The beautifully detailed cladding of the Hypolux Bank includes both granite blocks and metal panels. *(Architect: Richard Meier. Photograph © Scott Frances/Esto. All rights reserved)*

19

DESIGNING EXTERIOR WALL SYSTEMS

The *exterior wall enclosure* (also called the *building envelope*) is the part of a building that must defend the interior spaces against invasion by water, wind, sunlight, heat and cold, and all the other forces of nature. Its design is an intricate process that merges art, science, and craft to solve a long list of difficult problems. The exterior wall also typifies a paradox of building: Those parts of a building that are exposed to our view are also those that are exposed to wear and weathering. The outermost layer of the exterior wall is the most visible part of a building, one to which architects devote a great deal of time to achieve the desired visual effect. It is also the part of the building that is most subject to attack by natural forces that can spoil its appearance.

DESIGN REQUIREMENTS FOR THE EXTERIOR WALL

Primary Functions of the Exterior Wall

The major purpose of the exterior wall is to separate the indoor environment of a building from the outdoors in such a way that indoor environmental conditions can be maintained at levels suitable for the building's intended use. This translates into a number of separate and diverse functional requirements.

Keeping Water Out

The exterior wall must prevent the entry of rain, snow, and ice into a building. This requirement is complicated by the fact that water on the face of a building is often driven by wind at high velocities and high air pressures, not just in a downward direction but in every direction, even upward. Water problems are especially acute on tall buildings, which present a large profile to the wind at altitudes where wind velocities are much higher than at ground level. Enormous amounts of water must be drained from the windward face of a tall building during a heavy rainstorm, and the water, pushed by wind, tends to accumulate in crevices and against projecting mullions, where it will readily penetrate the smallest crack or hole and enter the building. We will devote a considerable portion of this chapter to methods for keeping water out.

FIGURE 19.1
A steel-framed Chicago office building during the installation of its aluminum, stainless steel, and glass curtain wall cladding. Notice the diagonal wind braces in the steel frame. *(Architects: Kohn Pedersen Fox/Perkins & Will. Photo by Architectural Camera. Permission of American Institute of Steel Construction)*

Preventing Air Leakage

The exterior wall of a building must prevent the unintended passage of air between indoors and outdoors. At a gross scale, this is necessary to regulate air velocities within the building. Smaller air leaks are harmful because they waste conditioned (heated or cooled) air, carry water through the wall, allow water vapor to condense inside the wall, and allow noise to penetrate the building from outside. Building code requirements for airtightness of building enclosures are growing more stringent. Sealants, gaskets, weatherstrips, and air barrier membranes of various types are all used to prevent air leakage through the exterior wall.

Controlling Light

The exterior wall of a building must control the passage of light, especially sunlight. Sunlight is heat that may be welcome or unwelcome. Sunlight is visible light, useful for illumination but bothersome if it causes glare within a building. It includes destructive ultraviolet wavelengths that must be kept off human skin and away from interior materials that will fade or deteriorate. Windows should be placed and proportioned with these considerations in mind. Exterior wall systems sometimes include external shading devices to keep light and solar heat away from windows. The glass in windows is often selected to control light and heat, as discussed in Chapter 17. Interior shades, blinds, and curtains may be added for further control.

Controlling the Radiation of Heat

Beyond its role in regulating the flow of radiant heat from the sun, the exterior wall of a building should also present interior surfaces at temperatures that will not cause radiant discomfort. A very cold interior surface will make people feel chilly when they are near the wall even if the air in the building is warmed to a comfortable level. A hot interior surface or direct sunlight in summer can cause overheating of the body despite the coolness of the interior air. External sun shading devices, adequate thermal insulation and thermal breaks, and appropriate selection of glass are potential strategies in controlling heat radiation.

Controlling the Conduction of Heat

The exterior wall of a building must resist the conduction of heat into and out of the building. This requires not merely satisfactory overall resistance of the wall to the passage of heat, but also avoidance of *thermal bridges*, wall components such as metal framing members that are highly conductive of heat and therefore likely to cause localized condensation on interior surfaces. Thermal insulation, appropriate glazing, and thermal breaks are used to control heat conduction through the exterior wall, as we will

FIGURE 19.2
The curtain wall of Chicago's Reliance Building, built in 1894–1895, has spandrels constructed of white terracotta tiles. *(Architect: Charles Atwood, of Daniel H. Burnham and Company. Photo by Wm. T. Barnum. Courtesy of Chicago Historical Society ICHi-18294)*

observe in the two chapters that follow. Building codes specify minimum values of thermal resistance of wall components as a way of limiting the conduction of heat and also as a way of controlling the condensation of moisture on cold interior surfaces.

Controlling Sound

The exterior wall serves to isolate the inside of a building from noises outside and vice versa. Noise isolation is best achieved by walls that are airtight, massive, and resilient. The required degree of noise isolation varies from one building to another, depending on the noise levels and noise tolerances of the inside and outside environments. The exterior wall for a hospital near a major airport requires a high level of noise isolation. The exterior wall for a commercial office in a suburban office park need not perform to as high a standard.

Secondary Functions of the Exterior Wall

Fulfillment of the primary functional requirements of the exterior wall leads unavoidably to a secondary but equally important set of requirements.

Resisting Wind Forces

The exterior wall of a building must be adequately strong and stiff to sustain the pressures and suctions that will be placed upon it by wind. For low buildings, which are exposed to relatively predictable winds, this requirement is fairly easily met. The upper reaches of taller buildings are beset by much faster winds whose directions and velocities are often determined by aerodynamic effects from surrounding buildings. High suction forces can occur on some

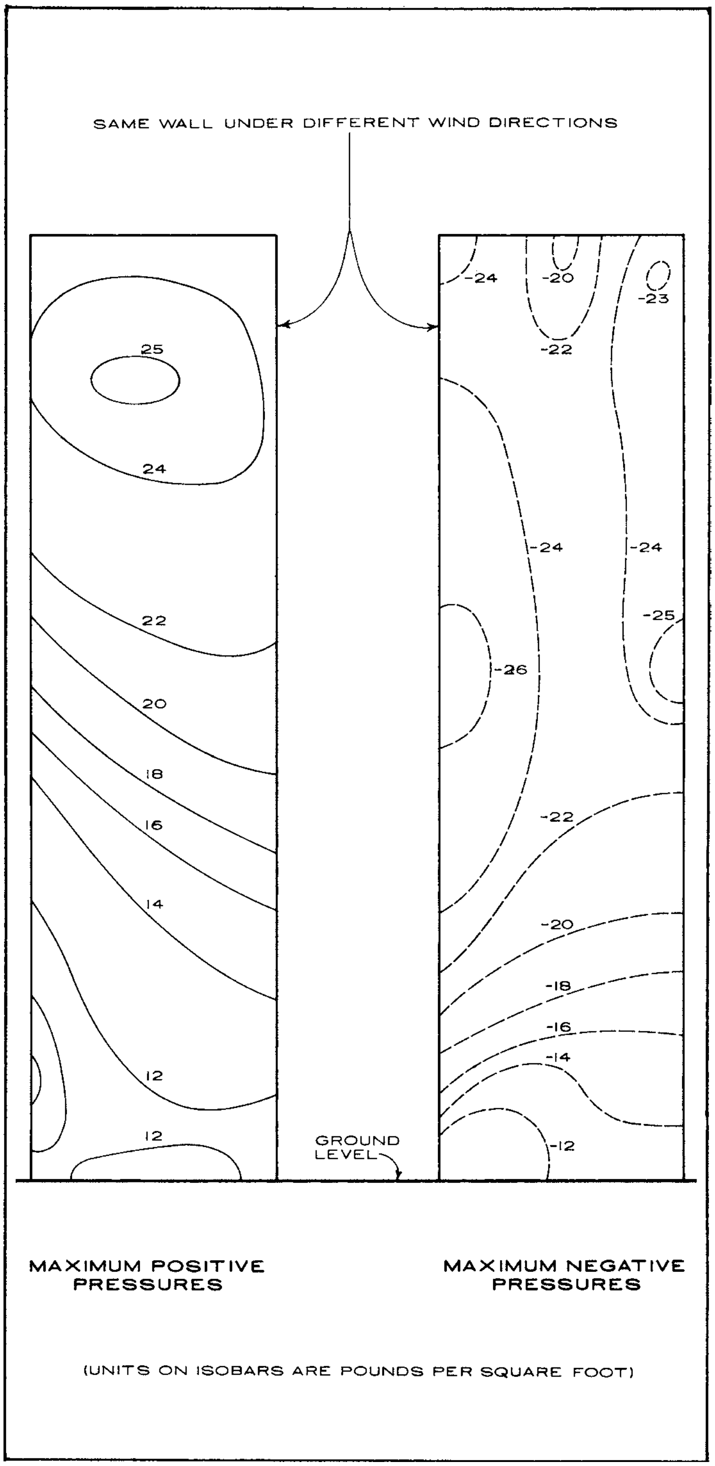


FIGURE 19.3
An example of expected positive and negative wind pressures on the cladding of a tall building, shown here in elevation, as predicted by wind tunnel testing. The building in this case is 64 stories tall and triangular in plan. Notice the high negative pressures (suctions) that can occur on the upper regions of the facade. The wind pressures on a building are dependent on many factors, including the shape of the building, its orientation, topography, wind direction, and surrounding buildings. Each building must be modeled and tested individually to determine the pressures it is expected to undergo. *(Reprinted with permission from AAMA Aluminum Curtain Wall Design Guide Manual)*

portions of the exterior wall, especially near corners of the building (Figure 19.3).

Controlling Water Vapor

The exterior wall of a building must retard the passage of water vapor. In the heat of summer or the cold of winter, vapor moving through a wall assembly may condense inside the assembly and cause staining, loss of insulating value, corrosion of metals, and decay of wood. The exterior wall must be constructed to resist the diffusion of water vapor and to restrict the leakage of moisture-laden air in order to prevent the transfer of water vapor to parts of the wall where it may condense.

Adjusting to Movement

Several different kinds of forces are always at work throughout a building, tugging and pushing both the frame and the exterior wall: thermal expansion and contraction, moisture expansion and contraction, and structural deflections. These forces must be anticipated and allowed for in designing a system of building enclosure.

Thermal Expansion and Contraction

The exterior wall of a building has to accommodate movements due to changes in temperature at several levels: Indoor/outdoor temperature differences can cause warping of cladding panels due to differential expansion and contraction of their inside and outside faces (Figure 19.4*a*). The exterior wall as a whole, exposed to outdoor temperature variations, expands and shrinks constantly with respect to the frame of the building, which is usually protected by the exterior wall from temperature extremes. And the building frame itself expands and contracts to some extent, especially between the time the exterior wall is installed and the time the building is first occupied and its indoor temperature is controlled.

Moisture Expansion and Contraction

Masonry and concrete exterior wall materials must accommodate their own expansion and contraction that is caused by varying moisture content. Bricks and building stone generally expand slightly after they are installed. Concrete blocks and precast concrete shrink slightly after installation in a building as their curing is completed and excess moisture is given off. These movements are small but can accumulate to significant and potentially troublesome quantities in long or tall panels of masonry or concrete. In smaller buildings, wood cladding components are the types of components most susceptible to moisture movement, as discussed in Chapter 3.

