Chapter 1

Basics

You have to learn the rules of the game. And then you have to play better than anyone else.

ALBERT EINSTEIN

Good building design and good exterior building enclosure design don't just happen. "Good" is a broad, subjective, and sometimes overused term, used primarily to describe the visual aspects of design. It is open to many interpretations. In exterior building enclosure design, visual appearance is generally considered the major component of good design. It has been said before that beauty is in the eye of the beholder. Exterior appearance is very important; however, exterior building enclosure design is more than just visual appearance. It is the integration of the science of physics with the science of materials. It is the integration of materials, material properties, and performance design principles. It requires a basic understanding of building and construction sequencing. It is the application of science and design principles with the art of composition. It is in this intersection of science, art, materials, construction, and many other factors where design and technology, art, and science become architecture. In complete design of exterior building enclosures, beauty is more than skin deep.

Understanding the Basics

Every building design and the associated exterior enclosure design are unique for the particular project. This is the case no matter the size or location of the project. Large or small or any size in between, exterior building enclosures are planned, researched, designed, detailed, and executed to look good and achieve defined performance levels per criteria established for the specific project. Before beginning exterior enclosure design for a project, it is imperative that the architect possess or acquire a basic understanding of the intended and necessary functions of the enclosure, the elements and forces acting on and influencing the enclosure design, performance design principles and associated physics, and the basic types of exterior building enclosures. In conjunction with these items noted, project delivery methods will determine the extent of detailed design to be performed by the architect and design team or by delegated detailed design to participants of the construction team. This embedded or acquired knowledge and identification of design responsibility, coupled with the design intent, is required to provide complete enclosure design.

Some exterior building enclosures are fairly simple. However, with higher performance expectations, emerging technologies, and regulatory standards, proposed designs may require a higher level of detail, documentation, and construction technology to execute. As the old English proverb states: "You have to crawl before you can walk, and walk before you can run." So, getting exterior enclosure basics defined and understood is the first step. The moral is that you have to understand the basics in order to advance to more sophisticated levels of design performance and execution. This is paramount. For those unfamiliar with the basics outlined above, these principles will be presented initially at a foundation level and then applied to enclosure systems and types later, in the system case study sections. For those who are familiar with these basics, read on. You may find the foundation descriptions useful for their application to the design process discussed in subsequent chapters and the systems/case studies where the basics are applied.

Process

Architectural design is a process-oriented profession and activity. Exterior building enclosure design is also a process. Exterior building enclosures are one of the most visible and technically complex aspects of architecture. Enclosure design intent, performance design principles, system design, fabrication and construction methodologies, and completed exterior enclosures must be studied, researched, and articulated in a meaningful and systematic way or inevitably something will be missed and/or left out. As an architecture student during an interview for a summer intern job, I received some valuable advice when showing my modest portfolio of student work. "You can't learn it all, you can't memorize it all, and you will never know it all. What you can do is develop, implement, and practice a problem-solving process." I have carried this with me during my years of practice.

Enclosure design process has its "Do's" and "Do Not's."

DO'S:

1. Research and continue learning.
2. Listen.
3. Keep an open mind.
4. Accept criticism, and determine what to accept and what to reject.
5. Understand the basics of materials, structural principles, natural elements, natural and human-created forces, thermal transfer and properties, and acoustics.
6. Study manufacturing processes.
7. Distill information.
8. Think with graphics.

DO NOT'S:

1. Do not be afraid to try multiple ideas.
2. Do not be too proud to redesign and redraw.
3. Do not limit your imagination.
4. Do not forget for whom or what the building design and exterior enclosure is designed.

Exterior design is a process that is tailored to the specific needs of the project. In order to be a complete design process, the process must define and answer the five W's: What, Why, Who, Where, and When, as well as one H: How. This chapter discusses the "What" (basics and topics of exterior enclosures) and "Why" each topic is applicable. For example: What is the extent of the exterior building enclosure? What are the intended functions, and why do they influence design? What are the forces on the exterior enclosure, and what do they influence? What are some of the performance design principles, and why are they applied within enclosure systems and system interfaces? What are some of the types of exterior enclosure systems?

The topics identified are applicable, in part or whole, to all exterior enclosures and their design. These may appear abstract in some cases, until they are applied. Subsequent chapters will address: Who are the participants, and what are their roles? What levels of design are addressed, and when does each occur in the design process? What levels of documentation, collaboration, and coordination occur, and when does each occur in the process? What is expected by builders in the construction process? Why is a particular enclosure system selected, and how is it used? Where are the design basics and performance principles applied to actual case studies? How does it all come together in architecture?

The design process can be creative and lead to innovative solutions faster, and with more joy than pain, if you imagine, research, analyze, collaborate, imagine again, test solutions, refine solutions, document, and execute.

Definition

Prior to initiating a discussion of the basics, it is necessary to define—for the purposes of this book—the exterior building enclosure. It is the enclosing membrane in vertical, sloped, horizontal, or other geometric configurations separating exterior elements and forces from interior occupied areas. The exterior building enclosure begins either at grade or within the height of the building and terminates either on itself or at a roofing system. Roofing systems perform similar functions as the exterior enclosure, but are not described or discussed here. Similar design concepts, principles, design/detailing approaches, and performance functions apply to roofing systems; however, only the interfaces of the exterior building enclosure to roofing systems will be reviewed in this book.

Exterior enclosure systems may be load-bearing or non-load-bearing. A load-bearing exterior enclosure provides enclosure and is also the primary or secondary building structural system. A non-load-bearing enclosure provides a cladding envelope but is not the building primary or secondary structural system. Non-load-bearing cladding systems are often suspended from or contained within and supported by the primary building structural system or other structural supporting elements or systems. Load-bearing and non-load-bearing enclosures are designed to accommodate elements such as air, water, and sun, and withstand applied loads created by natural forces such as wind, seismic, thermal (expansion and contraction), and other forces. Load-bearing and non-load-bearing exterior building enclosure systems must include methods to control and prevent water intrusion, limit air infiltration, admit and control sunlight, control thermal transfer, control acoustics, and perform for a long period of time with minimal maintenance or repair. The term "enclosure system" is a key word and a central concept. An enclosure system is an assembly or combination of parts, components and materials forming a complete or unified whole. An exterior building enclosure is a system made of connections, anchorage components, framing elements, weatherproofing materials, insulation materials and components, and infill materials. All of these materials and components must be researched and understood to ascertain their respective characteristics, strengths, weaknesses, and compatibilities then arranged and ordered in a working combination with principles of physics.

Functions

Whether load-bearing or non-load-bearing, exterior enclosure systems perform multiple functions. While each of these functions can be discussed and reviewed as an individual topic, the multiple functions are interrelated and influence each other. Each exterior building enclosure has primary functions that include:

1. Structural function: The ability of the system to support itself and the applied loads.
2. Weathertightness: Keeping natural elements outside.
3. Energy efficiency: Performing to high levels by reducing energy consumption. Energy efficiency goes hand in hand with weathertightness.
4. Accommodating building movements. This goes hand in hand with structural.

Additional functions, depending on the design requirements, may include acoustics, blast/threat resistance, and other force resistance or performance features.

STRUCTURAL

Owners, architects, engineers, and builders agree that a building is only as good as the strength of its foundation. If the foundation is weak or faulty, the building is doomed. If the foundation is solid and strong, the building will stand for a long time. This concept applies to exterior building enclosure systems as well. The enclosure system must be of sufficient strength and appropriate system depth to support its own weight, accommodate and transfer exterior forces, and span the necessary distances, vertically and horizontally, to supporting building structural elements. In load-bearing conditions, the exterior enclosure system must be of sufficient strength to accommodate the supporting primary building structural demands and transfer applied exterior loads and forces to the foundation. In exterior enclosure cladding applications, the exterior enclosure system must be of sufficient strength to accommodate its own loads (self-weight, often referred to as dead load), applied loads, and forces, and to transfer these through enclosure anchorage assemblies to the primary building structural system. The enclosure must be fully functional during and after the loads are removed. Elements and forces that impose the applied loads are discussed in this chapter.

To withstand exterior forces and support its own loads, the exterior enclosure is designed as a system. The

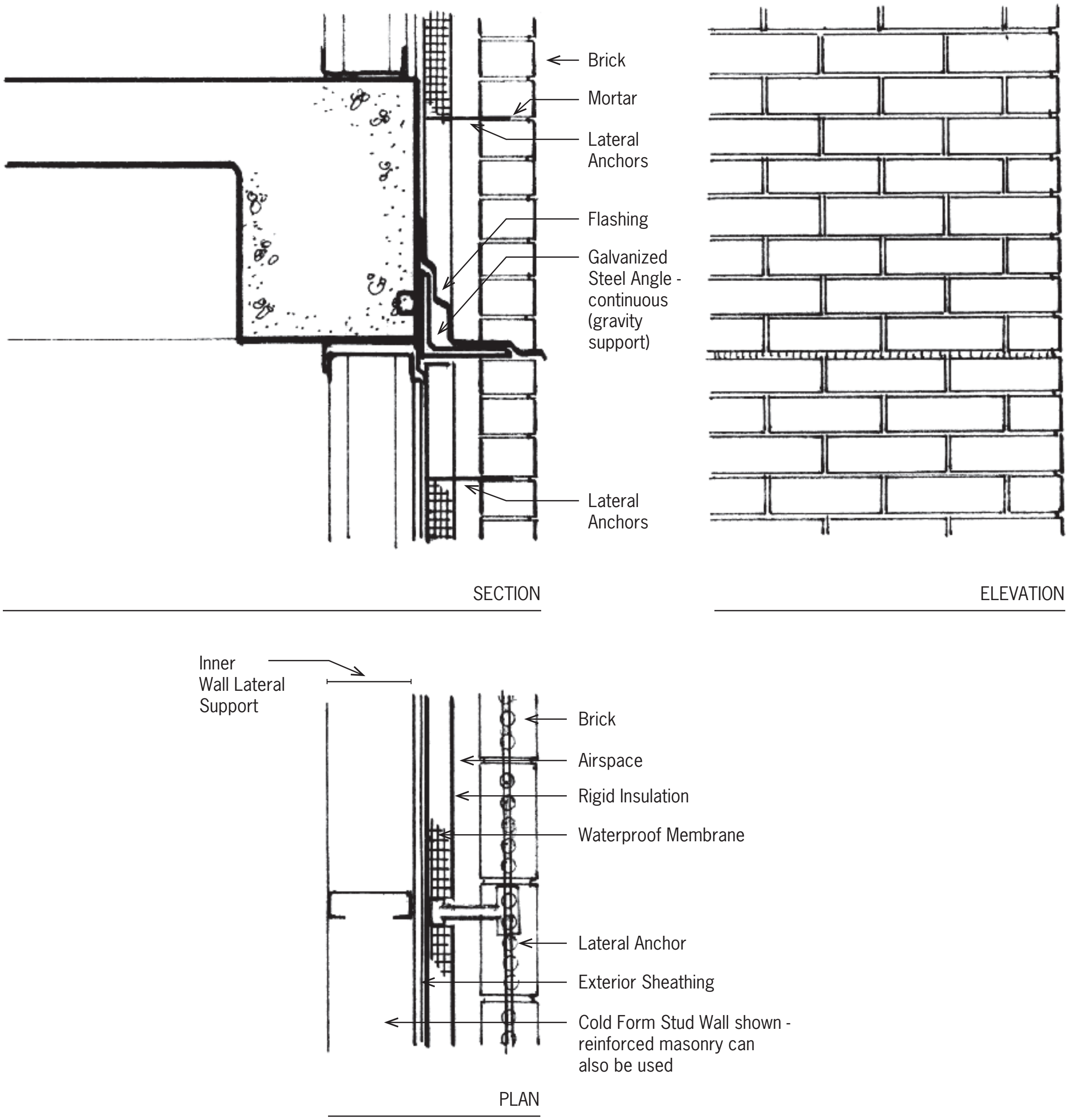


FIGURE 1.1 Materials and components must work together as an assembly in an exterior enclosure system. Brick masonry wall systems rely on a gravity support for the brick self load, the inner wall for lateral support, lateral anchors spaced appropriately, and the brick and mortar for the enclosure system structural integrity.

system consists of components, and using the chain analogy, the enclosure structural integrity is only as good as the weakest link or component. Whether the enclosure is an opaque and planar composition such as brick masonry wall (Figure 1.1), a framed masonry natural stone wall (Figure 1.2), or an opaque and transparent composition such as curtain wall (Figure 1.3), the systematic design approach is similar. The structural performance characteristics of each of the components within the system must be understood in order to develop the basic system structural design approach. Materials performing as supports in the system structure

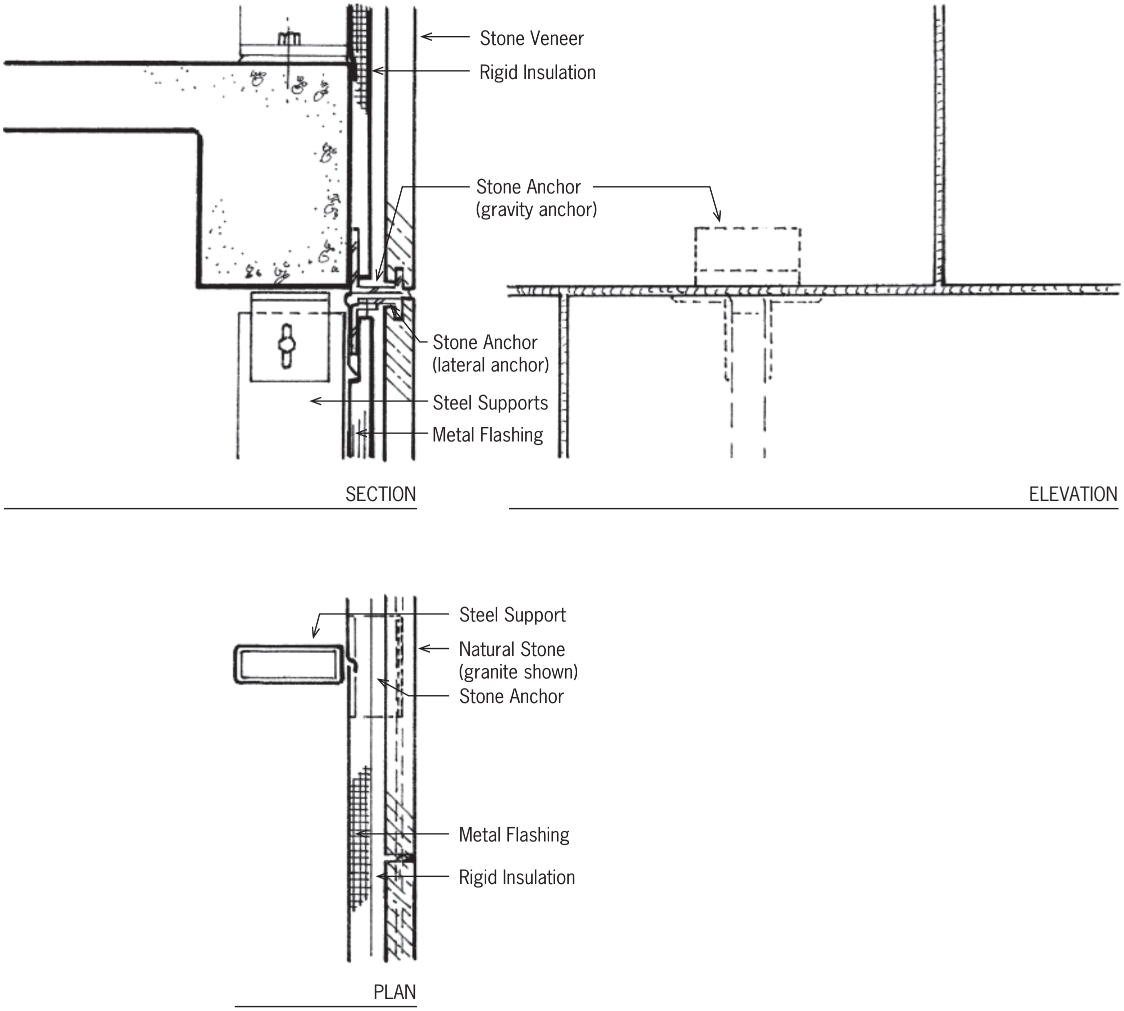


FIGURE 1.2 Framed masonry natural stone wall systems rely on the primary building structure and the steel supports illustrated for gravity and lateral support. The stone itself accommodates and transfers lateral loads to the stone anchors, and the stone anchors support the stone self/dead and lateral loads. The stone cladding itself accommodates and transfers loads for the enclosure system structural integrity.

have inherent strengths and weaknesses. The goal is to accentuate the strengths and minimize—or eliminate—the weaknesses. Superimposed on the enclosure system is the behavior of the building structural system. Under loading, beams and slabs deflect, columns shorten, and the primary structural frame may "drift" or lean when lateral wind or seismic loads are applied. Primary building structure deflection movements are illustrated by the diagrams in Figure 1.4. Primary building structural movements are covered in more detail later in this chapter. It is important to note that the enclosure structural characteristics and the supporting primary structure characteristics must be evaluated, reviewed, and designed in concert with each other.

Each component within the enclosure system has certain and distinct structural properties. The structural capacity of a component is dependent upon material properties, size, thickness, orientation, method of attachment, and geometry. Components within a system will deflect from their own weight

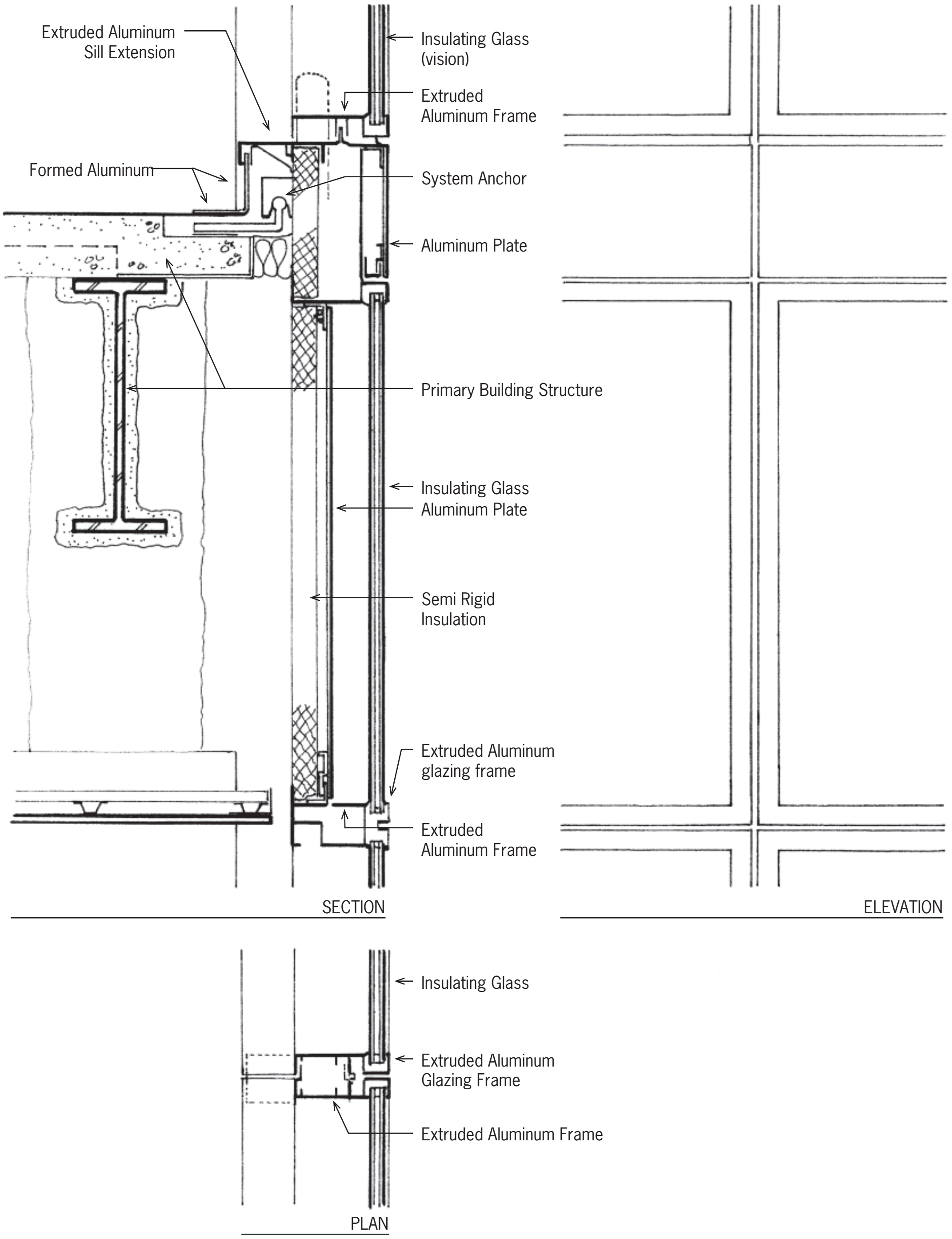


FIGURE 1.3 Curtain wall systems rely on the system anchor to support the enclosure system dead load. The glass and aluminum plate accommodates and transfers lateral loads to the extruded aluminum frame for the enclosure system structural integrity. The extruded aluminum frame carries the dead load of the glass and other infill or cladding materials, and transfers lateral loads to the system anchor, which transfers loads to the primary building structure.

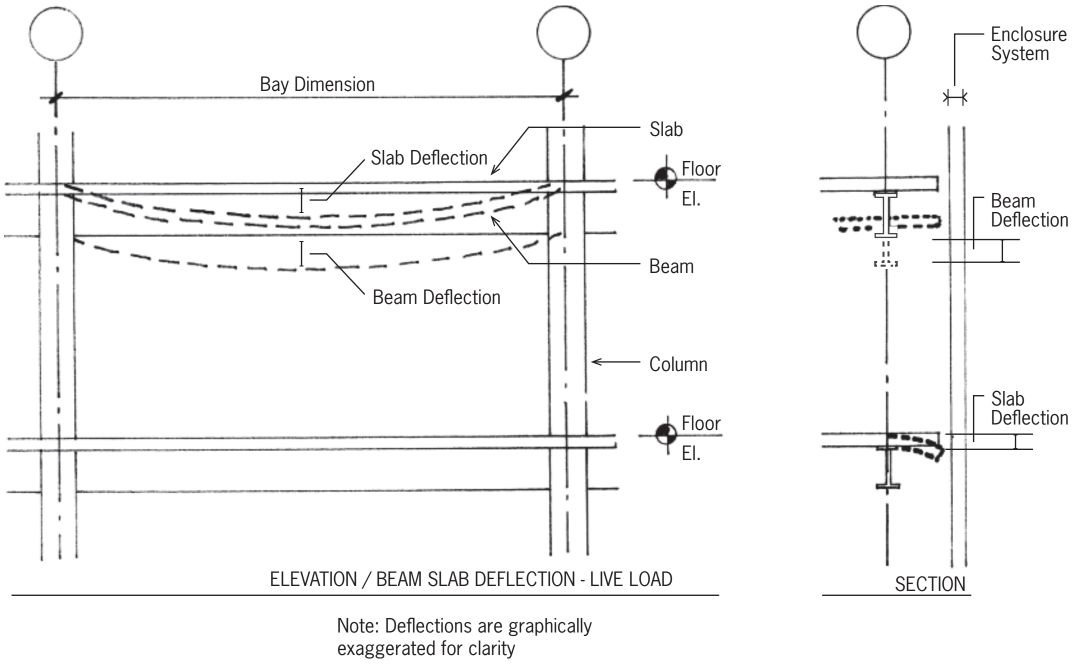


FIGURE 1.4 Primary building structural elements react to loads imposed. Imposed loads include dead loads and live loads that create structural deflections that must be addressed in the enclosure design. Note both deflections shown in elevation and section can occur simultaneously.

