Energy Challenges related to Recladding Early Model Curtain Walls

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ABSTRACT

Fenestration systems installed in the 1970's and 1980's are often thought of as having poor energy efficient characteristics. This was a transitional period for the energy related performance characteristics of the systems. Current high performance Low E coatings that are commonly used today were not available during this time period. Instead, highly reflective coatings were utilized in order to control solar heat gain. Additionally, Insulating Glass Units (IGU's) were just beginning to be used, but it was not common practice to provide them. Many of the framing systems were not thermally broken, although some began utilizing components that increased their thermal performance. There are examples of buildings from this transitional period that utilize a combination of these practices that resulted in impressive performance for the time. However, sophisticated modeling tools used today to predict performance of the individual components, systems, and how they interacted with the building were not readily available in the past to predict or optimize performance.

When some early systems are modeled, it is sometimes found that the performance is not significantly worse that what current energy codes require. In some cases, the performance can actually be better. It is important to recognize and evaluate the performance of the original system when it requires replacement. It is very possible that poor selection of modern materials based on their assumed "high performance" can result in a system that is either no better than, or possibly worse, than the original. Whole building energy modeling can be utilized to verify that new systems will not under perform when compared to the original.

This paper provides a brief review of early fenestration system performance levels, and history of recent energy code requirements related to fenestration. This background information is provided to supplement a case study that will illustrate the concern of under estimating the performance of early fenestration systems.

The case study will explore energy and thermal performance issues and challenges related to recladding/reglazing an early 1980's building. The original system included highly reflective IGU's that provided very low solar heat gain. It also utilized a curtain wall framing system that incorporated components which resulted in an increased level of thermal performance. The system suffered from several deficiencies such as wide spread air and water infiltration and failing IGU's. Additionally, the aesthetic associated with highly reflective glazing is often no longer considered appealing to many designers and building owners. The system needed to be revitalized and modernized. The situation proved difficult to develop solutions that incorporated relatively clear glazing (to provide the desired aesthetic) using modern conventional products that would match or exceed the overall thermal performance of the original system.

This paper concludes that careful consider and evaluation must be performed when upgrading early fenestration systems that may already utilize relatively high performing components and materials.

Key Words: Curtain Wall, Total Product Thermal Performance, SHGC, Recladding, ReGlazing, Energy Modeling, Thermal Modeling.

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INTRODUCTION

Curtain wall and glazing systems installed in the 1970's and 1980's often may be thought of as having poor energy performance. This was a transitional period for fenestration systems as it relates to energy performance. Current high performance Low E coatings that are commonly used today were not available during this time period. Instead, highly reflective coatings were utilized to control solar heat gain. Additionally, Insulating Glass Units (IGU's) were just beginning to be used, but it was not common practice to provide them. Many of the framing systems were not thermally broken, although some began utilizing components that increased their thermal performance.

While these technologies were available, it was not necessarily common to put into practice, nor required by building codes of the time. This is why this timeframe can be considered a transitional period. Commonly used systems often did not necessarily perform at high levels. However, there are instances where higher performing systems were used. Why does this matter? It can be an easy mistake for a design professional to assume that these early systems suffer from poor performance. Often, this assumption is based solely on the age of the system. When these early systems are modeled, it is sometimes found that the performance is not significantly worse that what current energy codes require and, in some cases, it can actually be better.

Due to the assumption that modern materials perform better than their predecessors, it is critical to recognize and evaluate the existing system performance when considering replacement of these early systems. It is very possible that poor selection of modern materials based on their assumed "high performance" can result in a system that is either no better than the original or potentially worse. To avoid this, one should understand the recent history of fenestration development and code requirements.

Energy related issues must be viewed in a holistic manner in order to truly evaluate the performance of a system. The following factors need to be included in an evaluation.

- U-factor (Thermal transfer)
- Solar Heat Gain Coefficient (SHGC)
- Window to Wall Ratio (WWR)
- Air Leakage
- Local Climate
- Building Form / Cardinal Orientation
- Building Function / Occupant Usage

Whole building energy modeling can be utilized to evaluate all of these factors in a holistic manner based on project specific conditions.

In order to understand the risk of poor system selection, a review of early fenestration system performance levels and a history of recent energy code requirements related to fenestration is provided. This background information is provided to supplement a case study that will illustrate the concern of under estimating the performance of early fenestration systems. The case study will explore energy and thermal performance issues and challenges related to recladding/reglazing an early 1980's building.

FENESTRATION ENERGY PERFORMANCE ATTRIBUTES

U-FACTOR

The U-factor is a value that measures heat transfer through a material or system. To understand heat flow through fenestration, two components must be considered, the glazing and the framing. The combined performance of the two is often referred to as the "Total Product U-Factor". Computer thermal modeling or physical testing is required to determine the Total Product U-Factor. The thermal resistance of both the glazing and the frame will impact the Total Product performance and can be evaluated individually. However, the Total Product performance must be determined in order to accurately understand the performance of the complete system and to perform accurate whole building energy modeling.

Glazing

One of the major developments in glazing was the advent of Insulating Glass Units (IGU's). An IGU is a glazing unit that is composed of at least two panes of glass that are separated by a sealed air space. Units that utilize two panes are often referred to as double pane glass, and units that have three panes are referred to as triple pane glass. IGU's were first introduced in the 1930's. However, many commercial buildings only utilized single pane glass for several decades. It was not until, the 1970's and 1980's that IGU's began to gain traction. The most significant increase of use was during the 1980's. Even at that point many states did not have an energy code that would require its use. As a result, many buildings did not include IGU's during this transitional period.

Single pane glass does not provide much thermal resistance. The Center-of-Glass (COG) U-factor of single pane glass is approximately 1.025 Btu/h·ft^{2}·ºF (≈ R1). Much of the thermal resistance can be attributed to the interior and exterior air films. A double pane IGU has a COG U-factor of approximately 0.5 Btu/h·ft^{2}·ºF (≈ R2), a 50% decrease in heat transfer. Triple pane IGU's can produce a COG U-factor of approximately 0.3 Btu/h·ft^{2}·ºF (R3.33). The addition of Low Emissivity (Low E) coatings will improve the performance of IGU's. For example, a clear double pane IGU with a high performance Low E coating can produce a COG U-factor of 0.28 Btu/h·ft^{2}·ºF (≈ R3.5) and when included on a triple pane unit, 0.22 Btu/h·ft^{2}·ºF (≈ R4.5). The use of Argon gas in the space between panes can also further improve the performance. There is a wide range of improvement that can be expected depending on the type of Low E coating, the number of coatings used, and the type of gas used in the airspace. The values above are provided to illustrate some methods used to obtain improved performance.

Frame Types

The thermal performance of the overall fenestration system can be significantly impacted by the framing. Typically, the performance of the frame is less than the glazing. In general, less framing results in better total product performance, i.e. reduced U-factor. Far too often, only the COG value is considered when evaluating the thermal performance of fenestration, when in reality the framing can have more of an impact on the system performance. Framing systems began utilizing components that increased their thermal performance during the transitional period. In some instances, the thermal improvement was a byproduct of glazing methodology and how the system achieved its air and watertight integrity. Thermal enhancement was not necessarily the primary objective of the framing methodology.

This paper will focus on aluminum curtain wall framing systems. The thermal performance of frames can vary significantly. Aluminum is a highly conductive metal that provides little resistance to heat transfer. Most early curtain wall systems did not have any type of thermal improvement incorporated into the frame profile. For the purposes of this paper, frames without any thermal enhancements are referred to as “Non-Thermal”.

To combat the poor thermal resistance of aluminum, a material of lower thermal conductivity is often inserted between the interior and exterior frame components. This material is generically referred to as a thermal break. There are many methods to provide thermally enhanced frames. The National Fenestration Rating Council (NFRC) has developed definitions to standardize the various types of thermal enhancements. They have divided the enhancements into two major categories: thermally improved and thermally broken. NFRC 100, “Procedure for Determining Fenestration Product U-factors” provides definitions of these and also establishes procedures for testing and verification of Total Product U-Factors (**FIGURE 1**).

> ***Thermally improved (TI) members***: system members with a separation ≥ 1.60 mm (0.062 in.) separation provided by a material [where thermal conductivity ≤ 0.5 W/mK(≤ 3.6 Btu·in./h·ft2·°F)], or open air space between the interior and exterior surfaces. Such systems include members with exposed interior or exterior trim attached with clips and all skip/debridged systems.
>
> ***Thermally broken (TB) members***: system members with a minimum of 5.30 mm (0.210 in.) separation provided by a low conductance material (where thermal conductivity ≤ 0.5 W/mK (≤ 3.6 Btu·in./h·ft2·°F), or open air space between the interior and exterior surfaces. Examples of such systems include, but are not limited to, pour and de-bridged urethane systems, crimped-in-place plastic isolator systems and pressure glazed systems with intermittent fasteners.
>
> ***Thermal break***: a material of low thermal conductivity that is inserted between members of high conductivity in order to reduce the heat transfer. Thermal barrier material conductivity shall not be more than 0.52 W/mK (3.60 Btu·in./h·ft2·°F).

FIGURE 1: Definitions per NFRC 100.

As indicated by these definitions, the difference between the two types of thermally enhanced frames is primarily the thickness of the thermal break. Fenestration systems constructed from thermally broken members will provide higher thermal resistance (better performance) then those that are constructed from thermally improved members. In **FIGURE 2**, THERM© 5.2 computer models illustrate the difference between basic non-thermal, thermally improved, and thermally broken framing systems. The models represent generic framing systems that are not specific to a particular manufacturer.

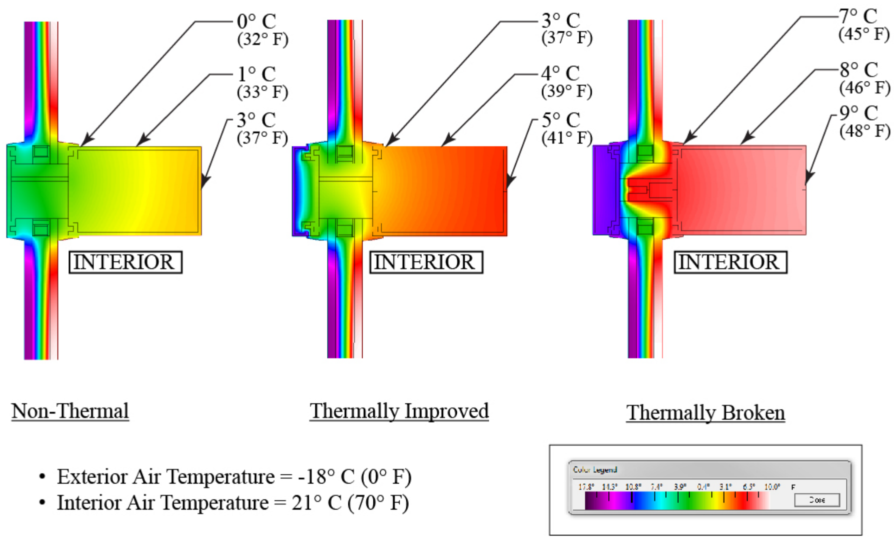


FIGURE 2: THERM 5.2 Thermal models of various curtain wall frames.

The interior temperatures of the Thermally Improved frame are higher than the Non-Thermal Frame, and the interior temperatures of the Thermally Broken Frame are higher than the Thermally Improved frame. This is directly related to the U-factor as well. As the U-factor of the system lowers, less heat is transferred through the system which results in higher interior surface temperatures. The Total Product U-factor of the three systems illustrated in **FIGURE 2** is provided below. They are based on the NFRC 100 standard size of 78-3/4 inches x 78-3/4 inches and include a clear double pane IGU with a high performance Low E coating on the number two surface which has a COG U-Factor of 0.28 Btu/h·ft^2·ºF.

