Building Envelope Design Guide

The National Institute of Building Sciences (NIBS) under guidance from the Federal Envelope Advisory Committee has developed this comprehensive guide for exterior envelope design and construction for institutional / office buildings. The Envelope Design Guide (EDG) is continually being improved and updated through the Building Enclosure Councils (BECs). Any edits, revisions, updates or interest in adding new information should be directed to the BEDG Review Committee through the 'Comment' link on this page.

Introduction

Below Grade Systems

- Foundation Walls
- Floor Slabs
- Plazas, Tunnels, Vaults

Wall Systems

- Cast-In-Place Concrete
- Exterior Insulation and Finish System (EIFS)
- Masonry
- Panelized Metal
- Precast Concrete
- Thin Stone

Fenestration Systems

- Glazing
- Windows
- Curtain Walls
- Sloped Glazing
- Exterior Doors

Roofing Systems

Atria Systems
Introduction

Intended Audience and Subject Matter

The National Institute of Building Sciences (NIBS)—under contract from the Army Corps of Engineers, the Naval Facilities Engineering Command, the US Air Force, the General Services Administration, the Department of Energy, and the Federal Emergency Management Agency—has developed this comprehensive federal guide for exterior envelope design and construction for institutional/office buildings.

The scope covers buildings constructed of steel, reinforced concrete, reinforced masonry and reinforced concrete masonry units and includes low-rise, mid-rise and high rise buildings. Typical buildings include administration (office) buildings of all sizes, from a small one-story base administration building to a twenty-story inner city agency office facility. Other building types include firehouses and police facilities, courthouses, military residences, many types of laboratories, various types of education buildings, hospitals, extended care facilities, clinics and many types of recreational buildings. Special use buildings such as airplane hangers, testing facilities, and stadiums, single family residences and wood frame structures are not included.

Though specifically intended for Federal Government agency projects, the information in the guidelines will also be applicable to many privately developed projects—whether of a commercial or institutional nature—which are essentially similar in use and construction to equivalent governmental structures. Because the guidelines are intended for use in the design of governmental structures, the intent is to provide a long-lived structure based on lifecycle costing since governmental ownership is typical in perpetuity. Thus a high standard of construction and maintenance is advised to achieve the aims of the agencies involved.

Format

This is the first time a group of Federal agencies has developed a set of guidelines to be used for the design and construction of their buildings. Its publication and use is meant to assist in the development of uniform design and construction criteria for the Federal government. Instead of taking form as a printed document, which would be revised at long intervals, the Guide is made freely available as a "virtual" information source on the World Wide Web within the Whole Building Design Guide. It is anticipated that government agencies will devise methods of using the Guide to create their own "customized" documents to suit their building types, locations and administrative needs and to further their individual design and construction goals.

Private owners and their designers are free to use the Guide as a resource and can develop their own customized documents or simply refer their designers to useful sections of the Guide. The Guide is not a building code and does not attempt to specify mandatory criteria. Instead it provides design oriented information meant to assist designers in making informed choices of materials and systems to achieve performance goals in their buildings.

The Guide will be a "living" information source that will continually expand and change. It will be interactive, allowing users to enhance the content by adding resource papers, reporting on experiences, and helping to maintain a dialog with Guide management.

Scope
Richard Rush, in his book *The Building Systems Integration Handbook*, defines a building in terms of only four systems:

- Structure
- Envelope
- Mechanical
- Interior

In this categorization, "The envelope has to respond both to natural forces and human values. The natural forces include rain, snow, wind and sun. Human concerns include safety, security, and task success. The envelope provides protection by enclosure and by balancing internal and external environmental forces. To achieve protection it allows for careful control of penetrations. A symbol of the envelope might be a large bubble that would keep the weather out and the interior climate in."

Dr. Eric Burnett and Dr. John Straube, in a number of writings, have also described the envelope in terms of performance and function. According to them, the envelope "experiences a variety of loads, including, but not limited to, structural loads, both static and dynamic, and air, heat and moisture loads." The enclosure must then support structural loads and control environmental loads, which include both long-term and short-term loads. The enclosure is also often used to carry and distribute services within the building. In addition, the envelope (primarily the wall) has several aesthetic attributes that can be summarized as finishes. (This description of the envelope is expanded in the wall section of this *Guide*.) Thus the systems and assemblies of the envelope are one of the four main building systems both in terms of their physical existence and in their contribution to overall building performance.

For this guide the building envelope also includes the below grade basement walls, foundation and floor slab (although these are generally considered part of the building's structural system) so that the envelope includes everything that separates the interior of a building from the outdoor environment. The connection of all the nonstructural elements to the building structure is also included. Finally, it is recognized that the exterior envelope plays a major role in determining the aesthetic quality of the building exterior, in its form color, texture and cultural associations.

The following Building Envelope Systems are covered in separate chapters:

1. **Below Grade** construction
2. **Exterior Walls**, both structural (providing support for the building) and nonstructural (supported by the building structure)
3. **Fenestration**, both windows and metal/glass curtain walls
4. **Roofs**, both low- and steep-slope
5. **Atria**.

This guide demonstrates that the design of the envelope is very complex and many factors have to be evaluated and balanced to ensure the desired levels of thermal, acoustic and visual comfort together with safety, accessibility and aesthetic excellence. As can be seen from the list of functions of the building envelope detailed in the Function and Performance section, the envelope plays a role in almost every building function, either directly or indirectly in its relationship to other building systems.

Figure 1 illustrates the envelope systems of a typical building.
The guidelines for each of these systems are authored by an expert in the subject matter and are presented in the following uniform format:

- **Introduction**—An overall description of the system
- **Description**—The physical elements and properties of the system
- **Fundamentals**—A discussion of the design objectives to achieve ranges of performance
- **Applications**—The range of applications for building functions and external conditions
- **Details**—Generic construction details in CAD format with commentary
- **Emerging Issues**—A survey of significant current research and development
- **Codes and Standards**—Code philosophy and limitations and a summary of currently applicable codes and standards
- **Resources**—References, major publications, industry and professional associations, and Web sites

In addition, the following performance issues are examined for each of the envelope systems:

- Thermal performance
- Moisture protection
- Fire safety
- Acoustics
- Daylighting and perimeter visual environment
- System maintainability
- Material durability

Beyond these major performance issues the following more specialized building performance topics are covered by separate authors in concert with the principal system authors and, where appropriate, integrated into the main text for each system:
- Seismic safety
- Safety against blast and chemical, biological and radiological (CBR) attack
- Safety against extreme wind
- Safety against flood
- Indoor air quality and mold prevention
- Sustainability and HVAC integration

The Whole Building Design Guide

The Building Envelope Design Guide is one of a series of guides in the Whole Building Design Guide (WBDG) that are intended to assist designers in the integrated design of assemblies and systems. As such, the Building Envelope Design Guide follows the general format of other guides in the WBDG and are internally linked to Resource Pages and other levels and sections of the WBDG.

The Whole Building Design Guide (www.wbdg.org) is an evolving Web-based resource intended to provide architects, engineers and project managers with design guidance, criteria and technology for "whole buildings". Accordingly, the WBDG covers the whole range of today's issues in building design, such as sustainability, accessibility, productivity, and safety—both from human and natural hazards. The WBDG is constantly augmented with updated and new information and is structured as a "vertical portal", enabling users to access increasingly specific information as they navigate deeper into the site.

The concept of the Whole Building Design Guide has been formalized to achieve four main goals:

1. To simplify access to government and non-government criteria and standards information using a web-based approach so that valuable time is not wasted searching for this documentation.
2. To replace outdated, redundant paper-based criteria documents.
3. To guide managers and A&E firms through a "whole building" approach to building design so that high performance, longer-lasting buildings are produced.
4. To provide a brief, up-to-date and informative resource that covers general and specific topics in an encyclopedic form. However, unlike a traditional encyclopedia, the WBDG enables the user to build up a private store of relevant information by direct links to other resources available on the Internet with a few mouse clicks.

The WBDG has become a primary gateway to up-to-date-information on a whole range of Federal and private sector building-related guidance, criteria and technology from a "whole building" perspective. Users are able to access information through a series of "levels" by way of three major categories: Building Types, Design Objectives, and Products and Systems. At a lower level are Resource Pages, which are succinct summaries on particular topics written by experts. Pages within the WBDG are cross-linked to each other, and hyperlinked to external Web sites, publications and points of contact, allowing easy access to related information. Agency-specific information is accommodated in a Participating Agency section. Other features include relevant Federal mandates, news headlines and a robust search engine.

The WBDG Web site is provided as an assistance to building professionals by the National Institute of Building Sciences (NIBS) through the funds and support of the NAVFAC Criteria Office, the U.S. General Services Administration (GSA), and the Department of Energy through the National Renewable Energy Laboratory (NREL) and the Sustainable Buildings Industry Council (SBIC). A Board of Direction and Advisory Committee, consisting of representatives from Federal agencies, private sector companies and non-profit organizations guide the development of the WBDG.

The Evolution of the Building Envelope

The Building Envelope Design Guide will constantly evolve, with its users participating in this evolution rather than simply using a set of fixed, definitive guidelines. They will thus be advancing the evolution of the building envelope itself. The first building envelope that protected humans from the elements was probably a cave that provided a degree of privacy and security. The earliest building envelopes were dome-shaped structures that combined wall and roof (Figure 2A). At an early stage, however, the two dominant forms of envelope evolved, depending on climate and available materials: the timber frame and the masonry wall (Figure 2B and 2C). Early shelters in the warm climates of Africa and Asia used timber or bamboo frames clad with leaves or woven textiles. In other regions and climates heavier indigenous materials
such as stone, rock and clay baked by the sun were used to provide more permanent shelter and protection from the heat and cold (Figure 2D).

To this day rural regions in lesser developed countries still construct these forms of shelter. In the developed world we still use envelopes of timber frame and masonry walls, although both have evolved into a wide range of materials—some natural, others synthetic. Roofs evolved independently as waterproof elements with their own set of materials.

Thus, eventually the roof, wall and floor became distinct elements of the building envelope that have continued to this day with very little change in concept, use and even material. A medieval dwelling might have walls of wood, brick or stone, a wood roof structure, a slate tile or thatch roof and a floor of stone or hardened dirt. Such a dwelling can still be found today in many regions of the United States and the world.

To take one element of the envelope, the wall, its basic performance requirements have remained the same from medieval times to this day: protection of the interior from the elements and security for its occupants. However, our expectations have vastly increased, both in terms of absolute performance and the ability to control the impact of exterior water, sunlight and the ambient outside temperature on our interior environment. Depending on a society’s structure and economy, such needs as degree of permanence of our exterior system, its scale and adornment and our desire to have a wide variety of exterior envelope choices may also vary considerably.
Compared to most of today's walls, the medieval or renaissance masonry wall was simple. Initially, the wall was a single homogeneous material—stone or brick—exposed on the exterior and interior. Such walls are still constructed today, although the wall is more likely to be reinforced concrete or concrete block. Before long, the historic wall would become adorned: a rough structural stone would be faced on the exterior with a precisely cut and fitted facing of fine stone or marble, and the interior would be faced with smooth plaster (Figure 3).

As soon as the structural wall became faced with different finish materials, the beginnings of variable performance capability emerged. The separation of the structure and facing presaged the layered exterior wall of today. The structure of rough cut stone could rise independently from its facing, which could be prefabricated in the craftsman's shop. The high-quality facing and its detailing also provided protection from the weather for the structural masonry within (Figure 4).

Historic buildings and even historic revival buildings accomplished many of the building envelope functions by default: thick, heavy masonry was fireproof and good for insulation in both summer and winter. It was excellent acoustically and, with sheltering roofs and good water protective details, was reasonably watertight and draft free by the standards of the time. However, by modern standards, the wall had fixed and limited performance capabilities.

The big change in the concept of the wall—and the real beginning of today's concept of the building envelope—occurred with the invention of the steel, (and later, the reinforced concrete) frame in the nineteenth century. The exterior wall could become a screen against the elements and no longer be needed to support the floors and roof. However, for several decades steel frames were buried in masonry walls, and buildings continued to be designed in gothic or renaissance styles. The modern architectural revolution beginning in the early 20th century changed this, and by mid-century the steel or concrete framed office building with its lightweight metal and glass curtain wall had become the new world-wide vernacular for larger commercial and institutional buildings.

When the wall became a nonstructural screen-in and no longer supported the upper floors and roof, it lost the beneficial attributes of mass but gained in providing performance options. Whole new industries arose that would develop insulation and fireproofing materials, air and moisture barriers and interior and exterior facings. More recently, the exterior wall has become a major subject of building science studies, largely because of the wall's key role in managing heat gain, heat loss and moisture penetration. As a result, the modern wall now consists of a series of performance "layers" (Figure 5).
A cross section of a typical layered exterior wall of today illustrates the complexity that this approach leads to in practice (Figure 6).

Figure 6. This section through a typical nonstructural exterior wall within a steel frame building structure shows the complexity of the layered approach in its application. (Architectural Graphic Standards)

A different material may achieve each performance requirement, with each performing a separate function, or some materials may perform multiple functions. For example, the air barrier may simply be a coating on a support layer.

**Function and Performance**

The complexities of today's wall can also be exemplified by listing its **functional** requirements, or needs that must be met. There are at least 13 distinct needs, as listed below. Most of these functions also apply to fenestration and the roof and a few also apply to below grade construction (see Table 1 in Section 7). Each function (with a few exceptions) has its own performance standards and methods of measurement, methods of testing for compliance, and acceptability criteria.

1. **Structural**: If the wall is not part of the main building structure, support own weight and transfer lateral loads to building frame.
2. **Water**: Resist water penetration.
3. **Air**: Resist excessive air infiltration.
4. **Condensation**: Resist condensation on interior surfaces under service conditions.
5. **Movement**: Accommodate differential movement (caused by moisture, seasonal or diurnal temperature variations, and structural movement).
6. **Energy conservation**: Resist thermal transfer through radiation, convection and conduction.
7. **Sound**: Attenuate sound transmission.
8. **Fire safety**: Provide rated resistance to heat and smoke.
9. **Security**: Protect occupants from outside threats.
10. **Maintainability**: Allow access to components for maintenance, restoration and replacement.
11. **Constructability**: Provide adequate clearances, alignments and sequencing to allow integration of many components during construction using available components and attainable workmanship.
12. **Durability**: Provide functional and aesthetic characteristics for a long time.
13. **Aesthetics**: Do all of the above and look attractive.
14. **Economy**: Do all of the above inexpensively.

**Performance** refers to the desired level (or standard) to which the system must be designed for each of the above functions.
functional requirements. For example, what dimensions of movement must be accommodated, and what is the expected useful life, or durability, of the system.

Cost Management

The building envelope represents a substantial percentage of a building’s cost. (Some typical costs presented as a percentage of the whole building cost are shown in Table 1, below.) For a multi-story building, the envelope costs (dominated by the cost of walls and fenestration) may even exceed 20% of the total building construction cost.

The envelope is also a critical system in the determination of the overall performance of the building, with an emphasis on the thermal environment, lighting and acoustical characteristics. It is the prime determinant of the exterior aesthetic quality of the building. Clearly, the balance between the cost of the building envelope and its levels of performance will be of great importance in achieving the most cost-effective design of a building.

Table 1. Typical building envelope costs as a percentage of whole building cost

<table>
<thead>
<tr>
<th>BUILDING TYPE</th>
<th>FLOOR SLAB</th>
<th>EXTERIOR WALL</th>
<th>ROOFING</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOSPITAL, 4-8 floors</td>
<td>0.6</td>
<td>9.5</td>
<td>0.6</td>
<td>10.7</td>
</tr>
<tr>
<td>MANUFACTURING PLANT,</td>
<td>6.4</td>
<td>9.5</td>
<td>6.7</td>
<td>21.6</td>
</tr>
<tr>
<td>1 floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OFFICE, 12-20 floors</td>
<td>0.3</td>
<td>19.9</td>
<td>0.4</td>
<td>20.6</td>
</tr>
<tr>
<td>JR. HIGH SCHOOL, 2-3</td>
<td>2.3</td>
<td>14.5</td>
<td>2.5</td>
<td>19.3</td>
</tr>
<tr>
<td>floors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: Means Square Foot Costs)

The Building Envelope Design Guide does not attempt to provide cost information for estimating purposes. There are a number of reasons for this:

1. Construction costs fluctuate and rapidly become out of date. Published indices attempt to ameliorate this problem but they tend to be very broad in scope and are of limited use in application to a specific project. Also the state of the local market at the time of bidding and construction often has a major effect on cost.
2. Construction costs vary greatly according to the project location. In broad terms, in the U.S. there is approximately a 200% spread between the least and most costly states in terms of construction cost.
3. Very rapid change in cost—generally upward—in such key materials such as steel and lumber are common and cannot be predicted in advance.
4. Government agencies and other institutions and businesses that manage large construction programs generate detailed cost information that refers particularly to the type and quality of the buildings they construct. This forms a valuable database that is specific to the owner's location and needs. Architectural and engineering firms and contractors also develop cost data that applies to their projects.
5. Specialty construction cost estimating and management firms develop very large and detailed databases on cost because they are focused entirely on cost management issues. On any significant project they should be employed from the outset as part of the design team with responsibilities for cost management.

For these reasons, the developers of the Building Envelope Design Guide believe that cost management should be based on local informationprocured before the design process for budgeting purpose and during the design process for cost management purposes. The use of life-cycle costing, economic analysis and value engineering can be used to the extent that they suit the owner's economic goals. Clearly an agency or institution that expects to own a building for its entire useful life is well advised to budget on a life-cycle, and many government agencies now require that this be done.

Private owners may have other aims, but the ultimate building operators will all benefit from a building in which life-cycle costs have been considered. A future in which it is clear that energy costs must be expected continually to rise—with the possibility of energy itself becoming scarce within today’s building lifetime—makes it the more necessary to design for minimum energy usage consistent with meeting functional and environmental needs. Building envelopes designed with opportunities for the use of day lighting and natural ventilation obviously can play a major role in such considerations.
The systems and elements that comprise the building envelope are each discrete assemblies that, in many instances, are designed by specialist consultants and installed by specialist sub-contractors. The mechanical system, for example, will be designed by a specialist engineering consultant and installed by several different mechanical sub-contractors. Some assemblies have a variety of methods of design and procurement. A metal and glass curtain wall may alternatively be a proprietary catalog assembly, a custom assembly designed by the architect with input from manufacturers or a consultant, or designed by a consultant to meet the architect’s requirements. Each system, however, also has functional, performance, design and construction relationship to others.

Functional performance for the thermal environment, moisture protection, sustainability and durability are shared by all 4 of our major subsystems: walls, fenestration, roofing and below grade. Thus each has to be designed to contribute its appropriate share of the overall functional effectiveness in meeting the performance requirements for the whole building. Acoustic performance for the exterior is the responsibility of the wall system and, to a lesser extent, the fenestration, while daylight transmission and control is the responsibility of the fenestration and the roof (if there are skylights, although these will be designed by the fenestration designers). Natural ventilation, if provided, will be a fenestration design problem but will also have major repercussions on the HVAC design. If the HVAC system employs perimeter heating or cooling this must be integrated with the envelope performance requirements. Interior air quality is primarily an HVAC issue, mainly concerned with outside air supply and filtering. The exterior wall will also have some performance requirements relating to materials and permeability.

These relationships and some others are "flagged" in the matrix shown in Tables 2 and 3. Table 2 shows the list of basic performance requirements that are covered in this guide. Table 3 shows the list of secondary performance requirements that are covered. In addition, aesthetics is shown as an "influence". Unlike the other performance requirements, aesthetics is not subject to scientific testing and measurement. Nonetheless—particularly for the wall and fenestration systems of the building envelope—it is a powerful influence in the system and material selection process. The attributes of color, texture and pattern are familiar. The attribute of "association" refers to issues such as the use of stone to represent solidity and permanence (besides its possible measurable attributes of durability), or the desire of some colleges to require red-tile roofs on new campus buildings.

The group of practice considerations refers to issues that appear in all systems and are critical to the successful implementation of the whole project, from concept to commissioning. Innovation refers to emerging methods, materials and processes that may improve the performance, cost or appearance of a system as a whole or any element of it.

**Table 2. Function and Performance Relationships of the Building Envelope: Basic Performance Requirements**

**Key:**
- X Major determinant or influence
- (X) Minor determinant or influence

<table>
<thead>
<tr>
<th>SYSTEMS</th>
<th>WALLS</th>
<th>GLAZING</th>
<th>ROOF</th>
<th>BELOW GRADE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASIC PERFORMANCE REQUIREMENTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Wall and glazing insulation and relative quantities largely determine thermal performance in medium and high rise buildings (small footprint), roof more influential in low rise (large footprint).</td>
</tr>
<tr>
<td>Moisture Protection</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>All systems important, particularly glazing interface with walls, roof interface with skylights.</td>
</tr>
<tr>
<td>Acoustics</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td></td>
<td>Protection against outside acoustic environment. Walls major determinant, with glazing a secondary influence.</td>
</tr>
<tr>
<td>Light Transmission</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td></td>
<td>Glazing major determinant, both quantity and location: roof may be important if skylights are provided.</td>
</tr>
<tr>
<td>IAQ</td>
<td>(X)</td>
<td>(X)</td>
<td></td>
<td></td>
<td>HVAC system is major determinant, together with natural ventilation (operable windows) if provided. Wall openings (grilles)</td>
</tr>
</tbody>
</table>
must provide outside air supply to HVAC system.

Mold Protection (X) (X)  HVAC system is major determinant, together with natural ventilation (operable windows) if provided.

HVAC Integration X X (X)  Wall and glazing insulation are critical in determining HVAC loads, together with roof if large footprint building.

Natural Ventilation X  Operable glazing is traditional way of providing natural ventilation, but coordination with HVAC system is essential to ensure energy efficient system.

Durability X X X X  All systems contribute to overall durability of building.

Sustainability X X X (X)  Materials and performance of walls, glazing and roof have major influence: below grade construction may contribute but few alternative are available for design and construction.

**Table 3. Function and Performance Relationships of the Building Envelope: Safety, Aesthetics, Practice and Innovation**

*Key:*

- **X** Major determinant or influence
- **(X)** Minor determinant or influence

<table>
<thead>
<tr>
<th>SYSTEMS</th>
<th>WALLS</th>
<th>GLAZING</th>
<th>ROOF</th>
<th>BELOW GRADE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SAFETY REQUIREMENTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire Protection</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Wall, glazing and roof materials are critical and strongly regulated by code. HVAC and fire protection systems are key systems for smoke and fire reduction and elimination.</td>
</tr>
<tr>
<td>Floods</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td>Below grade and first floor wall construction are critical but building location is the key determinant. Protection of low level glazing is important.</td>
</tr>
<tr>
<td>High Winds</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Building envelope is particularly vulnerable to high winds because wind action attacks the building exterior surfaces.</td>
</tr>
<tr>
<td>Seismic</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>Building structure is main defense against earthquakes. Heavy nonstructural precast wall panels and glazed curtain walls may need special attachment detailing to structural frames subject to large racking deformations in high seismic zones. Heavy roof materials (tile) are vulnerable and need positive attachment.</td>
</tr>
<tr>
<td>Blast, CBR</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Building structure is main defense against blast: non-structural wall panels and glazing need special design and attachments to structure, roof may contribute debris due to suction effect. HVAC main protection against CBR.</td>
</tr>
<tr>
<td><strong>AESTHETIC INFLUENCES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aesthetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Aesthetic issues primarily relate to building exterior (public view) and interior of exterior wall (occupant view).</td>
</tr>
<tr>
<td>Color</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Related to materials: natural (stone etc) metals (metallic or painted finishes) and availability of a range of alternatives.</td>
</tr>
<tr>
<td>Texture</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Smooth (metals), smooth to rough (natural materials, such as marbles, granites etc) and cast textures on concrete.</td>
</tr>
<tr>
<td>Pattern</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Primarily related to joints between panels and glazing, and the size and shape of panels.</td>
</tr>
<tr>
<td>Associations</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Local context and cultural associations, e.g. natural stone versus stucco.</td>
</tr>
<tr>
<td><strong>PRACTICE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pervades the choice of all materials and systems.</td>
</tr>
</tbody>
</table>
The functional and performance relationships shown are also accompanied by physical connectivity. Many of the building envelope assemblies are connected to and supported by the building structure. Since the envelope receives certain loads—such as wind and seismic, and, in some instance—blast, its members must be capable of distributing these loads to the building structure besides resisting them within their own subsystems. Obviously, if the HVAC system employs perimeter heating and cooling, the distribution system will be part of the overall building HVAC distribution. The physical relationship of the roof assemblies to the structure is critical to their performance.

These relationships mean that the building envelope cannot be designed in isolation. It is a function of design management to ensure that the performance attributes and the physical connections between the envelope and the rest of the building are integrated in concept and execution from the commencement of the design process.

Safety, Security and Building Codes

Safety has long been the traditional focus of building codes, starting with the earliest codes related to fire safety. Protection against earthquakes has been the subject of codes in seismic regions for the last three quarters of the twentieth century. These codes have become very highly developed and have a strong engineering and scientific base assisted by governmental, institutional or industrial programs of research and development. Some codes also mandate requirements for floods and high winds, but these are much less developed than those for earthquakes.

In general, the intent of codes has been to mandate minimum standards that provide acceptable safety at an affordable cost. While codes also provide some property protection, this has not been a major target and has not been a stated intent of the codes. Many features of building codes are understood to represent a minimum standard and in practice are almost always exceeded for reasons of comfort and amenity. For example for many decades all U.S. building codes have agreed that the minimum floor area of a bedroom is 70 square feet with a minimum dimension of 7 feet in any horizontal direction; however, few bedrooms in even the most economical tract house are of this size.

Codes that do not appear to offer an accepted everyday benefit—and that are seen as adding cost to the project—are all too often treated as a maximum. This has created problems when buildings correctly designed and constructed to a seismic code have suffered significant damage—which the code permits, provided that life safety is not compromised. In part owing to the success of codes in protecting public safety, attention has begun to shift toward property protection because of the large economic losses incurred by earthquakes, high winds and floods. This loss is only partly due to the cost of repair and reconstruction; deeper economic losses are incurred by business and service interruption and losses such as market share and tourism.

As a result, designers are being encouraged to create designs for performance against natural hazards that are appropriate for a building’s occupancy, function and importance. This means designing for an acceptable level and type of damage. This also generally means designing for performance above that anticipated by normal code-conforming design.
Another development in design against natural hazards has been the encouragement of multi-hazard design. The intent here—as in many other developments in the design process—is to implement a higher level of design integration. This involves ensuring that buildings subject to more than one natural hazard—for example both floods and earthquakes—take advantage of design methods that assist in countering all the hazards that apply and identify and find solutions for those instances where measures may conflict. Thus while elevating a building above grade is an excellent solution for design in a flood plain, great care must be taken to avoid "soft first stories" that have proven disastrous in earthquakes.

While building safety has traditionally focused on natural hazards, building security is focused on societal and political hazards—those created by criminal or disaffected members of our own society or foreign elements that see the U.S. as an enemy. Some degree of concern has always been present in design, of which keys and locks are the most familiar. Remote surveillance systems have been around for some time in retail stores and other sensitive environments. The tragedy of September 11, 2001 and the condition of war that has existed since that time have thrown a much more intense light on the need for building security.

The major difference between attack hazards and natural hazards—beyond a deliberate attempt to damage the building and cause casualties—is that of probability. Although natural hazards vary greatly in probability there is considerable statistical information on the issues of where, how big and how often a given hazard will occur, and considerable scientific study is devoted to this topic. Human-caused hazards have very little history, and the relatively few instances provide a very poor statistical database. As a result, it is at present very hard to know the extent to which it is prudent to take steps to mitigate attack by blast and/or chemical, biological and radiological (CBR) weapons. Meanwhile, much research and development is underway, ranging from testing vehicle barriers to the development of building code provisions that reduces the risk of progressive collapse from damage as a result of bombing.

This is an area that may be expected to evolve rapidly. Some of this evolution will be technical. Some will be societal and political as it begins to become apparent how large and how long-term the threats remain. The questions of where, how big and how often need much more convincing answers than are available at present before the full impact on building design can be gauged. Meanwhile, this subject is superimposed on the traditional range of issues with which the designer must grapple. Again, the need is for design integration with of security concerns considered from the outset.

**Innovation**

Although many historic materials are still in use—roofs are still constructed of copper and slate, and walls employ natural stone—the building envelope has been a prime target of innovation since the first quarter of the twentieth century. Innovation has been most significant in the wall and fenestration systems of the envelope and has been driven by four main influences:

- Cost reduction for a competitive market
- Enhanced performance
- Material innovation and industrial research & development
- Aesthetics

These influences are all related to one another. Much industrial research and development has been aimed at obtaining a competitive edge through performance improvement or cost reduction. For example, pre-cast concrete fabrication enjoyed about two decades of great success because the material and shapes appealed to architects. Innovation in pre-casting techniques, form design and fabrication and surface finishes resulted from collaboration with architects and the effort to be competitive as a supplier. Ultimately, however the pre-eminence of the pre-cast panel faade was seriously threatened by the rise of glass fiber reinforced concrete, a synthetic material innovation that was lighter and more economical than concrete and more easily formed into sculptured shapes.

The construction industry is intensely competitive. Much of this stems from the traditional approach to contractor and supplier selection—the competitive bid. This places a premium on lowest cost, resulting in innovation by contractors and sub-contractors trying to get an edge on their competitors. Another aspect of cost is that of reduction in construction time, which translates into cost reduction for a building project's entire stakeholder. Thus, for example, the separation of the building envelope wall and fenestration from the structure enabled the structure to be erected faster, while prefabricated components such as curtain wall assemblies and pre-cast panels were fabricated off-site.

The effort to reduce on-site labor through componentization also originated in the effort to reduce costs and construction
time. It is noteworthy that the building industry was able to achieve extraordinary feats of construction time using traditional materials when labor costs were low. For example, the Empire State Building in New York City was constructed in just over 12 months—at the height of the great depression—by laborers working 24 hours a day for a contractor who used the first fast-track scheduling process. A booming construction industry and post-war labor costs soon made such an approach prohibitive.

Aesthetics has also been a powerful influence on the envelope. The most significant application—that of the development of the curtain wall—depended initially on the creation of a market by architects. Since the first all-glass skyscrapers were sketched by Mies van de Rohe in 1919 and 1921 (Figure 7), architects strove to achieve ever simpler and purer glass forms.

![Figure 7. All-glass office buildings, conceived (but never constructed) by architect Mies van de Rohe in 1919 (left) and 1921 (right).](image)

The metal and glass curtain wall became a feature of some of the seminal works of the International Style that dominated world-wide design after World War II. Le Corbusier’s Pavilion Suisse, Paris (Figure 8A) designed in 1929 was one of the most influential. The most significant development of the curtain wall, however, occurred in the United States. First designed as an expensive, refined and elegant custom artifact, it gradually became a standard commodity, and today is the least costly way to enclose a structure. Perhaps more important, for several decades the glass box perfectly symbolized, in its image of contemporary elegance and modernity, the aspirations of American corporate architecture from Wall Street to Main Street. The United Nations building of 1947 (Figure 8B) and the Lever Brothers building of 1952 (Figure 8C) had enormous impact on architects and owners alike. Within a few years every city in the U.S. had its blue, glass-curtain walled cubes, from corporate headquarters to modest savings and loan branches (Figure 8D). Today, very refined custom walls are still being conceived that can demonstrate an extraordinary scale and delicacy (Figure 9).
Many problems, such as leakage and obtaining pleasing glass colors, had to be solved in early curtain walls. Manufacturers and influential architects working together managed to do so. The first curtain walls were expensive, custom-made assemblies. The proprietary curtain wall has now evolved into the least expensive way of cladding a building. However, very refined custom walls are still being conceived that can demonstrate an extraordinary scale and delicacy. (Figure 9)

Future innovations still in their infancy are the double-skin curtain wall that aims to provide controlled natural ventilation and hybrid systems that aim to achieve substantial energy savings as a hedge against an uncertain energy future. (Figure 10)
Conclusion

A number of categorizations of the systems or subsystems that comprise a building are in existence. Richard Rush, in his book *The Building Systems Integration Handbook*, defined only four systems:

- Structure
- Envelope
- Mechanical
- Interior

Thus the systems and assemblies of the envelope are one of the four main parts of the building both in terms of their physical existence and in their contribution to overall building performance. The envelope protects the other systems from harsh aspects of the outside. It also works in conjunction with the other systems to ensure a safe and benign environment for the building occupants. Thus the envelope is a gatekeeper, allowing certain aspects of the exterior into the building, rejecting some and changing the nature of others. The design of the envelope is very complex and many factors have to be evaluated and balanced to ensure the desired levels of thermal, acoustic and visual comfort together with safety, accessibility and aesthetic excellence.

This guide provides information and recommendations to assist the designer in achieving their goals. While levels of performance are discussed and many quantitative criteria are explained, no mandatory requirements are stated. Those are the purpose of building codes and regulations. This guide assumes that any design work will conform to code requirements but deal also with many functions that, while not subject to code, are essential for building excellence.
Introduction

Many buildings constructed today extend one or several floors below grade level. These below grade areas provide functional spaces for uses such as storage, office space, mechanical/electrical rooms, parking, tunnels, crawlspaces, etc. While below grade areas in buildings provide important critical functions for the building, the subject of below grade building enclosure systems, although widely addressed during construction practices is not always wholly understood. The below grade portion of the building enclosure is seldom analyzed numerically in design. Acceptance of poor performance of the below grade building enclosure is typical and historically not questioned. Leaking into basement areas is a common problem for building operators and managers. Air quality, such as radon, and conditioning in terms of humidity levels are often a concern.

Durability of design and materials is mandatory with below grade enclosure systems. Unlike some other building components that might be designed to be replaced several times within the overall building service life, below grade systems need to be built to approximate overall service life. Below grade systems are often inaccessible for repairs and extremely costly if repairs or modifications are necessary. For below grade enclosure systems design and materials must not focus on the first initial cost but consider the life cycle costs of various design options. Also of great importance is to prevent damage during construction that could go undetected until the building is in service creating costly repairs or inadequate performance.

Description

These Design Guide sections describe the basic components of below grade enclosure systems and categorize its functions, provides guidelines for design considerations and provides details for adaptation for actual building projects. The scope of these sections is limited to the enclosure elements of the below grade portion of the building and does not consider interior elements. Below grade enclosures are typically comprised of 3 main elements:

- Foundation Walls
- Floor Slabs
- Plazas/Tunnels/Vaults

For each of the three elements the following items are discussed:

1. Introduction—Overall Discussion
2. Description—Elements and Properties
3. Fundamentals—Principles of Design
4. Applications—Ranges or Uses, Climates, Risk
5. Details—Construction Details with Commentary
6. Emerging Issues—Research and Development
7. Codes/Standards—Allowances and Limitations
8. Resources—Documents, Associations and Web Sites

Figure 1 graphically illustrates the 3 main elements and the typical loadings for below grade building enclosure systems.
Fundamentals

As with other building enclosure systems, the functions of each of the elements of the below grade building enclosure can be grouped into four categories, as follows:

1. **Structural Support Functions**—to support, resist, transfer and otherwise accommodate all the structural forms of loading imposed by the interior and exterior environments, by the enclosure and by the building itself. The below grade enclosure is often part of the building’s superstructure.

2. **Environmental Control Functions**—to control, regulate and/or moderate all the loadings due to the separation of the interior and exterior environments; largely the flow of mass (air, moisture, etc.) and energy (heat, sound, etc.).

3. **Finish Functions**—to finish the enclosure surfaces—the interfaces of the enclosure with the interior and exterior environments. Each of the two interfaces must meet the relevant visual, aesthetic, wear and other requirements.

4. **Distribution Functions**—to distribute services or utilities such as power, communication, security, water in its forms, gas, and air conditioned air to, from and within the enclosure itself.

The four function categories, i.e. Structural Support, Environmental Control, Finish and Distribution, are expanded in general terms for each of the three elements of below grade enclosures.

Applications

The success of below grade building enclosure systems is largely dependent on the ability to control moisture. The control of moisture can only be achieved with proper investigation, design and construction practices. Also of importance is to understand where problems are likely to occur. Kubal suggests the following principle:

"The 90%/1% Principle: As much as 90 percent of all water intrusion problems occur within 1 percent of the total building or structure exterior surface area."
Therefore, attention to detail, particularly at penetrations is critical to the performance of below grade enclosure systems. Kubal suggests another principle that is equally important:

“The 99% Principle: Approximately 99 percent of waterproofing leaks are attributable to causes other than material or system failures.”

Failures typically occur from improper design or construction practices not material failure itself. Putting these two principles together Kubal states:

“By considering these two principles together, it can be expected that 1 percent of a building’s exterior area will typically involve actual and direct leakage and that the cause will have a 99 percent chance of being anything but material failure.”

Recognizing that the performance of below grade building systems relies so heavily on design and construction aspects, it is critical to discuss the overall design and construction process.

The performance of the below grade enclosure systems is influenced by the design and construction process. The design and construction process can be divided into three (3) phases:

- Investigation Phase
- Design Phase
- Construction Administration Phase
  - Troubleshooting following construction when leakage occurs is also considered as a closing section of the following guideline.

Through rigorous application of the criteria and design features presented the overall performance of the system for characteristics including moisture, thermal, air quality, fire safety, and acoustics can be achieved.

Investigation Phase

The investigation phase deals primarily with determining the site conditions prior to the design development. For virtually all construction projects, soil specimens are taken that provide basic information concerning soil conditions. These soil conditions once combined with water table information can identify the ground water characteristics in the vicinity of the site. It is these ground water characteristics taken as a benchmark that govern and contribute heavily to the success or failure of the below grade building enclosure system.

Interpretation of site boring (and other site related) information should be made cognizant of the time of year boring was taken. For example, evaluating soil-boring conditions with respect to ground water could produce one result if samples were extracted during the spring months and under conditions of heavy rain or run-off from snowmelt. Similar samples taken at a later time in the year such as August or September following a dry season could result in different ground water conditions.

Site work should also consider the conditions in the vicinity associated with surface characteristics; drainage slope, permeability, and other utilities or other features. Underground storage tanks, sewer lines, reservoirs, water ways or water shed paths need all be examined when considering the overall site conditions.

Structure Use Requirements—Following the site assessment, the structure use requirements concerning the need for absolute dryness or hundred (100%) percent waterproofing should be considered. Structures have variable demand for underground services. Structure utilization is a significant element of the original investigation process and should be fully considered during development of the criteria and the waterproofing, moisture capture and overall water management system.

Following the assessment of usage, a system for subsurface water management should be examined. There is both an internal water management techniques, such as sump pumps or dewatering systems in the basement, or external foundation drains that all need to be coordinated to achieve effective water management at the time of design. Once again, the requirements for specific needs and features of the building basement and sub-basement system must be fully considered in order to achieve the desired result.
Design Phase

The design of the waterproofing system must follow the selected structural design system. Until the structural system is selected and certain features of the design established, it is not practical to develop an effective waterproofing system or water management system other than at a conceptual level. This document develops the concepts, principals and standards as opposed to specific detailing for each condition. Common details are provided for features of water management, waterproofing protection and the basics of system installation. Sound engineering judgment and expertise is needed to apply these guidelines and procedures to a particular project.

Clear definition of the penetrations required in the structural wall or floor system must be established. Detailing of these penetrations to make them water tight under all conditions of use are paramount to the success of below grade enclosure systems.

Proper specifications to address the various issues associated with water management should be done consistent with the typical specifications format. Where special requirements occur to amplify or highlight certain needs for the structure in question, special notations or supplemental specifications should be drafted that address the waterproofing system characteristics and particulars. Such specifications are typically accompanied by detailing of the various aspects of the waterproofing installation. This detailing once established in concept and for intent for specification requirements (prescription vs. performance) can be supplemented by manufacturer details addressing the particulars of a given waterproofing system. These details commonly deal with such things as penetrations, joints, drains, sumps and moisture collection systems.

Construction Administration Phase

Adequate construction administration involving the review of material submittals and installation sequences are important to performance, as is on site observation by the design professional to verify that the construction is being completed in general accordance with the design document drawings and specifications. A well planned design improperly implemented will not provide adequate performance.

With the construction process underway, steps must be taken to properly coordinate the waterproofing applications or waterproofing requirements with the general contractors scheduling. It is frequently the case that schedules are compressed and the needs of waterproofing exterior walls once satisfactorily curing is achieved can produce kamikaze type efforts with respect to exterior wall waterproofing. The conditions under which waterproofing must be installed in order to be effective and meet the manufacturer specification for warranty must be clearly spelled out. Exterior wall drainage application and subdrain discharge must be complete at this time.

Coordination meetings at the time of construction that include the waterproofer and any sub-trades required to install the waterproofing such as installation work should also be identified and coordinated. Features and characteristics of each installation and system should be examined closely.

Troubleshooting

Troubleshooting of the system either at the time of construction or performed in a water test should be considered. A special interest for water testing or troubleshooting before the fact relates to overhead structures that must retain water but will be subsequently buried or backfilled following construction. All aspects of troubleshooting at the time of construction should be considered.

Details

Details related to below grade building enclosure systems with commentary are as follows:

1. Foundation Walls—CAD Details
2. Floor Slabs—CAD Details
3. Plazas/Tunnels/Vaults—CAD Details

Emerging Issues
The following are emerging issues in below grade building enclosure systems:

1. System monitoring during service (waterproofing, protection, drainage grids or boards, soil separator/ filter fabrics)
   - Waterproofing
   - Water transmission rates vs. age—against physical variables head, membrane type, ground water chemistry
   - Elastomeric properties vs. age—against physical variables head, membrane type, ground water chemistry
   - Protection layer breakdown vs. age
   - Drainage layer effectiveness vs. age—against water table, applied loads, soil separator type
   - Soil filter/separator fabric type vs. permeability when used with various backfills
   - Leak detection systems

2. Designing for long term system maintenance
   - Injection grout systems for post construction leaks
   - Wall weep ports to discharge impounded water
   - Internal contained leak collection system at wall floor interface
   - Interior positive side water proofing protection/membrane systems
   - External secondary perimeter drain fields

3. Service life prediction from below grade waterproofing
   - Getting the maximum service-life from exterior systems

4. Integration of existing systems with new adjacent (newly constructed) facilities
   - Solving continuity problems

5. Enhancing systems in place;
   - How to extend the existing system with targeted maintenance
   - What options are available
   - How can they be adapted to existing constructed systems
   - Data utilization considerations

Relevant Codes and Standards

Conform to local codes and ordinances with regard to groundwater situations except where provisions provided in this document are more stringent or complete.

Additional Resources

WBDG

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®


Introduction

The foundation wall of a building may be a cast-in-place concrete retaining or basement wall or a structural wall complete with load-bearing pilasters. Materials used may be concrete or reinforced masonry. The foundation wall system may include an earth retention system of soldier piles and wood lagging or shotcreted rock requiring consideration of waterproofing applied to the earth retention system. For most portions of the foundation wall, water removal and control is of prime importance. In the upper areas of the foundation wall thermal loading considerations must be addressed.

Description

This section provides specific description of materials and systems common in foundation walls and below grade building enclosure systems in general. Descriptions and guidelines are provided in the following sections:

- Drainage Materials
- Filter Fabrics
- Damproofing
- Waterproofing Membranes
- Protection Board
- Insulation Materials
- Waterstops
- Drainage Pipe

Drainage Materials

Drainage Materials for below grade enclosures include:

- Aggregate Drainage Layers
- Prefabricated Synthetic Drainage Layers

**Aggregate Drainage Layers**—Aggregate drainage layers include graded pea-gravel aggregate or coarse sands. Graded pea gravel refers to naturally rounded stone between 3/16 inch and 3/8 inch in diameter. Coarse sands varying from No. 30 to No. 8 sieve are suitable. Gap-grading the sand provides uniform grain size, which accelerates drainage flow rates.

**Prefabricated Synthetic Drainage Layers**—These products are comprised of a combination of plastic composite drainage cores with adhered geotextile fabrics. The plastic composite drainage cores are available in all type of configurations of drainage cores and are available in polypropylene, polystyrene and polyethylene. The geotextile prevents adjoining soil from clogging up the drainage system and are available in various forms including nonwoven for clay type soils and woven or small opening geotextiles for sandy or high-silt type soils.

Design considerations include selection of appropriate design to achieve flow rate required. Typical widths of ¼ to ½ inch provide drainage flow rates 3 to 5 times the capacity of commonly used natural backfill materials. These systems are advantageous in their light-weight design and cost effectiveness. Although marketed to be used with excavated soils as backfill instead of granular drainage layer, it is recommended that a full system approach be used in key applications that
include a synthetic drainage layer and granular drainage layers.

Filter Fabrics

Geotextile filter fabrics are also used for separation of differing soil types in below grade enclosure applications. This separation of differing soil types maintains flow rates of soils used as drainage layers and minimizes settlement from finer materials filling in more coarse materials. Geotextile fabrics include polypropylene, polyester or nylon fabrics in either woven or non-woven varieties resulting in varying flow rates.

Damproofing

Damproofing materials are primarily spray or roller applied bitumen based coatings applied up to 10 mils (0.25 mm) in thickness. These materials can be solvent based or water emulsions. Damproofing is always applied to the positive side, or wet side, of the structural element.

Waterproofing Membranes

Waterproofing membrane systems include both negative and positive side waterproofing. Positive side waterproofing systems are applied to the face of the element that is directly exposed to moisture, the exterior face. Negative side waterproofing systems are applied to the surface of the element opposite the surface exposed to moisture. Positive systems are available in numerous materials and forms. Negative systems are limited to cementitious systems.

Waterproofing membranes can be categorized into 4 types:

1. Cementitious Systems—These systems contain Portland cement with and sand combined with an active waterproofing agent. These systems include metallic, crystalline, chemical additive and acrylic modified systems. These systems can be applied as negative or positive side waterproofing.
2. Fluid Applied Systems—These systems include urethanes, rubbers, plastics and modified asphalts. Fluid membranes are applied as a liquid and cure to form one monolithic seamless sheet. Fluid systems can be applied to vertical and horizontal applications. For foundation wall applications typical fluid applied systems are 60 mils in thickness.
3. Sheet-Membrane Systems—Sheet membranes used in below grade applications are similar to the materials used in roofing applications and include thermoplastics, vulcanized rubbers and rubberized asphalts. The thickness of these systems varies from 20 to 120 mils.
4. Bentonite Clays—Natural clay systems, known as bentonite act as waterproofing by swelling when exposed to moisture thus becoming impervious to water. This swelling can be 10 to 15 percent of the thickness of the base material. Clay panels and sheets are popular for use in blind-side waterproofing applications such as on retaining earth systems and elevator and sump pits.

Protection Board

Protection Boards are used to shield waterproofing membranes from construction damage and ultraviolet radiation. The most commonly used protection board is an asphalt board material that may have a polyethylene film on one side if it is desired to prevent bonding. For some membrane applications, such as hot applied bitumen systems the protection board is embedded into the wet membrane and forms an integral part of the waterproofing membrane. Asphaltic protection boards are available in 1/16, 1/8 and ¼ inch in thickness. Other materials such as insulation boards or prefabricated synthetic drainage layers are sometimes used as protection for membranes.

Insulation Materials

Insulation materials used in below grade enclosure applications are primarily limited to rigid extruded polystyrene board among insulation materials due to the need for high compressive strengths and moisture resistance. For vertical wall applications, grooved insulation boards with applied geotextile fabrics can be used as a protection board for the waterproofing membrane and serve the function of a synthetic drainage layer.

Waterstops
Waterstops should be utilized at construction joints in below grade walls, footings and other elements where a waterproof system is required. These systems prevent the passage of water across these cold-joints. Waterstops are manufactured products available in a wide range of configurations and sizes. Common materials include polyvinyl chloride (PVC), neoprene, and thermoplastic rubber.

**Drainage Pipe**

Drainage pipes, typically 4" or 6" in diameter, used in below grade systems are primarily made of corrugated PVC or polyethylene and in some cases porous concrete. PVC and polyethylene pipes are available in smooth or corrugated configurations and are slotted on the bottom half of their cross-section to allow water infiltration.

**Fundamentals**

Figure 2 is an overall schematic that characterizes the four functions i.e. Structural Support, Environmental Control, Finish, and Distribution as they relate to the below grade enclosure elements of foundation walls.

![Fig. 2. Foundation Wall Schematic](image)

The four function categories, i.e. Structural Support, Environmental Control, Finish and Distribution, are expanded in general terms for foundation walls.

**Structural Support Functions**—The foundation wall system of the below grade building enclosure must be designed and constructed to support both vertical and lateral loadings.

Vertical loads exist from the dead, live and lateral loads from the structure and the wall itself. The foundation wall may be an integral part of the load bearing design of the building carrying column and floor loads from above, either as distributed loads on the wall or point loads on pilasters integral to the wall system. These walls may also be used in the lateral resisting system for the building.

Lateral loads on foundation walls exist from the soil, surcharge and hydrostatic pressure loads. Soil loadings vary with soil type and whether soil is treated as active or passive. Hydrostatic pressure loads may exist in cases of high water tables or flood events. Typical hydrostatic and soil pressures generally range from 30 to 62.4 psf per foot of depth. Surcharge loadings may include live loads from pedestrian walkways or from vehicular roadways. In many cases around commercial office buildings, areas designed as pedestrian areas must also include consideration for emergency vehicular loadings.
In many cases the foundation wall is required to resist all of these loads directly with the wall designed as a cantilever retaining wall with a large base footing or as a basement wall spanning vertically between the foundation element and supported floors. Other cases may include an earth retention system, such as piling and timber lagging, facilitating construction and designed to resist the lateral loads leaving the foundation wall to resist primarily vertical loads.

Special loadings such as blast loads are a design consideration in parking areas under and next to buildings. While the first control of these abnormal load events are through security entry control systems and restricted access, structural design considerations may also be required in the design of the foundation wall system.

**Environmental Control Functions**—The exterior environment that the foundation wall is subjected to includes environmental control loadings such as thermal, moisture, tree roots, insects, and soil gas. The interior environment that the foundation wall is subjected to includes environmental control loadings such as thermal and moisture. The performance of the foundation wall system depends on its ability to control, regulate and/or moderate these environmental control loadings on each side of the foundation wall to desired levels.

Likely, the most predominant environmental control loading for foundation wall systems is moisture. Moisture control is dealt with in a multiple screen/barrier type of design approach. For surface moisture loadings such as rain, snow and sprinklers the first line of control is the upper screen at the exterior surface. This upper screen may be comprised of relatively permeable landscape areas to impermeable pavers, concrete or asphalt surfaces that will shed the majority of surface moisture. The effectiveness of this initial screen in shedding moisture may influence the design of the other components of the system.

Moisture that penetrates through the upper screen needs to be directed to the exit drain located at the base of the foundation wall. This is accomplished through a drainage system to the exterior of the wall that is typically a free draining granular material. Backfilling with native, poor draining soil is not recommended as this will maintain an active water load on the foundation wall and limit its ability to control moisture ingress to the interior. As moisture moves from the upper screen through the drainage system on the exterior towards the exit drain, moisture will inevitably make its way toward the surface of the foundation wall itself. Depending on the quantity of water that makes its way through the upper screen, a drainage system at the surface of the foundation wall may be required to direct this water expeditiously toward the base of the foundation wall and the exit drain.

In many foundation wall situations with low water table elevations, the combination of the upper screen, the exterior drainage system, the near surface drainage system and the exit drain will control the majority of the water. This can be accomplished with pumping systems. In areas with greater moisture loads from hydrostatic pressure from high water tables or sensitive interior environments, a waterproofing membrane should be applied to the surface of the foundation wall in lieu of damproofing. Waterproofing membranes are predominantly applied to the positive (exterior) face of the foundation wall, however, there are negative side waterproofing systems that can be applied to the interior of the foundation wall.

Even when it is necessary to apply a waterproofing membrane, it is recommended to also utilize a system approach including components of exterior drainage system, near surface drainage system and exit drain. The removal of the moisture in the most complete and expeditious manner will decrease the probability for intrusion of the system.

Thermal considerations are of limited concern with depth along the foundation wall as there is a constant, thermal design condition on the exterior. As most foundation wall systems have substantial mass, e.g. concrete, insulation may only be of importance to moderate interior temperatures in the upper portions of the foundation wall where temperature conditions will fluctuate. However, the use and location of the insulation is more important on the control of moisture in terms of preventing condensation on interior wall faces for the entire height of the foundation wall. Condensation is possible in below grade conditions in warmer more humid summer conditions as below grade spaces tend to be cooler in the summer because of the insulating effect of the backfill soil. This cooling effect combined with general poor air circulation in underground spaces can result in condensation on interior wall surfaces. The higher soil temperatures on the exterior
also create the need to provide at least a damproofing on the exterior of the foundation wall to resist the strong interior vapor drive. In fact, in some situations, conditioned below grade spaces are subjected to a constant inward vapor drive as in the summer the interior space is air conditioned and in the winter the interior space is heated resulting in a lower vapor pressure than the exterior condition as the soil stays relatively constant in terms of vapor pressure.

**Finish Functions**—There are two areas of finishes that are of importance in relation to foundation walls. The first area is the finish to the interior space. This finish is dependent on the interior use whether it be a controlled office environment or a non-controlled parking environment. Typical finish systems may include paints, stucco, or framed walls with drywall. In many applications the interior finish is simply the interior surface of the material used for the foundation wall, i.e. concrete or concrete masonry units.

The second area is the finish to the exterior near grade level. Proper treatment of this area is critical in terms not only of aesthetics but also durability. Damproofing/Waterproofing in all situations should be carried up above the upper screen and integrally tied into the building faç flashing and waterproofing. Many waterproofing membranes need to be shielded from ultraviolet radiation to prevent deterioration and as such some type of exterior finish is required. The most basic finish is parging or an external insulation finish system applied at the base of the wall. In many cases the exterior faç element, whether it be brick, stone, etc. is carried down to just below grade level to properly transition and protect this sensitive area.

**Distribution Functions**—Foundation walls may contain distribution systems such as electrical and electronic runs. At times these systems are run internally in the interior surface finish system or in ceiling space. Distribution systems within the foundation walls themselves must be treated with careful consideration, as they can also be conduits transporting air and moisture within the structure.

**Applications**

**Upper Screen Design Considerations for Surface Runoff**

Many areas around a building’s perimeter at grade are subjected to high amounts of surface runoff from the high use of fenestration and impermeable wall faç materials such as thin stone and EIFS. The first and most effective defense against this water is to slope the upper screen surface away from the building a minimum of 5% near the building edge. Proper design to connect downspouts into perimeter drain systems directly instead of flowing onto the area directly adjacent to the foundation wall is prudent in design.

Important design considerations include sloping the surface away from the structure. Providing a suitable drainage system from the upper screen through the granular backfill and synthetic drainage layer down to the exit drain.

**Exit Drain Design Considerations**

Drainage pipe at the perimeter of the foundation wall should be surrounded by a free draining granular material that is wrapped in filter fabric to prevent fines from filling in the porous spaces of the granular material. Drainage pipe should have a slope of at least 0.5%, but preferably 1.0%.

**Damproofing/Waterproofing Membrane Selection**

The designer must consider the overall water management system relative to site conditions and loadings to determine if damproofing or waterproofing is required. If in doubt, it is clearly prudent to err on the conservative side and provide a waterproof system.

For waterproof systems the first consideration is whether to use positive or negative side water proofing. Although negative side waterproofing is advantageous from the standpoint of repairability most foundation wall applications utilize positive side waterproofing.

For positive side waterproofing the next design decision is to use fluid applied or sheet products. Sheet products are advantageous in terms of consistency in product material properties and thickness but have significant drawbacks due to the numerous laps that are required. Laps should be installed so that the upper sheet is lapped over the lower sheet so that water is shed naturally across the lap.
With fluid membrane systems, proper application in terms of coverage and thickness is important to performance. Fluid systems are applied as positive side waterproofing and need to be protected by a protection layer. Most fluid applied systems will degrade with exposure to ultraviolet radiation. The key advantage to fluid systems is their self-flashing abilities as the material is applied in liquid form.

Membrane Protection

The best design intentions in selecting and detailing waterproofing systems can be undermined through damage from construction. The installation of protection boards or insulation layers as quickly as possible after membrane installation is critical. Prefabricated synthetic drainage layers are sometimes used in lieu of protection board for protecting waterproofing membranes. Caution is advised with use over softer liquid applied materials as the drainage layer may dig into and breach the membrane. With these softer waterproofing membranes protection board is recommended under the synthetic drainage layer.

Building Façade Termination—Of critical importance in any building is the proper detailing and integration of the vertical building faç system and the below grade building system. The integration of the two systems requires careful consideration to insure that all moisture, air and thermal criteria for each system are satisfied at the transition interface. There is a combination of environmental design loadings at this interface such as surface water, runoff, and cavity wall drainage.

Facade terminations often produce the accumulation of moisture at or near the grade line of the building with the surrounding area. A special flashing behind face stones of buildings or special flashing and treatment of the exterior slab edge where it is adjacent to ground features is required.

Special treatment is also needed at all door entries. Common practice for wall terminations or door entries is to provide slope away from the building as previously indicated. Limiting the direct contact of moisture with the isolation or flashing detail at the envelope seal is a very effective practice.

Penetrations

Condition appraisals and trouble shooting of below-grade structures reveals common sources of leakage that arise from penetrations. These penetrations are any openings in the wall or structural system that once waterproofed provide an avenue of breech for moisture entry into the building. Sewer pipe penetrations, water line entry penetrations, drain basins in the floor slab or sleeves for electrical, gas or communication are all common penetrations, typically with their own design or detailed features. These features, however, leave much to be desired with respect to sealing and waterproofing. Penetrations can also become quite exotic such as steam penetrations or other features that require special treatment. Because of the unique nature of penetrations and Special Features, no single rule or criteria can govern or apply to the effective treatment thereof. However, classification of common penetration types and features helps to ensure effective treatment and proper function.

Isolation, insulation and waterproofing of certain piping that undergoes large temperature changes is often underestimated. Where expansion and contraction of the services or pipes entering the building occurs, a sleeve through the wall that is discontinuous with the penetration piping is required. Sealing these generally requires application of preformed neoprene or elastomeric boots that seal to the housing and to the exterior pipe. Other surfaces such as gas pipes, signal or electrical should generally be done with due consideration for the nature of the sleeve through the exterior wall and the depth penetration below grade.

Common knowledge suggests that the seals serve as a back-up function and that avoiding moisture build-up is the principle objective for obtaining a leak free building at penetrations.

Wall Expansion Joints

Wall expansion joints should be designed to accommodate the anticipated movement. Historical evidence indicates that wall movements below grade are generally nominal and the effective work of the seal is limited. For treatment of leaks providing amplified external drainage media similar to that required on the exterior wall is highly effective. Special emphasis is placed on evacuating the water at the wall base to avoid water build-up in the back fill or drainage system.
Wall/Floor Construction Joints

Construction joints have been effectively treated in most applications by a manufacturer’s recommended details. The construction joints typically exhibit only limited movement and as such are generally not as susceptible to leakage as expansion joints. A multiple layer detailing of the membrane, proper isolation and allowance for joint detailing is generally effective for construction joints. A cementitious or mason's mortar cant covered with an elastomeric flashing extending to the edge of the footer and several inches above the cant has proven historically effective.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe® Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Foundation Wall—Typical System (Detail 1.2.1)  
Foundation Wall System—Foundation Lagging (Detail 1.2.2)  
Foundation Wall—Liquid Membrane System (Detail 1.2.3)  
Foundation Wall—Sheet Membrane System (Detail 1.2.4)  
Foundation Wall—Pipe Penetration Detail (Detail 1.2.5)  
Foundation Wall—Construction Joint (Detail 1.2.6)  
Foundation Wall—Wall Expansion Joint (Detail 1.2.7)  
Foundation Wall—Façade Transition (Detail 1.2.8)  

Emerging Issues

For emerging issues refer to General Overview section.

Relevant Codes and Standards

For codes/standards refer to General Overview section.

Additional Resources

WBDG

PRODUCTS AND SYSTEMS

Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

For resources including texts, guides, and web pages refer to General Overview section.
Introduction

The base floor within a building may simply be a cast-in-place concrete slab-on-grade with limited design considerations for structural support or environmental control functions. The base floor may also be comprised of a mud or structural foundation slab complete with waterproofing and wearing slab with the overall system designed to carry structural hydrostatic pressure loads and maintain a controlled environment. Floor slabs are often the source of leakage into the building with slab cracking of common concrete materials being a primary cause. Issues of controlling soil gas emissions such as radon may also be of importance.

Description

This section provides specific description of materials and systems common in floor slab systems. Descriptions and guidelines are provided in the following sections:

- Finish Floor Coverings
- Concrete Floor Slab
- Aggregate Drainage Layers
- Under Slab Vapor Retarder
- Waterproofing Membrane
- Protection Board
- Prefabricated Drainage Layers

Finish Floor Coverings

Depending on the interior space the finish floor covering may be the exposed concrete surface itself or various floor coverings such as wood, vinyl floors or carpet. Many adhesives used in applying floor coverings are sensitive to moisture requiring the use of a waterproof system or lengthy drying times if a poly vapor retarder is used.

