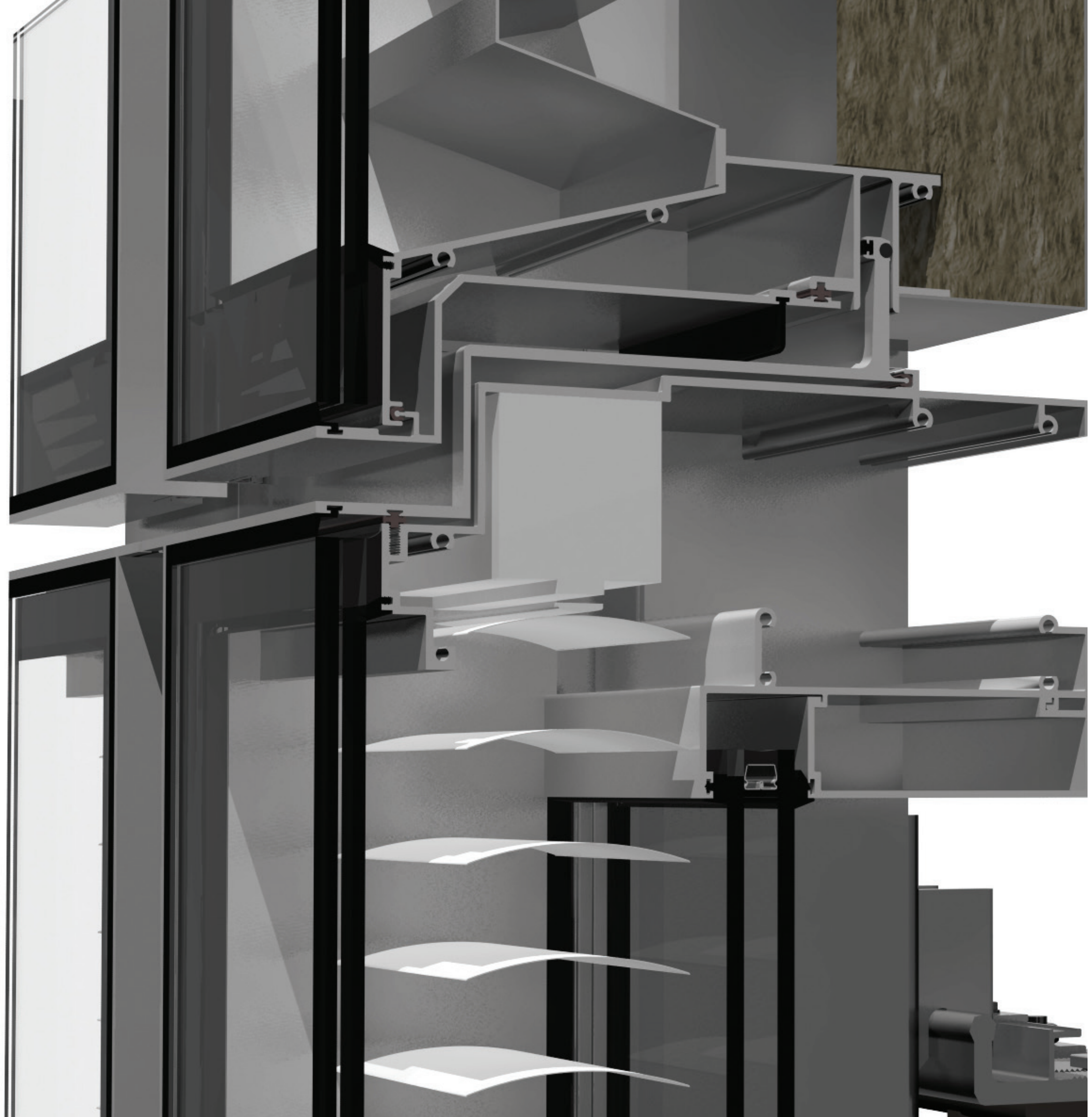


HIGH-PERFORMANCE FACADES

MIC PATTERSON, LEED AP [BD+C] + JENNIE MATUSOVA

A definition of high performance, whether used in the context of buildings or their sub-assemblies (facades), is elusive and nebulous, often incorporating trending key words like "sustainable" and "technologically advanced" to describe works that are often neither. A concise and consistent definition for what constitutes a high-performance facade is simply not found in literature or dialog today. The difficulty lies in pinpointing the most significant contributors to the performance of a facade, with contenders ranging from metrics such as U-value to the physics of a double-skin facade cavity to the role of facade commissioning. There is no clear answer. However, several leading research initiatives have attempted to hone in on the increasingly exaggerated attributes of high-performance facades in architecture and engineering literature.

FACT OR FICTION

In its 2006 report High Performance Commercial Building Facades for the California Energy Commission, the Lawrence Berkeley National Laboratory (LBNL) team defined facade performance as a product of technological solutions "based on fundamental building concepts for daylighting, solar heat gain control, ventilation and space conditioning.[1]" The "high" part of the moniker signifies an intelligent combination of these strategies based on details unique to a project, such as siting, materials and building system integration. Although many effective facade strategies could include passive and relatively low-tech solutions (i.e., correct solar orientation, overhangs, etc.), the reality is often increasingly complex designs that involve advanced materials, automated dynamic components and integrated climate controls.

In America, the tendency towards a more high-tech approach to performative facades is often the result of both clients and architects wanting to create a distinctly "sustainable" image. A roundtable discussion of 24 industry professionals led by LBNL confirmed this mentality, with one architect stating:

> "What it comes down to is whether that difference in payback [for an advanced facade] 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.[1]"

This mindset is a relatively recent phenomenon characteristic of the U.S. marketplace and less a factor in Europe, even though high-performance facades have been a part of European architecture for well over two decades. In Europe, the greater proliferation of advanced facade technologies has been "driven in part by higher energy prices, stricter building codes, and higher expectations regarding the quality of the working environment," (Yudelson, 2009) as explained in High-Performance Facades: Design Strategies and Applications in North America and Northern Europe, another report for the California Energy Commission by the Center for the Built Environment (CBE). European markets have legislated standards for building envelope performance, whereas American construction has relied on the adoption of voluntary (occasionally incentivized) sustainability standards and green building and product rating systems (LEED, Green Globes, Cradle-to-Cradle).