- Non-Thermal Total Product U-Factor ≈ 0.55 Btu/h·ft^2·ºF
- Thermally Improved Total Product U-Factor ≈ 0.49 Btu/h·ft^2·ºF
- Thermally Broken Total Product U-Factor ≈ 0.45 Btu/h·ft^2·ºF

The Total Product U-Factor can also be impacted by the method in which the glazing is secured to the framing. For example, a curtain wall system that is captured on all four sides will have a different U-Factor than a similar structural sealant glazed (SSG) system. The following represents approximate Total Product U-Factors for a typical pressure wall curtain wall system and a SSG system.

- Captured Total Product U-Factor ≈ 0.45 Btu/h·ft^2·ºF
- SSG Total Product U-Factor ≈ 0.38 Btu/h·ft^2·ºF

Frame Configuration

The configuration of the curtain wall framing also has an impact on the Total Product U-factor. Lower ratios of glass in relation to the framing will produce higher Total Product U-Factors. Basically, more framing equals lower performance. **FIGURE 3** illustrates three different glass to frame ratios of the same curtain wall system, a four sided capture pressure wall system.

- 95% Glass to Frame Ratio
  - Frame Configuration = 10 ft by 7 ft
  - COG U-Factor = 0.28 Btu/h·ft^2·ºF
  - Total Product U-Factor ≈ 0.35 Btu/h·ft^2·ºF

- 89% Glass to Frame Ratio
  - Frame Configuration (NFRC 100 Standard Size)= 6 ft 6-3/4 in. x 6 ft 6-3/4 in. (78-3/4 in. x 78-3/4 in.)
  - COG U-Factor = 0.28 Btu/h·ft^2·ºF
  - Total Product U-Factor ≈ 0.45 Btu/h·ft^2·ºF

- 87% Glass to Frame Ratio
  - Frame Configuration = 2 ft by 7 ft
  - COG U-Factor = 0.28 Btu/h·ft^2·ºF
  - Total Product U-Factor ≈ 0.50 Btu/h·ft^2·ºF

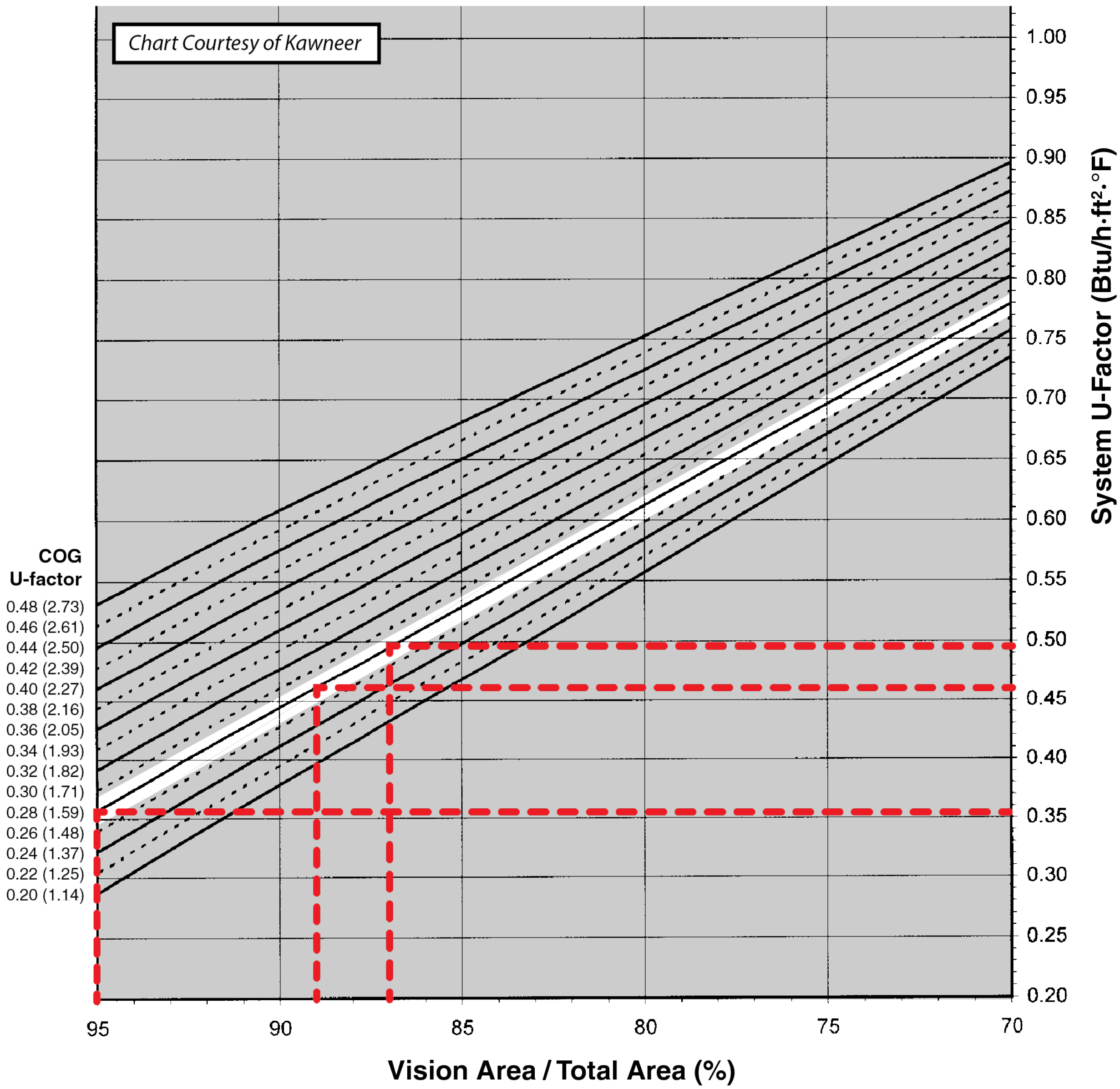


FIGURE 3: Total Product U-Factors of three Glass to Frame Ratios.

This reduction in performance is not unique to the vision portion of a fenestration system. Opaque insulated spandrels are also impacted by the frame type and size. **FIGURE 4** illustrates the significant loss of performance of a four sided captured curtain wall system based on two different frame configurations. The spandrel insulation is installed in a traditional manner, in-filled between the framing.

- 95% Panel to Frame Ratio
  - Frame Configuration = 10 ft by 7 ft
  - COP R-Value = R16
  - Total Product U-Factor ≈ 0.11 Btu/h·ft^2·°F (≈9.1)

- 87% Panel to Frame Ratio
  - Frame Configuration = 2 ft by 7 ft
  - COP R-Value = R16
  - Total Product U-Factor ≈ 0.19 Btu/h·ft^2·°F (≈R5.3)

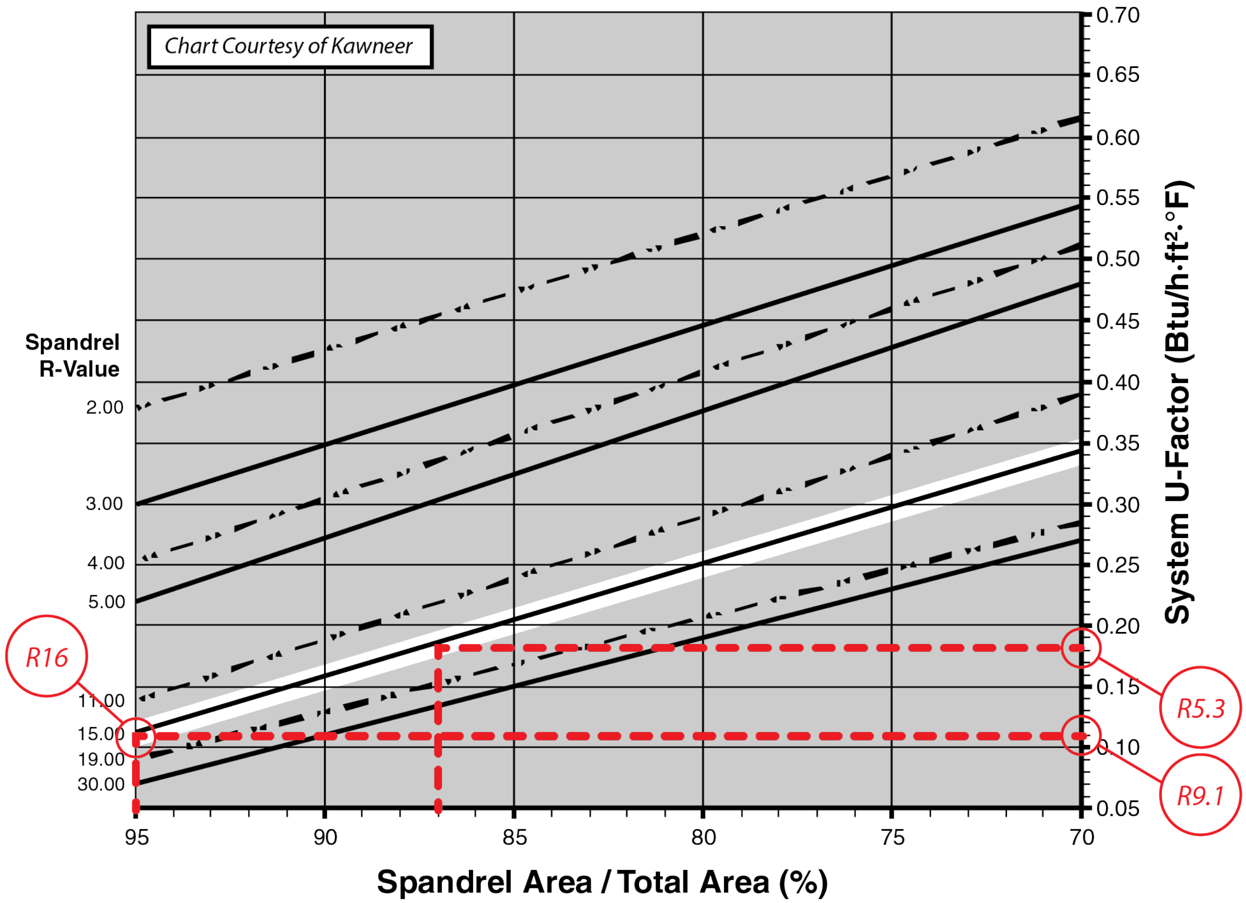


FIGURE 4: Total Product U-Factors of two Panel to Frame Ratios

As indicated, the total product thermal performance is significantly degraded by the framing. This is not unique to this particular curtain wall system. Other curtain wall systems where the insulation is installed between the framing will perform similarly. This is an important point to consider. Far too often, the COP thermal performance is used when performing whole building energy modeling. The Total Product Thermal Performance for both the vision and spandrel must be understood, determined, and utilized when performing whole building energy models in order to provide accurate results.

SOLAR HEAT GAIN COEFFICIENT (SHGC)

The SHGC is the fraction of solar radiation that enters a space through the fenestration system by direct transmission and by inward re-radiation of absorbed heat. IGU's help control thermal transfer due to conduction, the U-factor. However, without specialty coatings, they will not have much impact on solar heat gain. High performance Low E coatings commonly utilized today to control solar loading were not available during the transitional period.

For many years, tinted glass was the primary method available to reduce solar loading for early fenestration systems. To aide in blocking the solar heat gain without the need for tinted glass, coatings began to be developed and introduced in the 1960's. The coatings are produced by fusing thin metallic layers onto the glass surface. They often provided very low SHGC values, typically below 0.20 and potentially below 0.10. These coatings are not the relatively clear Low E coatings that are common in modern construction. While they produced high performance, they also came with high exterior reflectance and limited visible light transmittance (VLT). This type of coating is often not desired from an aesthetic and human comfort perspective.

