Window Performance Rating, Building Codes, and Utility Programs

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The National Fenestration Rating Council in the United States and the Canadian Standards Association in Canada have developed standards for rating the performance of windows. The procedures are two of the first to combine testing and simulation methods. They are being written into state and federal building codes, and provide a foundation for utility incentive programs promoting high performance windows. These programs and new glazing and framing technologies have been catalysts in the rapidly changing window industry. Given this high rate of change, product integrity needs to be maintained along with an open environment for technology advancements.

Introduction

This is another chicken-and-egg story: which came first - the technology or the regulations? With the stress on energy conservation in the 1970's, low-E coatings provided a major breakthrough for reducing window energy losses. Concurrently, building energy efficiency standards were being drafted. As both window technology and federal and state building codes matured, they began to play off of each other. Codes and technology have prompted so much change in the window industry, that the need for a uniform method for rating and comparing products became apparent. The integration of coating technologies, gas fills, and low conductivity materials into window designs raised questions concerning the actual benefit from these new designs. Claims of R-10 windows (a U-value of 0.6 W/m^2-°C or 0.1 $Btu/hr\text{-}ft^2$-°F) turned heads and reinforced the cry for a uniform rating procedure.

Many regulatory agencies and utilities have developed their own methods for judging window energy performance; window manufacturers have relied on in-house proprietary methods, and universities and research laboratories have developed research-level tools for analyzing the thermal performance of windows. Over the last few years, these organizations have coordinated their efforts to establish consensus performance rating procedures for windows. In 1991, the National Fenestration Rating Council (NFRC) in the United States adopted NFRC 100-91 for determining window U-values. In the same year, the Canadian Standards Association (CSA) passed standard A440.2 for determining window thermal performance.

The NFRC and CSA procedure are alike in that they are the first rating systems for windows to specify both testing and computation methods. These procedures are experiencing a rapid transition into state and federal building regulations and utility incentive programs. This, in turn, is causing the window industry to re-evaluate their products to ensure compliance with building codes and qualification for utility incentive programs.

Windows

Thermal Performance

The overall thermal performance of windows is related to the U-value and the solar heat gain properties of the window. The U-value is a measure of the heat that goes through a window per unit area and temperature. By multiplying the U-value by the window area and the temperature difference between the inside and outside air temperatures, the total heat going through the window in the direction of the lower temperature is found.

Solar heat gain through a window is represented by either the solar heat gain coefficient (SHGC) or the shading coefficient (SC). The SHGC equals the solar transmittance of the window plus the fraction of energy that is absorbed in the glass and flows inward, and is always a value between 0.0 and 1.0. The total solar heat gain through a window equals the SHGC multiplied by the incident solar radiation. The SC is the SHGC divided by the SHGC for a single pane of 3mm double strength glass. The shading coefficient is slowly being phased out.

The thermal performance of available window products varies across the continent. In the Northwest, building codes and utility programs are pushing U-values of

2.3 W/m^2-°C (0.40 Btu/hr-ft^2-°F) and less. In southern parts of the United States, single-pane aluminum windows with U-value around 6.0 W/m^2-°C (1.0 Btu/hr-ft^2-°F) dominate the market. The best performing windows in terms of solar heat gain depend on the building site, orientation, and climate. Climate and cost-effectiveness are important issues, and changes will continue to occur throughout the country as building codes address these issues.

Historically, window thermal performance was represented by a glass-only U-value, and the frame and the spacer separating the glass panes were neglected. Studies have shown that the frame and spacers can have a significant effect on the overall thermal performance of a window, and have led to the characterization of windows as complete units. Testing methods existed for measuring this total U-value, and eventually computer simulation tools were developed to calculate the total U-values. Validation studies between testing and computer simulation results continue, and so far agreement to well within 10% has been found for nearly all cases (Elmahdy 1990; Klems and Reilly 1989).

