



Emerging Applications and Trends of Double-Skin Facades

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Double-skin facades have historically been more common among European high-rises in part because energy prices are significantly higher in Europe than in the United States. The use of double-skin facades (DSF) in the United States for commercial buildings presents a variety of challenges and impediments, including a longer payback period on initial investment. An emerging trend in double-skin facades is the divergence of approaches related to scale. Many designs can be separated into modular systems, or a single multi-story cavity. In the United States recent applications of double-skin facades include educational institutions and residential high-rises. This paper presents an overview of the challenges of double-skin facades systems in the United States. Additionally, detailed case studies of four recent double-skin facade systems are presented.

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	Arons (2000)	Kragh (2000)	Oesterle et al. (2001)	Uutttu (2001)	Compagno (2002)	Lee et al. (2002)	BBRI (2002)	Wigginton (2002)	Saelens (2002)	Herzog et al. (2004)	Pirazzis (2006)	BESTFACADE (2007)	Streicher (2007)	Manuelide et al. (2008)
ADVANTAGES														
Acoustical Insulation		•	•	•	•				•	•	•	•	•	
Winter Thermal Insulation			•	•	•	•	•	•				•	•	•
Summer Thermal Insulation								•						
Night Cooling	•		•	•	•	•	•			•		•	•	•
Energy Savings	•													
Natural Ventilation	•		•	•	•	•	•	•				•	•	•
Thermal Comfort	•	•			•	•	•	•	•	•				
Reduction of Wind Pressure					•							•	•	•
Daylight								•		•				
Transparency – Aesthetic		•	•	•		•	•					•	•	•
Security						•						•	•	•
Improved Protection of Shading Devices			•	•	•						•	•	•	•
Lower Construction Costs (compared to other intelligent technologies)				•								•		
Renovation/Preservation Applications														•
Fire Escape												•		
Low SHGC	•	•			•							•		
DISADVANTAGES														
Higher Investment Costs	•	•	•		•	•	•	•	•	•	•	•	•	•
Maintenance Costs			•	•	•	•	•	•	•	•	•	•	•	•
Operational Costs			•		•	•	•	•	•	•	•	•	•	•
Overheating		•	•	•								•	•	•
Increased Air Flow								•						
Poor Cross Ventilation												•	•	
Increased Structural Weight												•		
Daylight			•					•	•	•	•	•	•	•
Increased Electrical Loads by Lighting													•	
Acoustic Insulation/														
Cavity Sound Transmission			•	•		•	•	•	•	•	•	•	•	•
Fire Protection			•		•	•	•	•	•	•	•	•	•	•
Reduced Floor Area	•											•	•	•
Overestimated Energy Savings													•	•

Table 1. Advantages and disadvantages of double-skin facade systems. Review of multiple sources [1-14].

1 INTRODUCTION

Double-skin facade solutions have been increasingly considered over the last 20 years as a means to save energy while providing access to daylight and natural ventilation. Table 1 is a summary of common advantages and disadvantages cited by others [1-14]. The most frequently cited benefits of double-skin facades are acoustics [1] and retrofitting potential. The principal drawback of double-skin facades is the increased cost compared to traditional curtain wall systems.

The use of double-skin facades is more common in Europe in part because energy prices are significantly higher than in the United States. Over time, inevitably increasing energy costs and new building performance policy will expedite the return on investment. While double-skin systems are implemented regularly in Europe, the rest of the world has lagged in implementing, or investing in, high-performance facade technology. To date these structures have been implemented sparsely in Japan, China, Canada and the United States. The

use of double-skin facades in the United States for commercial buildings presents a variety of challenges and impediments:

- They are not common building technology
- Historically, architects/engineers in the U.S. are not very familiar with radiant systems
- Until recently an integrated design approach requiring coordination and collaboration across building design disciplines and trades had been counter to the traditional segregation of the U.S. trades functioning relatively independent of each other
- Early integration of facade consultants is not a common design process for architects
- Double-skins are more costly compared to conventional glazed facade (CGF) systems
- U.S. building codes do not require access to daylight and fresh air in office environments as the European codes mandate
- There is no engineering discipline responsible for shading and blinds, often

- resulting in neglect for these systems
- Maintenance of sun-tracking motorized shading is a paramount concern of owners
 - Lower social expectations for healthy work environments compared to European nations.

