DESIGN IMPLICATIONS OF GLAZING RATIO RESTRICTIONS

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Abstract

Recent energy codes set the trend for significant improvements to the thermal performance of the building enclosure. These new codes challenge building owners who desire large expanses of vision glass to utilize higher performance technologies. The implication of glazing ratio on glazing system U-values and spandrel panel design will be presented including a comparison of prescriptive versus performance-based approach to code compliance. Through case studies of high-rise residential towers, this paper will present solutions involving both traditional glazing technology as well as emerging technologies that provide solutions that comply with these stricter energy codes. The paper is based on an analysis undertaken to quantify the impact of the glazing ratio on the design of a glazing system. Looking beyond "code compliance", the effect of thermal bridging will be demonstrated using the latest 3D thermal modeling. The implications of "raising the bar" when comparing a "code-compliant baseline building" to the "proposed building" and its impact on LEED projects will be discussed. This will be of interest to designers looking to understand the implications of the restriction imposed on glazing ratio as well to the manufacturer of glazing systems looking to provide systems that meet these new requirements

Introduction

This paper examines how the maximum allowable glazing ratio mandated by current energy codes affects the design and construction of buildings. The scope of this paper is commercial buildings, which include high-rise multi-unit residential buildings. The scope is limited to the thermal performance of the building enclosure. These case studies are based on analyses undertaken during the design of multi-family high-rise residential buildings. Energy codes stipulate requirements for the energy efficient design and construction of commercial and residential buildings. In the Unites States some states have adopted ASHRAE Standard 90.1, Energy Standard for Buildings except Low-Rise Residential Buildings. This standard is also often referenced in the Canadian context such as the new SB-10 standard in Ontario. However, in the United States, most states have adopted the 2009 International Energy Conservation Code (2009 IECC). Every three years energy codes are revised to continuously improve the energy efficiency of new and renovated buildings. Consequently, stricter energy conservation measures are adopted with each code cycle.

Demonstrating Compliance with Energy Codes

Energy codes typically have three options for demonstrating compliance: prescriptive, performance, and trade-off. Prescriptive requirements are specified minimum performance requirements in the code. Using the performance option, compliance is demonstrated through whole-building computer simulation to show that a proposed building has an annual energy performance that is less than or equal to the annual energy performance of the standard prescriptive design over a typical meteorological year. In ASHRAE 90.1-2007 and the 2009 IECC, annual energy performance is based on predicted annual energy cost. Hence this method is also called the energy cost budget method. In the 2009 Washington State Energy Code (WSEC 2009), based on the 2009 IECC, annual energy performance is based on annual energy consumption. ASHRAE 90.1-2007 and the 2009 IECC have a third option for demonstrating compliance of the building enclosure called, respectively, "building enclosure trade-off option", "total UA alternative", and "component performance building enclosure option". UA is the overall rate of heat transfer through the building enclosure per unit of time induced by a unit temperature difference between the environments on each side of the enclosure. It is equal to the sum of weighted product of thermal transmittances (that is, the U-factor) and area of roofs, opaque wall areas, fenestration areas, etc. All of these third options are "trade-off" options, which can be thought of as an intermediate path between the prescriptive and performance paths. Using the trade-off option, buildings whose design heat loss rate is less than or equal to the target heat loss rate will be considered in compliance.

Maximum Allowable Fenestration Area: 40%

With most states having implemented the 2009 IECC during the global financial crisis of 2007-2012, relatively few buildings were permitted under this new code, and hence few designers have had to deal with the challenges of complying with the new thermal performance requirements of the building enclosure. One of these new requirements is a 40% limit on fenestration area. For those buildings permitted under the new code, this new limit has had a significant impact on the design of so-called "glass" buildings.

Under the prescriptive building enclosure requirements of ASHRAE 90.1-2007, Section 5.5.4.2 Fenestration Area states, "the total vertical fenestration areas shall be less than 40% of the gross wall area" and "the total skylight area shall be less than 5% of the gross roof area". Fenestration is defined as "all areas (including the frames) in the building envelope that let in light, including windows, plastic panels, clerestories, skylights, doors that are more than one-half glass, and glass block walls."