Structural Movements

The exterior wall must adjust to structural movements in the frame of the building. Building foundations may settle unevenly, causing distortions of the frame. Gravity forces shorten

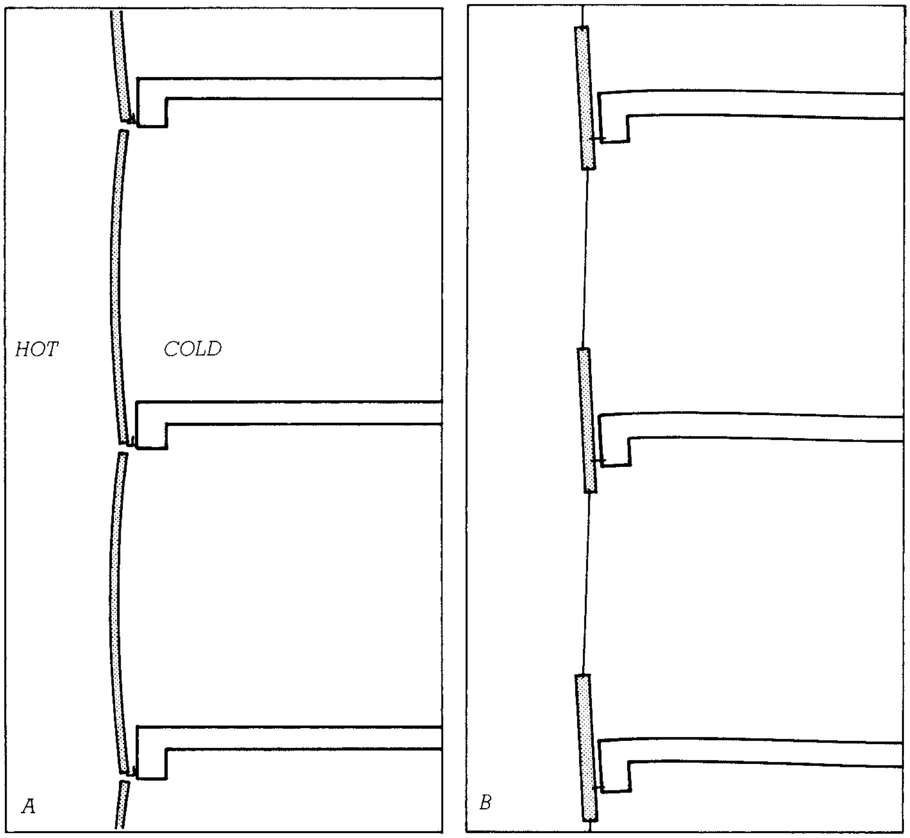
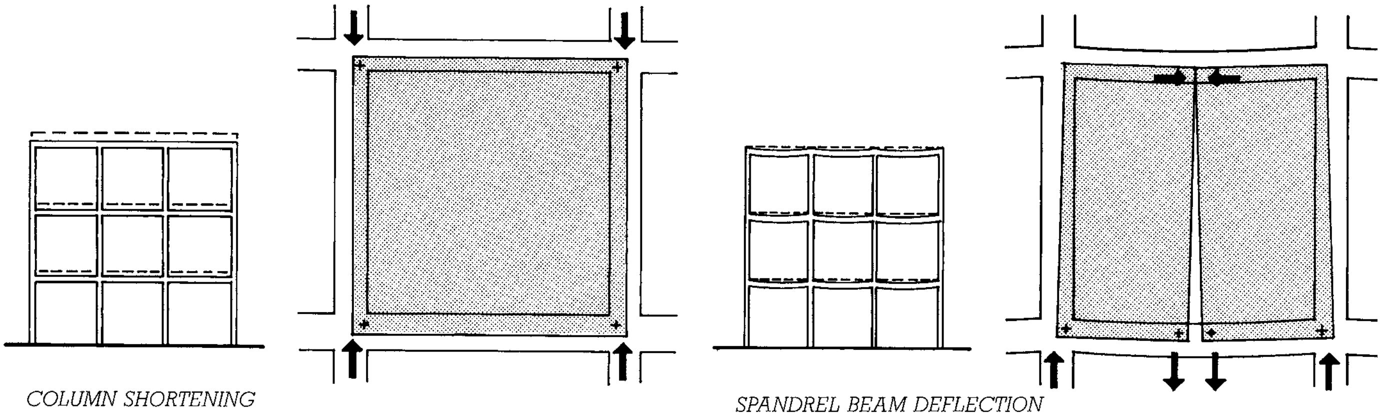
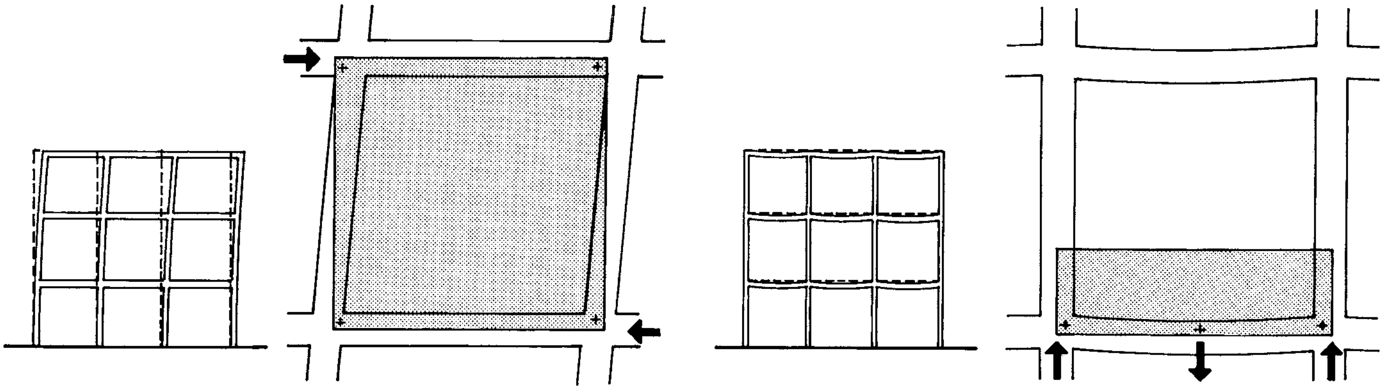


FIGURE 19.4
Distortions of curtain wall panels, illustrated in cross section. (*a*) Bowing caused in this case by greater thermal expansion of the outside skin of the panels than of the inside skin under hot summertime conditions. (*b*) Twisting of spandrel beams because of the weight of the curtain wall.



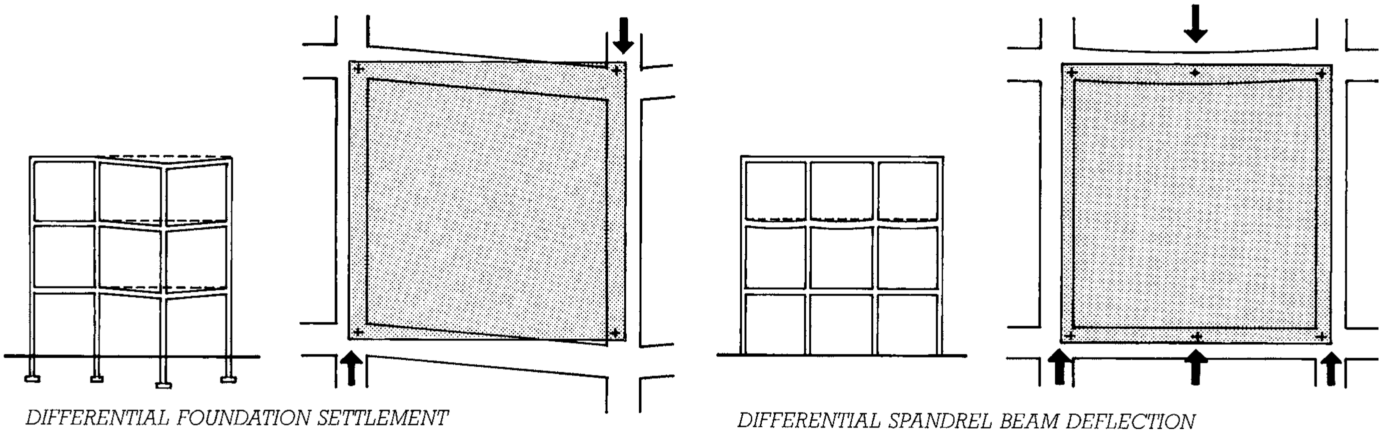
COLUMN SHORTENING

SPANDREL BEAM DEFLECTION



WIND AND EARTHQUAKE DEFORMATIONS

SPANDREL BEAM DEFLECTION



DIFFERENTIAL FOUNDATION SETTLEMENT

DIFFERENTIAL SPANDREL BEAM DEFLECTION

FIGURE 19.5

Forces on curtain wall panels caused by movements in the frame of the building, illustrated in elevation. In each of the six examples, the drawing to the left shows the movement in the overall frame of the building, and the larger-scale drawing to the right shows its consequences on the curtain wall panels (shaded in gray) covering one bay of the building. Points of attachment between the panels and the frame are shown as crosses. The black arrows indicate forces on the wall panels caused by the movement in the structure. The magnitude of the structural movements is exaggerated for clarity, and some inadvisable attachment schemes are shown to demonstrate their consequences. Forces such as these, if not taken into account in the design of the frame and cladding, can result in glass breakage, panel failures, and failure of the attachments between the panels and the frame.

CONSIDERATIONS OF SUSTAINABILITY IN EXTERIOR WALL SYSTEMS

For many if not most buildings, the design of the exterior wall has a greater effect on lifetime energy consumption than any other factor. A poorly designed all-glass box loses excessive amounts of heat in winter and gains excessive solar heat in summer. Its undifferentiated faces show no awareness on the part of the designer of the effects of orientation on energy transactions through the walls of a building.

- Glass should be used where it can supply daylighting and provide views. If it cannot be effectively shaded, it should be avoided where summertime overheating could otherwise occur or where occupants could be subject to excessive glare at times of the day when the sun is low in the sky.
- In many buildings, windows that can be opened and closed by the occupants can help reduce energy costs.
- Opaque areas of the exterior wall should be well insulated.
- Thermal bridges should be eliminated from the exterior wall.
- The entire building envelope should be detailed for airtightness. Fresh air should be provided by the building's ventilation system, not by air leakage through the exterior wall.
- Where appropriate, south-facing glass can be used to provide solar heat to the building in winter, but care must be taken to avoid glare, local overheating, and ultraviolet deterioration of interior surfaces and furnishings that are exposed to sunlight.
- As photovoltaic cells become more economical, consideration should be given to using south-facing surfaces of the exterior wall to generate electrical energy.

columns and cause beams and girders to which the exterior wall system is attached to sag slightly. Wind and earthquake forces push laterally on building frames and wrack panels attached to the faces. Long-term creep causes significant shortening of concrete columns and sagging of concrete beams and slabs during the first year or two of a building's life.

