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RATING AND LABELING OF ENERGY PERFORMANCE OF WINDOWS AS A TOOL FOR PROMOTING ENERGY EFFICIENCY PRACTICES IN BUILDINGS

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ABSTRACT

A technically accurate, credible, and cost-effective energy performance rating system aided by use of accurate simulation software has lead, over the last decade, to a transformation of the building fenestration market and industry in North America. A transformation continues to spread to other countries. These simulation tools provide the technical basis for fenestration design, rating, labeling, promotion, marketing and regulation (both voluntary and mandatory).
In the United States, window thermal performance is rated under the auspices of the National Fenestration Rating Council (NFRC). NFRC's rating system utilizes simulations of window energy performance, validated by a limited number of measurements, through administrative and technical procedures to produce fair, accurate and credible ratings of fenestration performance. It is through the use of both good science and credible certification procedures that industry and the marketplace put credence into a rating system that is shaping what products are specified, selected, and thus produced.

This paper will examine the role of simulation software in the design and rating of fenestration, and the lessons learned from the experiences of the NFRC rating system. Current developments in both software and rating systems in the United States and elsewhere will be addressed, along with efforts to harmonize the technical basis for software. The paper concludes with expectations for improvements in many developed and developing nations in the design, specification and selection of energy efficient windows.

INTRODUCTION

In the United States, window thermal performance is rated under the auspices of the National Fenestration Rating Council (NFRC). NFRC's rating system utilizes simulations of window energy performance, validated by a limited number of physical test measurements, through administrative and technical procedures to produce fair, accurate and credible ratings of fenestration performance. It is this use of both good science and credible certification procedures that industry and the marketplace put credence into a rating system that is shaping what products are specified, selected, and thus produced in the market place. Prior to the establishment of NFRC, U-factors and air leakage rates were the only energy related indices and they were determined according to various different procedures and without much credibility. U-factors were routinely reported for center of glass, rather than whole window, and those values could vary as much as 100%. NFRC has added Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) to the matrix of rated values. Currently, several additional indices have undergone or are undergoing NFRC approval. UV, and Condensation Index (CI) have been approved, while Long Time Energy Performance Rating, Annual Energy Rating (AER), and Thermal Comfort Rating are in line for development and approval.

The United States Department of Energy (U.S. DOE) has been an NFRC partner from its beginning in 1989 and has allocated significant funding for research in support of the NFRC mission. In 1992, the Energy Policy Act (EPACT) was enacted by the U.S. Congress, which required the establishment of a window energy performance rating and labeling system. NFRC was charged with the development and implementation of that system. The requirements under the EPACT were addressed, in detail, in a Notice of Determination prepared by the U.S. DOE and published in the Federal Register in 1994. This notice also presented a strong federal commitment to technical support for the comprehensive NFRC rating and labeling program, and the need for international harmonization of window energy performance standards.
The national Model Energy Code developed since 1995, which is often used as a basis for regional energy codes in United States, requires NFRC approved U-factors and Solar Heat Gain Coefficients for compliance with a code. International Energy Conservation Code, which replaces Model Energy

Code, as well as the newest ASHRAE standard 90.1, , are referencing all current NFRC indices.

Through its partnership with the industry, US DOE has established "The Window Industry Technology Road Map" to identify research tools for use by the industry. US DOE has also funded establishment of the Energy Efficient Window Collaborative to equip and educate window practitioners who design, develop, specify and select energy efficient windows. To clearly mark excellence in energy performance, US DOE, in partnership with the industry and the Environmental Protection Agency (EPA), has established the Energy Star Windows program. The Energy Star Label provides a powerful tool in promoting energy efficiency. Both of these programs are intended to transform the market towards energy efficient fenestration products and NFRC ratings. As a result, in the past 10 years, the energy performance of average installed window in a new construction has increased significantly and has contributed to increased energy efficiency of new buildings.

BACKGROUND ON SIMULATION TOOLS

Before the advent of personal computers, modeling of heat transfer in building structures was primarily done in research laboratories using expensive mainframe computers and one-of-a-kind numerical modeling programs. Architects and designers on one end, and manufacturers on the other end, had to rely on the data obtained from full scale thermal testing, which was expensive and time consuming, and therefore only limited number of test specimens were investigated. This was not only affecting designers and manufacturers, but also code officials and ultimately consumers, who had to settle for sporadic and unreliable data about the energy performance of fenestration and other building products.

