

double skins



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Facade TecNotes Series

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# Double Skin Facades

## Executive Summary

Double skin facades (DSF) were first introduced in the 1990's with the intent of mitigating the transmission of airborne noise through building envelopes. In addition to the acoustic performance, potential thermal enhancements realized in the building facade by this technology have resulted in growing interest in DSF technology in the past decade.

The cost of energy is increasing at an unprecedented rate. This factor, coupled with the potential for natural ventilation and daylight harvesting, is reducing the life cycle costs of DSF, making them a relevant design possibility for the construction of high-rise buildings. Furthermore, the success of recently completed projects has been encouraging to the building owners and developers looking for low risk, high performance cladding

solutions. The number of projects under design in the USA utilizing DSF technology has increased over the past five years, and is expected to continue to rise in the future.

The development of DSF technology has occurred over the past few decades primarily in Europe, although a handful of projects have been completed in the US (see page 38 for a partial listing). Numerous studies involving the design, engineering, construction, performance attributes, and costs of DSF technology have helped to shed light on the potential of this building system.

We have embraced this trend at Enclos through an aggressive research and development effort intended to enhance our in-house expertise with this impor-

tant emergent technology, and to make our own contributions to the development of the technology in the process. This quickly led to involvement with our architect clients in the application of DSF technology on various building projects.

Two case studies are presented here of recently completed projects in New York City and Chicago. These projects have received national recognition and demonstrate our current adeptness with the application of DSF technology.

A technical discussion follows the case studies, exploring various performance attributes of DSF. The first section of this document provides a general overview of the capabilities and philosophy of Enclos Corp.





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## Introduction to Enclos Technology

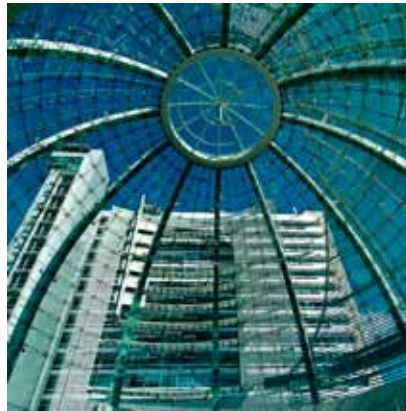
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### Custom Curtainwall Systems



Enclos offers the most innovative curtainwall systems in the marketplace, combining aesthetic, performance and economic considerations into optimum solutions to our client's needs. Our inventive unitized systems have evolved through their application on numerous major building projects to represent the state-of-the-art in curtainwall technology and performance. Sophisticated system design features and installation methods have paralleled this evolution, resulting in improved economy as well as superior performance.

### Structural Glass facade Systems



The integration of glass and structure is a predominant attribute of this expressive building form, often employed to maximize transparency in large public spaces. Enclos has played a leadership role in the development and application of this cutting-edge technology, including a range of structure types:

- cable nets
- cable trusses
- long-span truss systems
- grid shells
- spaceframes
- all-glass structures

Our glazing system types include point-fixed types in both drilled and clamped versions, as well as framed system types; all custom designed in response to specific project requirements. For more information see the section titled, Structural Glass Facades and Enclosures.

Enclos is expert in the design, engineering, fabrication, assembly and erection of custom facade systems, providing complete design/build services to the construction marketplace.

We specialize in innovative architecture and challenging building projects. No project is too large, no building site too difficult for our seasoned operations teams.

Our work experience includes many projects with specialized materials, complex geometry, and innovative structural and mechanical system designs.

Enclos curtainwall and facade and skylight systems incorporate state-of-the-art materials and performance.

The attributes most appreciated by our clients however, are our site management capabilities and our track record of meeting demanding project schedules.

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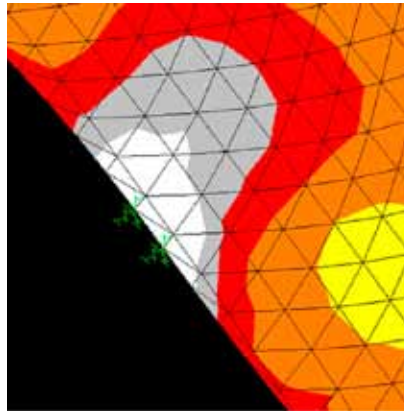
## Service and Technology

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Managing the project delivery process is the core strength of Enclos, something at which we excel beyond all our competition. This capability provides us consistent control over the vital requirements of schedule, quality and cost, and allows us to consistently deliver top quality economically and on time. This capability is the basis for our many long term relationships with developers, general contractors and architects.

Each new project undertaken by Enclos is treated as unique, and a custom delivery strategy is developed in direct response to the singular set of considerations presented by the project. This custom strategy however, is developed through a uniform process unique to Enclos that embraces the spectrum of activities from preconstruction through design, engineering, procurement, fabrication, assembly, and erection. This process, developed and refined through the successful completion of hundreds of remarkably diverse facade and curtainwall installations, serves to mitigate the inherent risk of a challenging building project by enhancing the predictability of performance, schedule and cost.

### Design and Engineering



The foundation of a successful facade or curtainwall project is innovative system design and engineering. Our D&E group develops custom solutions to each new project, derived from a robust framework of Enclos technology and know-how. Design considerations range from the aesthetic and performance requirements determined in collaboration with the architect, to the fabrication and installation requirements that must be anticipated by the system design to assure a successful project completion.

An in-house team of engineers, architects and designers over 100 strong comprise the Design and Engineering Group at Enclos Corp, representing a unique talent pool that has consistently delivered innovative, effective and elegant solutions to the most demanding building facade requirements. Autocad, Inventor, Revit, Space Gass, Strand 7, FloVENT CFD, are among the many tools that comprise our design development process. Building Information Modeling (BIM) is another service we provide our clients.

### Project Management



Project management is an empowered function at Enclos Corp, and key to our success. Personnel skilled and experienced in project management are vital to the success of any construction project. Our project management teams lead design development, production engineering, fabrication and assembly, and field operations, bridging these various activities to form an organized, unified continuum of project development throughout the design and build process. Enclos project management personnel receive extensive training and years of on the job experience before being appointed to the position and entrusted with the responsibility of running their own projects.

Our people understand the critical importance to a building project of on-time, on-budget performance, a fact which our past clients can best attest to. We will happily provide you with such references.

## Fabrication



Curtainwall fabrication and assembly is a critically important part of the project development process. Enclos Corp maintains dedicated manufacturing operations in key geographic locations capable of providing fabrication services for the most complex designs and the most challenging project schedules. Our facilities incorporate state-of-the-art equipment and processes for curtainwall unit fabrication and assembly. In addition, to provide adequate capacity for the fluctuating demands typical of the building marketplace, we have developed a network of outside fabrication sources, all of whom have been rigorously trained and qualified in all aspects of Enclos systems materials, fabrication and assembly, and all of whom have successfully provided services on prior Enclos projects.

## Quality Assurance



Design or material supply problems surfacing in manufacturing are a frustrating and costly annoyance; design or manufacturing problems surfacing on the building site are a disaster. There is far too much at stake in the building process to settle for anything less than top quality and the programs that consistently deliver it. Effective quality programs garner the participation of everyone in the organization from top to bottom while reaching throughout the web of company operations and activities. We have developed and refined our quality assurance and quality control programs over the span of many years and hundreds of diverse project experiences, another way that our deep experience works for you. These programs are robust and all embracing, ranging from management systems and procedures to the minutia of in-line quality verification processes. In addition, we develop a specific quality plan for each new project based on an analysis that identifies and accounts for any unique aspect of the project whether it be material type, location, site condition, performance requirement or design detail.

## Site Operations



Enclos has been awarded many of its projects over its competitors because of its reputation for performance on the building site.

Everyone involved in the construction process knows the critical importance of the building site, the playing-field for the contracting teams. This is where the myriad complexities of a construction project converge and coalesce into architecture. The building site must be a particular focus for systems such as the skin where a large part of the process takes place off site; design, engineering, fabrication and assembly all precede the delivery of material to the site and the commencement of field installation. Yet the site is where all must come together. These preceding activities must be accomplished with a keen eye to the site, anticipating unique site-specific requirements and developing effective installation strategy to assure an efficient and effective performance.

Field operations are a core strength of Enclos Corp, and the attribute for which we are most widely recognized by the building community.

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## Structural Glass Facades and Enclosures

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A new facade technology has emerged over the past three decades driven by the pursuit of transparency in architecture among leading international building designers.

This new technology has evolved primarily in long-span applications of approximately 20 feet and over, and can be categorized by the various structural systems employed as support. New glazing systems are also a part of this emergent technology, with the various point-fixed systems finding most frequent use.