Concrete Floor Slab

In typical office environments, the concrete floor slab itself is comprised of 4" to 6" thick concrete reinforced with one layer of welded wire fabric at mid depth.

Aggregate Drainage Layers

Drainage layers under floor slabs are typically comprised of 6 to 8 inch thick layer of ¾ inch granular material that is gap graded to increase drainage rates.

Under Slab Vapor Retarders

Under slab vapor retarders may include polyethylene sheets, asphalt/polyethylene composite sheets or polymer modified bitumen sheets. The most common used vapor retarder is 2 layers of 6 mil polyethylene sheets. Two layers are used to reduce puncturing and provide redundancy at seams.
The four function categories, i.e. Structural Support, Environmental Control, Finish, and Distribution, are expanded in general terms for floor slab systems.

**Structural Support Functions**—The floor slab of the below grade building enclosure must be designed to carry downward vertical gravity loadings as well as any upward soil or hydrostatic pressure loadings.

Downward vertical gravity loadings exist from the floor slabs dead weight and any occupancy live loads. In many deeper structures the floor slab may also be a matt foundation slab carrying significant building column and wall loads.

Floor slabs may also resist upward soil or hydrostatic pressure loadings. Upward soil pressures may be applied to the floor slab in situations where it is acting as a matt foundation and the building point loads on the foundation results in an upward pressure on the floor slab.

In areas such as crawlspaces and unoccupied basement areas the structural support component involving a concrete slab may not be needed. In these areas, environmental control functions may still need to be addressed.

**Environmental Control Functions**—The exterior environment that the floor slab is subjected to includes environmental control loadings such as thermal, moisture, insects, and soil gas. The interior environment that the floor slab is subjected to includes environmental control loadings such as thermal and moisture. The performance of the floor slab system depends on its ability to control, regulate and/or moderate these environmental control loadings on the interior of the floor slab to desired levels.

As with foundation wall systems, the control of moisture is likely the most important environmental control function. Moisture control is dealt with in a drainage and barrier type of design approach. For cases with hydrostatic pressure from ground water levels the first phase of control of moisture can be accomplished through pumping and dewatering systems to artificially drive down the nature water table level. The second component of the moisture control system includes a granular drainage layer below the floor slab to allow an area for moisture to accumulate and dissipate or to be pumped out or drained into an exit drain or sump system. In many floor slab situations with low water table elevations or dry conditions, the granular drainage layer and exit drain will control the majority of the water. There may be no need for an active pumping system.

The key question that remains is whether to provide a waterproof membrane or a vapor retarder below the floor slab. A vapor retarder resists vapor migration in the absence of hydrostatic pressure. Waterproofing resists both vapor migration and hydrostatic pressure. Generally, a vapor retarder can only be eliminated on well drained sites with water tables well below the floor slab surface and the use of floor finishes unaffected by vapor migration. However, most building codes require a vapor retarder as a minimum amount of moisture protection. In these cases, the vapor retarder should consist
of a double layer of 6 mil polyethylene installed between the granular drainage and the floor slab. This layer has the added benefit of minimizing shrinkage stresses and cracking in the floor slab due to the reduction in shrinkage restraint.

Waterproofing membranes are needed in situations with hydrostatic pressure or moisture sensitive interior environments. Waterproofing membranes are typically applied to a mud slab cast on a granular drainage layer or applied to compacted earth. Protection of the waterproofing membrane from damage during construction is critical. Protection is typically provided with a protection board application directly to the waterproofing membrane soon after membrane installation. Detailing of waterproofing at all terminations and penetrations are critical. Top side waterproofing of floor slabs is not recommended for any situation.

Other environmental loading conditions may include soil gas such as radon. Migration of soil gas into interior environments can be controlled through the proper use and detailing of a polyethylene type of vapor retarder or a waterproofing membrane. Proper laps, protection during construction and attention to detailing at all terminations and penetrations are critical to fully control migration of soil gas.

**Finish Functions**—With floor systems the only finish of concern is to the interior space. This finish is dependent on the interior use whether it be a controlled office environment or a non-controlled parking environment. Typical finish systems may include carpet, tile or adhered flooring. The proper control of vapor migration loadings is critical with tile or adhered flooring applications that need proper adhesion. In some applications such as interior parking or storage space the interior finish is simply the interior surface of the concrete floor slab. In others, such as crawlspace, the finish may be the vapor retarder.

**Distribution Functions**—The floor slab may contain distribution systems such as electrical feeders, electronic conduit, mechanical piping or heating systems.

**Applications**

There are two main types of base floor detailing that are distinguished by the requirements of the interior space and the exterior environment:

- Base Floor Slab—Typical System
- Base Floor Slab—Waterproof System

**Base Floor Slab—Typical System**

A typical base floor slab where the design criteria includes controlling water vapor transmission into the interior space but is not concerned about waterproofing the base floor due to hydrostatic pressure loads can be referred to as an imperfect barrier system. The components of the system include a well compacted yet well draining granular drainage system placed directly on unexcavated, undisturbed ground. The granular drainage system provides a collection area for moisture to accumulate and dissipate as well as a firm support for slab loadings. A 2 layer - 6 mil polyethylene vapor retarder is placed between the granular drainage system and the concrete slab to minimize moisture vapor transmission or soil gas transmission into the occupied space. The concrete floor slab itself provides structural support for floor loads and suitable backup for floor coverings and finishes. With interior space use of parking there is no need for the polyethylene vapor retarder unless desired for minimizing cracking and curling from concrete slab shrinkage.

**Base Floor Slab—Waterproof System**

A typical base floor slab where the design criteria include controlling moisture migration and water vapor transmission into the interior space can be referred to as a waterproof system. The components of the system include a well compacted yet well draining granular drainage system placed directly on unexcavated, undisturbed ground. The granular drainage system provides a collection area for moisture to accumulate and dissipate as well as a firm support for slab loadings. To provide a solid base material on which to apply the waterproofing membrane a mud slab or compacted earth layer is provided. In some instances with significant hydrostatic pressure or to accommodate building loadings a matt foundation slab is used in lieu of the mud slab. The waterproofing is then applied directly to the matt foundation slab and protected with protection board. In this case a wearing floor slab is poured on top of the protected waterproofing system.

**Below-Grade Penetrations**
A general element that is common to all buildings yet frequently not fully detailed or addressed during design is penetrations. These penetrations are any openings in floor slab that once waterproofed provide an avenue of breech for moisture entry into the building. Sewer pipe penetrations, water line entry penetrations, drain basins in the floor slab or sleeves for electrical, gas or communication are all common penetrations, typically with their own design or detailed features. These features, however, leave much to be desired with respect to sealing and waterproofing. Penetrations can also become quite exotic such as steam penetrations or other features that require special treatment.

Isolation and Expansion Joints

Isolation joints do accommodate minor movements between structural elements and/or fixtures that penetrate through or around them. Both a prime and a back-up seal are effective as a means of reducing leakage. Raising the slab profile also works well. As with expansion joints, the detailing of concrete gradients or slope at isolation joints to prevent direct accumulation of any transient moisture is also highly effective. The same rules concerning drainage grid material or a flow path continuation from joints to drain basins should be considered during the design process.

A common ground rule applicable to keeping joint sealant systems leak free is to be certain that the moisture evacuation or drainage systems are properly in place and connected to the sub grade layers. The joint seal systems, although the primary line of defense can provide effective seal against any minor or surface water migration. Eliminating the possibility of a build-up of water head against all joint seal systems is considered the main function of sub-drain systems.

Mechanical Floor Drains and Pump Systems

Floor drains in floor slabs require treatment by proper design for back flow valves or special treatment for flow capacity depending upon the use of the structure. Where sump pumps are installed special back water valves or back pressure valves are needed to prevent flow back. The application or installation of pump assemblies and certain sumps requires proper coordination and effective treatment of the discharge system to avoid leakage through mechanical penetrations.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Below Grade Slab—Waterproof System (Detail 1.3.2)  DWG | DWF  PDF

Emerging Issues

For emerging issues refer to General Overview section.

Relevant Codes and Standards

For codes/standards refer to General Overview section.

Additional Resources

WBDG

PRODUCTS AND SYSTEMS

Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

For resources including texts, guides, and web pages refer to General Overview section.
Introduction

Buildings frequently have plazas, vaults, tunnels or extensions below grade. The planning, development, detailing and construction of waterproofing for such features are significant. Although much more complex and far more maintenance intensive, these features are generally not treated with the same detailing attention that roof assemblies receive. In all such areas regardless of membrane detailing, protection, drainage and isolation along with thermal considerations must be incorporated into the design. Requirements for overhead waterproofing in tunnels or building obtrusions are significant and need to be treated accordingly. Design of the plaza surfaces, green-scape and tree or soil planter features, above the buried element also requires special design consideration.

Over the past 2 decades, plazas and special use features (fountains, planters and even athletic function) have become a more common and complex element in structure design. Tunnels and vaults, although a historic feature, are also experiencing increased design demand as they are upgraded to higher levels of service to accommodate; utilities, mechanical services or signal and communication conduits.

Plaza decks, tunnels and vaults are subject to some of the most accelerated and vigorous deterioration and distress of any structural system. Harsh exposure conditions from; exposure, moisture, thermal effects, weathering and traffic often reduce these systems serviceability at a rate even surpassing that of parking and bridge deck slabs. Accordingly, special analysis of plazas, tunnels and vaults as unique and novel; aesthetic, wearing, moisture protection and isolation and structural support systems, should be performed.

Plaza systems generally disintegrate and become unserviceable for 3 reasons, the first; ineffective design, the second poor construction and the third abnormal "unexpected" loadings. Other common causes of plaza deterioration or failure are; severe exposure including freeze thaw, chemical applications, overload and or improper materials selection and application.

Each of the above categories (listed features) is capable of working independently or in concert with other elements to cause premature plaza surface or waterproofing distress (service impairment) or subsequent damage over years of use exposure and traffic.

Description

This section provides specific description of materials and systems common in plazas, tunnels and vaults.

A plaza system is any supported slab that provides; green-scape, tree planters, vehicle and pedestrian movement over occupied space. Unlike the roof of a building, which is only exposed to weathering and the elements, plazas have numerous special features, supplemental to their common waterproofing characteristic. Depending on the type of structure the vehicular use may be limited to cleaning equipment or light vehicles. Under special circumstances plazas may be required to support truck and bus traffic or even construction equipment. A unique defining characteristic is the waterproofing requirement over occupied space, which at some level in the plaza system interfaces with the wearing surface and/or green-scape or tree-planters to produce high potential for distress, membrane leaking and or plaza surfacing degradation.

Figure 4 illustrates the basic components of a plaza system. The components of tunnels and plazas are similar.
Description and guidelines are provided in the following sections:

- Wearing Surface
- Fill slab
  - Isolation layer/Drainage Layer and flow path system
  - Membrane and protection layer
- Structural Slab Support System

Wearing Surface

The wearing surface of a plaza is any surface subjected to pedestrian or vehicular traffic. Concrete, brick pavers, granite paving blocks, asphalt paving blocks and or pre-cast elements are all common to plaza wearing surface systems. In more recent years cement paving blocks consisting of high strength stamped or compressed cement units are also finding significant usages as plaza wearing surfaces.

Fill Slab

The fill slab is anything that occupies space on the plaza above the membrane and below the wearing surface. Historic fill slabs typically involve the use of; graded sand, asphalt material, pea gravel or a sand cement mortar setting bed. Pea stone is also commonly used which also provides the added function of improved drainage. More recently, Styrofoam voided areas or loose earth or lightweight concrete are used on horizontal applications of tunnels/vaults/plazas. These insulation systems have very high compressive strength properties (up to 10,000psf) making them resistant to crushing. In addition they are lightweight, cost effective, water resistant and serve as another layer of protection for the waterproofing.

Isolation Layer/Drainage Layers and flow path system (including drain basins)

Isolation/ drainage layers were provided historically beneath plazas where plantings were common surface features. The older drainage layers consisted of pea gravel and or a separator fabric over pea gravel to allow for drainage of surface moisture from the membrane to the inlet basins. Current isolation layers consist of a combination of geo-synthetic materials, used individually or in composite, or used in combination with the pea-stone drainage fill. The combination systems often reduce the demand for pea stone sill and speed construction. Two types of isolation must be considered when designing plazas, horizontal and vertical.

- **Horizontal Isolation**—Special isolation systems are created with materials that provide a slip plane, allowing the upper plaza surface (when subjected to large thermal movements), effective shear relief from the lower plaza system. The buried system components may or may not accept or respond to heat from the structure below and often experience very limited thermal swings, relative to the exposed surface.
- **Vertical Isolation**—Rigid wearing surfaces, subject to direct or indirect exposure to the elements, expand and

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**Fig. 4. Plaza System Schematic**

- **1 - Plaza Wearing Surface**
  - Brick Concrete Pavers
  - Precast or Granite
  - Typical Op
  - Exposed Agg.

- **2 - Fill slab**
  - Sand Mortar Setting Bed
  - Asphaltic Fill
  - Pea Gravel

- **3 - Isolation/Drainage Layer**
  - Sand
  - Pea Gravel
  - Geo Synthetics

- **4 - Membrane & Protection Course (including Insul.)**

- **5 - Structural Slab Support System**
  - 2-WAY FLAT PLATE SLAB
  - 1-WAY SLAB ON BEAM
  - POST TENSIONED SLAB-BEAM SYSTEM
  - PRECAST SYSTEM TES, HOLLOW CORE, FILIGREE

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contract during summer and winter cycles respectively. By doing so, they are at risk of locking to and over stressing the membrane, causing failure and subsequent leakage into the occupied space below. To accommodate horizontal movement of the wearing surface, strategically and uniformly space isolation joints, commonly ¼ to ½ inches wide, are required on 20 to 40 foot centers. Such joints should contain a free draining compressible filler, with a suitable sealant. Vertical isolation joints also reduce the horizontal thrusting that potentially damages perimeter walls or penetration features.

Drain Basins are perhaps the most critical plaza performance feature and must have a 2 stage or "promenade" plaza drain assembly. The first stage of the drain basin, weep holes/ screens or perforations, remove surface moisture from the structural slab membrane interface. The second stage, the "exposed upper grate", removes moisture from the exposed wearing surface. Both must remain open and functional for the plaza to resist premature deterioration. Numerous performance evaluations confirm that preventing the "Bathtub effect", for plaza surfacing and subcomponents, including the membrane and isolation layer, are highly effective at reducing membrane failure and plaza wear surface disintegration. Maintenance of catch basins helps to promote long term plazas durability.

**Membrane and Protection Layer**

The structural slab supports the plaza surfacing system and includes a special waterproofing membrane or roofing material to prevent moisture leakage into the occupied space below. Structural slab membranes, often referred to in plaza applications as buried membranes are provided with a protective wearing system or protection course directly above the membrane, so that construction of the upper plaza can proceed with minimum risk of membrane damage. All of these components are essential to proper plaza performance.

In certain plaza systems, insulation is provided directly on top of the membrane and protection layer. This component then functions as a foundation layer for the upper plaza wearing surface, which should be provided with appropriate isolation systems between the insulating layer and the wearing course. These materials can be provided with compressive strengths up to 60 psi for use in horizontal applications such as tunnels/vaults/plazas to prevent crushing and settlement. A drainage layer at this interface, provided with horizontal isolation, is highly effective at promoting long-term system durability. The insulation also promotes long-term membrane performance by keeping it in a more agreeable service environment with reduced freeze thaw effects.

**Structural Support Systems**

The structural slab system used to support plazas can be any one of the basic slab designs. The 2-way flat plate was the most common historic slab system use for plazas. This was followed later by the one-way slab over beam systems, which were also common for plaza support. In the later years pre-cast structural systems have found use in plaza support as well as post tensioned slab systems.

It is recognized that the various types of structural systems have a greater or lesser degree of flexibility and deflection under plaza design live and dead loads. Accordingly, variable requirements on the plaza membrane system and the fill slab or interfacial isolation layers, are appropriate to proper plaza system design.

**Fundamentals**

**Structural Support Functions**—Tunnels/Vaults/Plaza areas typically have structural slabs and beam elements that are subjected to high dead and live loadings. Dead loads include overburden from soil, planters, pavers, fountains, mechanical equipment, etc. Live loads may include loadings from pedestrian walkways or from vehicular roadways. In many cases around governmental buildings, areas designed as pedestrian areas must also include consideration for emergency vehicular loadings.

Structural systems for tunnels/vaults and plazas are typically cast-in-place concrete systems, either conventionally reinforced or post-tensioned. The use of precast concrete elements for these areas should be avoided due the difficulties in obtaining effective joint and surface waterproofing.

**Environmental Control Functions**—The exterior environment that the tunnels/vaults/plazas are subjected to includes environmental control loadings such as thermal, soil, tree roots, moisture, insects, and noise. The interior environment that the tunnels/vaults/plazas are subjected to includes environmental control loadings such as thermal and moisture. The performance of the tunnel/vaults/plaza system depends on its ability to control, regulate and/or moderate these
environmental control loadings on each side of the foundation wall to desired levels.

As with other below grade systems, the most predominant environmental control loading for tunnel/vault/plaza systems is moisture. Moisture control is dealt with in a multiple screen/barrier type of design approach. For surface moisture loadings such as rain, snow and sprinklers the first line of control is the upper screen at the exposed surface. This upper screen may be comprised of relatively permeable landscape areas to impermeable pavers, concrete or asphalt surfaces that will shed the majority of surface moisture. The effectiveness of this initial screen in shedding moisture may influence the design of the other components of the system.

Moisture that penetrates through the upper screen needs to be efficiently directed off of the supported surface or to the drains provided in the tunnel/vault/plaza. This is accomplished through a drainage system of free draining granular material. Backfilling with native, poor draining soil is not recommended, as this will maintain an active water load on the tunnel/vault/plaza and limit its ability to control moisture ingress to the interior. As moisture moves from the upper screen and through the drainage system, moisture will inevitably make its way toward the surface of the tunnel/vault/plaza itself. A drainage system at the surface of the tunnel/vault/plaza is required to direct this water toward the exterior wall or to drains. In all cases a waterproofing membrane is required to effectively waterproof horizontal surfaces of tunnels/vaults/plazas. In no case would a damproofing or vapor retarder be sufficient to prevent leaking to the interior. The water is directed from the horizontal surface of the tunnel/vault/plaza to the adjacent walls. The side walls of tunnels and vaults are to be treated with similar consideration as foundation wall systems.

A critical design consideration is the continuation of the waterproofing on horizontal tunnel/vault/plaza elements to adjoining above or below grade waterproofing systems. This intersection, which may include expansion joints, flashings or differing materials, requires special consideration.

Thermal considerations may be a concern for shallow tunnels/vaults/plazas and insulation may be provided on top of or on the underside of the structural ceiling element. The use and location of the insulation is important on the control of moisture in terms of preventing condensation on interior faces of the tunnel/vault/plaza. Condensation is possible in below grade conditions in warmer more humid summer conditions as below grade spaces tend to be cooler in the summer because of the insulating effect of the backfill soil. This cooling effect combined with general poor air circulation in underground spaces can result in condensation on interior wall surfaces. The use of insulation above membranes also is beneficial in reducing the overall temperature range the waterproofing membrane material is subjected to which can reduce the potential of cohesive failure under elongations.

**Finish Functions**—Tunnels and vaults will typically only have finish functions on the interior face of the element while plaza systems have both internal and external considerations. The interior finish is dependent on the interior use whether it be a controlled office environment or a non-controlled parking environment. Typical finish systems may include paints, stucco, or framed walls with drywall. In many applications the interior finish is simply the interior surface of the material used for the foundation wall, i.e. concrete.

In plaza areas the exterior surface will likely be important from an aesthetic viewpoint with many plaza areas using a combination of landscaping and pavers.

**Distribution Functions**—The structural slab of the tunnel/vault/plaza may contain distribution systems such as electrical feeders, electronic conduit, mechanical piping or heating systems. Plaza soil areas also may contain mechanical and sprinkler lines.

**Applications**

There are two main types of systems used in plazas, tunnel and vault areas that are distinguished by the exterior use:

- Planter Areas
- Wearing System

**Planter Areas**

Major design points include providing a structural slab that slopes to the exterior of the element or to drain. A waterproofing membrane fully adhered and protected by a protection board. The insulation board may be needed in shallow applications to provide some thermal resistance but also when located above the membrane keeps the
membrane above the dew point temperature preventing condensation on the underside. In some cases tapered insulation is provided below the waterproofing membrane to provide slope to the waterproofing membrane where the structural slab is flat. This practice is not recommended for the dew point considerations, as well as the effectiveness of the waterproofing membrane installation. A synthetic drainage layer located above the insulation material will direct any moisture penetrating upper soil screens. A well compacted granular drainage layer provides a solid, yet economical fill material in planter areas. The compacted granular drainage layer should be separated from the finer planter soil with an specifically designed filter or soil separator fabric.

Wearing System

Major design points are similar to that described for planter areas. In addition the wearing surface should be designed for aesthetic and functional purposes but also to provide the first screen to surface water. Crack free design and appropriately spaced and sealed construction/isolation joints are important. If at all possible in the design sloping this wearing surface to the drain or exterior will limit the amount of moisture entering the system. Proper design of the wearing surface, insulation board and synthetic drainage layer is a critical issue to handle vehicular loadings.

Membrane Selection

Fluid applied membranes or sheet membranes can be used in plaza systems. One of the most proven, durable waterproofing system is the hot applied modified bitumen systems. The combination of rubber derivatives and an asphalt base provide superior crack-bridging and chemical resistance performance. Urethane systems are typically 60 mils in thickness, where modified bitumen systems are 180 to 215 mils in thickness.

Unbonded applications are not recommended for these systems. Laps and detailing of penetrations are critical.

Building Façade Termination

Of critical importance in any building is the proper detailing and integration of the vertical building façade system and the below grade building system. The integration of the two systems requires careful consideration to insure that all moisture, air and thermal criteria for each system are satisfied at the transition interface. There is a combination of environmental design loadings at this interface such as surface water, runoff, and cavity wall drainage.

Below-Grade Penetrations

A general element that is common to all buildings yet frequently not fully detailed or addressed during design is penetrations. There are essentially three (3) types of penetrations that are common. Others also exist. These penetrations are any openings in the wall or structural system that once waterproofed provide an avenue of breech for moisture entry into the building. Sewer pipe penetrations, water line entry penetrations, drain basins in the floor slab or sleeves for electrical, gas or communication are all common penetrations, typically with their own design or detailed features. These features, however, leave much to be desired with respect to sealing and waterproofing. Penetrations can also become quite exotic such as steam penetrations or other features that require special treatment.

A special area requiring detail treatment and application of all previous features described for plantings, plazas, and waterproofing relates to planters that abut building faces. Of all systems that tend to be problematic and produce serious maintenance problems for structure owners, plantings at building faces tend to rank high on the list. Isolating the planter system from the building wall is considered a good first step to achieve effective treatment of aesthetics and building operations and envelope integrity. Where planter assemblies are constructed monolithic or integral walls and pro
manufacturer's requirements for treatment of sleeves and/or special diaphragms and boots to accommodate sealing the penetration against moisture and/or other vagrant migration is necessary.

Overhead Floor Expansion Joints

Overhead floor expansion joints perform satisfactorily when the joint surfaces above are within the building line enclosure of the structure. Special problems and treatment is needed however, when the joints are exposed directly to the elements and plazas. For this case, treatment of the joints by raising the concrete joint openings above the surrounding surface is highly effective for preventing moisture collection at the joint and leakage when the joint seal system fails. Special design detailing that allows for construction of the expansion joint at the high point in a plaza structural slab profile is also effective for reducing exposure and thereby minimizing operational problems.

Although below grade areas are often used for electrical and mechanical space this practice must be treated by special waterproofing details to minimize the risk of leaking and in some cases excessive humidity levels affecting electrical components performance or durability.

Positive Drainage

The most basic requirement for proper plaza design, is proper slope to drain provided by the structural slab. Commonly known as gradient, this feature allows water that percolates down to the membrane, a means of flowing towards and discharging into the drain basin. Both historic and recent experience however, strongly suggests that without proper subsurface "structural slab" gradient both designed and constructed, undesirable ponding frequently occurs on the structural slab above the membrane. Typical flat slabs, regardless of the structural design system used for the supporting floors, can be a constant source of leakage headaches for the plaza owner.

The supported structural slabs in all plazas, tunnels and vaults should slope a minimum of 2% away from the building or toward the exterior of the element. It is not sufficient to just slope the wearing surface or even used tapered insulation to create slope while using a flat structural slab. A durable design will include positive drainage of structural elements to drain any water that penetrates to this point.

Horizontal Isolation

Horizontal isolation, simply stated, involves providing a relief mechanism or system directly beneath the rigid wearing surface. The most widespread and aggressive forms of early membrane destruction are associated with wearing surfacing installation directly above the membrane and protection layer. Unless an effective shear relief plane is provided, normal thermal cycles cause the rigid wearing surface to expand and contract pulling on and often a rupturing the membrane. Water then migrates to the structural slab, becomes ponded and upon reaching a crack, leaks into the occupied space below.

Vertical Isolation

Because of normal expansion and contraction caused by thermal movements, isolation must periodically be provided, so that rigid elements don't lock up and bind against each other or their perimeter abutments. Significant forces can develop during normal expansion and contraction cycles. In extreme cases, rupturing, crushing or displacement can occur. Most common evidence of this characteristic is found in examining drain basin's, which are often sheared off at the structural slab/plaza wearing surface interface.

Sub Drainage

Not withstanding effective drain basin installation, (see next paragraph), the major problem with many aging plazas is failure to allow subsurface drainage. Historically, this function was provided by a loose layer of pea gravel, usually made up of one-quarter inch to 3/8 inch diameter round gravel. This layer, when properly connected to the drain basins, permits water to flow readily off the structural slab surface. (Ironically it also allowed horizontal shear relief or horizontal isolation layer when used beneath rigid surfaces) Regardless of the nature of subsurface drainage selected, it must be continuous along the flow path to the drain basin and covered with a proper separation and filter layer from planted areas and other potential contaminates, in order to maintain effectiveness. Without proper filtration, drainage grid cells
will rapidly collect filtrate and plug even the best drainage layer.

**Basin Drainage**

Plaza drains must be designed to accommodate runoff not only from the wearing surface, but also from the membrane covered structural slab below. In order to be effective, drain basin's must have special weep ports at the structural slab level, so they can accommodate subsurface a runoff. Surface grates must have narrow lens openings, so that pedestrian traffic can safely traverse the exposed surface. Finally, drain basins should be isolated from the plaza wear surface to reduce the shear effects described earlier. Past experience has repeatedly shown that construction inefficiencies, relative to maintaining an open area at the weep ports, is the single most common cause of subsurface water entrapment.

**Materials Properties**

The importance of selecting the right materials for plaza system components can never be overstated. There is a wide selection of materials available depending on the final aesthetic and functional requirements desired. Because no consistent guidelines are available to the architect, each project is a novel design experience. Without proper guidance, architects and engineers and other design professionals normally do the best they can with locally available materials and recognized systems.

The best guidance that can be provided involves thoughtful consideration of the systems operating environment. Those systems designed and installed in harsh exposure environments, defined as areas where freezing and de-icing are common, should receive maximum design detailing for good drainage and durable surface and subsurface systems to withstand frost breakup.

For those areas subjected to normal thermal cycles and more moderate climate; isolation, drainage and proper separation layers are still all required. Damage to membranes, from improperly isolated wearing surfaces, can be just as severe and destructive in the southern states as in northern climates. There are few, if any plazas that can be effectively designed without proper horizontal and vertical isolation combined with the other factors described above.

**Details**

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

- **Plaza System—General Concept (Detail 1.4.1)** [DWG] [DWF] [PDF]
- **Plaza System—Wear Slab Base (Detail 1.4.2)** [DWG] [DWF] [PDF]
- **Plaza System—Wear Slab Base @ Wall (Detail 1.4.3)** [DWG] [DWF] [PDF]
- **Plaza System—Bonded Wear Slab (Detail 1.4.4)** [DWG] [DWF] [PDF]
- **Plaza System—Planter Areas (Detail 1.4.5)** [DWG] [DWF] [PDF]
- **Floor Drain—Plaza Area (Detail 1.4.6)** [DWG] [DWF] [PDF]
- **Expansion Joint—Plaza Area (Detail 1.4.7)** [DWG] [DWF] [PDF]

**Emerging Issues**

For emerging issues refer to General Overview section.

**Relevant Codes and Standards**

For codes/standards refer to General Overview section.
PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

For resources including texts, guides, and web pages refer to General Overview section.
Introduction

The basic function of the envelope or enclosure of a building or structure is to protect the covered or otherwise conditioned interior spaces from the surrounding environment. This fundamental need for shelter is a concept that is as old as the recorded history of mankind. However, as our needs have evolved and technologies have advanced, the demand placed on designers to both understand, and integrate, a wide range of increasingly complex materials, components, and systems into the building enclosure has grown in equal proportion. This is particularly true when one considers the emerging threat of terrorism and the impact of that threat on the design and construction of the building enclosure. However, despite the recent emphasis on blast-resistant wall systems and hardening of the building enclosure (see the Blast Resistance section for additional information on this topic), uncontrolled rainwater penetration and moisture ingress remain two of the most common threats to the structural integrity and performance of the building enclosure.

This guide, and the additional resources referenced herein, is intended to facilitate a better understanding of the basic principles behind heat, air, and moisture transfer (including bulk rainwater penetration and precipitation management) through the exterior walls of a building or structure. Specifically, it focuses on six (6) commonly specified exterior wall systems in the United States, and illustrates how proper selection, use and integration of the various materials, components and systems that comprise those wall systems is critical to the long-term durability and performance of the building enclosure.

Description

Selected Terms and Definitions

The following is a summary of selected terms and phrases used throughout this design guide. The definitions provided below are not intended for general design and construction application. Instead, they are intended only to provide a general understanding of these terms as they relate specifically to building envelope design and performance as discussed in this design guide:

**Exterior Cladding**: Generally defined as a protective layer or finish affixed to the exterior side of a building enclosure system.

The term "cladding" is often used as a general reference to a wide variety of naturally occurring and synthetic, or man-made, building envelope materials, components and systems. Typically, these elements are quarried, manufactured or otherwise developed and/or altered to render them suitable for use on the exterior of a building or structure, and are frequently derived from, or tailored to, the available resources, raw materials and climatic conditions unique to a particular geographic region or exposure. Exterior cladding is generally the first, though not necessarily the primary line of defense against bulk rainwater penetration.

**"Wet" Zone**: The section of an exterior wall system or assembly that is intended, by design, to be exposed to the short and long-term effects of bulk rainwater penetration and/or moisture ingress. Typically, it is the zone located on the outboard side of the innermost drainage plane in an exterior wall system or assembly.

**"Dry" Zone**: The section of an exterior wall system or assembly that is not intended to be exposed to the short and long-term effects of bulk rainwater penetration and/or moisture ingress.
Typically, this is the zone located on the inboard side of the innermost drainage plane in an exterior wall system or assembly. Materials in this zone often have a relatively low moisture tolerance, and very little, if any, storage capacity for moisture.

**Drainage Plane**: Any element exposed to weather or otherwise residing at the line between the "wet" and "dry" zones of an exterior wall system or assembly.

This plane is generally intended to be either waterproof and vapor-impermeable or water resistant and vapor-permeable depending upon wall type, material selection, and climate, and is designed to shed bulk rainwater and/or condensation downward and outward in a manner that will prevent uncontrolled water penetration into the conditioned spaces of a building or structure. In a barrier wall system, the exterior cladding also serves as the principal drainage plane and primary line of defense against bulk rainwater penetration. In cavity wall construction, however, the principal drainage plane and primary line of defense against bulk rainwater penetration is located inside the wall cavity, generally on the inboard side of the air space (either directly applied to the outboard surface of the exterior sheathing layer or, in the case of insulated cavity walls, on the outboard surface of the rigid or otherwise moisture-impervious insulation layer).

**Air Barrier**: Any element, or combination of elements, that is intended, by design, to control the movement of air across an exterior wall system or assembly.

In order to remain effective, the air barrier must: a) reside within the wall assembly; b) be continuous in three-dimensions from roof-to-wall-to-foundation, c) consist of materials and components that are, either individually or collectively, sufficient in stiffness and rigidity to resist air pressure differentials across the exterior wall assembly without permanent deformation or failure and; d) be durable and structural rigid to withstand the construction process.

The interior and exterior air pressures across an air barrier system that need to be examined include, but are not limited to, pressures caused by wind, stack effect, and mechanical systems.

Air barriers may be located at different locations within a wall system, and the placement of the air barrier needs to be indicated by the designer on the drawings. Please see the table and details within the WBDG that show various methods of forming an air barrier system. Some materials that are part of the air barrier may also have vapor retarder properties. The designer must carefully consider placement of the air barrier when the air barrier material(s) will act both as an air barrier and as a vapor retarder to determine if drying of the system will be inhibited by the location of this material within the assembly. Portions of the air barrier may require regular maintenance and an allowance should be made within the design to accommodate this maintenance.

**Air Retarder**: Any element that effectively resists or otherwise slows, either intentionally or unintentionally, the rate of airflow across an exterior wall system or assembly.

Depending upon its measurable level of resistance to airflow, the air retarder can, in certain instances, be incorporated into the overall air barrier for an exterior wall system or assembly. However, these products alone typically cannot prevent airflow across a wall assembly and, as such, should not be used in lieu of an effective air barrier.

**Vapor Retarder**: Any element that is intended to control or otherwise limit the flow of water in its vapor form (diffusive vapor flow, or vapor "drive") across an exterior wall system or assembly.

The selection and placement of a vapor retarder within an exterior wall system or assembly must be in compliance with applicable building codes and regulations, and should also be carefully considered with regard to material selection and the specific use, occupancy, location and climate of a building or structure. It is not uncommon, for example, to discover that individual elements of an exterior wall system or assembly will function inadvertently as "misplaced vapor barriers" in that assembly. Depending upon the predominant direction of diffusive vapor flow across the wall system, this can result in unplanned moisture in the "dry" zone of the wall assembly. This can lead to in-service (and often concealed) corrosion of mild steel anchors, fasteners, metal studs and related components and accessories, as well as moisture-related degradation of wood, gypsum wallboard and similar moisture-sensitive materials, and potential mold growth. A climate-specific, Hygrothermal or similar analysis of moisture transfer through a given exterior wall design is often desirable to further address this concern, particularly as it relates to proper material selection at each layer of the exterior wall assembly.

**Insulating Element**: Any element, or combination of elements, that is intended to control or otherwise regulate heat loss
and heat gain across an exterior wall system or assembly.

In general, the insulating element in an exterior wall system or assembly should be selected and located in a manner that is designed to minimize the risk and effects of thermal bridging ("shorts") and subsequent condensation in the "dry" zone of the assembly. Insulating elements that are selected for placement in the "wet" zone of an exterior wall system or assembly (considered desirable in colder climates of the United States) should be carefully considered during the design phase, and must contain the physical properties and material characteristics necessary to remain fully functional and intact when in the presence of water. Selected rigid insulation products can, when properly detailed, also function as an internal drainage plane within a cavity wall system.

**Structural Element:** Any element, or combination of elements, in an exterior wall system or assembly that is intended to effectively resist both live (wind) and dead loads acting on a building or structure through the efficient and effective distribution of those loads to the underlying (or exposed) structural frame.

On projects where the design intent is to incorporate, expose, or otherwise express primary elements of the structural frame as part of the exterior wall system, it is critical that these elements be selected, detailed and specified in a manner that will allow for a fully integrated, thermally efficient, weather-tight building envelope. This is particularly true at interface conditions between exposed structural elements and adjacent "infill" sections of exterior walls, where a failure to properly coordinate drainage planes and maintain a continuous thermal break or line of thermal separation across these interfaces can lead to uncontrolled bulk rainwater penetration, condensation, and similar unwanted moisture at the dry side of the wall assembly.

**Interface Condition:** Interface conditions are generally considered to be the lines of separation, or transition, between individual façade elements in an exterior wall system or assembly. These conditions typically include interfaces between two or more differing wall types occurring within the same wall system (eg: a drained masonry cavity wall adjacent to a precast or EIFS barrier wall system), as well as the lines of separation, or transition, that exist at the perimeter of window openings, mechanical ventilation, electrical conduit, plumbing lines and similar exterior wall penetrations, as well as roof-to-wall, foundation-to-wall, and wall-to-exterior paving interfaces.

Each of these conditions must be considered carefully during the design and submittal review phases of a project in order to successfully coordinate construction tolerances, as well as to anticipate the impact of installation sequencing on the overall constructability and performance of these details. Large-scale, three-dimensional details of these conditions are often desirable, and may be necessary on larger, more complex projects in order to ensure continuity of drainage planes, separation between "wet" and "dry" zones of the exterior wall, air barrier continuity, and overall constructability of the wall system. Similarly, when preparing a performance specification that allows several different glazed aluminum window and/or curtain wall products during bidding, it is also desirable for the architect to select a particular manufacturer and design the interface details around that system. The selected product or system should then be acknowledged in the project specifications so that, in the event that a substitution is made or alternate is submitted for review and consideration, the contractor is required to include interface detailing in those submittals that is consistent with the detailing (and, therefore, the design intent) shown in the original construction documents. This approach ensures that the architect and contractor are properly focused on the importance of interface detailing during the design and bidding phases of the project, and substantially reduces the risk that refinements made during the shop drawing review process will result in added costs to the owner.

**Flashing:** Any element, or combination of elements, intended to collect, contain or otherwise divert bulk rainwater to the exterior side of a building enclosure system. The principal purpose of flashing is to prevent bulk rainwater penetration into the dry zone of an exterior wall system or assembly and, subsequently, the interior, conditioned spaces of a building or structure. These elements are typically located at interface conditions between primary façade elements of a building enclosure system.

In cavity wall construction, *through-wall* flashing is typically required, at a minimum, above all wall penetrations and at similar interruptions to the downward flow of rainwater inside the wall cavity. Typically, these materials should be designed in a manner that directs rainwater *beyond* the exterior wall surface, and should be assembled using materials that are UV stable, non-corrosive and impervious to the potentially negative effects of extreme temperatures and changes in moisture content. Flashing terminations must also be fitted with a self-supporting, fully sealed end-dam to prevent rainwater from entering the dry zone of an exterior wall system or assembly.

**End-Dam:** Any element, or combination of elements, designed to prevent rainwater collected by a through-wall flashing...
system from entering the dry zone of an exterior wall system or assembly at wall penetrations (such as window openings), building corners and similar terminations is a single line of flashing.

**Moisture Management System:** Any element, or combination of elements, intended to control or manage the safe distribution of moisture through an exterior wall system or assembly. A properly designed moisture management system typically addresses each of the following three (3) processes for a given geographic region or climate:

- Precipitation and Bulk Water Movement
- Air Flow
- Diffusive Vapor Flow

The effects of precipitation and bulk water movement, which includes both frozen (snow/ice) and unfrozen (rainwater) precipitation, must be controlled and safely distributed at the building enclosure. Issues to consider when addressing this process include average annual rainfall for a given region and exposure, predominant wind direction and average wind speed during typical rain events, rainfall type and volume, and the rate of wetting that occurs at a given façade element or substrate within the "wet" zone of an exterior wall system or assembly.

Air and diffusive vapor flow are two processes that are particularly vulnerable to improper material selection at each layer of an exterior wall system or assembly. This is particularly true with regard to the proper location and placement of drainage planes, air barriers, and vapor retarders in a given wall assembly, and the behavior of those elements in a given geographic region or climate. Understanding the storage capacity and rate of drying unique to each material selected for use at each layer of an exterior wall system or assembly is critical to the long-term durability and performance of the overall building enclosure. Improper material selection at one layer of an exterior wall assembly can negatively influence the in-service durability and performance of each successive layer, thereby limiting or rendering ineffective the ability of the entire assembly to effectively resist bulk rainwater penetration and moisture ingress.

Computer modeling, together with input and assistance from a design professional specializing in building envelope design and performance, is often desirable to further evaluate these issues. In addition, a submittal requirement for the contractor to develop a comprehensive building enclosure quality assurance program is also desirable, particularly on larger or more complex projects, in order to ensure that each element of the exterior wall moisture management system is properly installed and tested for air and water penetration resistance, as well as thermal performance, prior to installation and acceptance by the design professional and architect/end-user.

**Wetting:** Wetting can occur as a result of direct or indirect exposure of a façade element, or elements, to bulk rainwater penetration, as well as due to diffusive or convective vapor flow across an exterior wall system or assembly that results in condensation inside the wall system. Once wetted, capillary transfer within, or between, layers of an exterior wall assembly can also occur, and can be further exacerbated by moisture loads inherent to an exterior wall product or material shortly after initial installation.

**Drying:** Drying can occur by two processes: evaporation and desorption. The following will generally influence the rate of drying of an element within an exterior wall system or assembly:

- Orientation and exposure of the wetted material within an exterior wall system or assembly
- Level of saturation of the wetted material
- Indoor and outdoor ambient air temperature and relative humidity
- Physical properties of the material itself
- Individual vapor permeance of each layer of an exterior wall system or assembly
- Overall vapor permeance of an exterior wall system or assembly
- Rate and condition of ventilation air moving across the system

Each of these characteristics must be considered during the design phase of a project, and should be carefully evaluated with regard to the geographic region, climate, orientation, and exposure that is specific to each project.

**Storage Capacity:** Storage capacity is the ability of any material or element in an exterior wall system or assembly to safely absorb and "hold" moisture.

A variety of materials commonly used in exterior wall design and construction can safely absorb and store relatively
significant levels of moisture. However, these materials (such as clay brick, concrete masonry and some natural stones) can also be susceptible to long-term, moisture-related deterioration and failure if exposed to repeated and prolonged wetting during the normal service life of a building or structure. In addition to the potentially negative effects of freeze-thaw cycling and efflorescence (the deposit of soluble salts at or near the exposed surface of masonry that often results in discoloration and spalling) that can occur during the drying process in masonry, this is also of particular concern when these materials are located in the "dry" zone of a wall system or assembly. In this location, repeated and prolonged wetting of these materials can contribute to in-service deterioration of adjacent materials through capillary action, as well as the potential for mold growth inside the concealed spaces of the wall system or assembly. Typically, the use of materials with relatively high storage capacities for moisture, particularly when used as a means for moisture management in an exterior wall system or assembly, should be located in the "wet" zone of the wall.

Diffusive Vapor Flow: The transfer of moisture in its gaseous state through the various layers of an exterior wall system or assembly.

The rate and predominant direction of diffusive vapor flow is directly related to, and influenced by interior and exterior ambient air temperatures and relative humidity, as well as differences between interior and exterior vapor pressures and the individual vapor permeability of each layer in a given exterior wall system or assembly. As noted previously, moisture-related problems due to improperly located vapor retarders within an exterior wall system or assembly are often the result of improperly inhibited or otherwise restricted diffusive vapor flow. This is particularly true in mixed-humid climates, where the predominant direction of diffusive vapor flow in a given year can be difficult to accurately predict.

Gravity Flow: The flow of moisture through an enclosure after a wetting event caused by the downward force of gravity on water in its liquid state.

Capillary Action: The absorption of moisture into small voids in a material until the void is full. Capillary action, or "wicking" of water into cellulose-based façade elements, such as wood and wood fiber-based products, is a common source of in-service, moisture-related deterioration of exterior wall systems and assemblies.

Wind-Driven Rain: The process by which rainwater is "driven", or forced, through an exterior wall system or assembly, due either to existing voids in the wall system itself, or to voids created by allowable, in-service deflection of the wall system under applied wind loads.

In the design of glazed aluminum windows, curtainwall, skylights and storefront framing systems, effective control and management of wind-driven rainwater are basic design concepts that have been well understood for over 40 years. The design of these systems, and the corresponding performance classes assigned to the various products available from this industry, are predicated on the performance of these systems when subjected to simulated wind-driven rain events during both laboratory and field mock-up testing. The test pressures used during these tests are influenced by building height and gust factors unique to each project, and are typically calculated using basic wind speeds assigned to each geographic region of the United States by both local and national building codes.

Advective Moisture Flow: The bulk movement of air as a mechanism for the transfer of moisture in its vapor state across an exterior wall system or assembly.

For example: In humid and mixed-humid climates, moisture-laden air that enters into an enclosure and comes in contact with elements below the dew point (due to the element being at a cooler temperature) can result in condensation within the enclosure and may lead to long-term moisture problems. An example of this is relatively humid, unconditioned exterior air entering into a steel stud wall during the summer cooling season, where it then comes into contact with steel stud surfaces that are sufficiently low in temperature for condensation to occur on the steel stud surface.

Convective Moisture Flow: The bulk movement of moisture involving the transfer mechanisms of molecular diffusion and advection.

For example: The drying rate of a rain-saturated brick veneer can be predicted through an analysis of this process, thereby further defining the potential impact that this and similar materials with a relatively high storage capacity for moisture can have on inward-acting diffusive vapor flow across an exterior wall system or assembly.

Conductive Heat Flow: The flow of heat through direct molecular contact, either through a single material or through multiple materials. For solid materials (and thus building materials), this is the method by which most heat flow or transfer typically occurs. For example, materials used in an exterior wall assembly that are considered to be highly
Conductive to heat flow can result in significant heat loss or gain through the assembly if not thermally protected, or separated, within the enclosure.

**Convective Heat Flow:** The flow of heat by molecules (either liquid or gas) via a change in their heat content. This method of heat flow can happen between fluids and solid elements, or strictly within fluids.

**Radiation:** The transfer of heat by electromagnetic waves through a gas (or vacuum), and requires a line of sight between the source and the contact surface. Since all objects above absolute zero radiate heat, the net transfer of heat is the condition that must be considered. Radiation is a relatively common mechanism for some methods of heating and cooling (radiant heating or cooling, for example), and is also a concept that must be understood to properly employ shading devices for passive heating and cooling of exterior wall systems and assemblies.

**Infiltration:** The introduction of unconditioned air into the conditioned, interior spaces of a building or structure due to voids in the enclosure system.

**Exfiltration:** The loss of conditioned air from a building or structure due to voids in the enclosure system, and/or the introduction of conditioned air into unconditioned spaces of an exterior wall assembly.

**Mixing:** The process by which unconditioned air and conditioned meet, and mix, within an exterior wall assembly. Depending upon the air temperature and relative humidity in the cavity space at the time that mixing occurs, condensation may form on the colder elements located in the dry zone of the wall assembly (such as metal studs during the summer cooling season).

**Change of State:** A change of state, or phase change, from liquid to gas, or from liquid to solid, which results in a gain or loss of energy. The movement of energy can become latent heat. Changes of state occur at constant temperature.

A basic understanding of these terms and phrases is required in order to properly understand and interpret the information conveyed in this guide by the design professional.

**Basic Exterior Wall Types**

Exterior wall types commonly associated with above-grade, commercial building enclosure design and construction in the United States can generally be classified as follows: as a cavity wall, a barrier wall, or a mass wall. Following is a summary of the characteristics of each wall type:

**CAVITY WALL**

A cavity wall (also referred to as "screen" or "drained" wall systems) is considered by many to be the preferred method of construction in most climatic and rainfall zones in the United States. This is due primarily to the pressure-equalization that can be achieved, and the redundancy offered by this type of wall assembly to resist uncontrolled, bulk rainwater penetration. A term commonly used to describe clay brick and/or concrete masonry wall systems installed over a largely open, unobstructed air space/drainage cavity, this term is now used more generically to define any wall system or assembly that relies upon a partially or fully concealed air space and drainage plane to resist bulk rainwater penetration and, depending upon the design, to improve the overall thermal performance at the building enclosure. Drained cavity walls typically include the following general characteristics:

- An exterior cladding element that is intended to either shed or absorb the majority of bulk rainwater penetration before it enters the concealed spaces of the wall assembly (the initial, though not primary, line of defense against rainwater penetration in this type of wall assembly).
- A drainage cavity, or air space, that is intended to collect and control rainwater that passes through the exterior cladding element and re-direct that water to the building exterior. The cavity may be ventilated for pressure equalization, either mechanically or passively, to facilitate this process by preventing negative pressure that may draw rainwater across the cavity into the "dry" sections of the wall assembly via anchors, wall ties, and similar penetrations).
- An internal drainage plane that is intended to function as the primary line of defense against uncontrolled rainwater penetration. This layer serves functionally as the dividing line between the "wet" and "dry" sections, or "zones," of the exterior wall assembly. This layer can be created using a variety of both dry sheet-good or wet, trowel-applied products depending upon the climate in which the building is to be located and the desired level of vapor permeability necessary to prevent condensation and potential mold growth on the dry side of the exterior wall.

...
Although a drained cavity wall offers many advantages over the other three (3) types of exterior wall systems discussed in this section, it should be noted that an improperly designed and/or executed cavity wall system can be very disruptive and costly to properly and effectively repair after construction is complete. Corrosion of mild steel wall ties, structural connections and related wall elements, together with interior mold growth, often remain concealed from view in this type of wall system, and can continue for a period of years before manifesting themselves in a location that can be readily observed and remediated. Furthermore, because the primary drainage plane and many of the most critical interface details are often concealed inside the wet zone in this type of wall system, direct intervention and repair of these elements can be highly invasive and disruptive to an occupied building, and will often negatively impact the overall appearance of the building. To mitigate these concerns, a comprehensive building envelope quality assurance program similar to the program discussed later in this section is often considered extremely desirable with this type of wall system in order to ensure that critical cavity wall elements are properly designed and effectively installed at the time of original construction.

In pressure-equalized, "rainscreen" cavity wall systems, the primary drainage plane, and principal air barrier are located in the same plane between the wet and dry zones of the wall assembly. In colder climates, the insulation is also placed outboard of the innermost (primary) drainage plane in this type of wall assembly, inside the wet zone (drainage cavity) of the wall. This approach, which dates back to the 1960’s in North America, can be extremely effective in resisting uncontrolled, bulk rainwater penetration. However, the principal advantage of this system, which is to prevent a negative air pressure differential from occurring across the exterior wall assembly (a condition that can "draw" rainwater through the enclosure and into the building), can also be extremely difficult to effectively achieve in the field. This is due primarily to the relatively complex detailing often required at exterior wall penetrations through the concealed air barrier and primary drainage plane, and the correspondingly high level of workmanship required to effectively seal those conditions to prevent the flow of unconditioned air inward across the exterior wall assembly.

**BARRIER WALL**

As the name implies, this term is commonly used to describe any exterior wall system of assembly that relies principally upon the weather-tight integrity of the outermost exterior wall surfaces and construction joints to resist bulk rainwater penetration and/or moisture ingress. This type of wall system is commonly associated with precast concrete spandrel panels, certain types of composite and solid metal plate exterior cladding systems, and early generation exterior insulation and finish systems (EIFS). Although often considered a more cost-effective and, therefore, desirable alternative to either cavity or mass walls assemblies, barrier walls are cause for some concern in that they: a) offer only a single line of defense against bulk rainwater penetration; b) often include relatively complex interface details that require a level of workmanship in the field that is beyond the capabilities of the individual trades, and; c) require a relatively high degree of routine maintenance to remain effective in the long term, resulting in increased long-term maintenance costs. In short, this system can arguably be considered a "zero tolerance" wall system, whereby any defect in design, installation, or workmanship can result in immediate and direct rainwater penetration into the dry zone of the exterior wall system or assembly and, more critically, the conditioned spaces of a building or structure.

**MASS WALL**

Unlike a cavity wall system, where the wall is constructed with a wall cavity and through-wall flashing to collect and redirect bulk rainwater to the building exterior, mass walls rely principally upon a combination of wall thickness, storage capacity, and (in masonry construction) bond intimacy between masonry units and mortar to effectively resist bulk rainwater penetration. For economic reasons, mass walls are less common in design and construction today. However, when constructing an addition, or incorporating a portion of an existing building into a new building or structure, the design and behavior of mass walls relative to storage capacity and both heat and moisture transfer must be understood by the design professional. In addition to bulk rainwater penetration and moisture ingress that is often difficult to track (and therefore effectively isolate and repair) in this type of wall construction, the potentially negative effects of drying must also be considered when designing around or otherwise restoring this type of wall system. Evaporative drying across this type of wall assembly, either to the interior or exterior, can contribute to efflorescence (soluble salts deposited at or near the wall surface, which can lead to visible discoloration and spalling), deterioration of interior portland cement plaster finishes (a relatively common finish in mass walls constructed in the early 20th century), and
organic/microbial growth on either the interior or exterior exposed wall surfaces.

*Left: Figure 1. Cavity Wall Diagram and Right: Figure 2. Barrier Wall Diagram

As wall gets wet

*Figure 3. Mass Wall Diagram
Figure 4. Basic Elements of the Exterior Wall
1. Exterior Cladding (Natural or Synthetic)
2. Drainage Plane(s)
3. Air Barrier System(s)
4. Vapor Retarder(s)
5. Insulating Element(s)
6. Structural Elements

Figure 5. Wall System Functions
Rain protection of mass walls, and understanding the rate the wall will get wet, the amount of moisture it is capable of storing, and the drying rate become important design considerations, as exceeding the safe storage capacity for long periods of time may create long term moisture problems for the surrounding substrates that might come in contact with the mass wall. In some cases, if adjoining or renovating an existing building while constructing an addition or a new building, it may be appropriate to retrofit a mass wall and turn it into a drained wall, especially if interior finishes have been experiencing moisture related problems caused by water and/or moisture infiltration through the system.

Common Elements of an Exterior Wall

Each of the above wall types, or combination thereof, generally consists of the following basic elements, or layers:

- Exterior Cladding (Natural or Synthetic)
- Drainage Plane(s)
- Air Barrier System(s)
- Vapor Retarder(s)
- Insulating Element(s)
- Structural Elements

Several of these layers may, at the discretion of the design professional, serve multiple purposes. For example, in barrier wall design and construction, the exterior cladding material may be designed to function both as the primary drainage plane and principal air barrier for a building or structure. Similarly, in cavity wall construction, rigid insulation placed inside the exterior wall cavity, if properly detailed, may also function as the air barrier and a drainage plane for a given exterior wall system or assembly.

Decisions such as these are typically made during the Schematic Design phase of a project, when basic programmatic requirements such as building use, orientation, environmental exposure, and overall response to the surrounding climate (micro and macro) are first given consideration by the design team. These decisions are then further refined during the Design Development and Construction Document phases of a project, when a more detailed and specific response to issues and concerns related to air/moisture transfer through the building enclosure, material selection, coordination of drainage planes, interface detailing, and the long-term durability and performance of exterior wall systems and assemblies is required. This process can be defined as a building enclosure assessment process. Throughout this process, it is both useful and advantageous for the design professional to consider the building enclosure as a series of layers that, with proper material selection and the effective coordination of drainage planes at interface conditions,
should result in a fully integrated, thermally-efficient and weather-tight building enclosure. The ability of the material to meet the design intent at each layer, whether it is intended to be the drainage plane product, a vapor retainer, an air barrier or part of the rainwater management system, must be analyzed. Careful review of the material properties at each layer, including the air and vapor permeance, resistance to bulk water entry (depending on where the material is located within the assembly), structural rigidity, and bulk-water storage capacity needs to be completed. Once completed, the building enclosure system as a whole need to be critically examined to understand how the materials and components are interacting.

The durability, and the limitations and appropriateness of the materials used for the building enclosure, especially for critical layers such as the drainage plane and air barrier, also require close examination during the building enclosure assessment process. This review is critical as the use of inappropriate or less durable building enclosure products may result in unplanned premature failure of the enclosure and higher long-term maintenance costs that are greater than initial costs of the superior material or component.

Interface Conditions

Uncontrolled rainwater penetration and moisture ingress are two of the most common threats to the structural integrity and performance of the building envelope. Together, they represent up to 80% of all construction-related claims in the United States. Of these failures, there is a growing body of evidence based on our experience, that suggests that errors and omissions in the design and installation of the façade interfaces, rather than in the façade materials, components and systems themselves, are the primary (and most frequently overlooked) sources of uncontrolled rainwater penetration through the building envelope. To better understand the factors influencing this trend, one must first begin with an examination of the design phase of a project.

Often, the proper integration of related components of a building façade is doomed from the start. All too frequently, the demands of both time and budget combine to create an environment where architects are forced to develop a series of largely generic building envelope details in a short period of time in order to get a project out to bid. While this approach may be successful in bringing the design phase in "on time and under budget," it often proves short-sighted and costly for an owner when an incomplete set of construction documents is the result. Although it is difficult for an architect who has prepared a performance specification to fully detail façade interface conditions during the design phase of a project, due in large part to fact that the actual products and product profiles to be supplied for a job are not yet known, it is critical that the construction documents carry enough information to convey both the importance of a fully-integrated building façade and the design intent of the architect with regard to how those materials and systems (and their often conflicting levels of detail and specified performance) will be reconciled at the interfaces.

A failure on the part of the architect to provide this information prior to bidding effectively shifts the design responsibility for these conditions from the architect to the general contractor and/or the individual subcontractors responsible for each portion of the work. This approach, while perhaps expedient in that it can reduce the initial design cost and limit the liability and exposure of the architect, has the practical effect of elevating the shop drawing submittal process from a simple review for "overall design intent" to an exercise in additional (and often complex) detailing that is beyond the capacity of the contractors involved and, more importantly, beyond the scope of the originally bid work and the contractual responsibilities of the individual subcontractors.

"Value Engineering"

The impact of these and related decisions on the initial cost of a building or structure also must be considered, particularly during the owner/contractor "value engineering" (VE) process. Efforts by the contractor or owner/developer to reduce the initial cost of a building or structure by applying the principles of value engineering to the design and construction of the building enclosure must be carefully weighed by the Architect/Engineer-of-Record against the best long-term interests of the owner/end-user based on the intended service life of the building or structure. This is particularly true with regard to laboratory and field performance testing, as well as the selection of through-wall flashing materials and related moisture management systems and accessories. In too many instances, pre-construction
laboratory mock-up and field quality assurance tests typically required by the design professional to verify the
constructability and performance of the building enclosure are considered cost-prohibitive on a project and, therefore,
eliminated during the VE process. Similarly, through-wall flashing materials selected by the design professional, in part,
for long-term durability and performance (such as stainless steel or lead-coated copper flashings and drips) are often
substituted for lower performing materials that, despite their lower initial cost, are significantly more vulnerable to
in-service degradation and failure. The cost associated with successfully addressing uncontrolled rainwater penetration
and moisture ingress arising out of decisions made during the VE process can be significant, and the work highly
disruptive and invasive. Again, the desired outcome of the VE process must be carefully weighed by the design
professional against the long-term interests of the owner/end-user, and the intended service life of the building or
structure.

Fundamentals

Basic Functions

The envelope, or "enclosure," of a building or structure serves a variety of basic functions. As noted by Burnett and
Straube3 and others, the enclosure is a separation between the interior and exterior environment that experiences a
variety of loadings, including, but not limited to, structural loadings, both static and dynamic, and heat, air, and moisture
loads. The enclosure must then control these loads and support these loads. This includes both short-term and long-term
loadings. The enclosure can also be used to carry or distribute some services within the building. In addition, the
enclosure will have several aesthetic attributes, which can be summarized as finishes. We have attached a brief
description of the intent of design for three of these loadings: heat, air, and moisture.

3Dr. Eric Burnett, Dr. John Straube, Various Technical Papers and Publications

Burnett and Straube have defined four general building enclosure function categories. All enclosure elements have to
provide the following functions:

- Support
- Control
- Finish (aesthetics)
- Distribution of Services (where required)

SUPPORT

Enclosures, including exterior wall systems, must be capable of withstanding all internal and external forces applied to
them. The majority of these forces are structural loading. The loads include both static and dynamic loading including, but
not limited to, dead load, live loads, wind loads, earthquake loads and possible blast loads. These loads have to be
properly supported, resisted, and transferred.

CONTROL

Enclosures, including wall systems, have to be able to control mass, energy, and particulate flows both within and across
the system. These include, but are not limited to, heat, air, moisture, smoke, odor, fire, blast, birds, and insects.

FINISH

The finish function at both the exterior and interior is the aesthetics of the finished surface, the visual, textural, and other
aspects the designer wishes to convey with the visible elements of the system. Of the elements of an enclosure, wall
systems typically have the largest consideration for finish.

DISTRIBUTION

This function relates to the distribution of services through a building, both within a single element, and also through
multiple elements.

Design Considerations
It is important to have a basic understanding of the mechanisms that can affect air and moisture transfer and how material selection, design, and construction can impact the proper drying of a building enclosure in any climate. In particular, architects, engineers, contractors, building scientists, owners and others involved in the construction and maintenance of the building enclosure must understand the wetting and drying process, the safe storage capacity for moisture of the materials specified, and the manner in which those materials are likely to behave in a given climate. They must understand how poor design and/or construction with limited regard to the wetting/drying/storage process can have a potentially devastating impact on the long-term durability and performance of the building enclosure.