Low E Coatings

In order to combat the aesthetic and low VLT issues, a new type of coating called Low E was developed. These coatings are much clearer when compared the earlier highly reflective coatings. Pyrolytic Low E coatings, also known as "hard coats", started to be introduced in the 1970's. Pyrolytic coatings are ultra-thin metalized coatings that are fused to the surface of the glass. They provided reduced SHGC's when compared to clear IGU's, but not as low as the highly reflective coatings. The SHGC of pyrolytic coatings is in a general range of 0.5 to 0.7. This value is highly dependent on the coating and tint of the glass substrate. While better than clear IGU's, the performance is still inferior to highly reflective coating.

In the late 1980's, a new technology was developed to produce Low E coatings. Magnetic Vacuum Sputter Deposition produced coatings with lower SHGC's than the Pyrolytic's. They also provided higher visible light transmittance and even lower reflectance. These coatings are commonly referred to as Sputter Coats or as "soft coats". The development of soft coat Low E coatings continues to this day. There are hybrid coatings, often referred to as semi-reflective Low E coatings. These coatings have a higher reflectivity than standard soft coat Low E's, but they also drive down the SHGC even further. The goal is to create an IGU with very low SHGC, high VLT, and clearest appearance. The SHGC for soft coats has an even wider range due to wide variety of types and glass substrates. However, assuming the coating is on a clear substrate, the SHGC can range from 0.2 to 0.6. To date, there are still no clear Low E coatings that will limit solar gain as well as highly reflective coatings when applied to clear substrates.

Note, both Low E coating technologies will also increase the thermal performance of an IGU via conduction (lower U-Factors). Soft coat technologies will produce the best IGU U-factors when compared to reflective and hard coats.

Impacts of the Window to Wall Ratio (WWR)
As indicated, Low E coatings cannot provide the low levels of SHGC that are inherent to highly reflective coatings. This is critically important for buildings that have a high window to wall ratio (WWR). The WWR is the ratio of the amount of vision glazing on a building compared to the amount of opaque wall. Buildings with a low WWR, can tolerate glazing that has a higher SHGC as there is less area exposed to the solar load. On the other hand, a lower SHGC is more important on buildings with a high WWR as there is much more glazing that can impact the overall energy performance of the building.

WWR calculations typically are not specific to the individual elevations of a building. The calculation generally combines the amount of vision and opaque portions of the wall from all elevations into one total sum. However, the cardinal direction of the glazing must be considered in order to truly understand the energy related impact. It is very possible that certain elevations are not actually exposed to the sun. For these conditions, the SHGC is not as critical. A building may have a high WWR but with little of the vision glass exposed to direct sunlight. In this case, the U-factor becomes much more critical. On the other hand if the majority of the vision glazing is exposed to the sun, then the SHGC is likely the more critical performance metric to consider. This notion begins to address directional specific glazing, where different types of glazing are utilized on different elevations. This is not a new design concept. However, it is often not considered on many projects.

Climate
The climate in which a building is located can have a significant impact on the selection of the glazing's SHGC. A glazing unit with a low SHGC is certainly most critical for buildings located in cooling dominated climates such as the mid and southern regions in the USA. In heating climates, units with a higher SHGC can be beneficial as the additional solar load can reduce the amount of manmade heat.

It is easy to assume that in a cooling climate, units with a very low SHGC should be used. However, there may be an instance where there is a limited amount of glazing or the glazing may be protected from the sun in some fashion. If either of these is the case, than the SHGC may not be critical. Similar issues need to be considered in heating climates. If a building has a significant amount of glazing without any protection, then higher SHGC may no longer be of benefit. Even buildings located in a heating climate may still have a cooling dominated portion of the year where a low SHGC is beneficial. The cooling demand due to the solar load in the summer may offset the benefit gained in the winter months in buildings with a high WWR.

Cloud cover can also have an impact on the SHGC selection. There may be areas that are perceived to be in a cooling dominated zone, but may experience a high percentage of time with cloud cover that will reduce the solar load. Similarly, the argument that higher SHGC is beneficial in heating climates may not really matter if there is a high percentage of cloud cover during winter months in a particular locale. The WWR must also be evaluated based on the climate. Again, depending on cloud cover the WWR may or may not have a significant impact in the overall performance when evaluating the SHGC. However, the WWR may still have a significant impact based on the U-Factor of the glazing. For example, a building in a heating climate with a high WWR may suffer more from thermal transfer in the winter regardless of the yearly SHGC impact.

PERFORMANCE ATTRIBUTE DETERMINATION

The issue of determining optimum values for the SHGC and U-factor must be evaluated in a holistic manner. Each project should be handled on a case by case basis that considers all aspects of the building and climate throughout an entire year. Sophisticated whole building energy modeling tools are available today that can be used to assist in determining the appropriate values for a project specific application. These modeling tools typically include the impact of climatic conditions, orientation, and elevation specific performance metrics. However, other factors such as building type, building function/use, and mechanical system selection will also have an impact on the results of the model. In some cases, these other factors can completely override any benefit of high performance fenestration systems. While these energy modeling tools are becoming easier to use and apply, far too often performance values are applied to project in a sweeping manner without performing a comprehensive analysis.

AIR LEAKAGE

Historically, air leakage in fenestration systems was not a primary driver in their design and construction. They were generally produced in a relatively airtight manner as leaky or drafty fenestration systems are certainly not desirable. However, similar to the U-factor of the frames, air leakage of early systems was not commonly measured and tested as it is today. Similarly, the ability of a fenestration system to resist air leakage was often a byproduct of making the system watertight.

Modern fenestration systems are tested to determine the expected air leakage. Many modern systems will meet an air leakage rate of 0.06 cfm/sf when tested at pressures between 1.57 psf and 6.24psf. This was not necessarily the case for earlier systems. Many early fenestration systems were not tested for air leakage.

It is also common to find deficiencies in early fenestration products that would lead to much worse air leakage than what we expect from today’s systems. In particular, sealant and gasket technologies that were common for the time were not as robust as materials that are available today. It is common to find failed sealants and gaskets that have shrunk over time in early systems. Both of these issues will lead to significantly higher air leakage rates.

ENERGY CODES AND STANDARDS

The introduction of an energy code is a relatively recent development in the history of buildings in the United States. In the 1970’s, energy codes were just beginning to be developed, and in many locations they were not required during the transitional period. Many jurisdictions adopt either ASHRAE Standard 90.1 “Energy Standard for Buildings Except Low-Rise Residential Buildings” or the International Energy Conservation Code (IECC) as the required commercial energy code, both with similar requirements.

The original version of ASHRAE Standard 90, “Energy Conservation in New Building Design”, was first published in 1975 as a response to the energy crisis. However, it was not necessarily adopted as code for several years. The standard was updated in 1980, but was not updated again until 1989. This version of the standard became codified as part of the 1998 IECC. In 1999 a complete revision to the standard was issued and it has been on regular maintenance since that point with new versions in 2001, 2004, 2007, 2010, and 2013. These standards lead to companion IECC codes of 2003, 2006, 2009, and 2012. The documents provide multiple compliance paths: prescriptive, trade-off, and whole building energy modeling. This paper is limited to discussion of the prescriptive path of ASHRAE 90.1 related to fixed glazing.

The requirements related to fenestration have gone through changes throughout the developmental stages of the standard. Variations on the requirements related to U-Factor, SHGC, WWR, and air tightness all have changed in some fashion. The requirements are also dependent on the type of fenestration product. Categories have varied over the development but typically have included non-metal framing, metal framing of curtain wall or storefront, metal framed entrance doors, and metal framing (all others). The requirements are also dependent on location specific climatic conditions and are divided into seven climate zones. To illustrate the changes throughout the development of the codes, **FIGURE 5** summarizes the prescriptive requirements related to metal framed curtain walls for ASHRAE 90.1 in Climate Zone 5.

		U-Factor	SHGC		WWR	Air Tightness
ASHRAE 90 / 90.1	1975	*Note 1*	*Note 2*		*Note 1*	NR for Fixed
	1980	*Note 1*	*Note 2*		*Note 1*	NR for Fixed
	1989[Note3]	0.0 - 0.68	0.0 - 0.87		19% - 59%	0.15 cfm/sf
	1999[Note4]	0.46 - 0.57	0.26 - 0.49$_{WSE}$	0.36 - 0.49$_{N}$	0% - 50%	0.4 cfm/sf
	2001[Note4]	0.46 - 0.57	0.26 - 0.49$_{WSE}$	0.36 - 0.49$_{N}$	0% - 50%	0.4 cfm/sf
	2004[Note4]	0.46 - 0.57	0.26 - 0.49$_{WSE}$	0.36 - 0.49$_{N}$	0% - 50%	0.4 cfm/sf
	2007	0.45	0.4		<40%	0.4 cfm/sf
	2010	0.45	0.4		<40%	0.06 cfm/sf

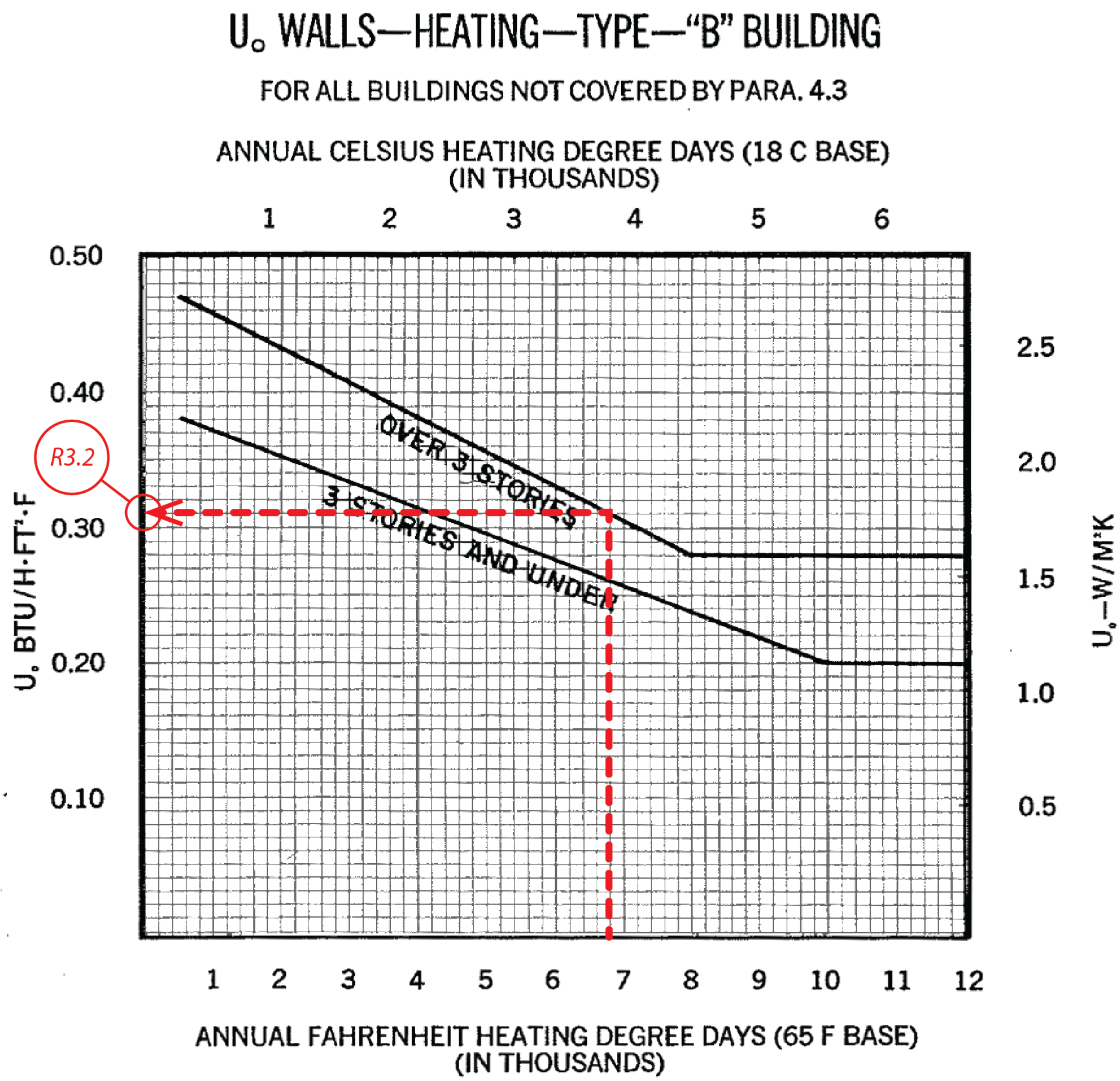
Note 1: An Average Thermal Transmittance value that includes ratio of thermal transmittance of opaque wall and fenestration based on climate specific Heating Degree Days. The value essentially incorporates the WWR, as the result is dependent on the amount of fenestration in relation to the amount of opaque wall. There is no direct comparison to the current code fenestration U-Factor requirement. Refer to ***FIGURE 6*** *for an example.*

Note 2: The SHGC is not directly prescribed. Instead it, along with many other performance values, is used to determine a Solar Factor. The allowable Solar Factor for a building is also based on the climate specific latitude that a building is located. There is no direct comparison to the current code SHGC requirement.

