The NFRC Window U-Value Rating Procedure

D. Arasteh, P.E.
Member ASHRAE

R.C. Mathis

W. DuPont

ABSTRACT

During the 1980s, the availability of energy-efficient window components and products grew faster than the ability of the window and building industry to analyze their performance accurately and efficiently. As a result, a coalition of industry and public sector groups formed the National Fenestration Rating Council (NFRC) in an effort to provide standard methodologies to rate the thermal performance of windows. The NFRC's first task was to develop a methodology for evaluating the thermal transmittance (U-values) of fenestration products. This procedure, published in 1991 as NFRC 100-91 *(NFRC 1991) and already referenced by state codes in Alaska, California, Idaho, Minnesota, Oregon, and Washington, allows the manufacturer to use a unique combination of advanced computer simulation tools coupled with improved laboratory test methods. Since most manufacturers offer dozens, and often hundreds or thousands, of individual products, each with significantly different U-values, these simulation tools are an essential component of the rating system's cost effectiveness. This paper discusses this procedure and its intended use in more detail, and outlines the NFRC's future plans for developing rating procedures for solar heat gain coefficients, optical properties, infiltration, condensation resistance, and annual energy impacts.*

INTRODUCTION

Determining the thermal properties of fenestration products has been a controversial task for several decades. Beginning in the mid-1980s with the advent of low-emissivity and gas-filled windows, this task became even more complicated and its resolution more imperative. In order to prevent individual states from determining their own potentially different or even conflicting standards and procedures, the National Fenestration Rating Council (NFRC) was established in 1989. The NFRC's members include representatives from the glass industry, the window component industries, window manufacturers, the building industry, utilities, state energy offices, consumer groups, and design professionals. Three standing committees (technical, ratings codes and standards, and pubic relations) were established.

The NFRC's first task was the development of a procedure to determine the thermal transmittance (U-values) of window products. While existing test and calculation procedures were already in use by manufacturers or required by some states, their use was inconsistent. These existing procedures were often modified by the particular user, used incorrectly to represent additional products, not checked for accuracy, and often lacking in credibility. The need for a uniform rating procedure was long overdue, as evidenced by confusion among consumers and specifiers, dubious claims, and the relatively wide variation in energy use between window products (much greater than wall insulation, which is clearly rated). The NFRC's objectives were, therefore, to develop a procedure for determining U-values that would be

- uniform and accurate,
- capable of analyzing conventional as well as advanced products,
- applied uniformly, and
- consistent with the needs of industry, state governments, utilities, design professionals, builders, consumers, and federal agencies.

During 1990 and 1991, the NFRC U-value subcommittee met frequently to develop the procedure summarized in this paper. Released in July 1991, the procedure was named *NFRC 100-91: Procedure for Determining Fenestration Product Thermal Properties (Currently Limited to U-Values).*

While the NFRC technical committee focused its attention on the development of a U-value standard, it also established other subcommittees charged with the development of procedures to determine solar heat gain coefficients, optical properties, infiltration rates, and condensation resistance. Subcommittees were also established to examine second-level issues such as annual energy performance (the interaction of all properties for specific environmental conditions) and long-term performance effects.

SCOPE

An accurate procedure for determining window U-values must distinguish between products that have different

Dariush Arasteh is a staff scientist in the Building Technologies Program, Lawrence Berkeley Laboratory, Berkeley, CA, and is also chairman of the U-Value Subcommittee, National Fenestration Rating Council (NFRC). R. Christopher Mathis and William DuPont are scientists at D&R International, Silver Spring, MD, and serve as administrative director and technical director, respectively, of the NFRC.

performance values. The following factors influence U-values and are therefore recognized by the NFRC procedure:

- frame operator type,
- frame material,
- frame design,
- product size,
- number of glazing layers,
- types of glazings,
- glazing layer coatings,
- gap widths between glazings,
- gas fills, and
- use of muntin bars or divided lights.

The procedure is applicable to all fenestration products (windows, doors, skylights) with a few exceptions. Detachable shading systems will influence overall product U-values, but their use cannot be guaranteed and thus they were excluded from the procedure. Shading systems that are an integral part of the window product are included. Since garage doors separate nonconditioned spaces from the outside, they were also excluded.

