



Curtain Wall Systems

A Primer

Committee on Curtain Wall Systems



EDITED BY
Ali M. Memari, Ph.D., P.E.



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A Primer

Prepared by
the Committee on Curtain Wall Systems of
the Architectural Engineering Institute of
the American Society of Civil Engineers

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PREFACE

As the trend in building envelope system design moves toward significantly more transparent elements instead of opaque systems, the role of architectural glass is becoming more important than it once was in traditional window and curtain wall systems. Expectations of today's curtain walls that use architectural glass or other glazing products exceed the basic functions of providing natural lighting and protecting the interior from environmental effects such as wind and rain. Curtain wall systems are now expected to conserve energy, provide occupant comfort by controlling heat flow and solar radiation, and, in some cases, even convert solar energy to electricity. Last but not least, curtain wall systems are expected to perform acceptably when exposed to natural disasters such as hurricanes, earthquakes, and man-made hazards such as explosions and blasts. As these functions imply, depending on the application, proper design, fabrication, construction, and maintenance of advanced and efficient curtain wall systems demand involvement of professionals from several fields of engineering and building technology.

Design of building envelope systems in general and curtain wall systems in particular is not part of the curricula in architecture, architectural engineering, and civil engineering programs. The professionals whose work involves design, fabrication, and construction of such systems likely receive their training on the job and learn the fundamentals and design principles through experience of working on various projects. Few books and guidelines specifically address most major aspects of interest in glass curtain wall systems. The main goal of this book is to provide one such reference for beginners with no prior knowledge of curtain wall systems. The book is considered a primer because it does not treat the various subjects discussed at great depth. This book's chapters provide an introduction to several topics related to curtain wall and glazing systems, including material properties; manufacture, fabrication, and construction methods; various loading types and testing methods; design

methodologies with respect to wind, seismic, and blast; building physics with respect to waterproofing and energy efficiency; and some technological innovations and new developments in glazing systems and design, and construction of complex forms.

This book can help design professionals to better understand not only many aspects of curtain wall systems but also how such systems may affect other building systems they work with. The book can also help with more efficient design of building structural and envelope systems. The book is deemed appropriate as a textbook for students in civil and architectural engineering and architecture programs and also as a reference for building owners, architects, engineers, fabricators, contractors, and building code officials.

CHAPTER 1

INTRODUCTION

Faron A. Morris

The architectural appeal of glass comes from its most obvious properties—light reflectance and transmittance. In daylight, glass reflects its surroundings. On a high-rise tower blue sky is seen reflected on a clear sunny day, clouds on an overcast day, and lit offices at night. Glass gets your attention. The dynamic, always-changing appearance of a glass-clad tower is not possible with any other building material. Light transmission allows natural indoor lighting and a view from inside the building, providing a closer connection to the natural outdoor environment. Reflectance and transmittance—properties unique to glass—have increased its popularity and use in multistory construction.

The wall of glass seen in high-rise construction is a sophisticated manufactured product called curtain wall. Separating and moderating the interior building environment is its primary function. As an environmental separator it must keep out air and water; reduce heat loss in cold weather and reduce solar heat gain in warm weather; safely support wind loads, which become significant on high-rise buildings; accommodate thermal movement due to temperature fluctuations throughout the day and changing seasons; and accommodate building interstory movements caused by wind, live, and seismic loads. In certain geographical locations, extreme events require special design consideration for impact forces from flying debris in hurricane winds or large interstory movements caused by seismic events. Other special design considerations include reducing fire spread from floor to floor or across a floor at the structural slab edge and preventing injury to occupants from a blast event.

This primer will highlight the materials used in the manufacture of curtain wall in high-rise construction and discuss specialized aspects of curtain wall design and analysis for extreme events such as earthquakes

and bomb blasts. This information is not readily available because the curtain wall industry is relatively young compared with other well standardized construction industries such as structural steel, timber, and concrete. Material-specific information is spread across the glazing, sealant, plastic, and aluminum extrusion industries and is not generally taught in college or university courses, though in recent years architectural engineering programs are focusing more on building science and cladding. This primer compiles a basic review of the many aspects of curtain wall and current topics that affect the design and performance of curtain wall all in one document.

This primer's focus is on factory-assembled (unitized) and site-assembled (stick system or stick built) curtain wall in which transparent glazing is the predominant infill. Types of cladding not addressed in this primer include punched windows, strip windows, skylights, structural glass, and point-supported glass façades.

This primer is written for the individual outside the curtain wall manufacturing and consulting industry who possesses little to modest prior knowledge and wants to learn more about this specialized field. The target audience for this primer comprises architects, structural engineers, HVAC engineers, general contractors, building owners, and building operators.

CHAPTER 2

DEFINITION AND TYPES OF CURTAIN WALLS

Faron A. Morris

Also known as cladding or building façade, curtain wall is the skin of a building; its primary function is as separator or boundary between interior and outdoor environments. Curtain wall is light compared with other façades such as masonry and precast, and its name derives from the way it hangs from the structure like a curtain. Thus curtain wall is non-load bearing, meaning it supports no vertical structural loads aside from its own weight.

Several definitions regarding the production of curtain wall are worth mentioning to aid in understanding the processes involved. These are fabrication, assembly, glazing, and installation. Fabrication encompasses all machining operations, including cutting, drilling, milling, and punching. These operations are performed on the aluminum extrusion framing members. Assembly involves the fastening together of aluminum framing members to create a frame to support the glazing infill. Joints in the frame need to be covered with sealant to make the frame air and water tight. Insulation is attached to spandrel openings. Glazing involves attaching the infill to the vision or spandrel frame opening. The most common infill is an insulated glass unit but also can be an aluminum, stainless steel, or granite panel. A vision or spandrel frame opening is the area between aluminum framing members occupied by an infill. Installation pertains to any work performed on the construction site.

The two types of curtain wall are characterized by the manner in which they are produced: stick built and unitized. Stick-built curtain wall is fabricated in the shop and shipped in pieces to the site where it is assembled and glazed. The installation process combines assembly and glazing, because most of the wall production occurs onsite. Stick-built walls have higher site labor costs (site labor is generally costlier than shop labor),

because most of the assembly and glazing takes place there, which also results in a longer schedule to enclose a building. However, the biggest drawback of stick-built systems is that installation (assembly and glazing) is done outdoors in full exposure to the weather. Sealants are an important component of curtain wall that prevent air and water infiltration. Sealant durability depends on good adhesion to the joint surfaces they are sealing, and good adhesion requires clean and dry joint surfaces, which can be difficult to obtain in variable weather conditions outdoors. Regulated temperature and humidity, such as exists in an indoor environment, are conducive to more reliable sealant application.

Stick-built walls are assembled on the building and consist of tubular aluminum profiles. Mullions are assembled first, then horizontals are fastened to the mullions with clips or spigots. Glazing begins once enough framing has been installed and progresses up the tower to complete building enclosure.

Unitized curtain wall is fabricated and assembled at the manufacturer's shop, then shipped to the site for installation. Unitizing benefits from indoor assembly and glazing, because a controlled environment improves curtain wall durability. The time required to close in a building is greatly reduced with unitized systems because most of the production is done in the shop. Installation simply involves placing preassembled and preglazed frames on the building. Often unitized curtain wall installation follows immediately after erection of the structure. As a result, building close-in time is greatly reduced. Unitizing requires split members that interlock with the adjoining frame in a male-female interlocking method that incorporates gaskets for a joint that is both air and water tight.