Before the first energy crisis in early 70's there wasn't great concern about energy performance of windows and other fenestration systems. Very limited number of products were evaluated for their thermal performance and it was all done by testing. Even then, architects and designers were mainly concerned about comfort and liability issues (e.g., premature failure of the installed fenestration system, etc.). Poor thermal performance didn't just mean higher energy bills but also meant condensation, mold, material deterioration, comfort complains, and other associated issues.

Due to high cost of thermal testing, limited number of products could be evaluated and it was up to a particular testing laboratory to establish quality criteria for the test. It wasn't unusual that thermal testing results coming out of these laboratories could differ by as much as 100%. During the first years of energy crisis, these same numbers were used to advertise "great" performance of some of the fenestration products. At that time, computer models were only used for research purposes and mostly in national laboratories and academia. These first computer models were used to better understand energy performance of windows and physics behind their thermal performance. Also, some of the early computer modeling research was used to develop simplified algorithms for incorporation into the first generation of dedicated computer modeling tools. Advent of personal computers (PC) and lowering of cost of computing precipitated accelerated development of these tools.

About 20 years ago, first "user friendly" computer programs that were designed to calculate one-dimensional (1-D) heat transfer in insulated glazing units (IGU) only, were released to general public under the name WINDOW 1.0 (Rubin 1982, Rubin et al. 1985). About 15 years ago, first dedicated computer program to calculate two-dimensional (2-D) heat transfer in frames and edge of glass was released in Sweden (Jonnson 1985) and followed shortly by couple of other programs in Europe (KOBRU) and Canada (FRAME). Initially, 2-D programs were utilizing finite difference method (FDM), and only simple rectangularized geometries, with very limited number of grid points, were allowed. Early versions of computer modeling tools had limited accuracy, but nevertheless brought consistency to the process of estimating energy performance of fenestration systems. The cost of computer modeling using personal computer was much lower than the cost of physical testing and an excellent tool for designers to evaluate their product performance without having to build one. The Computer tool provided a means to significantly increase the number of evaluated products that are actually produced by the manufacturers.

Not coincidentally was National Fenestration Rating Council born at the dawn of the introduction of these first "user friendly" PC based computer programs for simulating thermal performance of windows. While first editions of these programs had very limited functionality, they represented a leap in convenience of use, consistency of results and even accuracy. A "Joint U.S./Canada Research Project on Window Performance", initiated in 1989, undertook a round robin comparison of testing and simulation, proving the accuracy of simulation. This has created favorable conditions for the establishment of the national rating system that was sufficiently accurate and fair, while low in cost and affordable. The United States and Canada started using computer modeling for its certification process 10 years ago, and the number of certified products had exponentially increased ever since. Today, almost 100,000 unique products have NFRC certified labels in the U.S. alone.

Today, the latest generation of computer tools (THERM 5, WINDOW 5, OPTICS 5, and RESFEN 4, also available as a suite WINDOW5+) offers significant improvement in accuracy, ability to model wider range of fenestration products (e.g., projecting products, such as skylight and garden windows, commercial systems, etc.), to provide new indices, like condensation resistance index (CI), UV fading factor, etc., and finally improvements in user friendliness and ease of use. The details about simulation tools, their capabilities and results are available in other published papers (Arasteh et al. 1998, Curcija, et al. 1998, Griffith et al. 1998, Huizenga et al. 1999) and won't be repeated here. See Figure It is clear that continued and expanded use of computer modeling tools will continue to be backbone of successful rating and certification system, and improvement in products design. However, testing will continue to be used as a means of quality control and a validation check for simulation work.