In general, moisture moves from higher temperatures to lower temperatures, from a higher pressure to a lower pressure (whether air or vapor pressure), and from areas of higher moisture content to areas of lower moisture content. However, these driving forces do not always act in the same direction, and can be affected by interior and exterior air pressure differences, moisture loads, and material vapor pressure differences. Moisture transferred by these mechanisms may occur through capillary action, gravity forces, diffusion, or through voids in a substrate. In a humid or mixed-humid climate during warmer months, moisture may also be deposited within the building enclosure when warm moisture-laden exterior air transferred through voids in the exterior substrate is allowed to come in contact with and mix with cool conditioned air that is leaking from the interior.

The location and source of the moisture must be properly considered and implemented during the design and construction process to ensure a durable building. External moisture sources, such as rainwater, irrigation systems, planters, and moisture-laden air, as well as interior moisture sources, such as plumbing leaks, sprinkler failures, or improperly exhausted bathrooms, kitchens, laundry rooms, steam rooms, or swimming pools are common sources of moisture that must be properly controlled. A total system approach needs to be considered so that sections of the design do not drastically alter the assumptions of the enclosure designer, or mechanical system designer.

An effective building enclosure should also include a continuous and defined air barrier that is rigid enough to survive wind loading and air pressures across it, durable enough to remain intact throughout construction, and installed in such a way that it is continuous between building elements. The air barrier should be thought of in three-dimensional terms rather than a two-dimensional drafting detail. It is not desirable in a mixed-humid climate to have an air barrier material that also has vapor retarder properties since depending on where the air barrier is placed in the assembly it has the potential to hamper drying to the interior in warmer months and to the exterior in colder months. In other climates (cold, hot-humid) it is not desirable to have the air barrier material have vapor retarder properties if it is to be placed on the cold side of the wall, since this can create a moisture problem during drying.

If a vapor retarder is required, it should only be installed on the warm side of the wall. However, the warm side of a wall or other building element is defined differently in cold, warm, and mixed climates. Based on research by several practitioners, and recommendations, a vapor retarder may not be required in some mixed-humid climates at wall elements where the building needs to dry to the interior in the summer and to the exterior in the winter. However, design of a system without a vapor retarder needs to be examined and closely coordinated with the design of the mechanical system.

A moisture problem generally occurs when the building element susceptible to damage (such as rot, corrosion, and microbial growth) is exposed to air, and allowed to remain "wet" at a level that is above its safe storage capacity for moisture for an extended period of time. This can occur when a building element is exposed to direct and repeated rainwater penetration, or is otherwise inhibited in some way from effectively "drying" due to improper design and/or construction. If left untreated, these materials, which very often contain organic, cellulose or cellulose-based products, will then create a condition inside the wall assembly that is conducive to mold growth and other moisture related damage.

**Performance Issues**

**THERMAL PERFORMANCE**

*Heat Transfer*

There are four methods by which heat can move through any substance. These are conduction, convection, radiation, and heat transfer through a change of state. Designers need to understand heat transfer in order to determine
allowances for thermal movements (both contraction and expansion) of each element and between elements, in order to calculate the energy efficiency of the design and determine potential energy use for the structure, examine durability and to examine the risk of moisture related problems, based on temperature and mainly the risk for freezing or condensation within the system. As defined by Straube [4] and others, and expanded on here, the following are definitions that can be applied to heat transfer.

**Conductive Heat Flow:** The flow of heat through direct molecular contact, either through a single material or through multiple materials. For solid materials (and thus building materials), this is the method by which most heat flow or transfer typically occurs. For example, materials used in an exterior wall assembly that are considered to be highly conductive to heat flow can result in significant heat loss or gain through the assembly if not thermally protected, or separated, within the enclosure.

**Convective Heat Flow:** The flow of heat by molecules (either liquid or gas) via a change in their heat content. This method of heat flow can happen between fluids and solid elements, or strictly within fluids.

**Radiation:** The transfer of heat by electromagnetic waves through a gas (or vacuum), and requires a line of sight between the source and the contact surface. Since all objects above absolute zero radiate heat, the *net* transfer of heat is the condition that must be considered. Radiation is a relatively common mechanism for some methods of heating and cooling (radiant heating or cooling, for example), and is also a concept that must be understood to properly employ shading devices for passive heating and cooling of exterior wall systems and assemblies.

**Change of State:** A change of state, or phase change, from liquid to gas, or from liquid to solid, which results in a gain or loss of energy. The movement of energy can become latent heat. Changes of state occur at constant temperature.

When designing, it is important to have a working knowledge of these concepts, as well as how various HVAC systems are used not only to heat and cool a space, but also to distribute fresh air and to pressurize a building. Although there are several commercially available software programs that can be used to calculate the energy efficiency of a building enclosure system, these software programs are somewhat limited in that they cannot accurately determine the net effect of air transfer through voids in the enclosure system on heat loss or gain across an exterior wall system or assembly.

**MOISTURE PROTECTION**

**Air Transfer**

Air can transfer both heat and moisture through an enclosure system. Voids in the air barrier, and at interfaces in the enclosure, can allow a significant amount of conditioned air to exit the building and, conversely, a significant amount of unconditioned exterior air to enter the building. Because air is a much larger transfer mechanism for moisture than vapor flow, the following processes must be adequately controlled as part of the building enclosure moisture management system:

- **Infiltration:** The introduction of unconditioned air into the conditioned, interior spaces of a building or structure due to voids in the enclosure system.
- **Exfiltration:** The loss of conditioned air from a building or structure due to voids in the enclosure system, and/or the introduction of conditioned air into unconditioned spaces of an exterior wall assembly.
- **Mixing:** The process by which unconditioned air and conditioned meet, and mix, within an exterior wall assembly. Depending upon the air temperature and relative humidity in the cavity space at the time that mixing occurs, condensation may form on the colder elements located in the dry zone of the wall assembly (such as metal studs during the summer cooling season).

**Moisture Transfer**

Moisture transfer can occur through a building through multiple mechanisms. Moisture related problems are perhaps the largest set of problems buildings experience within the United States. The design community needs to have a better understanding and employ better design practices to reduce the number of moisture related problems that buildings within the United States experience. Elements within the wet zone of the building (outside of the final drainage plane or barrier) are allowed to become wet. The susceptibility of the elements within the wet zone to moisture related problems needs to be carefully examined as well as the susceptibility of inadvertent wetting of elements within the dry zone.
Several proprietary software programs are now commercially available and can be used to examine the wetting, storage of moisture, and drying of the enclosure based on actual rainfall and climate specific data. Designers need to ensure that these three processes are understood, and that the enclosure will properly balance the wetting, storage capabilities, and drying of the enclosure.

**Wetting:** Wetting can occur as a result of direct or indirect exposure of a façade element, or elements, to bulk rainwater penetration, as well as due to diffusive or convective vapor flow across an exterior wall system or assembly that results in condensation inside the wall system. Once wetted, capillary transfer within, or between, layers of an exterior wall assembly can also occur, and can be further exacerbated by moisture loads inherent to an exterior wall product or material shortly after initial installation.

**Drying:** Drying can occur by two processes: evaporation and desorption. The following will generally influence the rate of drying of an element within an exterior wall system or assembly:

- Orientation and exposure of the wetted material within an exterior wall system or assembly
- Level of saturation of the wetted material
- Indoor and outdoor ambient air temperature and relative humidity
- Physical properties of the material itself
- Individual vapor permeance of each layer of an exterior wall system or assembly
- Overall vapor permeance of an exterior wall system or assembly
- Rate and condition of ventilation air moving across the system

Each of these characteristics must be considered during the design phase of a project, and should be carefully evaluated with regard to the geographic region, climate, orientation, and exposure that is specific to each project.

**Storage Capacity:** Storage capacity is the ability of any material or element in an exterior wall system or assembly to safely absorb and "hold" moisture.

A variety of materials commonly used in exterior wall design and construction can safely absorb and store relatively significant levels of moisture. However, these materials (such as clay brick, concrete masonry and some natural stones) can also be susceptible to long-term, moisture-related deterioration and failure if exposed to repeated and prolonged wetting during the normal service life of a building or structure. In addition to the potentially negative effects of freeze-thaw cycling and efflorescence (the deposit of soluble salts at or near the exposed surface of masonry that often results in discoloration and spalling) that can occur during the drying process in masonry, this is also of particular concern when these materials are located in the "dry" zone of a wall system or assembly. In this location, repeated and prolonged wetting of these materials can contribute to in-service deterioration of adjacent materials through capillary action, as well as the potential for mold growth inside the concealed spaces of the wall system or assembly. Typically, the use of materials with relatively high storage capacities for moisture, particularly when used as a means for moisture management in an exterior wall system or assembly, should be located in the wet zone of the wall.

**Diffusive Vapor Flow:** The transfer of moisture in its gaseous state through the various layers of an exterior wall system or assembly.

The rate and predominant direction of diffusive vapor flow is directly related to, and influenced by interior and exterior ambient air temperatures and relative humidity, as well as differences between interior and exterior vapor pressures and the individual vapor permeability of each layer in a given exterior wall system or assembly. As noted previously, moisture-related problems due to improperly located vapor retarders within an exterior wall system or assembly are often the result of improperly inhibited or otherwise restricted diffusive vapor flow. This is particularly true in mixed-humid climates, where the predominant direction of diffusive vapor flow in a given year can be difficult to accurately predict.

**Gravity Flow:** The flow of moisture through an enclosure after a wetting event caused by the downward force of gravity on water in its liquid state.

**Capillary Action:** The absorption of moisture into small voids in a material until the void is full. "Wicking" of water into cellulose-based façade elements, such as wood and wood fiber-based products, is a common source of in-service, moisture-related deterioration of exterior wall systems and assemblies.
Advective Moisture Flow: The bulk movement of air as a mechanism for the transfer of moisture in its vapor state across an exterior wall system or assembly.

For example: In humid and mixed-humid climates, moisture-laden air that enters into an enclosure and comes in contact with elements below the dew point (due to the element being at a cooler temperature) can result in condensation within the enclosure and may lead to long-term moisture problems. An example of this is relatively humid, unconditioned exterior air entering into a steel stud wall during the summer cooling season, where it then comes into contact with steel stud surfaces that are sufficiently low in temperature for condensation to occur on the steel stud surface. Moisture-related problems due to diffusive vapor flow can also occur with a misplaced vapor retarder.

Convective Moisture Flow: The bulk movement of moisture involving the transfer mechanisms of molecular diffusion and advection.

For example: The drying rate of a rain-saturated brick veneer can be predicted through an analysis of this process, thereby further defining the potential impact that this and similar materials with a relatively high storage capacity for moisture can have on inward-acting diffusive vapor flow across an exterior wall system or assembly.

Wind-Driven Rain: The process by which rainwater is "driven", or forced, through an exterior wall system or assembly, due either to existing voids in the wall system itself, or to voids created by allowable, in-service deflection of the wall system under applied wind loads.

In the design of glazed aluminum windows, curtainwall, skylights, and storefront framing systems, effective control and management of wind-driven rainwater are basic design concepts that have been well understood for over 40 years. The design of these systems, and the corresponding performance classes assigned to the various window and door products available from this industry, are predicated on the performance of these systems when subjected to simulated wind-driven rain events during both laboratory and field mock-up testing. The test pressures used during these tests are influenced by building height and gust factors unique to each project, and are typically calculated using basic wind speeds assigned to each geographic region of the United States by both local and national building codes.

FIRE SAFETY

Please see each individual wall type section for specific information on fire safety.

ACOUSTICS

Please see each individual wall type section for specific information on acoustics.

PRODUCTIVITY

It is widely understood, and has been shown in a variety of different studies, that human comfort is directly related to productivity and performance. This is particularly true in the workplace, and has been a core principle of good design practice with regard to commercial space planning and the design of the building enclosure for years. The amount of daylight allowed into interior spaces, and the individual control of thermal comfort in office spaces, are two things that sustainable design tries to capture to improve worker productivity. The thermal efficiency of the enclosure becomes critical to allowing individual temperature control of an occupant’s space, as a highly inefficient enclosure will allow more heat gain and loss and may cause unintended thermal cycling. Additionally, air infiltration at fenestration elements, window condensation problem, and direct water ingress will all provide occupants with distractions that will pull their attention away from the task at hand.

The indoor air quality (IAQ) can also be affected by a moisture related failure in the building enclosure. Microbial growth may occur within the exterior wall assembly or at any other building element may create a condition where "free" uncontained mold is able to make it to occupied space and potentially affect the occupant’s health and well being. Please see the Mold section for more information.

It is therefore imperative that the enclosure, the boundary that is meant to separate the interior environment from the exterior environment, be carefully designed and constructed so that a thermal, air, or moisture related failure does not occur that can eventually lead to affecting occupant comfort levels and thus negatively impact worker productivity.
MATERIAL/FINISH DURABILITY

All dissimilar metals and metal accessories that reside inside the "wet" zone of exterior wall assemblies require separation with a non-metallic, UV-stable isolator to prevent galvanic-induced corrosion of the less noble metal. Similarly, galvanic potential caused by rainwater run-off between dissimilar metals should also be considered during design and detailing of exterior wall assemblies.

Please see each individual wall type section for specific information on material finishes and durability.

MAINTAINABILITY

Please see each individual wall type section for specific information on maintainability.

Quality Assurance

The following is an outline of a proposed building envelope quality assurance (commissioning) program currently being developed by committee for potential use and incorporation into NIBS Guideline No. 3. The information presented is in narrative form. However, it should be understood that, in order to be effective, this process must be expanded to include sub-tasks and milestones intended to address the individual quality assurance requirements of each façade material, component or system, as well as the goals and requirements unique to each project.

Also see other WBDG Commissioning pages: Building Commissioning, Determine Project Performance Requirements, Document Compliance and Acceptance, Plan the Commissioning Process


PRELIMINARY DESIGN MEETING

A preliminary design meeting should be held between the building enclosure quality assurance specialist (hereinafter referred to as commissioning agent) and the owner, owner's representatives, architect of record, mechanical engineer, contractor (if already determined and hired) the mechanical commissioning authority, other consultants (including the LEED consultant if sustainable design is required), and other applicable members of the design team to discuss the project and the commissioning agent's involvement as a sub-consultant to the mechanical commissioning authority, and to better understand what objectives the owner wishes to achieve. Any drawings and specifications already prepared should be made available to the commissioning agent prior to this meeting. From this meeting, the commissioning agent should be able to develop a list of building enclosure elements that may potentially affect the building enclosure objectives (high thermal efficiency) that the team is intending to capture, and what elements may be improved to maximize other potential objectives that team may be able to pursue, based on the owners needs. The commissioning agent will also identify what systems of the building enclosure may likely require a more thorough review and what types of performance testing should be included in the contract documents to verify air and water penetration resistance of the fenestration, wall, and roofing systems, and if appropriate, portions of the foundation system. The above building enclosure quality assurance process is supplementary to the integrated design process regarding the total building design and development.

SCHEMATIC DESIGN AND COORDINATION

The architect of record, mechanical engineer and, if appropriate based on the scale and complexity of the project, the commissioning agent should meet to discuss the design intent, and complete design charettes to determine potential design options and building enclosure systems for the design, the owner's requirements, and develop an initial basis of design. As part of this process, the design team should identify and review the overall design intent of the building enclosure systems (barrier versus rain screen versus cavity wall), material selection choices, interface complexities, budget restraints, and specific site specific climate concerns that the enclosure design will need to address. The design team should consider whole building integration and the interaction of the building enclosure with the mechanical systems. This set of charettes may be done separately from initial charettes with the architect of record and other consultants (such as a LEED consultant) to aid the team in determining initial project decisions and direction. The architect will then need to prepare initial schematic designs and 3-D models of the intended structure and site-specific building orientation.
The architect of record and other members of the design team, together with the commissioning agent, should review and research materials for the various systems and assemblies now identified as potential systems that will satisfy the owner requirements. In developing the design, computer modeling for a variety of different attributes and elements that will affect the system should be completed. Various system and sections should be evaluated and compared. The design team should model sections and different combinations of materials and assemblies for vapor drive, moisture storage capacity, environmental impact, geographic implications, siting, exposure, microclimate/macroclimate, solar/shading, thermal efficiency and rainwater resistance, especially wind driven rain. Energy modeling and moisture analysis modeling should both be completed. Computer modeling for heat and moisture transfer should be completed on wall, roof, window and similar building envelope components and assemblies. Moisture transfer modeling will aid the designer in determining if the envelope they have picked may experience long term or short-term moisture problems. Various programs are available to complete the moisture-modeling task, with the better programs being based on long-term historical climate data and region specific wind driven rain data. Energy modeling is useful in refining the thermal design characteristics that can in turn be used to optimize the mechanical system design. From this, a refined set of design documents should be developed, including initial material specifications.

Depending on the project stage for the design team, the commissioning agent should peer-review one initial set of the Design Development drawings and outline specifications pertaining to the building enclosure and provide a written summary of issues and concerns noted during this review. The commissioning agent should provide additional information to the mechanical commissioning authority to be included in the draft commissioning plan and specifications pertaining to the building enclosure systems and subsystems.

Preliminary Construction Documents

The commissioning agent should review relevant portions of the construction documents and project specifications at roughly 50 percent completion, and provide a written summary of issues and concerns noted during this review related to heat, air, moisture transfer and bulk rain water penetration resistance. The commissioning agent can then perform a value engineering review, if requested, to indicating areas where cost tradeoffs can be reasonably applied to reduce the overall cost of the project without significant sacrifice to the long-term durability and performance of the building enclosure. During this review, the commissioning agent should pay particular attention to the requirements in the specifications for samples, technical data, mock-ups, performance testing, and the details at interface conditions as shown on the drawings. The objective of this review will be to identify issues and concerns that may compromise the water tight integrity and moisture and thermal performance of the building enclosure.

During this portion of the commissioning process, the design team may need assistance in developing conceptual details and may require additional information for the building enclosure systems. If any details, plans, or specification sections are modified by the architect of record in response to this review, the commissioning agent should review those changes prior to issuance of the construction documents for bidding. If elements recommended for change by the commissioning agent have not been accepted by the architect of record, they should notify the commissioning agent as to why and the commissioning agent will then need to provide written documentation to the owner, indicating what risks may be associated with not implementing those changes.

One or more meetings will need to be completed with the design team, the owner and owner's representatives, the mechanical commissioning agent, and other appropriate consultants to discuss design options and costs, systems and elements that should not be eliminated, and the inherent risk in doing so. “Value engineering” decisions will be critical during these meetings. Interface conditions will need to be discussed. The following items should not be removed from the project as a means to save up front dollars. These include interface flashings, preconstruction mock-ups, and any and all areas of enclosure redundancy that are critical to the durability of the structure. It has been our experience that with many of the up-front dollars saved by say, eliminating flashings, the dollars for repair are much more than twice the cost.

Final Construction Documents

After the comments developed during the "50%" peer review have been evaluated and applied by the design team, the architect of record and other members of the design team can proceed with finishing the construction documents,
including all drawings and technical specifications. The final assemblies and systems identified will have to again be checked to ensure that they will satisfy the owner requirements. Additional computer modeling including energy modeling and moisture analysis modeling will likely need to be completed, depending on changes being made to the documents based on the initial review comments by the commissioning agent. The modeling should be useful in refining the decisions made during the design development phase. The impact of preliminary cost estimates may lead the team to look at a variety of alternatives. The design team will need to explore different and timely/more cost-effective means to achieve the same end, but without sacrificing core objectives of the commissioning process. The design team should emphasize long-term durability and performance of materials; components and systems that comprise the building envelope and consider the impact of each design decisions on the "whole building design." Mechanical systems should be concurrently examined with the building envelope decisions.

If the process is managed effectively by the architect, this step should be relatively easy in that proper materials are already in the budget for the project and adequate detailing is the only remaining hurdle. The commissioning process will help to ensure a more complete set of CDs as the design team will likely be more thorough in selecting materials not only as a renewable resource, but for long-term durability and performance. The interfaces and detailing completed should be at a much higher level than noncommissioned projects, partly based on the initial commissioning review.

Peer Review Prior to Bidding

The commissioning agent will review one set of the final architectural drawings and applicable specification sections for the building enclosure and provide comments on remaining concerns on the enclosure design paying particular attention to the details and interfaces as shown on the drawings. The commissioning agent will again also review and comment on the requirements in the specifications for samples, technical data, mock-ups, and performance testing. The objective of this review is to identify details, requirements, or methods which may compromise the water tight integrity and thermal performance of the building in order to call these identified items to the attention of the architect of record and the owner for their action. Issues such as constructability and material compatibility need to be examined by the commissioning agent and specific guidance should be supplied via written documentation to the owner and the architect of record at each phase of review. Materials that appear to be poor choices based on durability and a potential for rapid replacement need to be identified, especially on sustainable projects, where product replacement requiring new resources in a short time frame should be examined versus the use of a more durable product that may not be as environmentally appropriate on first selection.

If any details, plans, or specifications are modified by the architect of record, the commissioning agent will need to review these prior to issuance of the design documents. If elements recommended for change have not been completed, the commissioning agent should provide written documentation to the owner, indicating what risks may be associated with not implementing these items.

The peer review process is an important step in assisting the architect of record in making good decisions on the selection of materials, and method of integrating those materials into a durable building envelope.

BID REVIEW

The commissioning agent should be available to provide assistance to the owner and the architect of record in reviewing submittals, if included with the bid, for any proposed product substitutions for building enclosure elements, to determine the risk or equivalence of the proposed substitution.

"Value Engineering"

Efforts by the contractor or owner/developer to reduce the initial cost of a building or structure by applying the principles of value engineering to the design and construction of the building enclosure must be carefully weighed by the Architect/Engineer-of-Record against the best long-term interests of the owner/end-user based on the intended service life of the building or structure. This is particularly true with regard to laboratory and field performance testing, as well as the selection of through-wall flashing materials and related moisture management systems and accessories. In too many instances, pre-construction laboratory mock-up and field quality assurance tests typically required by the design professional to verify the constructability and performance of the building enclosure are considered cost-prohibitive on a project and, therefore, eliminated during the VE process. Similarly, through-wall flashing materials selected by the design professional, in part, for long-term durability and performance (such as stainless steel or lead-coated copper flashings
and drips) are often substituted for lower performing materials that, despite their lower initial cost, are significantly more vulnerable to in-service degradation and failure. The cost associated with successfully addressing uncontrolled rainwater penetration and moisture ingress arising out of decisions made during the VE process can be significant, and the work highly disruptive and invasive. Again, the desired outcome of the VE process must be carefully weighed by the design professional against the long-term interests of the owner/end-user, and the intended service life of the building or structure.

SHOP DRAWING AND SUBMITTAL REVIEW

Concurrent with the architect of record and engineer of record review of shop drawings, the commissioning agent will need to review shop drawings prior to release and fabrication for building envelope requirements and provide written comments to the owner and architect of record.

Depending upon the scale and complexity of the project, the commissioning agent should be retained to assist the architect/engineer of record with his/her review of contractor submittals pertaining to the building envelope to verify their conformance with the contract documents and owner requirements. Regardless of whether review of all of the submittals is needed, contractor submittals for any building enclosure products the contractor would like to use as a substitute will also need to be examined by the commissioning agent, paying particular attention to the comparability of the substituted product, its possible durability, compatibility with adjacent materials, and whether it not it has any material properties, such as a lower vapor permeance, that increase the potential for a moisture-related failure.

BUILDING ENVELOPE PRE-CONSTRUCTION COORDINATION MEETING

The commissioning agent will need to participate in one kick-off meeting prior to beginning construction with the various members of the design and construction teams, including, but not limited to, the owner, owner's representatives, architect of record, mechanical engineer, general contractor, and all subcontractors that will be involved in the construction of the building envelope, including, but not limited to, the roofing, wall system, flashing, sealant, fenestration, concrete, steel, HVAC, electrical, interior framing and drywall contractors and the mechanical commissioning authority and other applicable members of the design and construction team. This meeting will be to discuss construction sequencing and the coordination of trades and the reporting that will be completed during construction of the building envelope and related other elements.

Building Envelope Pre-Installation Meetings with Individual Trades

The commissioning agent will also need to participate in each of the pre-installation meetings to review and discuss critical aspects of the construction, as well as to re-emphasize the importance of coordination among the trades to ensure the successful integration and weather-tight installation of the various materials, components, and systems that comprise the building enclosure.

Laboratory and Field-Constructed Mock-Ups and Performance Testing

Depending upon the size, scale, and complexity of the project, both laboratory and field-constructed mock-ups to verify constructability and performance should be given serious consideration by the design team. This is particularly true with regard to verification of structural performance, as well as air and water penetration resistance and the thermal efficiency of the building enclosure. Pre-construction mock-ups should be designed to include primary façade elements and interface conditions that are: a) unique to the design of the building or structure, b) representative of the entire building enclosure, and; c) reflective of actual job conditions that will be encountered in the field. Contractor personnel used to construct the mock-ups should be the same personnel who will be responsible for the actual work in the field, and should be made fully aware of changes, modifications or refinements in the design and/or installation of the building enclosure resulting from the mock-up and performance testing process.

A certified, independent testing laboratory qualified to perform each of the tests included in the project specifications should be retained to perform all laboratory and field testing. The design professional, commissioning agent, and representatives of the owner/developer, general contractor (or construction management firm) and appropriate subcontractors should be present during all tests, and should document, in writing and with supporting photographs and sketches, any changes in the building enclosure design arising out of the mock-up and performance testing program. Individual test methods, standards and required test pressures will vary based on the material, component or system.
being tested and the climate, location and exposure unique to each project. Test pressures should be carefully coordinated by the design professional in the project specifications to ensure that the specified test pressures for each system are uniform and consistent across the entire wall system or assembly, and meet or exceed the performance levels required by local, state, and national building codes.

ON-SITE CONSTRUCTION OBSERVATION AND QUALITY ASSURANCE SERVICES

The commissioning agent will need to review the contractor’s quality assurance inspection plan. To ensure that the findings and recommendations accepted by owner and the architect of record are properly executed and tested in the field, the commissioning agent will have to provide periodic, on-site review of the work in progress during the course of construction at the building envelope. A written record of deficiencies should be maintained by the commissioning agent and forwarded to the architect/engineer of record, owner, and general contractor in a timely manner throughout the construction process, together with a written record of how and when each deficiency was corrected in the field.

During this process, it is anticipated that the commissioning agent will participate in weekly or bi-weekly Building Envelope Quality Assurance Meetings chaired by the general contractor, with the appropriate subcontractors in attendance, to review and discuss issues and concerns noted by the commissioning agent during the previous week and what action will be taken to address those concerns. Our experience suggests that a minimum on-site presence of two (2) days per week will be required for most projects.

PROJECT CLOSE-OUT

A final walk-through and "punch-list" survey of all deficiencies remaining on the project should be completed by the commissioning agent, architect/engineer of record and the owner. The commissioning agent may complete additional testing and commissioning of the envelope at this stage.

BUILDING ENVELOPE MAINTENANCE GUIDE AND TRAINING

The commissioning agent should prepare a Building Envelope Maintenance Guide necessary to properly train on-site engineering and maintenance staff on the proper maintenance of the building envelope. This guide should also include a collection of all necessary closeout documents related to the building envelope, such as warranties and information on the materials utilized, including the appropriate catalog information, supplier, manufacturer, and ordering/contact information. The owner and staff should also be given guidance as to what elements will typically require outside contractor assistance for maintenance.

Applications

The United States has several distinct climate zones, and a variety of rainfall zones. These are currently described in the EEBA Builder's Guides. Understanding these zones is critical when examining the choices of materials and the methods for integrating those materials into any element of an enclosure. Additionally, designers will need to examine site specific conditions that relate not only to the physical location of the building with regard to surrounding buildings, but the orientation of the building with respect to wind, rain and other precipitation, the sun, as well as whether the building is to be placed in a dry or humid climate, in a hot or cold climate or if there will be intermixing of these climates or climate characteristics.

See the tables for guidance by wall system type for climate-specific considerations that are imperative to the success of any enclosure design.

Details

Contained within this guide are a series of details that cover the following interface conditions; conditions that based on our experience are poorly or not appropriately detailed, or not detailed at all in many of the design packages we have peer reviewed as well as poorly constructed. Additionally, the majority of building enclosure failures we have seen within the wall system can be related back to an omission or other error related to these details. Each wall system section contains some of the fourteen details listed below with elements specific to that wall system. The details, graphics and related information shown above are intended to illustrate basic design concepts and principles only and should be considered collectively with the appropriate narrative sections of the Whole Building Design Guide (WBDG). The
information contained herein is not intended for actual construction, and is subject to revision based on changes and/or refinements in local, state and national building codes, emerging building envelope technologies, and advancements in the research and understanding of building envelope failure and failure mechanisms. The actual design and configuration of these and similar details will vary based upon applicable local, state and national building code requirements, climatic considerations, and economic constraints unique to each project. Full compliance with the manufacturer’s recommendations and recognized industry standards for each building envelope material, component and system specified for this and similar exterior wall assemblies is recommended, and should be reflected in the appropriate sections of the project specifications.

The details are for the following elements and interfaces:

- Head and jamb flashing
- Sill and jamb flashing
- Interface between interior and exterior wall
- Vertical expansion joint
- Typical round penetration
- Typical square penetration
- Through wall flashing
- Inside corner detail
- Outside corner detail
- Wall to balcony transition
- Horizontal interface between barrier and drained wall
- Vertical interface between barrier and drained wall

The details included in this guide are available in CADD format. CADD utilizes a series of layers to define elements. As noted earlier in this section (General Overview of Exterior above Grade Wall Systems), any building enclosure assembly can be thought of as a series of layers. The details for this guide have each building enclosure element defined as its own "layer" (the exception is on the stone details, where a second layer is utilized for each element on the step-by-step details to allow the element being installed in a particular step to be more prominent). By turning layers on or off within the CADD details, the user of this guide can see more clearly the intent of each element.

The details are not climate specific. As such, a series of tables have been included in this guide with recommendations for wall systems based on climate zones as defined by EEBA’s Builder Guides. The details, the tables, and the information in this guide should be used in its entirety. If, for example, the climate zone being designed for required an exterior side vapor retarder, the designer should review the layers they have indicated on the project specific design and locate all layers that would have a permeance that would define it as a vapor retarder. The design team should review each layer utilizing a hygrothermal analysis (and common sense) to determine if the wall system they intend to utilize has a vapor retarder at the intended location and whether a misplaced vapor retarder is placed at a location other than that intended in the design. Conceptually, a master detail could be set-up by the design team during the Schematic Design phase with text identifying each product and its properties (air permeance, vapor permeance, thermal resistance, structural rigidity or load bearing capacity, etc.) and the design intent at each layer (drainage plane, air barrier, vapor retarder, thermal element, structural element etc.). The standard CADD layering terminology could then be renamed to clearly label the products and each layer and its intent. The building enclosure assessment could be completed on this initial section or series of sections for materials being considered for use on the project by reviewing what the intent of each layer is, whether it meets the intent, and whether any of the materials other properties create a potential for a moisture-related failure, by, for example, being a misplaced vapor retarder.

It is recommended that a set of details be included in the construction documents illustrating a fully integrated and effective air barrier system layer, drainage plane layer (including interfaces with flashings), and insulating element layer. Overall isometric or similar 3-dimensional details that clearly indicate each layer and interface condition may also be required. Details specific to a certain element that may not be clearly shown on an overall detail (such as a flashing splice) should be called out on the overall detail and a separate detail included indicating the installation of this element. Details should be included for each unique interface, transition, or penetration on the project.
Once the air barrier layer and products have been chosen and verified, a series of sections and plan views of the building should be developed showing air barrier continuity. This continuity could be traced out on the drawings. This is necessary to determine how the various materials will need to overlap and be sealed at openings and penetrations, at transitions between various wall types, at the foundation, and at the roof. A series of air barrier details are required to ensure proper construction of the air barrier system and to ensure its continuity. If the details are developed using a system in CADD that allows each layer to be turned off and on, showing the full view of the air barrier when it is needed and a partial view on an overall detail, the designer may spend less time in completing their set, as one set of details could be used to develop each detail set (i.e.—overall, drainage plane and flashing, air barrier and thermal barrier). The air barrier details should include 2-Dimensional and 3-dimensional isometrics clearly showing the location of the air barrier elements with respect to other elements and how the various materials for the air barrier system will be integrated. At a minimum, the following details should be developed:

1. At the interface between wall types, whether between a barrier or cavity wall or two types of cavity wall
2. At expansion joint locations
3. At penetrations (roof, below grade or wall)
4. At louver locations
5. At door and fenestration (window, curtainwall, skylight, etc.) openings
6. At the roof-to wall transition for each type roof or wall type on the project
7. At the wall-to-below-grade transition
8. At inside and outside corners
9. If the sheathing or exterior side rigid insulation product has an air permeance value that qualifies it as a material to be used for an air barrier (see Tables) and is intended to be used as such, joint sealing and fastener sealing methods
10. Roof membrane joints
11. At sun-shade or other similar penetrations
12. At all other unique, project-specific conditions requiring additional information to complete the air barrier system installation

DRAINAGE PLANE AND FLASHING DETAILS

Once the drainage product(s) have been chosen and verified, a series of sections and plan views of the building should be developed showing drainage plane continuity. This continuity could be traced out on the drawings. This is necessary to determine how the various materials will need to overlap and be sealed at openings and penetrations and coordinated with flashings, at transitions between various wall types, at the foundation, and at the roof. A series of drainage plane details are required to ensure proper construction of the drainage plane as part of the moisture management system and to ensure its continuity and proper integration with flashing elements. The drainage plane details should include 2-Dimensional and 3-Dimensional isometrics clearly showing the location of the drainage plane material with respect to other elements and how the various materials for the precipitation and bulk water management system will be integrated. At a minimum, the following details should be developed:

1. At all through-wall, window, door or other wall fenestration, and all penetration flashings
2. At all roof flashing locations, particularly hatches, mechanical equipment curbs and skylights
3. At the interface between wall types, whether between a barrier or cavity wall or two types of cavity wall
4. At expansion joint locations
5. At penetrations (roof, below grade or wall)
6. At louver locations
7. At door and fenestration (window, curtainwall, skylight, etc.) openings, including head, jamb, and sill flashings
8. At the roof-to wall transition for each type roof or wall type on the project
9. At roof, plaza, or other drain locations
10. At the wall-to-below-grade transition
11. At inside corners
12. At outside corners
13. At sheathing and/or back-up wall joints
14. Roof membrane joints
15. At sun-shade or other similar penetrations
16. At all other unique, project-specific requiring additional information to complete the drainage plane and flashing
INSULATING ELEMENT DETAILS

Once the insulating element layer and products have been chosen and verified, a series of sections and plan views of the building should be developed showing the insulating element(s) continuity. This continuity could be traced out on the drawings. This is necessary to determine how the various materials will need to overlap and be coordinated at openings and penetrations, at transitions between various wall types, at the foundation, and at the roof. A series of insulating element details are required to ensure proper construction of this system and to ensure its continuity. The insulating element details should include 2-Dimensional and 3-Dimensional isometrics clearly showing the location of the insulating element(s) with respect to other elements and how the various materials for the insulating element will be integrated. At a minimum, the following details should be developed:

1. At the interface between wall types, whether between a barrier or cavity wall or two types of cavity wall
2. At the roof-to wall transition for each type roof or wall type on the project, particularly continuity at the top of parapets, where ice dams may form in colder climates if interior heated conditioned air is allowed to enter the parapet and come in contact with the parapet cap with no insulating element below the cap
3. At the wall-to-below-grade transition
4. At expansion joint locations
5. At penetrations (roof, below grade or wall)
6. At louver locations
7. At door and fenestration (window, curtainwall, skylight, etc.) openings
8. At inside corners
9. At outside corners
10. At connections
11. At shelf-angles
12. At sun-shade or other similar penetrations
13. At all other unique, project-specific requiring additional information to complete the insulating element installation

Emerging Issues

Hybrid Exterior Wall Systems and Emerging Technologies

In recent years, technological advancements in the design and manufacture of building enclosure materials, components and systems, together with an increasingly refined understanding of air/moisture transfer and the behavior of wind-driven rain on the building enclosure have lead to the development of several hybrid and sustainable exterior wall systems, several of which include:

- Trombe Walls
- Dynamic Buffer Zone and Mechanically Ventilated Walls
- Double-Skinned Façades
- Integrated Photovoltaics
- Passively Ventilated Wall Systems
- Radiant Heating and Cooling using Thermal Mass
- Passive Heating and Cooling
- LEED and Green Buildings

These and similar hybrid wall systems are often derived, at least in part, from the concepts embodied in one or all of the above-referenced Basic Exterior Wall Types. They typically include design features and individual building elements that are intended to improve or otherwise enhance the long-term durability and performance of the building enclosure, and are often adapted in response to issues and concerns that are unique to a particular geographic area and/or climatic region in which a building or structure is to be designed and built. Use and integration of these and similar hybrid wall systems should be given careful consideration by the Architect/Engineer-of-Record during the schematic design phase of a project. They should be discussed in detail with the owner/end-user, with particular emphasis placed on the overall design and installation complexity of the proposed exterior wall system(s), as well as the impact of those systems on the
short and long-term cost, maintenance burden, durability, and performance of the building enclosure.

Relevant Codes and Standards

Code and standards applicable to each wall type are included in each of the individual sections for each wall type.

Additional Resources

WBDG

DESIGN OBJECTIVES

Functional / Operational—Ensure Appropriate Product/Systems Integration, Functional / Operational—Meet Performance Objectives

PRODUCTS AND SYSTEMS

Section 07 92 00: Joint Sealants, See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

Previous Building Envelope Federal Design Guidelines


Relevant Professional Associations

- The American Institute of Architects (AIA)
- American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)
- American Society of Civil Engineer's Architectural Engineering Institute (ASCE-AEI)
- Construction Specifications Institute (CSI)
- SAVE International, "The Value Society"

Relevant Research Organizations

- Building Engineering Group at the University of Waterloo (BEGHut)
- Canadian Mortgage and Housing Corporation
- Energy and Environmental Building Association
- Fraunhofer Institute for Building Physics
- Canada's Institute for Research in Construction (IRC)
- National Institute of Building Sciences (NIBS)
- Oak Ridge National Laboratory (ORNL)
- Pennsylvania Housing Research Center (PHRC)

Design Guides

- EEBA Climate Specific Builder's Guides
- CMHC Best Practice Guide—Flashings
- Department of Energy Wall System Guide
- Department of Energy Building Guide

Standards and Codes Links
Government Links

- Consumer Products Safety Commission (CPSC)
- Department of Energy (DOE)
- Environmental Protection Agency (EPA)
- Federal Emergency Management Agency (FEMA)
- Department of Housing and Urban Development (HUD)
- National Oceanic and Atmospheric Administration (NOAA)

Air Barrier Associations and Information

- Air Barrier Association of America
- Canada's National Air Barrier Association

Green Building and Sustainable Design Resources

- United States Green Building Council
- Development Center for Appropriate Technologies
- Rocky Mountain Institute
- Cradle-to-Cradle Design Approach (MBDC)
- Biomimicry
- National Center for Photovoltaics

Historic Preservation Resources

- Advisory Council on Historic Preservation
- Association for Preservation Technologies
- National Park Service—Heritage Preservation Services—Preservation Briefs
- National Trust for Historic Preservation
- Preservation Directory

Fire Safety Organizations

- International Firestop Council
- National Fire Protection Association
- The Fire Safety Institute

Other Organizations

- Wiss, Janney, Elstner Associates, Inc.
- Building Science Corporation
- Carl Walker
- Simpson, Gumpertz and Heger, Inc.
- TL Smith Consulting Inc.
Building Envelope Design Guide - Cast-in-Place Concrete Wall Systems

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Wiss, Janney, Elstner Associates, Inc.
Last updated: 01-02-2007

Introduction

The Executive House in Chicago is generally known as the first reinforced concrete skyscraper. At the time of its completion in 1959, it was the tallest reinforced concrete building in the United States at 39 stories, or 371 feet. In 1962, the twin towers of Marina City in Chicago set a new record at 588 ft above grade. These distinctive circular, reinforced concrete towers also served as an early example of a cast-in-place concrete wall system. Subsequently, Chicago's Lake Point Tower built in 1968 and Houston's One Shell Plaza built in 1970 set new records at 645 ft and 714 ft, respectively. While both of the latter buildings are clad in materials other than concrete, their innovative structural systems are reflected in their façades and established the precedent for many of the cast-in-place concrete wall systems seen throughout the United States.

Description

A cast-in-place concrete wall system is an exposed structural system that also serves as the façade. Openings or penetrations in the structural system are generally infilled with windows, masonry, or some other cladding material.

Fundamentals

Cast-in-place concrete wall systems are generally defined by the building's structural system, which consists of the vertical (gravity) load resistant system and the lateral (wind and seismic) resistant system. The vertical load resistant system may be further subdivided into the horizontal framing (floor system) and the vertical framing (column and walls). The lateral resistant system includes moment resisting frames, shear walls, braced frames, or a combination of these systems.

A concrete structure designed and constructed in the United States is governed by the minimum provisions of the ACI Building Code. While most of the design provisions of the Code dictate minimum strength (safety) requirements, the Code also prescribes serviceability and durability requirements. Certain factors which influence the design of the structural system also impact the exterior wall. These factors include deflection, cracking, concrete cover, and corrosion protection.

Performance Issues

THERMAL PERFORMANCE

Cast-in-place concrete walls derive their thermal performance characteristics primarily from the amount of insulation placed in the cavity or within the backup wall.

MOISTURE PROTECTION

The most common moisture protection system used with cast-in-place concrete wall systems is a barrier system incorporating an adequate joint seal. In some cases where additional moisture protection is needed, the application of a sealer or a concrete coating is also used. Sealers can be either clear or pigmented if used as an enhancement of the precast appearance. Film-forming coatings usually offer a higher level of performance but will have a significant impact on
the appearance of the precast concrete unit.

The cast-in-place concrete wall should also be designed to provide the appropriate level of durability for the planned exposure. Durability can be improved by specifying minimum compressive strengths, maximum water to cement ratios, and an appropriate range of entrained air.

FIRE SAFETY

At relatively high temperatures experienced in fires, hydrated cement in concrete will gradually dehydrate, reverting back to water (steam) and cement. This results in a reduction in strength and modulus of elasticity (stiffness) of concrete that, in some instances, can result in spalling. The overall fire resistance of concrete is influenced by aggregate type, moisture content, density, permeability, and nominal thickness. "Carbonate" aggregates, such as limestone, dolomite, and limerock, have been found by some to improve the overall fire resistance of concrete due to their ability to absorb some of the heat from a fire. Similarly, concretes with lower unit weights (densities) will also offer improved fire resistance, as will dried light-weight concrete. In contrast, concrete with relatively low moisture content, low water-cement ratio, and highly impermeable concrete may spall when subjected to fire.

1Gustaferro, Armand H., "Fire-Resistant Concrete", MC Magazine Archive

ACOUSTICS

A cast-in-place concrete wall system and precast concrete panel façade will provide similar performance regarding sound transmission from the exterior to the interior of the building. See Precast Concrete Wall Systems for additional information, as well as the industry and trade association web site links listed at the end of this section.

MATERIAL/FINISH DURABILITY

The key issue to be addressed in design of a cast-in-place façade element is durability related to environmental exposure such as moisture, carbonation of concrete, and other factors that can contribute to the distress and deterioration of concrete.

Concrete deterioration may occur for two principal reasons: corrosion of the embedded steel resulting in concrete deterioration, and degradation of the concrete itself. Concrete normally offers protection to embedded reinforcing steel through its alkalinity.

Concrete deterioration due to corrosion of embedded steel is usually related to moisture, and is typically in the form of cracking and delamination of the concrete. Where embedded reinforcing steel is not protected by the alkaline environment of the concrete, and the steel is exposed to moisture, corrosion occurs. The corroded steel expands significantly in volume, which results in expansive forces on the adjacent concrete, causing it to crack and spall. This is visually apparent in cracking and delamination of the concrete and rust staining at the location of embedded steel.

Carbonation results in the loss of alkalinity within the concrete to the level of the reinforcing steel. Carbonation normally occurs only in the vicinity of the exposed surface of the concrete, but in some cases may extend to the level of the steel. Once this occurs, the concrete offers no protection to the embedded reinforcing steel, and corrosion begins. Carbonation occurs from a combination of moisture and carbon dioxide.

Corrosion of embedded reinforcing steel is often due to calcium chloride added to the concrete as an accelerator during original construction or later from de-icing salts used in northern climates. Chloride ion in combination with moisture results in corrosion of the embedded steel and resulting deterioration of the surrounding concrete. Sea water, or other marine environments, provide large amounts of chloride.

The exposed surface of the concrete is also vulnerable to weathering from the elements. This may typically be observed as erosion of the concrete paste. Especially in northern regions where precipitation has been found to be highly acidic, exposure has resulted in more significant erosion of the paste on the exposed surfaces.

Freeze-thaw damage results from the freezing of concrete that is saturated with water. This type of damage appears as degradation of the surface, including severe cracking, extending into the concrete. It was accidentally discovered that portland cement concretes that incorporate microscopic air bubbles provided resistance to cyclic freezing and thawing. The air-entrainment provides "relief valves" that protect the concrete. Air-entraining agents are now generally (but not
always) added to cement or concrete used in exposed applications that are in areas of the United States subject to sub-freezing temperatures.

Alkali-aggregate reactions result when alkalis normally present in cement react with silicious aggregates in concrete that is exposed to moisture. The reaction produces a toothpaste-like gel that develops over years or decades until the forces created expand and crack the concrete. Most such deleterious aggregates can be detected by experience or test, and low-alkali cements can be used in new construction to prevent significant reactions.

Sulfate attack is produced by the reaction of excessive amounts of sulfate salts with cement components that are exposed to moisture. The reaction leads to the development of expansive forces that eventually crack the concrete. The sulfate salts may come from the environment (e.g., sulfate waters or solids), or from one or more of the concrete constituents (e.g., aggregates, cement, or proprietary product providing fast set).

Other forms of concrete deterioration exist, including freeze-thaw damage, alkali-aggregate reaction and sulfate attack, but less common in cast-in-place concrete wall systems.

MAINTAINABILITY

Durability of concrete and resistance to deterioration is dependent on durability, proper design, and good workmanship. This will also be true for the materials used to repair existing concrete. A mix design for durable replacement concrete should utilize materials similar to those of the original concrete mix and include air-entrainment, appropriate selection of aggregates, and adequate cement and water content. Good workmanship should address proper mix, placement, and curing procedures. In all cases, a good mix design will enhance good workmanship for durable repair concrete.

In designing repairs to existing concrete, parameters must be established to define the goals of the project based on visual evaluation and laboratory studies. A key concern is the aesthetics of the repair, to match the existing concrete as closely as possible both visually and structurally. Another governing concern is to select repair interventions that retain as much as possible of the original material; however, an adequate amount of distressed concrete must be removed to provide a durable repair.

All repairs of existing concrete require proper preparation of the substrate to receive the repair material. This typically includes sandblasting, airblasting, or other appropriate means to provide a clean surface to which the repair can adequately bond. Bonding agents are commonly used on the substrate surface to enhance the bond of the repair.
Existing reinforcing steel that is exposed during the repair may require cleaning, priming, and painting with a rust-inhibitive coating. In most cases, the repair area should be reinforced and mechanically attached to the existing concrete.
Reinforcement may be regular steel, epoxy-coated steel, or stainless steel, depending on the conditions.

Proper placement and finishing of the repair is important in achieving a match to the original concrete. Appropriate curing is essential for a durable repair; wet curing is recommended to reduce the time of curing and the potential for surface and shrinkage cracking.

The preparation of trial repairs and mockups to refine the repair design, and also to evaluate repair procedures is a wise procedure. Mockups also permit evaluation of the visual and aesthetic acceptability of the repair design.

Because concrete deterioration is primarily the result of moisture penetration, rehabilitation may also entail application of a decorative surface coating or clear penetrating sealer. These water-resistant coatings and sealers should be breathable and alkali-resistant.

Various repair methods and techniques are available in the market today to reduce the rate of corrosion of embedded reinforcing and associated deterioration of the concrete. One method is cathodic protection, which utilizes an auxiliary anode so that the entire reinforcing bar is a cathode. (Corrosion is an electro-chemical process in which electrons flow between cathodic (positively-charged) and anodic (negatively-charged) areas on a metal surface; the corrosion occurs at the anodes.) Cathodic protection is intended to reduce the rate of corrosion that occurs to embedded steel in concrete, which in turn reduces concrete deterioration.

Cathodic protection is only one of many evolving techniques available to protect concrete. Another technique currently available is realalkalization, which involves returning the concrete to its natural alkaline state.

Applications
Cast-in-place concrete wall systems have been in use in the United States for many decades. Much of the early
development of this construction type occurred in Chicago, primarily due to the influence of the Portland Cement
Association and innovative structural engineers like Fazlur Khan. The permanence of this building type is evident by the
number of prominent cast-in-place concrete buildings built in the 1950’s and 1960’s that still exist and remain functional
today.

See Appendices for climate-specific guidance regarding building enclosure design.

Emerging Issues

Ordinances related to the maintenance of façades, including cast-in-place concrete wall systems, have been enacted in
New York and Chicago. As the inventory of older buildings increases, the maintenance of these building façades and the
life safety issues associated with their deterioration will also increase.

The mechanisms that generally contribute to the deterioration of cast-in-place concrete wall systems are well known.
Improvements in design standards and repair technology will result in improved performance.

The necessity to make building envelopes blast-resistant has forced reconsideration of the cast-in-place concrete façade
as a design option.

Relevant Codes and Standards

- American Concrete Institute ACI 318—Building Code Requirements for Structural Concrete
- American Concrete Institute ACI 301—Specifications for Structural Concrete
- Concrete Reinforcing Steel Institute (CRSI)—“Reinforced Concrete Fire Resistance”

Additional Resources

WBDG

PRODUCTS AND SYSTEMS

Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide
Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications,
MasterSpec®

Publications

- Concrete Homes Magazine

Organizations

- American Concrete Institute (ACI)
- Concrete Reinforcing Steel Institute (CRSI)
- Autoclaved Aerated Concrete Product Association (AACPA)
- Concrete Homes Council
- Insulating Concrete Form Association (ICFA)
- Portland Cement Association (PCA)

Other

- Spray-Applied Concrete Wall Systems
Introduction

Exterior Insulation and Finish System (EIFS) is an exterior wall cladding that utilizes rigid insulation boards on the exterior of the wall sheathing with a plaster type exterior skin. EIFS in its current basic form was developed in West Germany in the 1960s by Dryvit and introduced in the United States in 1969. The Dryvit system consisted of expanded polystyrene (bead board) attached adhesively to the sheathing and covered with a lamina composed of a modified cement base coat with woven glass fiber reinforcement and a textured colored finish coat. Over the years, variations of this system have been developed.

Description

The most common type of EIFS is the polymer based (PB) system. This system has a nominally 1/16 inch thick reinforced base coat applied to the insulation prior to application of the finish coat. The insulation typically consists of closed expanded polystyrene (EPS) and can be either adhesively or mechanically attached to the sheathing. The second and less common type of EIFS is the polymer modified (PM) system. This system has a nominally 3/16 inch to 1/2 inch thick reinforced base coat applied to the insulation prior to application of the finish coat. The insulation typically consists of extruded expanded polystyrene (XPS) and is mechanically attached to the sheathing and or wall structure.

EIFS is available in two basic types: a barrier wall system or a wall drainage system. Barrier EIFS wall systems rely primarily on the base coat portion of the exterior skin to resist water penetration. Therefore, all other components of the exterior wall must either be barrier type systems or be properly sealed and flashed to prevent water from migrating behind the EIFS and into the underlying walls or interiors. Wall drainage EIFS systems are similar to cavity walls; they are installed over a weather barrier behind the insulation that acts as a secondary drainage plane. The weather barrier must be properly flashed and coordinated with all other portions of the exterior wall to prevent water from migrating into the underlying walls or interiors.

Fundamentals

All EIFS are proprietary systems and the components of the system should not be modified beyond the limits stated in the manufacturer’s literature. The design of the interface with other components of the wall system is the responsibility of the wall designer. Details should make clear the design of the final construction. If necessary, the sequence by which the wall assembly is to be constructed is addressed in the details. In general, construction conditions of the EIFS that should be detailed if they exist on the building include terminations, openings, joints, objects mounted onto the surface and special treatments to the surface.

Performance Issues

THERMAL PERFORMANCE

The popularity of EIFS comes from its insulating qualities to reduce thermal loads on the exterior building wall and the light weight, low cost, and the ability of the system to be sculpted into shapes and patterns to achieve different aesthetic effects. The thermal performance of the exterior insulation is based on the thickness of the insulation selected. The insulation should never be installed or modified to less than 3/4 inch in thickness.
MOISTURE PROTECTION

Problems observed with in-service EIFS installations are primarily related to moisture intrusion. EIFS provides protection against moisture infiltration at the base coat; however, moisture migration through openings for windows, flashings and other items, or holes and cracks in the EIFS itself, have allowed leakage to occur on EIFS clad buildings. With barrier EIFS installations, or where weather barriers and flashing are improperly installed in conjunction with wall drainage EIFS installations, moisture has entered the wall system at these locations and caused damage to the wall sheathing and framing. The extent of these occurrences on wood frame structures has led to class action lawsuits.

FIRE SAFETY

Consult the EIFS Industry Members Association (EIMA) for additional information on this topic.

ACOUSTICS

Consult the EIFS Industry Members Association (EIMA) for additional information on this topic.

MATERIAL/FINISH DURABILITY

EIFS finish coats come in a wide variety of colors and textures similar to those of stucco. Since the base coats are relatively thin, especially in PB systems, they are susceptible to impact damage. Color retention is relatively good.

Common Problems for EIFS are as follows:

- Failure to install or properly install sealant joints around windows, doors, pipes, conduits, and other penetrations of the field of the EIFS.
- Failure to flash window and door openings in the field of the EIFS to divert leakage through the window or door to the exterior.
- Failure to install diverters (kick-out flashing) at ends of roof flashing terminating in the EIFS wall.
- Failure to properly backwrap edges of EIFS at terminations and penetrations in the field of the EIFS.
- Failure to install expansion joints at floor lines in EIFS applied over wood frame construction.
- Failure to notch insulation boards at corners of openings for windows and doors to avoid insulation board joint at the corner of the opening.
- Failure to install diagonal mesh in lamina at corners of openings for windows and doors.
- Failure to terminate EIFS above grade, especially in termite prone regions.
- Installation of decks over EIFS without proper flashing.
- Unrepaired impact damage.
- Inadequate base coat applications at corners.
- Inadequate base and finish coat application in reveals.
- Installation of reveals at board joints.
- Lack of adequate slope on skyward facing surfaces.
- Damage from ropes, cables, etc. to EIFS parapet tops.

MAINTAINABILITY

Maintenance of the EIFS lamina and sealants at penetrations or terminations is critical to the performance of the water resistive characteristics of the EIFS. Holes and cracks should be repaired as soon as possible. Repair methods for holes and cracks in EIFS are simple and the manufacturers publish recommended methods. Maintenance of joints sealants is the same as that for other types of wall claddings, except that care must be taken to prevent damaging the EIFS when existing sealants are removed.

Applications

See Appendices for climate-specific guidance regarding building enclosure design.
Details

Please see the details section and consult the manufacturers web pages referenced in this section for additional information regarding this topic. Due, in part, to issues and concerns related to the integration of EIFS with surrounding wall systems and wall penetrations in both residential and multi-family, commercial-scale construction, the EIFS industry and its members have developed a series of informative and well-developed, three-dimensional details for façade interfaces and related conditions that are useful starting points for detailing EIFS.

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Drained EIFS Roof Interface Kickout Flashing  DWG | DWF | PDF
Drained EIFS Window Head and Jamb  DWG | DWF | PDF
Drained EIFS Window Sill and Jamb  DWG | DWF | PDF

Emerging Issues

Emerging issues in the EIFS industry include:

- Drained EIFS
- Improved Interface Detailing for Exterior Wall Penetrations
- Developing Field Test Standards for Water Penetration Resistance (ASTM)

Relevant Codes and Standards

There are virtually no limitations on the locations where EIFS can be used as an exterior wall cladding beyond those imposed by codes. These occurrences of water infiltration have also led to many code restrictions on the use of EIFS. These code restrictions are evolving and changing as further testing is developed and implemented. Most codes require a code evaluation report for the selected manufacturer's system and may impose additional restrictions on the use of barrier EIFS. Applicable local codes should be consulted prior to designing EIFS claddings.

Codes also restrict the maximum thickness of the insulation, particularly with regard to fire protection. Most codes limit thickness to 4 inches maximum or require a study of the average fuel contribution of the insulation.

Additional Resources

WBDG

DESIGN OBJECTIVES
Functional / Operational—Ensure Appropriate Product/Systems Integration

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

Major resources for information regarding EIFS and its proper use are manufacturer's catalogs containing product description and standards, specifications, details, and installation instructions; the Exterior Insulation Members Association (EIMA); and ASTM International.

Publications

- CMHC Best Practice Guide—EIFS
Organizations/Manufacturers

- EIFS Industry Manufacturers Association (EIMA)
- Dryvit Systems, Inc., an EIFS manufacturer.
- Parex, an EIFS manufacturer.
- Senergy, an EIFS manufacturer.
- Sto Corporation, an EIFS manufacturer.
- The EIFS Institute provides consumer information about EIFS.
Introduction

Masonry has been used in building construction for thousands of years in construction. It can be used to form a durable cladding system and to achieve various aesthetic effects. The masonry units can be oriented in different positions to create different patterns on the exterior wall. In addition to forming the exterior cladding, masonry walls can serve as a portion of the structural framing for the building. Masonry walls also typically increase the fire resistance of the wall system or structural elements.

Masonry walls can be single or multi-wythe. A wythe of masonry refers to a thickness of wall equal to the thickness of the individual units.

Description

Masonry is typically site constructed (laid) using manufactured masonry units and site mixed mortar. The units are laid in mortar to various heights, with the strength of the assembly being achieved during curing of the mortar. Masonry can form structural elements (typically bearing walls, columns, or pilasters) and/or the finished cladding system.

Masonry Units

Several different types of masonry units are commonly used. Common masonry unit types include clay and concrete units, which may be solid or hollow, and glazed or unglazed. Other masonry unit types include cast stone and calcium silicate units.

CLAY UNITS

Clay brick units are typically used in brick masonry construction. Depending on the clay used and the method of forming the units during manufacturing, clay units have various colors, sizes and textures. Other types of units include glazed brick (both clay and concrete) units, concrete brick, calcium silicate brick, and hollow clay tile (typically used in older masonry buildings).

Clay masonry units are typically formed of soft clay extruded into the required shape in the manufacturing plant. Several different finishes can be formed on the exterior surface of the brick such as wire cut or sand finished, depending on the method used to form the brick into the desired shape. Brick units are then heated in a kiln (fired) to a temperature of 1100 to 1200 Fahrenheit degrees in order create the structural properties of the units.

The units can be hollow (cores occupy greater than 25% of unit) or solid. Units categorized as solid typically contain cores for handling and to allow more uniform firing. For most exterior walls, units categorized as solid are used.

The standard for clay masonry units is ASTM C216 (Standard Specification for Facing Brick (Solid Masonry Units Made from Clay or Shale)). In this standard, and in building specifications, clay units are categorized by grade (NW, MW or SW) and type (FBA, FBS and FBX). The masonry grade depends on the required durability of the units. Typically, Grade SW (severe weathering) is recommended in most areas of the US. These units are much more resistant to freeze-thaw cycling. MW (moderate weathering) units should only used in areas where freezing cycles are not anticipated. NW (negligible weathering) units should only be used in interior conditions where the interior air is conditioned and there is no
exposure to moisture.

The type of unit depends on the required dimensional tolerances. Typically Type FBS is specified unless unusually tight tolerances are required. Where tight tolerances are required, Type FBX should be specified. Type FBA units are typically used to create a rustic appearance with a high dimensional tolerance.

Glazed clay masonry units should meet the requirements of ASTM C126 (Standard Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units).

CONCRETE MASONRY UNITS (CMU)

Concrete masonry units (CMU) are made from a mixture of portland cement and aggregates under controlled conditions. The units can be made to various dimensions, but typically have face dimensions of 8 inches high by 16 inches wide (nominal). Concrete masonry units are typically made in forms to the desired shape and then pressure-cured in the manufacturing plant. The units are often used when masonry is to form a load-bearing wall or an interior partition between spaces within a building. Concrete masonry units can be manufactured in different sizes and with a variety of face textures.

Concrete masonry units should meet the requirements of ASTM C90. The units are categorized based on the weight (lightweight, normal weight and heavyweight). Structural masonry units are either normal weight or heavyweight. Lightweight units are used for non-load-bearing conditions or as veneers.

Since these units are typically larger than brick units, the construction time required for laying the units is typically less than that for brick. The units can be solid or hollow (two or three cores) and can have solid or flanged ends. The cores provide continuous vertical voids that are often reinforced. Steel bars are placed in the cores with grout installed surrounding the bars. In this fashion, the wall acts similar to a reinforced concrete element.

Mortar

Mortar is typically composed of cement, lime and sand, although lime mortars can also be composed in which no cement is used. Components and proportions of mortars vary depending on the desired mortar properties. Mortars consisting of portland cement and lime as well as sand are most common. Premixed mortars must be carefully reviewed to determine the actual components of the mix.