A building clad with reflective glass may appear to be all glass, but curtain wall consists of more than just glass. Typical curtain wall is made up of transparent vision glass and opaque spandrel-glass infills supported by a metal framework of aluminum extrusions (Fig. 2-1). Other commonly used infills are stainless steel panels, painted or anodized aluminum panels, granite, marble, limestone, combination glass and metal panel (called a shadow box), louvers, and vents. Spandrel infills are insulated for increased thermal performance and opaque (nontransparent) to hide the slab edge and ceiling cavity. A typical spandrel infill consists of insulation adhered to a galvanized steel sheet called a backpan or foil back insulation, premanufactured insulation adhered to aluminum foil, inboard of a single lite or insulating glass unit (IGU). The backpan or foil is the air-vapor barrier preventing air and water from infiltrating to the interior. Because of its brittle nature, glass requires contact with soft materials called glazing gaskets such as high durometer (rigid) rubber or silicone to prevent breakage. Low durometer (soft) rubber or silicone gaskets are used at split vertical and horizontal members to form seals against air and water. Preventing air and water infiltration to the interior is a major

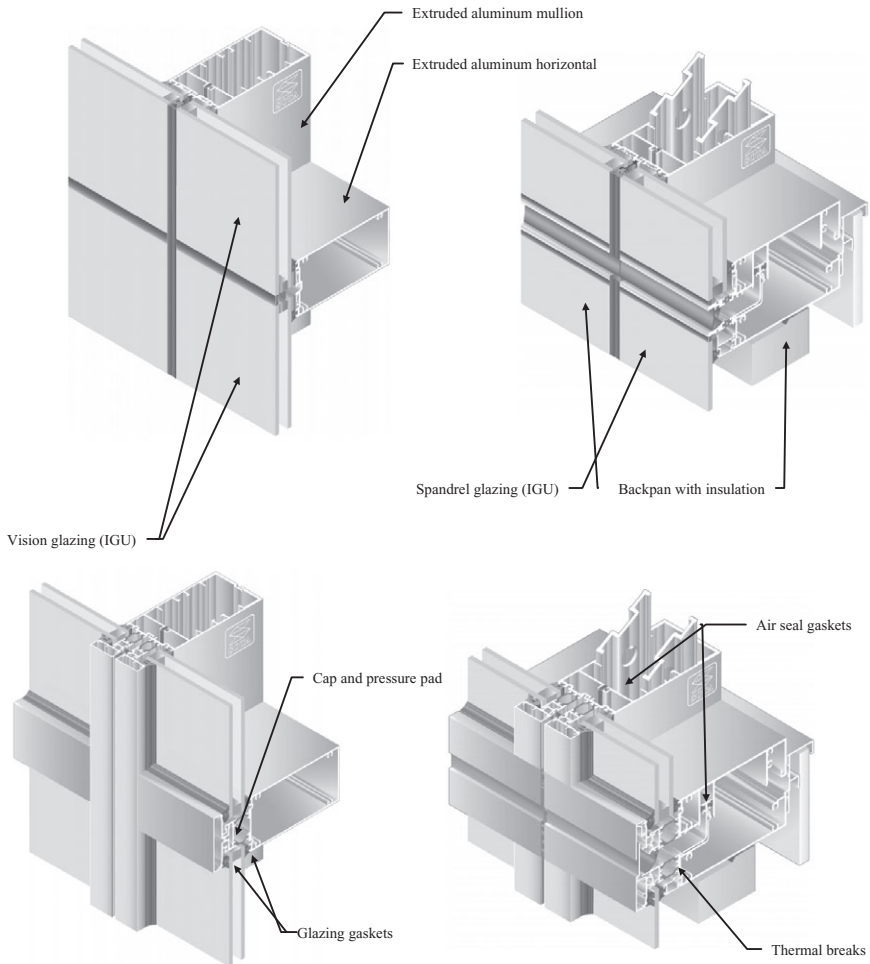


Fig. 2-1. Unitized curtain wall components

Source: Thermo3 Series Curtain Wall System, courtesy of Sota Glazing, Inc., Brampton, Ontario, Canada

function of curtain wall. Glass and extruded aluminum are intrinsically nonporous to air and water, but at frame joinery where aluminum members connect, hair-line gaps between extruded aluminum framing members require sealing with sealant or tape. Because aluminum is highly conductive, thermal performance is obtained by separating inboard aluminum extrusions from outboard extrusions with thermal breaks. These are made from plastics, such as PVC or nylon (polyamide), to improve thermal performance by physically separating highly conductive

aluminum extrusions. The low-conductivity plastic separates exterior extrusions from interior ones to reduce heat loss through conduction and prevent condensation in heating-dominated climates and heat gain in cooling-dominated climates.

The aluminum extruded members that comprise a curtain wall frame have specific names shown in Fig. 2-2. The vertical extrusions are called mullions or verticals. They support the infill and horizontals by carrying lateral wind loads and infill self-weight to the anchor. The top horizontal member in the vision opening is called the head or header. The bottom horizontal member in the vision opening is called the sill. An intermediate horizontal with vision or spandrel above and below is called an intermediate horizontal. The mating horizontals at the split between two frames are called the expansion joint members. Horizontal members are also referred to as transoms or rails. Horizontals carry wind load to the mullion and the self-weight of their infill materials.

Frame openings are areas glazed with one of the previously described infill materials. Vision openings contain a transparent IGU that can be double or triple glazed with one or more lites that are tinted (colored), mirror coated, or low-e coated. Spandrel openings contain nontransparent (opaque) infill materials, including glazing with opaque coating and are insulated for increased thermal performance.

The way glazing is retained by the framing has a visual effect on curtain wall's appearance and provides a degree of creative freedom for the architect specifying the wall. Two methods called capped systems and structural silicone glazed systems use distinctly different means of glazing retention. Capped systems physically hold the glazing infill with aluminum extrusions, combined with rubber glazing gaskets, to lock it to the frame. From the outside the glazing appears to have a picture frame of painted or anodized aluminum around it. There are variations of capped systems where all four sides can be captured, called four-sided captured systems. Any combination is possible, including horizontally captured and vertically siliconed and vice versa. Random or patterned cap locations across an elevation are also options. The profile of the cap can be any shape possible within the limits of the aluminum extruding process.

Structural silicone glazed (SSG) systems employ structural silicone sealants that adhere the glazing to the frame—effectively gluing the glazing to the frame. Structural silicone sealants have been engineered using advanced chemistry to create a safe and reliable product for this specific application. The visual difference is a cleaner, uncluttered appearance, giving the impression, from a distance, of a wall of continuous glass. The thin joints between frames seem to disappear at a distance.

