CHAPTER 2

Water Barriers and Flashings

2.1 MANAGING WATER

Water deteriorates materials—it rots wood, oxidizes metals, and provides a growth medium for mold and mildew. Wet components such as fiberglass batt insulation do not function as well. Water causes swelling or expansion of some materials and can transport pollutants and dissolved substances such as the salts that cause efflorescence. Continual freezing and thawing of wet materials adds additional forces—water increases 4 percent in volume when it freezes. Corrosion of steel also produces forces, as the iron oxide takes up more volume than the steel it replaced. In the worst case, water ingress may threaten life safety, as when the steel anchoring system of a cladding begins to corrode.

Water can enter a wall from rain or snow or ice melt. Improperly adjusted sprinkler heads that direct water to the exterior wall and poorly functioning or designed gutter systems and scuppers are other sources of water entry. The form or articulation of the vertical envelope can help or hinder the control of the water flow down the face of the exterior wall. Air pressure differentials and capillary suction across the wall can draw water through the wall. Condensation of vapor from interior or exterior sources produces water. Wet construction applications—such as pouring concrete floor toppings, dry-walling, and some sprayed-on insulation such as cellulose—add moisture to a wall. Water may enter wall components dur-

Water Definitions

Terms used to describe water, in its various phases, and water management systems vary from region to region and between the United States and Canada. The discussion below explains these differences and sets the vocabulary for this book.

- The term *moisture* is often used to denote either liquid water or water vapor. To avoid confusion, in its liquid form water will be termed *water,* and water vapor will be differentiated by the use of the term *water vapor* or simply *vapor.* Only when discussing a combination of water and water vapor will the term *moisture* be used.
- *Moisture* is also useful to describe water or vapor that has been absorbed or bound by a material, for example, the "moisture content of wood."
- There are a number of products designed, as a second layer of defense, to stop water from entering a wall. The term *water barrier* will be used for all of these. Building paper, felts, and building wraps have been called sheathing membranes in Canada and weather- or water-resistive barriers and drainage planes in the United States. Building wraps are commonly called house wraps. (*SBPO* will be used only for nonperforated, nonwoven, spun-bonded building wraps such as Tyvek.) Below grade, the terms *waterproofing* and *damp-proofing* are often used.
- When the face of the exterior wall stops all water, it is called a barrier wall in the United States and a face-sealed wall in Canada. When the wall relies on an exterior "seal" to stop all water, it will be termed a *face-sealed barrier wall.*
- An *internal drainage plane wall* has a drainage plane or narrow cavity and a water barrier behind the cladding. This is also called a concealed barrier wall or a concealed weather barrier wall.
- The term *drainage cavity wall* will be used when the cavity is greater than ⅜ inch (10 mm) in width and drainage is provided. Other terms used are *drain screen* and *rain screen.*
- *Pressure-equalized rain screens (PER)* are perhaps the most misunderstood of wall types. The term *PER* or *rain screen* will only be used if the wall is a drainage cavity wall with a vented, compartmentalized cavity and a continuous, supported air barrier system.
- Pressure-equalized joints between face-sealed cladding units are another method of water management. They are called *pressure-equalized joints* or *PE joints.*
- *Drained, two-stage joints* are sealant joints between face-sealed panels that are drained. The standard, single sealant joint is a *face-sealed joint.* See Chapter 4 for more information on joint design.

ing manufacturing, transporting, or storing of the materials. Using gas heaters during construction adds moisture to the interior. Stopping water is critical. As noted in "ASTM Practices for Increased Durability of Building Constructions Against Water-Induced Damage" (E241), "except for structural errors, about 90% of all building construction problems are associated with water in some way."[1]

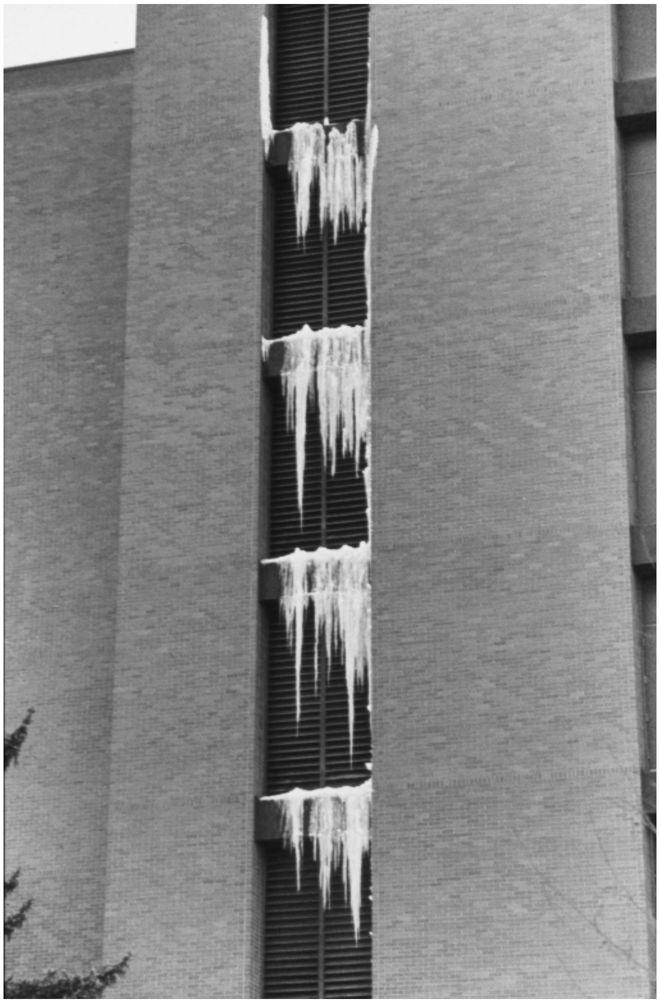


FIGURE 2.1 There are occasions when water comes from the interior — pipes break or HVAC equipment malfunctions. The failure of mechanical equipment flooded the interior of this university building. The water flowed to an exterior vent, where it froze on reaching the outside. Photo by G. Russell Heliker.

FIGURE 2.2 It is easy to see where the downspout is discontinuous from the deterioration of the brick on this exterior wall. Drainage systems should be maintained to ensure that they are directing water away from the wall, not toward it. Neglecting this problem made for a more costly rehabilitation. Photo by Linda Brock.

2.2 WATER MANAGEMENT SYSTEMS

Moisture trapped in the wall during construction can be limited with the active on-site involvement of the architect, especially when backed by carefully written specifications and detailed drawings. Air barrier systems, thermal insulation, and vapor retarders all play a role in controlling condensation of water vapor in a wall. Water management systems prevent the entry of water from the exterior.

The four basic systems used to manage water are:

- face-sealed barrier walls
- internal drainage plane walls
- drainage cavity walls
- pressure-equalized rain-screen walls

They are described below in order of their relative cost and effectiveness. With cladding materials such as metal, which is watertight, the management of water ingress occurs at the joints between the cladding units. These joints can be face-sealed, two-stage drained joints, pressure-equalized joints, or open joints.

