Draft

Nonresidential Fenestration

Measure Evaluation Report
2008 California Building Energy Efficiency Standards

February 15, 2006

CONTENTS

Overview

Description

The proposed changes would modify how nonresidential fenestration is modeled in two ways. The first change would provide a more accurate modeling procedure for all nonresidential fenestration by incorporating a more accurate modeling procedure already available in the DOE-2.1E reference method. The second change would recognize an improved method of dealing with site built fenestration systems such as curtain walls and store fronts.

More Accurate Reference Method

The first measure would modify the way that nonresidential fenestration is modeled in the reference method. DOE-2.1E has two methods of modeling fenestration: the U-factor/shading coefficient method and a more detailed method that uses angular dependent performance data generated from Window 5.0. The CEC requires that National Fenestration Rating Council (NFRC) data be used for code compliance purposes and the available data contained on the label is limited to U-factor, SHGC, and VLT. For this reason, the only method recognized in the nonresidential ACM manual is the U-factor/shading coefficient method. The data needed for the more detailed modeling procedure is not presently available from NFRC.

The more detailed method is considered to be more accurate and when the two methods are compared, there are significant differences. Compared to the detailed method the U-factor/shading coefficient method overestimates the performance of single glazed, reflective, heat absorbing (tinted) products and underestimates the performance of double, clear, low-e products. See Figure 1.

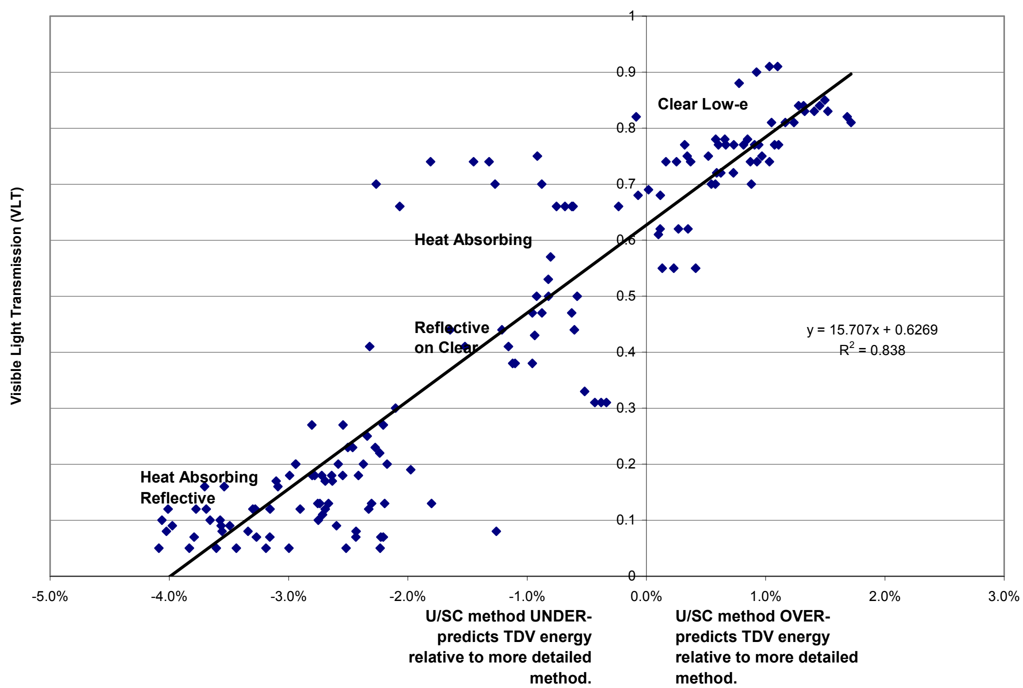


Figure 1 – Comparison of the U/SC and Detailed Fenestration Modeling Procedures
Source: Results were generated by Architectural Energy Corporation for the DOE-2 library of glazing products, excluding suspended film products.

The proposed change would provide a procedure for NFRC to provide detailed modeling information for use in the California compliance process. The necessary detailed performance data is produced as part of the NFRC certification process, but it is not maintained in the NFRC database or the Certified Product Directory (CPD). As part of this change, NFRC would modify the software used by NFRC simulation laboratories so that the detailed data is saved and provided back to NFRC.