Similar requirements exist in the 2009 IECC. Under the prescriptive building enclosure requirements, Section 502.3.1 Maximum Area states that the vertical fenestration area shall not exceed 40% of the gross wall area and that skylights shall not exceed 3% of the gross roof area. Fenestration is defined as "skylights, roof windows, vertical windows (fixed or moveable), opaque doors, glazed doors, glazed block and combination opaque/glazed doors."

In all these codes, the limitation on fenestration area—or glazing area as it is called in the 2009 WSEC—essentially comes down to a limit on the area of vision glass. Fenestration area is all areas (including frame) in the building enclosure that let in light. One can still design an all-glass building using the prescriptive path as long as no more than 40% of the gross wall area is vision glass. The spandrel glass need not be opaque as long as it is the cladding on an opaque wall (such as in a curtain wall shadow box). With the new codes, buildings taking the performance or trade-off paths to compliance with the aim of increasing the area of vision glass more than 40% must now demonstrate that the "effective U-value" of the opaque wall area—be it spandrel glass or some other opaque cladding systems—meets or exceeds the overall U-value of the prescriptive approach. This is made even more challenging with the additional requirements to also account for heat loss due to thermal bridging. The amount of thermal bridging that must be accounted for varies by code. For example, the 2009 IECC states "the UA calculation shall be done using a method consistent with the ASHRAE Handbook of Fundamentals and shall include the thermal bridging effects of framing materials". The 2009 WSEC takes it even further when defining continuous insulation as "insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings". As we will demonstrate in this case study, it can be difficult to significantly exceed the 40% limit on the vision glazing area using glazing systems that are commonly available on the market today.

Impact of Glazing on Energy

Why does the energy code limit the area of vision glazing? Glazing performance is directly related to both heating and cooling loads in buildings. The thermal performance of glazing units and their framing system drive the majority of heat loss through the building enclosure. Furthermore, typical glazing assemblies significantly under-perform with respect to heat loss when compared to typical opaque wall assemblies, especially when considering the implementation of the codes' requirement for continuous insulation. Solar gain through vision areas is one of the three main sources of heat gains (the other two are lighting and people). Solar gains are a major component of cooling loads. Unmanaged heat gains can have a significant impact on the design of commercial buildings; therefore, unlike in residential building, the code specifies maximum solar heat gain coefficients (SHGC). For example, in the prescriptive residential requirements of 2009 IECC Section 402.1.1, there is no SHGC requirement in climate zones 4 to 8, and it is 0.3 in climate zones 1 to 3; whereas in the prescriptive commercial requirements, the SHGC requirements are more stringent in climate zones 1 to 3, and there are requirements in all climate zones. Although commonly available technologies such has low-emissivity coatings can mitigate solar heat gains, the impact on cooling loads is still significant when large amounts of glazing are used.

The objectives of placing a limit on the maximum fenestration area are to minimize heat loss in winter and heat gains in summer. On building projects that are targeting a larger fenestration area, the limit will encourage designers to use new technologies to minimize heat loss and solar heat gain to trade-off the additional heat exchange though large fenestration areas.

As our case study will demonstrate, buildings designed with fenestration areas greater than 40% will require higher performing glazing in better thermally designed framing systems to achieve glazing U-values significantly below the 2009 WSEC mandated value of 2.27 W/m2·K (0.40 Btu/h·ft2·°F). Designers will need to consider opaque wall assemblies that have much more thermal resistance than what is common today. However, the real challenge will be in achieving higher U-values for spandrel glazing in all-glass buildings. As we will demonstrate in this case study the inherent thermal bridging of the framing system can significantly impact the performance of the opaque wall assembly in these buildings especially when the three-dimensional (3D) heat loss between the vision glazing and spandrel glazing is considered.