(dead load) and the location and magnitude of the applied loads. The material, size of the components, connections between components, and deflection direction and magnitude when subjected to applied loads must be addressed in the enclosure design. Enclosure structural components consist of framing, connections, infill, cladding and system anchorage. Enclosure system framing support elements are typically designed with stiffness as the primary criterion. The stiffness design criterion, which is stated in terms of deflection, varies depending on the infill or cladding material being supported, joinery size, system assembly, and other factors. Stiffness and deflection are usually defined as $X = L/number$. X is the deflection and is usually stated in inches (or fractions of an inch) or millimeters. L is the span length or distance between points of support or anchorage. This length is typically stated in inches or millimeters. The denominator "number" is dependent on the cladding or infill material being supported or the desired criterion established as the maximum bending (deflection) allowed. A higher denominator results in a lower resulting deflection X. Industry standards and building codes are valuable sources to review for suggested allowable deflections. Simplified diagram examples of supporting framing elements, type of cladding, and the resulting deflections are shown in Figures 1.5a, 1.5b, 1.5c. Deflection criteria are dependent on the type of system. System deflection specifics are covered in more detail in the systems descriptions/case study sections. This is a point that was made clear in an early design studio critique between an architecture student and professor at a jury critique. The professor was reviewing a building section of the student's proposed design. An exterior enclosure wall was shown spanning from one floor to approximately four floors above and was drawn with two lines representing approximately 3 inches (76 mm) in system depth. The student, who, for the purposes of anonymity, will be referred to as Mr. Smith, was challenged by the professor's observation. "Mr. Smith, this wall looks to be about 60 feet (18.28 m) tall and is illustrated as very thin. Looks to be—ummm—3 inches (76 mm) deep or so." The

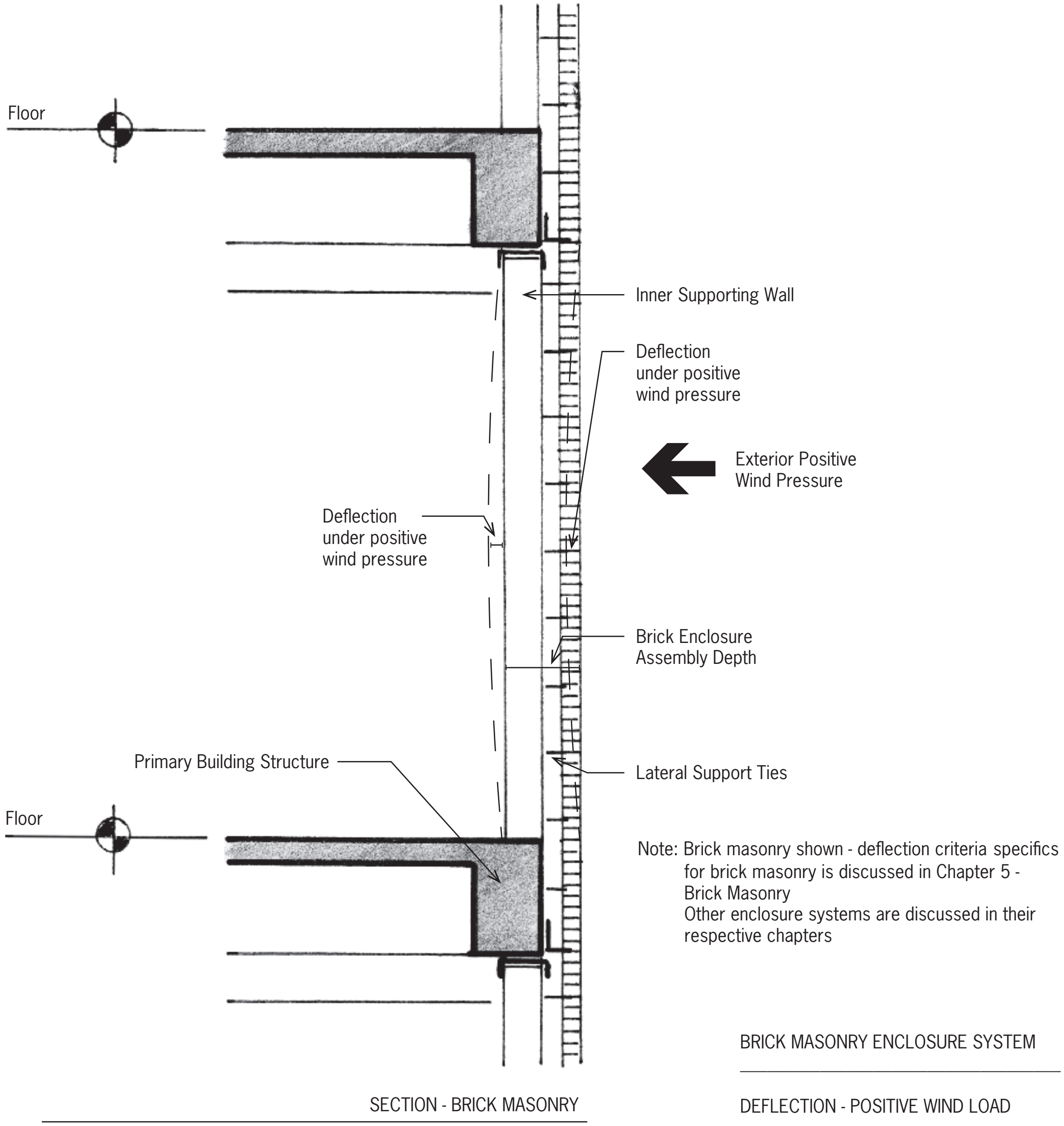


FIGURE 1.5a Brick masonry enclosures deflect between primary support boundaries when exposed to exterior wind pressure loads.

professor paused for a moment and then stated: "It must be made of the revolutionary new material called 'Smithite,' which can span infinite distances in minimal thickness." The professor then moved on to the next critique. The point that any system requires a certain depth to span ratio—however blunt and brutal in its delivery—was made.

WEATHERTIGHTNESS

The exterior building enclosure system is the enclosing membrane separating the exterior elements and forces from the interior spaces and occupants, and is required to be weathertight. For purposes of defining weathertightness, air and water are considered here. Sunlight,

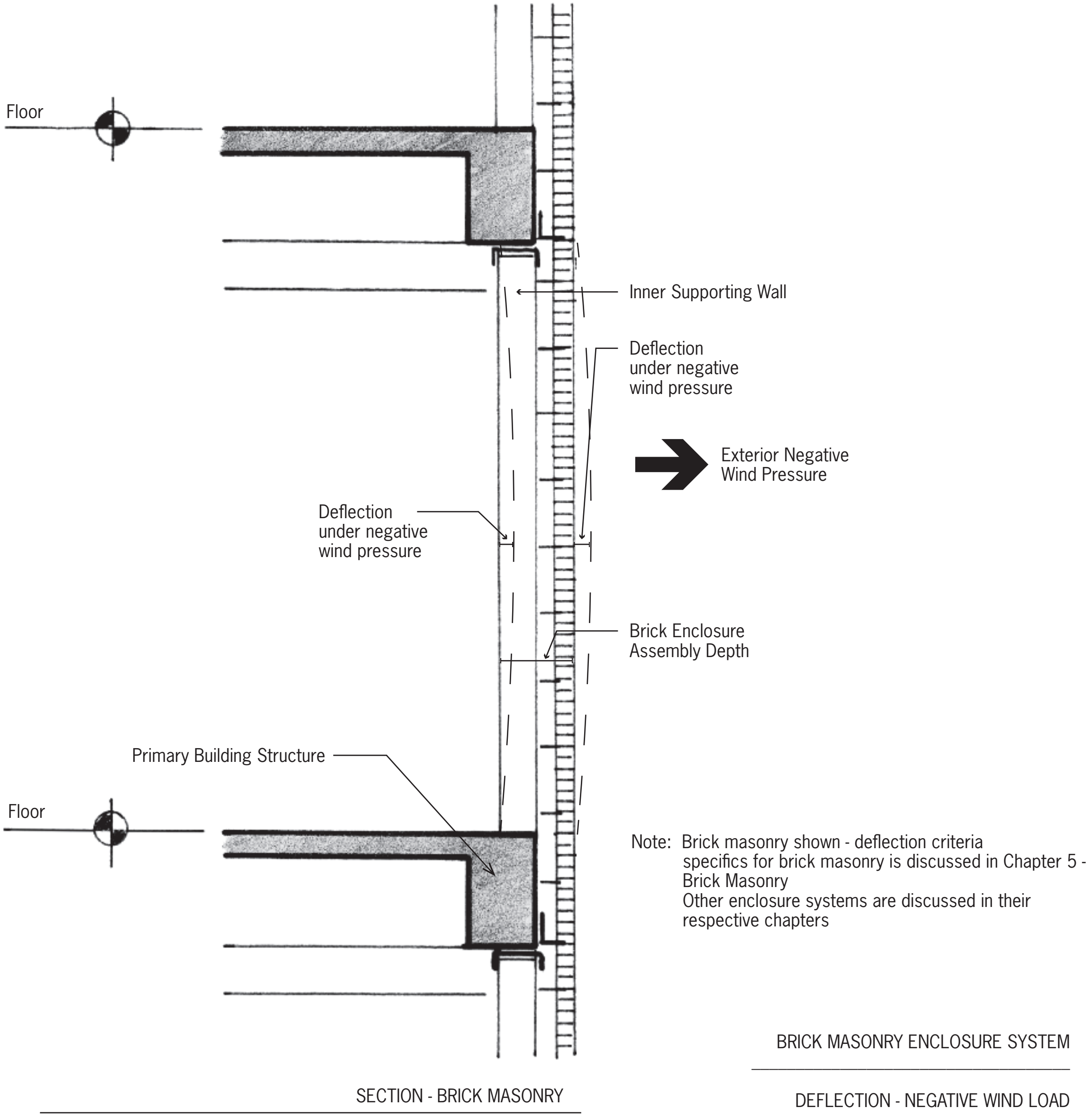


FIGURE 1.5b Brick masonry enclosure deflection diagram when exposed to negative exterior wind pressure loads.

temperature, wind, and other forces influence weathertightness. These are discussed in the energy efficiency section. To achieve a weathertight building enclosure, water intrusion and air filtration must be controlled. Water must be managed and discharged to the exterior without penetration of water to the interior occupied spaces or to portions of the enclosure designed as dry, allowing the enclosure system to dry after the source of the water is removed. Excessive air infiltration must also be prevented. Weathertightness is the enclosure's ability to protect against air infiltration within prescribed limits and to prevent water leakage. Air and water act together, so both must be considered together in weathertight enclosure design. Weathertightness is a

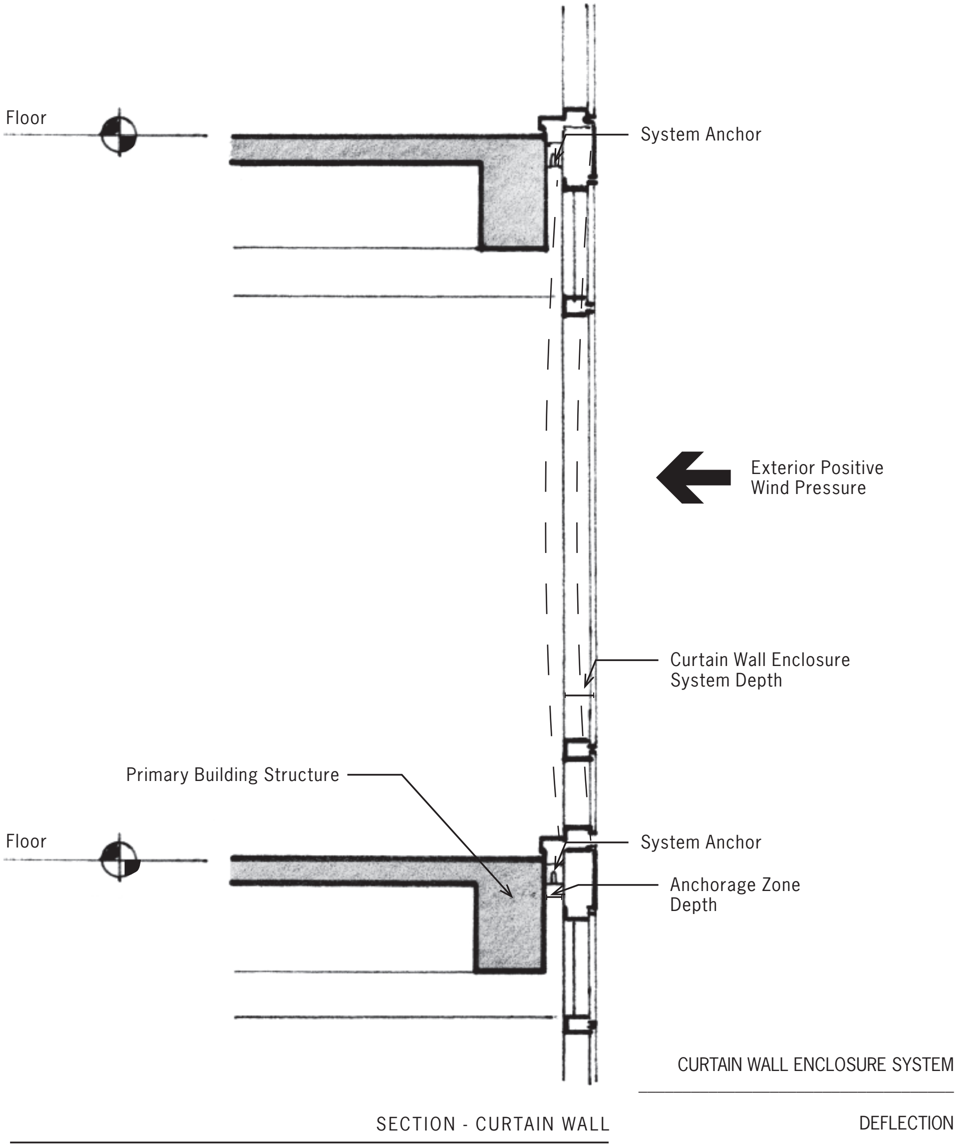


FIGURE 1.5c Curtain wall systems utilize the infill and/or cladding materials and the system framing material and depth to accommodate and transfer wind loads to the system anchor. The system anchor transfers loads to the primary building structure. Negative wind pressure creates deflection in the opposite direction. Note infill materials also deflect when subjected to lateral loads.

function whose importance is obvious, but the methods to actually achieve a weathertight enclosure are often not fully understood or thoroughly tracked through the building enclosure system(s) design and associated graphic details. Graphic details must define materials and connections of materials, therefore defining layers to control and manage air and water.

Enclosure system materials and the associated joinery within and between materials greatly influence how a weathertight enclosure is achieved and maintained.

Enclosure system materials and components—framing and infill—are inherently either weatherproof or porous. Materials such as glass and metal are impervious to air and water penetration, so when one is designing with these materials, the focus is on the joinery method, location of the joinery within the system, and the type of joinery materials used when one material or one system meets another. Materials such as concrete, masonry, wood, and stone have levels of porosity. When these materials are present in the enclosure design, additional material(s) must be incorporated in conjunction with these cladding materials. Either porous materials must allow storage of water, which can be released to the exterior after the water source is removed, or the enclosure system must contain a combination of water impervious flashings, gutters, and drainage openings to control and discharge water to the exterior when these materials are present.

Local climate and geography can greatly influence the action and effect of air and water on the exterior enclosure. It is easier to observe when an exterior enclosure system is not watertight than when there is air leakage. Obvious evidence of water such as leaks or moisture in the form of condensation can be visually detected in accessible areas. Water or moisture that occurs in nonaccessible areas often results in significant damage. Air infiltration and exfiltration—also known as leakage in and out—is a little more difficult to observe. The intended function of the exterior enclosure is to control the water and to eliminate or minimize the air infiltration to the interior to an acceptable level. This is a bit more challenging to observe and quantify. Water control is achieved by either keeping water to the exterior or controlling the water through layers in the enclosure and removing it to the exterior, allowing drying. Where air goes, water generally follows and can be observed.

To achieve a weathertight building enclosure design approach, it is best to establish a primary line of defense against air whose location is defined within the enclosure system, preventing air leakage. This primary air line is often the primary water protection line as well. Water can be controlled using multiple layers to reduce the quantity of water reaching each succeeding layer. Air, on the other hand, cannot be diminished or reduced in quantity using the multiple layer approach, as it follows the water path until it reaches the primary air line and stops. So the design of the primary air line is imperative and key.

You can't fool Mother Nature. You also can't beat Mother Nature. However, if you understand the functional need to provide a weathertight enclosure system, and the basics of what moves air and water from one place to another, you can control these elements and peacefully coexist with Mother Nature. The forces that move the elements of air and water and the design principles that provide the primary and secondary lines of control are discussed later in this chapter.

ENERGY EFFICIENCY

Enclosures consist of opaque (spandrels, column covers, etc.) and transparent (vision glass with or without frames) areas. No matter the style, composition, or specific cladding material, the basics are opaque and transparent areas. Transparent areas allow views in and out and admit natural daylight into interior spaces. An energy-efficient exterior building enclosure entails admitting natural light in vision areas, while minimizing the heat gain or heat loss and maximizing insulation values in the opaque areas to control temperature and condensation. Energy efficiency in the enclosure is also influenced by minimizing air leakage, because energy is required to heat or cool interior air. The goal is to maximize energy efficiency and occupant comfort. There are several "big picture" considerations and resulting analyses that inform the design and the functional requirements of an energy-efficient enclosure. These are:

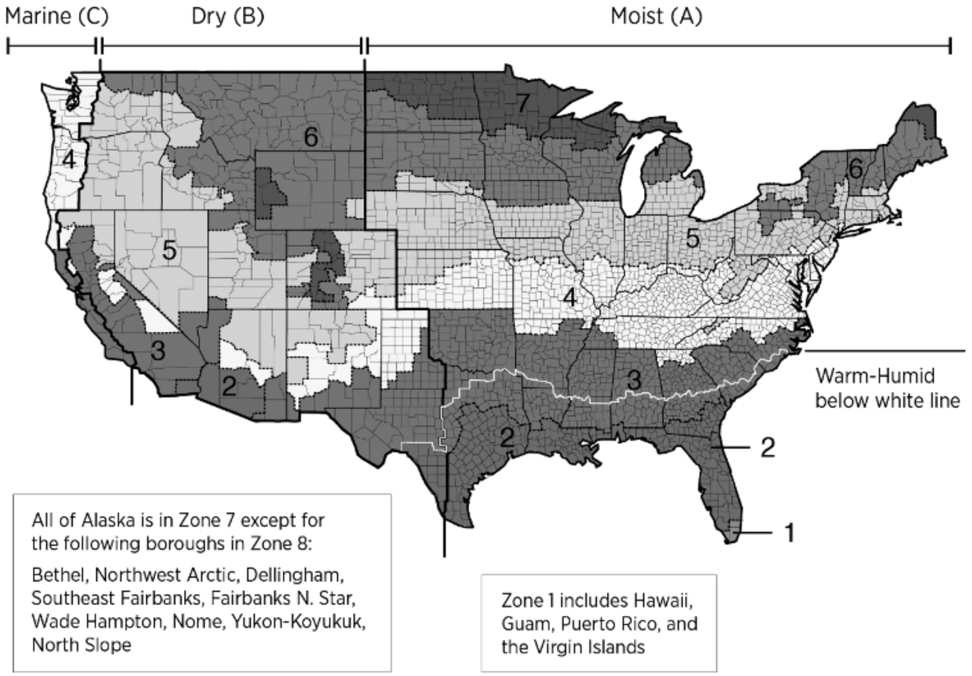
1. Local climate and geography
2. Building shape and orientation
3. Material selections, quantity, and placement

Local Climate and Geography

Architects must understand (or in some cases be reeducated about) and interpret the natural characteristics of the micro and macro climates of the region and local site in which a building and its exterior building enclosure are being designed. Some architects work locally and regionally. Some projects are far removed from the daily environment of the architect. When the architect is designing in a location where he or she is a visitor or invited guest, it is essential to achieve an understanding of the natural and man-made environment in which each building is designed. Time must be spent on-site obtaining the "feel" for the climate. This can be accomplished on two levels. First, appropriate and sometimes exhaustive research should be made into daily and seasonal weather patterns. Second, physically visit the site and experience firsthand the heat, cold, humidity, sunlight, and breezes. Firsthand experience is invaluable. When designing an exterior building enclosure "in your own backyard" (i.e., a location with which the architect is familiar), weather patterns and the natural environment are known through personal experiences.

There is reliable empirical climate data to evaluate seasonal variations in solar, temperature and diurnal temperature variations, humidity, and air movement/wind that can be obtained through dependable sources. There is no substitute for experiencing and breathing the local environment and microclimate effects of sun, wind, temperature, shade, water, and topography. Excellent lessons can be learned by studying indigenous architecture and buildings. Air travel has reduced the size of our planet by making travel easy. Local building customs, materials, massing, and orientation evolved as a result of the local inhabitants' intimate knowledge of and responses to the local environment. Indigenous architecture provides valuable clues, lessons, and real-life solutions to practical exterior building enclosure concepts and systems that have provided shelter for generations. These can be interpreted into a new building enclosure design vocabulary in multiple and often innovative ways. The moral is: Learn from the past.

Local climate is the prevailing weather conditions of a region. These include temperature, humidity, precipitation, sunshine, clouds, and wind throughout the year, averaged over a series of years. Geography will influence climate conditions of regions into microclimates. Temperature is arguably the most recognized and easily understood. Regional climate maps divided by temperature-oriented climate zones are available through the International Energy Conservation Code (IECC), ASHRAE, US Department of Energy, and others. An example of a climate map for the continental United States is shown in Figure 1.6.



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

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

FIGURE 1.6 ASHRAE climate zone map. Climate maps outline performance basics per region. A continental U.S. example is shown.

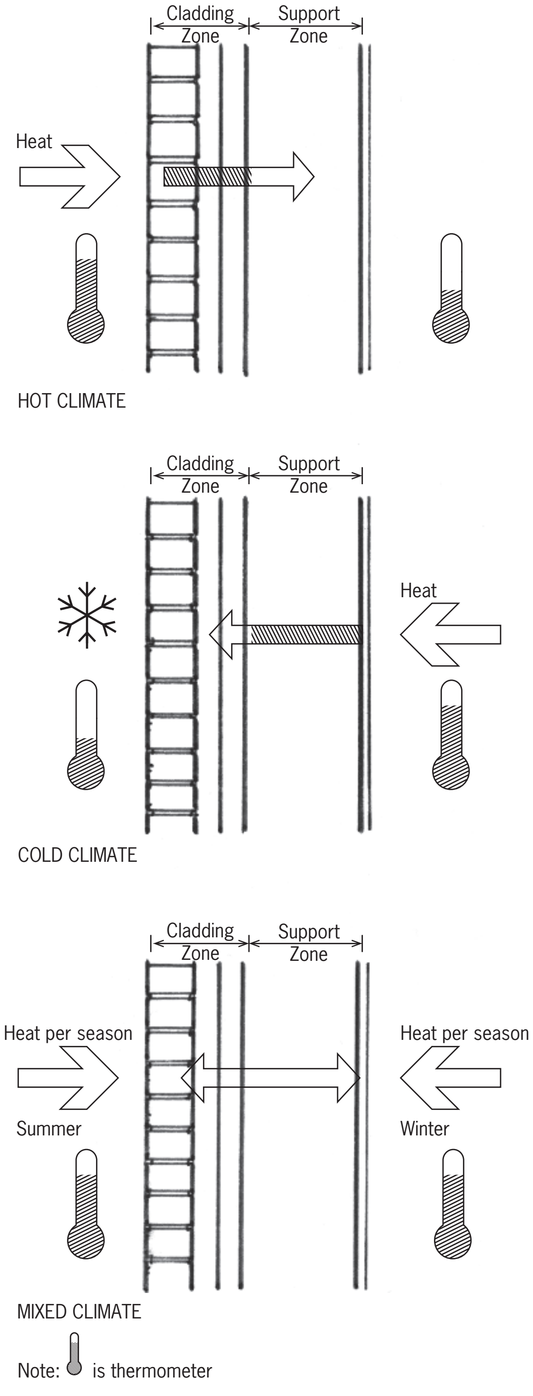


FIGURE 1.7 Enclosure heat flow profile. Heat flows from hot to cold. Climate and interior design conditions determine heat flow direction through the enclosure.

