WINDOW DESIGN AND SELECTION: GUIDING PRINCIPLES

DR. JOHN STRAUBE, UNIVERSITY OF WATERLOO

Standard principles of enclosure design should be followed, with some special concerns:

Control air flow by using an effective air barrier. An air barrier is needed to control airflow through all enclosures. A line of air tightness from the wall air barrier system through the window and IGU should be drawn in 3-D.

Control surface condensation. The glazing edge and the frame are most critical. In skylights, the use of condensation gutters should be considered. There are many combinations of frames, spacers, and glazing available that can provide a wide range of performance. Limiting & controlling the interior humidity should also be considered.

Use a screened-drained strategy to control rain penetration. Window systems include joints and elements. Elements tend to be watertight, joints tend to leak. In almost all cases, drained systems are preferred, and essential for skylights. Sub-sills flashing under window units are almost always required for full rain penetration control. Window sills must have end dams and projecting drip edges.

Design for structural load transfer and movements. Always design the load transfer mechanisms from the window through the connectors and secondary structure (framing, masonry, etc.) to the main structure. Windows are not designed to take loads from the building. Therefore, movement joints or flexible materials should be designed and provided where ever movements could be expected. This means a space above and around all windows. Use dry joints (e.g., gaskets or drained and pressure equalized) where ever possible. Include realistic construction tolerances and provide a design that allows for them. Curtainwalls must be able to accommodate the deflection of floor slabs and the shrinkage and settlement of tall buildings.

Keep the interior of the frame warm. Place as much mass inside the thermal break (in metal windows) and wall insulation as practical without violating other principles. Locate the plane of the window as far to the inside as possible to maintain its temperature closer to the interior. Beware tight-fitting curtains and wind coverings that prevent convective exchange with the interior, thereby causing cold windows.

Balance solar heat gain, heat loss, and light transmittance. These three properties of the window (glazing plus frame and spacer) are critical to the in-service performance of the window. Balance the heat gain, heat loss and light transmittance to meet the climate and build use. Low solar heat gain and high light transmittance (to offset the need for artificial lighting) are the most important in warm climates and/or large buildings with internal gains. For smaller buildings in cold climates, low heat loss and high solar gain are the most important features.

Consider maintenance and repair. All windows need to be cleaned on the inside and outside surfaces. How will a broken piece of glazing be replaced? How will any caulked joints be renewed? The hardware on operable windows can fail early and often. Choose carefully.

TECHNICAL PERFORMANCE OF WINDOWS AND CURTAINWALLS

Windows and curtainwalls behave differently than opaque enclosure elements for a number of reasons. The primary concern is that view and daylighting be preserved while heat loss and gain is minimized. Windows have very poor thermal resistance (i.e., R-value) relative to opaque enclosure elements.

The key measures of window performance are:

1. U-Factor (or R-value)
2. Solar Heat Gain Coefficient (SHGC), and
3. Visible Transmittance (VT).

The air leakage rating (a measure of the rate of air loss through a window under a specific pressure differential) is also important, but not addressed here.