Case Study on Maximizing Fenestration Area

The first case-study building is a multi-family high-rise residential building located in western Washington. It has an all-glass custom-designed curtain wall, five levels of below-grade parking, two levels of retail space, and 19 residential floors. The gross wall area is 7,786 m2 (83,809 ft2). The design goal was to maximize vision glazing areas (upwards of 80%) to take advantage of abundant views of the region's natural beauty and to appeal to consumer demand for dramatic floor-to-ceiling windows.

Starting with a code-matching building that has 40% vision glazing and opaque walls with R-3.3 m2·K/W (R-19 h·ft2·°F/Btu) batt insulation and R-1.5 (R-8.5) continuous insulation, the target heat loss rate (UA) is 7908 W/K (14,991 Btu/h·°F). Of this, 1502 W/K (2841 Btu/h·°F) is for the opaque enclosure, and 6406 W/K (12,150 Btu/h·°F) is for fenestration. The relative UA of the fenestration compared to the opaque portion of the enclosure shows that 81% of the heat loss is through the fenestration (6406/7908 ×

100% = 81%). That leaves a very small percentage of the opaque wall heat loss (19%) that can be used to offset additional fenestration heat loss from a larger fenestration area. A better fenestration U-factor will not change the fact that most of the heat loss is through the fenestration.

At this point the developer was confident that a fenestration U-factor of 1.99 W/m2·K (0.35 Btu/h·ft2·°F) would be attainable with the custom-designed curtain wall. This U-factor is a weighted average that includes the vision glazing and the framing for the vision glazing as well as also factoring for the operable windows. Note that this glazing system already has a much better U-factor than the code maximum U-factor of 2.27 W/m2·K (0.40 Btu/h·ft2·°F). By incrementally increasing the thermal performance of the glazed spandrel assembly (expressed as 1/U, or the "overall effective R-value"), the authors calculated the maximum allowable fenestration area for a given opaque wall thermal performance as shown in Figure 1.

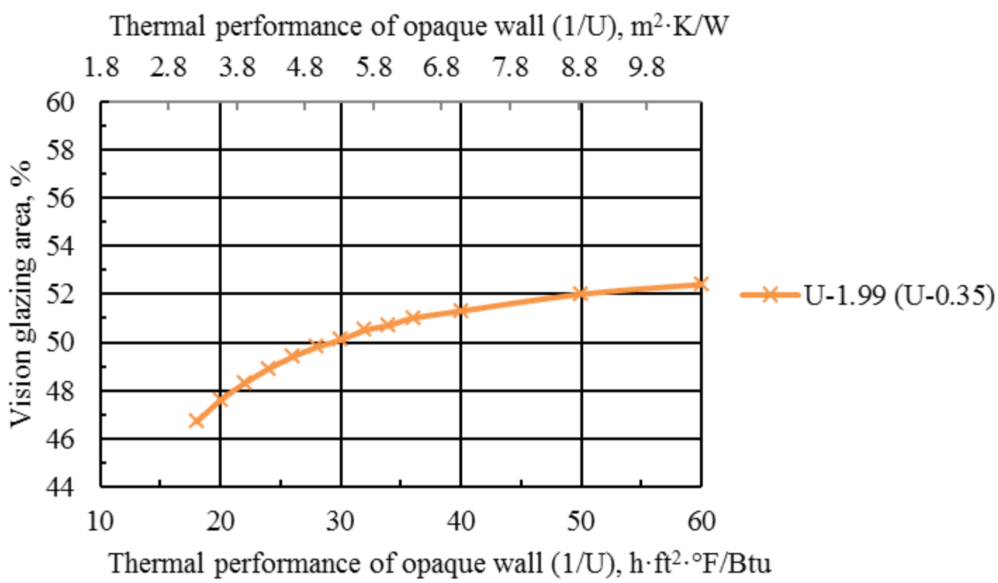

Figure 1. For U-factor of 1.99 W/m^2·K (0.35 Btu/h·ft^2·°F), the maximum allowable fenestration area