Previous thermal transmittance test procedures did not always address air infiltration in a systematic manner. Heat transfer due to air infiltration is a separate phenomenon and should be included in an infiltration index, not a thermal transmittance or U-value index.

The procedure does not address issues relating to long-term durability or installation. These issues are the subject of current research and discussions.

PRINCIPLES

Previous U-value procedures were all based on laboratory testing or generalized procedures. Many unresolved issues plagued these testing programs and generalized methods. These included:

1. *Expense:* Laboratory tests typically cost on the order of $1,000 per test. When manufacturers may have hundreds and often thousands of different individual products, the expense of testing all these products becomes prohibitive. This would become even more expensive if different states required different test methods.
2. *Inefficient use of resources:* Many manufacturers have similar products (i.e., a basic wood frame with double glazing with a half-inch air space). It did not seem necessary to insist on testing products when information on a product could be ascertained based on existing information.
3. *Repeatability:* While a properly run laboratory test will produce a U-value to a reasonable accuracy, it will not always produce the same number, and testing might fail to properly distinguish between two or more products with performance levels in a tight range (i.e., the testing error may be greater than the performance differences); this is especially true with high-performance products.
4. *Applicability:* General "default tables" often did not characterize the thermal performance impacts of subtle frame designs and changes and the use of new designs or advanced materials.

As a result of these issues, the U-value procedure focuses on the use of advanced computer simulation programs to compute heat transfer rates through window systems. Simulations are relatively inexpensive (as compared to laboratory testing), especially if there are many similar products. Computer programs can use known correlations (i.e., heat transfer rates as a function of gap width) or mathematical descriptions of physical phenomena (i.e., radiative heat transfer), thereby eliminating the need for redundant efforts. Finally, computer simulations will properly distinguish between similarly performing products, i.e., a simulation program will accurately predict the difference in improvements between a gap width of 0.25 inch and a gap width of 0.28 inch, a difference in performance that might not be large enough to be identified with testing.

However, a simulation result is only as good as its input. In order to ensure proper simulations, spot-testing to validate a series of calculations was added to the procedure. The logistics of this procedure are discussed in the next section.

DESCRIPTION

Most manufacturers produce a series of products with a framing material (i.e., aluminum, thermally broken aluminum, wood, vinyl) and an operator type (i.e., casement, sliding window, double hung, etc.) as the primary descriptive characteristics. This group of products is often referred to as a product line (i.e., wood casements, aluminum sliders, etc.). The U-value procedure adopted this common classification system, breaking up a manufacturer's product offerings into manageable product lines and then defining a product line approach.

Within each product line, a manufacturer typically offers a two-dimensional array of individual products. Glazing options include the choice of glazing layers, glazing coatings, gas fills, spacer designs, use of muntins or divided lights, etc. The NFRC procedure thus requires that individual U-values be determined for each product with a different glazing option. A range of sizes is also typically offered and the issue of size had to be addressed by the procedure. Defining U-values for each size of each glazing option was considered excessive and difficult to implement. Size variations are considered in the procedure by determining U-values for two standard sizes. These two standard sizes—size AA and size BB—vary with operator type and were chosen to represent typical sizes for residential and commercial products, respectively. The manufacturer thus ends up with an $N \times 2$ (where N is the number of glazing options) matrix of products that needs to be rated for each product line. An example is given in Figure 1.

Manufacturers may determine U-values for all the entries in the matrix by using the computer simulation methodology specified in NFRC (1991) and outlined in Figure 2. This procedure allows the manufacturer to simulate all the individual products within a product line with advanced simulation tools.

The simulation procedure breaks the window into five component parts, as shown in Figure 3. The WINDOW 3.1 computer program is used to calculate properties for the center-of-glass region (LBL 1988; Arasteh et al. 1989). All other areas of the window are areas where two-dimensional effects must be considered. For these areas, the FRAME computer program (EE 1991) is used. The total window U-

Operator Type: *Slider* Frame/Spacer Profile Designation: *AITB 372-SSA1*

Glazing Description	Model Size AA (36x60)	Model Size BB (48x72)
Double Glazing, Clear, 1/2" air gap, 1/8" glass	?	?
Double Glazing, Bronze Tinted, 1/2" air, 1/8" glass	?	?
Double Glazing, Clear, 1/2" air gap, 1/8" glass, between glass muntin bars	?	?
Double Glazing, Low-E on #2 (e = 0.20), 1/2" Argon gap, 1/8" glass	?	?
Double Glazing, Low-E on #2 (e = 0.20), 1/2" Argon gap, 1/8" glass, snap-on exterior muntin bars	?	?