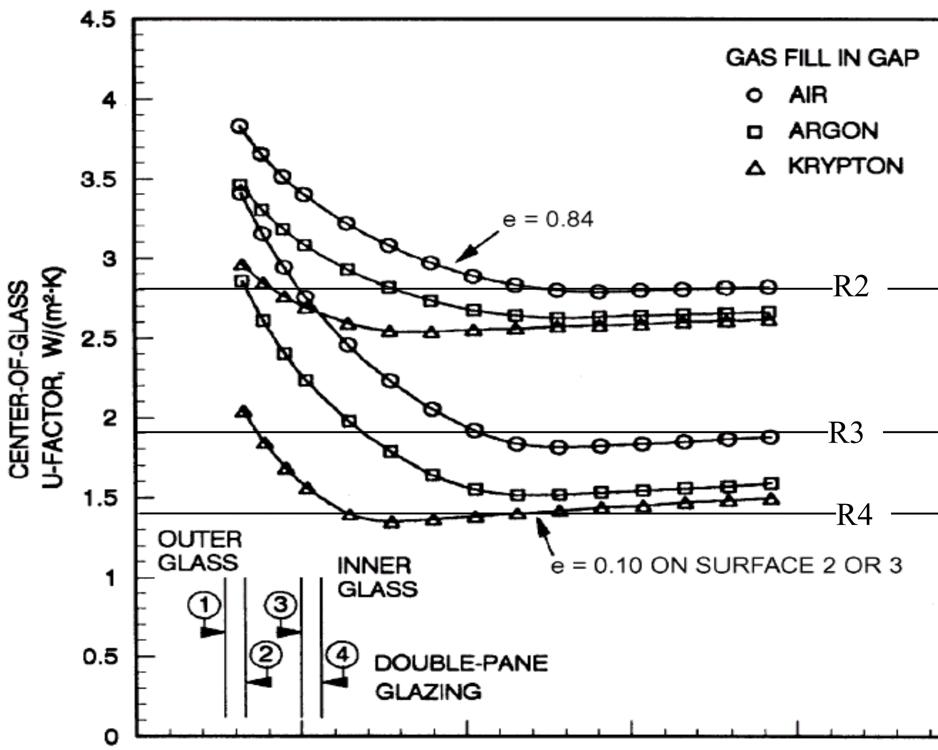
The U-Factor is a measure of how easily heat travels through an assembly. The lower the value, the lower the amount of heat transfer through the window (from the interior to the exterior). Some manufacturers rate thermal performance using R-Factors. R-Factor is the inverse of the U-Factor, i.e., $1/U = R$, $1/R = U$. For example: a U-Factor of 2 is the same as an R-Factor of 0.5.

The overall or "total" or "whole window" U-Factor of any window depends on:

1. The glazing's radiation transmission properties (i.e. glazing coatings)
2. the type of gas fill between the panes (air, or inert argon or krypton)
3. the materials and design of the spacer separating the glass panes, and

4. frame materials and design.

Figure 1 shows the dramatic reduction in glazing unit U-value (increase in R-value) for advanced glazing – imperial R-values of 4 are technically and economically feasible. Low-E coatings can be seen to be very powerful (and e=0.04 coatings are now available). Triple glazings with coatings, fills and super spacers allow for glazing with as much as twice this performance (i.e. half the U-value or double the R-value).