Note 3: ASHRAE 90.1 1989 contains a prescriptive performance method that is heavily dependent on the performance of the fenestration used in the design. Basically, the allowable WWR is determined by the internal load density of the building, projection factor, shading coefficient, and U-Factor of the selected fenestration system. As the performance of the U-Factor and SHGC of selected fenestration decreases, the allowable WWR decreases, and vice versa. Refer to ***FIGURE 8*** *for an example.*

Note 4: Requirements vary per every 10% increase in WWR. As the WWR increases, the required performance increases as well.

FIGURE 5: Summary of prescriptive requirements related to metal framed curtain walls for ASHRAE 90.1 in Climate Zone 5.



Note: *The red dashed line indicates the Average Thermal Transmittance Value (≈ 0.31 Btu/h·ft2·ºF, or an R3.2) that includes the thermal transmittance ratio of opaque walls and fenestration based on climate specific Heating Degree Days (Heating Degree Days similar to Climate Zone 5). If one were to average the code prescribed thermal performance requirements for opaque walls, fenestration, and WWR from 2010 ASHRAE 90.1, the results would not be much better than what was originally recommended in the 1975 version. Refer to **FIGURE 7** for the resultant Average Thermal Transmittance based on 2010 prescriptive requirements.*

FIGURE 6: 1975 ASHRAE 90 - Average Thermal Transmittance Value based on specific Heating Degree Days.

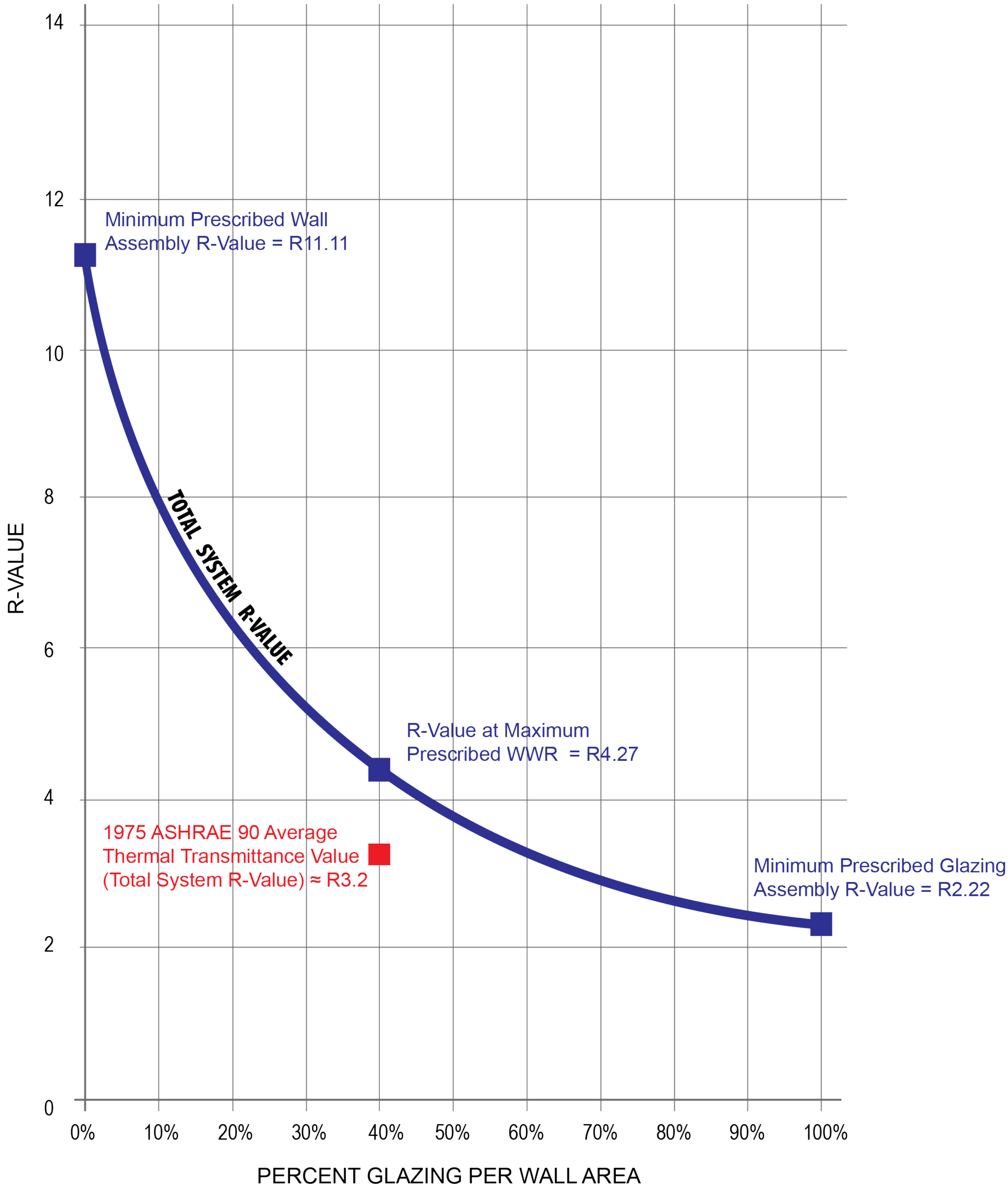


FIGURE 7: 2010 ASHRAE 90.1 – Prescriptive opaque wall and fenestration requirements at maximum allowed 40% WWR which results in an average thermal transmittance of approximately R4.27, only R1.07 better than the 1975 recommendation of R3.2.

ALTERNATE COMPONENT PACKAGES FOR: TABLE NUMBER: 8A- 26

HDD50 =	2601 - 3200	Omaha NE	Moline IL	Providence RI	Youngstown OH
CDD65 =	501 - 1150	Chicago IL	Fort Wayne IN	South Bend IN	
VSEW =	560 - 845	Burlington IA	Hartford CT	Akron OH	
		Indianapolis IN	Toledo OH	Avoca (Scranton) PA	
		Detroit MI	Allentown PA	Pittsburgh PA	

FENESTRATION (Max. Pct. Fenestr.)

INTERNAL LOAD DENSITY (ILD) RANGE	PROJECTION FACTOR (PF) RANGE	SHADING COEFF RANGE (SCx)	BASE CASE Uof 0.68 to 0.46	BASE CASE Uof 0.45 to 0.39	BASE CASE Uof 0.38 to 0	PERIMETER DAYLIGHTING Uof 0.68 to 0.46	PERIMETER DAYLIGHTING Uof 0.45 to 0	PERIMETER DAYLIGHTING Uof 0.38 to 0 (VLT>=SC)
0 - 1.50	0.000 - 0.249	1.000 - 0.71	22	25	27	23	27	28
		0.709 - 0.60	25	30	32	25	32	34
		0.599 - 0.50	27	34	37	27	35	38
		0.499 - 0.38	29	38	42	30	39	44
		0.379 - 0.25	32	45	50	32	45	51
		0.249 - 0.00	36	53	62	36	53	62
	0.250 - 0.499	1.000 - 0.71	28	35	37	28	36	40
		0.709 - 0.60	31	40	44	31	41	46
		0.599 - 0.50	33	44	49	32	45	51
		0.499 - 0.38	34	48	54	34	49	56
		0.379 - 0.25	37	54	62	36	54	63
	0.500 +	1.000 - 0.71	32	48	47	32	44	49
		0.709 - 0.60	34	48	53	34	48	56
		0.599 - 0.50	36	52	59	35	52	60
		0.499 - 0.38	37	55	64	37	55	64
1.51 - 3.00	0.000 - 0.249	1.000 - 0.71	19	22	22	23	27	29
		0.709 - 0.60	23	[illegible]	27	26	32	35
		0.599 - 0.50	25	30	31	29	36	40
		0.499 - 0.38	28	34	37	31	41	45
		0.379 - 0.25	32	41	45	34	47	54
		0.249 - 0.00	37	52	59	39	56	66
	0.250 - 0.499	1.000 - 0.71	25	30	31	29	37	40
		0.709 - 0.60	29	35	38	32	42	47
		0.599 - 0.50	31	40	43	34	46	53
		0.499 - 0.38	34	44	49	36	50	59
		0.379 - 0.25	37	52	58	39	56	66
	0.500 +	1.000 - 0.71	30	38	40	33	44	50
		0.709 - 0.60	33	43	47	36	50	58
		0.599 - 0.50	36	48	53	37	53	63
		0.499 - 0.38	38	52	59	39	57	67
3.01 - 3.50	0.000 - 0.249	1.000 - 0.71	18	19	20	23	27	28
		0.709 - 0.60	21	23	24	26	32	34
		0.599 - 0.50	23	27	28	28	36	39
		0.499 - 0.38	26	31	33	31	40	45
		0.379 - 0.25	30	38	41	34	46	53
		0.249 - 0.00	36	48	54	38	55	66
	0.250 - 0.499	1.000 - 0.71	23	27	28	28	36	39
		0.709 - 0.60	26	32	34	31	41	47
		0.599 - 0.50	29	36	39	33	45	52
		0.499 - 0.38	32	41	44	35	49	58
		0.379 - 0.25	35	48	53	38	55	65
	0.500 +	1.000 - 0.71	28	34	36	32	43	50
		0.709 - 0.60	31	39	42	35	48	57
		0.599 - 0.50	33	44	48	36	52	62
		0.499 - 0.38	36	48	54	38	56	67

Daylight Sensing Controls

OPAQUE WALL (Max. Uow)

LIGHT WEIGHT WALL / MASS WALL

ILD 0 - 1.50:

Uow (HC<5)	HC RANGE	PCT FEN	INT INS	EXT INS
0.082	HC >= 5	22	0.085	0.10
	HC >= 10	22	0.091	0.11
	HC >= 15	22	0.095	0.11
	HC >= 5	64	0.085	0.098
	HC >= 10	64	0.089	0.10
	HC >= 15	64	0.092	0.10

ILD 1.51 - 3.00:

Uow (HC<5)	HC RANGE	PCT FEN	INT INS	EXT INS
0.082	HC >= 5	19	0.086	0.10
	HC >= 10	19	0.093	0.12
	HC >= 15	19	0.10	0.12
	HC >= 5	67	0.085	0.10
	HC >= 10	67	0.090	0.11
	HC >= 15	67	0.094	0.11

ILD 3.01 - 3.50:

Uow (HC<5)	HC RANGE	PCT FEN	INT INS	EXT INS
0.082	HC >= 5	18	0.086	0.11
	HC >= 10	18	0.094	0.12
	HC >= 15	18	0.10	0.13
	HC >= 5	67	0.085	0.10
	HC >= 10	67	0.090	0.11
	HC >= 15	67	0.095	0.11

OTHER CRITERIA

Minimum R-Value				Max Uo	
WALL BELOW GRADE:	10			ROOF:	0.053
UNHEATED SLAB ON GRADE:	24"	36"	48"	WALL ADJACENT TO UNCOND SPACE:	0.13
Horizontal	17	14	11	FLOOR OVER UNCOND. SPACE:	0.048
Vertical	8	6	4		

FIGURE 8: 1989 ASHRAE 90.1 - Example of a building in a location similar to Climate Zone 5 that has a fenestration U-Factor of 0.39 – 0.45, an Internal Load Density of 1.51 - 3.00, a Projection Factor of 0.0 to 0.25, and a SHGC of 0.25 to 0.379. Based on these selections, the maximum allowable WWR results in 41%. This is very comparable with many recent versions of the standard.