Figure 1 *Sample NFRC product line.*

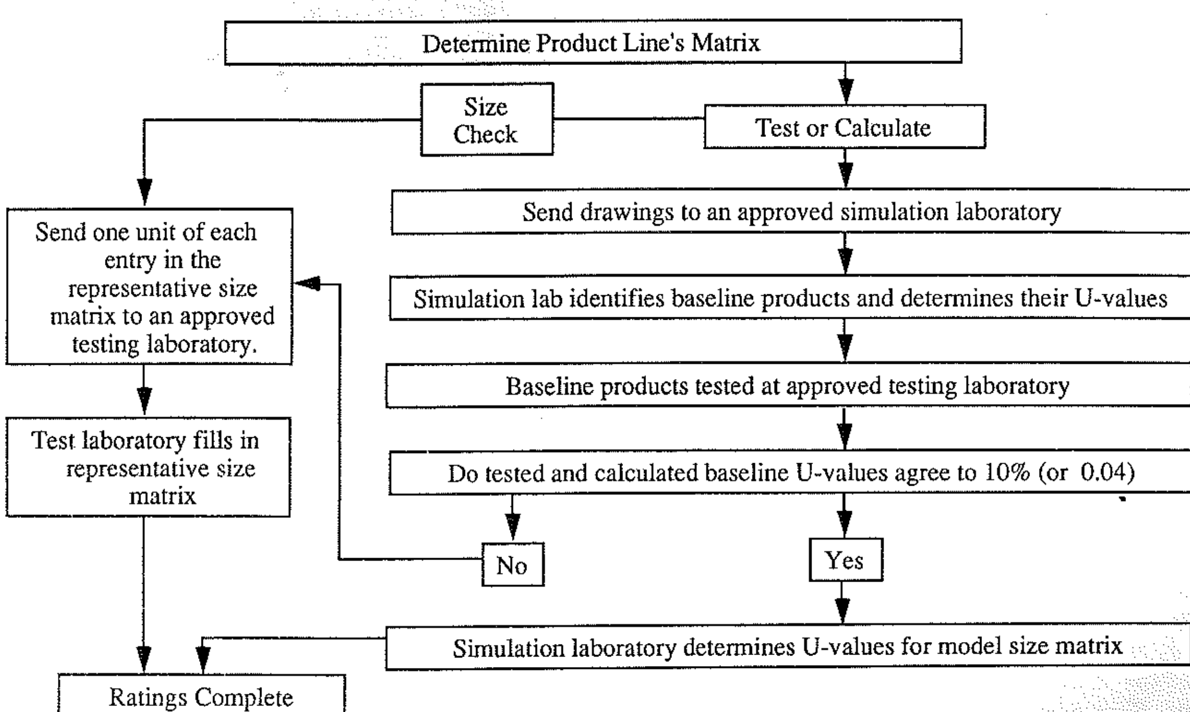

Figure 2 *Schematic of NFRC U-value rating procedure.*

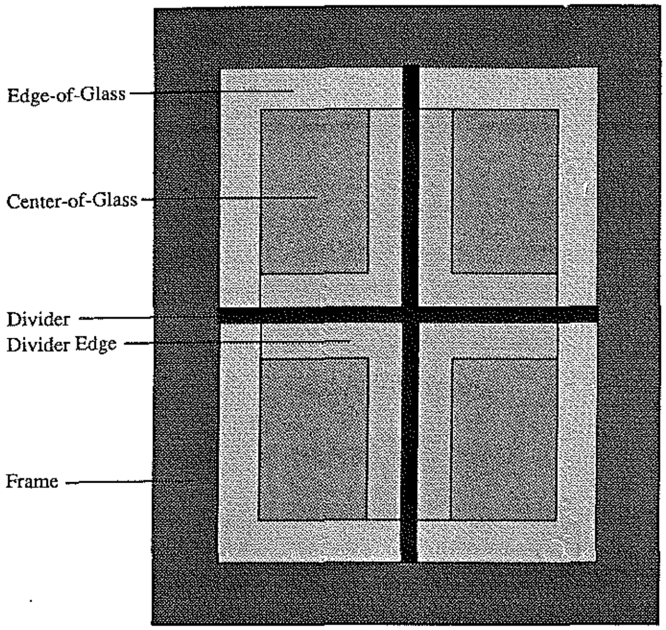

Figure 3 *Component window areas used for the calculational procedures of the NFRC U-value rating procedure. Edge-of-glass areas are those areas that extend 2.5 inches outward from the frame and include two-dimensional heat transfer effects from the frame and spacer. Divider-edge areas extend 2.5 inches outward from the divider (if used) and include two-dimensional heat transfer effects from dividers.*

value is then calculated by area-weighting the component U-values. For specific details, see NFRC (1991).

Updates of these two programs (WINDOW 4.0 and FRAME 3.0) are now available. These two programs are linked so that total window U-values can be calculated by WINDOW 4.0. The programs' operation is consistent with the requirements of the NFRC procedure.

The use of the WINDOW and FRAME computer programs as a method of determining U-values has been validated for a wide variety of windows as part of a joint U.S./Canadian research project conducted over the past several years. Simulations agreed well with laboratory and field testing (Klems and Elmahdy 1992). Differences were largest for windows with low U-values or where the window properties were not known well enough to be modeled properly.

The two products within the product line matrix with the highest and lowest simulated U-values are known as the baseline products. Following simulations of the baseline products, state-of-the-art hot-box test methods are used to evaluate the thermal transmittance of these two baseline products. Simulated values for the entire product line are considered validated if the results for the two tested products are equivalent with the simulations for those two products. Equivalence is defined as $\pm 10\%$ or 0.04 Btu/h·ft^2·°F, whichever is greater.

The test method employed has been under development for a number of years at ASTM and includes a number of significant improvements over previous ASTM and industry-sponsored test methods. Many of these improvements are the direct result of the research and review of participants in the NFRC. Among the improvements in the fenestration test method employed in NFRC (1991) are

1. specific test conditions to promote improved measurement accuracy and use in building load analyses;
2. more precise calibration procedures, resulting in better equipment performance tracking;
3. elimination of potential areas of laboratory error through better product installation techniques;
4. improved sensor and instrumentation schemes;