Nevertheless, CBE's report assembles a number of fundamental design strategies seen across a range of both European and American case study buildings. The seven key strategies identified are:

- Massing and orientation
- Transparency
- Solar control (glazing coatings, fixed and automated shadings, etc.)
- Natural ventilation
- Double-skin facade
- Semi-conditioned atria
- Integrated lighting and HVAC controls

All of these have pronounced effects on minimizing building energy use while "simultaneously enhancing the comfort and well-being of the building's occupants" (Zelenay, Perepelitza, and Lehrer, 2011, 1). The most effective and efficient buildings are designed holistically, integrating the facade strategy with other building systems and the overall design. When taken in broad strokes, one can start to see recurring combinations of strategies that have proven effective under certain climate conditions. For example, when combined correctly, integrated facade and HVAC systems in temperate areas such as coastal California can be particularly valuable because the mild climate "provides an opportunity to eliminate the need for cooling altogether.[2]" Ultimately, though, the success of facade performance depends on so many other design factors unique to a project that each case must be considered as a distinct challenge without any prescribed solutions. Although more effective, this kind of custom, tailored approach to design makes any kind of quantitative comparison much more difficult.

All of this tends to leave us with more questions then answers:

- What is the relationship between performance and complexity?
- Are high-performance facades/buildings good for the environment ("green")?
- What is the time scale for high-performance facades, and is it a short or long term solution?
- How do we measure performance, and what metrics define a high-performance facade?

DEFINING HIGH PERFORMANCE

High performance in the building sector is most often calibrated to energy efficiency, more specifically, energy efficiency during the operations phase of a building. Human health and productivity are also frequent considerations of contemporary architecture, and certainly essential to the high-performance building dialog. Energy performance, health and productivity are also fundamental elements of sustainability. In fact, a review of the literature reveals that high performance is often regarded as synonymous with sustainability. While energy consumption and resulting emissions are a central issue, comprehensive assessment of building performance yields a far more complex set of considerations. New buildings today are often erroneously labeled high performance. Buildings that do legitimately qualify for high-performance standing may not meet the true measure of sustainability. A more concise definition is required to bring clarity to these various ambiguities.

The term "high performance" is prone to ambiguity and misuse in a number of sectors, and its usage in the construction industry is no exception. The term is commonly applied to both buildings and their facades, and often to the materials of which they are comprised, such as "high-performance glass." Part of the problem is the relative nature of performance. Consider automobile performance, since cars are more commonly and easily measured by quantitative performance metrics. High performance in automobiles is typically measured in acceleration, speed and handling, with companies like Ferrari, Lamborghini and Porsche as top contenders. But what if fuel efficiency is the primary consideration? Wouldn't the Toyota Prius be a top contender for a high-performance vehicle by this measure? Or what if the playing field is changed from the track or highway to rugged off-road terrain? How would a Ferrari fare on the rocky rutted back roads of the Baja Peninsula? An entirely different kind of performance is called for. Additionally, sports cars are expensive — but is higher cost a necessary accompaniment to high performance, or could cost-benefit be developed as a performance metric? What about the complexity that seems to parallel performance improvement? Is there room in the high-performance dialog to embrace simplicity?

Performance then is contextual – it is not an inherent property of a material, product, system or building. So-called high-performance glazings are not high performing if misused. The context must be defined as a function of the application and conditions of use, and then relevant performance attributes can be considered. Buildings share a common set of attributes, but performance criteria may vary widely. An office building, residential tower, warehouse and hospital all have different performance requirements as a function of use. An office building in Toronto has different performance requirements than a similar building in Phoenix, as does a high-rise residential building in a dense urban setting when compared to one in a residential neighborhood. Therefore, relevant performance evaluation criteria must be established, along with appropriate metrics, baselines, data collection and validation strategies.

The US Energy Independence and Security Act of 2007 (EISA 2007, sec. 401-12, 13) defines a high-performance building as one that "integrates and optimizes on a life cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations." Broad strokes indeed, yet a useful list of fundamental considerations. Interestingly, the Act differentiates between high-performance buildings and high-performance green buildings, implicitly acknowledging that high-performance buildings are not inherently green.

According to the Act, a high-performance green building is a high-performance building that outperforms similar buildings in the following areas:

- Resource efficiency, including energy and water.
- Indoor environmental quality, including thermal comfort, lighting and acoustics "that affect occupant health and productivity."
- Environmental impacts to air and water, waste generation.
- Use of bio-based, recycled and nontoxic materials.
- Reuse and recycling.
- Systems integration.
- Reduced environmental impacts resulting from transportation.
- Consideration of human and environmental health impacts.

FIGURE 1
The outer layer of Loyola University's Richard J. Klarchek Information Commons (Chicago, Illinois) double skin is a cable net glass wall. The inner layer of the dual-skin is a point-fixed system that uses cast fixings to clamp insulated glass panels to vertical extrusions. The double skin provides a sealed cavity between the two layers that is used as an acoustic and thermal buffer between inside and out, and as a source of ventilated air under controlled conditions.