As indicated, there have only been relatively minor changes in the prescriptive performance values related to fenestration in the past thirty five years. The U-Factor has only changed from 0.68 to 0.45 and the SHGC has varied from 0.26 to 0.49, both depending on the orientation and WWR. The WWR has fluctuated from between being variable, to restricting it to 40%. The air leakage requirements have fluctuated significantly and only recently has there been a significant increase in air leakage performance requirements. There is a real need to review the requirements and demand more from fenestration systems.

DISCUSSION

Why is understanding the history of performance and energy codes important?

Buildings today are designed based on the idea that modern systems perform better than their predecessors. However, as indicated, there were systems available and used in the 1970's and 1980's that performed as good, or better, than modern systems.

When considering replacement of early fenestration systems it is important to recognize and evaluate the original system's performance. A design professional can wrongly assume that early fenestration systems suffer from poor performance based solely on the age of the system. This is not surprising as it was not necessarily required or common to utilize high performance systems during this era.

Fenestration systems installed in the early 1980's are already over 30 years old and we are in a period of time in which many of these systems are in need of repair or replacement. Unfortunately, many modern systems that are commonly used are no better than some of the early model systems. When designing new systems to replace the existing, it is very possible that poor selection of modern materials based on their assumed "high performance" can result in a system that is either no better, or possibly even worse, than the original.

Great care and evaluation must be taken when rehabilitating transitional systems to prevent selection of new systems that are inferior to the original. Whole building energy modeling can be utilized to evaluate the performance in a holistic manner based on project specific conditions. If adequate evaluation is not performed, replacement systems can actually result in an owner paying more for their energy usage after the remediation is complete than they did with the original system.

The following case study explores issues and challenges related to recladding/reglazing an early 1980's building.

CASE STUDY

The following case study will explore energy and thermal performance issues and challenges related to recladding/reglazing an early 1980’s university office/classroom building located in southeast Michigan. The building was designed in the mid to late 1970’s and constructed in 1980. It utilized multiple types of fenestration systems including punched windows, storefronts, skylight/atrium, and curtain wall (**FIGURE 9**). The curtain wall system was the most prevalent system and is the focus of this case study.

The original system included highly reflective IGU’s that provided very low solar heat gain. It also utilized a curtain wall framing system that incorporated components which resulted in an increased level of thermal performance. The system suffered from several deficiencies such as wide spread air and water infiltration and failing IGU’s. Additionally, the aesthetic associated with highly reflective glazing is often no longer considered appealing to many designers and building owners. The system needed to be revitalized and modernized. The situation proved difficult to develop solutions that incorporated relatively clear glazing (to provide the desired aesthetic) using modern conventional products that would match or exceed the overall thermal performance of the original system.

FIGURE 9: 1980’s university office/classroom building with highly reflective glazing.

EXISTING SYSTEM DESCRIPTION

Curtain Wall Frame

The existing curtain wall system was an aluminum pressure wall system that was very similar to many pressure wall systems that are commonly used today. The primary difference between the existing and modern systems was the thickness of the material that is used to isolate the exterior pressure plate from the structural mullion. The existing isolator was approximately ⅛ inch thick, where as many current systems are approximately ¼ inch thick. The original isolator enhanced the thermal performance of the system, but it is not considered a true thermally broken frame per NFRC definitions due to the thickness of the isolator.
FIGURE 10 illustrates the typical original curtain wall mullion.

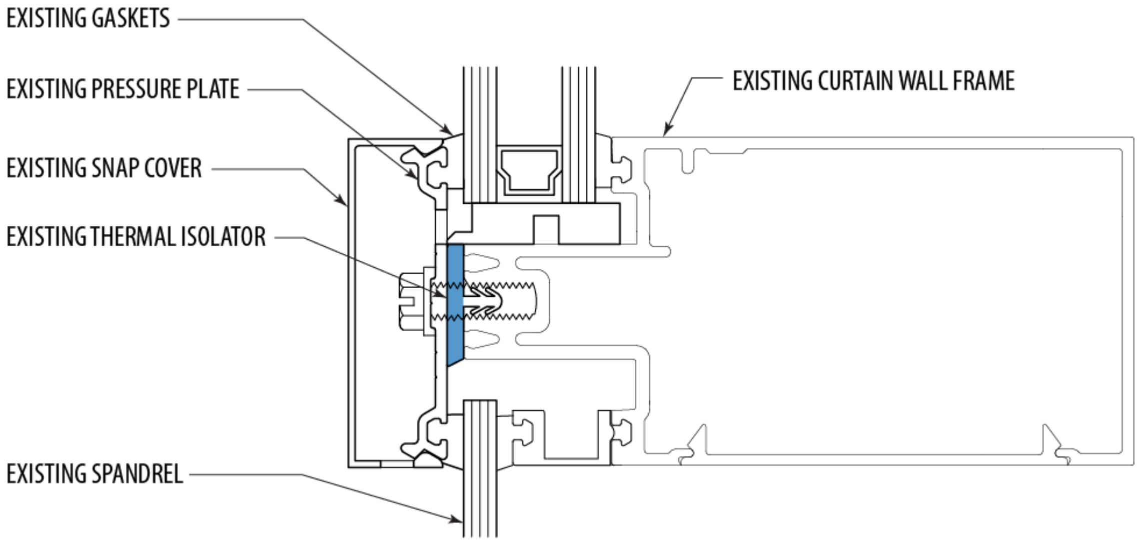


FIGURE 10: Typical existing curtain wall mullion.

Glazing
The vision glass was a double pane IGU with a highly reflective coating on the number two surface. The individual lites were ¼ inch thick with a ½ inch airspace. The exact properties of the existing glass type were not able to be determined. However, the Owner indicated that failed or broken units were replaced with IGU's that incorporated, a stainless steel reflective coating, to provide a matching appearance. For the purposes of the evaluation, the performance properties of this unit was assumed as the baseline for future comparison. The Visible Light Transmittance (VLT) of the unit was only 8% which allowed little natural light into the building. However, they provided a moderate COG U-factor of 0.38 Btu/h·ft^2·°F (≈ R2.6), and control solar heat gain extremely well with a SHGC of 0.13.

Spandrel
The spandrel area of the system was glazed with ¼ inch thick opaque reflective glass to match the vision units. Foil-faced semi rigid fiberglass insulation, 3 inches thick, was installed between the mullions behind the glazing.

Vents
Roller vents were installed directly below the vision units and can be seen as the red horizontal stripe in **FIGURE 9**. The roller vents were abandoned several years ago, and a 1 inch thick insulated metal panel was installed on the interior side, covering the units (**FIGURES 11 - 12**).

FIGURE 11: Roller Vent.

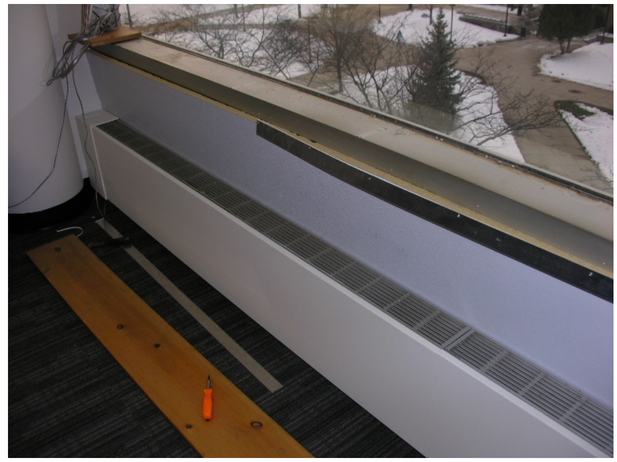


FIGURE 12: Metal panel covering roller vent.

Condition of the Existing System

The building experienced significant and persistent water and air leakage for several years. An evaluation was performed to determine the condition of the curtain wall system and to provide recommendations for corrective measures. Observations of the systems were made from the interior and exterior. Glazing units at the vision and spandrel were removed to observe the condition of the internal components of the system.

Several issues related to the curtain wall system were identified. Some of the issues observed can be directly linked to the air and water leakage of the system. However, there were several other issues identified that demonstrate the systems aging condition.

The following is an abbreviated list of observed items that were contributing to the air and water leakage (**FIGURES 13 – 18**).

- Failed seals at transitions to adjacent enclosure systems.
- Deteriorated and failed glazing sealants, gaskets, and tapes.
- Glazing gaskets that have shrunk.
- Loose, displaced, and missing glazing gaskets.
- Damaged and deteriorated internal sealants.
- Blocked weep holes
- Lack of end dams at sill flashing.
- Roller vents fixed in open position.
- Damaged, displaced, and missing snap covers.
- Unsealed insulation at spandrel and roller vents.

The leakage experienced was primarily due to the condition of the air and water resistant components of the curtain wall. As with all construction materials and assemblies, the original system and its components have a limited life expectancy. In this case, materials critical to maintaining air and water tight performance became degraded to the point that they could no longer serve their primary purpose. Their serviceable life expectancy was exceeded, and corrective measures were required throughout the system to stop the leakage.

FIGURE 13: Deteriorated seals and gaskets.

FIGURE 14: Failed sealants.

FIGURE 15: Failed internal sealants.

FIGURE 16: Water staining, back of spandrel.

FIGURE 17: Unsealed insulation.

FIGURE 18: Deteriorated glazing tape.

OPTIONS FOR CORRECTIVE MEASURES

Several corrective measures were developed to provide the Owner options that varied in cost, performance, and complexity. In order of complexity and cost, the options provided for consideration were as follows:

OPTION 1: Completely over-seal the curtain wall, essentially creating a barrier wall. This option did allow for upgrading of the system. This option would be the least expensive, but is not considered a long term repair.

OPTION 2: Refurbish existing curtain wall. Remove existing glazing and replace with new glazing, sealants, and gaskets to match existing appearance or to provide a new appearance. This option has a moderate cost, but requires significant effort to clean and prepare the existing curtain wall framing.

OPTION 3: Complete replacement of the curtain wall to provide a new appearance. This option is the most expensive, and can cause the most disruption to the building occupants. However, this option provides a complete restart of the systems life expectancy.

The options were discussed with the Owner and it was clear that they desired a new appearance but did not want to completely remove and replace the existing curtain wall. This decision pointed to Option 2. However, the primary difficulty with this direction is that the existing curtain wall system remains in place. Significant effort is required to clean and prepare the existing system in order to ensure adequate bond of new sealants. If the substrates are not cleaned appropriately, there is a risk that new sealants would not be chemically or adhesively compatible with the existing substrates.

