EXTERIOR BUILDING ENCLOSURES

Design Process and Composition for Innovative Facades

C. Keith Boswell, FAIA

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Finally and most of all, thank you to Cathy Boswell. You are my biggest supporter and critic. Your patience, encouragement, and unwavering commitment are the reason I get up every morning.

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

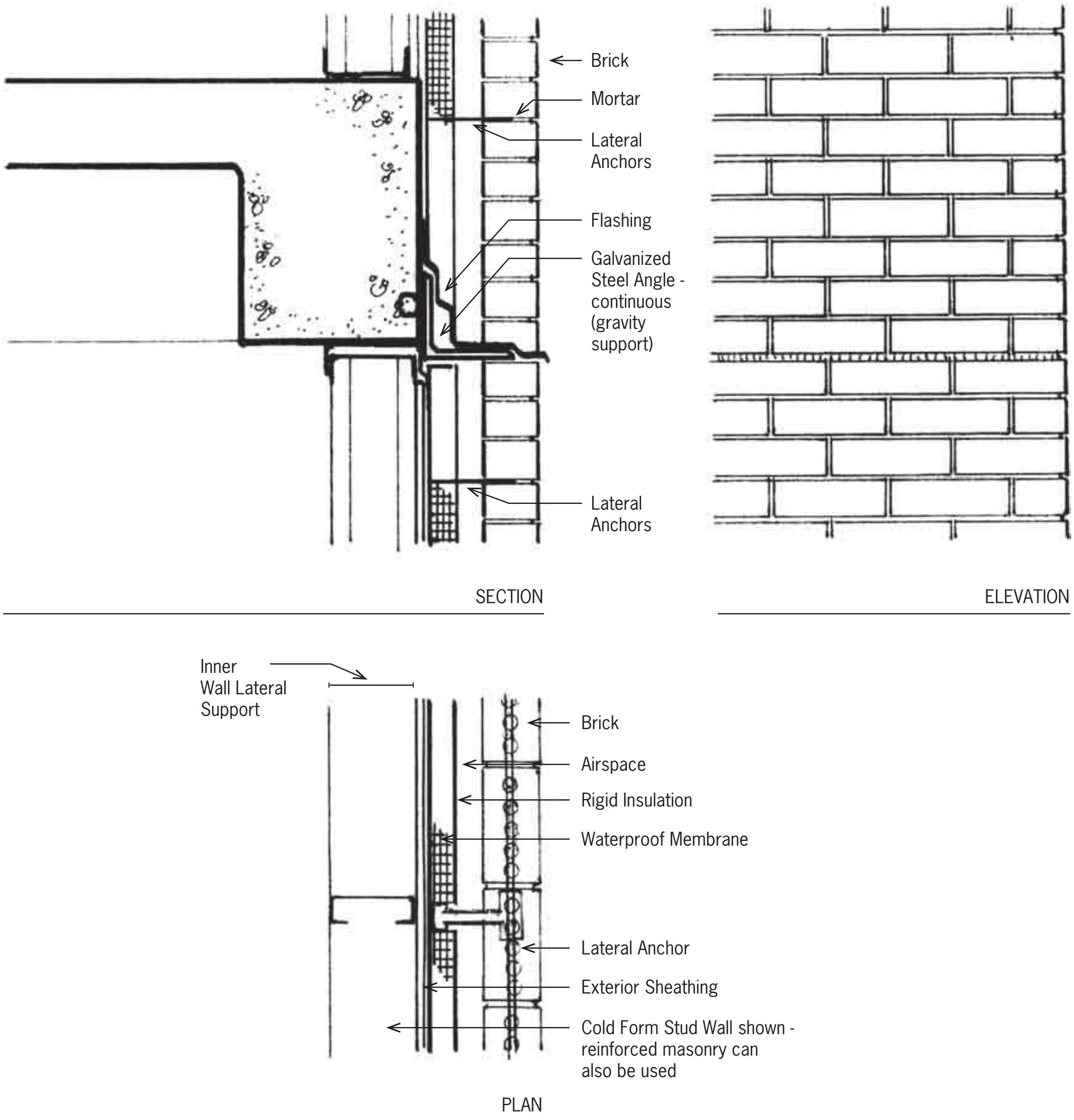

FIGURE 1.1 Materials and components must work together as an assembly in an exterior enclosure system. Brick masonry wall systems rely on a gravity support for the brick self load, the inner wall for lateral support, lateral anchors spaced appropriately, and the brick and mortar for the enclosure system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

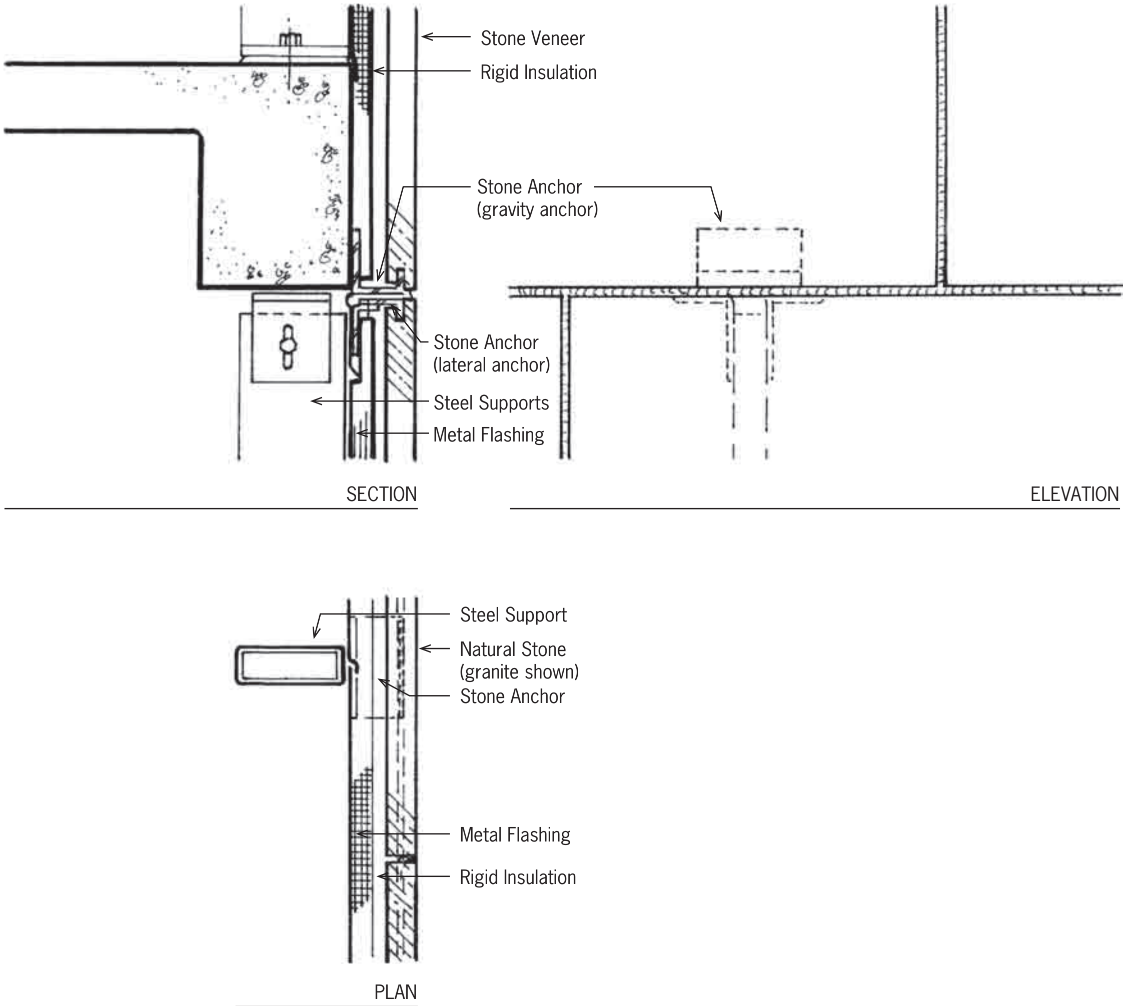

FIGURE 1.2 Framed masonry natural stone wall systems rely on the primary building structure and the steel supports illustrated for gravity and lateral support. The stone itself accommodates and transfers lateral loads to the stone anchors, and the stone anchors support the stone self/dead and lateral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