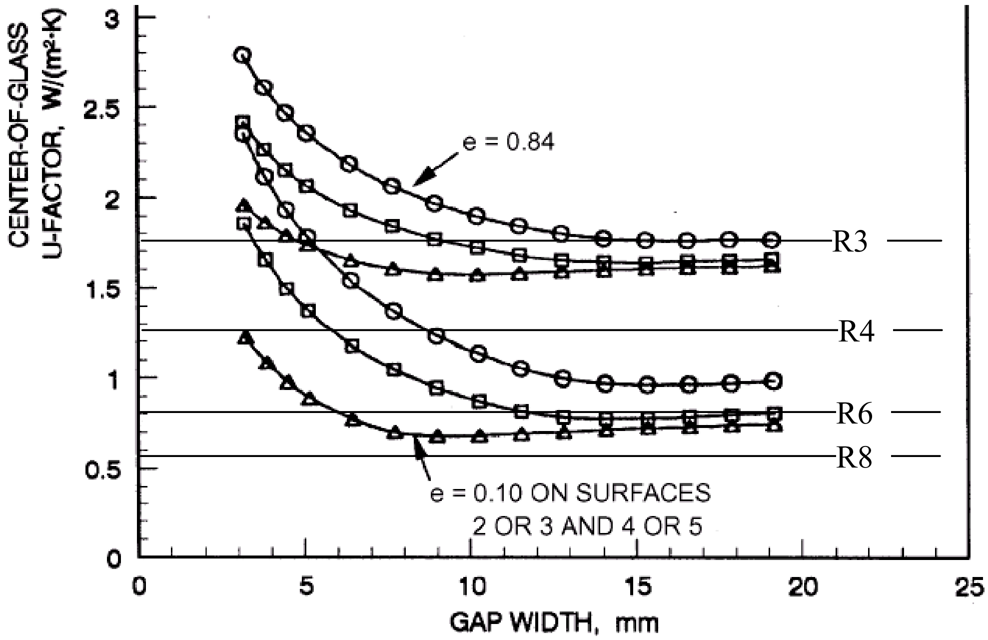


Figure 1: U-value (metric) versus Airspace Thickness for Different Fill Gases and Coatings (From ASHRAE HOF 2001). $U_{metric}/5.67 = U_{imperial}$. mm/25.4=inch.

Because of the large effect of the frame, the glazing unit's thermal performance is typically rated at the "center of glass", well away from edge effects, while the window performance is rated based on the frame and the window as a unit. Because of the significant and often poor performance of the frame, windows with large uninterrupted glazing areas are generally less expensive per square foot and have higher performance than those with small areas.

For example, Table 1 lists the U-value (in metric units) for a range of typical windows. For a common commercial situation e.g., a fixed thermally-broken aluminum window with metal spacers and air-filled double glazing, the U-value of 6.4 W/m^2 (an imperial R-value of less than 1!) is many times poorer than that provided by a simple opaque wall (which is at least R12, often R20). Hence, normal windows lose a significant quantity of heat on cold nights, and have poor condensation resistance.

Table 1: Representative U-values (W/m^2) for Glazing products (ASHRAE HOF 2001)

Frame Material	Type of Spacer	Operable			Fixed			Garden Window		Plant-Assembled Skylight			Curtain Wall[e]		
		Single[b]	Double[c]	Triple[d]	Single[b]	Double[c]	Triple[d]	Single[b]	Double[c]	Single[b]	Double[c]	Triple[d]	Single[f]	Double[g]	Triple[h]
Aluminum without thermal break	All	13.51	12.89	12.49	10.90	10.22	9.88	10.67	10.39	44.57	39.86	39.01	17.09	16.81	16.07
Aluminum with thermal break[a]	Metal	6.81	5.22	4.71	7.49	6.42	6.30			39.46	28.67	26.01	10.22	9.94	9.37
	Insulated	n/a	5.00	4.37	n/a	5.91	5.79			n/a	26.97	23.39	n/a	9.26	8.57
Aluminum-clad wood/ reinforced vinyl	Metal	3.41	3.29	2.90	3.12	2.90	2.73			27.60	22.31	20.78			
	Insulated	n/a	3.12	2.73	n/a	2.73	2.50			n/a	21.29	19.48			
Wood /vinyl	Metal	3.12	2.90	2.73	3.12	2.73	2.38	5.11	4.83	14.20	11.81	10.11			
	Insulated	n/a	2.78	2.27	n/a	2.38	1.99	n/a	4.71	n/a	11.47	9.71			
Insulated fiberglass/ vinyl	Metal	2.10	1.87	1.82	2.10	1.87	1.82								
	Insulated	n/a	1.82	1.48	n/a	1.82	1.48								
Structural glazing	Metal												10.22	7.21	5.91
	Insulated												n/a	5.79	4.26

Note: This table should only be used as an estimating tool for the early phases of design.
[a]Depends strongly on width of thermal break. Value given is for 9.5 mm.
[b]Single glazing corresponds to individual glazing unit thickness of 3 mm (nominal).
[c]Double glazing corresponds to individual glazing unit thickness of 19 mm (nominal).
[d]Triple glazing corresponds to individual glazing unit thickness of 34.9 mm (nominal).
[e]Glass thickness in curtainwall and sloped/overhead glazing
[f]Single glazing corresponds to individual glazing unit thickr
[g]Double glazing corresponds to individual glazing unit thickn
[h]Triple glazing corresponds to individual glazing unit thickn
n/a Not applicable

New technology windows can provide dramatic increases in the thermal performance of the glazing unit by improving all 4 factors affecting U-value and providing the correct SHGC.