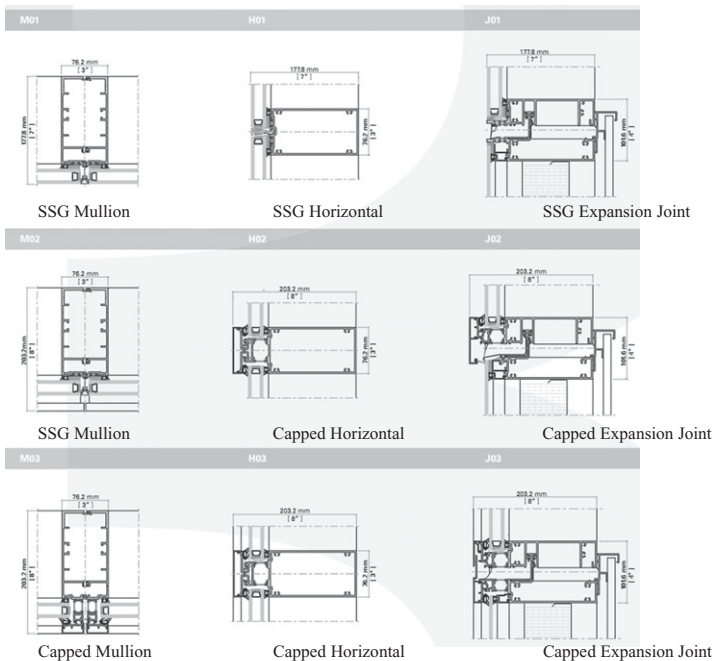
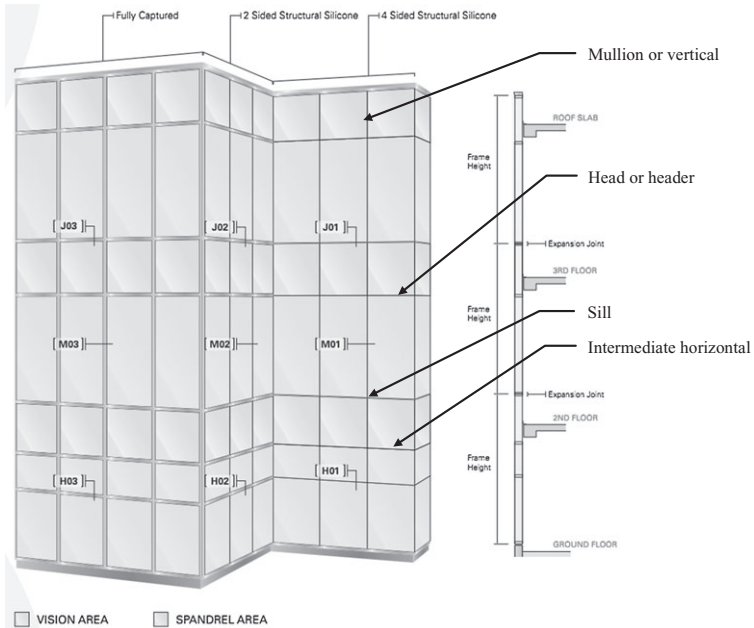


Fig. 2-2. Typical curtain wall elevation featuring SSG and capped glazing
 Source: Thermo3 Series Curtain Wall System, courtesy of Sota Glazing, Inc.,
 Brampton, Ontario, Canada

CHAPTER 3

MATERIALS AND CONFIGURATIONS

Dudley G. McFarquhar, Ph.D., P.E.

This chapter provides an overview of some common materials used with curtain wall systems and some different configurations of some elements. Note that curtain wall systems are proprietary and consist of multiple components. For that reason, this chapter presents an overview of these systems' basic parameters.

Curtain wall is a term that describes a building envelope component. It is a nonload bearing façade that provides protection from the exterior environmental elements. A curtain wall system typically comprises extruded aluminum framing with infill glazing or opaque substrates. The curtain wall does not provide any stiffness to the building structure. Whereas curtain wall framing supports its internal elements, the frame itself is supported by the building structure.

The curtain wall is subjected to critical environmental elements including lateral loads (e.g., wind, seismic), temperature, humidity, moisture, and defined building movements. In special cases, the curtain wall can also be designed to mitigate forces from hurricanes, missile impact, and blast loads.

3.1 MATERIALS

Curtain wall comprises clear and opaque elements that are critical to its performance and longevity. The clear component is predominantly glazing (Fig. 3-1), while the opaque areas may consist of myriad components: opaque spandrel glazing, metal panels and louvers, natural stone (Figs. 3-2 and 3-3), concrete panels, and glass fiber–reinforced concrete (GFRC) panels.



Fig. 3-1. Winspear Opera House, Dallas, TX; an example of all clear glazed façade

Source: McFarquhar Group Inc.; reproduced with permission



Fig. 3-2. One Shell Square, New Orleans, LA; an example of a high-rise building with a glazing and natural stone façade

Source: McFarquhar Group Inc.; reproduced with permission



Fig. 3-3. Kuala Lumpur City Centre, Kuala Lumpur, Malaysia; an example of glazing and metal panels

Source: Courtesy of Thornton Tomasetti; reproduced with permission

3.1.1 Glazing

Glass is a very important architectural component of a curtain wall system. It provides the building occupant vision to the exterior and introduces daylight to the interior space. The concepts of energy impact on a building as well as energy transfer is very important to the glazing makeup and its performance. Energy has always been a critical component of the research done by the differing glass unit manufacturers and is an ongoing issue that is being reviewed closely by the glazing and related industry communities. Glass is characterized by type, color, size, and strength.

Glass Type The type of glass units can be assigned to three basic groups: monolithic, insulating units, or laminated lites (GANA 1997). Monolithic glass comprises a singular thickness. It is usually used in various thicknesses ranging from 6mm (1/4-in. nominal) in spandrel glass to 12mm (1/2-in. nominal) for glass handrails, or thicker as needed for strength aesthetics and other parameters, for example, in some lobby glass applications depending on the supporting curtain wall framing

application. It is also used in glass-mullion applications and can be an element such as a glass fin.

Insulating glass unit describes a glazing assembly of two glass lites separated by an air space. For example, a 25 mm (1-in. nominal overall) insulating glass (IG) consists of two 6 mm ($\frac{1}{4}$ -in. nominal) thick glass lites with a 12 mm ($\frac{1}{2}$ -in. nominal) thick air space. Insulated glass has four glass surfaces numbered 1 through 4 from exterior to interior (Fig. 3-4). These surfaces allow the glazing unit to incorporate elements such as tints and low emissivity (low-e) coatings, thus modifying the amount of light and energy transmitted into the interior space. Depending on the level and color of tint, the reflectivity is also affected. For example, a silver-tinted glass is highly reflective, whereas darker tints absorb the light. Other elements such as photovoltaic cells can be used to generate energy in insulated glazed units. This higher technology with cell placement and wiring, however, adds some cost to the glazing system. Insulated glass can also be used in structural glazing applications, which will be discussed later in the chapter.

Laminated glass describes an assembly consisting of multiple layers of monolithic glass lites assembled with a laminate interlayer membrane between the lites. The interlayer thickness varies from 0.04 mm to 0.23 mm (0.015 to 0.090 in.). Combinations of two or three glass lite laminates are

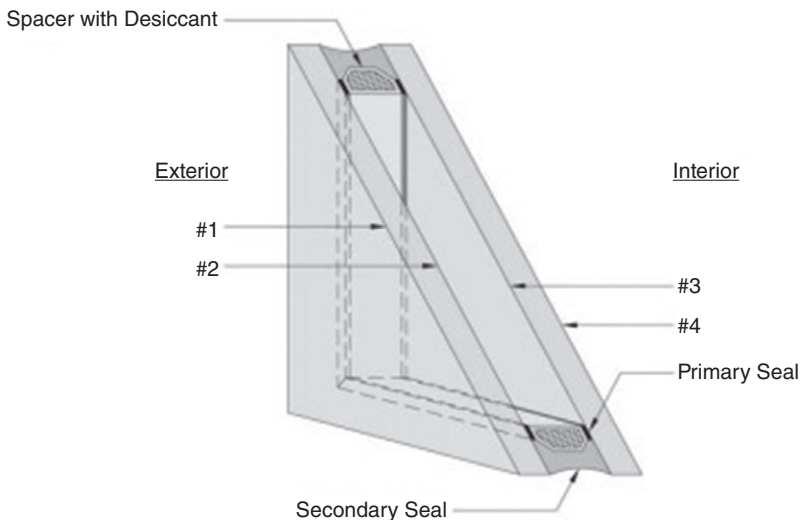


Fig. 3-4. Insulated glass unit makeup

Source: GANA Glazing Manual: 50th Anniversary Ed. (GANA 1997); reproduced with permission from Glass Association of North America (GANA), www.glasswebsite.com

common for different applications. Considering that these combinations increase laminated glass lites strength, they are used in a variety of applications. They can be incorporated in insulated glass units for missile impact resistance or sound transmittance. Other applications include forced entry protection and safety applications in overhead glazing such as skylights (Fig. 3-5).