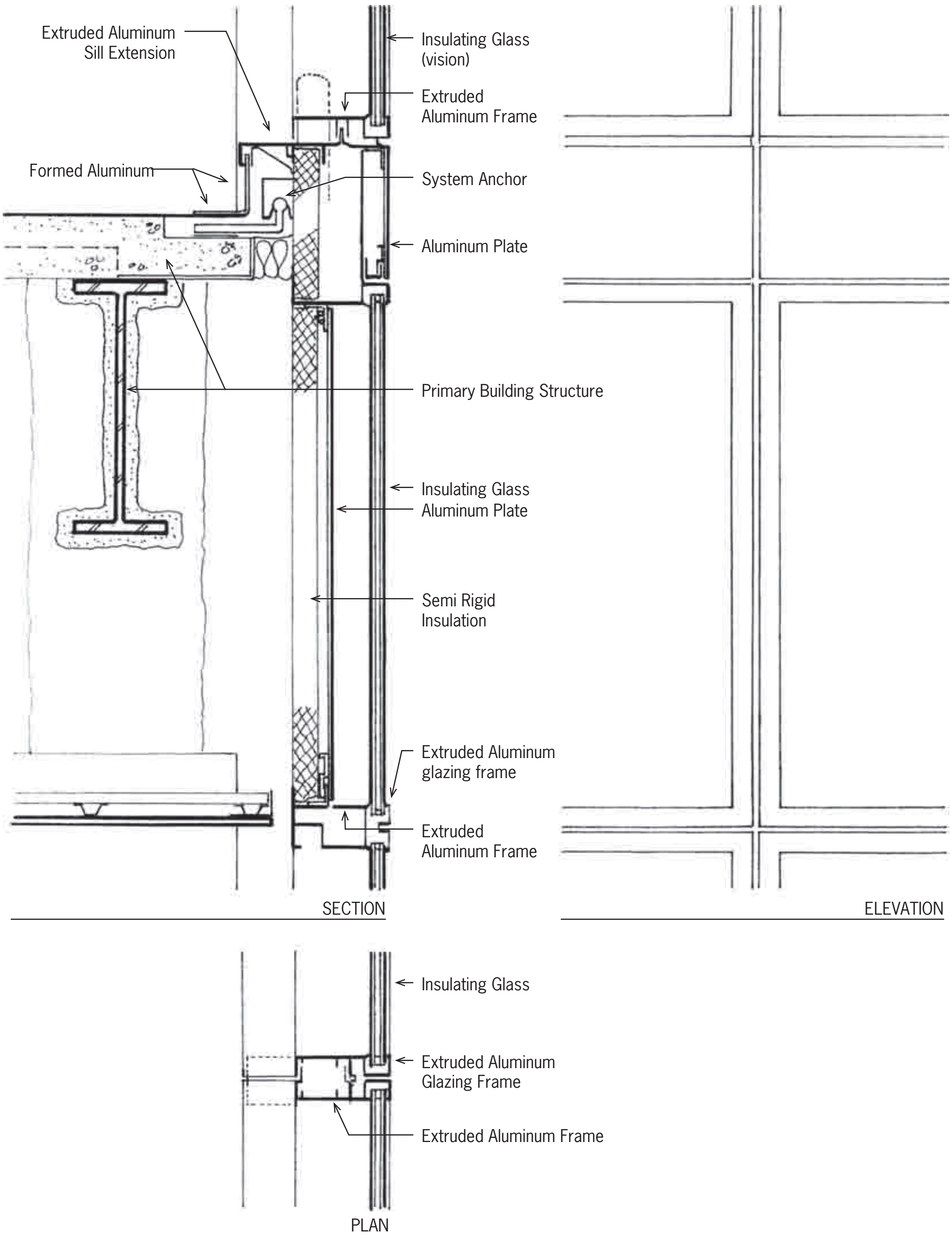

FIGURE 1.3 Curtain wall systems rely on the system anchor to support the enclosure system dead load. The glass and aluminum plate accommodates and transfers lateral loads to the extruded aluminum frame for the enclosure system structural integrity. The extruded aluminum frame carries the dead load of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

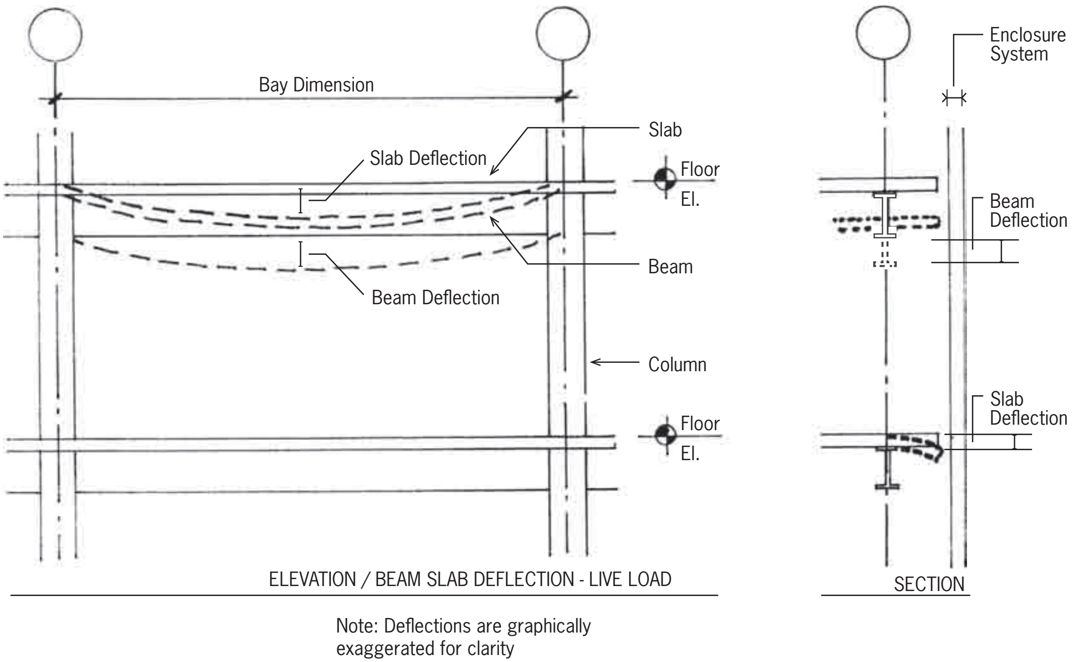

FIGURE 1.4 Primary building structural elements react to loads imposed. Imposed loads include dead loads and live loads that create structural deflections that must be addressed in the enclosure design. Note both deflections shown in elevation and section can occur simultaneously.

