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Authors
Arasteh, D.
Finlayson, E.
Huang, J.
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Dariush Arasteh, Elizabeth Finlayson, Joe Huang, Charlie Huizenga,*
Robin Mitchell, and Mike Rubin

Building Technologies Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
1 Cyclotron Road
Berkeley, CA

Center for Environmental Design Research
*University of California
Berkeley, CA

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Abstract

Measuring the thermal performance of windows in typical residential buildings is an expensive proposition. Not only is laboratory testing expensive, but each window manufacturer typically offers hundreds of individual products, each of which has different thermal performance properties. With over a thousand window manufacturers nationally, a testing-based rating system would be prohibitively expensive to the industry and to consumers.

Beginning in the early 1990s, simulation software began to be used as part of a national program for rating window U-values. The rating program has since been expanded to include Solar Hear Gain Coefficients and is now being extended to annual energy performance.

This paper describes four software packages available to the public from Lawrence Berkeley National Laboratory (LBNL). These software packages are used to evaluate window thermal performance: RESFEN (for evaluating annual energy costs), WINDOW (for calculating a product's thermal performance properties), THERM (a preprocessor for WINDOW that determines two-dimensional heat-transfer effects), and Optics (a preprocessor for WINDOW's glass database).

Software not only offers a less expensive means than testing to evaluate window performance, it can also be used during the design process to help manufacturers produce windows that will meet target specifications. In addition, software can show small improvements in window performance that might not be detected in actual testing because of large uncertainties in test procedures.

Introduction

Windows typically account for 3 Quads of annual energy use or approximately one-fourth of the energy used by the U.S. building sector. Installing energy-efficient windows could drastically reduce this energy demand. However, an accurate rating and widely used labeling system is needed to help consumers and designers select efficient windows and optimize them for specific applications.

Rating and labeling systems for the thermal performance of windows and other fenestration products have recently gained widespread acceptance in the United States, Canada, Australia, and New

Zealand. Similar programs are being considered in the United Kingdom, Russia, Korea, and elsewhere. The success of such programs results in large part from the availability of software that can consistently and accurately evaluate the thermal and optical performance of windows and other fenestration products at a fraction of the cost of testing them.

Software is essential to support a window performance rating system because:

- testing is expensive and lengthy.

- manufacturers have thousands of different products, many that are different from each other in subtle ways (e.g., the tint of glass used) that can significantly affect energy performance.

- manufacturers can most effectively produce efficient windows that meet particular performance specifications if window performance data can be generated during the design process before products are actually available for testing.

- some performance properties (like annual energy ratings) are virtually impossible to test for but can be simulated.

- simulations produce consistent results (large uncertainties in test procedures mean that small improvements may not be detectable by testing; these improvements would show up in simulation results, however).

Software tools are used as part of rating systems in the same way that laboratory test facilities would be used to examine actual products: independent simulation laboratories, accredited by an independent agency, perform simulations and report the results.

Properties for Evaluating Window Performance

Historically, window thermal performance has been reported in terms of:

- U-factor: the amount of heat loss (or gain) through a window; the inverse of R-value

- Solar Heat Gain Coefficient (SHGC): the fraction of incident solar radiation that comes through the window

- Visible Transmittance: the fraction of visible light that is transmitted by the window

- Air Infiltration: the air leakage through the window.

These properties need to be evaluated under standard environmental conditions (indoor and outdoor temperatures, wind speeds, etc.) in order for performance ratings to be comparable among products. These are the properties of most interest to engineers, architects, and other professionals and are also used in energy codes because they are, to first-order, static properties that belong to the window itself rather than the building in which it is installed. Software can model window U-factor, SHGC, and Visible Transmittance in typical installations (Air Infiltration is virtually impossible to model).

In addition to the above factors, thermal performance ratings would be most useful to consumers if they indicated the energy and cost impact of a particular window in a typical application. Such an assessment can be based on knowledge of the window's properties (U-factor, Solar Heat Gain, Visible Transmittance, and Air Infiltration.) Software simulations have long been used in similar ways to evaluate building energy impacts; however, modeling has typically focused on whole building performance rather than the impacts of specific components such as individual windows.

# Software Tools Developed at LBNL for Rating Systems

To meet the needs of window rating systems in the U.S. and other countries, LBNL has developed a series of publicly available PC programs for determining window thermal and optical performance.

WINDOW (Arasteh, Finlayson & Huizenga 1994) is the cornerstone of LBNL's fenestration software series; it calculates total window U-factors, SHGC, visible transmittance, and other related optical properties. WINDOW 4.1 uses a heat-transfer analysis method that is consistent with the National Fenestration Rating Council (NFRC) rating procedure. WINDOW can be used to analyze products made from any combination of glazing layers, gas layers, frames, spacers, and dividers under any environmental conditions and at any tilt. As input, WINDOW requires information on the optical performance properties of a window's glazing materials (see discussion of Spectral Database and Optics program below) and the results of a detailed two-dimensional heat-transfer model on the window's frame and edge thermal performance. This heat-transfer information can be generated using THERM (see below). The software program FRAME (Enermodal Engineering Ltd. 1991), developed in Canada, also performs two-dimensional heat-transfer calculations.