For example, to get to a 50% fenestration area, the glazed spandrel assembly would have to have an overall effective R-value of about R-5.3 m2·K/W (R-30 h·ft2·°F/Btu). With 50% fenestration, the proposed UA is 7894 W/K (14,964 Btu/h·°F). Of this, 904 W/K (1714 Btu/h·°F) is for the opaque enclosure, and 6990 W/K (13,250 Btu/h·°F) is for fenestration. Thus the relative UA of the fenestration compared to the opaque portion of the enclosure shows that now 89% of the heat loss is through the fenestration (compared to 81% for a code-matching building).

Taking it One Step Further

The next step was to look at how improving the fenestration U-factor could help increase the amount of allowable vision glass. Using the same incremental procedure described above, the authors calculated the maximum allowable fenestration area for fenestration U-factors ranging from 1.76 to 1.99 W/m2·K (0.31 to 0.35 Btu/h·ft2·°F) in 0.06 W/m2·K (0.01 Btu/h·ft2·°F) increments. The resulting required thermal performance of the glazed spandrel assembly for a given fenestration U-factor is shown in Figure 2.

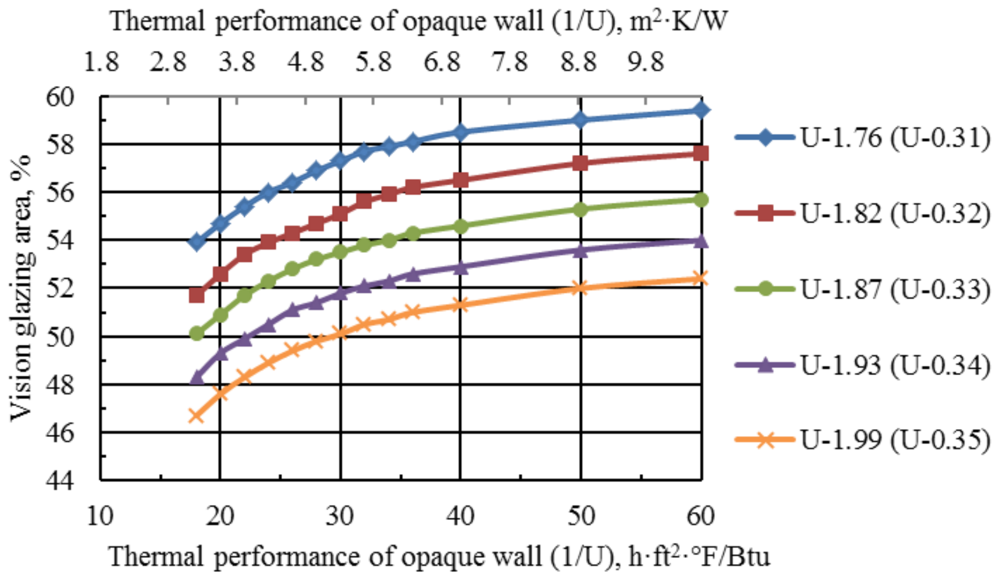

Figure 2. Maximum allowable fenestration area for a given thermal performance of the opaque.

The results show that very significant improvements to thermal performance of the fenestration system would be required to increase the maximum allowable fenestration area. Even with a U-factor of 1.76 W/m2·K (0.31 Btu/h·ft2·°F) and an overall effective R-value of R-5.3 m2·K/W (R-30 h·ft2·°F/Btu), the maximum allowable fenestration area is only about 57%. However, based on the project's budget and technical constrains, specifically the limitations of the operable windows, the design team determined that a fenestration U-factor of 0.35 and overall effective R-value of the glazed spandrel assembly of R-33 was the most realistic choice. This allowed the project to have a fenestration area of 51%—a far cry from the architect's original vision of upwards of 80% vision glazing. Two-dimensional (2D) thermal modeling (THERM 2012) was used to determine the U-factor of the curtain wall. The curtain wall is thermally broken. The thermal model accounts for 2D thermal bridging through mullions and steel studs in the wall. In order to maximize the amount of floor-to-ceiling vision glass, the designer chose to orient the spandrel panels vertically instead of horizontally.