Such windows typically have low-E coatings, gas fills, top quality frames (large thermal breaks in aluminum of fibreglass materials), and insulated “super” spacers. Table 2 gives some values for different frame, glazing, and spacer combinations. Triple-glazed windows with fibreglass frames can have metric U-values below 1.0 W/m^2.

The increased cost of highly insulating glazing can often be offset wholly or in part by a reduction or elimination of perimeter heating in commercial buildings with high internal heat gain. In house, the use of super windows allows the heating ducts and registers to be grouped along the interior walls, saving in duct costs and fan power. These savings can best be achieved if super windows are incorporated in the initial design stages.

The Solar Heat Gain Coefficient (SHGC) is the fraction of incident solar radiation that enters the window and becomes heat. For example, if the SHGC of a glazing unit is 0.50, and the sun is shining on the window with an intensity of 500 W/m^2, 250 W/m^2 will enter the building This heat gain includes both directly transmitted and absorbed solar radiation. The lower the SHGC, the less solar heat that the window transmits through the glazing from the exterior to the interior, and the greater its shading ability. In general, South facing windows in houses designed for passive solar heating (with a roof overhang to shade them in the summer) should have windows with a high SHGC to allow in beneficial solar heat gain in the winter. East or West facing windows that receive large amounts of undesirable sun in mornings and afternoons, and windows in houses in hot climates, should have a low SHGC.

The visible transmittance (VT) refers to the percentage of the visible spectrum (380-720 manometers) that is transmitted through the glazing. When daylight in a space is desirable, as in showrooms and studios, high VT glazing is a logical choice. A typical clear, single-pane window has a VT of 0.90, meaning it admits 90% of the visible light. Low VT glazing such as bronze, grey, or reflective-film windows have often been used in office buildings to reduce solar heat gain and glare. Modern spectrally selective (SS) windows allow for a high VT with a low SHGC. These SS windows reduce allow for significant daylighting and psychological benefits in climates with little winter sun. However, excess window area will still increase the risk of glare.

Although there are few guidelines, a VT of over 0.6 is perceived as clear by many observers, and a value of 0.5 will often be acceptable. The change in color created by tinting combined with SS will allow for more daylight with less heat gain, but may be objectionable from an architectural desire to have clear glass.

WINDOW FRAMES

As described above, the frame plays a very important role in the thermal performance of a window or curtainwall since the R-value of modern glazing units can be quite high.

The impact of frames can be seen in Table 2 where Total Window (glazing plus the frame) and Center of Glass (in brackets) for different types of aluminum windows are compared. The frame has an increasing impact on the U value as the performance of the glazing increases and also has an impact on the SHGC and VT.

Table 2: Representative Metric U-values for Representative Aluminum Windows (Center of Glass in Brackets)

Glazing Types in thermally broken aluminum frame	U W/m^2	SHGC	VT
Single-glazed, clear	6.10 (5.1)	0.79 (0.86)	0.69 (0.90)
Double-glazed, clear, 12.7 mm gap	3.22 (2.73)	0.58 (0.76)	0.57 (0.81)
Double-glazed, bronze	3.22 (2.73)	0.48 (0.62)	0.43 (0.61)
Double-glazed, spectrally selective, 12.7 mm gap (low heat gain)	2.45 (1.80)	0.31 (0.41)	0.51 (0.72)
Double-glazed, spectrally selective, argon filled 12.7 mm gap	2.11 (1.42)	0.31 (0.32)	0.31 (0.44)
Triple-glazed, kypton, 6.4 mm, spectrally selective	1.47 (0.68)	0.37 (0.49)	0.48 (0.68)

The most common available frame materials are:

1. Wood
2. Vinyl
3. Aluminum
4. Fibreglass

Each material and its pros and cons are described below.