There are different mortar types depending on the required strength. Mortars for new construction are typically Types N, S, or M. For repairs to existing buildings, some other types such as Type O, or even softer mortars, may be required to replicate the original mortar properties. The most common masonry types and uses in new construction are as follows:

- **Type N**—Used in general masonry walls above grade. This is the most common masonry mortar used in non-structural applications in new construction. This has good bond qualities and good resistance to water penetration.
- **Type S**—Typically used in structural masonry applications. Has a higher proportion of cement and subsequently can have increased shrinkage of the mortar.
- **Type M**—Typically used only in below grade applications.

Mortar proportions and mixing requirements are outlined in ASTM C270 and in the appropriate Technical Notes published by the Brick Institute of America (BIA). Generally, mortars are mixed on site with water to achieve a wet fluid mix, with sufficient water for workability. The mortar is retempered (additional water added to the mix) periodically to maintain workability. After two hours, the bond of fresh unused mortar to new units is significantly reduced. Therefore, mortar that is unused within two hours should be discarded.

Fundamentals

Installation

Masonry must be installed on a solid, rigid base. This is typically a concrete foundation or structural steel or concrete beam system. Most building codes do not allow the weight of the masonry to be supported be wood framing, due to the strength loss of the wood member when exposed to moisture. The support system must be designed for small
deflections (typically 1/600th of the span) to avoid cracking of the masonry.

The masonry units are laid in a bed of mortar. The horizontal joints between units are called bed joints while the vertical joints are called head joints. Clay brick masonry should include solid (full) head and bed joints. In concrete masonry it is common to lay the units with mortar only on the face shells (face shell bedding). This is due to the size of the cores and the difficulty in installing mortar in the webs between cores without allowing significant amounts of mortar to fill the cores. Full bedding of concrete masonry units is typically only performed where a portion of the cells will be filled with grout. Where grouting is performed, mortar should be kept from falling into the cells since this will form a weak plane in the grout.

Coursing

Masonry units can also be different sizes and shapes to accommodate specific project needs. The units can also be oriented in various ways to form varying aesthetic effects. Common coursing patterns are as follows:

- **Stretchers**—units are oriented horizontally with the full face exposed (most common)
- **Headers**—units are oriented perpendicular to the face of the wall with the end exposed (can be true or false headers)
- **Soldiers**—units are oriented vertically with the full face exposed
- **Rowlock**—units are oriented perpendicular to the face of the wall with the end and face exposed (often used at sills and at tops of walls)

Expansion and Shrinkage of Units

Following manufacture, clay masonry units expand when exposed to moisture. This volumetric change in the unit results in an accumulated growth of the wall system that is irreversible. Concrete masonry units typically shrink following manufacturing. These movements, if not accommodated in the design of the masonry elements, can cause cracking, spalling, and displacements in the masonry. For this reason, expansion joints are required in clay masonry construction, particularly in areas exposed to the exterior in where the units will become wet. Expansion joints are typically required at corners, offsets, and other changes in wall plane; changes in wall construction; and at regular spacings (typically 20 to 30 feet on center maximum, depending on the units). Guidelines for expansion joint design/layout are provided in Brick Industry Association (BIA) Tech Note 18A.

Concrete masonry walls are typically reinforced with joint reinforcement for shrinkage control. Depending on the size and spacing of the reinforcement, the spacing of control joints will vary. However, control joints are required in all concrete masonry walls. Guidelines for control joint placement are provided in National Concrete Masonry Association (NCMA) Tek Note 10-A.

Both clay and concrete masonry also undergo cyclic thermal movements. These materials expand in warm temperatures and contract in cold temperatures. The movement joints must also accommodate these movements.

Wall Systems

Masonry walls can be of several different types:

- **Veneer** (wall system provides cladding and only resists transfers wind loads to a structural backup)
- **Structural/Load Bearing Wall** (can be cladding but also provides load bearing system)

Water penetration through exterior masonry elements exposed to rain should be anticipated. Water typically flows through separations between the mortar and the units. This can be due to bond separations, voids, and cracks. Water penetration can also occur, although typically to a lesser degree, due to absorption through the units and mortar. Systems must be provided in exterior masonry construction to address water penetration into the wall system.

Masonry Veneer

Masonry veneer consists of an exterior wythe of masonry that forms a cladding material only. Lateral support for the masonry veneer is required. This is typically provided by an interior wall. Common interior walls (backup walls) are
Critical components in masonry veneers exposed to moisture include:

- Drainage cavity behind veneer wythe
- Flashing system at base of veneer
- Seals for the cavity at fenestrations (window, door, louver frames, etc.)
- Lateral tie system to anchor veneer to the structural back-up
- Vertical support system to support weight of veneer
- Provisions for expansion/contraction of the wall system

Veneer walls are designed as "drainage walls" in respect to their resistance to water penetration. An air space/drainage cavity should be installed behind the masonry veneer to allow water that penetrates the masonry to flow down to the base of the wall, where it can be directed to the exterior. This drainage cavity should remain open to allow water to freely drain. Where restrictions in the cavity exist, flashings are recommended to collect water and drain it to the exterior. This is required at openings in the masonry such as at windows, supports, etc. At the base of the drainage cavity, a flashing system should be installed that consists of a three-sided pan, typically formed by metal and/or membrane materials, to collect water that penetrates into the drainage cavity and direct it to the exterior via drains or weeps. These flashings must be designed to be watertight, particularly at corners, laps, and terminations of the masonry. End dams are required at terminations to prevent water from flowing laterally off the flashing and into the adjacent construction. Common flashing materials are stainless steel, copper, and lead-coated copper. These metal flashings are durable, can be sealed, and include soldered corners and end dams. Membrane materials such as rubberized asphalt and EPDM can also be used in conjunction with metal flashings to seal the top of the metal flashing to the backup construction.

It is critical that a moisture barrier be present on the interior face of the drainage cavity (on the surface of the backup) to prevent the passage of water into the backup construction. The recommended cavity width behind the masonry veneer is 2 inches minimum.

In summer months, the air space behind the brick veneer will typically contain air that is hot and humid relative to the interior. This air can achieve a relatively high vapor pressure relative to the interior. In winter months, this air space can be filled with relatively cold air in relation to the interior. This is particularly true in northern climates. If this air contacts the interior portion of window frames or interior finishes, condensation can result. For this reason, cavity seals are typically recommended at windows, doors, and other openings to prevent the passage of cavity air (and moisture) to the door/window frames.

Vertical support for the masonry veneer is typically provided at each floor line. For a brick masonry veneer, provisions must be made at each of the vertical supports to accommodate vertical expansion of masonry. This is accomplished by omitting the mortar between the top course of masonry and the underside of the support. This joint should be designed to accommodate the vertical expansion of the masonry, as well as structural deflections of the support. In concrete structures, creep of the concrete frame should also be accommodated.

Metal ties are required to provide the lateral attachment of the veneer to the backup wall. These are typically spaced at 16 inches on center in each direction.

**Structural Masonry Walls**

Structural masonry walls are typically constructed using concrete masonry. The concrete masonry can be reinforced both vertically and horizontally to achieve the required flexural resistance. Vertical reinforcement that is installed within the cells of the concrete masonry is generally grouted solid. Horizontal reinforcement is typically installed using prefabricated welded wires that are embedded in the bed joints. Although this horizontal reinforcement improves the strength of the masonry, particularly for horizontal spans, but also serves to control shrinkage cracking.

If structural masonry walls are to serve as the exterior walls, a second wythe of masonry is typically recommended. In this construction, the masonry can be built as a composite wall (both wythes act as a unit to resist loads) or as a non-composite wall (individual wythes act independently to support loads). Since water penetration through the exterior wythe of masonry is to be expected, the reliance on a single wythe of masonry as the exterior wall system is typically not recommended. If single wythe exterior walls are to be installed, a barrier should be provided on the exterior surface, such
as a fluid-applied, breathable masonry coating or over-cladding (EIFS, metal panels, stucco and similar) to prevent water penetration into the masonry. Admixtures can be used in the fabrication of concrete masonry units to reduce water penetration due to absorption into units themselves. However, the admixture must also be mixed into the mortar in order to achieve proper bond. These systems can be effective in reducing the amount of water penetration into the masonry; however, they should not be relied upon to eliminate water penetration.

THERMAL PERFORMANCE

Masonry is typically a large thermal mass that can be heated and cooled by it’s exposure to the sun and the exterior temperatures. Masonry exposed to sunlight can achieve temperatures well in excess of 100 degrees Fahrenheit. The masonry absorbs heat and will radiate the heat to the surrounding components of the wall system. During cold temperatures, masonry will be cool, particularly in shaded exposures. In design, the thermal performance characteristics of the masonry are typically based primarily on the insulation placed in the wall cavity or within the backup wall. The masonry is typically assumed to provide little insulating value.

FIRE SAFETY

Masonry provides a significant improvement in fire safety for building walls. Concrete masonry is typically used for firewall construction. The fire resistive characteristics are based on the thickness of the masonry.

ACOUSTICS

Because of the mass, masonry wall systems can provide better sound insulation than lighter wall systems such as metal panels. To improve acoustical performance, concrete masonry is typically filled with insulation to eliminate the voids in the cores.

MAINTENANCE

When properly constructed, masonry wall systems require relatively little maintenance as compared to other wall systems. The service life of the masonry can be 100 years or more, depending on the detailing and maintenance. The most frequent maintenance is the regular replacement of sealant in expansion joints, perimeter of openings (windows, doors, etc.) and at through wall flashings. The time frame for sealant replacement depends on the sealant used but usually ranges from every 7 to 20 years.

Repointing of the mortar joints in exterior masonry is typically required between 20 to 30 years after installation, depending on the type and quality of the original masonry installation.

Applications

See Appendices for climate-specific guidance regarding building enclosure design.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Clay Brick Head and Jamb Flashing  DWG | DWF | PDF
Clay Brick Inside Corner  DWG | DWF | PDF
Clay Brick Outside Corner  DWG | DWF | PDF
Clay Brick Sill and Jamb Flashing  DWG | DWF | PDF
Clay Brick Through-Wall Flashing  DWG | DWF | PDF

Emerging Issues
New developments in masonry wall design include the use of pre-stressed masonry. This consists of building a concrete masonry wall with cables within the cells, similar to a pre-stressed concrete element. After the wall is built, the cables are tensioned and anchored to the masonry. This can greatly increase the resistance of the masonry wall to flexural loads and bending.

The necessity to make building envelopes blast-resistant has forced consideration of reinforced masonry façade design options with respect to water integrity and thermal performance.

Relevant Codes and Standards

- American Concrete Institute ACI 530—Building Code Requirements for Masonry Structures & Specifications for Masonry Structures
- American Society of Civil Engineers ASCE-7 Minimum Design Loads for Buildings and Other Structures
- Brick Institute of America BIA Technical Notes
- National Concrete Masonry Association—NCMA "Tek" Notes
- American National Standards Institute (ANSI)
- ASTM International

Additional Resources

WBDG

DESIGN OBJECTIVES
Functional / Operational—Ensure Appropriate Product/Systems Integration

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants, See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

Publications

- CMHC Best Practice Guide—Brick Veneer Steel Stud
- CMHC Best Practice Guide—Brick Veneer Concrete Masonry Unit Backing

Organizations

- Brick Industry Association (BIA)
- National Concrete Masonry Association (NCMA)
- Masonry Institute of America (MIA)
- International Masonry Institute (IMI)
- Masonry Advisory Council (MAC)
- Masonry Contractors Association of America (MCAA)
- The Council for Masonry Research (CMR)
- The Masonry Society (TMS)
Building Envelope Design Guide - Panelized Metal Wall Systems

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Last updated: 01-02-2007

Introduction

A wide variety of panelized metal wall systems are available for installation as a building's exterior wall cladding. Each system must be specially adapted to its intended building use. Metal wall panels are usually fabricated of aluminum but can also be manufactured from steel, stainless steel, copper, or composite materials.

The following types of metal panel systems are available:

Lap-Seam Metal Panels

These panels are formed out of metal sheets and are typically ship-lapped with adjacent panels. At panel edges, gutters or sealant tape are typically included as part of the system. The panels are typically erected in strips up to 4 feet wide and 20 feet long. The thickness of the metal sheet is generally less than 0.05 inches (1.10 mm.)

Composite Metal Wall Panels

These panels feature two sheets of metal adhered to a core material. These composite panels are usually stronger than lap-seam panels and provide built-in insulation to the wall system. The thickness of the metal sheet is generally less than 0.05 inches (1.10 mm.) The overall panel thickness varies, depending on the insulation, from 1.2 inch to over 2 inches. Composite metal wall panels are often ship-lapped with adjacent panels similar to lap-seam panels. Types of composite panels include:

- **Foamed-Insulation Core Metal Wall Panels**: These panels have metal facings with insulation foamed into place during fabrication.
- **Laminated-Insulation Core Metal Wall Panels**: These panels have the metal facings laminated to preformed insulation boards. Panels can have tongue-in-grove joints for interface with adjacent panels or framed edges where perimeter extrusions attach the panels.
- **Honeycomb Core Metal Wall Panels**: These panels have metal facings bonded to a honeycomb core.

Flat Plate Metal Wall Panels

These panels are typically fabricated out of 1/8 inch thick metal plate. The panels are then bent to the desired profile. Stiffeners and support structure can be welded or adhered to the flat plate. Since these panels are manufactured out of plates, they have very high impact resistance and durability compared to other types of panels. Some manufactures will adhere flat plate to metal extrusions to create their system.

Metal-Faced Composite Panels

These panels consist of metal facings adhered to a thin thermoplastic core. The thickness of the metal sheets is typically less than 0.05 inches (1.10 mm.) and the overall panel typically is up to 1/4 inches thick (6 mm). The resulting composite panel is then bent to the desired profile. These panels are not as impact resistant as flat plate; however, depending on the size of the panels, stiffeners can be welded or adhered to the rear surface of the panels.

The size of flat plate and metal-faced composite panels is generally less than 10 feet by 10 feet. These panels are...
generally fastened by proprietary installation systems.

The thickness of the system depends on the structural support system for the panels. The greater the size and span of the panel, the deeper the thickness of the system. The thickness of the metal panel system can range from 2 inches deep for small panels to over 6 inches deep if the panels are large and need to span end to end between supports. The panels can be either directly fastened to the structural system or be fastened to a secondary structural system of metal studs, hat tracks and supporting channels. The hat channel and support system can also be part of the water resistive design for the panels, especially for more complex systems which include flat plate and metal-faced composite panels.

A wide variety of designs are used to prevent water leakage for metal panel systems including face sealed barrier systems, weeped drainage systems, and rainscreens. Rainscreen metal panel designs can be pressure equalized and back-ventilated. In ventilated rainscreens, the majority of water is collected and channeled to the building exterior at the face of the panels, but a back-up membrane must be present to divert water to the exterior.

In general, simpler metal panel systems tend to be barrier systems while larger, more complex buildings feature drainage systems with back-up membranes or rainscreen design principles.

Description

Metal Types

Metal can be aluminum, stainless steel, copper or steel. Aluminum is the most common material used due to its cost, corrosion resistance, and durability. In high-end applications, stainless steel and copper can also be used. Several manufacturers fabricate steel panel systems, which require protective coatings for resistance to corrosion.

Support and Anchorage Systems

Metal panel systems are engineered to support gravity, seismic and wind loading. The fastening of the panels also needs to accommodate interstory drift requirements in seismic zones. The support system of the panels needs to be able to accommodate tolerance from existing construction and fabrication.

The metal panels are typically screwed or bolted on a structural frame which often consists of metal studs.

Joints and Joint Detailing

Since metal is impervious to water, panel joint design is critical to the water tightness of the system. A metal panel building typically has an extensive number of joints. How the joints perform is a factor of the panel design and construction. If the metal panel system is designed based on a barrier system design, the joints between the metal panels are typically face sealed. If the system is a rainscreen or drainage design, the joints between the panels are typically left unsealed. Some designers select a rainscreen or drainage system for both performance characteristics and the aesthetic criteria of unsealed joints.

Compared to concrete or masonry cladding elements, metal panel systems have higher coefficients of expansion for thermal movement. Designers of metal panel systems need to calculate the expected movement of metal panels due to changes of temperature. For example, a 20 foot long aluminum extrusion may expand or contract 0.30 inches when subjected to a 100 degree temperature change.

Joints between panels must be wide enough to accommodate thermal expansion and differential movements between panels. Joint sizes can vary from 1/4 inch wide for small panels to 1 inch wide for larger panels. Factors that influence joint size include panel size, panel location on the building, and tolerance issues. Generally, larger panels require larger joints than smaller panels.

If the joint needs to be sealed, the metal panel edges must be configured with a return so that a properly designed sealant joint with backing materials can be installed. Sealant does not provide durable performance when adhered to metal panels less than 1/4 inch thick. Sealant joint design must also include provisions for two sided adhesion for joint expansion and contraction.

Common Backup Wall Elements
The following elements are often found in a metal panel cladding system:

- **Insulation:** With the exception of insulated metal panels, metal panels do not typically provide any insulation value to wall systems. When non-insulated metal panels are used, the insulation is typically provided by batt insulation set within the stud wall behind the metal panel cladding.

- **Air and Moisture Barrier:** While face sealed systems do not require an air and moisture barrier, drainage and rainscreen metal panel typically require a secondary air and moisture barrier system. The selection of the air and moisture barrier is an important decision that needs to be customized to the specific nature of the metal panel system, the exterior sheathing, geometry, and HVAC requirements of the building. The air and moisture barrier may include building papers, house wraps, elastomeric coatings, or peel-and-stick waterproofing membranes.

- **Metal Stud Framing:** The design of the metal stud framing needs to be integrated with the panel design and fastening system.

**Fundamentals**

**Metal Panel Design**

Metal panel systems are generally proprietary designs in which a manufacturer adapts his system to the architect's design. As part of the design, the architect will select a type of metal panel system and provide architectural details that depict the relationship of the metal panel system to the adjacent building systems. Generally, architects do not provide comprehensive detailing for the metal panel system as part of the construction documents. The project specifications and shop drawings, as well as shop drawing and submittal review, are critical to the success of the project.

When the designers select the metal panel system, they need to determine if the system requires an air and water barrier or rain screen. The air and water barrier requirements need to be clearly shown on the contract documents since the metal panel manufacturer does not provide for these systems or their detailing.

In the specification, the designer must select the types of metal panels that will meet design criteria and also establish the panel performance criteria. Performance criteria need to include:

- Wind loading
- Seismic design criteria
- Deflection criteria
- Air infiltration criteria
- Water test performance criteria
- Panel flatness criteria
- Panel tolerance criteria
- Thermal movement criteria
- Performance testing criteria
- Fire resistance ratings, if required
- Sound transmission criteria
- Insulation criteria
- Performance criteria for air and moisture barrier or rainscreen

After the project is bid, the contractor selects a metal panel system based on the specification. The shop drawing review process is critical to the success of a project. During this process, the manufacturer adapts his system to the specific building. The shop drawings are accompanied by structural calculations that need to be performed by a structural engineer licensed in the project state; (this is especially important for states in high seismic zones). During the shop drawing review process, the manufacturer, installer, general contractor, and architect need to review the interface of the metal panels to adjacent systems such as windows and other cladding systems. If the building features a secondary air and moisture barrier or rainscreen, the structural attachment of the metal panels needs to be reviewed to verify that it does not compromise the secondary barrier. During the shop drawing review process, construction tolerances for joint sizes need to be reviewed and accepted by the manufacturer, installer, general contractor and architect.
**Structural Aspects of Design**

Metal panel systems are typically considered nonstructural elements that are used to form a curtain wall; however, these nonstructural elements typically must be structurally designed.

The panels must be designed to resist out-of-plane loads (such as wind or seismic loads), and must be also designed to resist in-plane loads (seismic loads and vertical/dead loads). Loads from the panels must be transmitted to the building's structural frame. In addition, the panels must allow thermal movements and must be designed so that they do not act to restrain the building's structural system as it deforms under lateral and gravity loads.

Often, metal panel systems are proprietary and the design of the panels is based in part on in-house research by the metal panel manufacturer. Steel panels may be designed using AISC's *Specification for the Design of Cold-Formed Steel Structural Members*; and aluminum panels may be designed according to The Aluminum Association's *Specifications for Aluminum Structures*. The design of composite panels may not comply with any standard uniformly recognized by the model building codes and therefore would need to be based on proprietary testing.

**Performance Issues**

**Thermal Performance:** Non-insulated metal panel wall systems derive their thermal performance characteristics from the amount of insulation placed in the cavity or within the backup wall.

**Moisture protection:** Metal panel systems can be barrier systems, drainage systems or rainscreen systems. As discussed in the *Joints and Joint Treatments* section, the design of metal panel joints is critical for the watertight performance of the panel system.

**Fire safety:** Metal panel systems are typically not a fire rated system. The design of the metal panel wall systems may need to include fire-stopping at floor levels. Metal panel systems are typically not flammable. Insulated and composite panel systems need to be reviewed to verify that the insulation and thermoplastic cores are not flammable.

**Acoustics:** Metal panel systems, except for some types of insulated panels, typically do not offer much sound insulation. The design of the back-up wall cavity for metal panels typically provides for sound insulation.

**Impact Resistance:** With the exception of flat plate metal systems, metal wall panel systems typically have low impact resistance. Metal panels can be damaged or dented by impact loading, which can include swing stage scaffolding. High-rise buildings, which require window washing or periodic maintenance, should be designed with impact resistant panels.

**Material/Finish Durability:** The finish of the metal panel system is important for system performance. The most common durable finishes applied on metal panels include fluoropolymer, powder, and anodized coatings. Fluoropolymer and powder coats provide a very wide range of colors as well as color uniformity. Anodizing is generally limited to dark metallic colors for many applicators, and for a large job the color of the panels can vary slightly due to the anodizing process. Generally, shop applied coatings perform much better than field applied coatings.

Another durability consideration is the panel material. Stainless steel, copper, and aluminum panels are constructed of materials that have a high corrosion resistance. Some systems use mild steel panels. If the coating on a mild steel panel fails, the panel will start to corrode. Coating performance is, therefore, critical for steel panel durability. Compared to aluminum and stainless steel, mild steel panels have less durability. Porcelain enamel coatings are often used on steel panels and provide good durability, but these coatings can be vulnerable to damage in the field.

**Potential Problems**

**Pitting:** Over time, as metal panels are exposed to weather and pollution, their protective coating can be attacked resulting in a pitted appearance. While the pitting is not a structural concern, the pitting detracts from the appearance of the panel and the building.

**Oil Canning:** Oil canning is characterized by pillowing or waviness of the metal panel. The oil canning can be caused by problems in fabrication, design, or installation. Oil canning detracts from the appearance of the panel, since part of the
selection criteria for metal panels is often flatness. Some glossy panel finishes can also make oil canning more apparent. No industry standards exist to define what degree of oil canning is acceptable. When selecting metal panels, the designer should discuss flatness criteria with the panel manufacturer to order to set design criteria. The panel support design, shipping, and erection process all need to be performed with the intent of limiting oil canning to acceptable levels.

Flat plate metal wall panels are least vulnerable to oil canning compared to other types of panels, which are fabricated out of thin sheets of metal.

**Shadowing:** Installing welds or stiffeners on the backsides of metal panels can result in shadowing, a condition in which the weld or stiffener is visible on the panel face.

**Dissimilar Metals:** The use of dissimilar metals can result in two types of problems: water runoff staining and galvanic corrosion.

When water runs off one type of metal onto another, it can stain and corrode the other metal. One example of this is water runoff from copper staining aluminum. Runoff from metal surfaces can also stain some types of stones and other materials.

Galvanic corrosion occurs when one type of metal is in physical contact with another type of metal. The less noble metal will corrode, and this corrosion can affect the panel structural strength. When dissimilar metals are in close proximity, they should either be physically separated or reviewed for galvanic action potential.

**Maintainability**

Metal panel systems, when properly designed and constructed require little maintenance. However, over the life of the structure need cleaning and sealant replacement are required.

If the system includes sealant, the time frame for sealant replacement usually ranges from 7 to over 20 year periods, depending on the sealant used and the joint design.

Over time, dirt and pollutants will be deposited on metal panels. If the dirt is not removed periodically, pollutants may attack the panel coating system and cause pitting. While pitting on aluminum and stainless steel is not a structural concern, it is unsightly. To mitigate the build-up of pollutants on metal panels, periodic cleaning at approximately 10 year intervals (depending on exposure to dirt and pollutants) is recommended.

**Applications**

Metal panel wall systems have a wide range of applications and can be designed to achieve a wide range of architectural styles. Their use is appropriate for construction in all climates and environments.

See Appendices for climate-specific guidance regarding building enclosure design.

**Details**

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer, Download Adobe Reader.

**Metal Panel Head and Jamb Flashing** [DWG] [DWF] [PDF]

**Metal Panel Inside Corner** [DWG] [DWF] [PDF]

**Metal Panel Outside Corner** [DWG] [DWF] [PDF]

**Metal Panel Sill and Jamb Flashing** [DWG] [DWF] [PDF]

**Metal Panel Through-Wall Flashing** [DWG] [DWF] [PDF]

**Emerging Issues**
Consult the Metal Construction Association (MCA) and related industry/trade groups for emerging issues related to the individual base metal material (copper, zinc, aluminum and similar) and/or fabrication method (solid plate, composite and similar) of interest on your project.

Relevant Codes and Standards

- American Architectural Manufacturers Association (AAMA)
- American National Standards Institute (ANSI)
- American Iron and Steel Institute (AISI)
- American Institute of Steel Construction (AISC)
- American Welding Society (AWS)

Additional Resources

WBDG

**DESIGN OBJECTIVES**

Functional / Operational—Ensure Appropriate Product/Systems Integration

**PRODUCTS AND SYSTEMS**

Section 07 92 00: Joint Sealants, See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

**Organizations**

- ASTM International (ASTM)
- American Architectural Manufacturers Association (AAMA)
- American National Standards Institute (ANSI)
- American Iron and Steel Institute (AISI)
- American Institute of Steel Construction (AISC)
- American Welding Society (AWS)
- National Association of Architectural Metal Manufacturers (NAAMM)
- Sheet Metal and Air Conditioning Contractors National Association (SMACNA)
- Metal Construction Association (MCA)
- Copper Development Association (CDA)
- Nickel Development Institute (NDI)
- American Zinc Association (AZA)
- Steel Insulated Panel Association (SIPA)
- The Aluminum Association, Inc. (AA)
- Aluminum Anodizers Council (AAC)
- Aluminum Extruders Council (AEC)
- American Galvanizers Association (AGA)
- Architectural Spray Coaters Association (ASCA)
- National Coil Coaters Association (NCCA)
- Canadian Sheet Steel Building Institute (CSSBI)
Introduction

Architectural precast concrete has been used since the early twentieth century and came into wide use in the 1960s. The exterior surface of precast concrete can vary from an exposed aggregate finish that is highly ornamental to a form face finish that is similar to cast-in-place. Some precast panels act as column covers while others extend over several floors in height and incorporate window openings.

In most cases, the architect selects the cladding material for appearance, provides details for weatherproofing, and specifies performance criteria. The structural engineer designs the structure to hold the cladding, designates connection points, and evaluates the effects of structural movement on the cladding. The precast concrete manufacturer designs the cladding for the specified loads, erection loads, connection details, and provides for the weatherproofing, performance and durability of the cladding itself.

Precast concrete wall systems offer a wide variety of shapes, colors, textures, and finishes to the designer. As a result, the assessment of samples is a key component in the use of precast concrete. The majority of the review and approval process is conducted at the precast plant prior to precast panel production. This assessment is in addition to the quality control and field testing that takes place during the production phase.

Typically, each precast panel is independently supported to the building structure using an assemblage of metal components and anchors. Joints around each of the precast panels are usually filled with sealant.

Description

Precast Panel Types for Building Envelopes

There are generally four types of precast panels used as part of building envelopes:

1. Cladding or curtain walls
2. Load-bearing wall units
3. Shear walls
4. Formwork for cast-in-place concrete

Precast cladding or curtain walls are the most common use of precast concrete for building envelopes. These types of precast concrete panels do not transfer vertical loads but simply enclose the space. They are only designed to resist wind, seismic forces generated by their own weight, and forces required to transfer the weight of the panel to the support. Common cladding units include wall panels, window wall units, spandrels, Mullions, and column covers. These units can usually be removed individually if necessary.

Load-bearing wall units resist and transfer loads from other elements and cannot be removed without affecting the strength or stability of the building. Typical load-bearing wall units include solid wall panels, and window wall and spandrel panels.

Precast concrete shear wall panels are used to provide lateral load resisting system when combined with diaphragm action of the floor construction. The effectiveness of precast shear walls is largely dependent upon the panel-to-panel
In some cases, precast panels are used as formwork for cast-in-place concrete. The precast panels act as a form, providing the visible aesthetics of the system, while the cast-in-place portion provides the structural component of the system.

**Support and Anchorage Systems**

The connections for precast concrete panels are an important component of the envelope system. Precast manufacturers utilize numerous different types of anchors but they are often characterized as gravity and lateral types of connections.

The primary purposes of the connection are to transfer load to the supporting structure and provide stability. The criteria used to design precast connections including but not limited to:

- Strength
- Ductility
- Volume change accommodations
- Durability
- Fire resistance
- Constructability

**Joints and Joint Treatments**

The numerous joints in a precast concrete envelope are an important aspect of the facade design. The joints between precast units or between precast and other building components must be maintained to prevent leakage through the precast wall system.

Joint design should consider the structural, thermal, and all other factors that affect the performance and movement of a joint. The joint seal should of course be adequately designed to withstand the movement of the joint.

**Common Backup Wall Elements**

In commercial construction, the most common back-up wall element for architectural precast concrete wall systems is an insulated, metal stud back-up wall assembly.

**Fundamentals**

**Structural Aspects of Design**

Precast concrete wall systems are most often constructed as a curtain wall or veneer, in which no building loads are transferred to the concrete panels. Most typically the precast concrete wall system must resist lateral loads directly imparted on it, such as from wind and earthquake; as well as vertical loads resulting from the self weight of the precast wall system. These loads must be transmitted through the wall system and secondary structural elements to the building's structure. Other loads such as erection, impact, construction related, and transportation must also be taken into account in the design. It is important to evaluate the design, detailing and erection of precast panels in order to avoid imposing unwanted loads onto the panels.

The concrete panels are designed in accordance with PCI Design Handbook-Precast and Prestressed Concrete (MNL 120), Design Responsibility for Architectural Precast Concrete Projects (ACI 533.1R-02), and ACI 318 Structural Concrete Building Code. Steel elements of a wall system are designed in accordance with AISC specifications for steel construction. Precast concrete elements are designed in accordance with ACI and PCI specifications.

Joints between panels must be wide enough to accommodate thermal expansion and differential movements between panels. Joints between panels are most commonly sealed with sealant to prevent water penetration in the wall cavity. The wall cavity space and back up wall which is usually covered with a water resistant membrane provide a secondary
Performance Issues

THERMAL PERFORMANCE

Precast wall panels derive their thermal performance characteristics primarily from the amount of insulation placed in the cavity or within the backup wall, which is commonly a metal stud wall in commercial construction.

MOISTURE PROTECTION

The most common moisture protection system used with precast concrete wall systems is a barrier system incorporating an adequate joint seal. In some cases where additional moisture protection is needed, the application of a sealer or a concrete coating is also used. Sealers can be either clear or pigmented if used as an enhancement of the precast appearance. Film-forming coatings usually offer a higher level of performance but will have a significant impact on the appearance of the precast concrete unit.

The precast concrete panel should also be designed to provide the appropriate level of durability for the planned exposure. Durability can be improved by specifying minimum compressive strengths, maximum water to cement ratios, and an appropriate range of entrained air.

FIRE SAFETY

Precast concrete wall systems are not considered to provide any improvement in fire safety over cast-in-place concrete. In fact, for high-rise buildings precast concrete panels can pose a serious safety hazard when a fire occurs that damages the panel connections and causes a panel to then fall from the building. See Cast-In-Place Concrete Wall Systems for additional information, as well as the information included under Resources in this section.

ACOUSTICS

A precast concrete wall system and cast-in-place facade will provide similar performance regarding sound transmission from the exterior to the interior of the building. However, distressed and open joints between panels can provide a condition in which sound transmission to the interior may be increased.

MATERIAL/FINISH DURABILITY

Precast concrete panels used in wall systems have many different finishes and shapes. Often the finish will include the abrasion or modifying of the surface by sandblasting, exposing aggregate, acid washing, bush-hammering, or other techniques. Each of these finishes presents a different challenge in producing a durable precast concrete panel. Sandblasting a concrete surface can produce a surface that is less resistant to moisture penetration. As a result, a surface treatment, such as a sealer, should be considered where this technique is used for finishing.

A precast panel with a highly architectural surface will present challenges in development of a concrete mix and placement of reinforcing steel. More complicated profiles in the surface of the panel usually require more workability in the concrete mix, better consolidation techniques, and often more post-production surface repairs. Precast panels with differing depths of surface profiling also require more care in maintaining sufficient concrete cover over the embedded reinforcing steel. In summary, the more complicated the appearance of a precast concrete panel, the more challenging and important the review and approval process and quality control program.

Most distress and deterioration encountered with precast concrete wall systems can be attributed to problems during erection, anchors used to attach panels to the structure, or corrosion of the embedded reinforcing steel. Panel cracking, displacements, or other distress conditions can occur at locations where anchors are inadequately or improperly connected. Poor construction is often the result of poor quality control and out of tolerance fabrication or erection of the panels. Also, damage from handling during construction can result in panel cracking, some of which may not become evident for several years.

Evaluation of future precast concrete durability is performed in several ways. Often requirements are specified (air entrainment, maximum absorption, minimum compressive strength, etc.) to enhance the durability of the concrete. History
of the concrete mix and finish can also provide useful information. ACI 318 specifies various criteria for acceptance of a concrete mix. In addition, water-to-cement ratio, minimum compressive strength, air entrainment range and other criteria are also listed. If necessary, freeze-thaw testing can also be conducted in accordance with ASTM C666.

In addition to a precast concrete mix meeting the requirements and recommendations of ACI 318, evaluation and study of the historic performance of a particular concrete mix in a similar exterior environment can also be performed. Petrographic evaluation (ASTM C856) is also commonly used to evaluate aggregate in an effort to identify the mineral composition of the concrete and particularly the aggregate, and based on these observations and past knowledge of those characteristics, to predict future performance. Another method of evaluation is to expose samples of the concrete to an accelerated weathering procedure, and evaluate physical and mechanical properties for changes.

**MAINTAINABILITY**

When properly constructed precast concrete panels systems require some maintenance. The most important maintenance item for precast panels is the sealant in joints and protection system, if used. If a sealer or concrete coating has been used for aesthetics or to minimize moisture penetration into the panel, the sealer or coating will require reapplication. The time frame for the sealant and surface protection systems varies widely but usually ranges from every 7 to 20 years.

**Applications**

Precast concrete wall systems allow a wide variety of colors, finishes and architectural shapes. Precast concrete can be used in environments that allow the use of conventional cast-in-place concrete. In addition, precast concrete may be made in a controlled environment and erected in an environment that would not allow site casting of concrete. The concrete used in precast panels should be designed to be durable in the environment in which it will be used.

See the tables for guidance by wall system type for climate-specific considerations that are imperative to the success of any enclosure design.

**Details**

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- **Architectural Precast Window Jamb and Sill** [DWG] [DWF] [PDF]
- **Architectural Precast Round Penetration** [DWG] [DWF] [PDF]
- **Architectural Precast Square Penetration** [DWG] [DWF] [PDF]
- **Architectural Precast Interface Between Vertical and Horizontal 2-Stage Joint** [DWG] [DWF] [PDF]
- **Architectural Precast Window Head and Jamb** [DWG] [DWF] [PDF]

**Emerging Issues**

The necessity to make building envelopes blast-resistant forces reconsideration of precast concrete joint and connection designs.

**Relevant Codes and Standards**

- American Concrete Institute ACI 318—*Building Code Requirements for Structural Concrete*
- American Concrete Institute ACI 301—*Specifications for Structural Concrete*
- Precast/Prestressed Concrete Institute PCI MNL 120—*Design Handbook-Precast and Prestressed Concrete*

**Additional Resources**
WBDG

DESIGN OBJECTIVES
Functional / Operational—Ensure Appropriate Product/Systems Integration

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

American Concrete Institute (ACI)
- ACI 318—Building Code Requirements for Structural Concrete
- ACI 301—Specifications for Structural Concrete
- ACI 201.2—Guide to Durable Concrete
- ACI 533.1R—Design Responsibility for Architectural Precast Concrete Projects

ASTM International
- ASTM C 33—Aggregates in Concrete
- ASTM C 457—Air Void
- AGGREGATE REACTIVITY
- ASTM C 856—Petrographic Analysis of Hardened Concrete

Precast/Prestressed Concrete Institute (PCI)
- PCI MNL 122—Architectural Precast Concrete
- PCI MNL 117—Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products
- PCI MNL 120—Design Handbook—Precast and Prestressed Concrete
- PCI MNL 127—Recommended Practice for the Erection of Precast Concrete
- PCI MNL 124-89—Design for Fire Resistance of Precast Prestressed Concrete

Publications
- CMHC Best Practice Guide—Architectural Precast Concrete Walls

Organizations
- Architectural Precast Association (APA)
- National Precast Concrete Association (NPCA)
- Precast/Prestressed Concrete Institute (PCI)
- Tilt-Up Concrete Association (TCA)
Introduction

Thin stone wall systems used for exterior building envelopes typically consist of stone panels ranging in thickness from 3/4 inches to 2 inches. Most panels are fabricated from granite, while marble; limestone, travertine, and sandstone are also used to a lesser extent. A common panel thickness is 1-3/16 inch (3 cm). Overall panel dimensions can vary significantly for different buildings, depending on the strength of the stone used and architectural affect desired. However, maximum panel dimensions are usually approximately 3 to 4 feet and usually not more than approximately 6 feet. Typically each panel is independently supported to the building structure or back up system using an assemblage of metal components and anchors. Joints at the perimeter of each panel are usually 3/8 inch in width and are filled with sealant. A drainage cavity is typically located behind the stone panels to collect and divert to the exterior water that penetrates through the joints.

For certain applications, such as at building entrances and near grade level installations of limited extent, the stone system may not incorporate a drainage cavity but instead be a barrier system. In this type of system, the stone is applied directly against and attached to solid masonry backup such as concrete masonry units (CMU) or concrete. In these localized applications, several panels may be stacked.

Description

Stone Types

Granite is the most commonly used stone type in thin stone wall systems. The commercial classification of granite usually refers to a stone that includes any visibly granular igneous rock consisting of mostly feldspar and quartz minerals. This commercial term encompasses a wide variety of geologic stone types rather than only the limited number that fall under the geologic classification of granite. Geologically, marble is a metamorphic rock resulting from the recrystallization of limestone. While less commonly used in this type of application today, marble is also sometimes used in thin stone wall systems. Commercially, the term marble refers to many rocks with a wide variety of geologic classifications. These can be true marbles of calcite and dolomite, as well as dense limestones which will polish, serpentine rocks, and travertine. Sedimentary rocks such as limestone and sandstone can also be used in thin stone wall systems. However, panels fabricated from these stone types are usually not less than 2 inches in thickness because of the lesser strengths of these stones relative to granite and marble. Commercially, limestone refers to rocks that are both limestone and dolomite. Sandstone belongs to the commercial "quartz-based" group which includes stones with high quartz and silica contents.

Support and Anchorage Systems

There are two primary types of stone installation. The first is the "hand-set" method, in which each stone is individually attached to the building's primary structural frame or onto a secondary wall framing system. The second is the panelized installation method, in which the stone panel or multiple panels are preinstalled onto a frame or attached to a precast concrete panel. The frames or panels are transported to the building, where the entire assembly is attached to the building's structural frame or secondary structural members or framing system.

In either installation system, anchors must be used to attach and support the stone panels to the building's primary or secondary structural members. These anchors can be either mechanical or chemical and can be designed to accommodate the variety of stone types and applications. Proper anchorage is crucial to ensure the longevity and aesthetic integrity of the thin stone wall system.
secondary framing system, or to the panelized system frame or element. Anchors that are in direct contact with stone are usually constructed of non-corroding metals such as Type 304 stainless steel or aluminum.

HAND-SET SYSTEMS

There are numerous types and styles of anchors used to support and anchor individual stone panels. Commonly used anchor types include:

- Kerf supported stone with stainless steel or aluminum angles
- Side supports, dowels, straps, and disks
- Undercut anchor
- Embedded Adhesive Pin Anchor

PANELIZED SYSTEMS

- Precast Systems
- Steel Truss Systems

JOINTS AND JOINT TREATMENTS

In most applications, joints and joint treatments in thin stone wall systems will include one or more of the following:

- Mortar
- Elastomeric Sealant
- Epoxy

Depending upon the overall design of the wall assembly and manner in which the stone is set, the appropriate use of these materials will vary from project to project. Joint mortar should be carefully evaluated relative to mix design and compressive strength, particularly with regard to load transfer (either intentional or inadvertent), bond intimacy (necessary for improved water penetration resistance) and the potential for moisture and/or thermally-induced degradation/spalling of the mortar and/or surrounding stone. Joint sealant should be carefully evaluated for elongation and movement capacity, adhesion, cohesion, and staining of stone substrates. Epoxies should be evaluated for adhesion and bond strength, as well as UV stability.

*Note: In general, it is not advisable to rely exclusively on epoxies to bond two or more sections of stone together to form a single shape. Stainless steel threaded dowel pins or similar mechanical attachment, together with stone "liner blocks" as required, are typically recommended for these applications. Consult the appropriate industry standard for further guidance.*

Joint profiles on exterior wall surfaces should also be designed with a positive slope to shed rainwater away from the building in a manner that will prevent "ponding" of water along the joint. When designing for joint sealant, overall joint widths should be designed to accommodate differential thermal movement between individual stone veneer panels without damage to the stone substrate or failure of the sealant. Joint configurations should also be designed to conform to the sealant manufacturer's guidelines and applicable industry standards for width-to-depth ratios, and minimum bond surfaces at joint substrates.

COMMON BACKUP WALL ELEMENTS

- Insulation
- Air and moisture barrier
- Metal stud framing
- CMU
- Flashing

Fundamentals

Structural Aspects of Design
Stone wall systems are traditionally constructed as a curtain wall or veneer, in which no building loads are transferred to the stone panels. Most typically, the stone wall system must resist lateral loads directly imparted on it, such as from wind and earthquake, as well as vertical loads resulting from the weight of the stone wall system. These loads must be transmitted through the stone wall system and secondary structural elements to the building’s structure. Other loads related to impact, construction, and transportation must also be taken into account in the design.

Steel elements of a stone wall system are designed in accordance with the American Institute for Steel Construction (AISC) specifications for steel construction. Precast concrete elements are designed in accordance with American Concrete Institute (ACI) and Portland Cement Institute (PCI) specifications.

The stone portions of the wall system are usually designed in accordance with industry recommended safety factors, Allowable Stress Design (ASD), and physical/mechanical properties of the stone determined by testing of that particular stone. For granite, based on the recommendations of the National Building Granite Quarries Association (NBGQA) and the Dimension Stone Design Manual, a safety factor of 3 is usually used for granite panel stresses away from connections, while a safety factor of 4 is usually used for stresses in the granite at connections. For example the maximum mid-span bending or flexural stress determined by structural analysis for a panel is compared to and must not exceed the allowable stress, which is the average flexural strength of tested specimens divided by 3, the safety factor for granite away from connections. Based on the recommendations of the Dimension Stone Design Manual a safety factor of 5 is commonly used for marble panel stresses that result from wind loading. For travertine, limestone, and quartz-based stone, a factor of safety of 8 is recommended. The Indiana Limestone Institute Handbook recommends a safety factor of 6 be used for Indiana Limestone.

Joints between panels must be wide enough to accommodate thermal expansion and differential movements between panels; 3/8 inch wide joints are typically used. Joints between panels are most commonly sealed with sealant and are the primary line of protection against water penetration into the wall cavity. The wall cavity space and the backup wall, which is usually covered with a water resistant membrane, provide a secondary line of protection against water penetration into the building. Through-wall flashing is usually located throughout the height of the wall at regular intervals to divert water that enters the cavity back to the exterior.

Performance Issues

THERMAL PERFORMANCE

Thin stone wall systems derive their thermal performance characteristics primarily from the amount of insulation placed in the wall cavity or within the backup wall. The stone and supporting elements of the wall provide little insulating value.

MOISTURE PROTECTION

The most common moisture protection system used with stone wall systems is the wall cavity drainage system described above. Rain screen systems are also used with thin stone wall systems. In these systems, the primary water resistant barrier is located on the surface of the backup wall, joints are left unsealed, and the stone panels provide a rain screen that minimizes the amount of water that can reach the backup wall. Barrier systems are sometimes employed on certain stone wall systems where the stone panels are in direct contact with the backup wall.

FIRE SAFETY

Stone wall systems are not considered to provide any improvement in fire safety for the building exterior wall. In fact, for high-rise buildings stone wall systems can pose a serious safety hazard when a fire occurs that breeches the exterior envelope. Because stone exposed to intense heat from fire can crack and the cracked portions of stone can fall from the building, fire safety personnel may be in danger from falling stone.

ACOUSTICS

Because of their mass, stone wall systems may provide better sound insulation than lighter wall systems such as metal panels.

MATERIAL/FINISH DURABILITY
Stone used in stone wall systems can have several finishes: for granites and marbles, a polished, highly reflective finish is common. Thermal finish is a rough textured finish that is often employed with granite. Also, smooth honed finishes are commonly used on all stone types used in stone wall systems. Granites have had a long history of durable service. Certain marbles have a long history of successful use. However some marble types, particularly white marbles of pure calcite, have been found not to be durable materials because of their susceptibility to deterioration from heating and cooling cycles. Travertine, limestone, and sandstone have a good history of use as thick stone wall elements but their service history as thin stone wall elements is fairly limited, particularly in terms of durability. However, few notable material related failures have been encountered.

Most distress observed in stone wall systems can be attributed to anchors used to attach stone panels to the structure. Panel cracking, displacements, or other distress conditions can occur at locations where anchors are inadequately or improperly connected to the stone. Poor construction is often the result of poor quality control and out of tolerance fabrication or erection of the panels. Also damage from handling during construction can result in panel cracking, some of which may not become evident for several years.

Evaluation of future stone durability is performed in several ways. History of use of a stone can in certain circumstances provide useful though limited information. Evaluation and study of the historic performance of a particular stone type in service is the most commonly used approach, and is used on almost all projects where stone is being evaluated for use in an exterior environment. More important than reviewing past performance is review of the physical and mechanical properties of a particular stone. The stone's tested properties are often compared to minimum standards or to the physical and mechanical properties of other durable stones, or historic data for that stone. Petrographic evaluation is also commonly used to evaluate stone in an effort to identify the mineral composition and microstructure of a stone, and based on these observations and past knowledge of those characteristics, to predict future performance. Another method of evaluation is to expose samples of stone to an accelerated weathering procedure, and then evaluate the stones physical and mechanical properties for changes.

MAINTAINABILITY

When properly constructed, stone wall systems require relatively little maintenance as compared to other wall systems. Typically the only maintenance required is replacement of sealant in joints between panels; the time frame for this activity depends on the sealant used but usually ranges from every 7 to 20 years. However, it should also be noted that periodic review and evaluation of thin stone veneers may be desirable in order to determine if any evidence of structural distress exists in the panels due to strength loss (selected marbles) and/or accumulated stresses at anchor points. Similarly, periodic review and evaluation of exposed stone surfaces may also be desirable, depending upon the location and exposure of the building, to determine the nature and extent of any discoloration or staining that may exist in order to develop a cleaning program that is not overly aggressive and, as such, results in irreversible damage to the stone substrate.

Applications

Stone wall systems have been employed to achieve a wide range of architectural styles, aesthetic affects, and appearances. Generally, thin stone wall systems are used in all environments. However certain stone types such as certain marbles may not be appropriate for environments with significant thermal cycling.

See Appendices for climate-specific guidance regarding building enclosure design.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Stone Veneer Drainage Plane Continuity at Anchoring Device  DWG | DWF | PDF
Stone Veneer Through-Wall Flashing  DWG | DWF | PDF
Masonry Typical Coping Termination  DWG | DWF | PDF
Emerging Issues

Although there are several proprietary anchoring systems that have been developed in recent years to facilitate the uniform, systematic installation of more traditional thin stone veneers, one of the more interesting recent developments in this industry has been the emergence of "ultra-thin" stone panels in commercial construction. Although this technology was developed over 25 years ago, ultra-thin stone panel systems have become an increasingly popular alternative in recent years for façade applications on larger, more complex multi-story commercial office and retail projects. These products, which were developed, in part, to provide a light-weight alternative to traditional thin stone veneers, typically include a natural stone facing fully adhered to a fiber-reinforced epoxy "skin," over an aluminum honeycomb-reinforced back-up. The fiber-reinforced epoxy skin is, according to manufacturer's literature, intended to provide a waterproof barrier, improved flexural strength and impact resistance. Use of "ultra-thin" applications should be carefully evaluated where longevity is an important performance factor. The designer should examine thermal movement in extreme cyclical surface temperature environments and detailing at corner joints.

As noted in the General Overview section of this guide, this type of panel system should be carefully evaluated by the design professional when considering exterior cladding materials for a building or structure. Issues such as long-term weatherability and the potential impact of differential thermal movement and/or edge-penetration of moisture on the bond strength between the stone facing and substrate layer should be included in this evaluation. Similarly, interfaces between this and similar types of "barrier" wall systems and the surrounding construction should be fully detailed by the design professional to prevent uncontrolled rainwater penetration.

The necessity to make building envelopes blast-resistant will force reconsideration of traditional joint and connection details and methods.

Thin stone installation systems developed abroad offer advanced technology over more traditional systems. New anchoring systems, enabling anchorage at the rear face of the panel rather than on end, offer greater strength at both the stone/anchor and the anchor/structure connections. In addition manufacturers of systems offering "curtain wall-like" technology promise reduced field installation time.
Relevant Codes and Standards

- American Society of Civil Engineers *ASCE-7—Minimum Design Loads for Buildings and Other Structures*
- American National Standards Institute (ANSI)
- ASTM International
- American Iron and Steel Institute (AISI), for stainless steel anchors in direct contact with stone

Additional Resources

**WBDG**

**DESIGN OBJECTIVES**

Functional / Operational—Ensure Appropriate Product/Systems Integration

**PRODUCTS AND SYSTEMS**

Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

**Organizations**

- Building Stone Institute (BSI)
- Canadian Stone Association
- Cast Stone Institute
- Indiana Limestone Institute of America, Inc. (ILI)
- Marble Institute of America (MIA)
- National Building Granite Quarries Association, Inc. (NBGQA)
- National Tile Contractors Association (NTCA)
- Natural Stone Council
- Terrazzo Tile and Marble Association of Canada (TTMAC)
- Tile Council of America (TCA)
Glazing

Glass has been used for thousands of years to allow daylight into our buildings, while providing weather protection. The development of the float glass process in the 1950's allowed the economical mass production of high quality flat glass and virtually all architectural glass is now produced by this process. The vast majority of new windows, curtain walls and skylights for commercial building construction have insulating glazing for energy efficiency and comfort. This glazing Chapter is complementary to the other fenestration sections of the Design Guide.

Windows

Prior to 1900, windows in the U.S. were predominantly wood frame, with some custom metal windows (iron, bronze, steel) in institutional construction. Around 1900, some British manufacturers of custom metal windows adopted the technology of rolled steel shapes to produce special rail profiles for windows. Two of the more prominent British steel window companies opened U.S. manufacturing companies to produce rolled steel windows. The fire resistance of steel windows with wire glass helped popularize steel window use in the U.S. in the early 1900's. Catastrophic fires in Baltimore, Boston, Chicago and San Francisco led to the development of building regulations that restricted the use of combustible materials in many types of construction. After World War II, the technology of extruding aluminum frames developed and aluminum windows began to gain popularity. By the 1990's, aluminum-framed windows accounted for approximately 65% of the commercial window market. Wood, vinyl and steel-framed windows comprise most of the remaining 35% of the market.

Curtain Walls

A curtain wall is any exterior wall that is attached to the building structure and which does not carry the floor or roof loads of the building. This includes heavy wall types such as brick veneer and precast concrete panels. In common usage, curtain walls are often defined as thin, usually aluminum-framed walls containing in-fills of glass, metal panels, or thin stone. This chapter addresses this narrower definition of curtain walls. Aluminum framed wall systems date back to the 1930's, and developed rapidly after World War II when the supply of aluminum became available for non-military use.

Sloped Glazing

Skylights have been used for over a century to provide interior daylighting. Early skylight systems consisted of plate glass (later wire glass) in metal frames and frequently incorporated both an exterior skylight and a decorative interior "diffuser" or "laylight". Most contemporary skylights now consist of insulating glazing captured in aluminum frames that in many configuration (e.g. single slope, ridge, pyramid, barrel vault). Skylights are engineered systems that are assembled from standard or custom extrusions provided by skylight manufacturers, and i.e. units made by glazing fabricators, but they share common design elements required to make them perform. This chapter uses the term "skylight" to describe field-assembled systems of sloped glazing. In the construction industry, the term "skylight" is often applied to relatively small shop-fabricated unit-skylights, frequently with plastic glazing. These unit skylights are not specifically addressed in this chapter.

Exterior Doors
This Chapter includes entrance and exit doors, as well as industrial loading dock doors. It primarily addresses waterproofing and durability requirements. The following describes common functions served by the door types covered in this chapter: Entrance and exit doors generally serve as building entrances for the general public or as service entrances for building operations personnel. They typically serve double-duty as building entrance under normal operation conditions, and as emergency egress. The International Building Code (IBC), government regulations, including the Americans with Disabilities Act (ADA), and local codes govern many entrance/exit door requirements pertaining to life safety and accessibility. These requirements are beyond the current scope of this chapter.

Additional Resources

WBDG

DESIGN OBJECTIVES
Functional / Operational—Ensure Appropriate Product/Systems Integration

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®
Introduction

Glass has been used for thousands of years to allow daylight into our buildings, while providing weather protection. The development of the float glass process in the 1950s allowed the economical mass production of high quality flat glass and virtually all architectural glass is now produced by this process. The vast majority of new windows, curtain walls and skylights for commercial building construction have insulating glazing for energy efficiency and comfort. This glazing Chapter is complementary to the other fenestration sections of the Design Guide.

Description

The following covers brief descriptions of commonly used glass and glazing components:

Architectural glass comes in three different strength categories. **Annealed glass** is the most commonly used architectural glass. Because it is not heat-treated and therefore not subject to distortion typically produced during glass tempering, it has good surface flatness. On the downside, annealed glass breaks into sharp, dangerous shards.

Heat-strengthened and fully-tempered glass are heat-treated glass products, heated and quenched in such a way to create residual surface compression in the glass. The surface compression gives the glass generally higher resistance to breakage than annealed glass. **Heat-strengthened glass** has at least twice the strength and resistance to breakage from wind loads or thermal stresses as annealed glass. The necessary heat treatment generally results in some distortion compared to annealed glass. Like annealed glass, heat-strengthened glass can break into large shards. **Fully-tempered glass** provides at least four times the strength of annealed glass, which gives it superior resistance to glass breakage. Similar to heat-strengthened glass, the heat-treatment generally results in some distortion. If it breaks, fully-tempered glass breaks into many small fragments, which makes it suitable as safety glazing under certain conditions.

**Laminated glass** consists of two or more lites of glass adhered together with a plastic interlayer. Because it can prevent the fall-out of dangerous glass shards following fracture, it is often used as safety glazing and as overhead glazing in skylights. The plastic interlayer also provides protection from ultraviolet rays and attenuates vibration, which gives laminated glass good acoustical characteristics. Because laminated glass has good energy absorption characteristics, it is also a critical component of protective glazing, such as blast and bullet-resistant glazing assemblies. See Building Envelope Design Resource Page Blast Safety for more information.

**Coated glass** is covered with reflective or low-emissivity (low-E) coatings. In addition to providing aesthetic appeal, the coatings improve the thermal performance of the glass by reflecting visible light and infrared radiation.

**Tinted glass** contains minerals that color the glass uniformly through its thickness and promote absorption of visible light and infrared radiation.

**Insulating glass units** (ig units) consists of two or more lites of glass with a continuous spacer that encloses a sealed air space. The spacer typically contains a desiccant that dehydrates the sealed air space. The air space reduces heat gain and loss, as well as sound transmission, which gives the ig unit superior thermal performance and acoustical characteristics compared to single glazing. Most commercial windows, curtain walls, and skylights contain ig units. Most perimeter seals consist of a combination of non-curing (typically butyl) primary seal and cured (frequently silicone) secondary seal. The service life of an ig unit is typically determined by the quality of the hermetic sealants installed between the glass and the spacers, and the quality of the desiccant.
Fundamentals

Thermal Performance (Conduction, Solar Radiation, Thermal Break, Comfort)

Glass and glazing selection play a key role in determining the overall building’s thermal performance. Fenestration thermal performance requirements must be integrated with the design of the building's heating and cooling systems. Single glazing has poor thermal performance and is suitable only for applications where thermal performance is irrelevant, such as interior applications or installations where interior and exterior temperatures do not vary substantially. The vast majority of architectural glazing consists of IG units. The thermal performance of insulating glazing depends mainly on the solar energy transmittance through the glazing, the reflectance of the glazing (measured by the shading coefficient—the ratio of the solar heat gain through the glazing to the solar heat gain or loss through a lite of 1/8 in. thick clear glass), the width of the air space, and the material and configuration of the spacer around the perimeter of the unit. Low-emissivity (low-E coatings) limit heat gain through the glazing by reflecting heat energy. Reflective coatings reduce interior solar heat gain by reflecting solar energy.

Thermal performance of glazing is expressed by its thermal conductance, which a measure of air-to-air heat transmission due to thermal conductance and the difference between indoor and outdoor temperature. Conductance is expressed in terms of U-value. A lower U-value indicates reduced heat transfer through the glass. Thermal modeling of specific fenestration assemblies using computer programs such as THERM allow estimation of total U-values for fenestration assemblies and help predict thermal performance.

Moisture Protection (Water Penetration, Condensation Resistance)

Since glass itself is impervious to water penetration, glazing waterproofing performance is determined by the glazing method chosen (e.g. wet glazing versus dry glazing) and drainage details of the framing system. Wet glazing most commonly consists of a gunable (“wet”) sealant installed over a preformed tape or gasket. Dry glazing systems utilize extruded rubber gaskets as the glazing seals. This system is also referred to as compression gasket glazing because the system relies on compression of the glazing gasket to seal against air infiltration and water penetration. The systems are sometimes mixed, most commonly with exterior wet glazing and interior dry glazing.

Condensation occurs if the temperature of interior frame or glazing surfaces falls below the dewpoint temperature for the interior air. Glazing strategies for limiting condensation include providing glazing with a low U-value and providing supplemental heat to the glazing to increase surface temperatures.

Visual (Daylighting, Aesthetics)

Glass appearance is influenced by several factors, including tinting (colorants added to the glass batch), reflective and low - E coatings, and opacifiers (for spandrel glass).

Sound (Acoustics)

Acoustic performance of exterior building envelope assemblies is expressed in terms of the Outdoor—Indoor Transmission Class (OITC) rating, which is a measure of the sound transmission loss during standard tests. High sound transmission loss, and therefore good sound insulation, is desirable in most applications. An integrated strategy to limit sound transmission through building walls requires review and testing of the entire wall system, since even small discontinuities in the wall assembly can negate the benefits of a well designed glazing system with a high OITC rating. In general, a higher fenestration OITC rating can be attained by incorporating laminated glass, and insulating glass assemblies (double or triple glazing) because the laminate damps vibration and the air space limits sound transmission. Additional mass in the form of thicker glass lites also helps sound absorption.

Safety Glazing

Fully-tempered or laminated glass is commonly used for safety glazing. Tempered glass limits the risk of injury by fracturing into small fragments. Laminated glass limits the risk of injury by retaining the fractured glass on the plastic interlayer and thereby limiting fall-out of glass fragments. Safety glazing must be identified with an indelible label on the
glass indicating its conformance to federal safety standards published by the Consumer Products Safety Commission (CPSC).

Wire glass typically does not meet CPSC requirements for safety glazing but is used for fire-rated glazing.

Health and Indoor Air Quality

Glazing can contribute to health and indoor air quality problems (by supplying water for mold and mildew growth) by allowing water leakage or condensation.

Durability and Service Life Expectancy

Glass is one of the most durable construction materials, substantially resisting the effects of normal weathering for decades. But glass is also a classic brittle material, suffering significant strength degradation from scratched edges or chips. Most glazing durability problems fall into the following categories (in roughly descending order of failure frequency):

Fogging of ig units is caused by condensation of moist air that penetrates into the air space of insulating glass units through or around the hermetic seal of the unit. Seal failure is usually caused by prolonged water exposure of the perimeter seal, such as occurs when ig units are glazed into frames that do not have functional weep holes to drain water leakage. Premature seal failure can also be caused by discontinuities, poor bond or thin applications of the perimeter seals. To assess the susceptibility of ig units to seal failures, representative units are tested by cycling the units through heating and cooling cycles in accordance with ASTM E-774. Units that pass the test are grouped in three performance levels: Class C, Class CB, and Class CBA. Studies have shown that, in the absence of other deficiencies such as water immersion, after about 20 years the failure rate of Class C or CB units will be about 15% and the failure rate of Class CBA units will be about 2.5%. The desiccant contained in the spacer helps condensation resistance by absorbing moisture built into the unit. Spacers with bent, welded, or soldered corners, rather than corners constructed with slip-in corner keys, are more reliable because they provide a stable surface for primary and secondary seal adhesion.