The NFRC website would be modified so that compliance software can provide the CPD number of a NFRC fenestration product and receive the detailed performance file needed for simulations. DOE-2 and EnergyPlus require slightly different information so both formats would be available from the NFRC website. The compliance software would need to be on-line when simulations are made and the NFRC website would need to be active and responsive. A request would be made by the compliance software and the file would be passed back and the data would be included in the simulation. This would occur “behind the scenes” so that there are no opportunities to modify the data. This process is illustrated in Figure 2.

1	2	3	4	5
Design Process	**Preliminary Compliance Documentation**	**Detailed Fenestration Performance Data**	**Final Compliance Documentation**	**Building Permit Application**
The architect selects a shop-built fenestration product and includes an “or equal” clause in the specification.	The compliance author enters the NFRC CPD number in the user interface of the compliance software. After input is complete the “run” button is pressed.	The compliance software addresses the NFRC website with the CPD number and receives a text file with the detailed data needed for the simulation.	The compliance software uses the detailed data and produces a report, if the project complies.	The compliance documentation is submitted to the building department for review and approval.

Figure 2 – Manufactured Fenestration – The Performance Compliance Process during Design

With the recommended procedure, it will be necessary to identify a detailed fenestration performance file with each fenestration product used in the standard design building. At present, the prescriptive tables (see §143(a) of the standard) only specify a U-factor and SHGC. The detailed data is available, however, from the 2001 research that resulted in the current fenestration requirements. A similar approach is already used with opaque constructions, e.g. a reference is made to a table number, row and column in Joint Appendix IV for each prescriptive requirement.

Site Built Fenestration

In 2001, the CEC required NFRC label certificates for site built fenestration with a surface area larger than 10,000 ft² and in buildings larger than 100,000 ft². With the 2005 update, the building area threshold was eliminated, leaving only the 10,000 ft² threshold. In addition, the 2005 standards eliminated the option of using SHGC data from glazing manufacturers.

The label certificate for site-built fenestration is not widely used in California. Information available from the NFRC indicates that 12 label certificates were issued in California during the years 2001 through 2005 or 2.4 per year.

Instead, engineers, architects and contractors are using the default values. ACM-NI 2005 has reasonable default values when the total site-built fenestration area is less than 10,000 ft². For projects with site-built fenestration area 10,000 ft² or greater, the restrictive defaults contained in Table 116-A (U-factor) and Table 116-B (SHGC) must be used. Use of the default values and no reasonable option for NFRC label certificates has reduced or eliminated incentives for the use of high performance site-built fenestration systems in projects with more than 10,000 ft² of site-built fenestration, since the same low-performing default is required to be used regardless of the fenestration product actually used in the building.

This change would modify the NFRC label certificate process to be more workable. Instead of the current label certificate process which applies to the entire assembly, the modified process would result in component LCs for the three major components of site built systems: the glazing, the spacers and the frame. NFRC would develop a Certified Products Directory (CPD) for these system components. In addition, NFRC would develop software that would combine component performance data and produce an overall rating for site-built fenestration systems.

Figure 3 shows how the compliance process would work. In some respects it is similar to the process described above for manufactured fenestration products. The difference is that the compliance author would specify not just one CPD number for each window, as is the case for manufactured or shop built fenestration, but at lease three CPD numbers, one for the frame, the glazing(s) and the spacer. Since an IG unit can consist of different types of glazing, more than one CPD number may be needed to describe the IG unit.

With the prescriptive process, the compliance author would visit the NFRC website with the three CPD numbers and generate a LC for the fenestration system. This LC would be attached to the prescriptive compliance documentation to show that the U-factor and SHGC meet the prescriptive criteria. The system LC would also document the glass, spacer and frame products that define it. This LC would survive the compliance process and make its way to the job site so that it can be verified by field inspectors or persons responsible for acceptance testing.

The process is similar with the performance process, except that the three CPD numbers are entered into the compliance software; the compliance software addresses the NFRC website and acquires the data needed for simulations (a detailed file like described above for manufactured fenestration); the simulation is performed and if the project complies, documentation is produced which includes the design LC for the fenestration system.