Glass Color Glass color has become an important feature in characterizing building façades (Fig. 3-6). Manufactured glass has an inherent natural greenish tint due to the iron content in the glass. Clearer glass

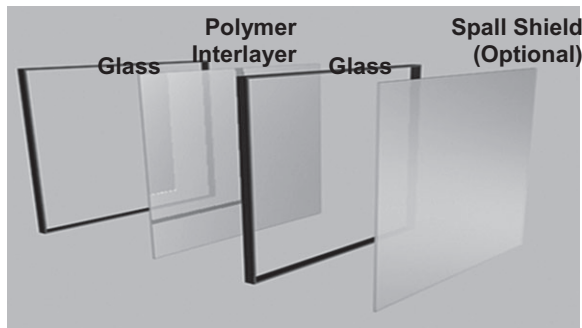


Fig. 3-5. Representation of laminated glass makeup

Source: McFarquhar Group Inc.; reproduced with permission



Fig. 3-6. Winspear Opera House, Dallas, TX; example of unique glass color to define aesthetics

Source: McFarquhar Group Inc.; reproduced with permission

can be made by reducing the iron content, and now such low-iron glass is available commercially. Another method of introducing color into glazed façades is to use tints on the #2 or #3 surface of an insulated glass lite unit. Myriad colored tints can be used in combination, such as a reflective tint combined with a low-e tint to reduce the heat transfer through a glass unit. The spandrel glass lite is opaque and can be monolithic or insulated units with the back interior #3 surface painted.

Glass Size Glass size limitations are primarily related to the limitations of the float plant or autoclave that provides tempering of the glass lite and the loading requirements. The size of glass lites is also limited based on the individual lite thickness. For nominal usage in commercial glazing, 6 mm (¼-in. nominal) thick glass is used for insulated glass and laminated glass lites, but size can vary depending on the application and loading constraints.

Glass Strength Glass strength is described by three categories: annealed, heat strengthened, and fully tempered. Note that glass is strong in compression but much weaker and susceptible in tension.

Annealed glass (AN) is float glass, based on its unique manufacturing process. It is fabricated in a continuous flow and cut into large sheets, which are then cut into smaller lites as needed. On a relative scale of strength factor (SF), annealed is the weakest with an SF of 1.

Heat-strengthened glass (HS) is float glass that has been passed through a quick cooling process. This cooling process develops a compression layer on the exterior surfaces, which inherently increases the strength of the glass. A relative SF of about 2 is common for this kind of glass, suggesting that HS glass may be as much as twice as strong as AN glass.

Fully-tempered glass (FT) is float glass that is subjected to a controlled quick temperature cooling process, which significantly increases the strength within the compression layer in the glass lite. An SF of 3.8 to 4 is common, suggesting that FT is nearly four times as strong as annealed glass. An application of this glass type is used for safety glazing because of the small cubes or shards that result from glass breakage in failure mode. The size of the shards minimizes the potential for damage. Nominal tempered glass units are designated in buildings with a label as “knock out” lites in case of an emergency for access or exit.

3.1.2 Natural Stone

Natural stone is incorporated in many curtain wall projects as accent perimeter bands, column covers, or spandrel covers. Natural stone types are varied and include granite, limestone, sandstone, travertine, and marble. Travertine and marble tend to be more suited for interior work

because of their response to exterior weathering effects. However, their intricate veining provides a lot of aesthetic options for architects. More traditional stones, such as granite and limestone, may be incorporated into a curtain wall system as individually installed supported panels referred to as “handset stone” (Fig. 3-7) or individually supported on steel frame trusses referred to as stone trusses (Figs. 3-8 and 3-9).



Fig. 3-7. Naples Philharmonic Museum, Naples, FL; an example of natural stone façade (granite)

Source: Courtesy of Thornton Tomasetti; reproduced with permission



Fig. 3-8. Stone truss panel being installed

Source: Courtesy of Atlantic Exterior Wall Systems, LLC; reproduced with permission



Fig. 3-9. Stone truss panel being hoisted from transportation vehicle; note the steel frame back-up behind the stone panels

Source: Courtesy of Atlantic Exterior Wall Systems, LLC; reproduced with permission

Several methods are used for stone attachment, such as stainless steel anchors, aluminum extruded anchors, dowels and epoxy, and mechanical anchors (such as Type 31 anchors). Type 31 anchors include a custom “keyed” slot in the stone that allows the anchorage to be concealed. Stone panel thicknesses vary from 3 cm (1¼ in.) to 5 cm (2 in.) in granite and travertine, whereas limestone can vary from a minimum thickness of 5 cm to large cubic projecting profiles such as cornices and columns on courthouse projects. Available references, such as the Marble Institute of America (MIA, 2011), the Indiana Limestone Institute Design Manual (ILI, 2007), and others provide guidelines for stone attachment and profile concept. However, an important recommendation for all stone cladding is the need for stone panel component connections to be designed and reviewed by a registered professional engineer or architect. Natural stone is a material (Fig. 3-7) that needs testing to determine appropriate safety factors. Due to the variety of stone types available on the commercial market, a careful visual review is required to estimate their project performance.

3.1.3 Precast Concrete Panels

Precast concrete panels are typically used for column covers and horizontal spandrel covers. They are often fabricated in long lengths depending on the modular grid of the project and often provide the perimeter

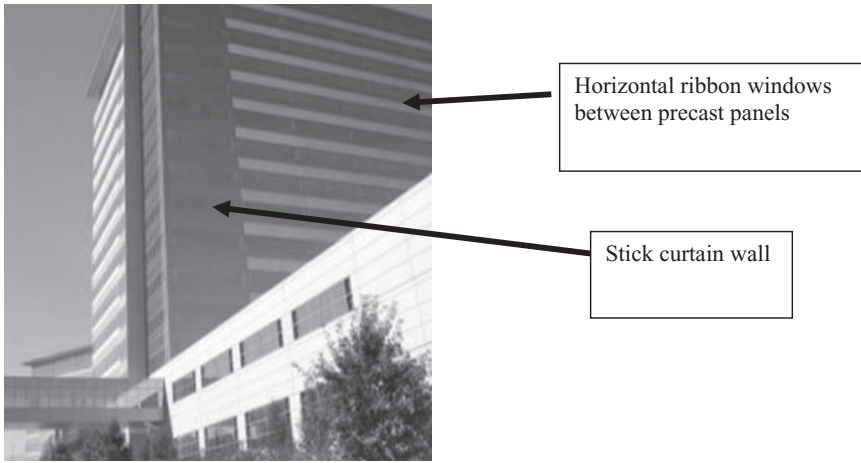


Fig. 3-10. Blue Cross Blue Shield, Richardson, TX; an example of multiple façade types on a building

Source: Courtesy of Corgan Associates; reproduced with permission

support for infill windows such as ribbon windows (Fig. 3-10). The exterior of the panels can be articulated during the forming process to express a certain architectural intent. They are connected to the building structure with very heavy, specially designed connections, such as embeds, because of the size and the weight of the panels.

3.1.4 Glass Fiber–Reinforced Concrete (GFRC) Panels

Glass fiber–reinforced concrete panels are lighter than precast concrete panels and consist of a thin concrete mixed with reinforcing fiber. These panels can be formed to different sizes and profiles. However, they require a sufficient amount of anchors for internal load distribution and localized response to lateral loads.

3.1.5 Metal Panels

The two types of metal panels are monolithic and composite. Monolithic panels can be glazed into curtain wall framing similar to glass, and composite panels can be individually installed on backup track systems. Composite panels are a laminate of two thin exterior metal plates with an inner layer of insulation. They provide additional thermal characteristics such as heat gain reduction and heat loss from the interior space. The panel installation can be accomplished by a dry-glaze method or a wet-glaze method with sealant, depending on project conditions. Anchorage

of these panels is generally accomplished with fasteners to return edges of the panels.

