Arnold Schwarzenegger
Governor

HIGH-PERFORMANCE COMMERCIAL BUILDING FAÇADES

PIER FINAL PROJECT REPORT

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High-Performance Commercial Building Façades

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http://gaia.lbl.gov/hpbf/main.html

Cover photo: Deutsche BahnAG Office tower at Sony Center, Berlin. Architect: Helmut Jahn.

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Executive Summary

There is a significant and growing interest in the use of highly-glazed facades in commercial buildings. Large portions of the façade or even the entire facade are glazed with relatively high transmittance glazing systems, and typically with some form of sun control as well. With origins in Europe the trend is expanding to other regions, including the United States. A subset of these designs employ a second layer creating a double envelope system, which can then accommodate additional venting and ventilation practices. The stated rationale for use of the these design approaches varies but often includes a connection to occupant benefits as well as sustainable design associated with daylighting and energy savings. As with many architectural trends, understanding the reality of building performance in the field as compared to design intent is often difficult to ascertain. We have been particularly interested in this emerging trend because prior simulation studies have shown that it should be technically possible to produce an all-glass façade with excellent performance although it is not a simple challenge. The published solutions are varied enough and sufficiently complex that we undertook a year-long international review of "advanced facades" to better understand the capabilities and limitations of existing systems and the tools and processes used to create them. This is also intended to create a framework for addressing the missing tools, technologies, processes and data bases that will be needed to turn the promise of advanced facades into realities. This summary, available as a PDF file and a web site, reports those findings.

At the beginning of this scoping study, our initial impression or reaction to this architectural trend toward all-glass transparent façades was objectively critical. The concepts and claims were impressive, particularly those being applied to double-skin façades. Ventilation concepts, dynamic shading, and daylighting were being used to achieve improved indoor air quality, energy efficiency, thermal comfort, and occupant performance. Many of the building physics concepts discussed were not new; in fact, they have been advocated by researchers for decades. The difference was that these concepts were being applied or wrapped in a new design aesthetic. Why now? What was instigating this architectural trend? Were the architects and engineers who worked behind the scenes actually realizing their performance goals? Our questions stemmed from our in-depth knowledge of just how difficult it is to properly engineer these advanced façades. For many of these concepts, there are many unknowns: optical and thermal modeling of these systems is not routine, and coupling heat transfer and air flow from an isolated façade system to the whole building is complex. In addition, we wondered how clients were able to afford and justify the increased design, materials, and construction costs for these complex façades when in most of our experience, the financial bottom line was always pointed out as the determining factor.

Our work began by sorting out the various building physics concepts being applied to buildings touted by the architectural press. Many of the descriptions were garbled or incomplete. Some were counterintuitive or downright confusing. We compiled a list of the concepts being applied to these advanced façades and described how these technical concepts were being realized in typical commercial buildings. With one-on-one interviews and a roundtable discussion, we then looked into what is involved with the design, engineering and implementation of such systems. How were architects and engineers able to convince clients to use these advanced façades systems despite increased costs? How were others able to jump the cost barrier? Our interviews re-

Glass box, Berlin

vealed the differences in life-cycle economics between the U.S. and Europe. We also reviewed the design tools used to engineer and evaluate the performance of these systems, specifically the thermal and daylighting tools as related to building energy use and occupant comfort. Some of the fundamental limitations of these tools were reviewed. Finally, we performed a literature search to find third-party studies on how these buildings performed after they were built. It was extremely difficult to find any objective data on the performance of actual buildings, particularly double-skin façades and adaptive façades. Several detailed building case studies are given with information based on published architectural press articles. Links to other building case studies are also given.

At the conclusion of this scoping study, we have gained an appreciation and better understanding of this new trend towards all-glass façades. In Europe, there is an earnest attempt to achieve high-performance using advanced façade concepts. In the U.S., architects and engineers are further behind but remain interested in pursuing the stated overarching environmental and performance goals. There remain several critical needs that must be satisfied before such systems can be routinely engineered. Design tools must provide enhanced power to accurately model complex integrated building systems but paradoxically must be made easy to use in the early design process. Algorithms to model optically complex façade elements must be developed and validated, as must airflow models for large cavity façade systems. A variety of thermal coupling strategies between the façade and the whole building must be adequately simulated. Simulation code to test and develop control algorithms for dynamic systems must be made more available, robust and open. Regulatory standards and procedures for rating complex advanced façades and demonstrating compliance with local energy codes must be modified to more easily accommodate these complex systems. Post-occupancy, third party monitored data must also be collected, analyzed and made available to the architectural community in order to better understand and improve upon the performance of these systems. Architectural design guidelines and building case studies will help architects and owners better understand the applicability of various concepts to their specific building projects.

The field of advanced facades is a rapidly evolving work-in-progress. We invite readers to contact us with information on the subjects described above, at ESLee@lbl.gov.

Background

This study focuses on advanced building façades that use daylighting, sun control, ventilation systems, and dynamic systems. A quick perusal of the leading architectural magazines, or a discussion in most architectural firms today will eventually lead to mention of some of the innovative new buildings that are being constructed with all-glass façades. Most of these buildings are appearing in Europe, although interestingly U.S. A/E firms often have a leading role in their design. This "emerging technology" of heavily glazed façades is often associated with buildings whose design goals include energy efficiency, sustainability, and a "green" image.

While there are a number of new books on the subject with impressive photos and drawings, there is little critical examination of the actual performance of such buildings, and a generally poor understanding as to whether they achieve their performance goals, or even what those goals might be. Even if the building "works" it is often dangerous to take a design solution from one climate and location and transport it to a new one without a good causal understanding of how the systems work.

In addition, there is a wide range of existing and emerging glazing and fenestration technologies in use in these buildings, many of which break new ground with respect to innovative structural use of glass. It is unclear as to how well many of these designs would work as currently formulated in California locations dominated by intense sunlight and seismic events. Finally, the costs of these systems are higher than normal façades, but claims of energy and productivity savings are used to justify some of them. Once again these claims, while plausible, are largely unsupported.

There have been major advances in glazing and façade technology over the past 30 years and we expect to see continued innovation and product development. It is critical in this process to be able to understand which performance goals are being met by current technology and design solutions, and which ones need further development and refinement.

The primary goal of this study is to clarify the state-of-the-art of the performance of advanced building façades so that California building owners and designers can make informed decisions as to the value of these building concepts in meeting design goals for energy efficiency, ventilation, productivity and sustainability.

What is a high-performance commercial building façade?

Glass is a remarkable material but its functionality is significantly enhanced when it is processed or altered to provide added intrinsic capabilities. The overall performance of glass elements in a building can be further enhanced when they are designed to be part of a complete façade system. Finally, the façade system delivers the greatest performance to the building owner and occupants when it becomes an essential element of a fully integrated building design. This work examines the growing interest in incorporating advanced glazing elements into more comprehensive façade and building systems in a manner that increases comfort, productivity and amenity for occupants, reduces operating costs for building owners, and contributes to improving the health of the planet by reducing overall energy use and environmental impacts. We explore the role of glazing systems in dynamic and responsive facades that provide the following functionality:

- Enhanced sun protection and cooling load control while improving thermal comfort and providing most of the light needed with daylighting;
- Enhanced air quality and reduced cooling loads using natural ventilation schemes employing the façade as an active air control element;
- Reduced operating costs by minimizing lighting, cooling and heating energy use by optimizing the daylighting-thermal tradeoffs;
- Improved indoor environments leading to enhanced occupant health, comfort and performance.

In addressing these issues, façade system solutions must of course respect the constraints of latitude, location, solar orientation, acoustics, earthquake and fire safety, etc. Since climate and occupant needs are dynamic variables, in a high performance building the façade solution must have the capacity to respond and adapt to these variable exterior conditions and to changing occupant needs. This responsive performance capability can also offer solutions to building owners where reliable access to the electric grid is a challenge, in both less-developed countries and in industrialized countries where electric generating capacity has not kept pace with growth. We find that when properly designed and executed as part of a complete building solution, advanced facades can provide solutions to many of these challenges in building design today.

— Stephen E. Selkowitz, Building Technologies Program Head, Lawrence Berkeley National Laboratory.

Overview of this study

This study is organized around five major topics:

- **Technological solutions** used to create high-performance building facades include those that provide daylighting, solar control, natural ventilation, and active load management capabilities. These solutions are described in terms of how they conceptually address specific energy-related objectives. We focus on solutions that have energy-savings potential for California (cooling-load dominated) commercial buildings.
- **Design process** involves the conceptualization, analysis, procurement, and implementation of a façade. This section explains the integrated collaborative process between the architect, building owner, and engineers needed to properly design these advanced technological solutions. We present the perspectives of architects, engineers, and building owners, first as individual interviews and then as round table responses to topical themes. We also present or summarize talks given at a workshop event.
- **Design tools.** For many of these technological solutions, commercially-available design tools are not available to predict the performance of these systems. We identify a small subset of available tools and explain some of the limitations of their use.
- **Performance assessments** of existing or proposed "high-performance" façade systems are typically based on simulations, reported field studies, or monitored studies. There are many claims in the architectural press – improved comfort, better indoor air quality, improved acoustics, increased energy-efficiency – but few third-party assessments as to whether the claimed performance benefits are actually realized. We review what little performance data there are.
- **Building case studies** are given to illustrate how various concepts have been realized architecturally. Most have been derived from architectural press sources. Others are listed with links to other information sources.

The following methods were used to derive information for this study:

- Interviews and focus groups with industry, A/E firms, owners, and system suppliers
- Review of existing literature
- Collaboration with scientists from the International Energy Agency (IEA) Task 27 Performance of Solar Façade Components and COST C13 Activities

Automated tubular grid skylight controls daylight at Munich Airport.

1. Technological Solutions

The variety of technological solutions used to produce "high-performance" commercial building façades are based on fundamental building physics concepts for daylighting, solar heat gain control, ventilation, and space conditioning. The following descriptions of the various advanced building energy-efficiency strategies are therefore related to these fundamental concepts. In isolation, it's fairly easy to understand the basis and realization of a single given strategy (e.g., daylighting), but designers and engineers typically combine several strategies (daylighting + solar control + ventilation) to achieve high performance. Case studies are in Section 4 to illustrate how combined strategies are played out in built form.

The selection of the following technological solutions was made for California-specific cooling-load dominated commercial buildings. For this building type and climate, window solar radiation and conduction heat gains contribute to both total energy use consumption and peak demand. Lighting loads can be offset with daylight in perimeter zones (or skylit in core zones) in this state where sunshine is plentiful. Careful control of these loads can help to significantly reduce annual operating costs and improve occupant comfort. Curtailment of these loads during peak summer mid-day hours can also reduce the need for further generation (power plant) capacity within California and can lower emissions.

Substantial interest in double-skin facades and active façade systems continues to occur in the European Union (EU). Over the 1990s, there has been numerous buildings constructed with complex, interactive building facades, many for which there are few post-occupancy data to confirm that design claims have been successfully realized. It is important to note that while this strategy is discussed in this section, applicability to the California climate may be uncertain. The EU climate is substantially cooler than California and the latitude is higher; the design of these facades may be more applicable to U.S. northern climates. California locations may require a different set of technology and design solutions to meet performance requirements.

Rock and Roll History Museum, Cleveland, Ohio

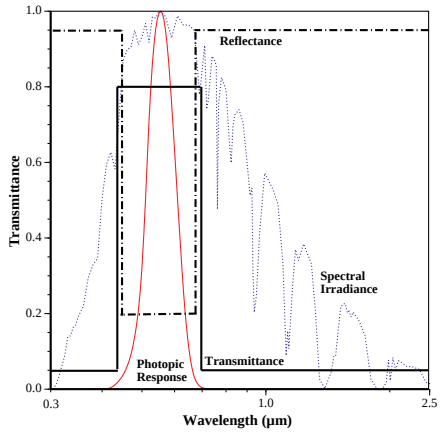
Solar control facades

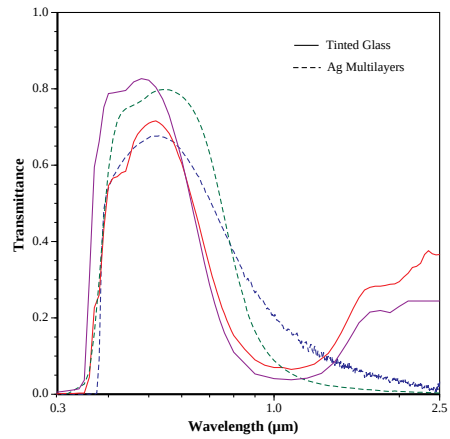
Spectrally selective solar control

Spectrally selective glazing is window glass that permits some portions of the solar spectrum to enter a building while blocking others. This high-performance glazing admits as much daylight as possible while preventing transmission of as much solar heat as possible. By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand. Because new spectrally selective glazings can have a virtually clear appearance, they admit more daylight and permit much brighter, more open views to the outside while still providing much of the solar control of the dark, reflective energy-efficient glass of the past. They can also be combined with other absorbing and reflecting glazings to provide a whole range of sun control performance.

Left: Solar spectral properties of an ideal spectrally selective glazing. The photopic response curve represents the eye's response to light.

Right: Solar transmission spectra of the best available spectrally selective glazings.





Because of its solar heat transmission properties, spectrally selective glazing benefits both buildings in warm climates where solar heat gain can be a problem and buildings in colder climates where solar heat gains in summer and interior heat loss in winter are both of concern. In other words, different variants on these glazings are appropriate for residential and commercial buildings throughout the United States. The energy efficiency of spectrally selective glazing means that architects who use it can incorporate more glazing area than was possible in the past within the limitations of codes and standards specifying minimum energy performance. When spectrally selective glazing is appropriately used, the capacity of the building's cooling system might also be downsized because of reduced peak loads.

Spectrally selective glazings screen out or reflect heat-generating ultraviolet and infrared radiation arriving at a building's exterior surface while permitting most visible light to enter. Spectral selectivity is achieved by a microscopically thin, low-emissivity (low-E) coating on the glass or on a film applied to the glass or suspended within the insulating glass unit. There are also carefully engineered types of blue- and green-tinted glass that can perform as well in a double-pane unit as some glass with a spectrally selective low-E coating. Conventional blue- and green-tinted glass can offer some of the same spectral properties as these special absorbers because impurities in tinted glass absorb portions of the solar spectrum. Absorption is less efficient than reflection, however, because some of the heat absorbed by tinted glass continues to be transferred to the building's interior.

Spectrally selective glazings can be used in windows, skylights, glass doors, and atria of commercial and residential buildings. Note that it may not provide reduced glare control even if solar gain is reduced. This technology is most cost effective for residential and nonresidential facilities that have large cooling loads, high utility rates, poorly performing existing glazing (such as single-pane clear glass or dark tinted glass), or are located in the southern United States. In the northern U.S., spectrally selective low-emissivity windows can also be cost effective for buildings with both heating and cooling requirements. In general, the technology pays back in three to 10 years for U.S. commercial buildings where it replaces clear single-pane or tinted double-pane glass and for most commercial buildings in the southern U.S. where it replaces conventional high-transmission, low-emissivity, double-pane windows. Spectrally selective glazing is applicable in both new and retrofit construction.

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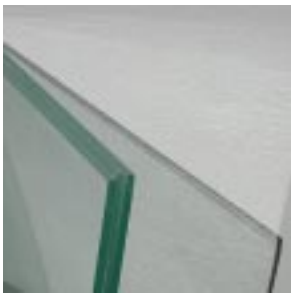
Angular selective solar control

Okasolar between-pane louver system (above)

Serraglaze prismatic glazing (below)



Angular selective facades provide solar control based on the sun's angle of incidence on the façade. The main technical objective is to block or reflect direct sun and solar heat gains during the summer, or during the majority of the cooling season for a given building type, but admit diffuse sky-light for daylighting.

Several engineered, fixed louver systems have been designed specifically to address this technical objective for the European Union (EU) climates and latitudes. For example, the Okasolar between-pane louver system consists of 2-cm-wide mirrored aluminum louvers with a unique geometrical profile. Direct sun is blocked and reflected out while diffuse sky-light is admitted from the sky. The optimum vertical angle of blockage occurs along the north-south axis at solar noon.

Research to develop angular selective coatings on glass has proven to be challenging and has not yet resulted in a commercial product. Thin film coating techniques can to create microstructures that in principle, selectively reflect visible or solar radiation based on bi-directional, hemispherical angles of incidence. Energy and daylighting performance of such structures has been evaluated by Sullivan et al. 1998 (see References below).

Interesting variations on this theme include between-pane louvers or blinds with a mirrored upper surface, to be used in the clerestory portion of the window wall, or exterior glass lamellas (louvers) where the upper surface is treated with a reflective coating. These systems fully or partially block direct sun and redirect sunlight to the interior ceiling plane (see Daylighting Facades description next), given seasonal adjustments.

Conventional louvered or venetian blind systems enable users or an automated control system to tailor the adjusted angle of blockage according to solar position, daylight availability, glare, or other criteria. Another variant includes between-pane acrylic prismatic panels that are either fixed or used as a system of exterior louvers to block direct sun and admit diffuse daylight. For vertical windows, the panels must be adjusted at least seasonally to block sun and to prevent color dispersion. Fixed systems can be used in roof applications.

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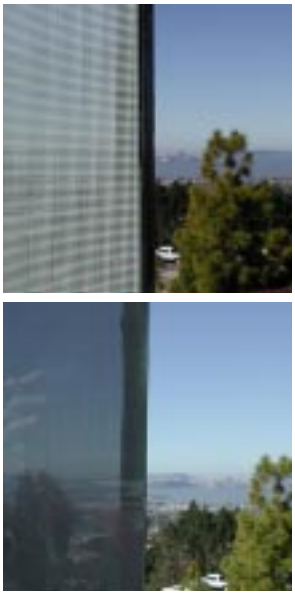
"[Ceramic frit glass] had a minor effect on the building's energy performance for the Blue Cross/Blue Shield Headquarters in Chicago (BD&C 10/98) but allowed extensive overhead glazing in the UA terminal at O'Hare in the late 1980s and to meet ASHRAE Standard 90… Most projects use white-colored frit. Frits do reduce the shading coefficient of the glass, but low-E coatings provides more effective reductions." Building Design and Construction, July 2000.

Solar filters

Solar filters indiscriminately absorb or reflect a portion of both direct and diffuse solar radiation. Overhangs, fins, "lightshelves", or a secondary exterior skin made of filter material are applied to south, east, or west-facing facades to cut down on incident solar radiation levels and diffuse daylight. Filters may be made with an opaque base material (woven or perforated, metal screens or fabric) or transparent base material (etched, translucent, or fritted glass or plastic).

Generally, the effectiveness of solar control is normally in proportion to the percentage of opaque material and will vary with the thickness, opacity, reflectance/absorptance of the material, and position within the façade. Interior fabric roller shades can provide modest solar heat gain control if its exterior-facing surface reflectance is high (white or semi-reflective). Translucent composite fiberglass panels (e.g., Kalwall) used as part of the window wall also provides modest solar control.

Between-pane absorptive shade systems, such as those used in double-skin facades, can also lead to thermal stress on the window system and to increased solar heat gain, if inadequately placed, due to the increased surface temperature of the absorbing shading layer. Localized solar absorptance can cause increased thermal stress and possible glass breakage with fritted glass.

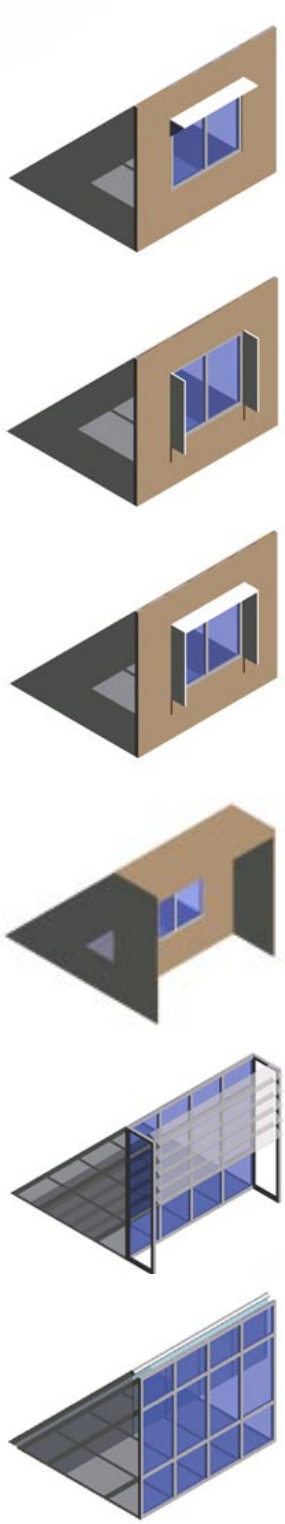


Ceramic-enamel coatings on glass

The architectural trend over the past one to two decades has been to use filtering material (fritted and etched glass). Ceramic-enamel coatings on glass (fritted glass) rely on a pattern (dots, lines, etc.) to control solar radiation. The pattern is created by opaque or transparent glass fused to the substrate glass material under high temperatures. The substrate must be heat strengthened or tempered to prevent breakage due to thermal stress. A low-e coating can be placed on top of the frit. To reduce long-wave radiative heat gains, it's best to use the absorbing fritted layer as the exterior layer (surface #2) of an insulating glass unit.

Initially, filters were used in the non-view portions of the roof or window wall. There is an increased trend to use filters in the view portions of the window wall for aesthetic visual effect. Such use can impair view and increase glare significantly, particularly if backlit by direct sun, since the window luminance within one's direct field of view is significantly increased. Perforated blind systems provide solar control with daylight admission, and can improve visual comfort through the reduction of the luminance contrast at the window.

Exterior solar control



Exterior solar control can be provided by overhang, fin, or full window screen geometries — the shape and material of which defines the architectural character of the building. The general concept is to intercept direct sun before it enters the building. Once direct sun enters the building, the only way it can get back out is through reflection (only the visible and near-infrared wavelengths of solar radiation can be reflected back out) or indirectly by convection and long-wave radiation. Exterior solar control should be designed to intercept direct sun for the periods of the year when cooling load control is desired (which tends to be 6-8 months out of the year in California for most commercial buildings). Shading systems that cover the entire face of the window (screens, blinds, etc.) should be placed back from the exterior glass surface to allow free air flow. A prevalent type of solar control in Europe is retractable louvers and blinds and is discussed briefly here.

Louvers and blinds are composed of multiple horizontal or vertical slats. Exterior blinds are more durable and usually made of galvanized steel, anodized or painted aluminum or PVC for low maintenance. Appropriate slat size varies and tends to be wider for exterior use. Slats can be either flat or curved. With different shape and reflectivity, louvers and blinds are used not only for solar shading, but also for redirecting daylight.

While fixed systems are designed mainly for solar shading, operable systems can be used to control thermal gain, reduce glare, and redirect sunlight. Operable systems (whether manual or automatically controlled) provide more flexibility because the blinds can be retracted and tilted, responding to the outdoor conditions. Glossy reflective blinds can be used to block direct sunlight while redirecting light to the ceiling at the same time. This might generate glare, depending on the slat angle, if direct sun is reflected off the slat surface into the field of view.

Louvers and blinds perform well in all climates. For commercial buildings in hot climates, the system may be more energy-efficient if placed on the exterior of the building while blocking solar radiation. For buildings in cold climates, the system can be used to provide more daylight and absorb solar radiation.

Sketches of various exterior shading systems (at left, from top to bottom)

Horizontal overhang protects south facades from high-angle sun during the day.

Vertical fins protect window facades from east and west low-angle sun.

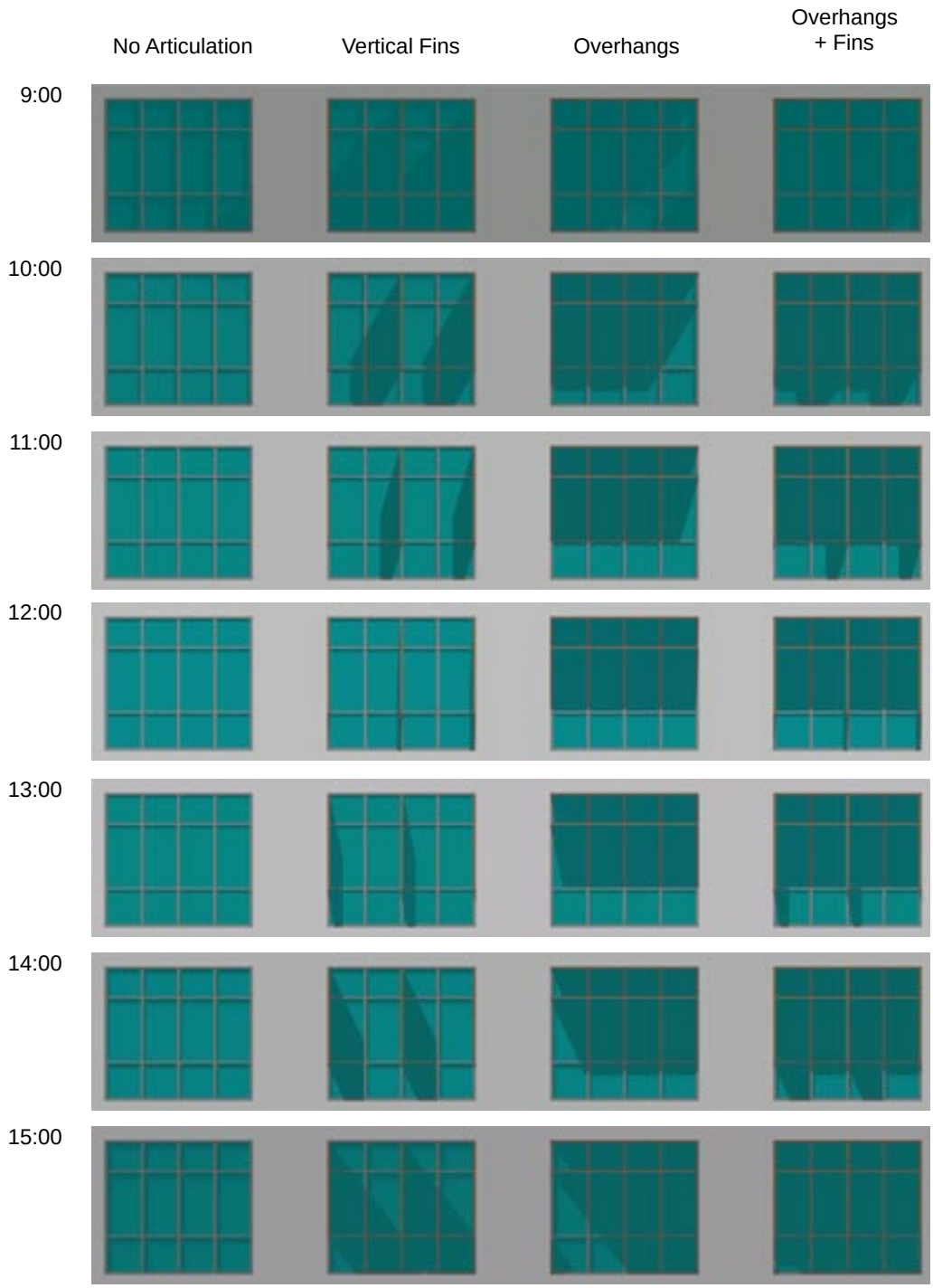
Overhang and fins combined can be applied to buildings in hot climates.

Window setbacks, where the window plane is pushed inward from the face of the building, can provide good shading potential.

Fixed or moveable horizontal louvers provide shading similar to an overhang with improved daylight potential.

Interior blinds can be controlled to accommodate occupant preferences.

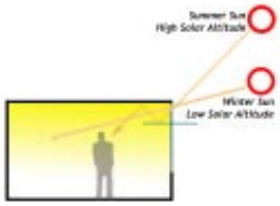
Shading simulation of fins, overhangs, and overhangs and fins on south façade over course of June 21. The combination of overhang and fins (right picture) protects the window the most throughout the day compared to no protection (left picture). This simulation is given for June 21st at 1-hour increments from 9:00 AM to 3:00 PM for a latitude of 34˚N (San Francisco).



Daylighting facades

Conventional side-lighting concepts distribute flux principally 0-15 feet from the window wall causing glare, high contrast, and excessive brightness, leaving the remainder of the perimeter zone and the core "in the dark." Light-redirecting systems rely on principles of reflection, refraction, diffraction or non-imaging optics to alter or enhance the distribution of incoming daylight within the building's room cavity. The benefit of improved distribution is not only increased potential to offset electric lighting requirements with daylight across a greater depth within the perimeter zone but also to improve lighting quality and visual comfort. Similar technologes can improve skylight performance when ceiling height and/or spacing are not adequate.

Most of the systems described here are detailed in a separate document produced by the International Energy Agency Task 21 Daylight in Buildings. A book and/or CD-ROM is available to those residing in the U.S. or Canada. See http://eetd.lbl.gov/Bookstore.html under Practical Guides & Tools for Energy Users for "Daylight in Buildings: A Source Book on Daylighting Systems and Components" to find out how to obtain a copy. For those residing outside of the U.S. or Canada, please visit http://www.iea-shc.org.



In summer, when the sun is high in the sky, lightshelves block direct sun at both the upper and lower windows. In winter, low sun can penetrate to the back to the space through the clerestory, pre-heating occupied space in the morning, and providing light when needed. Tinted glazing can be used at the lower view window, while clear glazing can be used at the clerestory to increase daylight admission.

Sunlight redirection

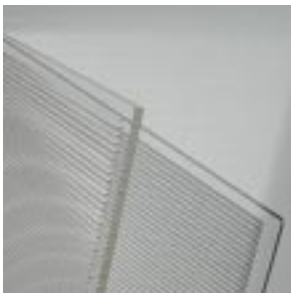
We make a distinction between light-redirecting systems designed principally to redirect beam sunlight versus diffuse skylight, although with any system, both sources of daylight are affected. Systems using direct sunlight are most effective on the south façade, and for practical geometric simplicity and efficiency, are designed based on seasonal variations in solar altitude. For moderate to hot climates, such as those of California, daylighting strategies must be integrated with solar gain control.

Light shelves are typically a horizontal exterior projection that uses a high reflectance, diffuse, or semi-specular (shiny) upper surface to reflect incident sunlight to a given interior depth from the window wall. Variations include the use of prismatic aluminized films on the upper surface to increase reflective optical efficiency without mirrored imaging, compound geometries tailored to specific solar altitudes, and moveable systems that can be tuned seasonally or tuned to alter the depth of redirection.

Between-pane light shelves employ many of the same principles of their larger counterparts but can be fabricated in volume and protected from dirt and dust between two panes of glass. The Okasolar system mentioned earlier uses triangular section louvers to block sun and can reflect/redirect sunlight to the interior. Optical efficiency with respect to redirection may be poor since the primary design intent is to diffuse incoming daylight.

Laser-cut panels, developed in Australia, use simple linear horizontal cuts in an acrylic panel to refract light at the juncture of the linear grooves. The angle of refraction is a basic material property, so efficiency is dependent on the frequency and spacing of the grooves and thickness of the panel. For practical purposes, there are limits on panel size and spacing within the insulating glass unit (IGU) due to the high coefficient of expansion of acrylic. View is slightly distorted/impaired and glare is not controlled with this system.

Prismatic acrylic panels (described earlier in Solar Control section) also work on the principle of refraction to redirect incident sunlight. The panels are



Laser-cut acrylic panel

serrated on one side forming prisms or sawtooth linear grooves across the face of the panel. The angles of two sides of the prism are engineered to block certain angles of sunlight and refract and transmit others. For some designs, one or both surfaces of the prism is coated with a high-reflectance aluminum film. The panels should be applied to the exterior of the building and should be adjusted seasonally to compensate for the variation in solar altitude.

Holographic optical elements (HOE) use the principle of diffraction to redirect sunlight. An interference pattern of any specification can be printed/stamped on a transparent film or glass substrate, then laminated between two panes of glass. Diffractive optical efficiency tends to be poor, but may improve as the technology is developed. The HOE technology is in a demonstration phase in Germany.

Sun-directing glass are long, slightly curved sections of glass that are stacked and placed between panes of glass. The refractive index of glass is again combined with geometry to redirect sunlight to the ceiling plane.

In all of the above systems, view is distorted or impaired so placement of such systems above standing view height is typically recommended. With many of the transparent systems, glare is not controlled since the direct sun increases the luminance of the panels well above acceptable limits for most office tasks.