Aluminum

Although steel and bronze windows were used in the past, almost all metal windows are now made from aluminum since this material is easy to extrude into many structurally efficient hollow shapes, is easy to work, and durable. Aluminum is also strong and stiff, resulting in slimmer and shallower frames relative to other material choices.

Aluminum is, however, a very good conductor of heat (well over a thousand times more conductive than wood!). Hence it cannot be used in thermal efficient windows without providing a large thermal break between the inside and the outside. Small thermal breaks (e.g., a plastic strip 3/8" thick) do improve the performance, but larger breaks (e.g., ¾" and more) are usually needed to improve the R-value of the frame above R2 or R3.

Wood

Wood is the traditional material used for window frames. The insulating values are better than average, and wood's strength and stiffness results in reasonably strong frames. However, wood requires treatment to prevent decay, and this means impregnation with preservatives and periodic exterior maintenance.

Wood frames can be clad on the exterior with vinyl or aluminum. While the cladding reduces wetting of the wood and essentially eliminates periodic maintenance, leaky windows will still rot.

Wood-Plastic Composites

Wood plastic composites have recently entered the market. These frames are made from a mixture of wood, plastic, and adhesive. They reduce the need for high quality lengths of wood, eliminate rot, insulate as well as wood while being stronger.

Vinyl

Hollow frames extruded from Polyvinyl chloride (PVC) are popular because of their low cost, low maintenance, and acceptable thermal performance (about that of wood, depending on design). Vinyl expands and contracts much more than wood or metals and hence can bow and warp as well as expand and contract, and soften when heated by intense sun. The material is also not very stiff, resulting in greater fame size and deflections. For large windows, metal stiffening elements must be inserted, lowering the thermal performance.

Fiberglass

Fiberglass frames are hollow sections made of pultruded fibreglass and resins. Fibreglass is stiffer and stronger than wood (although weaker than aluminum), conducts less heat in, does not rot or warp, and expands and contracts at the same rate as the glass it contains. Many companies fill the hollow shapes with insulation to improve the thermal performance. A polyurethane finish is often used, allowing a wide range of colors and even paints can be applied. Wood extensions and veneers from some manufacturers allows for the look of wood on the interior, the strength and durability of metals, and the best thermal performance.

Construction Details

The smaller the length of window frame per unit area of window the less heat flow that can pass through the frame. Hence, for energy efficient performance windows should be grouped together and intermittent mullions avoided. Glue applied or interior snap in grills have the same aesthetic impact with little thermal effect.

All frames have corners, and these corners are susceptible to failure, water leakage and distortion. Wood joinery is usually easy to make strong and durable, although the proper design must be used. Hollow sections of aluminum, vinyl, or fibreglass are glued, welded, or screwed together. All can be used to form a good corner, but a poor job of gluing and welding can often cause failure in the field in the case of large movements or rough installation.

Water will often leak past the weather stripping between the exterior of the glass and the frame. Although weather stripping should have no gaps at the corners, it will still leak some water, and this water must be drained from the glazing rabbet with proper drain holes (3/8" in size and protected from driving rain) in the sill extrusion. Interior weather stripping or glazing tape is usually part of the air barrier in the window frame. This seal must be made as tight as possible and be able to withstand expansion and contraction of the glass and movement of the window during operation.

CURTAINWALLS

Curtainwalls are a popular building enclosure choice for many commercial buildings, and are often seen as synonymous with modern architecture. Curtainwalls are non-load bearing building enclosures formed from a grid of aluminum (and occasionally steel) elements with glass and stone infill. Most curtainwall systems are suspended in front of the primary structural elements, which can be a new or existing structure of concrete, steel, masonry or even wood. Hence, they offer a flexible enclosure system that can be used in new or retrofit construction to provide a range of aesthetics and performance.