Energy Codes and Sustainability Rating Systems

Designing for higher glazing ratio under the new code gets significantly more challenging for project pursuing sustainability ratings. To earn more than three points under LEED Energy and Atmosphere Credit 1 to optimize energy performance (LEED 2012) the design team must demonstrate through whole-building energy simulation that the energy cost performance of their proposed design exceeds the baseline design. The baseline design is a building meeting ASHRAE 90.1-2007. The challenge lies in the fact that the bar has been raised across all building systems including energy using systems, energy conversion equipment, and building enclosure components. The baseline design is already an energy efficient building. Where once the energy performance savings from HVAC and lighting systems could be counted upon to make up for shortfalls in the performance of glazing systems, now the new baseline has started to closed the gap on the performance expectation of these systems. This means that unless a project makes use of unusual measures for these systems or incorporates some aspect of site generated energy, there is no longer sufficient energy savings to allow for a significant increase in glazing area. Going forward on most projects the building enclosure will have to be at least code neutral from an energy performance perspective in order for any energy savings from the HVAC and lighting systems to be used to demonstrate above code performance.

In a second case-study building, again a high-rise residential building located in the same jurisdiction as the first case study, this time the goal was to achieve a LEED Gold rating. It has a window-wall system with a combination of metal and glass spandrel panels. The building has four levels of below-grade parking, one level of retail space at grade, 11 residential floors and roof level amenity spaces. Initially starting with a glazing ratio in excess of 60% the design was revised to a code-matching ratio of 40% vision glazing. The fixed glazed portions of the window wall were better than the code prescriptive requirement: they had a U-value of 1.82 W/m2·K (0.32 Btu/h·ft2·°F) based on a thermally broken aluminum framing system and low-e glazing with warm edge spacers and argon filled cavity. The operable windows did not meet the 2009 WSEC requirements: they had a U-value of 2.38 W/m2·K (0.42 Btu/h·ft2·°F). The opaque spandrel areas had a better than code U-value of 0.27 W/m2·K (0.048 Btu/h·ft2·°F) based on an insulated back pan design with 100 cm (4 in.) of spray foam insulation applied across the interior face of the system. The U-value of insulated slab-edge covers was 0.50 W/m2·K (0.089 Btu/h·ft2·°F). The mechanical and lighting systems included such high performance features as high efficiency through-wall heat pumps in each unit, high efficiency domestic hot water heaters, domestic hot water heat recovery, and occupancy sensor-controlled lighting in parking garage and stairwell. Despite all of these energy conservation measures, whole-building energy simulation demonstrated that the energy cost performance of their proposed design bettered the baseline design by only 17.2% (worth three EAc1 points). Therefore the design achieved the Energy and Atmosphere Prerequisite Credit 2 for minimum energy performance of 10% improvement above the baseline (that is, two EAc1 points) and one additional EAc1 point. But to achieve LEED Gold the project was going to have to look at securing credits from the other categories. As it was the project was already over budget, and the developer conceded and accepted that a LEED Silver rating was a more achievable goal given the project constraints.

As the above case study demonstrates, even when using whole building energy modeling, the new codes have raised the performance expectations on MEP systems which mean that there is not as much efficiency to trade off against short falls in the performance of the building enclosure. In a similar case study from the Ontario market, an investigation was carried out to assess the energy performance of typical high-rise MURB construction in the Toronto area under the new SB-10 Standard. The SB-10 performance path energy requirements are to meet 25% better energy performance than the MNECB.

Energy modeling was carried out using eQUEST v3.64 on an existing model for a 40-storey high-rise condominium in Downtown Toronto. The original model's energy conservation measures (ECM) were removed to compare 'standard' MURB high-rise construction to the new Supplementary Standard SB-10 requirements.