Recognizing the importance of structural glass facade technology, Enclos took action to acquire the technology and expertise required to play a leadership role in implementing and further developing this innovative technology in the US marketplace. As a result, we are now providing complete inhouse services for both the curtainwall and structural glass facade areas of the building skin, all as a single-source package backed by the deep technical and financial resources of a national specialty contractor.

Characteristics of structural glass facade technology include: highly crafted and exposed structural systems with long-spanning capacity, integration of structure and form, complex geometries, extensive use of tensile elements, specialized materials and processes, an integration of structure and cladding system, and a complex array of design variables .

Cable Nets



Frei Otto developed and popularized cable nets as a structural system in the 1960s and 70s. Architect Helmut Jahn with engineering firm Schlaich Bergermann applied the technology in a most innovative manner as a flat cable net supported glass facade for the Kempinski Hotel in Munich, circa 1992, fueling widespread interest in this structural form in glass facade applications.

Cable nets represent the ultimate in elegant minimalist structural systems and can provide optimum transparency when the effect of a sheer glass membrane is desired. The glass is supported by a net geometry of pre-tensioned cables. Designs can be flat, or the net can be pulled into double-curvature. A clamping component locks the cables together at their vertices and fixes the glass to the net. Large pre-stress loads in the net structures require the early involvement of the facade design/ build team with the building engineer.

Cable Trusses



Another minimalist structural system is that of cable trusses. While cable trusses can vary widely in both truss design and configuration with vertical, overhead, vaulted and domed forms easily achieved, the trusses themselves are most often characterized by spreader strut elements representing the only compression members in the structural system. As with cable nets, these systems rely on the pre-tensioning of truss elements to provide stability, and thus benefit significantly from the early involvement of the facade design/ build team.

Grid Shells



Grid Shell structural systems are another means to minimize the visual mass of structure. Configurations can be vaulted, domed and double-curved. Systems can be welded, bolt-up, or some combination of each. Grid shell structures with integrated cable bracing can produce a highly efficient structure with a refined aesthetic. Cable pre-tensioning may be required on such systems. Grid shells can be used in vertical and overhead applications, as well as to form complete building enclosures.

Glass Fin Systems



This is the earliest form of structural glass facade dating back to the 1950s and the French Hahn system used at the Maison de la Radio in Paris in 1953. Here 2-story glass plates were suspended and laterally stiffened by the use of glass fins set perpendicular to the plates at the vertical joints between them. This technology was popularized by the Willis Faber & Dumas Building, Ipswich, England circa 1972. In this curving facade designed by Foster Associates, multiple plates of reflective glass are suspended to provide one of the first examples of an entire building facade in frameless glass. This project inspired a diffusion of glass fin technology in numerous applications throughout Europe and America starting in the 1970s and continuing today. Glass fin-supported facades still represent one of the most transparent forms of structural glass facades and an economical solution especially at lower spans.

All-Glass Systems



Glass facades are comprised of a glass system supported by some form of structural system (except glass fin-supported walls in which the glass is hung and braced laterally with fins). As the pursuit of transparency is a frequent reason for the use of structural glass facade technology, point-fixed (frameless) glass systems are most often integrated into the facade design. These can be systems where the glass is perforated and bolted or non-perforated and clamped. Such systems typically provide optimum transparency and design elegance. However, the structural systems employed in structural glass facades can easily be designed to accommodate any type of glass system. In some applications framed systems can provide certain practical or economical advantage.

Enclos is capable of developing and providing any type of custom glazing system for structural glass facade applications.

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## A Vocabulary of Transparency; Castings, Cables and Machined Fittings

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In addition to the glass and structural systems that comprise structural glass facade technology are the components that in turn comprise these systems, components quite unlike those typically used in exterior wall systems. The use of tensile elements in the form of steel cables and rods is a primary design strategy to dematerialize the structure and enhance the transparency of a facade design. Compression elements are frequently minimized or eliminated, and where present are crafted from cast and machined components in an elegant expression of exposed structure. The fittings and components that tie these structural members together are similarly crafted. An entirely different set of material and process considerations come into play.

The Enclos design team has mastered these materials and processes as a necessary prerequisite to their appropriate application in component design. We can develop and provide custom designs of remarkable diversity in response to your particular project needs. Where appropriate, we can also source off-the-shelf components from a variety of suppliers, all carefully qualified to Enclos Corp standards and subject to our uncompromising quality assurance program. All this, from concept design through installation, as part of a single-source package from the largest national specialist in structural glass facade technology.

### Cables



Bridge builder and engineer John A. Roebling first manufactured wire rope in America in the 1840's. These materials ultimately found their way into the vernacular of architecture through such stunning works as Mathew Nowicki's Dorton Arena of 1952 and the Ingalls Rink at Yale University of 1958 designed by Eero Saarinen. Structural glass facade technology has embraced these tensile materials as a means to minimize the structural profile of the support system. Wire rope composition, material type, finish, and end terminations are all important considerations in specifying these materials, which are available from a relatively limited number of manufacturers and specialty fabricators. Enclos Corp has put many of these manufacturers through its rigorous qualification process, resulting in several exceptional vendor/partners that have successfully provided materials on various structural glass facade projects that we have completed in recent years.

## Rods



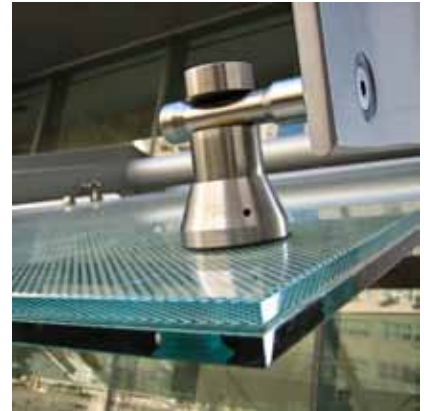
The use of steel rods as a substitute for cable in the design of structural glass facades was a practice borrowed from the yacht racing industry, and popularized in the Louvre Pyramid designed by IM Pei. The rods are most commonly fabricated from ASTM A316 stainless steel because of the material's combination of strength and corrosion resistance. In high load applications or when super thin profiles are desired, there are other higher strength stainless options. The rod terminations are often custom designed and can be quite refined, with the intent of minimizing or eliminating any exposed threads, turnbuckle or other tensioning mechanism. Rod fabrication typically involves slipping the end fittings over the rod and upsetting the rod ends through a process called cold-heading. Alternately, equally elegant threaded fittings have also been developed. Depending upon the design of the structure, cable systems can have significant advantages over rod systems, particularly with respect to cost. However, some feel that the refined appearance of a rod system is worth a premium cost.

## Castings



Casting is an ancient process with a longtime role in the construction industry, including the naming of a "cast-iron architecture" during the industrial revolution resulting from a dramatic increase in the availability of low cost cast materials. Castings were much later used to spectacular affect in the gerberettes and other components for the Center Pompidou by architects Rogers and Piano. The casting of structural components however, demands a high level expertise in both the design and fabrication process. Cast nodes for the space frame structure on the Javits Convention Center in New York were famously discovered during construction to contain cracks, requiring the disassembly of nearly half the structure and a project delay of nearly two years. An intimate knowledge of the materials and processes of casting is critical to the development and implementation of a custom cast structural component. While most of the castings utilized in structural glass facades are glass-fixing components of stainless steel, such as the "spider" fittings that attaché point-fixed glass to the supporting structure, many options exist in both material.

## Machined Components



In many respects, structural glass facade technology is more closely akin to the automotive industry than it is to conventional construction. Spider fittings are about as far from the brick as a building component can be. Structural glass facades are highly engineered structures built to very high tolerances. There is also an important visual aspect to the components because of their use in exposed structural systems. Despite a widespread pursuit of facade transparency, many designers choose to express this exposed structure in dramatic fashion, sometimes even at the expense of ultimate transparency. These factors and considerations make the use of machined components a frequent and effective choice. We design custom components or specify off-the-shelf parts as appropriate, and source both from our network of vendor/partners.

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## Research & Development

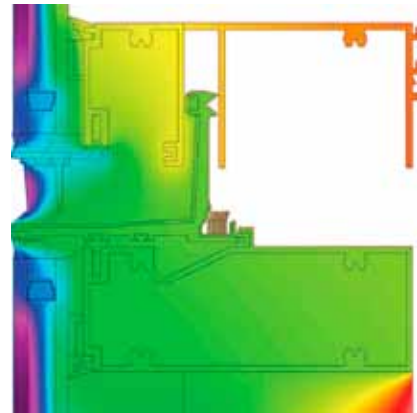
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Enclos Corp is known for providing technically superior exterior wall systems at competitive prices, and in fact this is one of our core commitments to our clients. We achieve this through a progressive ongoing program of research and development. This program has resulted in continuous refinements to our core systems, as well as yielding new system designs with improved performance attributes. The bulk of the current R&D program falls within the following categories:

Security design and blast-resistant facade technology is a particular expertise of Enclos demonstrated by a portfolio of completed projects meeting the most demanding security requirements, including many federal courthouse projects, and remains an ongoing focus of our R&D program.