1	2	3	4	5
Design	**Preliminary Compliance Documentation**	**Label Certificates**	**Final Compliance Documentation**	**Building Permit Application**
The architect works with site-built component manufacturers and designs the curtain wall or store front application. The plans and specifications document the spacer, glass and frame.	The compliance author documents the choice of spacer, glass and frame.	NFRC maintains certified product directories for site-built components and software for combining the performance of these components into an overall rating for the fenestration system.	The final compliance documentation includes a LC for each site-built system used in the project.	The compliance documentation is submitted to the building department for review and approval. This includes a LC for the site-built product used to show compliance.
	Prescriptive The compliance author visits the NFRC website	NFRC produces a LC for the system that documents the CPD number of each component and shows the U-factor, SHGC and VLT for the system	The compliance documents show the U-factor and SHGC used for compliance and include copies of the design LCs.	Once approved the documentation is kept at the job site for review by field inspectors or by those responsible for acceptance testing.
	Performance The component CPD numbers are entered into compliance software	NFRC produces a LC like for the prescriptive process, but also produces a detailed fenestration performance file that is passed back to the compliance software for use in the simulation.	The detailed performance file is used in the simulations and a copy of the LCs are printed with the compliance report.	Once approved the documentation is kept at the job site for review by field inspectors or by those responsible for acceptance testing.

Figure 3 – Site-Built Fenestration – The Compliance Process during Design

Figure 4 illustrates how compliance is verified in the field. The design LC produced in the compliance process (Figure 1 above) is based on specific system components. Closed specifications are not an option with most construction projects, either because it is the policy of the owner or so that more competitive bids can be achieved. This means that the glazing contractor will take bid proposals from multiple frame manufacturers and multiple IG manufacturers. As bids are evaluated, the NFRC website would be visited to verify that the various combinations meet the specifications needed for compliance. If a proposed combination has an equal to or lower U-factor, an equal to or lower SHGC and an equal to or higher VLT, it is assumed to perform better. Appendix B has data that shows that this is a reasonable assumption.

The spacer, glass and frame manufacturers would provide data to the glazing contractor who would produce the LC for the system by visiting the NFRC website. The LCs for both the components and the system would be maintained at the job site (like all label certificates) so that someone can verify that a complying system is used in the field, e.g. on that has U-factor, SHGC and VLT better than or equal to what was assumed in the compliance process.

An additional acceptance test would be developed and included in ACM NJ 2008. This acceptance test would require that the architect, engineer or contractor recognized by the California practice act sign a Certificate of Acceptance and submit it to the building department.

1	2	3	4	5
Specified Fenestration System The glazing contractor requests bids and contracts for a site-built product that performs equal to or better than the product used to show compliance. The test is: $U_c \le U_d$ $SHGC_c \le SHGC_d$ $VLT_c \ge VLT_d$ The glazing contractor produces a LC based on the component LC for the frame, spacer and glass.	**Spacers** Spacer manufacturer provides LC to the IG fabricator when product is shipped. **Glass** Glass manufacturers or coaters provides LC to the IG fabricator when product is shipped	**IG Unit** The IG fabricator verifies that the spacers and glass provided by vendors meets the specification and passes the LC's on to the glazing contractor. Note: the IG fabricator may also be the glass manufacturer or coater.	**Constructed Fenestration System** The general contractor or construction manager files the LC's for the components as well as the system in the job site office	**Acceptance Testing** An architect, engineer, or contractor recognized by the California Practice Act visits the job site and verifies that the LC's for the spacer, frame, glass and system are on file. The system LC is compared to the LC on the compliance documents to verify that: $U_c \le U_d$ $SHGC_c \le SHGC_d$ $VLT_c \ge VLT_d$
	Frames Frame manufacturer provides LC to the glazing contractor when the product is shipped			

Figure 4 – Site-Built Fenestration – Chain of Custody for Label Certificate in the Construction Process

Type of Change

The change would modify the calculation procedures and assumptions for modeling nonresidential fenestration. This change would not add a compliance option or a new requirement, but would affect the way that trade-offs are made. The result is that the range of fenestration products used in nonresidential buildings would be more fairly and more accurately modeled by the reference method. The changes would affect both the Standard and the nonresidential ACM manual.

Energy Benefits

Both the more accurate reference method and the modified label certificate procedure for site built fenestration will result in energy savings. The more accurate reference method will result in energy savings by making it more difficult for single glazed, reflective coated, heat absorbing products to comply and by making it easier for high performing low-e products to comply. The site-built label certificate requirements will result in energy savings by providing an incentive for the use of high performing site built systems (at present the defaults must be used and advanced and high performing products are not recognized).

Non-Energy Benefits

Insofar as the changes result in better windows used in nonresidential buildings, thermal comfort will be improved, which will result in greater occupant productivity and possibly higher property values if energy bills and comfort are taken into account in property valuation. The proposed changes are expected to have an insignificant effect on maintenance, environmental impact, indoor air quality, health and safety.