Following basic physics, heat transfer moves from hot (or warm) to cold. Moisture also moves from hot to cold. Moisture also moves from more to less. Therefore, in colder climates where interior heating is predominant, moisture will move from the building interior toward the exterior. Conversely, in hot climates and hot/humid climates, moisture moves from the exterior towards the interior. In mixed climates with hot and/or hot/humid seasons and cold seasons, the flow of heat and moisture moves out-to-in or in-to-out, depending on the exterior climate seasonal conditions and interior space conditions. This recognition of climate and the resulting thermal, air, and moisture physics determines design locations for air and water defense lines, discussed earlier, and drying areas within the enclosure system. Example diagrams are shown in Figure 1.7.

Building Shape and Orientation

Building shape and orientation have a direct impact on the energy efficiency of the exterior enclosure. Shape and orientation also influence an appropriate ratio of transparent area to opaque insulated area. Thoughtful and informed orientation can maximize opportunities for innovative exterior building enclosures to respond to and coexist with the natural climate and environment. This is a basic premise of passive energy efficient design. Farmers and others who rely on the land and on nature for their existence refer to this type of design as common sense. Building orientation can maximize passive solar heating when needed and avoid or minimize heat gain when cooling is needed. It can also provide opportunities for natural ventilation and daylighting throughout most of the year by utilizing and maximizing the characteristics of the local climate.

Appropriate building orientation is geographic and site specific. Most architects recognize that southern exposure is a key physical orientation option for passive solar energy design strategies in the northern hemisphere. Building orientation in the northern and southern hemispheres has different "rules of the game," as indicated in Figures 1.8a–d. Site-specific features such as topography, trees, bodies of water, breezes, and other local factors create site-specific design opportunities. Building shape and orientation influence the type and quantity of vision glass area, type and thickness of insulation required in opaque areas, and opportunities

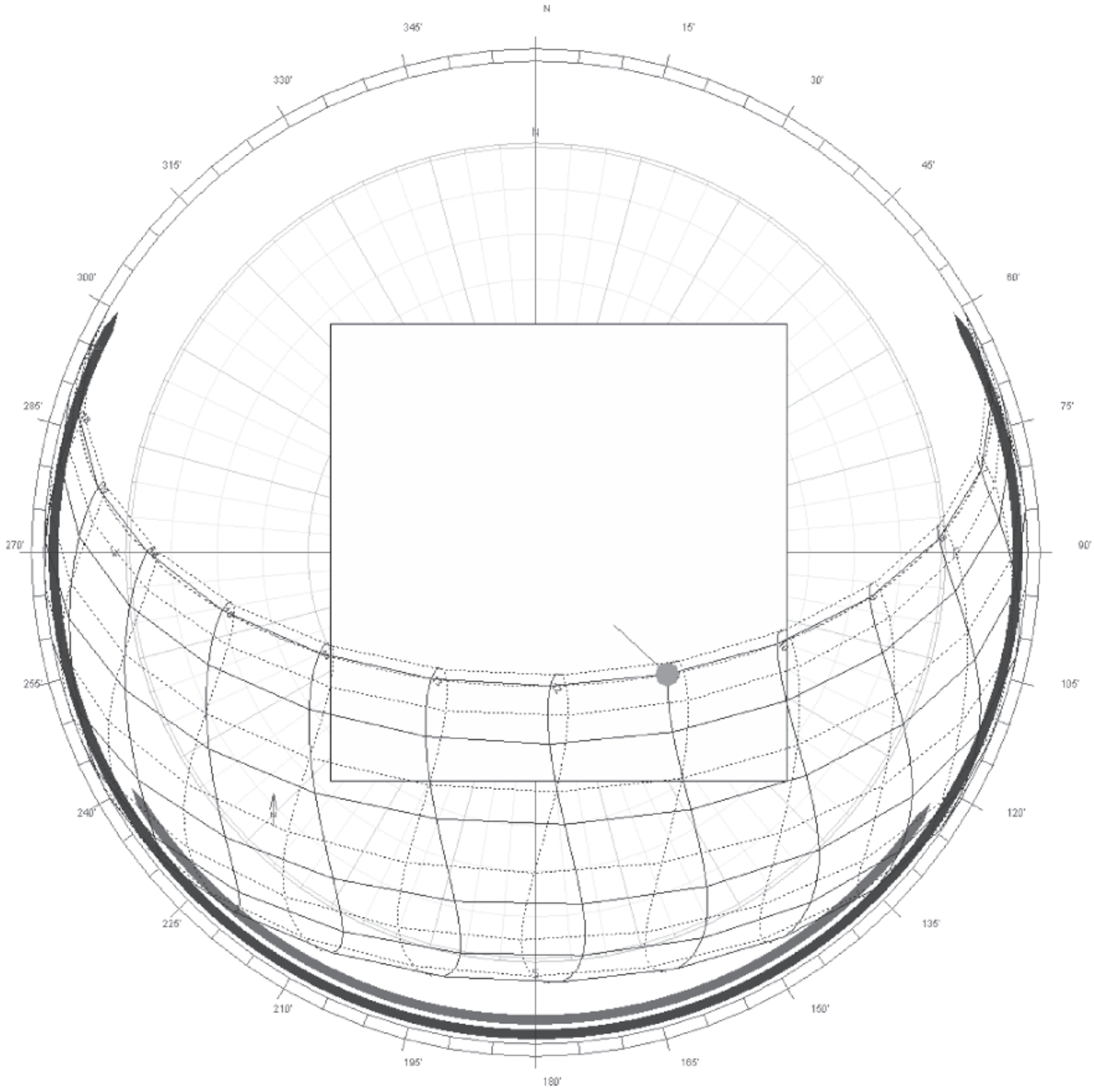


FIGURE 1.8a Solar path is three dimensional (altitude [vertical] and azimuth [plan]) and provides enclosure design information and opportunities through understanding sun angles during the year. Example shown is for San Francisco, California, in the northern hemisphere at 37.775 degrees North Latitude.

for overhangs, sunshades, wind deflectors/baffles, or other solar/daylight control or mitigating devices, as well as solar and/or wind generation design options.

Material Selection, Quantity, and Placement

Each material in the enclosure assembly design has its own specific qualities as an insulator or a conductor for thermal transfer. Research is required for every enclosure design in order to understand the performance characteristics of building materials. There are several basic units of measure used to define a material's thermal qualities. These are: R-value, U-value, solar heat gain coefficient, and visible transmittance.

R-value is a measure of the thermal resistance of building materials (resistance as *R*) to the flow of heat

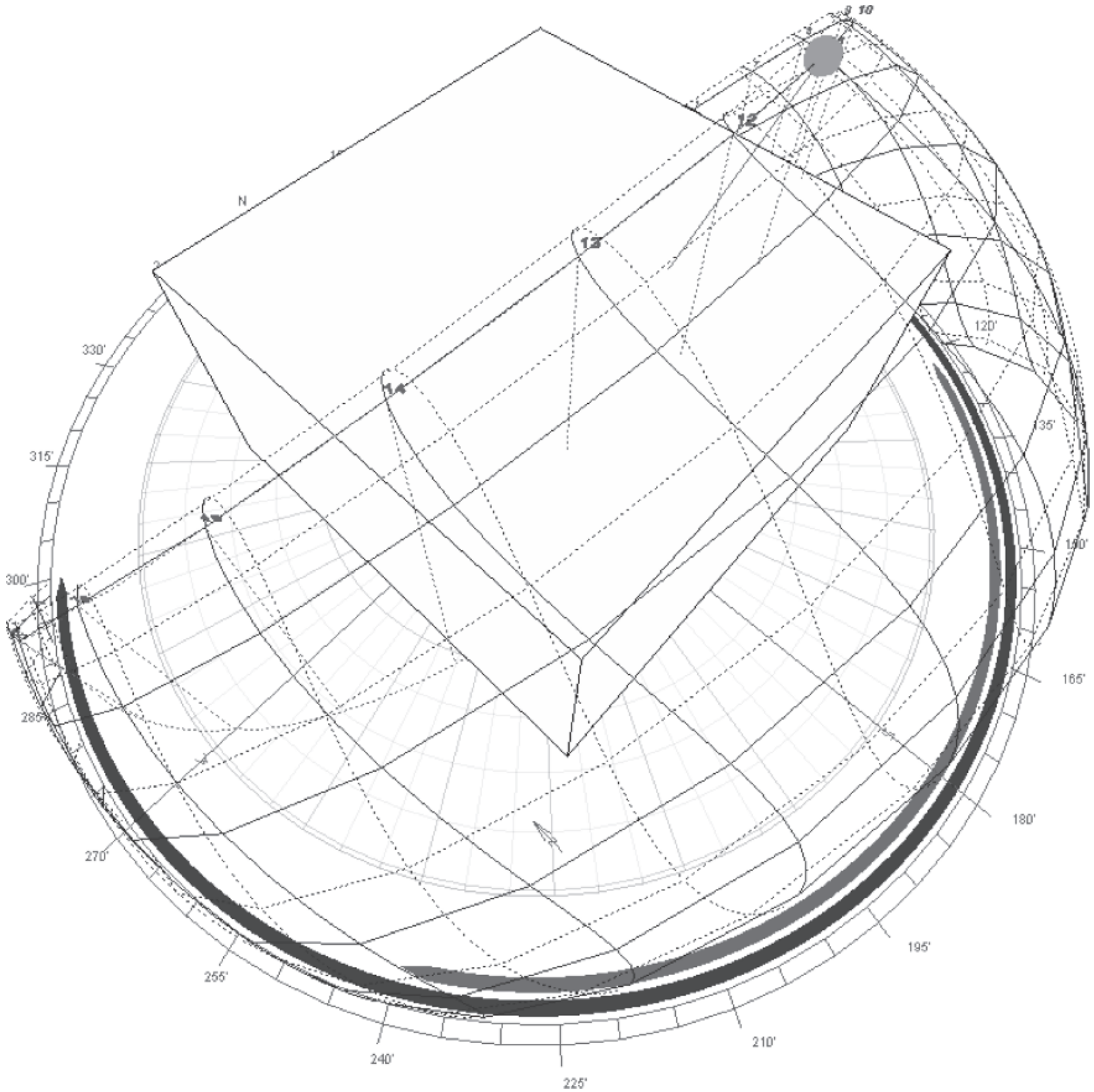


FIGURE 1.8b Solar path isometric. Example shown is for San Francisco, California, in the northern hemisphere.

and cold. The higher the R-value, the better the material is as an insulator. R-values for materials in the United States are typically provided in R-value per inch. To establish the overall R-value of an exterior building enclosure system, add together the R-values of each of the materials within the enclosure system. The determination of a total R-value for an exterior enclosure is typically performed using a steady state calculation. Temperature and exterior climate are not consistent (steady); however, this calculation is an essential basic first step in exterior design. An example of a total R-value for an enclosure system is illustrated in Figure 1.9. This is a very straightforward example. Each material shown remains in the same plane and location in the enclosure assembly. The R-value can be easily calculated and increased by increasing the

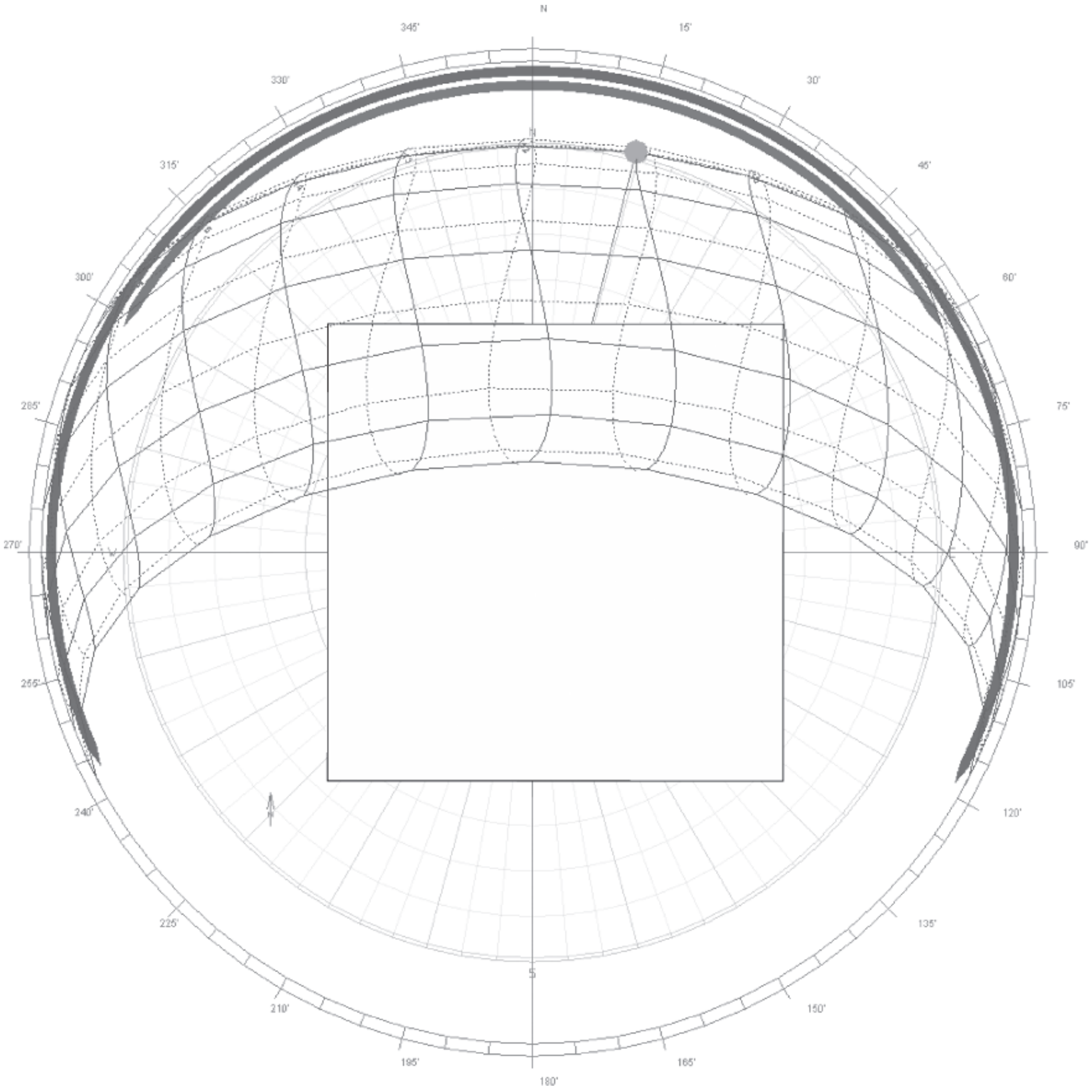


FIGURE 1.8c Solar path for Sydney, Australia, in the southern hemisphere at 33.868 South Latitude..

thickness of insulation. Additional interior layers can be added—carefully—to increase the R-value. Beware of potential thermal weak links at primary building structure locations. It is important to consider and remember that in some cases the cross section of an enclosure may not consist of the same thickness of materials across the entire enclosure. This is an instance where three-dimensional design thinking must be applied. It is best when insulation is continuous and—depending on climate—often toward the exterior of the primary air and water line. Insulation location in the enclosure assembly is also climate based. However, there are designs where the insulation is contained between framing members such as studs, framing supports, or similar elements. When this occurs, care must be exercised in mitigating or preventing thermal breaches or "bridges" by continuing the insulation material. Insulation should be wrapped

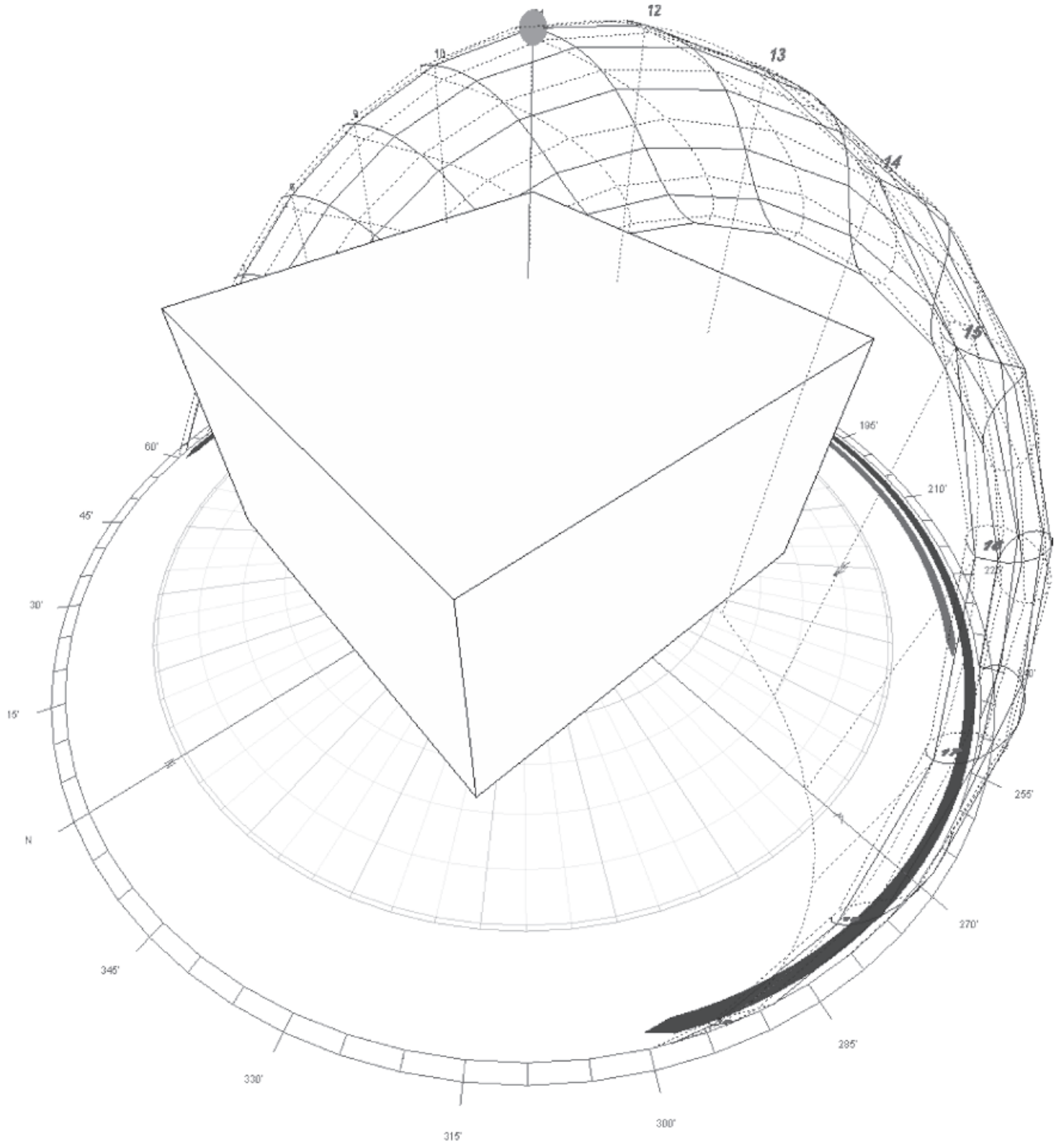
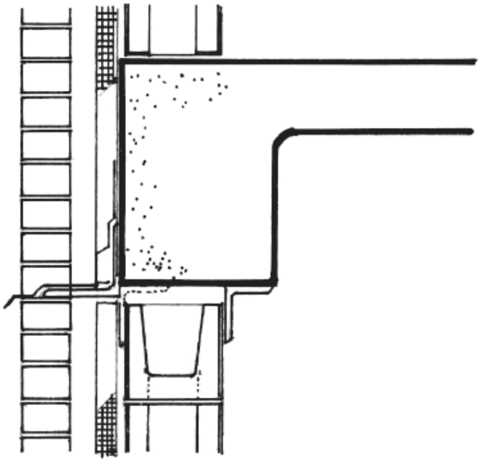


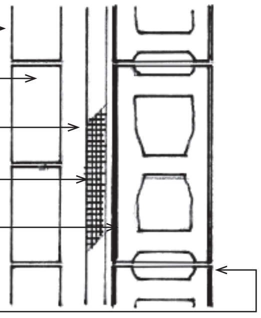
FIGURE 1.8d Solar path isometric. Example shown is for Sydney, Australia, in the southern hemisphere.

either behind or in front of the framing. Design and construction of enclosure systems where the insulation is contained between framing members will result in a reduction of the overall R-value because of thermal discontinuities between framing members.

U-value, or U-factor, is the inverse of the R-value, $U = 1/R$. In the U.S., this is expressed in units of BTU/(h°F ft^2). It is different in Europe and other parts of the world where Kelvin temperature is used in lieu of Fahrenheit, and metric measurements in lieu of imperial. The U-factor is the overall heat transfer coefficient in a nonsolar (i.e. exterior and interior temperatures) condition. The U-factor defines how well the material functions as a conductor. U-values are



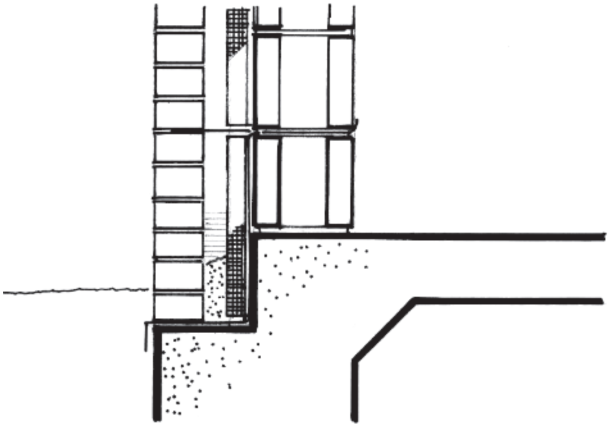
SECTION



- Outside Air Film
  R = .17
- Brick Veneer
  R = .74 (for 4-inch nominal)
- Air Cavity (2")
  R = 1.03
- Rigid Insulation (2" shown)
  R = 10
- Waterproofing
  R = .20
- Inner wall (8-inch nominal)
  R = 1.92
- Inner Air Film
  R = .68

R = 14.74

PLAN



SECTION

FIGURE 1.9 Overall thermal resistance (R-value) is defined by the composite of the enclosure component material R-values.

often provided in lieu of R-values for glass and metals. Glass infill is not a very good insulator compared with insulation materials in insulated opaque areas. So when using glass, use high-performance glass appropriately. U-factors indicate the rate of heat flow due to conduction, convection, and radiation resulting from temperature differences between the exterior and interior.

For transparent materials such as glass, the solar heat gain coefficient (SHGC) measures how glass blocks heat generated by sunlight from entering through transparent glazed portions of a building enclosure. Stated in a slightly different way, the SHGC is the fraction of solar radiation from sunlight that passes through the glass and becomes heat inside the building. SHGC is expressed as a number between 0 and 1. The lower the SHGC number, the less solar heat the glass transmits. The less the solar heat gain in a hot climate, the smaller the cooling system. The smaller the cooling system, the less energy is consumed. There may be design opportunities where heat gain is desired, so the reverse application may apply. Glass and glass framing (window frames) utilize both U-factors and SHGC numbers. Glass products have performance criteria established by the manufacturers after these products have been tested by accredited independent testing laboratories using standardized tests. The performance of glass assemblies has a direct influence on the quantity of glass that should be included in the enclosure design to achieve energy efficiency and the resulting size of the building mechanical system to compensate for the solar heat gain or heat loss.