If building movements due to temperature differences, moisture differences, structural stresses, and creep are allowed to be transmitted between the frame and the exterior wall, unexpected things may happen. Wall system components may be subjected to forces for which they were not designed, which can result in broken glass, buckled cladding, sealant failures, and broken cladding attachments (Figure 19.5). In extreme cases, the building frame may end up supported by the exterior wall, rather than the reverse, or pieces of cladding may fall off the building. A number of provisions for dealing with movement from all these causes are evident in the details of exterior wall systems presented in the two chapters that follow.

Resisting Fire

The exterior wall of a building can interact in several ways with building fires. This has resulted in a number of building code provisions relating to the construction of building exterior wall systems, as summarized at the end of this chapter.

Weathering Gracefully

To maintain the visual quality of a building, its cladding must weather gracefully. The inevitable dirt and grime should accumulate evenly, without streaking or splotching. Functional provisions must be made for maintenance operations such as glass and sealant replacement and for periodic cleaning, including scaffolding supports and safety equipment attachment points for window washers. The cladding must resist oxidation, ultraviolet degradation, breakdown of organic materials, corrosion of metallic components, chemical attack from air pollutants, and freeze-thaw damage of stone, brick, concrete, concrete block, and tile.

Installation Requirements for the Exterior Wall

The exterior wall system should be easy to install. There should be secure places for the installers to stand, preferably on the floors of the building rather than on scaffolding outside. There must be built-in adjustment mechanisms in all the fastenings of components of the wall system to the frame to allow for the inaccuracies that are normally present in the structural frame of the building and the wall components themselves. Dimensional clearances must be provided to allow the wall components to be inserted without binding against adjacent components. And most important, there must be forgiving features that allow for a lifetime of trouble-free enclosure function despite all the lapses in workmanship that inevitably occur—features such as air barriers and drainage channels to get rid of moisture that has leaked through a faulty sealant joint or generous edge clearances that keep a sheet of glass from contacting the hard material of the frame even if the glass is installed slightly askew.

CONCEPTUAL APPROACHES TO WATERTIGHTNESS IN THE EXTERIOR WALL

In detailing the exterior wall for water resistance, we work from a secure theoretical base, which can be stated as follows:

In order for water to penetrate a wall, three conditions must be satisfied simultaneously:

1. There must be water present at the outer face of the wall.
2. There must be an opening through which the water can move.
3. There must be a force to move the water through the opening.

If any one of these conditions is not satisfied, the wall will not leak. This suggests three conceptual approaches to making a wall watertight:

1. We can try to keep water completely away from the wall. A very broad roof overhang can keep a one- or two-story wall dry under most conditions. When designing the exterior wall of a taller building, however, we must either shelter each opening with its own small roof—frequently not a realistic option—or else assume that the wall will get wet.

2. We can try to eliminate the openings in a wall. We can build very carefully, sealing every seam in the wall with membranes, sealants, or gaskets, attempting to eliminate every hole and crack.

This approach, which is called the "barrier wall approach," works fairly well if done well, but it has inherent problems. In a wall made up of sealant-jointed components, the joints are unlikely to be perfect. If a surface is a bit damp, dirty, or oily, sealant may not stick to it. If the worker applying the sealant is insufficiently skilled or has to reach a bit too far to finish a joint, he or she may fail to fill the joint completely. Even if the joints are all made perfectly, building movements can tear the sealant or pull it loose. Because, in this approach, the sealant is on the outside of the building, it is exposed to the full destructive forces of sun, wind, water, and ice and may fail prematurely from weathering. And whatever the cause of sealant failure, because the sealant joint is on the outside face of the wall, it is difficult to reach for inspection and repair. Thus, in practice, the barrier wall approach proves unreliable.

In response to these problems, exterior wall designers often employ a strategy of *internal drainage* or secondary defense, which accepts the uncertainties of external sealant joints by providing internal drainage channels within the wall to carry away any leakage or condensate and backup sealant joints to the inside of the drainage channels. The ordinary masonry cavity wall facing exemplifies this strategy: The cavity, flashings, and weep holes constitute an internal drainage system for any moisture that finds its way through the facing bricks. Internal drainage systems are an important component of every metal-and-glass curtain wall system on the market, as we will see in Chapter 21.

3. We can try to eliminate or neutralize all the forces that can move water through the wall. These forces are five in number: gravity, momentum, surface tension, capillary action, and air currents (Figure 19.6).

Gravity is a factor in pulling water through a wall only if the wall contains an inclined plane that slopes into, rather than out of, the building. It is usually a simple matter to detail the exterior wall system so that no such inclined planes exist, though sometimes a loose gasket or an errant bead of sealant can create one despite the best efforts of the designer.

The *momentum* of falling raindrops can drive water through a wall only if there is a suitably oriented slot or hole that goes completely through the wall. Momentum is easily neutralized by applying a cover to each joint in the wall or by designing each joint as a simple *labyrinth*.

The *surface tension* of water, which causes it to adhere to the underside of a cladding component, allows water to be drawn into the building. The provision of a simple *drip* on any underside surface to which water might adhere will eliminate the problem.

Capillary action is the surface tension effect that pulls water through any opening that can be bridged by a water drop. It is the primary force that transports water through the pores of a masonry wall. It can be eliminated as a factor in the entry of water through a wall by making each of the openings in a wall wider than a drop of water can bridge or, if this is not feasible or desirable, by providing a concealed *capillary break* somewhere inside the opening. In porous materials such as brick, capillary action can be counteracted by applying an invisible coating of silicone-based water repellant, which destroys the adhesive force between water and the walls of the pores in the brick.

The solutions described in the four preceding paragraphs are easy to implement. With relatively straightforward geometric manipulations of the joint, the possibility of leakage caused by four of the five forces that can move water through an opening in a wall can be eliminated. The fifth force, *wind currents*, is the force most difficult to deal with in designing a wall for watertightness. We can neutralize it by employing pressure-equalized wall design.

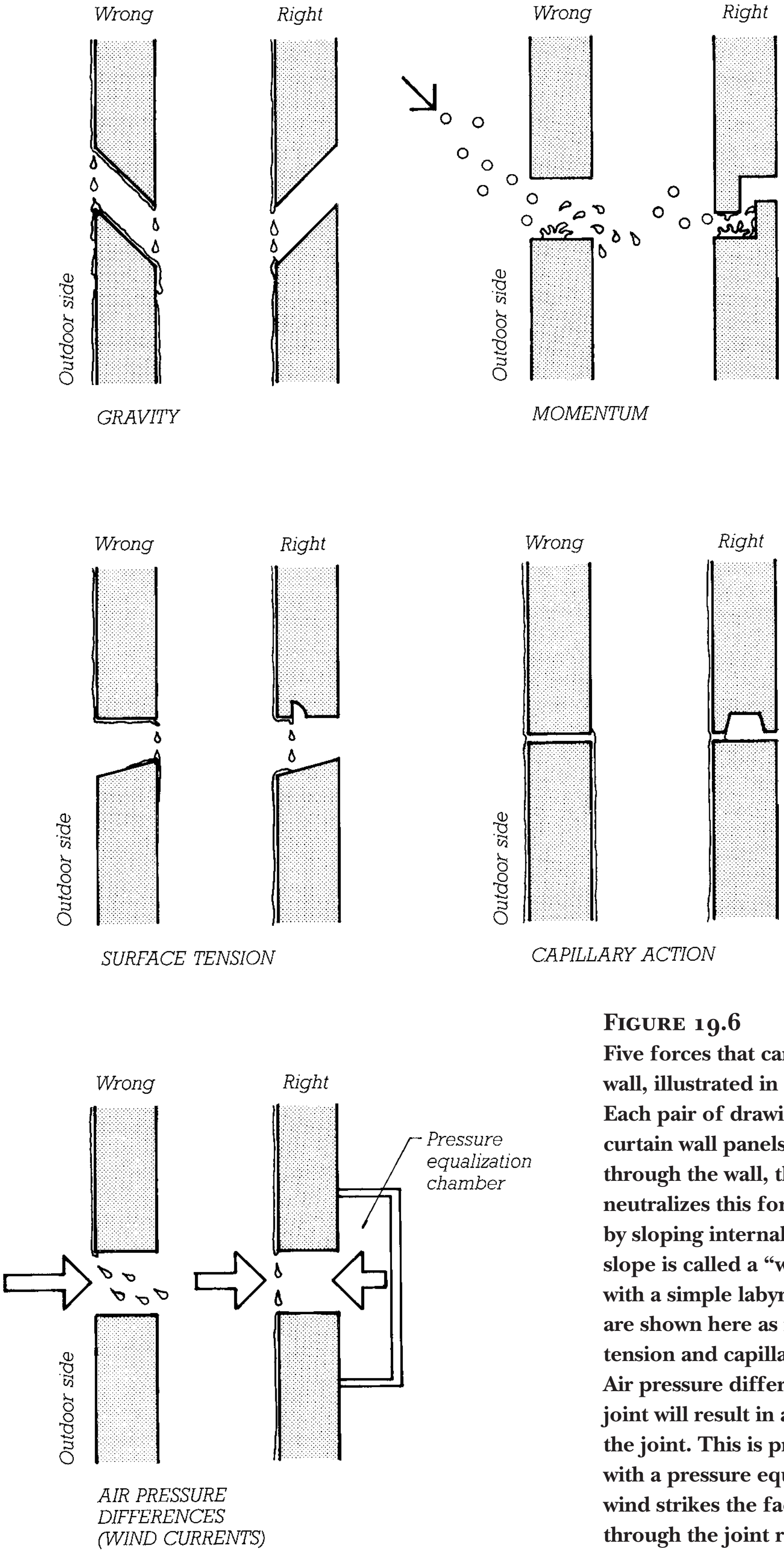


Figure 19.6
Five forces that can move water through an opening in a wall, illustrated in cross section with the outdoors to the left. Each pair of drawings shows first a horizontal joint between curtain wall panels in which a force is causing water leakage through the wall, then an alternative design for the joint that neutralizes this force. Leakage caused by gravity is avoided by sloping internal surfaces of joints toward the outside; the slope is called a "wash." Momentum leakage can be prevented with a simple labyrinth, as shown. A drip and a capillary break are shown here as means for stopping leakage from surface tension and capillary action, which are closely related forces. Air pressure differences between the outside and inside of the joint will result in air currents that can transport water through the joint. This is prevented by closing the area behind the joint with a pressure equalization chamber (PEC), as shown. When wind strikes the face of the building, a slight movement of air through the joint raises the pressure in the PEC until it is equal to the pressure outside the wall, after which all air movement ceases. Each joint in an exterior wall, window, or door must be designed to neutralize all five of these forces.

Rainscreen Cladding and Pressure-Equalized Wall Design

The generic solution to the wind current problem is to allow wind pressure differences between the outside and inside of the exterior wall to neutralize themselves through a concept known as *pressure-equalized wall design.* This involves the creation of an airtight plane, the *air barrier,* behind the outer face of the wall. The air barrier is protected from direct exposure to the outdoors by an unsealed, labyrinth-jointed layer known as the *rainscreen.* Between the rainscreen and the air barrier is a space known as the *pressure equalization chamber (PEC).*

As wind pressures on the exterior wall build up and fluctuate, small currents of air pass back and forth through each unsealed joint in the rainscreen, just enough to equalize the pressure inside the PEC with the pressure immediately outside it (Figure 19.6). These currents are far too weak to carry water with them. A small flaw in the air barrier, such as a sealant bead that has pulled away from one side of the joint, is unlikely to cause a water leak because the volume of air that can pass through the flaw is still relatively small and is probably insufficient to carry water. By contrast, any flaw, no matter how small, in an external sealant joint without an air barrier behind it will cause a water leak, because the sealant joint itself is wetted (Figure 19.7).