With respect to panel structural performance, metal panels include certain intrinsic design features, such as ribbed or embossed panel profiles, that actually provide additional stiffness to the plate and prevent an aesthetic perception of bowing or “oil canning.” Along with the architectural profile, the choices of high-end finishes and colors provide a plethora of possibilities, thus allowing great aesthetic flexibility in the coverage of building façade square footage (interior or exterior).

3.2 CURTAIN WALL FRAMING ELEMENTS

Commercially available curtain wall framing elements are primarily extruded aluminum and/or steel framing (AA 2000). The choice depends on the aesthetic choices made for the façade, module spacing, and grid and load considerations.

3.2.1 Aluminum Curtain Wall

Conventional curtain wall framing systems comprise aluminum framing with glazed openings (glass, metal panels, or natural stone).

Aluminum framing is available in different system depths for the vertical and horizontal elements. The profiles can be open or closed depending on the application. One of the significant architectural advantages of using aluminum framing is that multiple profiles can be readily extruded to develop special shaped framing or accent profiles such as bullnoses. The extrusions generally have sharp edges (except for curved profiles), which accentuates a clean finish. Multiple layers of coating protect the aluminum metal depending on the project specifications, whereas the system depth is primarily dictated by wind load requirements. Figs. 3-11 and 3-12 show examples of aluminum frame systems. These frame elements are assembled by fasteners and shear elements and can be field assembled or factory assembled depending on the system and scheme of installation.

Note that some verticals appear to have a closed shape, but they often have open three-sided profile shapes with a closure snap that creates the appearance of a closed shape. This concept is used in some cases for installation sequence and access to anchorage of the top and bottom horizontal members. Several manufacturers in the industry produce custom shapes and systems. This chapter will not discuss particular nuances of individual systems because such information is proprietary.

In general, the design performances of these elements are governed by local and national building codes, such as the International Building Code (ICC, 2006), ASCE 7-10 (ASCE 2010) Wind Load Codes, and guidelines by



Fig. 3-11. Tubular mullion system

Source: Courtesy of Oldcastle BuildingEnvelope®; reproduced with permission



Fig. 3-12. Tubular mullion system

Source: Courtesy of Oldcastle BuildingEnvelope®; reproduced with permission



*Fig. 3-13. Examples of available literature or code guidelines
Source: McFarquhar Group Inc.; reproduced with permission*

the American Architectural Manufacturers Association (AAMA 1987, 1989; Fig. 3-13). These publications establish limits for deflection and stresses. Because the aluminum frames are extrusions, they can consist of different alloys. The more common aluminum framing alloys are 6061-T6, 6063-T5, 6063-T6, and 6005-T5. Depending on the alloy temper, they have differing stress characteristics. For metal comparison, aluminum alloys 6061-T6 and 6005-T5 are nearly as strong as steel in yield strength. Figure 10 provides an example of some of the guideline literature used over the years and available for designing these systems. These manuals are constantly being updated and adopted by the varying local jurisdictions at different time intervals.

3.2.2 Aluminum Framing Systems

There are two main categories of curtain wall systems assemblage: field-assembled systems, commonly referred to as stick systems (Fig. 3-14), and shop-assembled systems, referred to as unitized systems (Figs. 3-15 and 3-16). Unitized system refers to module-size units that are preassembled. These frame types are generally split mullions (i.e., they have two mating profiles) with horizontal subframing. The glass is generally structurally bonded to the framing using structural grade silicone,



Fig. 3-14. Great America Building, Cedar Rapids, IA; example of stick wall system

Source: Courtesy of Wausau Window and Wall Systems; reproduced with permission



Fig. 3-15. Unitized or shop-assembled system

Source: Courtesy of Oldcastle BuildingEnvelope®; reproduced with permission



Fig. 3-16. Unitized or shop-assembled system

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which requires close monitoring and quality control during the sealant application and cure time. In this case, the glass is “adhered” to the aluminum framing.

The system type suitability is often a function of the job site constraints. Both systems can be installed properly. These are some of the advantages of unitized wall systems:

- The assemblage is done in a controlled shop environment.
- Erection is completed more quickly.
- Horizontal wrapping of floors provides more a systematic building envelope closure.
- There is less handling of components in the field.

The most critical function that the curtain wall is expected to perform is air and water infiltration control. Air is controlled by baffles at weep hole locations, rubber gaskets (i.e., wedge or wiper), air membrane and perimeter sealant at the framing or sill pan conditions depending on the system. Water infiltration is controlled by perimeter sealant and an internal weepage system that facilitates the exterior discharge of any water that collects inside the glazing pocket of the framing. Weep holes with supporting baffles that prevent dirt and bugs from accumulating inside the framing cavity are located in horizontal elements.

3.2.3 Steel Framing and Elements

Steel backup framing is used in several curtain wall systems. The steel framing can be implemented as individual elements, such as frame “sticks,” or as an assembly in trusses. Both horizontal and vertical trusses are used. Horizontal trusses may be used for stone panel support by developing module units. For natural stone, such as granite, steel trusses consisting of a combination of steel channels and/or tubes are used to support individual stone panels.

Vertical trusses such as bow trusses or tube pipe trusses, can be used to support glazing. These truss types provide the backup stiffened element that provides the main resistance to lateral loading and transfer these loads back to the building structure. Often these trusses can be assembled in combinations, for example on a large skylight to span across larger openings, as depicted in Fig. 3-17.

Another steel element that has design elegance due to transparency is steel cables used in cable net walls (see the example in Fig. 3-18). These cables are pretensioned and provide a more transparent look to the façade with minimal framing. However, the perimeter anchorage for this system must be robust and properly designed because cables are only strong in tension. For these systems, the deflection allowed is significantly greater than it is for traditional framed systems. However, significant cost is associated with these wall types in comparison with traditional metal-framing systems.



Fig. 3-17. Winter Garden, New York (at World Trade Center)

Source: Courtesy of Thornton Tomasetti; reproduced with permission



*Fig. 3-18. UBS Tower, Chicago, IL; example of a cable net wall
Source: Courtesy of Thornton Tomasetti; reproduced with permission*

The steel truss and cable net wall offer some unique attachment configurations for vertical glass, sloped glass, or transitioning façades such as corners. They are all custom fittings fabricated for the particular application.

3.3 TYPES OF GLAZING PANEL CONSTRUCTION

The following section discusses several methods of constructing or installing glazing panels, including dry glazed, wet glazed, structural silicone glazed (SSG), point supported, cable net, and double skin walls.

3.3.1 Dry Glazed

Dry-glazed application refers to the use of rubber gaskets, and structural tape in some cases, thus using compression to restrain the glass unit or metal panel inside the glazing pocket of the framing (Fig. 3-19). The rubber gaskets are extruded and custom profiled with darts for retention inside the manufacturer's custom system. Typically, the rubber gaskets are on either side of the glazed element, and the wedge gasket is the primary compression-applied element. Depending on the system, panels can be glazed from the interior or exterior.

