen test" checks the completeness of:

- Rainwater protection.
- The insulation layer.
- The air barrier.

To verify continuity, create sections in which each of these moisture-control elements is traced in a different color to show that the design specifically accounts for them. Contractors can then easily check the sections against their experience with materials, trades and sequencing. The sections will also provide maintenance workers in buildings and grounds with information useful in ordinary maintenance work or in the event of a problem during building use.

PROCESS

Rainwater Protection Continuity

To demonstrate complete rainwater protection using the section drawing, place a pen on a material that forms a capillary break between the rain-control materials that get wet and the inner portion of the enclosure that must stay dry. Without lifting the pen off the paper, trace from the center of the roof around the walls, windows, and doors and along the foundation to the center of the foundation floor.

Figure A-1 serves as documentation of rainwater protection continuity. The following describes the traceable capillary break in a sample section. Starting at the center of the roof:

- The roofing membrane is the first line of defense, protecting the water-sensitive inner materials from rain and snowmelt.
- Tracing the roofing membrane from the center of the roof to the edge of the roof, the roofing membrane rises up the parapet wall where it flashes beneath a metal coping, which also forms a metal fascia.
- The fascia forms a drip edge, channeling water away from the cladding.
- An air gap between the drip edge and the brick veneer forms a capillary break, protecting the materials beneath the coping from rainwater.
- Behind the brick veneer, air gap and foam board, a self-adhering water resistant barrier (WRB) applied to the gypsum sheathing forms a capillary break between the damp brick and the inner wall assembly.
- The WRB laps over the vertical leg of a head flashing, protecting the window from rainwater with a drip edge and an air gap. Weep holes allow water to drain from behind the brick cladding.
- The window frame, sash and glazing form a capillary break system that sits in a pan sill flashing at the bottom of the window.
- The pan sill flashing forms a capillary break protecting the wall beneath from seepage through the window system.
- The pan sill flashing shingles over the WRB in the wall beneath, which shingles over a flashing that protects the bottom of the wall system.
- The water-resistant barrier shingles over a flashing that protects the bottom of the wall system where the foam sill seal makes a capillary break between the foundation and the bottom of the framed wall, connecting with:
  - One inch of extruded styrene foam insulation making a capillary break between the top of the foundation wall and the edge of the floor slab.
  - Polyethylene film immediately beneath the slab forms a capillary break between the bottom of the slab and the fill below. NOTE: If the bed of fill beneath the slab consists of pebbles greater than ¼ inch in diameter and contains no fines, then it forms a capillary break between the soil and the slab.

Apply the same procedure to the insulation layer (Figure A-2) and the air barrier (Figure A-3).

[23] Figures A-1, A-2, and A-3 were updated in April, 2014.

Figure A-1 The Blue Line Traces the Elements of the Capillary Break in the Rainwater Control System for a Section Through a Building