In order to avoid the extensive effort required to clean and prepare the existing curtain wall framing, a method to reuse the existing structural mullions was developed that allowed for several variations of exterior cladding to be explored, basically, a hybrid of Options 2 and 3. It included the use of a custom veneer pressure wall system. The existing snap covers, pressure plates, glazing, gaskets, sealants, insulation, and vents were all removed. The new veneer system was installed over the tongue of the existing system (**FIGURE 19).** Limited cleaning of the existing substrates was required since the new extrusion covered the area where old sealants were present.

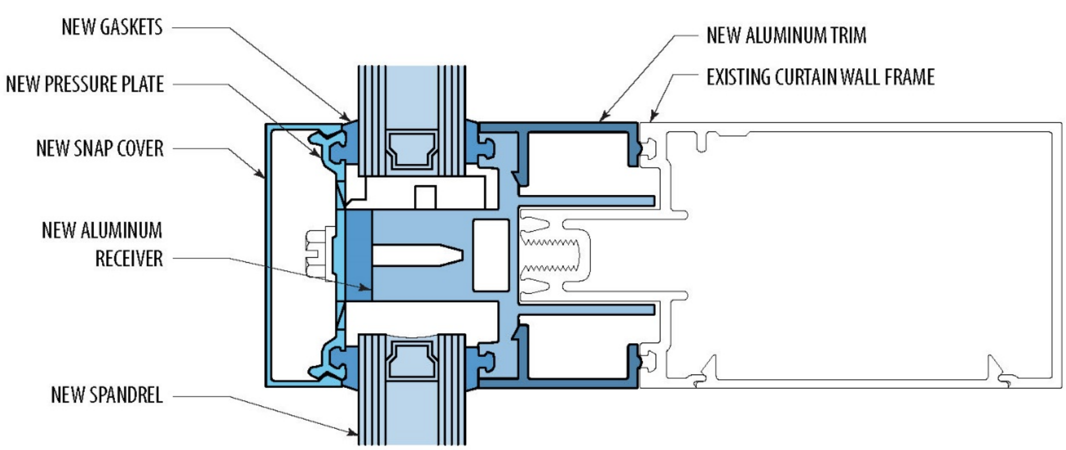


FIGURE 19: New pressure wall veneer system applied over existing curtain wall mullion.

THE CHALLENGE
As previously indicated, the aesthetic associated with highly reflective glazing is often no longer considered appealing to many designers and building owners. The Owner of this facility specifically wanted to eliminate the dated appearance caused by the reflective glazing. They wanted a more modern transparent (clear) appearance. In order to achieve the Owner's aesthetic goals, the final design included relatively clear glazing at the vision units, translucent glazing at the vent location, and metal composite material at the spandrel (**Figure 20**).

FIGURE 20: Initial rendering of the selected design.

The primary challenge with this project was ensuring the new system would not increase the yearly energy load of the building and not exceed the existing cooling capacity.

Why would this happen? Surely with 30 years of advancements in the fenestration industry, it would not be possible to provide a system that would perform worse than the original?

On the contrary, the existing system had quite impressive performance characteristics for the time, especially its ability to reject the solar load. The new clear appearance is not nearly as efficient at blocking the heat gain. The amount that was previously being rejected by the highly reflective glazing is not easily achieved when using relatively clear glazing, even with new Low E coating technologies. This is an important consideration with regard to occupant comfort, energy conservation, and the capacity of the existing heating and cooling systems of the building. On the other hand, the new clear appearance provides additional heat gain in the winter months when it can be beneficial.

In order to counter the solar gain and not increase the energy load of the building, a combination of increased spandrel insulation, improved IGU U-factor, shading devises, and improved curtain wall framing all had to be incorporated into the design.

How would one know how much offset is needed? The answer is through a process of comparative energy modeling. In this case, energy modeling software Trane Trace 700 was utilized to provide confidence that the new design would not perform any worse than the existing.

The first step in the design process was to identify the performance values of the existing system. Due to the age of the existing materials, the actual performance values could not be obtained. In order to err on the conservative side, modern material values were used during the design evaluation and energy modeling. Once the values were determined, a baseline energy model was performed. The result of the baseline energy model produced an energy usage benchmark that was used to compare and contrast the impacts of new design options.

EXISTING SYSTEM PERFORMANCE VALUES

- **Vision Units** (1 inch Reflective IGU)
  - SHGC: 0.13.
  - COG U-Factor = 0.39 /h·ft^2·ºF.
  - Glazing to Framing Ratio = 94%.
  - Total Product U-Factor = 0.46 Btu/h·ft^2·ºF.
  - Refer to **FIGURE 21** for Total Product U-Factor based on Kawneer Data.

- **Spandrel** (3” Semi-rigid Fiberglass)
  - COP U-Factor: 0.0833 Btu/h·ft^2·ºF (≈ R12)
  - Spandrel to Framing Ratio = 92%
  - Total Product U-Factor = 0.16 Btu/h·ft^2·ºF (≈ R6.25)
  - 50% reduction due to framing.
  - Refer to **FIGURE 22** for Total Product U-Factor based on Kawneer Data.

- **Roller Vents** (1” Insulated Metal Panel)
  - COP U-Factor: 0.2 Btu/h·ft^2·ºF (≈ R5).
  - Vent to Framing Ratio = 80%.
  - Total Product U-Factor = 0.37 Btu/h·ft^2·ºF (≈ R2.7).
  - 80% reduction due to framing.
  - Refer to **FIGURE 22** for Total Product U-Factor based on Kawneer Data.

- **Air Leakage**
  - Assumed 0.5 ACH.
  - The air leakage was not measured.
  - The value is one of the defaults in the energy modeling software described as a pressurized building with poor construction.
  - It is a conservative value, based on the amount of deficiencies observed. It is quite possible that the system leaked more than the assumed value.

- **Window to Wall Ratio**
  - Approximately 30%

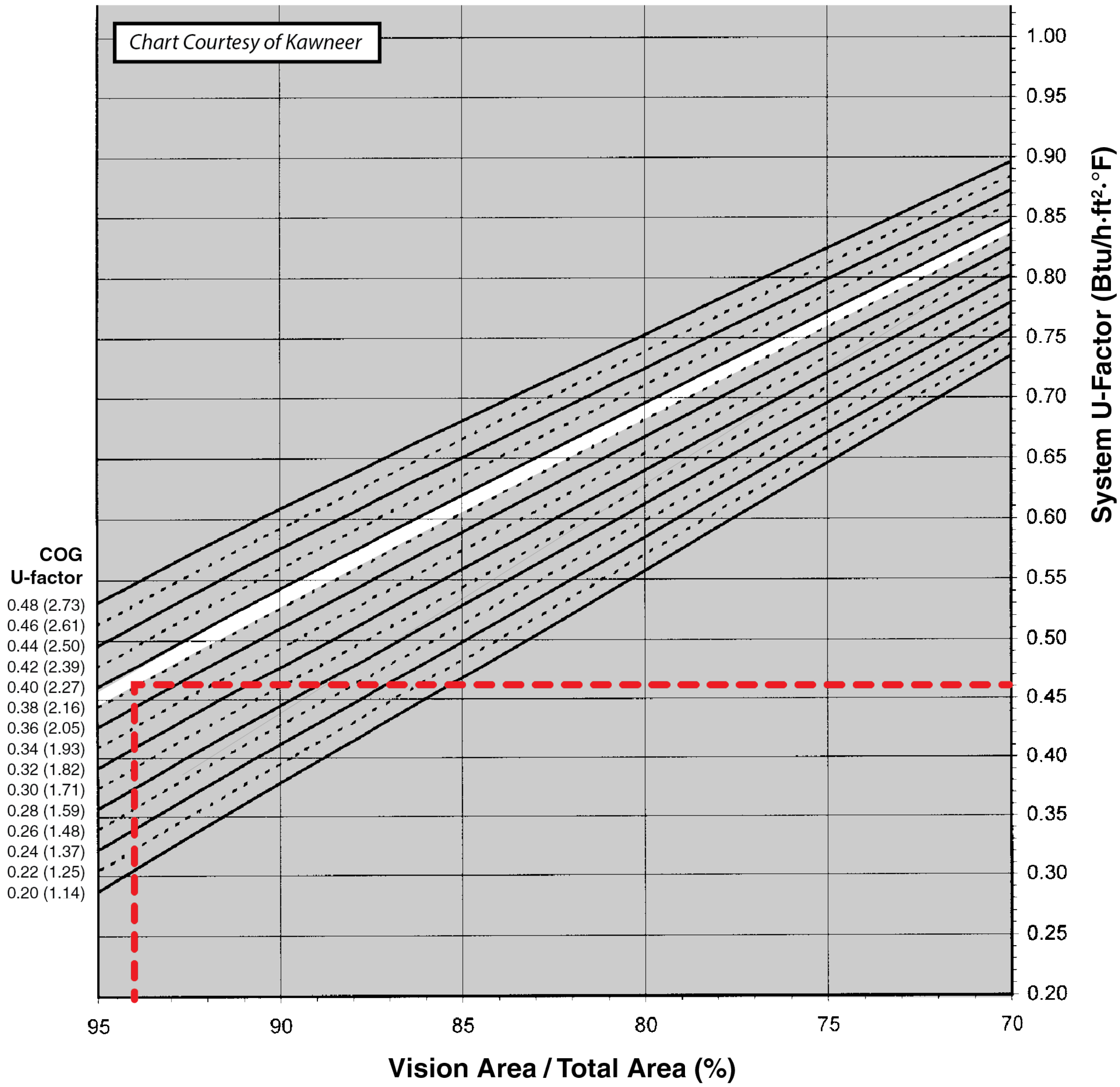


FIGURE 21: Total Product U-Factor for Existing IGU at vision glazing.

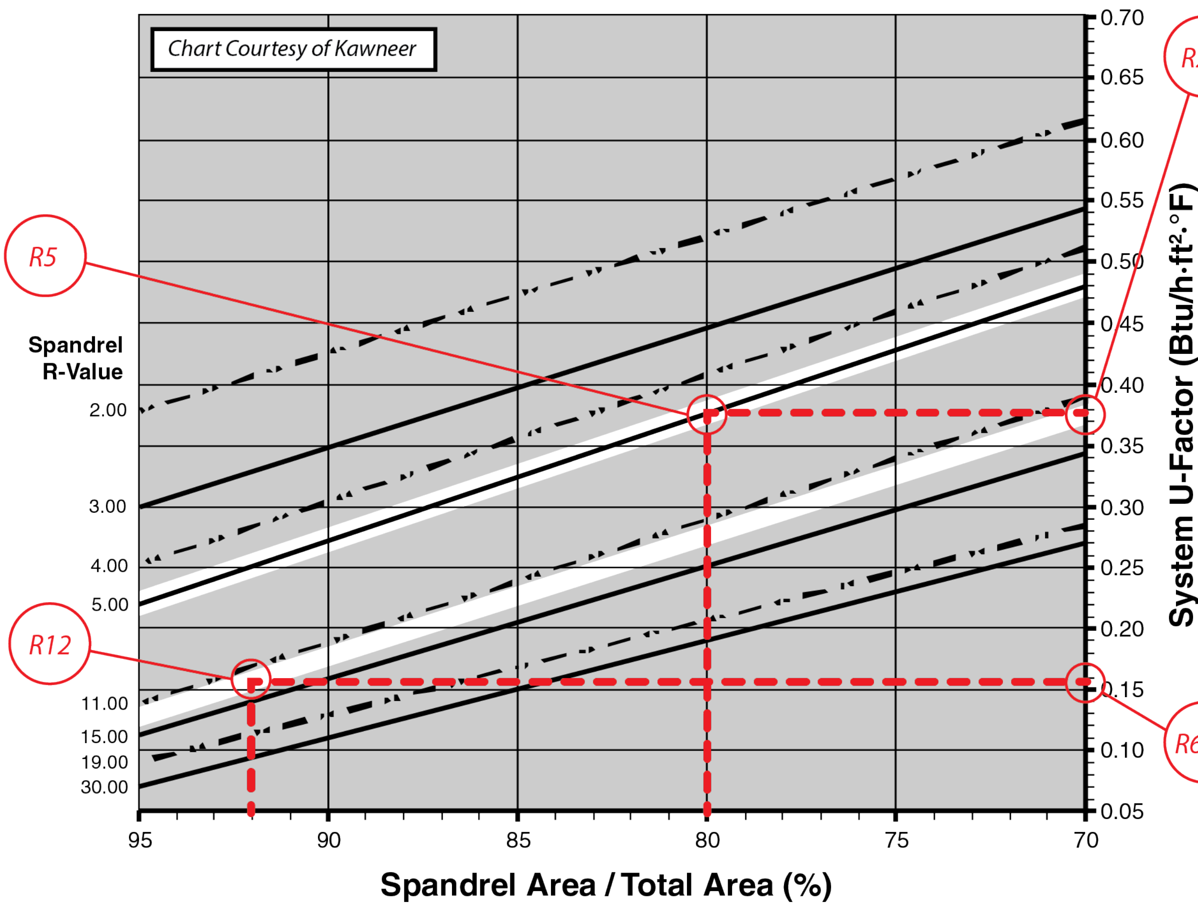


FIGURE 22: Total Product U-Factors for Existing Spandrel and Vent Areas.