Requirements to reduce energy consumption and provide increased energy conservation have been elevated over recent years and have a direct influence on glass and insulation material selection, quantity, and placement. Exterior enclosure designs are required to comply with requirements of local code jurisdictions. The International Energy Conservation Code (IECC) has been adopted by many local jurisdictions. Several states such as California have their own energy codes. Many states recently expanded their model codes to include specific energy codes. For commercial buildings there are two compliance methods to use to determine an acceptable extent of glass in the enclosure design. One is to utilize ASHRAE 90.1, and the other method is Design by Acceptable Practice. The latter is a prescriptive method that defines enclosure requirements for seventeen (17) climate zones and designates percentages of allowable glass in four (4) fenestration area tables. Each method establishes a minimum standard which is sometimes referred to as “less bad”. The challenge is how to efficiently make enclosures perform to high(er) energy goals.

Visible light transmittance (VLT) is the percentage of visible light that is transmitted through glass. The VLT is expressed as a number between 0 and 1. The higher the number, the more visible light is transmitted through the glass. Coupled with light transmittance is the solar heat gain coefficient (SHGC). Glass type, glass performance, quantity of glass, orientation of the glass, and the project’s requirements for energy consumption and conservation are all early evaluation factors in building enclosure design efforts.

Composing the design of the exterior building enclosure requires a balance of material selections, material location and the resulting R values, U factors, SHGC, and VLT selections will be discussed in the design process section in later chapters.

ACCOMMODATE SYSTEM MOVEMENT AND STRUCTURE MOVEMENT

The location and size of each material (framing or infill cladding) within the system have a direct effect on joinery, joinery materials, and joinery details. Details at material joinery within an enclosure system and systems interfaces are important. There are many opinions as to what constitutes a detail. A detail is defined as a condition where two or more materials come together. Joinery and movement are analogous to the chicken and egg—which comes first? Types and mechanics of movement influence joinery design. Joinery design accommodates certain types of movement and determines the type, size, and materials in the joint.

There is a quote from the film *The Wizard of Oz*: “It is always best to start at the beginning.” Buildings are dynamic; they move. Exterior enclosure systems are dynamic; they move. Beginning with the primary building superstructure: Columns, beams, slabs, and the like, deflect, sway, and drift. Similar to the human body, the primary building superstructure is the bones, and the exterior building enclosure system is the skin. As the bones move, the skin reacts in kind. Discussions with a building’s structural engineer can be enlightening and occasionally discouraging. Structural beams spanning between columns deflect when superimposed dead loads are applied. Dead loads are items that are physically attached to the superstructure, including superstructure self-weight, enclosure cladding, and so forth. Beams also deflect when live loads, such as occupants, are applied. The conventional engineering live load deflection standard for beam design is *L* (the span length) divided by 360. The formula is simple: *L*/360. For a beam supporting an exterior enclosure spanning 30′0″ the resulting deflection would be: *L* (30′0″ × 12″ = 360″)/360 = 1″. In an exterior enclosure that utilizes sealant in a horizontal joint to accept structural movement which has a maximum movement capacity for expansion and contraction of +/- 50%, the resulting correct joint size would be 2″. This 2″ dimension does not include the enclosure fabrication and installation tolerances, which will increase the joint size slightly. Imagine the joint size, following the *L*/360 approach for beams that span longer dimensions such as 40′0″ to 50′0″ and the resulting joinery. A diagram of structural beam deflection parallel to the enclosure is shown in Figure 1.10. Examples of joinery design by enclosure systems are discussed in the enclosure systems/case study chapters.

There are several approaches to joinery design utilizing joinery materials between enclosure materials. The use of sealant materials in the joints is one. Another approach in movement joint design utilizes concealed gaskets. This approach results in an open joint appearance (no sealant, since the gaskets are often integral to the system, accommodating the movement and providing weathertightness capability). This allows the movement in a smaller exterior visual joint size than the sealant approach. However, the concealed gasket assembly will occur either above or below the joint and does have an influence on the supporting profile size when viewed in section. An example of a sealant joint and gasketed joint is shown in Figure 1.11. Often in discussion with a structural engineer, tighter deflection limits can be established to “tune” the structure and the joinery sizes to comply with the visual and performance design requirements. Similar structural movements apply to structural slabs for horizontal joinery design.

Wind loads are applied to a building, resulting in sway or “drift” in the primary structure. This is typically expressed as the displacement of one floor in relation to the next floor above or below. Columns deflect and impart movement to vertical and horizontal joinery. A diagram example of building drift due to wind is shown in Figure 1.12. Seismic movement also creates building drift, and, depending on the primary structural system design, earthquake magnitude and building height can impose significant drift values from floor to floor. This is illustrated in the seismic force section of this chapter. The enclosure system (the skin) must be designed to accommodate the movement of the building structural frame (the bones).

Moving outward from the primary building structural system, the exterior building enclosure system itself is dynamic when forces act on the enclosure. A variety of forces including temperature and sunlight, discussed later in this chapter, influence the functions and size of the joinery. Wind forces acting on an enclosure will create deflections perpendicular to the plane of the enclosure on both horizontal and vertical cladding infill and supporting elements. The extent of deflections and the location of the movement will influence the type and size of joinery. Temperature variations and changes will create expansion or contraction. Each material has its own inherent expansion/contraction properties. For example, metals exhibit higher coefficients of expansion than masonry. The common denominator is that all materials expand and contract, which contribute to joinery design considerations. The greater the temperature change, and the larger the size or length of material, the greater the movement will be, and the larger the required joint size to accommodate the thermal expansion or contraction. It is also important to note that movement due to thermal changes occurs vertically and horizontally.

Movement not recognized and accommodated in enclosure design by properly located, sized, and designed joinery results in stresses that have to go somewhere other than the joint. Stresses that are not relieved through joinery create increased stresses within the enclosure materials themselves. When this occurs, material bending or buckling may, and usually does, occur. Imparting undesired stresses into cladding, infill and framing elements is not advisable in exterior enclosure design.

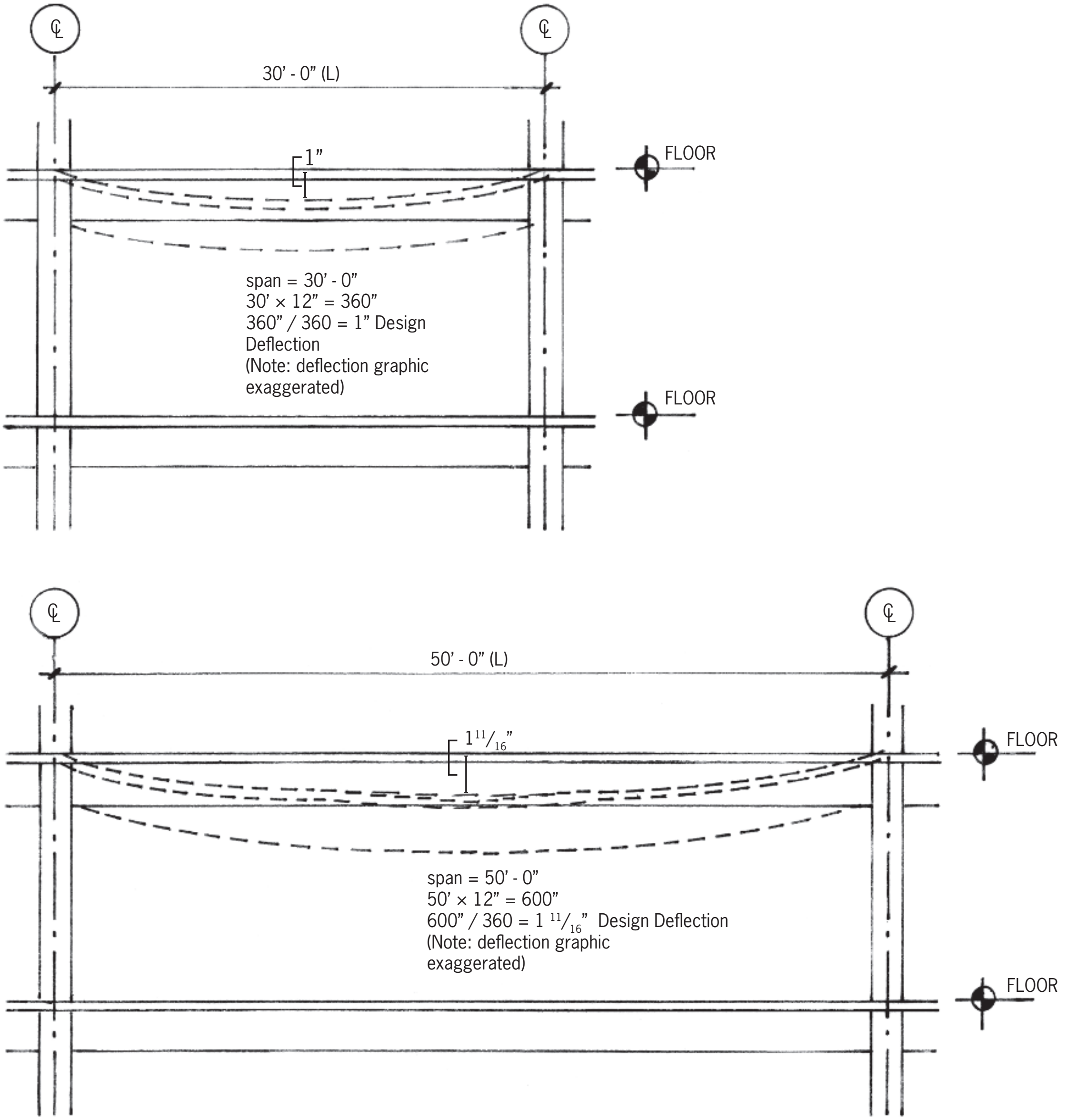


FIGURE 1.10 Structural beam deflection utilizing an *L*/360 structural design criterion. Resulting deflections for longer spans require larger enclosure joinery or enhanced specific structural design criteria to reduce beam deflections.

The movement acting on the exterior enclosure by the structural system and exterior forces varies for every project. However, both types do occur in every exterior building enclosure. The important fact is that these movements will occur. Once identified, the extent, location, and quantity of movement can be defined and established. Once movement is quantified, movement joinery can be sized for the location in the system joinery. Once location is established, the appropriate type of joinery design and materials can be applied to the enclosure design.

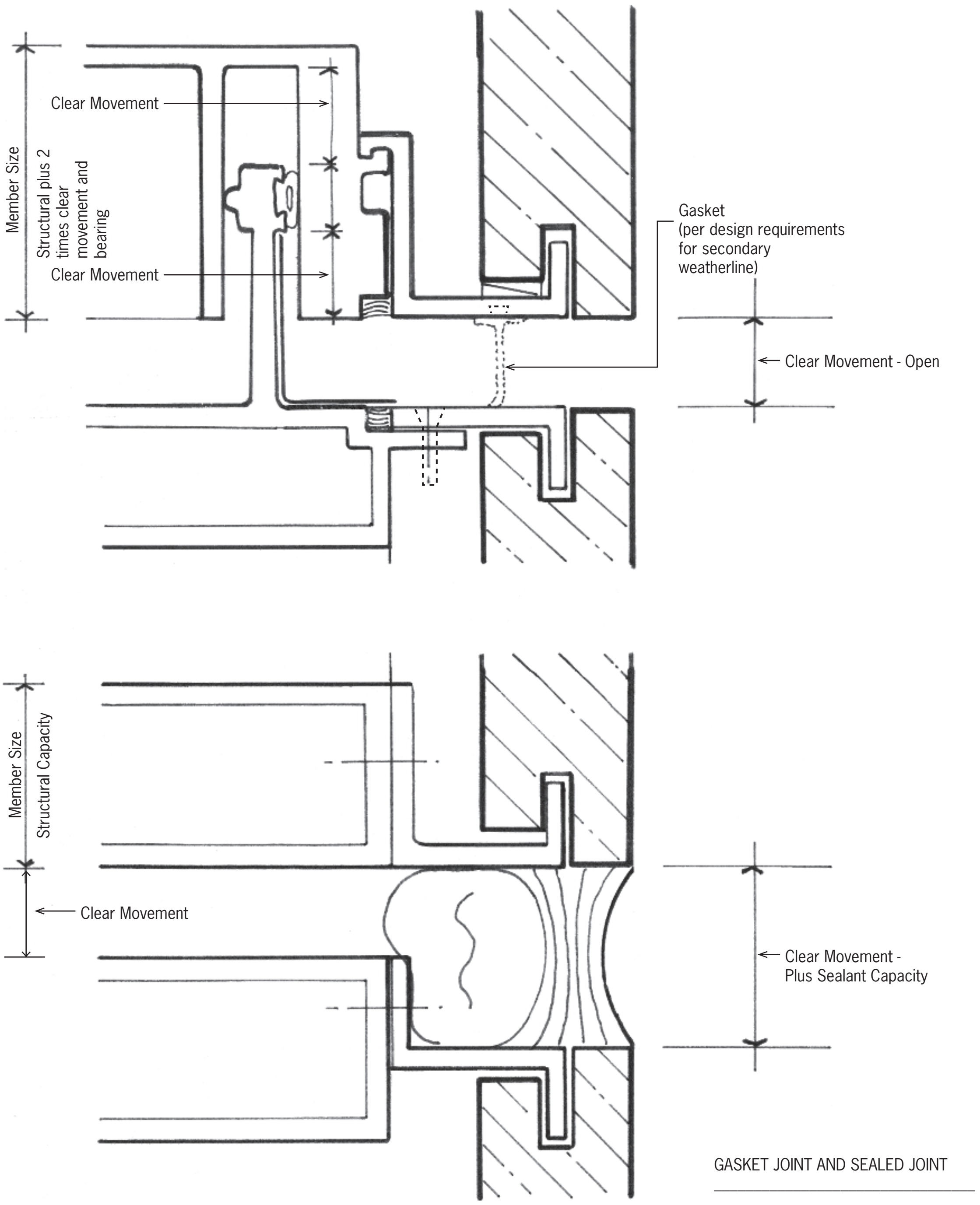


FIGURE 1.11 Open or gasketed joints may result in smaller expressed exterior joint sizes than sealant. Gasket joinery systems often require a larger amount of space in concealed areas to accommodate the concealed gasket components.

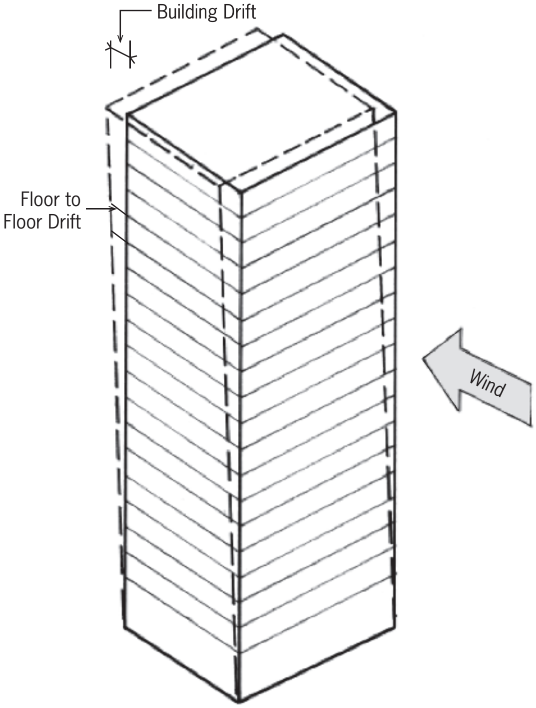


FIGURE 1.12 Lateral wind forces create building drift. Drift per floor influences enclosure design items such as materials, materials size, shape, joinery, and other issues.

Elements and Forces on the Exterior Enclosure

Prior to beginning enclosure schematic design, and definitely before the more detailed design development effort, there must be an assessment and evaluation of the natural elements (air, water, and sun) discussed earlier, natural forces, and human-created forces that will act on the enclosure. With a fundamental understanding of the forces and their magnitude, design methodologies and performance design principles can be applied and integrated into the enclosure system design, to achieve the necessary performance.

Newton's third law of motion is: "To every action there is always an equal and opposite reaction." An enclosure system design needs to accommodate each and every force: the action. This accommodation and response is the equal and opposite reaction. Forces are identified in two groups:

1. Exterior forces
2. Interior forces

Natural exterior elements and their associated forces include wind, precipitation, air, temperature, sunlight, gravity, and seismic force. These can be studied and examined independently; however, multiple elements and forces usually act concurrently on the enclosure. For the majority of building types, natural forces are applicable in the design of the exterior enclosure. In specialized building types, higher force levels or other additional human-made forces create more case-specific design parameters. Human-created exterior forces and conditions include noise, forced entry, ballistic impact, explosive blasts, and built surroundings that must be addressed in the enclosure design.

There are interior forces that influence the enclosure design. These interior forces include primary building structural system movement created by live loads, dead loads, column shortening, and wind or seismic drift; temperature control requirements; humidity control requirements; and noise.

Many papers and publications have used the analogy of a selective filter to describe the exterior building enclosure. This is an interesting conceptual abstract. Most architects have difficulty translating this to reality. The exterior enclosure is a selective filter used to moderate conditions between the exterior and the interior environments. The enclosure as selective filter provides a barrier to some elements and forces or allows passage of others. The enclosure must be a barrier to air, water in its multiple states, and unauthorized people, and it must be a selective filter for light, temperature, and air. The filter serves the multiple functions of (1) withstanding the exterior forces of nature and human beings, (2) controlling and filtering the inward and outward flow of heat, cold, water, air, light, and sound, and (3) providing a weathertight and safe enclosure that protects the building occupants and the enclosure itself.

The matrix presented in Figure 1.13 identifies natural and human-created forces along one axis, and design requirements along the other axis. Forces that influence design as a primary consideration are indicated by the symbol "P" in the matrix. Forces that influence enclosure design as a secondary

EXTERIOR ELEMENTS AND FORCES

	NATURAL							NATURAL & HUMAN		HUMAN CREATED
DESIGN	WIND	PRECIPITATION (INCL HUMIDITY)	AIR INFILTRATION	TEMPERATURE	SUNLIGHT	SEISMIC	GRAVITY	NOISE	BLAST	BALLISTIC
STRUCTURAL	P	S	S	S	-	P	P	S	P	P
WEATHERTIGHTNESS	P	P	P	P	P	P	S	S	-	-
THERMAL COMFORT	S	P	P	P	P	S	-	S	-	-
MOVEMENT	P	P/S	P/S	P	P	P	P	-	S	S
LIGHT TRANSMISSION	-	-	-	P	P	-	-	-	S	S
ACCOUSTICS	S	S	S	S	S	-	-	P	S	S
SECURITY	-	-	-	S	S	-	-	-	P	P

P = Primary
S = Secondary
- = Not Applicable

FIGURE 1.13 The table identifies primary exterior elements and forces and their influence on the enclosure design. Note: Fire resistance is not shown, however, this is a primary enclosure design consideration. Specific building types and their enclosure design may involve other forces not illustrated here.

consideration are indicated by the symbol “S.” Where forces have little or no influence, the symbol “-” is used.

Following are descriptions of the natural and human-created forces identified in Figure 1.13. Included with each force listing are some methods to define and determine the magnitude of the force and the resulting design performance criteria to address the force. The matrix illustrated is general. It should be fine-tuned specifically for the enclosure design opportunity.

FORCE TYPE: WIND

Wind is one of the primary exterior forces: it reacts on the exterior enclosure as a lateral load for vertical, horizontal, or sloping exterior enclosures. Wind forces significantly influence the structural design of the enclosure. Wind speed is expressed on the enclosure as a pressure. Cladding, infill materials, and framing members’ sizes and thickness, as well as connections and anchorages, are determined by the maximum wind loads and the resulting pressures exerted on the enclosure. The primary goal is to transfer the lateral wind load pressures from the enclosure system through the enclosure system anchorage into the primary building superstructure. Wind creates positive and negative (suction) pressures. The shape and height of the building also influence the magnitude and location of the pressures. An example of a tall building with pressure contours is shown in Figure 1.14a, and with wind pressure contours converted to blocks of pressure areas in Figure 1.14b. An example of a building with an irregular floor plan and the resulting pressures is shown in Figure 1.15. Wind speeds result from climate and microclimate. These vary by region, topography, and surroundings. Wind forces must be determined for the maximum positive pressure and the maximum negative pressure to determine the higher—and therefore governing—design pressure value. In addition to the enclosure structure considerations; created by wind pressure, wind also drives water.

Defining Wind Speeds and Pressures

There are two primary methods to determine the wind speed and the resulting pressures on the exterior enclosure. These are (1) building code and related standards, and (2) wind tunnel testing.

Building Code and Related Standards

In the United States, the building code method utilizes a combination of the applicable building code used by the authority having jurisdiction (AHJ) and the American Society of Civil Engineers (ASCE) 7 Section 1609. These two documents determine the basic wind speed and the exposure category. For discussion purposes, the applicable building code will be the 2009 International Building Code (IBC). Each locale has its own applicable code. Which code or standard to follow should be determined early in the design. The basic wind speed is indicated in region maps in the building code. The basic wind speed is associated with annual probabilities and adjusted for wind gusts. There are some specifics and exceptions for special wind speed areas such as hurricane zones and mountains or gorges. These are determined by local jurisdictions on a local case-by-case basis. The basic wind speed is provided in MPH in the U.S. for the determination of the wind load on the structure and the enclosure. The wind directions have an exposure category assigned to reflect the characteristics of the ground surface irregularities upwind of the site. Natural topography, vegetation, and constructed features are factored into the surface roughness category. The building code method to determine exterior cladding pressures is a relatively simple procedure to calculate loads based on height, shape, and location. For buildings with irregular shapes, high rise, or other special conditions, a more project-specific wind tunnel test should be conducted.

