Building Envelope Technology Symposium

Not Your Grandfather's Windows: New Glazing and Fenestration Technologies to Meet Expanding Energy- and Peak Power-Reduction Goals

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ABSTRACT

New objectives for building envelope performance, coupled with a serious refocusing on the peak power demands on our utilities (defined primarily by building energy use and time of use), require a reevaluation of the importance of fenestration performance. This paper will review the array of window and glazing systems currently available and summarize the boundary conditions of their currently available energy ratings, quantify the energy and power implications of broader marketplace adoption of current technologies, describe several of the emerging window and glazing technologies, and quantify the HVAC sizing and operations implications of different fenestration choices.

SPEAKER

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Chris Mathis has served as a scientist in the Insulation Technology Laboratory at the Owens-Corning Fiberglas Technical Center, was the director of the Thermal Testing Laboratory for the National Association of Home Builders Research Center, and director of marketing for Architectural Testing, Inc., a private laboratory specializing in the performance of buildings and building products. He was a founding member and the first director of the National Fenestration Rating Council. Today, his business focus is to work with strategically aligned clients, leveraging that knowledge and understanding to improve buildings, building products, and the codes and standards that govern them.

NOT YOUR GRANDFATHER'S WINDOWS: NEW GLAZING AND FENESTRATION TECHNOLOGIES TO MEET EXPANDING ENERGY AND PEAK POWER-REDUCTION GOALS

ABSTRACT

From Miami to Maine to Malibu, fenestration technologies have been a focal point in trying to improve the building energy performance and building energy codes around the nation. However, at their best, most window systems still are the least efficient aspect of any building envelope. Even though today's most energy-efficient window and glass technologies have evolved to deliver unprecedented levels of performance, they still have very little market penetration, and adoption of these proven technologies remains slow. Business as usual often remains the impediment to achieving specific energy and sustainability goals.

New objectives for building envelope performance, coupled with a serious refocusing on the peak power demands on our utilities (defined primarily by building energy use and time of use), require a reevaluation of the importance of fenestration performance. From commercial buildings to residential, from new construction to rehab, all face the challenge of choosing the right glazing system that will durably deliver long-term, predictable, and reliable energy and power savings.

Architects, engineers, specifiers, and other professionals in the buildings arena should update their current knowledge base about window and glass technology prior to any new or rehab construction project. Specific project objectives—with regard to new energy codes, sustainability, green building objectives, daylighting objectives, local utility peak-power concerns, building operating schedule, and others—can dramatically affect the decisions made about window and glazing type.

This paper will briefly review the array of window and glazing systems currently available and summarize the boundary conditions of their currently available energy ratings for U-factor (thermal transmission) and solar heat-gain coefficient (SHGC). We will discuss some of the HVAC implications of window and glazing choice and several of the emerging window and glazing technologies will be described, citing their energy and power implications and anticipated limitations.

We will also show examples of unanticipated loopholes and biases in the energy code that can easily undermine efficiency and sustainability objectives, depending on window selection criteria. We hope to provide architects, engineers, specifiers, and others interested in building envelope performance with practical guidance on product types, performance, selection tools, code compliance, and specification pitfalls.

BRIEF SUMMARY OF FUNDAMENTALS

Windows generally remain the weak link in our building envelope energy performance. Even with proper attention to key elements of good building design (such as attention to orientation, shading, and appropriate glazing selection), windows still are net-energy penalties for most buildings. We can lessen this energy penalty and, in some cases, even make windows a net-energy benefit. But in today's production home environment and with our cookie-cutter commercial building mentality, we rarely give these critical design and selection variables the full attention they need or deserve.

The problems associated with selecting the right windows and glazing are amplified by the many changes that have occurred to window and glazing technology over the last decade. No longer can we merely specify "aluminum windows" or "wood windows." Most windows today are complex engineered systems composed of dozens of different materials designed to give functionality, finish, color, security, and a variety of other performance attributes. Energy efficiency is just one of many critical performance attributes that will not fit behind one of those simple, outdated generic window descriptors.