Similar to ig unit seal failure, laminated glass can delaminate when the edge of the laminated glass is in contact with water over extended periods, causing the interlayer to debond from the glass surface.

Glass fracture is typically caused by impact or by weakening of the glass through the development of cracks, chips or surface scratches. Edge and surface damage can result from careless handling or glass-to-metal frame contact. Fully-tempered glass can break spontaneously from Nickel-sulfide impurities.

Maintainability and Repairability

Except for cleaning, glass is generally maintenance-free. Glass used in masonry walls requires frequent cleaning when the building is new to remove alkalis that leach out of the masonry and will etch the glass if left on too long. Some acids used in common masonry cleaners, such as hydrofluoric acid, can dissolve the glass surface and mar it permanently. The deteriorating effect of cleaners is acutest if the glass has a reflective coating on the exterior surface. Cleaning methods for glass should be mild and non-abrasive.

The glazing seals between the glass and framing must be replaced periodically to maintain good performance. Properly installed silicone wet seals should last 10 to 20 years; gaskets 15 to 20 years.

Replacement of failed ig units is facilitated if the units are glazed from the interior, see the discussion in the relevant window, curtain wall and skylight portions of the design guide, but this glazing configuration typically has less reliable waterproofing performance. Fogged i.g. units cannot be repaired.

Sustainability

I.g. units have a shorter service life (most practitioners estimate it at 15 to 30 years) compared to monolithic glass, which, if not physically damaged, has an infinite lifespan. The energy savings afforded by i.g. units usually pays for the replacement cost if the units last more than 15 years. Actual payback periods vary substantially by location.
On the downside, i.g. units are typically not recycled: since they consist of a mix of glass, metallic glass coatings, sealants, and aluminum spacers, i.g. units require significant and costly effort to separate the constituent materials. Furthermore, glass is manufactured from relatively inexpensive and abundant raw materials, which makes glass recycling unattractive. At the end of their service life, i.g. units are generally discarded as general trash. Crushed glass is sometimes utilized as hard fill. Most glass manufacturing plants recover glass discarded during the float glass manufacturing process and combine them with other batch materials for subsequent production. Overall, the most promising strategy to limit the amount of glazing in the waste stream is find ways to extend the service life of i.g. units.

Applications

Improving Waterproofing Performance

The waterproofing performance of the glazing system depends on the following:

- Details of the framing system that promote drainage,
- internal framing seals,
- external (i.e. glass-to-frame) seals, and
- frame perimeter seals and flashings.

Glazing sealants cannot exclude all water, so providing internal drainage is critical; see the discussion in the relevant window, skylight, curtain wall and door portions of the design guide.

Wet-glazed systems generally prevent water entry around the glass and into the glazing pocket much better than dry-glazed systems. Replacement intervals for dry gaskets and the cap bead of wet-glazed systems are about equal. Table 1 lists advantages and disadvantages of both systems. For maximum watertightness, a wet-glazed system, consisting of pre-shimmed butyl tape glazing tape and silicone cap bead, should be specified.

Table 1—Wet vs. Dry Glazing

<table>
<thead>
<tr>
<th>Glazing System</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Glazing</td>
<td>• Improved resistance to water penetration</td>
<td>• Requires exterior access for installation, maintenance and glass removal</td>
</tr>
<tr>
<td>(Gunable wet seal over back-up rod or glazing tape)</td>
<td>• Protects i.g. unit edges and laminated glass from water and premature deterioration</td>
<td>• Highly workmanship dependent (surface preparation, weather, etc.)</td>
</tr>
<tr>
<td></td>
<td>• Reduces glass movement (&quot;walk&quot;)</td>
<td>• Costs more than dry glazing</td>
</tr>
<tr>
<td>Dry Glazing</td>
<td>• Can be done from interior</td>
<td>• Not as watertight</td>
</tr>
<tr>
<td>(pre-formed rubber gasket)</td>
<td>• Less dependent on field workmanship and weather</td>
<td>• Gaskets can shrink, creating openings for water penetration</td>
</tr>
<tr>
<td></td>
<td>• Generally less costly than wet glazing</td>
<td>• Gaskets can roll into pocket and place uneven stress on glass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Glass can &quot;walk&quot;</td>
</tr>
</tbody>
</table>

Improving Insulating Glass Durability and Thermal Performance

The durability of ig units is dependent on the quality of the hermetic seal and the level of protection from water afforded by the glazing seal and the window frame system. The following design requirements are critical to ig unit durability:

**Dual seals** (butyl-based primary seal and silicone secondary seal) are more reliable and durable than single-seal systems. The continuity and uniformity of both primary and secondary seals is critical, and continuous seals should be stipulated in the specifications. The spacer should be filled with desiccant and constructed with bent, welded, or soldered corners rather than corner keys. The units should carry a CBA rating per ASTM E774 to ensure comparable units have reasonable durability.

Other critical glazing features that should be specified to reduce the risk of i.g. unit seal failure include properly sized
setting blocks (min. 1/4 inch thick) to raise the edge of the ig unit glass above water level in the glazing pocket. The setting blocks must be wide enough to support the entire ig unit cross section and be notched to allow water to drain toward the weep holes. Setting block material must be chemically compatible with the i.g. unit secondary seal. The frame design must promote water drainage away from i.g. unit (i.e. sloped glazing pockets, large (3/8 in. diameter) weep holes, and drainage within each glazing opening (i.e. do not use vertical mullions as "downspouts"); see the discussion in the window, sloped glazing and curtain wall sections.

Glass manufacturers publish center-of-glass U-values. The perimeter of insulating glass typically has a higher U-value due to heat transmission through the spacer. Fenestration framing will also have a different U-value. Therefore, window and curtain wall manufacturers publish total U-values based on specific glass products glazed into their systems. Heat loss and condensation problems almost always occur near the glazing perimeter. Thermal analysis of the entire window or curtain wall system, including all perimeter conditions, is required for high-humidity applications or buildings where condensation is a concern.

Improving Laminated Glass Durability

Similar to i.g. unit failure, failure of laminated glass by delamination is frequently caused by long-term exposure of the glass edge to moisture. Design recommendations to limit the risk of laminated glass failure include the following:

- Protect the edges of laminated glass from exposure to water to limit the risk of delamination. In general, glazing installation details that promote good waterproofing performance and i.g. unit durability (see paragraphs Improving Waterproofing Performance and Improving Insulating Glass Durability and Thermal Performance above), will also result in improved laminated glass durability.
- Some materials used for laminated glass interlayers, such as polyvinyl-butyral (PVB) are not compatible with many building sealants, so some delamination will occur with butt-glazed joints where the sealant is in contact with the interlayer.
- Check the track record of laminated glass products that have several added plastic interlayers for increased impact resistance as some combinations of interlayer products adhere poorly and can cause delamination.

Designing for Fracture Resistance

Design recommendations to limit the risk of glass fracture include the following:

- Avoid glass-to-frame contact. Provide setting blocks and anti-walk pads to separate the glass edge from the metal. Follow GANA glazing guidelines.
- Use heat-strengthened glass for high temperature applications, such as spandrel glass, and where greater resistance to bending and thermal stresses, compared to annealed glass, is required. Limit the residual surface compressive stress to 7,500 psi to reduce the risk of breakage due to Nickel Sulfide (NiS) impurities. Producing heat-strengthened glass within these limits is difficult and requires tight control of the production process to avoid exceeding the upper limit for residual surface compressive stress and introducing the potential for NiS fracture.
- Use fully-tempered (FT) glass where required by code, but avoid use in areas where breakage poses a risk to safety due to the potential for spontaneous breakage from NiS impurities. Where the use of FT glass is unavoidable, and where its breakage poses a threat to people or property, heat-soak the FT glass to reduce the risk of spontaneous breakage due to nickel sulfide inclusions. This additional processing step adds cost and time, but is warranted where the consequences of glass fracture are significant. Alternatively, use laminated glass for safety glazing and fall-out protection. In many applications where FT glass is used, heat-strengthened glass is adequate to meet strength demands and reduces the risk of spontaneous fracture.
- For all glass types avoid edge and surface damage. Such damage concentrates stress from normal wind or thermal loads, especially for tinted glass or spandrel glass enclosing un-vented spaces.

Determining Glass Thickness

Use ASTM Standard E1300—“Standard Load Practice for Determining Load Resistance of Glass in Buildings" to select appropriate glass thickness to resist service loads.

Special Considerations for Overhead (Sloped) Glazing

The design and selection of glass for overhead glazing requires special attention to the following considerations; see
Sloped Glazing for additional information:

The high degree of solar exposure and stratification of warm air beneath the glass results in higher temperatures, increased thermal movement and stresses. The increased strength demand generally requires heat-strengthened glass. The inboard lite of sloped glazing should be laminated for fall-out protection.

Dead loads, snow loads, seismic loads, live loads and wind loads must be analyzed in combinations as required by codes and good engineering practice. Service loads typically include maintenance workers walking on the glass and framing. Unlike wind loads, snow loads are long-duration loads. Glass strength diminishes with duration of loading so time of loading must be included in the analysis. ASTM E1308 addresses long-duration loads. The structural strength of glass is time-dependent and decreases with the length of load application.

Designing for UV Protection

Ultraviolet radiation can cause material deterioration. Methods to provide UV protection, e.g. for libraries or museums, include providing laminated glazing (the PVB interlayer absorbs UV), certain applied films, or curtains and shades. Depending on the thickness of the PVB interlayer, laminated glass can filter out more than 99% of the UV radiation. Applied films are easily scratched and eventually experience color changes, so they are less durable than laminated glazing.

Design Considerations for Safety Glazing

The International Building Code (IBC) Section 2406, state and local building codes, and federal safety standard CPSC 16 CFR Part 1201—Safety Standard for Architectural Glazing Materials, require safety glazing in specified hazardous applications, including:

- Glass in interior and exterior doors and sidelites
- Glass within 36 inches (horizontal) of walking surfaces, with bottom edge less than 18 inches and top edge greater than 36 inches above walking surface, and glass area greater than 9 sf.
- Glass in guards and railings

These code provisions are minimum requirements. Prudent design practice may dictate the use of safety glazing for other applications.

Available manufacturing techniques may limit combinations and choices for glass assemblies; e.g. bent, heat-strengthened or fully tempered, and laminated glass is difficult to achieve because the heat treatment warps the glass and makes mating glass surfaces during laminating difficult.

Logistical and Construction Administration Issues

Inspection and maintenance of exterior glazing sealants requires access to the exterior of windows and curtain walls. Provisions for this access (e.g. suspended scaffolding tie-off anchors) must be made during the design.

Primary and secondary seal continuity and uniformity of minimum width requirements for i.g. units is critical to durability and should be spot-checked on a representative number of actual production units, not just mock-up samples, prior to installation. Mock-up or sample installation often save time and money in the long run as it highlights potential production, lead time, coordination, and performance problems. The production quality of the glazing components and their proper configuration must be checked on a statistically relevant sample of production units.

Glass must be handled carefully during transportation and installation to avoid edge damage and reduce the risk of later glass fracture. Refer to GANA manual for appropriate handling techniques and PPG’s Technical Bulletin TD112—Handling Do’s and Don’ts to Reduce Glass Breakage.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.
This detail illustrates commonly found poor design and installation features that contrast with the good design features of the next detail, Schematic of Good Glazing System.

- The lack of weep holes in the glazing pocket allows water accumulation and promotes i.g. unit and laminated glass failure.
- Without anti-walk pads, the i.g. unit may "walk" and contact metal frame edges. Glass-to-metal contact may lead to glass edge damage and fracture.
- Fastener penetrations through the glazing pocket allow leakage into the wall cavity below. If sill flashing is present, fasteners set through the glazing pocket will puncture the flashing and cause leakage.
- The flat sill allows water to pond and increases the risk of leakage. Missing sill flashing allows water leakage into the wall cavity.
- Without an integral return edge, the frame provides inadequate bonding substrate for the perimeter sealant. A poorly configured perimeter seal will not be durable and will promote leakage past the window jamb.

The most important features illustrated in this schematic detail are glazing pocket weep holes, sloped-to-drain sill glazing pocket and sill flashing.

- The glazing pocket weep holes drain water that penetrates the glazing seals. A well-drained glazing pocket prolongs the service life of the insulating glass (by reducing the exposure of edge seals to water), and reduces interior leakage.
- The sill flashing is sloped to the exterior to promote drainage. The window sill frame is attached through the back to a structural clip angle, to avoid fastener penetration of the horizontal portion of the sill flashing.
- The wet glazing seal provides better water penetration resistance than dry glazing (gaskets).
- The anti-walk pad at the window jamb prevents the glass from "walking" in the glazing pocket and contacting the metal frame.
- The perimeter of the window frame includes substantial return legs that provide adequate bonding surfaces for a properly configured sealant joint at the window perimeter.

### Emerging Issues

**Self-cleaning or easy-to-clean glass** was recently developed and uses titanium dioxide coatings as a catalyst to break up organic deposits. It requires direct sunlight to sustain the chemical reaction and rainwater to wash off the residue. Anorganic deposits are not affected by the coatings.

**Photochromic coatings** incorporate organic photochromic dyes to produce self-shading glass. Originally developed for sunglasses, these coatings are self-adjusting to ambient light and reduce visible light transmission through the glass. In architectural glass they are typically used to provide shading.

Glass with **electrochromic coatings** utilizes a small electrical voltage, adjusted with dimmable ballasts, to adjust the shading coefficient and visible light transmission. Like photochromic coatings, they are intended to attain lighting energy savings.

**Point-supported glazing** is sometimes used in wall systems that are all glass. These systems utilize mechanical anchors at discrete locations near the glass edge, rather than continuous edge supports. Edge-supported glass is typically sized according to glass load resistance charts; see ASTM E1300. These charts do not apply to point-supported glazing, which requires specific structural engineering analysis.

### Relevant Codes and Standards

**General Glazing Information**

Thermal Performance

- **AAMA 1503 Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections**
- **AAMA 1504 Voluntary Standard for Thermal Performance of Windows, Doors and Glazed Wall Sections**
- **AAMA 1505 Voluntary Standards for Thermal Transmittance and Performance**

Acoustical Ratings

- **AAMA 1801 Voluntary Specification for the Acoustical Rating of Windows, Doors and Glazed Wall Sections**

Additional Resources

WBDG

**DESIGN OBJECTIVES**

Functional / Operational—Ensure Appropriate Product/Systems Integration

**PRODUCTS AND SYSTEMS**

Section 07 92 00: Joint Sealants, See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

- Lawrence Berkeley National Laboratory, information on emerging issues and energy efficiency
- Department of Energy, information on emerging issues and energy efficiency
- PPG Industries—A glass manufacturer’s website with good glossary, general information on glass and glazing technology and useful technical bulletins
- U.S. Green Building Council, information on the LEED program, news articles related to Green building
- Oikos® Green Building Source, information on sustainable design and Green building, including glazing, windows, skylights, and emerging technology related to sustainable design
Introduction

Prior to 1900, windows in the U.S. were predominantly wood frame, with some custom metal windows (iron, bronze, steel) in institutional construction. Around 1900, some British manufacturers of custom metal windows adopted the technology of rolled steel shapes to produce special rail profiles for windows. Two of the more prominent British steel window companies opened U.S. manufacturing companies to produce rolled steel windows. The fire resistance of steel windows with wire glass helped popularize steel window use in the U.S. in the early 1900’s. Catastrophic fires in Baltimore, Boston, Chicago and San Francisco led to the development of building regulations that restricted the use of combustible materials in many types of construction.

After World War II, the technology of extruding aluminum frames developed and aluminum windows began to gain popularity. By the 1990’s, aluminum-framed windows accounted for approximately 65% of the commercial window market. Wood, vinyl and steel-framed windows comprise most of the remaining 35% of the market.

Description

The following describes commonly used window and frame components:

Window units can be fixed, operable, or a combination of the two. Fixed windows generally offer better air infiltration and water penetration resistance, and require less maintenance, than operable windows.

There are many configurations of operable window, broadly classified as sliding seal windows or compression seal windows. Compression seal windows generally provide better long-term air infiltration and water penetration resistance than sliding seal windows because they reduce friction and wear on the weatherstripping.

Compression seal windows include the following:

- Awning (Top hinged, project out bottom)
- Hopper (Bottom hinged, project in top)
- Casement (Side hinged, project in or out)
- Vertically or horizontally pivoted windows

Sliding seal window types include the following:

- Single, double and triple hung windows, either with balance hardware or springs to retain sash in open position and assist lifting
- Horizontal sliding windows

An important design consideration for operable windows is resistance to wind loads in the open position. Unfortunately, the industry provides little guidance on this issue. Sliding seal windows are always supported on two sides whether open or closed. Projecting windows rely on operating hardware for support against wind loads. The operating hardware for projecting windows may not be adequate for severe exposures.

Commonly used window frame materials include aluminum, steel and wood. Aluminum frames are the most widely used window frame material, and provide design flexibility because of the wide range of available stock systems and the relative economy of creating custom extrusions. Steel frames are less common than aluminum; there are relatively few
manufacturers who produce high quality steel windows. Design flexibility is generally limited by the available stock rolled shapes. The cost premium for custom shapes is larger for steel frames than for aluminum frames. **Wood** frames are widely used in the residential market, often with aluminum or vinyl cladding to reduce maintenance, and are growing in commercial use. There are a limited number of manufacturers who produce wood windows using naturally durable woods such as teak, mahogany, cypress or domestic hardwoods such as white oak. Many wood window manufacturers use fast-growth soft woods that are not rot-resistant. Cladding of wood frames with aluminum or vinyl can accelerate wood rot if the cladding joints are not made permanently watertight.

A critical element of successful window design is integration with adjacent wall components to create a functioning wall system. Reliable wall system design (see the Building Envelope Design page on *Exterior Walls*) generally includes a water resistant barrier behind the wall cladding, an air barrier and sometimes a vapor retarder. The "punched" window openings in the wall system threaten to create holes in the water/air/vapor barrier(s). Careful detailing is required to integrate water/air/vapor barriers with the window frames and maintain their continuity at the window perimeters.

**Fundamentals**

**Thermal Performance (Conduction, Solar Radiation, Thermal Break, Comfort)**

Overall window thermal performance is a function of the glazing (see *Glazing*), frame and perimeter details.

Window frame conductance is a function of the frame material, geometry and fabrication (e.g. thermal breaks in metal frames). **Wood** has low thermal conductivity and provides good thermal performance inherently. **Steel** has higher thermal conductivity than wood. Thermally broken steel windows are not generally available in the U.S. Narrower steel sightlines result in higher percentage of glass area than wood or aluminum frames. The overall U-value of steel frames compares favorably with aluminum frames, but less favorably with wood frames. For projects with humid conditions and condensation risks, the steel and aluminum frame should be oriented with as much of its thermal mass on the warm (and humid) side of the wall as possible.

**Aluminum** has the highest thermal conductivity of the three materials. It is common practice to incorporate thermal breaks of low thermal conductivity materials, traditionally polyurethane and more recently nylon, for improved thermal performance. Disadvantages of thermal breaks include inability to continuously weld frames and reduced frame strength and stiffness. Polyurethane in "poured and de-bridged" thermal breaks can shrink if not mechanically locked to the frame and in some instances embrittle. Back-up mechanical attachment of the two halves of the frame is recommended (skip debridging or "t-in-a-box") for poured and de-bridged thermal breaks.

Proper placement of insulation in the voids at the window perimeter and maintaining continuity of the air barrier reduces drafts and energy loss around windows.

**Moisture Protection (Water Penetration, Condensation Resistance)**

**Water penetration resistance** is a function of glazing details (see *Glazing*), frame drainage details, weatherstripping (for operable windows) and perimeter details.

Key frame drainage features include slope to the exterior at surfaces that collect water (sloped glazing pocket sill), large (3/8 in. diameter) weep holes, three per sill minimum, and drainage at every horizontal frame (i.e. do not use vertical frames to drain past horizontal frames). Design the drainage system to handle condensation as well as rain where condensation is likely.

High performance windows will generally include dual weather stripping for improved air/water penetration performance.

Window perimeters should have flashings (sill, jambs and head) that are integrated with the waterproofing at adjacent walls (see *Exterior Wall*). Slope head and sill flashings to the exterior for prompt drainage. Many windows leak at sill-to-jamb corners. To collect this leakage and drain it to the exterior, sill flashings with a panned up interior leg and end dams are required. Do not penetrate the horizontal portion of the sill flashing with window fasteners. Instead, where attachment of the sill frame is required, provide an attachment angle inboard of the window sill and fasten through the upturned leg of the sill flashing into back of the sill frame.

Perimeter sealants are useful for limiting air and water penetration through the outermost plane of the wall, but should
not be relied upon as the sole air/water penetration barrier.

Visual (Daylighting, Aesthetics)

Key visual features of windows include glazing appearance (see Glazing) and window frame sightlines. Sightlines are a function of both the width and depth of the window frame. Where narrow sightlines are desired, the strength and stiffness of steel frames permits the use of relatively slender frames compared with aluminum or wood.

Sound (Acoustics)

The acoustic performance of windows is primarily a function of the glass and glazing (see the discussion in Glazing). Sound insulation of windows can be improved by increasing the mass of the frames (albeit typically with a negative effect on thermal performance), improving the airtightness of the perimeter construction, placing sound absorptive materials at the perimeter of the windows, increasing the I.G. unit airspace, using laminated glass, and using I.G. units of uneven glass thicknesses. Providing sound isolators (such as rubber shims) at window attachments is a measure generally reserved for applications such as sound studios.

Safety

FIRE SAFETY

- For fenestration in fire-rated walls, provide fire-rated steel frames with suitable glazing (wired glass or fire-rated ceramic “glass”).
- Provide knock-out glazing panels (typically fully tempered to reduce shards) for venting and emergency access from the exterior.
- Emergency egress requirements frequently dictate the geometry and size of operable sash.

FALL-OUT PROTECTION

- Limit stops on operable sash, or approved window guards over window openings are used to prevent children from falling out of windows. Insect screens do not provide fall-out protection.

MAINTENANCE ACCESS

- Window washing tiebacks are often provided to stabilize access equipment used by maintenance/cleaning crew.

Health and Indoor Air Quality

Water leakage through or around windows frequently contributes to IAQ problems by supplying moisture for mold growth. This leakage can often remain concealed within the wall system and not become evident until concealed wall components experience significant deterioration and mold growth requiring costly repairs.

Durability and Service Life Expectancy

Window durability problems depend to a large degree on the window framing material and its assembly details.

Aluminum frames are inherently corrosion resistant in many environments if anodized and properly sealed or painted with baked-on fluoropolymer paint. Aluminum frames are subject to deterioration of the coating and corrosion of aluminum in severe (industrial, coastal) environments and galvanic corrosion from contact with dissimilar metals. Frame corner seals constructed using sealant are prone to debonding from prolonged contact with moisture and from thermal, structural, and transportation movements.

Steel windows depend on an applied coating for corrosion resistance. Coating systems that include a galvanic protection primer (zinc-rich paint, hot dipped galvanizing) in combination with a barrier coat of paint provide significantly better corrosion resistance than coating systems that rely on a barrier coat of paint alone. Steel frame corners can be welded watertight, producing superior durability against frame corner leakage compared to aluminum and wood windows.

Wood frames are prone to separation of frame joints from moisture, thermal, structural, and transportation movements. Wood that is not pressure-treated or not naturally rot resistant is prone to rot from prolonged contact with moisture.
Wood coatings deteriorate rapidly. Exposed wood is subject to UV deterioration. Wood that is clad with aluminum or vinyl often deteriorates more rapidly than painted wood. This is primarily due to the propensity for aluminum and vinyl claddings to leak at joints resulting in water penetration into the wood frame and deterioration due to limited drying potential of the wood when encased in aluminum and vinyl.

Operating hardware on operable windows wears from normal operation, and can be damaged by wind loads when the window is left in the open position. Side-hung windows are generally a poor choice for applications with high wind loads.

**Maintainability and Repairability**

Windows and perimeter sealants require maintenance to maximize their service lives. Perimeter sealants, properly designed and installed with high quality material, have a typical service life of 10 to 15 years although some breaches are likely from day one. Perimeter sealants require meticulous surface preparation to minimize breaches and maximize surface bond.

Wood frames and ungalvanized steel frames require frequent inspection and maintenance of coatings. Steel frames that have galvanic protection under the paint can generally tolerate longer intervals between paint maintenance than those without galvanic protection.

Aluminum frames are painted or anodized. Factory applied fluoropolymer thermoset coatings have good resistance to environmental degradation and require only periodic cleaning. Recoating with an air-dry fluoropolymer coating is possible but requires special surface preparation and is not as durable as the baked-on original coating.

Anodized aluminum frames cannot be "re-anodized" in place, but can be cleaned and protected by proprietary clear coatings.

Operable windows may require replacement of hardware after many operating cycles.

**Sustainability**

The best strategy for sustainability of windows is to employ good design practices to ensure the durability (maximum service life) of the installation.

The use of durable tropical hardwoods (teak, cypress, mahogany) is controversial due to declining populations of native timber and unsustainable harvesting techniques and some public agencies prohibit the use of tropical hardwoods on their projects. The Forest Stewardship Council (an independent, membership-based organization that promotes responsible management of the world's forests through developing standards, a certification system, and trademark recognition) certifies sources for sustainable harvesting, but may include some controversial tree plantations. Domestic hardwoods such as white oak are an acceptable, but less durable, option, but there are a limited number of manufacturers who use these hardwoods.

Steel frames, if not substantially weakened by corrosion, can be removed, refinished and reinstalled.

Aluminum and steel frames are typically recycled at the end of their service life. Salvage and demolition contractors generally require a minimum of 1,000 sq ft or more of window/curtain wall to make material recycling economical (smaller amounts are generally disposed as general trash). Recycling is less economical if the aluminum is contaminated with sealants, fractured glazing, etc., as salvage companies pay considerably less for the material. There is a limited market for salvaged steel and wood frames.

Energy efficiency is also important when designing for sustainability. Windows with an Energy Star rating, a government-backed program aimed to protect the environment by promoting energy efficiency, will help to improve thermal efficiency of the window system and reduce energy consumption.

**Applications**

**Establish System Track Record**

Select a window with a demonstrated track record in similar applications and exposures. Verifying track records may
require significant research by the designer. ASTM E1825 provides guidance.

Review laboratory test results of window systems or similar custom systems for air, water, and structural resistance, heat transmission, condensation resistance, sound transmission, and operability. Verify that tests pertain to the window under consideration and not a version of the window with the same product name but of different construction.

**Designing for Waterproofing Performance**

Window design should start with the assumption that window frame corners, glazing seals, and perimeter sealant joints will leak at some point during normal service life. Provide frame sills with weeped glazing pockets, sloped to the exterior, to collect water that penetrates the glazing and drain it to the exterior. Do not use vertical mullions as drain leaders. Provide a sill flashing with an upturned back leg and end dams to collect and drain frame corner leakage; provide jamb flashings to direct perimeter leakage down to the sill flashing.

An effective strategy to reduce the exposure of windows to weather is to recess windows from the exterior face of the wall. Projecting horizontal features (e.g. roof overhangs) also help shield windows from the weather.

Critical window perimeter details are discussed below; also reference Details 3.2-1 through 3.2-3:

**Sill Flashing:** Use durable metal flashings (stainless steel) where sill flashings will be exposed. Slope sill flashings to the exterior; provide an out-turned drip edge over face of wall cladding. Provide an upturned leg (1 inch minimum, greater for high wind exposures) at the interior, and end dams soldered water tight. Do not penetrate the horizontal portion of flashing with fasteners. To fasten the sill frame, provide an attachment angle inboard of the window sill and fasten through the upturned leg of the sill flashing into the inboard leg of the sill frame. Membrane flashings may be appropriate where the sill flashings are concealed and drain down into the wall cavity behind the cladding or onto sloped precast concrete or stone sills, but are less durable than metal.

**Jamb Flashing:** Jamb flashings may be metal but more typically are a flexible membrane. Where jamb flashings are part of the air barrier system, they must be metal or membrane continuously supported by a substrate capable of withstanding the design air pressures. Membrane flashings that bridge gaps must be continuous for the full height of the window, i.e. no lap seams, because there is no support at the gap against which to roll the lap seam watertight. Jamb flashings and wall waterproofing must be lapped and fully adhered at their intersection. Jamb flashings must be fully sealed to the window frame. Mechanical attachment of the jamb flashing to the window is generally required because there is insufficient surface area on which to adhere the flashing and rely on adhesion alone. The jamb flashings must be shingled over the sill flashing end dams and back leg to direct water that runs down the jambs into the sill pan.

**Head Flashing:** Use durable metal flashings (stainless steel). Slope window head flashings to the exterior; provide an out-turned drip edge over top of window frame. Extend head flashings several inches beyond the window frame. Provide end dams soldered water tight. Provide minimum 4-inch upturned leg and counterflash with wall waterproofing membrane adhered to the vertical leg of the metal flashing. For punched windows in openings that do not allow extension of the head flashing beyond the opening (e.g. concrete openings) use dual sealant joints in lieu of head flashing to capture water and direct it to the jamb flashings.

Critical glazing pocket details specific to frame materials are discussed below.

**Aluminum frames:** Slope the glazing pocket to promote drainage (reduces water exposure of insulating glass unit seals and frame corner seals).

**Steel frames:** Fully weld all frame corners for watertight construction. Stock rolled shapes generally do not have sloped glazing pockets. Because steel frames typically have narrow profile and therefore shallow glazing pocket, weep covers and foam baffles are critical to air infiltration and water penetration performance.

**Wood frames:** Many manufacturers do not provide weep holes in their typical windows, but wept glazing systems are required to obtain glazing warranties from I.G. unit manufacturers unless the glass manufacturer makes a specific accommodation to the window manufacturer. A separate recessed drainage channel in the glazing pocket allows drainage to the weep holes. Muntins (e.g. true divided lites) are rarely wept, and rely on glazing seals to prevent water infiltration into the glazing pocket. All I.G. units in true divided lites must be set on setting blocks. Use fixed interior glazing stops where possible to provide maximum water penetration resistance over time.
All: Coordinate placement of setting blocks with weep holes to avoid blocking drainage paths.

Coordinate attachment details with flashing details to avoid penetrating the flashings.

Designing for Condensation Resistance

AAMA’s Window Selection Guide provides guidance on window selection for condensation resistance. Establish the required Condensation Resistance Factor (CRF) based on anticipated interior humidity and local climate data and select a window with an appropriate CRF. Designers should be aware that the CRF is a weighted average for a window assembly. The CRF does not give information about window cold spots that could result in local condensation. Projects for which condensation control is a critical concern, such as high interior humidity buildings, require project-specific thermal modeling. Careful analysis and modeling of interior conditions is required to accurately predict condensation on the glass and frame. Windows that are set well outboard of perimeter heating elements will have air temperatures along their interior surface that are significantly lower than the design wintertime interior temperatures. Thermal modeling of the building interior using Computational Fluid Dynamics (CFD) software can help establish a reasonable estimate for air temperatures at the inside surfaces of the glass and frame. These interior air temperatures are inputs for window thermal modeling software such as THERM.

Use thermally broken aluminum frames or wood for best condensation resistance. The thermal break must be properly positioned with respect to the wall system to avoid exposing the aluminum frame inboard of the thermal break to cold air "short circuiting" the thermal break; see Detail 3.2-2.

Consider frame geometry for thermally conductive frame materials (aluminum, steel). Minimize the proportion of framing exposed to the exterior to improve condensation resistance.

Refer to AAMA 1503 for descriptions of test method, parameters and equipment for determining U values and CRF’s for window products.

Designing for Finish Durability

**Aluminum:** Class I anodic coatings (AAMA 611, supercedes AAMA 606, 607 and 608) and high performance factory applied fluoropolymer thermoset coatings (AAMA 2604, supercedes AAMA 605) have good resistance to environmental degradation.

**Wood:** Since wood readily absorbs moisture, wood finishes will have a limited service life if protective coatings are not properly maintained. Slope all exposed wood surfaces to promote drainage. Seal and paint all surfaces of mahogany window frames before glazing because bleed-out of tannins will interfere with sealant adhesion.

**Steel:** Steel frames that have galvanic protection under the paint can generally tolerate longer intervals between paint maintenance.

**All frame materials:** Shielding windows from the weather by recessing them back from the exterior face of the wall and/or providing roof overhangs or projecting head flashings is an effective strategy for maximizing the service life of window finishes.

Hardware

AAMA’s "Window Selection Guide" includes a useful overview of the operating hardware options for the various types of operating windows. Important design considerations for window hardware include life cycle serviceability, ability of operating hardware to resist wind loads when the window is in the open position, and resistance to forced entry for windows that are readily accessible from the exterior.

AAMA 910, "Voluntary "Life Cycle" Specifications and Test Methods for Architectural Grade Windows and Sliding Glass Doors", sets forth means for testing that simulates the normal wear that can be expected during the life of a typical architectural grade product. The testing is required for all windows seeking Architectural Class designation.

An important design consideration for operable windows is resistance to wind loads in the open position. Unfortunately,
the industry provides little guidance on this issue. Sliding seal windows are always supported on two sides whether open or closed. Projecting and side-hung windows rely on operating hardware for support against wind loads. The operating hardware for projecting or side-hung windows may not be adequate for severe exposures.

AAMA 1302.5, "Voluntary Specifications for Forced-Entry Resistant Aluminum Prime Windows", sets guidelines for construction and testing of aluminum windows to reduce vulnerability to forced entry.

Other AAMA Hardware Standards include

- AAMA 901—Voluntary Specification for Rotary Operators in Window Applications
- AAMA 902—Voluntary Specification for Sash Balances
- AAMA 904—Voluntary Specification for Multi-Bar Hinges in Window Applications

Logistical and Construction Administration Issues

The service life of even the most durable window is likely to be shorter than that of the surrounding exterior wall construction. Therefore, the design of the window and perimeter construction should permit window removal and replacement without removing adjacent wall components that will remain.

The service life expectancy of components that are mated with the window into an assembly should match the service life expectancy of the window itself. Require durable flashing materials, non-corroding attachment hardware and fasteners, and moisture resistant materials in regions subject to wetting.

Laboratory testing: For projects with custom windows, require laboratory testing of a mock-up window prior to production of windows for the project. Have a window specialist present to document mock-up window construction.

Field Mock-up: For all windows, stock or custom, require construction and testing of a field mock-up representative of the wall/window assembly for assembly testing and verification.

Testing of production windows: Require the field testing of production windows for quality assurance of window fabrication and installation. Require multiple tests early in the construction phase to catch problems early.

Shop drawing coordination: Require window installation shop drawings showing all adjacent construction and related work, including flashings, window attachments, interior finishes, and indicating sequencing of the work. Shop drawings should show isometric or axiometric details of corner assemblies.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) for Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Window Head Detail in Cavity Wall (Detail 3.2-1)  
This detail shows head construction at an aluminum window set in a masonry cavity wall.

- A through-wall metal flashing at the base of the brick cladding above the window protects the window head from leakage through the wall above—see Exterior Wall Claddings.
- The attachment at the window head may require slotted holes to accommodate differential movement between the window frame and the back-up wall.

Window Sill Detail in Cavity Wall (Detail 3.2-2)  
This detail shows sill construction at an aluminum window set in a masonry cavity wall.

- A metal sill flashing extends from the back-up wall across the cavity and over the top of the brick cladding, and turns down the face of the brick cladding. The flashing is sloped to the exterior to promote drainage, and is supported on sloped blocking and a sloped mortar bed. A non-curing glazing tape between the upturned leg of the flashing and the window serves as an air seal.
- A secondary sill flashing, a flexible membrane, is installed under the metal flashing as a second line of defense.
The flexible membrane shingles over the wall waterproofing in the cavity below the window.

- The window has weep holes in the face of the frame, with weep covers to reduce water penetration from wind driven rain.
- The thermal break of the window frame is positioned to align with the wall insulation, to prevent exposing the warm side of the frame to the cold and creating a thermal "short circuit."
- See discussion of *Schematic of Better Glazing Detail* in *Glazing* for additional commentary on window attachment.

**Window Jamb Detail in Cavity Wall (Detail 3.2-3)**  
*DWG | DWF | PDF*

This detail shows jamb construction at an aluminum window set in a masonry cavity wall.

- A Z-shaped jamb flashing extends from the back-up wall to the interior face of the window. The outboard leg of the flashing is integrated with the wall waterproofing membrane. The inboard leg of the flashing is sealed to the window frame for an air seal. The jamb flashing is shingled into the sill flashing at the window sill.

### Emerging Issues

See *Glazing* for discussion of emerging issues related to glazing.

**Smart windows** control visible light transmittance by using e.g. photochromic or electrochromic coatings. Some *high R-value glazing* includes the use of evacuated insulating glass units, which limit conductive and convective heat loss compared to conventional i.g. units. **Air-flow windows** incorporate a separate interior glass of lite and uses either supply or exhaust air to modulate the surface temperature of the i.g. unit. **Energy Star** is a federal initiative to help consumers identify energy efficient products, including windows. Available energy star ratings include residential windows only, but the program is expanding to commercial buildings.

### Relevant Codes and Standards

**Window Design and Selection**

- *[AAMA Window Selection Guide]*
- *[ANSI/AAMA/NWWDA 101/I.S.2 Voluntary Specifications for Aluminum, Vinyl (PVC) and Wood Windows and Glass Doors]*

**Thermal Performance**

- *[AAMA 1503 Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections]*
- *[AAMA 1504 Voluntary Standard for Thermal Performance of Windows, Doors and Glazed Wall Sections]*
- *[AAMA 1505 Voluntary Standards for Thermal Transmittance and Performance]*

**Air Infiltration**

- *[ASTM E283 (laboratory)]*
- *[ASTM E783 (field)]*

**Water Penetration Resistance**

- *[ASTM E331 (laboratory)]*
- *[ASTM E547 (laboratory)]*
- *[ASTM E1105 (field)]*

**Acoustical Performance**

- *[AAMA 1801 Voluntary Specification for the Acoustical Rating of Windows, Doors and Glazed Wall Sections]*
Anodized Coatings

- AAMA 609 Cleaning and Maintenance Guide
- AAMA 610 Cleaning and Maintenance Guide
- AAMA 611 Voluntary Specification for Anodized Architectural Aluminum

High Performance Organic Coatings

- AAMA 2604 Voluntary Specification for High Performance Organic Coatings on Aluminum Extrusions and Panels

Additional Resources

WBDG

DESIGN OBJECTIVES
Functional / Operational—Ensure Appropriate Product/Systems Integration

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants, See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

- American Architectural Manufacturers Association, information on aluminum, wood and vinyl windows
- Steel Window Institute, information on steel window manufacturers
- National Research Council Canada, information on good design practice, research, and emerging issues related to the building envelope
Introduction

A curtain wall is defined as thin, usually aluminum-framed wall, containing in-fills of glass, metal panels, or thin stone. The framing is attached to the building structure and does not carry the floor or roof loads of the building. The wind and gravity loads of the curtain wall are transferred to the building structure, typically at the floor line. Aluminum framed wall systems date back to the 1930's, and developed rapidly after World War II when the supply of aluminum became available for non-military use.

Curtain wall systems range from manufacturer's standard catalog systems to specialized custom walls. Custom walls become cost competitive with standard systems as the wall area increases. This section incorporates comments about standard and custom systems. It is recommended that consultants be hired with an expertise in custom curtain wall design for projects that incorporate these systems.

Description

The following are brief descriptions of commonly used curtain wall framing methods and components.

Curtain walls can be classified by their method of fabrication and installation into the following general categories: 

- **stick systems** and **unitized (also known as modular) systems**. In the stick system, the curtain wall frame (mullions) and glass or opaque panels are installed and connected together piece by piece. In the unitized system, the curtain wall is composed of large units that are assembled and glazed in the factory, shipped to the site and erected on the building. Vertical and horizontal mullions of the modules mate together with the adjoining modules. Modules are generally constructed one story tall and one module wide but may incorporate multiple modules. Typical units are five to six feet wide.

- Curtain walls can also be classified as **water managed** or **pressure-equalized** systems. See **Moisture Protection** below.

Both the unitized and stick-built systems are designed to be either interior or exterior glazed systems. Interior and exterior glazed systems offer different advantages and disadvantages. Interior glazed systems allow for glass or opaque panel installation into the curtain wall openings from the interior of the building. Details are not provided for interior glazed systems because air infiltration is a concern with interior glazed systems. Interior glazed systems are typically specified for applications with limited interior obstructions to allow adequate access to the interior of the curtain wall. For low rise construction with easy access to the building, outside glazing is typically specified. For high-rise construction interior glazing is sometimes used due to access and logistics of replacing glass from a swing stage.

In exterior glazed systems, glass and opaque panels are installed from the exterior of the curtain wall. Exterior glazed systems require swing stage or scaffolding access to the exterior of the curtain wall for repair or replacement. Some curtain wall systems can be glazed from either the interior or exterior.

Typical opaque panels include opacified spandrel glass, metal panels, thin stone, and other materials, such as terra cotta or FRP (fiber-reinforced plastic).

Vision glass is predominantly insulating glass and may have one or both lites laminated (see **Glazing**), usually fixed but
sometimes glazed into operable window frames that are incorporated into the curtain wall framing.

Spandrel glass can be monolithic, laminated, or insulating glass. The spandrel glass can be made opaque through the use of opacifiers (film/paint or ceramic frit) applied on an unexposed surface or through "shadow box" construction, i.e., providing an enclosed space behind clear spandrel glass. Shadow box construction creates a perception of depth behind the spandrel glass that is sometimes desired.

Metal panels can take various forms including aluminum plate, stainless steel or other non-corrosive metal, thin composite panels consisting of two thin aluminum sheets sandwiching a thin plastic interlayer, or panels consisting of metal sheets bonded to rigid insulation, with or without an inner metal sheet to create a sandwich panel.

Thin stone panels are most commonly granite. White marble should not be used due to its susceptibility to deformation due to hysteresis (thin stone is not covered in this chapter).

The curtain wall often comprises one part of a building's wall system. Careful integration with adjacent elements such as other wall claddings, roofs, and base of wall details is required for a successful installation.

Fundamentals

System Types

Face-sealed, water-managed and pressure-equalized rainscreen systems are the three systems that are available. Normally, pressure-equalized rain screen systems provide the highest levels of resistance to air and water infiltration, with water-managed systems the next most reliable.

Pressure-equalized rain screen systems function by blocking all of the forces that can drive water across a barrier. See the article on Moisture Protection for a complete explanation of how pressure-equalization resists water passage. As related to curtain wall systems, PE rain screen systems design the inside face of glass and the inside face of the glazing pocket and the interconnecting gasket or wet seal as an airtight barrier. The outside face of glass, exterior glazing materials and the outer exposed face of aluminum framing function as a rain screen, shedding water away. Between the exterior rain screen and the interior air barrier a pressure-equalization chamber is formed in the glazing pocket, which serves to reduce water penetration by eliminating (equalizing) the pressure difference across the rain screen that tends to force water into the system. Minor amounts of water that may penetrate the system are weeped harmlessly to the exterior.

Water-managed systems appear similar at first glance, incorporating drains and weeps from the glazing pocket, but no effort is made to create an air barrier or "zone-glaze" each glass or spandrel unit, and therefore a larger amount of water is forced into the system and must be weeped away. Also, since no air barrier exists, the pressure differential between the glazing pocket and the interior may be strong enough to force water vertically higher than interior gaskets, resulting in leaks. Weep holes in a water-managed system function largely to drain water that enters the glazing pocket while weep holes in a pressure-equalized system function primarily as vents to allow air movement between the exterior and glazing pocket. Weeping of water is only a secondary function. Note that the easiest way to recognize a pressure-equalized rain screen system is to note that the glazing pocket around each individual unit of glass is isolated airtight from adjacent units, most obviously with plugs or seals at the gaps between screw splines at mullion intersections. Detailing of spandrels, shadow boxes and interface with adjacent construction must maintain the continuity of the air barrier and rainscreen to function properly with a pressure-equalized rainscreen curtain wall framing system.

Some aluminum curtain wall systems are still designed as face-sealed barrier walls. They depend on continuous and perfect seals between the glass units and the frame and between all frame members to perform. The long-term reliability of such seals is extremely suspect and such systems should be avoided.

Thermal Performance (Conduction, Solar Radiation, Thermal Break, Comfort)

Overall curtain wall thermal performance is a function of the glazing infill panel, the frame, construction behind opaque (spandrel and column cover) areas, and the perimeter details.

Curtain wall frame conductance is a function of the frame material, geometry and fabrication (e.g. thermal break).
Aluminum has a very high thermal conductivity. It is common practice to incorporate thermal breaks of low conductivity materials, traditionally PVC, Neoprene rubber, polyurethane and more recently polyester-reinforced nylon, for improved thermal performance. Some "poured and debridged" polyurethane thermal breaks shrink and stress forms in the thermal break when the exterior aluminum moves differently from the interior aluminum due to temperature differences. Back-up mechanical attachment of the two halves of the frame is recommended (e.g. skip debridging or "t-in-a-box"). A true thermal break is ¼" thick minimum and can be up to 1" or more, with the polyester reinforced nylon variety. Some curtain wall systems incorporate separators that are less than ¼", making them "thermally improved". The deeper thermal breaks can improve thermal performance and condensation resistance of the system.

Some curtain wall systems utilize "pressure bars" (also referred to as "pressure plates") that are fastened to the outside of the mullions to retain the glass. These systems frequently include gaskets that are placed between the pressure bar and mullions and function as thermal breaks and help with acoustic isolation. These systems require special care in design and construction to ensure continuity of the gaskets at horizontal and vertical transitions. Gaskets are also used to cushion the glass on the interior and exterior faces of the glass. The problem with gaskets is that they tend to be stretched during installation and will shrink back to their original length in a short time; they will also shrink with age and exposure to ultraviolet radiation. There is usually a gap in the gasket at the corners after shrinkage occurs. With a properly designed system the water that enters the system at the gasket corners will weep out through the snap cover weep holes. To mitigate shrinkage of gaskets back from the corners the use of vulcanized corners and diagonally cut splices are recommended.

Thermal performance of opaque areas of the curtain wall is a function of insulation and air/vapor barriers. Due to the lack of interior air adjacent to opaque curtain wall areas, these areas are subject to wide swings in temperature and humidity and require careful detailing of insulation and air/vapor barriers to minimize condensation. Some curtain wall systems include condensation drainage provisions, such as condensate gutters, that are intended to collect and weep condensate from spandrel areas to the exterior; such condensate gutters and weeps are a violation of the air barrier of the curtain wall unless they are outboard of the backpan. See discussion of back pans below.

At the curtain wall perimeter, maintaining continuity of the air barrier reduces airflows around the curtain wall. Integration of perimeter flashings helps ensure watertight performance of the curtain wall and its connection to adjacent wall elements. Proper placement of insulation at the curtain wall perimeter reduces energy loss and potential condensation issues. Insulating the mullions in a spandrel area may lead to excessive condensation in cold climates unless it can also be assured that humid air from the interior will never come in contact with the mullions. The spandrel area is typically not heated, thus the interior environment does not warm the mullions and offset the migration of the cold temperatures deep into the wall. In the vision area the interior heat helps to mitigate the cold and prevents condensation. For this reason, do not insulate between the interior portion of mullions and adjacent wall construction either.

**Moisture Protection** (Water Penetration, Condensation Resistance)

Water penetration resistance is a function of glazing details (see Glazing), frame construction and drainage details, weatherstripping and frame gaskets, interior sealants (for operable windows, see Windows), and perimeter flashings and seals. Water can enter the exterior wall system by means of five different forces: gravity, kinetic energy, air pressure difference, surface tension, and capillary action. To mitigate water infiltration, all of these forces must be accounted for in the system design.

Unlike discontinuous windows, which are smaller units and can rely to a high degree on sill flashings to capture frame corner leakage, curtain walls cover large expanses of wall without sill flashings at each glazed opening. Water penetration of curtain wall frame corners is likely to leak to the interior and/or onto insulating glass below. Watertight frame corner construction and good glazing pocket drainage are critical for reliable water penetration resistance.

**Visual** (Daylighting, Aesthetics)

Key visual features of curtain walls are glazing appearance (see Glazing) and sightlines. Sightlines are defined as the visual profile of the vertical and horizontal mullions. The sightlines are a function of both the width and depth of the curtain wall frame. Lateral load resistance requirements (wind loads, spans) generally dictate frame depth. Where narrow sightlines are desired, steel stiffeners inserted into the hollow frame of aluminum extrusions can help reduce frame depth.
Sound (Acoustics)

The acoustic performance of curtain walls is primarily a function of the glazing and internal seals to stop air leakage (covered elsewhere). The sound attenuation capability of curtain walls can be improved by installing sound attenuating infill and by making construction as airtight as possible. Incorporating different thicknesses of glass in an insulated glass unit will also help to mitigate exterior noise. This can be accomplished by increasing the thickness of one of the lites of glass or by incorporating a laminated layer of glass with a noise-reducing interlayer, typically a polyvinyl butyral or PVB.

Back Pans

Back pans are metal sheets, usually aluminum or galvanized steel, that are attached and sealed to the curtain wall framing around the perimeter behind opaque areas of a curtain wall. In cold climates insulation should be installed between the back pan and the exterior cladding in order to maintain the dew point outboard of the back pan so that the back pan acts as an air and vapor barrier. Back pans provide a second line of defense against water infiltration for areas of the curtain wall that are not visible from the interior and are difficult to access. Water infiltration in opaque areas can continue for extended periods of time causing significant damage before being detected. Back pans also are to be preferred over foil vapor retarders in high performance and humidified buildings as convection currents short-circuiting the insulation can cause condensation, wetting and ultimately failure of these spandrel areas.

Shadow Boxes

Shadow box construction creates the appearance of depth behind a transparent lite of glass by incorporating a metal sheet into the curtain wall behind the lite. The metal sheet should be at least two inches behind the glass and may be painted or formed to create a texture, but reflective surfaces add the most visual depth to the wall. Insulation should also be installed behind the shadow box if interior finishes prevent room air from contacting this area. The system should be designed to collect any condensation that may collect on the exterior side of the metal sheet and drain it back to the exterior. Shadow boxes present a variety of challenges related to venting the cavity behind the glass, that can allow dirt on surfaces difficult to clean, or sealing the cavity and risking excessive heat build-up. Either way, the cavity may be at temperatures significantly above or below interior conditions with only thermally conductive aluminum between them. This can lead to condensation or surfaces so hot they can burn. Careful detailing can provide a method to thermally isolate the cavity from the interior. An interior back pan behind the insulation is desirable as well, to avoid condensation on the metal shadow box from the interior.

Support of Curtain Walls

Curtain wall systems must transfer back to floor structure or intermediate framing both their own dead load plus any live loads, which consist primarily of positive and negative wind loads but might also include a snow load applied to large horizontal areas, seismic loads, maintenance loads and others. Unfortunately, the curtain wall will likely demonstrate movement caused by thermal changes and wind significantly different than movement of the building structure. Therefore the connections to anchor the curtain wall must be designed to allow differential movement while resisting the loads applied.

In stick-framed aluminum curtain wall, vertical mullions commonly run past two floors, with a combined gravity/lateral anchor at one floor and a lateral anchor only at the other. The splice between the vertical mullions will also be designed to allow vertical movement while providing lateral resistance. In large areas of stick framed curtain wall, a split vertical mullion will be introduced periodically to allow thermal movement. Note that this movement slightly distorts the anchors at the vertical mullions. Individual units of glass must accommodate the movement of the surrounding aluminum frame by sliding along glazing gaskets, distorting the gaskets or a combination of both. The movement of the glass within the frame and the movement forced in the anchors tend to induce additional stresses into a stick framed system.

Unitized curtain wall systems accommodate the differential movement between the structure and the thermal movement of the frame at the joints between each curtain wall unit. Because these units are frequently custom designed, the amount of movement to be accommodated can be carefully engineered into the system. Anchoring of unitized curtain wall typically consists of a proprietary assembly with three-way dimensional adjustability. The anchors occur at each pair of vertical mullions along the edge of slab or spandrel beam. Frequently, unitized systems span from a horizontal stack joint
located at approximately desk height up to the anchor at the floor line above and then cantilevering past the floor to the next horizontal stack joint. The stack joint is designed to resist lateral loads while the two floor anchors resist gravity and lateral loads. One of the two floor anchors will allow movement in plane with the unitized system.

**Safety**

**FIRE SAFETY**

Fire safing and smoke seal at gaps between the floor slab-edge and the back of the curtain wall are essential to compartmentalize between floors and slow down the passage of fire and combustion gases between floors. A substantial ½" thick minimum poured smoke-seal is required to separate air return and supply plenums from each other, and for infection control in hospitals. Laboratory-tested fire rated assemblies may be required in unsprinklered buildings by some codes as Perimeter Fire Containment Systems when the floor assemblies are required to be fire-resistance rated. The ratings of the Perimeter Fire Containment System must be equal to or greater than the floor rating. These systems provide confidence that the materials used for perimeter containment remain in place for the specified duration of the required rating in a fire event.

Fireman knock-out glazing panels are often required for venting and emergency access from the exterior. Knock-out panels are generally fully tempered glass to allow full fracturing of the panel into small pieces and relatively safe removal from the opening. Knock-out panels are identified by a non-removable reflective dot (typically two inches in diameter) located in the lower corner of the glass and visible from the ground by the fire department.

**MAINTENANCE ACCESS**

The curtain wall should be designed for accessibility for maintenance. Low-rise buildings can generally be accessed from the ground using equipment with articulated arms. For high rise construction the building should be designed for swing stage access for window cleaning, general maintenance, and repair work, like glass replacement. Davits and fall arrest safety tieback anchors should be provided on the roof and stabilization tie-offs provided on the face of the wall to comply with OSHA standards CFR 1910.66, CFR 1910.28 and ANSI/IWCA I-14.1 "Window Cleaning Safety Standard".

**Health and Indoor Air Quality**

Curtain wall leakage, both air and water, can contribute to IAQ problems by supplying liquid water and condensation moisture for mold growth. This leakage can often remain concealed within the wall system and not become evident until concealed wall components experience significant deterioration and mold growth, requiring costly repairs.

**Durability and Service Life Expectancy**

Common curtain wall durability problems include the following:

**Glazing failures** (see Glazing). Glazing problems specific to curtain wall construction include visual obstruction from condensation or dirt, damage to opacifier films from material degradation, condensation and/or heat build-up, and IGU issues/laminated glass issues.

**Failure of internal gaskets and sealants** from curtain wall movements (thermal, structural), prolonged exposure to water (good drainage features reduce this risk), heat/sun/UV degradation (age). Repairs (if feasible) require significant disassembly of curtain wall. If restoration of internal seals is not physically possible or not economically feasible, installation of exterior surface wet sealing at all glazing and frame joints is often performed.

**Failure of exposed gaskets and sealants**, including perimeter sealants, from curtain wall movements (thermal, structural), environmental degradation. Repairs require exterior access.

Aluminum frames are inherently corrosion resistant in many environments if anodized and properly sealed or painted with baked-on fluoropolymer paint. Aluminum frames are subject to deterioration of the coating and corrosion of aluminum in severe (industrial, coastal) environments and galvanic corrosion from contact with dissimilar metals. Frame corner seals constructed using sealant are prone to debonding from prolonged contact with moisture and from thermal, structural, and transportation movements.
Maintainability and Repairability

Curtain walls and perimeter sealants require maintenance to maximize the service life of the curtain walls. Perimeter sealants, properly designed and installed, have a typical service life of 10 to 15 years although breaches are likely from day one. Removal and replacement of perimeter sealants requires meticulous surface preparation and proper detailing.

Aluminum frames are generally painted or anodized. Factory applied fluoropolymer thermoset coatings have good resistance to environmental degradation and require only periodic cleaning. Recoating with an air-dry fluoropolymer coating is possible but requires special surface preparation and is not as durable as the baked-on original coating.

Anodized aluminum frames cannot be "re-anodized" in place, but can be cleaned and protected by proprietary clear coatings to improve appearance and durability.

Exposed glazing seals and gaskets require inspection and maintenance to minimize water penetration, limit exposure of frame seals, and protect insulating glass seals from wetting.

Sustainability

The best strategy for sustainability of curtain walls is to employ good design practices to ensure the durability (maximum service life) of the installation and to use systems that have a good thermal break and high R-value (values as high as R-7 are possible with triple-glazed systems). Also, the use of low-e and spectrally selective glass coatings can significantly reduce energy loads and improve comfort close to the wall.

Aluminum and steel frames are typically recycled at the end of their service life. Salvage and demolition contractors generally require a minimum of 1,000 sq ft or more of window/curtain wall to make material recycling economical (smaller amounts are generally disposed as general trash). Recycling is less economical if the aluminum is contaminated with sealants, fractured glazing, etc., as salvage companies pay considerably less for the material. There is a limited market for salvaged steel and wood frames.

Applications

Establish System Track Record

Select a curtain wall with a demonstrated track record in similar applications and exposures. Verifying track records may require significant research by the designer. ASTM E1825 provides guidance.

Review laboratory test results of systems or similar custom systems for air, water, and structural resistance, heat transmission, condensation resistance, sound transmission, and operability. Verify that tests pertain to the system under consideration and not a version of the system with the same product name but of different construction.

Designing for Waterproofing Performance

Curtain wall design should start with the assumption that external glazing seals, perimeter sealant joints and curtain wall sills will leak. The following summarizes recommended features:

- Select frames with wept glazing and pocket sills sloped to the exterior to collect water that penetrates the glazing and drain it to the exterior. Do not use vertical mullions as drain conductors. Each glazing pocket should be fully isolated from adjacent glazing pockets. Provide a sill flashing with end dams and with an upturned back leg turned up into the glazing pocket at the base of the curtain wall to collect and drain curtain wall sill leakage; provide jamb flashings to direct perimeter leakage down to the sill flashing.
- Key frame drainage features include slope to the exterior at surfaces that collect water (slope top of exposed horizontal mullion surfaces, slope at flashings), large (3/8 inch diameter or a slot 5/16" x 3/8" minimum) weep holes closely spaced (three weep holes per each section of horizontal mullion between vertical mullions, typically), and drainage at every horizontal frame (do not use vertical frames to drain past horizontal frames). Use as many 1/4-inch by 2-inch slots as required for pressure-equalized systems. Design the drainage system to handle condensation as well as rain.
- Curtain wall perimeters should have flashings (sill, jambs and head) that are sealed to the air and water barrier at
adjacent walls. Slope head and sill flashings to the exterior to promote drainage. Integrate curtain wall sill flashings with sill flashings or base of wall flashings of adjacent walls. Curtain wall should have a primary air/water seal between the shoulder of the tube at the plane of the glazing pocket and the air barrier of the adjacent construction.

- Perimeter sealants are useful as a rainscreen for limiting air and water penetration through the outermost plane of the wall, but should not be relied upon as the sole air/water penetration barrier.
- Coordinate placement of setting blocks with weep holes to avoid blocking drainage paths.

Glazing Methods and Their Impact on Performance

Pressure Plate Glazing: In this system the glass and infill panels are installed from the exterior, typically against dry gaskets. The outer layer of gaskets is installed and the gaskets are compressed against the glass by the torque applied to fasteners securing a continuous pressure plate. The plate is later typically covered with a snap-on mullion cover. This system provides reasonable performance but is susceptible to leaks at corners or joints in dry gaskets. For improved performance four-sided gaskets can be fabricated at additional cost or wet sealants can be installed to provide a concealed interior toe bead or exposed interior cap beads. Pressure plate glazing allows the easiest method to seal an air barrier from adjacent construction into the air barrier of curtain wall system.

Interior Dry Glazing: In this system the glass and infill panels are installed from the interior of the building, eliminating the need for substantial scaffolding and saving money. The frame is fixed and exterior dry gaskets are installed. Typically only the top interior mullion has a removable stop. The glass unit is slid into a deep glazing pocket on one jamb far enough to allow clearing the opposite jamb and is then slid back into the opposite glazing pocket and then dropped into the sill glazing pocket. The removable interior stop is installed and finally an interior wedge gasket is forced in. Sometimes this method is called "jiggle" or "wiggle" glazing because of the manipulation necessary to get the glass into place. Performance is slightly reduced because dry metal to metal joints occur at the ends of the removable stop at a point that should properly be air and watertight. Wet sealant heel beads will improve performance and some systems include an extra gasket to form an air barrier seal. Installation of spandrel panels may need to be installed from the exterior.

Structural Silicone Glazing: In this system the glass or infill unit is adhered to the frame with a bead of silicone. Outer silicone weather seals supplement the structural seal. Unitized systems are frequently structural silicone glazed, especially if four-side SSG is desired. Two-sided SSG, with pressure plate glazing or wiggle glazing on the other two sides is acceptable to be field installed.