The following outlines the building's major characteristics typical of current practices in Toronto MURB high-rise construction:

Enclosure:

- Window Wall Construction
- Double Glazed, Aluminum Frame, Thermally Broken Windows (R=1.9)
- Glass Spandrel Panels, R-12, Mineral Wool in Metal Backpan (R=5.3)
- 70% Window-to-Wall Ratio

Mechanical:

- 4 Pipe Fan Coil system
- Low-Efficiency Boiler and Mid-Efficiency Chiller
- Corridor fed ventilation

The results are as follows:

End-Use	**Design (GJ)**	**MNECB Reference (GJ)**	**% Savings**
Lighting	2799	2886	3.02%
Receptacles	1376	1372	-0.29%
Heating	15721	13456	-16.83%
Cooling	1581	1371	-15.32%
Pumps	2130	3070	30.62%
Fans	1179	2332	49.43%
DHW	4802	4806	0.08%
Exterior Lighting	38	38	0.00%
Elevators	900	900	0.00%
% Savings Relative to MNECB			**-0.98%**

In the next stage of this study, the effect of easy to implement energy saving measures or 'lowest hanging fruit' with a focus on MEP systems were modeled as these measures can be expected to be first implemented by a design team when attempting to improve energy performance. The following measures were added to the preliminary design case:

- Variable speed pumps
- 5% reduction to window-to-wall ratio (WWR)
- Increase to mid-efficiency domestic hot water plant and assumed 15% reduction in hot water load through low-flow fixtures
- Forced-draft boiler, with 80% thermal efficiency replaced with high-efficiency condensing boiler
- Addition of occupancy sensors to underground parking garage lighting

The results are as follows:

End-Use	Design (GJ)	MNECB Reference (GJ)	% Savings
Lighting	2649	2886	8.19%
Receptacles	1376	1372	-0.29%
Heating	8902	12585	29.26%
Cooling	1564	1220	-28.22%
Pumps	1921	2342	17.99%
Fans	1814	2332	22.22%
DHW	3869	5014	22.83%
Exterior Lighting	38	38	0.00%
Elevators	900	900	0.00%
% Savings Relative to MNECB			**19.7%**

The results indicate that implementing the 'lowest hanging fruit' still fell short of the required 25% energy savings relative to the MNECB reference building despite a sizable benefit from incorporating the condensing boiler and its improved part-load performance curves.

The results also suggest that more extreme measures are required to achieve the 25% threshold. One such measure is incorporating individual suite ERV's; a trend that is becoming more common in high-rise MURB designs that are targeting LEED certification. As a comparison, the same model with conservative in-suite heat recovery effectiveness showed energy savings of 26% relative to the MNECB baseline.

Energy Codes and Reality

The first case study above was based on overall effective R-values and accounted for thermal bridging as required by the energy code. Standard practice in North America to account for thermal bridging within the building enclosure is to consider thermal bridging within an assembly, for example a steel stud wall, but to ignore thermal bridging at architectural and structural details—including interfaces—where walls, windows, floors, and roofs come together. Whole-building energy modeling procedures for performance-based compliance in energy codes and standards are either silent on thermal bridges relating to details and transitions (such as slab edges, shelf angles, and sheet metal flashings), they allow these thermal bridges to be ignored through partial or full exemptions, or the procedures reduce the apparent significance of thermal bridges through oversimplification. The reasons for these omissions appear to be based on:

1. The belief that details do not have a significant impact on the overall building enclosure performance and on whole building energy use because they comprise a small area compared to the total enclosure area.
2. Past experience that shows it would take too much effort to quantify all thermal bridges, which often have complex three dimensional (3D) heat flow paths.
3. The lack of comprehensive thermal transmittance data for standard details.