Because wind pressures across the face of a building may vary considerably at any given moment between one area of the face and another, the PEC must be divided into airtight compartments small enough so that volumes of air cannot rush through the joints in higher-pressure areas of the face and flow across the air chamber to lower-pressure areas, carrying water with them as they go. The appropriate size of these chambers may vary considerably, depending on the design of the wall system and the wind forces to which it is exposed. Broadly speaking, PECs are normally no taller than one story or wider than one or two columns bays. In some applications they may be significantly smaller.

The term *rainscreen principal* originated with the concept of pressure-equalized wall design, and at one time it was used exclusively in reference to pressure-equalized cladding systems. More recently, the term *rainscreen cladding* has come to be applied more broadly to any cladding system with a system of internal drainage, regardless of the extent of compartmentalization of the drainage space and the degree of pressure equalization that can be achieved. In practice, varying degrees of pressure equalization are achievable, and the line between cladding systems best characterized as simple rainscreens or pressure-equalized walls is often indistinct.

A Pressure-Equalized Wall Design

Figure 19.8 depicts a cladding design that embodies the rainscreen and pressure-equalization principles in very simple form. No surface joint sealants or gaskets are used. The metal rainscreen panels do not touch one another, but are separated by generous gaps that preclude capillary movement of water, provide installation clearances, and allow for expansion and contraction. All four edges of each panel are shaped so as to create labyrinth joints. The forces of surface tension and gravity are counteracted by sloping surfaces and drips.

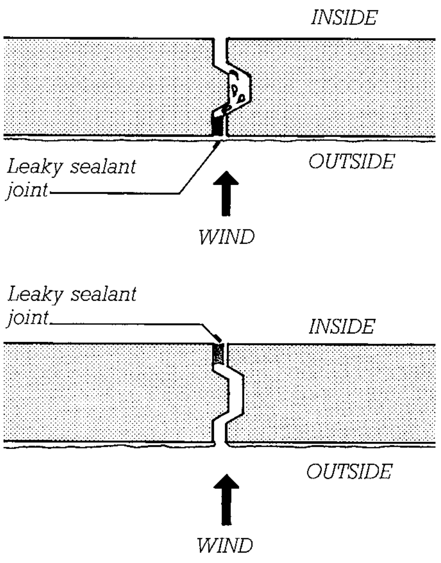
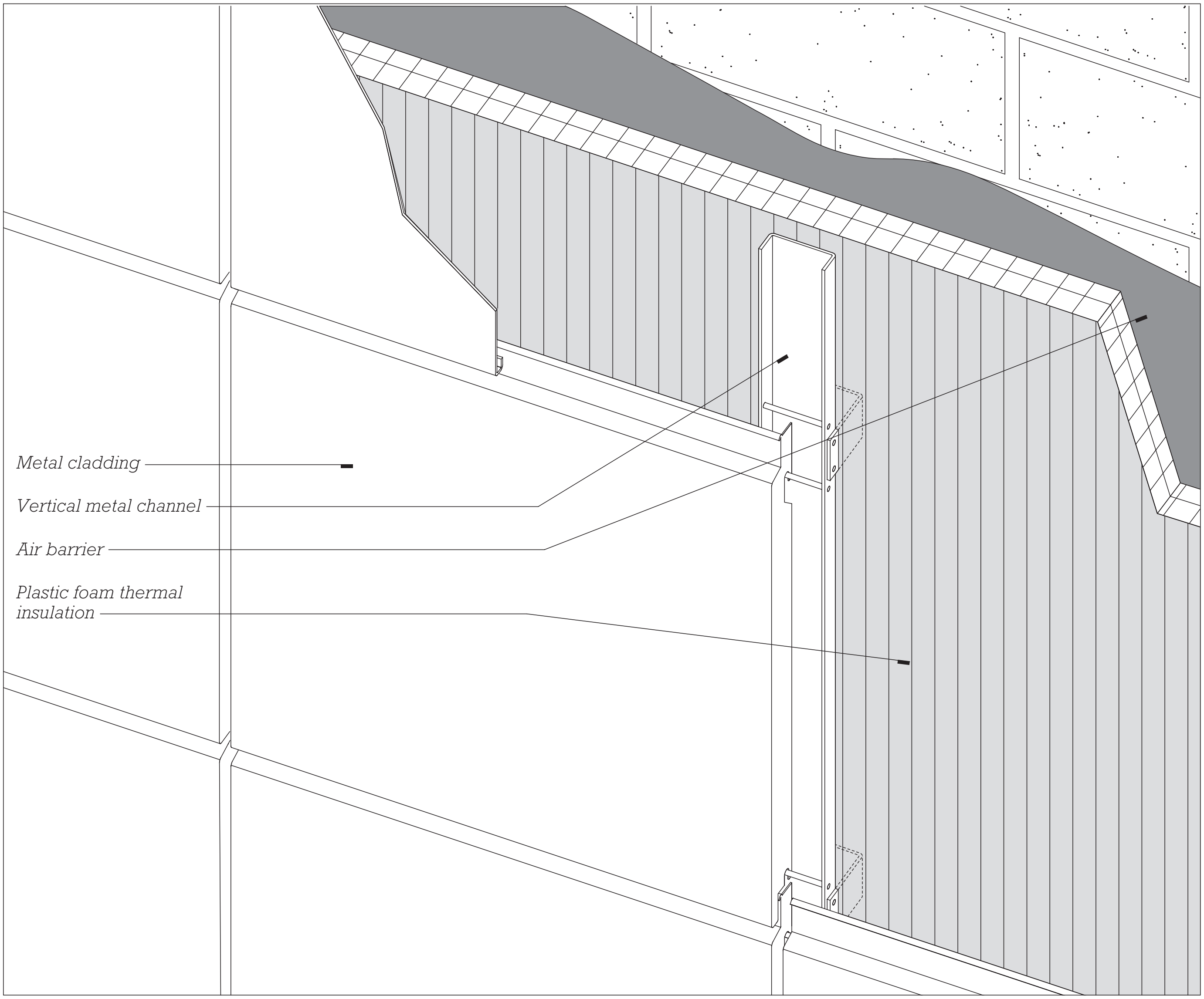
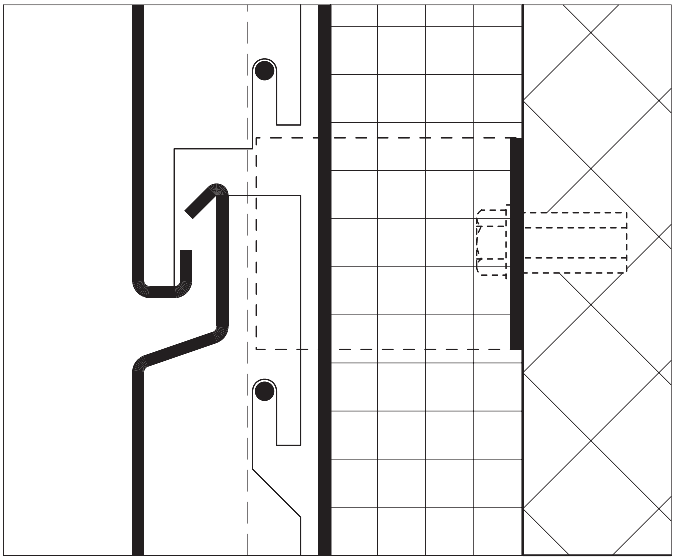
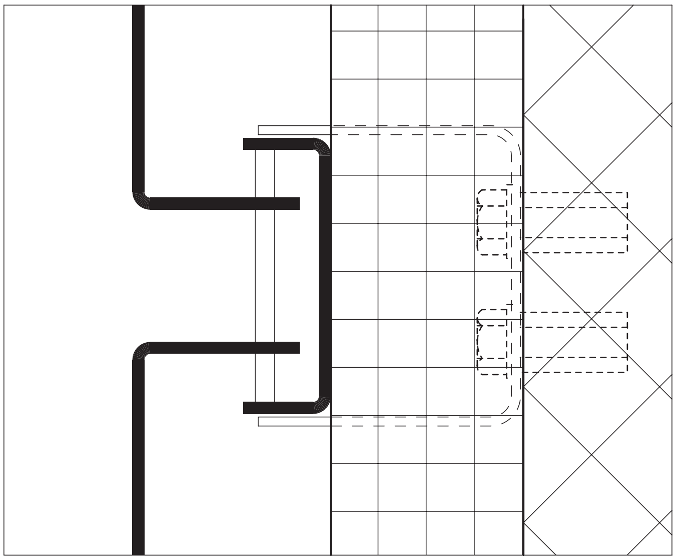


FIGURE 19.7
Leakage through a defective vertical sealant joint between curtain wall panels, shown in plan view. In the upper example, the sealant joint is at the outside face of the panels, where it is wetted during a storm. Even a small current of air passing through the defective joint carries water with it. In the lower example, with the defective sealant located on the inside of the panels where it remains dry, air leakage through the joint is insufficient to transport water through the joint, and no water penetrates.

FIGURE 19.8
The rainscreen in this exemplary cladding system is made up of metal panels, each formed from sheet metal. The design team included Wallace, Floyd Associates, Inc., Bechtel/Parsons Brinckerhoff, Stull and Lee, Inc., Gannett Fleming/URS/TAMS Consultants, and the Massachusetts Highway Department.




SECTION THROUGH HORIZONTAL JOINT


PLAN OF VERTICAL JOINT

Installation is simple and forgiving of minor lapses in workmanship: Metal U-shaped clips are bolted to the backup wall, which is coated with an airtight mastic to create an air barrier. Rigid insulation panels are adhered to the wall, allowing the clips to project through. Vertical metal channels are bolted to the clips. Finally, the metal panels that make up the rainscreen are simply hung on horizontal rods that are supported by the channels, much as pictures are hung on hooks on a wall. The space between the metal rainscreen panels and the insulation acts as an internal drainage space.

To achieve a pressure-equalized design, horizontal metal angles, not shown, are installed between the channels at one- or two-story intervals. The vertical channels further divide the PEC into narrow compartments. (The spaces between the edges of the panels and the channels are narrow enough to restrict airflow sufficiently to achieve a pressurized design. If more complete compartmentalization is needed, compressible foam rods or gaskets can be installed alongside the channels to create more airtight boundaries at these locations.) When wind drives rain against this wall, small quantities of air flow through the open joints in the rainscreen until the pressure in the PEC equals the pressure outside. These airflows are insufficient in volume or velocity to carry water with them.