Butt-Glazing: SSG is frequently mistakenly referred to as butt-glazing. True butt-glazing has no mullion or other back-up member behind the joint and relies solely on a sealant, typically silicone, between the glass units to provide a perfect barrier seal.

Designing for Condensation Resistance

AAMA's Curtain Wall Design Guide provides guidance on window selection for condensation resistance. Establish the required Condensation Resistance Factor (CRF) based on anticipated interior humidity and local climate data and select a curtain wall with an appropriate CRF. Designers should be aware that the CRF is a weighted average number for a curtain wall assembly. The CRF does not give information about cold spots that could result in local condensation. Projects for which condensation control is a critical concern, such as high interior humidity buildings, require project-specific finite element analysis thermal modeling using software such as THERM. Careful analysis and modeling of interior conditions is required to accurately estimate the interior temperature of the air at the inside surfaces of the glass and frame. Curtain walls that are set well outboard of perimeter heating elements will have air temperatures along their interior surface that are significantly lower than the design wintertime interior temperatures. Thermal modeling of the building interior using Computational Fluid Dynamics (CFD) software can help establish a reasonable estimate for air temperatures at the inside surfaces of the glass and frame. These interior air temperatures are inputs for the thermal modeling software. Include lab mock-up thermal testing in addition to CFD modeling for analysis of project-specific conditions. Unusual or custom details, such as copings, deep sills, projected windows, spandrel areas and shadow box can dramatically alter performance.

Use thermally broken or thermally improved aluminum frames for best performance. At the perimeter of the curtain wall, the thermal break must be properly positioned with respect to the wall system/insulation to avoid exposing the aluminum
frame inboard of the thermal break to cold air ("short circuiting" the thermal break). Special insulation provisions may be required where curtain walls project beyond adjacent cladding systems (e.g., an insulated perimeter extrusion or metal panning).

Consider frame geometry for thermally conductive aluminum frame materials. Minimize the proportion of framing exposed to the outdoors.

Refer to AAMA 1503 for descriptions of test method, parameters and equipment for determining U factors and CRF's for window products. Refer to NFRC 100 for U Factor and NFRC 500 for condensation resistance.

**Designing for Solar Heat Gain Control and Solar Optical Properties**

The use of glazed curtain walls can present challenges in balancing the desire for more natural daylight versus addressing the heat gain typically associated with such systems. Occasionally, there are concerns relating to having too much uncontrolled daylight, sometimes referred to as glare. The challenge is to strive for the highest visible light transmittance (VT) and the lowest solar heat gain coefficient (SHGC) while not preventing the glass from being too reflective when viewed from both the exterior and the interior, while controlling glare. This glass performance data are obtained from data using the Lawrence Berkeley National Laboratory (LBNL) Window 5.2 program with Environmental Conditions set at NFRC 100 criteria. NFRC 200 is used to determine the VT and SHGC values while the solar optical properties are determined using NFRC 300. Typically, for products more widely available on the market, the aforementioned values are readily available from glass manufacturers/fabricators.

**Designing for Finish Durability**

Aluminum: Class I anodic coatings (AAMA 611, supersedes AAMA 606, 607 and 608) and high performance factory applied fluoropolymer thermoset coatings (AAMA 2605) have good resistance to environmental degradation.

**Unitized Systems**

Unitized systems are typically custom designed. There is a wide range of systems on the market from manufacturers that provide varying levels of reliability. Unitized systems range in performance ability from industry standard to high performance walls. It is thus recommended that projects specifying unitized curtain wall systems incorporate a team member who has a breadth of experience in designing and working with unitized systems.

Unitized systems are typically pressure equalized rain screen systems. The units should be completely assembled in a factory and shipped to the site for installation on the building. The units are placed on the floors, bundled in crates, using the tower crane and lowered into place using a smaller crane or hoist owned by the glazing contractor. The mullion dimensions tend to be slightly larger than a stick system due to their open section as compared to the tube shape of a standard stick curtain wall section. The advantages of the unitized system derive from the more reliable seals achievable from factory construction and the reduced cost of labor in the factory versus that of high rise field labor. Units can be assembled in a factory while the structural frame of the building is being constructed. Where stick systems require multiple steps to erect and seal the wall, unitized walls arrive on the site completely assembled allowing the floors to be closed in more quickly. Unitized systems also require less space on site for layout thus providing an advantage for urban sites with space limitations.

Unitized systems generally rely on rain screen design principles and gaskets and/or the interlock of mating frames for moisture protection at joints between adjacent modules. The interlocking vertical mullions will typically have two interlocking legs. One leg will be in the plane just behind the glazing pocket and the other at the interior face of the mullions. The interlocking leg in the plane of the glazing pocket will be sealed by gaskets and is the primary line of defense against water and air infiltration. More robust systems will also include a gasket at the interior interlock. Systems whose connecting legs lock also compromise the ability of the system to accommodate movement. Some unitized designs are sensitive to small irregularities in the spacing of adjacent modules; for example, if the module joints are slightly out of tolerance, gaskets may not be properly compressed and moisture protection may suffer. Robust designs include multiple lines of defense, realistic tolerances and adjustability for erection of modules.

The four-way intersection refers to the location where four adjacent units meet. This is where field labor must seal between adjacent units to achieve a weather tight wall. The interlocking legs of the horizontal mullions are the most...
critical interface of a unitized system. Water that infiltrates the interlocking vertical mullions drains to the interlocking horizontals that must collect and divert this water to the exterior. The top horizontal mullion of a unit incorporates upstanding vertical legs that mate with cavities in the bottom horizontal of the unit above. These upstanding legs have gaskets that seal against the walls of the bottom horizontal. Some designs provide one upstanding leg that provides one line of defense against air and water infiltration. More robust systems will provide two upstanding legs with gaskets on both legs. A splice plate or silicone flashing that is installed at the top of the two adjacent units as they are erected on the building is typically required.

The vertical mullions of unitized systems typically anchor to the slab edge as they pass by. The stack joint is the horizontal joint where units from adjoining floors meet. Placing the stack joint at the sill of the vision glass (typically 30” above the floor) will minimize the dimension of the vertical mullions. This positioning utilizes the back span of the mullion above the anchoring point at the slab to counteract the deflection of the mullion below the slab. Also placing the stack joint above the floor provides a more convenient location for field workers to achieve the critical seal at the four-way intersection.

While two story spans are feasible, the weight of the unit is doubled which may require increased structural capacity to accommodate the increased load. Wind load bracing should be incorporated at the single span height to avoid increasing the vertical mullion dimension to accommodate the increased span. Steel can be added to a unitized system to increase its spanning capability. However, unlike a stick system which has an integral hollow shape, the split mullions must be allowed to move independently to accommodate the building movement thus complicating the introduction of steel. Large units may also increase transportation costs from the factory to the site and erection costs of placing the units on the building.

Thermally broken unitized systems are available, utilizing similar technology as that used in stick curtain wall systems.

Logistical and Construction Administration Issues

The service life of even the most durable curtain wall may be shorter than that of durable adjacent wall claddings such as stone or brick masonry. Therefore, the design of the curtain wall and perimeter construction should permit curtain wall removal and replacement without removing adjacent wall components that will remain.

The service life expectancy of components that are mated with the curtain wall into an assembly should match the service life expectancy of the curtain wall itself. Require durable flashing materials, non-corroding attachment hardware and fasteners, and moisture resistant materials in regions subject to wetting.

Laboratory testing: For projects with a significant amount of custom curtain wall, require laboratory testing of a mock-up curtain wall prior to finalizing project shop drawings. Have a curtain wall consultant present to document mock-up curtain wall construction and verify mock-up performance. Specify that laboratory tests are to be conducted at an AAMA Accredited Laboratory facility.

Field Mock-up: For all curtain walls, stock or custom, require construction and testing of a field mock-up representative of the wall/window assembly. This is best scheduled prior to the release of shop drawings for window production, so that there is an opportunity to make design changes based on the test performance of the field mock-up. Specify that field tests be conducted by an independent third party agency accredited by AAMA.

Field testing of curtain walls: Require the field testing of curtain walls for air infiltration and water penetration resistance, for quality assurance of curtain wall fabrication and installation. Require multiple tests with the first test on initial installations and later tests at approximately 35%, 70% and at final completion to catch problems early and to verify continued workmanship quality. Require additional testing to be performed if initial tests fail.

Shop drawing coordination: Require curtain wall installation shop drawings showing all adjacent construction and related work, including flashings, attachments, interior finishes, and indicating sequencing of the work.

Curtain wall systems, especially unitized systems, require expertise on the part of the building designer, the manufacturer, the fabricator, and the installer. For all but the simplest of systems, the designer should consider engaging an outside consultant, if such expertise is not available on the staff.
The following details can be viewed online in Adobe Acrobat PDF by clicking on the PDF to the right of the drawing title.

Download Adobe Reader.

### Typical Elevation—Stick-Built Curtain Wall-Pressure Equalized-Outside Glazed
(Figure S – 1)  PDF

This elevation shows a typical stick-built curtain wall set in a punched opening in a masonry cavity wall.

- Elevation includes splice joints to accommodate thermal movement of the curtain wall frame.

### Curtain Wall Head—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 2)  PDF

- A through-wall metal flashing at the base of the brick cladding above the curtain wall protects the curtain wall from leakage through the wall above— (see Exterior Wall) for integration of the these components.
- Locate exterior perimeter sealant joints behind trim cover to prevent water inside trim cover from bypassing the exterior sealant joint.

### Curtain Wall Jamb—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 3)  PDF

- Locate exterior perimeter sealant joints behind trim cover to prevent water inside trim cover from bypassing the exterior sealant joint.

### Curtain Wall Sill—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 4)  PDF

- Continuous metal sill flashing at the base of the curtain wall protects the wall framing below from leakage through the curtain wall. Sill flashing should have upturned end dams and fully sealed corners.

### Intermediate Mullion—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 5)  PDF

- Intermediate horizontal should be wept to the exterior and prevent water from draining onto the head of the glazing unit below. Care must be taken to ensure all corner frame joints in the glazing pocket are sealed to prevent leakage to the interior.
- Locate setting blocks as to not obstruct water drainage from the glazing pocket.
- Provide anti-walk blocks at the jambs of the glazing units. Blocks should be gapped 1/8-inch from the edge of the glazing unit.

### Isometric of Finished System—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 6)  PDF

### Isometric of Curtain Wall Sill—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 7)  PDF

### Isometric of Vertical Curtain Wall Mullions—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 8)  PDF

### Elevation of Horizontal Pressure Plate—Stick-Built System-Pressure Equalized-Outside Glazed (Figure S – 9)  PDF

### Isometric of System Assembly Unitized Curtain Wall System (Figure U–1)  PDF

This elevation shows a typical unitized curtain wall assembly hung from the edge of the floor slab.

- Differential movement between curtain wall units is accommodated at the vertical and horizontal unit joints.
- The unit shown is composed of vision glazing and a glazed spandrel shadow box with an insulated back pan.

### Isometric of Open Stack Joint Unitized Curtain Wall System (Figure U–2)  PDF

- A continuous vertical gasket provides the primary weather seal at the pressure equalized rainscreen zone of the assembly.
- Foam glazing tape weather seal is discontinuous at horizontal panel joints to achieve pressure equalization between weather and air seals at vertical unit joints.
- A splice cover is applied over the horizontal stack joint between units to provide continuous waterproofing behind and below the pressure equalized wet zone of the vertical stack joint.
The units are connected with a field applied splice sleeve that contains an index clip to align the next unit above the joint horizontally as it is being set.

Isometric of Completed Stack Joint Unitized Curtain Wall System (Figure U–3)  
- Glazing pocket weeps are protected from wind-driven rain and pressure by a glazing trim cover containing weep slots in the bottom which are offset from the sill glazing pocket weep slots and the glazing setting blocks at glazing panel quarter points.
- The primary air and water seal at the stack joint should have sufficient height and drainage to prevent water head from overtopping the gaskets. Gasket height should correspond to the curtain wall design pressure.
- Exterior cover splice sleeves are installed at the face of the stack joint during unit field installation.

Vision Glass Jamb Unitized Curtain Wall (Figure U–4)  
- Units are designed and installed with horizontal and vertical clearance gaps to allow for differential movement and accommodate construction tolerances.
- Pressure equalized rainscreen gaskets form a primary weather seal at the face of the unitized vertical stack joint in line with the horizontal rainscreen gasket at the unit sill below.

Unit Stack Joint Unitized Curtain Wall (Figure U–5)  
- Single or double glazing can be used at the spandrel area which is backed by a finish metal panel to form a shadow box.
- Spandrel glass adapters are used to reduce the depth of the glazing pocket to accommodate reduced profile of spandrel glass. Spandrel glass adapters should be fully bedded in sealant and integrated with glazing pocket corner seals to prevent water leakage from glazing pocket to building interior.
- Unit dimension of mating head and sill extruded profiles allows for specified floor to floor deflection at the stack joint.

Intermediate Horizontal Unitized Curtain Wall (Figure U–6)  
- Intermediate horizontal members provide for divisions between vision panels or between vision and opaque or spandrel panels.
- Intermediate horizontals stop at the face of the vertical unit jamb members at each end.

Jamb at Spandrel Area with Anchorage to Slab Unitized Curtain Wall (Figure U–7)  
- Units are hung from the top or face of the adjacent floor or building structure using mated brackets and field applied bolts with a minimum of clearance for access and assembly.
- All connections and brackets located within the units insulated or primary weather seal zones are sealed with appropriate sealant materials during field installation.

Unit Anchor to Slab Edge Section Unitized Curtain Wall (Figure U–8)  
- Floor and ceiling closure is provided for fire and acoustical separation using code approved assemblies.

Emerging Issues

*Smart* Curtain Walls, like smart windows, control visible light transmittance by employing electrochromic or photochromic glass coatings; see the discussion in *Glazing*. **Double-skin systems**, which employ a ventilated space between the inner and outer walls are rare in the U.S., but have been constructed in Europe and Asia where energy costs are much higher. Similar in concept to air-flow windows, the ventilated space is intended to conserve energy by modulating the temperature conditions inboard of the curtain wall. During the heating season, the space acts as a buffer between the exterior and interior, and can be used to temper outdoor supply air. During the cooling season, warm interior air is exhausted into the space. There is currently discussion among building science experts that, at least for cold climates, a less expensive way of achieving energy savings might be through the use of curtain walls with high (over R-6) insulating values. **Point-supported glass, structural glass mullions** and use of **tension structures** are recent technologies.

Relevant Codes and Standards
Curtain Wall Design and Selection


Thermal Performance

- AAMA 1503 Voluntary Standards for Thermal Transmittance and Performance
- AAMA 501.5 Test Method for Thermal Cycling of Exterior Walls
- NFRC 100 Procedure for Determining Fenestration Product U-Factors

Solar Heat Gain Coefficient

- NFRC 200 Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence

Solar Optical Properties

- NFRC 300 Test Method for Determining the Solar Optical Properties of Glazing Materials and Systems (PDF 184 KB, 16 pgs)

Air Infiltration

- AAMA 501 Methods of Test for Exterior Walls
- ASTM E283 (laboratory)
- ASTM E783 (field)
- NFRC 400 Procedure for Determining Fenestration Product Air Leakage

Water Penetration Resistance

- AAMA 501.1 Methods of Tests for Exterior Walls - Dynamic Test (laboratory)
- AAMA 501.2 Methods of Tests for Exterior Walls - Hose Test (field)
- ASTM E331 (laboratory)
- ASTM E547 (laboratory)
- ASTM E1105 (field)

Condensation Resistance Factor

- AAMA 1503.1 Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors, and Glazed Wall Sections
- NFRC 500 Procedure for Determining Fenestration Product Condensation Resistance Values (PDF 256 KB, 16 pgs)

Seismic Loads

- AAMA 501.4 & 501.6 Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts and Recommended Dynamic Test Method For Determining the Seismic Drift Causing Glass Fallout from a Wall System

Structural Uniform Loading by Static Pressure

- ASTM E 330 (laboratory)

Acoustical Performance

- AAMA 1801 Voluntary Specifications for Acoustical Ratings
Anodized Coatings

- **AAMA 609 Cleaning and Maintenance Guide**
- **AAMA 610 Cleaning and Maintenance Guide**
- **AAMA 611 Voluntary Specification for Anodized Architectural Aluminum**

High Performance Organic Coatings

- **AAMA 2604 Voluntary Specification for High Performance Organic Coatings on Aluminum Extrusions and Panels**

Additional Resources

**WBDG**

**DESIGN OBJECTIVES**
Functional / Operational—Ensure Appropriate Product/Systems Integration

**PRODUCTS AND SYSTEMS**

Organizations

- **American Architectural Manufacturers Association (AAMA)**—information on aluminum curtain walls.
Introduction

Skylights have been used for over a century to provide interior daylighting. Early skylight systems consisted of plate glass (later wire glass) in metal frames and frequently incorporated both an exterior skylight and a decorative interior "diffuser" or "laylight". Most contemporary skylights now consist of insulating glazing captured in aluminum frames that in many configuration (e.g. single slope, ridge, pyramid, barrel vault). Skylights are engineered systems that are assembled from standard or custom extrusions provided by skylight manufacturers, and i.e. units made by glazing fabricators, but they share common design elements required to make them perform. This page uses the term "skylight" to describe field-assembled systems of sloped glazing. In the construction industry, the term "skylight" is often applied to relatively small shop-fabricated unit-skylights, frequently with plastic glazing. These unit skylights are not specifically addressed in this page.

Description

The following covers brief descriptions of typical skylight components:

**Supporting members:** Rafters spanning from sill to ridge, cross bars between the rafters, and pressure bars that that clamp the edges of the glass to the rafters. The pressure bars are frequently covered by rafter caps to conceal the fastener heads and shield them from rainwater.

**Infill panels:** Generally glass (see Designing for Finish Durability—I.G. Unit Failure Avoidance and Fracture and Glazing Retention (below) for typical configuration and design advice), but also proprietary translucent products, such as fiberglass sheets or fiberglass sandwich panels (not addressed in this page).

Fundamentals (Functions)

**Thermal Performance (Conduction, Solar Radiation, Thermal Break, Comfort)**

Skylights experience significant summertime solar heat gain and wintertime heat loss that must be calculated and accounted for in mechanical design. This aspect of the design is discussed in the Building Envelope Design Guide page Atria Systems. The thermal performance of a skylight is largely a function of the thermal performance of the glazing; see the discussion in Glazing on thermal performance.

**Moisture Protection (Water Penetration, Condensation Resistance)**

Functionally, skylights are roofs and are therefore exposed to a larger volume of rainwater and are much more susceptible to water leakage than vertical fenestration systems. Even for new, well-sealed skylight assemblies, some leakage beyond the exterior glazing is inevitable. Similar to windows and curtain walls, skylights are subject to wintertime condensation when the surface temperature of the interior glass surfaces falls below the dew point for the interior conditions. The leakage and condensation must be collected and drained to the exterior with a continuous drainage system consisting of interconnected condensate gutters and sill flashing.

See the discussion on moisture protection in Glazing that applies here as well.
Visual (Daylighting, Aesthetics)

Skylights have historically been used to daylight interior spaces, taking advantage of both the energy savings and positive psychological effect of natural over artificial light. The exterior appearance of skylight surfaces is largely determined by the glazing used; see the discussion in Glazing.

Sound (Acoustics)

Like other glazing systems, sound transmission through skylights is largely a function of the sound transmission through the glazing. See Glazing for a discussion. Similar to window and curtain wall systems, reducing sound transmission through skylights requires an integrated strategy that includes not only decreasing the sound transmission through the glazing (e.g. by adding laminate thickness, laminate layers, glass thickness, or airspace), but also through the perimeter construction (i.e. reducing air leaks).

Safety

Skylights increase the hazard associated with glass breakage substantially. Building codes have long stipulated post-breakage glass retention for skylights in non-residential buildings to help protect occupants. Effective glass retention requires either laminated glass, glass with an anchored film on the inboard surface, or separate interior screens to capture falling glass.

Fire safety (e.g. automatic sprinklers and smoke evacuation requirements) are addressed in Atria Systems.

Health and Indoor Air Quality

Commonly used skylight framing and glazing materials (e.g. aluminum framing, rubber gaskets, cured silicone sealants) typically do not contribute to indoor air quality problems. But water leakage from poorly designed or constructed skylights, or from defective perimeter flashings, can and often do contribute to mold and mildew growth and resultant indoor air quality problems. Design and construction details that exclude water penetration are critical to avoiding indoor air quality problems. See Applications and Design Advice (below) for design detail guidance.

Durability and service life expectancy

Aluminum is inherently corrosion resistant in most environments; see the discussion in Windows, which applies here as well.

Causes of i.g. unit failure in skylights are discussed in Glazing. The additional exposure to the effects of ultraviolet light, which accelerates aging of glazing sealants, and to larger amounts of precipitation, tend to stress sloped glazing considerably more than vertical glazing and translate into reduced life expectancy of skylight glazing compared to windows. Typical industry warranties are five years for sloped insulating glazing, compared to ten years for vertical glazing.

Maintainability and Repairability

Service life and required maintenance for typical aluminum frame coatings are discussed in Windows. Finishes on sloped frame surfaces, and perimeter sealants on sloped glazing, deteriorate at a faster rate than for vertical windows for the reasons noted in the paragraph above.

Skylights require cleaning of both the interior and exterior glazing surfaces. For larger skylights, cleaning requires special access provisions, such as dedicated scaffolding or anchors for suspended scaffolding or industrial rope access equipment. These access provisions must meet Occupational Safety and Health Administration (OSHA) standards.

Sustainability

I.g. units in skylights have a shorter life expectancy than i.g. units installed in vertical windows and curtain walls. Nonetheless, where energy consumption is a concern, there are no reasonable alternatives to insulating glazing for skylights.
The natural light provided by skylights can reduce electricity demand for lighting. The USGBC's LEED rating system allows credits for daylighting, and skylights are a common design feature in Green buildings. Reduced lighting costs are often outweighed by increased energy demands for heating and cooling of the interior space as a result of increased heat loss or heat gain through skylights compared to conventional roofs. Case-by-case engineering analysis is required to determine the energy payback, and life cycle cost associated with skylights; see the discussion in Atria Systems.

The "recyclability" of glazing and aluminum framing is discussed in Windows.

Applications and Design Advice

Establish System Track Record

Similarly to curtain walls and discontinuous windows, the first step to a successful design is the selection of a skylight system which has a demonstrated successful track record in similar applications and exposures. ASTM E1825—Standard Guide for Evaluation of Exterior Building Wall Materials, Products, and Systems provides guidance for evaluating a system's track record. In addition to the system's track record, the designer should evaluate laboratory test results for the system (structural wind resistance, water penetration and air leakage resistance, condensation resistance, etc.) to establish that the stock system is capable of meeting the site-specific project performance requirements.

Design for Waterproofing Performance

A successful skylight design acknowledges that it is unlikely to prevent water penetration through the skylight under all conditions, and provides a collection system to guard against leakage and condensation drips. The following are good design practices for skylights:

- Provide a continuous system of gutters, integral with the skylight rafters and cross members, to collect leakage and condensation. The cross member gutters must be notched at their ends to assure drainage into the rafter gutters. Water must be drained from gutter to gutter and never onto i.g. units below.
- Provide an exterior wet seal. A wet seal consisting of non-curing butyl glazing tape and an exterior silicone cap bead, and installed with proper workmanship, provides better waterproofing performance than a dry gasket.
- Select a system with continuous rafters. Skylights frequently leak where individual rafter sections are spliced together to make up a single longer section because the gutters are not continuous. Providing membrane patches or similar repairs to splice rafter gutters together is not reliable. Most skylight manufacturers can fabricate, finish, and ship rafter sections up to 30 ft. long. However, transporting, hoisting, and installing very long rafters is difficult and the logistics of this work (e.g. truck access, crane required for hoisting, etc.) must be worked out during design.
- Provide a continuous metal sill flashing to collect leakage and condensation. The flashing should be sloped and drain to the exterior. See Exterior Wall for integration of the sill flashing with the exterior envelope of the building.
- Provide flush-glazed horizontal mullions without exterior applied pressure bars to avoid bucking water run-off.
- Provide a minimum skylight slope of 3/12.
- Coordinate the waterproofing with the attachment details. Providing a sloped sill flashing typically requires a sloped curb.

Design for Condensation Resistance

Skylights are prone to condensation in cold regions. The skylight design should include establishing the required condensation resistance factor (CRF) based on anticipated interior humidity and local climate data, and selecting a system that meets this CRF. Similar to windows, the U-value for the glazing is not sufficient to define the energy use or condensation potential for the whole system, including the framing. The designer must evaluate the entire system including perimeter conditions, for condensation potential. For high interior humidity buildings, such as swimming pools or museums, computer modeling of the skylight and its thermal and moisture exposure, is required to prepare a design that
limits or avoids condensation.

**Coordinate with Mechanical, Structural, and Lighting Designer**

Coordinate the skylight configuration and proportions with the MEP designer. Excessive heat loss or gain and excessive light levels or glare, are frequent complaint about skylights. The mechanical design must include provisions to accommodate the thermal loads imposed by the skylight. Sometimes shading is necessary to reduce light levels. See [Atria Systems](#) for additional discussion.

Access provisions for skylight cleaning may require significant structural capacity. Current OSHA-required design loads for safety tie-offs are 5,000 lbs. Scaffold anchors or safety tie-offs cannot be supported by typical skylight framing and require dedicated structural framing.

**Design for Differential Movement**

Most skylights are framed with aluminum rafters, which undergo significant movement in response to daily and seasonal temperature changes. This movement must be accommodated in the attachment detail to prevent the introduction of stresses caused by restrained movement. Rafters in typical single-slope skylights have a single pinned gravity load anchor and one or more wind load anchors in sliding connections. The structural attachment details must be determined on a case-by-case by the structural engineer and the skylight manufacturer. In some systems, structural steel framing supports the aluminum skylight framing. Since steel and aluminum have significantly different coefficients of thermal expansion, the aluminum-to-steel connections must be designed to accommodate the expected differential thermal movement.

**Designing for Finish Durability**

See the discussion in [Windows](#). Note that the service life of finishes on sloped frame surfaces is shorter than for vertical frame surfaces.

**Designing for Glazing Durability—I.G. Unit Failure Avoidance**

As for other fenestration system, the key to avoiding i.g. unit fogging due to in-service conditions is to keep water away from the glazing perimeter. Skylights that employ discrete metal stops to support the bottom edge of the glazing are less susceptible to ponding water than systems with a continuous sill support that may allow water to accumulate. Design strategies that limit water penetration (see above) are critical to glazing durability. See [Glazing](#) and [Windows](#) for additional discussion of i.g. unit failure.

**Designing for Glazing Durability—Fracture and Glazing Retention**

As in windows and curtain walls, good glazing practice that prevents glass-to-metal contact is necessary for fracture avoidance. I.g. units must be installed with appropriately spaced setting blocks and anti-walk pads. See the discussion in [Glazing](#).

Skylight glazing is sometimes broken by flying stones from adjacent ballasted roofs or gravel-surfaced roofs, or by fragments from glass breakage above the skylight. The skylight design should include a review of the potential for such damage, including the possibility of gravel ballast being blown off adjacent roofs. Providing roof parapets or avoiding gravel roof ballast altogether limit the risk of breakage. In locations where debris impacts are likely, skylights can be protected with a protective metal grate installed on the top surface above the glass. Where there is an elevated risk of glass breakage, or the consequences of glass breakage are significant, providing thicker-than-minimum PVB interlayers (e.g. 0.06 or 0.09 in. instead of typical code-required 0.03 in.) in the laminated interior lite is appropriate. All lites in the skylight glazing should be heat-strengthened to limit the risk of fracture. Monolithic fully-tempered glass should not be as the inboard lite of a skylight to avoid fall-out associated with spontaneous fracture; see the discussion in [Glazing](#).

**Logistical and Construction Administration Issues**

Similar to other exterior wall and roof systems, the most important construction administration tasks for a successful
skylight project are mock-up testing and quality assurance during construction. The following are critical:

- Require continuity between the shop drawing process and construction. Some curtain wall and skylight manufacturers work diligently with the designer during the shop drawing process, but do not work equally hard to convey the important installation details to the field crews during the installation phase. Requiring a manufacturer's representative familiar with the system and the shop drawings on site during construction helps ensure implementation of the design as shown on the shop drawings. This is especially important at the beginning of the work.

- Design the skylight and perimeter construction to allow component replacement. Match the life expectancy of components that are mated together into an assembly. For example, detail skylight transitions to adjacent roofs to allow replacement of the roof membrane without disassembly of the skylight. Use durable flashing materials, such as stainless steel sill flashing, instead of membrane flashing.

- Skylights that avoid horizontal pressure bars (see above), rely on structural silicone glazing to transfer wind suction loads from the glazing to the cross bars. Adhesion testing (typically performed by the silicone manufacturer) is required to verify design values for structural silicone joints. Also, for structural glazing, the sealant manufacturer must review the skylight shop drawings to check for appropriate sealant joint design, sealant joint constructability, and field application methods.

- Verify skylight performance using mock-ups. The mock-ups should include all representative perimeter construction details (sill, hip, head, rake), and should be tested for air and water penetration resistance.

Details

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Sloped Glazing—Eave Flashing (Detail 3.4-1)  [DWG]  [DWF]  [PDF]

The detail shows a skylight eave detail on a framed curb.

- The sill has a continuous metal sill flashing that collects condensation and leakage. Skylight rafter gutters are notched to allow drainage onto the flashing.

- The curb has a sloped sill (shown here constructed with a bent steel plate) to provide a sloped substrate for the sill flashing.

- The skylight framing incorporates weep holes in the glazing pocket (to limit the risk of i.g. unit failure), the condensate gutter in the sill closure piece, and the sealant joint between the sill closure and the metal sill flashing. Weep holes are covered with weep hole baffles or open-cell foam to close off entry ways for insects.

- The skylight framing attachment to the building structure below incorporates provisions for thermal movement.

Sloped Glazing—Sill Detail at Transition to Steep Roof (Detail 3.4-2)  [DWG]  [DWF]  [PDF]

The detail shows a skylight eave detail within a steep roof assembly. It is similar to Detail 3.4-1 except that the metal sill flashing also provides counterflashing for the steep roof assembly. See Roofing Systems for more discussion on steep-slope roofing systems.

Sloped Glazing—Vertical Rafter Detail at Transition to Steep Roof (Detail 3.4-3)  [DWG]  [DWF]  [PDF]

The detail shows a skylight rake detail within a steep roof assembly. A metal counterflashing for the step flashing that forms the transition from the roof to the rafter is integrated into the pressure bar detail. See Roofing Systems for more discussion on steep-slope roofing systems.

Sloped Glazing—Ridge Detail at Transition to Steep Roof (Detail 3.4-4)  [DWG]  [DWF]  [PDF]

The detail shows a skylight ridge with a steep roof assembly.

- The top of the skylight is protected with a continuous cricket. The cricket is sloped to shed water toward the skylight rakes. The metal flashing of the cricket must be selected to limit the risk of galvanic corrosion of the aluminum rafter caps.

- The membrane underlayment for the cricket flashing must be heat resistant to prevent premature aging or bleed-out of adhesives. See additional discussion in Roofing Systems on underlayment membranes.
The detail illustrates the proper integration of the skylight cross bar with the vertical rafters.

- Like the rafters, the cross bar incorporates integral gutters to collect and conduct condensation and small amounts of leakage. The cross bar gutters are notched to allow drainage into the larger rafter gutters beyond.
- The weight of the i.g. unit is supported on aluminum stops that are keyed or screw-fastened into the cross bar.
- A screw-applied shear block within the cross section of the cross bar transfers structural loads from the cross bar to the skylight rafters. The concealed shear block complicates skylight assembly significantly, but provides more reliable attachment than screwed connections.
- The flush glazing sealant detail between the top and bottom light is more reliable than horizontal pressure bars, but typically requires structural silicone glazing to withstand wind loads.

The detail shows a vertical rafter cross section.

- Integral rafter gutters collect condensation and small amounts of leakage and conduct them to the sill flashing; see above.
- A continuous snap-on cover conceals the pressure bar and fasteners that retain the glazing unit. A separate cover provides more reliable protection against leakage than exposed pressure bars and fasteners, which are prone to leakage at fastener penetrations.

The detail shows an isometric cut-away view of the main skylight components and illustrates the continuity of the water management system formed by the cross-bar gutters, rafter gutters, and sill flashing.

- Condensation that forms on the inboard side of the i.g. units and on the cross bars drains to the integral cross bar gutters. Notched ends in the cross bar gutters allow drainage into the rafter gutters.
- The rafter gutters are collected on the sloped sill flashing (see Details 3.4-1 and 3.4-2) and drain to the exterior at weeps in the sealant joint between flashing and skylight frame sill.

Emerging Issues

*Easy-to-clean glass* with titanium dioxide coatings is sometimes used in sloped glazing to reduce the maintenance effort associated with glass cleaning; see the discussion in [Glazing](#).

*Building-integrated photovoltaic (BIPV) systems* are integrated into the building envelope to convert sunlight into electrical energy. The solar cells that are part of the system are sometimes built into roofs and skylights rather than exterior walls to take advantage of the additional sunlight captured by sloped surfaces. Because the solar cells are generally not specifically designed as waterproofing elements, they typically require installation outboard of the building envelope. See the [BIPV Resource Page](#) in the Whole Building Design Guide for additional information.

Relevant Codes and Standards

**Skylight Design and Selection**

- [AAMA Manual 4 Skylights and Space Enclosures](#)

**Thermal Performance**

- [AAMA 1503 Voluntary Standards for Thermal Transmittance and Performance](#)

**Air Infiltration**

- [ASTM E283](#) (laboratory)
- [ASTM E783](#) (field)
Water Penetration Resistance

- **AAMA 501 Methods of Tests for Exterior Walls**
- ASTM E331 (laboratory)
- ASTM E547 (laboratory)
- ASTM E1105 (field)

Acoustical Performance

- **AAMA 1801 Voluntary Specifications for Acoustical Ratings**

Anodized Coatings

- **AAMA 609 Cleaning and Maintenance Guide**
- **AAMA 610 Cleaning and Maintenance Guide**
- **AAMA 611 Voluntary Specification for Anodized Architectural Aluminum**

High Performance Organic Coatings

- **AAMA 2604 Voluntary Specification for High Performance Organic Coatings on Aluminum Extrusions and Panels**

Additional Resources

WBDG

**DESIGN OBJECTIVES**
Functional / Operational—Ensure Appropriate Product/Systems Integration

**PRODUCTS AND SYSTEMS**
Section 07 92 00: Joint Sealants. See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

- **American Architectural Manufacturers Association**, information on sloped glazing systems

Also see the additional resources listed in **Glazing**, **Windows**, and **Curtain Walls**.
Introduction

This Chapter includes entrance and exit doors, as well as industrial loading dock doors, and addresses waterproofing and durability requirements, primarily. This Chapter covers aluminum- and steel-framed doors, with or without glass panel in-fills, and frameless glass doors. It does not cover wood-framed doors. The following describes common functions served by the door types covered in this chapter:

Entrance and exit doors generally serve as building entrances for the general public or as service entrances for building operations personnel. They typically serve double-duty as emergency egress. The International Building Code (IBC), government regulations, including the Americans with Disabilities Act (ADA), and local codes govern many entrance/exit door requirements pertaining to life safety and accessibility. These requirements are beyond the scope of this chapter.

Industrial Doors provide access for material handling in buildings. Although functionally "doors", they are typically rolling or coiled gates, or sliding security grilles, that can open large apertures in a building wall to allow unloading and loading trucks that back up to an elevated dock, or to allow building access for vehicles.

Description

The following presents brief descriptions of commonly used door types and their components:

Common door types include:

- Swing doors, generally serving Entrance/Exit functions.
- Revolving doors, generally serving Entrance/Exit functions.
- Industrial (e.g. overhead) doors, serving material handling and security functions.

Commonly used door materials include aluminum, steel, wood and glass. Doors that are integrated with commercial storefronts are typically aluminum frames with glass in-fills, or all glass. Steel-clad doors are generally utilized for service entrance/exit functions. Wood doors are most commonly employed in low density residential construction. Monumental wood or wood-and-glass doors are sometimes used in commercial or institutional buildings. Wood doors are beyond the scope of this chapter.

Industrial doors are used for material handling, not for pedestrian access. Their main function is to provide security. They are, therefore, frequently not designed for building envelope performance. Security grates or doors are typically installed over more conventional storefront systems. Typical materials for exterior applications are steel, aluminum, and stainless steel. The doors also frequently incorporate glass in-fill panels. Rolling doors typically consist of a steel frame that is anchored to the perimeter construction to resist wind and operating loads, structural guides for the door edges, and a hood that contains the rolled up "curtain" when the door is in the open position. Larger industrial doors are motorized; smaller units can be operated by manual push-up, chain hoists, or cranks. Motorized doors are often opened and closed with automatic gate operators.

Fundamentals (Functions)

Egress
Egress requirements for Entrance/Exit doors are governed by the applicable building code based on building use, occupancy load, and door type (swing, sliding or revolving). Chapter 10 of the IBC—Means of Egress—contains egress requirements, including minimum door height and width, maximum door leaf width, panic hardware, step down dimensions to the exterior, requirements for threshold geometry, door swing direction (in direction of egress travel for occupancy loads greater than 50 people or for high hazard occupancy), illumination, operating force, signage, etc. Revolving doors must fold flat in the direction of egress and have outswinging doors nearby. A further discussion of egress requirements for Entrance/Exit doors is beyond the current scope of this chapter.

**Accessibility**

The intent of accessibility regulations is to allow persons with physical disabilities to independently enter and use a building. Because non-compliant doors can present obstacles to wheelchair-bound individuals, door design must account for accessibility. Accessibility requirements for Entrance/Exit doors are governed by the applicable building code as well as federal regulations. Chapter 11 of the IBC—“Accessibility”, contains requirements for number, location, and configuration of doors that comply with the ADA. For the purposes of this Chapter, discussion of accessibility is limited to the features of accessible doors namely their low threshold heights required to accommodate wheelchairs, that affect their waterproofing performance. A more detailed discussion of accessibility requirements is beyond the scope of this chapter.

**Thermal performance (conduction, solar radiation, thermal break, comfort)**

Doors are frequently problematic components of a building's thermal envelope. Typical issues include heat loss from air movement during operation, heat loss from air movement through the perimeter detail, and radiant heat loss through the door materials themselves. Door frames that do not incorporate adequate thermal isolation form thermal bridges that tend to lead to wintertime condensation. Overall door thermal performance is a function of the type of operation (e.g. swing, sliding, revolving), the glazing (if applicable), the frame and perimeter details, the sash and sash weatherstripping, and the door materials.

Aluminum-framed doors that are part of curtain wall or storefront assemblies sometimes have thermally-broken frames and insulating glass units, which provide improved thermal performance. See the discussions in Glazing and Curtain Walls. Opaque entrance doors or loading dock doors often have foamed-in-place insulation between their exterior and interior metal skins, which typically provides better thermal performance than insulating glass. These insulated doors must have internal stiffeners to stiffen the face skins and provide adequate structural performance.

Heat loss from air leakage is the most significant challenge to thermal performance for heavily used entrance and exit doors. Strategies to limit air loss and improve thermal performance for these doors include:

Revolving doors minimize heating and cooling losses from air movement and minimize wind effects on door operability. Since they cannot be left open, they also make mechanical loads on the building more predictable, and are therefore preferable for the building’s HVAC design. In colder climates, air curtains provide a barrier of fast-moving warm air that limits penetration of cold exterior air while the door is open and are frequently used with sliding doors. The warm air may also be used to raise the surface temperature of the doors, which limits condensation. Entrance vestibules with separate inner and outer doors provide improved energy performance over a single entrance door, mainly by limiting loss of conditioned air during door operation.

When they are closed, all doors rely on weatherstripping between the operable sash and the door frame to limit air movement.

Because the irregular articulated surfaces and mounting hardware of rolling doors do not lend themselves to weatherstripping, the perimeter construction of loading dock doors is notorious for poor air penetration resistance. Because these doors are typically specified for warehouses, garages, and similar applications, thermal performance is often a secondary concern. The air penetration resistance of rolling doors can be improved by providing heavy duty weatherstripping, including vinyl or wool pile weatherstrips along the jambs, a neoprene bulb wiper strip at the front of the curtain, and a neoprene baffle at the top of the coil. These features also help with water penetration resistance; see below.
Moisture protection (water penetration, condensation resistance)

Water penetration resistance is a function of glazing details (see Glazing), frame drainage details, weatherstripping and perimeter details (head, jamb and sill flashing). See Windows for general guidelines on perimeter details of punched openings, which apply to doors as well.

Outswinging doors generally resist water and air penetration better than inswinging doors, because the upturned leg of the threshold is on the interior side of the door and also because exterior positive wind pressures tend to compress the door leaf against the weatherstripping.

Entrances/exits are often recessed from the plane of the exterior wall to avoid opening out into a public way, but also to provide shelter from wind and weather. Entrance vestibules with inner and outer doors provide improved moisture protection performance over a single entrance door. The vestibule itself can be designed to tolerate water by providing water resistant finishes (e.g. concrete or tile), a waterproofing membrane beneath the finishes, and a floor drain. Where a full vestibule is not feasible, an overhanging awning provides some protection from the rain.

Door thresholds frequently leak. To collect this water penetration and drain it back to the exterior, sill flashings with a panned up interior leg and end dams are required. The sill flashing, if properly designed and installed also serves to collect and expel water that is collected by the jamb flashing, which has to shingle into the sill flashing. The waterproofing performance of door thresholds can be improved by increasing the threshold height, but threshold height is frequently limited by ADA requirements.

Visual (Daylighting, Aesthetics)

Entrances and Exits frequently include glazed doors. Key visual features of glazed doors include glazing appearance (see Glazing) and frame sightlines. Frameless (all glass) doors maximize the glass area, generally at a cost premium.

Sound (Acoustics)

The acoustic performance of doors is primarily a function of the air leakage around the door, the materials (see Glazing for a discussion of strategies to limit sound transmission for insulating glazing, which is applicable to doors with large vision lites or all-glass doors). Sound attenuation through doors can be improved by increasing the mass of the frames and sash, improving the airtightness of the glazing, sash-to-frame and frame-to-perimeter joints, and placing sound-absorptive materials at the perimeter of the doors.

Revolving doors and entrance vestibules with inner and outer doors provide improved acoustic performance by limiting air leakage during door operation.

Safety

Glass in doors should be safety glazing; see the discussion in Glazing.

Motorized rolling doors and security grates must have a safety system that reverses the direction of door travel when they encounter an obstruction. This feature is intended to prevent serious injuries from pinching or crushing. Obstruction-sensing devices include pressure sensors in the leading edge of the door, or photo eye sensors. Motorized revolving doors require similar obstruction-sensing devices.

Operating and Security hardware, Access control

Operating and security hardware and access control are key design features for doors. Important design issues include:

- Panic hardware for egress doors
- Electronic access control systems
- Automatic operators for security and accessibility
- Locking hardware
Health and Indoor Air Quality

Water leakage through or around doors can contribute to indoor air quality (IAQ) problems by supplying moisture for mold growth. This leakage can often remain concealed within the wall system or flooring and not become evident until concealed wall components experience significant deterioration and mold growth. See the section on moisture protection (Section 3.4 above) for a discussion.

Revolving doors and double-wall vestibules limit ingress of airborne pollutants and dust particles by reducing air flow through doors. The U.S. Green Building Council’s LEED Rating System includes credits for Indoor Chemical and Pollutant Source Control. To obtain a portion of the credits, a project must have "permanent entryway systems (grills, grates, etc.) to capture dirt, particulates, etc. from entering the building at all high volume entryways.” The grills and walk-off mats necessary for this system are often housed in a vestibule.

Durability and Service Life Expectancy

Wear and Tear: Since they are used intensively, doors will typically have a shorter service life and higher maintenance requirements than other building envelope components such as curtain walls and windows. Entrance doors must be able to handle the ingress/egress demands of the building. Intensity of use is measured by cycles of operation. ANSI A250.8—Recommended Specifications for Standard Steel Doors and Frames, and ANSI A250.4—Test Procedure and Acceptance Criteria for Physical Endurance for Steel Doors, Frames, Frame Anchors and Hardware Reinforcings, establish the following Performance Classifications and swing-and-latch test cycles:

- Level C, Standard Duty — 250,000 cycles
- Level B, Heavy Duty — 500,000 cycles
- Level A, Extra Heavy Duty — 1,000,000 cycles

Life cycle operation durability is a function of door leaf (i.e. sash) construction (e.g., size and thickness of aluminum frames, thickness of steel sheet facings), frame construction, durability of hardware, etc.

Corrosion Resistance: Aluminum frames are inherently corrosion resistant in many environments if anodized and properly sealed or if coated with baked-on fluoropolymer paint. Aluminum frames are subject to accelerated deterioration of the coating and corrosion of aluminum in severe (industrial, coastal) environments, and galvanic corrosion from contact with dissimilar metals. Doors and storefronts are frequently exposed to de-icing salts that degrade frame and sash finishes and base materials.

Steel doors depend on an applied coating for corrosion resistance. Coating systems that include a galvanic protection primer (e.g. zinc-rich paint, hot dipped galvanizing) in combination with a barrier coat of paint provide significantly better corrosion resistance than coating systems that rely on a barrier coat of paint alone.

Maintainability and Repairability

Doors and perimeter sealants require maintenance to maximize their service lives. Perimeter sealants, properly designed and installed with high quality material, have a typical service life of 10 to 15 years although some breaches are likely from day one. Perimeter sealants require careful surface preparation to minimize breaches and maximize surface bond.

Ungalvanized steel frames require frequent inspection and maintenance of coatings. Steel frames that have galvanic protection under the paint can generally tolerate longer intervals between paint maintenance than those without galvanic protection. Hollow steel doors with direct exposure to the weather often rust prematurely, even if they are galvanized and frequently repainted, because water inevitably finds its way between the exterior and interior steel sheets, causing the doors to rust from the inside out.

Aluminum frames are painted or anodized. Factory applied fluoropolymer thermoset coatings have good resistance to environmental degradation and require only periodic cleaning. Recoating with an air-dry fluoropolymer coating is possible but requires special surface preparation and is not as durable as the baked-on original coating.
Anodized aluminum frames cannot be "re-anodized" in place, but can be cleaned, restored visually, and protected by proprietary clear coatings that require frequent re-application.

Door hardware requires frequent inspection, adjustment, and lubrication.

**Sustainability**

The best strategy for sustainability of doors is to employ good design practices to ensure the durability (maximum service life) of the installation.

Aluminum and steel frames can be recycled at the end of their service lives. Salvage and demolition contractors generally require a minimum of 1,000 sq ft or more of curtain wall/storefront to make material recycling economical (smaller amounts are generally disposed as general trash). Recycling is less economical if the aluminum is contaminated with sealants, glass fragments, etc., as salvage companies pay considerably less for the material.

Aluminum window and door frames generally do not incorporate post-consumer recycled material because manufacturers have reported problems with the appearance and durability of anodized coatings. Manufacturers report fewer problems with paint coatings. Most production facilities are set up to recycle their own aluminum scrap (e.g. cuttings, rejected frame sections).

Energy efficiency is an important factor when designing for sustainability. Vestibules and revolving doors improve energy performance.

**Applications**

**Establish System Track Record**

Select a door with a demonstrated track record in similar applications and exposures. Verifying track records may require significant research by the designer. ASTM E1825 provides guidance.

Review laboratory test results of door systems for air, water, and structural resistance, heat transmission, condensation resistance, sound transmission, and operability. Verify that tests pertain to the specific door under consideration and not a version of the door with the same product name but of different construction.

**Designing for Waterproofing Performance**

Designers can provide the following to improve the waterproofing performance of entrance doors:

- **Vestibules or awnings** shield the doors from wind-driven rain.
- **Trench drains** along the door sill, and paving surfaces that slope away from the door, reduce ponded water against the sill.
- **Waterproofing membranes** that extend under the entire vestibule, and shed water toward the exterior (e.g. extensions of the plaza waterproofing) can collect and discharge water that penetrates past the doors. The waterproofing membrane and interior flooring must be carefully detailed to prevent water damage to interior floor finishes from water collected on the membrane, for example, water from the exterior wicking upward in a sand setting bed used to support stone flooring.
- **Continuous perimeter flashings** that collect and expel water that penetrates through or around the frames are vastly more effective than relying solely on perimeter seals or weatherstripping to keep water out. See Windows for guidance on head, jamb and sill flashings that are applicable to doors. These details must be adjusted to reflect the door threshold geometry and fastening requirements. The horizontal portion of the sill flashing must not be penetrated with threshold fasteners. Instead, where attachment of the threshold is required, an attachment angle should be provided inboard of the threshold and fastened through the upturned leg of the sill flashing into the back of the threshold. The threshold should then be recessed flush with the finish floor to avoid a tripping hazard and to protect the inboard upturned leg of the flashing. Where the recessed attachment angle and flashing cannot be accommodated, the sill flashing should have a small upturned leg concealed within the threshold, but inboard of the innermost weatherstripping and fasteners. The sill flashing must extend beyond the jamb to collect leakage from the jamb flashing.
- **Raised door sills and thresholds elevated above the sidewalk to shed water** provide for more reliable
waterproofing details at entrance doors but are almost always at odds with ADA requirements; see 3.4 above for door sill flashing recommendations. Where such limitations do not exist, a minimum threshold height of 6 in. (more if the door sill will be subject to drifted snow) is advisable. Entrance doors at grade will almost always have a flush sill to satisfy ADA regulations, reduce tripping hazards, and to facilitate deliveries. Consider alternative designs utilizing ramps and platforms to comply with ADA requirements while allowing favorable curb, threshold and flashing heights.

- **Out-swing doors**: Outswinging doors generally resist water and air penetration better than inswinging doors, because the upturned leg of the threshold is on the interior side of the door and also because exterior positive wind pressures tend to compress the door leaf against the weatherstripping.

- Weatherstripping alone, even double weatherstripping, is typically not sufficient protection from wind-driven rain in high exposure locations.

- **Roofing**: Vestibules projecting beyond the face of a building require a competent roof. See Roofing Design for design advice on roofing systems.

### Designing for Condensation Resistance

Use thermally broken aluminum frames for improved condensation resistance. AAMA's Window Selection Guide provides guidance on glazed door selection for condensation resistance. Establish the required Condensation Resistance Factor (CRF) based on anticipated interior humidity and local climate data and select a door with an appropriate CRF. Designers should be aware that, similar to windows, the CRF is a weighted average for a door assembly. The CRF does not give information about door cold spots that could result in local condensation. When evaluating a potential door system, carefully review the data contained in the CRF test report for the specific product. The report will contain a listing of interior surface temperatures and locations on both the frame and glazing. In many cases, comparing surface temperature data to the expected interior dewpoint temperature can provide a better measure of condensation resistance than the CRF alone. Projects for which condensation control is a critical concern, such as high humidity buildings, require project-specific thermal modeling. Careful analysis and modeling of interior conditions is required to accurately predict condensation on the glass and frame. Doors that are set well away from perimeter heating elements will have air temperatures along their interior surface that are significantly lower than the design wintertime interior temperatures. Thermal modeling of the building interior using Computational Fluid Dynamics (CFD) software can help establish a reasonable estimate for air temperatures at the inside surfaces of the glass and frame. These interior air temperatures are inputs for window thermal modeling software such as THERM.

Consider frame geometry for thermally conductive frame materials (aluminum, steel). Maximize the mass of framing exposed to the interior to improve condensation resistance.

Refer to AAMA 1503 Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors, and Glazed Wall Sections for descriptions of test method, parameters and equipment for determining U values and CRF’s for door products.

Vestibules and air curtains reduce heat loss at inner doors and creation of cold spots. Both reduce the potential for condensation problems.

### Designing for Finish Durability

**Aluminum**: Class I anodic coatings (AAMA 611, supercedes AAMA 606, 607 and 608) and high performance factory applied fluoropolymer thermoset coatings (AAMA 2604, supercedes AAMA 605) have good resistance to environmental degradation.

**Steel**: The thin steel used in conventional steel-clad doors with steel frames makes galvanized coating as a base for paint a must.

**All frame materials**: Shielding doors from the weather by recessing them back from the exterior face of the wall and/or providing roof overhangs or projecting head flashings or drips is an effective strategy for minimizing water penetration and maximizing the service life of door finishes.

### Hardware

*This section to be developed*
Logistical and Construction Administration Issues

The service life of even the most durable door is likely to be shorter than that of the surrounding exterior wall construction. Therefore, the design of the door and perimeter construction should permit door removal and replacement without removing adjacent wall components that will remain.

The service life expectancy of components that are mated with the door into an assembly should match or exceed the service life expectancy of the door itself. Require durable flashing materials, non-corroding attachment hardware and fasteners, and moisture resistant materials in regions subject to wetting.

Laboratory testing: For projects with custom doors, require laboratory testing of mock-up door prior to production of doors for the project. Have a building technology specialist present to document mock-up door construction.

Field Mock-up: For all doors, stock or custom, require construction and testing of a field mock-up representative of the wall/door assembly for testing and evaluation of constructability, sequencing of trades and integration with adjacent wall elements.

Testing of production doors: Require the field testing of production doors for quality assurance of door fabrication and installation. Require multiple tests early in the construction phase to catch problems early.

Shop drawing coordination: Require door installation shop drawings showing all adjacent construction and related work, including flashings, door attachments, interior finishes, and indicating sequencing of the work. Shop drawings should show isometric or axiometric details of corner assemblies.

Details

See Below-Grade Systems and Wall Systems for more discussion on waterproofing membranes and wall systems.

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

Vestibule Detail with Double Doors (Detail 3.5-1)  DWG | DWF | PDF

This detail shows the construction of a waterproofing membrane under a vestibule.

- The exterior waterproofing membrane continues into the vestibule and is turned up against a curb. The membrane and finish floor slope to the exterior.
- The exterior and interior doors have double sweep gaskets to improve air and water penetration resistance.

Revolving Door Detail (Detail 3.5-2)  DWG | DWF | PDF

This detail shows the construction of a waterproofing membrane under a revolving door.

- The exterior waterproofing membrane continues into the vestibule and is turned up against a curb. The membrane and finish floor slope to the exterior.
- The revolving door frame is mounted to a curb to improve its water penetration resistance.
- The revolving door leaves have sweep gaskets to improve air and water penetration resistance.

Door Sill Detail (Detail 3.5-3)  DWG | DWF | PDF
This detail shows the construction of a sill flashing under a door sill. The sill is mounted flush without a raised curb.

- The door sill has a concealed sill flashing with an upturned end-dam. The flashing has to extend beyond the jamb and is integrated with the jamb flashing; see Detail 3.5-4.
- The sill flashing shingles over the plaza or foundation wall waterproofing membrane below.

Door Jamb Detail (Detail 3.5-4)  

This detail shows the construction of a door jamb.

- The door has a continuous jamb flashing that is integrated with the wall waterproofing. The flashing is sealed to the door frame to provide a continuous air barrier.
- The jamb flashing shingles into the sill flashing; see Detail 3.5-3.

Door Head Detail (Detail 3.5-5)  

This detail shows the construction of a door head flashing.

- The door has a continuous head flashing that is integrated with the wall waterproofing. The flashing extends beyond the face of the wall, is sloped toward the exterior, and has a drip.

Emerging Issues

**Biometric Access Control Systems** include devices that verify a person's identity based on unique personal biometric characteristics, such as fingerprints, before allowing access to high-security areas. Biometric access control systems have been in use for years, but have seen increased use and development recently because of homeland security concerns.

**Blast-Resistant Door and Window Assemblies** are discussed in the Resource Page Blast Safety.

**Energy Star** is a federal initiative to help consumers identify energy efficient products, including doors and windows. Available energy star ratings include residential products only, but the program is expanding to commercial buildings.

Relevant Codes and Standards

**General Building Code Requirements and Safety**

- International Building Code (IBC), Chapters 10 and 11
- UL Bulletin 325 "Safety for Door, Drapery, Gate, Louver, and Window Operators and Systems"

**Accessibility**

- 28 CFR Part 36—ADA Standards for Accessible Design

**Design and Selection**

- ANSI A250.4 for Steel Doors and Frames
- ANSI A250.8 for Steel Doors and Frames

**Thermal Performance**

- AAMA 1503, *Voluntary Standards for Thermal Transmittance and Performance*
- AAMA 1504, *Voluntary Standards for Thermal Transmittance and Performance*
- AAMA 1505, *Voluntary Test Methods for Thermal Performance of Fenestration Products with Multiple Glazing Options*
Air Infiltration

- ASTM E283 (laboratory)
- ASTM E783 (field)

Water Penetration Resistance

- ASTM E331 (laboratory)
- ASTM E547 (laboratory)
- ASTM E1105 (field)

Acoustical Performance

- AAMA 1801—Voluntary Specifications for Acoustical Ratings

Anodized Coatings

- AAMA 609—Cleaning and Maintenance Guide
- AAMA 610—Cleaning and Maintenance Guide
- AAMA 611—Voluntary Specification for Anodized Architectural Aluminum

High Performance Organic Coatings

- AAMA 2604—Voluntary Specification for High Performance Organic Coatings on Aluminum Extrusions and Panels

Additional Resources

WBDG

DESIGN OBJECTIVES

PRODUCTS AND SYSTEMS
Section 07 92 00: Joint Sealants, See appropriate sections under applicable guide specifications: Unified Facility Guide Specifications (UFGS), VA Guide Specifications (UFGS), DRAFT Federal Guide for Green Construction Specifications, MasterSpec®

- American Architectural Manufacturers Association, information on aluminum and wood doors.
- Steel Door Institute, information on steel-clad doors.
- Door and Access Systems Manufacturers Association International, includes information on industrial and loading dock doors, standards pertaining to rolling door performance, and technical data sheets that address installation and design advice.
- Cornell Iron Works, rolling door specialists, includes a good terminology section on industrial and loading dock doors.
Introduction

Prior to the mid-to-late 1970s, almost all low-slope roofs were asphalt or coal tar built-up roofs. However, during the last two decades of the 20th century, a variety of other types of low-slope roof systems began to compete with traditional built-up roofs (BUR). These newer systems included modified bitumens, single-plies, sprayed polyurethane foam, and metal panels. While the modified bitumen systems are related to BUR, the other low-slope alternatives are radically different. Along with new choices of membrane materials, plastic foam roof insulations also emerged in the 1970s. The abundance of materials from which to choose has greatly complicated roof system design.

To select, detail and specify the most appropriate roof system for a project, the architect should ideally have at least a general understanding of the available material options. The purpose of this section is to provide design guidance to architects designing low- and steep-slope roof assemblies on new Federal office buildings.

Note: Low-sloped roofs are defined as those roofs with a slope less than or equal to 3:12 (25 percent). However, with the exception of metal roofs, most low-slope roofs have a slope of about ¼:12 (2 percent). Steep-slope roofs are defined as those roofs with a slope greater than 3:12 (25 percent). As discussed in the Description section, some materials can be used on both low- and steep-slopes, while others are limited to either low- or steep-slope.

Scope

The Description section discusses roof assembly materials, including roof decks, air and vapor retarders, roof insulations and roof coverings. The Application section discusses system selection criteria, warranty considerations, key elements of drawings and specifications, and construction contract administration. The Details section discusses and presents various details. The remaining section are Emerging Issues, Relevant Codes and Standards, and Additional Resources.

For below-grade waterproofing and plaza decks, see Below Grade Systems. For seismic considerations, see Seismic Safety. For blast considerations, see Blast Safety.

Project Delivery

Delivering a successful roof involves two distinct phases. The first phase is the design process. In this phase, the architect needs to have a basic understanding of roof assembly materials and system options, and an understanding of roof design considerations. After identifying the project's requirements, a roof system should be selected that optimally responds to an integration of the project's requirements and the system selection criteria. After the roof system is selected, the specifics of the system (such as deck type, insulation type(s) and thickness, fastener patterns, and warranty requirements) are developed and details are designed. This phase is culminated with the preparation of specifications and drawings that communicate the architect's design concept and requirements to a professional roofing contractor for execution of the work.

The second phase is construction contract administration. In addition to the traditional activities, such as submittal review and field observation, the architect should also inform the building owner about the importance of semi-annual roof inspections and routine maintenance.

Guide Limitations
This Guide is intended to give a relatively brief introduction to roofing and provide special criteria applicable to Federal office buildings. It addresses the basics, but does not delve deeply into the subject. After gaining a general understanding of the roof assembly options and various issues associated with them, an architect has a choice to make: Either elect to further expand his or her skills and knowledge, or work with professional roofing contractors or roof consultants. Years ago, it was uncommon for architects to work with a roof consultant or call upon a trusted contractor for advice. But the complexities brought on by the BUR alternatives now demand the inclusion of a roof consultant as part of the design team, if this expertise is not developed within the architect’s office.

At the very least, architects should have some key reference materials in their office. These materials are discussed within the following Sections. If an architect desires to develop his or her expertise rather than use consultants, a concerted and continuing effort will be necessary.