Wind Tunnel Testing

Another method to determine wind speeds and the resulting pressures on the exterior enclosure is wind tunnel testing. In wind tunnel testing, a massing model is built, usually in acrylic, and is placed in a wind tunnel. The wind tunnel has a long tunnel section to model the upwind terrain. The model of the terrain is done in more detail closer to the building site. The wind tunnel air flow exhibits characteristics similar to the actual wind conditions over the terrain approaching the building. A scale model of the

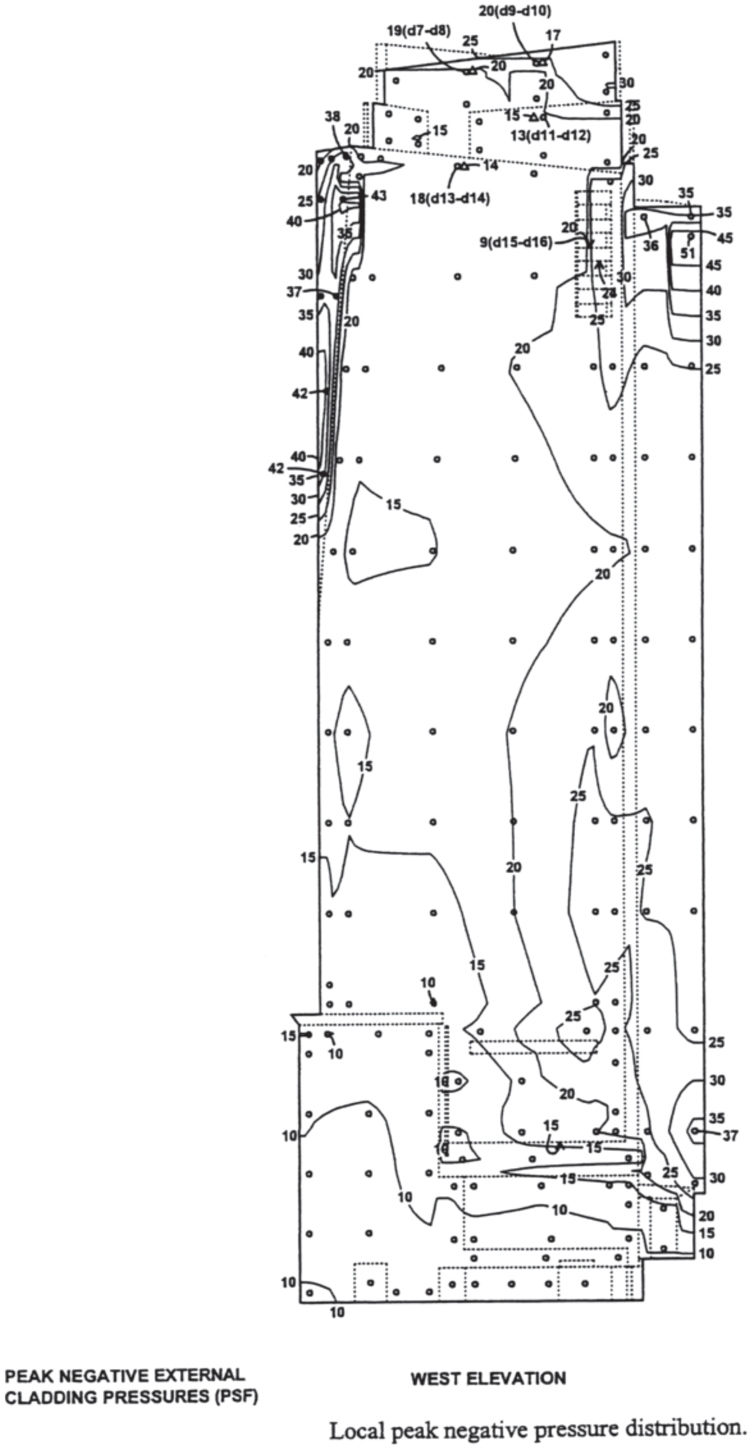
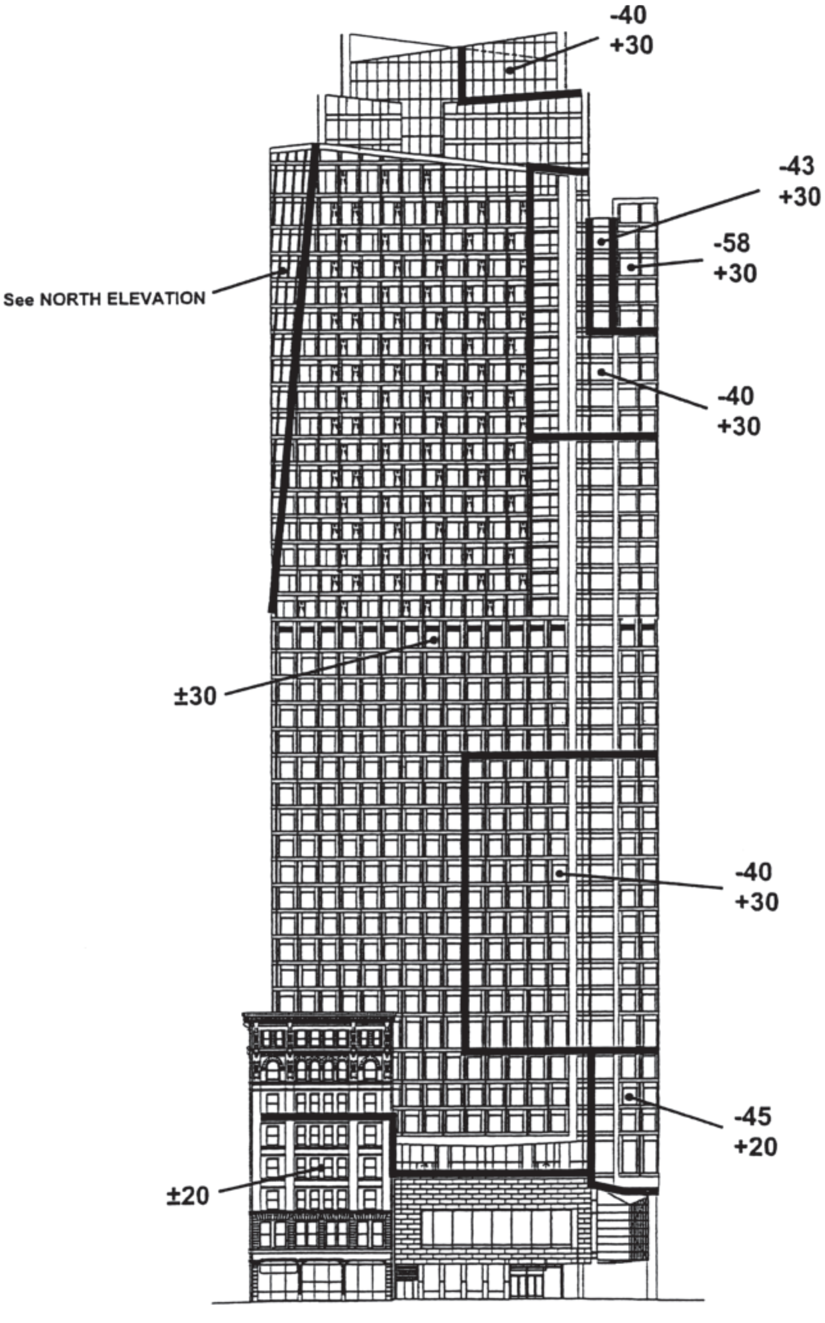
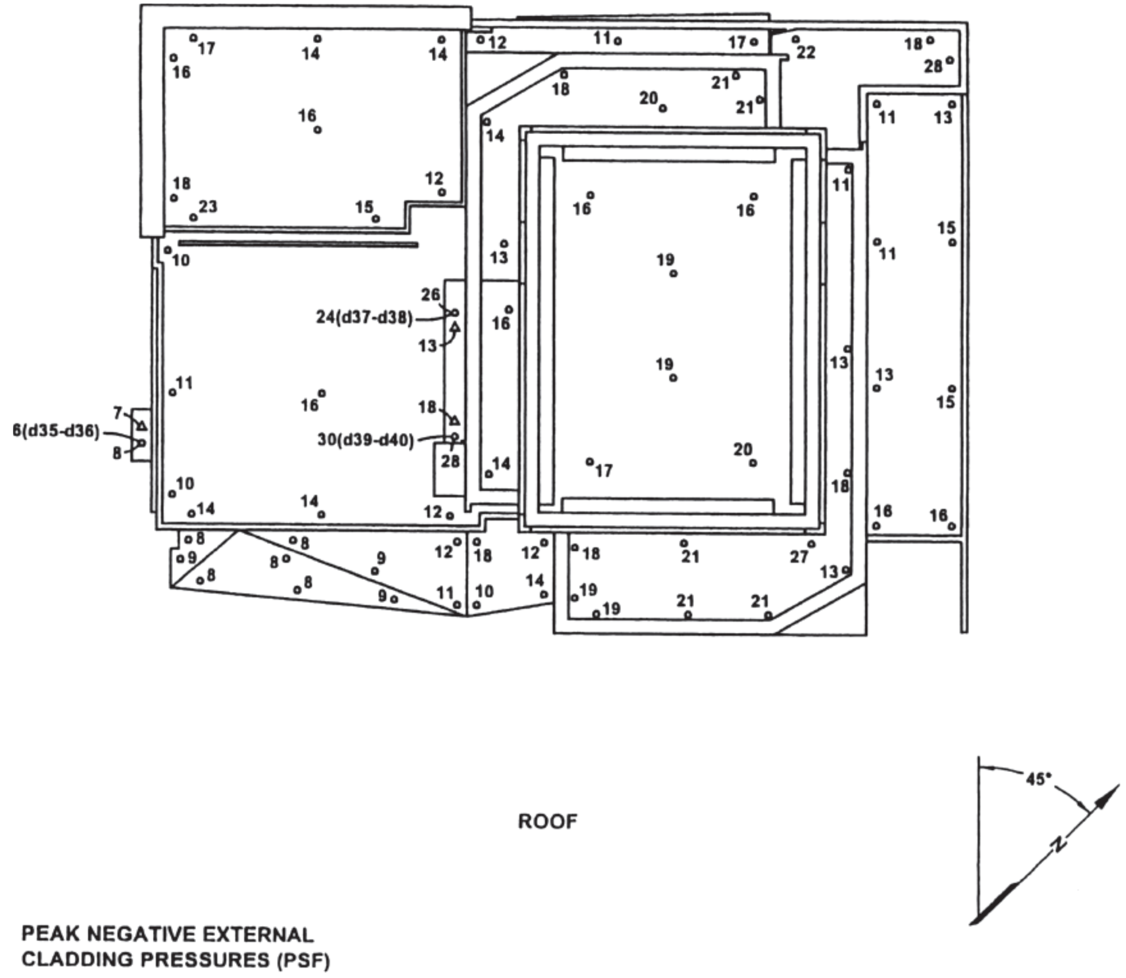


FIGURE 1.14a Building elevation with wind pressure contours (negative pressure shown). The building shown is the St. Regis Hotel and Residences in San Francisco, CA. *CPP Wind Engineering*



Peak cladding zones.

FIGURE 1.14b Building elevation with wind pressure contours converted to block pressure areas per elevation. *CPP Wind Engineering*



Local peak negative pressure distribution.

FIGURE 1.15 Roof plan, shapes, height, and other features create project-case-specific wind pressures for horizontal enclosures and parapets. The wind tunnel plan shown is the St. Regis Hotel and Residences in San Francisco, CA. *CPP Wind Engineering*

proposed design is built with numerous holes, often referred to as "taps." The taps are connected by tubing to pressure transducers and record the pressure on the faces of the massing model. The model is placed in the wind tunnel and is rotated in increments of 10 degrees for a full 360 degrees where measurements are made at each increment of rotation. The scale building model with taps and the surrounding environment, including topography and other buildings, is tested using wind speeds and directions obtained from local weather sources. The recorded pressures are provided, with a report and graphics illustrating the tap locations and pressures. A photo of a high-rise project in the wind tunnel is shown in Figure 1.16.

The corresponding tap pressure results from this wind tunnel model and testing are shown in Figure 1.17. Wind pressure contours and pressure block diagrams are derived from the tap pressure readings.

The resulting wind pressure to be used in the design may be a single value for the exterior building enclosure. For larger buildings, the wind pressures may be identified in pressure zones. After identifying the singular pressure or multiple pressure zones and the location on the enclosure surfaces, determinations can be made regarding what pressure will be used for the design of the enclosure system(s). Enclosures can be designed to a selected pressure and strategically reinforced for higher pressures, referred to as "hot spots."

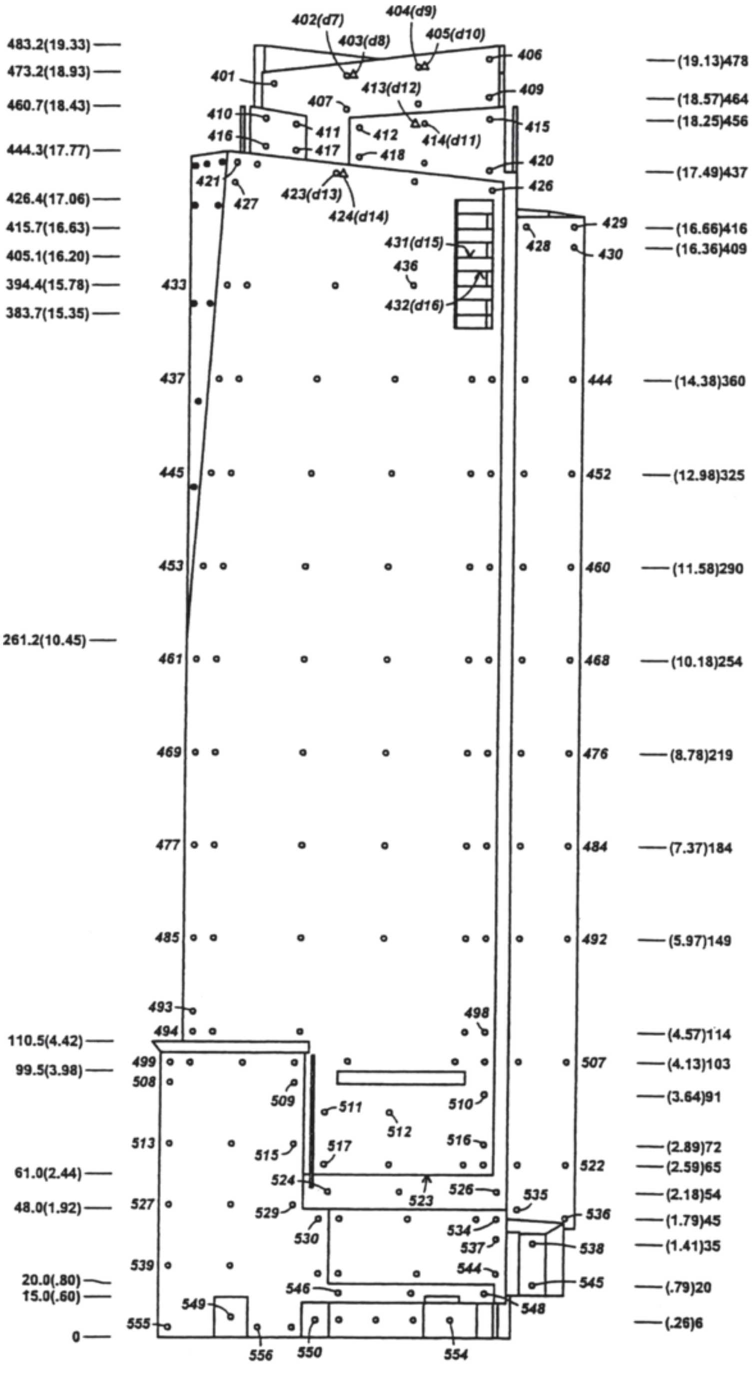
An additional design evaluation is the resulting drift of the primary building structure due to wind loads. The magnitude of drift is influenced by surface area, height of the building, and the type and stiffness of the primary building structure. Structural engineers provide the architect with the design drift to be used in the evaluation and design of the enclosure.

With definition and understanding of the wind pressure results, design performance criteria can be established for framing, infill, cladding, cladding attachments, system anchorage, and enclosure surface areas. Each enclosure system type has its own unique standards and criteria. Enclosure performance criteria to accommodate wind pressure loads are identified in the systems descriptions and associated case study chapters in this book.

Design Performance Criteria: Framing and Cladding Combined

The deflections of the framing members and enclosure plane must recognize the type of infill or cladding material (glass, metal, stone, brick, etc.) and the method of attachment and clearances required. The cladding materials, like the framing or supporting elements, also deflect under wind load, and the boundary conditions of the cladding infill at the framing members must be reviewed and designed together. Deflection criteria is dependent on the enclosure system and associated materials within the system.

FIGURE 1.16 Scale model of the St. Regis Hotel and Residences and surroundings in a wind tunnel. *CPP Wind Engineering*



WEST ELEVATION
Tap and structural dimensions

FIGURE 1.17 Building elevations with pressure "tap" locations and results. *CPP Wind Engineering*

Deflection performance criteria is discussed in chapters 5 through 9 for specific enclosure systems.

Design Performance Criteria: Wind Drift

Wind drift is the amount of sway, off-center, in a structure when subjected to the maximum wind pressure. This drift value is typically given in inches or fractions of inches per floor, and is determined by the structural engineer. It is important to evaluate the drift for typical floor-to-floor heights, and if there are taller atypical floors, consult the structural engineer for drift values on these floors as well.

The wind drift value per floor, the framing system, the infill or cladding attachment method, and the type of system anchorage connection of the enclosure to the primary building structure are factors in the system and joinery design. The drift value should be evaluated both parallel and perpendicular to the plane of the enclosure. Cladding or infill is generally considered to be rigid. Therefore, the attachment of the cladding or infill to the framing is typically evaluated as slipping in a pocket or rabbet (such as glass "captured" and glazed into a mullion frame) or fixed (such as glass that is adhered with structural silicone). Other cladding or infill materials have similar slip or fixed attachment conditions.

The framing components assembled as a framing system can be viewed as a rigid framing system or a deforming framing system. "Rigid" is defined as the framing configuration remaining in its original shape under loading. "Deforming" is defined as either the framing members bending or the connectors allowing movement, both of which allow the framing configuration to change to a shape other than the original. A rigid framing system is used where cladding or infill is fixed. A deforming framing system is used where cladding or infill is attached in a captured method, allowing cladding or infill to move within a frame or at a cladding connection without damage. System anchorage connections of the framing to the structure should be designed and specified to accommodate movement both parallel to the plane of the enclosure and perpendicular to the plane of the enclosure. For a rigid frame, the connections should allow for tipping or sliding parallel to the plane and rotation or stairstepping perpendicular to the plane. The drift of the primary building structure frame parallel and perpendicular to the enclosure plane is illustrated in Figure 1.18a. An enclosure movement diagram of a rigid frame is superimposed on the structural drift. This is illustrated in Figures 1.18b and 1.18c. In deforming frames, the movement parallel to the plane of the enclosure results in the frames deforming to a parallelogram or other shape without damage to the cladding or infill. Deforming frames are illustrated in Figure 1.19.

Drift perpendicular to the enclosure results in system rotation perpendicular to the plane. The enclosure tips or leans inward or outward in relationship to the gravity and lateral system connection locations. Each method has its own design and detail implications at typical conditions and at inside and outside corners. Examples of outside-corner diagrams are shown in Figure 1.20. Inside-corner frame movement conditions are similar. These diagrams are illustrated to a conceptual level. Drift movements are discussed in detail by enclosure system in the systems/case study chapters 5 through 9.

ELEMENT AND FORCE TYPE: PRECIPITATION/WATER

Precipitation, in the form of rain, snow, sleet, hail, and humidity, is various states of water, and water must be managed in the exterior enclosure. The term "managed" is key. Water management includes water penetration and discharge. As noted earlier, most forces act concurrently. Water in the absence of other forces is influenced by gravity. When water contacts an exterior enclosure, it will follow the influence of gravity and flow in a downward direction. Water combined with the force of wind will flow in multiple directions, even upwards. Water can also be moved by surface tension and capillary action across surfaces and joints. Water can be moved by pressure differences, air movements, and kinetic energy. A diagram illustrating methods of water movement and transfer is shown in Figure 1.21.

Water combined with the wind forces previously described can enter very small openings. Establishing a design and the resulting detail methodology to prevent water migration through the exterior enclosure

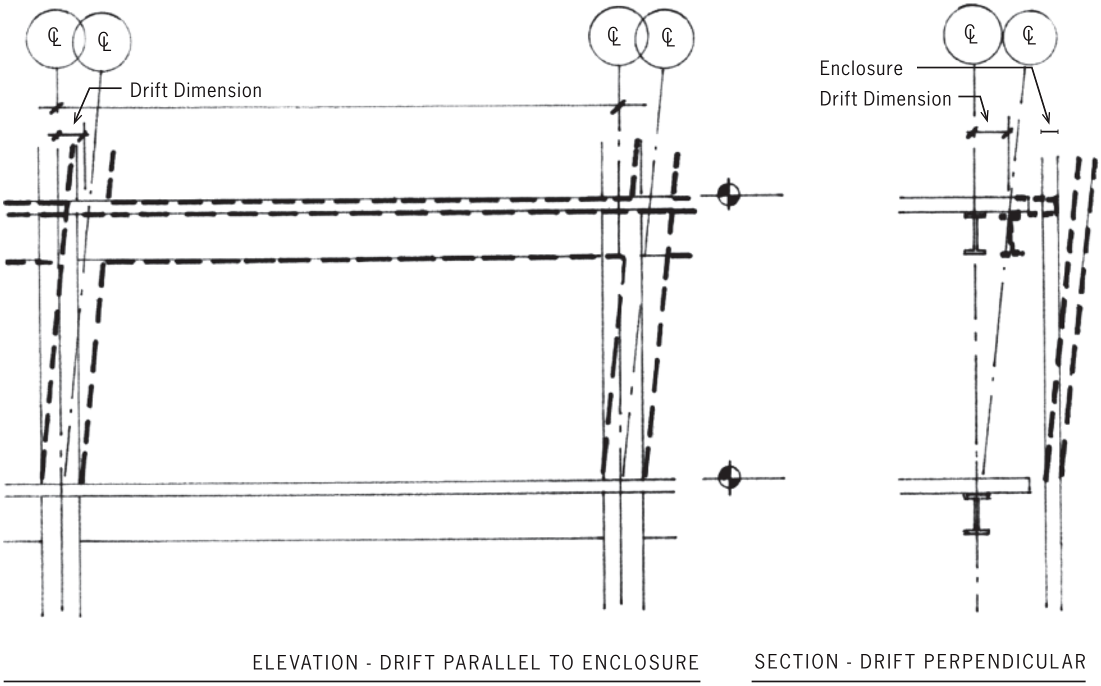


FIGURE 1.18a The primary building structure displaces, or "drifts," under lateral loads. These drifts are defined as wind or seismic induced. The primary building structure "leans" parallel and perpendicular to the enclosure. Seismic drift creates similar and often more significant drift, depending on the floor-to-floor height, building height, and structural system.

to the building interior can be accomplished in a variety of ways. Again, it is important to first understand the fundamentals of the forces in order to select the most appropriate design solution. For water to enter an enclosure, three conditions must be present. These are: (1) a water source, (2) an opening, and (3) some type of force to move the water through the opening. All three must be present. If any one of the three is removed, there can be no transfer of water through an enclosure.

One approach is to design an impervious enclosure to keep the water completely to the exterior. This theory means exterior and interior are completely separated. Another approach reduces water quantity through multiple layers in the enclosure. The layers reduce water quantity; reduce the pressure differences between the enclosure and interior; allow storage, then drainage; and allow drying. This is the concept of water management.

Defining Water (Rain) Quantities and Directions

Historical weather data can be obtained through a number of sources and agencies. Some of these are: NASA, EnergyPlus, the U.S. Department of Energy, and the National Oceanic and Atmospheric Administration (NOAA) National Weather Service. There are many other available sources. The primary objective is to ascertain weather trends and patterns. Local meteorological data are compiled at airports and are available with historical

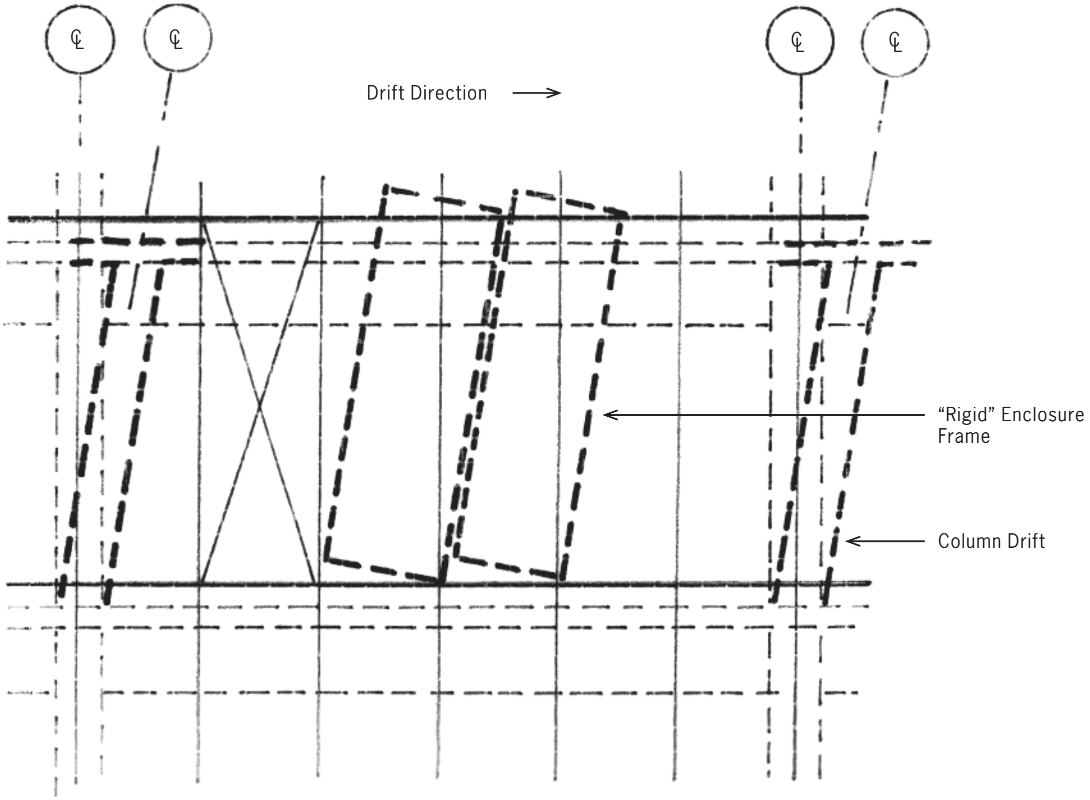


FIGURE 1.18b A drift diagram of a curtain wall with the fixed infill creating a rigid frame. The movement shown is a "tipping" enclosure condition parallel to the enclosure plane.

background to establish reliable local weather patterns relating to the regional climate or microclimate of the area. In addition to annual rainfall, or depending on the location, other important design parameters are snow amounts, the quantity of rainfall in a one-hour time frame, and daily amounts of precipitation.