5. use of more uniform standard reference materials for calibration; and
6. methods for effectively quantifying the radiant environment in the hot box, thereby eliminating another source of interlaboratory test variability.

If the manufacturer wishes, all entries in the product matrix may be filled in with results from laboratory tests in accordance with the improved test method. This method may be significantly more expensive if there are a large number of glazing options for a particular product line.

CONCLUSIONS AND FUTURE WORK

NFRC (1991) defines a comprehensive, accurate, and cost-effective means of evaluating the thermal transmittance (U-values) of fenestration products. The technical validity of the components of this procedure (i.e., the simulation tools and the testing procedure) has been validated as part of previous research efforts. A comprehensive validation study of the procedure, aimed at demonstrating its proper use and ironing out logistical issues, is in process. The use of NFRC (1991) has been referenced by state codes in Alaska, California, Idaho, Minnesota, Oregon, and Washington. Other states, as well as the federal government, are in the process of determining when and how to best use this standard. Many national and regional manufacturers are beginning to rate the performance of their products in accordance with NFRC (1991).

The effective use of NFRC (1991) requires the establishment of a means for ensuring its proper application. To this end, the NFRC is in the process of developing accreditation procedures for determining the technical competence of simulation and testing laboratories and a certification and labeling program for identifying the thermal performance of windows that have been rated using NFRC procedures.

U-values are the first of five properties for which the NFRC is in the process of developing rating procedures. Standards for rating the solar heat gain coefficient, optical properties, infiltration, and condensation resistance factors are in the process of being written. While the NFRC's initial efforts are focused on as-built performance indices, future efforts are expected to be directed at the long-term performance indices. Finally, the NFRC is also working to develop a procedure to analyze the interaction of these five properties or the annual energy impacts of windows in residential or commercial buildings.

ACKNOWLEDGMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Buildings Systems and Materials Division of the U.S. Department of Energy under contract no. DE-AC03-76SF00098.

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