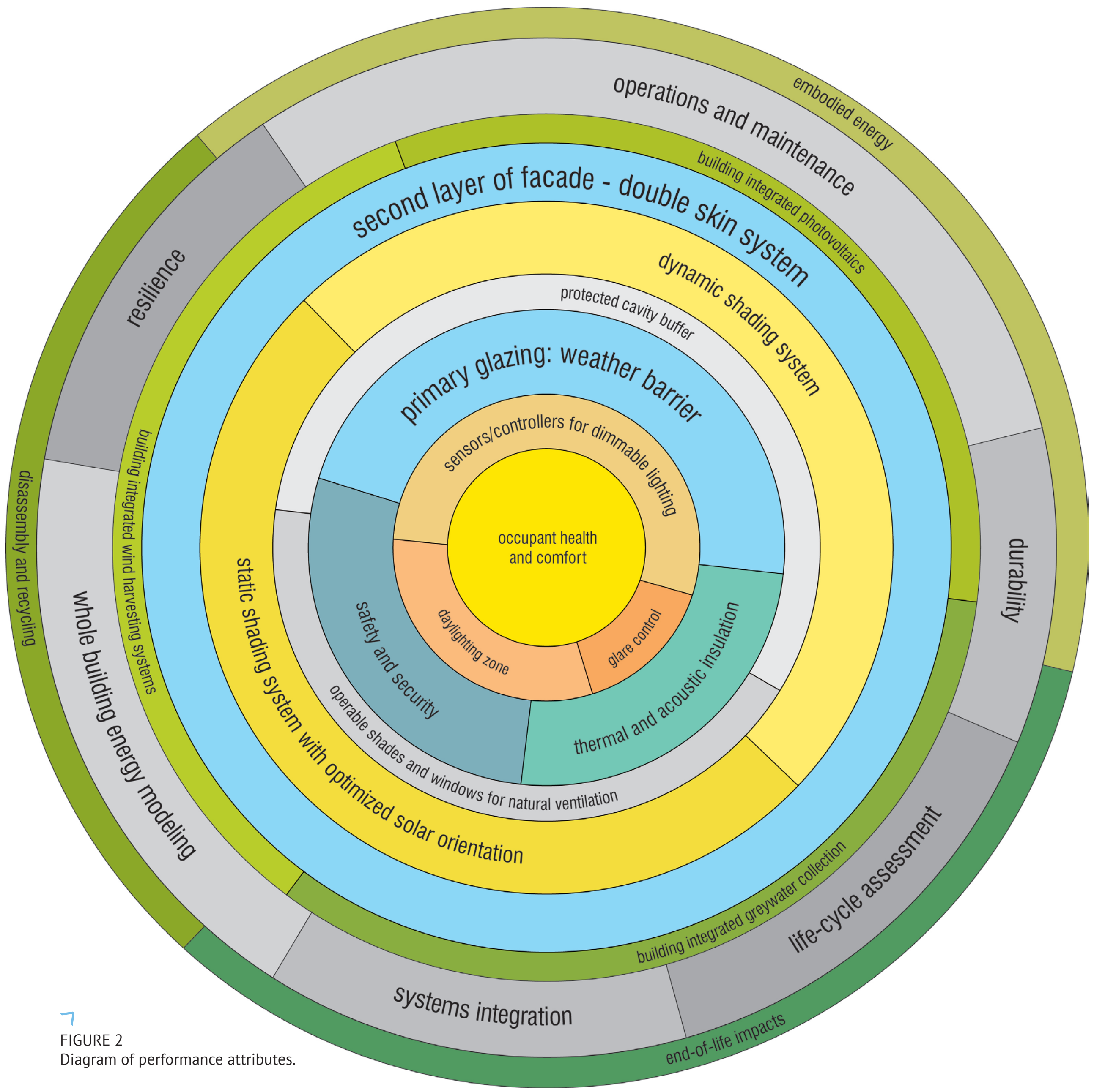


FIGURE 2
Diagram of performance attributes.

It is important to note that these definitions (both high-performance and green high-performance buildings) are consistently rendered in the context of building life cycle, a term the Act goes on to define as:

> "...all stages of the useful life of the building (including components, equipment, systems, and controls of the building) beginning at conception of a high-performance green building project and continuing through site selection, design, construction, landscaping, commissioning, operation, maintenance, renovation, deconstruction or demolition, removal, and recycling..." (EISA 2007, sec. 401-12, 14)

Other definitions for high performance exist, and more are certainly possible, but the EISA definition serves as well as any as a basis for deriving performance attributes appropriate to the building facade.

PERFORMANCE ATTRIBUTES: WHAT TO CONSIDER AND MEASURE

While EISA develops a set of attributes for high performance and green high performance, qualitative terms like "integrates, optimizes and outperforms" are subjective and relative measures that yield no concise metrics for evaluation. The National Institute of Building Sciences (NIBS) is one of the organizations working to define these needed metrics, baselines, benchmarks and verification strategies, specifically with respect to the building envelope. The building envelope is the nexus of many, often conflicting, functional demands, or as NIBS states: "many high-performance attributes interact at the envelope" (National Institute of Building Sciences n.d., 4). NIBS has leveraged EISA 2007 to define a set of performance attributes relevant to the building envelope, with an emphasis on enhanced security. The following attributes are similarly derived.

ATTRIBUTES FOR DETERMINING PERFORMANCE OF THE BUILDING FACADE

Building energy performance is significantly impacted by various attributes of the facade. The building skin provides thermal insulation, mitigates air infiltration and controls solar energy radiation, providing daylighting opportunities to reduce electricity consumption and heating loads resulting from artificial lighting. Solar energy harvesting technologies will one day contribute to net-zero and net-plus energy buildings. Natural ventilation through the facade can play a significant role in building energy efficiency.

ENVIRONMENTAL IMPACTS of the building facade include energy consumption and resulting emissions over the operations phase of the building lifecycle, as well as larger, more lasting impacts. The lifecycle context requires that embodied energy, disassembly and end-of-life impacts also be considered. Waste generation through the building lifecycle is another important consideration.

SAFETY and SECURITY are provided to the building occupant by the facade systems (at the most fundamental level, keeping bugs and burglars out, and babies in). Protection from weather extremes includes impact resistant design practices. Blast loading criteria is now commonplace in facade design. NIBS references ballistic, chemical, biological and radiological protection.

DURABILITY is an often neglected but fundamental aspect of performance and sustainability for all building systems, with special significance for the facade in its protective role of separating inside from out. In the majority of cases, a predicted service life for a building and its facade system goes undefined. Most damage and deterioration in a building can be traced to moisture penetration and migration through the building skin. Weathering is a particular concern for the exposed elements of the facade. Renovation requirements should be anticipated and planned for over the full building lifespan.

COST-BENEFIT, or ECONOMIC EFFICIENCY, is yet another important performance consideration, which takes into account at what cost performance attributes are being amplified, verses the benefit the improvement provides. As discussed in Part One of this ongoing series, high performance and green programs are often motivated by promotional and image interests (greenwashing) and may ignore simpler and less costly solutions capable of providing equal or greater benefit at less cost, solely because they do not provide a high-profile green "wow" factor.

HUMAN COMFORT, HEALTH, and PRODUCTIVITY are profoundly affected by the facade system. The facade provides thermal and acoustical comfort, daylight, visual comfort and glare control, as well as connection to the natural environment. Natural ventilation through the facade can greatly enhance indoor air quality. Favorable biophilic facade attributes are well documented in providing a more productive and healthier indoor environment (Terrapin 2012). Even small improvements in productivity can quickly trivialize related first costs.

SUSTAINABILITY criteria are included by the EISA in evaluation of high-performance systems. This opens the evaluation to the wide and varied considerations — and the inexact science — of sustainability. Many of the issues discussed here are fundamental sustainability issues. These considerations also include emergent issues like resilience, or the ability of a system to withstand extreme and unanticipated future conditions. Sustainability considerations will drive future development of facade technology. Water harvesting, for example, will become an increasingly important function of the facade in many geographic areas as supplies of potable water diminish. Lifecycle Assessment (LCA) will become the framework for the sustainability metrics that will drive future development of facade technology.