(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

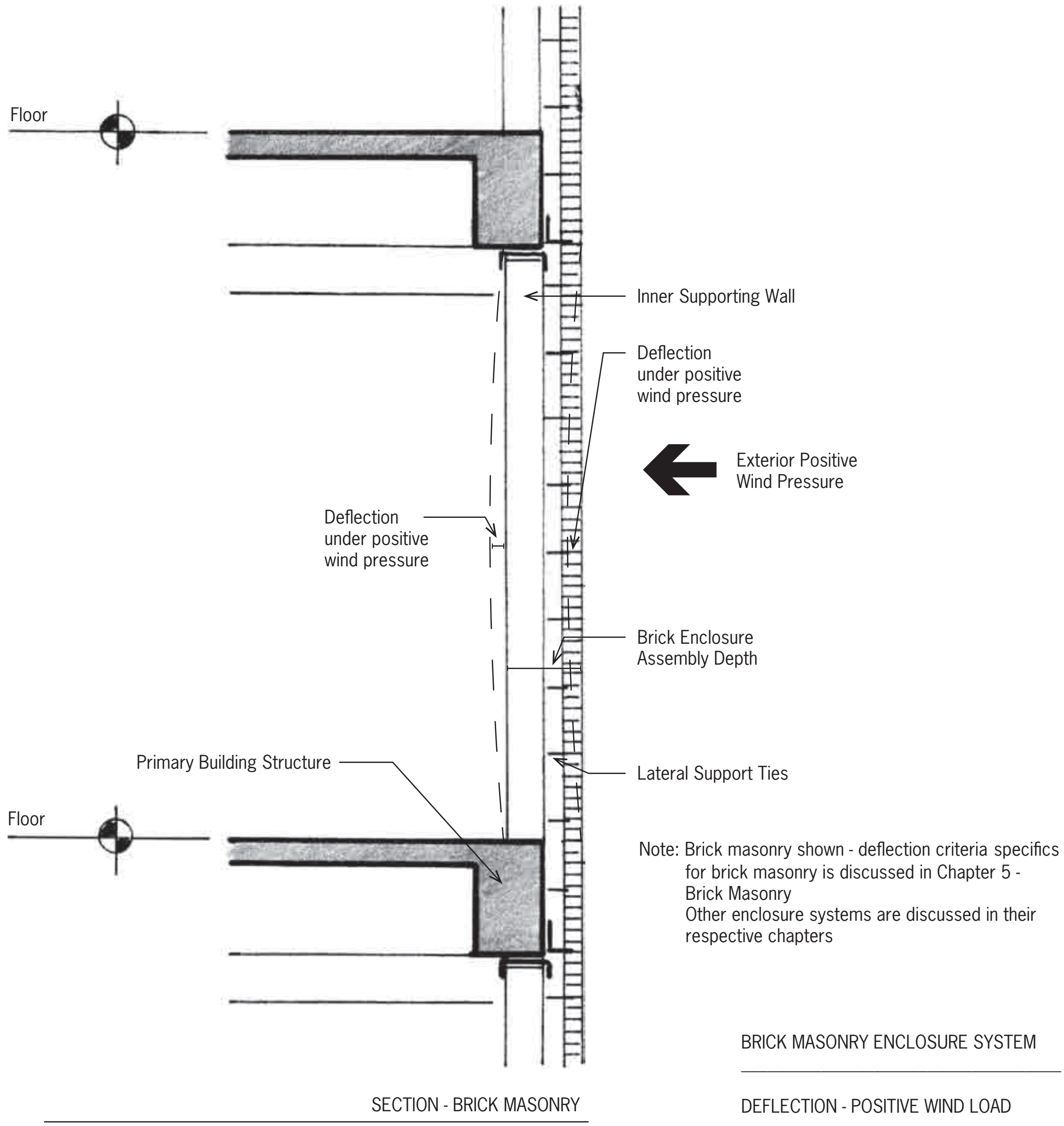

FIGURE 1.5a Brick masonry enclosures deflect between primary support boundaries when exposed to exterior wind pressure loads.

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 weather-tightness, air and water are considered here. Sunlight,

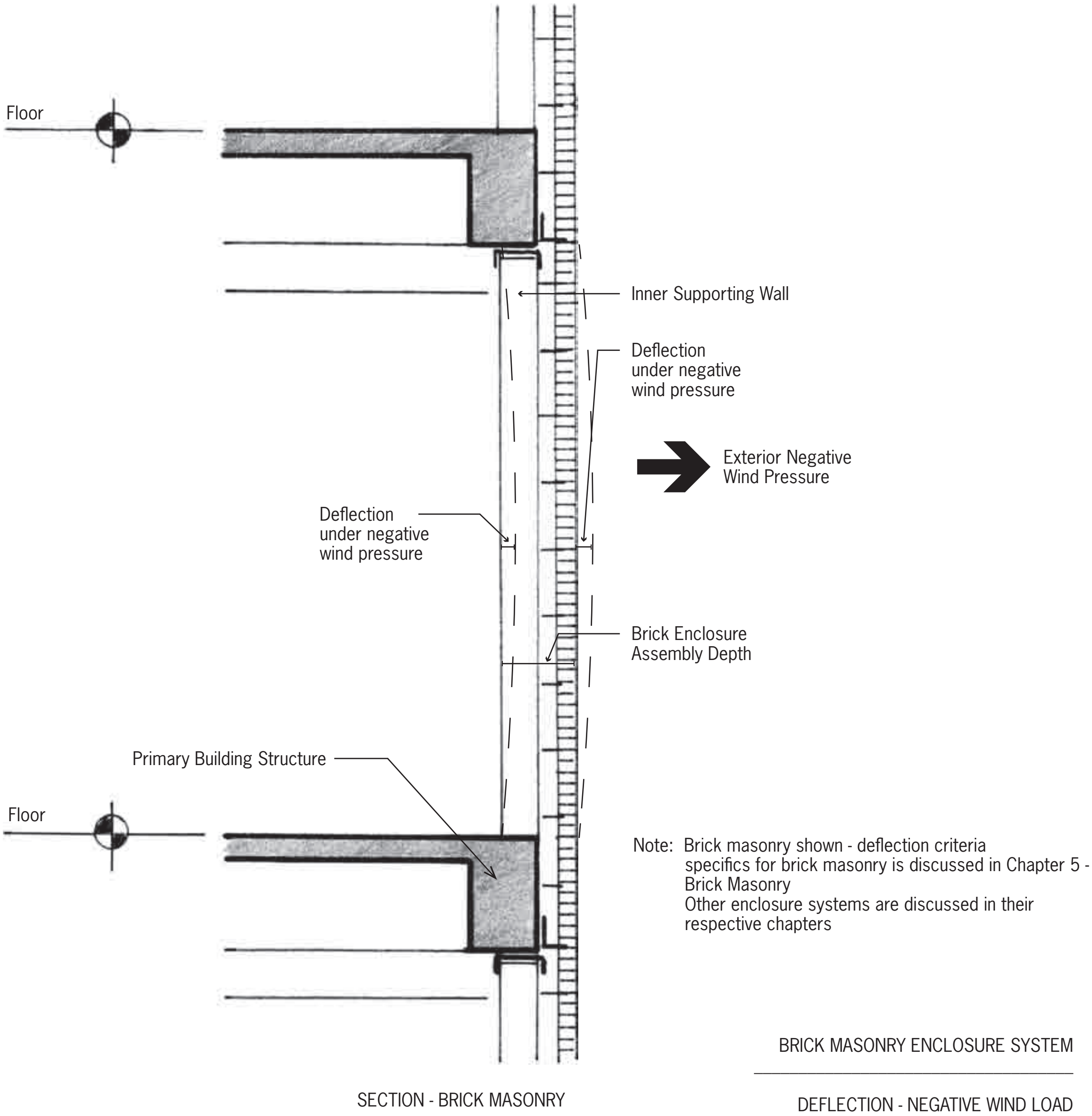

FIGURE 1.5b Brick masonry enclosure deflection diagram when exposed to negative exterior wind pressure loads.