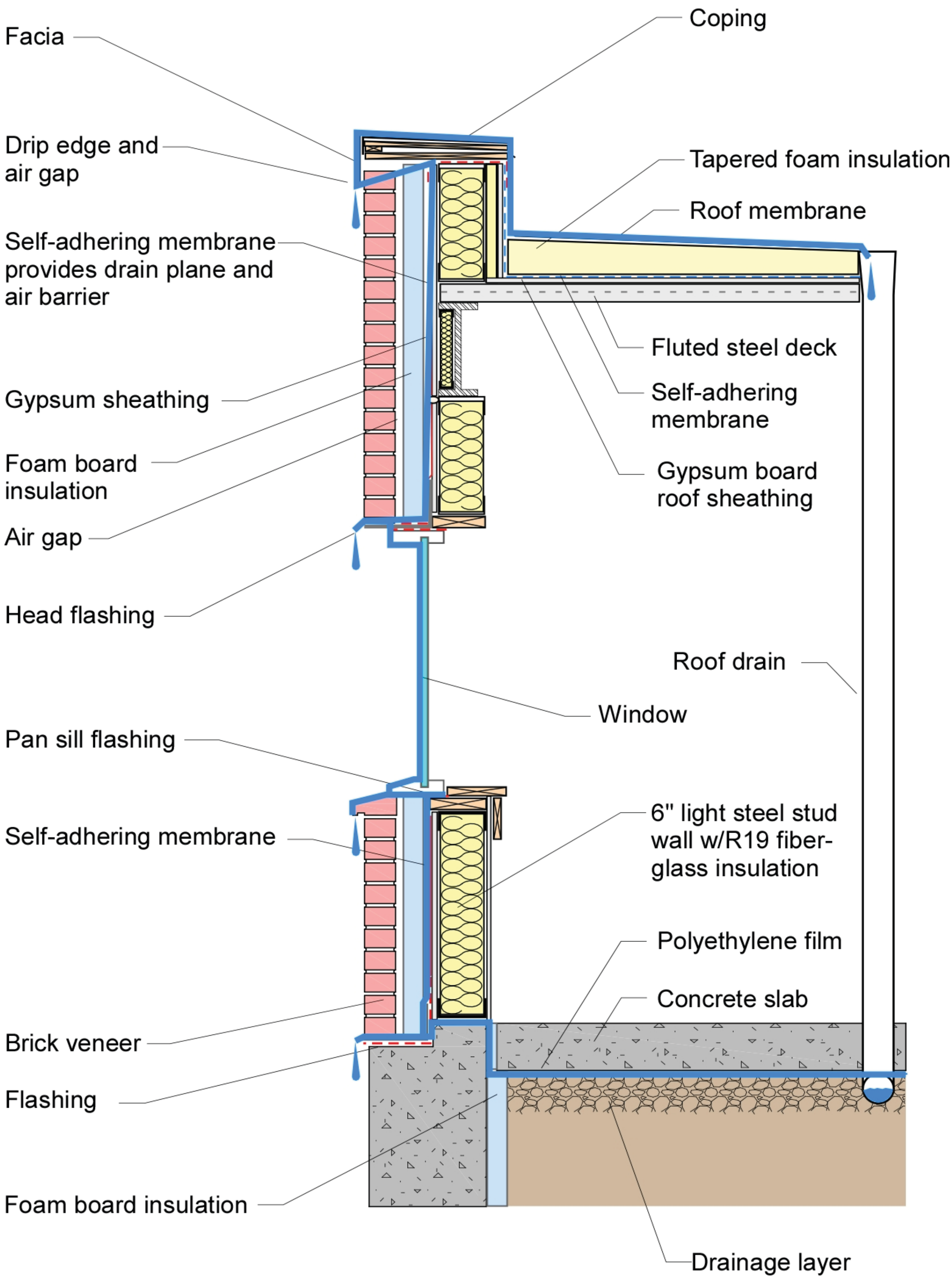


Figure A-2 The Red Line Traces Continuity of the Insulation Layer

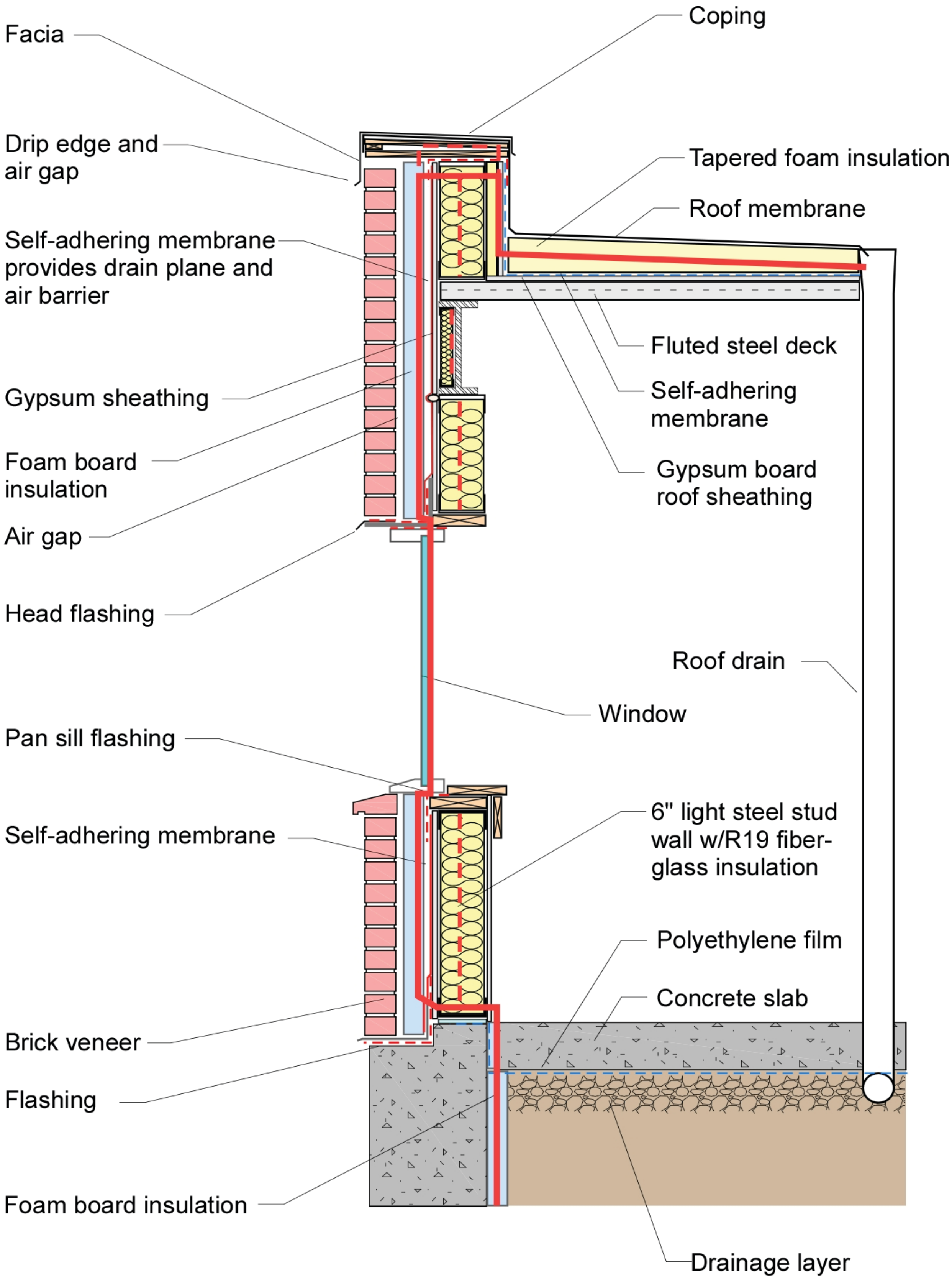
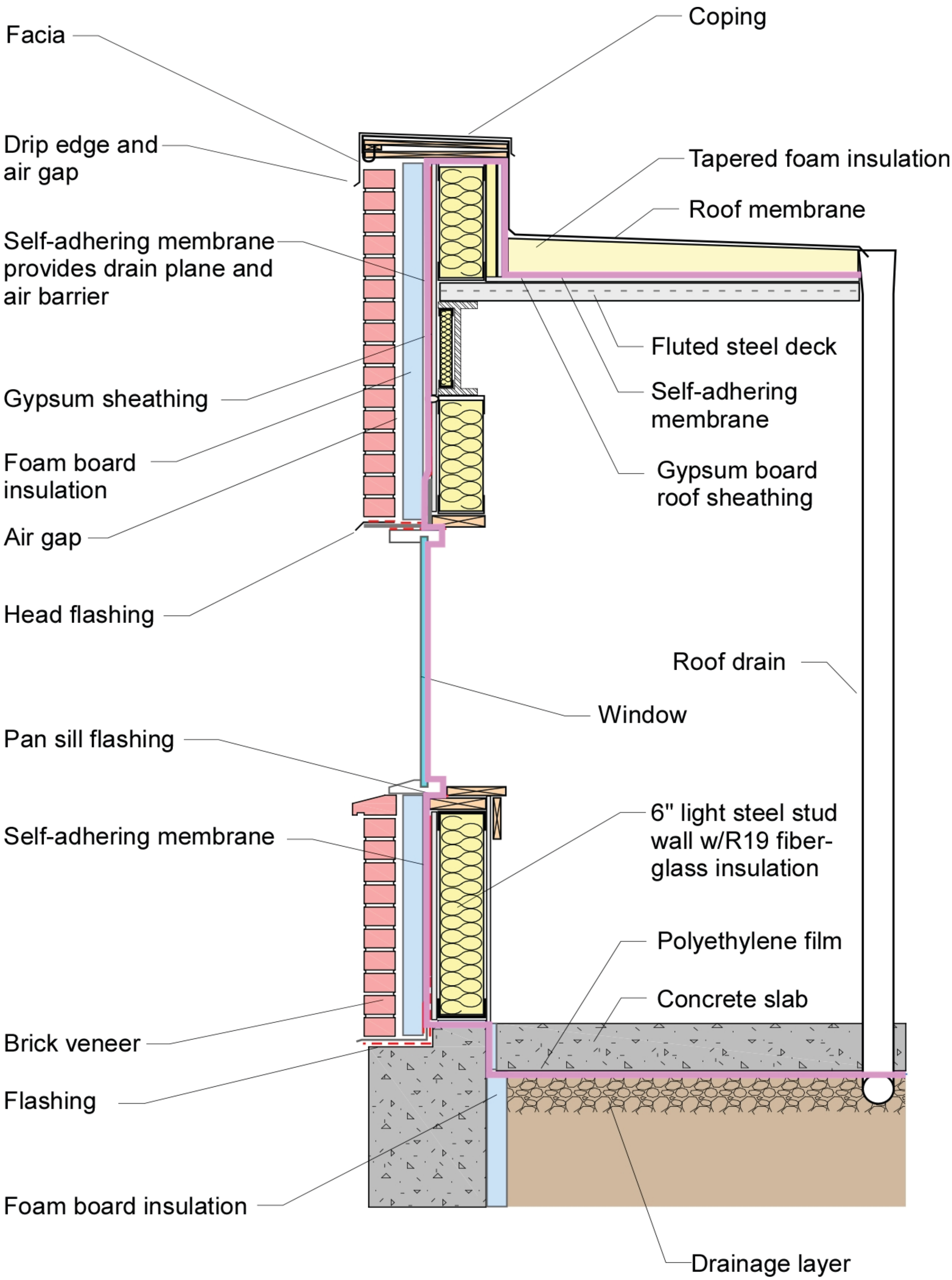


Figure A-3 The Purple Line Traces the Air Barrier Components



Insulation Layer Continuity

To demonstrate a continuous layer of insulating material around a section, place the pen tip on the insulating layer in the center of the roof and trace from one insulating material to the next around to either the bottom of the foundation wall or the center of the foundation floor.