The earliest modern curtainwalls were based on the stick system, which is basically assembled on the building site, piece-by-piece fashion, with all glazing and other infills installed on site. This approach allows for flexibility and cost-savings in smaller projects, but requires a high level of on-site quality control. Unitized curtainwalls, which became available in the mid-1970's, are assembled off-site under controlled conditions in storey-high units. This tends to result in more reliable quality, and is usually the preferred approach.

Curtainwall systems have evolved rapidly since their modern introduction, especially with respect to enclosure performance. The early systems experienced notorious deficiencies: rain penetration, condensation on the inside surfaces, glazing seals pumped out of the rabbet, glare and overheating. However, most of these difficulties have been overcome with improved detail design and materials. Today, most curtain wall manufacturers offer a line of components that can be used to create an excellent overall exterior wall system, albeit with lower thermal performance than many alternatives. Unfortunately, a significant proportion of modern curtainwalls still do not live up to their excellent potential as high performance enclosures.

The key technical issues that should be considered in the design and specification of a curtainwall can be listed under the headings of structure, movement, thermal, rain, and fire and sound.

The structural strength and movement issues are connected. The design must accommodate movement of the building structure to which it is attached (creep over time, temperature changes, sway of frames, and sag of floors). The curtainwall itself moves as it deflects under wind loads, and aluminum components expand and contract under temperature changes. Connections to the main structure must be able to accommodate the combined effect of these movements without imposing excessive loads onto the curtainwall system, while transferring wind, self-weight, and earthquake loads to the primary structure. The larger the unsupported curtainwall height the deeper the section must be. Typical sections are as small as 3"/75 mm but are typically 6"/150 to 8"/200 mm in commercial projects.

Thermal performance is one of curtainwall's weakest attributes. A typical opaque wall on a commercial building will easily achieve a thermal resistance of R12 (U=0.45 W/m^2 C). while a high-performance enclosure will easily prove R20 (U=0.30 W/m^2 C). The R-value of typical double-glazed curtainwall systems is less than R2.0 (U =2.6 W/m^2 C).

High performance double glazing units with low-E coatings, argon fills, and special super-spacers can achieve an R-value of 4.0 (U=1.35 W/m^2 C). In most systems, heat flow through the frame will bypass the improved thermal resistance of the glazing unit -- deep (over 1/2") high-quality thermal breaks are required. Poor quality thermal breaks are far too common, and the usual cause of heat loss and condensation problems. By combining good thermal breaks with high performance triple/quadruple glazing, some manufacturers can deliver curtainwall systems with thermal resistance values of over R8 (U=0.7 W/m^2 C). The opaque parts of a curtainwall can achieve reasonably high thermal resistance values (over R12), so long as a quality thermal break is installed. It is critical that the designer specify the *overall system R-value* (not just the glazing) and have this specified value supported by tests or 2-D computer calculations.

An opaque wall will have a Solar Heat Gain Coefficient of less than 0.05. (The SHGC is the fraction of the solar energy that strikes a wall that passes into the building). Clear double-glazing has a SHGC of about 0.72 and reflective glass a SHGC of as low as 0.10. In any case, the solar energy that enters a building through the glazing of a curtainwall is often many times greater than through an opaque wall. Hence, the glazing area and type (i.e., body tint and coatings) should be carefully selected to minimize air-conditioning loads and reduce glare and comfort problems. As described in the previous windows section, there is an amazing range of high-tech coatings available today that can provide excellent solar control (SHGC<0.30) while remaining almost transparent to the occupant (i.e., visual transmission of over 50%).

Cold weather condensation on the interior surface of curtainwalls is usually a symptom of poor thermal performance. Because aluminum is an excellent conductor of heat, all curtainwalls should use good thermal breaks to interrupt flow. Since some heat can still flow through a thermal break, even a thermally broken system will tend to have a lower thermal resistance than the glazing units alone. Not all thermal breaks are created equal, however, so a designer should investigate and always specify the desired condensation resistance of the frame and glass (by referencing a standard test method) and U-value of the actual system being considered for the project.