As illustrated, some of the performance values of the existing system are not much better than modern code requirements. There is not a significant difference in the Total Product U-Factor of the existing vision area (0.46 Btu/h·ft^2·°F) and the 2010 ASHRAE 90.1 requirement (0.45 Btu/h·ft^2·°F). On the other hand, the SHGC of the existing is significant lower, 0.13 versus 0.40.

Note, the Total Product U-Factor for the spandrel and vent areas are significantly lower than the COP values. At the spandrel the performance is reduced by approximately 50%, and the vent is reduced by approximately 80%. This illustrates the impact of the framing configuration. The vent area has much more framing than insulation when compared to the spandrel area.

The low SHGC of the existing system provided substantial energy savings during the summer months. Much of that benefit is lost when utilizing a relatively clear IGU for the vision areas. In order to make up for the lost performance, the other performance attributes of the new system were maximized. The new values were input into an energy model to determine the maximum allowable SHGC that could be used at vision area. The maximized values were based on relatively standard modern products. While there are some products available that can perform better than what was selected, the project budget did not support their use.

NEW SYSTEM PERFORMANCE VALUES

Values used in the new design to determine the maximum SHGC of the vision area.
Red Bold Italics indicate a negative change in performance compared to the existing system.
Green Bold Italics indicate a positive change in performance compared to the existing system.

- **Vision Units** (1" IGU, ***argon filled***)
  - SHGC: ***To Be Determined based on Energy Modeling Results.***
  - COG U-Factor: ***0.26 Btu/h·ft²·°F.***
  - Glazing to Framing Ratio = 94%.
  - Total Product U-Factor = ***0.37 Btu/h·ft²·°F***.
  - Refer to **FIGURE 23** for Total Product U-Factor based on Kawneer Data.

- **Spandrel Units** ***(4" mineral wool)***
  - COP U-Factor: ***0.06 Btu/h·ft²·°F (≈ R16.8).***
  - Spandrel to Framing Ratio = 92%.
  - Total Product U-Factor = ***0.125 Btu/h·ft²·°F (≈ R8)***
  - 50% reduction due to framing.
  - Refer to **FIGURE 24** for Total Product U-Factor based on Kawneer Data.

- **Roller Vents** ***(Replaced with Translucent IGU)***
  - COP U-Factor: ***0.26 Btu/h·ft²·°F.***
  - Vent to Framing Ratio = 80%.
  - Total Product U-Factor = ***0.61 Btu/h·ft²·°F***
  - Refer to **FIGURE 23** for Total Product U-Factor based on Kawneer Data.

- **Air Leakage**
  - Assumed ***0.3 ACH***
  - The air leakage was not measured.
  - The value is one of the defaults in the energy modeling software. Described in the software as a pressurized building with ***average*** construction.
  - Conservative value, considering how much tighter the new system should be due to elimination of deficiencies. However, there still may be other areas of the building that are still leaking air, so only a limited improvement was assumed.

- **Window to Wall Ratio**
  - Approximately ***35%***.

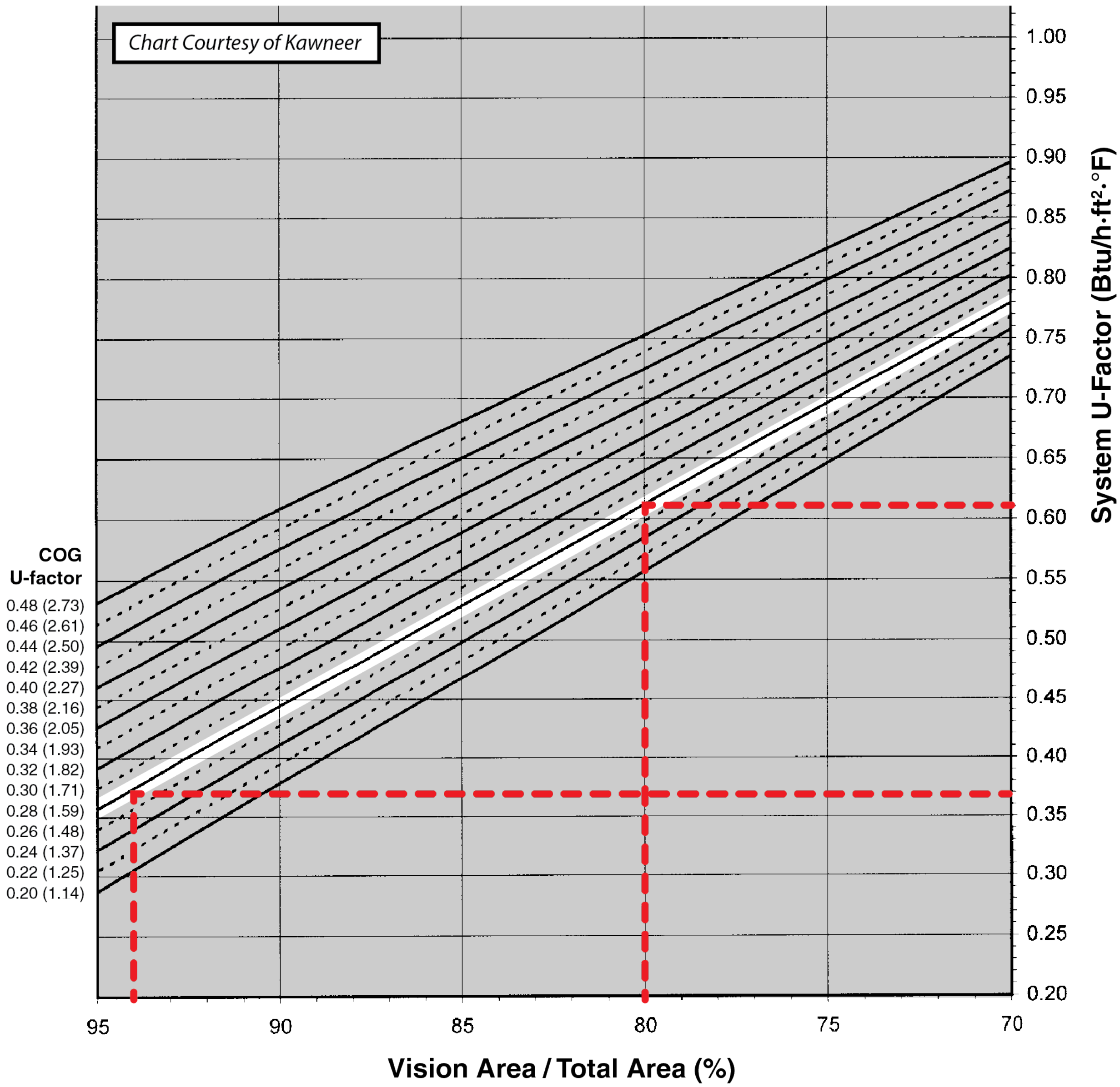


FIGURE 23: New Total Product U-Factors for IGU's at vision and roller vent areas.

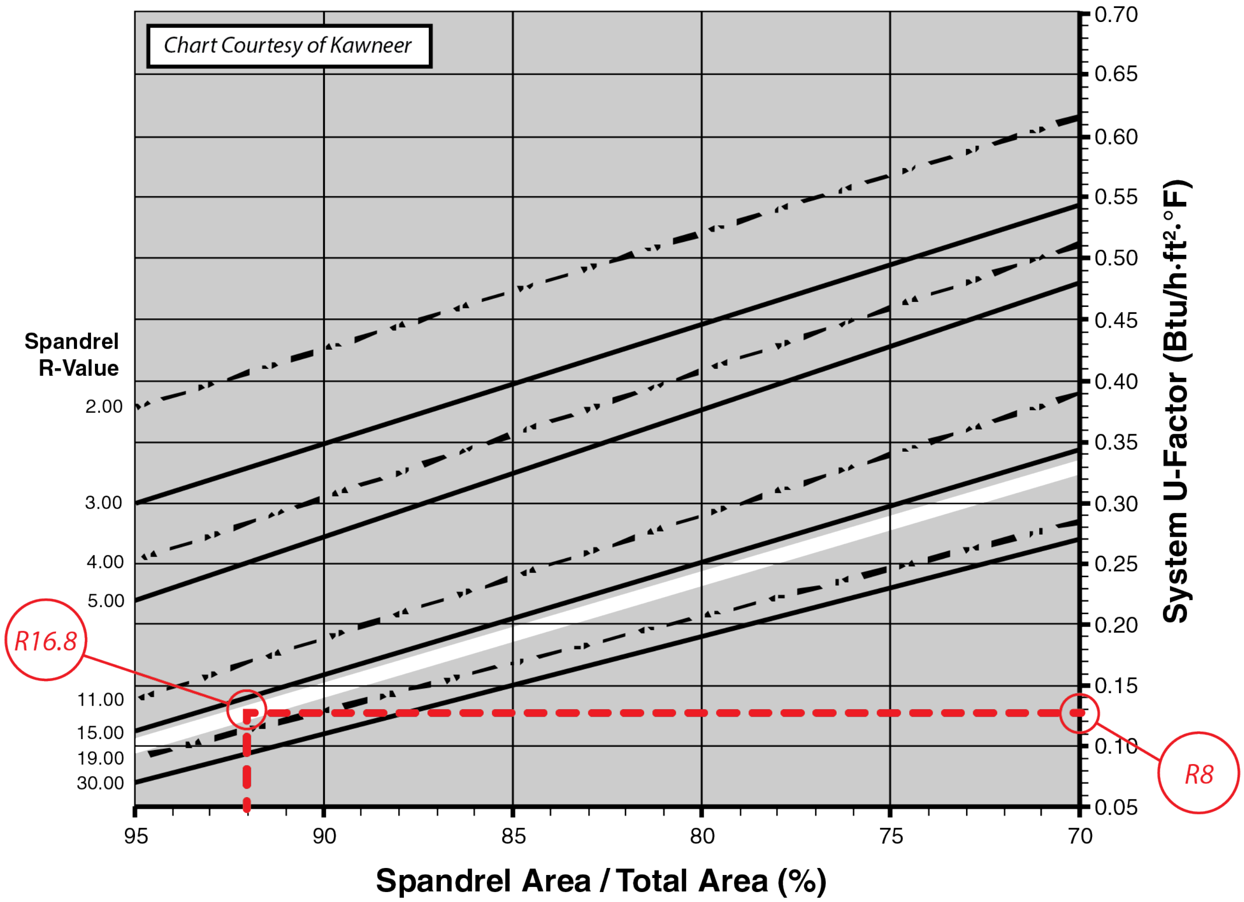


FIGURE 24: New Total Product U-Factor for spandrel areas.