Our security and blast-resistant technology is discussed in the pages immediately following.

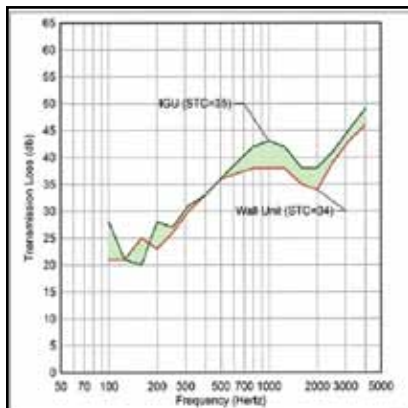
Thermal Performance



Rising energy costs and the energy performance of the nation's buildings have become predominant concerns. While the thermal performance of a curtainwall building skin is primarily dictated by the thermal properties of the glass makeup or panel cladding material, Enclos has focused its R&D effort on the performance of the framing system to both determine behavior and identify opportunities for improvement. The result has been thermal enhancements to existing systems as well as the development of premium systems with improved thermal performance.

In addition, our project work includes innovative dual-skin facades and cavity wall systems featuring the state-of-the-art in energy performance. We have in-house mechanical engineering capability and computational fluid dynamic analytical technology to assist in the design of these advanced wall and enclosure systems.

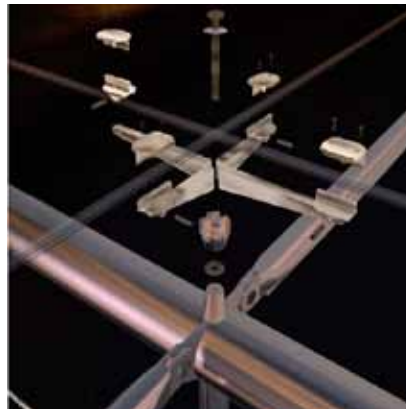
### Acoustical Performance



We have recently crossed an important threshold in the evolution of civilization; for the first time in history the majority of earth's people reside within our urban cities. This is reflected in the increasing density of these urban areas and evidenced by the many residential tower projects which have sprung up in cities around the world. Along with the increasing density has come escalating noise pollution. These factors have combined to produce a growing concern among developers, architects and building occupants regarding the acoustical performance of urban habitats.

In recognition of this, Enclos launched an R&D initiative intended to identify the key variables in the acoustical performance of its facade and curtainwall systems. The program involved testing inter-story as well as outside-to-inside acoustical behavior, and has resulted in refinements to basic systems as well as new premium curtainwall framing systems with superior acoustical performance.

### New System Development



Enclos facade and curtainwall systems are of known and proven performance, having been tried and tested in numerous mockups and hundreds of custom building applications over many years. They have consistently conformed to required specifications for water penetration and air infiltration, as well as other demanding specification requirements.

However, increasing urban density, rising fuel costs, and concerns over rapid climate change are resulting in escalating demands on the performance of the building skin. Anticipating this trend, Enclos has been hard at work developing new facade and curtainwall systems with improved behavior in all key areas of performance. We are confident that we can and will continue to provide technically superior systems at competitive prices.

### Testing and Prototyping



Testing is a key component of any R&D program. Testing activities as part of the Enclos program have involved explosive testing on blast-resistant designs, structural testing to hurricane wind loads, acoustical and thermal testing, among others. In addition, most of our custom curtainwall designs for particular building projects require some program of mockup testing, and we have performed many dozens of such tests over the years.

Enclos Corp has its own dedicated in-house test facility augmented by several major certified testing facilities across the nation that are used when special capabilities are needed and independent confirmation of performance is a requirement.

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## Green and Sustainable Facade Technology

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The building skin affects both the appearance and performance of a building like no other building system.

Facade and curtainwall systems are thus of paramount importance when considering issues of green building and sustainable design. We at Enclos understand the importance of leading the effort to improve the performance and sustainability of the building envelop, and we commit ourselves to supporting the design team in their sustainable design efforts.

We have LEED accredited professionals on staff, a mechanical engineering group with advanced CFD analysis capability, and the ability to perform whole-building energy analysis. An aggressive and ongoing research and development program assures you of state-of-the-art wall systems engineered and tested to the most demanding performance criteria. We are continuously seeking new materials and methods to further enhance this performance.

### LEED Certified Buildings



The Leadership in Energy and Environmental Design (LEED) Green Building Rating System has proven to be a viable and effective means of reducing overall energy consumption and improving the sustainability of building practices, while at the same time bringing increased value to a building as evidenced by higher occupancy and rental rates. The building skin is a paramount consideration in any building project, but presents particular opportunities in a project where LEED certification is part of the program.

Enclos understands the nuances of the LEED rating system particularly as it relates to the building skin.

### Dual-skins and Active Facades



This emergent technology is finding increased application in building projects where the attributes of transparent facades are desired yet the performance of the building skin is paramount. These facade designs can compensate for the inherently poor insulating properties of glass. In addition to providing a thermal barrier, the systems can also provide an effective means of ventilation, and often involve shading devices for the control of solar penetration and glare.

They can also provide significantly enhanced acoustical performance, and in certain applications are used for this reason alone. The Loyola Information Commons features a west facing double skin active facade with a cable net supported outer skin. This project was one of three featured at the McGraw-Hill Innovation Conference on Net-zero Energy Use in Buildings (Loyola is featured following).

Enclos can provide complete design/build services for custom double skin curtainwall systems or more complex long-span facade systems as required for any particular building project.

### Building Systems Integration



Optimizing energy performance in buildings requires an integrated approach to building systems design, analysis and implementation. Building-integrated photovoltaics (BIPV) is an increasingly popular approach for using the building skin as a means to harvest solar energy. More recent technique involves systems of lighting, lighting controls, sensors, and shading devices all integrated with the building skin, and in turn integrated with the building HVAC systems. Such design strategies can reduce heat gain or loss, control direct solar penetration and glare, harvest daylight to reduce cooling load, and even provide ventilation, producing a more comfortable interior space in the process.

Enclos Corp has the ability to develop custom integrated systems in response to your particular building performance requirements.

### From Net-Zero to Net-Plus



Oil prices may fluctuate in the short term, but in the long term there is little doubt that energy costs will continue to rise, as will the cost to the environment of unwise use of our energy resources in buildings. It is imperative that we improve the efficiency and sustainability of our built environment. Net-zero energy use in buildings is a goal being increasingly embraced by forward thinking building designers and developers. An even greater opportunity presents itself in the notion of our buildings as energy producers.

Enclos sees the potential for the building skin to make a major contribution in this regard, and toward this end we are committed to continuing to play a leadership role in facade system development.

# Case Studies



Richard J. Klarchek  
Information Commons  
Loyola University  
Chicago

owner Loyola University  
architect Solomon Cordwell Buenz  
engineer Halvorson & Partners  
gc Pepper Construction  
facade consultant CDC  
climate consultant Transsolar  
completion 2007  
program 4-story; 72,000 sqft  
building type library, education

**facade** design/build facade package including a custom point-fixed VS-1 system on east elevation and custom dual-skin active west elevation with cable net glass facade as outer skin and VS-1 system as inner skin  
**glass** monolithic and insulating glass by Viracon  
**description** high-tech library sits on waterfront, incorporates highly transparent facades but designed to use 50% less energy than conventional buildings





## Exterior Skin System

Located on the university's Lake Shore Campus, the four-story, 72,000 square foot Information Commons was awarded the 2007 Leaf Award for Best Use of Technology at the fourth annual Leading European Architects Forum in London, England. The building is also expected to earn Silver Level Leadership in Energy and Environmental Design (LEED) certification once operational. The building's advanced design and systems act to create an environment that maximizes comfort while reducing energy consumption. The project is designed to use about 50 percent less energy than a code-compliant building and is seeking Silver LEED certification.

The commons is essentially a four-story box incorporating limestone elevations to the south and north, with transparent full-elevation facades to the east and west. Under normal conditions one can stand to the west and see through the library with an unobstructed view of the lake.

A key component of the green design is the advanced facade technology used to achieve the east and west glass walls. The west face uses a double skin facade to manage heat flow and natural ventilation through the year. This is one of the first of such constructs in the US, and the first in Chicago. The facade features two layers of glass, separated by air space — a lot of air space — roughly 3 feet between the inner and outer layer.

Air circulates in the cavities between the facades, while four-inch horizontal blinds inside the outer glass layer track the sun's movement throughout the day. These blinds reflect away the heat of excess radiant energy when closed, while allowing natural daylight into the building when opened.

