BUILDING ENVELOPE DESIGN UNDER THE 2009 CODES: GLAZING RATIO REQUIREMENTS

by

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INTRODUCTION

This paper examines how the maximum allowable glazing ratio (also called fenestration area)—mandated by the latest energy codes—affects the design and construction of buildings. The scope of this paper is commercial buildings, which includes multi-unit residential buildings over three stories. The case-study is based on an analysis undertaken during the design of a high-rise residential building in western Washington. Energy codes stipulate minimum requirements for energy-efficient design and construction of commercial and residential buildings. In the Unites States there is no nation-wide energy code[1]. So code adoption and enforcement occur at the state and local level. Some states have adopted ANSI/ASHRAE/IESNA Standard 90.1-2007, *Energy Standard for Buildings except Low-Rise Residential Buildings* (ASHRAE 90.1-2007). However, most states have adopted the *2009 International Energy Conservation Code* (2009 IECC)[2]. And a few states—including California, Oregon, and Washington—have their own "home-grown" energy codes. 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. Since this paper's case-study building is in the state of Washington, the paper will also discuss some of the requirements of the *2009 Washington State Energy Code* (2009 WSEC).

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. For example, in western Washington (which is in climate zone Marine 4), steel stud walls enclosing a residential occupancy (other than single-family) are required to have a minimum of R-19 batt insulation plus R-8.5 continuous insulation without thermal bridges other than fasteners. Using the performance option, compliance is demonstrating through whole-building computer

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[1] Except for federal buildings.
[2] From the status of state energy codes and adoption maps on the U.S. DOE's Building Energy Codes Program website: http://www.energycodes.gov/states/maps/commercialStatus.stm.

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 reference design over a typical meteorological year. For example, if the proposed heating ventilation and air-conditioning (HVAC) system is much more energy efficient then the code-mandated minimums, energy simulation could be used to show that the expected energy savings from the HVAC can make up for the poorer thermal performance of a less-than-code-compliant wall. In ASHRAE 90.1 and 2009 IECC, annual energy performance is based on predicted annual energy cost. Hence this method is also called the *energy cost budget method*. In WSEC 2009, annual energy performance is based on annual energy consumption. ASHRAE 90.1-2007, 2009 IECC, and 2009 WSEC have a third option for demonstrating compliance of the building envelope called, respectively, "building envelope trade-off option", "total UA[3] alternative", and "component performance building envelope option". All of these 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[4].

MAXIMUM ALLOWABLE FENESTRATION AREA: 40%

With most states having implemented the 2009 IECC during the 2007-2012 global financial crisis, 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 envelope. One of these new requirements is the 40% limit on fenestration area. For those buildings that have been permitted under the new code (and where the new code is actually enforced), this new limit has had a significant impact on the design of so-called "glass" buildings.

Under the prescriptive building envelope 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 envelope requirements, *Section 502.3.1 Maximum Area* states that the vertical fenestration area

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[3] UA is the overall rate of heat transfer through the building envelope per unit of time induced by a unit temperature difference between the environments on each side of the envelope. It is equal to the sum of the products of thermal transmittances (that is, the U-factor) multiplied by their respective areas.

[4] The 2009 IECC and the 2009 WSEC require accounting for conductive heat loss and solar heat gain (refer to 2009 IECC, *Section 402.1.4, Total UA Alternative* and 2009 WSEC, *Section 1330, Component Performance Building Envelope Option*). However, the procedure in ASHRAE 90.1-2007 is more complex because it requires accounting for climate, lighting, thermal mass, and building orientation (refer to ASHRAE 90.1, *Section 5.6, Building Envelope Trade-Off Option* and *Normative Appendix C*).

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."

And there are similar requirements in the 2009 WSEC, although there is a subtle but importance difference. Under the prescriptive building envelope requirements, *Section 1323.1* states that the percentage of *total* glazing relative the gross exterior wall areas shall not be greater than 40% for the *vertical glazing and overhead glazing*. Although the requirement is specified in terms of glazing and not fenestration, the definition of glazing in the WSEC is similar to the definition of fenestration in ASHRAE 90.1-2007[5]. However, the requirement is in terms of *total* glazing, which includes skylights. Skylights are included in the glazing area even though they are not counted as part of the gross exterior wall area. This has the effect of further limiting vertical glazing areas on buildings when there is also a significant skylight area. One important exception to *Section 1323* is that glazing on "*the display side of street-level of retail"* can be excluded from the glazing area calculation.