2.2.1 Face-Sealed Barrier Walls

A face-sealed barrier wall implies that a cladding or exterior finish stops *all* water at the outside face of the wall. The cladding or coating is the water management system—there is no redundancy. Traditionally, the term *barrier wall* referred to a solid masonry or mass wall that formed a weather barrier because of its thickness. It leaked. It was just a much slower process, and one hoped that the wall dried before the moisture got to the interior. Today, poured-in-place concrete walls and concrete masonry walls are the most common true barrier walls. Concrete can take on a certain amount of water without detrimental effects, making these barrier walls an option that depends also on climate and exposure.

2.2.2 Internal Drainage Plane Walls

Most claddings allow for some passage of water, either through the material itself or at the joints. A secondary line of defense is required to stop any water that passes through the cladding and drain any condensed vapor. An internal drainage plane wall has a drainage plane up to ⅜ inch (10 mm) in depth as well as a water barrier and weep holes. The redundancy offered by the water barrier provides much more protection than the face-sealed barrier wall.

2.2.3 Drainage Cavity Walls

The drainage cavity wall—consisting of a cavity and a water barrier—has openings or weep holes at the base for drainage of any water that passes through the cladding and vapor that condenses in the cavity. It may or may not have additional openings to promote drying through air circulation. The cavity must be of sufficient width to stop water from bridging the gap—⅜ inch (10 mm) is the dividing line used in this book. A larger dimension may be necessary to compensate for construction tolerances and workmanship.

Face-Sealed Barrier Wall

The standard product for Exterior Insulation Finish Systems (EIFS) relies on a complete seal at the exterior face, including the joints. (Newer systems have introduced redundancy, with a water barrier and a drainage plane or small drainage cavities.)

Other examples include face-sealed concrete block, concrete, or stucco. Curtain walls, window walls, and claddings that rely on a single sealant bead to stop water from entering the wall between the units or panels are face-sealed barrier walls. A wall clad with siding of any material but no cavity and no water barrier, or one where the siding is in full contact with the water barrier, is also considered a face-sealed barrier wall.

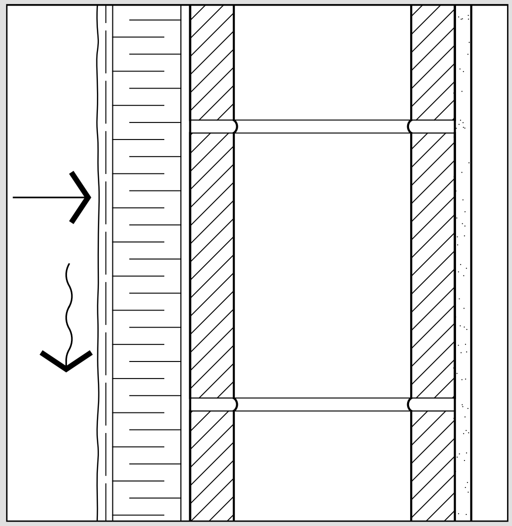


FIGURE 2.3

Internal Drainage Plane Wall

An internal drainage plane is common with stucco applications. Using building paper or one of the new, corrugated nonperforated building wraps as the water barrier, with a drainage screed at the base, increases the possibility for water drainage and, consequently, of the stucco drying. An internal drainage plane also describes walls with a drainage plane and a water barrier under wood, fiber-cement, metal, or vinyl sidings and proprietary, drained EIFS systems.

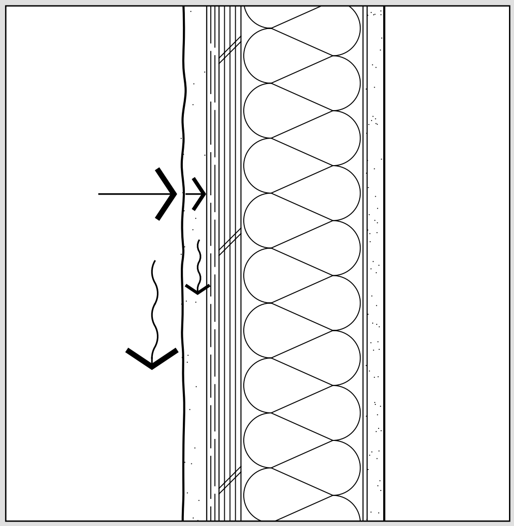


FIGURE 2.4

Drainage Cavity Wall

Although brick veneer in the past was part of a composite masonry wall, today the backup wall is as likely to be made of steel studs. Brick veneer requires a minimum cavity depth of 2 inches (50 mm) to ensure the cavity is kept free of mortar droppings during construction.

A drainage cavity wall is standard with many cladding systems such as stone veneer and panel systems of metal. It is also commonly used for wood cladding in many western European countries and is required in some jurisdictions, with excessive rain, in Canada.

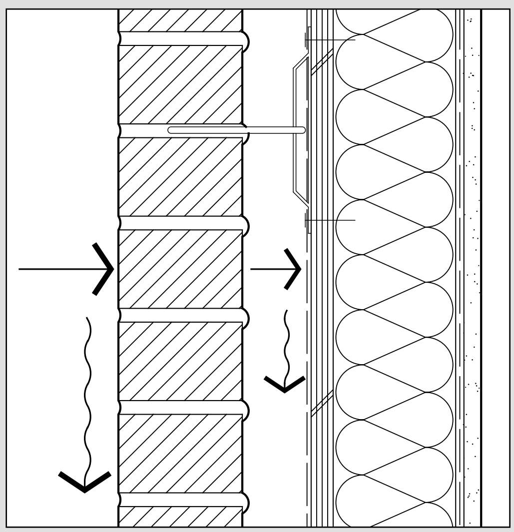


FIGURE 2.5

Pressure-Equalized Rain-Screen Wall

A pressure-equalized rain screen (PER) is a drainage cavity wall designed so that the air pressure of the cavity behind the cladding is similar to the exterior air pressure. *Pressure-moderating rain screen* is a more descriptive term for a PER, as designing a wall that will equalize the pressure instantly and under all conditions is not practical. The following must be in place for this system to work:

- Compartmentalized cavity to limit airflow from one area of the cavity to another
- Vents in compartments to allow for pressure equalization between the exterior environment and the compartment and to drain any water
- Air barrier system that is continuous and structurally supported

The size of vents required for a PER depends on the static and dynamic pressure equalization across the rain screen. Under dynamic-pressure conditions, the size is dependent on the volume of air in the compartment, the resistance to airflow at the vent holes, and the rigidity of the wall assembly. Static pressure is primarily dependent on leakage in the air barrier system.[1] *Construction Technology Update No. 17,* "Pressure Equalization in Rainscreen Wall Systems," published by the Institute for Research in Construction, provides an excellent primer in addition to the formulas for determining vent size.[2]

The use of vertical 1x spacers, or furring, at stud spacing for drainage and through-wall flashing at each floor, in wood-framed walls, comes close to creating the required compartment size for a PER. Combining this with a good air barrier system and vents can turn a light-frame wall with a drainage cavity into something approaching a PER at little additional cost (see Figure 2.7).