The outer layer of the double skin is a feat of technology in itself, a cable net supported glass wall.



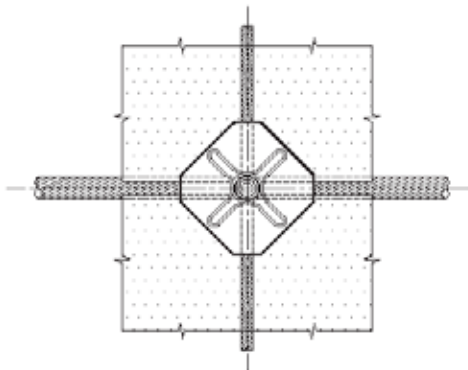
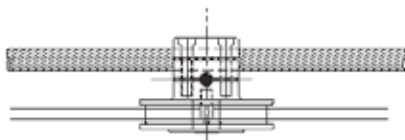
Richard J. Klarchek  
Information Commons  
Loyola University  
Chicago

A crossing network of tensioned vertical and horizontal cables form a net. Cast stainless steel clamping components clamp the cables at their intersections, and then act to fix the monolithic glass to the net. The inner layer of the dual-skin is a point-fixed system by Innovation Glass called the VS-1. The system uses cast fixings to clamp insulated glass panels to vertical extrusions.

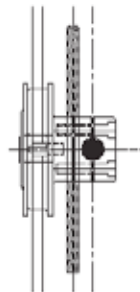
The joints between glass panels are treated with a field-applied silicone to provide a weather seal, as with the monolithic outer layer. The dual-skin thus provides a sealed cavity between the two layers that is used as a buffer between inside and out, and as a source of ventilated air under controlled conditions. The same VS-1 system is used as a single-skin facade for the entire expanse of the east wall.



*The exterior skin of the double skin wall is a flat cable net structure with intersecting vertical and horizontal cables. A four-part stainless steel casting serves to clamp the cable vertices and tie the glass to the net.*



*Exterior skin cable node*

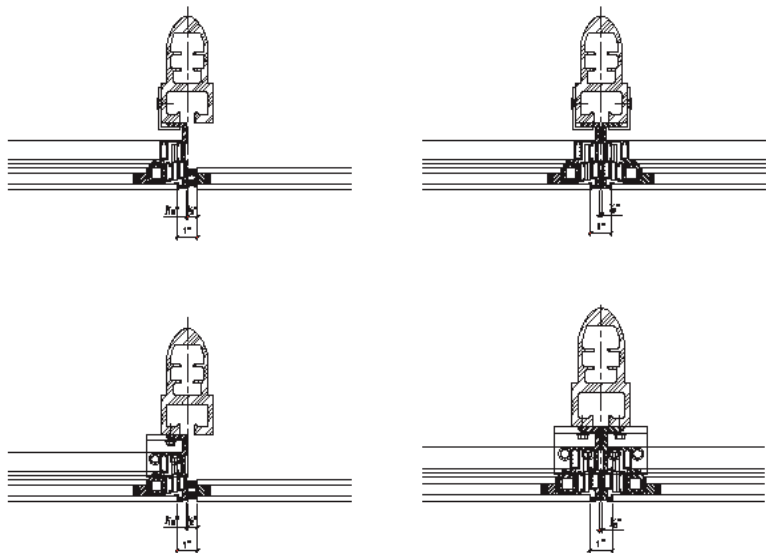


## Inner Skin System

The inner skin of the double skin wall system is provided by the VS-1 glazing system, an innovative product typically used as an exterior wall system. In fact, this system is used on the east wall of the building facing the lake. The VS-1 system uses a vertical mullion as the sole structural member; no horizontal mullion is used with the system. The glass is stepped away from the face of the mullion using a simple fixing com-

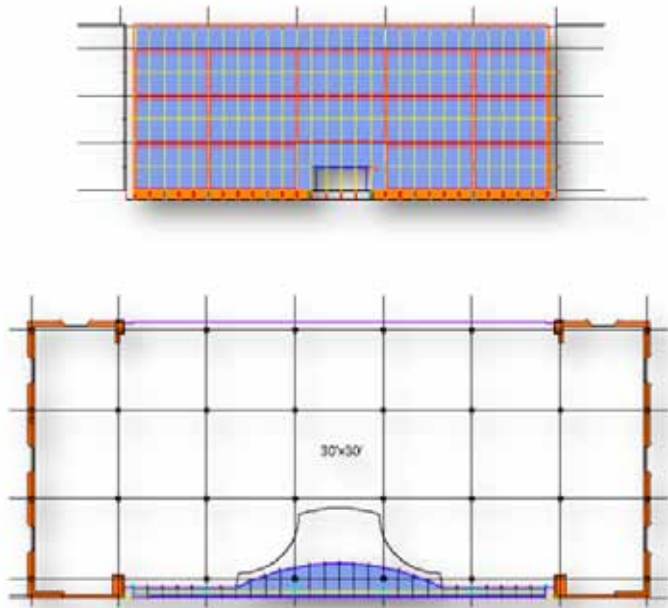
ponent that intermittently clamps the glass to the mullion without requiring any glass perforations. The glass fixing attaches to a channel built in to the outer face of the mullion. The weather seal is provided by a field applied butt glazed silicone joint providing superior reliability and longevity. The high relative transparency of the system made it ideal for use as the inner skin of the double skin wall.

*The interior skin of the double skin wall is comprised of an innovative point-fixed system with the glass offset from a system of vertical mullions that incorporate a glass fixing element. This same system is used as the exterior wall on the building's east side facing the lake.*

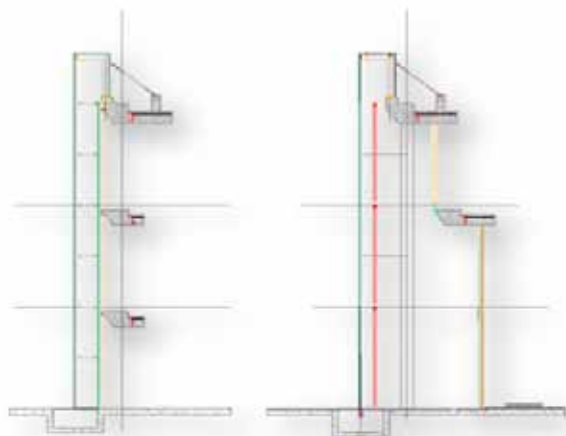


*Typical sections of VS-1 system*

Richard J. Klarchek  
Information Commons  
Loyola University  
Chicago



West Elevation and First Floor Plan



Sections through cavity wall

The advanced facade technology used on the Loyola Information Commons is important to both the green building movement and critical mission of improving the energy efficiency of the built environment. No building system impacts both the appearance and performance of architecture as does the building skin. Enclos is aggressively pursuing this mission with a robust research and development program, and is constantly looking for opportunities to exercise its advanced technologies as it did on the Loyola Information Commons.



## Riverhouse (One River Terrace) Manhattan

*Riverhouse is the first residential building in New York City to pursue a LEED Platinum rating from the USGBC.*



**owner** site 16/17 Development LLC

**developer** The Sheldrake Organization

**architect** Polshek Partnership

**architect of record** Ishmael Leyva Architects

**engineer** DiSimone Consulting Engineers

**gc** Plaza Construction

**facade consultant** RA Heintges & Associates

**completion** 2007

**program** 31-story tower with 2 wings at 14 and 16 stories; 264 condominium units

**building type** residential

**facade** complete design/build facade services including 7 unique system types with variations, including innovative unitized double skin curtain wall system; punched windows, strip windows, vertical strip curtain wall, one and two-story conventional curtainwall, glazed soffit, luminaries and structurally glazed system with stainless steel framing; various types and sizes of operable windows double skin system; custom unitized system with operable blinds in a ventilated cavity; thermally broken system with isobar technology

**glass** insulated glass throughout; double skin units use exterior clear 3/8 HS and interior IGU 1/4 clear HS x 1/2 argon x 1/4 clear HS with low-e on #2 surface

**description** this eco-conscious luxury condominium complex is a New York first and one of the greenest residential buildings in the country

The product of a visionary developer and legendary architect, Riverhouse has raised the bar on luxury, eco-conscious dwelling. Located adjacent to Battery Park, the building design manages to balance energy efficiency with a predominant use of transparent glass, optimizing view and access to natural light. This feat is partly accomplished through the use of an innovative double skin facade system.

The facade program for the Riverhouse was extraordinarily complex. A building designed to be responsive to local climate and site will not present the same face uniformly. Rather, the facade will articulate in response to the forces presented by these conditions. The Enclos design team developed 7 unique facade systems with variations of each system type in response to the architect's specifications. The systems range from the simple to the complex, but the most interesting is a custom double skin or dual-wall system developed to improve the efficiency of specific facade areas.