In all three of these codes, the limitation on fenestration area—or glazing area as it is called in the WSEC—essentially comes down to a limit on the area of *vision* glass. 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 and at least 60% is the cladding for the opaque portions of the envelope, such as spandrel glazing. 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). For example, **Figure 1** shows an all-glass building that has a combination of reflective and transparent vision glass (50% of the gross wall area) and reflective and opaque spandrel glass (also 50% of the gross wall area). Under the 2007/2009 prescriptive requirements, if this building envelope were designed today, it would not comply with current energy codes. Yet, this building is closer to current typical building designs, which often have vision glazing areas in excess of 60%. 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 account 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

[5] Except that the WSEC does not specifically mention plastic panels and the threshold of glass in doors is not specified.

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.

Figure 1. This building has a 100% glazed wall, but 50% of the wall area is vision glass (reflective and transparent) and 50% of the area is spandrel glass (reflective and opaque).

IMPACT OF GLAZING ON ENERGY

Why does the energy code care about thermal performance of 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.

There is an optimum fenestration area that minimizes the energy consumption in buildings but it is building- and envelope-specific. And depending on occupancy, it may or may not be climate-specific. Determining the optimum area requires whole-building energy simulation (commonly called energy modeling). The key to finding the optimum is to realize that there are trade-offs to be made between synergistic but competing design objectives. For example[6], in buildings with high internal heat loads, such as in typical commercial buildings, the relationships are:

1. Decrease window area or its solar transmission and cooling energy use is decreased; and
2. Increase window area or its daylight transmission and lighting energy use and associated heat gains are decreased.

The trade-offs apply to the building's perimeter, and are actually independent of climate. In both Chicago and Houston, the optimum fenestration area is 15% of the gross wall area for double-pane clear windows and daylighting controls (U = 0.60, SHGC = 0.6, and VT = 0.63)[7]. In the same cities, the optimum fenestration area jumps to 45% for triple-pane, clear low-e windows with overhang and daylighting controls (U= 0.20, SHGC = 0.22, VT = 0.37). However, it should be noted that these percentages were determined from energy simulation that ignored heat loss at thermal bridges. Therefore, we caution designers in applying these results blindly to all buildings. It would be instructive to reproduce the referenced study while also taking heat loss at thermal bridges into account.

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 code mandated value of 0.40 Btu/h·ft^2·°F (per the 2009 WSEC). And 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.

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[6] Example quoted from *High Performance Building Façade Solutions*, Lawrence Berkeley National Laboratories, http://lowenergyfacades.lbl.gov/concepts.html. Original source is Johnson, R., R. Sullivan, S. Nozaki, S, Selkowitz, C. Conner, and D. Arasteh. 1983. *Building Envelope Thermal and Daylighting Analysis in Support of Recommendations to Update ASHRAE/IES Standard 90.1*, Battelle Pacific Northwest Laboratories, Richland, WA.

[7] U is U-factor (thermal transmittance) and it includes the effects of framing but not the interface between framing and adjacent constructions, SHGC is solar heat gain coefficient, and VT is visible transmittance.

CASE STUDY ON MAXIMIZING FENESTRATION AREA

The case study building is a 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 (see **Figure 2**). The gross wall area is 83,809 ft^2. As Figure 2 shows, 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.

Starting with a code-matching building that has 40% vision glazing and opaque walls with R-19 batt insulation and R-8.5 continuous insulation, the target heat loss rate (UA) is 14,991 Btu/h·°F (of this, 2,841 Btu/h·°F is for the opaque envelope, and 12,150 Btu/h·°F is for fenestration)[8]. The relative UA of the fenestration compared to the opaque portion of the envelope shows that 81% of the heat loss is through the fenestration (12,150/14,991 × 100% = 81%). That leaves a very small percentage of the opaque wall heat loss that can be traded-off. And even a better fenestration U-factor will not change that fact that most of the heat loss is through the fenestration.

At this point the project design team was confident that a fenestration U-factor of 0.35 Btu/h·ft^2·°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. Note that this glazing system already has a much better U-factor than the code maximum U-factor of 0.40. By incrementally increasing the thermal performance of the glazed spandrel assembly (expressed as 1/U, or the "overall effective R-value"), we determined a range of maximum allowable fenestration areas as shown in **Figure 3**. 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-30. With 50% fenestration, the proposed UA is 14,964 Btu/h·°F (of this, 1,714 Btu/h·°F is for the opaque envelope, and 13,250 Btu/h·°F is for fenestration). Thus the relative UA of the fenestration compared to the opaque portion of the envelope shows that now 88% of the heat loss is through the fenestration (compared to 81% for a code-matching building). However, the architect felt that 50% glazing would not meet their design goal for large expanses of floor-to-ceiling vision glass, so we explored other options for increasing the fenestration area.