OPERATIONAL CONSIDERATIONS for the building facade include its integration with other building systems, the user interface, and maintenance and renovation requirements over the operational phase of the building lifecycle. Provisions must be considered to keep a building operational during planned renovation cycles, including disruptions to fuel and water supply, extreme weather conditions, and political instability.

Using the EISA definition then, a high-performance facade would be one that integrates and optimizes the above attributes on a lifecycle basis. A high-performance green facade is a high-performance facade that outperforms similar buildings with respect to key sustainability metrics as described above, again, on a lifecycle basis. Context, however, will determine the attribute set and the priority of those attributes as represented by the project specific criteria adopted for each attribute.

The EISA definition effectively leaves no performance attribute off the table when it comes to evaluating high-performance systems. But is it reasonable to "integrate and optimize" all of these attributes in each application? What if a facade application optimizes one area – energy efficiency, for example, but ignores durability analysis or acoustical performance? What about greenwashing? If a facade design employs high-performance materials and technology in an application where near equivalent performance could have been achieved with a simpler and less costly strategy (i.e., an expensive double-skin system where triple-glazed IGUs would have sufficed), is the system still deserving of the high performance designation? One begins to recognize how easily the term high performance may be applied with inadequate discrimination. High performance and green are terms that should be protected from dilution of meaning by clear definition and standards of practice.

While helpful to have some relevant performance attributes identified, related metrics are still lacking. The evaluation of some of these attributes may be inherently subjective, while others lend themselves to quantitative measure. In either case, appropriate evaluation criteria must be developed.

METRICS AND BEST PRACTICES

The path to a high-performance facade is simple in concept. In addition to the facade fundamentals — weather barrier, air and water seal, condensation resistance, safety and comfort — the high-performance facade must succeed in doing the following:

- Optimize daylight to reduce energy consumption and cooling load from electrical lighting
- Optimize view to provide a connection to nature
- Minimize glare
- Control solar heat gain
- Minimize heat loss in cold climates
- Provide natural ventilation to the greatest possible extent
- Optimize performance and minimize environmental impact over the lifecycle of the facade system

The complexity comes in the implementation of these provisions, a delicate balancing of often contradictory considerations. And that's just the beginning.

The context of high-performance facades was discussed in Part One, with a working definition adopted in Part Two, and relevant performance attributes explored in Part Three. This final, in-depth article aims to cut through the ambiguity of building facade performance and identify key metrics and best practices appropriate to the development of high-performance facade systems. The issues are many and complex, and although a fully detailed assessment is well beyond the scope of this report, additional resources are provided for reference in further research.

High-performance buildings and systems yield from high-performance processes: design, material procurement, fabrication, installation, commissioning and maintenance. High-performance design encompasses optimization of the attributes identified in Part Three over the building lifecycle, but high-performance attributes developed in design can easily be compromised during manufacturing and installation phases. A commissioning process helps assure that systems are operating as designed, and maintenance procedures are required to sustain performance levels over the lifetime of the building systems and assemblies. The following sections break down the various components and considerations that should be addressed at each stage of the design.

A FOUNDATION FOR PERFORMANCE

Basis of Design (BOD): This narrative becomes the roadmap to attaining building performance goals. Establish key performance benchmarks early as part of the BOD, including relevant green standards and rating systems (Energy Star, LEED, Green Globes, Living Building Challenge). Identify where code, standards and rating system requirements will be met or exceeded. Address how the facade systems will contribute to achieving these benchmarks as part of an integrated whole building design. These benchmarks become the building and system's performance goals.

Project Delivery Strategy: Adopt a project delivery strategy suited to the goals of a high-performance building project. The conventional design-bid-build strategy is generally inappropriate for this project type. Rather, consider design-assist, integrated project delivery, or other collaborative processes that facilitate the involvement of appropriate constituents early in the design process.

Service Life: Define a design service life for the building and the facade system. Assure that the estimated service life of the building, facade system, materials and sub-assemblies of the facade system are commensurate. ISO 15686, CSA S478-95.

Durability & Maintenance Plan: Adopt or develop a durability and maintenance plan for the facade system that supports the design service life. In addition to maintenance requirements, the durability plan should define major renovation cycles over the building lifespan. The Canadian version of LEED provides a point for durability planning.

Operating Manual: The operation of a high-performance building is often a complex affair placing demands on the facility's engineering team and building occupants. Operational procedures should be developed simultaneous of design development. Training strategies should be included.