Historically, we improved window performance by adding layers of glass. Each layer gave us added resistance to heat flow and different solar heat-gain properties, shown graphically in *Figure 1*. With callous disregard for the job site crew, efficiency advocates in the 1970s were envisioning quad glazing systems, trying to make a thin, visually transparent system compete thermally with a fairly well insulated wall.

Innovations in low-e coatings, frame

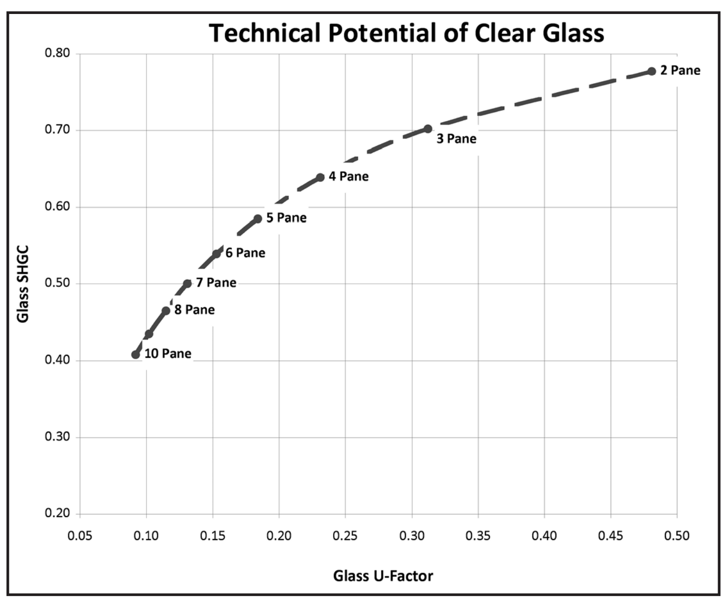

Figure 1 — U-factor and SHGC potential from multiple layers of clear glass. (Chart generated using ASHRAE Handbook values and equations for determining center-of-glass U-factor for multiple glazing layers).

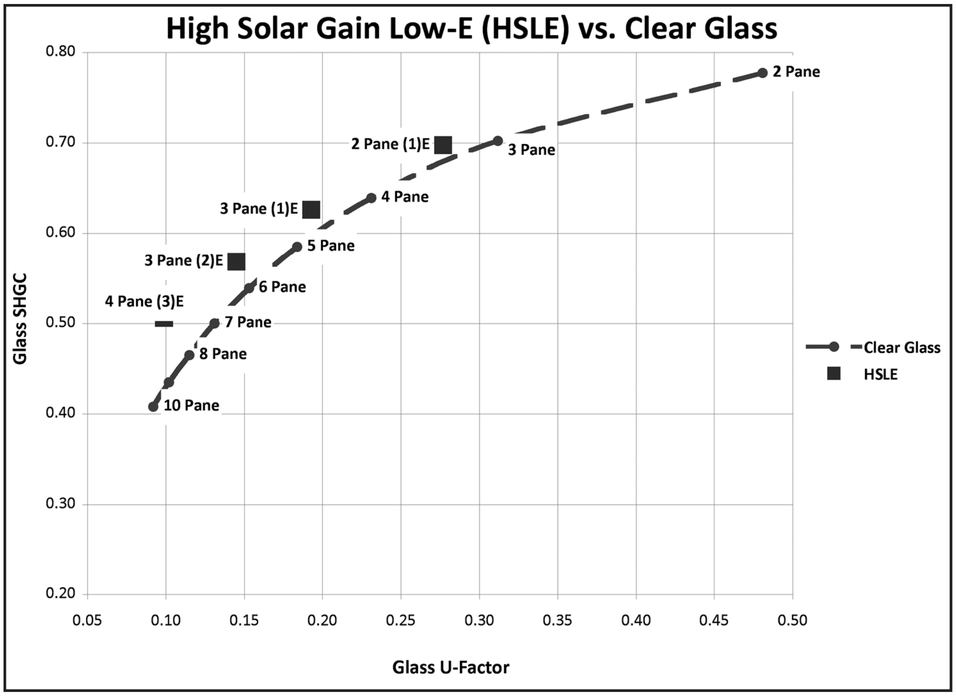

Figure 2 – First generation low-e coating impacts on glass energy performance.