Description

When specifying roof assemblies, designers have many materials from which to choose. This section provides a brief overview of the primary roof deck, air retarder, vapor retarder, insulation and roof covering materials used in the U.S. For further information on these materials, refer to *The NRCA Roofing and Waterproofing Manual* (published by the National Roofing Contractors Association). Roof system selection criteria are discussed in the Application section. Combining the various materials into assemblies is also discussed in *The NRCA Roofing and Waterproofing Manual* and in the Unified Facilities Guide Specifications.

The term *roof assembly* includes the roof deck, air or vapor retarder (if present), roof insulation (if present) and the roof covering. The term *roof system* refers to the air or vapor retarder (if present), roof insulation (if present) and the roof covering.

The following are included in this section:

**Roof Decks**
- Air Retarders
- Vapor Retarders
- Insulation
- Low-slope Roof Coverings (slope less than or equal to 3:12)
  - Built-up Roofs
  - Modified Bitumen
  - Single-ply
  - Sprayed Polyurethane Foam
  - Metal Panels
- Steep-slope Roof Coverings (slope greater than 3:12)
  - Metal Panels and Shingles
  - Asphalt Shingles
  - Slate
  - Tile

**Roof Decks**

Office buildings typically have steel or concrete decks, although plywood or OSB decks are also used on smaller buildings. The deck can have significant influence on the roof system.

Of the deck types, steel is the most common. Although prime-painted steel decks with welded connections are typically specified, it is recommended that galvanized decks be specified in order to obtain greater corrosion protection in the event of roof leakage. It is also recommended that screw-attachment be specified in lieu of welding, because screws provide more reliable attachment.
Air Retarders

If the roof membrane is monolithic (i.e., a membrane roof) it serves as an air retarder. However, separate air retarders are sometimes incorporated into roof systems. When air retarders are incorporated into wall systems, they are normally included to address moisture and/or energy consumption issues. When an air retarder other than the roof membrane is incorporated into a roof system, it is normally included to address wind performance issues as discussed in Wind Safety.

The deck itself can be a retarder if it is monolithic, such as cast-in-place concrete. When the deck is used as an air retarder, deck penetrations such as plumbing vents should be sealed, and the deck should be sealed at parapets. However, a separate sheet material such as 6 mil polyethylene, housewrap, a two-ply built-up membrane or a one-ply modified bitumen sheet is typically used to create an air retarder. Air retarders are further discussed in A Guide for the Wind Design of Mechanically Attached Flexible Membrane Roofs (2005).

Vapor Retarders

Vapor retarders are typically constructed with sheet materials such as 6 mil polyethylene, a two-ply built-up membrane or a one-ply modified bitumen sheet. Housewrap should not be used for a vapor retarder because it has inadequate vapor flow resistance.

Insulation

There are two categories of roof insulation, rigid and non-rigid. Rigid boards are typically used in low-slope assemblies. Non-rigid insulations are typically used in attic spaces and in pre-engineered buildings. See the section on Sprayed Polyurethane Foam for more information on this type.

RIGID INSULATION BOARDS

Board-stock insulation has sufficient compressive resistance to support the roof membrane. The following common types of rigid insulation boards are available:

**Perlite:** This is a low R-value insulation (R-2.78 per inch). It is commonly used as a cover board (see Note below). It has good fire resistance, but when exposed to water, it loses compressive resistance, turns to mush and can be easily compressed. ½” thick boards have a greater percentage of organic material content than do ¾” or thicker boards. Hence, when hot asphalt is applied over ½” boards, the potential for development of blisters in built-up and hot-applied modified bitumen membranes is increased.

Note: A cover board is a thin layer of insulation (such as perlite or wood fiberboard) or glass mat gypsum roof board. Cover boards are commonly placed over the primary thermal insulation (typically one of the plastic foam insulations) in order to provide an enhanced property, such as improved fire resistance, compressive resistance, or to avoid blistering or avoid a compatibility problem. Cover boards are also commonly used in re-covering to provide a separation layer between the existing and new roof membranes. Some types of cover boards are sometimes specified for use directly over steel roof decks in order to provide a thermal barrier to provide fire protection between steel decks and certain types of plastic foam insulation (the IBC specifies thermal barrier requirements).

**Polyisocyanurate:** This is a high R-value insulation (R-5.6 per inch using NRCA's "in-service" recommendation, or approximately 6.0 for one inch using the Long-Term Thermal Resistance (LTTR) method for determining resistance. This is one of the plastic foam insulations. It is widely used in low-slope roof systems.

**Polystyrene:** There are two types of polystyrene insulation, molded expanded and extruded expanded. The two types have distinctly different properties. Polystyrene is one of the plastic foam insulations.

Polystyrene boards should not be in direct contact with PVC membranes, otherwise the polystyrene will leach plasticizers out of the PVC. A suitable separator needs to occur between polystyrene and PVC.

*Molded Expanded Polystyrene (MEPS or EPS):* This is moderate R-value insulation (from slightly less to slightly more than R-4 per inch, depending upon density). The low-density product is relatively inexpensive. Solvent-based adhesive and hot asphalt disintegrate MEPS. Hence, if either of these are used, a suitable cover board needs to be installed over
the MEPS. MEPS can also be decomposed at high temperature. Therefore, MEPS should not be used underneath a black membrane unless a suitable cover board is installed between the MEPS and the membrane.

MEPS cells are filled with air. Therefore, unlike the other plastic foam insulations, MEPS does not thermally age (i.e., loose R-value over time). MEPS is not very resistant to water vapor—when exposed to water vapor drive, MEPS can absorb a considerable amount of moisture.

*Extruded Expanded Polystyrene (XEPS):* This is a high R-value insulation (R-5 for products with a minimum compressive resistance of 25 psi, R-4.6 for products with a minimum compressive resistance of 15 psi).

XEPS is very resistant to water vapor drive. However, as with MEPS, XEPS should not be exposed to solvent, hot asphalt or very high temperature. But unlike MEPS, in order to avoid membrane splitting, XEPS should be used below a built-up or modified bitumen membrane (even if a cover board is installed over the XEPS).

XEPS is the only insulation suitable for use above the roof membrane in protected membrane roof (PMR) systems (see section on this topic). However, boards intended for PMRs need to be specifically manufactured for this application. Some minor water absorption may occur in boards located above the membrane during the roof's service life. To account for the R-value reduction due to the water absorption, it is recommended that the roof designer reduce the board's initial R-value by 10%.

XEPS boards with extremely high compressive resistance are available for use in plaza decks where high compressive loads occur.

**Wood fiberboard:** This is a low R-value insulation (R-2.78 per inch). It is commonly used as a cover board. This board has good compressive resistance. However, when exposed to water, it loses compressive resistance and can be easily compressed.

**Composite boards:** Composite boards typically consist of two layers of different types of insulation that are laminated together in a factory. The primary insulation is typically polyisocyanurate or MEPS. The secondary layer is typically perlite, wood fiberboard, oriented strand board (OSB), plywood or gypsum board. Composite boards made with OSB or plywood are commonly referred to as "nail base." Some nail base products have a small ventilation cavity between the primary insulation and the OSB or plywood.

With some composite boards, the secondary layer (which is typically the top surface) is superficially adhered to the primary layer. With these boards, it is important to mechanically attach the composite board rather than adhere it. Otherwise the secondary layer could easily detach.

**BATT, BLANKET AND BLOW-IN INSULATION**

Batt, blanket or blow-in insulation is commonly used to insulate attics spaces. Blanket insulation is commonly used to insulate roofs of pre-engineered metal buildings. Fiberglass insulation is the most common batt/blanket insulation, and it is also available as a blow-in product. Cellulose (recycled newsprint) is also a common blow-in insulation. If cellulose is specified, specify a product that has been treated for mold and fire resistance.

*Note:* Batt insulation is insulation that is factory pre-cut into lengths of approximately 4', 8' or 9' and bundled without rolling. Blanket insulation is insulation that is supplied in a roll.

**Low-Slope Roof Coverings**

The following membranes are typically used on low-slope roofs, but may also be used on steep-slope roofs. When used on steep-slopes, the system's fire resistance may be reduced and/or special precautions may be needed when used on steep-slopes.

*Note:* Liquid-applied membranes are available, but are not commonly used. They should only be considered when unique circumstances occur.

**BUILT-UP ROOFS (BUR)**
Built-up membranes are composed of alternating layers of bitumen (either asphalt or coal tar) and reinforcement sheets (felts). Fiberglass felts are typically used for asphalt BURs, however, polyester felts are available. The asphalt is typically hot-applied, however, cold-applied asphalt is available (cold-applied asphalt incorporates solvent). The membrane is either adhered to the substrate in bitumen, or a base sheet (i.e., a heavy felt) is mechanically attached. When a BUR is installed over polyisocyanurate, NRCA recommends a suitable cover board be installed over the polyisocyanurate. Four plies of felt are recommended (if a nailed base sheet is installed, four plies are recommended in addition to the base sheet). "Heavy duty" fiberglass felts are available (ASTM E 2178 Type VI), but because of their stiffness, it is easier to construct unwanted voids in the membrane. Therefore, Type IV felts are recommended.

Exposed asphalt is susceptible to relatively rapid weathering. Therefore, BURs are surfaced with aggregate, a field-applied coating or a mineral surface cap sheet. If aggregate is specified, wind blow-off should be considered, see Wind Safety—Roof Systems. Coatings include aluminum-pigmented asphalt, asphalt emulsion (reflective or non-reflective), and acrylic. Coatings can enhance fire resistance. However, if coatings are specified, periodic recoating will be required. Because of future maintenance demands, coatings are not recommended. If a cap sheet is specified, it should be in addition to the 4 plies of felt.

ASTM standard D 312 is the product specification for asphalt. There are four Type of asphalt. Type I is much more susceptible to flow than Type IV. ASTM D 6510 provides guidance for selection of asphalt Type in BURs.

Base flashings are typically constructed with modified bitumen sheets.

Although coal tar is still available, the vast majority of BURs are constructed with asphalt.

MODIFIED BITUMEN (MB)

MB membranes exhibit general toughness and resistance to abuse. They are typically composed of pre-fabricated polymer-modified asphalt sheets. Polymers are added to bitumen to enhance various properties of the bitumen. The quality of MB products is highly dependent on the quality and compatibility of the bitumen and polymers, and the recipe used during the blending process. There are three primary types of MB sheets, as well as field-applied modified mopping asphalt:

Atactic polypropylene (APP): APP polymer is blended with asphalt and fillers. The mixture is then factory-fabricated into rolls that are typically one meter wide. The prefabricated sheet, commonly referred to as a cap sheet, is typically reinforced with fiberglass, polyester or a combination of both. The sheets are available smooth (i.e., unsurfaced); embedded with mineral granules of a variety of colors; or factory-surfaced with metal foil such as aluminum, copper or stainless steel. The aluminum foil is available in colored finishes. APP MB membranes are generally resistant to high-temperature flow.

To avoid surface cracking, a field-applied coating (such as aluminum-pigmented asphalt, asphalt emulsion or acrylic), factory-applied surfacing (granules or metal foil) or a sheet with protective reinforcement near the top should be specified.

APP MB membranes are typically composed of a base sheet and an APP cap sheet. The cap sheet is either heat-welded (i.e., torched) to the base sheet, or it is adhered in cold adhesive. Mechanically attached systems are also available.

Note: APP MB sheets are also available with a factory-applied tackifier on the underside of the sheet, which permit them to be self-adhering. Several manufacturers introduced these products in the early 2000s.

Sometimes one or more fiberglass ply sheets (as used in BUR) are mopped to the base sheet and then the cap sheet is installed. This configuration is often referred to as a hybrid system, as it essentially is a BUR with a MB cap sheet.
APP MB membranes can also be used in a protected membrane roof (PMR) configuration. In a PMR, XEPS insulation is placed over the membrane. The insulation is protected from ultraviolet (UV) radiation and wind blow-off by concrete pavers or large aggregate. When aggregate is selected, a filter fabric should be specified between the aggregate and insulation in order to keep the aggregate from getting into the board joints and underneath the boards. Alternatively, insulation boards with a factory-applied mortar surface may be specified.

**Styrene-butadiene-styrene (SBS):** SBS polymer is blended with asphalt and fillers. The mixture is then factory-fabricated into rolls with reinforcement and surfacing similar to APP MB sheets. SBS sheets generally have good low-temperature flexibility.

SBS MB is susceptible to premature deterioration when exposed to UV radiation. Although the sheets could be coated in the field, factory-surfacing is recommended.

SBS MB membranes are typically composed of a base sheet and an SBS cap sheet. The cap sheet is either heat-welded (i.e., torched) to the base sheet, or it is adhered in cold adhesive or hot asphalt. Mechanically attached systems are also available. Hot asphalt is not recommended for attachment of cap sheets because of the great potential for development of blisters.

As with APP systems, sometimes one or more fiberglass ply sheets are placed between the base sheet and the cap sheet.

Note: SBS MB sheets are also available with a factory-applied tackifier on the underside of the sheet, which permit them to be self-adhering. Several manufacturers introduced these products in the early 2000s.

SBS MB membranes can also be used in a PMR configuration. If a PMR system is specified, a minimum 4 mil [0.1 mm] polyethylene slip sheet should be placed between the membrane and the XEPS to prevent the insulation boards from bonding to the membrane. Otherwise, membrane tearing could occur when the insulation floats during a rainstorm.

**Styrene-isoprene-styrene (SIS):** These self-adhering sheets are blended with SIS polymer, asphalt and fillers. The mixture is then factory fabricated into either 3 feet or 1 meter wide rolls. The top of the prefabricated sheet is available with embedded mineral granules or a factory-laminated UV-protective surfacing, such as aluminum foil. The bottom surface has a release paper to keep the sheet from bonding to itself while rolled.

A similar product is commonly used under steep-slope roof coverings to provide ice-dam protection. However, the steep-slope underlayments do not have a UV-protective surfacing. SIS MB roof membranes currently capture a very small share of the low-slope market.

**Styrene-ethylene-butylene-styrene (SEBS):** SEBS polymer is blended with asphalt in a factory. The SEBS modified asphalt is then reheated at the job site in specially-designed tankers or kettles. The hot modified asphalt is applied in a manner that is virtually identical to BUR. The membrane is typically surfaced with aggregate. SEBS modified mopping asphalt is extremely expensive, and therefore not commonly used.

Modified mopping coal tar was introduced in the mid-1990s, but it has very limited market share.

**SINGLE-PLY**

The single-ply family of roof membranes is composed of thermoplastic and thermoset products. Single-ply sheets are factory-fabricated and installed in a single thickness. Single-ply membranes are relatively easy to install on steep or complex roof slopes. In comparison to BUR or MB membranes, they are also very light weight (except for ballasted systems). However, unless used in a PMR configuration, they do not offer nearly as much toughness and resistance to abuse as do BUR and MB membranes.

There are five primary methods for securing the membrane the roof deck or other substrate:

**Fully adhered:** The membrane is adhered in a continuous layer of adhesive. Some single-plies are also available with a factory-applied mortar surface.
factory-applied tackifier on the underside of the sheet, which permits them to be self-adhering (several manufacturers introduced these products in the early 2000s).

Ballasted: The membrane is loose-laid over the substrate and then covered with ballast to resist wind uplift. Ballast can either be large aggregate (for example, 1-½ or 2-½ inches nominal diameter, depending upon design wind speed), concrete pavers weighing 18 to 25 pounds per square foot (psf), or specially designed lightweight interlocking concrete pavers weighing approximately 10 psf [49 kg/m²]. Ballasted systems are limited to a maximum slope of 2:12.

If crushed aggregate is specified, a stone-protection mat between the membrane and aggregate should be specified to avoid puncturing the membrane. A stone-protection mat is also recommended when smooth aggregate is used because some sharp fragments are often among the smooth aggregates. Also, aggregates sometimes fracture into very sharp pieces after they have been installed. It is also a conservative practice to specify a mat to protect against abrasion and puncture from fragments during paver installation. A somewhat thinner mat is normally sufficient for paver-ballasted jobs.

Mechanically attached: The membrane is loose-laid except for discrete rows of fasteners. There are a variety of fastening and seam fabrication with this method, as described in A Guide for the Wind Design of Mechanically Attached Flexible Membrane Roofs (2005).
To avoid tear propagation in the event that the membrane is torn, it is recommended that only reinforced membranes be specified for this attachment method.

**Protected membrane roof.** See the Modified Bitumen (MB) section above.

**Loose-laid air-pressure equalization system:** The membrane is fully adhered around the roof perimeter, but elsewhere the membrane is only loose-laid. This system should only be used over an air-impermeable roof deck or over an air retarder. To compensate for minor air leakage between the membrane and the deck/air retarder, air-pressure equalization valves are installed at prescribed intervals. The valves are one-way: they allow air underneath the membrane to vent out, but outside air is prevented from flowing through the valve and underneath the membrane. As with mechanically attached systems, it is prudent to only specify reinforced membranes for this attachment method. This type of system is susceptible to wind blow off if future roof penetrations are cut through the deck/air retarder and left unsealed.

**Thermoplastic Single-plies**

Thermoplastic materials do not cross-link, or cure, during manufacturing or during their service life. Field-fabricated seams are typically welded with robotic hot-air welders. Hand-held hot-air welders are used to weld seams at flashings and penetrations. Thermoplastic membrane seams are typically extremely reliable, resulting in a very low incidence of seam failures. These sheets are normally around 5 to 12 feet wide [1.5 to 3.6 m]. Some manufacturers weld the sheets together in the factory to form large sheets that are then welded together on the roof. Primary membrane types in this category are:

**Polyvinyl chloride (PVC):** PVC membranes are among the oldest single-plies still available. If in contact with polystyrene insulation, the polystyrene will cause the plasticizers in the membrane to leach out. To avoid such membrane embrittlement, a separator sheet needs to be installed between the membrane and the polystyrene. To avoid membrane damage, a separator is also needed to isolate PVC from asphalt and coal tar products. The ballasted attachment method is not recommended because fine dust particles from the ballast or particulate fall-out from the atmosphere may leach plasticizers from the membrane. PVC membranes are available in a wide variety of colors. This membrane is often selected for steep-slope roofs where a strong or unique color is desired.

**PVC Alloys or Compounded Thermoplastics (also referred to as PVC blends):** These membranes are related to PVC membranes. They are primarily compounded from PVC, but they have additional polymers that provide somewhat different physical properties. Only a very small number of manufacturers make these products. The primary types of membranes in this category are: copolymer alloy (CPA), ethylene interpolymer (EIP) and nitrile alloy (NBP).

**Thermoplastic polyolefin (TPO)**

TPO is the latest thermoplastic membrane introduced into the marketplace. It was commercialized in North America in the early 1990s. It is formulated from polypropylene, polyethylene or other olefinic materials. Unlike PVC and PVC blends, TPO membrane do not rely upon plasticizers for flexibility, so embrittlement due to plasticizer loss is of no concern. TPO membranes are typically white, and are available in sheet widths up to 12' [3.6 m].

**Ketone ethylene ester (KEE)**

This membrane is also referred to as a tripolymer alloy (TPA), and the polymer is known by the trade name of Elvaloy. KEE sheets are similar to PVC.

**Thermoset Single-plies**

Thermoset materials normally cross-link during manufacturing. Once cured, these materials can only be bonded together with a bonding adhesive or specially formulated tape. Primary membrane types in this category are:

**Ethylene propylene diene monomer or terpolymer (EPDM):** EPDM is a synthetic rubber sheet. As of 2005, EPDM enjoys the largest market share of the single-plies in service in North America. EPDM membranes are extremely resistant to weathering, and they have very good low-temperature flexibility. However, EPDM is susceptible to swelling when exposed to aromatic, halogenated and aliphatic solvents, and animal and vegetable oils such as those exhausted from kitchens. On portions of roofs where the membrane may be exposed to these materials, an epichlorohydrin
membrane can be specified over the EPDM as discussed below. EPDM membranes are suitable at airport buildings, provided liquid fuel is not spilled on the membrane.

The sheets are typically available in widths of 10, 20 and 45 or 50 feet [3, 6 and 14 or 15 m], and lengths up to 200 feet [61 m]. Hence, on large roofs with very few penetrations, this type of membrane can be very economical to install. Most EPDM sheets are black, although white sheets are available. White sheets, however, are not nearly as resistant to weathering as black sheets. EPDM is typically non-reinforced. However, only reinforced sheets are recommended for mechanically attached and loose-laid air-pressure equalized applications. Reinforced sheets also offer some increased resistance to puncture and tearing when used in fully adhered and ballasted applications.

In fully adhered applications, typically a contact adhesive is applied to the substrate and the sheet. After the adhesive dries, the sheet is mated with the substrate. Another method of application uses fleece-backed EPDM, which is set in a low-rise sprayed polyurethane foam adhesive.

Field seams are fabricated with either a liquid-applied adhesive or specially formulated tape. Although tapes offer performance advantages over liquid-applied adhesives, the contractor still needs to exercise care in cleaning the EPDM prior to tape application, priming the EPDM and diligently executing the seam work as recommended by the manufacturer.

**Epichlorohydrin (ECH):** This sheet is similar in appearance to EPDM. ECH, however, is resistant to hydrocarbons, solvents and many greases and oils, so it can be used in areas of the roof that are exposed to chemical discharges that are harmful to EPDM. Because of its permeability, the ECH manufacturer recommends placing ECH over an EPDM membrane. Because it is so specialized, ECH is seldom used. Only one manufacturer produces it in North America.

**SPRAYED POLYURETHANE FOAM (SPF)**

SPF is a very unique type of roof system. The membrane is constructed by spraying a two-part liquid onto a substrate. The mixture expands and solidifies to form closed-cell polyurethane foam. The substrate can be either the roof deck, an existing roof membrane (provided the existing roof is suitable for re-covering), gypsum board or rigid insulation. The foam is applied with hand-held sprayers or by robotic sprayers. Each pass (or lift) of foam is typically between ½ to 1-½ inches [13 to 38 mm] thick. If a greater total thickness is desired, two or more passes are normally required. The total thickness of the foam can be easily varied to provide slope for drainage. The foam needs to be protected from UV radiation. This is typically accomplished by using one of the following surfacings:

**Acrylic coating:** This is the least expensive of the coatings, but generally offers the shortest service life (although the best acrylics can last longer than some of the polyurethane coatings). With acrylics, re-coating is required about every 10 to 15 years, depending upon the quality of the coating material, application and climate. They are typically white.

**Polyurethane coating:** When properly formulated, this coating offers long service life. This can be the toughest coating available in terms of impact and tear resistance, although a wide range of physical properties is available in this product category. Both one- and two-part coatings are available. One-part coatings are typically gray, although white is available. Two-part coatings are typically white.

**Silicone coating:** Silicone coatings offer exceptionally good weather resistance and long service life. These coatings are typically offered in a gray color, as silicone coatings pick up dirt (if a white silicone is installed, it will soon become gray). More than other coatings, silicone coatings are prone to being pecked by birds. To avoid the pecking, granules are commonly broadcast into the coating while it is wet.

**Mineral granules:** Mineral granules (similar to those used to surface asphalt shingles) can increase the durability of a coating and provide greater slip-resistance to persons on the roof. Course sand can also be used for these purposes. Granules or sand are broadcast into a coating while it is wet.

**Aggregate surfacing:** Properly formulated and installed SPF is quite resistant to liquid water. Therefore, aggregate of the size used on BUR systems can be applied directly over the foam. At parapets and equipment curbs, one of the
previously described coatings is applied on the vertical surfaces and out several inches onto the field of the roof. Because water vapor can migrate through the foam, the aggregate surfacing option should not be specified in situations where the annual net vapor flow is downwards. As with aggregate-surfaced BUR, consideration should be given to aggregate blow off.

Other considerations

The worker performing the spraying must be very skilled and knowledgeable. If the qualifications of the contractor and the spray mechanic cannot be reasonably assured, it is prudent to specify an alternative system.

SPF systems have several important attributes. Besides readily lending itself to complex roof shapes, SPF roofs are exceptionally thermally efficient, since they do not have mechanical fasteners or insulation board joints, which create thermal bridges. Also, field research has demonstrated that they have exceptionally good wind resistance. And notably, an SPF roof is not in imminent danger of leaking if the coating is weathered away or ruptured or the aggregate surface is displaced, provided that the penetration does not extend all of the way through the foam (which is generally unlikely). This attribute, is in stark contrast with the other low-slope system options, in which leakage typically occurs if the membrane is punctured.

METAL PANELS

Metal panels are not typically thought of as options for low-slope roofs. Some metal panel systems, however, can be used on very low-slopes. Although some manufacturers tout their systems as being suitable for slopes as low as ¼:12 (2 percent), NRCA recommends a minimum slope of ½:12 (4 percent). The greater the slope, the more reliable the leakage protection.

This section only addresses metal panels suitable for use on slopes of 3:12 (25 percent) and less. These panels can also be used on slopes in excess of 3:12. See Section 2.6.1 for metal panels that are only suitable for slopes greater than 3:12.

When installed on low-slopes (particularly slopes approaching ½:12 (4 percent) or less, a metal panel system needs to provide water infiltration protection all across the roof surface. Thus, low-slope metal panel systems should be designed and installed with the intent of making them membrane-like. To achieve this, the panel joints must be soldered or sealed together with sealant tape or sealant, or both. Also, fasteners that penetrate the panel at end-joint splices or flashings must be sealed with gasketed washers. It is more difficult to achieve a reliable and long-lasting watertight system on a very low-slope roof with metal than it is with the other low-slope membrane materials.

Steel or aluminum panels are typically specified for low-slope standing seam panels. Copper is also available, but not commonly used since low-slope roofs are not normally visible. For corrosion protection on steel panels, it is prudent to specify aluminum-zinc alloy (commonly known by the trade name Galvalume). Until the late 1990s, unpainted aluminum-zinc alloy panels had a factory-applied lubricant to facilitate roll-forming. The lubricant eventually weathers away, but installation smudges and fingerprints result in uneven appearance for awhile. A thin clear acrylic coat can be specified to provide a more even appearance and show the effects of weathering more gradually, as the acrylic weathers away. Acrylic-coated Galvalume is sold under trade names such as Galvalume Plus and Acrylume.

Normally low-slope panels are not painted. However, if the roof can be viewed from above, and it is desired to have a painted finish applied to either steel or aluminum panels, there are several finish options. The most common factory-applied coil coating is polyvinylidene fluoride (PVDF), commonly known by the trade names of Kynar and Hylar. PVDF is typically specified since if offers a large range of colors and is extremely resistant to color change over time. Painting can also be specified when it is desired to have a high emissivity.

Internal gutters and parapets at the eaves of low-slope metal roofs should be avoided, as it is less problematic to have the water flow over the end of the panels and fall directly to grade or drop into an external gutter that is below the plane of the panels.

There are two primary approaches to low-slope metal roofs:

Standing seam hydrostatic, or water barrier systems: These panel systems are designed to resist water infiltration under hydrostatic pressure. The panels have standing seams, which raise the joint between the panels above the water line. The seam is sealed with sealant tape or sealant in case it becomes inundated with water backed up by an ice dam.
Most hydrostatic systems are structural systems (e.g., the roof panel has sufficient strength to span between purlins or nailers). A hydrostatic architectural panel (which cannot span between supports) may be specified if a solid deck is provided. Most architectural panels are hydrokinetic, or water-shedding, and therefore require a slope greater than 3:12 (25 percent).

Some panels have snap-together seams, while others are mechanically seamed with an electrically powered mechanical seaming tool. On slopes of ½:12 (4 percent) or less, it is recommended that mechanically seamed panels be specified.

There are two basic types of standing-seam panel profiles, the trapezoidal rib and the vertical rib. Because of its appearance, the trapezoidal rib panel is typically used on industrial buildings and warehouses. The trapezoidal panel is difficult to make watertight at hips and valleys.

In addition to the standing seam panels, through-fastened panels (also referred to as R-panels) with exposed fasteners are available for low-slope systems with slopes in excess of 2:12 (17 percent). They should be considered hydrokinetic systems. This is a relatively inexpensive system. It has largely been replaced by standing seam systems, which eliminate leakage problems that are often associated with exposed fastener systems. Other exposed fastener systems include corrugated panels and 5-v crimp panels.

To avoid leakage problems at panel end-joint splices, it is preferable for the panels to be continuous from eave to ridge. If panels are quite long, job-site roll-forming may be necessary. However, full-length panels are sometimes impractical.

The Metal Roof Systems Design Manual by the Metal Building Manufacturers Association provides further guidance pertaining to metal roof systems.

**Flat seamed architectural panels**

This is also a hydrostatic, or water barrier, system. This traditional system requires a solid substrate. It also requires the use of metals that can be soldered, such as copper. This type of system is labor-intensive. Hence, it is relatively expensive. Because it demands diligent workmanship to provide long-term water protection, it is recommended that this system not be specified unless done so for architectural restoration or compatibility purposes.

**Steep-slope Roof Coverings**

The following roof coverings are commonly used on steep-slope roofs. These coverings are water-shedding, rather than waterproofing. Special underlayment provisions are required when slopes are relatively low. The NRCA Roofing and Waterproofing Manual provides underlayment guidance.

**METAL PANELS AND SHINGLES**

When used on slopes greater than 3:12 (25 percent), hydrokinetic, or water-shedding panel systems may be used. Hydrostatic (water barrier) systems may also be used. Architectural panels may be specified if a solid deck is provided. If a solid deck is not provided, structural panels need to be specified.

Metal shingles are also available in a variety of metals and designs. The performance varies greatly depending upon the product selected.

**ASPHALT SHINGLES**

Shingles are available with either fiberglass or organic reinforcement. Fiberglass-reinforced shingles provide greater fire resistance and are therefore recommended. In hail-prone areas, SBS modified bitumen shingles are recommended because of their enhanced resistance to impact damage.

In addition to the traditional three-tab design, laminated (architectural) shingles are available where a different
appealance is desired. Product standard ASTM D 3462 has limited criteria to distinguish various products in the marketplace. Therefore, warranty duration is normally used to attempt to distinguish commodity products from those that offer longer service life. However, the warranty duration is not necessarily an indication of performance. Shingles with a minimum warranty of 25 years is are recommended.

**SLATE**

Natural slates have the potential to offer several decades of service life. However, slate is heavy and very expensive. If slate is specified, a very durable underlayment is recommended, so that it does not prematurely degrade.

Specifiers are cautioned that synthetic materials are often marketed as slate. Some of these products are made from slate particles, while others are made from polymers or other materials. Synthetics should not be expected to offer a service life equivalent to natural slate.

**TILE**

Tiles can either be made from clay or concrete. Tiles typically can be expected to offer a longer service life than asphalt shingles. However, tiles are heavy and more costly than shingles.

**Applications**

After identifying the project's requirements a roof system should be selected that optimally responds to an integration of the project's requirements and the system selection criteria discussed in System Selection Criteria below. After the roof system is selected, drawings and specifications are prepared to communicate the architect's design concept to a professional roofing contractor. This section also covers warranty considerations, key elements of drawings and specifications, and construction contract administration.

**System Selection Criteria**

For most roofs, several different types of systems could serve quite well. But some roofs have unique characteristics that lend themselves to perhaps only a few systems. In order to select the most appropriate system for a project, ideally the architect should have at least a general understanding of the material and system options described in the Description section.

If the architect lacks a general understanding of the roof system options (particularly if the project is complex, unusual or very expensive), the architect should seek system selection input from a professional roofing contractor or professional roof consultant who is knowledgeable about all of the system options.

In the context of this section, system selection refers to selection from the primary system types discussed in the Description section (such as BUR, modified bitumen, single-ply, sprayed polyurethane foam, metal panels, asphalt shingles, slate or tile), as well as selection of membrane materials within system types (such as type of modified bitumen, type of single-ply membrane, type of surfacing on an SPF, type of metal panel profile, or type of shingle or tile), and where applicable, the attachment configuration (fully adhered, ballasted, mechanically attached, PMR, or loose-laid air-pressure equalized).

With a general understanding of the available system options, consideration of the following technical and non-technical criteria can lead to the selection of the most appropriate system and details for a project:

- system demise
- contractor familiarity and availability
- maintenance intensity
- nearby Government roofs
- technical considerations
- cost
- warranty
- implications of sustainable roof design

It is critical that the selected system sufficiently satisfy all of the criteria. Specific system selection recommendations are
SYSTEM DEMISE

The first step in the selection process is to determine what will likely cause the death of the roof system. For example: 1) is the project located in an area that experiences frequent and damaging hailstorms, 2) does the roof have numerous HVAC units, the service of which will generate perpetual abusive foot traffic, 3) will the roof be exposed to intense solar radiation throughout most of its life?

In some cases, one factor will likely cause system death. In other cases, perhaps two or three factors may be nearly equally as likely to end the roof's life. After identifying the likely cause(s) of death, it is incumbent upon the architect to select a system with characteristics that can combat the destructive force(s).

CONTRACTOR FAMILIARITY AND AVAILABILITY

Good application is crucial to the long-term success of a roof. During the system selection process, the following should be considered:

- Are contractors in the vicinity of the project site familiar with the system being considered? If not, either a system should be selected that the local contractors are familiar with, or a contractor should be brought in from outside of the project vicinity. It is important to avoid having a contractor install a system that he or she is not extremely familiar with.
- It is preferable to select a system that can be installed by contractors who have an office relatively close to the project site. By doing so, the contractor will be familiar with local conditions such as historical weather conditions during the projected application period and logistics.

MAINTENANCE INTENSITY

Because of uncertainties pertaining to future budgets for periodic maintenance, a roof system should be selected that has limited maintenance demands. Therefore for example, a system that requires re-coating more frequently than every 15 years is not recommended. Hence, rather than specify a modified bitumen membrane with a field-applied coating, a granule or foil-surfaced membrane is preferable to avoid future re-coating costs (see Figure 4-1.)

NEARBY GOVERNMENT ROOFS

If there are other Government roofs in the vicinity where the new building will be constructed, it is recommended that the architect request information on the type of systems, number of roofs within each system type, and the experience that the Government has had with the various types. If a specific system has been a good performer, it is probably best to use that system on the upcoming project, unless the new project has unique characteristics that another system would be better able to accommodate. Also, if the Government has periodic inspection, maintenance, and minor repairs performed by in-house maintenance personnel, one advantage of keeping with the same type of system is that they will not have to become familiar with another system type.

TECHNICAL CONSIDERATIONS

Most of the topics discussed in this chapter are technical in nature. Many of those considerations strongly influence the system selection. The considerations that influence system selection vary from job to job, depending upon the project location and requirements. When selecting a system it is important for the architect to determine whether the proposed system should more than just meet the minimum requirements. For example, if external fire resistance is particularly important for a project due to a strong threat from wildfires, then rather than just specify a system that meets Class A fire resistance, a better choice would be a system that has enhanced fire resistance, such as a paver-surfaced system.

COST
Many architects select a roof system primarily on initial cost. Although cost is an important element of a project, when cost is a governing factor in system selection, typically there are ramifications. If a less expensive system is selected, invariably something suffers in comparison with the system(s) that fell from consideration because of the greater cost. The cheaper system generally will not have the reliability or durability of other systems, it may be more maintenance intensive or it may not be as energy efficient. Over the life of the roof, the system with the lowest initial cost often is more expensive than other options that were discarded because of their higher initial cost.

In evaluating cost, it is important to look at the life-cycle cost (LCC). In addition to the initial construction cost, LCC includes energy consumption (for building heating and cooling), maintenance, repairs, length of service life, and disposal at the end of the roof's life. Of these factors, the most difficult to assess is the design service life.

The service life can have a dramatic impact on the LCC analysis. For example, if a 40-year service life is assumed, but the roof fails after 15 years, the true roofing costs will be much higher than calculated. Lack of good data on design service life is often a significant limitation to developing a reliable LCC. It is difficult to have confidence in a manufacturer's claim of, for example, a 30-year life for products that have been in the marketplace for only a few years. Accelerated aging testing is of limited help, as it has not progressed to the point where credible estimates of service life prediction can be made. The selection of a predicted service life should be conservative. For most low-slope systems, use of a service life in excess of 20 years should only be done with caution, evaluation and justification.

For most projects, the costs associated with eventual tear-off and disposal are seldom considered. Because some systems are inherently more difficult to tear-off than others, LCC analysis should consider this issue. Also, it may be possible to salvage or reuse some of the system components. For example, with a PMR, it would be reasonable to assume that much of the ballast and insulation could be reused on the replacement roof.

Although there are difficulties and limitations with the LCC approach, economic decisions based on LCC are preferable to those that only consider initial system cost. ASTM E 917, *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems* provides further information on LCC.

**WARRANTY**

Architects often give considerable weight to a manufacturer's warranty when considering a roof system and a specific manufacturer. As discussed in Section 4.2, many limitations are associated with most warranties. The warranty itself should not be the basis for selecting a system or a manufacturer.

**IMPLICATIONS OF SUSTAINABLE ROOF DESIGN**

If an emphasis on sustainable roof design is desired, sustainable design criteria can become major factors in the selection process, depending upon the degree to which sustainability is pursued. At the very least, the selected system should be thermally efficient, with consideration given to both R-value, reflectivity and emissivity. And for those buildings that are intended to have a service life in excess of 20 years, a system with enhanced durability should be selected to reasonably maximize the life of the roof to the extent that the budget allows.

See *Sustainability of the Building Envelope* for further information on sustainable design considerations.

**SPECIFIC ROOF SYSTEM SELECTION RECOMMENDATIONS**

The following roof systems are recommended, assuming compliance with sections above. Note: Special site or building conditions may preempt the following recommendations.

*Slopes less than 1:12*

- Metal panel systems are not recommended.
- Protected Membrane Roofs (PMR) are recommended. For the membrane, modified bitumen is recommended. If there is compelling reason to specify a single-ply membrane, EPDM is recommended. For ballast, concrete pavers or XEPS boards with a factory-applied mortar surface are recommended in lieu of aggregate.
- If there is compelling reason to not specify a PMR, a modified bitumen membrane is recommended. It is recommended that the membrane be set in cold adhesive or torched (where torching is appropriate).
If there is compelling reason to not specify a modified bitumen membrane, a single-ply membrane or SPF is recommended (provided it is reasonably assured that a qualified SPF contractor and spray mechanic will execute the work). If a single-ply is specified, an EPDM membrane is recommended if high reflectivity is not required. If high reflectivity is required, a PVC membrane is recommended. Use of self-adhering modified bitumen or single-ply membranes is not recommended, except for very small roof areas as discussed below. Single-ply membranes should only be specified when very limited foot traffic is expected.

- Very small roof areas: For very small roof areas, such as canopies and penthouses, self-adhering modified bitumen, EPDM or PVC membranes may be suitable.
- If the building is located in an area prone to wildfires or severe hail storms, paver-ballasted PMRs with protected base flashings are recommended.

**Slopes greater than 1:12 and less than or equal to 3:12**

Standing seam hydrostatic metal panel systems, as well as all of the systems recommended in the section above are recommended.

**Slopes greater than 3:12**

At slopes greater than 3:12, aesthetics often play a significant role is system selection. System selection primarily based on aesthetics is acceptable provided the provisions in the previous sections are not adversely compromised.

- Standing seam hydrostatic or hydrokinetic panels.
- Asphalt shingles are typically specified where initial cost is a primary factor in system selection.
- Copper panel systems, slate and tile are typically specified where there is compelling aesthetic reason to specify these relatively expensive systems.
- Modified bitumen, single-ply and SPF may be suitable on steep-slope roofs, provided snow slides are not problematic. If modified bitumen or single-ply membranes are specified, be aware of aesthetic issues (e.g., seam lines will be visible and highly reflective surfaces may become discolored and visually objectionable). Refer to the recommendations in section on slopes less than 1:12 if a modified bitumen or single-ply membrane is specified.

**Warranty Considerations**

A warranty is not a maintenance contract, nor is it an insurance policy. Furthermore, it does not ensure that leakage, damage caused by hail or wind, or another type of damage will not occur. Rather, a warranty defines specific legal rights and obligations of the building owner and warrantor. It includes remedies and exclusions. If the warrantor is out of business when a problem covered by the warranty is experienced, the warranty often becomes a useless piece of paper.

Since the 1970s, many warranties have become marketing tools rather than true reflections of demonstrated roof system performance. It is common to see 20-year warranties on roof systems that have only been in the marketplace for a few years. When architects rely on warranties for performance, rather than pay attention to the factors that actually affect performance, the potential for premature failure dramatically increases.

When warranties are specified, the specification typically requires the warranty to be issued by the roof membrane manufacturer. It is normally specified that the warranty include both the roof membrane materials (and perhaps other roof system components such as roof insulation) and the roofing contractor's workmanship. Material-only warranties are also available from manufacturers. A manufacturer's warranty establishes a direct contractual relationship between the building owner and manufacturer. For low-slope systems, the length of coverage for a manufacturer's warranty is typically 5 to 25 years, with 10 years being the most common.

**WARRANTY BENEFITS**

A warranty may have some merit if it means that the manufacturer will take steps to minimize the potential for future problems (such as reviewing the architect's specification and details and providing meaningful inspection during application). A warranty may also enhance the likelihood that a roof will be installed by a professional contractor. However, rather than relying on a warranty to obtain a qualified contractor, architects should specify contractor qualification requirements as discussed in the next section.

If a problem that is covered by the warranty occurs, and the warrantor is still in business, the presence of the warranty
may lead to a quick resolution of the problem. Virtually every warranty issued by a manufacturer covers repair of leaks caused by defective materials and workmanship (if the warranty is not for materials-only) provided that the cause(s) of the leakage is covered under the terms of the warranty. Without a warranty, the Government might have to pursue legal action to obtain relief. Pursuing legal action may be too costly if the problem is small. Also, the presence of a warranty provides a direct avenue for the Government to pursue a claim with the manufacturer if the manufacture does not respond to a problem covered under the warranty.

**WARRANTY LIMITATIONS**

Warranties are normally prepared to limit the manufacturer's liability to a narrow scope of provisions rather than to provide protection for the building owner. Warranties typically preclude claims based on other theories of liability, including negligence and breach of contract. In addition, warranties typically exclude the implied and express warranties established by the Uniform Commercial Code (UCC).

The UCC provides that goods shall be fit for their particular purpose. However, the length of coverage under the UCC is typically four years from the date of sale. While the provisions under the UCC may be more favorable to the Government than the provisions in a manufacturer's warranty, the Government can obtain coverage for a much longer time with a manufacturer's warranty.

Most warranties contain several unfavorable provisions, the most significant being:

- the exclusion of consequential damages (including damages to building interiors and contents, and business interruption)
- the limitation of wind coverage to wind speeds that are typically well below the design wind speed prescribed in the building code
- the exclusion of hail damage (see Figure 4-2)
- the limitation of leak repairs to patching the membrane rather than removing and replacing wet insulation
- only the manufacturer can determine the applicability of the warranty
- the inclusion of several provisions that could result in the building owner's inadvertent nullification of the warranty.

**RECOMMENDATIONS**

Don't make a roof system or manufacturer selection on the basis of a warranty. Select a system for its suitability to the project, as discussed in System Selection Criteria above.

Do not automatically specify a warranty. Rather, discuss the benefits and limitations of a warranty with the Government representative and have them decide what is in the Government's best interest.

If specification of a warranty is being considered, review the warranty section of NRCA's *Low-Slope Roofing Materials Guide* (or the *Steep-Slope Roofing Materials Guide*). If a warranty is desired, recommend that a Government attorney identify provisions of the manufacturer's standard warranty that are unacceptable, so that warranty provisions acceptable to the Government can be specified. The following are examples of changes to standard warranties that should be considered:

- delete warranty language that takes away Government rights
- delete warranty language that excludes other rights and remedies
- delete warranty language that sets a maximum dollar limit
- delete or modify the unfavorable items listed above in "Warranty Limitations."

**Key Elements of Drawings and Specifications**

After a suitable roof system has been selected, appropriate specifications and drawings need to be prepared to help ensure that the architect's design concept is understood and executed by a professional roofing contractor. The fate of many prematurely failed roofs is often set by poorly prepared documents (Figure 4-3). The importance of the architect's
diligence in preparing specifications and drawings cannot be overemphasized.

Figure 4-3. The wind load on this very wide gutter was transferred to the edge nailer, but the nailer attachment was not designed to account for the gutter uplift load. The nailer therefore lifted and caused a progressive peeling failure of the roof membrane.

The following elements are critical in communicating project requirements to the contractor:

Specifications
Roof Plan(s) and Details
Peer Review.

SPECIFICATIONS

To produce good specifications, the architect should first acquire a suitable guide specification. The following Unified Facilities Guide Specifications (UFGS) are available:

Roof decks: 03 51 00 (LWIC), 03 31 00.00 10 (cast-in-place concrete), 03 41 36.00 10 (pre-cast concrete), 03 52 00 (LWIC), 05 30 00 (steel), 06 10 00 (wood)

Insulation: 07 21 16 (blanket [attic]), 07 21 23 (loose fill [attic]), 07 22 00 (rigid)

Built-Up Roof: 07 51 13

Modified bitumen: 07 52 00

Protected Membrane Roof (using a variety of membrane types): 07 55 00

Single-ply: 07 53 23 (EPDM), 07 54 19 (PVC)

Sprayed Polyurethane Foam: 07 57 13

Metal Panels: 07 41 13 (architectural), 07 61 13.00 10 (structural standing seam), 07 61 14.00 20 (steel structural standing seam), 07 61 15.00 20 (aluminum structural standing seam), 07 61 01 (copper)

Flashing and sheet metal: 07 60 00 and 07 62 10 (copper)

Asphalt Shingles: 07 31 13

Slate: 07 31 26

Tile: 07 32 13 (clay and concrete)
After obtaining a guide specification, it is critical that the architect tailor it to the specific project. Information that is not applicable should be deleted. Applicable information should be adjusted if needed. Additional specification criteria should be added as necessary to suit the project. The following should be considered when developing Parts I, II and III of the roof specifications:

Part I—General

- **Fire and wind:** Specify fire and wind resistance requirements. For wind uplift, specify the test method required to demonstrate required resistance (see *Wind Safety Section 4.4 Roof Systems*). (Note: For shingles, slate and tiles, normally the resistance for the corner areas is specified for use throughout the entire roof area because these products are typically used on small roof areas. For large slate and tile roofs, if there is sufficient cost savings, both corner, perimeter and field resistances can be specified.)

- **Submittals:** Specify submittal of catalog data for all products, including installation instructions and, where applicable, maintenance and repair instructions. Specify submittal of samples only when necessary to evaluate the product. For example, it is normally not necessary to specify the submittal of an EPDM sample, because black sheets are typically specified and there is no factory-applied surfacing to evaluate. However, it may be appropriate to specify submittal of samples of a granule-surface SBS modified bitumen sheet in order to select the desired color and to qualitatively evaluate the granule coverage and embedment.

Specify that the following be submitted: demonstration of specified contractor qualifications, manufacturer review letter, manufacturer inspection reports, certification reports demonstrating that materials comply with referenced standards, certificates of analysis (when specified), and documentation demonstrating enrollment in the MBMA certification program (when specified). These items are discussed below.

- **Contractor qualifications:** Specify that the contractor has a minimum number of years of experience with the type of system specified (five years is usually a reasonable requirement). Also specify that the contractor is approved, authorized or licensed by the roof covering material manufacturer to install its product.

- **Manufacturer review:** Require the roof covering materials manufacturer to review the specification and drawings and advise in writing of their acceptance thereof, or to submit in writing their concerns and recommendations to resolve these concerns. Specify submittal of the review letter within a short time after contract award, so that if changes are needed there is sufficient time to develop them before the roofing begins.

- **Manufacturer inspection:** Require the roof covering materials manufacturer to inspect the roof application on the first or second day of application, and to perform an inspection upon completion of the application. Require submittal of the inspection reports.

- **Standards compliance certificates:** To help ensure that products furnished to the project comply with referenced standards, specify that certificates demonstrating compliance be submitted.

- **Certificates of analysis:** For those products where certificates of analysis are available, consider specifying certificates of analysis that provide quality control test results for specific manufacturing lots (lot numbers are printed on the product package label).

- **Certification program:** If a metal roofing system is selected, consider specifying that the manufacturer be certified through the MBMA Metal Roofing Systems Quality Certification Program. Further information about the program is provided in the MBMA *Metal Roofing Systems Design Manual*.

- **Pre-roofing conference:** Specify a two-stage pre-roofing conference. The first conference should be held a few or several weeks prior to the start of roofing, depending upon job size and complexity. The second conference should be held just prior to application. The purpose of the conference is discussed later in this section.

Specify that the conference be attended by the general contractor, roofing contractor’s project manager, superintendent (on large projects) and foreman, a representative of the roof covering materials manufacturer, and the mechanical, electrical and lightning protection system (LPS) contractors if mechanical, electrical or LPS work is associated with the roofing work. If a third-party inspection firm will be on the job, the inspector should also attend.

- **Quality control documents:** If a BUR, modified bitumen, EPDM or sprayed polyurethane foam system is specified, specify application compliance with the applicable quality-control document co-produced by NRCA:
  - Quality Control Guidelines for the Application of Built-Up Roofing
  - Quality Control Guidelines for the Application of Polymer Modified Bitumen Roofing
  - Quality Control Guidelines for the Application of Spray Polyurethane Foam-based Roofing
Quality Control Guidelines for the Application of Thermoset Single-Ply Roof Membranes

- **Weather limitations**: If there are weather-related limitations, they should be specified. If work will be performed during cold weather, special cold weather procedures should be specified (Figure 4-4).
- **Work hour limitations**: If there are limitations to the hours or days that can be worked, this should be specified.
- **Storage areas**: If there are limitations to on-site storage areas, this should be specified or shown on the drawings.
- **Load limits**: Specify the maximum allowable wheel load limits for roof application equipment, and specify the maximum allowable load (per square foot [per square meter]) for materials stored on the roof. Some rooftop equipment and some materials, such as pallets of pavers, are very heavy. Specifying load limits will allow the contractor to determine the appropriate type of equipment and material handling and storage techniques needed for the project.

**Part II—Products**

- **Materials**: Avoid specifying unproven products. Specify that the manufacturer shall have produced the specified materials for a minimum of five years.

If products are specified by referencing a product standard (such as ASTM), it may be appropriate in some instances to just list the standard. But many ASTM standards have grades, types or both within the standard. In these cases, the type and grade need to be specified. Also, additional information sometimes needs to be specified, such as product thickness. Products covered by some ASTM standards have a substantial range in physical properties. In some cases, it is appropriate to specify a physical property value(s) that is different from that specified in the standard so that a higher quality is obtained. However, this approach should not be used as a method to exclude essentially equal products just because one product has a slightly different value.

**Part III—Execution**

- **Protection of the completed work**: If other construction work will occur over the new roof, or if other construction trades will be on the new roof, specify appropriate protection measures.

**ROOF PLAN(S) AND DETAILS**

See Details for discussion of the roof plan(s) and details.

**PEER REVIEW**

On some projects, it is prudent for the architect to have their specifications and drawings peer reviewed by someone knowledgeable of the specified system. Peer review should be considered for office buildings with very valuable contents or operations, projects where the cost of the roofing work is very substantial, complex or unusual projects, and those projects where the architect believes his or her expertise is lacking.

**Construction Contract Administration**

During construction contract administration, the architect or the entity responsible for construction contract administration has several important tasks. These tasks need to be executed regardless of project size or location, although the amount of time devoted to the tasks will be dependent upon the roof size and other factors.

The following topics are discussed in this subsection:

- Submittal Review
- Pre-roofing Conference
- Field Observations
- Non-Destructive Evaluation (NDE)
- Project Close-out

**SUBMITTAL REVIEW**
It is incumbent upon the reviewer to be thorough, diligent and cautious during the submittal review process. (Note: In complex or unusual projects, or where the reviewer lacks sufficient expertise to adequately review the submittals, a professional roof consultant who is knowledgeable about the particular roof system should be retained to review the submittals.) The reviewer should:

- Verify that all of the specified submittals are received and approved.
- If a submittal item is to be resubmitted, make sure that it is. Sometimes items to be resubmitted are forgotten about. These items often become problems.
- Be cautious in approving materials, systems and details that are not in accordance with the contract documents. Minor changes may affect code compliance or roof system performance.

PRE-ROOFING CONFERENCE

It is important for the architect to work with the contractor to arrange for the conferences at the appropriate times, and to remind the contractor that all parties listed in the specifications are required to attend. The purpose of the meeting is to review the drawings and specifications to ensure that there is understanding and agreement by all parties. If there are problems with the design or other aspects of the project, the intent is to identify and resolve them prior to commencement of the roofing work. The architect should prepare minutes of the conference and provide them to the contractor for distribution to the other parties.

The first conference should be held a few or several weeks prior to the start of roofing, depending upon job size and complexity. The second conference should be held just prior to application. The advantage of two conferences is that the first can be held sufficiently in advance of application so that, if problems are discovered during the conference, there will be time to resolve them without delaying construction. Having the second conference just before application also provides an opportunity to verify that unresolved issues from the first conference have been dealt with, and it allows for a second review of critical issues just before commencement of work.

The agenda for both conferences is generally the same. Some items may be briefly covered in the first conference and then discussed more thoroughly in the second, or vice versa. Items that were discussed in detail in the first conference can often be quickly covered in the second meeting with brief mention and referral to the meeting minutes. The following should be undertaken at the conference:

- Review the salient features of the specifications, including schedule; product delivery, storage and handling; roof loading; weather conditions; unique or critical items specified in Part 3—Execution of the specifications; and protection of the completed roofing from work of other trades.
- Review the drawings, particularly the unique or critical aspects.
- Review submittal problems (for example, items that have not been submitted, or items that have been submitted but rejected).
- Ensure that the contractor has a copy of the contract documents and approved submittals at the job site, and any changes thereto.
- Discuss the contractor’s responsibilities regarding notification prior to roofing (for the purpose of alerting the field observer).
- Establish a line of communication between the field observer and contractor (and other parties that may be involved). If the field observer is not an employee of the architect, also establish a line of communication between the observer and the architect, and the extent of the authority that the observer has with respect to interpretation of the contract documents and the handling of unforeseen conditions.
- Immediately after the second conference, all attendees should review all of the roof deck areas to verify that they are ready for roofing. They should also review the parapets, curbs and penetrations. If a roof area is not ready, a later review of that area should be conducted prior to roofing. If corrective work is required, the corrective work should be reviewed prior to roofing.

FIELD OBSERVATIONS

For most projects, periodic observation by the architect is sufficient. But for others, full-time observation by the architect or a roof consultant is prudent. The purpose of the observation is to help ensure that the work is being executed in accordance with the contract documents.
The amount of observation will depend upon:

- Desired system reliability: If a highly reliable roof is desired, it should receive more field observation.
- Characteristics of the roofing system: Some systems are more demanding, or less forgiving, than other systems with respect to workmanship and weather conditions at time of application. Even if the work is being performed by a knowledgeable and conscientious contractor, demanding systems present challenges. They should therefore receive greater observation in order to help avoid inadvertent mistakes. An example where increased observation is helpful is when a modified bitumen membrane is applied in cold adhesive when the ambient temperature is near the lower boundary recommended by the manufacturer. Increased observation could prevent the application from occurring if the temperature drops below the minimum recommended temperature.
- Cost: As the cost of the roofing work increases, the amount of observation should also increase.
- Complexity: Complex or unique roofs (such as unusually shaped roofs) should receive greater observation.
- Qualification of the roofing contractor: If the contractor is marginally qualified, greater observation should occur (full time observation should be considered).

It is imperative that the observer understand thoroughly the system being installed. The observer should:

- Be provided with portions of the contract documents related to the roof.
- Be provided with a copy of the approved submittals.
- Be provided with copies of all changes related to the roof.
- Attend the pre-roofing conferences.
- Verify that the materials on-site are those identified in the approved submittals, and that the materials have FMG or UL labels when so specified.
- If a BUR, modified bitumen, EPDM or sprayed polyurethane foam system is specified, follow the quality control guidelines co-produced by NRCA.
- If fastener pull-out tests were specified, verify that the results are acceptable. If the values are lower than anticipated, the architect should provide the contractor with a revised fastening pattern that is commensurate with the test results.
- If it appears that wheel loads or stored material loads exceed the specified load limits, the contractor should be advised immediately.
- Bring to the immediate attention of the contractor’s job-site person (who was identified during the pre-roofing conference) any need for a change in the contractor’s work practices or a need for corrective work.
- As with submittal approval, be cautious in approving materials, systems and details that are not in accordance with the contract documents while performing field observations (Figure 4-5). For example, the roofing crew may desire to use different fasteners to attach the membrane because the approved fasteners were not sent to the job site. Before accepting the fasteners, determine if wind uplift test ratings will be affected and if the membrane manufacturer will approve the alternative fasteners. Another example is a penetration detail that the foreman desires to flash differently than detailed. Is the change proposed in order to provide a better detail, or is it being proposed because it is simpler and cheaper to install? If the proposed detail is not as conservative as the original detail, it should probably not be approved.
- Write daily reports and give them expeditiously to the contractor (and to the architect if the observer is not an employee of the architectural firm that designed the roof). Report copies should be included in the file prepared for the Government, as discussed in section 4.4.5.

NON-DESTRUCTIVE EVALUATION (NDE)

After completion of all building construction, but before occupancy, consideration should be given to NDE of the roof to check for excessive moisture within the roof system. The purpose of the NDE is to find areas of wet insulation caused by moisture entrapment during application or leakage caused by roof system defects. Infrared thermography is the recommended technique for those roof systems that lend themselves to this type of NDE. If rain has not fallen within a few weeks before the NDE is conducted, the NDE should be delayed until rain occurs. (Unless rain falls before the NDE is executed,
the a recent membrane puncture could go unnoticed because water has not entered the roof system.)

At the pre-roofing conference the contractor should be notified if NDE is to be conducted. (Notification may result in greater diligence in application and care of the completed roof).

PROJECT CLOSE-OUT

At the end of the project, the Government should be provided a file with the following items:

- contract drawings and specifications related to the roof
- approved submittals
- minutes from the pre-roofing conferences
- field observation reports
- pertinent construction correspondence related to the roof
- warranty (if specified)
- NDE of the roof.

Details

After the roof system is selected and the specifics of the system (such as deck type, insulation type(s) and thickness, fastener patterns, and warranty requirements) are developed, it is necessary for the architect to determine what details are needed and to design the details so that they are suitable for the project conditions.

**Roof Plan:** A roof plan should be drawn to scale and be sufficiently large to adequately convey information. It should show all penetrations and all expansion, seismic and area divider joints. The slope directions and approximate amount of slope should also be shown. The different wind uplift areas (field, perimeter and corners) should also be shown and dimensioned. References to all penetrations, roof edges and roof-to-wall details should also be indicated on the plan. (Note: For some standard details such as plumbing vents and roof drains, rather than include the detail on the drawings, referencing the manufacturer's detail in the specification is typically sufficient unless project conditions require enhancement to the standard detail). An example roof plan is shown in the Typical Roof Plan Layout detail below.

**General:** Details should be drawn to scale and should be sufficiently large to adequately convey the information. Illustrating details in section typically suffices. However, with complicated details, an isometric drawing may be needed.

At parapet and roof-to-wall details, the low-point of the roof should be drawn and a dashed line placed at the high-point if the roof elevation varies. See Parapet Wall Schematic detail below.

After details have been drawn, it is recommended that they be reviewed by a manufacturer prior to bidding, as discussed in the Applications section.

**Reference Details:** There are a variety of sources to draw upon for design of details. Various details for low- and steep-slope systems are included in *The NRCA Roofing and Waterproofing Manual*. The NRCA details are available on a CD-ROM. These details can be modified with CADD or incorporated directly into contract drawings. The NRCA details are widely accepted in the roofing industry and are generally recognized as being suitable for standard conditions.

Two noteworthy NRCA details are BUR-10 and Table 4 (from the Fifth Edition, 2001). BUR-10 shows a column-supported equipment stand. The detail provides recommendations for column height as a function of the width of the equipment. By following this guidance, stand-mounted equipment will be mounted high enough to allow roof mechanics sufficient room to work underneath the stand to properly install the new roof and future reroofing. Table 4 provides minimum clearances between adjacent penetrations and between penetrations and roof edges. It is recommended that the guidance in Table 4 be followed (the figure in Table 4 should be included in the contract drawings or referenced on the drawings or in the specifications).

The Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA) *Architectural Sheet Metal Manual* also has details that are widely accepted and generally recognized as suitable for standard conditions.

AIA's *Architectural Graphic Standards* also includes a variety of low- and steep-slope details. However, unlike the NRCA and SMACNA details, the details in *Architectural Graphic Standards* have not undergone extensive industry review.
While several of the details are suitable for standard conditions, some may be inadequate. Hence, this reference source may be valuable for some details, but the architect should scrutinize them.

Manufacturers of roofing products also promulgate standard details. These may also be suitable for standard conditions. Many of these details are available in CADD. However, manufacturer’s details typically include propriety names for various products used in the assembly. Hence, modification of the details to delete propriety names will typically be necessary.