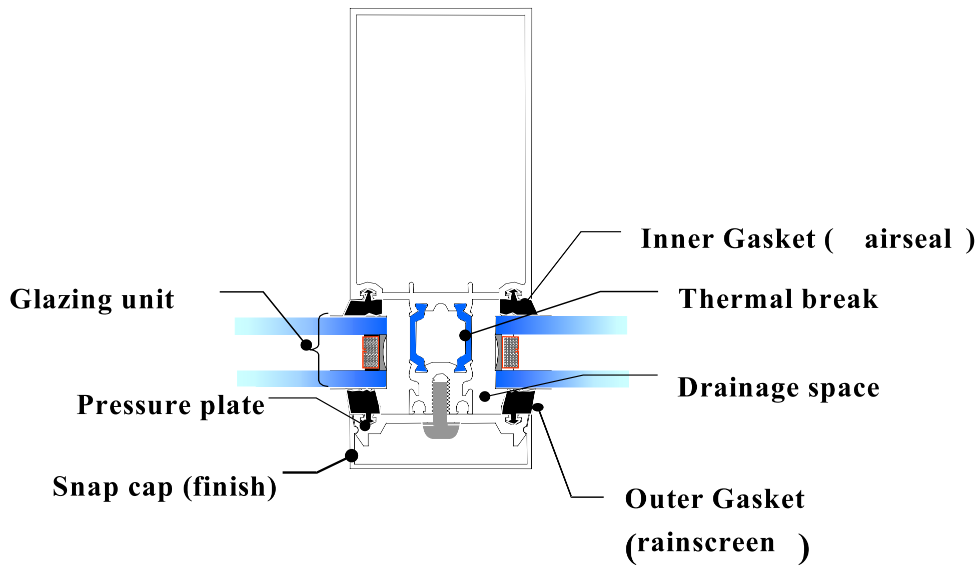
Air leakage through a curtainwall increases energy costs and reduces comfort in both the winter and summer. The air barrier system in a curtainwall is usually comprised of glass, metal framing, metal back pans, and the seals that connect all of these components. Care is required in detailing and construction to ensure that the air barrier is as tight as possible. To guarantee performance, the designer should specify a maximum allowable air leakage rate and the relevant test standard.

Rain control is a constant concern in all enclosure systems, and curtainwalls are no exception. In the past curtainwalls made extensive use of exposed sealants to control rain penetration. Because such seals demand the impossibilities of perfect workmanship and materials that do not deteriorate, they often failed and caused rain penetration problems. Quality curtainwalls today make use of drained (or pressure-equalized) joints that redirect water that penetrates the outer seal to the outside. Such drained systems still require careful detailed design, but offer a much more reliable and durable means of controlling rain penetration. Problems that still occur are often at three-dimensional intersections, so these should be given consideration in design. Full-scale rain penetration testing of mockups is generally recommended, as are drainage capacity tests.

Fire and sound control are often specific to a project and municipality. The most common issue in fire control is the provision of fire stopping at floor intersections. A reasonably high level of sound control can be achieved by carefully specifying glazing and by providing a very tight air barrier system. Thicker sheets of glass asymmetrical air spaces in triple glazing can provide excellent sound control.

Experience has shown that special care must be taken in the detailing of the interface between the curtainwall system at the parapet, at grade, and between other enclosure systems. Movements, air and water leakage, and condensation problems can easily occur at such regions, typically labelled "by others" on the manufacturer's design drawings.

Curtainwalls can provide the building owner with a durable and energy efficient enclosure, and the designer with a wide range of aesthetic choices. However, regardless of the style, cost, or type of system being offered good performance can only be achieved if care is taken by the designer working together with the manufacturer in detailing, specification, testing and inspection.



Typical Details of a Curtainwall Vertical Mullion

Check out downloadable pdf of an excellent "Efficient Windows buyers guide" at
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