Environmental Impact

Apart from reduced energy use, which has a positive impact, there are no significant environmental impacts associated with the proposed changes.

Technology Measures

The technologies that will be encouraged by the changes are already mature in the market. Furthermore, there are no issues related to useful life, persistence or maintenance.

Performance Verification

The proposed changes are expected to result in changes to ACM-NJ on acceptance testing of site built fenestration. A Certificate of Acceptance (COA) would be required. Like other COA, responsibility for signing would be defined by the California Practices Act: either a licensed design professional or contractor. In signing the COA, the responsible party would verify that the performance of the site built fenestration documented on the label certificate on record in the general contractor or construction manager's job site is equal to or better than the site built fenestration performance used in the compliance calculations.

Cost Effectiveness

The change in the NFRC process for site-built fenestration will reduce the cost of generating label certificates. The proposed changes will result in energy savings with no increased cost. The proposed change is not a mandatory measure or prescriptive requirement, so it is not necessary to demonstrate cost effectiveness. However, the proposed changes are not expected to add any significant costs to either construction or compliance. In the case of the label certificate process for site-built fenestration, the proposed approach of certifying site-built system component should be significantly reduced.

Analysis Tools

The DOE-2.1E reference method has the modeling capabilities needed to implement the proposed changes. What is needed however, are systems within the NFRC to make detailed fenestration performance data available to simulation tools and to combine the label certificates for spacers, frames and glass into a combined label certificate for the site-built product.

Relationship to Other Measures

None.

Methodology

TO BE PROVIDED LATER.

Analysis and Results

TO BE PROVIDED LATER.

Recommendations

TO BE PROVIDED LATER.

Material for Compliance Manuals

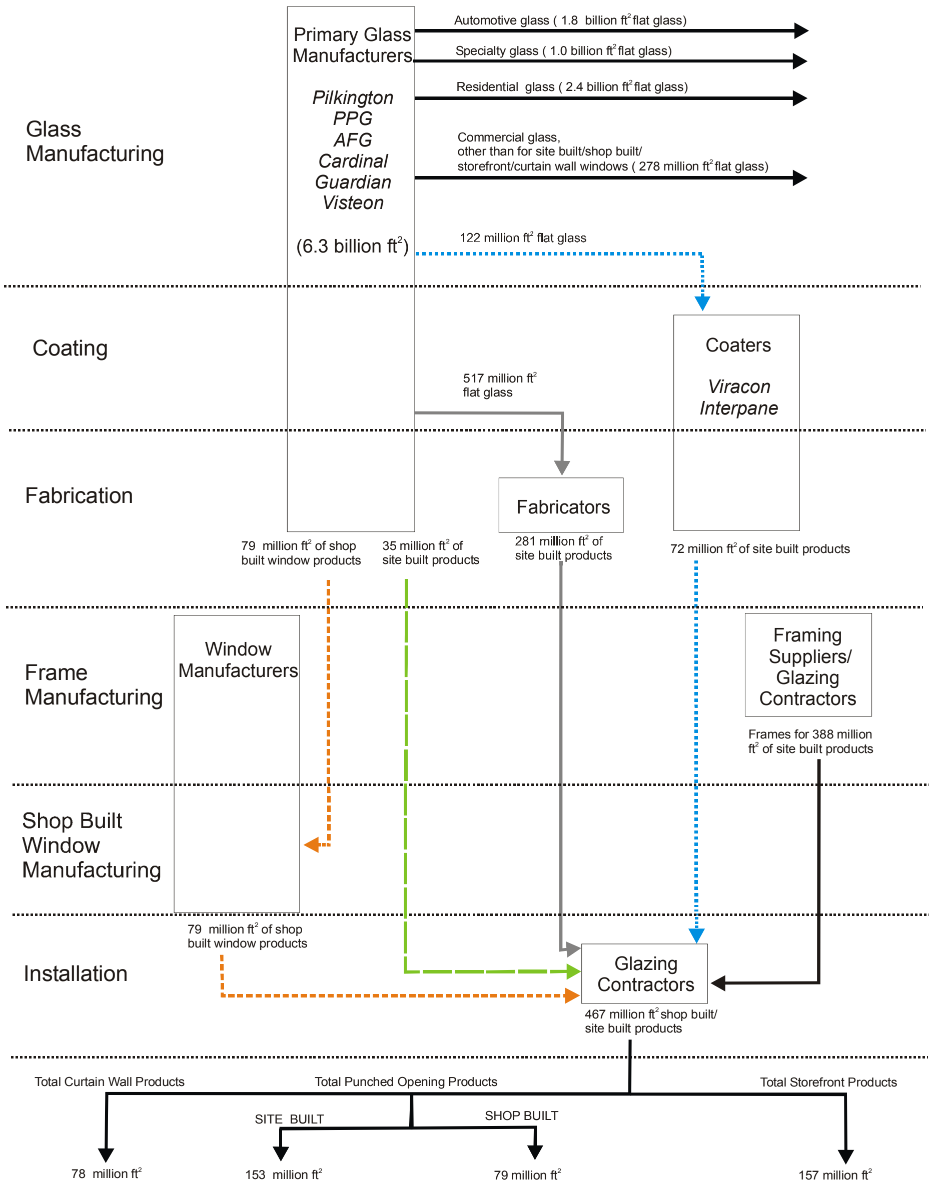
TO BE PROVIDED LATER.