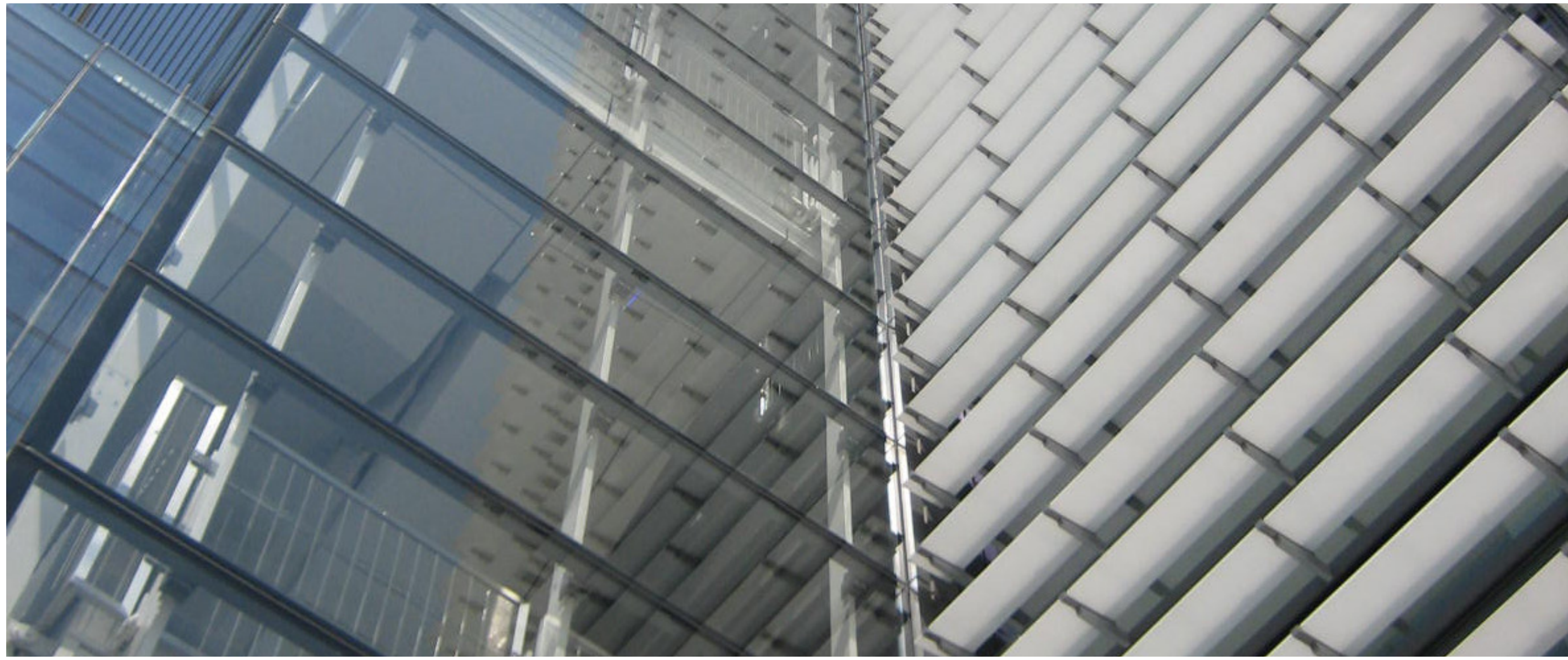


FIGURE 3
All exterior wall systems at the MGM City Center Aria Resort & Casino (Las Vegas) incorporate an integrated sunshade system with projecting fins. Fins range from two feet to eight inches deep as a function of location.

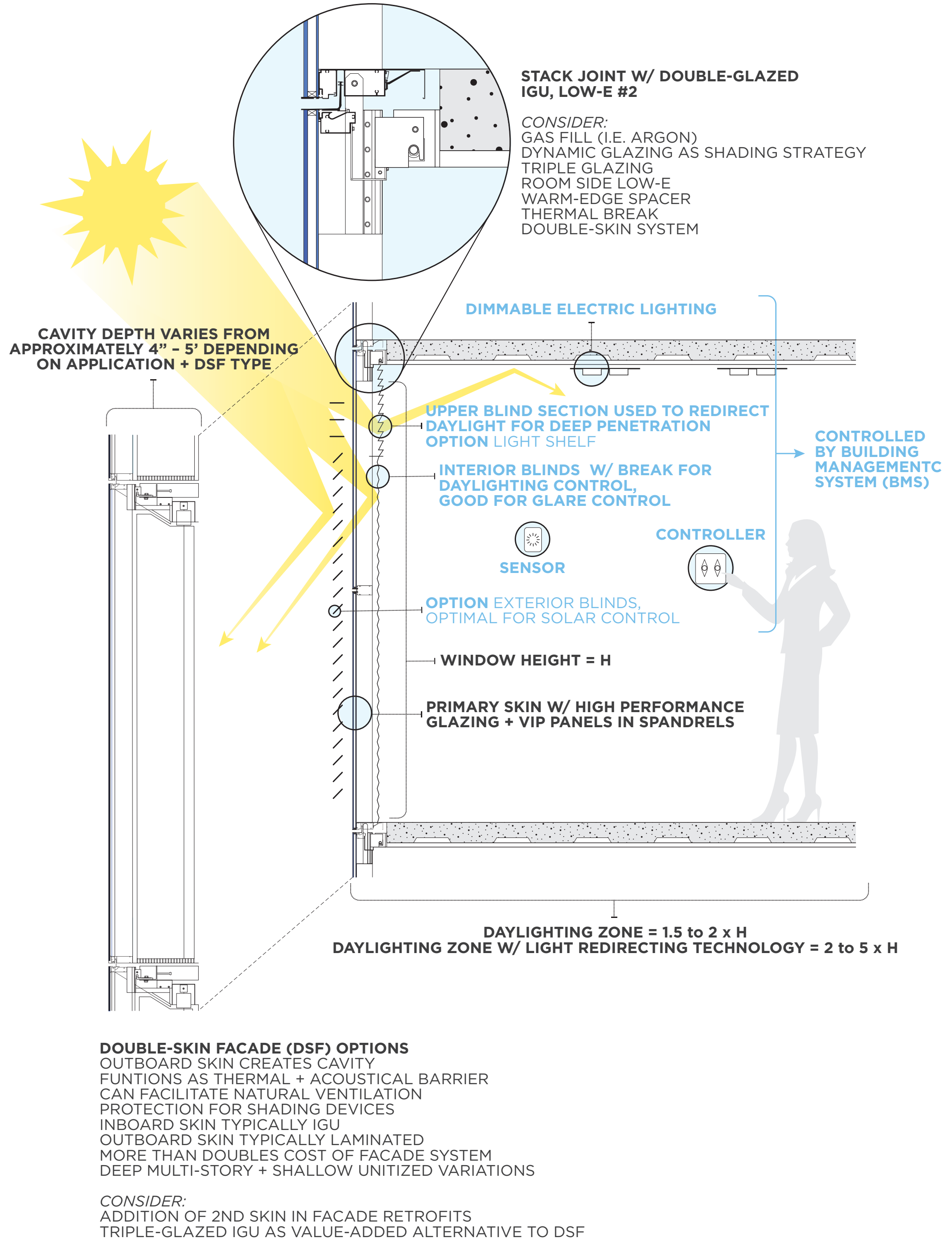


FIGURE 4
A diagram of high-performance facade integration for whole-building design.

Facade Commissioning: Commissioning is a process of assuring that the building owner gets what they ordered, and that it is performing per specifications. While the proof of performance is achieved near the time of project completion in most cases, the planning and process itself must start early in design. See more on commissioning in Proving Performance below.

SCHEMATIC DESIGN

An integrated design process requires that facade design be coordinated and linked with other building systems to achieve whole-building performance goals. It is a collaborative design process that requires the early involvement of all relevant constituents. The process commences with fundamental considerations of:

- Climate
- Building use
- Site conditions and characteristics

These considerations are used in determining:

- Building orientation – conditions will vary for each exposure of the building facade, where each elevation should be considered separately and its design varying accordingly.
- Materials, assemblies and systems design, including glass specification, material finishes, framing system design and shading systems. Virtually all aspects of the building facade are designed within the context of a building's specific climate, site and use.

Whole Building Energy Modeling: Should be mandatory for high-performance building designation. Must be developed early in the process and used as a basis for decision making during schematic design and design development.