design, thermal breaks in aluminum, low conductance spacers, and composite materials resulted in double glazed systems that could deliver U-factors approaching the quad glazed performance objective. *Figure 2* shows how glazing U-factors and SHGCs evolved with the first generation of low-e coatings. These early low-e coatings were designed to be highly transmissive of a large portion of the solar spectrum while fairly reflective to long-wave radiation (heat), making them much better insulators than their previous clear or tinted glass counterparts. Today, these low-e coatings are generally referred to as High Solar Gain Low-e glazings (HSLE).

As cooling-load management and reduction became increasingly important in building energy performance, the glazing industry responded with an increasing array of coating technologies. These new coatings could essentially be fine tuned to address specific solar transmission and reflection objectives while maintaining high degrees of visual clarity. While almost all of the low-e coatings provided low U-factors (less than 0.35 BTU/hr x sq ft x °F), these newer coatings began to focus on ever lower SHGCs, targeting cooling load reductions and addressing the growing peak power and air-conditioning demand.

Figure 3 shows how glass performance has dramatically changed from these early low-e coatings, now with coatings fine-tuned for various levels of additional solar control. These coatings enabled heretofore unachievable reductions in solar heat gain while maintaining highly visible transmittance. These new mid- and low-SHGC glazings provided dramatic cooling energy savings, reduced peak cooling loads (enabling smaller HVAC systems to be installed), and provided improved occupant comfort year round. (Note the dramatic downward shift in the SHGC values for double, triple, and quad glazing incorporating these new solar control coatings.

When we put these new glazings into a variety of different window-framing systems, we get a variety of whole-product performance values. For example, the same glazing in a low-conductivity frame (such as wood, vinyl, fiberglass, and others) will perform similarly (in terms of U-factor and SHGC) to the glass-only values. Putting this same glazing into a high-conductivity frame (such as aluminum or steel) can result in dramatically higher U-factors and SHGC values than those of the glass alone. The window industry has recognized this fact and has developed an array of improved thermal break technologies for highly conductive frames that are designed to get whole-window performance values much nearer to the glass values.

Figure 4 shows how whole-product performance (i.e., window performance)—even with a low-conductivity material such as vinyl—still shifts away from the glass-only values. The values shown here essentially represent the performance limits of passive (nonswitchable) glazing technologies in improved frames that are available today.

To protect against misleading performance claims describing glass-only or frame-only performance, the industry worked with the federal government, state agencies, and specifiers in the late 1980s to develop a reliable window energy-performance rating system. Today, most window