**Modifying Reference Details:** Whenever reference details are considered for inclusion in the contract drawings (or via reference in the technical specifications), the architect should determine whether or not the standard detail needs to be modified to account for unusual weather or building conditions. Standard details typically provide suitable performance when properly executed, provided the weather at the site and the building itself is "standard." If unusual weather conditions are expected during the life of the roof (such as very high wind loads, frequent wind-driven rain, accumulation of slush under snow), standard details may need to be modified to accommodate the non-standard conditions in which they will be required to perform in. For example, in areas where deep accumulation of slush under snow is anticipated, the height of base flashings should be increased above the typical 8” (200 mm).

Knowing when standard details are appropriate and when they are not (unless they are modified) requires judgment. To make a proper assessment of the adequacy of standard details, the architect needs to be keenly aware of weather and other special conditions that the roof will likely be exposed to during its expected service life. The architect also needs to possess adequate roof design knowledge. As discussed in Section 1, if the architect’s knowledge is limited, consultation with a qualified roof consultant or professional roofing contractor is recommended.

Guidance for modifying standard details and recommendations for custom details pertaining to wind resistance is provided in Wind Safety. Examples of custom details are given below.

The following details can be downloaded in DWG format or viewed online in DWF™ (Design Web Format™) or Adobe Acrobat PDF by clicking on the appropriate format to the right of the drawing title. Download Autodesk® DWF Viewer. Download Adobe Reader.

**Roofing System Cove Sealant Detail** [DWG] [DWF] [PDF]
**Roofing System Curb Between Roof System and Deck Membrane** [DWG] [DWF] [PDF]
**Roofing System Drain Detail** [DWG] [DWF] [PDF]
**Roofing System Edge Detail** [DWG] [DWF] [PDF]
**Roofing System Equipment Curb** [DWG] [DWF] [PDF]
**Typical Roof Plan Layout** [DWG] [DWF] [PDF]
**Roofing System Gooseneck Vent Detail on Concrete Deck** [DWG] [DWF] [PDF]
**Roofing System Gooseneck Vent Detail with Metal Deck** [DWG] [DWF] [PDF]
**Typical Ladder Layout** [DWG] [DWF] [PDF]
**Parapet Wall Schematic** [DWG] [DWF] [PDF]
**Roofing System Penthouse Edge Detail** [DWG] [DWF] [PDF]
**Roofing System Pipe Penetration with Pitch Pan** [DWG] [DWF] [PDF]
**Roofing System Collared Pipe Penetration Detail** [DWG] [DWF] [PDF]
**Roofing System Plumbing Vent Smooth Bitumen Roof** [DWG] [DWF] [PDF]
**Roofing System Plumbing Vent Granular Bitumen System** [DWG] [DWF] [PDF]
**Roofing System Plumbing Vent Bitumen System / Metal Deck** [DWG] [DWF] [PDF]
Emerging Issues

The introduction and rapid acceptance of single-ply membranes into the U.S. roofing market in the 1970s was likely the most significant roofing industry change in twentieth century. Another notable development in the 1970s was the widespread acceptance of plastic foam roof insulations, although this pales in comparison with the development of single-ply membranes. It is doubtful that another issue will be as revolutionary as the introduction of the single-plies. Since the single-ply revolution, changes in the roofing industry have been primarily driven by environmental and worker health issues and the pursuit of methods to reduce the amount of labor needed to install roof systems.

Environmental and Worker Health Regulations

The most notable impact of worker health regulations on the roofing industry pertained to asbestos. Prior to 1990, asbestos fibers were used in a variety of products, including asbestos-reinforced base flashings for built-up roofs, asbestos-fibrated roof coatings and asphalt roof cements and cement-asbestos shingles. The asbestos-containing roofing materials generally offered very good performance, but due to health concerns of workers exposed to asbestos fibers during product manufacturing, product installation and roof system demolition, asbestos-containing fibers have for the most-part been phased out. In many instances, the reinforcing fibers and products that were initially introduced to replace asbestos offered very poor performance.

In the late 1990s, health concerns related to development of mold in buildings were raised. Though the water necessary to initiate mold growth can come from a variety of sources such as leaking pipes and windows, leakage from roofs is a common source of water. Although the mold issue is in infancy (as of the early 2000s), thus far it has taught building owners, designers, contractors and roofing materials manufacturers, the importance of quickly responding to leakage reports. With quick response, the source of the leakage can be identified and corrected and steps taken to dry the building before significant mold bloom occurs.

The most notable impact of environmental regulations on the roofing industry pertained to phase out of chlorofluorocarbon (CFC) blowing agents in the 1990s. CFC was used to manufacturer extruded expanded polystyrene, polyisocyanurate and sprayed foam insulation. CFC was phased out because of its role in global depletion of atmospheric ozone. As an interim measure, hydrochlorofluorocarbon (HCFC) blowing agents were used in the 1990s and early into the 2000s. HCFC had a much lower ozone depletion potential than CFC. It was not until introduction of the third generation blowing agent, hydrofluorocarbon (HFC) that a blowing agent with a zero ozone depletion rating was available. The development of the second and third generation blowing agents was technically challenging. Though the phase-ins of the new agents were generally successful, product performance problems were experienced.

Environmental concerns have also affected products containing volatile organic compounds (VOCs). With some products, the VOC (commonly referred to as "solvent") content has been reduced. In other instances, there has been a move to water-based rather than solvent-based products. It is uncertain how successful the reduced VOC products and the newer water-based products will be.

Environmental concerns resulted in the following roof design trends beginning in the mid- to late-1990s:

- Highly reflective roofs: In response to the urban heat island phenomenon and concerns pertaining to smog, acid rain and climate change, there has been growing interest and regulations regarding highly reflective roof surfaces. Although originally this issue was aimed at large urban areas in the southern (hotter) areas of the U.S., highly reflective roofs are also being more frequently specified in those rural and northern areas where hot sunny summers occur.

  In cooling-dominated climates, there has also been interest and regulations regarding high emittance roof surfaces.

- Green (garden) roofs: Green roofs offer several potential environmental benefits, including, reduction of the urban heat island effect (via evapotranspiration and reflectivity), oxygen generation and reduced storm water runoff.

- Solar collectors: Following the 1973 Energy Crisis, many rooftops were retrofitted with solar collectors. These early collectors used solar energy to heat water. Many of these early collectors were inappropriately installed on the roof and resulted in significant roof membrane damage and water leakage. For a variety of reasons, the solar collector trend did not last very long. However, around the early 2000s, a new generation of rooftop solar collector was introduced. These new collectors use photovoltaic cells to produce electricity from the sun's energy. These collectors are prefabricated into mats that are integrated with the roof membrane. Photovoltaic cells can
also be laminated onto metal roof panels.

- Sustainable roof design: Highly reflective roofs, green roofs and use of solar collectors can all be considered as elements of sustainable design. However, sustainable design considers and incorporates many other issues.

Labor Reduction

Over the past several decades there have been a variety of application equipment, system designs and product developments aimed at reducing the amount of labor to install roof systems. Trends since the 1990s include the following:

- Wider sheets: Wider single-ply sheets for mechanically attached application are now available. Originally, sheets were approximately 5' wide. 10' wide sheets were eventually available, and then 12' wide sheets. With the wider sheets, fewer rows of membrane fasteners are required and there are fewer time-consuming field seams to fabricate.
- Use of non-bituminous adhesives in lieu of mechanical fasteners to attach insulation.
- Availability of self-adhering single-ply membranes: Self-adhering modified bitumen sheets were available in the 1980s, but several performance problems limited their widespread acceptance. Around the early 2000s, a variety of self-adhering single-ply membranes emerged, along with renewed interest in self-adhering modified bitumen membranes. In addition to potentially being faster to install, the self-adhering sheets eliminate the need for adhesives and torches (and the environmental, health and fire concerns associated with some of these other attachment method).
- Mechanized rooftop application equipment: Although a variety of mechanized application equipment (such as aggregate spreaders, roof cutters and tear-off machines) was in use prior to the 1990s, the weight of the equipment has increased. On larger jobs, it is not uncommon to see ATVs (four-wheelers) being used to transport materials on the roof. Larger, and thus heavier ballast spreaders are also available. While these heavier pieces of equipment should not be detrimental to buildings with strong roof decks and deck support structures, the heavier equipment can damage older buildings with weak (or deteriorated) decks and/or deck support structures.

The Future

It is likely that as the industry moves through the early part of the twenty-first century, there will be relatively minor, but important changes to products due to environmental, health or labor-saving issues. The introduction of significantly different types of roofing materials is unlikely. The trend towards more sustainable roof design and construction will likely continue.

The use of advanced roof design technologies, such as expert systems, may develop, but this is not likely to occur in the near future. Although, there may be somewhat greater use of computer programs to evaluate system options or performance issues, such as moisture gain within roof systems. The design of very robust roof systems may also become more common place on a limited number of buildings. For example, design of roof systems with much greater service lives on buildings that have very long service lives (such as a courthouse). Another example is design of a roof system with much greater resistance to the devastating effects of a strong hurricane (such designs have been implemented, but are not common - for further information, see Wind Safety—Section 4.7.5 Roof Systems.

Work that should be useful to designers, contractors and manufacturers is an imitative that was launched by the National Roofing Contractors Association. Referred to as "Performance Criteria for Constructed Roof Systems" (PCCRS), this program seeks to develop meaningful performance criteria for a variety of roof system types. The initial work is aimed at built-up, metal panel and sprayed polyurethane foam systems. Performance criteria for these systems should be available before 2010.

The past has shown that introduction of new materials and system designs has not be easy. After commercializing a new material or system design, it has typically taken several years for unexpected problems to be identified and successfully solved. Minor changes to materials and system designs have also often resulted in problems, but these have generally been less problematic and more quickly resolved. This age-old trend is likely to be repeated in the future. It is therefore incumbent upon designers and contractors to be cautious when specifying and installing new products and system designs.

Relevant Codes and Standards
Prior to 1990, the three model building codes (BOCA National Building Code, Standard Building Code and the Uniform Building Code) contained few provisions pertaining to roof systems. Additional provisions were added to these codes during the 1990s. The International Building Code (IBC) has many provisions related to roof systems, including reroofing projects. Code requirements pertaining to roof systems originally primarily addressed life-safety issues, such as fire resistance. However, the IBC also includes provisions pertaining to general serviceability, such as minimum roof slope.

Building code requirements can be quite different from those of the membrane manufacturer or FM Global. It is therefore important for the roof system designer to carefully consider the code requirements. The designer should determine if a building code has been adopted for the locale where the roof will be installed and, if so, what edition of the code is to be used. If the building occurs in an area that has not adopted a building code, it is prudent for the designer to voluntarily comply with the roofing-related provisions of a current edition of a model code such as the IBC.

The building code may have specific requirements regarding documentation to be provided to the building department. For example, the IBC has construction document requirements in sections 106.1.1 and 1603.1.4 (2003 edition).

Most building departments possess little expertise related to roof systems. Designers should therefore not rely upon the building department to discover non-code compliance during their plan review. Also, most building department’s inspectors do not inspect the roof system. Those departments that do inspect the roof likely possess insufficient knowledge of all of the systems that they could encounter.

Standards

There are a large number of standards pertaining to roof systems. The majority of them were developed by ASTM. The ASTM standards typically pertain to test methods (laboratory and field) and product standards. However, there are a few design and application guides:

- ASTM D 6510 Standard Guide for Selection of Asphalt Used in Built-up Roofing Systems
- ASTM D 6369 Standard Guide for Design of Standard Flashing Details for EPDM Roof Membranes
- ASTM D 5082 Standard Practice for Application of Mechanically Attached Poly(Vinyl Chloride) Sheet Roofing
- ASTM D 5036 Standard Practice for Application of Adhered Poly(Vinyl Chloride) Sheet Roofing
- ASTM D 3805 Standard Guide for Application of Aluminum-Pigmented Asphalt Roof Coatings

There are a few ANSI standards that pertain to roof systems, including:

- ANSI/SPRI ES-1 Wind Design Standard for Edge Systems Used with Low Slope Roofing Systems
- ANSI/SPRI FX-1 Standard Field Test Procedure for Determining The Withdrawal Resistance of Roofing Fasteners
- ANSI/SPRI RD-1 Performance Standard for Retrofit Drains

Underwriters Laboratory (UL) and FM Global have also developed a number of standards pertaining to test methods. In addition, FM Global has several Property Loss Prevention Data Sheets (the majority pertain to wind performance). Although the Data Sheets are not "standards" because they did not go through a consensus development process, they have essentially become de facto standards.

Additional Resources

WBDG

DESIGN OBJECTIVES
Functional / Operational—Ensure Appropriate Product/Systems Integration

PRODUCTS AND SYSTEMS
Section 07 41 13: Metal Roofing, See appropriate sections under applicable guide specifications: Unified Facility Guide
Key books and manuals, periodicals and websites:

Books and Manuals

- *The NRCA Roofing and Waterproofing Manual*: This very comprehensive document has information on roof decks, insulations, vapor retarders and a variety of low- and steep-slope roof coverings. The Manual is updated approximately every seven years. A copy of the current *Manual* should be in the office of every designer who designs roofs. Published by the National Roofing Contractors Association.

- *Low-Slope Roofing Materials Guide* and *Steep-Slope Roofing Materials Guide*: These guides, which are updated every other year, provide information on low- and steep slope roof coverings, including warranties. The *Low-Slope Roofing Materials Guide* also includes information on insulation and fasteners. The *Guides* lists manufacturers of the various types of products and provides information about the products. It provides a quick and convenient way to compare products within a given product category. Published by the National Roofing Contractors Association.

- *MBMA Roofing Systems Design Manual*: This manual addresses metal roof systems. Published by the Metal Building Manufacturers Association.

- *The Manual of Low-Slope Roof Systems* by C.W. Griffin: This book provides information on low-slope systems, including discussion of many fundamental design issues. Published by McGraw-Hill.

- *The Science and Technology of Traditional and Modern Roofing Systems* by H.O. Laaly: This very comprehensive book provides information on low- and steep-slope systems. Published by Laaly Scientific Publishing.

- *Modified Bitumen Design Guide for Building Owners* by ARMA: This document addresses modified bitumen systems. Published by the Asphalt Roofing Manufacturers Association.

- *Flexible Membrane Roofing: A Professional's Guide to Specifications* by SPRI. Published by SPRI.

Periodicals

- *Professional Roofing*: [www.nrca.net](http://www.nrca.net)
- *RCI Interface*: [www.rci-online.org](http://www.rci-online.org)
- *RSI Roofing/Siding/Insulation*: [www.rsimag.com](http://www.rsimag.com)

Websites

- *ASTM*
- *Asphalt Roofing Manufacturers Association*
- *EPA Energy Star*
- *FM Global*
- *Metal Building Manufacturers Association*
- *Metal Construction Association*
- *National Roofing Contractors Association*: This site includes a database of publications, including magazine articles and papers from technical conferences. Many of the listings can be downloaded.
- *Oak Ridge National Laboratory*
- *Polyisocyanurate Insulation Manufactures Association*
- *Roof Coating Manufacturers Association*
- *Roof Consultants Institute*: This site includes a database of publications, including magazine articles and papers from technical conferences. Many of the listings can be downloaded.
- *Sheet Metal and Air Conditioning Contractor's National Association*
- *Spray Polyurethane Foam Alliance*
- *SPRI*
- *Underwriters Laboratory Inc.*
Software

- **RoofNav**—RoofNav is a free Web-based tool developed by FM Approvals™ that provides fast access to the most up-to-date FM Approved roofing products and assemblies.
Introduction

(a'treem), term for an interior court in Roman domestic architecture and also a type of entrance court in early Christian churches. Today atrium means an enclosed multi-storied space that is open vertically to multiple stories.

NFPA 92B the current standard for smoke control in large spaces defines atrium as a large volume space created by a floor opening or series of floor openings connecting two or more stories that is covered at the top of the series of openings and is used for purposes other than an enclosed stairway; or other mechanical and utility service to the building. The International Building Code (IBC) defines Atrium similarly as an opening connecting two or more stories other than enclosed stairways, elevators, hoist ways, escalators, plumbing, electrical, air-conditioning or other equipment, which is closed at the top and not defined as a mall.

Atriums have many advantages as a building form over conventional modern building configurations. Atrium buildings appeal to people not only logically, but also emotionally by providing a connection to the outside inside. By bringing natural light into the interior, atriums offer larger, more efficient floor areas than conventional buildings. Atriums provide more desirable work environments by providing more space with a connection to natural daylight and the outside environment. Many believe that access to natural full spectrum lighting creates a more healthful and productive environment. There have been several studies that support this view.

The view into an atrium can and in most cases is more entertaining and connective than an exterior view as illustrated below at The Plaza of the Americas in Dallas, Texas.

An atrium is a pleasant all weather gathering place providing shelter from the more extreme climate conditions outside. The atrium replicates a desirable outdoor environment by providing the benevolent aspects of the outdoor environment; natural light, moderate temperatures while sheltering us from the harsher elements of extreme temperatures, rain, and winds.

Because atriums are so complex, they create unique interrelationships between fundamental elements that must be understood and accounted for in the final design. Atriums will contain many compromises; the designer must understand the negatives as well as the positives of each component in the relationship to the complete atrium environment. Many atriums have been built where unintended consequences have compromised the design.

The complexity of atrium design does not lend itself to prescriptive standards, but sound life safety principles must be incorporated into every atrium design. Good atrium design will maximize the natural environment to minimize energy consumption.

Atriums can be configured in an infinite number of ways, but atrium configurations should be always a reasoned response to the climatic and life safety goals. Typical atrium configurations can be totally surrounded by building elements or partially enclosed. They maybe top lit, side lit or a combination of both. The configuration of the atrium will dictate many of the fundamentals of atrium the components. The first consideration of atrium design is an acknowledgement of the necessity of fire and smoke management. Building configuration is the most significant factor in smoke management and thus must be fundamental to the design.
Fundamentals

Geometry

The shape and geometry of an atrium is both the product of and the reason for the adjoining occupied portions of the building. Inhabited by office workers, residents, or other uses, these spaces are impacted greatly by the configuration of the atrium space. The configurations can refer to the shape in two or three dimensions, the scale or the layout of the surrounding spaces and how they are connected to the atrium.

There are several simple and several complex basic configurations of atrium space. They are:

SIMPLE TYPES:

1. Single sided: Atrium abuts one side of the occupied portion of the structure.
2. Two sided: Atrium abuts two sides of the occupied portion of the structure.
3. Three sided: Atrium abuts three sides of the occupied portion of the structure.
4. Four sided: Atrium abuts four sides of the occupied portion of the structure.
5. Linear: Atrium sandwiched between two occupied portions of structure.

COMPLEX TYPES:
1. Bridging: Atrium connects several occupied portions of structure.

2. Podium: Atrium sits at the bottom or below an occupied portion of structure.

3. Multiple Lateral: Atrium spaces scattered throughout plan on single or multiple stories.


These different configurations can be developed to myriad architectural statements but the basic configurations remain recognizable. Which configuration is utilized by an individual designer is a function of (among other issues) personal taste, life safety issues, proposed uses of both the atrium and adjoining spaces, impact the atrium is wished to have climactically, geographic location, urban context, and scale of the atrium desired.

**Natural Lighting**

In the last couple of decades there has been dozens of scholarly papers and research studies on all aspects of indoor environment quality and its relationship to worker productivity and well being. In the United States, the oft-cited "West Bend" study by Walter Kroner and colleagues at Rensselaer Polytechnic Institute documented productivity gains from daylighting, access to windows, and a view of a pleasant outdoor landscape at the West Bend (Wis.) Mutual Insurance Company. According to the study, productivity gains in the new building increased by 16%, with the personal controls alone accounting for a 3% gain.(x)

Another frequently cited report is the Heschong Mahone Group study "Daylighting in schools," which was conducted on behalf of the California Board for Energy Efficiency. The researchers analyzed test scores for 21,000 students in 2,000 classrooms in Seattle; Orange County, Calif.; and Fort Collins, Colo. In Orange County, students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those with the least daylighting.(x)

Natural light as it pertains to atriums is a basic element of the design. The light within the atrium as well as the light transmitted to the adjoining occupied space needs to be considered. The light coming into the atrium is impacted by several factors:

The average brightness of the local sky is a factor. This will affect the amount and type of glazing used for the exterior skin. Sufficient openings should be provided for the amount of light expected at the bottom of the atrium space. Additionally, the type of glazing, whether transparent or translucent will impact the amount and quality of natural light admitted to the atrium. Below is an example of natural light from a sky lit atrium at EDS Corporate Headquarters in
The orientation of the glazing will have significant effect and needs to be a fundamental consideration. Glazing facing to the east or west should be avoided as it is difficult to control glare because direct sun at low angles will be admitted at some point during the day. Horizontal glazing at the roof should also be carefully considered because direct light is inevitable from this orientation. Diffuse natural light generally is the preferred form of natural lighting.

Reflectivity of wall surfaces facing the atrium should be a consideration. Bright surfaces will reflect light and maintain light levels deeper down into the atrium space and therefore transmit this light to the adjacent occupied spaces.

These issues must be balanced to provide an adequate amount of light at the occupied areas of the atrium as well as the quality of light desired for the proposed uses. Also a consideration is the amount and quality of light available to the spaces adjacent to the atrium. At the top of the atrium abundant light will be available and therefore it may be desirable to provide smaller openings to admit this light while providing more reflective surfaces in order to allow the light to penetrate deeper towards the floor of the atrium. Larger openings provided closer to the floor will admit a higher level of light, the deeper the atrium the more glazing will be necessary. To aid light in penetrating the adjacent spaces more evenly and deeper, light shelves can be utilized at each level facing the atrium. This strategy may require higher floor to floor dimension to operate sufficiently but will also reduce the need for general artificial light on each floor within a reasonable dimension of the atrium. In warmer climates, this reduction in artificial light may also improve the occupied space’s thermal performance and reduce cooling loads.

The light allowed into the atrium can be varied or controlled by external or internal shading devices. These can be configured in a number of ways, vertically, horizontally or at angles to accomplish the desired shading as well as act as a design element. The need for shading devices depends on the strength of light reaching the atrium skin and this depends on the location geographically. External shading devices are used to prohibit light from directly entering the atrium and therefore controlling the heat gain associated with direct light. Internal shading lets the heat in but prohibits direct light from getting down to the usable space of the atrium.

**Extterior Envelope**

Resistance to the elements is the primary focus of the atrium enclosure. Several components can make up the skin of the atrium. They are the walls, roof and any sloping surfaces that act to keep water and wind out of the interior space and control the amount and quality of daylight penetrating the space. (Refer to Wall Systems)

In order to accomplish these goals, openings in the atrium skin should be limited to those required for ventilation and smoke evacuation at the top and bottom and pedestrian access or exit at the bottom. The Pedestrian access or exit should be accomplished through revolving doors or power sliders or swing doors in a vestibule configuration. This will help control drafts in the atrium induced by the stack effect in these large spaces. The enclosure elements of the atrium have to react to the structural building frame as well. This is accomplished through the use of movement joints to resolve a variety of differential movement between the skin and the frame, different skin elements as well as different building elements. These joints should be tracked horizontally, vertically and diagonally to termination and detailed to maintain weather tightness along their entire length and at termination or transition points. Below are some simple details showing the tracking of an expansion joint through different conditions and materials.
Exterior glazing systems used in atrium enclosures should be of a high performance curtain wall system designed and constructed expressly for the purpose of spanning large distances while controlling water and air infiltration without the aid of water shedding overhangs or other protection. The interface of these systems with adjacent material and systems should be detailed carefully taking into account different movement and movement characteristics. One type of movement that can occur is due to thermal expansion and contraction of building materials. Different materials can experience large differential movements over the same temperature change. Slip connections can typically be utilized within building systems to account for this differential movement. Deflection is another type of movement that should be considered. Deflection joints can occur at every floor level or every other floor level depending on vertical spans and loads being carried. Different structural support conditions can also telegraph through the exterior skin as expansion or construction joints. Attention must also be paid to geographic location, wind loading on components and cladding which will vary. Some coastal regions will require the consideration for large and small missile impact zones on the exterior skin and this will further increase the required performance characteristics for the system. Below is a view of the inside of such a curtain wall system and the structural back up required to support it.

Roofing systems for atria can also pose severe challenges due to the desire to admit light through the roof using skylights or a translucent roof system. The roofing system should be designed to accommodate the expected volumes of water and/or snow by removing these from the roof in an adequately short period of time as well as supporting them structurally while this is accomplished. (Refer to Low and Steep Slope Roofing Assemblies)
Sloping skin elements provide a separate set of concerns. While neither wall nor roof, they take on characteristics of both. They must perform to maintain a weather tight seal, accommodate movement in multiple directions and tie into adjacent systems at difficult angles. Further, the prospect of providing exterior building maintenance (E.B.M.) systems on sloped surfaces is difficult, and additionally so if the slope is reversed to extend out while moving away from the floor. Support for staging rigs used to provide cleaning, maintenance, repair or glass replacement should be provided to keep the stage away from the glazing system as well as safely anchoring it to maintain lateral stability as the rig moves up or down the vertical of sloping surfaces. Vertical or sloping atrium faces have additional challenges as the interior surfaces requiring access may not be sufficiently close to a floor surface in order for maintenance to occur. Therefore an interior building maintenance system should be considered to operate similar to the E.B.M. system. These interior systems can be at least as complicated as the exterior systems and often times more so due to the design intent that they not be visibly heavy or obvious inside the atrium while offering the same level of access to the portions of the building skin as the exterior systems as witnessed below at 311 South Wacker Drive in Chicago, Illinois.

Glazing in a horizontal application requires protecting atrium occupants from falling glass either by utilizing wired glazing, laminated glazing or providing safety screening below the glazing.

Landscaping

There are three basic components to the landscaping or softscape of the atrium. The planting medium, the plants themselves and the space above the planting all contribute to the success of the planting.

Planting while the primary focus can be extremely difficult to predict what types will live thrive and survive in an atrium space. A qualified landscape consultant should be retained during design to select planting and oversee the project through installation and beyond. There are some basic guidelines to plant selection. Sub tropicals should be used as they can handle the fairly consistent climate within a building.

The planting medium also has significant impact on the overall effect. Starting with planter sizes that are appropriate for the selected plants, proper soil mixes, drainage/irrigation characteristics and nutrients that will be necessarily introduces to the planting areas following installation. These issues also should be left to the landscape consultant to determine and incorporated into the design by the building designer. Of these adequate drainage and water supply should be planned on by the designer from the start.

Once these issues are established, the design of the volume of space above and around the planting is where the designer can have the most influence. Plants derive their beauty from the energy they can absorb from their environment. Light, temperature, and humidity all contribute to the growth potential of the interior planting. The amount (both intensity and duration) and quality of light provided are factors to be considered. Light in the crown of the sky will be of higher intensity than at the horizon and therefore roof lit atria will provide higher light intensities than side lit ones. This light direction will also impact the growth patterns of the interior plants and therefore should be considered. If the light in the atrium is not of sufficient brightness to support the plants proposed, artificial light can be introduced. This light should be of the proper type, that is have acceptable color rendition and be of the right frequencies to promote plant growth. Typically it is not necessary to employ horticultural type lighting due to poor color rendition and little improvement in plant performance. The light range within the atrium should be maintained between 700 and 1,000 lux with a bare minimum of 500 lux for a duration of 12 hours per day(1). This light level can be achieved with daylight solely, and combination of daylight and artificial light or in extreme situations, solely artificial light. In any case, infra-red and ultraviolet light frequencies are detrimental to plant growth and should be filtered from the natural light if possible or not produced with artificial lighting. Artificial light should be turned off or reduced to minimum acceptable levels to provide safe pedestrian travel at night as the plants need to maintain good diurnal variation or distinguishable night/day cycles.

Temperature also plays a large role in the landscape’s success. Planting should be held back from sources of cold air such as unprotected entries (those without a vestibule or revolving door) cold spots due to uninsulated glazing,
mechanical air distribution locations. Planting needs to experience some temperature variation during the day and night again to maintain the proper diurnal variation. A range of 70-75 degrees F is good during the day with a range of 60-65 degrees F at night. A minimum temperature of 50 degrees F should be maintained at all times unless plants have been chosen specifically to exist at lower temperatures.

The humidity in the atrium is also at issue. Plants will naturally increase the humidity in an interior space. Mechanical systems typically will counteract this phenomenon however and maintaining a high humidity inside may not be possible. This is not a large problem as most plants will be able to exist in this environment without much difficulty but its effect must be understood because it might be of consequence. The entire life cycle of the planting should be incorporated into the understanding of the plants role in the atrium. Plants that require extra maintenance to be appropriate to their atrium environment should be understood and incorporated into the Atrium planning. An example might be ficus types that drop an inordinate mount of leaves and thus require excessive maintenance.

**Sound (Acoustics)**

There are many impacts on the acoustical performance of an atrium space. The designer needs to decide early on the uses and types of activities to be supported both within the spaces and in adjacent occupied areas. These can range from gatherings for various events, musical performances and dances, lobby and reception function, or simply transitory from one part of the building to the other.

The basic functions of the atrium space and adjacent occupied areas will greatly impact any acoustical systems being considered. First, within the atrium space, what is the acceptable ambient noise level at the floor and in what range can the noise level be expected based on the design being considered. Medium to low thresholds of noise from the HVAC system at the floor will require consideration at the design stage. If the Atrium configuration has a dome and/or other round focusing surfaces, then the materials such as reflective and acoustical absorbing must be carefully considered. Secondly, the range of functions must be considered. Range of functions could be for instance musical concerts, parties and receptions, sit down dinners where individuals are sitting and having a conversation with those in close proximity. The musical performances want to have slightly higher reverberation to support the music, but the others want to have lower reverb for better speech privacy and ease of conversation. An example of a place that needs to be designed for both music and speech would be a church, the design has to strike a balance to serve both functions.

Acoustical parameters such as reverberation time and speech intelligibility must be considered for these functions. For example, if gatherings for corporate events or receptions are important functions then the reverberation time should be lower so the speech intelligibility will be reasonable. When the speech intelligibility is poor it is difficult to hear a conversation clearly. This is commonly known as the "Cocktail Party Effect." It may be necessary to have the acoustical criteria set for a variety of functions, but if there is a lobby and reception function then localized absorption is desirable for a clear conversation between the visitor and receptionist.

**Thermal Control**

Atria typically involve large open spaces connecting multiple floors. In some instances the space can be large enough that individual zones of greatly varying temperatures may exist within the atria. These zones may develop air currents within the atrium that may be stronger influences than the HVAC system. If the space is large enough, it is possible to create 'rain' indoors.

When only one wall of the atrium is an outside wall, it is possible in the warmer seasons for the air next to the wall that absorbs the walls transmitted heat to rise. Depending on the height of the space, air currents could develop and become a strong enough force overpowering the influence the diffuser placement has over the air movement. With multiple walls, the problem can still occur but tends to be less substantial due to more uniform temperature profiles.

Air currents due to load concentration may rise and displace the stratified air at the top, forcing the warmer air down. When cooling loads assume that stratification will occur, the design should not include heavy localized loads or unbalanced exposures. Architectural configurations of atria that include these requirements are rare. Therefore it is recommended that cooling loads do not assume stratification unless it can be reasonably shown that strong thermal currents will exist in the particular design. The design concept of spot cooling only the occupied areas is acceptable, but high diffuser throw velocity must be maintained to counteract any thermal induced air currents.
Under heating conditions, if the atrium is topped with a skylight or poorly insulated roof, warm moist air from the occupant level may rise and be cooled by the top exposure. This could create condensation. This situation should be avoided, since it can potentially damage the structural components of the roof assembly. (Reference ASHRAE 1999 Applications, Chapter 4.8.)

Atria, unlike most designs in HVAC, should be viewed as a three dimensional volume from the start of the project. Normal engineering practices such as CFM per square foot, or square feet per ton usually do not apply to an atrium. The engineer should use sketches, sections, models, and plans to understand the space from three dimensions from the very start by working with the architectural team at the planning stages. It is key that the engineer understands all aspects of the atrium volume due to the impact on airflow movement and pressurization.

The smoke control system requirements for an atrium in many cases will dictate the HVAC design instead of the cooling or heating of the space. The smoke management system design should be well developed prior to designing the thermal comfort system. Once the smoke management intakes, fans, ducts, and diffusers are generally established based on the smoke management requirements, the potential to use these for thermal comfort can be considered. Again, it is key that the thermal comfort air system and smoke control system be implemented into the architectural design at the building planning stage. The smoke management system should not be compromised to take advantage of a designed thermal comfort system. The two systems must be designed in concert. The thermal air currents and any stratification during a fire event are completely different than in normal operation. This section only applies to the atrium thermal environment during normal operation. Refer to the Smoke Control section for the life safety design of the atrium. (Reference ASHRAE 1999 Applications, Chapter 51.)

The intended use of the atrium has an effect on the HVAC design and must be established early on in the design process. Is it a transient space only such as a hallway, or will seating be provided for people to lounge and interact? Will there be large gatherings of people during special events? What type of finishes and furnishings will be placed in the space? Will there be seasonal decorations such as a Christmas tree that will increase the fuel loading used for smoke control calculations? (Reference ASHRAE 1999 Applications, Chapter 51.13)

The use of the atrium may vary from the building it serves, atriums tend to be universal spaces used for many functions. Atriums are often used for large gatherings and functions. The anticipated occupant load the system is designed for should be documented and provided to building management. If the outside air ventilation system or the space thermal comfort system was not designed to accommodate dense occupant loads, the building management should understand the limitation on the use of the atrium.

If the space will be a transient space only, the design temperature range can be expanded. If seating, dining, or other uses where occupants will remain in the area for an extended time are intended then design temperatures should remain more stringent, similar to other spaces of similar use.

The following items should be considered:

- Large volumes of air are involved in the smoke control system. This air may need to be heated before introduction or the sprinkler system maybe subject to freezing.
- Air units must be designed to accommodate the 100% outside airflow to prevent component damage. This typically means involving a steam system in some way, which results in significant cost.
- Can the applied heating system respond quickly enough to the smoke control mode.
- How to heat the space if it has large expanses of glass.

Pressurization and Air Balance

Since an atrium by definition communicates or is adjacent to many different areas of the building, the pressure relationship between the atrium and other spaces is crucial to a successful design. In many cases, the atrium is also the main entrance to a building and the pressure relationship between the atrium and the outside is critical to the control of overall building pressurization.

The conditioning and ventilation of the atrium usually involves large quantities of air, so the infiltration or ex-filtration is an even smaller percentage of the total quantity of air being handled. This may require controls and instrumentation to be of a higher quality and accuracy than is typical in the remainder of the building. It also makes the initial, and ongoing,
balancing of the atrium systems more critical to the overall success of the project. This must also work in concert with
the smoke control pressure relationships. (Reference ASHRAE 1999 Applications, Chapter 51.12)

Stack effect and thermal currents may produce unanticipated influences on pressure relationships if not accounted for in
the design. Therefore the atrium systems should be designed to allow some flexibility at start-up and in the future to
adjust the balancing of the systems. This may include upsizing the atrium equipment to a condition greater than
calculated for outside air or relief/exhaust quantities. This same thermal stratification has significant impact on the smoke
control system operation in its ability to properly draw smoke and maintain pressure relationships. (Reference ASHRAE
1999 Applications, Chapter 51.13)

Since atriums are usually the focal point of the building and communicate with most all other spaces, atrium pressure
should be considered as the datum that all other spaces are compared to. If the atrium is maintaining a slightly positive
pressure relative to the outside, than most spaces should be designed to be neutral to the atrium and match the atrium
pressure thus maintaining a positive building pressure. If too many spaces are designed positive to the atrium, the
combined infiltration of air into the atrium may exceed its relief capabilities and over pressurize the building causing
excessive air movement at building entrances. Due to seasonal thermal effects, the system should utilize automatic
controls that will adjust the balance of the atrium based on outside temperatures or atrium pressures.

Fire Protection/Smoke Control

The most critical of all the technical issues to be solved in a successful atrium design is Life Safety because atrium
buildings break with orthodox concepts of Safety. Life Safety design for any building is difficult. It involves more than a
 provision for emergency egress, it requires attention to who will be using the building and what they will be doing.
Consideration must be given to communication, the protection of escape routes, and temporary areas of refuge allowing
reasonable time for the building occupants to reach safety.

Because of its critical nature both NFPA 101 "The Life Safety Code" and The International Building Code have extensive
code provisions for Atriums. Since the code provisions are extensive we will not recite them here but refer any design
team to an exhaustive review of the requirements. Both NFPA and the IBC give significant explanatory material to
atriums in their Life Safety Code Handbook and IBC commentary respectively. While similar they are not identical. A
significant difference is that the IBC is prescriptive and arbitrarily limits the number of floors that maybe open to the
atrium to three, where the Life Safety Code is more performance oriented and will allow the number of floors open to the
atriums without enclosure be based upon the results of the required engineering analysis.

One of the basic premises of atrium requirements is that an engineered smoke control system combined with an
automatic fire sprinkler system that is properly supervised provide an adequate alternative to the fire resistance rating of
a shaft enclosure. It is also recognized that some form of boundary is required to assist the smoke control system in
containing smoke to just the atrium area.

Both the Life Safety Code and IBC require that the atrium space be separated from adjacent areas by fire barriers
having a fire rating of 1 hour or equivalent. Both codes accept adjacent spaces to be separated by properly constructed
glass walls where automatic sprinklers have been installed to protect the glass. The sprinklers are to be located so as to
wet the entire surface of the glass.

The development of most code provisions has largely been a response to specific fires and the desire to prevent
recurrences. For example, in recent times many present code provisions were responses to the Coconut Grove Night
Club fire, the Chicago school fire, and the MGM Grand fire. Conventional doctrine dictates that to achieve Fire and Life
Safety that fires must be kept as small as possible and the effect of fire limited to as small an area as possible. This
philosophy has resulted in conventional building configurations employing compartmentalized construction of fire rated
floors and fire rated walls.

While atrium design breaks with conventional building configurations Fire / Life Safety in atrium buildings is comprised of
the same three elements as in conventional buildings—means of escape, smoke control, and fire control. Means of
escape, emergency egress is a fundamental plan issue and must be integral with the circulation concept of the building.
Emergency egress must be incorporated from day one. Smoke control strategies are also fundamental and must be part
of the initial ventilation concepts. Fire control and fire fighting provisions must also be integrated in to the original
concepts.
The basic concept of means of egress planning is that occupants can move away from a fire and reach a protected means of egress by their own unaided efforts. This route must remain tenable throughout the evacuation process. A complicating element that must be addressed is that in an emergency people tend to use the route they are familiar with. Occupants of office buildings can be trained by fire drills but visitors will only know the way they came in. Means of egress protected exit stairs should be on familiar routes and in intuitive locations and signed very clearly. Mean of egress should not be unduly exposed to potential hazards. (Refer NFPA 101) The Life Safety Code being more performance based requires that an engineering analysis be performed to demonstrate that smoke will be managed for the time needed to evacuate the building. To accomplish this, the analysis must prove that the smoke layer interface will be maintained above the highest unprotected opening to adjacent spaces, or 72” above the highest floor level of exit access open to the atrium for a time equal to 1.5 times the calculated egress time or 20 minutes, whichever is greater. For a protect-in-place occupancy, such as Healthcare, the evacuation time is considered to be infinite, which means that the smoke control performance criteria must be maintained indefinitely.

The fire record has shown that smoke is the primary threat to life from fire in buildings. Smoke is the most rapidly developed threat. Proper smoke control in an atrium building is an absolute must. Smoke control systems that are integral to the buildings ventilation systems are preferred over stand alone systems. Integral systems are more reliable because their components are constantly being monitored and maintained. (Refer NFPA 92B Guide for Smoke Management Systems in Malls, Atria, and large areas.) NFPA 92B, quantifies the physics associated with atrium smoke control and presents methodologies for system design in an understandable and useful format. The guidelines of NFPA 92B allow the system designer to design a system and prepare associated documentation to access for adequacy in meeting the performance criteria.

The basic nature of fire and smoke must be well understood by the design team in order to incorporate smoke control in to the physical configuration of the atrium from the earliest schematic designs. Well designed smoke control cannot be added to a design, it must be integral to the design.

Effective smoke control depends upon rapid control of fire size to limit smoke quantities to manageable volumes. Fundamental to effective smoke / fire control is early detection and suppression. Smoke and or fire detection systems must be designed to identify and locate a fire early in its development. The fire prevention and smoke removal strategies for the atrium will vary dependent on the location of the fire and the configuration of the atrium.

Large volumes and high ceilings significantly complicate and possibly delay early smoke and heat detection. Systems that can detect the smoke near the occupied floor levels and close to the potential fire sources are best. Smoke detectors should be placed in ceilings in spaces surrounding the atrium but located within the atrium enclosure. These include balconies, seating alcoves, corridors, lobbies, and other spaces that have typical ceiling heights. To detect smoke in the high ceiling area, detectors should be located near the atrium floor to detect smoke prior to rising and potentially dissipating in the large volume. If the space is tall enough, smoke will cool and begin to descend back to the floor level, without reaching the upper ceiling level. Beam detectors are one potential solution to detecting smoke at lower levels of the atrium. If used, the location of beam detectors transmitters and receivers must be carefully chosen to allow the proper coverage, and to allow easy access for adjustment, testing, and periodic maintenance. Smoke and or heat detectors should also always be placed at the highest ceiling level as a precaution in case the other detection systems did not activate. The figure below in a highly simplified form represents many of the items that must be considered in the smoke control system in an atrium.
Early suppression of a fire is essential to effectively limit the amount of smoke to manageable levels. Automatic sprinklers are the most effective means of fire suppression appropriate to atriums. The fundamental nature of atria presents challenges to the effective use of automatic sprinklers. In atriums with high ceiling heights, typical sprinkler designs provide marginal fire extinguishing capabilities and may actually be detrimental to the smoke removal system. Water from sprinkler heads located greater than 75 feet above the fire source may break up into a fine mist and evaporate before reaching the fire source. The evaporation of sprinkler water may cool the smoke and reduce the effectiveness of smoke removal systems, which were designed to pull the smoke from the top of the enclosure.

A qualified life safety consultant or fire protection engineer (FPE) involved early in the atrium design is the best source of potential fire detection and prevention system selection options. The FPE is knowledgeable in all of the atrium code issues. The codes and standards that address smoke control systems for atria are based on similar research and fundamental fire size and smoke generation models. ASHRAE 1999 Applications, Chapter 51 provides a broad design basis for smoke management that provides general directions to the designer. NFPA 92 is more specific and provides a set of calculations that can be performed by the FPE to determine the quantity of exhaust necessary to evacuate the smoke generated by the largest anticipated fire size. The calculations cannot anticipate all of the aspects that are unique to the atrium under design, and therefore should only be used for the most simple of atrium configurations. For all atria, and especially complex or tall atria, a qualified life safety consultant should be employed to assist in determining the smoke control system parameters. Currently the most comprehensive method of determining complex smoke management criteria is with computer fire modeling. (Reference ASHRAE 1999 Applications, Chapter 51.12) In many instances the results of the computer modeling will result in lower exhaust quantities being required, and therefore lowering initial project costs. The model allows multiple fire origins to be evaluated, and the resulting smoke removal system needs to be adequate for all anticipated fire origin location.

Computer modeling and visualization are important tools for understanding the processes of fire behavior. Fire models range in complexity from simple correlations for predicting quantities such as flame heights or flow velocities to moderately complex zone fire models for predicting time-dependent smoke layer temperatures and heights. Zone fire models' calculations can run on today's computers within minutes because they solve only four differential equations per room. Zone models approximate the entire upper layer with just one temperature. This approximation works remarkably well but breaks down for complicated flows or geometries. For such cases, computational fluid dynamics (CFD) techniques are required.
Even when the actual exhaust quantities were determined by use of a computer fire model, smoke management systems shall be designed in adherence to all other requirements of NFPA 92. Requirements such as the use of direct drive equipment in lieu of belt drive, protection of control wiring, emergency power, and the design and installation of a fireman’s control panel to allow manual operation of the smoke removal equipment is mandatory. (Reference NFPA 92)

**Maintenance**

The operation of the atrium can be diverse and requires close coordination between the designer and user to determine what aspects of the operation that are key. Some of the more critical elements are occupant comfort thru the air system, the mode of operation for the atrium and lighting considerations.

The key elements that the design engineer should consider in the atrium comfort system design are space temperature, energy efficiency and air system type. (Reference ASHRAE 1999 Applications, Chapter 4.8) These are described below.

**Space Temperatures**—The design temperature for the atrium can vary dramatically based on usage. If the space is to be a heavily occupied, constant use space, 75°F should be considered (summer design). However, if the space is a transient operation, a higher temperature of 78°F should be considered.

**Energy Efficiency**—Energy efficiency should be considered in the design such as these listed below.

- Upper level stratification
- Spot cooling where occupants are located
- Night (or unoccupied) setback points
- Triple pane glass
- Motorized shading advices

None of these energy efficiency means however should compromise neither the airflow requirements nor the fire protection or smoke control design aspects discussed in other sections.

**System Type**—While variable air volume systems are recognized for their energy saving ability, they should be carefully scrutinized in the design process for their ability to maintain proper atrium pressure control. Typically, large vestibules are utilized at the atrium entry. Consider using a constant volume air supply in the vestibule to overcome wind pressure at the entry point.

It is important that the designer works closely with the building user in the planning stages to determine the many modes of operation that are anticipated. The building user will set the modes of operation. Thru a firm understanding of the modes of operation desired, the designer can provide as much flexibility in the building control system to achieve a detailed level of control for HVAC zone control, temperature reset, lighting functions, etc.

The lighting of an atrium can be a significant challenge and the use of a specialized lighting designer should be considered. Atrium lighting schemes must be evaluated on an individual basis according to the function of the space and nighttime operation. The following should be considered:

- The lighting level should be maintained in the range of 15 footcandles either thru day-lighting or artificial means.
- If indirect schemes are possible, they should be considered.
- If the atrium is used as an egress, the lighting must be capable of immediate restart should normal power be lost.
- Planting and vegetation needs should be addressed. Point source lighting may be necessary.
- Develop a plan for lamp replacement in high ceilings.

**Applications**

The following are examples of atria that exhibit the above concepts in different combinations, locations and architectural styles. Hopefully they will help explain the concepts and give them physical representations.

**Case 1: Plaza of the Americas, Dallas, Texas**
The Plaza of the Americas in Dallas, Texas is an example of the bridging atrium, a complex form that utilizes the atrium to connect several buildings. In this case two twenty five story office towers, a twelve story hotel and a twelve story parking garage. There are retail shops at the two lowest levels, one below grade around an ice skating rink. Natural light is admitted to the atrium space through full height glazing at the side walls between the buildings being connected as well as through narrow skylights running across the roof in an angular fashion. Additionally, prisms are suspended inside the side wall glazing that produce interesting color patterns on the interior atrium surfaces.

The light entering the atrium is transmitted to the adjacent buildings through floor to ceiling clear glass. The exterior atrium and building glass is heavily tinted and has a 30" high spandrel sill limiting vision glass area to limit the amount of heat gain. The Atrium is oriented with its long axis north-south. The atrium space is climatically tempered as opposed to controlled. This saves energy costs for the attached buildings while limiting the expenditure for both capital and operational for HVAC equipment for the atrium.

The smoke control is achieved through smoke vents at the bottom and top of the atrium exterior walls activated through smoke detectors. This passive smoke control design produced in the late 1970's is not the recommended method of smoke control based on today's codes or standard of care.

The exterior skin is a glazed curtain wall system supported by steel wide flange beams spanning between the building structures which the atrium connects. The roof system consists of deep long span steel trusses covered with exposed metal deck, insulation and roofing. While functional, this roofing system might seem a little light for the volume of space enclosed. Exterior building maintenance is achieved with traditional davits, tiebacks and stages at the exterior while boatsains chairs rigged from the roof trusses accessed through a catwalk system. Stages could be rigged from the trusses also if required.

There is one bank of glass elevators exposed in the atrium which serve the parking garage which allow all tenants and visitors to enter the complex in a grand way seeing the whole atrium and building complex upon arrival. Each building also has an individual entrance accessible without entering the atrium. The lower portion of the atrium can be accessed from grade and has wide sidewalk like pathways adjacent to all buildings and overlooking the ice skating rink at the below grade level. Connection between the two levels is via two sets of escalators, the glass elevators or several sets of stairs.

Landscaping within the atrium is limited with small planting areas utilizing potted plants surrounded with mulch to give appearance of continuous planters. Additionally there are large palm trees in individual planters recessed into the lower level floor which are water proofed, drained and irrigated. This planting scheme minimizes the maintenance required for completely irrigated and drained planters while maximizing the effect of the landscaping provided.

This atrium application is also connected to adjoining properties via a sky bridge system which provides a link to a system of climate controlled accessways to other downtown buildings during the hot Texas summers. This atrium also provides a food court which is utilized by tenants as well as visitors from other area buildings. This provides economic help through leasing atrium space as well as producing income for tenants.

Case 2: Bayfront Medical Plaza, St. Petersburg, Florida
The Bayfront Medical Plaza is an example of a two sided atrium, a simple form which sits in the corner between two wings of a medical office building. The building is five stories with a two story space connecting the wings and the atrium on the face. The atrium is five stories high with full height glass on the exterior faces and punched opening between it and the building. It also connected to the adjacent parking garage via a sky bridge. The atrium is completely climate controlled with accessible floor space at the Ground Level and Level 2.

The Life Safety systems have a smoke evacuation system consisting of a coffered ceiling with vents and mechanical units for the venting of smoke. This system is activated by smoke detectors or sprinkler line flow switches. The building and atrium are fully sprinklered as well as the glass separating the building from the atrium in the punched openings.

The exterior skin of the atrium is a glass curtain wall system with tinted insulated glass in aluminum frames supported by a steel structural frame which is clad with GRG (glass fiber reinforced gypsum) panels and gypsum board furring. The roof is composed of steel wide flange beams covered with metal deck, insulation and roofing system. A suspended gypsum board soffit system creates the coffered ceiling which allows for mechanical systems and lighting to be placed aesthetically. Exterior building maintenance is achieved with davits and tie backs and stages while interior building maintenance is achieved through supports off of the steel structure.

Vertical transportation is independent of the atrium. The atrium acts as entry point for the building as well as collecting visitors from the parking garage across the street from the sky bridge and then down an escalator bank to the Ground Floor.

There is very little landscaping inside the atrium, several large potted plants, but extensive landscaping both hard and softscape outside of the atrium. The atrium also connects the main entry court with a more private courtyard behind the building.

This atrium provides a daylit entry to the building wings while offering a weather protected buffer for patients and visitors to get from their vehicles to the Doctor’s offices. It is a simple yet welcome addition to the Hospital campus.

**Case 3: Crawford Long Hospital, Atlanta, Georgia**

Crawford Long Hospital is a one sided Conservatory atrium, which is the most simple form that utilizes the atrium as an entry point to the building it serves. The building is a five story hospital with a 14 story medical office building above for a total of 19 stories. The atrium is a three story volume with waiting rooms for various departments and patient rooms overlooking the space offering a comfortable connection to many patient and visitor services. Natural light is admitted to the space through large glazed punched openings in the front wall and large gable ended sky lights in the roof. The atrium faces south to take full advantage of natural light. There is a pedestrian connection via sky bridge to an adjacent cancer center and parking garage located across the entry drive.
The atrium volume uses an engineered mechanical smoke control system that draws fresh air in at the bottom and exhausts smoke laden air at the top.

The exterior skin of the atrium is an expression of punched openings glazed with an aluminum and glass curtain wall system incorporating glazed in granite panels and gypsum board and wood accents on the interior. The atrium structure is steel framing tied into the concrete frame of the building. The roof is steel framing with metal deck, insulation and roofing system clad on the interior with a highly articulated coffered suspended gypsum board soffit system that provides a place to provide additional lighting as well as concealing the extensive mechanical and smoke control systems. This atrium requires little in the way of exterior or interior building maintenance equipment due to its minimal height. Most glazed areas can be serviced from a man hoist which can be brought in as needed. Davits and tie backs are provided at the exterior perimeter where necessary.

Vertical transportation for the building (elevators) is adjacent but separate from the atrium. Escalators are provided within the atrium from Lobby Level to Level Two in order to connect with the sky bridge. There is also access to stairwells adjacent to the atrium. Horizontal circulation is provided from the main entry which has an attached canopy extending over the entry drive through the atrium to any number of destinations including the buildings vertical transportation hubs.

Landscaping within the atrium is lush and extensive located in planters depressed into the floor structure and above the space below, waterproofed and provided with irrigation and drainage. The planting is extensive and provides shade and reduces the scale within the atrium.

**Case 4: EDS Corporate Headquarters, Plano, Texas**

EDS Corporate Headquarters is a sprawling suburban low rise campus north of Dallas, Texas. The buildings are designed as clusters of office space connected with skylit multi-story atria. This is an example of a multiple lateral atrium design. The atria are completely climate controlled and some heavily planted to offer the illusion of outdoor space without the extreme temperature swings of the North Texas region.

The life safety systems include mechanical smoke evacuation and fully sprinklered interior space below the extensive sky lights in the ceiling plane. The spaces adjacent to the atria are not separated from the atria with partitions of any kind typically. Smoke control and containment were achieved through separate mechanical systems. This system was extensively tested and performed well.

The adjacent spaces to the atria form the majority of the walls of the atrium, therefore there was very little vertical exterior skin design involved in this case. There are however extensive horizontal vaulted sky lighting systems design including the incorporation of interior building maintenance systems.

There are many grand stair cases both adjacent to and within the atria as well as elevators and escalators providing vertical transportation in the buildings.

The largest of the multiple atria is located in the center of the campus and is flanked by two large catenary trusses providing support for the floors of the space adjacent to the atrium.

These atria provide daylight, accessible common spaces for all company departments to use and a large gathering space for full company gatherings.

**Case 5: Methodist Willowbrook Hospital, Houston, Texas**
Methodist Willowbrook Hospital is a four story Hospital and Medical Office Building in suburban Houston, Texas with a linear atrium dividing the building between the hospital function and the Medical Office Building function. The atrium is completely climate controlled and has limited planting in the space.

The atrium has a fully mechanical smoke evacuation system per the building and life safety code the building is fully sprinklered. The atrium is separated from the Hospital by a one hour fire resistive partition with glazed openings as allowed per the building code and from the Medical Office Building by a 2 hour fire resistant rated occupancy separation.

Since the Hospital and M.O.B. form the two long sides of the atrium, there is very little vertical exterior skin for the atrium. It is located only at the two short ends above entry vestibules or occupied space and consists of glazed aluminum curtain wall. The majority of the natural light is admitted by the skylight at the roof plane. This configuration limits the area available for mechanical access to fresh air necessary for the smoke management system. This configuration presented many design challenges to the mechanical designer.

There is vertical transportation located in the atrium in the form of elevators located in the center of the space on axis with the main entry to the building and two grand stair cases between the Ground Level and the Second Level wrapping the elevator core.

The atrium houses waiting areas for some Ground Level departments as well as a dining area for the Hospital cafeteria and a piano for entertaining patients, employees and guests during the day and at special functions in the atrium.

Case 6: American Stores Corporate Headquarters, Salt Lake City, Utah

American Stores Corp. HQ is a 24 story office tower in downtown Salt Lake City, Utah. It is composed of an alternating series of 2 and 4 story vertical atriums that work their way up the building from the ground floor up to the top. There were 4 two story and 4 four story atriums. The atriums were a parallelogram in plan configuration and enclosed on three sides by a combination of restrooms, file areas, corridors, and conference rooms. The fourth side of the atrium was an exterior wall of the building and had exposed steel framing. The service areas were separated from the atrium by a one-hour fire wall configuration. The Conference Rooms were floor-to-ceiling glass walls and were protected by a deluge sprinkler system on one side of the glass. A mechanical smoke evacuation system was used in all of the atriums.

Emerging Issues

One emerging issue affecting exterior building maintenance or more directly, window washing is Self Cleaning Glass. This was a major find a couple years ago but has not proven out commercially. The system works by applying a coating of microcrystalline titanium oxide to the exterior surface of the glass panel. The coating is on the order of 15 nanometers thick. This added coating is activated by U.V. radiation from the sun after installation and from that point on two processes take place to keep the glass surface relatively free of visible dirt. First a photocatalytic process takes place that breaks down organic portions of surface dirt and loosens it from the face of the glass. Second when water either sprayed or from rain strikes the glass, the coating has hydrophilic properties which is to say that water droplets tend to pool together more readily and sheet flow off the glass more easily carrying the loosened dirt with it. The glass may still require manual cleaning but technically shouldn't need it as often as uncoated glass. The cost implications of using this product which is available from several manufacturers depends on many factors but is not yet being widely used. However, this could change in the coming months or years.

A second emerging trend is sustainability. This issue has come to the fore recently due in large part to the LEED (Leadership in Energy & Environmental Design) Certification process instituted by the USGBC (United States Green...
Building Council). While the LEED system for certification encompasses all disciplines involved in building design, the atrium can be an asset in this arena and should be included in the evaluation when owners and designers wish to pursue green building certification.

Federal agencies, both civilian and military, were among the earliest advocates of green building nationally. Today, U.S. government buildings comprise about 10% of the projects registered in the USGBC's LEED program.

The Leadership in Energy and Environmental Design Green Building Rating Program is, in the words of the U.S. Green Building Council, "a national consensus-based, market-driven building rating system designed to accelerate the development and implementation of green building practices. In short, it is a leading-edge system for designing, constructing, and certifying the world's greenest and best buildings." This statement at once reveals both the brilliance and the shortcomings of LEED for new construction in its current form—and points the way toward improvements that need to be addressed in its next iteration.

LEED works so well, first of all, because it is simple to understand. LEED is divided into five categories related to siting, water conservation, energy, materials, and indoor environmental quality, plus an innovation and design category. Finally, while LEED is supposed to produce "the world's greenest and best buildings," the process does not in and of itself guarantee optimal results. Clearly, it takes more than following a checklist to create a well-designed, fully integrated sustainable building.

Zone Fire Models

In the 1970s, NIST and others developed zone fire models that describe how fires evolve in compartments. These models divide each compartment into two spatially uniform volumes or zones. The upper layer contains the hot smoke and combustion products from the fire and the lower layer contains air at near ambient temperatures. Zone fire models require solving a mass and energy conservation equation for both the upper and lower layers; that is, two control volumes. However, the models neglect the momentum equation within a zone, because they assume that flow within a layer is quiescent. A simple form of the momentum equation, Bernoulli's Law, is used though to compute vent flow between compartments, using pressure differences. Additional equations can describe other physical processes, such as fire plumes and radiative, convective, and conductive heat transfer. Zone fire models predict the interface height between the two layers and layer its gas temperatures remarkably well because of the tendency of hot gases to stratify or form layers due to buoyancy.

Interestingly, a zone fire model doesn't include the most critical parameter. The fire itself isn't modeled but inputted in the form of heat-release rate data.

Fire simulation with CFD

The current state of the art in computer fire modeling is exemplified by NIST's latest contribution to fire modeling, the Fire Dynamics Simulator (FDS). FDS predicts smoke and/or hot air flow movement caused by fire, wind, ventilation systems, and other factors by solving numerically the fundamental equations governing fluid flow, commonly known as the Navier-Stokes equations. The downside is that CFD calculations can easily take days to run since they solve for many variables in each of hundreds of thousands or even millions of grid cells. These calculations generate far more output than the simpler zone models. While simple line plots are adequate for visualizing zone-fire-modeling results, we need more sophisticated techniques for interpreting the massive amounts of data generated by the CFD models.

Summary

Atriums are more than a kit of parts that can be combined into various configurations. Each fundamental element must be fully understood. The design process begins with the site and the natural environment. All subsequent decisions are effected by these determining conditions.

The designer must successfully blend and combine elements of the fundamentals of geometry, lighting, envelope construction, landscaping, acoustics, thermal control, pressurization and air balance, fire protected, life safety smoke control, and maintenance into a cohesive whole.

The most fundamental concept of successful atrium design is a good understanding of the complexity of the atrium
environment. Atriums are the most complex built environments that most designers will encounter. Atriums are composed of more component parts in more complicated relationships than any other building type. No fundamental component of an atrium should be accepted until its relationship with the whole is understood. For every component and every aspect of every component there will be beneficial aspects and also non-beneficial aspects. There will be "pros" and "cons" associated with every element. These attributes are not static, they will change with relationship to any or all of the other components or elements of the atrium.

In the final analysis successful atria are defined by three determinations; do they lift the human spirit, are they safe places to be and are they cost effective. Simple right.

**Relevant Codes and Standards**


**Additional Resources**

**WBDG**

**SPACE TYPES**

Atrium, Lobby

**DESIGN OBJECTIVES**

Functional / Operational—Ensure Appropriate Product/Systems Integration

**PRODUCTS AND SYSTEMS**


- **Atrium Buildings Development and Design** by Richard Saxon
- **Society of Fire Protection Engineers (SFPE)** for information regarding:
  - Publications, design guides, and tools for fire and smoke modeling
  - Performance-based building code compliance
- U.S. General Services Administration (GSA):
  - **Facilities Standards for the Public Buildings Service**, PBS-P100, 2005
  - 3. Architecture and Interior Design
  - 3.1 Basic Building Planning Principles
  - 3.2 Space Planning, Public Spaces
  - 7. Fire Protection & Life Safety
  - 7.16 Special Fire Protection Requirements, Atriums