2 EARLY PRECEDENCE

Double-skin facades started to emerge across Europe, Asia and the United States beginning in the 1980's. Many of the early constructions were implemented in low-rise buildings, shortly followed by numerous high-rise applications in the early 1990's. It wasn't until the early 2000's that the use of double-skin systems began to increase in the United States. These early examples sought to reduce energy consumption necessary to cool the building without having external shading devices. The use of natural ventilation alleviated the energy required for mechanical ventilation. The primary design objectives of these double-skin solutions are similar today.

The Occidental Chemical Center (1981)

Double-Skin Facades in the United States

Approximately 16 major double-skin facades to date:

- New York Presbyterian Hospital, New York, NY
- USC Eli and Edith Broad Center, Los Angeles, CA (2010)
- Cambridge Public Library, Cambridge, MA (2009)
- Cleveland Art Gallery, Cleveland OH (2009)
- Art Institute of Chicago - Modern Wing, Chicago, IL (2009)
- Information Commons, Loyola University, Chicago IL (2008)
- Riverhouse – One River Terrace, New York, NY (2008)
- UMass Medical School, Worcester, MA (2004)
- Foundry Square, San Francisco, CA (2003)
- Genzyme Center, Cambridge, MA (2003)
- Manulife Financial, Boston, MA (2003)
- Seattle Justice Center, Seattle, WA (2002)
- Levine Hall, Philadelphia, PA (2001)
- Yazaki North American, Canton, MI (2000)
- Occidental Chemical Building, Niagara Falls, NY (1982)
- University of Michigan Biomedical Science Research



building in Niagara Falls, New York is widely recognized as the first modern double-skin facade [8]. The 200,000 sf building consists of a nine-story square plan around a central core resulting in column-free office space. The reasons for implementing a double-skin facade had to do with thermal comfort, views, and the difficulty applying exterior solar control devices due to the site's high exposure with respect to wind [5]. The four-foot cavity is encompassed by blue-green tinted insulating glass exterior skin and single clear glazing interior skin. Within the cavity depth are operable white-painted louvers which vary position based on sunlight hitting a single sensor placed at the center of each elevation. The multi-story DSF reduces the impact of severe external temperatures by minimizing air infiltration from the cavity to the interior conditioned space. During the cold winter, the cavity acts as a thermal buffer.

In 2001 Kieran Timberlake Associates' design for Levine Hall at the Pennsylvania School of Engineering incorporated a six-story box-window unitized system primarily

on east and west exposures to enclose the interior offices, laboratories, meeting spaces and auditorium. The initial motivation for a pressure equalized double-skin unit was improved performance resulting in better indoor comfort with less energy consumption, and lower maintenance costs than standard curtain walls [15]. Air-intakes were located at the base of each frame, which draws interior air through the facade cavity before returning back into the room.

The double-skin was further explored in 2002 by NBBJ on the Seattle Justice Center in the form of a 13-story, 18,000-sf multi-story construct with a 30" cavity enclosed by single glazing to the exterior and insulated glazing to the interior. Within the cavity space there is a shading system consisting of semi-transparent roller blinds, which move in unison by floor according to historical seasonal data.

Other notable applications include the 14-story Manulife Financial, Boston, Massachusetts (2003), with a story-height double-skin designed by Skidmore Owings

and Merrill, and the Genzyme Center, Cambridge, Massachusetts (2003), a 121'-6" tall multi-story system designed by Behnisch Behnisch and Partner.

3 CASE STUDIES

3.1 One River Terrace, New York (2008)

This development, designed by Polshek Partnership with Ishmael Leyva Architects, is the first residential building in New York to achieve LEED Platinum rating, in part due to improved insulation values provided by a 2.5-ft or 5-ft, by 10.5-ft tall unitized double-skin facade used to enclose the 31-story, 264 condominium tower. The complex facade program includes seven different systems at different locations on the building's elevations responding to specific climatic conditions.