## Riverhouse (One River Terrace) Manhattan

The Enclos design and engineering team is over 100 strong, including architects and civil, structural and mechanical engineers. The development of the double skin system required extensive analysis provided by in-house CFD (Computational Fluid Dynamics) capability. The system is designed to provide a buffer between inside and out, and is attuned to seasonal climate variations as a function of cavity volume, passive dampers and operable vent design and positioning. Sun-control blinds located within the 5-inch cavity of the unit are controlled from inside the dwelling. All facade units are thermally-broken exterior to interior using state-of-the-art isobar technology. The system also incorporates large interior (in-swing) vents to facilitate maintenance and cleaning of the blinds and the exterior lite of glass.

With vents in the open position, outside air enters the cavity through the vents placed low in the units, rises as it is heated, and is exhausted to the outside through vents at the top of the unit, thus passively ventilating the cavity. During the cold season the vents are closed



and the cavity acts as a climate buffer between indoors and out, resulting in a 25% energy savings over conventional insulated glass units based on CFD projections.

Designing the double skin facade as a panelized or unitized system saved money in installation. The 10.5 feet tall units in modular widths of 2.5 or 5-feet were easily installed from inside the building. A custom, multi-component anchorage system designed to accommodate building movements and natural forces from wind, snow and seismic influences facilitated attachment of the facade units to the structure.

The extruded aluminum framing members of the units are protected with a high performance dual-coated, Polyvinylidene Fluoride metallic finish of automotive quality. The highest level of craftsmanship in both manufacturing and installation is required, as the units comprising the facade system act as the finished walls of the luxury interiors.



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## Cavity Dynamics

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Though “double skin facade” lacks a clear definition, two common classification strategies categorize by the airflow mode or the cavity geometry. The primary metrics by which DSF cavities are evaluated are temperature, airflow and daylight. These factors reflect comfort of the space and success between theoretical and as-built performance.

Common energy advantages of DSF include thermal insulation, the possibility of heat recovery through airflow, integrated shading strategies responsive to climatic conditions, and the ability to extract absorbed solar heat from the cavity. These polyvalent facades can be used to improve comfort (insulating thermal buffer, acoustics, ventilation, and inner surface temperature), achieve a transparent aesthetic, and fully-integrate with: active systems (photovoltaic, mechanical), passive systems (shading), and functional requirements such as circulation corridors. Many of these attributes have been the focus of research over the past decade, but the fundamental performance of DSF requires further evaluation to enable designers to appropriately design such systems. One attribute that has received little attention, although it has been acknowledged as an important factor, is the aero-physical behavior of DSF.

The interactions of applied wind excitation with the cavity pressure create a phenomenon called cavity dynamics. This concept is of prime importance in the design of DSF. Cavity volume, ventilation areas, and air permeability of barriers, all effect the passive air flow through the cavity. The resultant pressure profiles need to be considered for the design and sizing of glass and fram-

ing members. This analysis must further be expanded to include the effect of active air circulation used for thermal enhancement within DSF units.

Computational Fluid Dynamics (CFD) is fast becoming a standard design tool for the environmental analysis of double skin facade systems. CFD uses the principle of finite volume to compute a numerical approximation to the solution of mathematical models of fluid flow and heat transfer. The crucial elements of computational fluid dynamics are discretization, grid generation and coordinate transformation, solution of the coupled algebraic equations, turbulence modeling, and visualization. Enclos Corp has been utilizing CFD analysis for the study of complex flow-structure interaction in various applications.

The following is an overview of variables which affect the aero-physics of a double skin facade cavity.

### Steady State Response

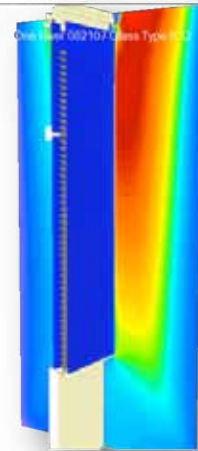
#### *Airflow Mode*

A DSF’s airflow strategy can be heavily influenced by building orientation and local climatic conditions. The various strategies can generally be separated into three physical functions:

- Second skin as a separate skin: few or no openings between cavity and exterior.
- Double skin cavity as a part of ventilation strategy.
- Multi-function space: cavity space fulfills corridor function.

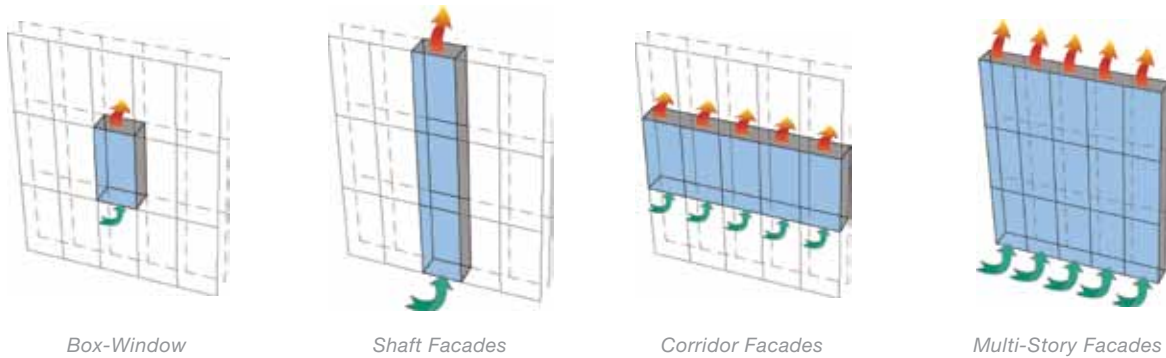
For double skin systems with cavity ventilation, the facades can be classified by the type of ventilation (natural or mechanical), origin of airflow, destination of airflow, and direction of airflow.

In designing a double skin facade it is necessary to meet comfort requirements and address the risk of overheating in the facade cavity. This requires a fundamental understanding of cavity dynamics, and the stack effect which states that hot air rises, and cool air sinks.



*Thermal analysis of DSF*

Since DSF are not totally sealed (cavity space is in contact with outside air via openings at the bottom and top), the stack effect will cause air infiltration. During the heating season, warmer cavity air rises up through the cavity and escapes at the top through ventilation openings. The rising warm air reduces the pressure in the base of the building, forcing cold air to infiltrate through open



doors, windows, or other openings. During the cooling season, the stack effect is reversed, but is typically weaker due to lower temperature differences. In a modern high-rise building with a well-sealed envelope, the stack effect can create significant pressure differences that must be given design consideration and may need to be addressed with mechanical ventilation. The pressure differences result in thermal uplift defined as:

$$\Delta p_{th} = \Delta \rho' * g * \Delta h * \Delta t_m \quad (\text{Eq. 1})$$

where:

- $\Delta p_{th}$  pressure difference of thermal uplift
- $\Delta \rho'$  specific change in air density with temperature change
- $g$  acceleration due to gravity
- $\Delta h$  effective uplift height
- $\Delta t_m$  mean excess temperature

In DSFs the effective uplift height is the difference between the air-inlet and air-outlet openings. For systems with fixed air openings, the use of adjustable louvers for the outer skin allows a better adaptability to vary intake air volumes in changing climatic conditions.

#### Geometry

Height and width are some of the most important parameters in designing a double skin facade system. The height effects the magnitude of thermal uplift which occurs in the cavity. The taller the space, the less comfort or cooling capacity will occur at higher floors because of stratification.

The width of the cavity impacts the airflow within. In a wider cavity, the

boundary layers are very small in comparison to the primary width. In a narrower cavity, the boundary layers at each side can get close enough to cause velocity profiles to merge. As the cavity narrows the transition between laminar and turbulent flow zones decreases. The air temperatures can increase in narrower cavities due to lower airflow velocity.

Airspeed is less affected by the cavity depth than the design of the openings to the cavity and their ratio to cavity volume. Some research scientists believe thin cavities can be more useful because they deliver a higher and hotter air flow in comparison to thick deeper cavities. This would be subject to specific site conditions and design objectives.

An important variable in the cavity geometry is the location and sizing of openings for intake and outlet. The steady state response airflow is governed by the continuity equation which states the theoretical balance of the product of the inlet area and air speed, and the product of the outlet area and air speed.

$$A_{in} * v_{in} = A_{out} * v_{out} \quad (\text{Eq. 2})$$

In this equation, A and v denote the area opening and air velocity respectively. This equation assumes that the air remains uninterrupted in the cavity from other impediments – in reality numerous factors influence the cavity temperature, and thus airflow. Using this principle, if the inlet opening is half the area of the outlet, then the inlet air velocity will be twice as much. It is always advantageous to locate the inlet and outlet

openings as close to the bottom and top respectively.