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

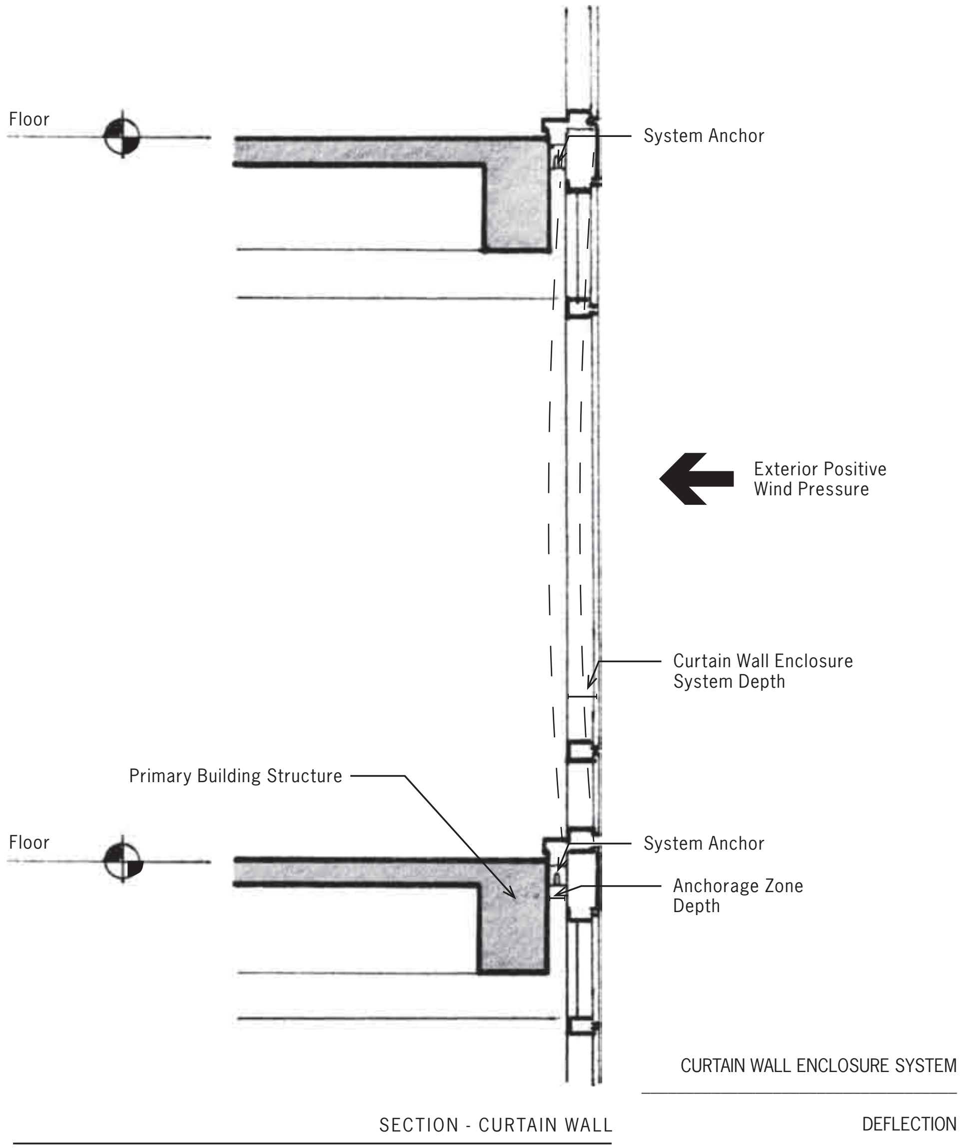

FIGURE 1.5c Curtain wall systems utilize the infill and/or cladding materials and the system framing material and depth to accommodate and transfer wind loads to the system anchor. The system anchor transfers loads to the primary building structure. Negative wind pressure creates deflection in the opposite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

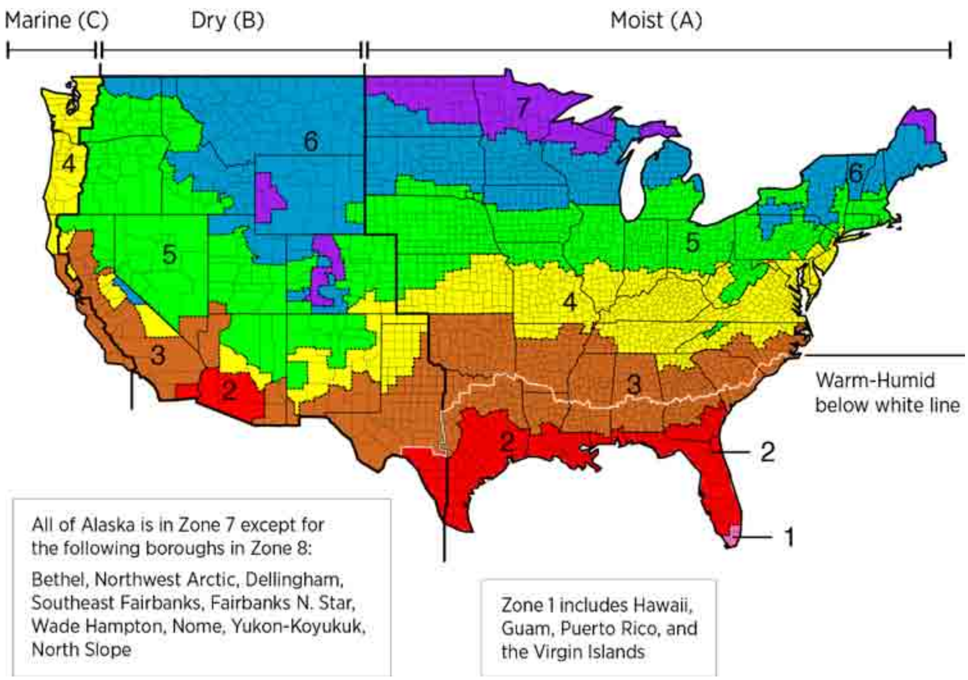

FIGURE 1.6 ASHRAE climate zone map. Climate maps outline performance basics per region. A continental U.S. example is shown.