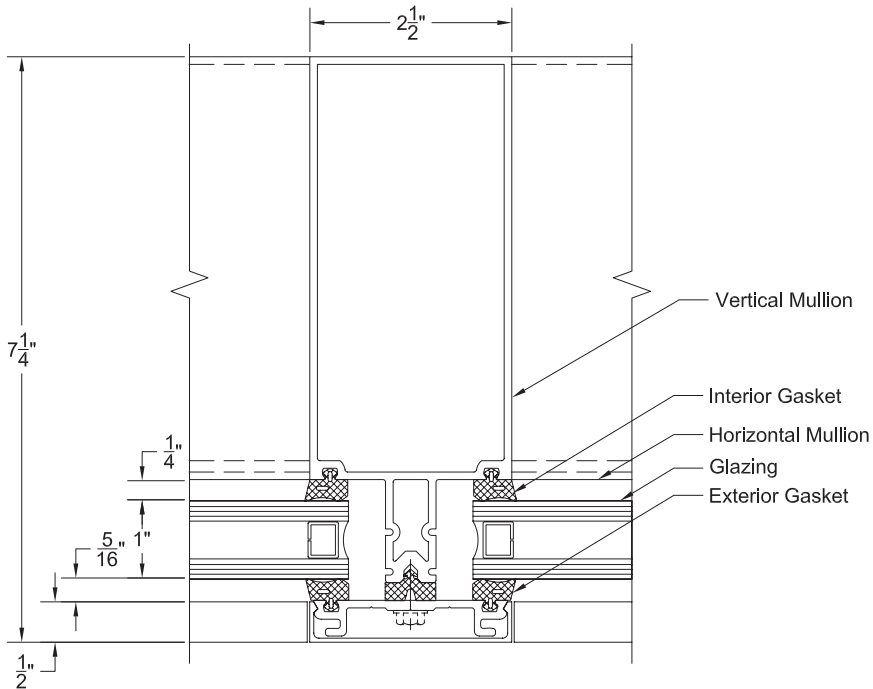


Fig. 3-19. Example of dry-glazed system with rubber gaskets (plan view)

Source: Courtesy of Oldcastle BuildingEnvelope®; reproduced with permission

3.3.2 Wet Glazed

Wet glazed application refers to the incorporation of silicone sealant as a primary element for attaching or installing the infill element. The process involves applying an external perimeter seal. Proper perimeter preparation is required for the sealant to function adequately.

One specific type of wet-glazed application is structural silicone glazed (SSG). SSG application requires careful preparation and monitoring of the sealant. The process involves adhering the glazed element to an aluminum frame. The bond between the silicone, the glass, and the aluminum frame provides structural resistance to lateral loading (Fig. 3-20). The recommendation is to conduct this installation process in a shop or factory clean environment because the sealant adheres less well to the dusty surfaces that would be typical in the field. The required contact width is a critical component for the structural integrity of the system based on safety factors such as sealant stiffness and stress capacity. SSG units may be fabricated for single- or two-floor heights (Fig. 3-21).

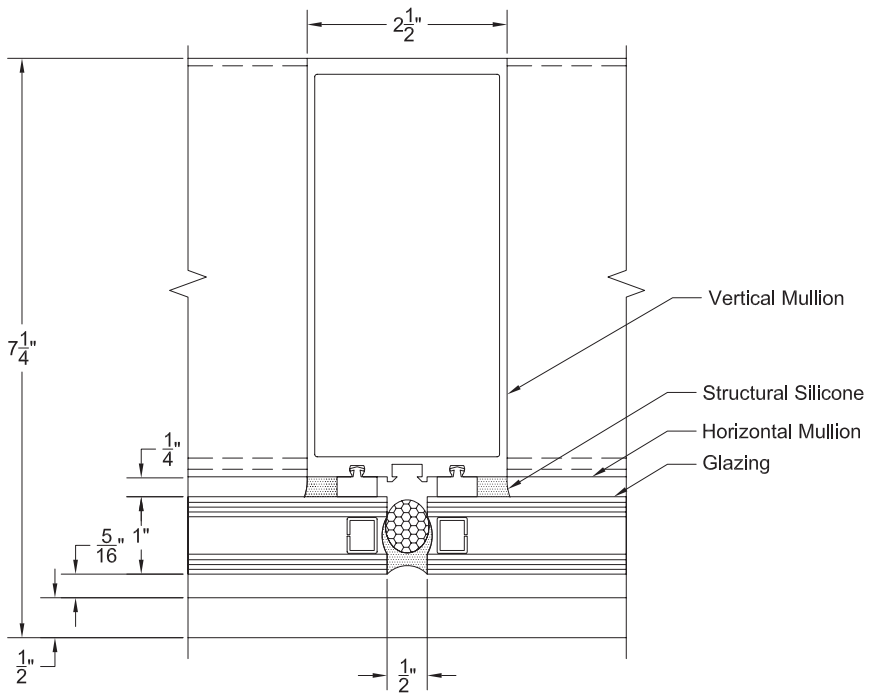


Fig. 3-20. An example of SSG application (plan view)

Source: Courtesy of Oldcastle BuildingEnvelope®; reproduced with permission



Fig. 3-21. Installing a structurally glazed unit in Ft Worth, TX

Source: Courtesy of Harmon Inc.; reproduced with permission

3.3.3 Point-Supported Glass Systems

Point-supported systems are custom and job specific in application and fittings (Figs. 3-22 to 3-24). The fittings are often driven by the architectural intent, and molds can be fabricated with a high level of engrained aesthetics and precision. The detailing is often elegant but requires a lot of coordination and dye control. This type of system requires proof testing of prototypes especially if the project has high complexity or geometrical challenge. The analysis of these systems often involves sophisticated finite element modeling to evaluate load transfer and stresses within and by the fitting elements.

3.3.4 Cable Net

As previously mentioned, the cable net wall is an elegant but somewhat expensive façade. The framing siteline is minimal and offers tremendous visual clarity for the patron (Fig. 3-25). However, it requires rigorous structural analysis and field coordination because of the resulting effect of loading on the structure. Because of the flexibility of the wall, the deflection under high lateral loading conditions may seem excessive and uncomfortable, but the wall functions well and serve its aesthetic requirements.



Fig. 3-22. Newark International Airport, NJ; example of point-supported glass and glass fins

Source: Courtesy of W&W Glass, LLC; reproduced with permission



*Fig. 3-23. Complex glazing connections; example of point-supported glazing
Source: Courtesy of W&W Glass, LLC; reproduced with permission*

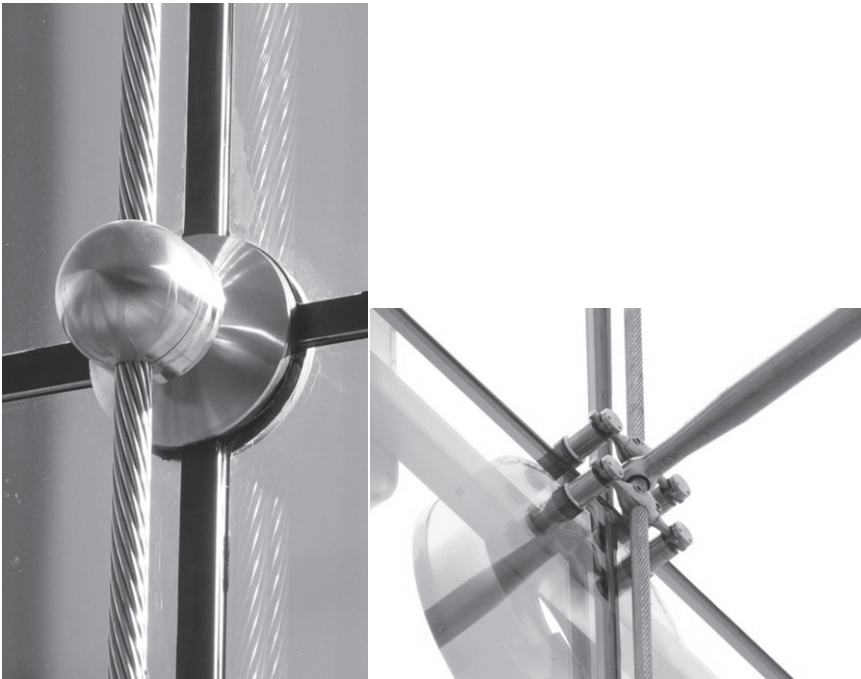


*Fig. 3-24. Examples of point-supported glass fittings
Source: Courtesy of W&W Glass, LLC; reproduced with permission*



Fig. 3-25. UBS Tower, Chicago, IL

Source: Courtesy of Thornton Tomasetti; reproduced with permission

3.3.5 Double Skin Wall

This type of curtain wall system is quite complex and duplicates the number of clad walls. It uses the cavity between the façades to control energy input from daylight and to incorporate mechanical ventilation using the warm air within the cavity space. It is commonly used in Europe and other regions. It is a more expensive wall compared with other, more conventional curtain wall systems. This wall type generally includes louvers, operable windows, sunshades, etc., with the focus and emphasis being placed on energy recycling as an everyday operation of the building. An example of a double skin façade is shown in Figs. 3-26 and 3-27.