The configuration and subdivision of the cavity geometry shapes the airflow dynamics. Four primary geometric configurations are illustrated above:

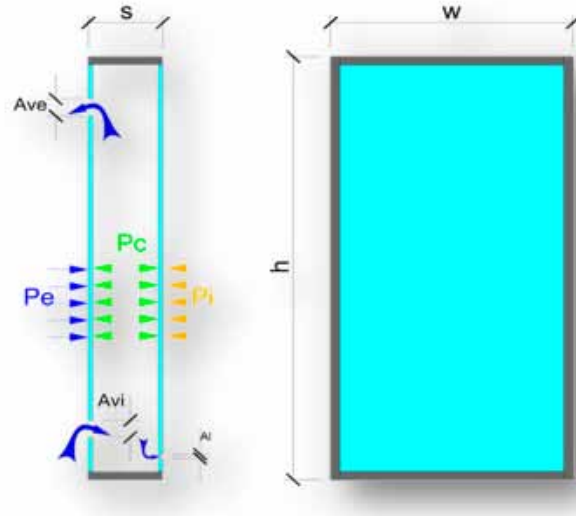
- Box-Window
- Shaft Facades
- Corridor Facades
- Multi-Story Facades

#### Transient Response

The use of a double skin facade may be advisable in naturally ventilating internal rooms of a building exposed to high levels of wind pressure and external noise, both common in high-rise applications. The interaction of the internal cavity pressure with the structural flexibility of the barrier surfaces result in a multi-variable dynamic system, which requires complex computational techniques. In general the solutions have been simplified in favor of more conservative loading assumptions or reliance on mock-up tests, neither of which is a practical nor reliable design approach. The use of wind tunnel tests has also been proven to be somewhat limited in the prediction of envelop pressure, since it is difficult to model the stiffness of the resisting elements and cavity openings.

The wind may have minimal effect at smaller scales in comparison to full scale. This is significant when considering a mock-up facade of a DSF for testing purposes. Does the mock-up truly represent the cavity configuration and physics? The effects of wind on the internal pressures of a three bay cavity may vary substantially from the internal pressures of a corridor facade

## Cavity Dynamics



with many bays. Depending on the cavity module, when sun and wind occur simultaneously the wind pressure can contribute to reduced internal temperatures by increasing the cavity airflow.

The amount of wind penetration is important in determining the cavity pressures for designing the interior facade. In addition, determining wind speeds can identify conditions that may result in damage to shading devices planned within the cavity.

Flexibility of the external wall plays a role in the volumetric change of the cavity and the short-term loading transferred from the exterior to the interior facade. Common materials for the frame of the outer glass skin include aluminum, galvanized steel, stainless steel or weathering steel. Depending on the configuration of the cavity, the magnitude of the volumetric ballooning effect due to wind pressure deflection and internal cavity pressures varies. A smaller span would be less affected than a larger span. A flexible structure, such as a cable net wall, would experience greater deflections and volumetric change than a stiffer system of similar configuration.

This multi-variable dynamic system requires a more intensive analytical process. The mathematics of the cavity is similar to the Helmholtz resonator theory, which states the equation of the motion of a slug of air through an opening as:

$$\rho_a l_e \ddot{X} + \frac{\rho_a}{2} |\dot{X}| \dot{X} + p_c = p_w \quad (3)$$

In this equation  $X, \dot{X}, \ddot{X}$  denotes the displacement, velocity and, acceleration of a slug of air through an opening into the cavity as a function of time. In the forging analysis  $p_c$  and  $p_w$  are functions of time. Parameter  $\rho_a$  is the air density and  $l_e$  is the effective length of the opening and is given by;

$$l_e = \frac{\sqrt{\pi A_{rs}}}{2} \quad (4)$$

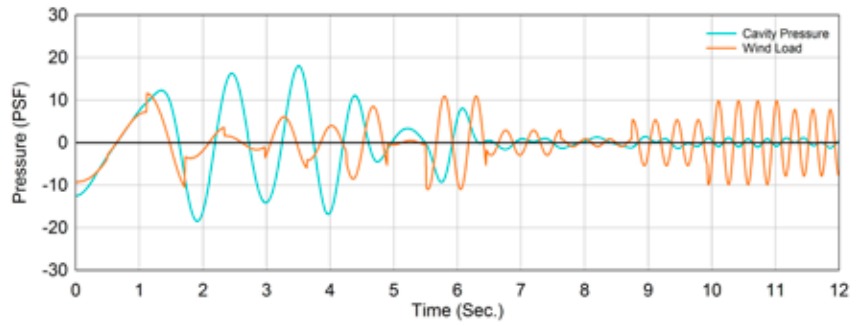
where  $A_{rs}$  is the total venting area for the panel. It is assumed there is no air flow through the air barrier, and the air adheres to the isothermal gas law, which states:

$$\frac{p_c}{\rho_c} = \frac{p_a}{\rho_a} = \frac{p_w}{\rho_w} \quad (5)$$

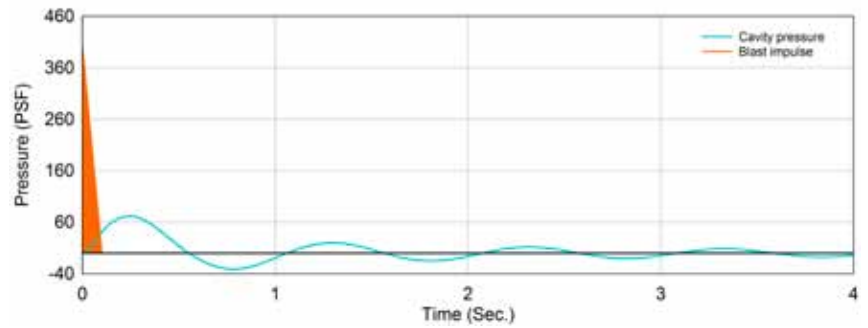
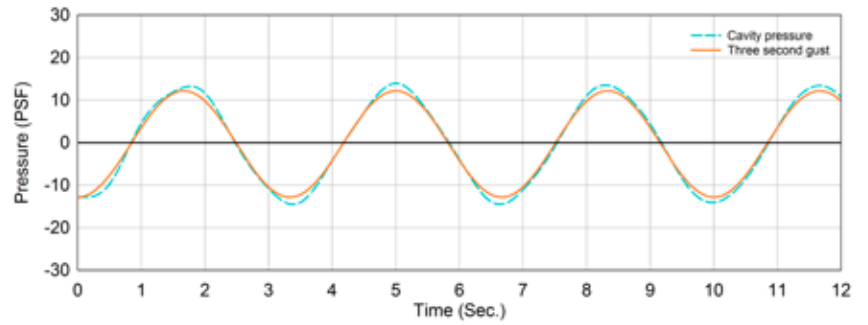
Here  $\rho_c$  and  $\rho_w$  are density of the air inside and outside the cavity, and are functions of time. The conservation of mass requires the rate of air flow through the vent opening to be equal to the rate of change of the mass in the cavity i.e.:

$$\rho_c C_d A_{rs} \dot{X} = \frac{\partial}{\partial t} (\rho_c V) \quad (6)$$

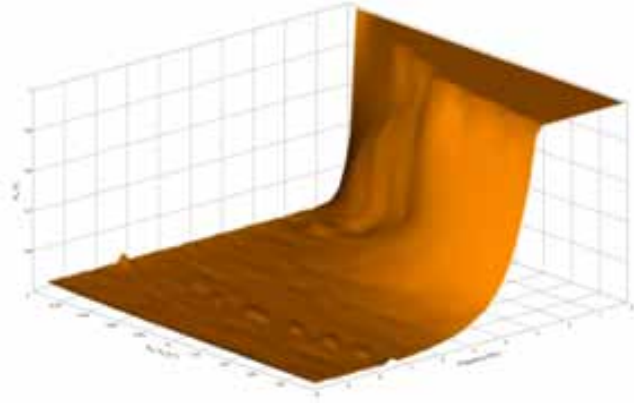
In this equation  $C_d$  is the discharge coefficient for the venting holes and is set to 0.65, and  $V$  is the volume of the cavity as function of time. Substituting equation (Eq. 5) into (Eq. 6) and subsequent differentiation of the result will yield the following expressions for  $\dot{X}, \ddot{X}$ :



Time-history response of 5'x12.5'x12" cavity to:  
 simulated wind load (top)  
 three second gust at 80 mph (middle)  
 4psi 28 millisecond blast. (bottom)



## Cavity Dynamics



Parametric study of cavity pressure as function of excitation frequency and cavity index (ratio of ventilation area to the cavity volume).

$$\begin{cases} \dot{X} = \frac{1}{C_d A_{rs}} \left( \frac{\dot{p}_c}{\rho_c} V + \dot{V} \right) \\ \ddot{X} = \frac{1}{C_d A_{rs}} \left( \frac{(\dot{p}_c V + \rho_c \dot{V})}{\rho_c^2} \dot{p}_c - \dot{p}_c^2 V + \ddot{V} \right) \end{cases} \quad (7)$$

where  $V, \dot{V}, \ddot{V}$  are the cavity volume, rate of change of the volume, and second derivative of the volume with respect to time.