OVERVIEW OF THE ENERGY PERFORMANCE RATING SYSTEM

NFRC rates fenestration products based on computer modeling results, and the label that is put on window contains numbers that are obtained from computer tools. However, results from computer models are first validated against the characteristic sample from the product line, also known as baseline product. In NFRC process, product line is defined first and it consists of an operator type products that essentially have the same frame material and design. Different glazing and spacer options are considered to belong to the same product line. Out of that product line, low end product (in terms of thermal performance) is identified and that product is then physically tested in a NFRC accredited hotbox test laboratory (NFRC 100). Computer simulation for that exact same product then needs to be within 10% of measured value in order to validate. Subsequently, all specimens from the product line are simulated only and these results are used for labeling purposes.

Currently, overall coefficient of thermal transmittance, U-factor (or sometimes called K-factor), Solar Heat Gain Coefficient (SHGC or sometime called g-value), Visible Transmittance (VT), and Air Leakage are rated indices. Condensation Index and Ultra Violate (UV) fading factor procedure are approved by NFRC and fenestration products would soon be rated for these indices. It is planned to also include Annual Energy Performance (AEP), Comfort and Long Time Energy Performance Rating . The most troublesome of these is AEP, because of strong dependence of this quantity on the location and climate. Number that would be considered very good in one region would not be so good in another. Some of the latest proposals call for multiple AEP, based on the region and climate. Currently, computer software RESFEN 4 provides a guideline for Annual energy performance of windows in a standardized home in a region for over 53 climates in the US and Canada.

To ensure that simulated numbers are accurate, each simulator in United States has to complete simulation training and exam and be officially accredited to perform computer simulations. A NFRC testing laboratory is inspected by NFRC personal to confirm its ability to meet strict testing standard requirements. Person responsible for NFRC testing has to meet minimum educational and experience requirements. The person responsible for testing is also required to demonstrate to NFRC that he understands and can perform testing in accordance with the NFRC regulations. The simulators and person responsible for NFRC testing, periodically go through mandatory re-training and re-certification process and have to complete at least one round-robin for simulation and testing annually. In addition, NFRC staff and members of accreditation policy committee perform bi-annual inspections where several files are randomly selected and evaluated and the operations of simulation and testing laboratories are closely examined. If the simulation laboratory is found to be in violation of certification process, its operations are suspended and responsible person has to go through re-training process.

The Rating System employs computer simulation and physical testing by NFRC-accredited laboratories to establish energy performance ratings for fenestration products and product lines. The Rating System is reinforced by a certification program under which fenestration manufacturers may label and certify fenestration products to indicate those energy performance ratings, if the ratings are authorized for certification by an NFRC-licensed certification and inspection agency (IA). The requirements of the rating, certification and labeling program (the Certification Program) are set forth in the *NFRC Product Certification Program* (NFRC-PCP). Through the Certification Program and its companion laboratory accreditation program (the Accreditation Program), set forth in the *NFRC Laboratory Accreditation Program* (NFRC- *LAP)*, and IA licensing program set forth in *NFRC Certification Agency Program (CAP)*, NFRC intends to ensure the integrity and uniformity of NFRC ratings, certification and labeling by ensuring that testing and simulation laboratories and IA's adhere to strict NFRC requirements.

In order to participate in the Certification Program, a manufacturer shall rate a product to be certified for one or more of the NFRC rating procedures to include those ratings on the NFRC Label affixed to its products. U-factor, SHGC and VT, and Air Leakage rating reports are obtained from a NFRC accredited laboratory and the rating are then reviewed by an Independent Inspection and Certification Agency (IA) which must issue a product certification authorization. Products that are labeled with the NFRC Temporary and Permanent Label in accordance with NFRC requirements are considered to be NFRC-certified.

NFRC accredited Inspection Agency is responsible for conducting in-plant inspections of manufacturer's manufacturing facilities, including review of manufacturer's quality control program in accordance with the Certification Program before granting the manufacturer the certificaion authorization to label their products.

At least once each year, NFRC publishes the *NFRC Certified Products Directory (CPD)*, listing product lines and individual products selected by the manufacturer for which product certification authorization has been granted following all NFRC-licensed IA's and NFRC-accredited testing and simulation laboratories requirements.