Figure A-2 shows the continuity of thermal insulation in a sample section.

- Beginning at the center of the roof, trace through foam insulation to the edge of the roof.
- Up a layer of foam board insulation to the wooden blocking at the top of the parapet wall.
- The wooden blocking connects to the top of the exterior foam insulation board insulation and the top channel of the light guage steel wall framing.
- The steel wall framing is filled with cavity insulation, and the thermal bridge through the steel is insulated by the exterior foam insulation.
- At the window head the steel lintel is a thermal bridge through the insulation system, the rough opening around the window is sealed using backer rod and sealant.
- The window jamb, sash and glazing system provide insulation continuity to the pan sill flashing at the bottom of the window.
- The exterior insulating foam sheathing and cavity insulation carry the insulation layer to the foundation.
- Foam sill seal provides thermal insulation between the bottom of the wall and the concrete foundation, which carries thermal protection below grade to the bottom of the foundation wall.
- Vertical foam insulation applied to the interior of the foundation wall completes the insulation layer.

Air Barrier Continuity

Continuity of the air barrier is demonstrated using the same method used for rainwater control and the insulation layer. For this example air barrier materials and the sealants used to connect them are identified from the center of the roof to the center of the foundation floor. Self-adhering membranes are used as examples in this section, but note that wall air barriers may be formed using alternate air barrier materials (e.g., fluid applied membranes, flexible sheets, rigid foam board insulation, and spray polyurethane foam).

- From the center of the roof trace the air along the self-adhering membrane on the gypsum roof sheathing to the edge of the roof.
- The self-adhering membrane continues up the gypsum board sheathing on the parapet wall where it connects to a transition membrane that spans the top of the parapet wall.
- From the transition membrane trace down the self-adhering membrane on the wall sheathing to an intersection with the window head flashing at the steel lintel.
- A transition membrane wraps from the bottom of the steel lintel into the rough opening where it connects to the window by sealant and backer rod.
- The window system forms the air barrier to the pan sill flashing where sealant makes the connection.
- The pan sill flashing carries the air barrier to the self-adhering membrane on the lower wall.
- A transition membrane connects to the concrete foundation.
- Polyethylene film or the concrete slab itself extend the air barrier to the center of the floor.

Appendix B – Roof Inspection Checklist

Parts of this inspection checklist are adapted from and used with the permission of the Government of The Northwest Territories Public Works and Services Asset Management Division.

Before performing a roof inspection:

- Review past inspection reports, construction documents and maintenance and repair reports.
- Review, learn and follow roof safety procedures.
- Use ladders to inspect steep roofs. Ensure all ladders comply with, and are maintained and used in accordance with, the Occupational Safety and Health Administration (OSHA) requirements in Title 29 of the Code of Federal Regulations (29 CFR).

Building:____

Address: ____

Roof Area or ID:____________________________________

Inspected by:__________________________ **Date:**________________

Item	**ID – Number to be used to identify problem on roof sketch** **G – Good, no action needed** **F – Fair, monitor condition periodically, plan necessary repairs** **P – Poor, immediate action needed** **N/A – Not applicable**						
Interior	**Interior Walls**	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Water stains	1					
	Water damage	2					
	Other wall problems	3					
	Ceilings	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Water stains	4					
	Water damage	5					
	Other ceiling problems	6					
	Roof Deck	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Water damage	7					
	Rusting	8					
	Settling/deflection	9					
	Deck deterioration	10					
	Other roof deck problems	11					
Exterior	**Downspouts/Leaders**	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing pieces	12					
	Loose pieces	13					
	Evidence of blockage	14					
	Damaged joints	15					
	Split joints	16					
	Surface ponding	17					
	Other downspout/leader problems	18					

	Exterior Walls	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Water stains	19					
	Water damage	20					
	Other wall problems	21					
Roof	**General Conditions**	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	General appearance	22					
	Traffic problems	23					
	Unauthorized access	24					
	Ponding	25					
	Debris	26					
	Physical damage	27					
	Deflection	28					
	Compressed insulation	29					
	Other roof problems	30					
Drainage System	**Gutters**	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing pieces	31					
	Loose pieces	32					
	Damaged pieces	33					
	Split joints	34					
	Corrosion	35					
	Loose fasteners	36					
	Debris in gutters	37					
	Slope to downspout	38					
	Other gutter problems	39					
	Internal Roof Drains	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing drain screens	40					
	Blocked drain	41					
	Other drain problems	42					
	Scuppers	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Blockage	43					
	Other scupper problems	44					
Roof Features	**Perimeter Edging/ Fascia/ Gravel Stop**	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing pieces	45					
	Loose pieces	46					
	Damaged pieces	47					
	Split joints	48					
	Corrosion	49					
	Loose fasteners	50					
	Other	51					
	Flashings	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing pieces	52					
	Loose pieces	53					
	Damaged pieces	54					
	Split joints	55					
	Corrosion	56					
	Loose fasteners	57					
	Other flashing problems	58					

	Roof-mounted Equipment (HVAC, Signs, Skylights, Etc.)	ID	G	F	P	N/A	REMARKS
	Flashings	59					
	Loose/missing access panels	60					
	Condensate piped to drain	61					
	Contamination around exhaust fans	62					
	Other equipment problems	63					
Roof Covering	**Membrane Roofs**	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Bare spots in gravel or displaced ballast	64					
	Cuts/punctures	65					
	Cracks/alligatoring	66					
	Blisters/fishmouths	67					
	Loose laps/seams	68					
	Ridging/wrinkling	69					
	Fastener back-out	70					
	Membrane shrinkage	71					
	Other	72					
	Shingled Roofs	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing shingle(s)	73					
	Loose shingle(s)	74					
	Buckled shingle(s)	75					
	Curled shingle(s)	75					
	Missing tab(s)	77					
	Granular loss	78					
	Other shingle problems	79					
	Metal Roofs	**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Loose or damaged seams/ joint(s)	80					
	Loose panel(s)	81					
	Worn panel(s)	82					
	Damaged panel(s)	83					
	Loose fastener(s)	84					
	Finish condition	85					
	Other metal roof problems	86					

Use this graph paper to sketch the roof plan. Include north arrow and the location of problems found during the inspection. Use the roof ID numbers on the checklist to identify specific problems.