The volume is defined as the original cavity volume in addition to any changes as the result of the flexibility of interior and exterior walls:

$$V = V_0 + \frac{4A}{\pi^2} [\delta_i(p_c) + \delta_e(p_w, p_c)] \quad (8)$$

in the above equation  $\delta_i(p_c), \delta_e(p_w, p_c)$  are peak deflections of the interior exterior walls as function of applied pressures. Substituting  $V$  and its first and second derivatives into (Eq. 3) and (Eq. 7), we can get the following differential equation for the solution of the cavity pressure as a function of time:

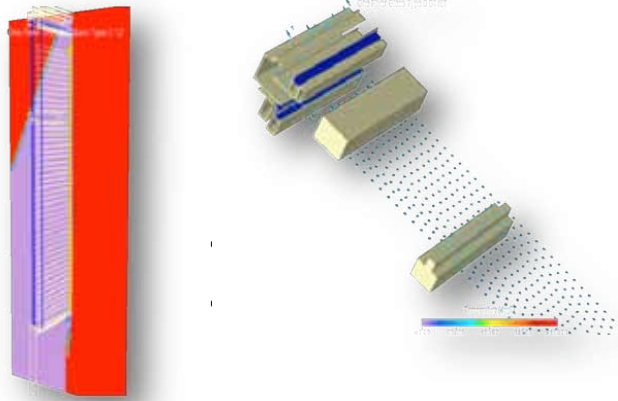
$$\alpha_1 \ddot{p}_c - \alpha_1 \dot{p}_c \dot{V} - \alpha_2 \ddot{V} + \beta_1 \dot{p}_c + \beta_2 \dot{V} (\dot{p}_c + \beta_2 \dot{V}) + p_c = p_w \quad (10)$$

Where  $\alpha_1, \alpha_2, \beta_1, \beta_2$  are parameters defining the geometry and material properties of the cavity. Solution of this equation represents the cavity pressure as function time for any given applied pressure

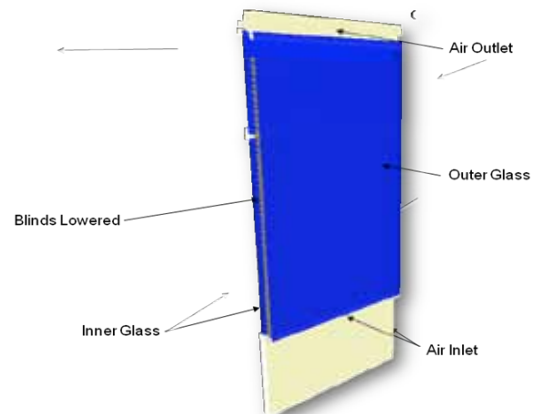
### Other Considerations

#### Glass Type

The selection of glazing for both the interior and exterior facade layers plays a role in the system flexibility, light transmittance, and cavity temperatures. The wide array of glass pane treatments are integral in the development of solar heat gain. Several treatments include low-iron (clear) glass, frits, and coatings such as low-e. For extreme summer conditions, low-e inner panes reduce the influence of high inner pane temperatures caused by increased cavity air temperatures. The benefit of low-e coatings is improved greatly when combined with appropriate solar shading.



Study of sun light energy through open and partially open blinds.



Study of air flow through the vents of a double skin unit with integrated blinds.

### Shading Devices

The interstitial space provides a convenient location to integrate shading controls which mediate the interior from the exterior spaces that bookend the cavity. However, such devices tend to be a source of heat gain within the cavity.

Heat absorbed by the shading device can be extracted by convection if air is removed along its surface and then removed from the cavity. If the device is not located appropriately, the shading system can re-radiate heat within the cavity increasing inner surface temperatures. The negative effects of shading devices are magnified in shallower cavities. It is better to place sun shading in the outer half of the cavity space, with an ideal location approximately a third of the facade cavity depth.

The configuration — or openness — of the shading device can alter the cavity airflow dynamics and temperatures. In the case of a Venetian blind shading system a louver angle of 45° would

allow air to flow through the shading plane, but not without creating local turbulent flows and variant zones of airflow and air temperature. In the case of closed blinds, the cavity is divided with distinct zones of upward and downward flow.

### Mechanical Strategies

Ultimately, the success of a DSF system relies significantly on the successful integration of control systems to continually adapt the cavity airflow variables to achieve desired levels of performance and comfort. This requires optimizing the design of the HVAC system, its integration with the DSF, and a control strategy to regulate the whole system. The risk of overheating the offices during the summer months is high when the design is not properly integrated with the HVAC system strategy. The mechanical and control systems within a DSF require rapid response to fluctuating outdoor conditions.

### Conclusion

Analysis of DSFs shows that their energy performance strongly depends on the way the cavity air is used. In order to correctly evaluate the energy efficiency of multiple skin facades, it is imperative not only to study the transmission gains and losses but also to take into account the enthalpy change of the cavity air and the role of cavity aero-physics.

Enclos Corp researches are engaged in an ongoing investigation of cavity dynamics as a means to properly analyze structural behavior of DSFs.

Our research involves the development of simulation systems as well as extensive testing and experimental studies of DSFs and their component parts.

## Acoustics

The decision on what facade concept to employ for building construction is usually dictated by the aesthetic and thermal requirements of the building program. However, with the recent environmental noise pollution concerns and the growth in construction of high-rise residential condominiums in noisy urban areas, prescribed acoustic requirements have become more prevalent in the design of building envelopes. Furthermore, the availability of new computational methods developed for use in the automotive, aircraft and entertainment electronics industries present an opportunity to advance acoustic analysis and performance considerations to a new level in the construction industry.

Acoustical performance evaluation of architectural products has been the subject of continuous interest in the past 40 years. The two main classification indices used are Sound Transmission Class and Outdoor-Indoor Transmission Class. The current practice is almost always experimental, and the sound transmission classification is not itself a measure of comfort or even sound dis-

STC	Subjective Description
30	Normal speech is heard and clearly understood
40	Normal speech is heard, but requires some effort to be understood
50	Loud speech can be heard with some effort. Music is easily heard
60	Loud speech cannot be heard. Music can be heard faintly
>70	Loud music can be heard faintly.
>75	Most noise is effectively blocked.

sipation, but rather a measure of relative performance. Furthermore, due to the nature of sound perception and nor-

malization methods, the results are not always consistent and intuitive, leaving room for interpretation and subjective assessment.

**Sound Transmission Class (STC):** a single number rating that is calculated using the ASTM E413 classification for the rating of sound insulation characteristics of interior walls and floor partitions exposed to typical office building noise (e.g., speech, radio, television, etc.). An STC contour curve is applied to the actual measured transmission loss data, and the transmission loss value on the contour curve at 500 hertz is the STC single number rating.

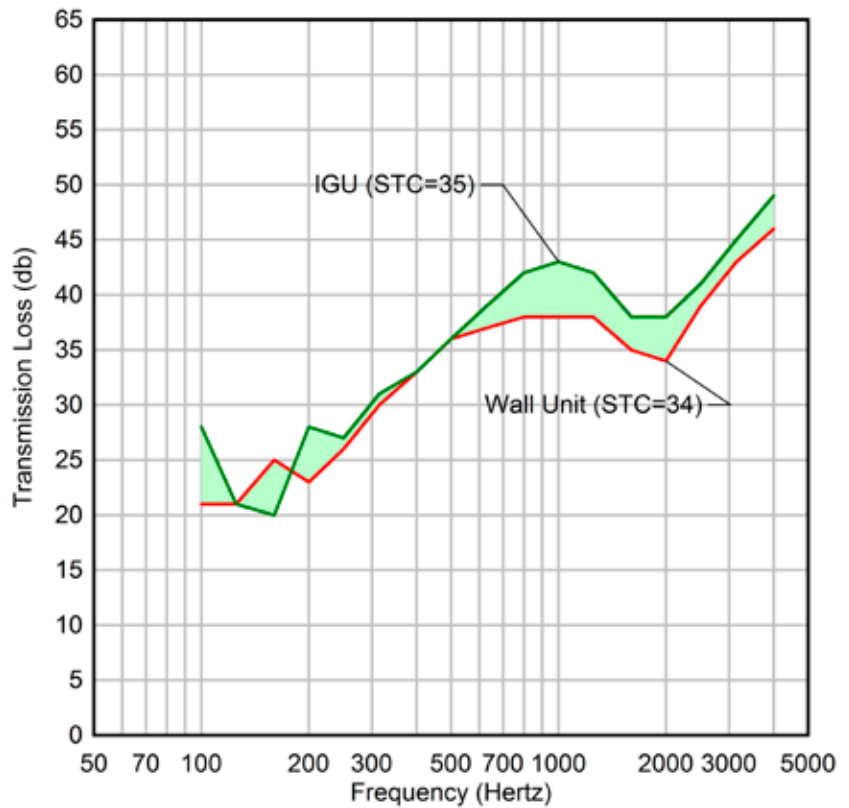
**Outdoor-Indoor Transmission Class (OITC):** a single number rating that is used to classify wall partitions, doors and windows which are exposed to lower frequency noise sources such as cars, trains and aircraft. The ASTM E1332 test method specifies the transportation spectrum and logarithmic summation that is applied to the transmission loss data to obtain the OITC rating.