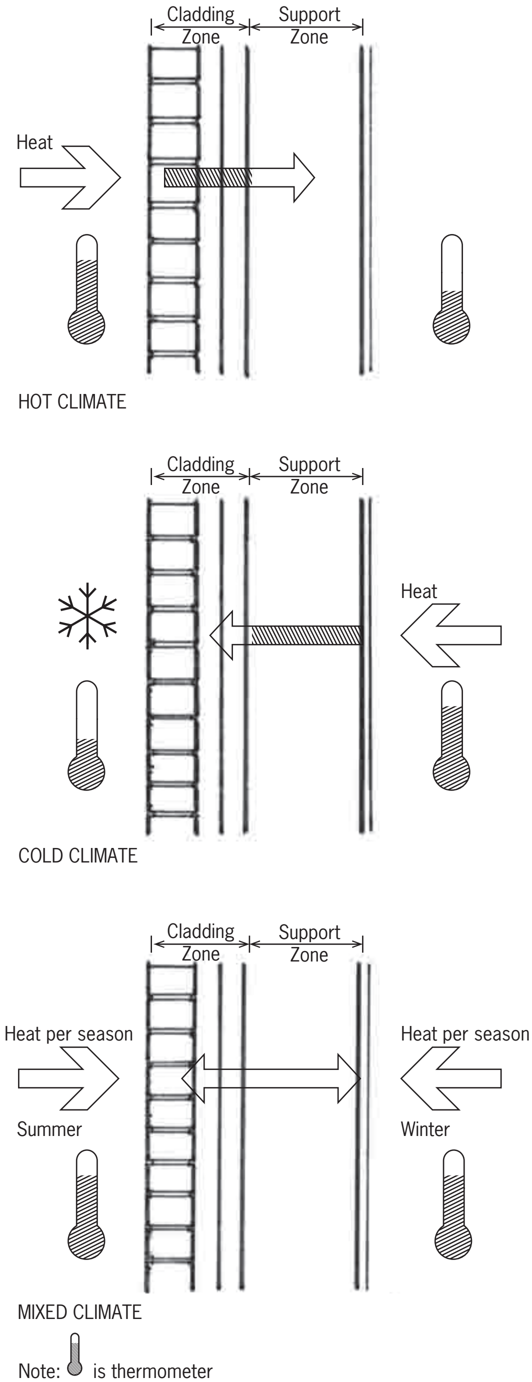

FIGURE 1.7 Enclosure heat flow profile. Heat flows from hot to cold. Climate and interior design conditions determine heat flow direction through the enclosure.

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

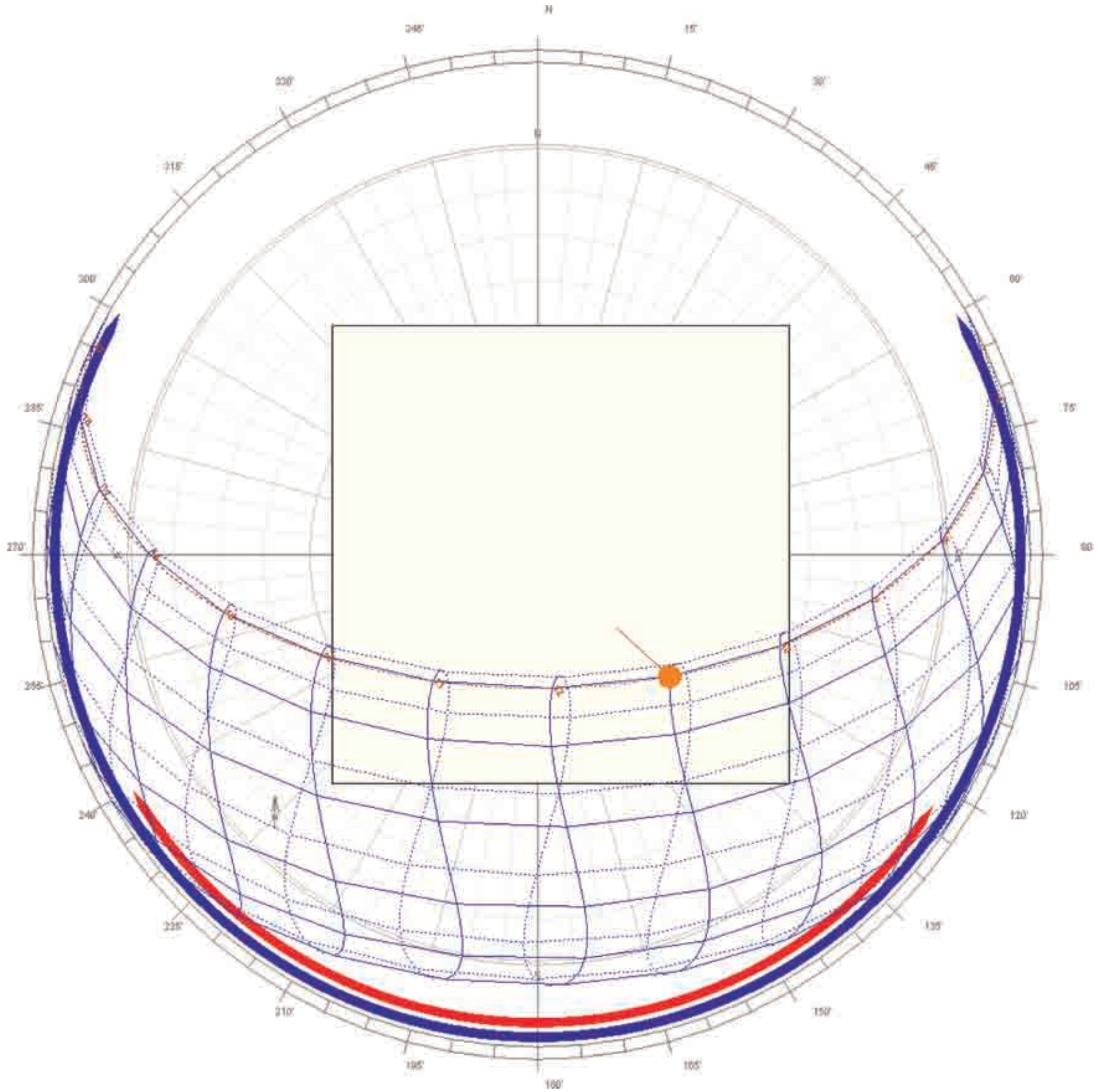

FIGURE 1.8a Solar path is three dimensional (altitude [vertical] and azimuth [plan]) and provides enclosure design information and opportunities through understanding sun angles during the year. Example shown is for San Francisco, California, in the northern hemisphere at 37.775 degrees North Latitude.