Under NFRC program, any person (the "Challenger") has the right to commence a Challenge to the accuracy of any NFRC product rating or NFRC product certification authorization of a fenestration product (a "Challenge"). A successful Challenge results in suspension or revocation of product certification authorization by NFRC, any and all rights of a product manufacturer/responsible party to use the NFRC name, mark, ratings, certification or label shall immediately cease with respect to the product or products suspended. If the product manufacturer/responsible party fails to discontinue use of the NFRC name, mark, ratings, certification, or label, NFRC has the right to obtain an immediate temporary injunction restraining the product manufacturer/responsible party from any and all further use of or reference to the NFRC name, mark, ratings, certification, or label and to the award of damages for harm to NFRC's name and reputation. NFRC also imposes strict fines for the misuse of NFRC ratings and faulty labeling. Figure 1 shows schematic presentation of the NFRC process, while Figure 2 shows organizational chart of NFRC.

Certified product indices, once they are approved through the rigorous NFRC process are printed on an approved temporary label, shown in Figure 3. As the number of certified indices grow, the label will undergo modifications from its present form. Membership of NFRC, through the democratic process of balloting and voting will decide which design will be used in the future labels. Also, an important aspect of NFRC labeling process is the use of permanent labels, which contain only absolutely necessary information and which are printed in a un-conspicuous place for future inspections, after the temporary label had been removed.

EFFECTS ON ENERGY EFFICIENCY

Fenestration is invariably the most significant component of the building envelope, in terms of its energy performance. In late seventies windows, doors and other fenestration products consumed more than one quarter of all cooling and heating energy for buildings in United States. In terms of overall energy consumption, fenestration products were attributed 5% of the total national energy consumption. This is huge number considering that windows represent small portion of building envelope and relatively small fraction of the overall building cost.

In the years since the inception of NFRC this picture has begun to change and today energy efficient windows represent significant portion of the total production. These new products not only save energy by reducing heat loss through their exposed areas and increasing heat gain in the winter due to solar radiation, but they also contribute to the reduction of lighting energy, which represents additional 5% of national energy consumption. This reduction in lighting energy is due to increased availability of daylighting from advanced windows while keeping cooling energy to a minimum. The effective use of daylighting is coupled with better control practices, so that lighting is minimized or completely eliminated when there is enough outside light.

Comprehensive rating system minimizes inaccuracies and false claims from manufacturers, enticing them to improve products to get better ratings. Energy codes are adopting NFRC and establishing minimum thresholds for various parts of the building envelope, including windows. In order to sell energy efficient windows, manufacturers of poorly energy performing products now have to change the design and improve thermal performance of their products.

There are several ways to improve thermal performance; 1) modification of the frame design; 2) improvement in glazing system; and 3) improvement in spacer design.

Frame improvements may be accomplished in several ways. Frame designs using highly conducting materials like aluminum can be replaced or modified with less conducting counterparts like PVC, wood or composite material, or introducing thermal break in the thermal path (i.e., insertion of insulating, but structurally sound material, like Urethane, in between outdoor and indoor side of the Aluminum extrusion framing). In recent years several new frame materials have been introduced in the market (e.g., various types of composite materials, or foam filled frame cavities), and existing materials have been improved (e.g., more durable and dimensionally stable PVC, various designs of thermal breaks, etc.). Figure 4 shows 10-year trend in residential U.S. and Canadian market for different frame materials. Years 2001 through 2003 are projected numbers, based on market research.

The most significant improvement can be achieved by the proper design of the glazing system. Sealed insulating glazing unit (IGU) can replace single or unsealed double-glazing. The advantages of the sealed IGU is that unit can be fabricated in a controlled environment, using low-emissivity (low-e) coatings inside glazing cavity and/or inert gas and that state can be preserved for a long time if the unit had been properly sealed. Typically, for a good seal, glass sheets need to be well washed and assembled in clean environment using good sealing materials like Polyisobutilene (PIB) for a primary seal and Polysulphide for a secondary seal. Figure 5 shows the configuration of a double and triple layer IGU.