Appendix C – Testing Moisture During Construction

The moisture content of wood, wood products and other porous materials is an important factor in mold growth and other moisture-related problems. A porous material susceptible to mold growth, such as wood, oriented strand board (OSB), medium density fiberboard (MDF) or untreated paper-faced gypsum board, will experience mold growth if its moisture content is too high. Damp porous materials that are resistant to mold growth, such as concrete products and treated lumber, may indirectly support mold growth by wetting vulnerable materials that are in contact with them. For example, untreated paper-faced gypsum board attached to damp lumber or concrete may be the site of mold growth until the damp materials dry.

Wood and wood products that contain a great deal of moisture should not be used in construction until their moisture content is below a certain percentage. Unfortunately, research on this dynamic is mostly confined to laboratory research and anecdotal reports from forensic cases. The *California Builder's Guide to Reducing Mold Risk* suggests an upper threshold of 19 percent moisture content for wooden materials. To avoid problems with shrinking or expansion, wood ideally should be installed at moisture content levels as close as possible to the average moisture content it will experience in service. The in-service moisture content of exterior wood depends on the outdoor relative humidity and exposure to rain and sun. The in-service moisture content of interior wood depends on the indoor relative humidity, which in turn is a function of moisture sources, ventilation rates and dehumidification. The in-service moisture content of exterior and interior wood depends on the climate in which the building is located and on the building's design and intended use. The U.S. Department of Agriculture's *Wood Handbook* recommends average moisture content of 15 percent or less, with maximum readings of 19 percent or less, to avoid dimensional change problems.

The moisture content of materials is usually expressed as the percentage of the weight of water in the material relative to the weight of the dry material. In laboratories, moisture content can be calculated by weighing the test sample while damp, drying the sample using heat or desiccant salts, and then reweighing the sample. Electronic meters with direct reading scales or displays have been developed for wooden materials. Their use on lumber is extensively documented. ASTM D 4444-92 (Reapproved 2003) *Standard Test Methods for Use and Calibration of Hand-Held Moisture Meters* describes several types of moisture meters, their use on wooden materials, and quality assurance/quality control (QA/QC) procedures.

Knowing the moisture content of porous building materials other than wood or wood products, such as gypsum board and concrete slabs or concrete masonry units, is also important. Some electronic moisture meters have calibrated scales for materials other than wood, for example concrete, brick and plaster. It has become common practice in the building diagnostic field to test materials other than lumber using electronic meters and to report the results using the scale for lumber. In this way, investigators report the moisture content of gypsum board, MDF and OSB as the wood moisture equivalent (WME). The *California Builder's Guide to Reducing Mold Risk* suggests an upper limit of 16 percent WME for gypsum board before finishing or installing cabinets. This limit translates roughly to 0.9 percent moisture content by weight for gypsum board.

The ability to measure material moisture content after construction is valuable for diagnosing post-construction problems such as water leaks, condensation and mold growth. It is recommended that builders and facility managers measure the moisture content of materials during post construction diagnosis and problem solving.

A second moisture dynamic, the emission rate of water vapor from materials such as concrete floors, can have a dramatic impact on flooring materials. For example, floor covering manufacturers specify the maximum water vapor emission rate of concrete over which coverings such as tile and carpet can be installed. Installing a covering on concrete that exceeds the maximum emission rate may cause the covering to fail, promote mold growth and void the manufacturer's warranty. It is recommended that the vapor emission rate of a floor be measured before coverings are installed (even when the installation occurs long after the building was constructed); whenever lifting tiles, blistered sheet vinyl, or other signs of floor failure are found; or when unexplained high indoor relative humidity in ground-contact spaces is encountered.

ASTM E 1907-06a *Standard Guide to Methods of Evaluating Moisture Conditions of Concrete Floors to Receive Resilient Floor Coverings* identifies eight methods of testing concrete slabs. The two most commonly used methods are:

- F 1869 *Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride.* This test is conducted using commercially available test kits. It is a quantitative test that provides a measure of the vapor, in pounds of water in a 1,000 square foot area, emitted over a 24-hour period. The test involves weighing a canister of calcium chloride desiccant, placing the canister on the slab to be tested, and covering the canister with an air-tight plastic dome supplied with the kit. The test typically is conducted for 60 to 72 hours. After that time, the canister is reweighed and the vapor emission rate is calculated. This test method is accepted by most floor covering manufacturers.
- F 2170 *Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes.* This method measures the head space relative humidity in a hole drilled partway through the concrete slab. It is gaining popularity in the field and has been used in Europe for many years.

Appendix D – Air Pressure Mapping

Air pressure mapping is used to determine whether air is moving through a building in a manner that contributes to condensation problems. Unplanned airflow will cause problems if either:

- Air is moving from the warm side of an exterior wall, the ceiling, or the basement to the cool side.
- Cold air is blowing from an air conditioning diffuser into a space where humidity is high.

To generate an air pressure map of a building, use:

- Floor plans showing the layout of each floor and the location of air handlers, supply diffusers, return grilles, and exhaust grilles.
- A micromanometer and flexible plastic tubing to measure pressure differences between indoor air and outdoor air, rooms and corridors, room air and plenum air, and room air and building cavities.
- A smoke bottle to determine the direction of air flow.

As depicted in Figure D-1, use a micromanometer to measure the pressure difference across a closed door. Note that the tubing is run from one port of the micromanometer to the far side of the door, while the other port (with no tubing) senses the pressure in the room. The micromanometer reads the pressure difference. The minus sign on the micromanometer interface indicates that the room is under negative pressure relative to the other side of the door.

Figure D-2 shows the pressure map of a building that consists of a single room with an operating 100-cfm exhaust fan. The room is depressurized 4 Pascals by the exhaust fan. The exhaust fan is represented by a box with an X in it and an arrow showing the direction of airflow out of the building. The line with an arrowhead on one end and a circle on the other signifies that air is being drawn into the building from outside.

This procedure can be applied to more complex buildings and airflows to document air pressure differences between rooms, indoors and outdoors, attics, basements, crawlspaces, utility chases and wall and ceiling cavities. Figure D-3 illustrates a pressure map of a more complex building when the air handler is running, the exhaust fans in the bathrooms are running, there is no wind, and all the interior and exterior doors are closed.