Sky-light redirection

The second category of light-redirecting systems designed for diffuse sky-light are effective for climates with predominantly cloudy conditions or for urban or other situations where the windows or skylights only "see" the sky. For such systems, the main design objective is to increase interior daylight levels overall with less emphasis on the depth of light redirection.

Anidolic systems use the principle of non-imaging optics to gather omni-directional diffuse light and guide the flux with mirrored curved geometries. This "focused" daylight can then be redirected along the ceiling plane and distributed via light ducts into the interior. The collector optics are created using plastic injection moulds then coated with a high-grade aluminum coating.

Holographic optical elements (HOE) can also be applied to the redirection of zenithal sky-light. Tilted glass HOE overhangs can be place over north-facing windows so that diffuse daylight is redirected into the building interior. The luminance level of the zenith region of an overcast sky (directly overhead) is typically much higher than horizon-level sky-light, therefore making this a promising strategy. The HOE glazing is still under development.

Double-skin facades and natural ventilation

The double-skin façade is a European Union (EU) architectural phenomenon driven by the aesthetic desire for an all-glass façade and the practical desire to have natural ventilation for improved indoor air quality without the acoustic and security constraints of naturally-ventilated single-skin facades.

The foremost benefit cited by design engineers of EU double-skin facades is acoustics. A second layer of glass placed in front of a conventional façade reduces sound levels at particularly loud locations, such as airports or high-traffic urban areas. Operable windows behind this all-glass layer compromise

"Dual-layered glass facades … allow natural ventilation in high wind environments such as at the upper stories of high-rise buildings. This type, the most popular in Europe, enables users to control their working environment while helping to eliminate "sick-building syndrome," which can result from an over-reliance on air-conditioning... According to some estimates by environmental engineers, certain types of ventilated facades show energy savings of 30 to 50 percent." Lang and Herzog, Architectural Record, August 2000.

this acoustic benefit, particularly if openings in the exterior layer are sufficiently large to enable sufficient natural ventilation. Another cited benefit is that double-skin facades allow renovation of historical buildings or the renovation of buildings where new zoning ordinances would not allow a new building to replace the old with the same size due to more stringent height or volume restrictions.

The second layer of glass provides opportunities for heat recovery during the cold EU winters and heat extraction during the summer. Shading systems placed within the interstitial cavity are protected from the weather. Thermal comfort is purported to be improved with this buffer space compared to conventional window systems.

The complexities and design variations of double-skin facades are large, requiring significant engineering expertise to design well. For California, we discuss two particular energy-efficiency strategies for double-skin facades: solar control and night-time ventilation. EU engineers caution their clients that energy-efficiency is not the foremost benefit of double-skin facades and that such benefit derived may well be small, depending upon circumstances. The architectural press counters with claims of significant energy savings.

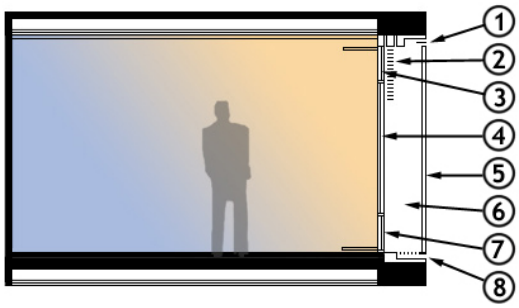
Heat extraction double-skin facades

Heat extraction double-skin facades rely on sun shading located in the intermediate or interstitial space between the exterior glass façade and interior façade to control solar loads. The concept is similar to exterior shading systems in that solar radiation loads are blocked before entering the building, except that heat absorbed by the between-pane shading system is released within the intermediate space, then drawn off through the exterior skin by natural or mechanical ventilative means. Cooling load demands on the mechanical plant are diminished with this strategy.

This concept is manifested with a single exterior layer of heat-strengthened safety glass or laminated safety glass, with exterior air inlet and outlet openings controlled with manual or automatic throttling flaps. The second interior façade layer consists of fixed or operable, double or single-pane, casement or hopper windows. Within the intermediate space are retractable or fixed Venetian blinds or roller shades, whose operation can be manual or automated.

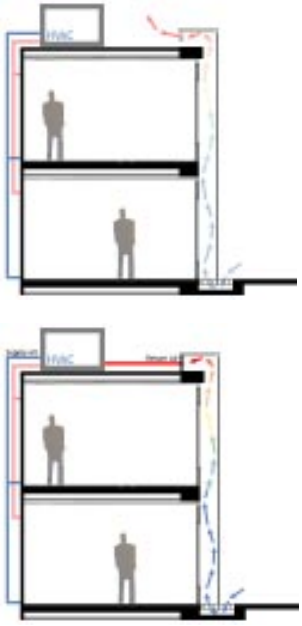
During cooling conditions, the Venetian blinds (or roller shades) cover the full height of the façade and are tilted to block direct sun. Absorbed solar radiation is either convected within the intermediate space or re-radiated to the interior and exterior. Low-emittance coatings on the interior glass façade reduce radiative heat gains to the interior. If operable, the interior windows are closed. Convection within the intermediate cavity occurs either through thermal buoyancy or is wind driven. In some cases, mechanical ventilation is used to extract heat.

The effectiveness of ventilation driven by thermal buoyancy, or stack effect, is determined by the inlet air temperature, height between the inlet and outlet openings, size of these openings, degree of flow resistance created by the louver slant angle, temperature of the louvers and interfacial mixing that may occur at the inlet or outlet openings if there is no wind. Box windows are single-story double-skin facades that are divided by structural bay widths or on a room-by-room basis. Shaft-box facades couple single-story box windows



1. Exterior upper air outlet
2. Controllable solar control device
3. Interior upper operable window (air inlet)
4. Interior operable or fixed view window
5. Exterior glazing layer
6. Air cavity
7. Interior lower operable window (air inlet)
8. Exterior lower air inlet

to multi-story vertical glass chimneys via a bypass opening at the top of the box window. The vertical height of the glass chimney creates stronger uplift forces due to increased stack effect. However, the upper stories of the shaft can become appreciably hot, lending to increased heat gains and thermal discomfort. Corridor facades are single-story facades that have no vertical divisions except those required at the corners of the building or elsewhere for structural, acoustic, or fire protection reasons. Here, air flow is expected to take a diagonal path across the face of the facades and inlet and outlet openings are staggered to prevent air exchange between the two openings.



Heat extraction (above)

Heat recovery (below)

The position of the Venetian blind within the air cavity affects the rate of the heat transfer to the interior and amount of thermal stress on the glazing layers. Placed too close to the interior façade, inadequate air flow around the blind may occur and conductive and radiative heat transfer to the interior are increased. The blind should be placed toward the exterior pane with adequate room for air circulation on both sides. With wind-induced ventilation or high velocity thermal-driven ventilation, the bottom edge of the blind should be secured to prevent fluttering and noise.

Heat recovery strategies can be implemented using the same construction to reduce heating load requirements during the winter. This strategy is normally not useful for the California climate and for commercial buildings, which tend to be cooling-load dominated year-round. Heat recovery strategies can be used for east- to south-facing facades to offset early morning start-up loads that occur typically on Mondays or periods following a holiday but careful engineering is required to avoid overheating during late morning hours.

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Night-time ventilation

During the summer and in the some climates where there is sufficient variation in diurnal and outdoor temperatures and a good prevailing wind, night-time ventilation can be used to cool down the thermal mass of the building interior, reducing air-conditioning loads. Heat gains generated during the day are absorbed by furnishings, walls, floors, and other building surfaces then released over a period of time in proportion to the thermal capacity of the

material. Removal of these accumulated heat loads can be achieved with a variety of cross-ventilation schemes that rely on wind-induced flow, stack effect, and/or mechanical ventilation.

In recent years, the concept of radiant cooling has been coupled with traditional cross ventilation schemes. For some climates and building types, this strategy can be used to completely eliminate the need for mechanical air-conditioning. Heavy-weight thermal mass is strategically located in exposed concrete ceilings. This mass is "activated" or cooled at night using outdoor air directed to flow over its unobstructed surface. During the day, occupants exposed to this chilled thermal mass perceive a cooler environment due to a radiative exchange with the low surface temperature of this thermal mass.

"Adaptive" thermal comfort is a key concept that must be accepted by the building owner, facility manager, occupants, and code officials. Interior temperatures are expected to exceed the limits defined by the ASHRAE Standard 55, which was originally intended for conventional HVAC applications. Field studies suggest that behavioral adaptations (changes in clothing level and air velocity, via local fans or operable windows) and psychological adaptations widen the range of acceptable interior temperatures – acclimatization or physiological adaptations are unlikely to result in significant changes (Brager and deDear 2000).

Therefore, occupants of these new buildings who are accustomed to air-conditioned space should be made aware of the design intent of naturally-ventilated buildings so that their expectations for thermal control will be more relaxed. Employers might also make greater accommodations such as a more relaxed dress code during peak summer periods and allow employees to shift work hours or even telecommute if thermal conditions are unacceptable.

Double-skin facades have been designed for the purposes of allowing night-time ventilation, with the reasons of security and rain protection cited as main advantages. However, single-skin facades are capable of having a larger proportion of unobstructed operable windows. The required percentage of facades openness is proportional to the internal heat load: for milder European climates or northern California coastal climates and for buildings where daytime solar loads are controlled, such a scheme may be feasible with a moderate degree of façade openness.

The building exterior and interior are often shaped to minimize obstructions to air flow. The exterior façade tends to be planar with few horizontal projecting obstructions, particularly if there is no strong prevailing wind direction. The depth of the building is minimized. The interior is designed to have minimal floor-to-ceiling obstructions. Furniture systems located near the window are designed to have an open structure. Privacy screens between offices are kept to minimal heights. Ceiling heights are greater than 9 ft (10-14 ft) and no plenums are used. Lighting fixtures are pendant hung. The ceiling surface may be shaped to encourage laminar flow and to channel air from the window wall to the opposing window wall.

As with any natural ventilation scheme, other factors must be considered: night-time humidity, moisture, and condensation control; magnitude of forces exerted on the windows, shading devices and internal furnishings by gusts or negative pressure; pollutant control; fire and security protection. Screens may be required to keep out birds and insects, reducing ventilation potential.

Implementation of such a scheme involves the use of motor-operated flaps and windows that are controlled via a centralized building automation

system. The sequence of operations must be designed and programmed for each unique site to accommodate the strategies for night-time cooling ventilation, heating conditions, fire emergencies, avoidance of condensation, closure against heavy rains, and occasional night-time occupancy. Exterior and interior sensors are used in each thermal zone to provide feedback for real-time operations. Commissioning and tuning the building must occur to ensure proper operations.

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Mixed-mode and natural ventilation

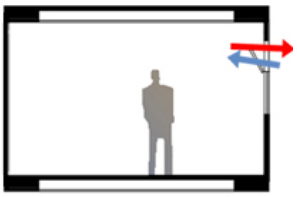
Conventional office buildings with airtight envelope systems are typically conditioned with mechanical heating, ventilating, and air-conditioning (HVAC) systems. Mechanical HVAC systems maintain fairly constant thermal conditions and can be applied in any geographical location. Since mechanical cooling and fan energy use account for approximately 20% of commercial building electrical consumption in the United States, the concept of integrating passive natural ventilation in conventional air-conditioned buildings has received attention from both the international and U.S. building industry. In addition, users are increasingly interested in measures that can improve indoor air quality via fresh air or free ventilation through windows, in part as a reaction to the problems that result from poorly maintained conventional HVAC systems (e.g., sick building syndrome, Legionnaire's disease, etc.).

Mixed-mode ventilation refers to a space conditioning approach that combines natural (passive) ventilation with mechanical (active) ventilation and cooling. The system has been used in the United Kingdom over the past 20 years. Only recently has ASHRAE decided to incorporate a new adaptive model for thermal comfort for mixed-mode (or hybrid) ventilation in ASHRAE Standard 55 (Brager et al. 2000). Mixed-mode ventilation is appropriate for the design of new buildings and the retrofit of older, naturally ventilated buildings, where internal loads have increased due to increased occupancy or equipment loads. Commercial buildings in moderate climates with access to unpolluted outdoor air, such as the coastal California, Oregon, and Washington can take advantage of passive cooling strategies by integrating natural ventilation with conventional HVAC systems.

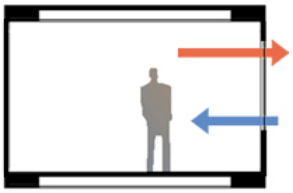
There are various ways to classify mixed-mode ventilation systems. In the context of high-performance building façades, mixed-mode ventilation can be classified based on how natural ventilation is provided and the mode of operation. There are three general modes of operation:

- Contingency: In this approach, the building is designed either as an air-conditioned building with provisions to convert to natural ventilation or vice versa. This approach is uncommon and is used only in situations where changes in building function are anticipated.
- Zoned: Different conditioning strategies are simultaneously used in different zones of the building. For example, an entire building may be naturally ventilated with supplemental mechanical cooling provided only in selected areas.

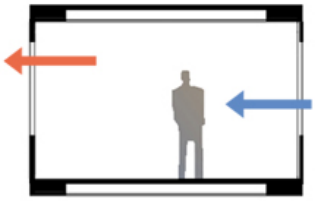
- Complementary: Air-conditioning and natural ventilation are provided in the same zone. This is the most common mixed-mode approach with various operational strategies: 1) *alternating* operation allows either the mechanical or the natural ventilation system to operate at one time, 2) *changeover* operation allows either or both systems to operate on a seasonal or daily basis depending on the outdoor air temperature, time of day, occupancy, user command, etc. — the system adapts to the most effective ventilation solution for the current conditions, and 3) *concurrent* operation where both systems operate in the same space at the same time (e.g., mechanical ventilation that has operable windows).



Single-sided, high opening: D ≤ 2H
With a single-sided, high level opening, ventilation is generally effective to room depths of up to 10 ft or less than two times the room height.



Single-sided, high and low openings: D ≤ 2.5H
With two openings located at the top and bottom level of the window, ventilation can be effective up to 30 ft or less than 2.5 times the room height. The higher window element can be left open for general ventilation while the occupant can maintain control over the lower window(s).



Cross ventilation: D ≤ 5H
When the room has windows on opposite sides, cross ventilation is effective up to 40 ft of the room depth or five times the room height.

Natural ventilation can be introduced in a variety of ways: 1) with *operable windows*, ventilation can be driven by wind or thermal buoyancy (or stack effect) to ventilate a single side of a building or to cross ventilate the width of a building; 2) *stack-induced ventilation* uses a variety of exterior openings (windows in addition to ventilation boxes connected to underfloor ducts, structural fins, multi-storey chimneys, roof vents, etc.) to draw in fresh air at a low level and exhaust air at a high level and 3) *atria* enables one to realize a variant of stack ventilation, where the multi-storey volume created for circulation and social interaction can also be used to ventilate adjacent spaces.

With single-sided ventilation using operable windows, there are general rules of thumb used to estimate the effective depth of ventilation. With clerestory windows, single-sided ventilation is generally effective up to a room depth of 10 feet, or less than two times the room height. For windows with separate upper and lower openings, ventilation can be effective up to a room depth of 30 feet, or less than 2.5 times the room height. The upper window element can be left open for general ventilation while the lower can be controlled by the occupant. With cross-ventilation, where a zone has windows on opposite sides, ventilation can be effective up to 40 ft of the room width or less than five times the room height.

The type of window affects the degree of resistance to inflowing air and therefore ventilation potential. Sliders can provide an 100% unobstructed opening while a bottom-hung tipped casement may only provide a 25% unobstructed opening. Screens or mesh used to exclude birds and insects also reduce ventilation potential. Ventilation through a double-skin façade, as previously discussed, can also occur. Windows may be operated manually or with mechanized arms, similar to those used on HVAC ventilation systems or fire control shutters. To promote user satisfaction, one should allow the automatic control system to be overridden by the occupant.

For all-glass facades, solar chimneys are essentially the glazed manifestation of a stack-induced ventilation strategy. A glass, multi-storey vertical chimney (shaft) is located on the south façade of the building. Operable windows connect to this vertical chimney. Similar to the heat extraction concept described above for double-skin facades, solar heat gains absorbed within the chimney causes hot air to rise, inducing cross ventilation from the cooler north side of the building. Mechanical ventilation can be used to supplement this ventilation if natural means are insufficient.

Stack-induced ventilation through atria work using the same principle as a solar chimney but can serve more functions. Atria can be situated in the core of the building or form a single-, double-, or triple-sided, all-glass, multi-storey zone at the exterior of the building. The roof is typically glazed. Atria can be used to provide daylight to adjacent spaces and can act as a thermal buffer during the winter season.

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Active Facades

Smart windows and shading systems have optical and thermal properties that can be dynamically changed in response to climate, occupant preferences and building energy management control system (EMCS) requirements. These include motorized shades, switchable electrochromic or gasochromic window coatings, and double-envelope macroscopic window-wall systems. "Smart windows" could reduce peak electric loads by 20-30% in many commercial buildings and increase daylighting benefits throughout the U.S., as well as improve comfort and potentially enhance productivity in our homes and offices. These technologies will provide maximum flexibility in aggressively managing demand and energy use in buildings in the emerging deregulated utility environment and will move the building community towards a goal of producing advanced buildings with minimal impact on the nation's energy resources. Customer choice and options will be further enhanced if they have the flexibility to dynamically control envelope-driven cooling loads and lighting loads.

Demand-responsive programs

A variety of different strategies have been implemented by utilities and other their customers in attempts to manage and reduce electric load. Most have been voluntary, with various economic incentives associated with the strategies. Demand responsive programs provide a means to economically incent customer's participation to shed load or use alternate energy sources during critical periods of high demand. In the recent context of the 2000-2001 California energy crises, the emphasis of such programs has been on a near immediate response to curtail energy loads to avoid impending electricity outages. In the long-term, there is a need to increase customer participation in managing finite regional and nationwide energy resources to reduce price volatility and improve system reliability (Kueck et al. 2001). Demand responsive programs and utility rate structures such as time-of-use (TOU) and real-time pricing (RTP) schedules cause customers to directly experience the time-varying costs of their consumption decisions and therefore act as an incentive for customers to actively manage their loads.

Many of the simple curtailment strategies utilized in California during the past summer enabled customers to shed load without incurring additional capital costs for existing as-is facilities. However, in some cases, these strategies significantly impacted the comfort and potentially the health and productivity of the building tenants. Strategies included increasing temperature set points in occupied spaces, reducing fan speed or run-time, switching off lighting, reducing outside air intake volume, and pre-cooling the building

during off-peak hours. Drawbacks of such strategies include thermal and visual discomfort; potential increases in CO_2 levels, and possible degradation of indoor air quality depending on the severity of the load response required. Preferable strategies are those that can provide significant load shed with minimum negative impacts to building tenants.

Utility load management programs have historically been aimed at reducing demand during critical times (such as summer or winter peak) using either direct load control (utility operates customer's equipment) or interruptible load programs (customer implements method of load shed). The critical summer peak for the commercial sector occurs in the afternoon and is driven predominantly by weather: hot temperatures and high solar gains. For example, the California statewide commercial building sector peaked at 23,000 MW at 2 PM, an increase of 15,000 MW from nighttime usage. Together, interior lighting and air-conditioning in the commercial sector make up 25% or 12,476 MW of the total 1999 California statewide peak load for all electricity use sectors (Brown and& Koomey 2002). Cooling loads are dominant in all large commercial building types and more than one-third is due to lighting and another one-third to solar heat gains through windows (Franconi and& Huang 1996).

Therefore, for interruptible load programs, strategies involving daylighting and window solar heat gain management offer significant demand reduction potential without the negative drawbacks of occupant discomfort. Peak daylight availability coincides with summer peak periods enabling reduction of lighting and cooling demand, given careful control of solar heat gains in perimeter zones. This is a *critical* concept associated with the strategies listed in the next section. Many people recognize that control of solar heat gains during peak periods can be accomplished by simply blocking all solar radiation before or just after it enters the window. People also recognize that admitting daylight (solar radiation) reduces the need for electric lighting. Determining the optimum energy balance between solar heat gains (increased cooling) and daylight (decreased lighting and cooling) is a critical issue and is key to optimizing window and lighting peak demand reductions during the summer. Other long-term opportunities not normally associated with window systems are those that allow windows to become part of the space-conditioning solution. Natural ventilation, heat extraction, and nighttime cooling strategies using operable windows reduce a building's dependence on mechanical cooling or shifts the load to off-peak hours.

Active load management window strategies

Demand responsive (DR) strategies below have been loosely defined as solutions that provide a 1-2 hour response or a 24-hour response to requests for load shed. Short-term solutions are those that can be implemented within existing buildings. Long-term solutions are those that are more cost-effective and practical to implement in new buildings or in buildings that are being extensively renovated.

GSW operable vertical shades, Berlin
(see detailed case study)

Short-term strategies for existing buildings

A. Occupants voluntarily close interior shades on all windows. Lighting is curtailed.

   Request is made over a central public address system or by email notification system. Flyers distributed before event could explain manual strategy. 1-2 hour notification.

B. Motorized interior or exterior shades are closed automatically by the facility manager during a load shed event. Lighting is curtailed. 1-2 hour notification.

Long-term strategies for new or renovated buildings

C. Automated exterior or interior shading systems combined with daylighting controls to reduce cooling and lighting loads. 1-2 hour notification.

D. Automated switchable windows controls (e.g., electrochromics) combined with daylighting to reduce cooling and lighting loads. 1-2 hour notification.

E. Heat extraction double-envelope facades with automated venting during peak periods to reduce cooling loads. Lighting loads could also be reduced with daylighting controls. 1-2 hour notification.

F. Pre-cooling of thermal mass using nighttime natural or mechanical ventilation through windows. 24-hour notification.

Strategy A involves a request to all building personnel via email notification, flyers, or the public address system to voluntarily close their window shades so that the entire window surface is blocked. If the shade allows one to modulate daylight (such as Venetian blinds or louvers), the occupant is asked to tilt the blind angle so that incoming daylight is sufficient to meet task lighting levels. Occupants near windows are also asked to switch off unnecessary lighting. This strategy can be applied to most commercial buildings without additional expenditures. Its effectiveness is dependent on the level of voluntary cooperation. Effectiveness is also dependent on baseline shade usage, shade type and reflectance, properties of existing window glazing, and window size and orientation. For example, white shades can reflect solar radiation back through the window if the window glazing has a high trans-

mittance. Impacts on occupants are limited to annoyance at the disruption. Impacts on demand can be as much as 3 W/ft^2 –floor in perimeter zones. If two- or three-stage fluorescent light switching exists in the building, demand reductions may be less.

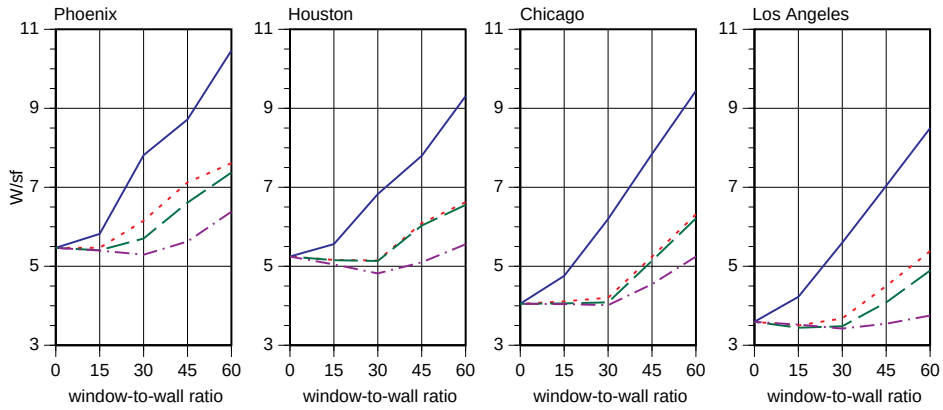
Strategies B and C are similar to A in that interior or exterior shades are used to reduce solar heat gains and manage daylight admission during critical peak periods. In this case, it is assumed that the facility manager through a central control system deploys the shades automatically. Lighting is curtailed either manually or automatically. Strategy B assumes that such a system exists within the building, which is admittedly unlikely for the majority of the commercial building stock. Retrofitting motors to existing static shades is costly. Strategy C assumes that new motorized shades are installed in new or existing buildings. If the building is new, the shades could be coupled to work with dimmable lighting using an integrated control system to achieve better reliability and energy efficiency. With existing buildings, switchable or dimmable lighting would need to be installed. Impacts on demand are similar to strategy A: as much as 3.5 W/ft^2 –floor in perimeter zones. Occupant disruption is likely as well; however, occupant override should be allowed during non-critical peak periods.

Strategy D uses low-maintenance, non-mechanical means to regulate solar heat gains and daylight. Switchable windows include electrochromic or gasochromic glazings, which can be modulated from a clear to a dark tinted state (similar to switchable sunglasses) with either a small-applied voltage (3-5V DC) or a minute influx of gas (e.g., hydrogen). Electrochromic glazings are commercially available in limited quantities in Germany. U.S. products are anticipated to enter the market in 2003. Gasochromic glazings are still under development. Competitively priced products are dependent on volume and on how quickly products get adopted into the marketplace. Electrochromic windows with dimmable daylighting controls regulate peak demand in a similar fashion to strategy C and are slated for new construction. Demand reductions can be as much as 4.75 W/ft^2 –floor in the perimeter zone.

Heat extraction double-skin facades (strategy E) rely on sun shading located in the intermediate space between the exterior glass façade and interior façade to control solar loads. The concept is similar to exterior shading systems in that direct solar radiation loads are blocked before entering the building, except that heat absorbed by the between-pane shading system is released within the intermediate space then drawn off by ventilative means. Cooling load demands are diminished with this strategy. During peak conditions, mechanical ventilation can be used to extract heat if natural means (via thermal buoyancy or stack ventilation) are insufficient. Impacts on peak demand are difficult to quantify due to the complexity of the heat exchange. Occupant impacts are minimal; again, override on shade use should be allowed during noncritical periods. Thermal comfort may be improved, compared to some façade systems, due to a reduction in the interior window surface temperature if designed correctly.

During the summer and in the some climates where there is sufficient variation in diurnal outdoor temperatures, nighttime ventilation (strategy F) can be used to cool down the thermal mass of the building interior and reduce air-conditioning loads. Heat gains generated during the day are absorbed by furnishings, walls, floors, and other building surfaces then released over a period of time in proportion to the thermal capacity of the material. Removal of these accumulated heat loads can be achieved with a variety of cross-

Peak electric demand (W/ft^2) for a west-facing perimeter zone



Case 1: Bronze, no shades and no daylighting controls
Case 2: Bronze, interior shades and daylighting controls
Case 3: Bronze, exterior shades and daylighting controls
Case 4: Electrochromic with no shades and daylighting controls
Peak electric demand for a west-facing perimeter zone in a prototypical 3-storey office building module as determined by the DOE-2.1E building energy simulation program. Cases 1-3 are given for a bronze double-pane window. The electrochromic window was controlled to maintain an illuminance level of 50 fc (538 lux). All systems use continuous dimming daylight controls and a lighting power density of 1.5 W/sq.ft (16.1 W/sq.m).

ventilation schemes that rely on wind-induced flow, stack effect, and/or mechanical ventilation. Deployment of such a strategy for peak demand reductions must be implemented given a 24-hour notification. In recent years, the concept of radiant cooling has been coupled with traditional cross ventilation schemes. For some climates and building types, this strategy can be used to completely eliminate the need for mechanical air-conditioning. Heavy-weight thermal mass is strategically located in exposed concrete ceilings. This mass is "activated" or cooled at night using outdoor air directed to flow over its unobstructed surface. During the day, occupants exposed to this chilled thermal mass perceive a cooler environment due to a radiative exchange with the low surface temperature of this thermal mass. Peak demand reductions can be significant particularly if all central cooling requirements are eliminated and if rules for proper daylighting are observed (see strategy C).

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Light-redirecting skylight, Berlin.

2. Design Process

The array of advanced technological solutions presented in the prior section is tantalizing to the innovative architect and engineer. What's involved with creating the architectural solutions such as those given in the Case Study section? What's the requisite mentality needed for the design team, building owner, and occupants? Are there design tools available that can help one quickly understand whether a given strategy is viable for a particular site? Clearly, the process needed to achieve high-performance in buildings requires an integrated approach, where a team of experts work together to engineer an architectural solution that is both functional, comfortable, energy-efficient, and perhaps inspirational.

This section discusses the design process for achieving a high-performance commercial building, the criteria used for decision-making, scenarios of decision-making and post-construction issues. Highlights of individual interviews made with architects, engineers, and owner representatives are used to illustrate some of the complex issues and processes involved with following through with a high-performance façade.

A round table and workshop event was held at Southern California Edison in Irwindale, California on April 30, 2002. Results from this event are presented in this document. The round table event solicited input from 24 representatives of architecture, engineering, academia, and industry to determine the driving force behind the interest in high-performance all-glass facades and to determine what information sources and design tools were used or needed to develop such façade systems. The workshop event featured five presentations by architects, engineers, and researchers who have implemented or studied advanced façade systems.

Decisionmaking process

Here, we define an "integrated" façade as a façade that is designed, analyzed, procured and operated as a *system.* This is in contrast to a façade that is treated as building *skin* and is considered only as a layered configuration defined by its construction and its impact on the building as such. In the past, building façades have seldom been treated as integrated systems. Many factors have contributed to that; lack of full understanding how they function in buildings is only one. Building procurement constraints, difficulties in multi-party communication and collaboration, and conflicting participant interests are some of the other.

Many parties that are in involved in building design, procurement and operation are also active participants in decision-making that results in integrated façades. These include the client, the architect, the façade systems specialist, the mechanical engineer, the cost estimator, the fire marshal, the structural engineer, the construction manager, the lighting consultant and the value engineer. Each decision maker plays a different role and often has different (possibly conflicting) goals that sometimes make decision-making difficult. For example, the architect may propose an integrated façade that poses additional requirements on the structural system design, which in turn may increase construction cost; the client may object to the higher cost and, in the attempt to reduce project cost, the value engineer may eventually eliminate the integrated system altogether.

Agreement among decision makers is harder to reach if their backgrounds and professional experience are heterogeneous. Integrated façades are typically very complex systems that require a high degree of technical understanding and consideration that range from thermodynamics and material sciences to air flow to lighting and daylighting to HVAC equipment and systems. Each of these has to be considered in its own right; consideration of one at the expense of another can result in systems with inappropriate one-sided performance, a malfunctioning system, or in the elimination of the idea.

Simultaneous discussion of all parties that need to be involved with the same information available to everyone is the most effective way to reach agreement and make decisions. Decision-making is much more difficult when it is done sequentially and with only selective information available. All too often parties join the decision making process while it is already in progress; they often miss the reasoning for the previously made decisions, are often given only the information someone else considers "pertinent" at the time, and are in general significantly less informed about the issues than some other participants.

Computer based tools can aid in decision-making. While no tools designed specifically for simulation and analysis of performance of integrated façade systems are available on the market today, some of the available general computer-based building tools can serve the purpose rather well when utilized by skilled staff who understand the capabilities and limitations of the tools. These are computer programs that can analyze or simulate a given aspect of performance of integrated façade systems. For example, "whole building energy tools" can simulate the energy performance of the entire building over prolonged periods of time, so one can see the effects of a particular integrated façade system on the building's energy consumption. Or, "daylighting" tools can show the impact of natural light that the façade system allows to penetrate the building on the consumption of electricity from electrical lighting. Such tools can serve a dual purpose: (a) to *predict* the performance of components, integrated systems and the overall building, and (b) to show *why* a given decision has a given impact, as well as to bring in the forefront the important underlying assumptions. Judicious use of such tools in the decision making process can provide answers to disputed questions, and can demonstrate cause and results of decisions to those who are less knowledgeable about the issue.

The following table is a partial list of commercial software available in North America that can be used in the planning, design, analysis and evaluation of integrated façade systems. Software in the figure is grouped by profession that uses the software as part of its regular work process. The figure does not include proprietary software that is in use exclusively by organizations that developed the software.

Criteria in decisionmaking

First cost is usually the criterion given most consideration in decision-making for integrated façade systems. This is unfortunate, as focus on first cost typically fails to consider the benefits of particular investment on life-cycle cost. All too often a building element that is more expensive to install than some other alternative works better and reduces operating, maintenance and replacement costs in the future use of the building.