Bibliography and Other Research

TO BE PROVIDED LATER.

Appendix A – Supply Side Actors

The information in this appendix is provided for reference and is taked from "A Characterization of the Nonresidential Fenestration Market, Nonresidential Fenestration Market Research", Eley Associates, July 25, 2002 Prepared for Lawrence Berkeley National Laboratory (LBNL) and the Northwest Energy Efficiency Alliance (NEEA)



NOTE: The term "flat glass" refers to single panes of glass.
The term "products" refers to final glazing products.

Figure 5 – Supply Side Market Flow

Source: A Characterization of the Nonresidential Fenestration Market, Nonresidential Fenestration Market Research, Eley Associates, July 25, 2002 Prepared for Lawrence Berkeley National Laboratory (LBNL) Northwest Energy Efficiency Alliance (NEEA)

Primary Glass Manufacturers

There are six PGMs that manufacture sheet glass from sand and cullet. The six PGMs have different business strategies and focus on different glazing technologies. All six of the PGMs tint glass, though some offer a broader spectrum of colors than the others. In general, they can be grouped into two different categories:

- The first group (three PGMs) produces a relatively large amount of glass. They apply pyrolytic coatings to some of their glass during the manufacturing process and ship 100% of their glass in cut-to-size sheets (not IG units). Their construction glass market is about 50% nonresidential and 50% residential. With the rise in popularity of sputter coatings, two out of the three PGMs have invested in sputter coating equipment and sputter coat some of their glass after the glass has left the float line and has been cut to size. The production of sputter-coated glass is increasing and is expected to further increase, while the volume of pyrolytic-coated glass has remained fairly static. Overall, low-e coatings are a fairly small portion of their production; only about 10%-15% of their shipped glass has a pyrolytic or sputter low-e coating.
- The second group (two PGMs) has invested heavily in low-e coating technology and focuses on the sputter-coated glass market. They do not manufacturer glass with pyrolytic coatings. One of these PGMs fabricates all of their glass into IG units on-site and ships the majority to window manufacturers. Nonresidential fenestration is only about 10% of this company’s construction market. Glass from the other PGM is either sent to other fabricators or made into an IG unit and shipped directly to the job site. The second company produces limited shades of tinted glass and will purchase tinted glass from other PGMs. Nonresidential is a significant, but not large, portion of this company’s market.

The sixth PGM produces less glass for the building market than the others and fits into neither of the above categories. They only produce clear or tinted glass, and all the glass they produce is shipped in sheets to fabricators or other PGMs.

Coaters

Three companies, other than the PGMs, are involved with applying sputter coatings to glass. They receive glass from the PGMs and do not manufacture any glass themselves.

Two of these companies have similar business models and specialize in sputter coatings. Both have internal research and development groups focused on improving the performance of their sputter coatings. About half of their glazing products have a low-e sputter coating, while the other half are reflective sputter coatings. The majority of their market is curtain wall and storefront glazing for medium-to-large projects. The lead times for sputter-coated glazing can be up to 16 weeks, but this is rarely a problem because the large building projects they are involved with have construction schedules that can accommodate a longer glazing delivery timeline. Their fenestration is shipped directly to glazing contractors at the job site. Nationally, IG units make up about 70% of their product. The 30% monolithic includes laminated, spandrel, and single pane glass. About 3%-10% of their IG units are filled with argon. Silk-screening ceramic frit onto glass is a small, but growing, market for both companies.