No matter the climate, water in some form or quantity will be present. In most, if not all, enclosure designs, there will be openings. The openings may be windows or joints between cladding or infill materials. In either case, both create potential openings for water penetration and leakage. As stated earlier, three items are required for water to enter through an enclosure. Since water will be present and openings will occur, the last item that can be evaluated in the design is how to remove the force that drives water or how to disassociate or decouple the water and the transportation force. This will be reviewed in the "Design Principles" section of this chapter. Enclosures are designed with either water-impermeable (glass, metals, etc.) or permeable (stone, concrete, brick, etc.) exterior cladding. Methods to control and manage water depending on the type of enclosure material and system are reviewed in the systems/case study chapters 5 through 9.

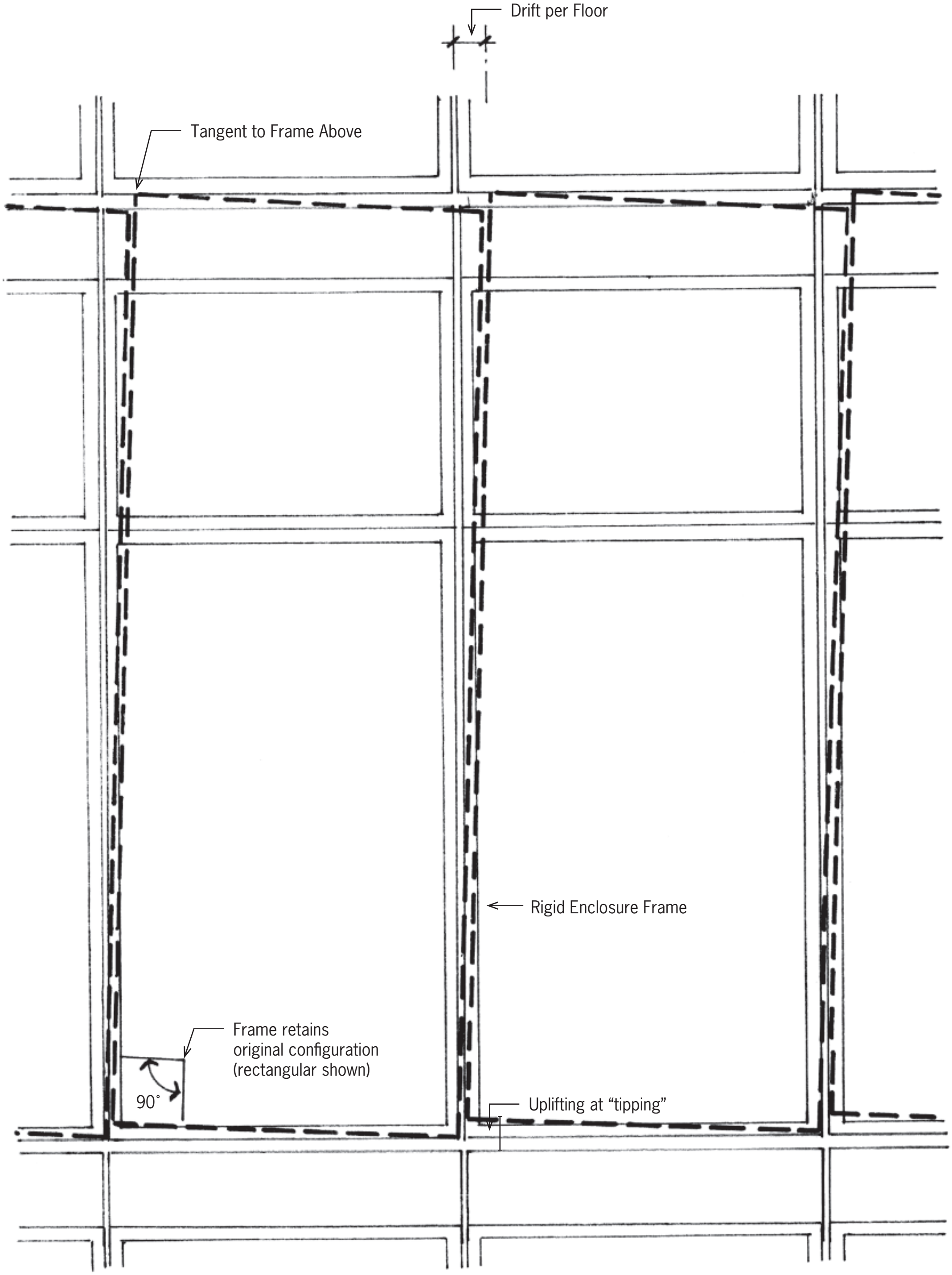


FIGURE 1.18c An enlarged view of a unitized curtain wall with the cladding infill in a rigid frame. The structural frame drift is parallel to the enclosure plane. The horizontal enclosure at the perimeter mullion frame-to-frame is sized so the frames do not touch when one floor is displaced in relation to the adjacent floor.

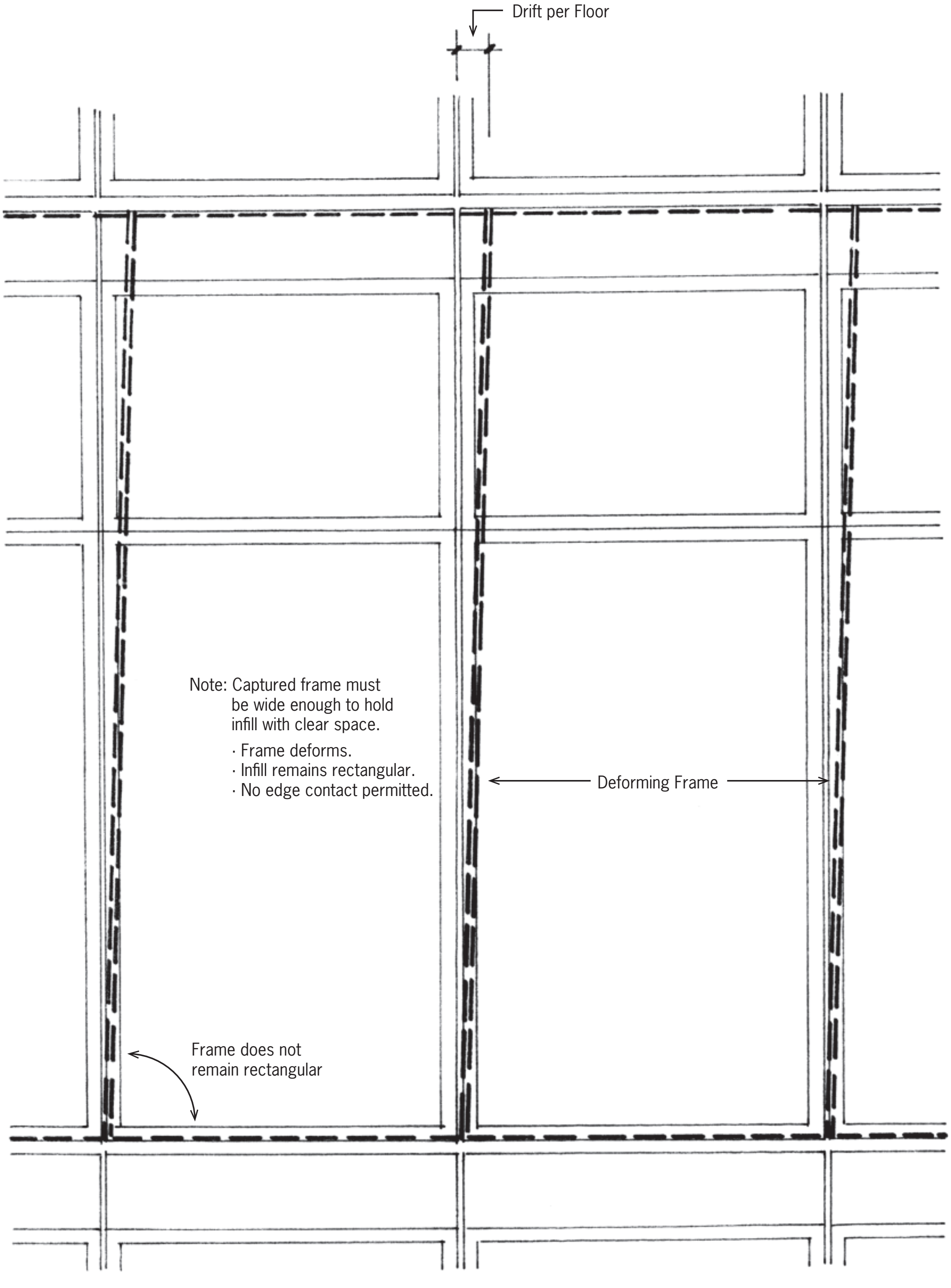


FIGURE 1.19 An enlarged view of a curtain wall with a deforming frame. The structural frame drift is parallel to the enclosure plane. The frame must be wide enough to prevent contact of the glass infill inside the captured glazing pocket, to avoid creating damage to the glass.

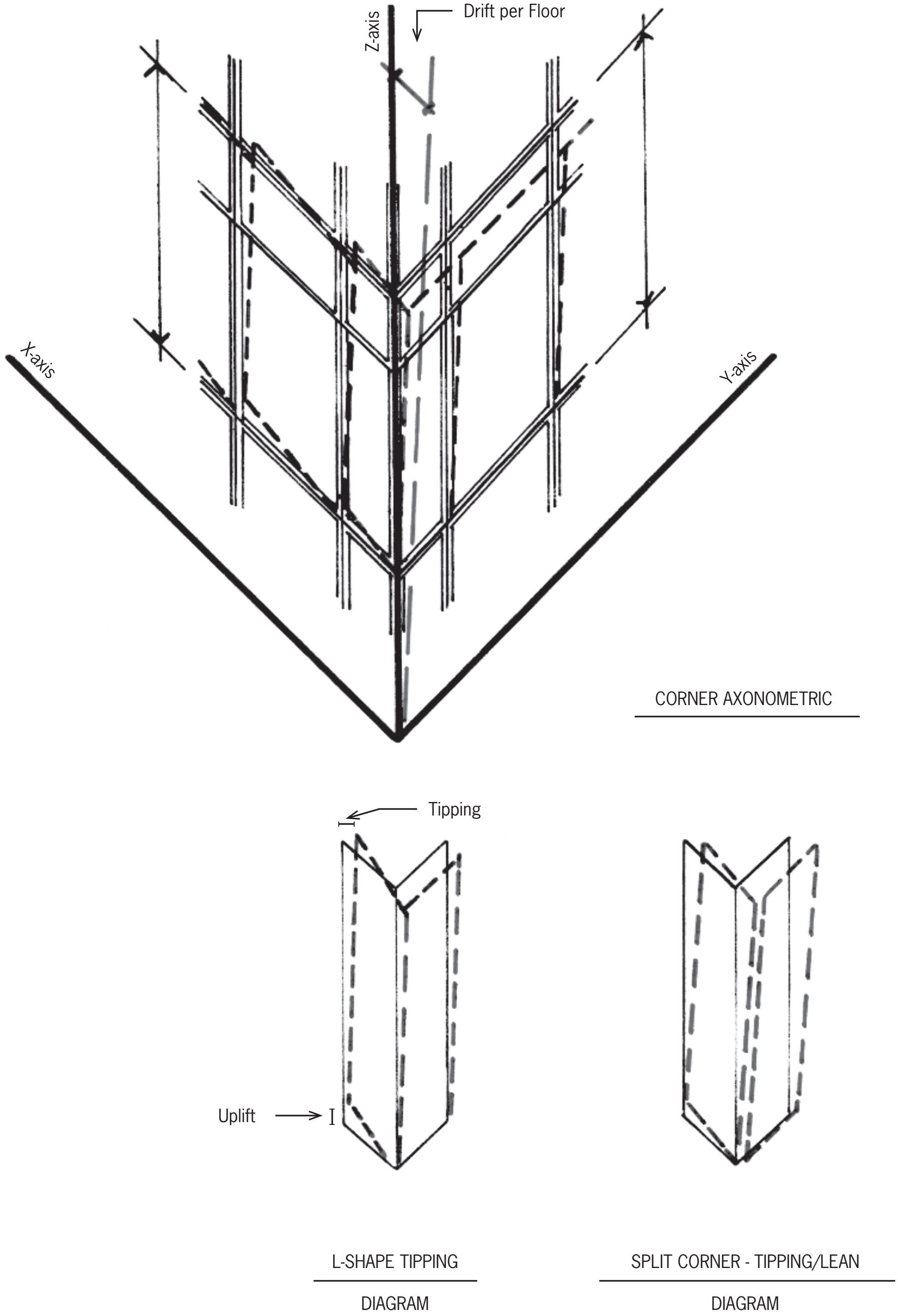


FIGURE 1.20 Primary building structural drift requires specific design and details for the enclosure corners. The diagram illustrates two options. The L-shaped corner tips and leans like an open book tipping on its binding. The "split" corner allows slipping at the corner seam when tipping on one side and leaning on the adjacent side. There are other methods to accommodate drift at corners.

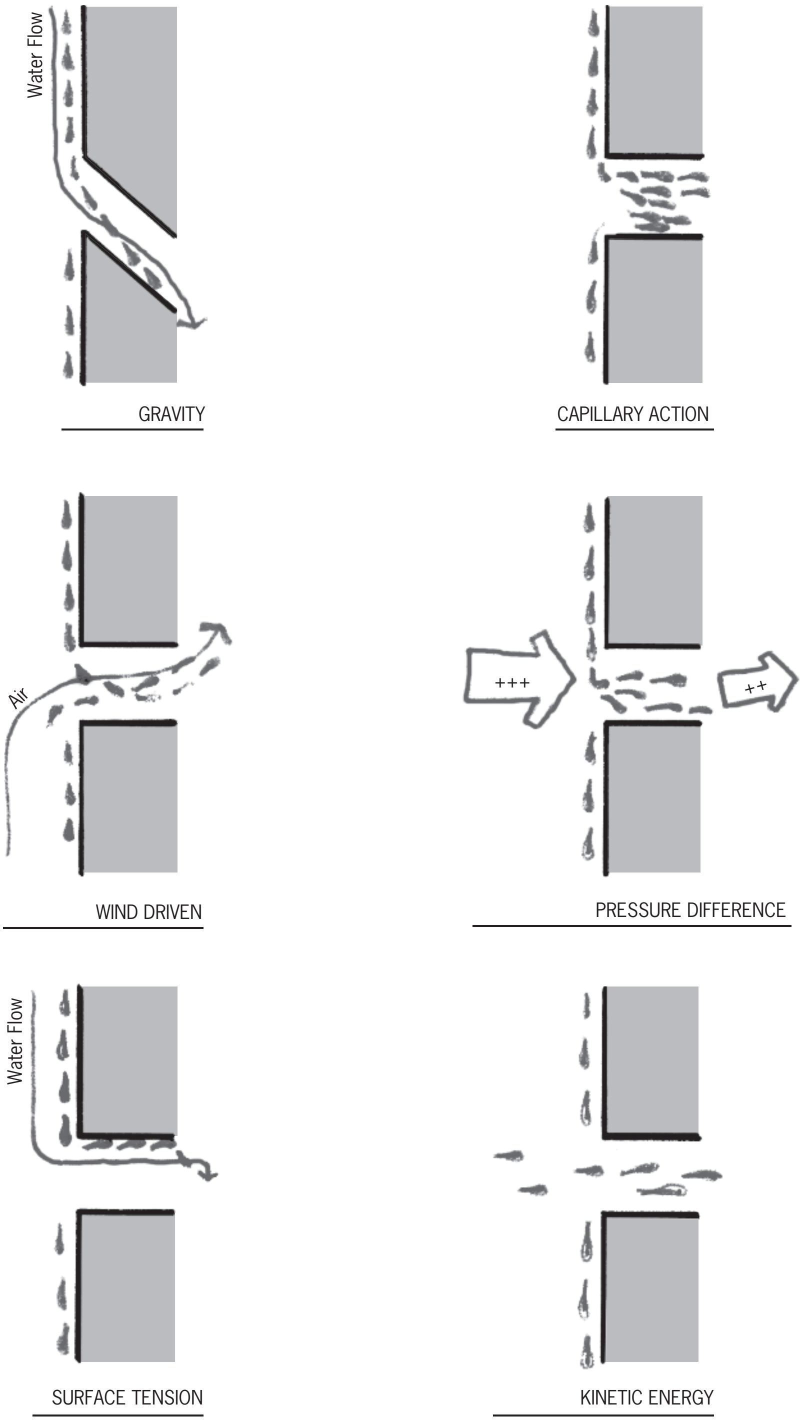


FIGURE 1.21 Water is moved by multiple physics.

ELEMENT TYPE: AIR, FORCE TYPE: INFILTRATION AND EXFILTRATION

Air infiltration and exfiltration are forces created by pressures resulting from the exterior wind pressure, stack effect, and the project's mechanical system. These may act independently, but they usually act in combination. Air movement and the enclosure's ability to be a barrier to air transfer from exterior to interior are interrelated with water control. Air contains water, and to keep the water out you need to keep the air out.

Air moves from higher pressure to lower pressure. If there is a pressure difference, air will move, carrying water in the process. Pressure-equalization is the principle of reducing air/wind pressure on the weatherproofing components of the enclosure, which is explained in more detail later in this chapter. This works to reduce the amount of water and the air/wind pressure, but not the quantity of air. Enclosures are designed with air barriers in a variety of ways. The air barrier must be continuous in three dimensions, be of a material or combination of materials of sufficient stiffness and strength to resist the air pressure differential, and be durable to withstand the construction process and perform during the enclosure service life. The location of the air barrier varies depending on the climate and the enclosure system design principle. This is explained in more detail in the "Design Principles" section of this chapter.

Defining Air Quantities and Direction

Defining air quantity is complex because of the dynamic nature of the exterior wind force and the multiple and varied pressures at locations on the exterior and interior of the enclosure. Air quantities used in the design of exterior enclosures are focused on an allowable amount of air leakage. All enclosures will have some air infiltration and exfiltration. The key is defining the acceptable level and developing a system that can meet that level or limit leakage to an amount below the allowable level. Referring to the filter analogy, air is more often selectively filtered from exterior to interior transfer. This is due to "real-world" design and construction inability to create a perfect air barrier in built reality. To determine an acceptable level of air infiltration, an allowable leakage is determined based on the linear length of openings in designs with air-impervious materials, and lengths of openings and material porosity in designs with air-pervious materials. There are multiple standards for design and for laboratory and field testing. This can be validated through testing for custom enclosures. Manufacturers of standard window and enclosure systems offer air leakage criteria that have been laboratory tested with their respective systems.

FORCE TYPE: TEMPERATURE

Exterior temperature ranges created by solar heat or cold are a dynamic force on the exterior enclosure. Temperature differences between the exterior and interior create heat flow through the enclosure. Heat flows by either: (1) conduction: direct transfer through materials, (2) convection: transfer by movement of heated gas (air) or liquid, or (3) radiation: transfer by waves through a medium such as gas (air) or a vacuum. Exterior and interior temperatures, along with thermal performance criteria specific to the building use, influence the type of cladding materials selected, the layers of materials in the enclosure assembly, and the type of insulation (R-value) required for controlling heat flow and therefore heat gain/heat loss. Temperature ranges also affect material expansion and contraction and the associated joinery design. Heat moves from hot/warm to cold. This is basics physics, so the exterior climate will determine whether the enclosure is transferring heat from the exterior to interior, or vice versa. Associated with temperature is condensation. As temperatures increase or decrease, there is the potential to achieve the dew point temperature on the enclosure assembly material surfaces. The enclosure materials selected for use and their placement in the system must be appropriate to the exterior to interior temperature differential.

Glass in vision areas functions more as a filter than a barrier to the temperature. Glass allows a percentage of daylight into the interior based on the glass assembly (single, multiple layers, or multiple layers with air space(s)) and coatings. Glass has a low R-value and is more conducive to heat gain/heat loss. This is more evident at the edges than in the center.

Glass also transmits heat through convection and radiation via air. Enclosure opaque areas offer opportunities for higher R-values with air space(s) and insulation and therefore a higher resistance to heat gain/heat loss. Metal framing components such as steel and aluminum are highly conductive and are the weakest thermal link in the enclosure system. Introducing thermal breaks in metals such as aluminum is a means to isolate the metal framing from direct exterior to interior temperatures. Thermal break locations determine a "thermal line" in metal, delineating exterior and interior. The goal is to locate as much metal mass to the interior of the thermal break line. This can improve the enclosure system's ability to resist or slow down temperature flow and energy transfer.

Exterior enclosures typically have transparent and opaque areas, so each must be evaluated and designed to determine the necessary R-value for each cross section, to address temperature. The exterior enclosure's ability to resist temperature differences between interior and exterior is related to the overall U ($1/R$) factors of the enclosure assembly. This is determined by the formula: $Uw = UiAi/Ag$, where Ui is the U value of a particular element or zone, Ai is the area of a particular element or zone, and Ag is the total wall area. This calculation is for conductance only and does not address convection or radiation due to solar effects.

Defining Temperature Range

To control heat gain or heat loss through the exterior enclosure system, exterior temperature ranges are established for heating and cooling seasons, on the basis of local climate data. Interior temperature and relative humidity design ranges are also established. These are relatively small ranges. Specific interior temperature and humidity range is linked to the building type and use. These are determined in consultation with the owner and the mechanical engineer. Once exterior temperatures for the building location and orientation and interior design temperature and humidity are established, the insulation R-value (and/or U-value) for the enclosure system can be established.

Each material and layer in the enclosure has some resistance to heat flow and its own unique insulation qualities. The variable is typically material density, thickness, and the location of the material within the system. Typically, heat flow is designed in a steady state one-dimensional flow. Heat flow, like design, is three dimensional. Daily ambient temperature ranges of 40°F +/− (4.44°C) and yearly temperature ranges between seasons of 100°F (37.78°C) are fairly common. Enclosure surface temperatures generated from direct solar exposure are much higher and are influenced by solar orientation and surface color. Surface temperature may range between 150° and 200°F (65.55°–93.33°C). For many materials such as metals with higher expansion/contraction coefficients, this has a definitive impact on joinery sizes. It is important to keep in mind that the larger or longer the material, the greater the expansion/contraction that each joint must accommodate.