Window Technology

Window technology has gone from simple single-, double-, and triple-pane windows to windows with thin metallic-oxide coatings (low-E coatings), special low-conductivity gas-fills, insulated spacers, and thermally improved frames. For example, a double-pane window with clear glass and a half-inch air gap has a center-of-glass U-value of 3.0 W/m^2-°C (0.5 Btu/hr-ft^2-°F). By substituting low-E coated glass for one of the clear glass panes, a center-of-glass U-value of 2.0 W/m^2-°C (0.35 Btu/hr-ft^2-°F) is obtained. By replacing the air with argon, the U-value is further reduced to 1.5 W/m^2-°C (0.26 Btu/hr-ft^2-°F).

Low-E coatings reflect energy back to where it came from. There are hard and soft coatings; the hard is more durable but is generally less effective at reducing the heat loss. The low-E coatings are deposited on glass, and polyester films that are suspended between two glazing layers. Solar control glazings have been developed to cut out a large portion of the solar energy while retaining high visibility. Both coating technologies and tints in the glass are being used to fine tune the glazing system for low u-values, high visibility, and to control the solar gains.

As for the gas-fills, argon has become standard in some product lines, and krypton is being explored as an option. Krypton is expensive and is not produced in large quantities, although the price has dropped considerably. With krypton, narrower gap widths can be used while retaining good thermal performance.

Spacers can be broken into two categories: metal and insulated (or warm-edge). Aluminum spacers are the most common, although they are being re-designed to compete with the insulated spacers which incorporate low-conductivity materials.

Frames are typically aluminum, wood, vinyl, or fiberglass. Depending on the operator type (picture, casement, slider, etc.) and size, an aluminum-framed window with a double-pane glazing system and a half-inch air space will have difficulty meeting standards that require U-values less than 4.2 W/m^2-°C (0.75 Btu/hr-ft^2-°F). Thermal breaks offer one solution, and are being designed into aluminum frames to block the transfer of heat through the frame and lower the overall U-values.

Windows with U-values less than 2.0 W/m^2-°C (0.35 Btu/hr-ft^2-°F) combine low center-of-glass U-values with vinyl or wood frames. The low center-of-glass U-value can be achieved with a suspended film between two glazings and argon filling. There is a low-E coating on one of the glass surfaces facing the gap but not directly facing the low-E surface of the suspended film. Filling the cavities in vinyl and fiberglass frames with insulating materials or redesigning the frame to suppress convection and radiation exchange in the cavities further reduces the energy losses. Figure 1 gives representative U-values for a double-hung window with different frame types and spacers.

Window Rating, Building Codes, and Utility Incentive Programs

Window Rating

The NFRC is a non-profit organization that was formed by representatives from the window industry, state and federal energy offices, utilities, and research laboratories in 1989. The goal of the NFRC is to develop uniform procedures for rating the performance of windows. They adopted NFRC 100-91 for determining window U-values in June, 1991, and are working on procedures to address solar heat gain, optical properties, annual energy use, infiltration, condensation, ultra-violet radiation degradation, and durability.

The U-value procedure describes the methods for testing and using computer simulation to determine window U-values - one of the first procedures to recognize both approaches. Existing test procedures include American