The third coater is part of a fabricating firm. This fabricating firm is associated with one of the PGMs and receives the majority of their glass from that PGM. The firm has branches throughout the country, but only one site has sputter coating equipment, which primarily produces reflective (not low-e) coated glass. The other branches do IG fabrication, tempering, heat treating, and laminating. About 60%-70% of their market is nonresidential. All of their products are shipped directly to the job site. They have seen an increase in low-e and high performance tinted glass, but this type of glass only makes up about 10% of their market.

Fabricators

Fabricators cut, temper, heat strengthen, laminate, and fabricate IG units from standard sheets of glass that they receive from PGMs. None of the fabricators interviewed receive glass from coaters (coaters generally fabricate their own glass). Fabricators provide glazing systems for curtain walls, site-fabricated commercial windows, and storefronts. Some fabricators specialize in a particular window type. Fabricators are involved with providing spacers, which could be aluminum, stainless steel, or thermoplastic. The fabricators are not involved with the frames. Fabricators can range from single location operations that serve a small region to operations with multiple locations that serve the entire country. Local operations hold a sizable share of the fabricating market. The largest 50 fabricators hold approximately 50% of the market, while the rest is served by smaller operations.

The majority of fabricated glazing that leaves a fabricator is shipped directly to glazing contractors. Fabricators strongly influence the glass options available to glazing contractors. While glazing contractors on large projects may directly receive fabricated glass from a national coater or PGM, glazing contractors on small and medium projects tend to work directly with a locally situated fabricator. Fabricators do not stock all glass types available from PGMs. They are reactive to market demand and typically stock only what is commonly specified.

Most fabricators interviewed state that approximately 25% of the fenestration they supply to the nonresidential market has a low-e coating, including both sputter and pyrolytic. This, however, varies greatly by region and fabricator. A fabricator serving Florida feels low-e fenestration is 25% of their stock, while a fabricator serving the Northeast states low-e is as high as 70%. One fabricator with locations throughout the country states that their fabrication sites in Tampa, Miami, Houston, and Dallas probably do not even carry any low-e glass, while their fabrication sites in New Jersey, Philadelphia, and Chicago probably stock nothing but low-e glass. All fabricators interviewed feel demand for low-e glazing is increasing.

Low-e glass is available from all the fabricators interviewed, but some are not equipped to handle sputter-coated glass and only offer pyrolytic low-e coatings. The two largest fabricators interviewed are equipped to fabricate IG units with sputter-coated glass. These two fabricators have also invested in the extra equipment necessary to temper post-temperable, low-e coated glass.

Most of the fenestration these fabricators put into the market are IG units, and the use of monolithic glass is decreasing. One fabricator, however, states that 30% of their fenestration is monolithic. The monolithic fenestration is primarily used for storefront/strip mall applications. Another fabricator states that 10% of their fenestration is uncoated IG units. This glass primarily goes to lower-end, strip-mall type buildings.

Fabricators rarely use argon fill (0%-15% of the time), and many of them question its ability to remain in the unit for the lifetime of the glazing.

Specialty Equipment Suppliers

The process of applying pyrolytic or sputter coatings is complex and requires specialized technology. A group of companies provide the equipment and technology to support these operations.

Some specialty equipment suppliers provide sputter coating equipment to PGMs and coaters. They have the capacity to build about three large machines per year, which range in cost from $10 to $18 million. Each machine can coat a load of glass every 30 seconds. Maximum glass dimensions are 144 in. x 100 in. in the U.S., and 126 in. x 236 in. in Europe. This results in about 10 million ft² to 50 million ft² of glass per year per machine, when operating continuously. The coating rate depends on the number of cathodes in the machine. Edge deletion and handling concerns are not common complaints by their clients. Improvements underway include increased productivity (deposition speed) and increased product quality (uniformity of the color, tightening of color variation).

Germany and other European countries went though widespread regulatory changes in the mid-1990s that created a surge in demand for coatings. Equipment manufacturers had no problem providing equipment to meet this surge. Even though sputter coatings are gaining popularity in the U.S., there is not a large increase in equipment requests. This may be related to the weak economy and the large investment required.

Other specialty suppliers provide chemistry technology to manufacturers of pyrolytic coatings. They have no competition other than the research divisions of their customers. One firm argues that even though the architectural trend is toward clear glass, there are times when the lower visible light transmittance (VLT) from a pyrolytic coating is adequate or desired. They are working towards designing low solar gain pyrolytic coatings that provide better visible light transmission without compromising the solar heat gain coefficient (SHGC).