Low-e coatings are very thin films, which are applied on a clear glass substrate. These spectrally selective coatings have very beneficial characteristics, due to their spectral selectivity. They are almost transparent in the visible spectrum of solar radiation, while being very reflective in long wave infra-red (far infra-red) spectrum. Because low-temperature radiation heat transfer almost completely occur in this spectral range, these coatings help reduce heat transfer through the glazing system. Low-emissivity coatings have been steadily improved over the last decade, achieving emissivity values as low as 0.03 (sputtered process). In addition to the reduction of emissivity in far infrared range (i.e., wavelengths of more than 2.5 microns), some new coatings exhibit lower emissivities (and therefore higher reflectances) in near infra-red range, which affects direct solar radiation transmission. These new types of coatings are effective in cooling dominated climates where the reduction of energy of direct solar radiation significantly reduces cooling load. These coatings have additional advantage that they let the visible portion of the solar spectrum while keeping out heat containing near infra-red spectrum. This ability is also known as spectral selectivity. Figure 6 shows the market penetration of different types of low-e coatings in 1999, while Figure 7 shows distribution of glazing coatings for each wood material type.

In addition to glass, new glazing systems may also incorporate thin plastic sheets (known under the trade name “heat mirror”), containing low-emissivity (low-e) coating on one or both sides. This configuration is very effective because it provide benefits of triple glazing without the added weight of third glazing layer.

Finally, improved spacer designs incorporating low conductivity materials reduce heat transfer through the interface between IGU and frame, and as an added benefit increase surface temperatures on the indoor glass surface, therefore reducing the potential for condensation. This is very important in northern climates where extreme cold temperatures can cause significant condensation inside rooms. This is one of non-energy benefits of improved thermal performance that may contribute to increased durability of fenestration products and improved air quality, because of the mold formation in the areas that are subject to frequent condensation. Figure 8 shows typical “warm edge” spacers, while Figure 9 shows the market penetration of various spacer designs in 1999.

Tightening of energy code requirements and NFRC rating system has pushed the envelope and manufacturers today produce and sell more energy efficient products than ever before. The energy efficiency of fenestration products has steadily improved over the last 10 years. The graph in Figure 10 shows the trend of decreasing U-factor over the last 10 years. This graph does not fully capture the trend in the reduction of U-factor because the data include all of NFRC participating manufacturers over the years. Because U-factors are not as important in cooling dominated climates, the windows manufactured for these regions and sold there have not kept up with the rest of the market in the improvement in U-factors, therefore skewing the data somewhat. However, the trend is clear and the future studies should identify only windows manufactured for the heating dominated climates, and should identify energy savings for windows manufactured for cooling dominated climates.

CONCLUSIONS

- Computer simulation has provided the industry an accurate and cost effective mean to rate their products for energy efficiency,
- Comprehensive energy rating and labeling system provides “level playing field” for manufacturers and gives them incentives to produce better and more energy efficient fenestration products,
- Energy efficiency of fenestration products have steadily improved over the past 10 years of NFRC existence,
- Additional performance indices, like condensation resistance, UV fading, etc, help improve both direct and non-direct energy performance and improve durability of fenestration products,
- Education and information dissemination to consumers has significantly improved and intensified since NFRC inception,
- With the NFRC rating and labeling system consumers have better tools to make informed decision when buying new or replacement windows, doors and skylights.
- Future work should identify criteria for measuring energy savings in cooling dominated climates and try to distinguish between windows manufactured and sold for different climates.
- Future market studies should investigate historical penetration of different kinds of low-e and other advanced coatings and predict future trends.
- Significant and continuing research investments and international technical cooperation in advanced simulation algorithms and tools, by the United States, Canada and other countries, have lead to accurate, technically credible computer simulation tools for determining window energy performance

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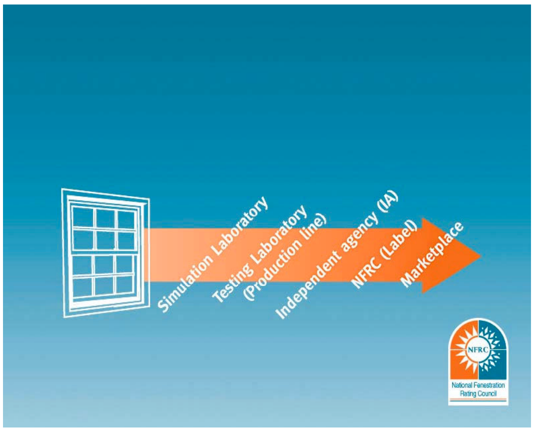