Pressure Equalization at Smaller Scale

The principles of rainscreen design and pressure equalization may also be applied on a small scale to guide us in many aspects of exterior detailing of buildings. Figure 19.9 demonstrates how this practice is embodied in the placement of weatherstrip in a window sill detail. In the correct detail, the weatherstrip, whose function is to act as an air barrier, is placed to the inside of the lower rail of the sash. The open joint under the sash rail, which is provided with a capillary break, acts as the PEC. Unless the weatherstrip is grossly defective, water cannot be blown through the joint by air pressure differentials. Notice how the other forces that could transport water through the joint are counteracted: A slope on the sill (called by architects a *wash*) prevents gravity from pulling water in. The groove in the lower edge of the sash that acts as a capillary break also acts as a drip to counteract surface tension. The L-shaped joint between the sash and the sill acts as a labyrinth to prevent entry by momentum.

In the incorrect detail, the weatherstrip can be wetted by rain. Any minor flaw in the weatherstrip will allow water to be blown through the joint.

Relatively few buildings rely completely on the rainscreen principle and pressure-equalized wall design for watertightness. However, there are very few contemporary cladding systems that do not employ these principles as an important part of their defense against water penetration. Consider again the familiar example of the masonry cavity wall: These principles can be seen in the brick facing wythe acting as a rainscreen, the backup wall as an air barrier, and the cavity, partially pressurized through weep and vent holes, as the PEC. Nevertheless, the surface of the outer masonry veneer is also frequently sealed with compounds to reduce its absorbency (an application of the barrier wall approach), and the cavity is flashed and provided with weep holes so that water that does penetrate the veneer can be safely channeled back to the exterior (an application of internal drainage).

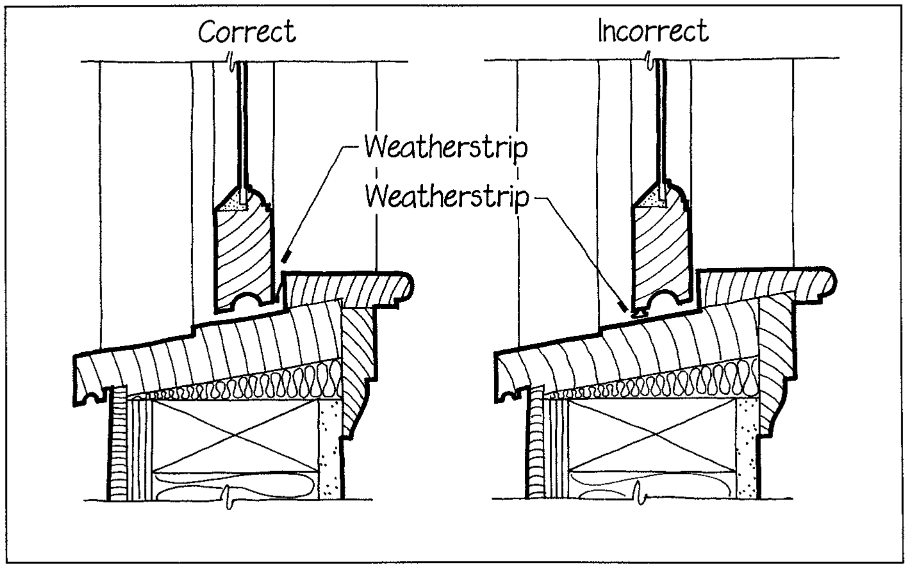


FIGURE 19.9
Applying the rainscreen principle to the detailing of the sill of a double-hung window. (*From Edward Allen,* Architectural Detailing: Function, Constructibility, Aesthetics, *New York, John Wiley & Sons, Inc., reproduced by permission of the publisher*)

SEALANT JOINTS IN THE EXTERIOR WALL

Most exterior wall systems require *sealant joints*, seams that are closed with rubberlike compounds. Systems that do not use sealants as water barriers in the face of the wall frequently use them to seal joints in the air barrier behind the face. The role of a sealant is to fill the joints between wall components, preventing the flow of air and/or water while still allowing reasonable dimensional tolerances for assembly and reasonable amounts of subsequent movement between the components. Sealant joint widths are usually ⅜ to ¾ inch (9–19 mm) but can be as small as ¼ inch (6 mm) and sometimes range up to 1 inch (25 mm) or more.

Sealants are often used to seal joints between panels of stone or precast concrete in a curtain wall (Figures 20.8 and 20.13), to seal the joint beneath the shelf angle in a brick curtain wall (Figure 20.3), and to seal joints between dissimilar materials, such as where a metal-and-glass cladding system ends against a masonry wall (Figure 21.12, details 6, 9, and 9A). Specially formulated sealants are used to seal between lights of glass and the frames that support them (Figure 17.17) and even to prevent the passage of sound around the edges of interior partitions (Figures 23.22, 23.23, 23.35, and 23.38).

FIGURE 19.10
Applying polysulfide, a high-range gunnable sealant, to a joint between exposed-aggregate precast concrete curtain wall panels, using a sealant gun. The operator moves the gun slowly so that a bulge of sealant is maintained just ahead of the nozzle. This exerts enough pressure on the sealant so that it fully penetrates the joint. Following application, the operator will return to smooth and compress the wet sealant into the joint with a convex tool, much as a mason tools the mortar joints between masonry units. (*Courtesy of Morton Thiokol, Inc., Morton Chemical Division*)

Sealant Materials

Gunnable Sealant Materials

Gunnable sealant materials are viscous, sticky liquids that are injected into the joints of a building with a *sealant gun* (Figure 19.10). They cure within the joint to become rubberlike materials that adhere to the surrounding surfaces and seal the joint against the passage of air and water. Gunnable sealants can be grouped conveniently in three categories according to the amount of change in joint size that each can withstand safely after curing:

- *Low-range sealants,* also called *caulks,* are materials with very limited *elongation* (stretching and squeezing) capabilities, up to plus or minus 5 percent of the width of the joint. They are used mainly for filling minor cracks or nonmoving joints, especially in preparation for painting. Most caulks cure by evaporation of water or an organic solvent and shrink substantially as they do so. None are used for sealing of joints in building exterior wall systems. (Although the term "caulk" is properly applied only to low-range sealants, in common usage it is frequently applied more broadly to mean any type of sealant, regardless of elongation capability.)
- *Medium-range sealants* are materials such as butyl rubber or acrylic that have safe elongations in the plus or minus 5 to 10 percent range. They are used in the building exterior wall for sealing nonworking joints (joints that are fastened together mechanically as well as being filled with sealant, as shown in Figure 19.11). Because these sealants cure by the evaporation of water or an organic solvent, they undergo some shrinkage during curing.
- *High-range sealants* can safely sustain elongations up to plus or minus 50 to 100 percent. They include various *polysulfides,* which are usually site mixed from two components to effect a chemical cure; *polyurethanes,* which may also cure by a two-component reaction or by reacting with moisture vapor from the air, depending on the formulation; and *silicones,* which all cure by reacting with moisture vapor from the air. None of these sealants shrink upon curing because none relies on the evaporation of water or a solvent to effect a cure. All adhere tenaciously to the sides of properly prepared joints. All are highly resilient rubberlike materials that return to their original size and shape after being stretched or compressed, and all are durable for 20 years or more if properly formulated and installed. Sealants for the working joints in exterior wall systems are selected from among this group. Polysulfide sealants have the longest history of use in such applications. However, improved formulations of polyurethanes and silicones now account for 90 percent or more of the high-range construction sealant market, with silicones generally considered the longest-lasting and highest-performing of the three.

Gunnable joint sealants are specified according to ASTM standard C920, which defines designations for sealant *Type, Grade, Class,* and *Use.* Type S sealants are *single-component* and require no jobsite mixing. Type M sealants are *multi-component* and must be mixed on the job-site before installation. Multicomponent sealants generally cure faster than single-component sealants. They also allow a greater variety in color choice, as dye packs can be added during mixing. Grade P sealants, also called *self-leveling,* are *pourable.* They are easily installed in horizontal paving joints. But for vertical wall joints, Type NS, *nonsag,* sealants must be used. Class defines the elongation capability of a sealant. A Class 25 sealant can tolerate 25 percent expansion and contraction under normal usage. A Class 100/50 sealant (the highest Class designation in the current standard) can tolerate 100 percent expansion and 50 percent contraction. A Use T, *traffic,* sealant can tolerate wear and physical abuse of pedestrian or vehicular traffic (most pourable sealants are also Use T); a Use NT, *nontraffic,* sealant is not suitable for traffic exposure and is normally intended for use in vertical wall joints; a Use I, *immersible,* sealant is suitable for sealing applications that will be submerged once the sealant has cured. Sealants may also be classified as Use M, G, A, or O, meaning that they have passed a series of tests demonstrating satisfactory adherence to mortar, glass, aluminum, or other materials, respectively. As an example, a multicomponent sealant intended for expansion joints between sections of aluminum curtain wall, which must be capable of 50 percent elongation, can be specified as Type M, Grade NS, Class 50, Uses NT and A.

Solid Sealant Materials

In addition to the gunnable sealants, several types of solid materials are used for sealing seams in the building exterior wall (Figure 19.11):

- *Gaskets* are strips of various fully cured elastomeric (rubberlike) materials manufactured in several different configurations and sizes for different purposes. They are either compressed into a joint to seal tightly against the surfaces on either side or inserted in the joint loose and then expanded with a *lockstrip* insert, as illustrated in Figures 17.17–17.19.
- *Preformed cellular tape sealant* is a strip of polyurethane sponge material that has been impregnated with a mastic sealant. It is delivered to the construction site in an airtight wrapper, compressed to one-fifth or one-sixth of its original volume. When a strip is unwrapped and inserted, it expands to fill the joint, and its sealant material cures with moisture from the air to form a watertight seam.
- *Preformed solid tape sealants* are used only in lap joints, as in mounting glass in a metal frame or overlapping two thin sheets of metal at a cladding seam. They are thick, sticky ribbons of polybutene or polyisobutylene that adhere to both sides of the joint to seal and cushion the junction. They are so sticky that they cannot be inserted into a joint, but must be applied to one side of the joint before it is assembled.