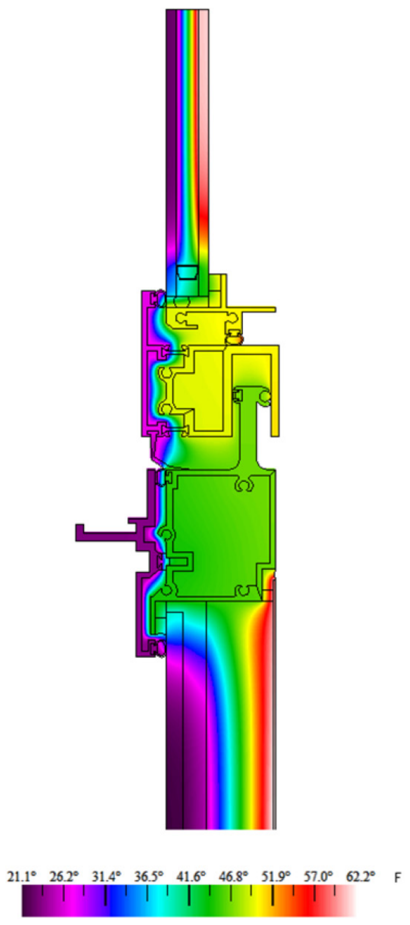
Window to Wall Ratio (WWR): With existing glazing technology, vision glass areas of over 30 to 35% impose unnecessary energy burdens on a building. In most cases this glass area is adequate to provide optimal daylighting and view. The common occurrences of much larger WWR in today's buildings are aesthetically and financially motivated (highly-glazed buildings produce higher occupancy and lease rates, a fact supported by any developer of premium commercial buildings). New glazing technologies may solve this problem, but likely at a considerable cost premium throughout the foreseeable future. Unless a highly glazed building is achieving near carbon neutral net-zero energy performance, a claim of green high-performance in such a building is arguable.

Daylighting Design: Should be mandatory for a high-performance building designation, using metrics from IES LM-83 to maximize daylight, minimize direct solar penetration and prevent glare. The daylighting collaborative is another resource.

Budgeting & Cost Analysis: Performance has cost implications. It is imperative that an appropriate context be created for evaluation of cost, or performance-enhancing features will either not develop or risk being lost to value engineering. First-cost or short term payback cost analysis will seldom support high-performance features. Lifecycle Costing Analysis (LCCA) is the appropriate methodology.

Aesthetics: The building skin impacts both performance and appearance like no other building system. The building design should respond to the context of local culture and neighborhood in its appearance and connection to neighboring public space. Large projects often include architectural artworks. Art glass in the building facade, as seen at the UCSF Medical Center at Mission Bay, is a recent example.

Lifecycle Assessment (LCA): Environmental impacts should be evaluated throughout the decision-making process of schematic



design and design development. LCA tools and processes facilitate this evaluation and provide for the consideration of embodied energy and end-of-life impacts. LCA is relatively new and still evolving. Current techniques are somewhat subjective and it remains an inexact science owing to the enormous complexity of the undertaking, but lifecycle inventory data is growing, and new simplified tools are emerging that provide for the integration of LCA in early design processes. Tools include:

- Green building studio
- Impact estimator
- BEES

Adaptability & Disassembly: Design for future adaptability to changing building use. Plan for facade disassembly, recycling and disposal at end-of-life. Account for resulting cost, energy consumption and environmental impacts. The CSA Group offers a guideline for the design of adaptability and disassembly in buildings.

HEALTH & SAFETY

A growing body of evidence documents the productivity enhancements provided by a healthy and comfortable indoor environment, an attribute providing a tremendous but often unrecognized financial benefit to a business enterprise as well as the health benefit to the employee.

COMFORT ASSESSMENT

- Thermal: Model MRT (mean radiant temperature; area-weighted average temperature of all surfaces) to evaluate thermal comfort of interior spaces.
- Acoustical: STC and OITC are the most common rating systems.
- Glare Analysis (interior and exterior): Metrics for glare analysis are emergent. Building designs with large WWR should require exterior glare analysis to avoid the kind of problems experienced by the Walt Disney Concert Hall, Vdara Hotel and Nasher Museum, especially if there is concave curvature to the facade.
- Interior Light Levels: Use IES recommendations as appropriate to workspace function.
- Indoor Air / Environmental Quality: Americans spend approximately 90% of their time indoors, making indoor air quality a primary concern. EPA IAQ. The forthcoming LEED v4 includes a major indoor environmental quality section.

Biophilia: Provide connection to nature through the provision of ample daylight, view and natural ventilation.

Security Analysis: The extreme loading conditions that may result from storm winds and blast loads are important considerations in facade design. Advances continue in the area of blast load facade engineering. Impact resistant specification criteria have developed in response to hurricane force winds, best represented by the South Florida Building Code with attention to glass in the building facade. Mullions are also addressed. Forced-entry at the accessible areas of the facade must be anticipated and prevented. TAS 202 covers testing procedures for windows and ground level glass systems. Similar requirements and procedures are migrating up the eastern seaboard in the wake of recent superstorms.

Resilience: Storm effects are increasing in parallel with storm strength in a pattern of rapid climate change. These effects must be anticipated and accommodated in building design such that buildings remain operational in the aftermath of super storms.

THERMAL PERFORMANCE

U-Factor: Work with assembly U-factor rather than other metrics such as center-of-glass U-factor.