Figure 1. Schematic Presentation Of NFRC Process

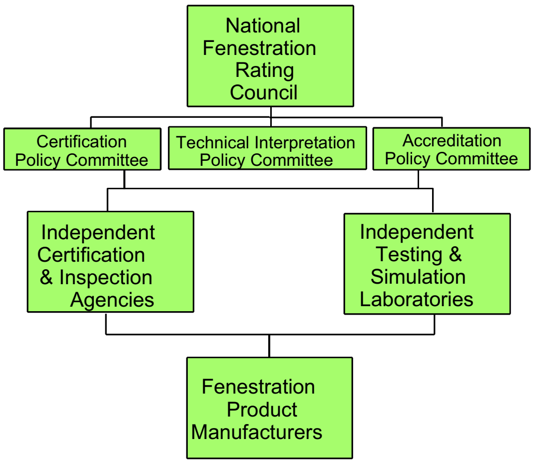
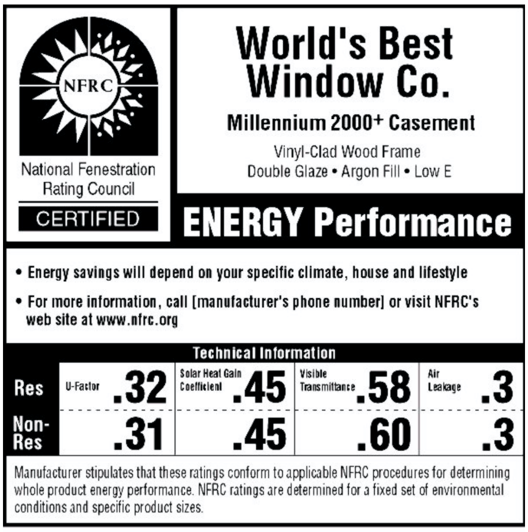


Figure 2. Organizational Structure of NFRC



NFRC

National Fenestration Rating Council

CERTIFIED

World's Best Window Co.

Millennium 2000+ Casement

Vinyl-Clad Wood Frame
Double Glaze • Argon Fill • Low E

ENERGY Performance

- Energy savings will depend on your specific climate, house and lifestyle
- For more information, call [manufacturer's phone number] or visit NFRC's web site at www.nfrc.org

Technical Information

	U-Factor	Solar Heat Gain Coefficient	Visible Transmittance	Air Leakage
Res	.32	.45	.58	.3
Non-Res	.31	.45	.60	.3

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product energy performance. NFRC ratings are determined for a fixed set of environmental conditions and specific product sizes.

Figure 3. Currently Approved NFRC Label

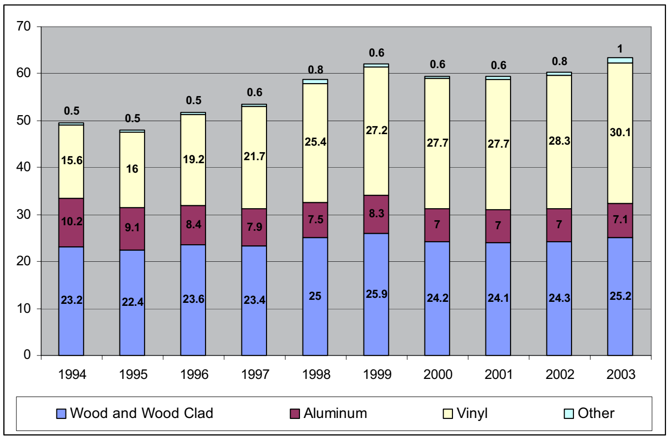


Figure 4. Total U.S. and Canadian Market for Residential-Type Window Units (Ducker 2000)