The box window double-skin system includes a 5-in cavity with heat-strengthened single-glazing to the exterior and a low-e coated insulated glazing unit on the interior. The outdoor air curtain provides a thermal buffer that can vary by season

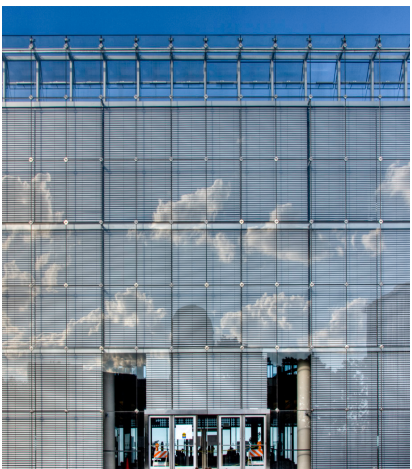


with passive dampers and operable vents. When the vents are open, outside air enters the cavity low in the units, rises vertically, and is exhausted through top vents. During the winter months the vents are closed to create a sealed cavity which acts as a thermal buffer, resulting in a 25% energy reduction compared to New York's energy code [16] based on design simulations. Within the 5-in cavity are sun-control blinds which can be manually operated from within the dwelling space. The system includes large interior vents to facilitate maintenance of the blinds and glass surfaces. The system did require intensive computational fluid dynamics (CFD) simulation to verify the thermal performance improvements.

3.2 Loyola Information Commons, (2007)

This 72,000 sf LEED Silver university building in Chicago designed by Solomon Cordwell Buenz is a high-tech library sited on the Lake Michigan waterfront to the east. High transparency walls are used on both the east and west exposures to preserve views of the lake and campus.

A 150-ft wide by 56-ft tall multi-story double-skin facade on the west face was designed to manage heat flow and natural ventilation throughout the year. The 3-ft cavity space acts primarily as a buffer to provide thermal insulation during cold winter months. The system is also designed to operate in a hybrid ventilation mode under controlled conditions. The interior is ventilated through the air cavity to relieve the high internal loads, while outdoor air enters the DSF at ground level and is



raised by thermal uplift before extraction at the roof return. Within the cavity space are 4-in horizontal blinds near the outer facade which track the sun's movement to maximize daylight while mitigating glare under changing solar conditions.

The interior of the double-skin is insulated glass units, point supported by patch plate clamps along vertical extruded mullions. The joints between the panels use field-applied silicon as a weather seal. The depth of the cavity space varies as the inner-facade curves inward to form a vestibule, which becomes part of the thermal buffer.

The exterior skin is an innovative application of two-way cable-net support structure. The crossing network of 29 tensioned vertical and six horizontal stainless steel cables support the 5-ft wide by 8-ft tall monolithic glass units at each corner with stainless steel clamping components. The slender cables along with a minimal field-applied silicone seal maximize the diaphanous appearance of the skin.

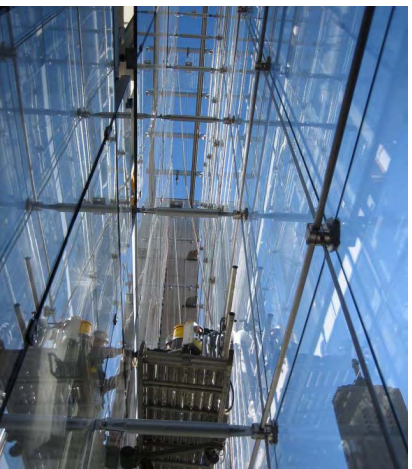


Figure 1 (top left). Mock-up of 5-in deep double-skin box windows placed within a unit assembly.

Figure 2 (top middle). West elevation of cable-net DSF.

Figure 3 (top right). Maintenance crew in DSF cavity.

Figure 4. Stainless steel two-way cable clamp patch plate (right middle) and cavity blinds (right bottom).