Table of commercial software tools

- Architecture
  - AutoCAD/Architectural Desktop
  - MicroStation Triforma Architectural
  - ArchiCAD
  - Allplan FT
  - FormZ
  - Revit
  - IntelliCAD
  - Datacad
  - TurboCAD
  - Vectorworks
  - Visio 2002 Professional
  - Bricsnet Architecturals
- Structural engineering
  - STAAD.Pro
  - Daystar
  - Space Gass
  - Larsa
  - P-Frame/S-Frame
  - STRAP
  - ETABS/SAP 2000
  - MicroStation Triforma Structural
  - Bricsnet Structurals
  - PROKON
  - OrthoGEN
  - Setroute
  - ELDS
- HVAC
  - MS Excel
  - Trace
  - HAP
  - E20-II
  - Elite's HVAC Solution
  - DOE-2 (and its derivates)
  - EnergyPlus
  - CFX
  - HEAVENT
  - AutoCAD/Mechanical Desktop
  - MicroStation Triforma HVAC
  - Right-Suite Commercial
  - Building Composer
- Electrical engineering
  - Actrix Technical 2000
  - Visio 2000 Technical
  - AutoCAD
  - VIA
  - ACERI Electrical Designer
  - promis.e
  - Raceway Wizard
- Lighting design
  - Radiance
  - Lightscape
  - Lumen Micro
  - Ecolumen
  - AGI32
- Acoustical analysis
  - Odeon
- Fire protection
  - AutoCAD
- Cost estimating
  - MS Excel
  - PrecisionEstimating
  - ICE Bidday
  - CostLink
  - WinEstimator
  - Trackpoint
- Code compliance
  - ComCheck
  - EnergyPro
  - PERFORM
  - CodeBuddy
  - ADA Checker
- Construction management
  - MictoStation V
  - ArchiCAD
  - Visio 2000 Technical
  - Primavera Enterprise
  - Primavera Expedition
  - CIFE 4D
- Construction
  - Primavera Enterprise
  - Masterspec
  - Specware
  - SpecLink
  - SpecHelper
  - Viewpoint
- Facities/occupancy management
  - ArchiFM
  - Archibus
  - FIS
  - SPANFM
  - ActiveAsset
  - Actrix Technical 2000
  - Visio 2000 Technical
- Building engineering/maintenance
  - PSDI Maximo
  - SPANFM
- Performance simulation
  - DOE-2 (and its derivates)
  - BLAST
  - EnergyPlus
  - ESP-r
  - Radiance
  - Odeon
- Commissioning
  - PACRAT
  - ENFORMA

Note: This is a snapshot of existing tools. Others may not be mentioned here in this list.

Not willing to invest more at the beginning to realize much larger savings later is a poor business strategy. A frequent reason for this is the fact that those who control construction (first cost) budgets are not the same individuals or groups as those who control operation and maintenance budgets. They have no incentive to invest in the future of the building and have every incentive to minimize what they view as *their* expenditure. It takes an informed and involved owner to resolve this contradiction.

There are several valid reasons for primary consideration of first cost. One is the physical limitation ("ceiling cost") of the budget. This may be simply because additional funding is not possible to obtain, or because the limitation is imposed for some other reason, such as a political process that is involved in all budgetary issues for the particular building. Such limitations are quite typical for public and institutional projects.

"Building as investment" strategy is another reason. The goal of speculative building construction is to build the building at the lowest possible cost and sell the finished or partially finished product for the highest possible amount. The only plausible increase in first cost is that which increases the sales value of the building by significantly more than the increase in first cost. Again, it takes an enlightened owner-speculator to realize that an integrated façade system *may* increase the building's sales value and to approve the additional cost if the proposed integrated façade system costs more than the alternative.

Financial considerations may be yet another reason for consideration of first cost. Factors such as owner's cash flow, corporate or personal capital investment strategy and constraints, rate of return and/or debt service may play a role in limiting the construction budget. Such factors are sometimes not shared by others, which makes the decision-making more difficult. In addition, the authority to make additional funding decisions may be obscure and decisions related to funding may be delayed until approval is obtained.

It is important to understand that integrated façade systems *do not have to* cause higher overall building cost. If a certain level of building performance is a goal, an integrated façade *system* that achieves that goal may actually cost less than an elaborate building skin that may or may not provide comparable performance. For example, a naturally-ventilated building may allow the building owner to downsize or eliminate the HVAC system resulting in a lower overall building cost.

Specific performance goals can be important criteria in decision-making and may be the catalyst in designing a specific integrated façade system. These can be a better energy performance of the building, better or specific response of the building to its surrounding environment, increased occupant comfort, lower operating cost, a "greener" building (i.e., a higher LEED rating), attained publicity, etc.

Operating and maintenance costs are other important criteria. If planned, designed and installed properly, integrated façade systems usually result in lower overall operating costs. The savings are mostly achieved from a reduced overall energy consumption in the building. Properly designed systems are usually easier to maintain because maintenance is accounted and planned for, specific performance can be monitored, and problems and malfunctions may be detected sooner.

Technical merit and constructability of the proposed integrated façade system can be an issue. The proposed system may include components that have not yet been proven to work together under some particular condition, may be

difficult to construct in the given location, or may cause general construction problems for the building. This is particularly true if deployment of new technology is involved.

Planning, design and procurement processes and *time lines and schedules* also need to be considered. The delivery of integrated façade systems often is in conflict with standard building procurement practices that may make the entire plan impossible to execute. This is particularly true if the proposed system adversely affects time to occupancy.

Several other "hidden" criteria may significantly influence decision-making. These range from ascertaining and maintaining control over the project or the particular issue at stake to achieving political goals and schedules to meeting personal goals and objectives to meeting expectations that are frequently evolving.

Typical scenarios and outcomes

Successful efforts in including integrated façade systems in a building always require a driving force in the decision making process. Such forces can be occupant driven (to reach higher level of comfort, for example), or occupant driven as perceived by the owner. The owner may feel obligated to be "green" or may strive for a specific LEED rating for the building. Stricter energy codes may also be a driving force.

Chances of success increase if the owner and the architect understand the benefits of integrated façade systems to the extent that they are willing to put these systems "off limits" during project value engineering. If change and cost cutting is unavoidable, they may still find a way for the remaining solution to work within the needed performance boundaries.

Given the many different possible circumstances, conditions and decision-making issues one can face in considering and proposing an integrated façade system for a building, the decision-making body or group may reach any of the following conclusions:

Approval – the benefits of the proposed façade system exceed its cost, and the projected value of the system overshadows any known drawbacks. The approval may be outright or conditional, pending the availability of additional or new information.

Rejection: Estimated first cost of the proposed façade system is too high – the cost of the façade system is higher than its foreseen benefits. If both the cost and benefits are fairly estimated, it is hard to argue for the proposed system, unless its value is not tangible and its goals and merits are not quantifiable.

Rejection: No additional budget is available – the cost of the proposed façade system is higher than the base alternative, and no additional funding is available to meet the excess cost, regardless of the expected benefits from the proposed system. As a rule of thumb, one must include the cost of any integrated façade system in the original building budget; one should not ever expect the owner to approve the incremental cost.

Deferred decision – final agreement cannot be reached. While the proposed façade system has merit, complete assessment cannot be made because critical information or a decision making party are not available at the time. While a deferred decision delays the design process and may adversely affect the project schedule, it also provides an opportunity to develop the integrated

Prismatic louver systems, Museum, Berlin

façade system proposal further and provide better or more complete information for the next decision making event.

Indirect approval: "Piggy-backing" on other approved issues or systems - the proposed integrated façade system is an integral part of a larger building system that is approved. It is accepted regardless of possible identifiable drawbacks because the larger system cannot function without it. Cost and other considerations of the integrated façade system are judged as part of the cost and benefits of the larger system.

Post-construction issues

Matching occupancy and use of the building to the original plans and assumptions is not always automatic or smooth. It can pose problems that may result in serious owner and/or occupant dissatisfaction. Building programmers and designers formulate requirements and solutions to respond to defined needs for space and occupancy. In the process, they make many assumptions and decisions that predetermine what the finished product is and is not capable of. The design of a building evolves over time, and early design decisions can sometimes preclude later refinement that may result in a better building. Future users and operators of the building are seldom aware of the assumptions made in the design and the limitations that may be inherent in the building as built; they often try to use or operate the building in a way it cannot and they do not understand its limitations and the reasons. Such problems are only augmented when ownership and the use of the building change.

The same is true of integrated façade systems. They are typically complex systems and their proper function depends on their proper use and operation, timely maintenance and a thorough understanding of how they work in dealing with problems and malfunctions. If the integrated façade system consists of a combination of components that were built by different manufacturers (sometimes for different purposes) and assembled as a "first of" or a unique system, the understanding of how they properly work together may require quite an effort. The average building occupant, building operator or manager often needs to be educated about how not to interfere with the system's proper function.

Integrated façade systems (or any other part of the building) sometimes do not work as expected because of component substitution during construction. The designed and specified system components may not be timely available, or alternatives may cost less; substitute components are used without consideration that they may not perform the way the original is supposed to. This can result in serious erosion of system performance that is hard to trace if the component is small and difficult to reach. To avoid such problems, one should commission any integrated façade system before delivering the building for occupancy, as should be the case with any other important system in the building.

Without measurement of system performance one can never be certain how well a given system is working. This is particularly true of integrated façade systems; since relatively few have been installed and monitored to date, too little empirical knowledge about them is available to be universally useful. To fully understand how such a system is working, it is necessary to measure and monitor the performance of the system. This requires decisions on what to measure and monitor that will define the performance in view of the original

system performance goals; it requires instrumentation, monitoring equipment and staff to do the work. Consequently, such activity requires a budget that must be planned for as *part of the original building construction budget*.

Highlights of interviews made with architects, engineers, and owner representatives

Interview with Maurya McClintock, Façade Engineer, Ove Arup & Partners, San Franciso, California, August 3, 2001.

Typical engineering firms involve mechanical, electrical, structural, and plumbing. There are special disciplines supported world-wide within Arup: civil, acoustics, facades, telecommunications, etc.

When is the engineer typically brought on to projects that involve complex façade systems?

Unfortunately, in comparison to both Europe and Austral-Asia, our experience has been that U.S. architects typically involve façade engineers much later in the design process – sometimes as late as 50% design development (DD) of the project. For advanced façade-building systems, a *team* effort between the architect and engineers is required to solve integrated design challenges, and to maximize these integrated performance benefits we have found that the team (everyone) must work together from project inception. In the case of a multi-headed client, where decision have to be made at multiple levels, it's even more important to get involved at this earlier stage.

Yes, the process of educating the client is typically longer for integrated projects, and an earlier involvement by more design team members implies a greater cost over time which is why we often see reluctance to involve the façade engineer until later (to reduce design costs). The price that is often paid is loss of potential interdependent performance and increased associated building performance cost.

To offset these higher design costs of longer design team involvement, we often get creative about appropriately limiting scope. We may propose to design/analyze façade performance impacts for the 1%- or 2%-design condition only rather than a full-blown investigation of the building's performance over a typical year. The level of analysis proposed is dictated by the client's desire and level of design team's need (depending on the complexity of the system) to understand the implications of the façade system design under typical operating conditions.

What does a high-performance facade mean to you?

Integrated design that looks at the façade as not merely the skin of the building but as a *system* that influences and is influenced by the local outdoor climate and the zone 15-20 ft inside the building. Integration and façade systems implies a design that balances numerous (and often conflicting) performance parameters.

It also implies a longer process and greater cost for engineering a system that considers cooling load, lighting and daylighting, comfort, operational, and aesthetic impacts. The client's mentality towards increased design time often drives the solution (we don't often get speculative developers as clients). Most of our current clients are 1-2% leading-edge clients. They demand

specific not generic solutions, tailored buildings not a cookie-cutter design that's then transplanted to any place in the country without regard to local climate conditions. Having said that, with education over these last couple of years, we *are starting to see* a shift in what we call "the mainstream" client's attitude to high-performance, integrated design.

Why do you think there's a trend now toward high-performance façade systems?

There's a number of new issues that are driving this trend. First, there is a perception that the occupant is driving the needs or program within the building and a desire of the building owner and client to competitively address those needs. In some cases, the needs can be equated to the desire for amenities (operable windows, motorized shading systems, etc.). In other cases, the needs can be equated with the desire for a more humane environment: access to fresh air, access to daylight, connection to outdoors, etc. Second, the ASHRAE 90.1-1999 and California Title-24 codes are stricter than before. To meet them and to achieve the aesthetic desired by some architects, such as an all-glass façade, one has to resort to more innovative and integrated façade system solutions. Third, there is a perception within the architectural and engineering design community that we should provide environmental stewardship for this world's future, a part of which is designing buildings which provide healthy environments while consuming less fossil fuels. The LEED benchmarking system for sustainable design is one way of tracking and quantifying the potential sustainable savings and is rapidly gaining recognition by the design community as a viable convincing mechanism. More clients are interested in obtaining a positive LEED rating. In some cases, cities or agencies are mandating minimum LEED ratings.

Are new technologies a requirement for high-performance façade systems?

Not necessarily. High-performance façade systems can be as simple as the application of natural (age old proven) processes in a simple (known) kit of parts that one assembles. (This was the technique we took with NBBJ on the design of the Seattle Justice Center facade. See the following NBBJ workshop talk.) However, there's no reason why new technologies can not be employed as viable parts of an appropriate design solution. However, at the moment many of these "new technologies" are expensive and one needs to rationalize the balance of costs with the architect and the owner. If, for example, the client wants a lot of clear glass and the orientation is southwest or west, the technological solution could be an operable internal blind (with local extract system) or an external motorized blind, or more advanced facades systems such as switchable glass or double-skin façade systems. The above is in order of increased performance but also increased first cost of the façade system. The client needs to be informed early on of these increased costs and tied to an understanding of resulting increased performance. The rough budget cost comparisons I typically work with during the early stages of design are: a "typical" curtain-wall is typically approximately \$65-85/ft^2 versus the cost of advanced façade systems can be upwards of \$150-\$250/ft^2. There must be an education process that affords an early realization and full understanding of the implications, so that the client can make well-informed decisions to engage or walk away from proposed design solution.

What is the value of analysis?

The process of analysis results primarily in an educational process for the client. This process must show the interdependency between systems and provide protection from value engineering. It must also show the interdepen-

dency between cost and performance variables. It sets the ground rules, and this must be done early on.

Some decisions are based initially on rules-of-thumb and expert judgment that is then validated through engineering analysis. Our analysis typically includes a whole host of issues: daylighting/ lighting, energy performance, structural, waterproofing, acoustics, indoor air quality, thermal comfort, visual comfort, glare assessment; however, the specific concerns are dictated by the client. For some clients, glare and VDT computer use may be the key issue. The design team, together with the client, tailor the scope of analysis to the specific project and educational needs.

How do you convince clients to take an integrated approach?

Again, education – we try to educate the client so that they understand the balances provided by integrated design and life-cycle costing. However, the client *must be willing to be educated*.

In some cases, this takes the form of explaining building physics concepts such as control of solar loads and daylight and how that benefits operations and the occupant. On other occasions, we talk dollars. The dollars "argument" here in the U.S. is often critical.

The client must agree to justify increased façade system first cost over an agreed life-cycle of the building – accounting for other building systems, occupant impacts and operational + maintenance costs. This is often difficult in our U.S. "throw-away society" and we often make the comparison to European development attitudes as part of our "education process":

1. U.S. developers and clients often demand a payback *on energy operation alone* of less than 3-5 years. Compare this to EU buildings which are often justified over a 20-30 year payback, and paying anywhere from 3 to 6 times the energy prices of the U.S. We just can not make a convincing argument for such clients – their interest is not in the long-term performance of the building and its impact on occupants.

2. Another reason why we're seeing high-performance facades in Europe is because of their approach to the building's ability to meet the needs of the occupants:

- there are codes for access to daylight and fresh air in many EU countries,
- there is a different cultural mentality in the EU – occupants refuse to work in buildings that don't supply what they see as "requirements" of a healthy work environment – which then essentially drives the development and realty markets.

For these clients, the initial capital cost of \$150-\$250/face-ft^2 of the façade can be more easily justified against the *full* operational cost/performance of the building.

We also try to discuss some of our past integrated building experience resulting in marginal increase in performance often obtained at no added cost. For example, for a 0-3% increase in capital costs, one can achieve 10-15% better performance (than stipulated by ASHRAE 90.1-1999.) For a 5-10% increase in capital costs, one can achieve 20-25% better performance.

How are advanced façade systems implemented in industry?

It is critical that the design team educate the contractors (and specialist subcontractors) as well. The typical construction process often puts the burden

(and risk) of engineering the façade on the vendor, particularly under design-build contracts which then carries a contingency cost. Some suggestions that have worked for us on past projects:

- One needs to involve the contractor and manufacturer early on, as part of the design team. For example, clients could pre-qualify the curtain-wall contractor and involve their expertise early on toward designing a least-cost solution that includes ease of construction, appropriateness and availability of existing components.
- One has to portray to the general contractor that the proposed façade system involves merely putting a kit of standard parts together in a slightly different way. Actuators, throttling flaps, power at the window wall may be perceived as unique, but such systems are used conventionally with mechanical systems and can be applied with the same labor in façade systems.

In addition, a number of European curtain-wall contractors provide generic solutions in the form of "standardized" advanced façade system units at a preliminary budget cost of around \$120-\$180/ft^2 (with a few Canadian manufacturers following suit). However, a number of design teams have found that these same dollars can be applied to a project- and *site-specific solution* tailored to a specific architectural and engineering aesthetic for increased performance for the money invested.

Interview with Russell Fortmeyer, Erin McConahey, Bruce McKinlay, Sam Miller, Regan Potangaroa, and Cristin Whitco, Ove Arup & Partners, Los Angeles, California, September 19, 2001.

Similar responses to previous interview with Maurya McClintock were not duplicated here.

Why do you think there's a trend now toward high-performance façade systems?

McConahey: There's an architectural trend toward greater transparency. People want a good visual connection to the outside, but the thermal requirements kills that transparency. With double-facades systems, one can improve thermal performance *and* gain transparency. For example, the Helicon Building in London involves an all-glass double façade. The façade forms a thermal flue that is 6-8 stories high. Motorized blinds (1.5 ft wide) rotate closure as the sun tracks across the sky – this is centrally controlled using the EMCS system, not the occupant. The U-value and effective SHGC computed with this sun shading system were adequate to meet the requirements of the building in this climate.

McKinlay: Sustainable architecture, with goals of improving connections between indoor and outdoor space and occupant controllability is another factor driving this approach.

Are you able to meet the needs of your client with existing tools?

McConahey: The tools aren't adequate yet, especially those in the public domain and if, in the case of multi-storey ventilation schemes, thermal links between multiple floors are required. Private domain tools, such as those developed in-house by Arup, are better. Title-24 compliance software doesn't analyze such things as parallel shading or perforated metal scrims.

How are advanced façade systems implemented in industry?

McConahey: In our recent experience with the Seattle Library, the architect (Koolhaus) developed the design and then convinced the client to accept it before we became involved. The client needs to be made aware that warranties can become a problem when different vendors provide different components of the built-up façade assembly. It's necessary to determine in advance who will be legally responsible for what. The specifications must carefully delineate who does what and who takes responsibility.

Do you follow-up with post-occupancy evaluations to determine if the façade functions as intended?

McKinlay: This area is evolving. We would like to maintain a continued relationship with the client, but often our scope is limited to designing the building, not conducting post-occupancy evaluations. The LEED program is really driving the increased concern for performance issues through the requirements of commissioning, measurement and verification. This is also consistent with Arup's interest to evaluate the success of our design, not just the client's. A shakedown commissioning is required of the contractor after six months. Often it takes two seasons to complete adjust and commission the system properly. A walk-through of the building with the contractor is typically conducted after one year, which is when many warranties expire. Typically, we don't get feedback from the client unless there is a problem.

Interview with Mark Levi, Building Management Specialist, U.S. General Services Administration, San Francisco, CA.

Mark Levi was asked to speculate on various building owner issues related to active window wall systems, including near-term automated venetian blind and dimmable electric lighting control systems.

On what basis are decisions to employ advanced façade systems made?

Implementation of window-lighting systems must consider the same criteria as other projects: project economics, impact on tenants, and impact on building maintenance and operations. Window-lighting systems might raise special concerns over the impacts on the appearance of the building, close exposure to occupants (i.e., unlike HVAC, individual occupants can "get at" venetian blinds and operable windows), and ability to make changes in the future as required by tenant agency alterations and relocations. Occupant psychology will be very important with automated blinds. If they want to open their blinds and the system does not want them to, they may do it anyway with unfortunate results. Occupants tend to like some control of their environment, so it is better to give it to them so they don't try to obtain it through inappropriate means, as well as to keep them generally happy. Optimization at the expense of occupant frustration will backfire in the long run.

What performance impacts are you most concerned with?

Automated blind systems must be occupant friendly and allow occupants to do what they want within reasonable bounds. Lighting systems must be easily adjustable – it must be a simple matter to increase the light level of a fixture in response to a complaint or to adjust lighting for a cubicle being located under what was once circulation space. For both lighting and blind systems, parts must be readily available and maintenance must be inexpensive and reason-

able for building maintenance staff. Routine dependence on an outside vendor or dealer for adjustments and minor repairs will generally not be acceptable.

In your experience with complex control systems in real buildings, what were the most critical issues or performance impacts that affected your rating of the "success" of a given technological strategy?

Two critical issues have been the cost and quality of vendor and dealer support, and the ability of building staff to maintain, operate and to some extent optimize the system. Both have been problems in some regards. Programming talent for building automation systems (BAS) tends to be somewhat scarce. At times there have problems with vendor and dealer support of some systems with regards to basic competence, cost and project management (i.e., organization of effort). It has been difficult to develop the level of maintenance staff maintenance necessary to make the best use of the various systems, and to do troubleshooting without having to rely on outside vendor and dealer support.

It is also necessary to watch carefully for various vendor lock-in strategies, some of which are not obvious (for example, embedding point identification data entirely within the vendor's graphics without any underlying data structure or filling in BACnet optional description fields, thus making the "open" communications only really open through the vendor's front-end software without laborious point description identification).

Interview with Kelly Jon Andereck, Environmental Coordinator, and Bernie Gandras, Technical Director, Skidmore Owings and Merrill (SOM), Chicago, IL, January 2002.

We discussed several of the regulatory issues that architects face when doing innovative façade designs.

We should start out discussion with a quote from a recent white paper by the Development Center for Appropriate Technology (DCAT): "… the most commonly stated reasons for denying green alternatives were lack of adequate supporting information (71.4%), and insufficient technical knowledge about the alternative (53.6%)." In fact, most if not all, leading edge building technologies in the U.S. are slow to come on line because of the lack of quantifiable analysis and case study histories.

The double-skin curtainwall is a typical example of breaking through the obstacles of disinterest, fear and the unacquainted. Although a series of excellent plate books and semi-technical references have been published mostly through the European Union, no definitive case study has clearly documented the entire development, process, measurement and verification of a double skin curtain walls in the U.S..

Currently, we're moving towards permit of a double-skin curtainwall in Massachusetts where temperature extremes are the norm and designing for winter is standard practice (we've been in design for over a year). The speculative office building uses approximately 93% glass, a double-pane low-e curtain wall exterior assembly, between-pane vertical blinds, and an interior monolithic clear glass. The air cavity between the interior and exterior glass layers is ventilated with room-side air and exhausted through the plenum via natural thermal buoyancy and room-side air pressure induced by the air-handling unit.

We initially championed this design because of the sound attenuation qualities, since the site is located near an airport. We made an additional assumption that the thermal characteristics could be of benefit to the overall energy performance of the building. Throughout the course of developing the envelope design, we used DOE-2.1E to conduct whole building energy simulations, first using gross areas and basic default values. Over time, we developed a more detailed DOE-2 model and have conducted continuous iterations with this model ever since.

The challenge of implementing this system appeared insurmountable because of the difficulty in meeting the requirements of the energy code. During design development, the state building code was amended. But unlike the state of California, this regulatory agency is only supported by a small technical staff and by an advisory committee of interested building professionals and representatives of other interested parties. In January 2001, the Massachusetts commercial energy code requirements allowed the use of whole building simulations to model the operation of the building. Its annual operating schedules were required with "…sufficient detail to permit the evaluation of the effect of system design, climatic factors, operational characteristics, and mechanical equipment on annual energy usage". The calculation procedure was based on 8760 hours of operation and incorporated the techniques recommended in the ASHRAE Handbook, 1997 Fundamentals Volume. In addition to these requirements, the revised energy code required that the fenestration thermal indices, U-value and solar heat gain coefficient (SHGC), be determined using procedures defined by NFRC 100, 301 and/or 200.

Determining the U-value and SHGC posed problems since there is no NFRC method to determine these values for the system we were considering. We would have to exclude the benefit provided by the venetian blinds and the ventilated air cavity, if we were to use standard NFRC procedures to demonstrate conformance with the code. To obtain credit, we needed to establish compliance through technical interpretation, addendum and/or revision of NFRC 200.

As we mentioned previously, the most commonly stated reasons for denying green alternatives or in this case, a double-skin curtainwall by any regulatory body may be lack of adequate supporting information. When both NFRC 200 and the state's energy code requirements were introduced, insufficient technical knowledge about double-skin facades prevented the state from having an alternative method to address these types of complex facades.

Consequently and in consult with the state's energy consultant, we decided to collaborate with a EU façade curtainwall manufacturer, the Permasteelisa Group, in order to both engineer and manufacture the curtainwall system as well to demonstrate compliance with NFRC 200 through technical interpretation. Permasteelisa used their own applied software to determine the U-value and SHGC of the façade assembly. In addition and as required, a full-scale mock-up was constructed, tested and evaluated. We then sent the testing methodologies, data and supporting documentation to NFRC for validation.

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Commonwealth of Massachusetts . 2001. Energy Code for Commercial and High-Rise Residential New Construction, Secretary of State, Commonwealth of Massachusetts, January 2001.

NFRC-200. 1995. NFRC-200: Procedure for Determining Fenestration Product Solar Heat Gain Coefficient at Normal Incidence, National Fenestration Rating Council, Inc., July 1995.

Round table at Southern California Edison

A three-hour round table discussion was hosted by Southern California Edison at the Customer Technology Application Center in Irwindale, California on April 30, 2001. Twenty-four representatives from the fields of architecture, engineering, academia, and industry were present (see below). LBNL led the discussion to determine the driving force behind the interest in high-performance all-glass facades and to determine what information sources and design tools were used or needed to develop such façade systems. Survey forms were handed out to poll attendees on various issues.

Michael O'Sullivan, Altoon & Porter Architects, Los Angeles
Erin McConahey, Arup, Los Angeles
Peter Barsuk, Cannon Design Architects, Los Angeles
Christoph Nolte, Carnegie Mellon University
Robert Jernigan, Gensler, Santa Monica
James Carpenter, James Carpenter Design Associates, Inc., New York
Davidson Norris, James Carpenter Design Associates, Inc., New York
James Benney, National Fenestration Rating Council
Kerry Hegedus, NBBJ Architects, Seattle
Robert Marcial, Pacific Energy Center, San Francisco
David Callan, Skidmore, Owings & Merrill, Chicago
Bernie Gandras, Skidmore, Owings & Merrill, Chicago
Raymond Kuca, Skidmore, Owings & Merrill, San Francisco
Thomas McMillan, Skidmore, Owings & Merrill, San Francisco
Steve O'Brien, Skidmore, Owings & Merrill, San Francisco
James Eklund, TRACO, Pennsylvania
Matthias Schuler, Transsolar Energietechnik GmbH, Stuttgart
Murray Milne, University of California Los Angeles
Richard Schoen, University of California Los Angeles
Scott Jawor, WAUSAU Window and Wall Systems
Todd Mercer, Webcor Builders, San Mateo
Alan Brown, Werner Systems Aluminum Glazing Systems
Julie Cox Root, Zimmer, Gunsul, Frasca Partnership, Los Angeles
Jeffrey Daiker, Zimmer, Gunsul, Frasca Partnership, Los Angeles

"There is hardly any architectural competition where a double-facade is not presented with fancy words such as Synergistic Facade, Intelligent Facade, High-tech Facade, etc. An expert must ask, when these impressive words are pushed aside, whether these promises can be realized and achieved?" —Karl Gertis, Director of Fraunhofer-Instituts of Bauphysik, Stuttgart, Germany, 1999.

Fashion or Trend?

The following premise was used to stimulate discussion:

- Claims without substance dominate the architectural press.
- Fashion is the driving force: transparent architecture and all-glass buildings, not environmentalism.
- Performance rationalizations are given *after* the fact, such as environmental architecture, improved performance, sustainability, LEED ratings, or occupant amenity.
- Problem: If fashion is dictating this all-glass trend, then motivation to deliver high performance is low.

Survey results

A single-page survey form was given to attendees to fill out after the discussion of this topic. The survey asked the respondent to rate various reasons why advanced façade systems might be considered for a commercial building project. The rating system was presented as a series of boxes to check with labels from 1 to 5, where 1 was labeled "unimportant" and 5 was labeled "critically important". Boxes 2 through 4 were unlabeled, so for the purposes of this discussion, we will call a rating of 4 "somewhat important", 3 "important", and 2 "somewhat unimportant." A rating of 0 indicated no response to a particular reason.

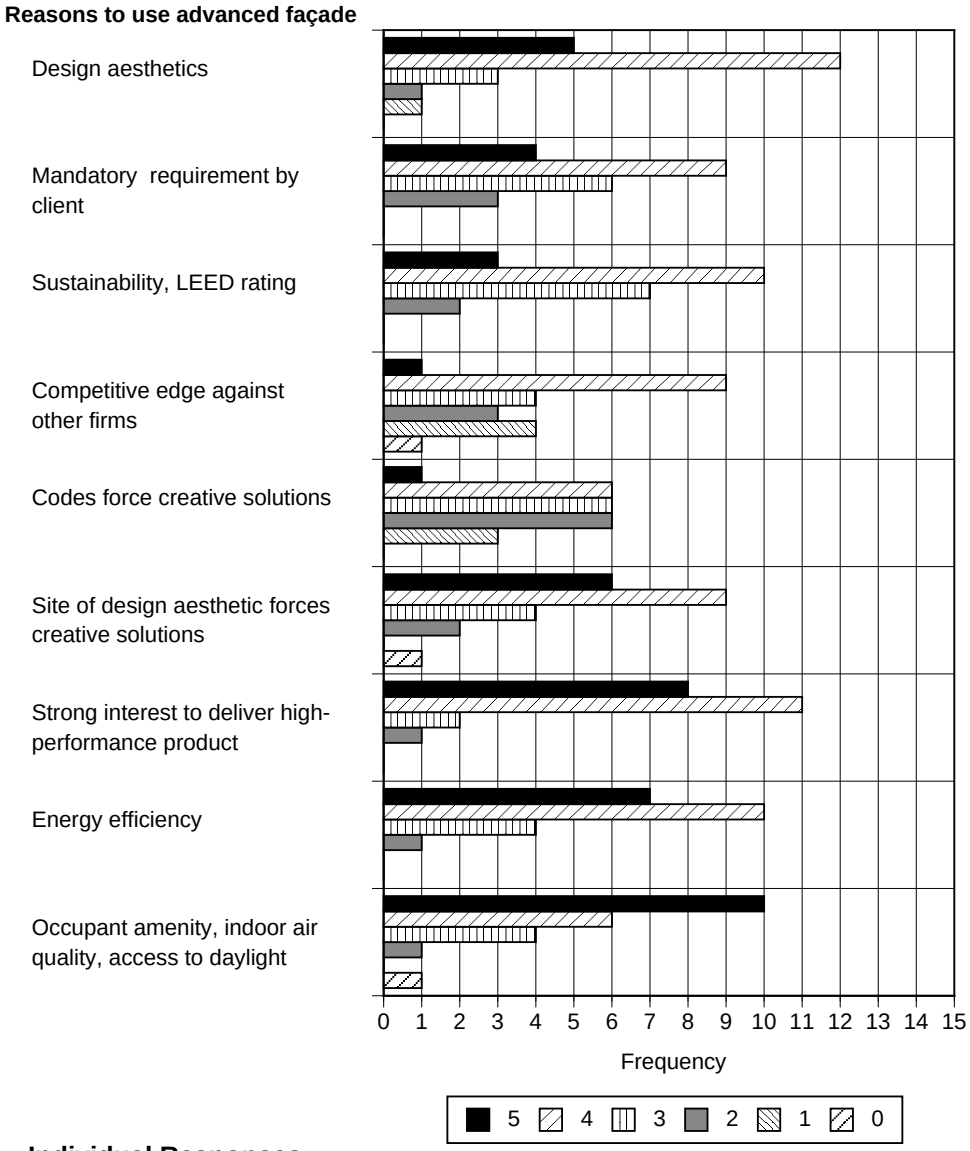
Nine options were given on the survey form as reasons to use advanced facades (see Figure). The options of citing and rating other reasons were also given. Of the total responses (n=22), the following was determined:

- 36% (n=8) thought that a strong interest to deliver a high-performance product was a critically important (rating=5) reason to use advanced facades, while another 50% (n=11) thought that this same reason was somewhat important (rating=4).
- 32% (n=7) thought that energy-efficiency was a critically important (rating=5) reason to use advanced facades, while another 45% (n=10) thought that this same reason was somewhat important (rating=4).
- 45% (n=10) thought that occupant amenity, indoor air quality, and access to daylight were critically important (rating=5) reasons to use advanced facades.
- 55% (n=12) thought that design aesthetics were a somewhat important (rating=4) reason to use advanced facades.
- 45% (n=10) thought that sustainability and LEEDS were a somewhat important (rating=4) reason to use advanced facades, while one person cited that the image of sustainability was critically important (rating=5).
- 41% (n=9) thought that either mandatory requirement by the client, competitive edge against other firms, or site or design aesthetic forces creative solutions were somewhat important (rating=4) reasons to use advanced facades.