However, recent work accounting for 3D heat flow through details (Morrison Hershfield Ltd 2011) has shown that the overall performance of many common wall assemblies is much less than what is currently assumed by many practitioners. Irrespective of the small areas of highly conductive materials that bypass thermal insulation, the effect on overall energy consumption is significant, and simple changes to assembly design may be more effective at reducing energy use than adding more insulation. In addition, accounting for these details is now easier because straightforward procedures to quantify the impact of common details have been developed and thermal transmittance data for standard details are now readily available in a catalogue published by ASHRAE Report 1365: Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings. Realistic expectations of building enclosure performance are necessary to make informed decisions related to building energy efficiency.

The 3D heat loss through curtain wall systems is very significant and should not be ignored. For example, using the results of 3D thermal modeling, installed insulation with a nominal R-value of RSI-5.8 (R-33) results in an assembly with an overall effective R-value of about RSI-1.6 (R-9). In fact, due to heat loss through exposed vertical and horizontal mullions in vision areas down to the opaque spandrel areas, at the intersection of vertical and horizontal mullions, and at curtain wall anchors, there is a diminishing return on the effectiveness of on installed insulation as shown by the results in Figure 3. With conventional materials and a typical "good" thermally broken curtain wall system, the overall effective R-value will be in the range of RSI-0.9 to RSI-1.6 (R-5 to R-9). However, with new materials such as vacuum insulated panels—about RSI-7 (R-40) per inch—and non-metal curtain wall framing, the authors are beginning to see these limitations exceeded.

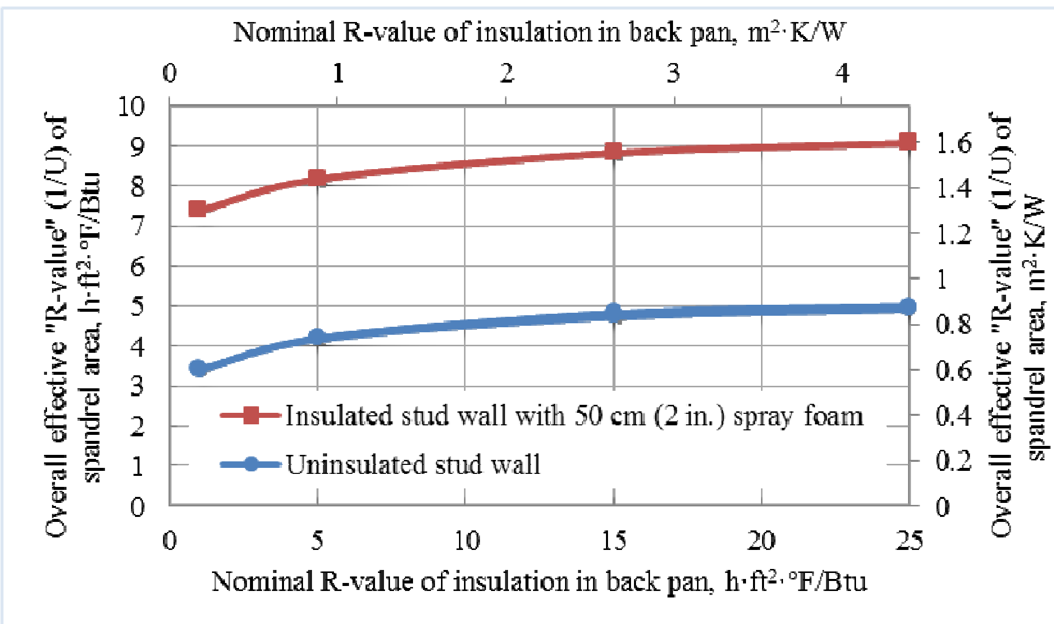

Figure 3. Overall effective "R-value" (1/U) of spandrel areas of curtain wall

The Need for Alternative Assemblies

As demonstrated by these case studies, glazing ratios in the range of 10% above the code prescribed level can be achieved using the current nominal thermally broken frames and good quality dual glazed units combined with highly insulated opaque wall assemblies. However, those projecting seeking higher glazing ratio or those seeking energy savings exceeding the code baseline will increasing have to turn alternate assemblies.