1. M. Z. Rousseau, G. F. Poirier, and W. C. Brown, "Pressure Equalization in Rainscreen Wall Systems," *Construction Technology Update No. 17* (Ottawa, Ont.: Institute for Research in Construction, 1998), pp. 4–5.
2. Ibid., 4–5.

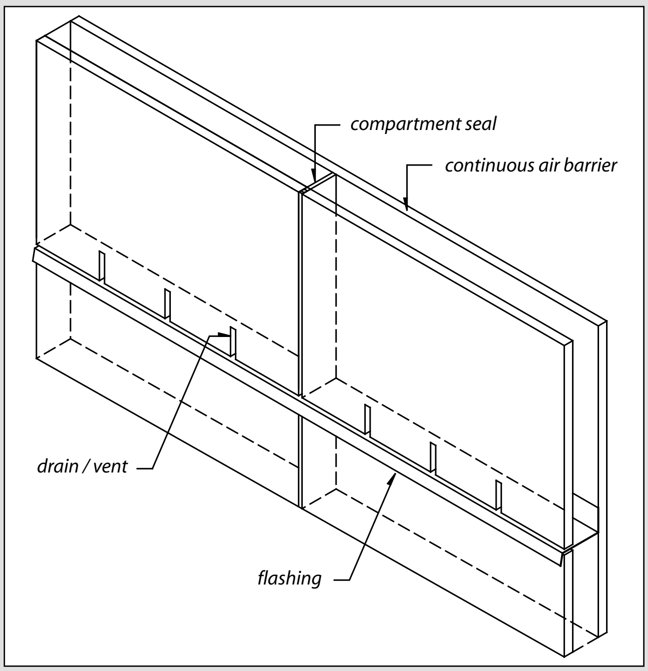


FIGURE 2.6

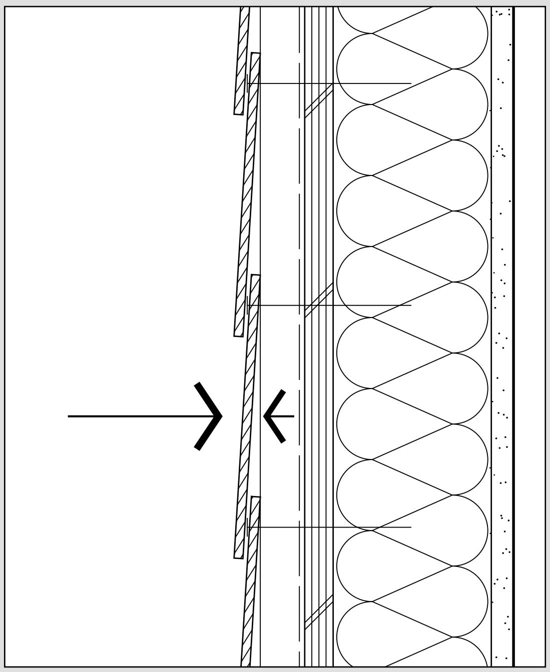


FIGURE 2.7

2.2.4 Pressure-Equalized Rain-Screen Walls

True pressure-equalized rain-screen walls are rare. A metal and glass curtain wall is an example of such a wall; but even this shows only moderate success. A report by Rick Quirouette, written for Canada Mortgage and Housing Corporation (CMHC) noted that "the most advanced rainscreen system design is the metal and glass curtain wall." But measurements in the field would appear to indicate substantially less than 25 percent pressure equalization in a spandrel even during low-pressure winds. However, Quirouette comments that even with these pressure differences, there did not appear to be any leakage during a "moderately severe storm." [2]

What Is a Rain Screen?

A rain screen means different things to different people. The word itself seems to suggest a panacea for all water entry problems. Often the term is used whenever there is a drainage cavity or even just a drainage plane with vents. As M. Z. Rousseau noted in "Facts and Fictions of Rain-Screen Walls," there is a "myth spread in the industry which claims that simply venting a cavity (no matter how big the cavity behind the exterior cladding . . . no matter how leaky the inner wall) does the trick of applying the rain-screen principle."[1] In Europe the term often refers to an open-jointed "screen."

Considered the Cadillac of water management, rain screens have sparked much discussion. The idea of a screen for the rain has been around for centuries. The principles of a "rain barrier" were explained in a small booklet produced by the Norwegian Building Research Institute in the early 1960s. G. K. Garden, of the National Research Council of Canada, introduced the concept to North America in 1963. In *Construction Building Digest: 40,* Garden named and detailed the requirements of our modern pressure-equalized rain screen—a compartmentalized and vented drainage cavity with a continuous air barrier.[2]

In its initial use, *rain screen* meant the outer leaf or cladding that "screened" the rain. An inner leaf acted as a drainage plane and stopped the movement of air. Originally called *two-stage weather tightening* (a term still used in Europe), this is sometimes called an *open* or *simple* rain screen in North America.

Used frequently for marketing purposes, there is no consensus on what the word means. To avoid confusion, this book only uses the term *rain screen* if there is pressure equalization. A better approach is to specify the components and their function. A PER is a recommended water management system for metal and glass curtain walls; but realistically, most wall types fall somewhere between a PER and a drainage cavity wall even when specified as a PER. Again the focus should be on function, not semantics.

The best advice is to concentrate on designing a well-functioning drainage cavity with a continuous air barrier system and detailing and specifying these functions such that they are affordable and constructable. Tom Schwartz, of Simpson Gumpertz and Heger, comments on the practicality of the drained cavity wall versus the PER: "Pressure equalization is a sound concept, but this complication of the time tested drained cavity wall approach may be unnecessary given the fact that properly designed and constructed cavity walls (i.e., without pressure equalization) are simple, cost effective, and reliable. Pressure equalization holds the promise of extending wall durability by reducing cavity moisture. But this advantage comes along with the risk of introducing performance problems due to the increased complexity of the system compared to traditional drained cavity walls."[3]

1. M. Z. Rousseau, "Facts and Fictions of Rain-Screen Walls," *Construction Practice* (Ottawa, Ont.: IRC-National Research Council of Canada).
2. G. K. Garden, *Rain Penetration and Its Control: CBD-40* (Ottawa, Ont.: Division of Building Research, NRCC, 1963).
3. Tom Schwarz (Simpson Gumpertz and Heger), in correspondence with the author, October 2003. Quoted by permission.