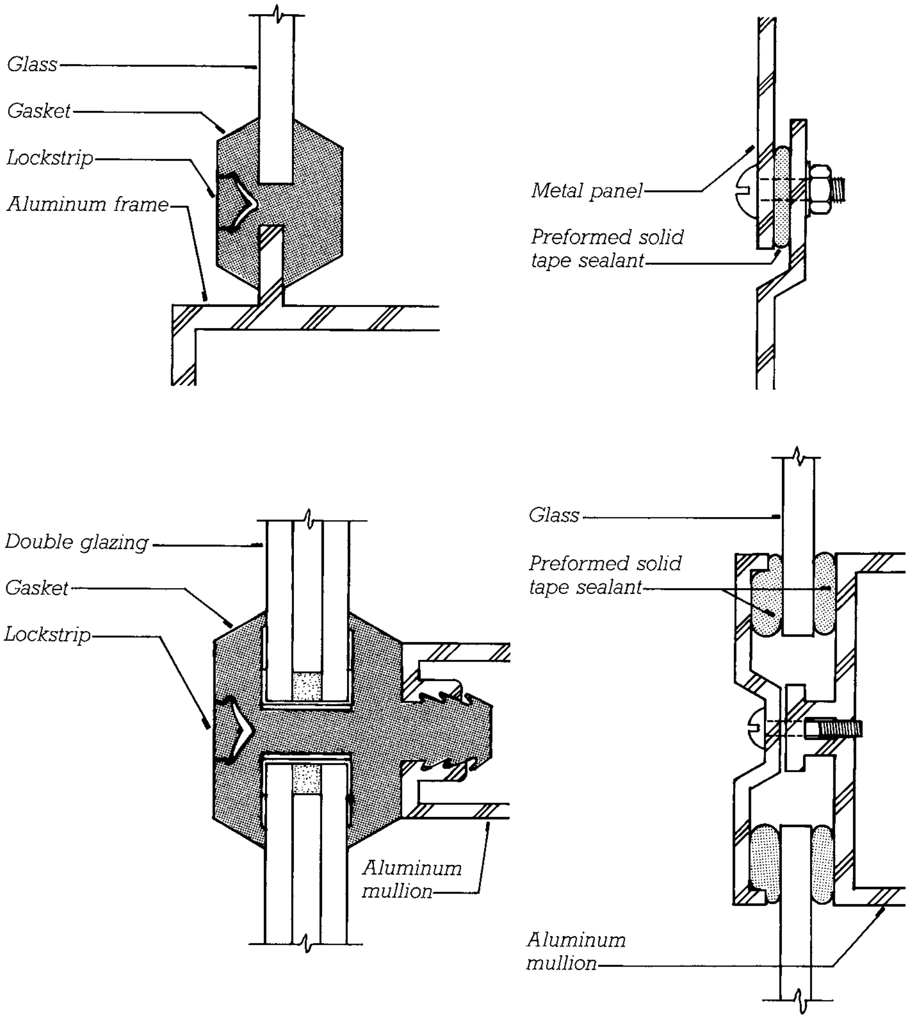


Figure 19.11
Some solid sealant materials. At the left, two examples of lockstrip gaskets. At the right, preformed solid tape sealants.

Sealant Joint Design

Figures 19.12–19.14 show the major principles that need to be kept in mind while designing a gunnable sealant joint. For a joint between materials with high coefficients of expansion, the time of year when the sealant is to be installed must be taken into account when specifying the size of the joint and the type of sealant. Sealant installed in cold weather will have to stretch less during its lifetime but will have to compress more in summer than the same sealant installed in hot weather, which will have to stretch more and compress less.

Installation procedures are also critical to the success of gunnable sealant joints in an exterior wall system. Each joint must be carefully cleaned of oil, dirt, oxide, moisture, or concrete form release compound. If it is necessary to improve adhesion between the sealant and the substrate, the edges of the joint are *primed* with a suitable coating. Then the *backer rod* or *backup rod* is inserted. This is a cylindrical strip of highly compressible, very flexible plastic foam material that is just a bit larger in diameter than the width of the joint. It is pushed into the joint, where it holds its place by friction, to limit the depth to which the sealant will penetrate in order to maintain the optimum proportions of the sealant bead and avoid waste of sealant material. Backer rod material is available in a large range of diameters to fit every joint.

The sealant is extruded into the joint from the nozzle of a sealant gun, filling completely the portion of the joint outside the backer rod. Lastly, the sealant is mechanically tooled, much as a masonry mortar joint is tooled, to compress the sealant material firmly against the sides of the joint and the backer rod. The tooling also gives the desired surface profile to the sealant. (The backer rod's role is now finished but, being inaccessible, the rod stays in the joint.)

Gasket sealants have generally proved to be less sensitive to installation problems than gunnable sealants. For this reason, they are widely used in proprietary cladding systems.

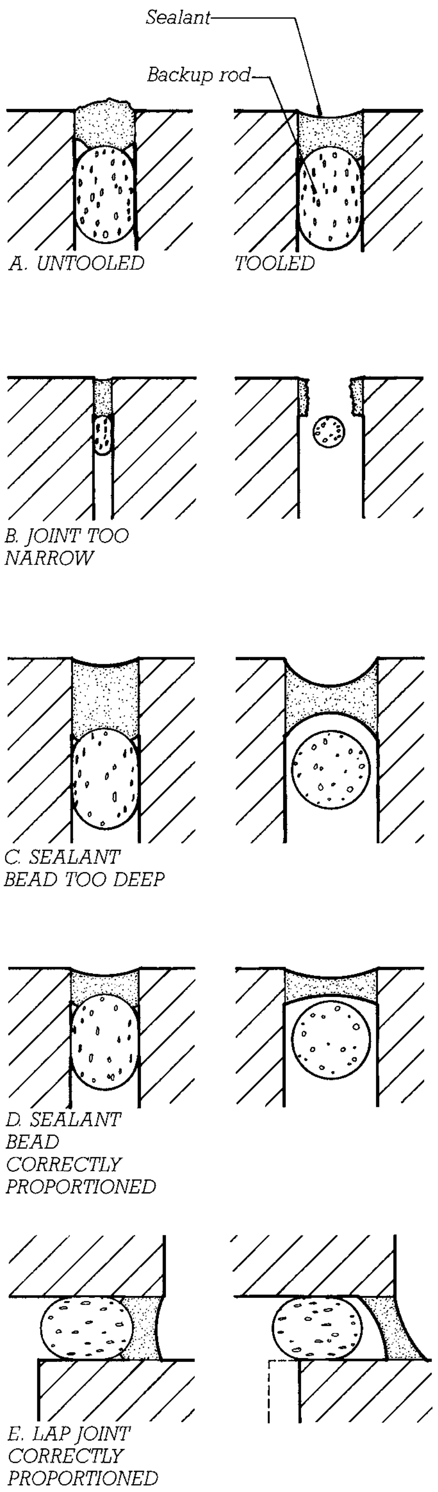


FIGURE 19.12
Good and bad examples of sealant joint design. ***(a)*** **This properly proportioned joint is shown both untooled and tooled. The untooled sealant fails to penetrate completely around the backer rod and does not adhere fully to the sides of the joint.** ***(b)*** **A narrow joint may cause the sealant to elongate beyond its capacity when the panels on either side contract, as shown to the right.** ***(c)*** **If the sealant bead is too deep, sealant is wasted, and the four edges of the sealant bead are stressed excessively when the joint enlarges.** ***(d)*** **A correctly proportioned sealant bead. The backer rod, made of a spongy material that does not stick to the sealant, is inserted into the joint to maintain the desired depth. The width is calculated so that the expected elongation will not exceed the safe range of the sealant, and the depth is between ⅛ and ⅜ inch (3 and 9.5 mm).** ***(e)*** **A correctly proportioned lap joint. The width of the joint (the distance between the panels) should be twice the depth of the sealant bead and twice the expected movement in the joint.**

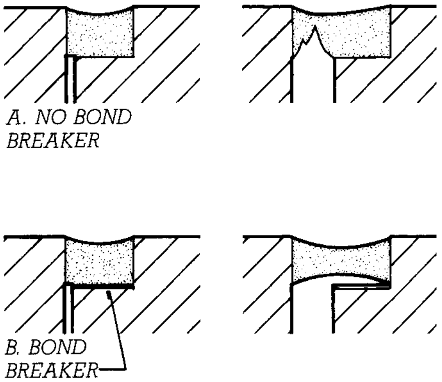


FIGURE 19.13
In three-sided joints, the sealant is likely to tear unless a nonadhering plastic bond breaker strip is placed in the joint before the sealant.

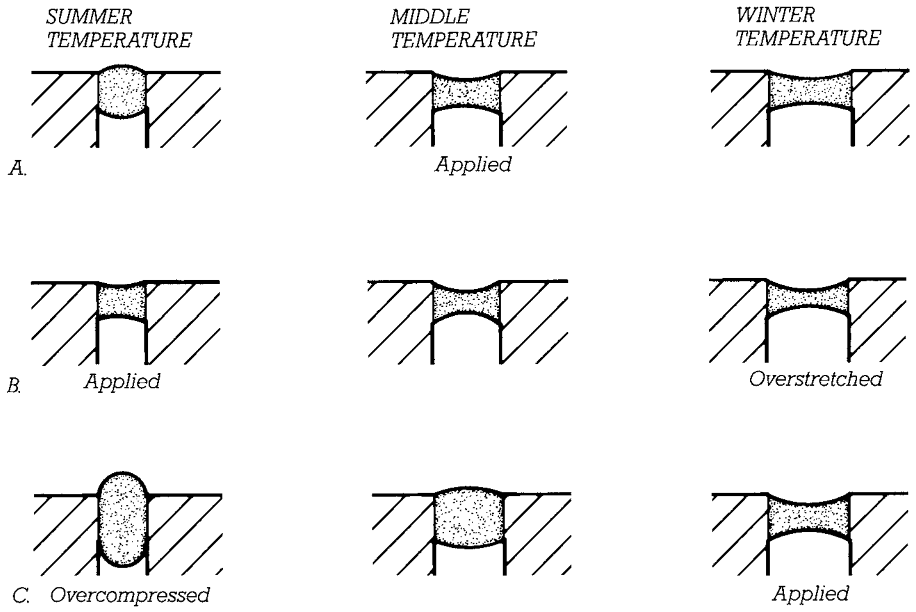


FIGURE 19.14
Sealants are best applied at temperatures that are neither excessively hot nor excessively cold. If cold- or hot-weather applications of sealants are anticipated, the joints should be proportioned to minimize overstretching or overcompression. Row *A* shows the behavior of a sealant applied at a medium temperature. Rows *B* and *C* show sealant applied at summer and winter temperatures, respectively.

Basic Concepts of Exterior Wall Systems

The Loadbearing Wall

Until the late 19th century, nearly all large buildings were built with loadbearing exterior walls. These walls supported a substantial portion of the floor and roof loads of the building, as well as separating the indoor environment from the outdoors. In noncombustible buildings, these walls were built of brick or stone masonry. Functionally, such walls had several inherent limitations. They were poor thermal insulators, and they were heavy, requiring large foundations and limiting their height to a few stories.

The *loadbearing wall* has been brought up to date with higher-strength masonry and concrete; components such as thermal insulating materials, cavities, flashings, air barriers, and vapor retarders have been added to make the wall more resistant to the passage of water, air, and heat; and the addition of steel reinforcing has allowed the wall to become thinner, lighter, and better able to resist wind and seismic loads. Loadbearing masonry and concrete exterior walls are often attractive and economical for low- and medium-rise buildings. High-rise residential towers with exterior loadbearing masonry walls also continue to be built, especially in Asia. These types of construction are illustrated and discussed in more detail in Chapters 8, 10, and 14.

The Curtain Wall

The first steel-framed skyscrapers, built in the late 19th century, introduced the concept of the *curtain wall*, an exterior wall supported at each story by the frame. The name "curtain wall" derives from the idea that the wall is thin and "hangs" like a curtain on the structural frame. (Most curtain wall panels do not actually hang in tension from the frame but are supported from the bottom at each floor level.) The earliest curtain walls were constructed of masonry (Figure 19.2). The principal advantage of the curtain wall is that, because it bears no vertical load, it can be thin and lightweight regardless of the height of the building, compared to a masonry loadbearing wall, which may become prohibitively thick and weighty at the base of a very tall building.