Figure D-1 Measuring Pressure Difference Using a Micromanometer

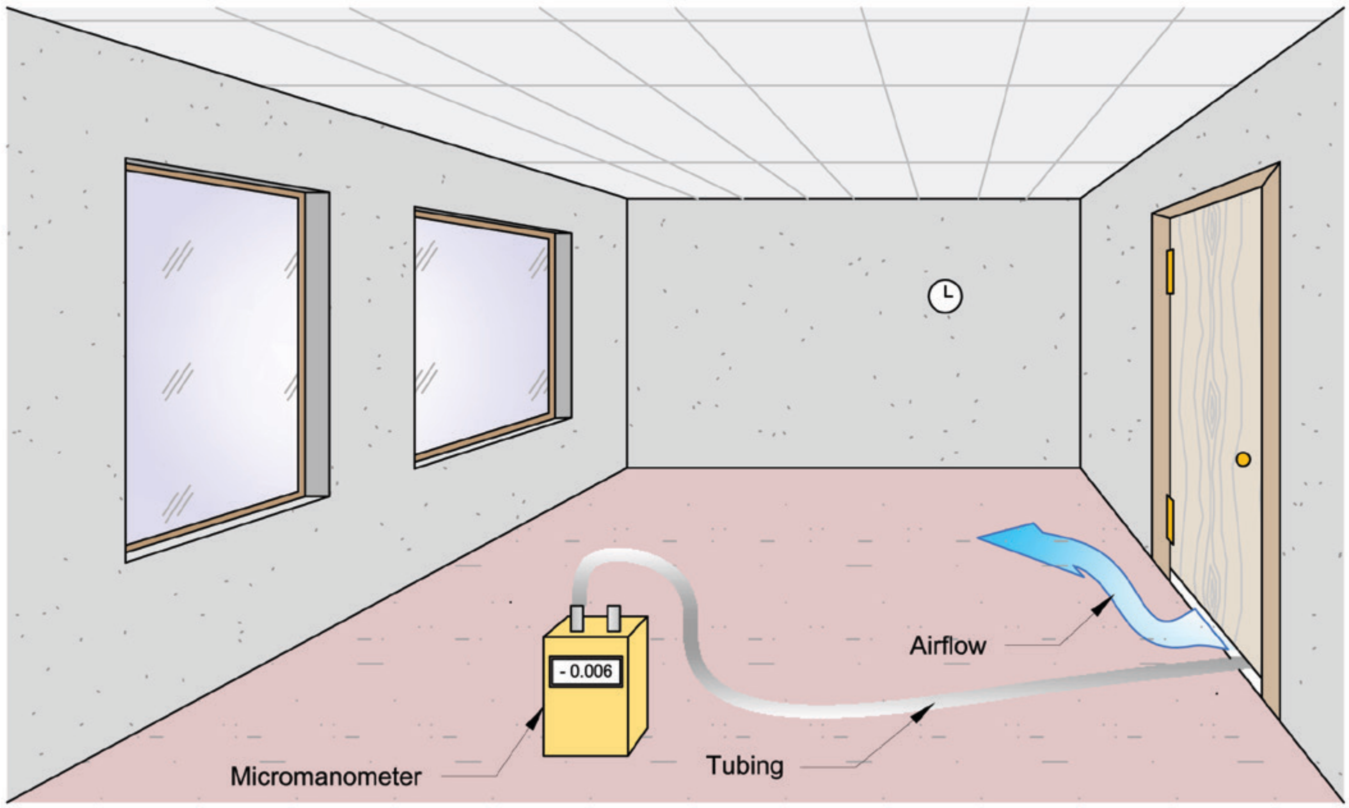


Figure D-2 Pressure Map of a Building Consisting of a Single Room

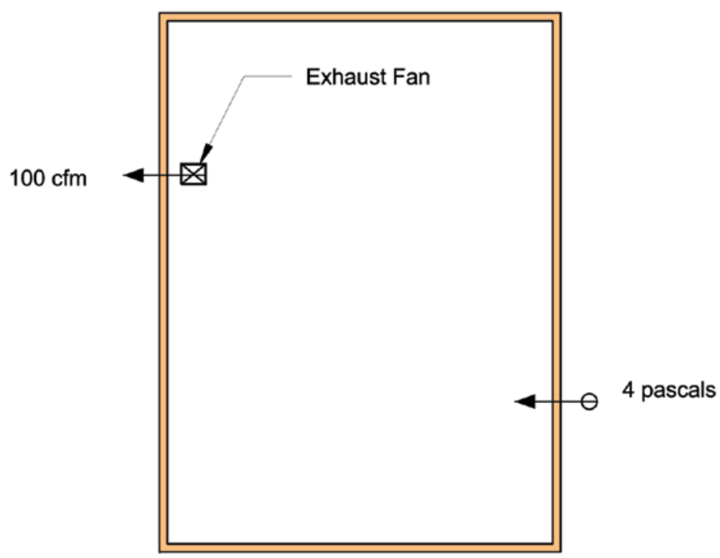
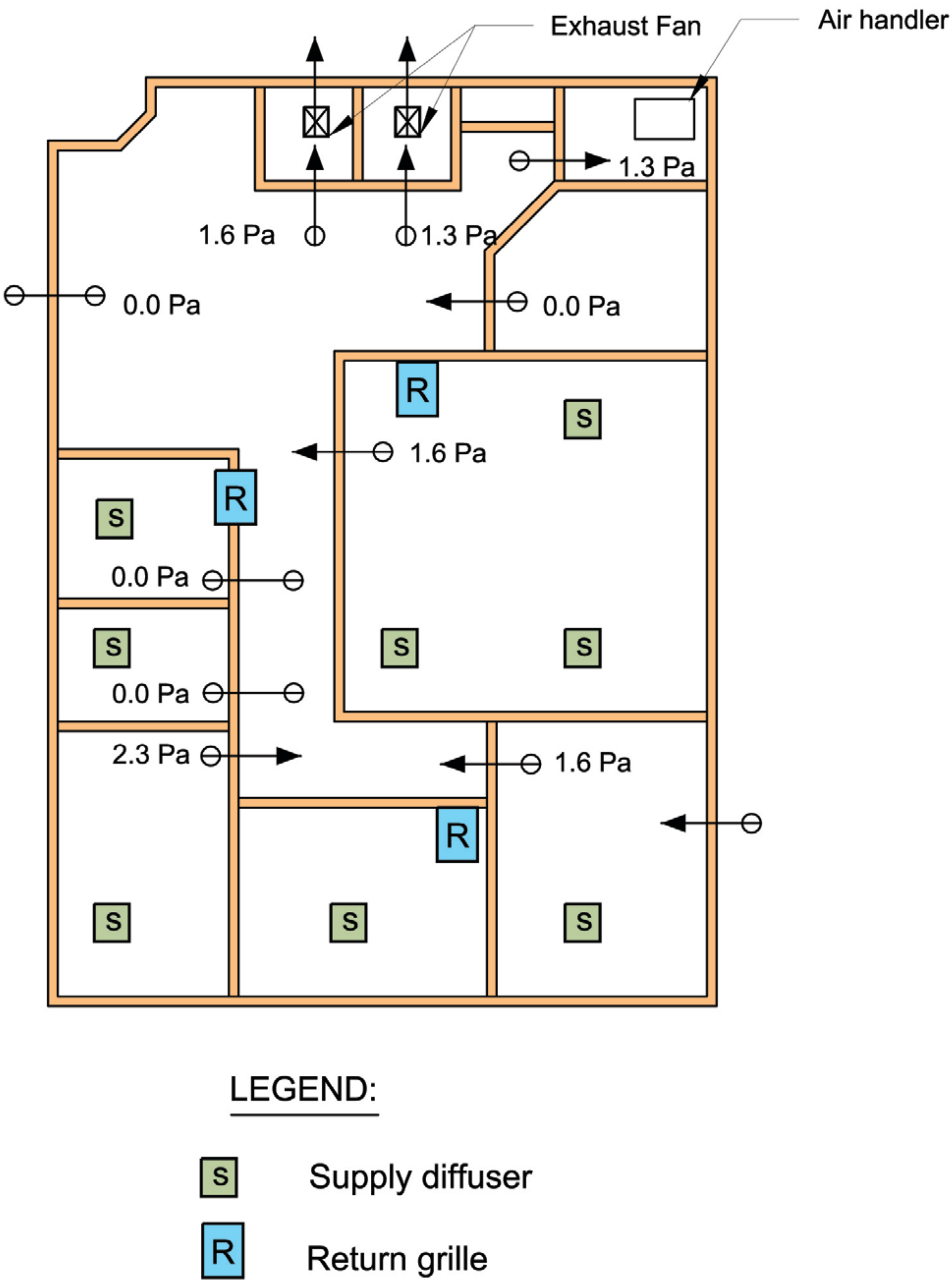