There is a number of existing high performance technologies on the market that have been in use on projects where extremes of climate or interior environment conditions dictated a high performance system. This includes such technologies as high performance thermal breaks for aluminum frames, triple glazed units including the use of suspended films, as well as double low-e coating for glazing units. Combined these technologies can deliver a U value below 0.30. To date the cost premiums associated with these assemblies has limited their applications. With the demands of the new energy codes, we should start to see increasing demand and a general trend towards a greater commoditization of existing high performance technologies

In addition there are a number of promising emerging technologies are being adapted to significantly improve the thermal performance of glazing systems both in terms of vision and opaque assemblies. Some of these include alternate framing material such as fiberglass traditional reserved for the low-rise residential market now being developed for more high-rise commercial construction. Likewise there are alternate glazing assemblies such as translucent fiberglass or polycarbonate panels insulated with nanogels to provide increased daylighting without compromising thermal performance. Vacuum insulating technologies are being applied to both vision glazing assemblies as well as spandrel assemblies to significantly improve their thermal performance. Electrochromic and thermochromic glass can be used to significantly reduce solar heat gain beyond what can be achieved with fixed shading devises. Lastly innovative integrated photovoltaic systems are providing for on-site energy generation that can significantly impact the energy cost budget for a project. Again the demands of the new energy code should drive a general trend towards an accelerated commercialization of these emerging technologies

Conclusion: The Future of Energy Codes

As challenging as the maximum fenestration area is, it will be even more challenging once the new 2012 IECC code is adopted. The 2012 IECC has decreased the maximum fenestration area to 30% of the gross wall area. As states adopt these codes, getting beyond 30% will be even more challenging than getting past 40% with the current code. Therefore it will be even harder to meet code if one wants to also exceed maximum fenestration areas using commonly available systems that are on the market today. With a maximum fenestration area of 30% in the baseline design, the total energy budget that the design team has to work with becomes even less. Whether it is to meet code or to earn points under Energy and Atmosphere to optimize energy performance, exceeding 30% fenestration area will require even higher performing enclosure systems or greater energy savings in other areas to trade-off.

The focus on continuously improving the energy efficiency of new building through energy codes will drive a demand for higher performance glazing and better thermal performing frames. It will also provide an incentive for emerging technologies and other innovative applications that can help improve the thermal performance of glazing systems. At the same time, it will also bring a closer examination of the justifications for increased applications of vision glass on projects. Increasingly designers will be required to demonstrate that increasing the fenestration area will add value to a project. The 2012 IECC will have an exception to the glazing ratio for building where 50% or more of the floor plate benefits from day lighting. In turn this will drive a need to address the benefits and impacts of increased glazing early in the conceptual design phase of the projects. Early collaboration between the design architects, mechanical engineers, and building enclosure consultants will be even more crucial on these projects.

REFERENCES

ASHRAE. 2007. ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings except Low-Rise Residential Buildings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2010. ANSI/ASHRAE/IESNA Standard 90.1-2010, Energy Standard for Buildings except Low-Rise Residential Buildings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE RP-1365, Morrison Hershfield Ltd. 2011. Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings.. Atlanta: American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc.

IECC. 2009. International Energy Conservation Code. Washington: International Code Council.

IECC. 2012. International Energy Conservation Code. Washington: International Code Council.

LBNL. 2012. THERM Finite Element Simulator, Version 6.3.45. Regents of the University of California. Developed and maintained by Lawrence Berkeley National Laboratory, Berkely, CA.

LEED. 2012. LEED 2009 for New Construction and Major Renovations. Washington: U.S. Green Building Council.

LEED. 2013. LEED v4 for New Construction – draft. Washington: United Stated Green Building Council. http://new.usgbc.org/credits/new-construction/v4-draft. Retrieved 2013 February 21.

WSEC. 2009. 2009 Washington State Energy Code. Olympia: Washington State Building Code Council.