These results strongly refute our earlier challenge/premise that the use of daylighting, solar control, double-envelope systems, natural ventilation, or active façade systems such as those seen in the architectural press are governed by style or fashion. The top three bullets all address motivations or reasons based on performance, not style. The top two bullets show that 77-86% of the respondents believe that high-performance and energy-efficiency were either critically important (rating=5) or somewhat important (rating=4) reasons to use advanced facades. Design aesthetics did come into play as a strong motivation: 55% believed that this reason was somewhat important (rating=4) for use of advanced facades.

There may be a strong bias since this round table discussion was instigated by a National Laboratory whose known mission is energy-efficiency and improving the performance in buildings and because it may be difficult, even in the privacy of filling out a survey form, to admit that architectural decisions to use a particular design approach is dictated by fashion or a trend. Individual's quotes below indicate the diversity of responses received.

Advanced Façade Systems: Fashion or Trend? (n=22)



Individual Responses

The discussion at the round table reflected the survey responses to some degree. Respondents did not come forth and state that advanced facades were based primarily on high-performance goals. Most stated that the use of advanced facades was based on a complex mix of design aesthetics, the desire for improved environmental quality, striving for at least an image of sustainability, and pragmatic economics.

From an academic or purely architectural perspective, the use of all-glass facades combined with advanced technological solutions is a rich, modern expression of form and function. James Carpenter spoke about this aesthetic in his afternoon talk (see below).

"I think that it is less an issue of fashion, per se, for the architect. For architects, the façade is really one of the last components of the building that is really left to their design capability, the one area that you focus on in a building. Simultaneously, it has been promoted in terms of glass performance over the last 10

to 15 years — the performance of the glass itself is improving to such an extent. I just think that it is a natural sort of convergence of glass industry initiatives in terms of the low-E and super low-E and double silvers. Certainly there is an underlying energy rationale. I think that fashion is perhaps the wrong term. Fashion means to me more style or something of that sort. I think that this is really a more earnest initiative in terms of design. Where do you apply your design skills? Are you applying it for style or are you applying it in a way that it has a real sort of contribution to the benefit of the building? There are people that might pursue it as fashion, but I don't think that is what has been motivating it to date." — Designer

Others conceded that advanced facades are popular because these facades convey a readily identifiable image or new design aesthetic of environmentalism and sustainability. Clients who wish to present an image of environmental stewardship look to the façade as a means of communicating this image.

"Our clients wanted to be a leader in terms of technology. They wanted to let everyone look at an example of it and say "What is that?" in order to get some kind of consciousness of what they were trying to do in terms of energy and better work environments. It wasn't *all* image, but they wanted to have the representation of being a leader, of trying something… They wanted to try some things and be the first to really push that kind of technology." — Architect on use of double-skin façade

"For most of these systems, the payback is so long term that it really has to be for other reasons. That is why – maybe fashion or whatever the right term is – you will see more buildings take on this type of technology: purely because it is sort of a corporate statement they are trying to make. They can acknowledge that payback is somewhat irrelevant." — Engineer

"Most of our clients are interested in sustainability, but how much will they pay for that is the question. Generally, when you start to look at these advanced facades, they cost a lot more than conventional facades and the payback becomes very questionable. What it comes down to is whether that difference in payback can be justified with the *image* of sustainability that the client can use as a type of advertising cost. It only works if people can *see* it. If you can't look at the building and see that there is something about it and that is sort of a reflection of the sustainability, then there is not as much interest in it. So if you end up with a wall that looks just like a conventional wall, even though it may be more cost effective and just as sustainable as one that is more spectacular, it does not work in the total equation." — Architect

"So there is no problem within the architectural and engineering profession if the façade is conveying the *image* of sustainability and the building delivers on the image. The potential problem is that it conveys the image but it does not deliver. People are uncomfortable and the energy bills are high." — Researcher

"The question of image comes to bear if you look at the market for the rehabilitation of 60's and 70's speculative office buildings where all the window walls are coming due. A commercial building is valued by its façade design, its lobby, its elevator lobbies, and elevator cab, and then, of course, by performance. One that comes to mind is an old building which went from a half-rented, smelly old building to a Class "A" building that is fully rented and in demand just because of the façade and those other elements. This can be done with half the cost of a new building, but what is even more important is that you can't build in those same places with that same kind of building volume anymore." — Architect

Some respondents explained that the trend started in Europe with the intent to deliver high-performance based on strict codes and standards for environmental quality (despite earlier buildings actually perhaps failing to deliver the stated performance). The current trend in Europe after the rage of double-skin facades being erected in the 1990s is more pragmatic, focusing on following through on performance claims. In the U.S., however, there is the "bandwagon" effect, where architects are interested in using such façade systems but there is general confusion as to the applicability of these façade types to different climate zones and building types. Engineers are able to convince the client to use such systems, based on improved environmental quality for instance, but then have the obligation of following through on such claims.

"In the first ten years [of the use of double-skin facades in Europe], these advanced façades were realized by star architects. It was a type of fashion so there was typically no discussion about costs. If you look at the RWE Tower (see Building Case Studies), it was not designed so that the additional cost would have to be paid back. It was more of a showcase: an advanced image of the company behind the façade. This was related to big names in architecture. Nowadays, unknown architects and investors are looking for this type of advanced facade for their new buildings. Now, suddenly, the cost factor comes in because they ask, "What will I have to pay in added costs and when will I get it back?" Now, by investing in the façade, you *have* to save in the mechanical system. Otherwise, it is really ridiculous to have both a double façade and a mechanical system — you are investing in both. So the client comes back and asks "Why?" or says "Just eliminate this advanced façade and keep the mechanical system." It is clear that the additional investment in the façade has to pay for a reduction in the mechanical system. In Europe, if you design the building correctly, you don't need mechanical ventilation or mechanical cooling and this depends a lot on the façade. If you do a good façade, you are done with all aspects. With unknown investors, they say "OK, with the competition in the market, it looks like we have to offer a heated, cooled, ventilated building at a minimal cost." — Engineer

"I think that we must recognize that there are psychological and sociological factors involved in the development of double-wall (air flow) facades in Europe — from a climate standpoint and the desire to have natural ventilation, to bringing more daylight into the workplace with more transparent facades. With natural ventilation, there are acoustical considerations to be dealt with as well as wind gusts and turbulence on facades that can be transferred to interior spaces unless they are tempered through the use of double-wall façades. When bringing this technology to the U.S., one must consider the significant climate differences from region to region as well as economic issues from a developer standpoint. Although these facades have the appearance of "high tech" and some may view their introduction into the U.S. as a trend with everyone trying to jump on the bandwagon, I believe their introduction is to try and get as much transparency in a building while meeting new energy codes. You can do a double-skin façade in a 50% opaque wall but I don't think that is the intent or direction architects will be going." — Architect

"I think that it is difficult in any of these discussions to nail down one system — the mechanical system or the facade — and attribute comfort to it, because obviously all these parts of the building are integrated and attribute to comfort. One believes that advanced facades do give better perceived comfort and I think that it has been demonstrated. Especially with the double-skin façade having ventilation and keeping surface temperatures very close to the mean radiant temperature of the room and thereby increasing your perceived level of comfort. Our clients have expressed an interest in that and these arguments

Solar shading, Berlin

have been successful. I think that in general what we are seeing is the tie back to this cost issue. Each of these projects requires substantial upfront effort on the part of the designer — which is why the term fashion is somewhat difficult to swallow. Fashion obviously won't build your building. We have to be fiscally responsible with our projects and our client's money, so it takes both the design, analysis and the engineering and then of course the financial engineering in the end, which is the biggest component that we try to provide our clients, to understand the total impact of the system over the life of the building, not just a simple payback." — Engineer

Convincing the Client

Premise

There are two types of clients (based on type and level of information needed to make a decision): a) the visionary client, who requires minimal information, and b) the pragmatic client, who requires substantial information to decide whether to proceed with innovation.

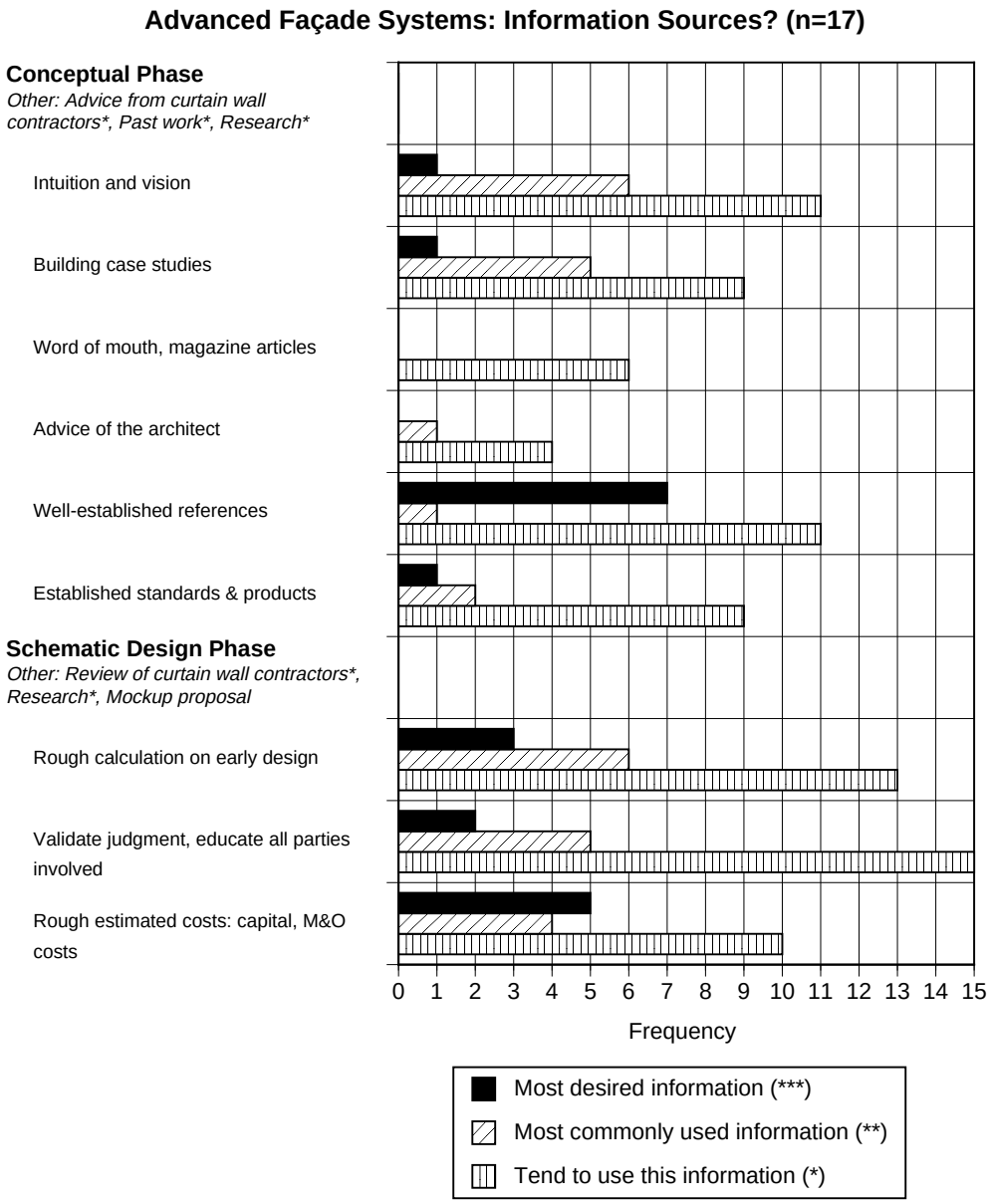
- What type of information is needed by the client to make decisions at each phase of design?
- For a single building project, is the client willing to invest in the types of engineering studies needed to obtain high performance?
- What is the degree of interest in the buildings industry to deliver a high performance product? Here, "interest" is measured by investment in design, engineering, commissioning, diagnostics, and maintenance toward high performance.
- What is the expectation that high-performance will be delivered?

Survey results

A single-page survey form was given to attendees to fill out after the discussion of this topic. The form listed various information sources that may be used to make decisions to use or continue to implement advanced facades at each phase of A/E design. The survey asked respondents to 1) check a box if they tended to use this information source for making decisions, 2) circle the single most commonly used information source, and 3) put a star next the single most desired information source, if available.

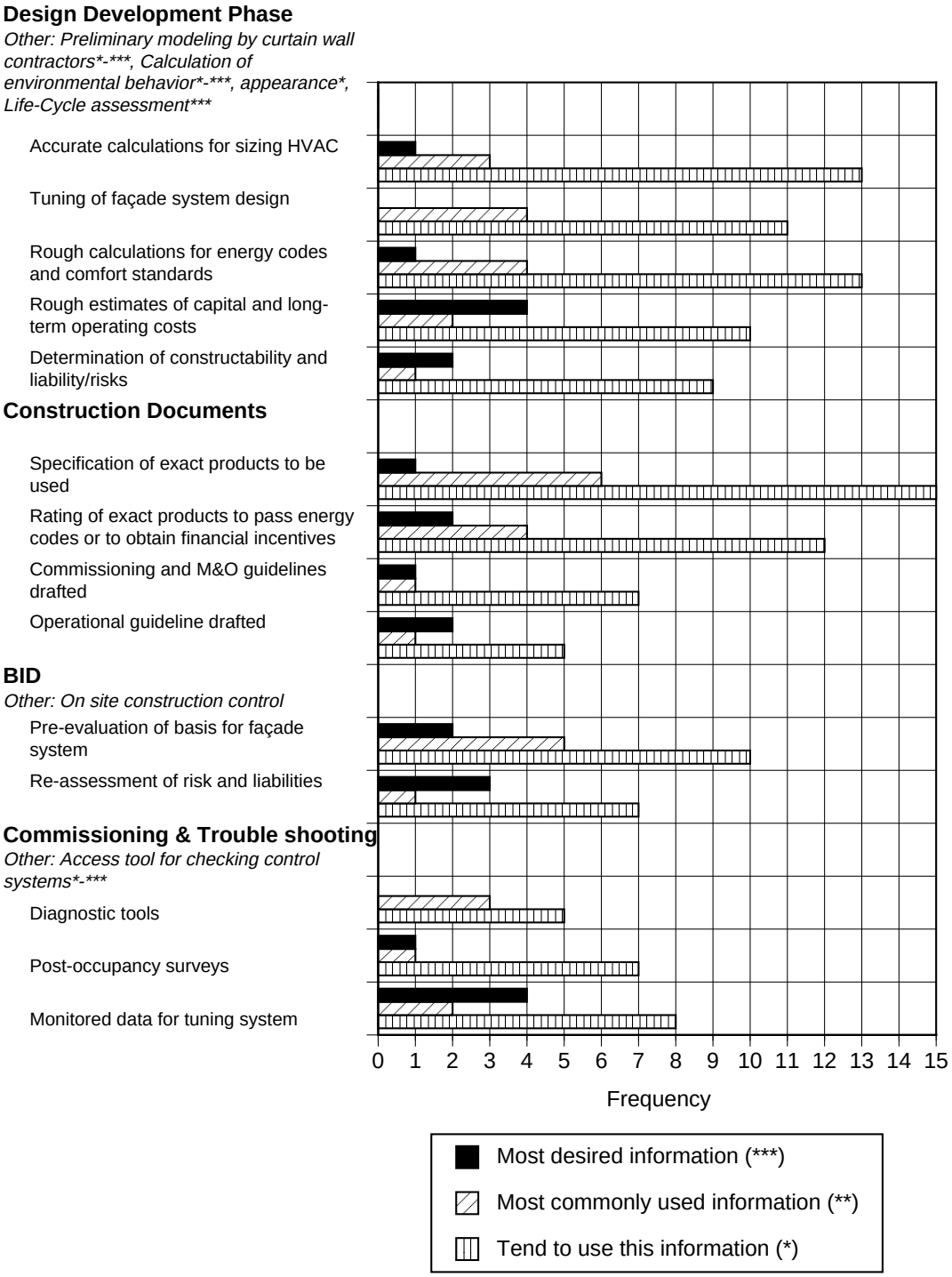
Several options were given for each design phase (see Figure). The options of citing and rating other reasons were also given. Of the total responses (n=17), the following was determined:

- 41% (n=7) thought that well-established references (third-party assessments, monitored data, surveys) were the single most desired information source, if available, in the conceptual design phase.
- 29-35% (n=5-6) thought that intuition/vision or building case studies were the single most commonly used information source for making decisions in the conceptual design phase.
- 65% (n=11) tended to use intuition/vision or well-established references (third-party assessments, monitored data, surveys) for making decisions in the conceptual design phase.



- 59-76% (n=10-13) tended to use rough calculations and estimated costs to make decisions, with 29% (n=5) citing that this was the single most desired information source for making decisions in the schematic design phase.
- 88% (n=15) used sources of information to validate judgment or educate all parties involved in the schematic design phase.
- 24% (n=4) cited rough estimates of capital and long-term operating costs using whole building annual performance calculations as the single most desired source of information needed to make decisions in the design development phase.
- 24% (n=4) cited rough calculations for energy codes and comfort standards or tuning the façade system design as the single most commonly used information source to make decisions in the design development phase.

Advanced Façade Systems: Information Sources? (n=17)



- 88% (n=15) tended to use specifications of exact products to make decisions, 35% (n=6) cited this as the single most commonly used information source, and 6% (n=1) cited this as the single most desired information source for making decisions in the construction documents phase.
- 70% (n=12) tended to use ratings of exact products to pass energy codes or to obtain financial incentives, 24% (n=4) cited this as the single most commonly used information source, and 12% (n=2) cited this as the single most desired information source for making decisions in the construction documents phase.
- 59% (n=10) tended to information sources that allowed one to re-evaluate the basis for the facade system and interdependent impacts if eliminated to make decisions, 29% (n=5) cited this as the single most commonly used information source, and 12% (n=2) cited this as the single most desired information source for making decisions in the bid/value-engineering/construction phase.
- 47% (n=8) tended to use monitored data to tune the system, 12% (n=2) tended to use this as the single most commonly used information source, and 23% (n=4) cited this as the single most desired information source for making decisions in the commissioning and troubleshooting phase.

Overall, individual responses indicated that all categories of information given in the survey form tended to be used to make decisions. In the early conceptual design phase, individuals relied most strongly on intuition/vision or building case studies to make the decision to proceed with advanced façade concepts, but many cited well-established performance data as the single most desired source of information. In the schematic design phase, rough estimated costs stood out as the single most desired source of information. In the design development phase, rough estimates of operating costs using whole building performance calculations were the single most desired information source. In the remaining construction documents phase, bid and value-engineering phase, and post-occupancy phase, very specific information about exact product ratings, risk/liability data, and monitored data were cited as the single most desired information source.

There was some ambiguity in the way the survey was constructed and interpreted. Respondents may have projected what sources of information they would tend to use if they had to make decisions about advanced facades. Many opted not to specify the single most desired information source, so the response between various reasons in this category may not be deemed significant (n<3-4 typically).

Individual Responses

The focus of this round table discussion was less about what types of information are used to convince the client to proceed with advanced facades and more about how to cover the costs of following through on the design of advanced facades. The presumption of most respondents was that the added costs were for the added engineering needed to deliver high performance (i.e., environmental quality, energy-efficiency, cost-effective products, products that do not incur liability). The difficulty for U.S. architects and engineers is that the client rarely had the added budget to cover such costs, either because they didn't' understand that such systems required extra fees or because some client's budgets didn't allow for life-cycle savings from operations to feed back into the capital budget. On the other hand, European clients are willing and

able to cover the costs of advanced facades because of their interest in long-term building performance and in keeping facility operating costs low (energy prices are substantially higher than in the U.S.). Some used the U.S. Green Building's Council's LEED (Leadership in Energy and Environmental Design) Building Rating System as a means of convincing the client to pay extra fees. Others have used utility design assistance programs such as California's Savings-by-Design program. Performance-based fees were also discussed.

"We are offering an additional service and we typically argue that we need to relate the façade to the behavior of the building as a whole investment in the building. It is a kind of convincing process to invest in better design. It is interesting that compared to the American market, in Germany, clients pay maybe double for the design than they would pay in the U.S." — Engineer

"I think that it is easier to try to convince a client to cover extra fees resulting from trying to follow the LEED program for sustainability than it is to go ahead and say that we will try and design an advanced façade and I need more money for it. I think that there is a big difference in terms of perception from the client's standpoint. They don't understand why the design of advanced facades and mechanical systems needs more money. They don't see that as something separate from what we normally do. But when we start talking about sustainability and following LEED and trying to get platinum and silver ratings for the building, that is something perceived as being extra. Even with that, we are faced with clients coming back and saying, "But that is why we came to you, that is your expertise, that is the better design that we get by going to architects like you." So even there we are facing difficulties." — Architect

"I think that a lot of people talk about sustainability and LEED as a reason to use advanced facades, but we still come back to the cost issue. I know of a couple of experiences where we have been trying to work with a double-façade on a museum project. The cost issue still is far and foremost for clients. Architects really need performance information and need to become articulate in that information because the more we can integrate the design with the performance of the building, the less likely we are to lose some of those design elements in value engineering. I think that we have a tendency in value engineering to pick things off. The more integrated we make the design with the facade or mechanical system, the less likely it is to lose them in the design process. That is really the essence of integration — designers can promote their fashion or design statement at the same time as they are promoting the performance of the building and articulating that with the client. Which then leads to the sustainability. You can start to then sell the client more on sustainability." — Architect

The following comments reflect the difficulty of dealing with institutional clients who have the desire but not the funds or infrastructure to follow through on high-performance design.

"I think that the Universities and some of the jurisdictions are now including, "Thou shall do everything that you can to be sustainable," but they don't have the money to do that. So in effect, they are kind of getting off the hook by saying that they want to be sustainable, but when you start presenting them with what it will take to get there or some of the upgrades that the design needs or the additional money needed for commissioning, there is quite a bit of reluctance to take money from what they perceive as their short-term goals to look at these long-term issues. That is the dilemma: long-term life cycle

Renovation of a historical facade, Berlin

assessment versus short-term turnover. I think that the challenge is to try to deliver substantive, life-cycle information to clients. Especially for universities and institutions with long-term ownership. I think it is just a matter of education and politics. I think that it is coming, but it is not there for us yet." — Architect

"With institutions like universities, first cost is everything. With institutions, capital funds come from one pocket and operating funds come from another pocket. So if you can pay back in the first six years, there has to be a way for these funds to come back to capital programs, not to be absorbed in the general fund. There is pressure to bring facilities and capital programs back together. Most State university institutions now compete with each other." — Architect

California's Savings-by-Design program seemed to be readily embraced by clients and the design team. Performance-based fees (explained below by a respondent) posed more problems. One respondent suggested that substantial engineering could be covered by the manufacturer, who can then take that knowledge and apply it to other building projects, but in fact that most manufacturers do not chose to invest in such expertise.

"We have been able to use the Savings-by-Design program that is sponsored by the utilities here in California to cover added design costs. There is an understanding that making a building perform better takes more work in the design phase and may cost more. I am totally in support of the utility's decision to split the cash between the design team and the owner to help look at not only some of these advanced facades, but all kinds of systems that could help reduce your energy demand. This type of program has helped us carry the cost of some of the extra engineering associated with determining upfront whether different technologies are appropriate for the building and proving whatever performance criteria we might want to achieve." — Engineer

"Performance-based fees is a concept where the A&E team gets some standard fee to produce a building that meets some performance requirement. If the building performs substantially better than expected, implying that extra effort went into the design, the fee is increased, but if the performance is lower than expected, then there is a penalty payment. One of the difficulties is that the A&E team may have little or no influence on the operation and occupancy of the building a year or two after the design is complete, so there is some serious risk there. You have to carefully think through what the metrics are, how do you bench mark that, how do you determine and normalize what the performance is for that building compared to a simulation you did three years ago using a weather tape and other assumptions. It is an interesting approach that begins to open up the possibility of fees that could be greater than they are now." — Researcher

"Performance-based fees have always struck me as a little odd. Now I have someone paying me to do something. Is that in the best interest of my client? Am I always going to be listening to my client or am I going to be listening to the energy company when decisions have to be made? Is there a conflict of interest there?" — Architect

"In our case, the client and the design team were both interested in getting whatever money we could to help better the building. I haven't found the Savings-by-Design program particularly onerous except that you do have to do the energy modeling to show that you use a certain percent less than a normal Title-24 building. We probably would have done that anyway using

the performance method of meeting Title-24, so we just fill out another piece of paper and write up a report that gets submitted to the utility. I don't think that is an antagonistic relationship and I don't think that there is a division of loyalty." — Engineer

"With the more elaborate systems, particularly point-supported glazing and double-skin facades, the engineering is so complex and so expensive that the manufacturers often pick up the engineering aspect of the job and do it for the client. If environmental issues are what is really driving the advanced façade, I think that we would be seeing more interest on the part of the manufacturers to pick up some of the additional engineering design that goes into making these facades work on an environmental level. We are not seeing that." — Architect

Critical Needs

Premise

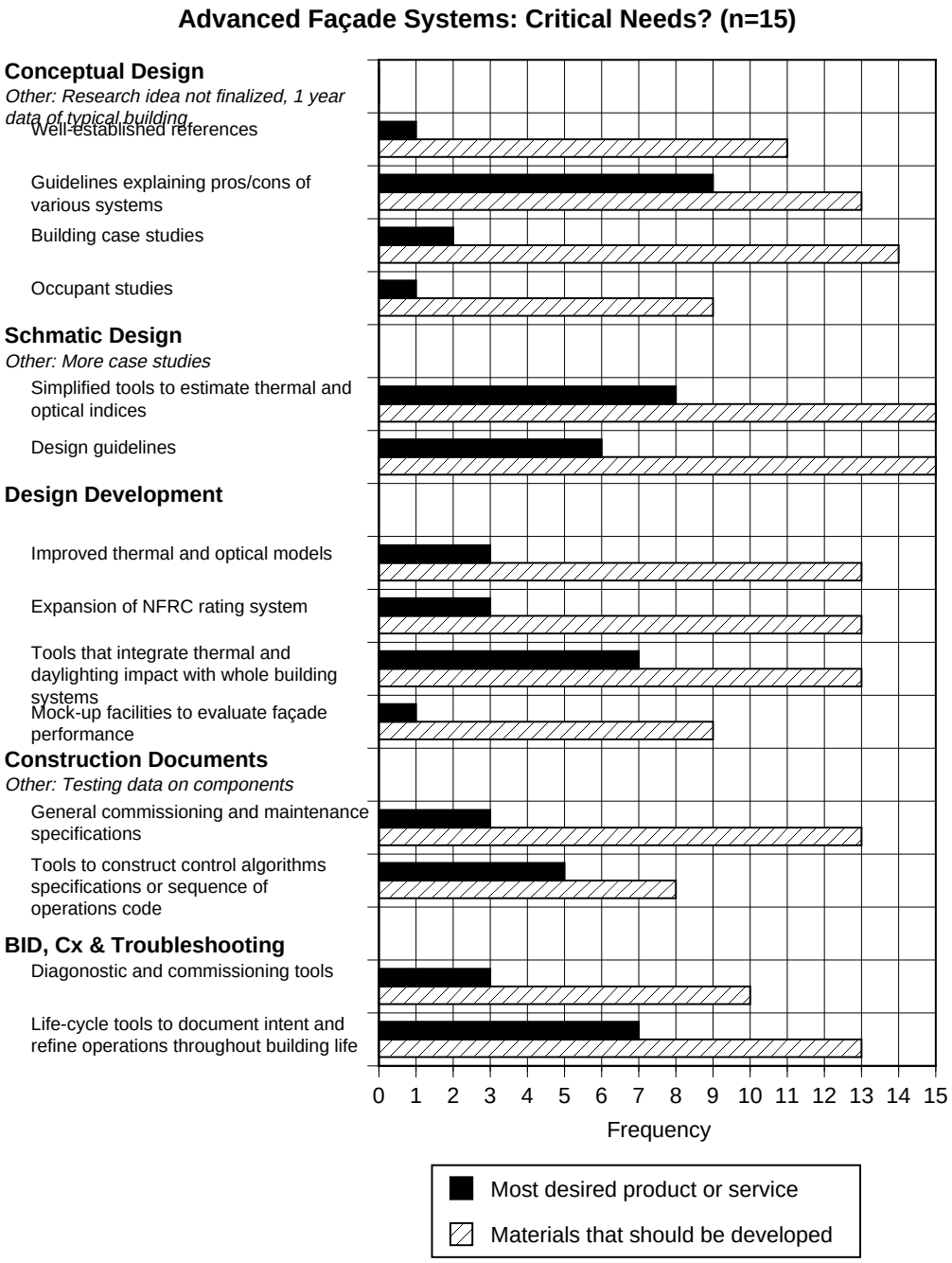
With more complex integrated façade systems, design and engineering requires the involvement and expertise of multiple disciplines to optimize whole building performance. This diverse design team needs to have various critical tools and information sources at their disposal to quickly narrow down the range of acceptable solutions. We posed the question of what are the critical needs of this design team? What are the short-term and long-term needs and what is their relative importance?

Survey results

A single-page survey form was given to attendees to fill out after the discussion of this topic. The form listed various products and services that may be developed (or further developed) to facilitate use of advanced façade systems at each phase of the design. The survey asked respondents to 1) check the box if they would like such material available for use, and 2) circle the single most desired product or service.

Several options were given for each design phase (see Figure). Of the total responses (n=15), the following was determined:

- 60% (n=9) thought that guidelines explaining the pros and cons of various systems for different climate zones were the single most desired product, while 87% said they would like this material available for use in the conceptual design phase.
- 53% (n=8) thought that simplified tools to estimate equivalent thermal and optical indices of advanced facades was the single most desired product, while 100% said they would like this material available for use in the schematic design phase.
- 40% (n=6) thought that design guidelines was the single most desired product, while 100% said they would like this material available for use in the schematic design phase.
- 47% (n=7) thought that tools that integrate thermal and daylighting impact of facades with whole building systems was the single most desired product, while 87% (n=13) said they would like this material available for use in the design development phase.



- 33% (n=5) thought that tools to construct control algorithm specifications or sequence of operations code was the single most desired product, while 53% (n=8) said they would like this material available for use in the construction documents phase.
- 47% (n=7) thought that life-cycle tools to document intent and refine operations throughout the building's life was the single most desired product, while 87% (n=13) said they would like this material available for use in the bid, commissioning, and troubleshooting phase.