Glazing Contractors

Glazing contractors install both shop-built and site-built fenestration in nonresidential buildings. They are involved with curtain wall, storefront, and punched opening windows, but many contractors specialize in a certain fenestration type. Glazing contractors generally procure glass from local fabricators, but many also receive glass directly from coaters or PGMs on larger projects. Some of the larger glazing contractors receive glass directly from PGMs. Large national glazing contractors hold a significant share of this market. The top 50 glazing contractors hold approximately 80% of the glazing contracting market.

Some of the glazing contractors interviewed obtain frames from a framing supplier. Other glazing contractors interviewed design and manufacture their own aluminum frames. These companies are often involved with custom design work. Both methods of obtaining frames can be found in large and small contract glazing companies. Glazing systems can be either pre-assembled or assembled at the job site. The pre-assembled method is called a unitized approach and is used for repetitive curtain wall systems or projects on a tight schedule. The unitized approach is commonly used in the Pacific Northwest because the high frequency of rain makes on-site assembly less desirable.

Many glazing contractors interviewed state that they are not involved in the selection process of fenestration systems. They simply comply with the specifications given to them by the architect. Other glazing contractors feel they play a larger role. They state that architects are concerned with the look of the glass, and it is up to the glazing contractors to match the look the architect desires with acceptable performance and an affordable price.

Glazing contractors want to use products that are locally available, and the type of systems they install are dependent on what is available in a specific region. For example, thermally broken aluminum framing is commonly manufactured in the Pacific Northwest and is the standard framing system in that region. Glazing contractors seem wary of the long lead times associated with supplying glazing systems that cannot be obtained locally. Long lead times (up to 16 weeks) may not be an issue for a large curtain wall building, but can adversely affect a small storefront/retail project.

All the glazing contractors interviewed feel they work on medium- to high-end projects and generally install high performance products. They point to projects such as strip malls, retail, and fast food restaurants as projects where low-cost glass is used. The California glazing contractors interviewed also state that monolithic glass and clear IG units are often installed in California projects.

Framing Suppliers

Glazing contractors that do not manufacture their own frames will obtain frames from a framing supplier. Framing suppliers manufacture metal framing systems for curtain walls, overhead glazing, and punched openings. Storefront frames are also supplied, but to a lesser extent. Some suppliers specialize in a specific product type. Framing suppliers include approximately five large national firms and numerous smaller companies that serve specific regions. Some of the suppliers are only involved with manufacturing the frames, which they send directly to glazing contractors for installation. Other framing suppliers obtain glass from local fabricators, national coaters, or directly from PGMs, and fabricate complete fenestration systems. The framing suppliers involved with fabrication also cut and temper some of the glass they receive. If sputter-coated glass is specified, they will order the glass pre-cut and tempered from a national coater or PGM. Both the glazed and unglazed framing systems are sold to glazing contractors for installation, though framing suppliers can be involved with managing the installation.

The framing suppliers interviewed state that thermally broken frames are used on all projects that are not in California or the South. The glazing contractors interviewed, however, feel that thermally broken frames are only sometimes used on projects outside of California and the South. All the interviewees agree that projects in California or the South very rarely use thermally broken frames. The national average of thermally broken frame use is about 66%.

Window Manufacturers

Window manufactures provide completely fabricated and framed fenestration systems. They primarily supply punched opening windows and are involved with nonresidential buildings that have this type of fenestration design, such as institutional buildings, academic buildings, hotels, and high-rise condominiums. They are also involved in replacement fenestration for historically significant buildings. The majority of their market is residential projects. Nonresidential projects only make up 8%-20% of the their market.

Window manufacturers receive glass directly from PGMs, some of which is prefabricated and some of which they fabricate on-site. Most manufacture their own frames. Frames from window manufacturers can be aluminum, wood, vinyl, or wood with an aluminum or fiberglass cladding. Each window manufacturer specializes in a particular combination of these frame types.

Since window manufacturers receive a significant portion of their glazing prefabricated from the PGMs, IG units with a low-e coating and argon fill are very common. Some window manufacturers provide as much as 85% of their product with low-e coatings. Argon fill is used in most fenestration with low-e coatings because the PGMs provide the IG units that way.

