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Evaluating Fenestration Products for Zero-Energy Buildings: Issues for Discussion



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# EVALUATING FENESTRATION PRODUCTS FOR ZERO-ENERGY BUILDINGS: ISSUES FOR DISCUSSION

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## ABSTRACT

Computer modeling to determine fenestration product energy properties (U-factor, SHGC, VT) has emerged as the most cost-effective and accurate means to quantify them. Fenestration product simulation tools have been effective in increasing the use of low-e coatings and gas fills in insulating glass and in the widespread use of insulating frame designs and materials. However, for more efficient fenestration products (low heat loss products, dynamic products, products with non-specular optical characteristics, light re-directing products) to achieve widespread use, fenestration modeling software needs to be improved.

This paper addresses the following questions:

1) Are the current properties (U, SHGC, VT) calculated sufficient to compare and distinguish between windows suitable for Zero Energy Buildings and conventional window products? If not, what data on the thermal and optical performance, on comfort, and on peak demand of windows is needed.

2) Are the algorithms in the tools sufficient to model the thermal and optical processes? Are specific heat transfer and optical effects not accounted for? Is the existing level of accuracy enough to distinguish between products designed for Zero Energy Buildings? Is the current input data adequate?

## BACKGROUND

Fenestration product thermal and optical properties (U, SHGC (or alternatively SC), VT) are routinely used by codes, the Energy Star program, and building energy analysis software to compare and evaluate the energy efficiency of products. Computer modeling to determine product properties of fenestration products has emerged as the most cost-effective and accurate means to quantify them. In the United States, the WINDOW/THERM/Optics suite (Mitchell et.al. 2001, Arasteh et.al. 1998, Optics 5 2001) forms the basis of the NFRC's rating and labeling system. These same tools are used by manufacturers as part of the design process so that they understand what changes to products are necessary to meet certain target performance factors (U, SHGC, VT).

These tools and the associated rating system have been effective in increasing the use of low-e coatings and gas fills in insulating glass and in the widespread use of more insulating frame designs and materials. However, as Apte et. al. have shown (Apte 2003), today's current generation of efficient window products (ENERGY STAR low-e, argon filled) does not come close to meeting the requirements of Zero Energy Homes. Similarly (Arasteh 2007), fenestration products with light re-directing properties and dynamic solar control are needed to make windows effective contributors to Zero Energy Commercial buildings.

This paper seeks to answer the following questions:

1) Are the current properties (U, SHGC, VT) calculated for the existing rating and labeling program sufficient to distinguish between windows suitable for ZEBs and conventional products? If not, what data on the thermal and optical performance, on comfort, and on peak demand of windows is needed. For example:

   a) How can one compare dynamic windows to static windows or dynamic windows, with different switching ranges, to each other?

   b) How can one compare a non-specular fenestration product (see Figure 1) to conventional specular product or other non-specular products on the basis of normal incidence SHGC and TV properties?

   c) How is a dynamic façade, with air moving between glass and the space, evaluated?

   d) What is the impact of varying solar spectral irradiance conditions and frame self-shading on the true solar heat gain through windows?

2) Are the algorithms embedded in the tools sufficient to model the thermal and optical processes? Are specific heat transfer and optical effects not accounted for in the modeling procedure? Is the existing level of accuracy enough to distinguish between products designed for ZEBs? Is the current input data supplied for NFRC ratings adequate? For example:

a) Will the approximations currently used for convection in frame air cavities be accurate enough to properly distinguish between advanced frame designs?

b) Does ignoring deflection in glazing cavities in highly insulating low-e/gas-filled units overestimate their performance significantly, particularly when compared to more planer vacuum or aerogel products?

c) For dynamic products, spectral data for at least two states will need to be provided. Do optical properties vary linearly for each wavelength interval.

d) For non-specular products, how important are spectral effects?

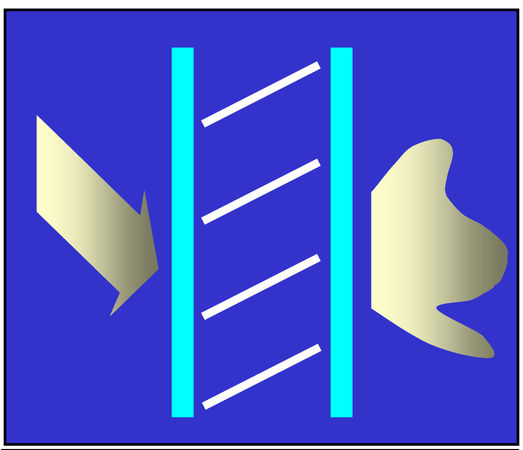

Figure 1: Non-specular glazing system

## FENESTRATION TECHNOLOGIES FOR ZERO-ENERGY BUILDINGS

Research at LBNL and other institutions internationally has led to the identification of four technologies which will be instrumental in the development of ZEB fenestration products. These are:

1) Dynamic Windows: Such technologies will allow products to modulate solar gains on a seasonal basis (for heating vs. cooling tradeoffs, primarily in residential buildings in middle and northern climates) and to modulate solar/visible transmittance in order to achieve the optimum balance between daylight and heat gain (for commercial buildings where daylighting is utilized). Dynamic windows will in the long run be achieved through coating technology improvements, although the use of mechanized, operable shading layers is a currently available technological option which must be considered.