The Spectral Database (Rubin 1998) which accompanies WINDOW is a compendium of spectral data (transmittances, reflectances, emissivities) on all major glass products produced in the U.S. for use in residential and commercial window products. These data are measured by manufacturers (who have participated in a round-robin collaboration to standardize measurement practices) and then undergo peer review as well as review by LBNL to check for consistency. The approximately 1,000 entries in this database represent single glass layers. Laminated layers (two pieces of glass "glued" together with a laminate material) are typically not reported in this database of measured values due to the large number of possible combinations. Likewise, "glue-on" or "applied" films combined with glass layers are also typically not reported in this database due to the large numbers of possible combinations.

In order to ensure that laminates and applied films can be incorporated into a window rating and labeling process, the Optics program has been developed. Optics (Rubin, von Rottkay & Powles 1988) is designed to allow its users to compute the properties of any laminate or applied film by specifying its composition. The properties of laminated glazing materials or glazings with applied films added to them can thus be created by Optics for use with the WINDOW program without the need to make a sample and measure its optical properties.

THERM (Finlayson et al. 1998) provides WINDOW with required two-dimensional heat transfer indices on window frame and edge performance. THERM's two-dimensional heat transfer analysis is based on the finite-element method that allows the user to model complicated frame details and even entire window cross-sections, if warranted. The latest version of the program, THERM 2.0, includes a radiation view-factor model that improves the program's accuracy for modeling products with self-viewing surfaces, such as greenhouse windows and skylights (see Figure 1). THERM is a Microsoft Windows™-based program that includes a graphic interface developed to allow for quick and accurate drawing of window cross-sections.
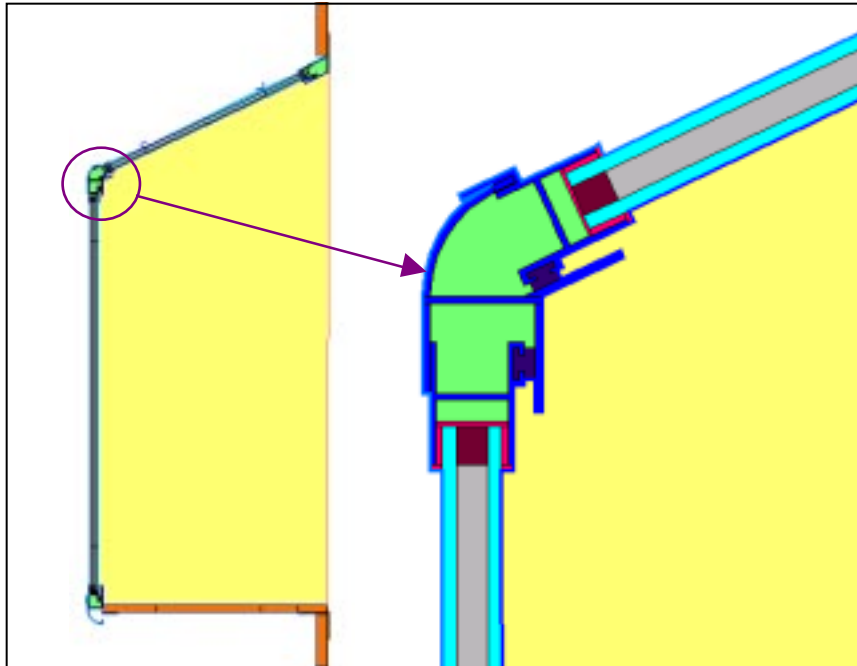
Figure 1. THERM 2.0 includes a radiation view-factor model that improves the program's accuracy for modeling products with self-viewing surfaces such as greenhouse windows and skylights.

RESFEN (Huang et al. 1997) can help consumers and builders pick the most energy-efficient and cost-effective window for a given application. It calculates heating and cooling energy use and associated costs as well as peak heating and cooling demand for specific window products. Users define a problem by specifying the house type (single- or two-story), geographic location, orientation, electricity, and gas costs, and building configuration details (e.g., wall type, floor type, HVAC systems). Window options are defined by specifying size, shading, and thermal properties: U-factor, SHGC, and air leakage rate. RESFEN calculates energy use and cost; different window options can be compared. RESFEN 3.0 is a major improvement over previous versions because it performs hourly calculations using a customized version of the DOE 2.1E energy analysis simulation program.

Issues and Conclusions

Not all products can be simulated using the four software programs described above. Test procedures are still necessary for the approximately 1% of products that cannot be modeled, as well as for advanced products not yet incorporated in the simulation programs. Spot testing is also needed to validate simulation tools, showing that real product performance is consistent with simulation results.

The use of software tools, such as those developed by LBNL, can save the cost of significant amounts of testing and provide the large numbers of data needed to support window thermal performance rating systems. Data obtained from software simulations are reliably consistent and reveal small changes in window efficiency that might be obscured by uncertainties in actual testing of products. Manufacturers can use simulation programs in the design process, to help achieve specified performance

targets. The integration of these four tools, WINDOW, THERM, Optics and the Spectral Database, and RESFEN allows the user to quickly and efficiently see the energy and cost impacts of component changes.

For more information on LBNL's fenestration modeling software and/or to obtain copies, see http://windows.lbl.gov or contact the author(s).

Acknowledgments

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