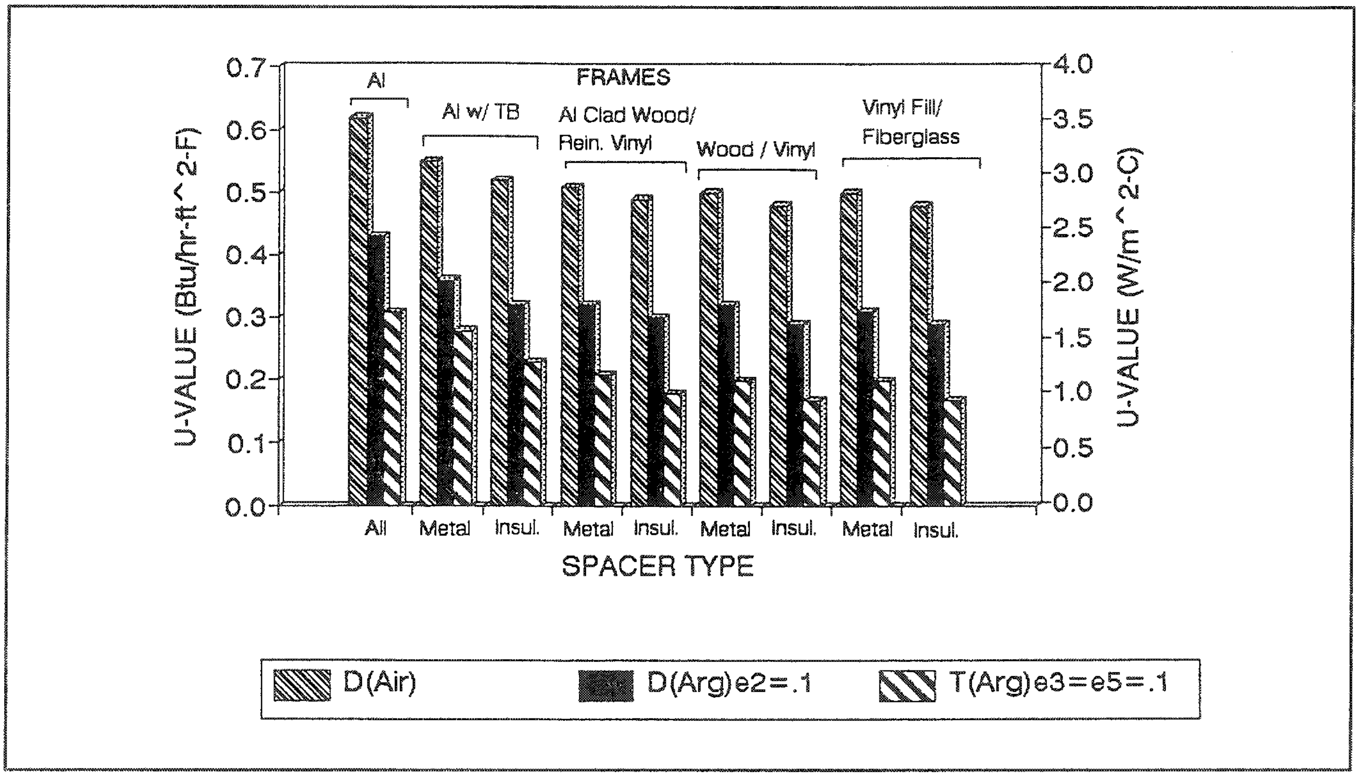

Figure 1. Total window U-values for fixed windows. All windows have half-inch gaps. The spacers are metal or insulated (Insul). For aluminum-framed windows, the spacer has a negligible effect on the overall window U-value, so the spacer is referred to as All. Key: D - Double-pane window; T - Triple-pane window; Arg - argon gas; en- low-E coating on the nth surface (counting glazing surfaces from the outside in); Al - aluminum; Al w/TB - aluminum frame with a thermal break; Rein. Vinyl - reinforced vinyl frame; Vinyl Fill - vinyl frame with foam-filled cavities.

Society of Testing and Measurement (ASTM) standards C 236 and C 976, and the American Architectural Manufacturers Association (AAMA) standard 1503.1. The NFRC test method applies the ASTM C 236 or ASTM C 976 test methods under specific environmental conditions. Although established standards organizations exist, the NFRC was founded to promote uniform rating procedures for windows alone based on existing test and calculational methods.

A manufacturer's products are categorized into product lines which consist of windows of the same operator type, such as double-hung windows. (For a more detailed description see NFRC 100-91.) The U-values of all windows in a product line are evaluated through computer simulation. The simulated U-values of the low and high-performance windows in each product line are compared with test results and must agree to within 10% of each other. If the testing and simulation results do not agree to within 10%, then the results are investigated and re-tested and/or re-simulated. The computer programs used are the most recently approved versions of the WINDOW (Lawrence Berkeley Laboratory 1988) and FRAME (Enermodal Engineering 1991) programs. Only under certain circumstances can all products be evaluated through testing alone.