Establish Design Performance Criteria: Temperature

Exterior temperature ranges create two design evaluations to determine the design criteria. These are: (1) controlling the passage of heat or cold through the exterior enclosure and (2) expansion and contraction of materials within the enclosure system.

Exterior temperatures are local climate dependent. Interior temperatures are building-use dependent. Local climate will determine if the performance criteria is to control heat gain, heat loss, or both. In hot climates the heat flow is from exterior to interior. In cold climates it is from interior to exterior. In mixed climates with both cold and hot seasons, heat flow is dependent on the time of year. Air flow through materials or at material intersections increases heat flow by bypassing materials. Joints or gaps between materials create thermal bridges. Design criteria are based on heat flow through full material cross sections, so gaps and discontinuities in materials must be avoided. Interior temperature and humidity are also influenced by quantity of occupants and other building systems such as lighting and equipment loads. These must be factored into the design criteria. Control of heat or cold through the enclosure influences enclosure design in the selection of materials, thickness in enclosure opaque areas, the extent and type of glass in the vision areas, and the joinery and attachment method of cladding and materials within the enclosure. To establish the extent of vision to insulated opaque areas, the R-value (thermal resistance) or the U-value (overall heat transfer coefficient, 1/R) must be defined in collaboration with the building mechanical engineer.

ELEMENT AND FORCE TYPE: SUNLIGHT

Sunlight consists of electromagnetic radiation in wavelengths of infrared light, visible light, and ultraviolet light, and it is a dynamic force on the exterior enclosure. Much of the energy from the sun consists of infrared radiation. This wavelength accounts for approximately half of the heating of the earth. Sunlight creates exterior temperature ranges, associated heat gain through the enclosure materials, and material surface temperatures discussed in the previous sections.

Sunlight incident on the enclosure determines the amount of light transmission through transparent openings by either direct or diffuse light. The design goal is to admit natural light and, depending on climate, to maximize or minimize the solar temperature heat gain/loss effects. Sunlight is a force for which the enclosure acts as a selective filter. Allowing natural light into a building through the exterior building enclosure is a design balance of light transmission and heat/glare control.

Sunlight ultraviolet (UV) wavelengths have distinct effects on materials, ranging from color loss to material degradation. Finishes will fade, chalk, and discolor with prolonged exposure to sun. Sealants and gaskets will dry and deteriorate at more rapid rates with prolonged exposure to sun.

Sunlight and the effects of shading and partial shading are particular design considerations for glass. Partial shading for tinted, coated, and annealed glass can create glass stress and the potential for breakage. Sunlight and shade exposure should be carefully considered as glass selection criteria.

Defining Sunlight Control

Determining sunlight and light incident on and entering the enclosure can be done through solar angle studies for the enclosure orientation. These can be evaluated at select seasonal times for sunlight altitude and azimuth as shown in earlier figures of this chapter. Computer programs have expanded the capacity to analyze multiple design options for glass type selection and the viability of exterior and interior shading controls.

Defining the amount of natural light is directly linked to temperature control. Building orientation and the location of transparent areas of the enclosure are the most direct means to achieve natural light levels within the building. Sunlight transmitted to the interior is measured in foot candles (FC). Building use determines design foot candle levels for natural light.

FORCE TYPE: SEISMIC

Seismic movement creates ground motion. This ground motion creates forces that are transferred through foundations and into the primary building structure, creating a sway or “drift” in the building structure during a seismic event. Seismic drift is similar to wind drift in that the primary building structure—and therefore the enclosure—will move. For exterior enclosure design in seismic zones, the larger of the wind or seismic drift will govern. The enclosure drift design is similar to the illustrations shown previously for wind drift.

Defining Seismic Drift

Seismic drift is defined as the differential movement of one floor over another above or below. Seismic drift is defined by the structural engineer. Drift can be defined as a percentage of movement over a height, or as a numerical value off-center over a height. It is more effective for the structural engineer to define numerical movements from floor to floor rather than a span/number. There are two levels of drift. These are (1) Delta “S” for serviceability drift and (2) Delta “M” for maximum drift.

Seismic Performance Criteria

Enclosure performance criteria for seismic event levels are different. Delta “S” (serviceability) means that the enclosure should be fully functional after this level of seismic event and the resulting building and enclosure movement. Delta "M" (maximum) means that the enclosure may have minor deformation damage with no breakage or structural disengagement. Framing and anchorage may experience slight deformation, but should remain intact. Infill materials may be damaged but are not designed or permitted to evacuate the openings.

FORCE TYPE: BLAST

Blast events create large pressures on the enclosure for very short durations. The pressures are positive shock waves followed by negative shock waves. In addition to the blast pressure, there are fragments and projectiles propelled by the blast.

Defining Blast Pressures

The actual characteristics of blast waves are complex. Specialty consulting structural engineers are required to provide the design blast pressures. The size of the blast charge and the distance from the charge to the enclosures will determine the pressure and the duration. While similar to wind pressure, the pressure magnitudes are extremely high and the duration is extremely short. Wind pressures are measured in lb./sq. ft. (kg/sq. m), while blast is measured in lb./sq. in. (kg/sq. mm), and the duration or impulse is measured in milliseconds for blast and seconds for wind.

Defining Blast Performance Criteria

In contrast to the effect of wind forces, the exterior enclosure will suffer damage in a blast event. This is due to much higher pressures than those created by wind pressure, and to damage from projectiles and debris generated by the blast. The performance goal for the enclosure is to protect the occupants. The enclosure framing will deform but cannot disengage. The infill, glass, or other materials can crack or experience damage but are not permitted to evacuate the openings, leaving the occupants vulnerable. System anchorage is designed for strength and cannot fail or disengage in a blast event.

FORCE TYPE: WATER VAPOR/ CONDENSATION

Control of water vapor and prevention of condensation are interrelated with temperature and heat flow. After water penetration, condensation is the most often reported enclosure performance issue. Just as heat flows from warm to cold, so does moisture. Air goes from higher to lower pressure, and air carries water and water vapor.

Defining Water Vapor/Condensation

Climate and the interior temperature and humidity design requirements influence water vapor transfer physics and the potential for condensation. Condensation is the change of vapor to liquid. Condensation occurs on surfaces which are cooler than the dew point temperature of the air containing vapor. As the air cools due to the cooler surface, the air is unable to retain the moisture, thereby releasing it in the form of water. Materials are either impervious or permeable to liquid water and to water vapor flow. Enclosure materials should be selected and located in the assembly with an understanding of vapor resistance or permeability. The location of an air barrier or vapor barrier should be based on climate, interior humidity and temperature, an understanding of the enclosure layers and the temperature in relation to the dew point, and consultation with the project's mechanical engineer.

Defining Water Vapor/Condensation Criteria

Design for condensation resistance is effectively a design to minimize the frequency and extent of condensation formation. There will be extreme conditions beyond the project's and building enclosure's basis of design, where some condensation may occur. The enclosure composition and materials should be arranged and designed to minimize the possibility of condensation and to allow drying of materials as temperatures and humidity return to the design range.

Condensation design criteria is related to temperature changes, which is related to moisture content in the air, which is inextricably linked to regional climate and building use. The base criteria is simple—no condensation—particularly internally within areas of the enclosure that are not vented and drained. In consultation with the mechanical engineer, determine the dew point temperature. After review of the climate data, select a location for the air/vapor barrier. This is located toward the warm side. Test thermal gradients through the enclosure section to determine if the dew point temperature occurs on surfaces of materials within the enclosure. Allow for a drying profile. Example wall section diagrams are shown in Figure 1.22.

FORCE TYPE: NOISE/ACOUSTICS

Traditionally, noise transmission is identified with exterior traffic, aircraft, railway, or other human-created noise. Natural noise generation can originate from water, wind, and thermal exposure; the latter creates sounds as a result of material expansion and contraction.

Defining Noise/Acoustics

Noise is defined in decibel ratings. The higher the decibel rating, the higher the noise level. The enclosure can be designed to a minimum acceptable transmission loss (TL) or Sound Transmission Class (STC). STC is the noise reduction of a material or an assembly of materials measured in a reverberation chamber. The TL or STC rating can be established in different ways, ranging from simple handbook approaches to more sophisticated analysis. In designs where the enclosure exterior encloses sound/noise-sensitive uses, it is advisable to engage an acoustic consultant to collaborate on determining the enclosure minimum performance criteria values.

Acoustical characteristics of the enclosure system and components include sound absorption and transmission loss. Sound absorption is the ability to control reflected sound through a material's or assembly's capacity to absorb noise. Noise reduction

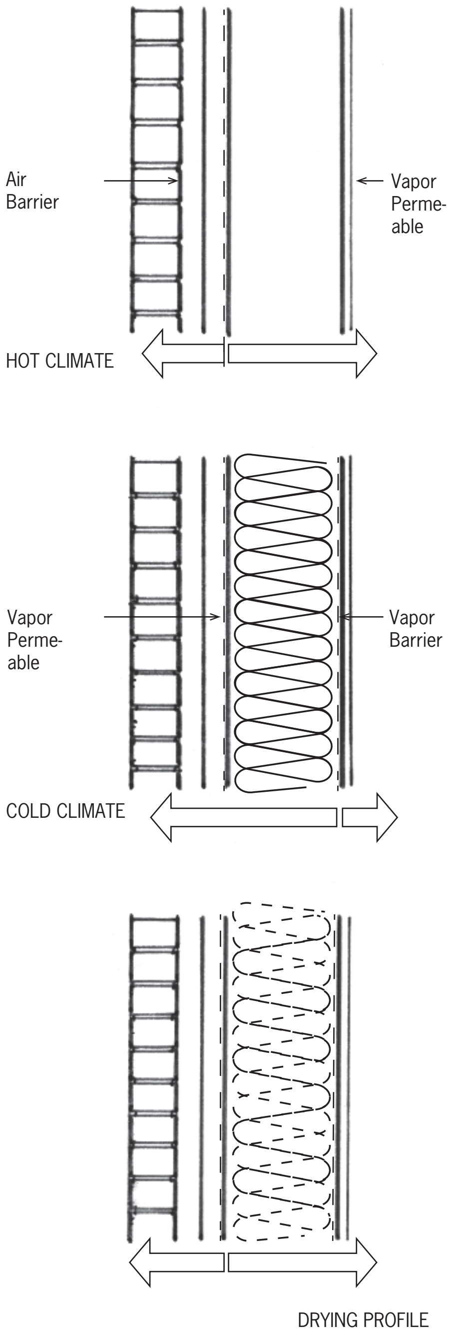


FIGURE 1.22 Vapor flow drying profiles. Vapor flow will influence the design and location of the vapor barrier. The enclosure materials must allow drying. Note: These are just a few basic examples. Each climate and enclosure assembly will yield specific design information.

coefficient (NRC) is the percentage of sound absorbed by a material under specific test procedures. Transmission loss is a measure of attenuation through an enclosure material or system.

Defining Noise/Acoustic Performance Criteria

The TL, STC, or NRC is dependent on the building's interior functional requirements and the composition of the enclosure. The design noise/acoustic level for the interior should be established in collaboration with the owner, acoustic consultant, and architect.

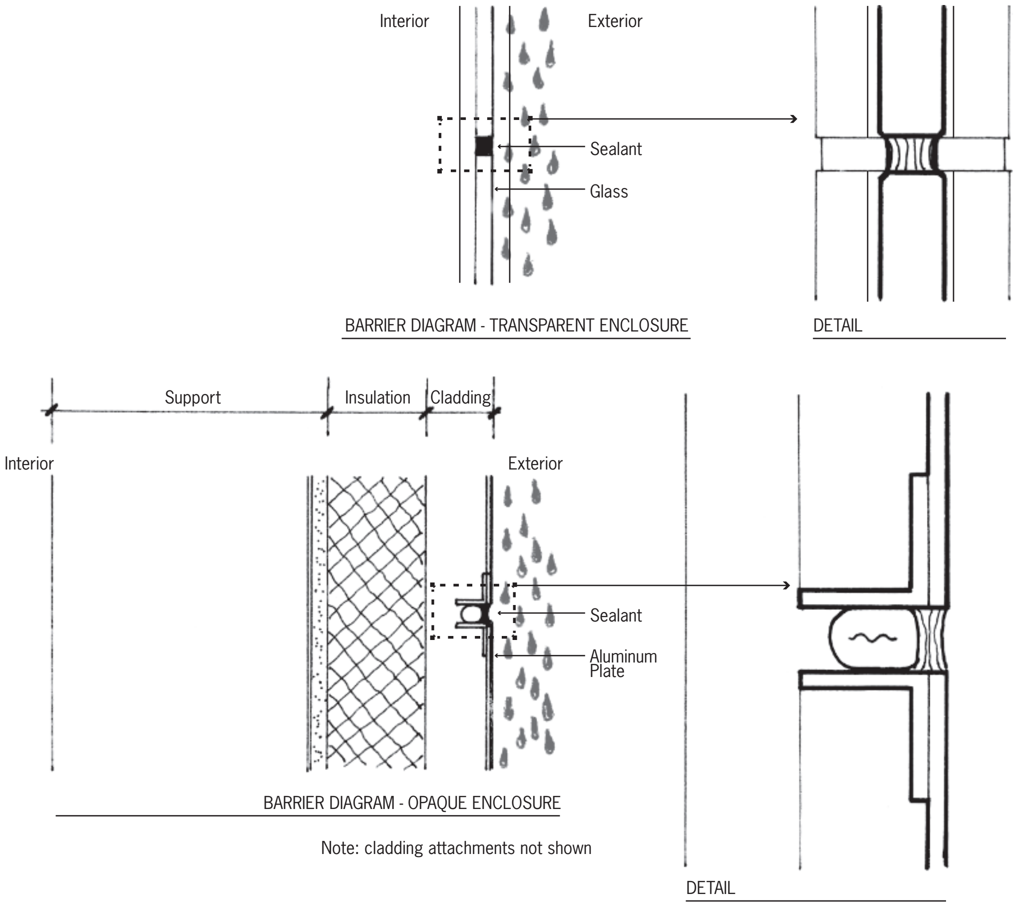
To determine the TL, STC or NRC enclosure value, the opaque and vision areas are typically considered separately and evaluated as a unified system. The vision area TL or STC is dependent on the glass thickness, the glass assembly, and the method of glass attachment. Glass thickness and its sound reduction capacity are mass dependent. Stated simply, the more mass and more flexible the material, the better it performs at reducing sound transmission. Thicker glass will transmit less sound than thinner. Laminated glass with polyvinyl butyral (PVB) or other types of interlayers aids in reducing noise transmission. Asymmetrical laminated glass assemblies utilize mass, the interlayer material, and variable mass to further reduce noise transmission. Opaque areas utilize a similar approach with usually thicker materials and the opportunity for insulation, which can perform dual roles of thermal and sound control. Specific STC rating levels can be approximated. To obtain actual STC rating levels on custom or standard system enclosures, testing mock-ups must be performed at certified testing laboratories.

Design Principles

There are performance design principles that can be utilized to control air infiltration and manage water penetration. Other elements and forces such as temperature, sunlight, condensation, and noise are controlled by cladding materials, glass selection, insulation, material type/placement/thickness/quantity, material and component placement and spacing, and building orientation. These elements and forces should be evaluated in concert with air and water management. Each principle described below has its own merits, complexities, and sometimes shortcomings. Certain enclosure systems and materials will influence which principle or which combination of design principles is appropriate. The following enclosure performance design principles focus primarily on air control and water management. These are: barrier, mass, rain screen, and pressure-equalized rain screen.

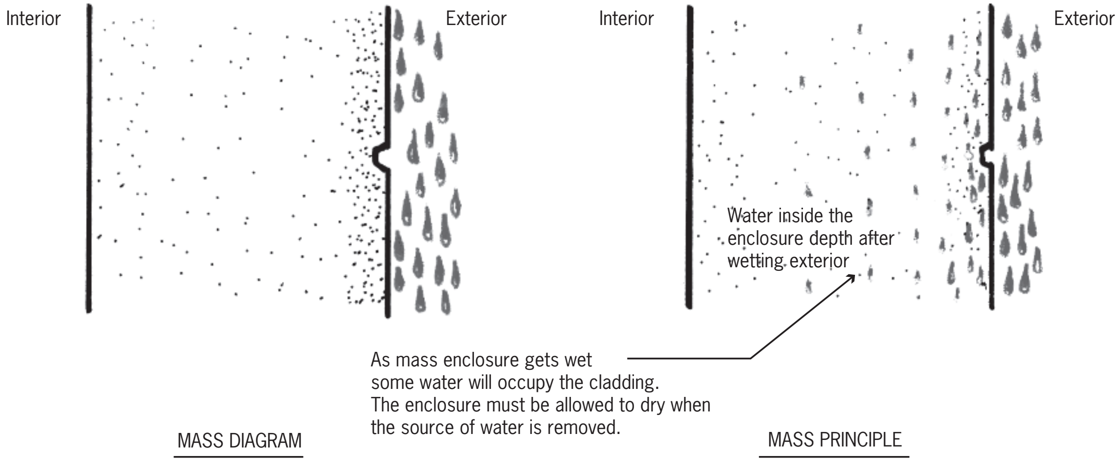
BARRIER

The barrier design principle relies on an assembly of water-impermeable exterior materials and sealed joints. This means every surface, recess, opening, joint, and joint intersection is completely and continuously sealed to keep air and water to the exterior of the enclosure. This method relies on perfection. No design is perfect, and construction is not perfect either. While the openings, joints, and their intersections may initially be installed to provide a consistent and continuous barrier of air- and water-impermeable materials, natural forces such as ultraviolet sunlight, wind, or resulting movements will eventually degrade the barrier usually at the joinery. Barrier designs usually rely on sealants as the primary material to provide the weather protection continuity at cladding material joinery. It should be noted that, strictly speaking, porous materials such as natural stone, concrete, and wood are not primary candidates for a barrier method; they serve only as the secondary water control, since these materials may allow the passage of water or moisture to the interior surface through the material. Gutter and other collection methods on the interior of the exterior material are discussed in the Rain Screen section. The joinery, joinery material, and intersections, when properly detailed and installed, are a continuous barrier. However, if the primary enclosure material is a porous cladding material, the system utilizing a barrier principle is not weathertight. Two examples of the barrier principle are illustrated in Figure 1.23.



Note: cladding attachments not shown

FIGURE 1.23 Two examples of the barrier design principle. Cladding materials shown are impervious to water penetration. Seals at joints must be continuous with no irregularities or openings, to achieve a successful barrier design.



As mass enclosure gets wet some water will occupy the cladding. The enclosure must be allowed to dry when the source of water is removed.

FIGURE 1.24 The mass design principle relies on the exterior enclosure material density and thickness. Exposed architectural concrete and architectural precast are examples of materials that employ a mass design principle.

MASS

The mass design principle relies on a combination of material thickness, storage capacity, and material density to resist air infiltration and water penetration. Architectural concrete, precast architectural concrete, and natural stone in thicker cross sections will often employ a mass principle. Joinery between mass materials or between mass materials and systems such as glass in openings typically utilizes a barrier principle in the form of sealant or gaskets. Joints in thicker mass-principle enclosures often utilize a dual line of sealants or gaskets. These may be continuous or have openings in the exterior line to pressure-equalize the cavity between seal lines. Pressure-equalization is discussed later in this section. When implementing the mass principle, attention should be paid to rainwater penetration, potential storage capacity of moisture in the mass material, air/water ingress at cracks, and the drying effects to the interior and the exterior. An example of the mass design principle is illustrated in Figure 1.24.

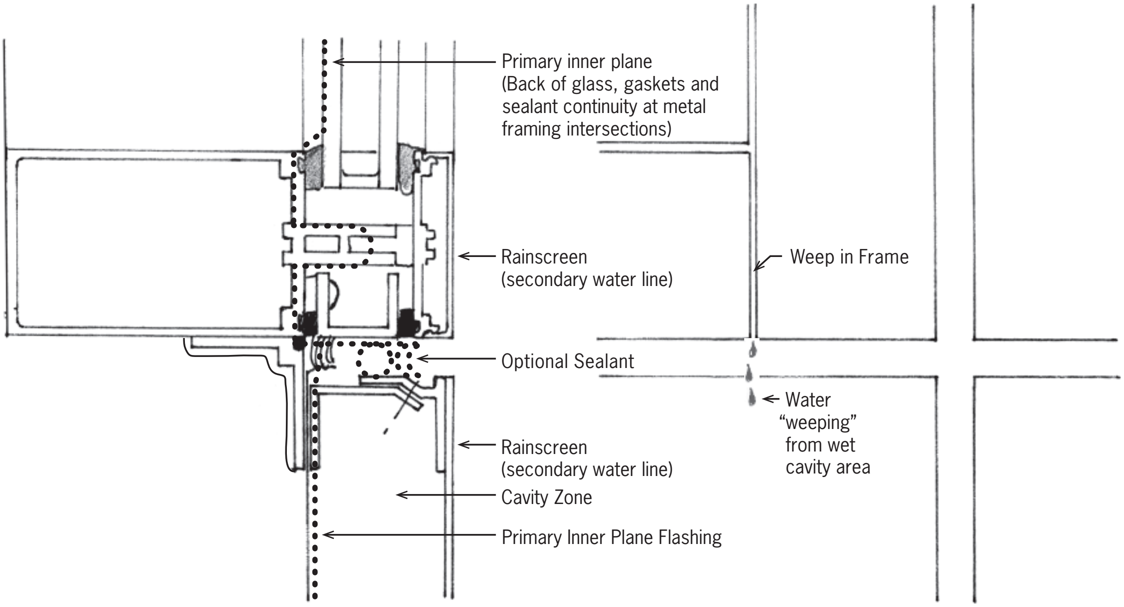
RAIN SCREEN

The rain screen design principle establishes two separate and distinct planes with a cavity between the planes. The outer exterior plane is a cladding material keeping the majority of the water on the exterior side of the enclosure. Joints between exterior cladding materials are either sealed or gasketed with sufficient openings and baffles (protection) to prevent significant water penetration. The inner plane is the barrier plane resisting air infiltration and the reduced amount of water. In a rain screen design approach, the design must provide layers and zones to reduce the quantity of water infiltrating from the exterior plane to the interior air (and water) barrier plane. The planes and zones are:

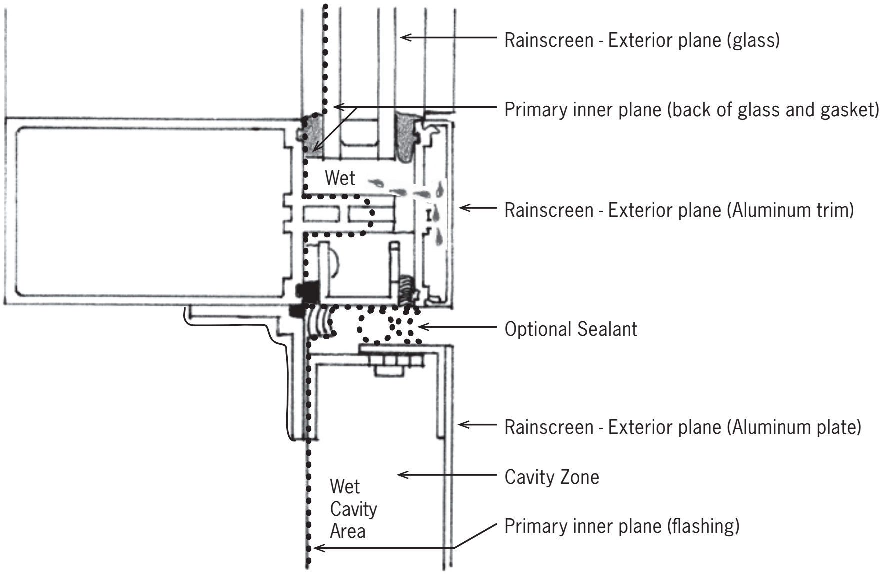
1. An exterior control plane sheds the majority of water. This plane is considered the secondary line of water protection.
2. The joinery in the exterior plane—both horizontal and vertical—is designed to minimize water penetration. The water that does penetrate the joinery is controlled and collected in the cavity zone, usually at horizontal locations and drained to the exterior.
3. A cavity zone between the exterior plane and the inner plane, of sufficient width to allow air circulation between the two planes. The depth of the cavity is dependent on the exterior plane material and on the presence or absence of insulation within the cavity zone. This cavity zone is considered a "wet cavity area," and the materials selected and located in the cavity must be capable of performing properly when wet.
4. A primary inner plane provides a continuous air and water barrier separating the cavity zone from the interior building spaces. This plane is considered the primary line of air and water protection.