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

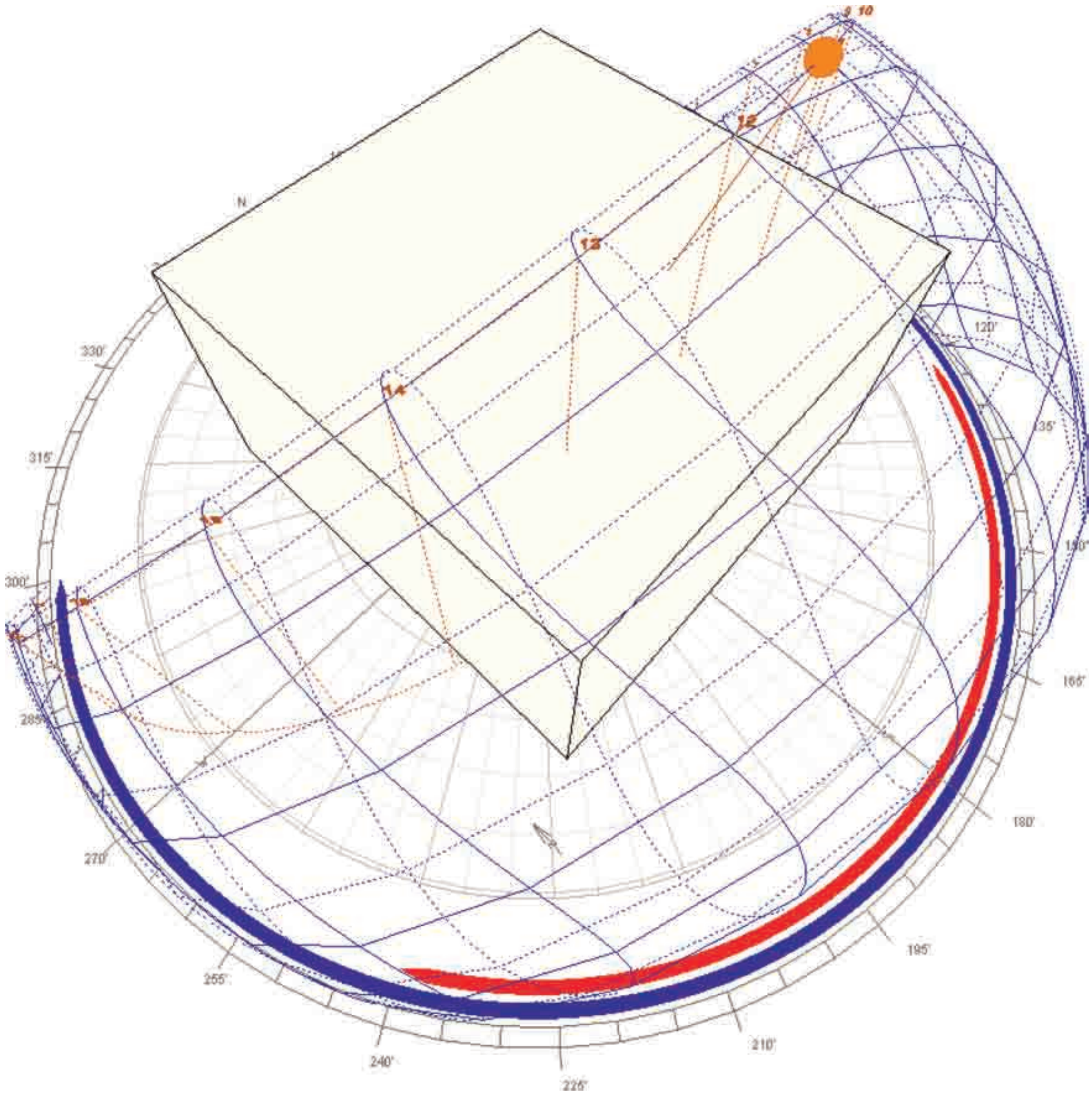

FIGURE 1.8b Solar path isometric. Example shown is for San Francisco, California, in the northern hemisphere.

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

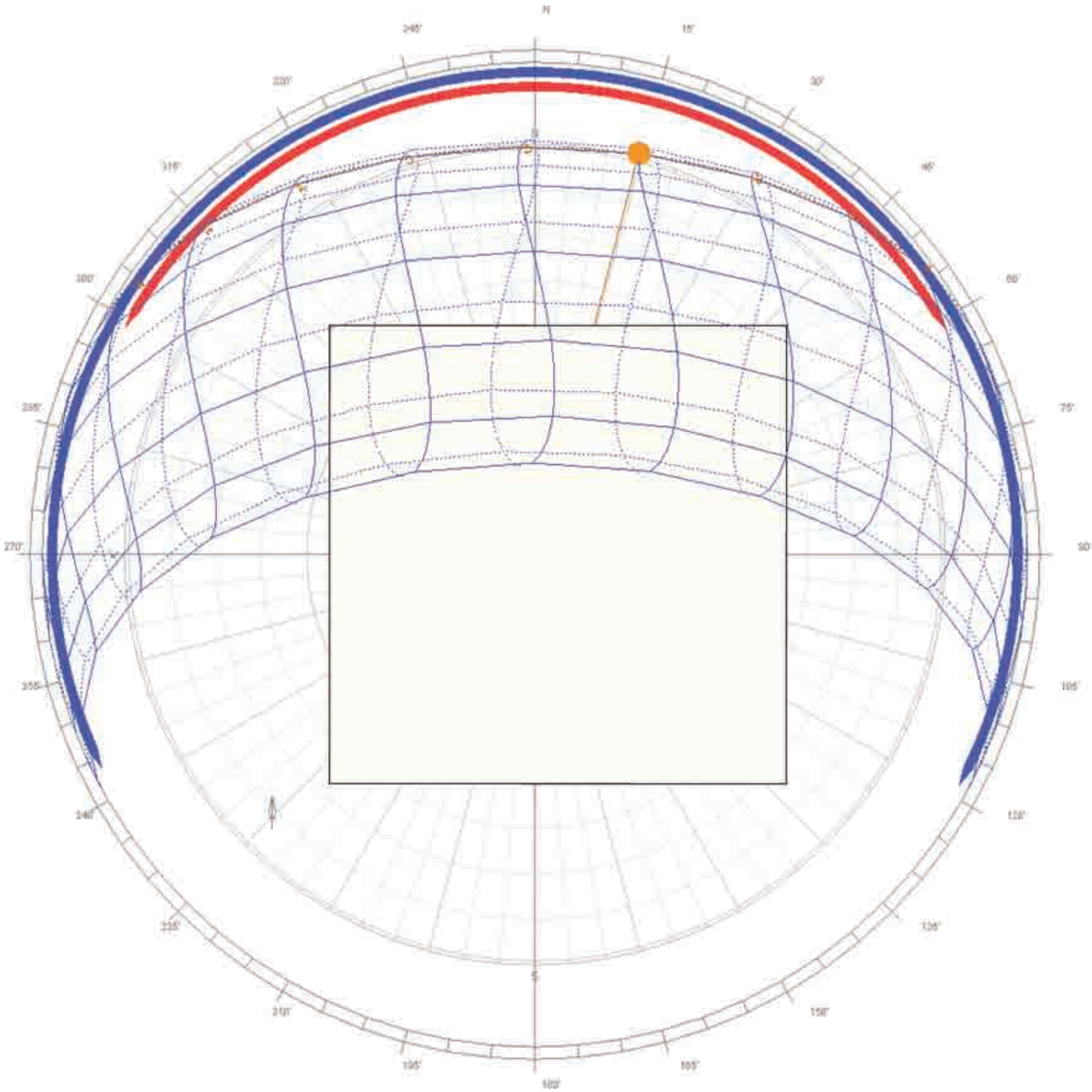

FIGURE 1.8c Solar path for Sydney, Australia, in the southern hemisphere at 33.868 South Latitude..