3.4 CURTAIN WALL ANCHORAGE

The curtain wall is uniquely anchored to the building at floor lines. The mode of attachment depends on the spans, wind or seismic loading, and temperature. The curtain wall can be supported by



Fig. 3-26. University of Southern California Stem Cell Research Facility, Los Angeles, CA

Source: Courtesy of W&W Glass, LLC; reproduced with permission



Fig. 3-27. University of Southern California Stem Cell Research Facility, Los Angeles, CA

Source: Courtesy of W&W Glass, LLC; reproduced with permission

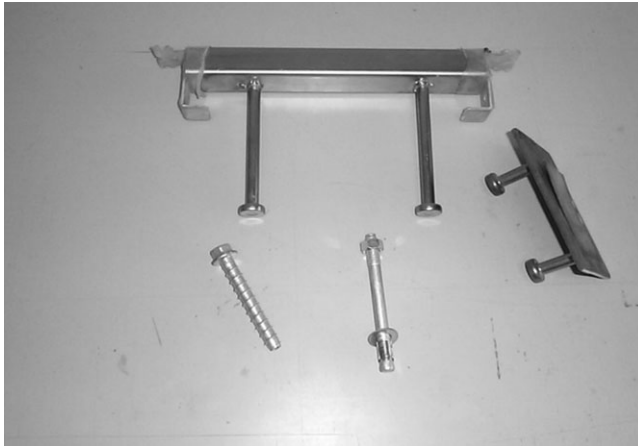


Fig. 3-28. Examples of curtain wall framing anchorage

Source: McFarquhar Group Inc.; reproduced with permission

- Extruded aluminum anchors;
- Steel plate anchors or steel angles (in either case with separator pads between dissimilar metals, i.e., aluminum and steel); and
- Steel bolts (through bolts or tapping bolts).

The anchorage attached to the building may be steel embed plate, steel channel anchors, welds, expansion bolts, and epoxy anchors (Figs. 3-28 and 3-29). Each method has its merits and must accommodate anticipated building movements and construction tolerance. These connection elements are generally in the spandrel areas and hidden from normal view. Curtain wall framing connections must be engineered for imposed loading constraints. Because perimeter conditions and wind loading vary from project to project, anchorage schemes should be evaluated on a project-specific basis. In fact, the wind loads on various parts of the building can be quite different, so attachment design may vary even on the same building project.

3.5 SUMMARY

The performance of the curtain wall façade remains the most important critical component of a building's defense against the exterior environment. At the microscopic level, the curtain wall requires a high level of detail for intricate components, extrusions, and their attachments; at the macroscopic level, the curtain wall defines a building with multiple material and configurations available.

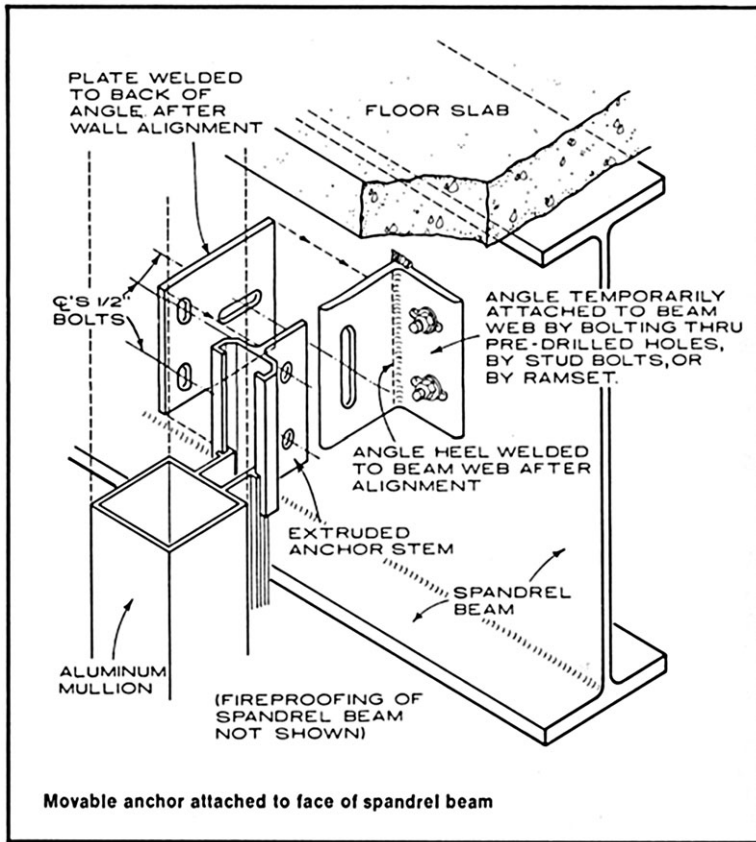


Fig. 3-29. Representation of curtain wall frame anchorage

Source: AAMA Curtain Wall Manual (AAMA 1987, 1989). Courtesy of American Architectural Manufacturers Association; reproduced with permission

As initially stated, curtain wall systems are very custom and proprietary. Several manufacturers develop unique systems to withstand wind loading, hurricane winds, blast loading, seismic loading, missile impact, and thermal and live load movements. All of these systems can have excellent features. Projects can be customized or use off-the-shelf systems. Having multiple curtain wall systems within the exterior façade of a particular building or complex is common. This combination of systems can use a variety of elements such as glazing, natural stone, concrete, and metal panels. The curtain wall systems also allow appendages, such as sunshades and aesthetic bullnose accent profiles, to be designed and supported within their gridwork.

The curtain wall represents the signature of the building. It is integral in expressing the intended geometric shape of the building and defining the façade's modular grid. Using available tint options allows the architect a wide range of hues to work with and manufacturer test data can enable energy studies to be conducted on the basis of either selected color or glass type scheme.

3.6 REFERENCES

- Aluminum Association (AA). (2000). *Aluminum design manual*, Washington, DC.
- American Architectural Manufacturers Association (AAMA). (1987). *Aluminum storefront and entrance manual, Vol. 3*, Des Plaines, IL.
- AAMA. (1989). *Metal curtain wall manual, Vol. 2*, Des Plaines, IL.
- ASCE/SEI. (2010). "Minimum design loads for buildings and other structures," *ASCE/SEI 7-10*, Reston, VA.
- Glass Association of North America (GANA). (1997). *Glazing manual*, Topeka, KS.
- Indiana Limestone Institute (ILI). (2007). *Indiana limestone handbook*, 22nd Ed. Bedford, IN.
- International Code Council (ICC). (2006). *International building code*, Country Club Hills, IL.
- Marble Institute of America (MIA). (2011). *Dimension stone design manual, Version 7.2*. Cleveland, OH.