The goal of the CSA was to develop a standard to allow consumers to compare the energy performance of windows. The standard A440.2 specifies an Energy Rating (ER) number that represents the total energy impact of the window over the heating season. The ER equals the solar heat gain minus heat and infiltration losses. The lower the U-value and infiltration losses are, and the higher the solar heat gain coefficient is, the higher the ER number is and the "better" the window rates.

The CSA procedure stipulates the methods for obtaining the SHGC, U-value, and air leakage. Like the NFRC procedure, it uses both simulation and test methods. The VISION computer program (University of Waterloo 1989) can be used to find the SHGC and the U-value of the glazing, and the FRAME program can be used to determine frame U-values. VISION is comparable to the

WINDOW program. SHGC can be evaluated by either computer simulation or testing using the Queen's method (Queen's University 1991). Air leakage is found through testing.

Building Codes

The goal of the NFRC is to develop uniform window rating procedures to be used throughout the country. Presently, primarily states on the west coast have taken steps towards adopting the NFRC U-value procedure into their building codes. The California Energy Commission (CEC) has contracted with the NFRC to develop a window rating and labelling program for California. Compliance with California's revised Title 24 Residential Building Energy Efficiency Standards (voluntary compliance as of July 1, 1992; mandatory compliance on January 1, 1993) requires windows to have a U-value no greater than 3.4 to 4.3 W/m^2-°C (0.60 to 0.75 Btu/hr-ft^2-°F) depending on the climate zone. Window U-values can be determined using the NFRC U-value procedure or taken from a default table. Wood and vinyl windows are required to have certification and labels by January 1, 1993; aluminum windows can assume the default table values until July 1, 1993.

As of January 1, 1992, Oregon began accepting window U-values rated and certified by NFRC, and required labels on windows. Prior to 1992, Oregon required windows to be tested to ASTM C 236 or to AAMA standard 1503.1, and they still accept these tests. By January 1, 1994, the only acceptable rating and certification method will be the NFRC procedure. Oregon's residential building codes provide for different prescriptive paths and a performance approach. With the prescriptive paths, the U-value can range from 2.3 to 3.4 W/m^2-°C (0.4 to 0.6 Btu/hr-ft^2-°F) depending on the climate. With the performance approach, the window U-value may go as high as 3.7 W/m^2-°C (0.65 Btu/hr-ft^2-°F). The commercial building codes are on a different revision schedule, but the intent is to have commercial products rated and certified to the NFRC procedure.

In Washington, physical testing to ASTM C 976 and C 236, or AAMA 1503.1 was required. As of July 1, 1992, rating and certifying windows to the NFRC procedure became optional.

Other states which have recognized the NFRC rating procedure in their codes include Alaska, Idaho, and Minnesota. As of January 1, 1992, Alaska accepted windows tested and rated to either AAMA 1503.1 or NFRC 100-91. Idaho will accept only NFRC certified rated products as of January 1, 1994. There is considerable interest from New York, and Florida will adopt the NFRC procedure once the NFRC establishes a solar heat gain procedure.

At the federal level in the United States, Senate bill S.2166 - the National Energy Security Act - was passed in February, 1992. The bill provides for, among other things, technical and financial assistance from the Department of Energy for the voluntary development of a national window rating program under the NFRC. In the House bill, the Comprehensive National Energy Policy Act, H.R. 776, the provisions for windows are similar to those in the Senate bill. Upon acceptance of both bills, the House and Senate will combine the bills and submit a final energy act to the President for his signature (Shafer 1992).