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

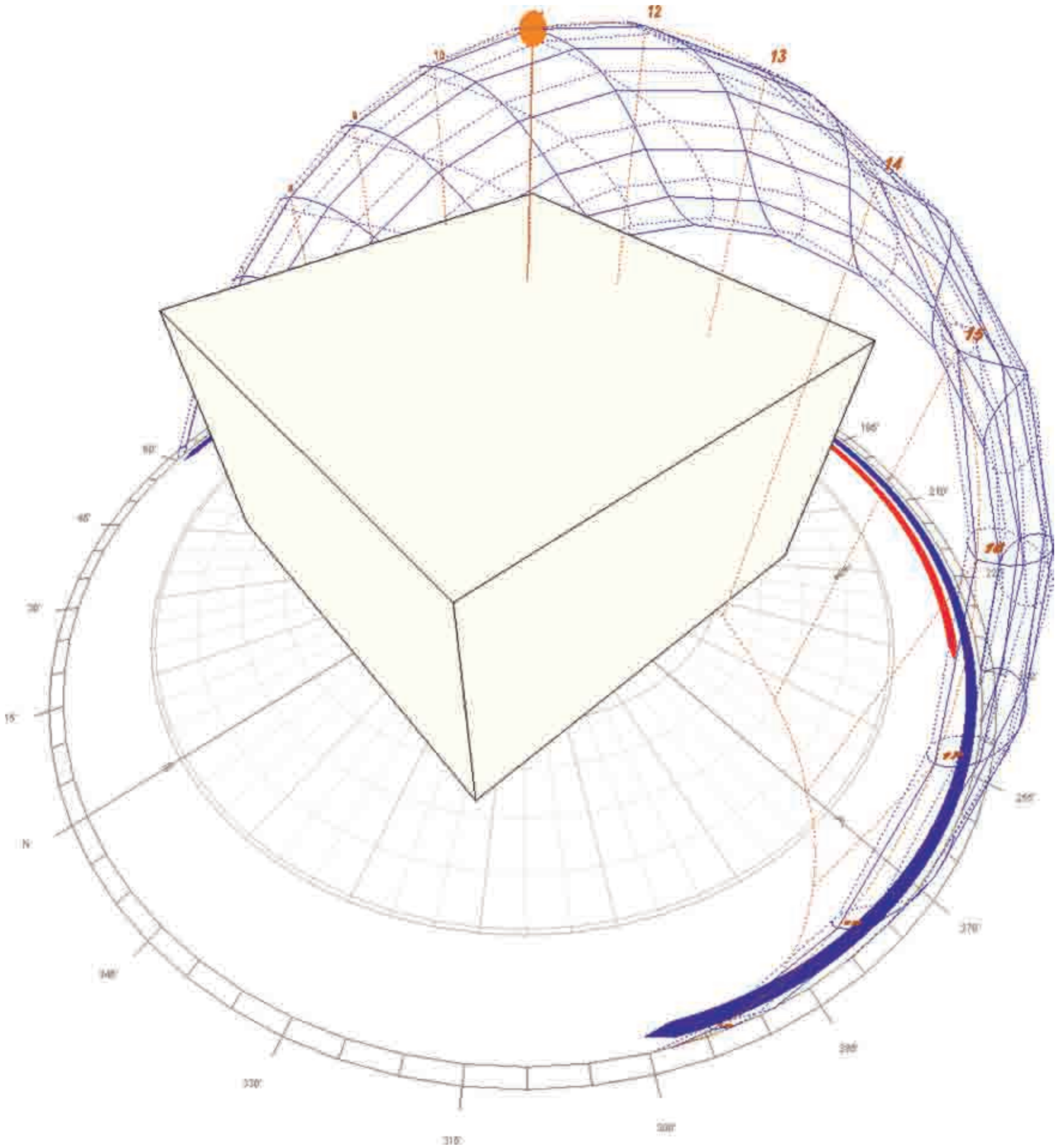

FIGURE 1.8d Solar path isometric. Example shown is for Sydney, Australia, in the southern hemisphere.

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

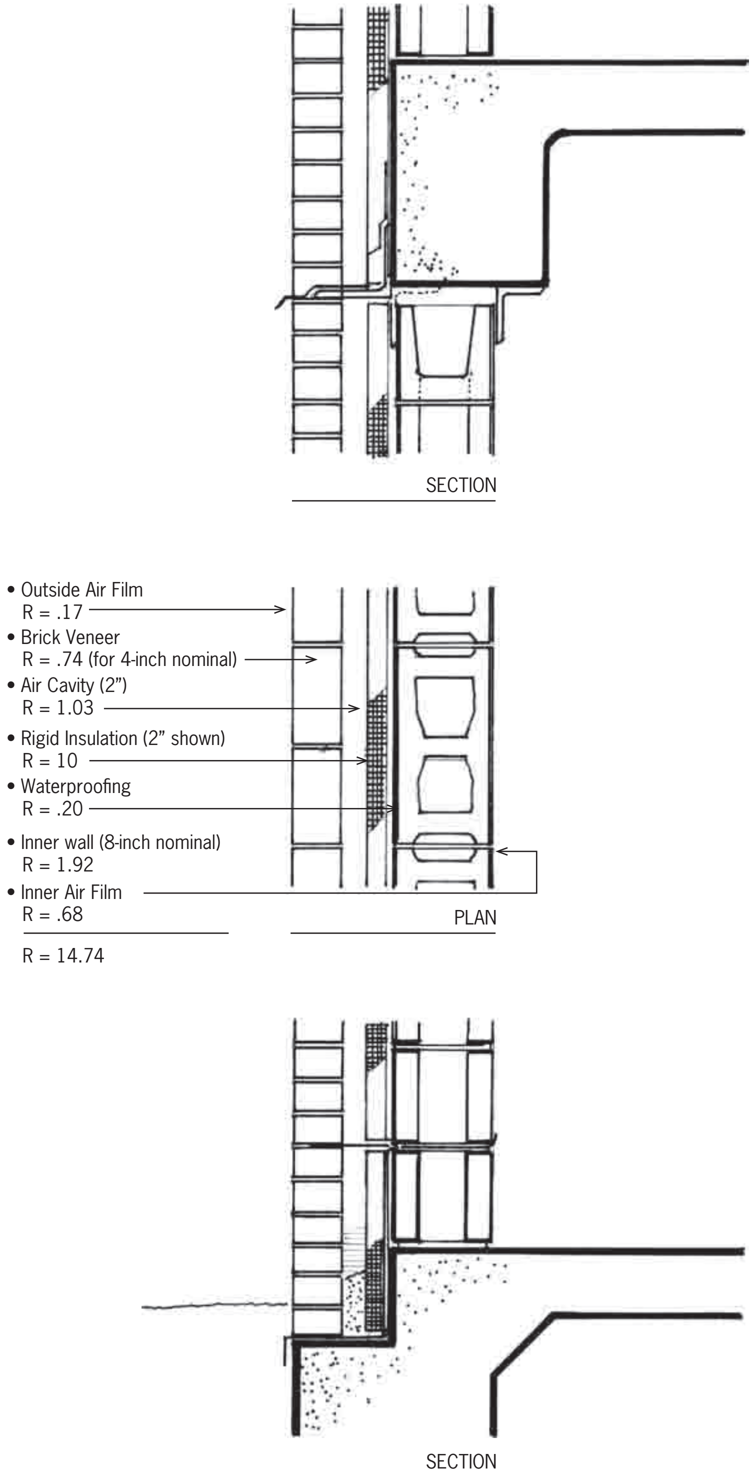

FIGURE 1.9 Overall thermal resistance (R-value) is defined by the composite of the enclosure component material R-values.

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.