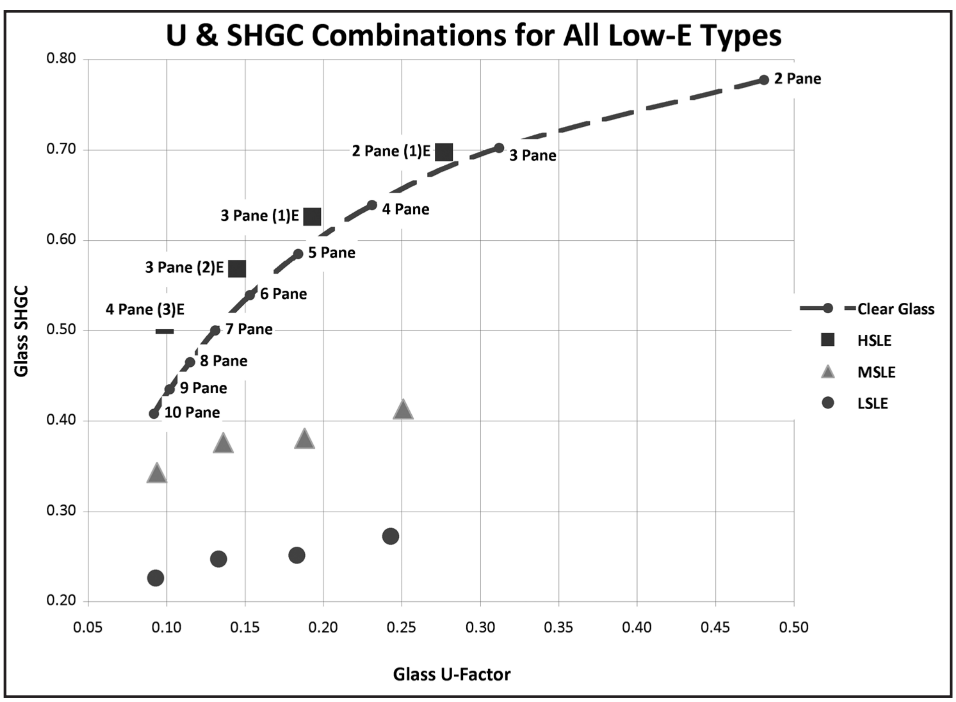

Figure 3 — Energy-performance spectrum of low-e coatings available today. HSLE = High-Solar Gain Low-E; MSLE = Mid-Solar Gain Low-E; LSLE = Low-Solar Gain Low-E.

systems carry the NFRC rating and energy-performance certification. (*Figure 5*).

As building efficiency demands grew, the demands on ever-improved window energy performance grew. Comparative U-factors and solar heat-gain coefficients (SHGCs) evolved from marketplace chaos to codes and incentive programs that specifically reference and reward improved window system performance.[1] Programs like EnergyStar® and others embraced these comparative ratings and have established marketplace incentives for selecting and specifying better windows.

As can be seen from *Figures 1* through *4*, there are technological limits to passive technologies. U-factor is constrained by coatings, wavelengths, layers, and the thermal conductance of the assembled materials. Similarly, there is a technological limit to how low one can go with solar heat-gain coefficients while still retaining the ability to see through the window. And while even lower SHGCs can be achieved, they usually come by compromising visual clarity and reducing daylighting potential.

Emerging technologies offer the promise of even better performance levels. For example, switchable glazings offer the hope of window systems that can be fine tuned to climate, occupant, and building needs, changing from highly transmissive to opaque, depending on the type and level of switching control. However, the cost of these switchable technologies is far beyond typical design budgets, and the durability of these systems over time is still being assessed.

Providing visual connection to the outdoors while also limiting unwanted solar gain are the two most critical elements of most window selection criteria. Solar control is so important that some of the emerging technologies focus on exterior coatings, frits, and shading systems to further assist in building-load management.

WINDOWS AND THE ENERGY CODE

Our nation's first commercial energy code was published by the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) in 1975.[2] As a response to the oil embargo, this code focused on quantifying and establishing reasonable performance limits for building components and systems. Soon, a residential energy code (the Model Energy Code) followed, defining minimum energy-performance attributes for homes. Today, the residential and commercial energy codes are