In the early phases of design (conceptual and schematic), most respondents desired explanatory products and services (guidelines, well-established references, building case studies (to better understand the application, uses, and pros and cons of advanced façade systems. In the latter phases of design (design development and construction documents), most respondents desired tools, simulation models, and mock-up facilities to better quantify the impacts of the design on whole building performance or to implement such designs properly (e.g., control algorithm specifications). Other tools needed for compliance were also desired (thermal-optical indices, NFRC rating procedures). For the bid and post-occupancy phases, diagnostic and commissioning tools were also strongly desired to ensure proper operations throughout the life of the building.

Individual Responses

Individual responses focused on the need for easy-to-use simulation tools. Full-scale, on-site, outdoor mock-ups of the façade and their adjacent building zone also played into the discussion, possibly because the use of mock-ups in Europe differs so substantially from the U.S. The use of simulation tools to assist with building diagnostics was also discussed.

It was evident from both individual responses and from private discussions that architects and even engineers were unsure of the value of applying these advanced façade concepts to their specific building or to regions within the U.S. This confusion surrounded primarily double-skin façades.

"The advantage in Germany, with double-skin facades, is that you can eliminate the air- conditioning and heating duct work and just have ventilation air, because people will accept ventilation air coming through the outside wall. This does not work in some regions of the US because there is too much humidity and condensation. There are a lot of issues that are specific to our climate zones that are not applicable to Germany, so we really don't know how these things operate here in a lot of cases." – Architect

"I don't think that we have done a good enough job of really looking at these different [performance] metrics for these types of structures in the different regions. Because they are *not* all applicable. I think that it has created a lot of confusion among clients and architects alike." — Engineer

"I am kind of on the other extreme [from European design solutions]. In Phoenix, you are not trying to grab a little piece of light, you are dealing with massive amounts of it. I think that a lot of it comes down to "Where is the best place to do these different systems?" One hundred percent outside air is very, very important. Is the façade the appropriate place to do that? I really question that I can have a building in Phoenix that will survive without a mechanical system." — Architect

With a whole building systems approach to analysis, engineers are finding that rules of thumb must be discarded for a performance-based approach to gain compliance with the energy codes and to understand and optimize the design. Because of the time involved to understand which façade systems are applicable and how various building systems work together, respondents wanted tools that were very easy to use (good user interface), sufficiently accurate, and gave reliable guidance in the very early stages of design. Several mentioned the need for a 3D interface between CAD and simulation tools to reduce costs and time.

"I think that one of the key things for reducing the cost of design for innovative buildings and innovative facades is again that the tools need to get better

for us. As the tools increase their usability, accuracy and precision, we will have a better opportunity to sell these ideas to our clients. Reduce our time and energy spent in improving the somewhat unproveable and that will lead to better integrated buildings." — Engineer

"When we are diving into sustainability and integrated buildings, we essentially have to abandon the rules-of-thumb approach to design. With our practice, we deal with projects all over the country and all over the world, so each job is essentially a new learning experience for that particular application. Whole building performance simulation tools like DOE-2 and EnergyPlus are really useful to us in quantifying the benefit we get from each system. It is going to require a substantial amount of learning and work on the part of the designers to put these tools to use on particular projects. Many of our colleagues at this round table event know this from experience: applying these advance facade technologies takes a lot of upfront effort. With one of our projects, it took 110 permutations of DOE-2 analysis for us to really understand what was happening dynamically with the building. We were able to quantify the results and provide the data to our client, and this gave us a leg to stand on as far as the life-cycle costs. I think that developing the whole building approach is really going to be the key here in the future, especially with compliance, because these advanced technologies and buildings that we are designing do *not* fit the prescriptive requirements of energy codes. We are always on the boundaries and we are always required to demonstrate essentially by performance. We should be developing the tools in those directions to aid us in doing this quickly, more efficiently and cheaper so that we can be good-quality architects and designers as well as profitable." – Engineer

"Additional tools (software programs) need to be developed for use during the schematic design phase, that enable the architect or engineer to analyze quickly three or four design alternates providing a level of assurance that one is going in the right direction from an energy standpoint." – Architect

"When you are looking at a fairly complex problem in schematics and you use a simplified tool, do you have the confidence that the simplified tool captures the complexity of performance that real systems have? What you don't want is to be pointed in a direction by a simplified tool and then six months later, as you get further into design, find out with detailed analysis, that it won't work and you start all over again." – Researcher

"The bottom line of what we are looking for is typically dollars. What are my energy savings? What is my increased first cost? What is my payback and what is my life-cycle cost? We are talking about energy tools with the precision of billions of BTUs. Our final result is hundreds of thousands of dollars or a million dollars in energy costs in the end. You have to ask yourself, "What is the accuracy required for this project?" Some projects require full accuracy. We try to measure it with as much precision as we can get, but there are other projects where it is simply not required. A general understanding of the energy use of the building, a simplified model may be sufficient." – Engineer

"I think the advantages in energy engineering is that we don't necessarily have to have a complete set of documents in order to have a more accurate picture of what the building is doing. We have a lot of bases of knowledge. We can model very accurately with less information today. I think that the key would be to have a sophisticated, accurate precise tool with a very simple interface. We don't necessarily need to simplify the assumptions or to simplify the quality of the information that we get from our computer tools, because

Automated louvers on a skylight system, Technology Museum, Berlin

the technology is already there. We need to simplify the application of the tool. When that is done I will be out of business, but I think that is the direction we need to go." – Engineer

"Most engineers don't mind the complexity associated with putting in a control sequence. But if it is complex to get 3D-geometries into the building, *that* feels like a waste of time. That is why the links with CAD are of particular importance to us." – Engineer

"It would be great if 3D information could be downloaded into some other analysis software, especially given the amount of changes that our designers like to make." – Architect

For those involved in dynamic system tuning, open code was also desired.

"Controls is a critical part of both the simulation tools and making advanced façade systems work in reality. What we have found so far is that with DOE-2 and EnergyPlus, there is not quite enough openness in the code to put in unique control sequences. The control sequences you have built into your simulations need to reflect that complexity of modes. Especially as we go to mixed-mode buildings, the software needs to be open enough and sophisticated. If the modeling tools don't allow you to do that, you do the 101 different snapshots, take all your snapshots and link them together, then make some predictions about how the controls perform." – Engineer

Fiber-optic array, Technology Museum, Berlin

The discussion on full-scale, outdoor mock-ups of the façade and their adjacent building zone began with their purpose in Europe: a) to verify overall performance (structural, weatherproofing, operations, energy) of the conceptual design over a period of a year at the building site, and b) to allow clients to view and fully experience the façade solution. Manufacturers will typically do mock-ups of the façade in the U.S. after the bid process, to work out physical details not verify performance. Mock-ups are also occasionally done to gain NFRC compliance in the U.S.

"Mock-ups are a serious added cost. In Europe, there is an awful lot of design time put in to developing software simulations of the building's performance, but ultimately there is at least two floors that are mocked up and tested for as much as a year in order to verify energy, structural, and weather performance." — Engineer

"In Europe, mock-ups are usually started during design development or in schematic design. This is a main point with these advanced facade systems: you had better invest this time in the design process rather than afterwards in the post-occupancy phase. In Europe, mock-ups are not done by the manufacturers. They are done by the design team or by test institutions, so it is more of an anonymous design solution not a specific product. It is more concept related rather than product related." — Engineer

"You build a mock-up on site so that the client can visit it weekly to get an impression of its performance. It is a fully equipped office with all the mechanical systems, so you get a feeling about this double façade, such as how it looks from the inside during different weather conditions." – Engineer

"In the US, we find that there is typically not enough time allowed in the construction process to do an accurate study of the mock-up. We are generally asked to compress the time to design a custom system, produce it, put it in a test chamber. Sometimes the building is even going up as we are still testing this exterior façade. I think we really ought to expand that time in order to get a better view of what's going on with this entire system. If we can consult with the architect ahead of time, generally we can get a decent schedule, but generally it is in the bid phase when we are presented with a set of construction documents, and if we are successful, then we go for the mock-up." — Manufacturer

"We would prefer selecting a curtainwall contractor very early in the project design phase and developing the double wall (air flow) façade in collaboration with the designers rather than independently, which may result in the bidding of these types of facades to contractors lacking the experience to implement them." – Architect

"With respect to NFRC (National Fenestration Rating Council) and current computer modeling available in the U.S., I do not believe the influence of air flow in a double wall facades can be modeled or tested." – Architect

In Europe, comparing simulated performance to measured performance is a fundamental issue to gaining client approval. Simulation tools rely on many fundamental simplifying assumptions and incomplete data. Therefore, prior to investing on the order of millions of dollars in a complex building system, mock-ups are also used to validate simulation data.

"When you talk about mock-ups of specific components in the building, we must remember that we are looking at an integrated building at this point. You would essentially have to build a building to mock up a building. So I think that computer simulation is the key because you have all the components at your fingertips. You are able to look at the interactions between the systems and most often than not, the advantages and disadvantages in the building are counterintuitive. When you look at the building and how it interacts with the HVAC and lighting system it is often times counterintuitive." – Engineer

"Typically we evaluate the concept by simulation and then most clients are relatively skeptical. There are nice pictures and colors if you show CFD simulations, for example, but who believes it? If you are constructing large building projects, the investors are quite critical. Often they come in and say, "Couldn't we prove this with a test?" Then it is easy in Europe to convince them to invest around $50,000 to $100,000 dollars for such a test." – Engineer

The difficulty of applying such data from either mock-ups and simulations to generalized guidelines in other climates and situations was discussed, emphasizing the need to combine the benefits of simulation tools with measured data.

"In one project, we established a protocol for testing and measuring the performance of daylighting systems in test rooms and I think five or six countries built test rooms and tested various systems in each room in each country. That was the good news, that you actually have some real performance data. The difficulty is say, the Norwegians tested an interesting light

shelf at their latitude for six months one year and now I am in Berkeley trying to figure out whether the Norwegian data can be transposed in some way between climates or latitude and so on. The answer, of course, is not without great difficulty. Which is where the tools come in. I think that there are tools for characterizing instantaneously the performance of the system. I think that some combination of those tools plus a snapshot of measured data is where we are heading." – Researcher

"A lot of these solutions are not static solutions. They are dynamic solutions. There are whole issues of operations in control sensors. Are they automatic or manual? How do you maintain performance over time? If you have a system that is dependent on something, such as louvers blocking direct sunlight, how do you get it installed right, commissioned and insure that over time it really works? History in the US is that there is great skepticism on the part of owners that it really works. Dynamic operation and user occupant interaction with controls are huge issues from my point of view with all these advanced systems. The tools need to be able to capture, in part, the dynamics of that performance and, if it is an occupant-operated system, how the occupants will use the system." – Researcher

Finally, the discussion focused on post-occupancy performance . The following questions were raised but not fully answered: a) do we want to know how the building is actually performing (exposing oneself to potential liability) and b) can simulation programs actually applied in all practicality to on-site commissioning, diagnostics, and tuning of the system?

"One thing to remember with LEED is that it is a certification of the design, not the product. It is a tool for us as designers to take ourselves to the next level, not necessarily as a control quality assurance issue for the building as a product. What happens when you find out that your façade isn't performing properly? What do you do? Who's liability is it? Do you want to find out?" – Researcher

"For the last question, the answer is clearly "yes", because you are either wasting energy and money or you are making people uncomfortable and less productive. The answer to liability and what do you do isn't quite so simple." – Researcher

"There is some movement to take some of the design tools, and make it into an on-line emulator that could be part of operations. You have spent all this time and energy into modeling and doing design optimizations, so why not put that knowledge into the operations of the building? With online diagnostics, it collects data, compares it to what it should do, and when it sees a discrepancy it can try and figure out what to do." – Researcher

"If you specify the control system, there is the general contractor and then the first sub, second sub or third sub who will finally translate this into a controls program. This is horrible! What you get back has nothing to do with the specifications. At this point, we are in the stone age, transferring from a kind of scientific design into a real control system." – Engineer

"There has been some research recently that has shown that while all the energy simulations programs have good agreement between each other, they don't necessarily have good agreement with reality. My question has always been, "Should we be benchmarking against our simulations or should we be validating our simulations against what's happening in real life?" In either case, having enough complexity in the programs is necessary to do it in either

direction. What kind of commissioning process should there be for a naturally ventilated building or a building that spends some of it time in a naturally-ventilated mode? Certainly there is no international standard for that." – Engineer

"It is the whole argument between precision and accuracy. Our tools can be very, very precise and horribly inaccurate. I agree with what you said exactly. That we should be configuring our tools to match reality rather than necessarily achieving some ideal operation." – Engineer

"I see two problems generally with these sort of things. First, it usually costs money to find out what the performance really was and that is often lacking, and the second is that invariably, especially when you are a leader and trying to do something new, usually things don't always go the way you thought or hoped. It is a question of "Is there a way of bringing that out in the open and discussing it in a proactive positive way as opposed to some how feeling that it is exposing any possible flaws?" It seems to me that the history in some of the large façade problems that we have seen in the states in the last 20 or 30 years is that they get settled in law courts. Understanding what went wrong is sealed in some kind of settlement and the rest of the profession does not have the opportunity to learn. There should be a feedback loop where we would all get to learn from each other. That is a challenge." — Researcher

Workshop talks given at Southern California Edison

The following 20-minute talks (followed by 10-minutes of Q&A) were given at the Customer Technology Application Center of Southern California Edison in Irwindale, California on April 30, 2001.

1:00	Welcome	Gregg Ander, SCE
1:15	Architectural trends with all-glass facades	James Carpenter, NY
1:45	Façade as ventilation device: Integration throughout the design process	Erin McConahey, Arup
2:15	Advanced glass facades: A look to Europe	Matthias Schuler Transsolar, Stuttgart
2:45	Convincing the client: A double-envelope façade at the Seattle Justice Center	Kerry Hegedus NBBJ Architects
3:15	Advanced façades research: Recent activities	Stephen Selkowitz, LBNL
3:45	Concluding remarks	Gregg Ander, SCE

Some talks, PowerPoint presentations, and/or images are included below with the permission of the speaker. For others, we have provided links or references that capture the essence of the speaker's talk.

James Carpenter is a sculptor and principal of James Carpenter Design Associates in New York, New York. As an artist, he is considered to be a foremost innovator in materials technologies. For more than 30 years, his work has focused on the exploration of light as a means to bring form to structure and reveal the environment. Mr. Carpenter has worked collaboratively with major architects in the U.S. and abroad on significant building projects. A recognized expert in glass technology and materials, Mr. Carpenter has consulted with glass companies such as Corning, Pilkington, and Schott. He is a graduate of the Rhode Island School of Design and an adjunct professor teaching structures at the University of Pennsylvania. http://www.jcdainc.com/

James Carpenter

The discussion this morning was quite interesting in terms of bringing people together from around the world that share an interest in the development of glass wall systems. Their focus has of course been on the predominant European development of double wall façade systems. The following speakers, Matthias Schuler and Erin McConahey from Ove Arup will be speaking on more technical issues and I thought that my role today, somewhat prompted by Eleanor Lee's comments this morning about "Is this whole drive for double walls really simply a *fashion* or is there an underlying desire to seek performance out of these walls and the understanding of what is driving the motivation for these walls?" I thought that I would talk about this issue of fashion or function, rather than undertake case studies of buildings. It would be important today to talk about these facade developments because it is extremely critical as to why these things are happening in our time, meaning over the last ten years. Historically, I think that we have to remember the very earliest double wall systems came from this country. Specifically, the Hooker Chemical Building in Niagara, NY was a very early example of an extremely deep wall system with internal blinds that existed as a lone example of double wall construction for many years. It is a very elegant building, certainly a generation ahead of its time. That building, in fact, has served as an example to many people in Europe as the potential model upon which to pursue these more environmentally focused initiatives of double-wall construction.

Coming back to the specific issue of fashion, it is a word that trivializes the effort being expended in this area by serious architects, but certainly, as with any change in a fundamental approach to building, less sincere practitioners will exploit only the visual characteristics and not environmental or cultural aspects. I think that it is more than fashion driving facade development today. Industry, over the last ten to fifteen years, starting with the low-E work done in Scandinavia and the eventual sort of rise to acceptance in this country through LBNL's, Southwall's, and the efforts of other manufacturers, have improved the performance of glass coatings to the point where we are very comfortable entertaining large areas of glass facades. This trend is a rejection of much work in the 70's, which relied heavily on heat reflective coatings or heat absorptive glasses, to answer solar issues. There is currently a rejection of the methods of construction of those decades and one now sees the reemergence of modernism and its entendant embrace of transparency. It is a rejection of post modernism and a reemergence and a reinterpretation of modernism. That is not so much a fashion as much as a philosophical and aesthetic undertaking that re-states philosophical arguments that were very much in the forefront of societal discussion at the turn of the last century. That discussion focused upon the openness of buildings to enhance interchange of the individual with the public and how urban environments can be more open and communicative in terms of their functions. I think what is really driving this is a coupling of industry developments and a reemergence of a more social agenda, an agenda that attaches a significant value to the energy used being part and parcel of that social agenda.

Bicton Conservatory, England.

Of the slides I have with me, I tried to cobble together a talk that might reflect some of these concepts. Obviously let's start with one of these earlier images - an image that we are all probably quite familiar with: the Bicton Conservatory in England which in the late 1840s represented one of the most extraordinary examples of glass structure and transparency in architecture. Comparing that building of 150 years ago to a very current building, the Peter Zumptor building in Bergenz, Austria, which is, in fact, a double wall construction but the double wall construction is different from the type of wall we have been discussing this morning. We have been talking about double wall systems, where you have cladding systems on a building and how you can control large-scale office environments with double wall construction. But this example is a pursuit of the double wall purely for an aesthetic goal and then underlying that is the energy issue. But, I think that this idea of working with glazing and information is part and parcel of this desire to pursue double wall cladding. In the double walls, we refer to them as screen walls or image walls or information walls, however those layers of information are presented to us and however they happen to be performing thermally, they are an enrichment of our day-to-day environment by the superimposition of these reflected images and how we both look out through these glass systems and how those glass systems inform our environment of both the urban environment as well as the green space environment.

Library Museum with ceramic fritting by Herzog/ deMeuron.

This is a Herzog / de Meuron project, which uses ceramic fritting. We are all familiar with an effort to reduce the light transmission of the glass itself, but in this case they are using the fritting pattern not as some abstract dot pattern, or linear pattern but they are quite literally imposing images of a collection (this is actually a library museum) and they have basically taken elements from the collection itself and imposed them on the surface of the building so it becomes a way of combining an informational role in terms of the building as well as its weatherproofing and it's enclosure for environmental performance simultaneously.

So I think there is this other level of thinking about double walls that we did not get into today as much as we might have, which is this drive for pursuing and exploring transparency and luminosity as a means to communicate the buildings' function which is something that has been lost in much architecture in recent years. The communication often is relied on in more historical attitudes or styles, where now I think we are re-embracing a modernist idea where you can let the building speak to the complexities of image and information that we are surrounded with through all different media.

This is an unusual building that is built out of regulet glass. These are structural glass "C" channels used predominately for industrial buildings. In this case, these regulet elements and the main office part of the building sleeve each other to form a double wall construction for the insulative characteristics.

This question of whether it is fashion, aesthetic, or purely thermal performance has to do with the rationalization of the cost for these systems. If they are seen exclusively as a mechanical device to improve performance, it is, as we all know, an almost impossible task to justify these walls financially over a short period of time. It takes a very, very long period of time for these systems to pay back their initial cost. However, if the design is coupled with a stronger position of the aesthetic and how it is operating in a broader social way, I think that the payback is a secondary question rather than a primary question. In order for us to explore these walls in this country, there will always have to be a broader base upon which to justify cost. We are never going to be able to make the case with our energy being so cheap that these systems can pay themselves back in any sort of a short time frame.

Bank in Berlin.

A subject brought up in this morning's session that is really critical in terms of thinking about these systems is that we are often thinking that double walls always need to be new buildings. Quite the opposite. I think that there are some extraordinary opportunities for using double wall systems in the recladding of existing buildings, whether it is a historical building like this example, which is a bank in Berlin, and improving its thermal performance, or whether it is recladding an existing building. An example of this is a 50's building shown here in LA or some very successfully reclad buildings in Germany. One example in Dusseldorf, which is the Stadtsparkasse building that was done by Christoph Ingenhoven, takes a 1960's building, strips the entire building down, reclads it with a double wall system and remakes the building. The building has become an entirely new structure with vastly improved thermal and daylighting performance and an entirely new, contemporary image. The client was able to reuse the frame of the existing building of a height that would never be allowed again in that particular location; if it was to be torn down and rebuilt, they would never be able to regain that original height. They were able to turn it into an entirely new space. These recladding ideas are potentially more significant than new construction opportunities and there may be another avenue for analyzing these double walls in the area of a reconstruction.

Kunsthalle, Bregenz,
Austria by Peter Zumptor.

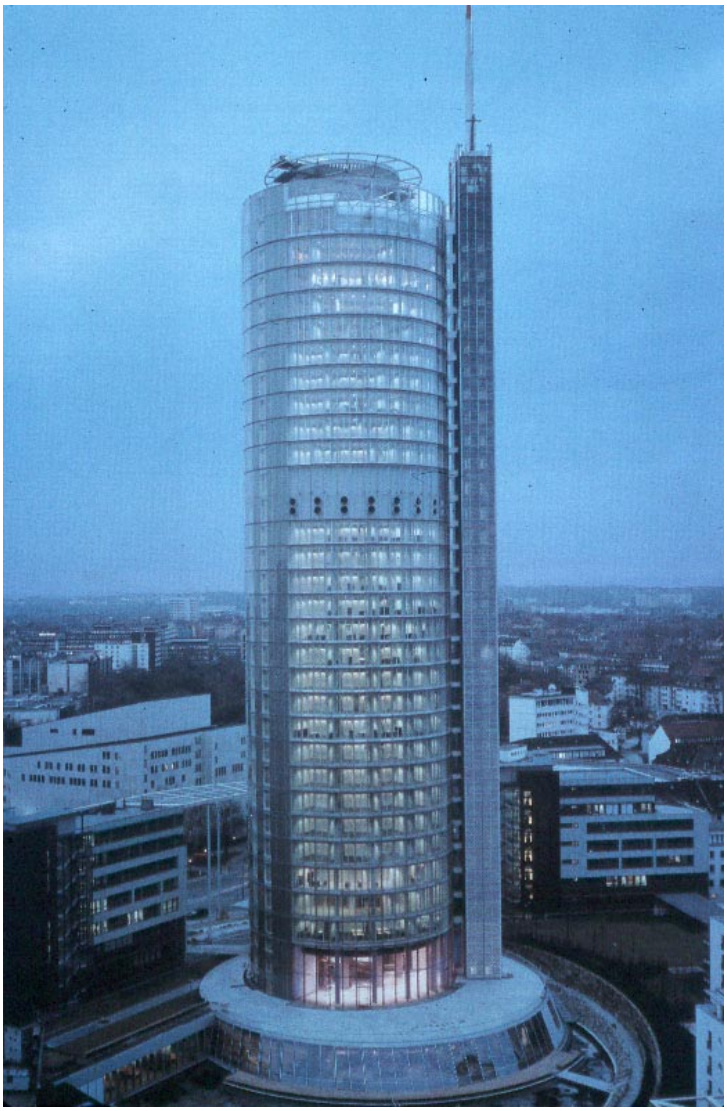
This is a building that most of you architects would certainly be familiar with: the Kunsthalle in Bregenz, Austria, a building by Peter Zumptor. A very simple idea, a concrete frame building very carefully made on the inside with the exterior of the building wrapped around this internal frame. The circulation for the building is inserted into the cavity between the layered or lapped glass skin and the concrete frame of the building. One sees the people walk up through and behind this skin, all the circulation is around the perimeter and you proceed into the exhibition spaces, inside the building. A very remarkable object that is a perfect cube, a cube of ice that sits on the lake in Bregenz and the construction of it is such that there are very large lights and they are lapped in both directions, meaning lapped both horizontally and vertically, the intent here is that the skin is again providing a simple thermal buffer between the exterior climate and the interior climate. There is obviously a great deal of ventilation going through the lapping of the glass panels, as well as venting at the top.

Again, in an animated way, this building activates itself within its urban environment by allowing for the presence of the visitors to be visible on the exterior of the building. In the evening, when it is all lit up and you have people moving through it, the building becomes an extraordinary lively object and I think this idea of reinforcing the participation of the building in it's urban environment rather than isolate itself from the urban environment.

Refractive glass wall, First Bank Place, Hawaii, James Carpenter Design Associates.

This image of an older project that we had done is in Hawaii. It is a wall for a building by KPF and it was a double wall building that was meant to translate light to the interior of the building, yet control the intensity of that light. Most of the images that I have been showing you have a double wall that affects its exterior presence. I wanted to show an example of how these types of structures could change the nature of light in the interior of the building. In this case, the clear outer skin forms a cavity, basically, that butts up against a translucent layer of glass that is bisected by a series of large prisms of glass that are the structure of the wall. These prisms transmit or project the daylight through the translucent glass walls to the interior. On the interior of the building, you experience a remarkable play of light while at the same time reducing the amount of heat that gets into the building itself. This is an example of how the double wall system or screen systems can work. Obviously, most of the buildings in Hawaii use very heavily coated glass from the 70's and 80's or a highly absorptive glass that appears opaque, creating an entire urban environment that is visually mute. You can't see into any one of the buildings in Honolulu and we were after just the reverse of that. Using the most transparent glass possible so that you look into the building and celebrate the unique qualities of light, visually opening the building to the public, engaging them with the internal workings of the building.

Essen, Christoph Ingenhoven.



Another example of a building constructed several years ago was designed by Christoph Ingenhoven in Essen. It is an example of the earlier types of these buildings and it prompted a lot of international attention focused on these double-wall systems. When you see this building in reality, it is extraordinarily small and has a very complex double wall system done by Gartner. This building serves as a touch point for many people in terms of double wall construction; an example of what might be done and how incredibly excessive this undertaking was. This is a building represents an extraordinary investment made on the exterior of the building for daylighting and energy conservation purposes; simultaneously this building, with a very, very small floor plate, has a fully-functioning mechanical system in it that would allow it to be operated with any type of curtain wall on it, including a conventional monolithic glass wall. It is a building that has a redundancy of systems and an extraordinarily small amount of floor area. It is an example of wonderful work spaces and provides this small town with an extraordinary urban identity, which is quite significant. That, of course, is one of the roles that these buildings have always played – that they serve as either a corporate or municipal role, communicating a unique, highly tuned agenda or identification for that company or that particular municipality.

This is the German Foreign Ministry Office in Berlin, a project we designed with Müller/Reimann Architects and with Matthias Schuler of TRANSSOLAR. We were involved in the curtainwall and roof of this building. It is a double wall system on a very different scale. The individual offices look into the atrium and then wrap around the exterior of the building. The windows are all operable but the additional layer of glass floats on the outside of the building and is there for both safety and security, as well as providing a buffer climate for the operable windows. So a double wall does not necessarily have to be full a cladding system. They can also function on a very small individual scale.

This last image is a way of using a double wall enclosure to allow for expressing a type of building that reads as a wood structure. The glass skin, providing the primary weather protection, allows for a reading of a luminous warm wood, inviting through this transparent skin. This is a goal that many architects are after. There is a desire for an enrichment of the urban and interior environments reaching out and communicating a message of interconnection with the environment, an engagement with our culture and daily experience. The initiative to pursue the double wall systems supercedes merely a fashion. Rather, it restates the architect's responsible role in advocating a transformation in our built environment and our cultural well-being.

Arup was founded in 1946 and it has grown into an international group of multi-disciplinary practices with nearly 6500 employees in 71 offices throughout the world. The ideals of founder Sir Ove Arup were, and are, driving forces within the firm. Foremost among his beliefs are "total design" – the integration of the design and construction processes and the interdependence of all the professions involved – the creative nature of engineering design, the value of innovation and the social purpose of design. Erin McConahey has been with Arup for 7 years: her first two years were in London England as part of the American Scholar program and the last five have been in the Los Angeles office, where she is currently a Professional Engineer working as an Associate in Mechanical Engineering.

Erin McConahey

A published paper will be available on the subjects presented in Ms. McConahey's SCE talk:

McConahey, E., P. Haves, and T. Christ. 2002. "The Integration of Engineering and Architecture: A Perspective on Natural Ventilation for the New San Francisco Federal Building." To be presented at the *ACEEE 2002 Summer Study on Energy Efficiency in Buildings: Energy Efficiency in a Competitive Environment*, August 18-23, 2002, Asilomar, Pacific Grove, CA and published in the Proceedings. Washington, D.C.: American Council for an Energy-Efficient Economy.

Matthias Schuler is a founder and managing technical director of TRANSSOLAR Energietechnik GmbH in Stuttgart, Germany. He has directed the engineering of many advanced façade buildings including the Deutsche Post Hochhaus in Bonn, Nord/LB in Hannover, and LVA Schleswig-Holstein in Lübeck. He currently lectures both at the University of Stuttgart and at the Harvard Graduate School of Design. He has published many popular press articles as well as co-authored the book "Glass Construction Manual". Mr. Schuler holds a Masters degree in Mechanical Engineering from the University of Stuttgart. http://www.transsolar.com

Matthias Schuler

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In older buildings, we had weather protection with a connection to the outside, fresh air, and external shading to control solar gains, which is now missing in buildings in North America. What we are looking for are solutions to meet thermal comfort demands and sun protection, light redirection that adapts to changing external conditions, noise protection and then a kind of rethinking of natural ventilation which was standard in buildings before they invented the fan. So if I could sum up what the facades of the future would do, they would do all of this and we could just hang a façade element when constructing a building and be done with all heating, ventilation, and cooling. This is the vision where I think facades will be in the future.

As an example, you have background research that shows that thermal comfort is more than just air temperature. It is also about radiative temperature. So if you have access to thermal mass, by getting rid of the suspended ceiling for example, you can increase or decrease the operative temperature, which is also mainly influenced by the temperature of the surrounding area. If you are able to cool the thermal mass actively or passively down, this acts as a kind of cooling supply for keeping your operative temperature down. This will then allow you to have the air temperature up at a higher level.

In terms of investments cost, however, there is a competition between a fully air-conditioned building and a naturally ventilated and naturally daylit building. With a naturally ventilated and daylit building, you are coming down from an operating cost in the range of $\$2.00/m^2$ to around $\$0.50$-$\$1.00/m^2$. On the investment side, you can drop down to a typical investment for the mechanical system in the range of around $\$200/m^2$ to around $\$50/m^2$, which means on the one hand you can save investment costs and on the other hand you can also save operating costs. I think that this is interesting; you can only be cost effective if you offset the investment you put into the façade. You have to save on the mechanical system to justify the cost of a double-facade system. You can't first build a fully air-conditioned building and then add an advanced façade. This will never pay.

Starting with a refurbishment building, this is a building from the 1960s in downtown Stuttgart. The intention of the investor was to save the money from mechanical ventilation and go for natural ventilation. The problem was the street noise level was around 65 dBA, which with manual ventilation would not be allowed by codes in Germany. So we added this kind of single-glazed screen glass façade on the outside, permanently ventilated, which allows us to drop the noise level down to the range of 8 to 10 dB. We are collecting data on how the real building behaves and we'll compare it to the simulation.

This is also a refurbishment, a university building in Mannheim. Originally, this was a glass-infill concrete structure, but after 20 years, the balconies were falling down and the building was condemned. This refurbishment involved just putting a single glazed screen façade in front of the original facade. The interesting thing is they kept the whole internal old façade, which increased the thermal behavior of the façade system with this kind of unheated buffer zone. You can keep the old façade and just add a screen on the outside. In this case, it allows us to go back to natural ventilation.

Kurkliniken Bad Colberg

Another example is a building located on a heavy, noisy street just four lanes, not the twelve that one sees in Los Angeles, so on the south and north side, we have this kind of buffer façade which allows natural ventilation. In this case, it is not cross-ventilated, it uses a chimney in the middle that takes air from the south and north sides into the building.

This IRS building in Stuttgart has a natural ventilation chimney in the middle of the high-rise building. You have this two-meter wide chimney, which runs partly as a supply and partly as an exhaust chimney throughout the building. There is a wind catcher on top of the building, which supports this natural stack effect with wind pressure. This building has been used for around five years and there is no air conditioning and no cooling devices. We kept the temperature in this case below what the German code is, which is in the range of 27-28° C.