TABLE 2.1 Water Management Systems

Components and Function	*Face-Sealed Barrier Wall*	*Internal Drainage Plane Wall*	*Drainage Cavity Wall*	*Pressure-Equalized Rain-Screen*
Drainage plane or cavity less than ⅜" (10 mm) in width		required		
Drainage cavity greater than ⅜" (10 mm) in width			required	required
Compartmentalized cavity				required
Water barrier in addition to cladding		required	required	required
Openings for drainage		required	required	required
Openings for venting		optional	optional	required
Openings for ventilation		optional	optional	not recommended
Structurally supported air barrier system	recommended	recommended	recommended	required

2.3 SELECTING THE RIGHT WATER MANAGEMENT SYSTEM

On low-rise buildings, particularly those with overhangs and in protected areas, a less efficient water management system may be acceptable. The Partnership for Advancing Technology in Housing (PATH), a collaboration of U.S. Housing and Urban Development (HUD) and the Federal Housing Administration (FHA), states that face-sealed barrier walls are effective in climates with less than 30 inches (762 mm) of annual precipitation whereas internal drainage plane walls are effective in areas with annual precipitation, from 30 to 50 inches (762–1270 mm). Drainage cavity walls are suggested for climates with less than 60 inches (1524 mm) of rain a year. Over this amount, a pressure-equalized rain screen (PER) is recommended.[3] It should be noted that, for the most part, the recommendations are for small, one to two story residences that are more likely to have overhangs and be protected from winds. (According to the U.S. Census Bureau, only about 7 percent of the housing units in the United States were higher than three stories and less than 16 percent were in buildings with five or more attached units in 2001.)[4] The Builder's Guides, published by the Building Science Corporation, recommend only using face-sealed walls in climates with less than 20 inches (508 mm) of annual precipitation—a more conservative and safe recommendation.[5] Again, these are recommendations for homes and smaller buildings.

This book recommends the following minimums in areas where water penetration is of concern and a long exterior wall life is desired:

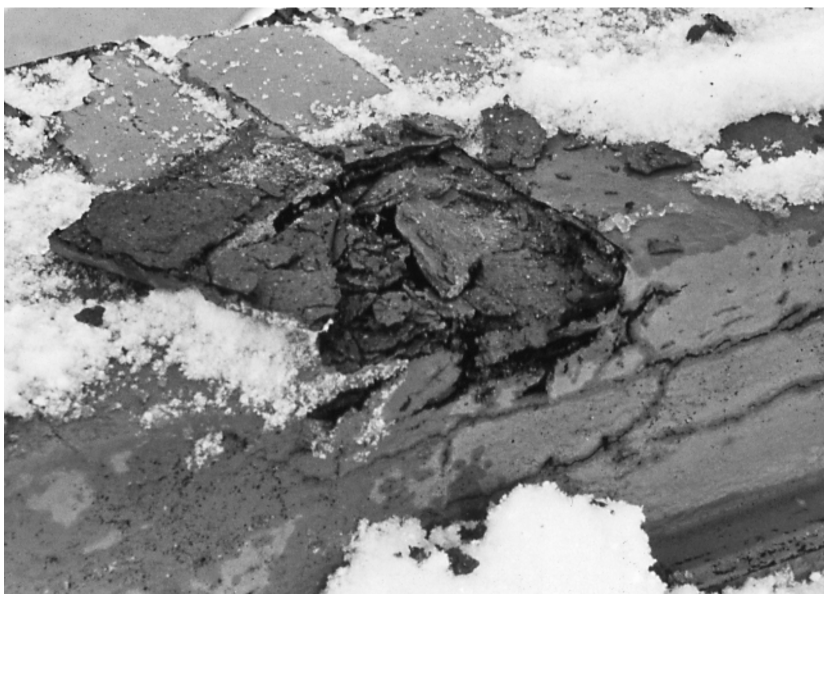
- A secondary line of defense in the form of a water barrier
- A flashed cavity of a constructable dimension to drain interstitial water to the exterior and break capillary action between the cladding and the backup wall, taking construction tolerances into consideration
- As complete an air barrier system as constructable and affordable

2.3.1 Deflect, Drain, or Dry? Vent or Ventilate?

An important part of managing water is ensuring that wet components dry before any damage occurs. Ventilating a drainage cavity accelerates the drying of components within the wall through evaporation. The amount of ventilation must be balanced between the drying potential and the increased potential for water entering the wall through the additional openings. In areas with high indices of wind-driven rain and long cool-wet periods, which slow drying, such as in the Pacific Northwest, it may be prudent to reduce the number of openings to only those required for drainage.

The surest way to stop water ingress is not to let the materials get wet in the first place. Deflection of water, by using overhangs and drips on flashings, will reduce the amount of water that flows down the wall. Drainage of water is equally important, be it from a cavity, the roof, the adjacent hard or soft landscaping, or any other potential "catch basin," however small or large. Venting, as opposed to ventilating, helps stop water from entering the wall by minimizing air pressure differences across the cladding. A pressure-equalized rain screen does not promote ventilation of the cavity—in fact, it does the opposite. The National Research Council of Canada (NRCC) recommends that vent holes be located at the same height, to reduce airflow through the compartment.[6]

FIGURES 2.8, 2.9 These photographs show conditions on a building when it was approximately 14 years old. It is located in an area that receives about 19 inches (480 mm) of precipitation a year. The bench (Figure 2.8), located on a bridge that connects two wings of the building and the parapet (Figure 2.9), were waterproofed with an elastomeric coating. When water entered the walls through the inevitable cracks and pinholes, it could not get back out. Freeze-thaw action exacerbated the damage. Photos by G. Russell Heliker.



2.3.2 Forces that Move Water

If water cannot be diverted, the only option left is to eliminate the forces that move water through a wall. The force of gravity can be a problem with any components that are not vertical. (However, wind on the exterior wall can cause water to flow uphill on vertical surfaces, particularly at building corners and parapets.) Any non-vertical surface exposed to water should be treated as a roof. This simple reasoning would do much to alleviate leakage in buildings. A sloping sill is *not* a wall; it is a roof and should be clad with materials appropriate for a roof. Surface tension, capillary suction, and momentum can be stopped through simple geometry. Minimizing air pressure differences across the cladding, with a PER, eliminates the final force.

FIGURES 2.10, 2.11 While we often see windowsills constructed of brick (Figure 2.10), few would consider using brick as a roofing material on a similar slope. The brick sills on this load-bearing masonry building from the eighteenth century (Figure 2.11) are protected with overlapping slate shingles. Photos by G. Russell Heliker and Linda Brock.

TABLE 2.2 Forces That Move Water Through The Wall

Force	*To Stop the Force*
Surface tension causes water to cling to the underside of horizontal surfaces.	• Incorporate a drip under all projecting horizontal surfaces. • Use only metal flashings with a drip edge.
Capillary suction draws water into permeable materials and small openings.	• Lap, or shingle, joints. • Ensure openings to the cavity are a minimum of 3⁄8 inch (10 mm). • Use materials with minimum absorption capacity or use a thickness that delays water transport through the material: "For example, 7⁄8 inch (22 mm) thick stucco that is subject to continuous wetting will saturate in two days. Therefore, if the building location often experiences rain for this long, change the material or shield the wall with an overhang." • Back (and end) prime wood siding with a water sealer.
Momentum or *kinetic energy* propels raindrops into unprotected openings.	• Shield openings from direct rain entry. • Splash water can be a problem at all horizontal planes, such as at the base of the wall.
Gravity draws water downward and into sloped openings.	• Use overhangs at the roof and over any openings. • Slope *all* nonvertical surfaces to the exterior a minimum of 5 percent, preferably 15 percent. • Slope parapet caps to the roof a minimum of 15 percent. • Avoid butt joints; use laps. • Lap horizontal joints. • Provide drainage holes or paths for all horizontal surfaces that act as troughs. • Recess windows and doors.
Air pressure differences draw water in the direction of lower air pressure.	• Minimize air pressure differences with a vented, compartmentalized drainage cavity and a structurally supported continuous air barrier system. • Detail a *complete* air barrier system for the entire enclosure.