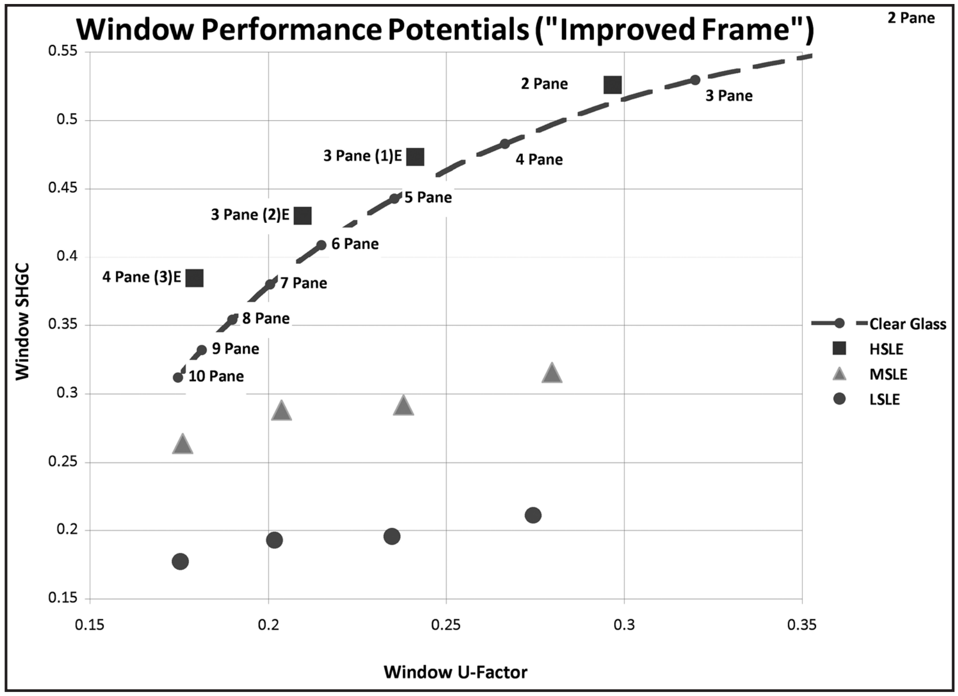

Figure 4 — Whole window U-factor and SHGC range available today. HSLE = High-Solar Gain Low-E; MSLE = Mid-Solar Gain Low-E; LSLE = Low-Solar Gain Low-E.

Figure 5 — NFRC label.

VERTICAL FENESTRATION (30% maximum of walls associated with the building envelope)								
U-Factor								
Climate Zone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Nonmetal framing	0.51 (0.32)a	0.40	0.35	0.32	0.30	0.30	0.26	0.25
Metal framing, fixed	0.73 (0.50)a	0.50	0.46	0.38	0.38	0.35	0.29	0.29
Metal framing, operable	0.81 (0.65)a	0.65	0.60	0.45	0.45	0.43	0.37	0.37
SHGC — All Frame Types								
Max. SHGC (assembly)	0.25	0.25	0.25	0.30	0.30	0.35	0.40	0.40
Min. VT/SHGC (assembly)								
Vertical fenestration	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

Values shown in parentheses are for extremely hot climates where the cooling design temperature exceeds 95ºF.
Note: Just a subset of the entire table is shown here.

Table 1 — Prescriptive fenestration requirements anticipated in ASHRAE 90.1-2010.

embodied in the International Energy Conservation Code (IECC). Many state codes have adapted the IECC for their specific use.

The IECC focuses on minimum levels of energy efficiency for buildings. Our early building-energy simulation programs initially focused on heating-energy use. As our recognition of the importance of air conditioning evolved, so did the computer programs. We soon realized that managing the loads from windows and glazing was one of the most critical energy-management practices we could employ. Today, those programs have evolved, enabling a fairly robust assessment of anticipated building-energy performance for both heating and cooling.

Both the residential and commercial energy codes evolved with two paths of possible code compliance. The first was a simple, prescriptive set of requirements that, when met, demonstrated compliance. The second path, called the performance path, allowed for computer simulations to be conducted allowing designers and engineers to try different combinations of variables that could meet the energy-performance targets. Prescriptive compliance offered the simplicity of a single checklist and easy enforcement. The performance path offered the flexibility of trying multiple options to achieve compliance. Both compliance paths have fallen victim to the law of unintended consequences.

UNANTICIPATED CONSEQUENCES

The early energy codes sought to establish different performance requirements for each building envelope element. By attempting to be all-inclusive, being certain to address all building materials, the codes established a structure of unintended bias that remains in place today. This bias evolved over time from trying to use economic criteria to help inform and set minimum efficiency requirements. Each building technology was evaluated separately as to its costs. As a result, steel walls have different minimum efficiency requirements than do wood walls or concrete walls. Similarly, aluminum windows have different energy performance requirements than nonmetal windows.

While this economics-based structure seems reasonable, it results in buildings with differing energy budgets based on the materials used. It assumes (at least at a mathematical level) that different building products do not compete for the same building element.