ENERGY MODEL RESULTS

The performance values of the new system components were input in the energy model and the SHGC was then tuned to produce a cooling load and annual energy use that was at least equal to the original design. The results of this process provided a SHGC that was specific to each elevation of the building that would need to be utilized in order to not increase the energy load of the building.

The following are the results of the modeling indicating the maximum allowable SHGC per elevation.

- West Elevation: 0.15
- South Elevation: 0.16
- East Elevation: 0.15
- North Elevation: 0.20

The original glazing had a SHGC of approximately 0.13. Even with all of the improvements made to the enclosure, the allowable SHGC did not change significantly, and at the time of the evaluation, there were no relatively clear Low E coatings that could meet these requirements. To date, although manufacturers continue to strive for this holy grail of fenestration, there are still no relatively clear Low E coatings that can meet this level of performance.

What does this mean? This seems counter intuitive, doesn't it?

Many are under the impression that having a moderately high SHGC is beneficial in heating climates. While this may be true in some instances, there are a number of factors that have an impact on this. We should not just assume that if a project is in a heating climate, then a moderate SHGC is beneficial. Depending on many other factors, such as building orientation, WWR, and how the mechanical equipment is operated, it is certainly possible that a lower SHGC is more beneficial. Whole building energy modeling can be used to avoid making inappropriate assumptions that may be based on only part of the story.

So what to do now?

MORE DESIGN EXPLORATION

The design team began exploring ways to lower the SHGC and still maintain the relatively clear appearance. External and internal shading devices were considered and although sacrificing the transparency of the vision units was not desired, providing glazing units with a lower SHGC was also entertained. Unfortunately, the project budget could not support the addition of an external shading devise, so that option was quickly removed from the possible solutions. However, the Owner was able to provide new interior shading devices as the existing devices were long overdue for replacement. The use of internal shades along with other glazing options was further evaluated to determine what it would take to meet the necessary SHGC.

Interior shading devices are available in several combinations and the improvement on the SHGC varies significantly based on the type of shade. Some shades will not have much of an impact at all and others can have a substantial impact on the overall performance. Some shade manufacturers have tested data of their shades in combination with IGU's of various SHGC values. The glass types that were originally being proposed in the initial design had a SHGC in the range of 0.23 to 0.29. A major reduction in the SHGC was needed to meet the requirement. In order to produce this significant reduction in the SHGC, a shade that is very opaque was required.

Unfortunately, the manufacturers did not have the proposed glass types tested with their specific shades. However, they did have material files for the shades that could be used with Lawrence Berkeley National Laboratory's Window 6.2 software. The project specific glazing and shade materials were evaluated in Window 6.2 to predict the total product performance. At the time, this was the most up to date method to determine the total product SHGC without testing. However, it was not an NFRC certified method.

Upon review of several shades, it was quickly determined that a very opaque white shade would be necessary to provide the level of performance required. The shade selected had an openness factor of less than 1%. The shade was combined with three different glazing options to produce the total product performance of each.

- Option 1: Double pane IGU with high performance Low E coating on clear glass (neutral appearance).

- Option 2: Double pane IGU with high performance Low E coating on light gray glass (slightly darker appearance than Option 1).

- Option 3: Double pane IGU with high performance slightly reflective Low E coating on gray glass (slightly reflective and darker appearance).

So how does one evaluate the performance of a non-permanent variable device such as an operable shade? When occupants open shades, it is rare that they are opened completely. It is common behavior for individuals to only open shades just enough to provide an acceptable view. Given this, the Owner accepted the idea of requiring that the shades be closed 80% as the new appearance was important to them. They also indicated that during the summer months (when the SHGC is most critical), 75% of the office occupants would not be in the building and they would be able to keep those shades closed. The Owner also agreed to have the cleaning staff set the shades to 80% closed every night in the event that it was opened during the day and then that particular room was not used the next day.

FIGURE 25 provides two different total product SHGC values for the three different glazing options combined with the shade. One of the values assumes that the shade is 100% closed, and the other assumes that it is 80% closed. Additionally, the original glazing performance is provided to compare against the design options. Note, while the SHGC of the existing glazing was 0.13, the required SHGC was increased to 0.15 due to the enhancements of the other new components.

Glass Type	U-factor Total Product	Visible Light Transmission	SHGC without Shade	SHGC 100% Shade Coverage	SHGC 80% Shade Coverage
Existing Highly Reflective	0.48	7.5%	0.13	NA	NA
Option 1 Clear with a Low E	0.35	62%	0.29	0.13	0.17
Option 2 Slight tint with a Low E	0.35	45%	0.23	0.12	0.15
Option 3 Gray, Semi-Reflective	0.32	14%	0.15	NA	NA

FIGURE 25: Total Product SHGC of proposed IGU's combined with an internal shading device.

- Option 1 could only meet the required SHGC if the shade was closed more than 80%; however, it does not require 100% closure.

- Option 2 was able to meet the requirement with the shade 80% closed.

- Option 3 did not require the use of a shade at all.

Based upon review of the results, the Owner decided to select Option 1, even though it required the most amount of reliance on the shading.

As time progresses, glass manufacturers continue to strive to produce glass units that maximize the VLT and minimize the SHGC. After the design was complete, but before construction started, a new Low-E coating was developed in which the Owner wanted to evaluate as a possible alternative. The new glazing was a double pane IGU with a high performance Low E coating on clear glass. This new coating had a slight reflective appearance, but not nearly as reflective as the original. The primary benefit of the new glazing is that it had a lower SHGC, similar to Option 2 but without the darker appearance. The Owner choose to select the new glazing which also reduced the reliance on the interior shades. **FIGURE 26** provides a comparison of the new glazing, the previously selection option, and the original.

Glass Type	U-factor Total Product	Visible Light Transmission	SHGC without Shade	SHGC 100% Shade Coverage	SHGC 80% Shade Coverage
Existing Highly Reflective	0.48	7.5%	0.13	NA	NA
Option 1 Clear with a Low E	0.35	62%	0.29	0.13	0.17
Installed Clear with New Low E	0.35	43%	0.23	0.12	0.15

FIGURE 26: Total Product SHGC of proposed IGU's combined with an internal shading device.

ENERGY USAGE

The Owner began monitoring the electrical energy usage of their individual buildings in 2012. Construction began in late 2012 and completed in late 2014. This only provides less than one year of pre-retrofit data that can be used to compare to future usage. **FIGURE 27** illustrates the total electrical energy use for the building for 2012 through 2014. The percent change and the local weather data including the total heating degree days, cooling degree days, and average annual temperature is also provided for comparison.

As indicated, both 2013 and 2014 resulted in a slight increase in electrical usage as compared to 2012. However, there are several other factors that likely impacted the results including weather, building operations, and how occupants used the building. The following are a few examples of the conditions that had an impact on the results.

- The project was under construction for portions 2013 and 2014.
  - Significant amounts of air infiltration and exfiltration occurred that required additional conditioning of the building.
  - Some of the equipment used to scaffold the building was electrically powered.
- In 2012, the building was not fully occupied. People were being moved to prepare for the construction activities. In 2014, the building was fully occupied which would result in much higher plug loads.
- Both 2013 and 2014 experienced more heating degree days and a lower mean annual temperature.

The monitoring only considers electrical usage. The campus is on a central boiler system that provides the majority of the heating during the winter. The additional benefit that is gained in the winter from the increased thermal performance and higher SHGC is not able to be quantified. Given all of these factors, the minor increase in energy usage is considered negligible, if not expected. If there was a direct way to normalize all of these factors and quantify the winter benefits for this building, it is expected that the building would perform better as a whole.

While there where challenges to overcome relating to the energy performance of the existing system, the project was successful in providing the aesthetics desired by the Owner, without sacrificing the performance of the enclosure.

	KWH Consumption Data		
	2012	2013	2014
January	73,160	101,408	71,230
February	86,174	79,114	103,076
March	73,461	79,770	72,679
April	82,587	86,743	103,871
May	82,056	78,936	63,789
June	88,342	Included in December	56,435
July	114,474	Included in December	120,859
August	114,992	Included in December	92,568
September	102,066	Included in December	125,295
October	86,281	Included in December	130,319
November	82,824	Included in December	84,112
December	58,934	642,511	87,693
Annual Total	**1,045,351**	**1,068,482**	**1,111,926**
Percent Change	NA	2.2%	6.4%
Heating Degree Days	5056	6267	7032
Cooling Degree Days	1081	838	594
Mean Annual Temp. ºF	54	50	47

FIGURE 27: Annual Energy Usage and Local Weather Data.

FIGURE 28: Completed Project.

FIGURE 29: Completed Project.

CONCLUSIONS AND RECOMMENDATIONS FOR THE FUTURE

As previously indicated, fenestration systems from the 1970's and 1980's often are thought of as having poor energy performance. However, there were products and systems available and used that perform similar to modern installations. This was a transitional period for fenestration systems as it relates to energy performance. It was not necessarily common practice or required by codes to use higher performing systems for the time. Given this, it is not uncommon for design professionals to incorrectly assume that these systems have poor performance, often based solely on their age.

It is critical to recognize and evaluate the actual existing system performance when considering replacement of these early systems. It is very possible that poor selection of modern materials based on their assumed "high performance" can result in a system that is either no better than the original or potentially worse. To avoid this, one should understand the history of product development and code requirements related to fenestration systems.

Additionally, as demonstrated, energy related issues must be viewed in a holistic manner in order to truly evaluate the performance of a system for a particular building in a particular location. At a minimum, the evaluation must include the following items.

- U-factor (Thermal Transfer)
- Solar Heat Gain Coefficient (SHGC)
- Window to Wall Ratio (WWR)
- Local Climate
- Air Leakage
- Building Form / Cardinal Orientation
- Building Function / Occupant usage

Whole building energy modeling that includes all of these aspects can be utilized to validate design decisions. When performing a holistic energy modeling exercise, it can sometimes be found that the performance of the earlier systems is not significantly worse that what current energy codes require and, in some cases, the performance can actually be better. Whole building energy modeling can be utilized to verify that new systems will not under perform when compared to the original.

In addition to energy modeling, it is strongly encouraged to perform whole building air leakage testing before and after an exterior enclosure renovation. Assessing the air leakage will provide realistic values that can be used in energy modeling, and can also be used to validate the performance of the new system installation. If the testing is paired with infrared thermography, additional thermal breaches in the building's enclosure may also be identified and remediated.

As a profession we also need to request and encourage energy usage monitoring. Justification of energy upgrades are not easy to come by. The industry needs to start tracking the performance of buildings now in order to have data for future comparison. Far too often we find ourselves saying "I wish I would have…" We have the opportunity of foresight in this arena. If we don't start tracking not now, then when?

Finally, as indicated, energy codes related to fenestration systems have not changed significantly since their inception. There is a need for more stringent energy requirements. If the codes require it, the industry will find a way to provide it. The codes can be a vehicle to push, and pull, the performance along. There are higher performing fenestration products currently available, but unfortunately they are not commonly used. In some instances, forcing improvement is the only way to move the industry.

Some early fenestration systems are currently providing what we now perceive as high performance. Just because something is old, does not necessarily mean that it will be a poor performer. Similarly, just because something is new, does not necessarily guarantee that it will perform at a high level. Curtain walls are an excellent example of this scenario. Careful consideration and evaluation is required when upgrading early fenestration systems from the 1970's and 1980's.

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