Figure D-3 Pressure Map of a More Complex Building



Appendix E – HVAC Inspection Checklist

Building:____________________ **Location:** _________________________ **Date:** ____________

Equipment: ___________________________ **Manufacturer:** ____________________________

Other ID:________________**File # :** ____________________ **Prepared by:**__________________

	Condition			Priority
Parameter	**OK**	**Not OK**	**Notes**	**L, M, H**
Outdoor Air Intake				
Bird screen				
Air flow unobstructed				
No close-by pollutant sources				
Mixing Plenum				
Clean				
Coils and Condensate Pans:				
Clean, no corrosion				
No odors				
No microbial growth				
Pans draining, traps filled				
Humidifiers				
Clean				
No standing water or overflow				
No microbial growth or mineral deposits				
Controls				
Set points				
Functioning				
Fans				
Clean, no corrosion				
No excess vibration				
Belts				
No excess noise or vibration				
No leakage				
Pressurization				
Filters				
General condition				
Installed properly (no bypass)				
No odors/visible pollution				

Appendix F – Site Drainage Maintenance

Regular maintenance of site drainage systems is necessary to ensure they perform effectively. Failing to regularly maintain drainage systems can lead to reduced performance or system failure. To help provide proper maintenance, a site drainage maintenance plan that describes specific maintenance requirements and schedules should be developed and used by the persons responsible for drainage maintenance.

The maintenance plan differs from the checklists provided in this appendix. The plan encompasses the entire site drainage maintenance requirements, while the checklists provide requirements for a specific drainage feature.

Maintenance Plan Requirements

The following site drainage maintenance plan requirements have been adapted from the *New Jersey Storm Water BMP Manual* (NJDEP04). Plans should include:

- The name, address and telephone number of the person or persons responsible for preventive and corrective maintenance of the site drainage systems.
- Specific preventive and corrective maintenance requirements. These requirements may be in the form of checklists.
- A schedule of regular inspections and tasks.
- Detailed logs of all preventive and corrective maintenance tasks, including all maintenance-related work orders.
- Necessary maintenance equipment, tools and supplies.
- Emergency action responses.
- Procedures and equipment required to protect the safety and health of inspectors and maintenance workers.
- Approved disposal and recycling sites and procedures for the sediment, debris and other materials removed from the drainage systems during maintenance.
- System component manufacturer's literature and warranties.
- As-built construction plans.

In addition, the plan should address the training of maintenance personnel in the operational theory of site drainage and in maintenance and health and safety procedures.

Site Drainage Inspection and Maintenance Recommendations

The following inspection and maintenance recommendations and checklists should be augmented by state or local code requirements as well as best management practices learned by persons maintaining the site drainage system.

Dry wells are to be inspected four times each year and after every storm that exceeds 0.5 inches of rainfall. Whenever possible, dry wells are also to be inspected before a major storm. Inspection consists of measuring infiltration rates and drain times by observing the water level in the test well. The actual drain time of the well should be compared with the time it would take to drain the maximum design storm runoff volume. If significant increases in drain time are noted, or if the dry well fails to dry within the design drainage time, maintenance is required.

Dry well maintenance involves removing debris, trash or sediment that may have washed into the well. In addition to the dry well, any roof gutters, sumps or traps connected to the dry well are to be inspected and cleaned or repaired as necessary.

Building:______________________________

Address: ______________________________

Dry Well ID/Location: ______________________________

Inspected by:____________________ **Date:**____________________

ITEM	**ID – Number to be used to identify problem on site sketch** **G – Good, no action needed** **F – Fair, monitor condition periodically, plan necessary repairs** **P – Poor, immediate action needed** **N/A – Not applicable**						
Roof Gutters, Leaders, Sumps and Traps		**ID**	**G**	**F**	**P**	**N/A**	**REMARKS**
	Missing pieces	1					
	Loose pieces	2					
	Evidence of blockage	3					
	Damaged joints	4					
	Split joints	5					
	Surface ponding	6					
	Cleaning required	7					
	Other problems	8					
Test Well Inspection	Water level	9					
	Obvious debris	10					

Vegetated swales are to be inspected four times each year and after every storm that exceeds 0.5 inches of rainfall. If swale vegetation consists of fast-growing grasses, the swales are to be inspected weekly. Whenever possible, swales are to be inspected before a major storm. Inspection consists of looking for debris, evidence of clogging and observable vegetation growth.

Vegetated swale maintenance consists of removing debris and sediment, maintaining the vegetation and ensuring the swale drains within 48 hours.

Building:____

Address: ____

Swale ID/Location: ____________________________________

Inspected by:____________________________ **Date:**____________________

ID – Number to be used to identify problem on site sketch
G – Good, no action needed
F – Fair, monitor condition periodically, plan necessary repairs
P – Poor, immediate action needed
N/A – Not applicable

	ID	G	F	P	N/A	REMARKS
Pea gravel diaphragm cleanliness	1					
Grass or other vegetation requires mowing	2					
Trash/debris in inflow forebay	3					
Erosion problems	4					
Vegetation requires replacement	5					
Swale does not drain within 48 hours – requires rototilling or cultivating	6					
Bottom sediment built up to 25 percent of original design volume – requires sediment removal	7					
Other problems	8					

Dry extension ponds are to be inspected twice each year and after every storm that exceeds 0.5 inches of rainfall. If side-slope vegetation consists of fast-growing grasses, the ponds are to be inspected weekly. Whenever possible, ponds are to be inspected before a major storm. Inspection consists of looking for debris, sediment build-up, erosion and observable vegetation growth.