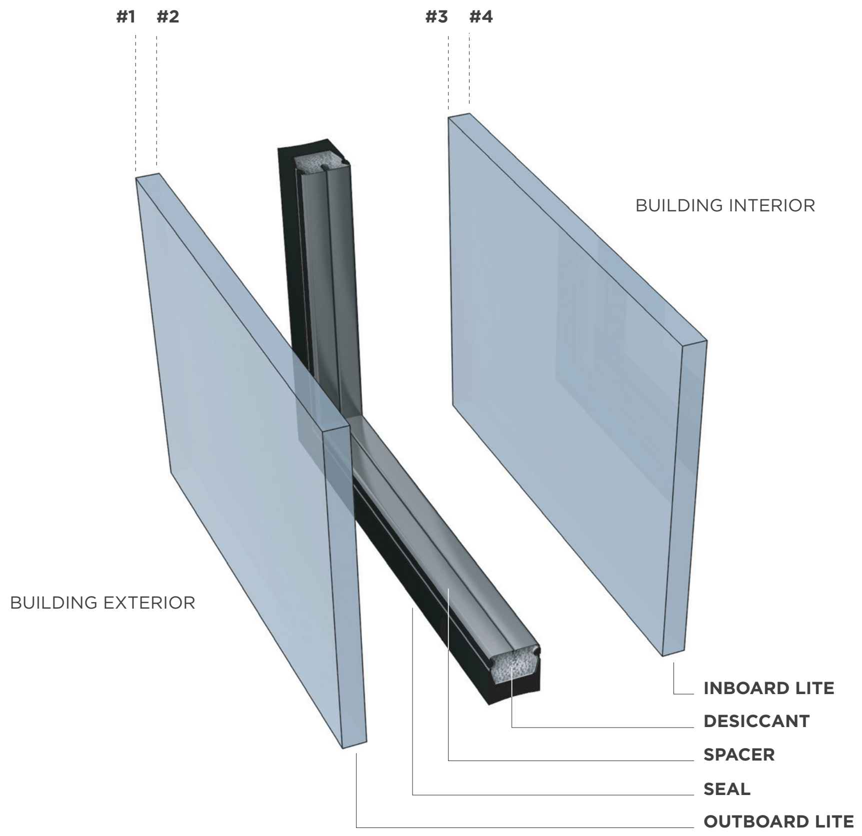
Glass: To optimize thermal performance use double or triple glazing, strategically placed spectrally selective low-e coatings, gas fills, nanogels for non-vision lites, and warm-edge spacers. Look for vacuum glass as a future high-performance product.

Wall Panels (opaque, translucent): Provide thermal breaks, adequate insulating material, backpans and carefully engineered shadowboxes to optimize thermal performance and CR. Consider the use of vacuum insulated panels (VIPs).

GLASS SPECIFICATION

Insulated glass units (IGUs) are highly engineered products of increasing diversity with complex behavior and appearance attributes. The appropriate application of these products in the building facade is an escalating challenge to the design profession, but pivotal to the success of contemporary highly glazed buildings. The issues are only briefly addressed here.

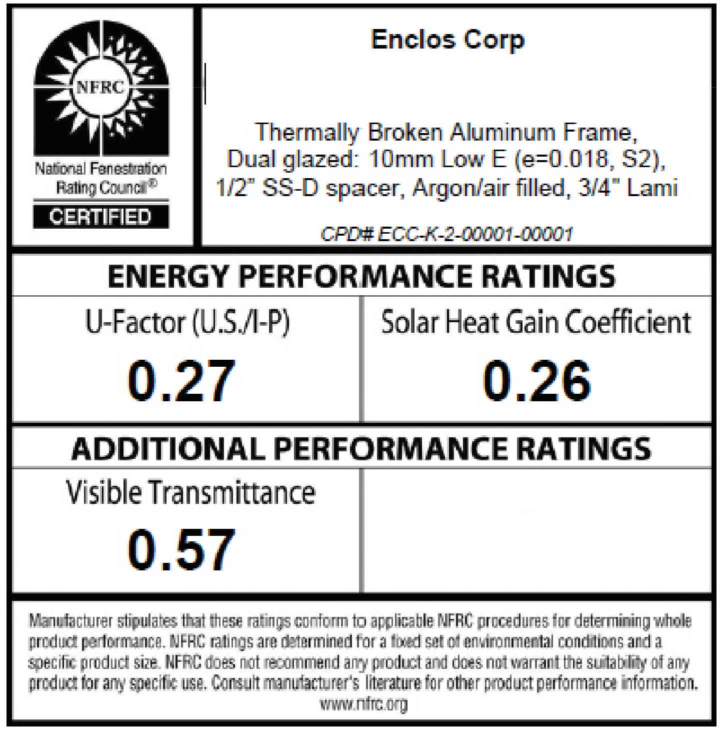
U-Factor: Thermal insulation metric, lower is better. High-performance double-glazed IGUs are as low as 0.30; triple-glazed as low as 0.13 (in combination with low-e and gas fill as described following). Use minimum 0.30, and buy as low as budget can support (note: use whole assembly value, not center of glass).



Solar Heat Gain Coefficient (SHGC): The fraction of incident solar radiation transmitted and absorbed as solar heat gain (a number between 0 and 1). The lower the number, the lower the solar heat gain — typically in the range of 0.20-0.50. Commercial buildings characteristically have high internal heat gain and consequently utilize low solar heat gain glazing even in colder climates. If the building energy design incorporates a passive solar heating strategy, higher SHGC values will be preferred (again, use whole assembly value, not center of glass).

FIGURE 5
Thermal analysis of a stack joint.

FIGURE 6
Diagram of an insulated glass unit (IGU) showing makeup and surfaces (#).


Enclos Corp

NFRC

National Fenestration Rating Council®

CERTIFIED

Thermally Broken Aluminum Frame, Dual glazed: 10mm Low E (e=0.018, S2), 1/2" SS-D spacer, Argon/air filled, 3/4" Lami

CPD# ECC-K-2-00001-00001

ENERGY PERFORMANCE RATINGS

U-Factor (U.S./I-P)	Solar Heat Gain Coefficient
0.27	0.26

ADDITIONAL PERFORMANCE RATINGS

Visible Transmittance	
0.57	

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product performance. NFRC ratings are determined for a fixed set of environmental conditions and a specific product size. NFRC does not recommend any product and does not warrant the suitability of any product for any specific use. Consult manufacturer's literature for other product performance information. www.nfrc.org

FIGURE 7
An example of an NFRC rating from a recently completed Enclos project.

FIGURE 8
The Lloyd D. George United States Courthouse remains a benchmark for post-Oklahoma City blast-resistant design today. The innovative systems developed by Enclos for this project were the first in the country to be subjected to full-scale testing to verify performance under blast loads.

VT/VLT (visible transmittance/visible light transmittance): the percentage of incident light transferred through a glazed assembly or the glass itself, respectively. Optimal daylighting and view often involves the attempt to balance high VT with low SHGC.

Condensation Resistance (CR): An NFRC rating on the scale of 1 to 100, with 100 being the highest corrosion resistance. Most consultants recommend a rating of at least 50 for window products. The design of high-performance facade systems should include rigorous thermal and condensation analysis to assure no condensation under predicted interior and exterior environmental conditions.

Low-e #2 / #3 Surface: In commercial glazing, where limiting solar heat gain is the predominant concern, the #2 surface is preferred.