At Enclos Corp we have developed analytical and numerical tools for the acoustical analysis and evaluation of curtainwall systems as a predictor of performance.

Enclos Corp employs ongoing in-house testing programs, building a database of captured performance data as a record of completed projects. This database in conjunction with the best-practice guidelines is used for system evaluation during the schematic design phase of project.

Double skin facades (DSFs) were originally conceived as means of mitigating the outside noise in the office buildings. To this end they achieve a significant increase in the transmission loss of the building skin. On average, a 10 dB gain can be realized by the proper utilization of DSF.

Typical insulated glass has a STC rating of 34 to 38. This rating will be compromised by the aluminum framing in the curtain wall on an average by 2 to 4 points. The performance can be im-



Transmission loss characteristics of an insulated glass unit and typical wall unit.

# Acoustics

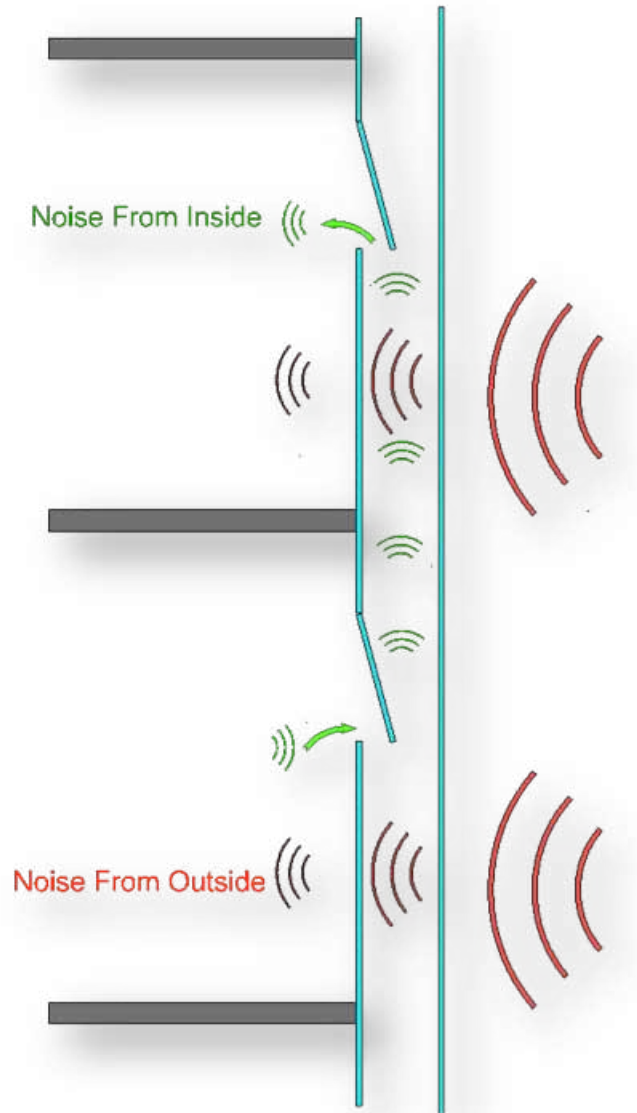
proves by the use of laminated glass.

To compute the overall acoustical performance of DSFs, the individual components need to be accurately tested in laboratory conditions. Then the composite effect resulting from the coupling of the various components can be simulated using advanced techniques, such as statistical energy analysis (SEA).

The main concept in SEA is that a structure (i.e., a curtainwall system) is partitioned into coupled “subsystems” and the stored and exchanged energies are then analyzed.

The transmission of sound via the cavity of the DSF is an important parameter when considering the acoustical insulation between the rooms located on the facade side.

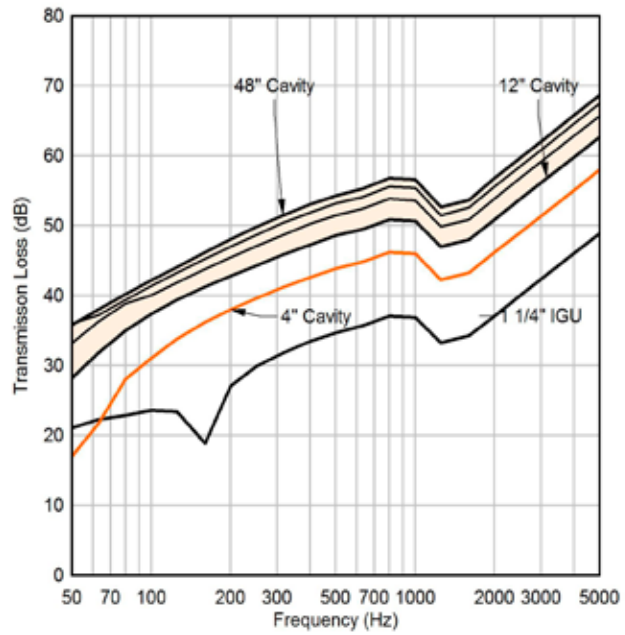
This can be an issue especially when the (glass) inner facade is operable. In DSFs the relative performance seems more pronounced in floor-to-floor condition verses room-to-room. This is due to the fact that typically in office buildings the room-to-room transmission losses (STC of 35 to 45) are considerably lower than floor systems (STC of 54 for a 6” concrete floor).



*Noise paths through a double skin facade*

Skin Type	STC	OITC
1 1/4" IGU	36	30
1 1/2" IGU	38	30
DSF 4" Cavity	46	40
DSF 12" Cavity	50	46
DSF 24" Cavity	53	49
DSF 36" Cavity	55	50
DSF 48" Cavity	56	51

The cavity depth is the prime parameter in the acoustical performance of DSFs. However there is an asymptotic limit to the depth efficiency of DFS. As can be seen from the accompanying table and graph, the increase in the STC value becomes negligible for cavity depths greater than 24". Furthermore the composition of the glass panel (laminated vs. monolithic) has a lesser effect in larger depth cavities.



Transmission Loss Response for various cavity depths



## Antecedent Technology

### US Double Skin Projects by Others



Building: Genzyme  
Location: Cambridge, MA  
Architect: Behnisch Architects  
Ventilation Type: Mechanically Ventilated  
Ventilation Mode: Air supply  
Vertical Partition: Multi Story

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Building: Levine Hall, Pennsylvania School of Engineering  
Location: Philadelphia, PA  
Architect: Kieran Timberlake Associates, LLP  
Ventilation Type: Mechanically Ventilated  
Ventilation Mode: Air exhaust  
Vertical Partition: Single Story

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Building: Manulife Financial  
Location: Boston, MA  
Architect: SOM  
Ventilation Type: Mechanically Ventilated  
Ventilation Mode: Indoor air curtain  
Vertical Partition: Single Story

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Building: Occidental Chemical, Hooker Building, 1980  
Location: Niagara Falls, NY  
Architect: Canon Design  
Ventilation Type: Naturally Ventilated  
Ventilation Mode: Outdoor air curtain, air buffer  
Vertical Partition: Multi Story

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Building: Seattle Justice Center  
Location: Seattle, WA  
Architect: Kerry Hegedus, DMJM  
Ventilation Type: Hybrid Ventilated  
Ventilation Mode: Outdoor air curtain  
Vertical Partition: Multi Story

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## Enclos Press Publications

*Inter-Story Acoustical Evaluation of  
Unitized Curtainwall Systems - 2008*

*Analysis and Design of Spandrel and  
Shadowbox Panels in Unitized Curtain  
Walls - 2009*

*Enclos: Collective Works - 2009*

*Facade TecNotes Series:*

*1 Skylight*

*2 Double Skin*

*3 Architecturally Exposed Structural  
Steel (AESS)*

*4 Airports*

*5 Healthcare*

*6 BIM and the Building Facade*

*7 Cable Nets*

*8 Security*

*9 LEED Skins*



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