When viewed in plan or section, as shown in Figure 1.25, the concept is direct and easily understandable. Architectural design and detailing is a three-dimensional effort. The joinery material configuration and size in plan and section of the exterior rain screen plane and the joinery intersections determine the quantity of water in the cavity. The inner plane providing a continuous air and water barrier must also be designed to accommodate building movement. The resulting building movement joinery must continue the primary air/water barrier, accommodate movement, and, because of the difficulty of maintenance access, have a long service life. All of these requirements can be achieved, but the importance of proper material selection, detailing, and installation is critical.

Publications, papers, and other printed material utilize a variety of descriptive terms such as "primary barrier" and "secondary barrier," and interchangeably assign these to either the exterior plane or inner plane. For the rain screen design principle described, the primary line of protection for air and water control is defined as the inner plane. This plane is a continuous separation of air and water between the interior building spaces and the exterior. The secondary line for water control is the exterior plane and the associated joinery with baffles or openings to allow drainage of the cavity. The secondary line deflects the majority of rain and allows air within the cavity zone. The delineation of the primary and secondary line is



SECTION ELEVATION



PLAN

FIGURE 1.25 The rain screen principle relies on a continuous inner air and water barrier plane, a cavity space, and an outer rain screen plane with joints designed to allow water to evacuate the cavity space. The joinery material is shown as "optional sealant". The greater the opening area in the rain screen plane, the greater quantity of water on the primary plane and cavity area.

shown on an opaque and transparent enclosure wall in Figure 1.26 and 1.27.

PRESSURE-EQUALIZED RAIN SCREEN

The pressure-equalized rain screen assembly combines the rain screen principle with a compartmentalized air chamber space in order to achieve an equal or near equal pressure between the exterior side of the enclosure and the cavity or air space separating the primary inner air and water line and the secondary (exterior) water line. The reason for the compartmentalized air space is that pressure-equalization can only occur within limited periods of time. Compartmentalization is essential since wind pressures across the face of the enclosure are dynamic and constantly changing. Reducing or removing the force moving water through the joints means that the materials and joinery of the inner layer "see," and therefore have to resist, less water. The reason for saying "less" instead of "no" water is that often the outer, or secondary, layer is a porous material that allows some moisture migration through the material itself or through joints in the exterior enclosure material into the cavity.

The pressure-equalized rain screen assembly consists of an outer layer (the rain screen), an air space, compartments within the cavity, and an inner wall or material that is impermeable with joints sealed, gasketed, or lapped and sealed. The air space cavity and the edge compartments define the pressure-equalized chamber. An example of this assembly is shown in Figure 1.28. The pressure in the cavity space is maintained to an equal or almost equal pressure with the air pressure toward the exterior of the rain screen. This equal pressure removes the force; therefore, a high percentage of the water remains on the exterior side of the rain screen. Since water may occasionally penetrate the rain screen through joints or the rain screen layer, the air space should allow drainage to the exterior. Insulation that is capable of withstanding moisture may be included in the cavity of a pressure-equalized assembly.

There are several familiar examples of rain screen/pressure-equalized assemblies, such as some wood-frame construction with a waterproof material on the exterior face of the framing and wood siding as the rain screen and blocking in vertical locations, some metal-framed or masonry inner wall with waterproofing, and a masonry veneer of brick or natural stone with air chamber compartments defined with horizontal and vertical definition; and certain window wall or curtain wall systems. Each of these assemblies has an air/water barrier on the inner surface of the air cavity. The inner wall is the primary air and water line, and the rain screen is the outer secondary cladding water line. Each pressure-equalized cavity assembly is drained to the exterior. The extent of the air cavity is determined by the placement of the primary line, the depth of the system, the boundary or delimiter edges that define the chamber, and the placement of the secondary rain screen line. An example of a pressure-equalized rain screen window wall is shown in Figure 1.28. The transition of the primary line in the window wall example to the spandrel at the head and sill requires knowledgeable and sometimes clever detailing to maintain the continuity of the primary line. An example of a unitized curtain wall that employs the rain screen pressure-equalized principle is shown in Figure 1.29. The primary difference is the size of the pressure-equalized chamber.

Corner intersections at both outside and inside conditions provide tremendous design opportunities and detailing challenges. Corner joinery has significant visual implications on and for the design intent. Examples of multiple corner configurations utilizing this principle are illustrated in the systems/case studies in chapter 8—Metal Framing and Glass. In addition to the visual composition of the corner and its design implications (performance principle and visual), the internal workings of insulation (thermal protection and R-value), air and water protection, and glazing (for solar control) must have a consistent detailing approach for the primary and secondary lines of protection defined in the enclosure wall plane.

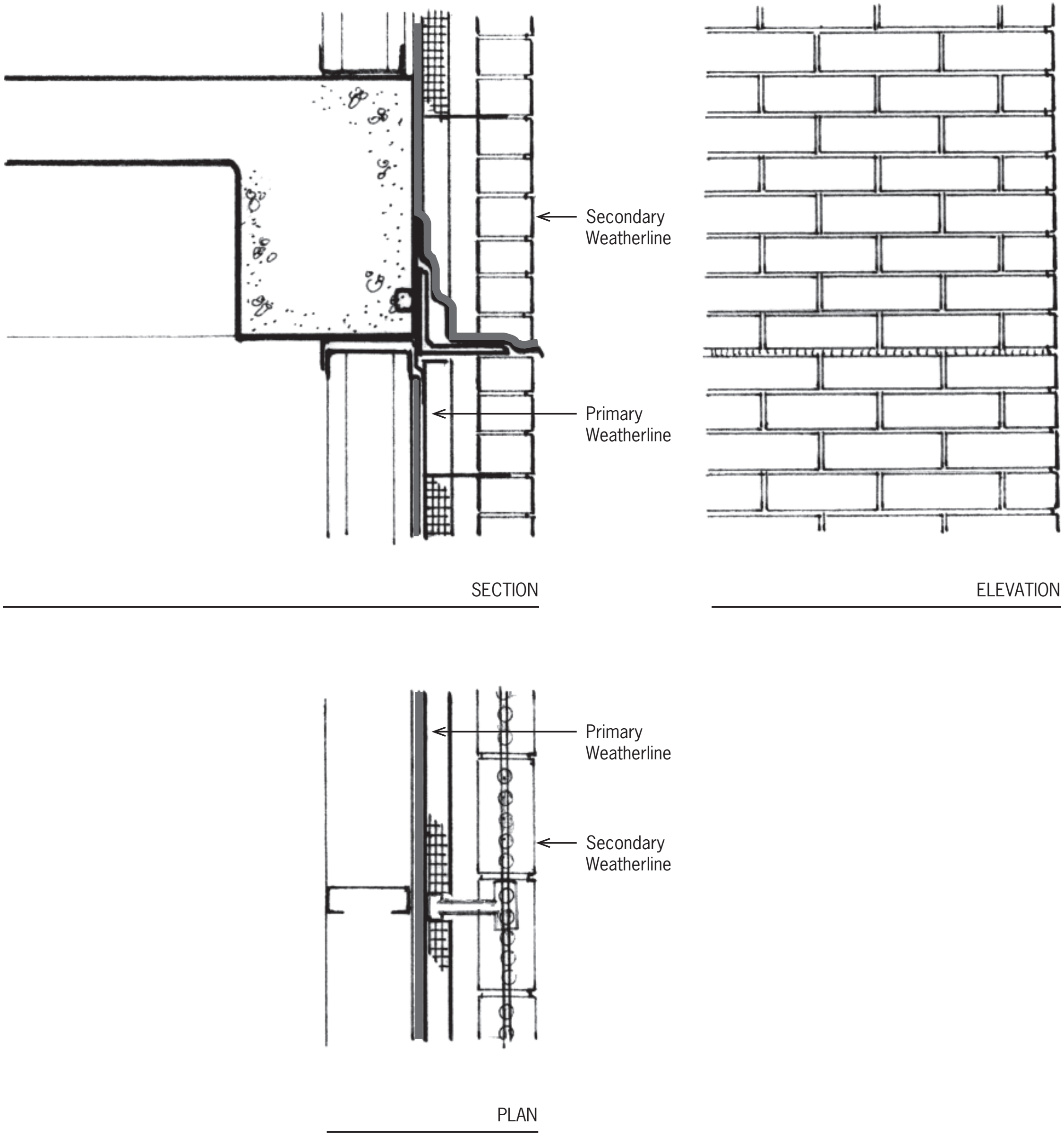
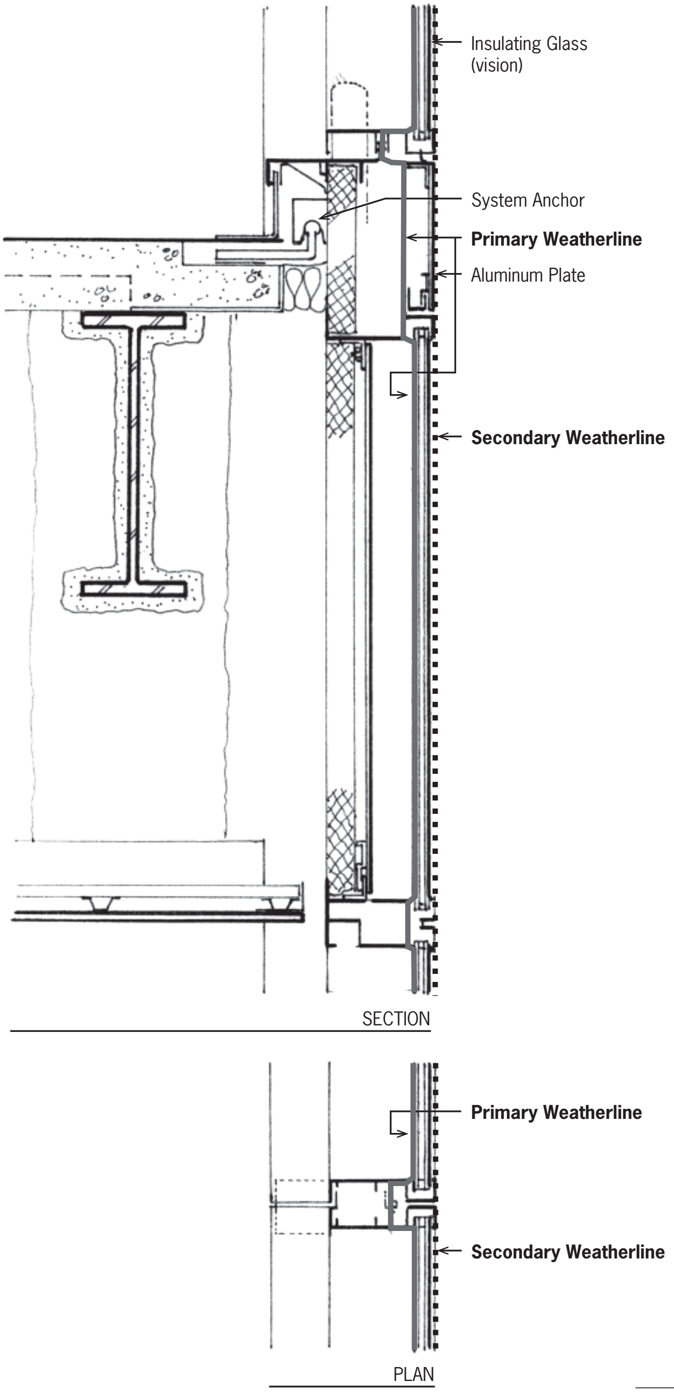


FIGURE 1.26 Brick masonry wall enclosures utilize primary and secondary weather protection lines.



PRIMARY AND SECONDARY WEATHERLINE

OPAQUE AND TRANSPARENT ENCLOSURE WALL

FIGURE 1.27 Curtain wall enclosures utilize primary and secondary weather protection lines. The primary (or inner) line can be located in various locations, depending on the system design.

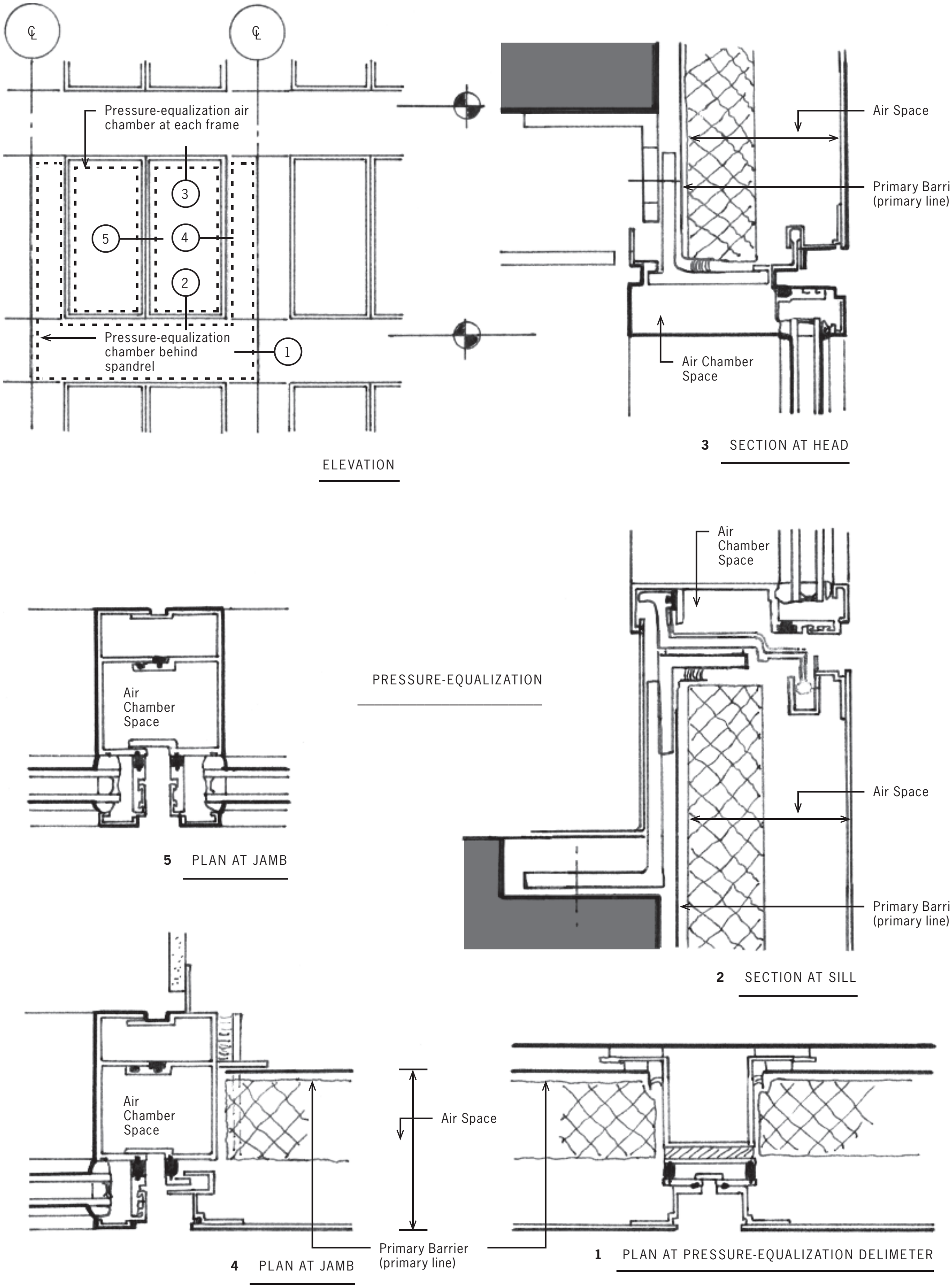
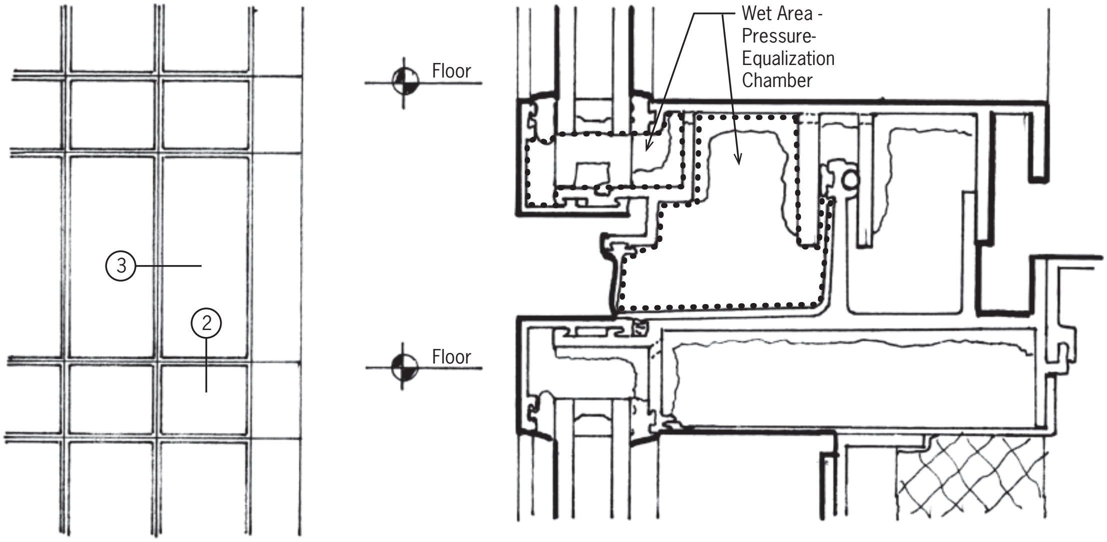
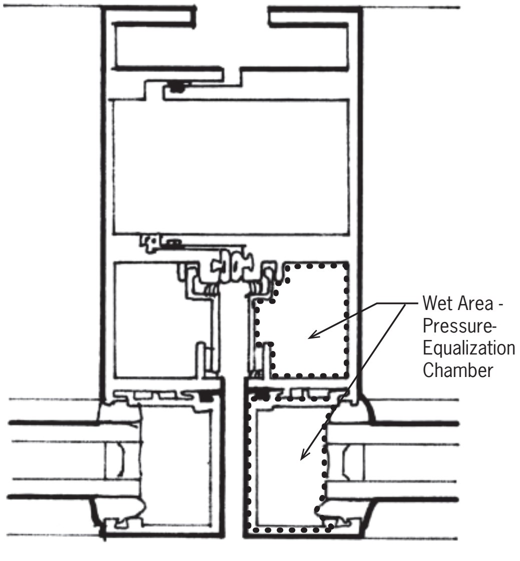


FIGURE 1.28 The pressure-equalization principle relies on a continuous primary weather protection line with ends—or delimiters—to define the pressure-equalization chamber.



1 BUILDING ELEVATION

2 SECTION DETAIL



3 PLAN DETAIL

FIGURE 1.29 The pressure-equalization principle in a unitized curtain wall.

Basic Types

The visual character, compositions, and materials in exterior enclosure systems are too numerous to count or classify. There are, however, three basic types of enclosures:

1. Standard
2. Customized standard
3. Custom

All of these three types can provide the intended functions, withstand the elements and forces, and adhere to one of, or a combination of, the weather protection design principles discussed earlier. Building designs often include multiple enclosure types where two or all three types will occur. While each must be designed and detailed with its own composition, materials, and performance requirements, the intersection of one system to another offers unique design and technical challenges and opportunities.

STANDARD ENCLOSURE SYSTEM

A standard exterior enclosure system is composed of materials, components, and details that have been designed and tested to certain performance criteria by a manufacturer. The composition of the materials can be modified to comply with the architectural design intent, within the qualifying parameters of the manufacturer. There are hundreds, if not thousands, of manufacturers' standard exterior enclosures. Standard enclosure systems have been developed by manufacturers to optimize repetition, manufacturing, or any number of efficiencies. Discussions with manufacturers regarding the specifics of their systems, to ascertain if the standard system can comply with the intended functions, accommodate the elements and forces defined for the project, and meet the visual design intent, are essential.

CUSTOMIZED STANDARD

There are times when a custom-designed enclosure may be above the project performance requirements, exceed the project budget, or simply not be applicable. There are times when a manufacturer's standard enclosure system meets several, but not all, of the project requirements. In these "in-between" scenarios, customizing a standard system may offer the most applicable and advantageous solution. When customizing a system, the extent of customization should be discussed and reviewed with the manufacturer. Some offer "stock customized" options. These are modifications that have little or no effect on performance, and are similar to options available on an automobile that can be incorporated, with the associated costs related to the level of customization. Further customization can be either modifications to visual components, such as trims, features, colors, and the like, or performance modifications to enhance the structural or weathertight performance to which the system has been previously tested or engineered to achieve.

CUSTOM ENCLOSURE SYSTEM

A custom exterior enclosure system is exactly what its name states. The materials, components, assembly, composition, and performance requirements are designed, fabricated, assembled, and installed specifically for a project. Custom enclosure walls range from familiar and recognizable systems such as brick masonry to exotic custom glass and curtain wall enclosure systems. There are many factors in the selection and design of a custom enclosure. The performance requirements necessary to resist the anticipated forces may exceed what is available from a standard manufacturer's system. The intended functions of specialized building types may require a project-specific solution. In many instances, a custom enclosure may be necessary to achieve the design intent.

Examples of all three enclosure system types are included in the system descriptions and case study sections of chapters 5 through 9.

Interfaces of Enclosure Types

There are occasions in building designs when a single enclosure system—whether custom, standard, or a customized standard—will suffice for the full extent of the enclosure. More often, building design solutions require multiple enclosure systems to achieve the visual, performance, and cost requirements of the project. The design challenges and opportunities occur in the interface between systems.

In these cases, individual requirements of each enclosure must be studied, identified, and documented with the additional level of design and detail on the system interfaces. The continuity of the primary air and water line must be maintained through the interface and transition. The location of the primary line may shift, but it must be continuous. It is helpful to design and detail this continuity by "tracking" a line where the pen or computer line never leaves the surface of the paper. If the "pen line" has to be picked up or can't bridge the transition, there is a discontinuity, which will allow air, water, sound, or other exterior elements and forces to penetrate the enclosure. It is also helpful to remember that any shifts in location are three-dimensional. This means that a plan shift often results in a section shift, and there is always a corner transition, which requires careful thought on material selection and constructability. Examples of continuous plane transition (no shift) and shifts in the plane of the primary air/water line are shown in the systems/case study chapters 5 through 9.

Summary

Exterior enclosure design, like building design, is a process. The process is tailored to the specific needs of the project, but it must define and answer the five W's: What, Why, Who, Where, and When, as well as one H: How, in order to be a complete process. This chapter has begun to define What and Why. What is the extent of the exterior building enclosure? What are the intended functions, and why do they influence design? What are the elements and forces acting on the exterior enclosure, and what do they influence? What are some performance principles? What are the types of exterior enclosure systems?

The topics identified are applicable in part or whole to all exterior enclosures and their design. These are the basics and may still appear abstract until applied. Subsequent chapters will address: Who are the participants, and what are their roles? What levels of design are addressed, and when do they occur in the design process? What are the levels of collaboration, documentation, and coordination, and when do they occur in the process? What occurs in the construction phase, and who is responsible for what? Why were certain enclosures selected for the building design? Where are examples of the basics applied to actual case studies? How does it all come together in architecture?