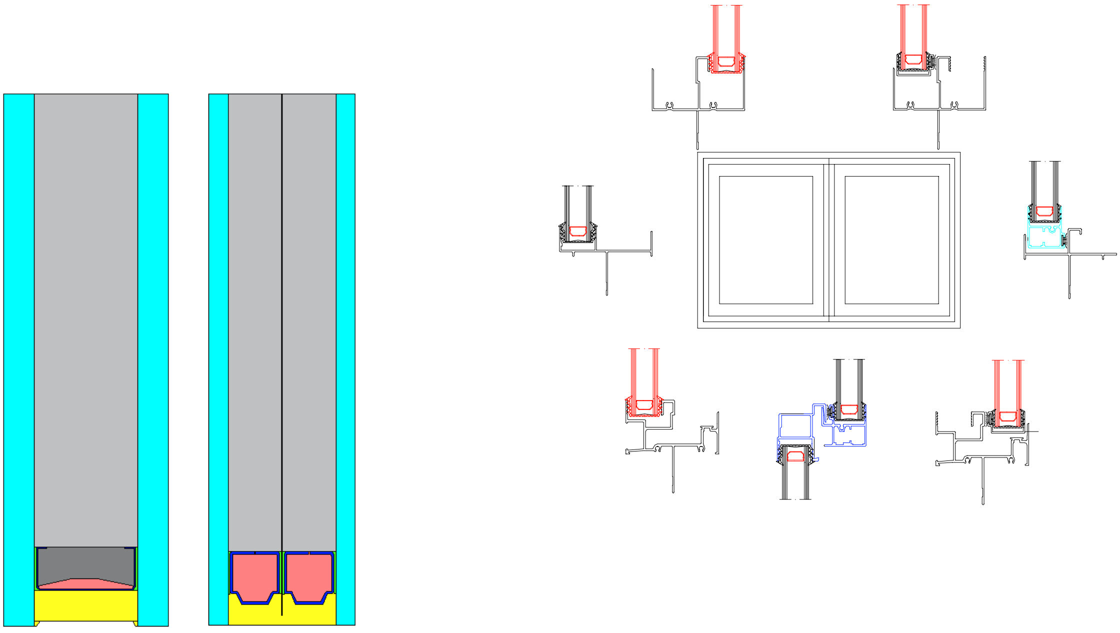


Figure 5. Double and Triple Glazed (Suspended Film) Glazing Configurations and Typical Window Configuration

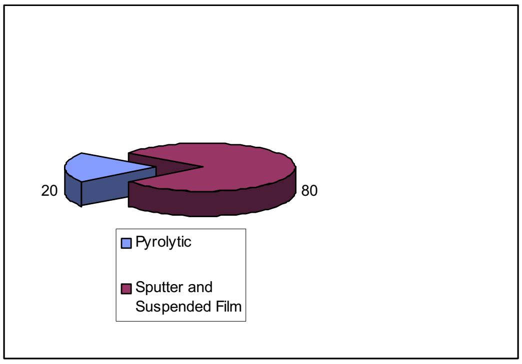


Figure 6. Market Penetration Of Different Types Of Coatings For Residential Windows (Ducker 2000)

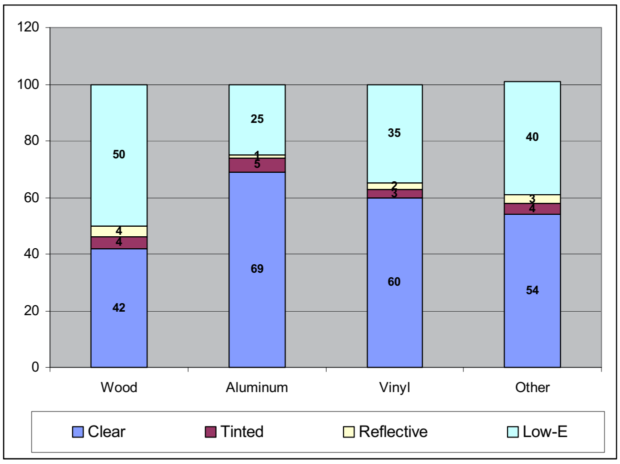
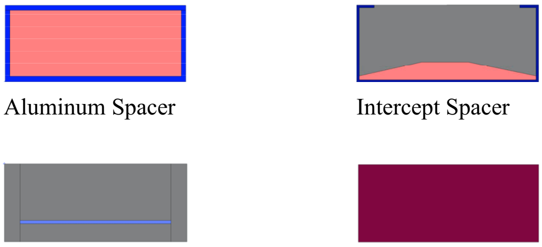