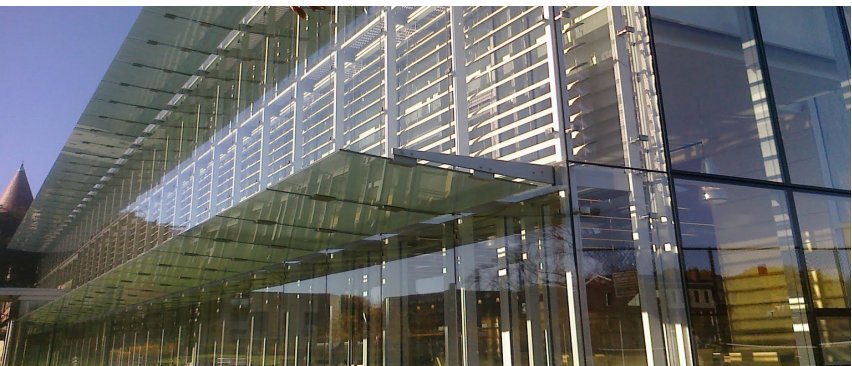


Figure 5 (top). Southwest view of DSF.

Figure 6 (middle). Point-clamped exterior facade with interior aluminum curtain wall facade.

Figure 7 (bottom). Interior space adjacent to the double-skin facade.

3.3 Cambridge Public Library (2009)

William Rawn Associates' design for a new 70,000 sf building alongside the preservation of the existing 35,000 sf historic library structure in Cambridge, Massachusetts includes a multi-story double skin facade to increase comfort and reduce operating costs. The transparent facade embraces the adjacent park and communicates a symbolic message of openness and welcoming.

The southwest facing double-skin facade by Gartner Steel and Glass GmbH, based in Würzburg, Germany, consists of inner and outer glass walls separated by a 3-ft deep by 40'-6" tall cavity. The two skins are supported by a series of vertical steel frames tied back to the building's primary structure. The framing supports the point-clamped monolithic exterior skin, large translucent glass shading canopies on the exterior that act as light shelves, aluminum blinds within the cavity, as well as the aluminum curtain wall interior skin utilizing insulated glass units.

An air inlet located at the bottom and an exhaust vent at the top are used to introduce airflow into the cavity. During winter months the bottom air inlet and top exhaust vent are closed to create a thermal buffer to insulate the interior spaces. In summer months, an outdoor air curtain is created by introducing cooler air through the air inlet into the cavity which rises as it warms and exits the top vent creating a stack effect. During the more temperate fall and spring seasons, an acceptable cavity temperature is maintained through operable windows, adjustment of air open-

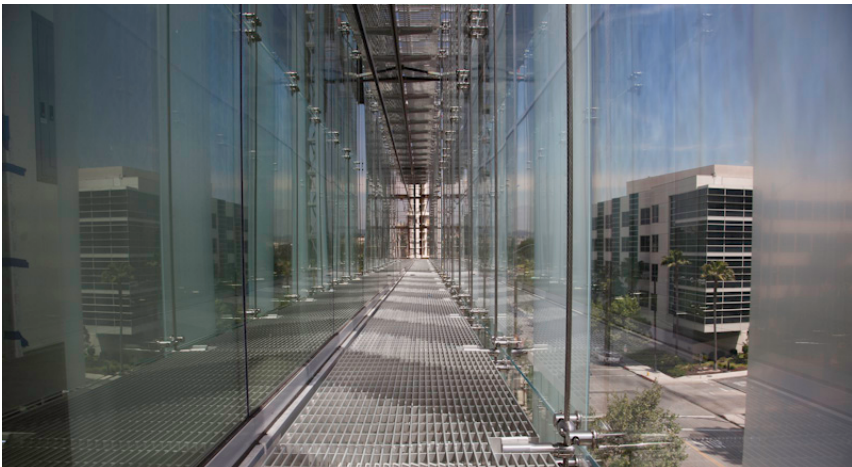


Figure 8. Interior view of southeast facing double-skin facade cavity.

ings and variant shading configurations providing natural ventilation to the interior.

Shading within the cavity is achieved via perforated aluminum Venetian blinds at the upper half of each floor which are used to minimize glare and provide even light levels to the interior library space. The operable louvers vary in position throughout the day and year by computer controls tied to the building management system. The shading slats are closed during winter days to reduce glare resulting from low sun angles. During summer months the louvers are configured to provide shading against high-angled sunlight.