Source: Adapted from W .C. Brown, G. A. Chown, G. F. Poirier, and M. Z. Rousseau, *Designing Exterior Walls According to the Rainscreen Principle,* Construction Technology Update No. 34 (Ottawa, Ont.: IRC, NRCC, 1999).

2.4 WATER BARRIERS AND THEIR PLACEMENT

2.4.1 Building Wraps

Microporous plastic water barriers that stop water and air but are permeable to vapor are called building wraps or "housewraps." Dupont developed the first in the late 1970s—a nonperforated, nonwoven, spun-bonded polyethylene called Tyvek HouseWrap—and a generic term was born. Today Tyvek water barriers are made of spun-bonded polyolefin and include HomeWrap, CommercialWrap, and also StuccoWrap. Another nonperforated building wrap is Typar HouseWrap, which is a coated spun-bonded polypropylene. The permeability of these products comes from the manufacturing process. Some plastic building wraps are mechanically punched or perforated for permeability. The term SBPO (spun-bonded polyolefin) is reserved for materials such as Tyvek that are made of nonperforated, nonwoven, spun-bonded polyolefin.

The perforated building wraps generally allow more water to pass than the nonperforated. Also many perforated building wraps are not classified as air barriers. Nonperforated building wraps are commonly used as an air barrier, the function for which they were originally marketed. Nonperforated building wraps generally have good vapor permeability. Tear resistance varies from product to product. Available in story-high widths, building wraps can be used to "weatherproof" a wall quickly. There is much research in this area, with new products continually coming on the market, some nonperforated. Dow has introduced Styrofoam Weathermate and Owens Corning has PinkWrap, both building wraps with some transparency. Self-draining building wraps, such as the nonperforated StuccoWrap, have a textured surface with small rivulets or channels for water drainage. More discussion on building wraps can be found in Chapter 3 under "Air Barrier Systems."

2.4.2 Building Paper and Felt

The conventional water barrier is building paper, an asphalt saturated Kraft paper, or felt. The common product is #15 or #30 felt, or Grade D building paper, with 20-, 30-, or 60-minute ratings. While sharing some similarities, building paper and felt also have different characteristics. Felt today is made from recycled paper fiber from corrugated boxes and newspapers. These cellulose fibers result in a material that is thicker and less dense than the Kraft paper used for building paper. The more open pore structure of the felt allows a high percentage of asphalt impregnation. The result is a thick, stiff material that has high water resistance but tends to crack when folded around corners. Building papers use cellulose fiber made from wood pulp, resulting in a dense, strong fiber mat. The tighter pore structure reduces the percentage of asphalt that can be impregnated. The result is a less saturated paper that is still water resistant but more vapor permeable and pliable around corners. Because building paper is substantially thinner than felt, two layers are often recommended to obtain a double drainage plane—for example, using two layers of 30-minute paper in place of one layer of 60-minute paper.

Both building paper and felt come in widths of 36 to 40 inches. Although air movement is decreased, they are not considered air barriers even with the seams taped. Both building paper and felt will absorb some moisture. Their vapor permeability increases when saturated, helping wet materials dry to the exterior. If any water leakage occurs to the inside of the building paper or felt, they can absorb the water, allowing it to pass to the exterior through evaporation.

As with all components, building paper and felt have evolved over the years. The new generations include a 30-minute double-ply building paper with 2-inch (50 mm) wide asphalt mastic strips at 16-inch (400 mm) intervals to increase water protection at nail and staple holes, a proprietary product of Hal Industries. Fortafiber has a two-ply paper with a 150-minute water holdout rating. Hal Industries also produces a corrugated two-ply building paper with a 150-minute water holdout rating.

2.4.3 Building Wrap or Felt?

A reputed problem with some building wraps, primarily the perforated ones, is that surfactants (surface-active contaminants) can reduce the surface tension of the water, making it easier for the water to pass through a smaller opening. Surfactants can be found in lignin from wood, such as cedar and redwood, and in substances such as soap, which is sometimes used though not recommended as a plasticizer with stucco. Other stucco additives can work as surfactants, leading some building envelope specialists to advise against using building wraps with stucco. These same surfactants have caused less severe problems with paper and felt. A good recommendation is to ensure that any material in direct contact with the water barrier will not create problems by asking the manufacturer to address the issue in writing.

Paul Fisette (of the University of Massachusetts), in an article titled, "Housewrap vs. Felt," discussed the problems with surfactants. He concluded that soaps and extractives from cedar do have an effect on the water resistance of building wrap. Testing by Fisette further suggested that nonperforated building wrap displayed better water resistance. Felt may seal better around nails and staples, depending on the thickness and asphalt content. However, in the end, Fisette decided that it does not matter "a whole lot" whether you choose a building wrap or felt if you get the flashing details right and are careful with installation.[7] In general, felt costs less than building wrap, but the installation cost is higher. Felt, and to some extent building paper, is manufactured by a large number of companies and rarely identified as a product. Felts are governed by a host of codes, from which the manufacturers can pick and choose, making it difficult to compare one to another. Building wraps are identified as products. However, comparisons are also difficult with building wraps, as different manufacturers may use different testing methods.

2.4.4 Sheet Membranes

Adhered sheet membranes can be hot- or cold-applied. In general, any roofing material suitable for a vertical application can be used as a water barrier if the substrate, attachment, and method of installation is acceptable—some are torched-in-place, creating a potential fire hazard during installation.

2.4.5 Self-Adhesive Membranes, or "Peel-and-stick"

The newest water barriers are self-adhesive sheet membranes, descriptively called peel-and-stick. They are manufactured by laminating a rubberized asphalt compound to a polyethylene film. Though the membrane is self-adhesive, many substrates require careful priming. Proper installation is critical, including lapping at edges and ends. It may be prudent to also attach the membrane mechanically—this can often occur in tandem with the fastening of another component such as rigid insulation to the exterior of the peel-and-stick. A popular combination is using products such as Grace Perm-a-Barrier or Bakor Blueskin over nonpaper faced gypsum sheathing. This combination requires a specific primer to bond with the moisture-resistant fibers of the sheathing. Peel-and-stick comes in widths from 4 to 36 inches (100–910 mm); the narrower widths are used to seal joints and for flashing.