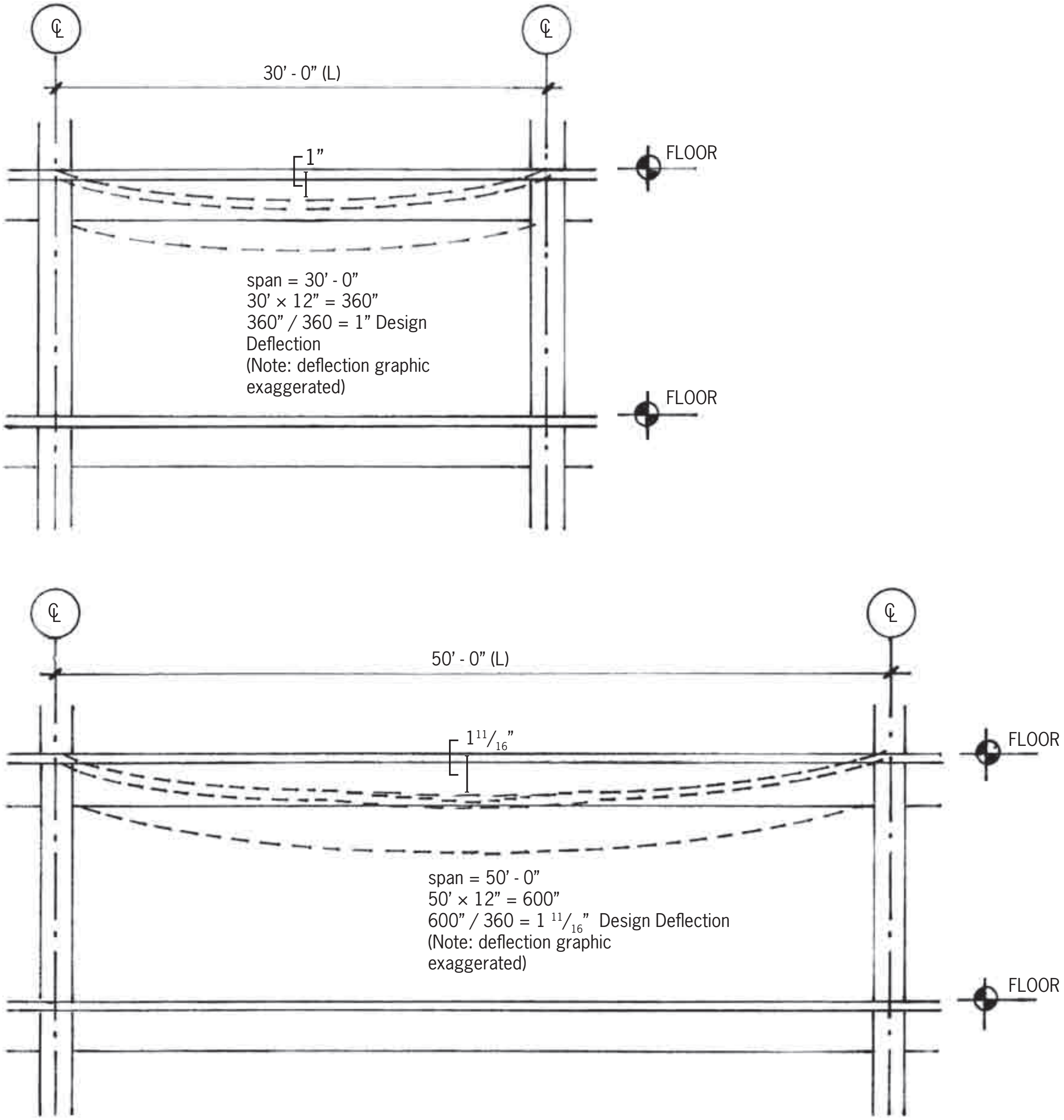

FIGURE 1.10 Structural beam deflection utilizing an *L*/360 structural design criterion. Resulting deflections for longer spans require larger enclosure joinery or enhanced specific structural design criteria to reduce beam deflections.

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.

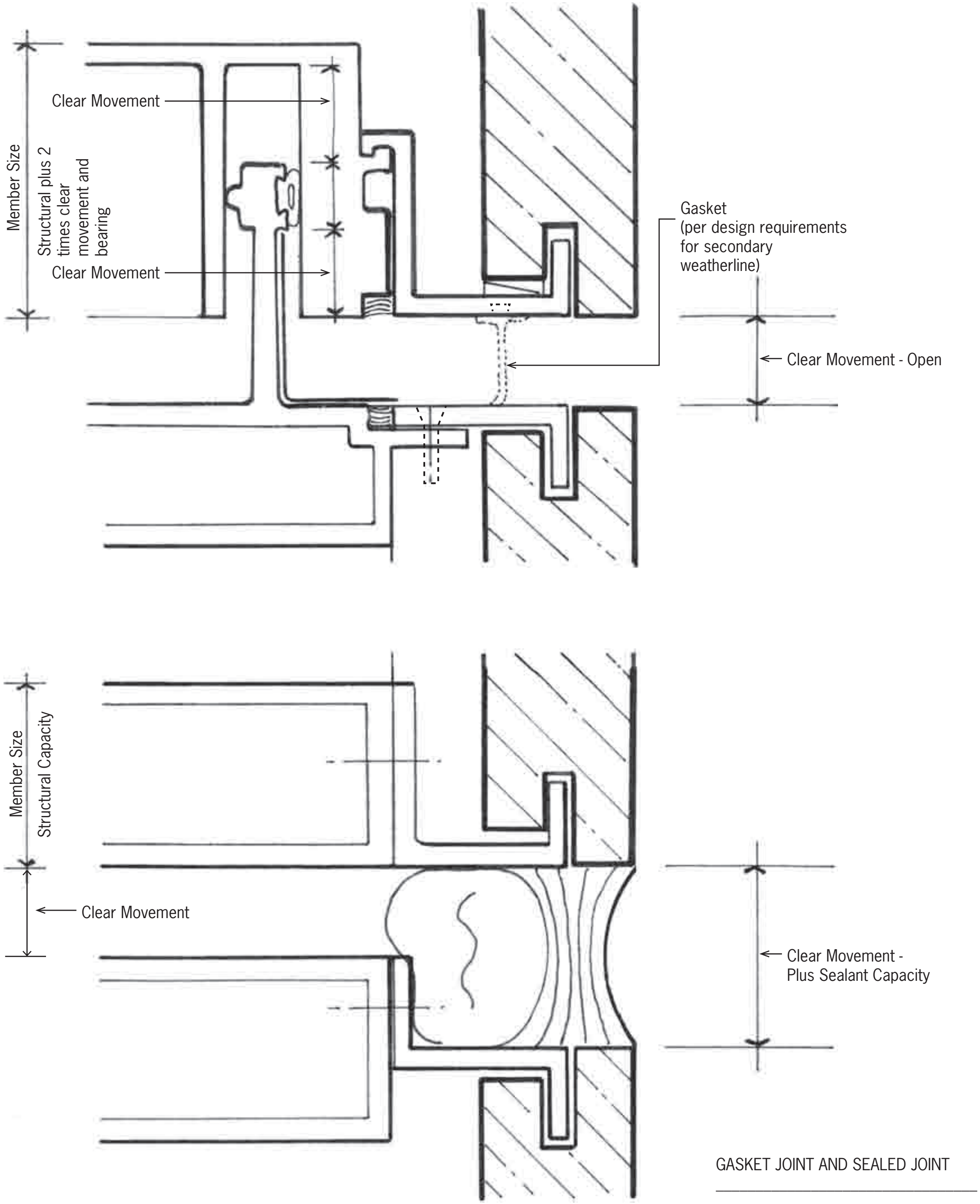

FIGURE 1.11 Open or gasketed joints may result in smaller expressed exterior joint sizes than sealant. Gasket joinery systems often require a larger amount of space in concealed areas to accommodate the concealed gasket components.