Pond maintenance consists of removing debris and sediment, repairing erosion, managing pesticides and nutrients and maintaining the vegetation.

Building:____

Address: ____

Pond ID/Location: ______________________________________

Inspected by:___________________________ **Date:**_________________

ID – Number to be used to identify problem on site sketch
G – Good, no action needed
F – Fair, monitor condition periodically, plan necessary repairs
P – Poor, immediate action needed
N/A – Not applicable

	ID	G	F	P	N/A	REMARKS
Erosion on pond banks or bottom	1					
Damaged embankment	2					
Sediment accumulation in the facility or forebay	3					
Side slopes need mowing	4					
Pesticide and nutrient management required	5					
Ground cover requires attention	6					
Bottom sediment built up to 25 percent of original design volume – requires sediment removal	7					

Wet ponds are to be inspected monthly and after every storm that exceeds 0.5 inches of rainfall. Whenever possible, ponds are to be inspected before a major storm. If side-slope vegetation consists of fast-growing grasses, wet ponds are to be inspected weekly. Inspection consists of looking for invasive species, debris, signs of damage or erosion, sediment accumulation and the need for managing or harvesting wetland plants.

Pond maintenance consists of removing invasive species, debris, and sediment; repairing erosion; and managing the vegetation.

Building: ____________________

Address: ____________________

Pond ID/Location: ____________________

Inspected by: ____________________ **Date:** ____________________

ID – Number to be used to identify problem on site sketch
G – Good, no action needed
F – Fair, monitor condition periodically, plan necessary repairs
P – Poor, immediate action needed
N/A – Not applicable

	ID	**G**	**F**	**P**	**N/A**	**REMARKS**
Invasive species	1					
Erosion	2					
Sediment build-up in pond or forebay	3					
Debris	4					
Wetland plant management required	5					

Pervious pavement areas are to be inspected weekly and after every storm that exceeds 0.5 inches of rainfall. Whenever possible, pervious pavement areas are to be inspected before a major storm. Inspection consists of looking for debris, sediment build-up, proper drainage after a storm, surface deterioration or spalling and observable vegetation growth.

Pervious pavement maintenance consists of removing debris and sediment and maintaining the vegetation.

Building:________________________________

Address: ________________________________

Pavement ID/Location:________________________________

Inspected by:________________________ **Date:**________________

ID – Number to be used to identify problem on site sketch
G – Good, no action needed
F – Fair, monitor condition periodically, plan necessary repairs
P – Poor, immediate action needed
N/A – Not applicable

	ID	G	F	P	N/A	REMARKS
Area requires cleaning	1					
Improper draining	2					
Sediment build-up	3					
Upland area requires mowing or reseeding	4					
Surface deterioration or spalling	5					

Areas paved with porous modular pavers are to be inspected weekly and after every storm that exceeds 0.5 inches of rainfall. Whenever possible, areas are to be inspected before a major storm. Inspection consists of looking for debris, sediment build-up, proper drainage after a storm, surface deterioration or spalling and observable vegetation growth.

Pervious pavement maintenance consists of removing debris and sediment and maintaining the vegetation.

Building:____

Address: ____

Pavement ID/Location:________________________________

Inspected by:________________________ **Date:**________________

ID – Number to be used to identify problem on site sketch
G – Good, no action needed
F – Fair, monitor condition periodically, plan necessary repairs
P – Poor, immediate action needed
N/A – Not applicable

	ID	G	F	P	N/A	REMARKS
Area requires cleaning	1					
Improper draining	2					
Sediment build-up	3					
Adjacent area requires mowing or reseeding	4					
Surface deterioration or spalling	5					

REFERENCES

American Society for Testing and Materials (ASTM). ASTM D4263– *Standard test method for indicating moisture in concrete by plastic sheet method.*

American Society for Testing and Materials (ASTM). ASTM F1869-04– *Standard test method for measuring moisture vapor emission rate of concrete subfloor anhydrous calcium chloride.*

Claytor, R.A., and T.R. Schueler. *Design of Stormwater Filtering Systems.* The Center for Watershed Protection. (CWP) Silver Spring, MD. Prepared for the Chesapeake Research Consortium, Solomons, MD, and USEPA Region V, Chicago, IL. 1996.

Code of Federal Regulations (29 CFR). Title 29– Labor. (Title 29 of the CFR outlines requirements of Occupational Safety and Health Administration [OSHA] for workers, which include standards for ladder use and maintenance.)

Forest Products Laboratory. *Wood handbook: Wood as an engineering material.* General Technical Report FPL-GTR-113. United States Department of Agriculture, Forest Service, Forest Products Laboratory. 1999.

James, William L. *Electric Moisture Meters for Wood. General Technical Report FPL-GTR-6.* United States Department of Agriculture Forest Service, Forest Products Laboratory. June 1988.

New Jersey Department of Environmental Protection, (NJDEP04). *New Jersey Stormwater Best Management Practices Manual.* Trenton, NJ. April 2004.

Appendix G – Dampness & Mold Evaluation

The National Institute for Occupational Safety and Health (NIOSH) has developed an observational assessment tool for dampness and mold in buildings. As of October 1, 2013, the tool was in review to become an official NIOSH document. The goal of the tool is to provide information for motivating remediation, prioritizing intervention, and evaluating remediation effectiveness.

The tool consists of:

1. A form used to evaluate signs of dampness, water damage, mold growth, and musty odors in rooms and areas throughout the building.
2. A Visual Basic© data entry application to enter data collected from hard copy evaluation forms for electronic record keeping and reports. Data is stored in a Microsoft Access© database. The software may also be implemented on PC-based tablets. The software is under development. Once completed, the software will be made available at http://www.cdc.gov/niosh/topics/indoorenv/mold.html.

For additional information or to receive a form and instructions for use, contact moldsheet#1@cdc.gov (mailto: moldsheet#1@cdc.gov).

Figure G-1 NIOSH Dampness and Mold Assessment Form for Schools

NIOSH PILOT-DRAFT NIOSH Contact: Michelle Martin 304-285-5734 or moldsheet#1@cdc.gov

Dampness & Mold Assessment Checklist DRAFT- NIOSH PILOT

Date:____________**Observer:**_________________________**Building:**_________________**Wing:**________________

Floor:______________**Room Number:**____________________**Room Type:** *Fill the bubble for the following room types.*

○ Classroom ○ Office ○ Hallway ○ Conference room ○ Bathroom ○ Custodial closet ○ Mechanical room

○ Storage ○ Library ○ Cafeteria ○ Gym ○ Auditorium ○ Kitchen ○ Locker room ○ Entrance area

○ Stairwell Other_________________________________

MOLD ODOR ○ NONE ○ MILD ○ MOD ○ HEAVY Source*______________________ ○ Source Unknown

Be sure to smell mold odor when you first walk into the room/area.