In Canada, the National Building Code requires at least double-glazed windows and thermally-broken aluminum frames. A proposed revision to the Ontario Building Code would require electrically-heated homes to use high-performance windows (i.e. windows that qualify for the Ontario Hydro Incentive Programs, see Section 5.3). Manitoba Hydro and British Columbia Hydro are planning to adopt the Energy Rating concept, but will likely use different targets to reflect their climates. Work is also underway on a National Energy Code, which will establish energy-efficiency guidelines for the entire country. This code will be incorporated into the 1995 National Building Code.

Utility Incentive Programs

Pacific Gas and Electric (PG&E) in Northern California has a High-Performance Window Program that rewards windows for their incremental decrease in both U-value and shading coefficient. The program goes beyond the Title 24 Building Standards by recognizing only windows with U-values below 3.7 W/m^2-°C (0.65 Btu/hr-ft^2-°F) and shading coefficients below 0.55. The greatest electricity load reduction comes from installing high-efficiency air conditioners, so these incentives apply only to homes which use air conditioning with a seasonal energy efficiency ratio (SEER) greater than 10.

The High-Performance Window Program will end December 31, 1992. Windows will then have to compete with all other energy conservation measures under the same performance-based incentive programs. They will also be required to carry an NFRC label after January 1, 1993. A 10% improvement over the Title 24 energy requirements qualifies a building, and it leaves the choice of energy-efficient measures to the architect/builder.

Bonneville Power Administration is implementing a Super Window Demonstration Project for electrically-heated homes. They are replacing the windows in 100 homes with windows having U-values below 1.1 W/m^2-°C (0.2 Btu/hr-ft^2-°F). They will monitor some of the homes before and after the windows have been installed. Windows qualifying for the project must be rated using the NFRC 100-91 procedure.

In Canada, Ontario Hydro offers $5.00 per square foot for high-performance windows installed in electrically heated homes. The $10 million program began in June, 1991, and will run for at least three years. New construction and retrofit for detached, semi-detached, low-rise multi-unit housing can apply for the rebate. The program specifies minimum ER numbers for windows and the windows must be evaluated using CSA A440.2. As of April, 1992, over 1000 products qualified. Generally speaking, the qualifying products have low-E coatings, argon gas fill, an insulating spacer, and an improved frame representative of a window U-value of 2.0 W/m^2-°C (0.35 Btu/hr-ft^2-°F). Ontario Hydro paid more than $1,200,000 over the first 1 1/2 years of the program.

The Future

U-value does not necessarily take precedence over all other window performance parameters; for now it is simply the easiest to quantify. In fact, combining U-value, solar heat gain, and infiltration into an annual energy use number may be the most logical approach to comparing window energy use; however, it is the most difficult especially given the climate variations and building stock across the United States. In the meantime, understanding these factors in relation to one another is crucial to both the selection of windows and product development.

Quality control is another crucial aspect, not only in terms of reproducible results but in product performance and durability. Selling a low U-value product that maintains that level of performance for only five years should not be acceptable. Also, pushing the structural capabilities of materials to their limit to achieve a low U-value and lower costs at the expense of product life serves only to undermine the market for energy-efficient windows.

After mentioning the difficulties with establishing an annual energy use number, we look to the CSA's window rating system in Canada. The CSA was already established and did not face the same barriers or competition as NFRC does as a new entity in the standards industry. The Canadian ER number relates specifically to the heating season, and captures the impact of U-value, solar heat gain, and infiltration on energy performance.

Some argue that because the ER number does not account for the building or surface orientation that the relative ranking among products is not an indication of the best window for all applications. This raises issues concerning the use of energy rating indices and their influence on product development and selection, and their relationship to thermal and visual comfort. These issues need to be addressed adequately before establishing total performance numbers so that the market does not exclude new technology that alters the way we do windows.

Conclusions

The NFRC and CSA window rating procedures provide accurate and less expensive alternatives for judging product performance, and a means to educate people as to product performance and design concerns. The rating methods also eliminate some of the problems with misrepresentation of product performance. Coupling the rating procedures with building codes and utility incentive programs promotes higher performance products, and ensures a higher level of accountability.

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