This is a building which is realized in Shanghai, opened in last November. In this case, the façade is what we call a fifth façade, which is the roof. The single membrane roof allows daylighting in the exhibition halls during most of the year, only a part of the year are the halls really used for exhibitions. This translucent membrane gets very hot in direct sun, 50-55°C. So in this case, we developed with the manufacturer, Ferrari, a new membrane which has a low E-coating on the inside and a sort of printing on the inside which cuts the long-wave radiation.

This is a restaurant that is fully glazed and set in the middle of the woods. Their concept was to have lunch in the woods protected by glass, so not only the walls, but the roof is glass. We developed a kind of double-shell glass roof. The lower shell is not glass but a coated foil which serves a lot of functions. On one side, it is micro-perforated so it performs an acoustical function. It is low-E coated so it does not emit the radiation. It is fritted to provide shading; it also creates a buffer space to provide additional insulation during the winter-time. This is then combined with preconditioned outside air through the floor. This is very effective because you can take long wave or short wave radiation out before it heats up the air.

Now, a little more detailed example I want to describe is a new building just under construction in Bonn. I think that when you talk about advanced façade systems you should not talk only about the architect, but the design. This team should work very early together to create this kind of integrated concept, because advanced façade systems do not stop at the façade. They go deeper and influence the ventilation system and the conditioning system. If you don't create an integrated concept, then you build an additional system and you can never pay for the additional costs at the facade.

So in this case, there was a kind of interesting definition by the client, his first priority was work place quality. It needs to have operable windows with limited heating and cooling ventilation control. He wants the building energy use to be 25% below code. He also wants to take advantage of the natural ground energy source, which means no mechanical cooling allowed. And he wants to minimize operating costs for heating, cooling, and ventilation. Keeping this in mind, we defined several approaches. The natural ground source delivers cold water in the range of 12-15°C. Normally, with 12-15°C you cannot run an air-conditioning system – you need 6°C. In this case, we ended up with a kind of radiative system. On the other side, you have to minimize loads – minimizing solar gains, external shading with protection, etc. We used a double façade system with adjustable throttling flaps on the outside to allow for operable windows.

The entire system ended up with a double skin façade, natural cooling, which I mentioned, activation of thermal mass, which means the ceilings are uncoated, operable windows and we added a decentralized ventilation system to allow for adjustments in the ventilation. We had nearly no shafts in the building which saves a lot of space and provides additional rentable space in the building.

With wind on the façade, especially in a round building, you get areas of negative and positive pressure. With a CFD calculation, you can easily see on one half of the building you have significant negative pressure from -40 up to +100 psi. Under these circumstances, if two people open the windows and the doors are open too, you just get normally a blast of uncontrolled outside air. Using a Transsolar simulation tool combined with other tools, we showed that with adjustable flaps on the exterior glass layer, we can equalize the negative pressure and positive pressure in front of the building and create a kind of average negative pressure within the double façade.

The decentralized supply system was part of the double façade system and provided pre-heating and pre-cooling. In this case, we are controlling the supply temperature depending on the outside dew point, which means that we are always keeping in the same range so no condensation can occur with this exchange. This is important: they are not for cooling, they are just for preconditioning the outside air to come in at the same level as room temperature. Their use depends on the internal loads, you may need them or not.

We did shading and ventilation full-scale tests, of just the façade module. We also compared simulations against these measurements to identify the ventilation efficiency of our supply system. Finally, we built a one-to-one two-story mock up on site so we could compare and verify the simulations to what we measured. The building is now going up.

Finally, I will just give you an impression about a building that we finished and has now been in use for some years by the company Audi. The building has a screen façade on the south side (right side of the diagram) acting as a buffer zone and a circulation space. Automated horizontal microlouvers provide a kind of adaptive façade. Once a day, all these 400 elements try to find the zero point. They are kind of reset. Each of these 400 elements is individually controlled with a little motor driven unit which is also computerized. They are adjusted once a day typically, depending on inside temperature and on lighting level, because it works also as a lighting control for offices behind it during this five minutes of the day. During this time, the building really looks like a movie screen. The façade changes from all clear to all white, suddenly starting to open or close. You see a certain precision. When it is kind of horizontal you can easily look out through it, so it keeps a certain transparency. In this case, a lot of the offices are oriented to this circulation space and are able to look out through the façade. You can also close a part of it, the upper part or lower part. If it is open, you can easily look through the building and have a kind of visual connection through the building.

Kerry Hegedus is an architect and has been working with Naramore, Bain, Brady and Johanson (NBBJ) Architects in Seattle, Washington since 1991. Projects include the Seattle Justice Center, Arizona Solar Oasis and the Safeco Field for the Seattle Mariners. Mr. Hegedus has a bachelor's of architecture at the University of Arizona and a masters of architecture and urban design from Washington University in St. Louis.

Kerry Hegedus

Note: [#] refers to the PowerPoint slide.

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[2] It turns out that the topic that the Lawrence Berkeley National Lab was interested in is how we "convinced the client" since this particular building I will talk about uses a double-skin façade for a thermal buffer and they are pretty rare in the US. The building is the Seattle Justice Center. The owner is the City of Seattle. Two uses are programmed in it: City of Seattle Police Headquarters and City of Seattle Municipal Courts. It is about 12 stories tall and about 4 months from completion. It is located on a half-block site in downtown Seattle.

[3] I broke it down to three basic criteria. First of all, it had to be aligned with the client's goals. We didn't come up with any premeditated idea and try to force it down their throats – it kind of grew out of what the client's goals were. Second, the thermal buffer is integrated into the building concept on multiple layers. We wanted to make it substantial and a part of the building, so that you couldn't just snap off or replace or value-engineer it out. Third is the research and development to confirm the benefits that we told the client we were going to obtain and to better fine-tune what that thermal buffer was going to be. The picture shows a façade model of the typical bay going up the whole nine stories.

[4] Some of the favorable factors that helped us convince the city were in place even before we started design. Our mayor, former mayor, Paul Schell, was formerly the dean of architecture at the University of Washington. One of our clients was an architect, which also helped. In terms of design and aesthetics, Seattle has a pretty rich heritage of being concerned about these ideas even though some of the buildings of the past do not necessarily reflect that. The city architect was an advocate of sustainable design and this was probably one of the key features, that they wanted to have a sustainable building but they didn't have the budget. That is why this is a reality check. This is something that we did with relatively little money with a client that really wanted to push themselves.

Some of the more physical characteristics was the site orientation and the location on the master plan. These were developed before we started design. The clients had similar goals of where the building should go as well as image and a LEED rating. The city acted pretty quickly to adopt the LEED ratings that came out at the beginning of 1999 and by November of that same year, the city had adopted it and said that they wanted all their future buildings to have a silver rating or better. So they were pretty aggressive. At the time, I am not sure that anyone knew what that meant. When we were first analyzing it, there was LEED version 1.0 and then they adopted version 2.0. Then something else that helped was the Berlin coincidence that I will get into in a little bit.

[5] The biggest thing was the LEED rating system and how were we going to accomplish the silver rating. Along with the LEED rating, they just didn't want to hide the sustainable features in the building, they wanted to create an awareness to the environment and to the public. They see a double

The Seattle Justice Center has a 9-storey high heat extraction double-skin facade.

curtainwall and people can start asking questions. They can start telling a story of the building and build some momentum. Then with the next project, they will try to do something more advanced and more integrated. The city also wanted to show sustainable design as an example of just good practice. They just didn't want to do things, the city wanted to show things that were the right things to do, and they wanted to lead by example.

From the image side, they wanted something that was inviting. Right now the buildings are not very attractive. People dread going there. Of course, the building houses the police and the courts so you usually go there for negative reasons. They are not good places to work in, they are not good places to visit, and there is just no real strong attributes to them. So they want something that invites people back into the government and they didn't want such a stand-off type of environment.

In terms of convincing the client, the glazing thermal buffer or thermal flue is a new concept. At first we had to worry about the fashion questions. Were we just trying to put two layers on here because it is trendy, or is it really going to have some benefit? So we went through a series of copying the client on book excerpts and articles. We wrote a short explanation of what our thermal buffer was, what precedent there was, and how the concept worked.

[6] Then to top it off, we had a sister-city relationship with Berlin. This was really fortunate because the clients were going there and they said, "While we are there, can we look at any buildings?" Yes! That might show you what a thermal buffer looks like. So there was some real good extreme examples of thermal buffers and how it integrates in the building. I gave them a map and showed them how to get there. I really wanted them to be excited about it and

it was the architect from the city council and the mayor. They were anxious to go look at it. They wanted to know about this thing called a thermal buffer. So I listed the buildings, they walked around and came back, and they were as excited as I was to sell it to them. But it was not about salesmanship. It was about creating the right thing for the building and I will get into some of those circumstances.

[7] There four considerations: 1) Location on the master plan, 2) building massing, 3) space planning/room layout, and 4) solar orientation. It is these many layers of consideration that made it important for integration into the building, something that you could not argue one point and the whole thing goes away. That is the real test of anything that you do in a building; if there is only one reason to put it there and it isn't functional, it will more than likely go away.

[8] The master plan. Our building is composed of two squares there to the right of the screen. It is really the first phase of the city campus. The city hall is across the street with the council chambers (it has a circle with a square through it) and this really became the back drop for the city council, which is more of an object building being designed by Bohlin Cywinski Jackson and Bassetti in Seattle. You can see that the master plan stopped at the city hall and then there were just these two blocks at the east end. And looking at what the master plan is, it creates this urban corridor to the north where the mass of the buildings are and then the parks and open space are on the south side, where it can get sun and get some public access. So how did it fit in the master plan? We are at the high part of the hill, in the far right. You can see kind of a current photo of how we fit in there.

[9] The Seattle Justice Center mass was broken down into two elements. The police became the stone portion: the solid sturdy, you couldn't bomb that part (or you couldn't think that you could bomb that part), and then there is the court side which had more of the public outreach items, where people went everyday for jury, to pay parking tickets, or utility bills. The city really wanted the courts to be more open to the public. That is why you see the separation of the stone mass and the glass. Also you can see where that would be an extension of the master plan – it really sets this one area off to be glazed and be different and to be the back drop for the city hall across the street.

[10] In terms of the planning layout, first this is facing southwest and so it is not the best of orientations. Considering the half-block configuration, this is what we had to deal with. We had a parking garage on the back side and we had two short ends that really were not going to be of any use for daylighting due to the depth of the block. So we really had to concentrate on the southwest elevation and how we could make that work. With glass, there is always those extremes of temperature variation and glare. What we ended up doing was pushing back the workstations and putting circulation right behind the glass layers. This made it so that people at the glass line did not control what everyone else in the whole space experienced. That was a big factor. Also in terms of the image. You don't have to worry about the desk being shoved up against the glass and people adjusting the blinds at all different levels. We wanted the facade to be really clean. We were very systematic and rigorous on this southwest side where the thermal buffer was. In terms of the bays and where the private offices were placed, we had "cabin creep" – we said that if you were going to creep your cabins into our open office space, they were going to be at the back so that daylight will at least have the opportunity to penetrate back into the space. We knew that everyone was not going to get

direct daylight but we wanted them to have *access* to direct daylight. Again, we were just trying to deal with the circumstances that we had.

On the police half, anything can happen. We tried to keep open office areas against the main core, but because of program variations and a lot of private offices, it just broke down systematically.

[11] The solar orientation. I hit on it that the southwest was our major elevation. If you have ever been to Seattle, it is a very beautiful place and people are very connected with their environment. Especially beyond the highest point of the hill, we wanted to give access to the views to the water and to the mountains beyond on a clear day. It is very important to feel in touch with our community out there and conversely, for it to be inviting. We wanted to have clear glazing so that you could see in. We wanted to try to maximize the glazing so that you could start to wonder what was going on in there, that it is not so forbidding. It is not tinted glass; it is not reflective. We just wanted to give something that the public would want to go in and experience.

[12] The research and development. To confirm these benefits, we did this analysis at schematic design. We were toying with the thermal buffer idea. The city hired Arup to come in and just go through all the city projects at the time to see if their sustainable strategies really held water. At which time we had Maurya McClintock from Arup come in. She went through our strategies and confirmed our strategy. We ended up hiring Arup to help us analyze thermal comfort and energy items with the building and to help fine-tune how to best make our thermal buffer work.

[13] We studied this thing in a lot of different ways. First we were testing just sun angles both in plan and section. How do you get the daylight to penetrate? Very typical things, but the start of the investigation.

[14] The modeling at different scales and at the different phases, different emphasis (like the façade). The one in the lower right hand corner is the daylighting model. We took it to the daylighting lab and made modifications, looked at sun angles at different times of the day, did stills, and tried to get an understanding of how this would work.

[15,16] There were computer simulations. This one was done relatively early as well to gain our understanding. These are probably about as far as we normally would have gone if we weren't trying to integrate the thermal buffer and really maximize the glazing. We knew that there were going to be more pressures to make this elevation perform. The Seattle Daylighting Lab really helped identify a lot of critical issues and there was a really big problem. Especially for the southwest orientation. We went through shading strategies, where the light shelf was, how far the blinds went down in the thermal buffer.

[17] What we have in the thermal buffer is monolithic glazing on the outside and insulated glass on the inside. In the gap, we have cat walks at the floor levels. These light shelves were initially eight feet above the finished floor. Then at first, we thought that we were going to have frit the upper portion to get some of the glare issues out, but we concluded through the analysis that what they really needed was a MechoShade. The MechoShades (semi-transparent shading) come down to 6 feet above the finish floor and balances against the city standard for partitions and cubicle heights, which is 5.5 ft high. Then we had the catwalk at the floor level and the light shelf at 8 feet above finish floor. All of these things kind of balance. It is a fine line of how much sun you are keeping out; for the critical times and swing times of the

year, it worked. Through all these things, again, we didn't have a big budget. The analysis was relatively simple but multi-faceted. We had to make sure that it would work with what we had.

Ove Arup really helped convince the client too. We had never done a vented façade before. We had been talking to a local engineer that had done some, but didn't have the bulk of the experience that Ove Arup had, so that really helped add some confidence from the owner's standpoint. This is one of the reasons why we hired Ove Arup, because they could do an extensive study and they have done 70 plus thermal buffers that have been built.

[18] In terms of value engineering, we were trying to see how far we could minimize it (thermal buffer). We didn't want any moving parts, because the city would not maintain it. Could it be whittled down to single glazing on the inside and was that going to be effective? We looked at different options and we also compared it to a traditional configuration.

I am not sure why Arup does this, but they calibrate things. These colors are for the percent of people *dissatisfied*. It seems to be a pretty negative way to go about it, but their philosophy is that they are going to always have about 10 percent of the people that are dissatisfied, no matter what is going on. That is always the goal, and that is the yellow here. You can see up against the glass on the far left, circulation zone, where we're not going to let people occupy the space.

[19] Further break down. In the end, you will notice on the third line down the energy analysis for the area studied, which was only 18 ft deep on the southwest side and on only two-thirds of the block. The thermal buffer equated to a 33% savings in terms of energy. In terms of the overall building, it calibrates way down to about 3%, but because it was a limited location it couldn't have that wide-spread effect. It was a lot of these little things that helped the building perform better.

[20] We had to work with the contractor. There was some scare factor in terms of seeing a double-wall facade. They wanted to do it the way they had done it before. We experimented with a process, a "design-build process." From our DD documents, we advertised and got two contractors (really subcontractors, because we had GCCM onboard at that time) that would develop their own designs. While we were doing constructions documents, they (Benson Industries) were doing their construction documents. We were working with them to develop two designs to meet our criteria. In doing so, we were allowing them innovation. They had the budget that helped allow for some additional innovation in the end. It is the first time that we tried that and it was a lot of work, but I think that there is some potential in that process. Early this morning at the SCE Round Table, we talked about the problem that by the time that you complete your construction documents there is not enough time to do a mock-up or change things with the contractor's feedback. This might be a way to start to get around some of those items.

[21] In the end, the only way that we knew that we were going to make this happen was to keep it simple. Use simple technology. We did not want to have to develop a lot of things, make custom extrusions, do a lot of wind tunnel testing. We started with integrating a lot of building concepts on sustainability and in the end, it kind of came down to just one that we tried to layer and tried to make work for our circumstances.

[22] I guess we won't know whether it is successful until it opens and if they are really comfortable and the people do connect to the building. But for now,

all I have to hang my hat on is that the city council member, when he came back, gave me his message that he was sold and I feel that the clients were convinced. All we have to do now is convince the occupants.

Stephen Selkowitz is the Program Head of the Building Technologies Department at the Lawrence Berkeley National Laboratory. He leads a group of architects, engineers and scientists who are studying all aspects of the thermal and daylighting performance of glazing materials and window systems. The group's work is supported by government, utilities, and industry. A major theme of the group's activities has been to convert fenestration from an energy cost to a net energy benefit, while improving comfort, amenity, and productivity. Selkowitz participates in a wide range of industry and professional activities, is a frequent speaker on the topic of fenestration and related building energy efficiency topics, and is the author of over 100 publications. Prior to joining LBNL he worked as an energy consultant and educator. He has a BA in Physics from Harvard and a Master of Fine Arts in Environmental Design from California Institute of the Arts.

Stephen Selkowitz

A published paper is available on the subjects presented by Mr. Selkowitz at SCE:

Selkowitz, S.E. 2001. "Integrating Advanced Facades into High Performance Buildings." Presented at Glass Processing Days Seventh International Conference on Architectural and Automotive Glass, June 18-21, 2001 in Tampere, Finland, and published in the Proceedings. LBNL-47948, Lawrence Berkeley National Laboratory, Berkeley, CA http://eetd.lbl.gov/BTP/papers/47948.pdf

3. Building Performance

Overview

In the Technological Solutions and Design Process sections of this report, we described high-performance commercial building façade solutions and the methods used to design such solutions. In reality, how have such buildings performed in the real world? What are the actual real-world energy savings that are being realized in these buildings? Are there side effects that cause the solution to be unacceptable to the occupant or are burdensome to the facility manager?

Design tools for daylighting, solar control, and ventilation within the context of advanced façade systems are discussed. We explain the basic use of some currently-available design simulation tools and the limitations of these tools to predict the performance of most of the technological solutions described in this document. References and weblinks to design tools are given, if available. We also list current international research activities underway to solve some of the fundamental tools issues that are encountered when designing these façade systems.

It has been extremely difficult to find any objective data on the performance of actual buildings implementing some of these solutions, particularly double-skin facades and adaptive facades. Subjective claims abound in the architectural literature. For some solutions, simulations can give a fairly good estimate of performance savings that can be achieved with solar shading strategies or daylighting. For other solutions, only measured data will suffice due to the complexity of interactions within the building. We reviewed a well-cited German article on double-skin facades that illustrated the controversy that is now on-going concerning double-skin façade systems. We also provide references to more detailed information.

Design Tools

"Before the glazed façade was designed by an architect in collaboration with the trade firms that would execute the work. Today, experts in load-bearing structures and materials, electrical specialists, security and fire-protection consultants, and professionals in thermal currents, computer simulation, and wind-tunnel testing are all likely to be involved in the development of the new façade systems. " — Eike Becker in the book: Headquarters Building of Verbundnetz Gas AG, Leipzig. 1999. Munich: Prestel Verlag.

"Green architecture requires close collaboration between architects and engineers. And a building's environmental components are not bolted-on attachments; they are designed for particular climate conditions and client needs." —NYTimes , April 16, 2000, p.37, section 2, by Herbert Muschamp and Architecture League website www.archleague.org.

Design tools enable architects and engineers to predict the performance of new building systems prior to construction and to improve the performance of existing building systems after occupancy. Performance includes a broad array of parameters: energy use, lighting quality and quantity, building operations, acoustics, condensation resistance, structural, etc. We limit this discussion to tools needed to predict the thermal and daylighting performance of façade systems as related to building energy use and occupant comfort.

Exterior overhangs, Nordic Countries Embassies, Berlin.

One would expect that with the increasing number of buildings that feature advanced facades, a suite of design tools would be available that enables designers (architects and engineers) to determine the impact of advanced facades on building performance. Such tools do exist for many systems, but these tools are generally developed in-house and are proprietary and/or require significant engineering expertise and time that is disproportional to the resources of a conventional project. Many of these tools are used simply to provide performance estimates under the worst-case design conditions. Year-round performance is typically not modeled unless called for by the energy codes or requested by the exceptionally diligent client. Yet, the architectural literature claims increased energy efficiency, improved comfort, improved indoor air quality, etc. Since no post-occupancy field evaluations have been done, how are these claims substantiated?

Pragmatically, A/E firms are tasked to solve complex, multi-dimensional problems within short order to meet the demands of the client and the budget. In this section, we describe the basic concepts or algorithms that are used to predict the thermal and daylighting impacts of facades on building performance (i.e. energy use, comfort, HVAC design, etc.). We explain how models for high performance facades differ from basic algorithms, and describe the research in progress or needed to properly model advanced facades.

For those readers who have no fundamental knowledge of how to determine heat gains or of the principles of heat transfer, we refer you to the 2001 ASHRAE Fundamentals Handbook, Chapters 29 and 30.

In simple terms, we define a façade system's thermal performance by the total transmitted short-wave solar radiation and heat transfer (conduction, convection, and long-wave radiation) through the façade. This total heat gain places a load on the mechanical system and/or results in a rise in air or skin temperature (for example, if sun shines on an occupant). Mechanical engineers use such information to determine how large to size the capacity of the building's space-conditioning system. Thermal performance indices are also used in energy codes, which often prescribe minimum or maximum values or allow a whole energy budget to be met if the building is simulated using state-approved calculation procedures.

The underlying indices for daylighting are based on the same fundamentals as thermal indices, but are not as critical with respect to energy codes and standards. Daylighting indices determine the visual performance and impact on occupants. In business-as-usual practices, daylighting indices are typically considered in a qualitative experiential manner (e.g., Building X used a glass with a visible transmittance (Tv) of 0.40 and it seemed fine, therefore it should be applicable to Building Y).

To arrive at such thermal and daylighting performance indices, one needs to look behind the scenes to understand why commercially-available design tools do not have the capabilities to routinely and easily model almost all of the systems described on this website.

The two main thermal performance indices, U-value and solar heat gain coefficient (SHGC), and daylighting indices, visible transmittance (Tv), are derived from measured data and computational models. These indices are based on the optical and thermal properties of individual glass, gap and shade layers. Optical properties include transmittance, reflectance, and absorptance properties. Thermal properties include long-wave emissivity, air film convective conductance, layer conductance and gas fill conductance. Solar radiation transmitted by a system of glass and shading layers depend on the solar transmittance and reflectance properties of the individual layers. Solar radiation absorbed by the façade system enters the glazing heat balance equation that determines the inside surface temperature of the glass and thus

the heat gain from the glazing. Transmitted solar radiation is absorbed by interior room surfaces and therefore contributes to the room heat balance (Winkelmann 2001).

For homogeneous transparent glass such as clear or tinted, uncoated or coated glass, simulation modeling is straightforward and accurate. Free software is available that provides optical data for all glass manufacturers' commercially available products and allows users to build up layer by layer any arbitrary assembly of glass layers, gas fills, and conventional spacers and frames (see WINDOW5, THERM and OPTICS reference below). Energy codes accept calculations made for these standard systems with these approved rating tools (for example, the ASHRAE 90.1-1999 accepts only National Fenestration Rating Council (NFRC) methods for determining U-value and SHGC). European and International Standards, such as EN410, EN673, ISO 9050, and ISO 10292, consider only non-diffusing materials and allow calculation of solar energy properties, color appearance, ultraviolet transmittance, and thermal emittance through spectral measurements performed at (near) normal incidence. For translucent materials, these standards recommend measurements made using an integrating sphere. Measurements for angular-dependent optical properties, view through, glare, redirection, diffusion and scattering have all been defined but not necessarily standardized.

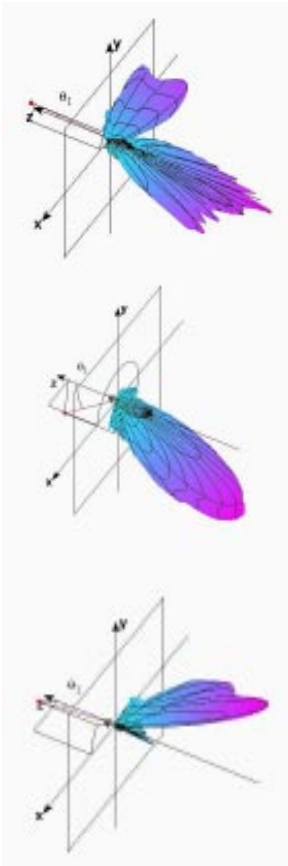
For systems that use any of the following types of materials and assemblies, tools do not exist or can be significantly inaccurate while energy codes require special procedures to arrive at approved ratings or indices:

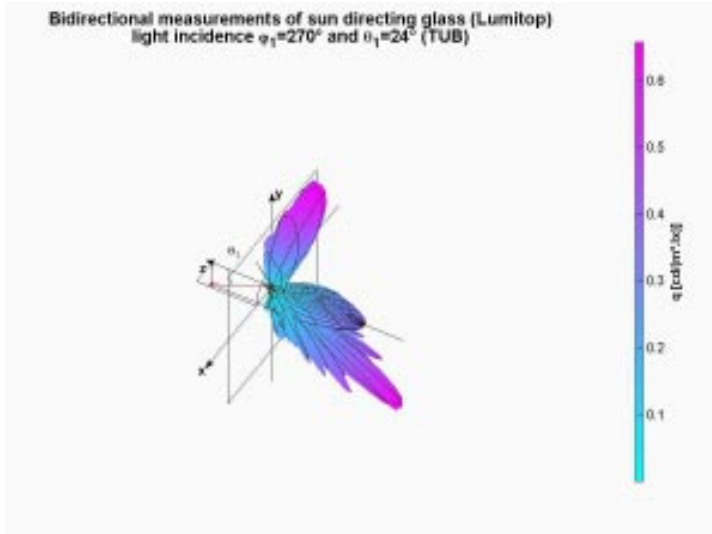
- Materials that transmit or reflect light in a non-linear manner, such as light-redirecting daylighting materials, prisms, metallic sun shades, angular selective coatings, louver or blind systems, woven metal fabrics, fritted, patterned or etched glass, etc.
- Systems that have between-pane air gaps with an aspect ratio greater than 1:40, between-pane shading layers, or that have forced or natural ventilation within the gap.

The first item is categorized as *optically complex*: for transparent or non-transparent materials with two-dimensional or three-dimensional complex geometries which scatter solar radiation in an unpredictable manner, determining thermal performance indices is not straightforward.

At this time, samples of such systems are measured by approved testing agencies (see NFRC reference below). Imagine, for example, a Venetian blind with a semi-glossy painted surface tilted at a particular angle. Some solar radiation passes directly through the open portions of the blind. The remaining solar radiation strikes the blind and is either reflected toward the room interior, or to an adjacent slat, or towards the outdoors, or is absorbed by the blind surface. The direction of scattering is determined by the surface properties and geometry of the slat. If the slat is blue, it scatters incident flux differently from a white slat (both spectrally and with outgoing angle). If the slat has a "satin" finish versus a "glossy" finish, or if the blind angle changes, the reflected pattern of flux also changes. This function of transmittance and reflectance as a function of incoming and outgoing angle is known as the bi-directional transmittance and reflectance function (BDTRF) property of a material or fenestration system (since transmittance, absorptance, and reflectance properties add up to 1.0, absorptance is determined by deduction).

Measuring the optical properties of complex systems is expensive, time-consuming, and requires significant expertise. Every combination of material,





The above diagrams depict BDTFs for sun directing glazing. The x- and y- axis give the direction or angle of incoming and outgoing flux and the z-axis gives the magnitude of the outgoing flux for a given direction.

color, geometry, angle, or mode of operation must be measured separately. Data files can be enormous. Test procedures are being discussed within the NFRC Solar Heat Gain Subcommittee. For example, the NFRC 201 is an interim test procedure to determine the SHGC of non-homogeneous glazing systems (glass blocks, other diffusing glazing systems, and projects with shading systems) which currently cannot be simulated. ASTM E-06.51.08, ASTM C-16.30.04, and ASTM C1199 SHG and Thermography task group are also working on test procedures to quantify U-value.

There are no comprehensive databases of BDTRFs for such systems and there are few simulation programs that routinely incorporate such data in their calculation of thermal and daylighting performance. Coming up with simple, inexpensive methods to characterize complex systems has been a problem facing researchers for years. An elegant alternative currently being explored by researchers is to determine optical properties computationally. This involves measuring the optical properties of individual materials. Forward ray-tracing programs are used to determine transmission and reflection coefficients based on the unique geometry and the measured optical properties of each layer in a facade system. The forward ray-tracing assumes a position of the source then traces that ray through the system as it is scattered, reflected, interreflected, or transmitted through the system. The end result is a percentage of total flux reflected or transmitted or reflected through the system as a function of angle of incidence and, if needed, spectral wavelength.

This method would allow any system or combination of systems to be modeled, if one simply knows the basic optical properties of the material. This method is as yet unproven. A proof-of-concept is currently underway at LBNL in collaboration with the École Polytechnique Fédérale de Lausanne (EPFL). Optical measurements of complex systems, done with a new digital scanning method in Switzerland (Andersen et al. 2001), are being compared to a ray-tracing model of the same system. Results are promising.

The coefficients will be generated in a unique program that contains optical libraries of basic materials or layers. A user would assemble their unique complex system properties to create a fenestration system. If this method proves to be valid and accurate, transmission and reflection coefficients could be available for any complex system. These coefficients could then be used to arrive at standardized U-value and SHGC values and also used in new

building simulation software programs to predict the daylighting and solar heat gain performance of complex systems in buildings.

For systems that involve ventilation within or through the envelope, the problem is equally challenging. Again, standard models have not been developed and implemented in a user-friendly manner. Computational fluid dynamic (CFD) software packages can be used to solve the problem, however users often obtain multiple solutions – any of which can be wrong unless one is an expert. Computational time for one design day condition can take a full day for a relatively coarse three-dimensional grid. Often, basic parameters are difficult to define: effective areas of ventilation, discharge coefficients (Cd), pressure coefficients (Cp), direction of flow, etc. Weather data and wind tunnel measurements are often needed to obtain these basic parameters. Algorithms for dampers and penetrations in the wall form some basis for this work (e.g., one assumes simply a large-area ventilation damper), however heat transfer through the window's transparent portions add to the complexity of the problem. Coupling between the thermal zone of the window and the whole building must also occur. Building energy simulation programs either do not implement such coupling or use of such features requires significant expertise to model (see description of EnergyPlus capabilities in this regard below).

In lieu of such developments, engineers are forced to approximate thermal indices or accept default or worst case ratings in order to pass energy codes. For many of these advanced building systems, engineers must work with code officials to arrive at acceptable computational methods for special cases.

Summary of Tools

"We have a 9-storey double-skin glazed curtainwall, consisting of a single-glazed exterior layer, a 2.5-ft-wide cavity , and an interior double-pane glass window wall. The cavity is not conditioned, only ventilated with outdoor air. We want to model this system using THERM and WINDOW5. The code requirement for this system is a NFRC-computed U-value of 0.50 Btu/h-ft^2-F or better for the vision areas. What method should we use to come up with a value that is accurate and acceptable to NFRC? The main problem is that the effective conductivity and temperature of the air cavity is unknown, but even if they were known, how would we determine the U-value?"

National Fenestration Rating Council provides procedures for rating window systems that are often required by state energy codes:

http://www.nfrc.org

See also a useful flowchart describing procedures for site-built or custom projects:

http://www.nfrc.org/sb_outline.html

Simulation programs available to determine the thermal and daylighting performance indices of conventional window systems include **WINDOW5, Optics5,** and **THERM**.

WINDOW 5.0 is a publicly available computer program for calculating total window thermal performance indices (i.e. U-values, solar heat gain coefficients, shading coefficients, and visible transmittances). WINDOW 5.0 provides a versatile heat transfer analysis method consistent with the updated rating procedure developed by the National Fenestration Rating Council (NFRC) that is consistent with the ISO 15099 standard. The program can be used to design and develop new products, to assist educators in teaching heat transfer through windows, and to help public officials in developing building energy codes.