Curtain walls may be constructed of any noncombustible material that is suitable for exposure to the weather. They may be either constructed in place or prefabricated. In the next chapter, we will examine curtain walls that are made of masonry and concrete. In Chapter 21, we will look at curtain walls that are made of metal and glass. In both chapters, we will see that some types of walls are constructed in place and others are prefabricated, but all are supported by the frame of the building.

BUILDING ENCLOSURE ESSENTIALS: AIR BARRIER

Air Leakage

Air can move through a building assembly wherever air pressure differences exist between one side of the assembly and the other. Such pressure differences can be created by wind forces acting on the external surfaces of a building, by *stack effect* (the tendency of tall buildings to act somewhat like chimneys, drawing air in at either the top or bottom and expelling it at the other end), and by building mechanical equipment such as exhaust fans and air handling systems (Figure A).

When outside air infiltrates a building through exterior walls and roofs, it increases building energy consumption. A 2005 study by the U.S. National Institute of Standards and Technology estimated that air infiltration can account for as much as 40 percent of a building's heating and cooling costs. Outside air infiltration also introduces unfiltered air pollutants and unconditioned air into the building's interior, where it can compromise indoor air quality and reduce occupant comfort. Air leakage transports water vapor into insulated walls and roofs, increasing the risk of condensation and moisture damage to building components. When air leaks between spaces within a building, it can disrupt pressure differentials maintained by HVAC systems for the purpose of controlling the spread of odors or contaminants between separately zoned parts of a building. For example, unpleasant cooking odors can be drawn from one apartment building living unit to another, car exhaust or gas fumes from a parking garage can infiltrate adjacent occupied areas, dust particles can be carried into a laboratory clean room, or bacteria can be introduced into a hospital operating suite.

Air Barriers

Air barrier materials act to reduce air leakage through a building assembly. Examples of air barrier materials include building wrap, gypsum wallboard, polyethylene sheet plastic, rigid foam insulation, liquid-applied membranes of various formulations, caulking, sealants, gaskets, tapes, and more. To function as an air barrier, a material must be resistant to the passage of air; it must have sufficient strength and rigidity to withstand the air pressure differentials that act upon it; where it spans movement joints, it must be sufficiently resilient to accommodate movement without failure; and it must be durable enough to perform its function throughout the life of the building.

The greater a material's resistance to the passage of air, the lower its *air permeance* and the better its performance as an air barrier. Air permeance is measured according to ASTM E2178 and is expressed as cubic feet of air per minute per square foot of area at 1.57 pounds per square foot (or 0.3 inch of water) of air pressure, or, in metric units, as liters per second per square meter of area at 75 Pascals of air pressure. An air permeance of 1 cfm/sf@1.57 psf is equal to approximately 5 L/s-m^2@75 Pa. The most commonly cited standard for air barrier materials is an air permeance not greater than 0.004 cfm/sf@1.57 psf or 0.02 L/s-m^2@75 Pa (Figure B).

An air barrier material must be able to resist air pressure, acting either inward or outward across the building assembly, without damage or excessive deflection. Flexible sheet materials such as building wraps, plastic sheets, roofing membranes, and flexible flashings are especially vulnerable. If not properly supported or adequately fastened, these materials can tear, stretch, or pull loose and become

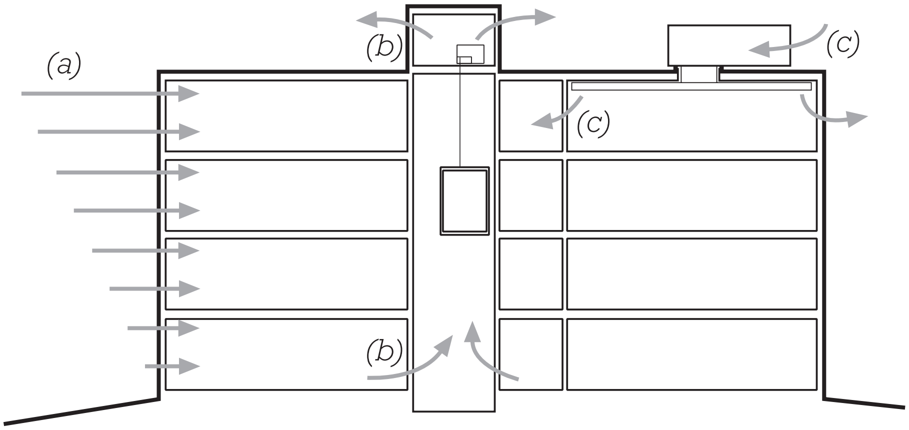


FIGURE A
Air pressure differences in a building can be caused by (*a*) wind, (*b*) the stack effect, such as within an elevator shaft, and (*c*) building mechanical systems.

	Air Permeance	
Material	**cfm/sf@1.57 psf**	**L/s-m^2@75 Pa**
Polyethylene sheet, 6 mil (0.15 mm)	~0	~0
Aluminum foil, 1 mil (0.025 mm)	~0	~0
Self-adhered modified asphalt membranes	~0	~0
Plywood, ⅜ inch (9.5 mm)	~0	~0
Extruded polystyrene rigid foam insulation, 1½ inch (38 mm)	~0	~0
Most low-slope roofing membranes	~0–0.002	~0–0.01
Proprietary high-density spray polyurethane foam insulation, 1½ inches (38 mm)	0.0002	0.001
Proprietary fluid-applied, vapor-permeable air barrier membrane	<0.0004	<0.002
Proprietary nonperforated polyolefin building wrap		
Commercial grade	0.001	0.005
Residential grade	0.007	0.036
Low-density spray polyurethane foam insulation, 3 inches (75 mm)	0.002–0.32	0.01–1.6
Gypsum wallboard, ½ inches (12 mm)		
Exterior sheathing	0.002	0.0091
Interior wallboard, unpainted	0.004	0.0196
Oriented strand board, ⅜ inch (11 mm)	<0.004	<0.02
Roofing felt, #30	0.037	0.1873
Nonperforated asphalt felt, #15	0.078	0.3962
Asphalt-impregnated fiberboard	0.163	0.8285
Tongue-and-groove planks	3.7	19
Glass fiber batt insulation	7.3	37
Cellulose insulation, sprayed	17	87

FIGURE B
Air permeance of common building materials. Shaded rows indicate materials exceeding recommended air permeance for air barrier materials.

ineffective as air barriers. Damage caused by air pressures can also lead to the failure of materials to perform other important functions, such as keeping liquid water out of the building or resisting the diffusion of water vapor. If an air barrier material remains intact but deflects excessively under alternating cycles of positive and negative air pressure, it can pump air in and out of a building assembly, reducing the effectiveness of insulation and increasing the risk of water vapor transport into the assembly. Air barrier materials must also be able to accommodate the normal thermal and structural movements that occur within building systems without undue wear or failure.

Air Barrier Systems

To limit air leakage into and out of a building, its conditioned space must be completely surrounded by air barrier materials, creating an uninterrupted *air barrier system* of surfaces, membranes, manufactured components, gap fillers, and joint sealers that can effectively resist air pressure differentials acting across this boundary. Careful attention to detail during design and construction is required to achieve this goal. All potential discontinuities in the air barrier system—gaps between panels, laps in sheet materials, transitions between dissimilar substrates,

BUILDING ENCLOSURE ESSENTIALS: AIR BARRIER *(CONTINUED)*

fastener penetrations, movement joints, penetrations for structure or services, installation space around window and doors frames, junctions between foundation, wall, and roof assemblies, gaps between operable doors and windows and their frames, and so on—must be made airtight by the use of tapes, sealants, caulks, flashing, gaskets, and other materials that can themselves meet the air permeance limits and structural requirements of an air barrier material. Due to the significant air pressure differentials acting across the air barrier system, even small gaps can allow large volumes of air and water vapor to pass through the building enclosure and must therefore be minimized to the greatest extent possible.

Air permeance standards for the performance of assembled air barrier materials are less stringent than those for individual materials, reflecting the reality that flawless, continuous sealing between materials and components is never possible. Recommendations for the maximum air permeance of *air barrier assemblies*, that is, collections of materials responsible for the air barrier performance of a complete wall, roof, or floor system, are in the range of 0.01 to 0.04 cfm/sf@1.57 psf (0.05 to 0.2 L/s-m^2@75 Pa). Acceptable air leakage rates for whole building air barrier systems, reflecting the combined performance of a building's connected air barrier assemblies, fenestration, and other enclosing elements, can be expected to be even greater.

Air Barrier Location

Air barrier materials can be located anywhere in an assembly as long as they form an interconnected airtight system. At the inside surface of the building enclosure, the Airtight Drywall Approach and Simple Caulk and Seal are air barrier systems consisting of gypsum wallboard combined with caulks, sealants, and gaskets to seal leakage paths around wallboard penetrations and between underlying framing members (Figure 7.22). These systems are relatively easy and inexpensive to install, making them especially popular for residential construction. They are less favored for commercial building types where frequent changes to interior partitions, finishes, and wiring make it unlikely that the continuity of a system depending on the careful detailing of these elements will be maintained over the life of the building.

Plastic sheeting, frequently used as a vapor retarder behind gypsum wallboard, also has low air permeance and can act as an air barrier. However, difficulty in sealing plastic sheet seams and penetrations, as well as a tendency for the plastic to stretch and deflect between supporting framing, limit this material's suitability in air barrier systems, especially for taller buildings or wherever else high air pressure differentials are expected.

Toward the middle of a building enclosure assembly, foam insulation can be sprayed into the space between studs, joists, and rafters, acting as part of an air barrier system in combination with caulks or sealants to seal leakage paths around framing members. Air barrier materials located close to the interior side of the building enclosure or within framing cavities also benefit from being protected from the exterior elements.

Toward the outside of the building enclosure, air barrier materials are frequently installed over sheathing in framed construction or on the exterior face of masonry or concrete backup walls. Building wraps, plywood or gypsum board sheathing panels, and fluid-applied or fully adhered sheet membranes may all be used in combination with various sealing and taping materials. In this location, air barrier materials are easy to install, with a minimum of complex intersections. Where penetrations occur for the anchoring of cladding or sheathing, they are usually easily sealed to ensure airtightness (Figure 20.1*b*).

CURTAIN WALL TESTING AND STANDARDS

Structural Performance and Resistance to Wind and Rain

For any new curtain wall design, it is advisable to build and test a full-scale section of wall to determine its resistance to infiltration of air and water and its structural performance under heavy wind loadings. There are several outdoor laboratories in North America that are equipped to conduct these tests. A full-scale specimen of the wall system, often two stories high and a bay wide, is constructed as the exterior wall of a chamber that can be pressurized or evacuated by a calibrated blower system.

Curtain wall testing is conducting according to the American Architectural Manufacturers Association standard *AAMA 501 Methods of Tests for Exterior Walls*, which itself references numerous other standards for specific aspects of the testing. The specimen is tested first for air infiltration, using ASTM E283, in which it is subjected to a static air pressure that corresponds to the pressure that will be created by the anticipated maximum wind velocity in the vicinity of the building. Air that leaks through the wall is carefully measured, and the rate of leakage is compared to specified standards.