One window manufacturer states that occasionally low-e coatings will be removed from a project, but feels this is rare. The manufacturer also states that occasionally architects working on historic renovations will want clear IG because they are concerned with the aesthetic look of a low-e coating, but also feels that this is fairly rare.

Appendix B – Analysis of DOE-2 Fenestration Library

An issue with the approach recommended for shop built windows is the potential for gamesmanship whereby compliance authors would model a fenestration product that performed especially well using the detailed model, and that a fenestration product would be substituted during the construction phase that has an equal to or better U-factor, SHGC and VLT, but which does not perform as well through detailed analysis.

To evaluate this potential, 173 fenestration constructions[1] were modeled in five climate zones. This creates 74,390 opportunities for the gamesmanship as described above[2]. Out of these possible opportunities for gamesmanship, there are 45 cases (only 0.06% of the cases) where a fenestration product had a better U-factor, SHGC and VLT, but TDV energy increased. These 45 cases are shown in the following table.

Table 1 – Analysis of DOE-2 Fenestration Library

This table shows the 45 substitutions, out of 74,390 possibilities, when the U-factor, SHGC and VLT were better but TDV energy increased. These cases are sorted from the largest difference to the smallest.

CZ	Basecase Fenestration	"Equivalent" Substitute Fenestration	Increase in TDV Energy
3	Triple Low-E (e5=.1) Clear	Double Tint Grey	1.63%
3	Triple Low-E (e5=.1) Clear	Double Tint Grey	1.44%
8	Triple Low-E (e5=.1) Clear	Double Tint Grey	1.21%
16	Triple Clear	Double Low-E (e3=.2) Clear	1.14%
8	Triple Low-E (e5=.1) Clear	Double Tint Grey	1.10%
14	Triple Clear	Double Low-E (e3=.2) Clear	1.00%
3	Triple Low-E (e5=.1) Clear	Double Tint Grey	1.00%
3	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.96%
12	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.96%
12	Triple Clear	Double Low-E (e3=.2) Clear	0.88%
8	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.81%
3	Triple Low-E (e2=e5=.1) Clear	Double Tint Blue	0.79%
3	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.78%
3	Triple Low-E (e2=e5=.1) Clear	Double Tint Bronze	0.70%
12	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.70%
8	Double Ref-A Tint-M	Single Ref-A Clear-L	0.65%
8	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.64%
8	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.54%
3	Triple Low-E (e2=e5=.1) Clear	Double Tint Blue	0.53%
3	Triple Low-E (e2=e5=.1) Clear	Double Tint Green	0.52%
16	Triple Clear	Double Low-E (e3=.2) Clear	0.49%
16	Triple Clear	Double Low-E (e3=.2) Clear	0.49%
3	Triple Low-E (e2=e5=.1) Clear	Double Tint Bronze	0.45%
14	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.45%
3	Triple Clear	Double Low-E (e3=.2) Clear	0.42%
3	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.39%
12	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.39%
16	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.38%

1 The DOE-2 library has more than 173 constructions, but this analysis did not consider constructions with suspended films or electrochromic products, which not common.

2 The number of possible comparisons are [(173*173)-173]/2 or 14,878 in each climate zone.

Table 1 – Analysis of DOE-2 Fenestration Library

This table shows the 45 substitutions, out of 74,390 possibilities, when the U-factor, SHGC and VLT were better but TDV energy increased. These cases are sorted from the largest difference to the smallest.

CZ	Basecase Fenestration	"Equivalent" Substitute Fenestration	Increase in TDV Energy
3	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.34%
3	Triple Low-E (e2=e5=.1) Clear	Double Tint Green	0.28%
8	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.27%
8	Triple Clear	Double Low-E (e3=.2) Clear	0.27%
8	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.24%
14	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.17%
12	Triple Low-E (e5=.1) Clear	Double Tint Bronze	0.15%
3	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.15%
8	Triple Low-E (e2=e5=.1) Clear	Double Tint Blue	0.15%
14	Triple Clear	Double Low-E (e3=.2) Clear	0.14%
14	Triple Clear	Double Low-E (e3=.2) Clear	0.14%
8	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.12%
8	Triple Low-E (e2=e5=.1) Clear	Double Tint Bronze	0.09%
12	Triple Low-E (e5=.1) Clear	Double Tint Grey	0.08%
12	Triple Clear	Double Low-E (e3=.2) Clear	0.07%
12	Triple Clear	Double Low-E (e3=.2) Clear	0.07%
8	Double Ref-C Tint-M	Single Ref-A Tint-L	0.01%