In addition to stopping water, peel-and-stick is an air barrier and usually a vapor retarder, making placement potentially problematic, depending on the location of the thermal insulation and the climate. Bakor has introduced a peel-and-stick called Blueskin Breather that is vapor permeable.

2.4.6 Fluid Applied Membranes

A similar type of barrier can be sprayed, brushed, or troweled in place. A peel-and-stick membrane or an embedded reinforcing mat is used to bridge transitions. Waterproofing coatings that do not include reinforcement to bridge cracks are not durable enough for exterior wall applications. There is concern that even some of the reinforced systems may not be able to withstand the differential movement of the substrate. Some of the fluid applied systems, such as Bakor's Air-Bloc and Sto Guard by Sto Corporation, are vapor permeable.

2.4.7 Sheathing Materials

Several sheathing materials are relatively impervious to water, including plywood and oriented strand board (OSB), although their moisture resistance changes as they take on water. OSB, in general, takes on more water than plywood. The nonpaper-faced gypsum sheathings are more impervious to water than the paper-faced sheathings. Fiber-faced Dens-Glass Gold was developed by Georgia-Pacific to give a stronger, more waterproof, reinforced face on which to apply EIFS. Fiberock by CGC and Weatherock by USGC are gypsum fiber composites. Although superior to exterior gypsum sheathing, nonpaper-faced gypsum sheathings are a marginal water barrier. With all sheathing materials, water entry is most likely to occur at the joints. Many tapes are available. While these may be adequate to stop air, stopping water running down the face of the sheathing is more difficult. The cost of adding a water barrier over sheathing is inexpensive insurance against water penetration.

2.4.8 Rigid and Foamed-in-Place Insulation

Insulation boards of impervious plastics or those faced with foil act as water barriers. Again the problem is at the joints. Some board insulations shrink with aging, exacerbating the problem. Shiplapped, extruded polystyrene, with all butt edges taped, will stop water better than insulation with untaped square edges. Dow Styrofoam manufactures boards with tongue-and-groove joints on all four edges. Some foamed-in-place insulations stop the majority of water, although trimming off the cured surface may allow more water to enter. Two-pound, and denser, spray polyurethane foam will resist water absorbtion even when trimmed. See the section on insulation in Chapter 3.

2.4.9 Paints and Sealers

New paints and sealers that stop water frequently come on the market. Many are very good water barriers, provided the substrate never moves, or they never have to bridge transitions. Applied in liquid form, they are meant to adhere fully to the surface. Movement at a crack in the substrate creates extreme stress within the bonded paint or sealer. An unbonded elastomeric coating sample may stretch many times its width, as frequently demonstrated in advertisements for these products. But 300 percent elongation may not be enough when fully bonded. These are good products with specific applications—they are just not suitable for stopping water in the long term on a substrate that moves. Any coating designed to keep out water will eventually fail, or water will enter the wall from another location such as a window. If the coating is not vapor-permeable, the moisture behind the coating will be trapped (see Figures 2.8 and 2.9). Some sealers, such as silanes and siloxanes, are highly permeable.

2.4.10 Drainage Mats

Drainage can be greatly enhanced by the addition of a drainage mat, a three-dimensional, tangled net of filament, which is attached to the water barrier. Most drainage mats are ¼ inch (6 mm) thick and 39 inches (1 meter) wide. The mats are stapled or nailed to the substrate with butt joints. Some mats come bonded to building paper. The mat is generally 3 inches (75 mm) narrower than the building paper, to allow for lapping of the paper. Senergy's Drainage Wrap is a plastic three-dimensional drainage mat bonded to 60-minute building paper. Drainage Wrap by Finestone is a similar product.

2.5 INSTALLATION

Water barriers should be lapped, or "shingled," with each other and with flashings to ensure that all interstitial water drains to the exterior of the wall. This is true for adhesive as well as nonadhesive products. Vertical laps of nonadhesive barriers should be sealed with a tape recommended by the manufacturer. There is more information on tapes in Chapter 3, "Air Barrier Systems."

The water barrier will be penetrated by fasteners attaching the barrier and other components. Additional sealing may be required around the penetrations. This is dependent on the barrier (some thicker asphaltic barriers claim to self-seal), the size of the penetration (staples versus large anchors), and the exposure. Water droplets can find a circuitous route into the smallest of openings. Water tightness at openings in this barrier, such as windows, is particularly critical.

The flashings and sealants that keep buildings watertight are part of water management systems. While it is impossible to eliminate sealants, reliance on these materials should be minimized. Chapter 4 covers sealants in more detail.

As with all components, be aware of what else the water barrier is stopping. It is critical to understand its ability to retard vapor and determine if this will cause a problem. If the water barrier is also a vapor retarder, it must be on the "warm side" of the thermal insulation to minimize condensation. All materials to the exterior of the water barrier must be able to withstand continual wetting, including claddings, insulation in the drainage cavity, and the metal fasteners attaching the cladding.

2.6 FLASHINGS

Designers often try to conceal flashings. If they understood the havoc that ensues when a wall flashing is terminated before it reaches the outside or a cap flashing extends down the face of the wall only a short distance or is omitted entirely, this practice would end. Better to spend time designing an aesthetically acceptable flashing profile than worry about replacing the cladding and perhaps other components down the road. Good design and durability of the flashing is important, as it is often costly and sometimes not possible to retrofit. Concealed flashing must last as long as the exterior wall. When the flashing is omitted, such as at the top of a parapet wall, an owner may retrofit the wall with a cap flashing after the building is complete, without the designer's consideration of aesthetics (see Figures 2.12 and 2.13).

Flashing is required at:

- Changes in the vertical plane of the cladding
- Penetrations or openings in the exterior wall, such as windows, doors, vents, hose bibs, light fixtures, and signage
- All horizontal interruptions through the cladding, such as a shelf angle for brick veneer

- The roof edge
- The top of a parapet wall
- Any termination of the water barrier

Checking each wall section for nonvertical surfaces, discontinuity in the water barrier, and terminations of cladding panels will point out many of the areas that require flashing. A second check of the exterior wall in plan will point out where the flashing extends around corners or will have to be lapped onto itself in long runs.

The *Architectural Sheet Metal Manual* (Sheet Metal and Air Conditioning Contractor's National Association, SMACNA) is an excellent reference for all types of metal flashing.[8] Flashings that terminate on the exterior of the building should be corrosive-resistant metal and should end in a drip. Some flashings require an adjustable depth to accommodate construction tolerances while maintaining a consistent edge at the outside. An example is the two-part shelf-angle flashing detailed in Figure 6.13. Others, used primarily on roofs, have a removable component so that the embedded flashing does not have to be replaced when the roof is replaced. Peel-and-stick or reinforced plastics can be used for flashings that are not exposed to the exterior or subject to wear and tear during construction and the life of the wall. Water barrier manufacturers, such as Dupont, have proprietary flashings; Dupont's FlexWrap and StraightFlash work as a system with Tyvek.