CHAPTER 4

TESTING MOCKUPS AND FIELD INSPECTION

Dudley G. McFarquhar, Ph.D., PE

Testing has proven invaluable to the performance (actual and expected) of curtain wall systems. Different types of testing can be implemented. Testing is often job specific and a function of the building-envelope complexity, project size, number of system types, and building usage.

Sequencing of testing is primarily done in two phases:

1. Prior to building construction by the testing of a mockup
2. In-field testing at different stages during construction

Testing of the curtain wall system provides valuable information about potential problems or validation of expected performance. It can be a great learning tool, especially in the scenario where multiple systems types and materials interface within the building envelope. Because all subcontractors are responsible for their scope or material type, the challenge always occurs at interfaces and in the necessary coordination among different trades.

Along with testing, field inspection of curtain wall installation is critical. Typical questions related to field inspection include the level of review required for a project, who will provide this review, how often will the review occur, and who has responsibility on the back end.

4.1 MOCKUPS

Mockups are prototypes representing and replicating sections or portions of the curtain wall system or building envelope. They often encompass aluminum framing, glazing, natural stone panels, metal panels, or

other perimeter materials as dictated by the project. The mockups can be constructed of different sizes and, if being tested in a laboratory, be limited to the laboratory test chamber's dimension or capability.

Mockups comprise basically two types: visual and performance.

4.1.1 Visual Mockups

Visual mockups are constructed primarily to review relative location of elements, finish of material, joinery (framing, wall, metal panels, and sealant), aesthetics of the curtain wall, and interior view of material finish and layout (Fig. 4-1). The visual mockup often is used as a benchmark for expected quality of material and consistency in installation and enables the contractor/subcontractor to demonstrate to the owners and the design team that the work will be properly executed to industry standards. Punched windows represent a good example in which the interface with the perimeter waterproofing needs to be coordinated and demonstrated. In several instances, the manufacturer's representative is involved to provide additional guidance to the subcontractor if needed. This element is important for maintenance of material warranty on the project. The visual mockup represents a cost-effective means of making changes in materials or colors prior to mass construction of the building. Architects especially like to use aesthetic mockups to explore or review different



Fig. 4-1. Example of a field visual mockup showing multiple substrates and components

Source: Courtesy of Corgan Architects, Dallas; reproduced with permission

materials. Visual mockups are often erected onsite as a reference quality assurance benchmark for the contractor.

4.1.2 Performance Mockups

Performance mockups are more sophisticated than aesthetic mockups, although a performance mockup does allow the design team and ownership to obtain an aesthetic view of the wall assembly. The performance mockup may be subjected to a sequence of tests, including lateral loading (i.e., wind loading) for structural response, seismic racking, water infiltration (static and dynamic), air infiltration, thermal performance, and sound transmission. Typically, the basic tests include lateral loading, water infiltration, and air infiltration. The lateral-loading tests focus on frame movement and anchorage resistance. Water-infiltration testing ascertains the waterproofing performance of the façade. Air-infiltration testing relates primarily to building energy concerns and directly concerns both the building's mechanical HVAC systems performance and the glazed system composition.

Performance mockups are created and tested in test chambers at a manufacturer's facility or an independent laboratory. One variation is simply to perform water testing on a site-constructed mockup to check framing and material jointing and frame weepage mechanisms (Fig. 4-2).

4.2 STANDARDS RELATED TO CURTAIN WALL SYSTEMS

Several standards relate to curtain wall systems. In some cases, voluntary specifications exist as well. The main organizations that provide guidance and recommendations related to curtain wall systems include

- American Society of Testing Materials (ASTM)
- American Architectural Manufacturers Association (AAMA), (AAMA 1987, 1989)
- Aluminum Association (AA), (AA 2000)
- American Society of Civil Engineers (ASCE) (ASCE 2010)
- Glass Association of North America (GANA), (GANA 1997)
- International Code Council (ICC) (ICC 2006) and similar

Other related organizations provide information or guidelines that concern curtain wall or the glazing industry, including

- National Fenestration Rating Council (NFRC)
- National Institute of Building Sciences (NIBS)–Whole Building Design (WBD)



*Fig. 4-2. Example of an installed two-story mockup for testing
Source: Courtesy of Construction Consulting International; reproduced with permission*

4.2.1 Representative Standards Listing

The following listing is not comprehensive but indicates the general types of testing and the sources for some testing protocols. Other test methods are published and available that include component-specific or variable-specific testing.

ASTM Within the following listing of test standards, the **bolded** text refers to more widely used or specified test protocols:

C717-09	Terminology of Building Seals and Sealants
C864-05	Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers
C920-08	Specification for Elastomeric Joint Sealants
C1193-09	Guide for Use of Joint Sealants
C1401-09a	Guide for Structural Sealant Glazing

E90-09	Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements
E283-04	Test Method for Determining Rate of Air Leakage through Exterior Windows, Curtain Walls, and Doors under Specified Pressure Differences Across the Specimen
E330-02	Test Method for Structural Performance of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
E331-00	Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference
E547-00	Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Cyclic Static Air Pressure Difference
E1105-00	Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference
E1186-03(2009)	Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems

AAMA

AAMA 501 Methods of Test for Exterior Walls

AAMA 501.4 Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind-Induced Interstory Drifts

AAMA 501.5 Test Method for Thermal Cycling of Exterior Walls

AAMA 502-08 Voluntary Specification for Field Testing of Newly Installed Fenestration Products

AAMA 503 Voluntary Specification for Field Testing of Metal Storefronts, Curtain Walls, and Sloped Glazed Systems

Note that AAMA (1987) and AAMA (1989) provides several design guides and technical reports.

4.2.2 Typical Prevalent Standards

The more prevalent industry standards focus mainly on air- and water-resistance performance. These elements may be tested in the laboratory

or in the field (on site). The more widely used tests are **ASTM E331**, **ASTM E1105**, and **AAMA 502**. In addition, several standards relate to the quality and performance of other curtain wall components, such as glazing, gaskets, and sealant (see the aforementioned ASTM listing of test standards) and analytical methodology.

4.3 TYPES OF TESTS

As previously noted, several types of tests are available to the industry and frequently used. This discussion focuses on the main types in common use. In general, testing can be divided into two main categories: mockup testing and component testing.

4.3.1 Mockup Testing

Mockup testing can be conducted in a controlled space such as an accredited laboratory or in the field. In the laboratory, more components can be tested than in the field because of setup and the fact that the environment is controlled within the test chamber. Elements such as deflection gauges or load cells can be strategically located to obtain data to compare with computational analysis generally performed by a registered professional on these system types. A mockup provides an excellent opportunity to observe a full-scale sample of the building façade (Fig. 4-3).

Laboratory Testing In the laboratory, the curtain wall system is installed to replicate the field connections, and the system is tested for the following performance aspects:

- Air infiltration (Fig. 4-4),
- Water infiltration (static and dynamic) (Figs. 4-5 and 4-6),
- Structural-loading response (wind, seismic) (Fig. 4-6)
- Debris impact testing (Fig. 4-10 to 4-12)

Air Infiltration Air infiltration is an important check because it indicates system tightness with respect to air flow. Air tightness is important because of the large number of units of this type to be installed on a typical high-rise building and ongoing building code demands and challenges to be energy efficient. Air infiltration also is checked on membranes used in building envelope and curtain wall construction. An example of this is shown in Fig. 4-4.

Water Infiltration Water infiltration generally is checked using a spray rack for static testing (Fig. 4-5) or a plane engine to spray water at a prescribed rate simulating a wind event for dynamic testing (Fig. 4-6). The



*Fig. 4-3. Example of an installed two-story mockup for testing
Source: Courtesy of Construction Consulting International; reproduced with permission*



*Fig. 4-4. Air tightness test of an envelope component ASTM 1186
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