Consider: In the commercial code, if one chooses an aluminum window for a project, then the U-factor and SHGC have to meet certain specific requirements. However, if one chooses a wood, vinyl, or fiberglass window product, then the maximum U-factor and maximum SHGC values are lower—again, resulting in different minimum energy budgets for a code-compliant building, depending on which product is being used!

Table 1 shows this current code structure and the performance requirements for fenestration in the commercial code. The values shown are the values proposed for the 2010 version of ASHRAE Standard 90.1—the national model code for commer-

	Climate Zone	Source Energy (Mbtu) for Heating and Cooling		
		Metal Operable	Nonmetal	Difference
Phoenix	2 Dry	1,751	1,642	7%
Houston	2 Humid	2,137	2,050	4%
Baltimore	4	1,807	1,709	6%
Minneapolis	6	1,748	1,616	8%

Table 2 — Source-energy summation for four climate zones, comparing metal and nonmetal windows.

cial buildings, slated for publication in September.

The energy code shows different maximum U-factors for fixed metal-framed windows, operable metal-framed windows, and nonmetal windows. U-factors are a measure of thermal transmission—a performance measure. Why do we care about what material the window is made out of?

Each designer will select the window design or frames that he or she wants for his or her project to meet (or exceed) the requirements of the code. (Note: This same structure exists for insulated roofs [depending on how they are insulated] and for insulated walls [are they steel, concrete, or wood?] and for floors, slabs, and basements. The implication is that these different materials are not competing for the same wall, roof, or floor area.) The consequences of this structure are shown below.

We considered just one example of the unintended consequences of this code structure, analyzing a medium-sized commercial building in four climate zones. The building analyzed is one of the DOE commercial benchmark buildings.[3] The building analyzed is a 3-story, 53,630-sq-ft office building with a 32% glazing area (as a percentage of the wall area) and a 1.5 aspect ratio.

Holding every other variable constant, what are the implications of merely changing from one code-compliant window and framing system to another (i.e., from metal to nonmetal)? *Table 2* shows the resultant summation of heating and cooling energy for the four options.

Several observations can be made. First, code-compliant does not mean equal energy. While the mix of heating to cooling may change, the medium office building's energy budget, peak-power demands, and carbon implications are dramatically different — just by selecting a different code-compliant window. From Houston to Minneapolis, there is a 4% to 8% difference in energy use.

So one unintended consequence of this regulatory approach results in an energy-performance loophole. In this example, a building that consumes 8% more energy is just as code-compliant as one that consumes less merely by selecting a metal product over a nonmetal one.

Another unintended consequence is that makers of nonmetal windows have a more stringent U-factor requirement to meet just because their base material is less conductive. Again, different energy budgets for different materials? Isn't the code about performance?

While the code marketplace sorts out these material biases, the implications of glazing performance on building energy use continue to take center stage. At the most recent ASHRAE meetings, one of the most controversial and significant energy-savings elements debated was the prescriptive value for the 2010 version of Standard 90.1, shown in *Table 2.*