Fill the bubbles for each column and row.	NA Mark "X"	DAMAGE or STAINS 0=NONE 1=<2ft² 2=2-33ft² 3=>33ft²	MOLD AREA 0=NONE 1=<2ft² 2=2-33ft² 3=>33ft²	MOLD DENSITY 0=NONE 1=MILD 2=MOD 3=HEAVY	WET or DAMP 0=NONE 1=<2ft² 2=2-33ft² 3=>33ft²		NOTES
		0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	Totals	
Ceiling		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Walls		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Windows		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Floors		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
HVAC systems		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Pipes		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Furnishings		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Supplies & Materials		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Other		⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③	⓪ ① ② ③		
Totals							
Average							

Glossary

Term	Definition
Air barrier	Any material, combination of materials or manufactured assemblies that are intended, by design, to control the movement of air across an exterior wall system or assembly.
Air handler	Equipment that includes a blower or fan, heating or cooling coils and related equipment such as controls, condensate drain pans and air filters. Does not include ductwork, registers or grilles, or boilers and chillers.
Alligatoring	Shrinkage cracking of the bituminous surface of built-up or smooth surface roofing, producing a pattern of deep cracks resembling alligator hide.
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.
Asphalt	A highly viscous hydrocarbon produced from the residue left over after the distillation of petroleum. Asphalt is used to water-proof built-up roofs.
ASTM	American Society for Testing and Materials.
Ballast	An anchoring material such as rock, gravel or pavers used to resist wind uplift forces on roof membranes.
Bitumen	A generic term for asphalt or coal tar pitch roofing.
Blister	A spongy raised portion of a roofing membrane as a result of pressure of entrapped air or water vapor.
Built-up roofing (BUR)	A continuous semi-flexible roof covering consisting of laminations or piles of saturated or coated felts alternated with layers of bitumen.
Cant strip	A continuous strip of triangular cross-section fitted into the angle formed by a structural deck and a wall or other vertical surface. Used to provide a gradual transition for base flashing and horizontal roof membrane.
Capillary break	A slot or groove intended to create an opening too large to be bridged by a drop of water in order to eliminate the passage of water by capillary action.
Chase	A groove or indentation cut into masonry to accommodate electric or plumbing lines.
Cladding	A panel applied to a structure to provide durability, weathering, corrosion and impact resistance.
CMU	Concrete masonry unit.
Commissioning	Start-up of a building that includes testing and adjusting HVAC, electrical, plumbing and other systems to ensure proper functioning and adherence to design criteria; also includes the instruction of building representatives in the use of the building systems.
Coping	The material or units used to form a cap or finish on top of a wall, pier, pilaster or chimney; a protective cap at the top of a masonry wall. It should be waterproof, weather resistant and sloped to shed water.
Crack	A break in a roofing membrane as a result of flexing, often occurring along a ridge or wrinkle.

Term	Definition
Cricket	A chimney flashing on the uphill side, resembling a small roof ridge, to divert rainwater around the chimney.
Drainage or drain plane	Any element exposed to weather or otherwise residing at the line between the "wet" and "dry" zones of an exterior wall system or assembly.
Dry well	A deep hole, covered and usually lined or filled with rocks, that holds drainage water until it soaks into the ground.
Eave	The protective overhang at the lower edge of a sloped roof.
Enthalpy	A measure of the total energy of a thermodynamic system. It includes the internal energy, which is the energy required to create a system, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure.
EPDM	Ethylene propylene diene monomer, a synthetic rubber sheet used in single-ply roof membranes.
Expansion joint	A deliberate separation of two roof areas to allow expansion and contraction movements of the two parts.
Fascia	The finish covering the edge of eaves of a flat or sloping roof or roof overhang.
Fishmouth	An opening of the lapped edge of applied felt in built-up roofing due to adhesion failure.
Flashing	Connecting devices that seal membrane joints, drains, gravel stops and other places where membrane is interrupted. Base flashing forms the upturned edges of the watertight membrane. Cap or counter flashing shields the exposed edges and joints of the base flashing.
Forebay	A small pool located near the inlet of a storm basin or other storm water management facility. These devices are designed as initial storage areas to trap and settle out sediment and heavy pollutants before they reach the main basin.
Gravel stop	A flanged device, normally metallic, designed to prevent loose aggregate from washing off the roof. It also provides the finished edge detail for built-up roofing assemblies.
HVAC	Heating, ventilation and air conditioning.
Hygrothermal	Pertaining to heat and humidity.
Impervious	Not letting water or moisture pass through or be absorbed.
Micromanometer	An instrument designed to measure minute differences in pressure.
Modified bitumen	Asphalt with the addition of polymer modifiers to increase cold temperature flexibility and warm temperature flow resistance and stability.
OSB	Oriented Strand Board. A type of particle panel product composed of strand-type flakes that are purposefully aligned in directions that make a panel stronger, stiffer and with improved dimensional properties in the alignment directions than a panel with random flake orientation.
Parapet	The part of the wall assembly above the roof.
Plenum	Space between a suspended ceiling and the floor above that may have mechanical and electrical equipment in it and that is used as part of the air distribution system. The space is usually designed to be under negative pressure.
Ponding	The collection of water in shallow pools on a roof surface.

Term	Definition
PVC	A generic term for single-ply plastic sheet membrane (polyvinyl chloride). Seams are fused by solvent or hot-air welding techniques.
R-value	The number of minutes (seconds) required for 1 Btu (joule) to penetrate one square foot (square meter) of a material for each degree of temperature difference between the two sides of the material. The resistance of a material to the passage of heat. The reciprocal of conduction (1/c).
Scuppers	An opening for draining water, as from a floor or the roof of a building.
Section	A drawing showing the kind, arrangement and proportions of the various parts of a structure. It shows how the structure would appear if cut through by a plane.
Shingle-wise	The overlapping of materials shingle style so that impinging water, such as rainwater, will run harmlessly down and out.
Slope	The ratio between the measures of the rise and the horizontal span.
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association.
Soffit	The finish on the underside of the roof overhang.
Spall	A fragment, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure or by expansion within the larger mass.
Stem wall	The vertical part of a concrete or masonry retaining wall.
Sump crock	A hole designed to collect water and other spilled fluids.
Swale	A vegetated, open-channel management practice designed to treat and attenuate runoff for specified water quality and volume.
TAB	Test, adjust and balance.
Tensiometer	An instrument used to measure the surface tension of liquids.
Vapor barrier	Material used to retard the movement of water vapor into walls and prevent condensation in them; applied separately over the warm side of exposed walls or as a part of batt or blanket insulation.
WBDG	*Whole Building Design Guide*.
Weep Holes	Small openings left in the outer wall of masonry construction as an outlet for water inside a building to move outside the wall and evaporate.

Indoor Air Quality (IAQ)