Low-e #4 Surface: Can be used in combination with low-e on #2 surface to produce U-factor approaching 0.20. However, CR is reduced because the prevention of radiative heat transfer from the interior leaves the glass surface colder. Warm-edge spacers will help, but careful analysis is required to identify cold spots where condensation may occur. Note that the #4 surface represents the interior surface.

Gas Fill: Consider the use of less conductive gases, such as argon, in place of air in the IGU cavity.

Warm-Edge Spacers: The metallic edge spaces typically used in IGUs to separate the glass lites are a weak link in the assembly. They act as a thermal bridge resulting in panel edge temperatures much lower than center of glass. Condensation and heat loss may occur in this area.

Triple-Glaze, Low-e, Gas Fill (consider as cheaper alternative to double-skin system, unless part of a natural ventilation strategy).

Future Tech: Vacuum glazing, U-factor approximately 0.08.

See a definition of these terms and much more here:

- glasswebsite.com
- commercialwindows.org

Easily accessible and usable tools are provided free by the LBNL. (windows.lbl.gov)

FRAMING SYSTEM

The frame of a curtainwall system can easily amount to 5-10% of facade surface area. The frame incorporates the air and moisture barrier, and may act as a thermal bridge between inside and out, significantly compromising the U-factor of a facade assembly.

Thermal Bridging: Aluminum is highly conductive. Provide full thermal breaks, especially in climates with a cold weather season as experienced in northern Europe, northern United States and Canada to prevent heat transfer and condensation on interior surfaces.

Typical air infiltration would be 0.06 CFM/sq-ft at 6.24 PSF static pressure (AAMA 501.1 / ASTM E 331). Typical water standard would be no uncontrolled leakage at 15 PSF static and dynamic (ASTM E 283).

SHADING STRATEGIES

Shading strategies are an important consideration in cooling load dominated climates, or those with hot a season, including northern North America and northern Europe.

Glass Makeup: Strategically located frits, spectrally selective and low-e coatings, blinds in the IGU cavity, dynamic glass (electrochromic, thermochromic, photochromic).

Shading Devices: Exterior is the best location to block heat gain, but results in maintenance issues because of exposure. Horizontal shading is best on the south exposure, and vertical best on east and west exposures (northern hemisphere). Interior shades and blinds are good for glare control, but too late for solar control. Instead, use split shades so the upper section can be used independently to bounce light deeper into the room while the lower section is used for glare control. Double-skin facades are sometimes used to provide a protected cavity for a shading system. Shading components in a double-skin cavity or IGU cavity may cause undesirably radiative heat gain.

VENTILATION

Ventilation Scheme: Operable windows and vents are an opportunity to substitute natural ventilation for mechanical cooling, thereby improving interior air quality and reducing energy consumption. Mechanical cooling may be entirely eliminated in some climates. Double-skin designs may facilitate natural ventilation strategies. A good performance metric is the percentage of the year that a building can be naturally ventilated, albeit a climate dependent metric, but one for which local benchmarks can be identified or established. The Tower at PNC Plaza, designed by Gensler with the aim of being the world's greenest building, is intended to be naturally ventilated for over 40% of annual work hours.

GENERAL DESIGN CONSIDERATIONS

Consider the use of dynamic glazings and shading systems as a means to tune such things as VLT and SHGC in response to changing environmental conditions.

Building Integrated Photovoltaics (BIPV): Consider BIPV as a means to offset building energy use, but only after all efficiency measures have been optimized.

Structural Design: Wind, seismic, impact and blast. Embrace resilient design practices that anticipate escalating natural and social forces.

Constructability Review: Provide ongoing evaluation throughout the design process of the impact of design decisions on fabrication and installation processes.

Pre-Construction Performance Mockups: Test typical conditions of each major wall type and their interfaces in the form of full-scale mockups. Do not skimp on the mockup program. Test protocols per ASTM E2099 – 00(2007) and related specifications. Visual mockups are becoming increasingly as common as the materials incorporated in the growth of facade in diversity. Test protocols per ASTM C 1036.

PROVING PERFORMANCE

Field-Testing Water & Air Infiltration: Post-construction field-testing is becoming increasingly common. Tests involve representative portions of the constructed facade, conducted in accordance with the requirements of AAMA 501.2 and AAMA 502.2.

Commissioning: Building facade commissioning is also trending as facade systems incorporate increasing complexity. Dynamic systems with sensors, controllers and operable shading devices, integrated with lighting systems and the

FIGURE 9
The Jerome L. Greene Science Center's facade program incorporates six wall types, including high-performance structural facades, double-skin walls, and a series of metal and glass canopies and vestibules.

building management system need the performance validation that commissioning provides. LEED provides points for one-time commissioning and additional points for a program of ongoing commissioning.

Post Occupancy Monitoring & Data Dissemination: This is desperately needed to demonstrate the effectiveness of current practices so that refinements can be made going forward. In the too few instances where such data is collected, owners are reluctant to publish it. Codes, standards and rating systems must embrace this and require proof of performance during the operational phase of a building. Cities like New York and Minneapolis are now requiring the publication of building energy consumption data.

SUSTAINABILITY

Consider lifecycle environmental impacts to inform the design development process, material and product selections. LCA provides the context for sustainable building practices, including material and energy consumption throughout the process from extraction to transport, manufacturing, construction, operations, maintenance, renovation cycles, and finally, disassembly and recycling/disposal.

Durability & Adaptability: Design for long building life. Considering the magnitude of the investment of resources represented by large commercial and multi-story residential buildings, they should be designed for long service life. This necessitates the anticipation and accommodation of the changing patterns of future building use and function. Longer building service life is an inherently sustainable attribute, but also exposes the building to the potential of additional cycles of changing use.

Simplicity: Use the simplest available option. Simplicity is an undervalued principle in the design of high-performance buildings, which are trending towards escalating complexity. This complexity must be evaluated in the context of sustainability: will these increasingly high-tech strategies contribute to the sustainability of the built environment? Some will, some will not. The attribute of durability, for example, is sometimes neglected in the evaluation of high-tech design practices and building assemblies. Consider passive design strategies for thermal control and natural ventilation.

Ultimately, sustainability is not determined at the level of an individual building, but buildings must contribute to the sustainability of the higher order systems of community, region, nation, and ultimately, planet.

CONCLUSION

Unsurprisingly, the implementation of a truly high-performance building is no easy feat. This article barely scratches the surface of the considerations relevant to the building skin alone. Energy efficiency, the most frequent focus of building performance, is not enough by itself. In order to truly earn a high-performance building designation, all of the considerations identified above must be considered and addressed in an integrated response to the building program.