3.4 Eli & Edythe Broad CIRM Center (2010)

The multi-story double-skin facade is located on the southeast face of the new stem cell research facility located on the campus of University of Southern California Keck School of Medicine in Los Angeles. The double-skin facade designed by ZGF Architects LLP was selected because the project demanded a ‘world-class’ facade.

The original concept used a shared cable truss to support the interior and exterior walls by drilled point supports (glass bolts) on both sides. This concept was ultimately scaled back to separate structural systems due to cost. The final design includes an interior skin with low-e coated insulated glazing supported by a unitized aluminum curtain wall system. The exterior laminated glass is cable-suspended from overhead cantilevered building structure. The vertical cables are supported by

T-shaped outriggers at each floor level to minimize cable span and deflections under loading. These steel outriggers double as support for maintenance grating and shading devices located within the cavity. Point-fixed bolted laminated glass attaches on a 5’3” vertical grid to the cables. The two skins enclose a 3-ft deep by 68-ft tall cavity, which acts as an outdoor air curtain by bringing fresh air into the lower cavity and using the stack effect to exhaust warm air through a series of automated, louvered vents at the parapet. These operable louvers allow the cavity to be opened or closed to optimize cavity temperature and airflow, which will reduce undesirable conductive gains and losses through the interior glass. The louvers are controlled by comfort temperature sensors located on the interior surface of the interior facade. Though considered in schematic design, natural ventilation is not introduced to the interior spaces due to the sensitivity of the laboratory environment.

Energy modeling was performed during design development as part of a life-cycle analysis of the whole-building model. The early concept included a double-skin facade on the west facade as well. In combination the two double-skin facades contributed toward a 40% reduction compared to Title 24 standards. Simulations were conducted using eQuest during schematic design and later evaluated through proprietary software after the deletion of the double wall on the west elevation. Computational fluid dynamics (CFD) analysis of the cavity was also performed using TRNSYS. Analysis of the double-skin facade was necessary to understand

its contribution in achieving the LEED energy efficiency credit. The project is on target to achieve LEED Gold certification.

Both the 200-ft long double-skin facade and the west glazed facade explore translucency effects to control interior light levels within the laboratory spaces. The southeast double-skin facade has an alternating pattern of full-coverage translucent frit between the interior low-e insulated glass and exterior laminated glass. This creates a completely translucent effect normal to the facade while permitting transparent angular views for the researchers located within. The use of different glass suppliers for the exterior skin and interior skin presented unique challenges in matching the appearance of the translucent frit treatment.

4 DIVERGENCE OF SCALE

An emerging trend in U.S. double-skin facade applications is a divergence of scale. Many designs can be separated into modular unitized systems, or a single multi-story cavity. Selkowitz previously acknowledged this divergent trend of miniaturization on one hand and large scale double-skins on the other [17].

The primary driver towards unitization of double-skin facade systems is economics. Advanced facades are typically customized and expensive, but designers are now seeking products which can be purchased off-the-shelf, prefabricated or unitized. Examples of this are the use of unitized products on Levine Hall and the custom unitized system on One River Terrace. Key benefits of unitized systems compared to large multi-story systems include easier repair and maintenance, as problems such as leakage or condensation are localized, and repair and replacement can be accomplished without disrupting the operation of the entire system. These advantages, along with economic forces favoring mass production as facilitated by the prefabricated systems, will result in accelerated future development for these system types.

The other end of the divergence spectrum is the trend towards large-scale, multi-story DSF. The three multi-story facades presented herein are geometrically similar with widths of 150 to 200 ft, heights of 40.5 to 68 ft, and depths of 3ft. The range of cavity height to depth aspect ratio is 13.5 to 22.7. Multi-story single-cavity applications are appealing to designers because



Double-Skin Facades in the United States

Multi-Story DSF Configurations in bold:

- **New York Presbyterian Hospital, New York, NY**
- **USC Eli and Edith Broad Center, Los Angeles, CA (2010)**
- **Cambridge Public Library, Cambridge, MA (2009)**
- Cleveland Art Gallery, Cleveland OH (2009)
- Art Institute of Chicago - Modern Wing, Chicago, IL (2009)
- **Information Commons, Loyola University, Chicago IL (2008)**
- Riverhouse – One River Terrace, New York, NY (2008)
- **UMass Medical School, Worcester, MA (2004)**
- **Foundry Square, San Francisco, CA (2003)**
- Genzyme Center, Cambridge, MA (2003)
- Manulife Financial, Boston, MA (2003)
- **Seattle Justice Center, Seattle, WA (2002)**
- Levine Hall, Philadelphia, PA (2001)
- **Yazaki North American, Canton, MI (2000)**
- **Occidental Chemical Building, Niagara Falls, NY (1982)**
- University of Michigan Biomedical Science Research Building

they possess a homogenous aesthetic from both the interior and exterior. These large systems can also possess a sense of grandeur and make a powerful statement, but require a more sophisticated understanding of cavity dynamics and systems interactions. These systems are often praised for their beauty, but criticized for under-performing.

5 LIFE-CYCLE ASSESSMENT / POE

The acceptance of double-skin facade systems ultimately depends on the life-cycle assessment costs. When comparing the cost of a double-skin facade to a single-skin facade system it is necessary to evaluate not just the investment, but the cost of operations over the structures' expected life. A standard method of life-cycle assessment of double-skin facade systems is necessary to consistently evaluate their feasibility of application. An even greater factor that could influence the use of double-skin facade applications is post-occupancy evaluation (and disclosure) of real performance data. This information could be compared to expected performance to hone in on an accepted life cycle assessment model for future designs.

As double-skin facades become more commonplace in buildings, familiarity with the technology will likely result in decreasing costs. The perceived risk associated with double-skin facades will decline. Design, engineering, fabrication, and installation costs are likely to decrease, and increasing competition will lead to further cost competitiveness. Finally, the factor that will reduce the payback period

of a DSF the quickest is increasing energy costs. Higher initial costs of material production will increase the initial investment for all facades, but operations costs and energy performance will be more critical in reducing the payback period for a double-skin facade.

6 ADAPTIVE REUSE

Double-skin facades are being considered for the renovation of older buildings. This is one of the most promising applications for double-skins, but further study is required. With increased environmental awareness, re-use of existing building stock is often a viable alternative to new construction. This approach may provide greater economy, modernize the appearance of a building, and improve energy performance, all while projecting a positive perception of environmental consciousness. Retrofitting with a DSF also avoids removal and land filling of the existing skin. The kind of buildings that fit the profile for a facade retrofit are typically structures that remain in the possession of one entity for a long period of time – government or institution.

7 STRUCTURAL AESTHETIC

The use of multi-story cavity spaces creates an opportunity to express a dramatic structural solution to the support of the two skins. This is evident in the use of a highly flexible two-way cable-net on the Loyola Commons and vertical cables on the Broad Center. It is also apparent in the conceptual quest for a singular structure supporting both facades on the Broad

Center (via cable truss), and the shared steel frame that supports the DSF at the Cambridge Public Library, that designers are intrigued by the double-skin as a whole performance envelope. The use of point supported glazing systems for the exterior skin is present in each of the multi-story case studies presented; corner patch plate clamps on Loyola Commons, bolted fixings on the Broad Center, and intermediate patch plate clamps on the Cambridge Public library. The use of innovative structural systems with double-skin facades will continue to be a symbiotic balance of transparency and technological iconism.

8 CONCLUSION

Double-skin facade applications developed in Europe as a means to save energy while providing access to daylight and natural ventilation. These projects evolved from more than just a climate-specific context. The double-skin also responds to regulatory and social contexts requiring higher-quality work environments in Europe than the United States. Likewise, the progression of DSF in the United States must look beyond a strictly climatic and environmental context. When considering the present sustainable pressures and economic uncertainty the DSF as a retrofit solution emerges as a viable solution to minimize energy consumption associated with new construction.

The challenges associated with double-skin facade implementation in the United States have been outlined. Four recent double-skin facades were evaluated primarily from a design, typological and

structural perspective. Four trends were acknowledged; divergence of scale, life-cycle assessment, adaptive reuse, and structural aesthetic. Though discussed within the context of the United States, these trends may or may not be consistent globally. The variety of the examples illustrates that there is not an ideal double-skin system and that it is necessary to approach each design with special consideration to project-specific conditions.

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