2) Highly insulating windows: Windows in the building stock in the United States are estimated to use 2 quads a year in heating energy. Even if all existing windows were replaced with today's ENERGY STAR low-e products (U values < 0.35 Btu/hr-ft2-F), windows related heating would still be over 1 Quad. Because heating loads are strongly tied to conductive losses, technologies which lead to lower window U-factors are the key to reducing heating energy. A 0.1 Btu/hr-ft2-F window is targeted as a product, which will meet the requirements of zero-energy homes

3) Low-Solar Heat Gain technologies: In climates where cooling is the dominant energy load, low-solar heat gain windows (i.e. SHGC <.2) may be more cost-effective than dynamic products, particularly for residential applications. Such products would have approximately half the solar heat gain compared to today's Energy Star products for the southern zone.

4) Daylighting and Dynamic Facade Technologies: While commercial buildings benefit from the technologies used in residences, the single largest energy use in most commercial buildings (particularly newer ones) is lighting and the use of daylighting technologies in smart facades to capture daylighting benefits addresses this need. To offset electric lighting energy three requirements must be met: daylight must be admitted and distributed as needed; overall intensity must be controlled to provide glare control and prevent overheating or adverse cooling impacts (see Dynamic Windows above); and electric lighting must be controlled (e.g. dimmed, to save energy and reduce demand). Targets are to develop daylighting technologies that displace 50-90% of annual electric lighting needs in perimeter zones, and extend perimeter zones to increase building-wide savings. Integrated façade solutions that achieve net 60-80% energy and demand savings compared to facades that meet ASHRAE requirements for typical climates are also targeted. These technologies must also address occupant glare and visual comfort needs which add to their market benefit.

Table 1 below identifies the simulation effects which need to be improved for each of these product types, for their proper assessment for use in ZEB's.

*Table 1: Simulation Issues for ZEB Window Technologies*

| **ZEB Window Technology** | **Issues for Static Properties** | **Issues for Build. Perf.** |
|---|---|---|
| Highly Insulating Windows<br>- aerogel insulations<br>- vacuum glazings<br>- multiple gas-fills, low-e<br>- high performance insulating spacers, frames | - Test methods to measure low-heat flux products with certainty and hot box methods for total products (for simulation validation), hot-plate methods for components (input for simulations)<br>- 3D vacuum pillar and edge model<br>- Deflection analysis simulation capability<br>- 2D/3D cavity convection and radiation<br>- 3D convection in frames<br>- frame radiation model | - Performance variations with temperature differentials will be a greater percentage of heat flow for low heat flow products<br>- SHGC, VT issues may become more complex for some products (see Complex Products below)<br>- transient model for phase-change spacers |
| Dynamic Windows | - Static properties in multiple states needed | - Annual simulations necessary to understand variations in ranges, controls |
| Complex Facades | - Heat transfer model (and validation of) for air flow glass facades<br>- Large scale FEM modeling of window systems | - “product” is integrated with building; performance is coupled with other building elements |
| Low-Solar Heat Gain Windows | - Validated test procedure<br>- SHGC impact incorporates varying solar spectra<br>- polarization impacts<br>- color vs. neutral appearance | - Simulation procedures to assess self-shading, frame effects<br>- Solar spectral irradiance changes by climate, season are more significant for some products<br>- prediction of angular dependence for peak loads |
| Complex (non-specular) Products, Daylighting and Solar Control Technologies | - Transmittance, Reflectance Measurement Analysis Capabilities for Complex Products, visible and solar<br>- Computer modeling capabilities of solar optical properties of complex products<br>- Development and Validation of heat transfer models through complex layers | - For non specular products, angular properties cannot be approximated by a “typical” pattern as with specular glass; bi-directional data is needed |
| All Technologies | | - Demonstration and Field Validation projects of initial prototypes to confirm performance, redirect final performance goals<br>- Definitive Residential modeling assumptions for high solar gain products and dynamic glazings<br>- Operating assumptions for typical commercial building types needed |

## LIMITS OF SINGLE VALUE PROPERTIES

Current procedures quantify product performance at a single set of environmental conditions with a single number for each physical phenomenon:

The *U-factor* quantifies the heat transfer as a function of temperature difference. In reality, this varies as a function of temperature conditions, wind speed, and solar radiation.

The *Solar Heat Gain Coefficient* quantifies the fraction of incident solar radiation which is admitted into the space (both directly transmitted and absorbed and then re-radiated/conducted inwards. The SHGC is defined at a fixed angle of incidence (normal to the glass), a fixed set of environmental conditions on the interior and exterior, and a defined set of incident beam solar radiation. No diffuse radiation is considered. Under real conditions, all of these conditions, and hence the real SHGC, vary.