If surface attachment of the flashing is absolutely necessary, the surface mounted reglet, or termination bar, should be designed for easy installion of the sealant. Flashing attachments should be designed to withstand wind loads—wind uplift can tear the metal coping off a building. Continuous cleats eliminate exposed fasteners, a potential leakage site. Another difficulty, and an often overlooked area, is designing the corners, joints, and terminations of the flashing. All such transitions should be welded, soldered, or sealed, including lapped joints. Flashing should always slope to the exterior. Preformed or fabricated corners and end dams should be used when possible.

Horizontal and vertical joints of metal flashing can be sealed in several ways. SMACNA's *Architectural Sheet Metal Manual* details a variety of metal locks and seams for lapped and butt joints. Another method of joining two pieces of metal flashing is to position a 1-inch (25 mm) strip of bond-breaker tape at both ends of the metal flashing. A peel-and-stick splice is then adhered for 3 to 4 inches (75–100 mm) on each side of the flashing. Leaving a ¼-inch (6 mm) gap between the two pieces of metal flashing, in combination with the bond-breaker tape, will allow expansion and contraction of the metal flashing while the peel-and-stick keeps the water out. If the joint is exposed, it can be covered with a metal plate. Lapped horizontal joints should be fully adhered with mastic sealant. Horizontal flashings should never be penetrated—an obvious but often disregarded caution. Metals should be designed in a gauge thick enough to prevent "oil canning" when visible. Flashings must be compatible with each other, their fasteners, and with the substrate.

2.6.1 Flashing Problems

Flashings frequently fail to keep water out of the wall. This is another area where design time, insistence on an adequate construction budget, and careful construction observation will pay off in the long run. Some of the more common problems are:

FIGURES 2.12, 2.13 The top of this parapet wall (Figure 2.12) was detailed by the architect with a decorative concrete block course. Aesthetically interesting, it leaked considerably. The owners retrofitted the metal flashing (Figure 2.13), which did a good job of keeping out the water, but the aesthetic was changed. Photos by G. Russell Heliker.

- *Discontinuous flashings:* Continuity should be detailed, specified, and carefully checked during construction. Horizontal and vertical joints and all other transitions should be detailed on the drawings. Specify a maximum length (to accommodate expansions and contraction) and a minimum length (to minimize the number of joints). Flashings frequently stop at either side of corners. A three-dimensional drawing can delineate how the flashing, and any counter-flashing, turns the corner (see Figure 2.16).
- *Lack of end dams at flashing terminations:* End dams are required with sill flashing, when one cladding system joins another, and at vertical expansion joints. Flexible flashings can be continuous through vertical expansion joints if there is enough slack in the flashing to accommodate the movement of the joint.
- *Punctured flashing:* Metal flashings can be easily punctured and flexible flashings more so. The flashing installation on a window shelf-angle lintel may be very good, but if the window installer shoots a powder-driven fastener through it when installing the head can, watertightness is compromised. Flexible flashings should be protected from bolt heads and other protruding objects.

- *Poor drainage:* In the best of worlds, all flashings would slope. This minimizes the chance that water will travel horizontally, inevitably finding the less watertight, horizontal lap.
- *Inadequate attachment:* Flashings high on a building are subjected to excessive wind loads. The fastening must consider these loads, along with the problems created by fastening directly through the face of the flashing. Continuous cleats can better resist wind uplift.

Constructability and the importance of good installation are sometimes overlooked in flashing design. Complicated areas requiring flashing should be detailed in a three-dimensional drawing. If it cannot be drawn, the contractor will have problems fabricating it. SMACNA's *Architectural Sheet Metal Manual* should be consulted for all metal flashing concerns. Installation should not be left to the cladding trades. A flashing contractor who understands the importance of continuity and good installation will do a better job.

FIGURES 2.14, 2.15 These two buildings in Krakow, Poland, show careful flashing of sills. While both may be remedial, they complement the appearance. The sills, even at the ocular window, of this stuccoed masonry building (Figure 2.14) are flashed in metal. In Figure 2.15, the layers of the wood windowsill have been carefully flashed, with small up-stands or dams at the ends. Photos by Linda Brock.

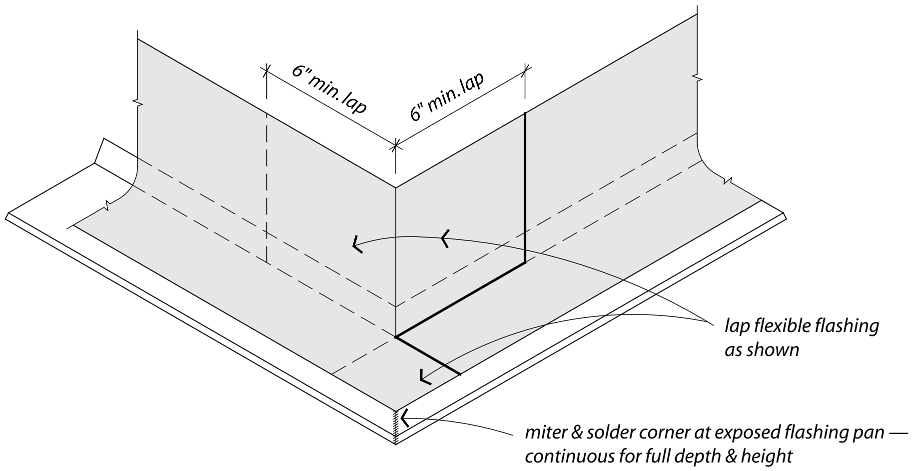


FIGURE 2.16 Three-dimensional drawings are necessary to show how flashings and other barriers turn corners. This drawing shows flexible flashing lapping a metal flashing pan to be installed on a brick-veneer shelf angle. Not shown is how the water barrier would turn the corner.

TABLE 2.3 Flashing Materials

Metal Flashing Materials	*Comments*	*Expansion Coefficient*
Aluminum	• Textured and prepainted finishes are available • Anodized finishes are not always uniform • Avoid contact with other metals and concrete or mortar unless separated with a bituminous layer • Corrosion resistant • Does not stain adjacent surfaces • Cannot be soldered • Factory weld	.0000129
Copper	• Color changes from reddish brown to brown to green patina, depending on atmosphere; in dry climates green may not be achieved • Corrosion resistant • Easy to work in the field • Can stain adjacent surfaces • Use lead-coated copper to avoid staining • Avoid contact with noncompatible metals • May be used in contact with cementitious materials	.0000094
Stainless steel	• Different finishes and colors available • Excellent corrosion resistance • Self-cleaning, low maintenance • Does not stain adjacent surfaces • Very durable • Superior resistance to metal fatigue • May be used in contact with cementitious materials	.0000096
Terne-coated stainless	• Weathers to a uniform dark grey • Highly resistant to corrosion in industrial, chemical, and marine environments • Does not stain adjacent surfaces • May be used in contact with cementitious materials	.0000097
Galvanized steel	• Can be factory painted • Economical • Durability dependent on type and weight of zinc coating • Stain resistant • Zinc coating must be repaired when damaged, cut, or drilled • Do not use in contact with copper, redwood, or red cedar unless separated with a bituminous layer • Check with manufacturer of fire retardant or preservation treated wood for compatibility • Do not use in severely corrosive atmospheres	.0000067

Source: Adapted from SMACNA, *Architectural Sheet Metal Manual,* B1–B8.