THERM is a state-of-the-art, Microsoft Windows™-based computer program developed at Lawrence Berkeley National Laboratory (LBNL) for use by building component manufacturers, engineers, educators, students, architects,

and others interested in heat transfer. Using THERM, you can model two-dimensional heat-transfer effects in building components such as windows, walls, foundations, roofs, and doors; appliances; and other products where thermal bridges are of concern. THERM's heat-transfer analysis allows you to evaluate a product's energy efficiency and local temperature patterns, which may relate directly to problems with condensation, moisture damage, and structural integrity.

Optics5 allows the user to view and modify glazing data in many new and powerful ways. Optical and radiative properties of glazing materials are primary inputs for determination of energy performance in buildings. Properties of composite systems such as flexible films applied to rigid glazing and laminated glazing can be predicted from measurements on isolated components in air or other gas. Properties of a series of structures can be generated from those of a base structure. For example, the measured properties of a coated or uncoated substrate can be extended to a range of available substrate thickness without the need to measure each thickness. Similarly, a coating type could be transferred by calculation to any other substrate.

"For unconventional systems, the main issues are: How to rate the system? How to gain compliance with California's Title-24? How do we get a rebate or incentive for innovative work if techniques aren't there to support or validate performance?"

These tools have been developed by LBNL and are available over the web:

http://eetd.lbl.gov/btp/software.html

The tools are accepted by NFRC for rating window systems. In some cases, these tools can be applied by NFRC-certified simulators, test labs and inspection agencies to determine ratings for non-standard products.

The **Windows Information System (WIS)** is a uniform, multi-purpose, PC based European software tool to assist in determining the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components. The tool contains databases with component properties and routines for calculation of the thermal/optical interactions of components in a window. WIS contains features often not found in other software packages including routines to characterize the performance of solar shading devices and ventilation in glazing cavities. Airflow is not simulated using CFD, but the tools has been found to yield acceptable approximations of center-of-glass U-value and SHGC.

http://erg.ucd.ie/wis/html_pages/diss_techwis.html

Daylighting algorithms and tools are described in detail in the International Energy Agency Task 21 Daylight in Buildings publication: "Daylight in Buildings: A Source Book on Daylighting Systems and Components". See http://eetd.lbl.gov/Bookstore.html under Practical Guides & Tools for Energy Users for "Daylight in Buildings: A Source Book on Daylighting Systems and Components". For those residing outside of U.S. or Canada, please visit http://www.iea-shc.org. Download the hyperlinked report 8.9.3 "Daylight Simulation: Methods, Algorithms, and Resources" from the CD-ROM directory.

RADIANCE is a lighting and daylighting visualization tool developed by LBNL and is available over the web:

http://eetd.lbl.gov/btp/software.html

This program can model very sophisticated window systems and complex systems, given BTDF measured data.

Daylighting and Electric Lighting Simulation Engine (DElight) is a simulation engine for daylight and electric lighting system analysis in buildings. The program's origin was the LBNL SUPERLITE program from the 1980s, but the new version has updated the code and added new capabilities. It accepts a bidirectional transmittance distribution function (BTDF) and calculates daylight factors. The program can analyze complex systems, where the daylighting window aperture is treated as a directional light fixture and coupled to the interior space. An exterior radiance model is being developed that takes into account how exterior obstructions modify the BTDF incoming flux.

http://eande.lbl.gov/Task21/DElightWWW.html

COMIS is an air flow distribution model for multizone structures. It takes wind, stack and HVAC into account and allows for crack flow, flow through large openings, and single-sided ventilation. The structure of COMIS (Conjunction of Multizone Infiltration Specialists) was developed at an LBNL workshop in 1987-88. The program has been validated by the International Energy Agency's Energy Conservation in Buildings and Community Systems Programme, Annex 23 on Multizone Air Flow Modeling.

http://www.eren.doe.gov/buildings/tools_directory/software/comis.html

DOE-2 and EnergyPlus

DOE-2 and the newer EnergyPlus are public domain programs developed by LBNL and other team members:

http://eetd.lbl.gov/btp/software.html

The DOE-2 program for building energy use analysis provides the building construction and research communities with an up-to-date, unbiased, well-documented public-domain computer program for building energy analysis. DOE-2 is a portable FORTRAN program that can be used on a large variety of computers, including PC's. Using DOE-2, designers can quickly determine the choice of building parameters which improve energy efficiency while maintaining thermal comfort. A user can provide a simple or increasingly detailed description of a building design or alternative design options and obtain an accurate estimate of the proposed building's energy consumption, interior environmental conditions and energy operation cost. DOE-2 has been used by national labs, universities, and industry for hundreds of studies of products and strategies for energy efficiency and electric demand limiting. Examples include advanced insulating materials, evaporative cooling, low-E windows, switchable glazing, daylighting, desiccant cooling, cogeneration, gas-engine-driven cooling, cool storage, effect of increased ventilation, sizing of thermal energy storage systems, gas heat pumps, thermal bridges, thermal mass, variable exterior solar and IR absorptance, and window performance labeling.

EnergyPlus is a new-generation building energy simulation program based on DOE-2 and BLAST, with numerous added capabilities. The initial version of the program, EnergyPlus 1.0, was released in April 2001. EnergyPlus includes a number of innovative simulation features – such as sub-hour time steps, built-in template and external modular systems that are integrated with a heat balance-based zone simulation – and input and output data structures tailored to facilitate third party module and interface development. Other capabilities include multi-zone airflow, moisture adsorption/desorption in building materials, radiant heating and cooling, and photovoltaic simulation.

With respect to the façade, EnergyPlus has the following capabilities. WINDOW5 algorithms are embedded in EnergyPlus so that for each time step WINDOW5 calculations are done within EnergyPlus. The frame, divider, and sash heat transfer calculations treats these elements essentially as U-values, where solar absorbed on these elements is transferred according to U-value.

For window shading devices, EnergyPlus models an interior or exterior shade as a pull down diffuser or a venetian blind. The venetian blind model uses a radiosity calculation similar to that in ISO 15099 to determine visible transmission and solar transmission and absorption as a function of angle of incidence. Interreflections between glass layers and between glazing and shading device are calculated. A heat balance calculation is performed on the glass and shading device layers. Long wave radiation exchange occurs between the inside glass and the room and between the interior shading device, if present, and the room. The temperature of each glazing layer is computed. Air film coefficients are assumed and these parameters can significantly impact how the shading device layer impacts the radiative and convective split. Shading devices more complex than blinds cannot be modeled.

EnergyPlus currently has some limitations. The window's air film coefficient must be validated (planned). One can use CFD calculations to determine air film coefficients for applications like ISO 15099 above, but such calculations take significant computation time (several hours) and turbulence models cannot be accommodated. For internal room reflections the daylighting calculation relies on a crude split-flux method and must be improved. Algorithms from DElight, which uses a radiosity-based method for internal reflections and a bidirectional transmittance function approach for transmission through complex fenestration, will be incorporated in 2002. The exterior radiance distribution from the ground and adjacent buildings is not well modeled. For example, if a glass building opposes the modeled building, there can be significant reflected heat gains from this opposing building. Semi-transparent photovoltaics cannot be modeled but normal photovoltaics can be.

Double-facades can be modeled in EnergyPlus, but with limitations. One treats the interstitial space as a thermal zone. EnergyPlus can model the radiation that is transmitted between the exterior glass and interior glass facades. The interstitial space can be treated as a plenum. The difficulty is in predicting how much heat gets picked up as it moves through this plenum. If venetian blinds are placed in this interstitial cavity, EnergyPlus assumes that the blinds are associated with the exterior window. Air movement with venetian blinds needs to be validated. To determine thermal loads on the interior space, the COMIS multizone air flow calculation, which is completely integrated in EnergyPlus, can calculate the coupling that occurs between this façade and the interior zone. EnergyPlus can model wind-driven, buoyancy, and mechanically vented air flow through the plenum, although such calcula-

tions have not yet been attempted. If the plenum has openings to the interior space, EnergyPlus can model this condition.

References

ASHRAE. 2001. ASHRAE Fundamentals Handbook. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.

Andersen, M., L. Michel, C. Roecker, J.L. Scartezzini. 2001. Experimental assessment of bi-directional transmission distribution functions using digital imaging techniques. Energy and Buildings 33 (2001) 417-431.

Winkelmann, F.C. 2001. Modeling windows in EnergyPlus. Proc. IBPSA, Building Simulation 2001, Rio de Janeiro, September 2001. LBNL-47972, Lawrence Berkeley National Laboratory, Berkeley, CA.

A general list of tools offered by the U.S. Department of Energy are available over the web at:

http://www.eren.doe.gov/buildings/tools_directory/software.html

Building Performance References

Daylighting performance

Monitored performance data of various innovative daylighting systems are given in the International Energy Agency Task 21 Daylight in Buildings publication: "Daylight in Buildings: A Source Book on Daylighting Systems and Components" in Chapter 4. See http://eetd.lbl.gov/Bookstore.html under Practical Guides & Tools for Energy Users for "Daylight in Buildings: A Source Book on Daylighting Systems and Components". For those residing outside of the U.S. or Canada, please visit http://www.iea-shc.org.

Daylighting image banks were created using the Radiance visualization tool for "typical" window configurations. These can be viewed at:

http://gaia.lbl.gov/rid/http://www.bwk.tue.nl/fago/daylight/varbook/index.html

Monitored daylighting data are given in the reference:
Fontoynont, M. and European Commission Directorate-General XII Science Research and Development (1999). *Daylight performance of buildings.* London, James & James (Science Publishers) for the European Commission Directorate General XII for Science Research and Development.

Retrofit sail to address shading problem in Waterloo Train Station, London. Architect: Nicholas Grimshaw.

Solar control performance

The **2001 ASHRAE Handbook: Fundamentals, Chapter 30** describes the underlying building physics of fenestration systems. LBNL with ASHRAE developed a simplified method for determining the SHG of shaded windows, which is detailed in the new handbook. For mechanical system design, engineers are interested in modeling shaded windows. With the old handbook, engineers would use the solar coefficient tables which were dispensed with in the 2001 version. A simplified method was needed to allow users to make gross assumptions for their calculations without reliance on dated calorimeter measurements.

http://www.ashrae.org

International Energy Agency (IEA) Task 27: Performance of Solar Façade Components. The objectives of this research task are to determine the solar, visual, and thermal performance of materials and components, such as advanced glazings, and to promote increased confidence in the use of these products by developing and applying appropriate methods for the assessment of durability, reliability, and environmental impacts. The scope of the task includes dynamic glazings, such as electrochromics, daylighting products, solar protection devices such as venetian blinds, and double-envelope systems.

http://www.iea-shc.org/

The Lund Institute of Technology in Sweden is conducting a Solar Shading Project which will 1) measure solar energy transmittance, 2) develop advanced computer programs and a user-friendly design tool (ParaSol) to predict the impact of shading devices on the energy use in buildings, 3) conduct parametric studies for the development of design guidelines, and 4) measure daylight conditions in rooms equipped with shading devices.

http://www.byggark.lth.se/shade/shade_home.html

Active façade performance

The École Polytechnique Fédérale de Lausanne (EPFL) is conducting two projects at the Laboratoire d'Energie Solaire et de Physique du Batiment called 1) Projet UE Smart Window: An Innovative, Adaptive, Independently-Controlled Window System with Smart Controlled Solar Shading and Ventilation and 2) Projet UE EDIFICIO: Efficient design incorporating fundamental improvements for control and integrated optimization. The projects involve the integration of intelligent systems using genetic algorithms and adaptive controls.

http://lesowww.epfl.ch

The National Research Council Canada, Institute for Research in Construction is conducting a three-year project on how office occupants actually use both manually- and automatically-controlled blinds and lighting systems. This will help establish realistic expectations about the possible benefits of daylighting in office buildings considering how occupants use blinds and other anti-glare devices.

http://www.nrc.ca/irc/

or contact Christoph Reinhardt at christoph.reinhart@nrc.ca.

The Centre for Window and Cladding Technology at the University of Bath, UK conducted a study called Integrated Building Control (IBC) to develop a window with automated vents and shading. Self-adaptive control strategies were applied to the window in order to moderate the environment in the room but allow for the needs of the occupant.

http://www.cwct.co.uk/pubs/

A monitored field test of large-area electrochromic windows was conducted by LBNL. Further work to evaluate EC windows will commence in mid-2002. For published results, see:

Lee, E.S., D. L. DiBartolomeo. 2000. "Application issues for large-area electrochromic windows in commercial buildings." *Solar Energy Materials & Solar Cells* 71 (2002) 465–491. LBNL Report 45841, Lawrence Berkeley National Laboratory, Berkeley, CA.

http://eetd.lbl.gov/BTP/pub/OMpub.html

Monitored lighting energy use and cooling load data, human factors data, and controls data from a full-scale field test were reported for an automated venetian blind and dimmable lighting system. For published results, see:

Lee, E.S., D. L. DiBartolomeo, E.L. Vine, S.E. Selkowitz. 1998. "Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office." *Thermal Performance of the Exterior Envelopes of Buildings VII: Conference Proceedings,* Clearwater Beach, Florida, December 7-11, 1998. LBNL Report 41443, Lawrence Berkeley National Laboratory, Berkeley, CA.

Vine, E., E.S. Lee, R. Clear, D. DiBartolomeo, S. Selkowitz. 1998. "Office Worker Response to an Automated Venetian Blind and Electric Lighting System: A Pilot Study." *Energy and Buildings* 28(2)1998:205-218. LBNL Report 40134, Lawrence Berkeley National Laboratory, Berkeley, CA.

http://eetd.lbl.gov/BTP/pub/ISpub.html

Double-skin facades and natural ventilation performance

COST C13 Action on Glass and Interactive Building Envelopes

The European Co-operation in the field of Scientific and Technical Research (COST) C13 Action on Glass and Interactive Building Envelopes involves the collaboration of approximately 30 scientists from 12 EU countries. The C13 action is a networking activity where scientists from the EU community are engaged to define the state-of-the-art R&D in the area of interactive facades, to collaborate on common research activities, to identify areas of future required research, and to disseminate results of the activity to the architectural and engineering community. Three scientific programmes or working groups (WG) have been defined for the COST Action C13: 1) architectural aspects, 2) quality of interior space, and 3) structural concepts. The programme is voluntary (no R&D funds) and slated to occur over a 3-year schedule (initiated around June 2000).

http://erg.ucd.ie/costc13/index.html

See reference to IEA Task 27 above.

The Chartered Institution of Building Services Engineers (CIBSE) publishes Applications Manuals: AM10, AM11 and AM13 on natural ventilation modeling.

http://www.cibse.org/

There is an international collaboration on research for natural ventilation and hybrid ventilation:

http://hybvent.civil.auc.dk

The Glass Construction Manual explains some of the fundamentals of double-skin facades as well as other advanced facade systems:
Schittich, C., G. Staib, D. Balkow, M. Schuler, and W. Sobek. 1999. Glass Construction Manual. Munich: Birkhauser Publishers for Architecture.

Multi-layer skin facade, debis Headquarters, Berlin.

The VTT Building Technology Group in Espoo, Finland is conducting a study on the development of tools for characterizing and planning double-skin facades. Results are as yet unpublished.

http://www.vtt.fi/rte/projects/

Helsinki University of Technology recently published a field study documenting post-occupancy conditions and the design/ construction process by Sini Uuttu called the Current Structures in Double-Skin Facades. The study can be accessed through the library at the portal:

http://www.glassfiles.com

Natural ventilation and night-time cooling strategies were designed for the new San Francisco Federal Building. See:

McConahey, E., P. Haves, and T. Christ. 2002. "The Integration of Engineering and Architecture: A Perspective on Natural Ventilation for the New San Francisco Federal Building." To be presented at the *ACEEE 2002 Summer Study on Energy Efficiency in Buildings: Energy Efficiency in a Competitive Environment*, August 18-23, 2002, Asilomar, Pacific Grove, CA and published in the Proceedings. Washington, D.C.: American Council for an Energy-Efficient Economy.

Some monitored data are given in the reference:

Oesterle, Lieb, Lutz, Heusler. 2001. Double-Skin Facades: Integrated planning. Munich: Prestal Verlag.

"A Critical Review of Double-Skin Facades"

There are very few articles that provide a critical review of double-skin facades and the few that are available are in German. We reviewed a widely cited German article written by Dr. Karl Gertis, who is the director of the Fraunhofer Institute of Building Physics in Stuttgart, Germany and renown expert in the field, and paraphrase part of the article below. The article is entitled: "Sind neuere Fassadenentwicklungen bauphysikalisch sinnvoll? Teil 2: Glas-Doppelfassaden (GDF)" published by ©Ernst & Sohn Bauphysik 21 (1999), Heft.

Gertis summarizes his findings as follows: Innovative façades have recently been developed – or rather have become fashionable. Glass double facades (GDFs) are at present being discussed in a very rigorous and controversial way. Some consider them an expression of modern design and a forward-looking, ecological façade concept with a promising future. Others consider them skeptically, i.e., as mistaken in our local (German) climate. In this paper, the different types of GDFs are explained systematically. The extensive GDF literature is evaluated critically. Building physics investigation results are presented. This results in an overall GDF synopsis in performance of acoustics, air flow, thermal, energy use, daylight as well as moisture and fire protection. Conclusion: Simulations cannot be relied on and practical measurement results are lacking. There is a lot of work to catch up on. It becomes apparent that GDFs – apart from special cases – are unsuitable for our local climate from the building physic's point of view. Moreover, they are much too expensive. If they are nevertheless designed in order to keep up with architectural fashion, building physics support is indispensable.

The paper then introduces the current situation. In Germany, GDFs are increasingly being introduced in high-rise buildings where there are few architectural competitions where a GDF is not presented with impressive terminology that belie any real results. Contractors and building owners also use this impressive terminology in cited literature. Putting aside these claims, one must question whether such promises are realized. One early scientific study with measured results showed that the Building of Economic Advances in Duisburg with a GDF facade has an annual total energy consumption of 433 kWh/m^2 (40 kWh/ft^2-yr) and should thus be qualified as an energy guzzler, who's energy consumption even surpasses some of the older buildings. The Commerze Bank in Frankfurt, which also has a GDF façade, has an annual total energy consumption of 169 kWh/m^2, (15.6 kWh/ft^2-yr) which will most likely prove to be too low.

After characterizing the different types of GDF systems, the author then goes on to explain what the current level of knowledge is on façade performance. In the early 1990s, much of the literature was extremely positive with no quantitative proof given for performance claims. The focus of the literature was how GDFs set new levels for energy use and quality of the work environment (the author notes that they are new levels in the negative sense!). A significant amount of non-critical literature has been published by architectural magazines. For many articles, the claimed performance has proven later to be wrong or untrue. From 1996 onwards, more critical reviews have been published indicating increased dissatisfaction with GDFs and countering the euphoric descriptions from the early 1990s. The author cites some problems noted in the literature. For example, window insect screens cannot be used with natural ventilation because the air flow is to weak to overcome the pressure loss over the air filter. During significant portions of the year, one

cannot achieve a comfortable indoor climate with natural ventilation through GDFs, and GDF buildings without active cooling fail. Arriving at a design solution for a GDF is possible but is much too expensive. And GDFs cannot be used as a substitution for room air-handling measures.

The author also notes several problems with literature that cite simulation results. First, the results are usually given for hypothetical boundary conditions with a simulation model developed early in the design process. Often the boundary conditions are not exactly stated so the results are fairly useless since no critical interpretation can be made. Other sources provide measurements made under laboratory conditions. Very few publications have real world measurements. The GDF building in Wurvdurg, which was built with many technical innovations such as radiant cooling, has an annual total energy use of 58.9 kWh/m^2-yr (5.4 kWh/ft^2-yr).

The author cites costs from various publications, noting that the investment costs are very high compared to conventional punched hole facades with high-efficiency windows. Costs such as \$680/m^2 and up are mentioned. In another reference, the added cost for a GDF is estimated at 70%. Another source mentions \$135-360/ m^2, while the costs for the GDF at Dusseldorf Stadttor (see Detailed Case Studies section) was given at \$585/m^2.

A summary table is then given by the author which is paraphrased in this report. He notes that the "con" arguments are often more important than the "pro" arguments and that more measurements under real-world circumstances are needed to clarify the real performance of these systems.

Detailed analysis of various performance parameters are then made by the author. With acoustics, several key points were made. For a given example, the potential sound reduction by a second exterior skin is compromised if the openings for ventilation exceed about 16% of the façade. The level of sound reduction achieved with a GDF can also be achieved with other measures. Partitioning the sound by dividing the GDF air cavity into smaller compartments can reduce sound transmittance to adjacent rooms; however, doing so can compromise other performance aspects of the façade (e.g., airflow, daylighting, etc.). With reduced exterior noise levels, the subjective perception of noise from adjacent rooms is increased. There are many GDF cases where interior dividing walls have to be retrofit with increased sound insulation.

With respect to airflow in the gap and air exchange within the room, the author critiques the assumptions behind several literature references. The references and other simulations assume that airflow in the gap will be upwards based on thermal driven flow and downwards based on wind load on the building (the higher wind load will give a higher static pressure). Actual airflow patterns in the gap will differ; there is instationary airflow exchange on the leeward and windward sides of the building and within the air gap. Instationary fluctuations in air pressure can be very strong. Also, airspeed in the gap gets smaller with increased exterior wind speed, due to the air resistance within the façade.

For Venetian blinds positioned in the air gap, the devices should be and remain reflective (in the wavelength that the exterior glass is transmitting) to prevent temperature increase in the air gap. This poses additional costs, since continuous cleaning of blinds is known to be complicated and involved.

The air temperature in the gap can create significant thermal discomfort and force closure of interior windows designed to allow natural ventilation. The

	Pro GDF arguments	Con GDF arguments
Acoustics	Gives better acoustical insulation against exterior noise	GDF has to be opened for ventilation and this will decrease the acoustical insulation of the air gap and will increase the acoustical transmission
Heating Energy in the Winter	GDF saves heating energy, because solar energy is captured as in a collector	Most of the buildings that we looked at have high internal heat loads and heating energy savings is not an issue
Cooling Energy in the Summer	Summer heat can be ventilated away through the GDF air gap	In a GDF air gap, we have strong heating in the summer, which will make the building behind the GDF very hot
Room climates for ventilation	GDF increases the climatic comfort in the room because of natural ventilation	With GDF, you can only achieve a comfortable climate in the room by using a mechanical HVAC system and the GDF air gap facilitates the transfer of odors
Solar Shading	GDF has the ability to apply a shading system that is protected from the outside in the air gap	A shading system can just be applied inside the building without using the GDF air space
Operable Windows	GDF allows the user to open windows even on very high buildings	With hardware, where you limit the amount you can open the window, you can use operable single façade windows in a skyscraper or very high building as well
Pressure needed to close interior doors in a building	On the windward side of tall buildings, GDF reduces the static pressure in the interior, which can result in less pressure needed to close interior doors compared to naturally ventilated buildings	If you use ventilated storm windows in the openings of a punched-hole façade to break the wind, you can also reduce the static pressure
Lighting	GDF enables the installation of light redirecting elements	Light redirecting is also possible with a punched-hole facade. The extra glazing layer in a GDF actually reduces the amount of daylight entering the building
Fire	With horizontal and vertical compartments, fire spread can be prevented in the air gap	The exterior glazing layer reduces the ability for smoke ventilation and the air gap increases the risk of fire spreading between floors or rooms
Condensation	With enough ventilation the GDF air space can be kept free from condensation	The inner surface of the outer pane - it is inevitable that there will be condensation and therefore you need frequent cleaning.
Cost	GDF lowers the operation costs of the building because of energy costs	GDF have extremely high investment costs and they increase the amount of operational cost because, for example, the cleaning of four glass surfaces

author gives an example where the temperature of a southwest-facing GDF is given as a function of air changes in the gap and the total solar transmittance of the exterior skin with shading devices. For an exterior air temperature of 30˚C, the air temperature of the gap can approach 40-50˚C. Substantial cooling is not achieved until the air change rate within the cavity is 20, which is hard to achieve with natural ventilation and reasonable air gaps, unless the façade is opened to more than 30%, which then eliminates the acoustical performance of the facade. In order to achieve low air temperatures in the gap, one could also reduce the total solar energy transmittance to a maximum of 0.30, but the interior room will get very dark and increase electric lighting energy use.

The author notes that GDF buildings usually have high internal loads, so dealing with high internal loads in the summer is more important than heating during the winter. An example is given of interior temperatures over time with different types of ventilation (mechanical with and without night-time ventilation versus GDF natural ventilation) and different levels of expected air changes per hour during the day and night. With natural ventilation through the GDF, the maximum interior temperature is 46˚C. The author concludes that the GDF and natural ventilation is almost a contradiction in terms (citing other research that confirms this from 1996-1997).

The article continues to discuss daylighting, moisture and condensation, and fire performance, however these portions of the article were not translated.

4. Building Case Studies

We gathered a list of buildings, both international and in the United States, which implemented high performance building facade systems. Some of these buildings are given in brief case studies, while others are listed in a case study roster. The information contained in the brief case study examples are collected from published articles, books, and websites, so some performance claims may be unsubstantiated.

The case study roster is organized by buildings' technological solutions. Note, many of these case studies integrate two or more types of façade systems.

Exterior view of south façade (top)

Floor plan with cellular offices on the north side and open plan on the south side (bottom)

Building Research Establishment

Building: Environmental Building, Building Research Establishment

Location: Garston, UK

System: Operable solar shading and stack ventilation

Architect: Fielden Clegg

Completion: 1991/1997

Project Description: Low-rise, low-energy office building for 100 people with stack ventilation, cross ventilation, and operable shading systems on the south building facade.

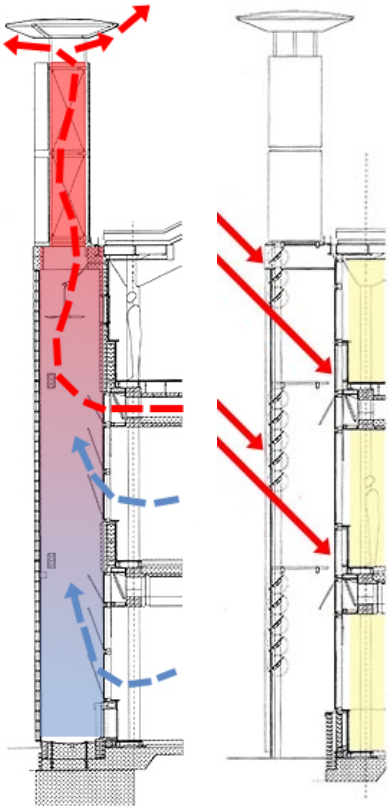
A key feature of this building is the integration between natural ventilation and daylighting strategies. The floor plan (shaded in yellow in the picture to the left) is divided into open-plan and cellular offices allowing cross ventilation in the open plan arrangement while the 4.5-meter-deep cellular offices are located on the north side with single-sided natural ventilation. A shallow open-office plan is coupled to a highly glazed façade. A wave-form ceiling structure is used. At the high point of the wave, a clerestory window allows daylight to effectively penetrate the space. A duct providing space conditioning and ventilation was placed within a hollow core at the low point of the wave-form structure.

For shading, translucent motorized external glass louvers (Colt International) are controlled by the building management system and can be overridden by the occupants. The glass louvers can be rotated to diffuse direct solar or to a horizontal position for view.

A stack ventilation system was designed as an alternative ventilation strategy for the open plan offices during extreme cooling conditions. Vertical chimneys were designed to draw hot air through the duct in the wave-form structure as well as through bottom-hung, hopper, etched windows. The exterior of the stacks are glazed with etched glass blocks, allowing daylight admission. Low-resistance propeller fans were mounted at the top-floor level, to provide minimum ventilation and to flush internal heat gains during the night.

Reference

Edwards, B. editor. 1998. Green buildings pay. London: E&FN Spon.



Cross section through the ventilation stack (left) and the glazed façade (right).

Exterior facade.

debis Headquarters

Building: debis Headquarters

Location: Berlin, Germany

System: Double-skin facade

Architect: Renzo Piano Building Workshop and Christoph Kohlbecker

Completion: 1991-1997

Project Description: 21-storey high-rise office tower with a double-skin facade.

This double-skin facade is divided into storey-high cavities. The exterior skin consists of automated, pivoting, 12-mm thick laminated glass louvers. Minimal air exchange occurs through these louvers when closed. The interior skin consists of two double-pane, bottom-hung, operable windows. The upper window is electrically operated. On the interior of the internal windows are Venetian blinds. Walkway grills occur at every floor within the 70-cm wide interstitial space and are covered with glass to prevent vertical smoke spread between floors. During the summer, the exterior glass louvers are tilted to allow for outside air exchange. The users can open the interior windows for natural ventilation. Night-time cooling of the building's thermal mass is automated. During the winter, the exterior louvers are closed. The user can open the internal windows to admit to the warm air on sufficiently sunny days. The building is mechanically ventilated during peak winter and summer periods (To<-5˚C, To>20˚C).

Reference

Compagno, A. 1999. *Intelligent glass facades: Material, practice, and design.* Basel, Switzerland: Birkhauser.

View from within the interstitial space.

Deutscher Ring

Building: Deutscher Ring Verwaltungsgebäude

Location: Hamburg, Germany

System: Double-skin façade

Architect: Architects BDA, Dipl.-Ing., von Bassewitz, Patschan, Hupertz und Limbrock, Hamburg

Completion: 1996

Project Description: 6-storey office building with an inner courtyard and a multi-storey link to the existing building.

On the south facade, an 80-cm deep by 24.10 m four-storey high double facade provides thermal and acoustic protection. The exterior skin is point-fixed, toughened, solar control, single-pane glazing. The interior skin consists of low-E coated, double-glazed, punched windows and spandrels. Blinds are positioned interior to the internal glass windows. There are staggered exterior openings at the base of the curtainwall (not clear whether at each floor or simply at the base of the four-storey facade). The top of the four-storey facade has a rainproof opening with overlapping glass panes that allow air exchange. For cooling, solar radiation absorbed by the exterior glazing layer is vented or extracted by natural convection through the top opening at the fourth floor. Some of the interior windows are operable to allow for cleaning within the interstitial space. Walkway grills occur at every floor within this interstitial space.

Reference

Hertzsch, E. 1998. Double Skin Facades. Catalog of Josef Gartner & Co. Munich: Peschke.

Düsseldorf Stadttor (City Gate)

Building: Düsseldorf Stadttor (City Gate)

Location: Düsseldorf, Germany

System: Double-skin facade

Architect: Petzinka, Pink & Partners

Completion: 1991-1997

Project Description: 16-storey towers with a 56-m high atrium in the center

Each tower has a corridor double-skin façade with a single-storey interstitial space that is 90-140 cm deep and 20-m long. The interior façade has double-pane, low-E glazed doors that pivot every second bay. The exterior façade is 12-mm fixed safety glass. High-reflectance Venetian blinds are located in the interstitial space. Mechanical ventilation is provided during peak summer and winter hours. Chilled ceilings provide radiant cooling. The building can be naturally ventilated for 60% of the year.

Reference

Compagno, A. 1999. Intelligent glass facades: Material, practice, and design. Basel, Switzerland: Birkhauser.

Hertzsch, E. 1998. Double Skin Facades. Catalog of Josef Gartner & Co. Munich: Peschke.

Lang, W. and T. Herzog (2000). Using multiple glass skins to clad buildings. Architectural Record July 2000: 171-182.

Oesterle, Lieb, Lutz, Heusler. 2001. Double-Skin Facades: Integrated planning. Munich: Prestal Verlag.

Exterior view (upper photo) and full-scale mock-up of the façade (lower photo).

Eurotheum

Building: Eurotheum

Location: Frankfurt, Germany

System: Double-skin facade

Architect: Novotny Mähner + Associates

Completion: 1999

Project Description: This residential and office mixed-use building is 100-m high and has a square 28 by 28 m plan. Only part of the building is designed with a double-skin façade, which provides natural ventilation for most of the year. Office space occupies the lower part of the Eurotheum Tower while the top seven floors are used for residential purposes.

The facade grid is 1350 mm wide and 3350 mm tall. Each unit, which is pre-fabricated off-site, consists of a 6-grid span, one-storey tall. The internal skin consists of thermally-broken aluminum frames and double-pane, manually-operated, tilt-and-turn windows. Power-operated blinds are located in the 34-cm-wide air cavity corridor. The external skin consists of single-pane, fixed glazing. Fresh air is supplied through 75-mm diameter holes in the vertical metal fins on each side of the glazing unit. Warm air is extracted through an exterior opening at the ceiling level. This opening is equipped with louvers to prevent the penetration of rain and is covered with anti-bird mesh.