Where air barriers fall to the exterior side of the building insulation, they can also protect against *wind washing*, in which exterior air currents within the assembly reduce insulation effectiveness. However, materials close to the exterior side of a building assembly must also be especially durable and able to perform satisfactorily while exposed to the effects of penetrating rainfall and large temperature fluctuations over the life of the building. In taller buildings, systems consisting of liquid-applied or sheet membranes that are fully adhered to rigid substrates are superior to flexible sheets such as building wrap. As noted earlier, loose sheet materials can be compromised by tearing or excessive deflection. Exterior-side air barrier materials also frequently play an important role in keeping liquid water out of the building enclosure, forming water-resistant drainage surfaces behind the outer cladding.

Unlike vapor retarders, there is no harm in installing multiple air barriers within one assembly. Multiple air barriers can provide the particular advantages of each type of system and can also provide redundancy, lessening the chance of a flaw in one material compromising a building's overall air leakage performance.

Air Barriers and Water Vapor Control

When air passes through a building assembly, the water vapor in the air is transported through the assembly as well. Where significant air pressure differentials exist between one side of an assembly and the other, the amount of water vapor transported through a building assembly by uncontrolled air leakage can be one or two orders of magnitude greater than that transported by water vapor diffusing directly through building materials. By controlling the flow of warm, moist air toward the cooler side of a building assembly, air barriers can play an important role in protecting against condensation within the assembly.

When designing air barrier systems, the water vapor permeability of the air barrier material must be considered. For example, in a heating-driven climate, an air barrier material located toward the outer, cooler side of an insulated building assembly must be vapor permeable to prevent the trapping of moisture within the assembly. Traditional building paper and breathable building wraps are good choices for use in this application; by contrast, a bituminous membrane, with low vapor permeability, would be a poor choice.

As a general rule, air barrier materials located on the cooler, lower-vapor-pressure side of a building assembly should always be vapor permeable. Conversely, air barriers located on the warmer, higher-vapor-pressure side of an assembly, may consist of materials with low vapor permeance and be designed to function as both an air barrier and a vapor retarder. For more information on vapor retarders and the control of water vapor diffusion in insulated building assemblies, see pages 658–661.

Building Code Air Barrier Requirements

The National Building Code of Canada (2005) sets quantifiable air permeance limits for air barrier materials and requires the control of air leakage with continuous air barrier systems in most buildings. The International Energy Conservation Code (2006) has more limited requirements for controlling air leakage, calling for the sealing of gaps through building envelope assemblies but without setting measurable criteria. At the time of this writing, several U.S. states have adopted more comprehensive air barrier system requirements based on Canada's model code, and it is likely that requirements for such systems will continue to spread in the United States over the coming years.

A static test for water penetration is next, using ASTM E331: The wall is subjected to a static air pressure while being wetted uniformly across its surface at a rate of 5 gallons per hour per square foot (3.4 L/m^2-min). Points of water leakage are noted, and leaking water is carefully collected and measured. A dynamic water penetration test may also be performed in accordance with AAMA 501.1, using an aircraft engine and propeller to drive water against the wall.

The structural performance of the wall is tested according to ASTM E330, in which a calibrated blower subjects the wall specimen to air pressures and suctions as high as 50 percent over the specified wind load, and the deflections of the structural members in the wall are measured. Optionally, tests for thermal performance, sound transmission, and the effects of thermal cycling, seismic loads, and movement of the structure to which the curtain wall is attached may also be performed.

While all these tests yield numerical results, it is also important that the behavior of the specimen be observed closely during each test so that specific problems with the design, materials, detailing, and installation can be identified and corrected. Most wall system specimens fail one or more of the tests for air and water leakage on the first attempt. By observing the sources of leakage during the test, it is usually possible to modify the flashings, sealants, weep holes, or other components of the design so that the modified specimen will pass the subsequent test. These modifications are then incorporated into the final details for the actual building.

After testing has been completed and final design adjustments have been made, production of the wall components begins, and deliveries to the site can commence as soon as the frame is ready to receive the system.

Curtain wall systems require careful inspection during installation to be sure that there are no defects in workmanship. Even seemingly small imperfections in assembly can lead to large, expensive problems later. As work progresses, installed portions of the curtain wall can be checked for water leakage according to AAMA 501.2. This involves directing water at the joints in the wall with a hose that has a specified nozzle and following specified procedures to isolate the causes of any leaks. Where deemed necessary, more elaborate instrumented field tests for water and air leakage can also be performed.

Thermal Performance and Other Properties

The thermal properties of curtain wall systems are most commonly tested according to AAMA 1503, for thermal transmittance, and AAMA 507 for solar heat gain coefficient, visible transmittance, and condensation resistance, although comparable NFRC standards may also sometimes be used. Curtain wall systems are adaptable to a great variety of glass types, frame sizes, and configurations. For this reason, determining precise U-factors and other properties for a particular system design usually requires more detailed analysis than, for example, when standard window configurations are specified.

Where impact or blast resistance is required, curtain wall systems can be tested to the same standards described in Chapter 18 for doors and windows.

THE EXTERIOR WALL AND THE BUILDING CODES

The major impact of building codes on the design of the exterior wall is in the areas of structural strength, fire resistance, and energy efficiency. Strength requirements relate to the strength and stiffness of the wall system itself and to the adequacy of its attachments to the building frame, with special reference to wind and seismic loadings.

Fire requirements are concerned with the combustibility of the wall materials, the fire resistance ratings and vertical dimensions of parapets and spandrels, the fire resistance ratings of exterior walls facing other buildings that are near enough to raise questions of fire spread from one building to the other, and the closing off (*firestopping*) of any vertical passages in the wall that are more than

FIGURE 19.15

Safing is a high-temperature, highly fire-resistant mineral batt material that is inserted between a curtain wall panel and the edge of the floor slab to block the passage of fire from one floor to the next. It is seen here behind a metal-and-glass curtain wall with insulated spandrel panels. The safing is held in place by metal clips such as the one seen in the foreground. *(Courtesy of United States Gypsum Company)* one story in height. At each floor, the space inside column covers and the space between the exterior wall system and the edges of floors must be firestopped, using a steel plate and grout, metal lath and plaster, mineral wool *safing*, or other material that can restrict the passage of smoke and fire through these gaps (Figure 19.15).

Energy conservation requirements are becoming more and more demanding. Most energy codes allow several alternative approaches to demonstrating compliance. In the prescriptive approach, minimum thermal resistances of panels, spandrels, and glass; vapor retarder performance; and maximum levels of air leakage are specified. For example, in the International Energy Conservation Code's prescriptive approach for commercial buildings, up to 40 percent of the above-grade walls may be glazed, with a maximum U-factor ranging from 1.20 to 0.35 (6.8-2.0 W/m^2-°K), depending on the climate zone in which the building is located.

Component trade-off and systems analysis approaches give the building designer more flexibility in selecting enclosure systems while demonstrating that the overall energy performance of the proposed design is equal or superior to that of the same building constructed to meet the prescriptive code requirements.

CSI/CSC
MasterFormat Sections for Designing Exterior Wall Systems

07 25 00	**WEATHER BARRIERS**
07 27 00	**Air Barriers**
07 90 00	**JOINT PROTECTION**
07 91 00	**Preformed Joint Seals**
	Compression Seals
	Joint Gaskets
	Backer Rods
	Joint Fillers
07 92 00	**Joint Sealants**
	Elastomeric Joint Sealants
07 80 00	**FIRE AND SMOKE PROTECTION**
07 84 00	**Firestopping**
	Fire Safing

Selected References

1. The Institute for Research in Construction of the National Research Council Canada has done pioneering work in theorizing about exterior wall design and performing tests and field observations to back up the theory. This work is summarized in a large library of reports on specific topics that may be viewed online at www.nrc.ca/irc/ircpubs. See, for example, the document entitled *Evolution of Wall Design for Controlling Rain Penetration.*

2. Brock, Linda. *Designing the Exterior Wall: An Architectural Guide to the Vertical Envelope.* Hoboken, NJ, John Wiley & Sons, Inc., 2005.

This book covers the building science underlying the performance of the exterior wall and provides examples of its application to the design of wall types ranging from light wood construction to metal curtain wall.

3. Brookes, Alan. *Cladding of Buildings* (3rd ed.). London, Spon Press, 1998.

This book provides a clear general introduction to cladding principles and material types.

4. Anderson, J. M., and J. R. Gill. *Rainscreen Cladding: A Guide to Design Principles and Practice.* London, Butterworth-Heinemann, 1988.

This clear, succinct summary of rainscreen cladding principles includes an extensive bibliography on the subject.

5. Amstock, Joseph S. *Handbook of Adhesives and Sealants in Construction.* New York, McGraw-Hill, 2000.

This book offers detailed information on all types of sealants, construction adhesives, joint and crack control in concrete, and firestopping, as well as the design, specification, and testing of sealant joints.

WEB SITES

Designing Exterior Wall Systems

Author's supplementary web site: **www.ianosbackfill.com/19_designing_cladding_systems**
Dow-Corning sealants: **www.dowcorning.com**
GE sealants: **www.gesealants.com**
Institute for Research in Construction: **www.nrc.ca/irc/ircpubs**
Whole Building Design Guide—Wall Systems: **www.wbdg.org/design/env_wall.php**

KEY TERMS AND CONCEPTS

exterior wall enclosure
building envelope
thermal bridge
stack effect
air barrier
air permeance
air barrier system
air barrier assembly
wind washing
internal drainage
gravity
momentum
labyrinth
surface tension
drip
capillary action
capillary break
wind current
pressure-equalized wall design
air barrier
rainscreen
pressure-equalization chamber (PEC)
rainscreen principle
rainscreen cladding
wash
sealant joint
gunnable sealant
sealant gun
low-range sealant, caulk
elongation
medium-range sealant
high-range sealant
polysulfide sealant
polyurethane sealant
silicone sealant
sealant Type
sealant Grade
sealant Class
sealant Use
single-component sealant
multicomponent sealant
self-leveling sealant, pourable sealant
nonsag sealant
traffic sealant
nontraffic sealant
immersible sealant
gasket
lockstrip
preformed cellular tape sealant
preformed solid tape sealant
priming (of sealant joints)
backer rod, backup rod
loadbearing wall
curtain wall
firestopping
safing

REVIEW QUESTIONS

1. Why is it so difficult to make cladding watertight?

2. List the functions that cladding performs and list one or two ways in which each of these functions is typically satisfied in a cladding design.

3. Using a series of simple sketches, explain the principles of sealant joint design. List several sealant materials suitable for use in the joints that you have shown.

4. What are the forces that can move water through a joint in an exterior wall? How can each of these forces be neutralized?

EXERCISES

1. Examine the cladding of a building with which you are familiar. Look especially for features that have to do with insulation, condensation, drainage, and movement. Sketch a detail of how this cladding is installed and how it works. You will probably have to guess at some of the hidden features, but try to produce a complete, plausible detail. Add explanatory notes to make everything clear.

2. Work out a way to add a rainscreen window with fixed double glazing to the cladding system shown in Figure 19.8.

3. Prepare a sample sealant joint, using a backer rod and silicone sealant obtained from a hardware store or building materials supplier. Apply the sealant to two parallel pieces of quarry tile or glass that are taped together with a spacer between them. After the sealant has had time to cure (a week or so), remove the tape and spacer and test the joint by pulling and twisting it to find out how elastic it is and how well the sealant has adhered to the substrate.