2.7 TESTING AND MEASURING WATER LEAKAGE

Mock-ups of the wall should be tested for water leakage. The wall should include flashings, sealant joints, and typical openings, such as windows. The walls can be constructed on-site or in a testing laboratory. If the budget is tight, the mock-up can be a section of the wall constructed in place. It should be noted that a wall built for inspection may be very different from a wall constructed at the end of the day on the twentieth floor of the building while it is raining. For this reason on-site supervision and continued testing is critical. Joints at tranitions and openings, in particular, should be tested. At a minimum, on smaller projects, a window and wall interface should be tested in-place. The window may be watertight, but that says nothing about the joint between the window frame and the wall.

Testing for water ingress includes both static and dynamic methods. Mock-ups may be two stories or more in height and several feet in width depending on the testing facilities. It may be prudent to include a short section of the roof to ensure that the roof and wall interface is watertight. American Society for Testing and Materials (ASTM) Standard E1105 tests water penetration with uniform or cyclic static air pressure in the field. ASTM Standard E331 tests water penetration in the laboratory with uniform static air pressure.

Water ingress is more difficult to measure after construction of the interior is complete, although if a leak is copious, it may be measurable by strategically placed buckets. Much can be learned from observing a building. Some of the undesirable effects, such as efflorescence and mold, are very good indicators of moisture problems; without water, there is no mold, staining, organic growth, or efflorescence beyond the expected "building bloom." Water entering through joints, such as at the interface of a window and a wall, can be measured using a water spray rack (ASTM E331) or, more simply, by aiming a hose at the suspected site of the leak and observing the interior, remembering that water will often travel a great distance before it daylights. American Architectural Manufacturers Association (AAMA) 501.2 "Field Check for Metal Storefronts, Curtain Walls, and Sloped Glazing Systems for Water Leakage" is a calibrated but still inexpensive test.

Simple tests can be done in the office. For an empirical test of the watertightness of a water barrier, fill a jar with water, cover it with the barrier, secure it with tape or by other means, and invert it over a container. While this may not provide a definitive answer, and certainly it is not scientific, it lets you compare two materials. You can then check with the manufacturer to see if their data confirms your assessment. Figure 2.17 shows a simple method of comparing the absorption of different materials.

Using a moisture meter during construction can show if excess moisture is trapped in the wall. DC-resistance or dielectric meters will provide a good estimate of the moisture in wood. They can be used for lumber as well as plywood and OSB. The meter readings need to be corrected for the wood temperature and species. The moisture content of wood used in wall construction should be no higher than 19 percent, as it begins to decay at around 28–30 percent. The moisture in studs should be measured at approximately 12 inches and 48 inches (300 and 1220 mm) from the floor and at a minimum of two studs per exterior wall. On multistory construction, the lower floors are usually the wettest. Enclosing a wet wood frame, or any wet component, with nonpermeable layers is asking for problems.

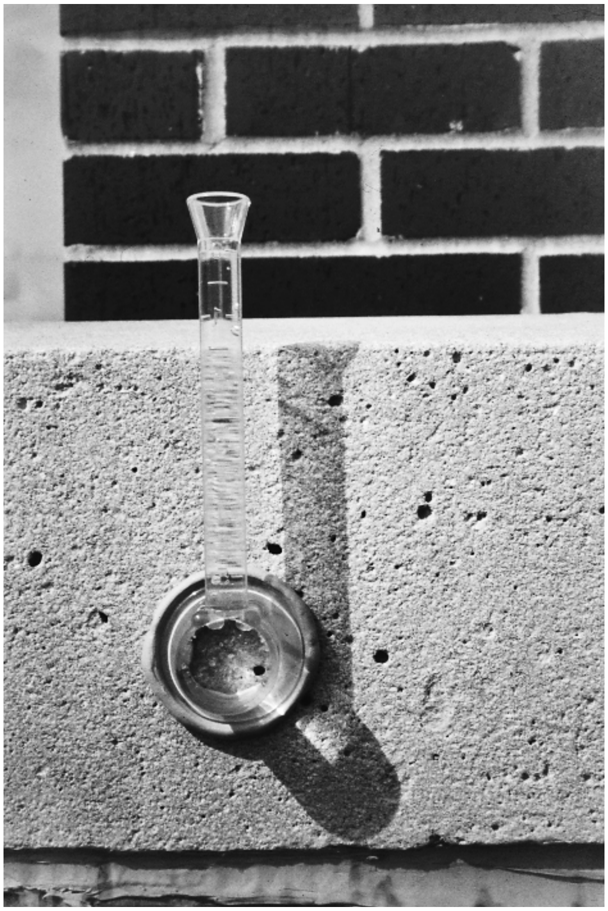


FIGURE 2.17 A simple test using a plastic tube adhered to the surface with soft putty provides quantitative information on how fast a material will absorb water. For more information about this water absorption test, see: Kim Basham and John Meredith, "Measuring Water Penetration," *Masonry Construction Magazine* (November 1995): 539. Photo by G. Russell Heliker.

2.8 QUICK NOTES: WATER INGRESS

- Claddings and finishes and windows and doors will leak at some point.
- Water will always find the way into a wall through the smallest of openings but has more difficulty finding a way out.
- Sheet water barriers should be lapped or shingled with each other and with the flashing.
- Vertical laps should be sealed.
- Wall flashings should be metal and extend to the exterior with a drip edge.
- Methods of controlling water include the following:
  - Face-sealed barrier walls
  - Internal drainage plane walls
  - Drainage cavity walls
  - Pressure-equalized rain-screen walls
  - Hybrid walls, which include face-sealed barrier panels with pressure-equalized (PE) joints, drained, or sealed joints
- Moisture trapped in the wall during construction will cause problems later, particularly if it is between components with low permeability.
- This book does not recommend sheathing, board insulations, or nonreinforced membranes and coatings as water barriers.

- Although a water barrier is forgiving of minor holes, such as those made with staples, they should be minimized whenever possible or sealed.
- The geometry of the exterior wall can help deter water and shed snow.
- Overhangs and drip edges are always a good idea.
- No water from the roof, parapet, or ground should be directed to the exterior wall.
- The way to avoid mold and mildew is to keep water out of the wall.

Finally, as noted by the contractor and author Michael Kubal, “As much as 90 percent of all water intrusion problems occur within 1 percent of the total building or structure exterior surface area. . . . [And] approximately 99 percent of waterproofing leaks are attributable to causes other than material or system failures.”[9] In other words, the best way to avoid water entry problems is with good design, particularly at the joints at interfaces of components and systems.