Figure 7. Distribution of Different Types of Coatings for Different Types of Frame Materials in Residential Windows (Ducker 2000)



Aluminum Spacer

Intercept Spacer

Swiggle-Strip Spacer

Super Spacer

Figure 8. Different Types of Spacers

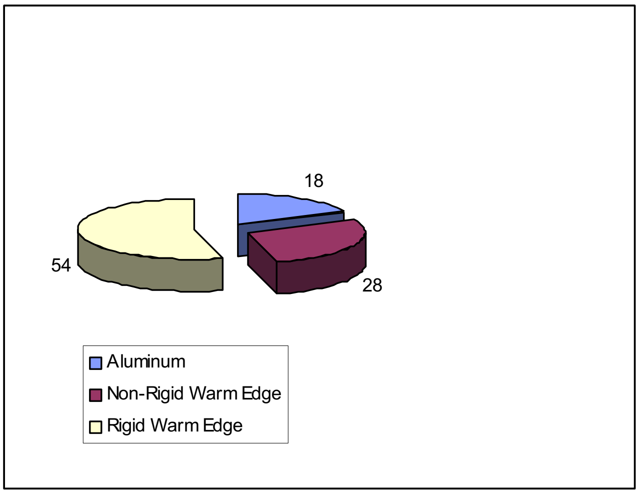


Figure 9. Market Penetration of Various Spacer Designs in 1999 (Ducker 2000)

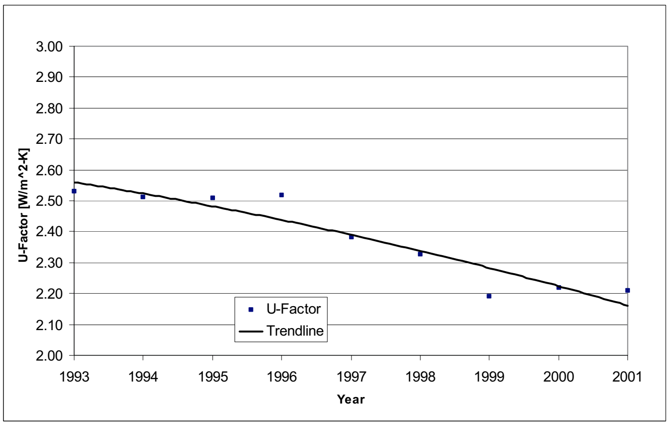
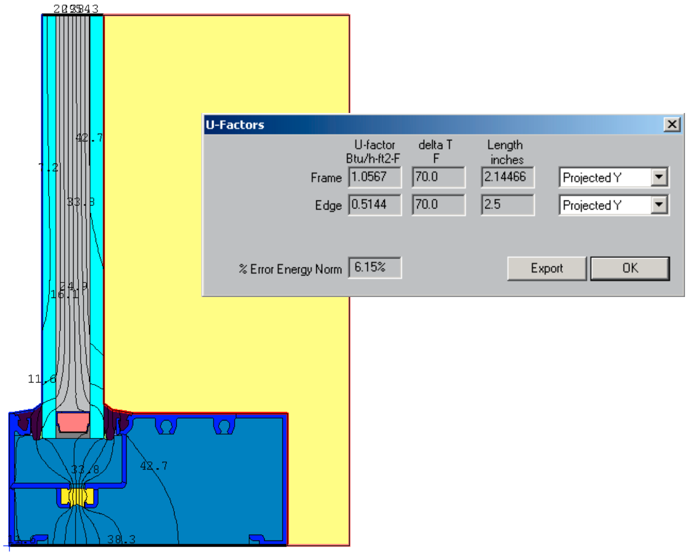


Figure 10. Average U-Factor for NFRC Certified Products



	U-factor Btu/h-ft2-F	delta T F	Length inches	
Frame	1.0567	70.0	2.14466	Projected Y
Edge	0.5144	70.0	2.5	Projected Y

% Error Energy Norm 6.15%

Figure 11. Simulation Results from THERM