Reference

Hertzsch, E. 1998. Double Skin Facades. Catalog of Josef Gartner & Co. Munich: Peschke.

http://www.hlzm.de/pdf/226Euroth_eng.pdf (no information on double-skin façade)

Exterior views of the vertical louvers on the west facade.

Exterior and interior view of the east triple-glazed facade system.

GSW Headquarters

Building: Gemeinnützige Siedlungs-und Wohnbaugenossenschaft mBH (GSW) Headquarters

Location: Berlin, Germany

System: Double-skin façade

Architect: Sauerbruch Hutton Architekten

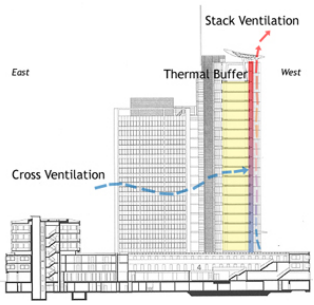
Completion: 1995-1999

Project Description: 22-storey, 11-m wide office building with cross ventilation and a double-skin thermal flue on the west-facing façade.

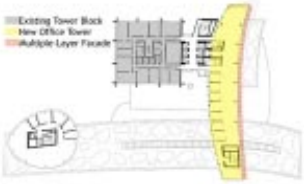
This 11-m wide office building allows for cross ventilation. The east façade consists of automatically and manually-operated triple-glazed windows with between-pane blinds. Louvered metal panels also occur on the east façade to admit fresh air independently from the windows. The west façade consists of a double-skin façade with interior double pane windows that are operated both manually and automatically and a sealed 10-mm exterior glazing layer. The interstitial space is 0.9 m wide. Wide, vertical, perforated aluminum louvers located in this interstitial space are also automatically deployed and manually adjustable. The louvers can be fully extended to shade the entire west façade.

Outside air admitted from the east façade provides cross ventilation to the opposing west façade. The prevailing window direction is from the east. The west façade acts as a 20-storey high shaft inducing vertical airflow through stack effect and thermal buoyancy. Where partitioned offices occur, sound-baffled vents permit airflow across the building.

During the heating season, the air cavity between multi-layer facade acts as a thermal buffer when all operable windows are closed. Warm air is returned to the central plant via risers for heat recovery. Fresh air is supplied from the raised floor system. Radiant heating and cooling are provided. Thermal storage in the ceiling and floor was created using exposed concrete soffits and a cementitious voided screed system. Various building systems such as lighting and diffusers are either integrated into the soffit or into the voided screed.



Sectional diagram showing wind- and stack-induced cross ventilation.



Typical floor plan of the office building, showing the existing tower on the left (gray) and the new 22-storey tower on the right (yellow).

Reference

—. 2000. "Urban green: headquarters building, Berlin, Germany." *Architectural Review* 208 (1246): 72-75.

Clemmetsen, N., W. Muller, and C. Trott. 2000. "GSW Headquarters, Berlin." *Arup Journal*, February 2000, pp. 8-12.

Hodder, S. 2001. "GSW Headquarters, Berlin." *Architecture Today* 116: 30-49.

Russell, J. 2000. "GSW Headquarters." *Architectural Record* 188(6): 156-161.

Office at Halenseestraße

Building: Office Building Halenseestraße

Location: Berlin-Wilmersdorf

System: Double-skin facade

Architect: Hilde Léon, Konrad Wohlhage

Completion: 1990-1996

Project Description: The top west-facing seven stories of this ten-storey building are designed with a double-skin facade. Facades on other orientations are conventional single-layer windows. The double-skin facade reduces noise from the adjacent highway towards the west.

The 12-mm single-pane external skin of this double-skin facade is completely sealed while the internal skin consists of sliding double-pane glass doors. A blind was installed within the 85-cm wide, 1-storey high interstitial space. Fresh air is mechanically drawn from the roof, then passed down to the intermediate space of the double-skin façade through vertical channels at both ends of the corridor. Air is extracted through the horizontal ducts leading to vertical channels situated in the center of the facade.

During the summer, the blinds can be used to block solar radiation while the interstitial space is mechanically ventilated. At night, internal heat gains are removed with mechanical ventilation. During the winter, solar gains pre-warm the air in the interstitial space.

Reference

Compagno, A. 1999. Intelligent glass facades: Material, practice, and design. Basel, Switzerland: Birkhauser.

Hertzsch, E. 1998. Double Skin Facades. Catalog of Josef Gartner & Co. Munich: Peschke.

The external skin consists of point-fixed toughened glazing and is held by a top and bottom rail.

Horizontal air-return duct on each floor.

Inland Revenue Centre

Building: Inland Revenue Centre

Location: Nottingham, UK

System: Solar chimney stack-induced cross-ventilation

Architect: Michael Hopkins & Partners

Engineer: Ove Arup & Partners

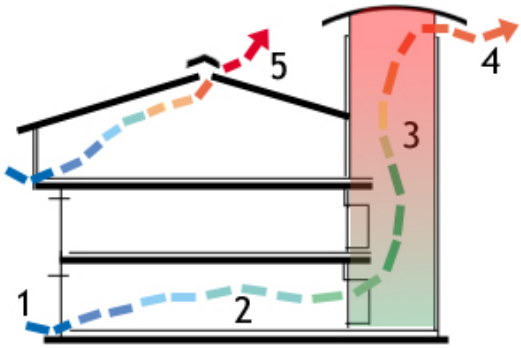
Completion: 1994

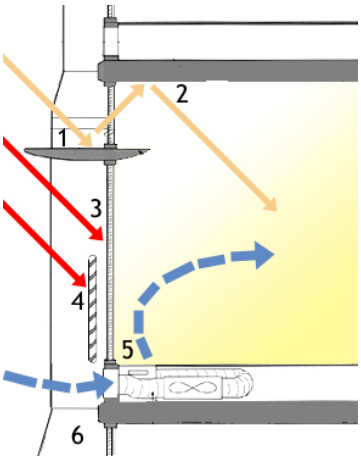
Project Description: Low-rise L-shape buildings with corner staircase towers. The main strategies are the maximization of daylight and engineered natural ventilation.

Reference

The Chartered Institute of Building Services Engineers (CIBSE). 1997. *Natural ventilation in non-domestic buildings: CIBSE applications manual AM10: 1997*. London: Chartered Institution of Building Services Engineers.

Willmert, T. 2001. "The return of natural ventilation." Architectural Record 189(6):137-146.





Cross Section Diagram Showing Ventilation Strategies

1. Fresh air is drawn through underfloor duct and grill which can be mechanically-induced.
2. Cross ventilation in office area (from open windows).
3. Warm air exhaust through the door, connected to the stair tower. Solar gain in the tower increases thermal buoyancy, warm air is drawn up through the tower by stack effect.
4. Operable tower roof moves up and down to control the rate of air flow.
5. On the top floor, warm air is exhausted at the roof ridge.

Section Diagram Showing Facade Strategies

1. Integrated lightshelf shades space in the perimeter zone and reflects light into the space.
2. Light-colored ceiling improves reflectance of daylight High ceiling (3.2 m) helps with thermal stratification. Exposed concrete soffit acts as thermal mass, absorbing daytime heat gain.
3. Triple glazing with between-pane adjustable blinds
4. Balcony and shading devices.
5. Fresh-air inlet with occupant-controlled fans allow windows to be closed in winter or to protect outside noise from entering the space.
6. External brick piers provide lateral solar shading.

Islip Federal Building and Courthouse

Building: Federal Building and U.S. Courthouse

Location: Islip, New York

System: Fixed horizontal louvers

Architect: Richard Meier

Completion: 2000

Project Description: 11-storey U.S. courthouse with horizontal louvers on the south facade. Horizontal exterior fixed louvers span across the entire south facade. The louvers are made of perforated metal which blocks direct solar radiation yet allows a small percentage of daylight to be admitted to the interior. The louvers are scaled to block unwanted solar radiation in the summer months and to allow its direct penetration during the winter months.

The main corridor runs along the length of the south façade, creating a thermal buffer to the interior courtrooms. The area shaded in green is the circulation space. The red shaded areas are the horizontal louvers on the facade system.

Reference

Global Architecture Document 2001 (January), no. 64: 10-27.

Giovannini, J. 2001. "Richard Meier and Partners and the Spectator Group: United States Courthouse and Federal Building, Central Islip, New York." *Architecture* 90(1): 78-89.

RWE AG Headquarters

Building: RWE AG Headquarters

Location: Essen, Germany

System: Double-skin facade

Architect: Ingenhoven Overdiek and Partners

Completion: 1991-1997

Project Description: 28-storey high-rise office tower.

The design of the RWE facade system was influenced by the clients' desire for optimum use of daylight, natural ventilation, and solar protection. All these demands resulted in a transparent interactive facade system which encompasses the entire building. The exterior layer of the double-skin façade is 10-mm extra-white glass. The interior layer consists of full-height, double-pane glass doors that can be opened 13.5 cm wide by the occupants (and wider for maintenance). The 50-cm wide interstitial space is one-storey (3.59 m) high and one module (1.97 m) wide. Outside air admitted through the 15 cm high ventilation slit at the base of one module is then ventilated to the exterior out the top of the adjacent module. Retractable venetian blinds are positioned just outside the face of the sliding glass doors (contributes to interior heat gains?) within the interstitial space. An anti-glare screen is positioned on the interior.

Daylight, direct solar and glare can be controlled with blinds and an interior anti-glare screen. The extra air cavity acts as a thermal buffer, decreasing the rate of heat loss between outside and inside. Fresh air is supplied through the opening at the bottom and warm air is exhausted through the opening at the top of the façade. During extreme cold conditions, the windows are closed. Warm air is returned to the central plant via risers for heat recovery in the winter. The façade provides good heat insulation in the winter and with the combination of slatted blinds, effective solar protection in the summer.

Reference

Briegleb, T. (edt.)(2000). *High-rise RWE AG Essen*. Basel: Birkhauser.

Compagno, A. 1999. Intelligent glass facades: Material, practice, and design. Basel, Switzerland: Birkhauser.

Hertzsch, E. 1998. Double Skin Facades. Catalog of Josef Gartner & Co. Munich: Peschke.

Stanford Medical Center

Building: Center for the Clinical Science Research, Stanford University

Location: Palo Alto, California

System: Solar Control

Architect: Normal Foster

Completion: 2000

Project Description: Low-rise research facility which integrated solar shading system and natural ventilation.

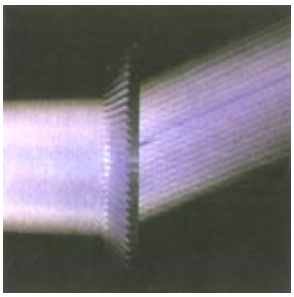
The facade system at the Center for the Clinical Science Research at Stanford University was designed in response to the moderate Palo Alto climate. To protect the building from sun, a series of large overhangs was placed to block direct sun on the south facade. The shading devices are made of a semi-opaque material, which allows a small portion of daylight to enter the interior space.

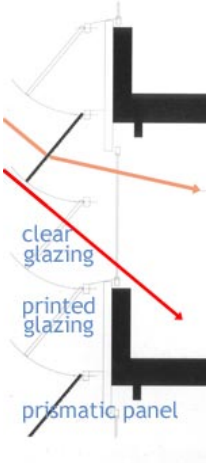
The Center takes full advantage of daylight by dividing the building mass into two separate buildings, separated by a linear atrium. The yellow shaded areas in the building section and plan (below) are occupied space in which each space has either north or south window access. The green shaded area refers to the linear atrium that runs east-west. A grill-like shading system that was installed on the atrium roof to filter strong California sunlight.

Reference

Findley, L. 2001. "Solar protection in Norman Foster's hands create an elegant gathering place for scientists at Stanford University's new Center for Clinical Sciences." Architectural Record 189 (7): 130-137.

Global Architecture Document 2001 (January), no. 64: 66-73.





Top: The prismatic panel reflects light to the desired angle.

Bottom: Sectional detail of the facade system.

CNA-SUVA Building

Building: CNA-SUVA Building

Location: Basel, Switzerland

System: Prismatic panel in double envelope system

Architect: Herzog and DeMeuron

Renovation Completion: 1993

Project Description: The renovation of a low-rise office building in Switzerland by the addition of exterior layer of prismatic panels.

The double-skin facade reduces heat losses in the winter and heat gain in the summer through optical control of sunlight. Within one floor height, the double-skin facade can be divided into three sections. The upper section is made of insulating glass with integrated prismatic panels which automatically adjusts itself as a function of the altitude of the sun. This panel has two functions: reflecting sunlight toward the outside and admitting daylight into the interior space. The vision window is made of clear insulating glass and is manually operated by the occupant during the daytime. The lower level window is automatically controlled to stay closed when solar and thermal insulation are desired.

Reference

Fontoynont, M. and European Commission Directorate-General XII Science Research and Development (1999). *Daylight performance of buildings.* London, James & James (Science Publishers) for the European Commission Directorate General XII for Science Research and Development.

Victoria Life Insurance Buildings

Building: Victoria Life Insurance Buildings

Location: Sachsenring, Cologne, Germany

System: Buffer Facade System

Architect: van den Valentyn & Tillmann, Köln

Completion: 1990-1996

The external skin consists of 15 mm laminated solar control glazing; the internal skin consists of solar control fixed glazing. Aluminum 50-mm-wide louvers are integrated into the 80 cm-wide corridors, which are equipped with walkway grilles for access.

Fresh air is supplied at the bottom level then is extracted at a 21 m height through power-operated vents. Both layers of this buffer double facade are completely sealed. The building is conditioned with a conventional HVAC system. Adjacent twin towers do not utilize the double-skin facade system.

The main advantage of the double-skin facade system is the improvement in thermal comfort. In winter, the air vents in the corridor can be closed, letting the air warm up, which reduces the difference between inside and outside temperatures and consequently reduces heat loss. Warm air increases the surface temperature of the glass, which makes the area near the windows more thermally comfortable. For this building, the large glass area provides daylight access, which enhances motivation, performance and productivity at work.

Reference

Compagno, A. 1999. Intelligent glass facades: Material, practice, and design. Basel, Switzerland: Birkhauser.

Hertzsch, E. 1998. Double Skin Facades. Catalog of Josef Gartner & Co. Munich: Peschke.

Building Case Study Roster: Solar Control Façades

System: Prismatic panel
Building: CNA-SUVA Building
Location: Basel, Switzerland
Architect: Herzog and Pierre de Meuron
Source: Fontoynont (1999)

System: Fritted glass façade
Building: Federal Building and U.S. Courthouse
Location: Phoenix, AZ
Architect: Richard Meier and Partners
Source: http://www.archrecord.com

System: Mirrored louvers
Building: Bruntland Center
Location: Toftlund, Denmark
Architect: Krohn & Hartvig Rassmussen
Source: Fontoynont (1999)

System: Operable façade
Building: Nordic Countries Embassies
Location: Berlin, Germany
Architect: Berger + Parkkinen Architects

System: Movable aluminum louvers, fabric fins
Building: Phoenix Main Public Library
Location: Phoenix, AZ
Architect: Will Bruder
Source: http://www.arup.com/expertise/casestudies.cfm
Source: http://arch.ced.berkeley.edu/vitalsigns/

System: East façade vertical fins
Building: Congress Center
Location: Valencia, Spain
Architect: Foster and Partners
Source: http://www.fosterandpartners.com

Solar Control Façades

System: Overhang and natural ventilation
Building: Center for Clinical Science Research Stanford University
Location: Stanford, CA
Architect: Foster and Partners

System: External louvers
Building: Federal Building and U.S. Courthouse
Location: Islip, NY
Architect: Richard Meier and Partners

System: External louvres
Building: Microelectronic Center
Location: Duisburg, Germany
Architect: Foster and Partners
Source: http://www.fosterandpartners.com

System: External shading device on high rise building
Building: Petronas Towers
Location: Kuala Lumpur, Malaysia
Architect: Cesar Pelli & Associates
Source: http://www.cesar-pelli.com
Source: http://www.skyscrapers.com

System: Louvers façade
Building: Van Andel Institute
Location: Grand Rapid, MI
Source: http://www.dewmac.com

System: Operable façade
Building: Sport Facility, Educare High School
Location: Guadalajara, Mexico
Source: http://www.archrecord.com

Solar Control Façades

System: Fritted glass as shading device
Building: Association of Professionals Engineers and Geoscientists of British Columbia (APEGBC)
Location: Burnaby, Canada
Architect: Busby + Associates Architects
Source: http://www.busby.ca
Source: http://arch.ced.berkeley.edu/vitalsigns/

System: Solar control
Building: Northwest Federal Credit Union
Location: Bellevue, WA
Architect: Miller Hull Partnership
Source: http://www.palcom.com
Source: http://arch.ced.berkeley.edu/vitalsigns/

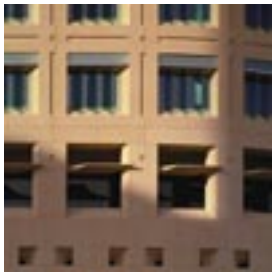
System: Overhang
Building: Revenue Canada
Location: Surrey, BC, Canada
Architect: Busby + Associates Architects
Source: http://www.busby.ca
Source: http://www.advancedbuildings.org

System: Fixed louvers
Building: MacDonald Office Building
Location: Helsinki, Finland

System: Overhang
Building: B3 British Petroleum
Location: London, UK
Architect: Nicholas Grimshaw and Partners
Source: Compagno (1999)

System: Overhang
Building: Phillips Plastic Corporation's Custom Facility
Location: Phillips, WI
Source: http://www.archrecord.com

Solar Control Façades



System: External shading devices
Building: United Gulf Bank
Location: Manama, Bahrain
Architect: Skidmore, Owings and Merrill, LLP
Source: http://www.som.com

System: Various external shading devices
Buildings: Apollo Office Building
Location: Amsterdam, The Netherlands
Architect: Skidmore, Owings and Merrill, LLP
Source: http://www.som.com

PG&E Daylighting Initiative Case Studies
Available online at:
http://www.pge.com/003_save_energy/003c_edu_train/pec/daylight/daylight.html

- ACE Hardware, Martinez, CA
- Marin County Day School, Corte Madera, CA
- Costco, Various Location in California
- California State Automobile Association, Antioch, CA
- Dena Boer Elementary School, Salida, CA
- Phillip Burton Federal Building, San Francisco, CA
- J. Paul Getty Museum, Los Angeles, CA
- McDonald Restaurant, Bay Point, CA
- National Gallery of Canada, Ottawa, Canada

Daylighting Façades

System: Roof monitor
Building: The Gap Headquarters
Location: San Bruno, CA
Architect: William McDonough + Partners
Source: http://dea.human.cornell.edu/ecotecture/Index.htm

System: Lightshelves
Building: Natural Resource Defense Council
Location: Washington, DC
Architect: Pei, Cobb, Freed, and Partners
Source: http://dea.human.cornell.edu/ecotecture/Index.htm

System: Lightshelves
Building: Sacramento Municipal Utility District Customer Service Center
Location: Sacramento, CA

System: Lightshelves
Building: Lockheed Martin Building 157
Location: Sunnyvale, CA

System: Lightshelves/ Atrium
Building: United Gulf Bank
Location: Manama, Bahrain
Architect: Skidmore, Owings & Merrill, LLP
Source: http://www.som.com/

System: Sawtooth roof monitors
Building: Atlantic Pavillion
Location: Lisbon, Portugal
Architect: Skidmore, Owings & Merrill, LLP
Source: http://www.som.com/

Natural Ventilation

System: Solar chimney stack-induced cross ventilation
Building: Inland Revenue Headquarters Buildings
Location: Nottingham, UK
Architect: Richard Rogers Partnership

System: Operable shading system, stack ventilation
Building: Building Research Establishment
Location: Garston, UK
Architect: Fielden Clegg Bradley Architects
Source: http://www.feildenclegg.com

System: Mixed-mode ventilation
Building: Center for Clinical Science Research, Stanford University
Location: Stanford, CA
Architect: Foster and Partners
Source: http://www.fosterandpartners.com

System: Operable window
Building: National Audubon Society HQ
Location: New York City, NY
Source: http://dea.human.cornell.edu/ecotecture/Index.htm
Source: http://arch.ced.berkeley.edu/vitalsigns/

System: Operable window
Building: Surrey Tax Centre (Revenue Canada)
Location: Surrey, British Columbia, Canada
Architect: Busby + Associates Architects
Source: http://www.busby.ca
Source: http://www.advancedbuildings.org

System: Mixed-mode ventilation
Building: Sacramento Municiple Utility District
Location: Sacramento, CA

Natural Ventilation

System: Operable window
Building: Gates Computer Science Center
Location: Palo Alto, CA

System: Natural ventilation
Building: Electronic Arts European Headquarters
Location: Surrey, UK
Architect: Foster and Partners
Source: http://www.fosterandpartners.com

System: Natural ventilation
Building: Chesapeake Bay Foundation
Location: Annapolis, MD
Architect: SmithGroup
Source: http://naturalvent.mit.edu/

System: Mixed-mode ventilation
Building: Charities Aid Foundation Offices
Location: West Malling, UK
Source: http://www.eatechnology.com

System: Natural ventilation
Building: Eastgate Development
Location: Harare, Zimbabwe
Architect: Micheal Pearce Partnership
Source: http://www.arup.com/expertise/casestudies.cfm

System: Natural ventilation
Building: Queens Building
Location: Leicester, UK
Architect: Short Ford Architects
Source: http://naturalvent.mit.edu/

Natural Ventilation

System: Solar chimney stack-induced cross ventilation
Building: Haj Terminal, King Abdul Azziz International Airport
Location: Jeddah, Saudi Arabia
Architect: Skidmore, Owings and Merrill, LLP
Source: http://www.som.com

Double Skin Façades and Natural Ventilation

System: Buffer façade
Building: Hooker Chemical Building
Location: Niagara Falls, NY
Architect: Cannon Design
Source: http://www.cannondesign.com

System: Buffer façade
Building: Business Promotional Center
Location: Duisberg, Germany
Architect: Foster and Partners
Source: Compagno (1999)

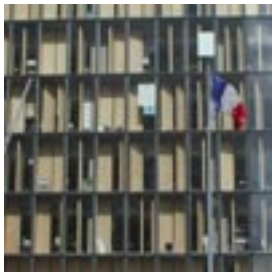
System: Buffer façade
Building: Deutscher Ring
Location: Hamburg, Germany
Source: Gartner

System: Buffer façade
Building: Sendai MediaTheque
Location: Sendai, Japan
Architect: Toyo Ito
Source: http://www.archrecord.com

System: Buffer façade
Building: Victoria-Ensemble
Location: Sachsenring, Cologne, Germany
Architect: T. van den Valentyn and A. Tillmann
Source: Compagno (1999)

System: Buffer façade
Building: Seattle Justice Center
Location: Seattle, WA
Architect: NBBJ, Seattle, WA

Double Skin Façades and Natural Ventilation



System: Pressurized air-cavity façade for condensation prevention
Building: Bibliotheque Nationale de France
Location: Paris, France
Architect: Dominique Perrault
Source: Compagno (1999)

System: Extract-air façade with solar shading
Building: Hong Kong and Shanghai Bank
Location: Hong Kong
Architect: Foster and Partners
Source: http://www.fosterandpartners.com

System: Extract-air façade with downward air-flow
Building: Lloyd's Insurance Company
Location: London, UK
Architect: Richard Rogers Partnership
Source: Compagno (1999)

System: Extract-air façade
Building: The Helicon Finsbury Pavement
Location: London, UK
Source: http://www.permasteelisa.com.sg/

System: Extract-air façade
Building: ITN Headquarters
Location: London, UK
Architect: Foster and Partners
Source: http://www.fosterandpartners.com

System: Extract-air façade
Building: Office Building Halenseestrabe
Location: Berlin-Wilmersdorf, Germany
Architect: Leon/Wohlhage Architects
Source: Compagno (1999)

Double Skin Façades and Natural Ventilation

System: Twin-face façade
Building: Commerzbank
Location: Frankfurt, Germany
Architect: Foster and Partners
Source: Compagno (1999)
Source: http://naturalvent.mit.edu/

System: Twin-face façade with fritted glass
Building: Gallery Lafayette
Location: Berlin, Germany
Architect: Jean Nouvel
Source: http://www.permasteelisa.com.sg/, Compagno (1999)

System: Twin-face façade by stack ventilation
Building: GSW Headquarters
Location: Berlin, Germany
Architect: Sauerbruch Hutton Architects
Source: Compagno (1999)

System: Twin-face façade
Building: Deutsche Post
Location: Bonn, Germany
Architect: Murphy/Jahn
Source: Compagno (1999)

System: Twin-face façade
Building: Dusseldorfer Stadttor
Location: Dusseldorf, Germany
Architect: Petzinka Pink and Partners
Source: Compagno (1999)
Source: http://naturalvent.mit.edu/

System: Twin-face façade
Building: RWE Building
Location: Essen, Germany
Architect: Ingenhoven Overdiek and Partners
Source: Compagno (1999)
Source: http://naturalvent.mit.edu/

Double Skin Façades and Natural Ventilation

System: Hybrid façade system
Building: Debis Headquarters Building
Location: Berlin, Germany
Architect: Renzo Piano Building Workshop
Source: Compagno (1999)

System: Hybrid façade system on the lower part of the building
Building: Aurora Place
Location: Sydney, Australia
Architect: Renzo Piano Building Workshop
Source: Compagno (1999)

System: Hybrid façade system
Building: Siblik Office Building
Location: Vienna, Austria
Source: Gartner

System: Hybrid façade system integrated with prismatic panels
Building: Swiss institute for accident insurance Building (SUVA)
Location: Basel, Switzerland
Architect: Herzog and Pierre de Meuron
Source: Fontoynont (1999)

System: Double skin façade
Building: Telus/William Farrell Building
Location: Vancouver, Canada
Architect: Busby + Associates Architects
Source: http://www.busby.ca

System: Double skin façade
Building: Verbundnetz Gas Headquarters
Location: Germany
Architect: Becker Gewers Kühn und Kühn Architekten

Double Skin Façades and Natural Ventilation

System: Twin-face façade, tilted slightly outward
Building: Library of the University of Technolgoy of Delft
Location: The Netherlands
Architect: Mecanoo Architects
Source: Compagno (1999)

System: Buffer façade
Building: New Parliamentary Building
Location: Westminster, London, UK
Architect: Michael Hopkins and Partners
Source: Compagno (1999)

Active Façades Systems

System: Electrochromic glazing
Building: LBNL Electrochromic Test Facility, Oakland Federal Building
Location: Oakland, CA
Source: http://eetd.lbl.gov

System: Operable shutter system
Building: Arab Institute
Location: Paris, France
Architect: Jean Nouvel
Source: Compagno (1999)

System: Automated external louvers
Building: Building Research Establishment
Location: Garston, UK
Architect: Fielden Clegg Bradley Architects
Source: http://www.feildenclegg.com
Source: http://naturalvent.mit.edu/

Active Façades Systems

System: Automated blinds
Building: San Francisco Public Library, Main
Location: San Francisco, CA
Architect: Pei Cobb Freed
Source: Jain (1998)

System: Automated blinds
Building: Gregory Bateson Building
Location: Sacramento, CA
Architect: Van Der Ryn Architects
Source: http://www.vanderryn.com

System: Automated blinds
Building: Pacific Bell Center
Location: San Ramon, CA

System: Automated Blind system
Building: Herman Miller SQA Headquarters
Location: Holland, MI
Architect: William McDonough
Source: http://dea.human.cornell.edu/ecotecture/Index.htm
Source: http://www.mcdonough.com

5. Resources

Links: Government and Professional Organizations

U.S. Department of Energy (DOE)
http://www.energy.gov

International Organization for Standardization (ISO)
http://www.iso.ch/iso/en/ISOOnline.frontpage

International Energy Agency (IEA)
http://www.iea.org

American Institute of Architects (AIA)
http://www.aia.org

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
http://www.ashrae.org

Illuminating Engineering Society of North America (IESNA)
http://www.iesna.org

Links: Energy Efficiency Research Organizations

Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, California
http://eetd.lbl.gov

American Solar Energy Society
http://www.ases.org

Florida Solar Energy Center
http://www.fsec.ucf.edu/
http://www.fsec.ucf.edu/~fen/

Daylighting Collaborative
Energy Center of Wisconsin
http://www.daylighting.org/index.html

Seattle Lighting Design Laboratory (LDL)
http://www.northwestlighting.com/index.html

California Institute for Energy Efficiency (CIEE)
http://ciee.ucop.edu

U.S. Department of Energy: Energy Efficiency and Renewable Energy Network (EREN)
http://www.eren.doe.gov

Energy Star
U.S. Environmental Protection Agency
http://www.energystar.gov

American Council for an Energy-Efficient Economy
http://www.aceee.org

Northwest Energy Efficiency Alliance
http://www.nwalliance.org

New York State Energy Research and Development Authority
http://www.nyserda.com

Energy Efficient Building Association
http://www.eeba.org/sites/default.htm

Northeast Energy Efficiency Partnerships, Inc. (NEEP)
http://www.neep.org

Building Research Establishment (BRE)
http://www.bre.co.uk

CIBSE: The Chartered Institution of Building Services Engineers
http://www.cibse.org

Links: Educational Resources and Research Organizations

Harvard University and M.I.T. Research on Advanced Building Envelopes
http://www.buildingenvelopes.org

Building Technology Group
Massachusetts Institute of Technology
Boston, Massachusetts
http://me.mit.edu/groups/bt

European Cooperation in the Field of Scientific and Technical Research
(EU COST C13)
Glass and Interactive Building Envelopes
http://erg.ucd.ie/costc13/index.html

Center for Window and Cladding Technology
University of Bath
Bath, United Kingdom
http://www.cwct.co.uk

Center for the Built Environment
University of California, Berkeley
Berkeley, California
http://www.cbe.berkeley.edu

Center for Building Performance and Diagnostic

Carnegie Mellon University
Pittsburgh, Pennsylvania
http://www.arc.cmu.edu/cbpd

Energy System Laboratory
Texas A&M University
College Station, TX
http://esl.tamu.edu/

Day Media: Multimedia Teaching Package on Daylighting
http://www.unl.ac.uk/LEARN/port/1998/daymedia/web/

Square One Research
Welsh School of Architecture
Cardiff University
Wales, United Kingdom
http://www.squ1.com

Institute for Research in Construction
National Research Council of Canada
Ottawa, Ontario, Canada
http://www.cisti.nrc.ca/irc/irccontents.html

Lighting Research Center
Rensselaer Polytechnic Institute
Troy, New York
http://www.lrc.rpi.edu

The National Solar Architecture Research
International Solar Energy Society
University of New South Wales, Sydney
http://www.fbe.unsw.edu.au/units/solarch/default.htm

Society of Building Science Educators
http://www.sbse.org/

Pacific Energy Center
Pacific Gas and Electric Company
San Francisco, California
http://www.pge.com/pec

Southern California Edison
http://www.sce.com

Energy Resource Center
Southern California Gas Company
http://www.socalgas.com/candi/resource_center/erc_home.shtml

Links: Window and Glazing Related

National Glass Association
http://www.glass.org/
American Architectural Manufacturers Association
http://www.aamanet.org/

National Fenestration Rating Council
http://www.nfrc.org/

Efficient Windows Collaborative (EWC)
http://www.efficientwindows.org

Extra Resources on The World Wide Web

Architectural Record: Continuing Education

http://www.architectureweek.com

- The return of natural ventilation/ July 2001
- Photovoltaic technology comes of age/ January 2001
- Designing with daylight/ November 2000
- Creating sleek metal skins for buildings/ October 2000
- Designing with structural fabrics/ September 2000
- Vinyl by design: A proven materials in the built environment/ July 2000
- Using multiple glass skins to clad buildings/ July 2000
- No air conditioning in this building?/ May 2000
- Using solid surfacing as exterior wall cladding/ May 2000
- Seismic systems that stand up to nature/ February 2000
- Finishing outside walls with ceramic tiles/ December 1999
- What it means to be green/ August 1999
- Integrated standard tagets the performance of windows and doors/ August 1999
- Bringing back 1960s buildings/ February 1999
- Building comfort with less HVAC/ December 1998
- Versatile aluminum window and door frames/ December 1998
- Break-through technology heightens the performance of windows and doors
- Improving glass performance/ August 1998

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