As with the SHGC, the *Visible Transmittance* (and other optical properties) vary significantly as a function of angle, and to some extent, on the composition of incident solar radiation.

With ZEBs, evaluating window energy performance at peak times will be as important, if not more important, than understanding their annual energy impacts. This is necessary because many ZEBs will have downsized or minimal HVAC systems and windows can often be significant contributors to peak loads. Past simulation studies have shown that while simplified simulations are reasonably accurate for predicting annual energy impacts of fenestration products, they are noticeably less accurate for quantifying peak demand.

Non-specular glazings are expected to play an important part in commercial ZEBs. In order to capture the daylighting benefits of such products, Visible Transmittances and SHGCs as a function of angle need to be quantified and used.

As has been discussed at length in the Energy Star Windows forums and in the NFRC Annual Energy Subcommittee, there are benefits to heating loads from a high SHGC. However, the extent of these benefits depends on many issues such as climate, house type, etc. As windows become even more efficient, these issues can be expected to magnify. Windows for ZEBs will have to involve some assessment of the building application.

## FUTURE PATHS

We see two possible approaches to addressing the issues raised here. These approaches are:

1) Improve building energy simulation programs so that they handle the implications of advanced and developing fenestration products, or

2) Give fenestration product analysis software, such as the WINDOW+ suite, the ability to evaluate fenestration product thermal and optical properties over a broad range of conditions (thereby making the output data more relevant to building simulation programs), instead of just calculating properties at design conditions. Specifically, fenestration analysis software could output a data file with performance indices on fenestration performance which are a function of various environmental parameters. This data file would then be used in a building energy analysis program either (a) directly in lieu of modeling the fenestration product explicitely or (b) as input for a streamlined model. This multi-dimensional file replaces standard indices such as U-factor, SHGC, Tvis.

While it is clearly beneficial to improve fenestration modeling capabilities within any building energy simulation program (approach 1), there are numerous benefits to developing approach 2. These include:

- Simplifying the process of specifying a fenestration product when using a building simulation program (i.e. pick from entries in a library). This assumes someone at a prior step has defined numerous representative fenestration products, but this is a process which can be done once and used many times.
- Ensuring consistency and product characterization accuracy by focusing fenestration modeling in fenestration modeling software, minimizing the need to rewrite similar algorithms many times in more general software.
- Defining an advanced or complex fenestration product accuretely requires significant input data. Such data (i.e. spectrally dependent angular data) may be best managed at the fenestration modeling software.
- Implementing these full algorithms in building energy simulation software, at each time step, will increase run-time significantly.

**Data Reporting**

Any data reported on window performance would have to be a function of environmental parameters:

- Indoor and outdoor temperatures
- Solar radiation direct and diffuse
- Sun position

The data that we propose reporting in a data file by fenestration analysis software would include the following values, which would be a function of the variables above:

- conductance for glass and frame, separately
- surface temperature for glass and frame, separately
- convective and radiative interior and exterior film coefficients

Other, static values to be reported, include:
- emissivity for glass and frame
- size
- BTDF and BRDF for solar and visible (bi-directional transmittance and reflectance)

[Note, for dynamic products, the above data will have to be defined for various states of the product: i.e. shades at various angles, electrochromics as various states.]

## CONCLUSION

If we are to succeed in our objective of zero energy buildings we recommend that the following steps be taken:

1. Develop technical capabilities so that annual energy effects and peak demand implications for all products, specifically those for ZEBs, can be determined accurately. Specifically, this means improving the WINDOW6 output file (designed for Energy Plus but potentially of use to other programs).connections for thermal issues and the Radiance to Energy Plus connection for daylighting calculations.

2. Using this proposed WINDOW6 to Energy Plus (or other appropriate building simulation software), evaluate and document errors from using single properties. We suggest evaluating the performance (annual energy, peak) of 6-10 candidate technologies and compare that to a simple evaluation based on just U, SHGC, and VT.

3. Evaluate the errors between the two methods and use this information to refine the format for this WINDOW6 file and for developing recommendations for modeling advanced fenestration products.

## ACKNOWLEDGEMENTS

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## REFERENCES

Apte, J. S., Arasteh, D., et al. 2003. "Future Advanced Windows for Zero Energy Homes." ASHRAE Transactions 109(2).

Arasteh D., H. Goudey, J. Huang, C. Kohler, and R. Mitchell. 2007 "Performance Criteria for Residential Zero Energy Windows", to be published at ASHRAE 2007 Winter meeting.

Arasteh, D., et. al. 1998. “THERM 2.0: Program Description,” LBNL Report 37371 Rev. 2, Berkeley, CA.

Mitchell, R., C. Kohler, D. Arasteh, C. Huizenga, T. Yu, 2001 "WINDOW 5.0: A PC Program for Analyzing Window Thermal Performance in Accordance with Standard NFRC Procedures", Windows and Daylighting Group, LBNL Report #44789, Lawrence Berkeley National Laboratory, Berkeley, CA, November.

Optics 5. 2001.LBNL Software and documentation. http://windows.lbl.gov/materials/optics5.