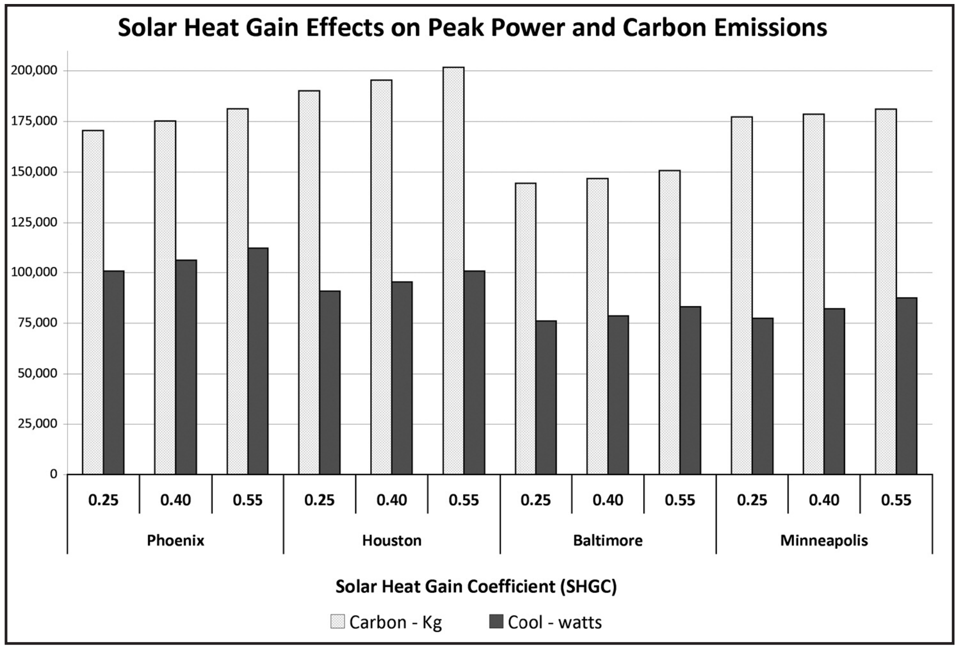

Figure 6 — Window SHGC impacts on peak power and carbon emissions.

WINDOW PERFORMANCE IMPLICATIONS ON LOADS AND POWER

While we focus on improving our energy codes, we also have to be aware of the implications of window selection beyond the boundaries of the building. Consider what happens each day as we "turn on" our buildings. As the day progresses, the demand for more electricity—especially for air conditioning—steadily increases. Managing and even reducing cooling loads become critical components of managing utility peak demand, as well as addressing carbon emission-reduction goals. *Figure 6* shows the impact of varying window SHGC on peak power demand and carbon emissions for this same medium office building in four climates.

So as we pursue green building, Energy Star® buildings, and other beyond-code objectives, the importance of cooling-load reduction cannot be overstated.

SPECIFICATION GUIDANCE FOR BUILDING PROFESSIONALS

There are many criteria that go into the selection of windows and glazing—from the strength to withstand tornadoes and hurricanes, to resistance to salt air on the coast, to providing ease of use and access to view, to low maintenance and long-term performance reliability, to energy attributes like U-factor and SHGC, to building façade aesthetics. And there are always trade-offs to be made. Does one want proven durability and long-term performance? Or are aesthetics more important? Is one measuring and trading carbon? Or should one be focused more on points for a rating system?

Following is a list of attributes that should be considered when selecting any window or glazing system:

1. Meet the design loads required by code for the building (based on wind speed, exposure class, location in wall, unit size, importance factors, and mean roof height).
2. Know the basic code requirements (air leakage, water penetration).
3. Know what your project requires (forced-entry resistance, impact resistance, operating force, safety glazing).
4. Know the energy requirements (certified U-factor and SHGC values).
5. Know the other window-related properties that will contribute to meeting overall design objectives (visible transmittance, daylighting potential,

glare management, views).
6. Clearly define any beyond-code objectives and the role that windows play in achieving those objectives (peak-power and demand-charge implications, carbon-emission implications).

CONCLUSION

This paper was meant to provide an overview of the primary energy-related issues associated with window and glazing selection. The array of available products and technologies has dramatically changed in just the past few years. The lessons learned about windows a decade ago may be totally inappropriate to today's energy-code requirements. Yesterday's technologies may be insufficient to address our beyond-code and green-building design objectives. Architects, engineers, and specifiers must consider the expanding array of technologies as opportunities but not forget to fully address all of the fundamental specification requirements that ensure proper window and glazing selection for each particular project.

FOOTNOTES

1 National Fenestration Rating Council.
2. ASHRAE Standard 90-1975, American Society of Heating Refrigerating and Air Conditioning Engineers, Atlanta, GA.
3. P. Torcellini, M. Deru, B. Griffith, K. Benne, M. Halverson, D. Winiarski, and D.B. Crawley, *ACEEE Summer Study on Energy Efficiency in Buildings*, DOE Commercial Building Benchmark Models, 2008.

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