[8] Calculations were made using the *2009 Nonresidential Energy Code Compliance Forms* from the Northwest Energy Efficiency Council, http://www.neec.net/energy-codes/.

Figure 2. The case-study building is an all-glass high rise-residential building.

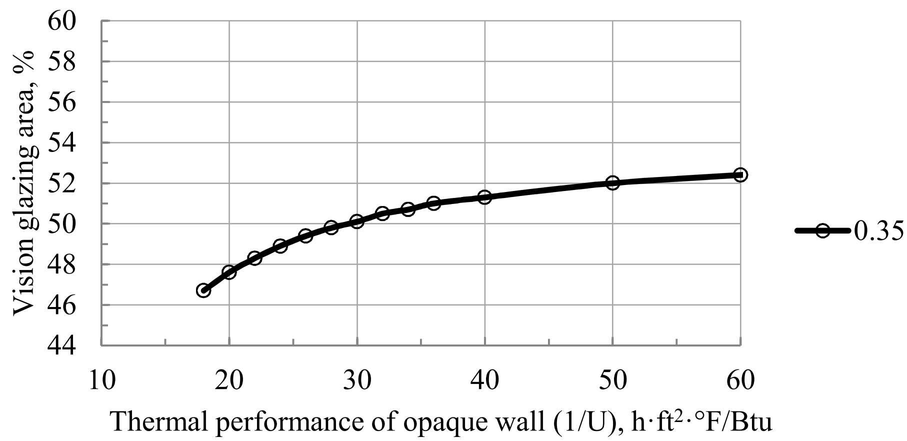

Figure 3. For a given fenestration U-factor of 0.35 Btu/h·ft^2·°F, the maximum allowable fenestration area increases as the overall effective R-values of the opaque wall (that is, the glazed spandrel assembly) increases but it approaches a limit of approximately 52% of the gross wall area.

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, we calculated the maximum allowable fenestration area for a range of fenestration U-factors ranging from 0.31 to 0.35 Btu/h·ft^2·°F in 0.01 increments. **Figure 4** shows the resulting required thermal performance of the glazed spandrel assembly for a given fenestration U-factor. The results show that very significant improvements to thermal performance of the fenestration system would be required to increase the maximum allowable fenestration area. But even with a U-factor of 0.31 and an overall effective R-value of R-30, the maximum allowable fenestration area is only about 57%. But based on the project's budget and technical constrains, 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. The glazed spandrel assembly is shown in **Figure 5**. Two-dimensional (2D) thermal modeling[9] 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 as shown in **Figure 6**.

[9] THERM Finite Element Simulator, version 6.3.45. 2012. Regents of the University of California. Developed and maintained by U.S. Department of Energy, Lawrence Berkeley National Laboratory.

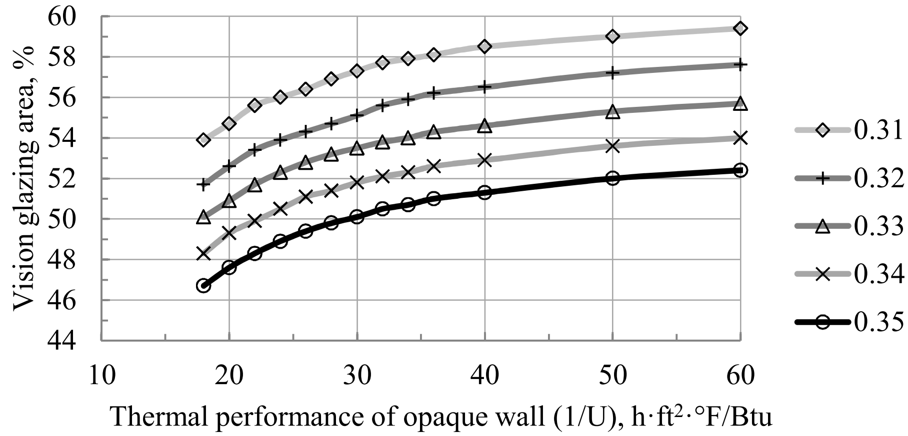

Figure 4. Maximum allowable fenestration area for a given thermal performance of the opaque wall (that is, the glazed spandrel assembly) assuming fenestration U-factors in the range of 0.35 to 0.31 Btu/h·ft^2·°F.

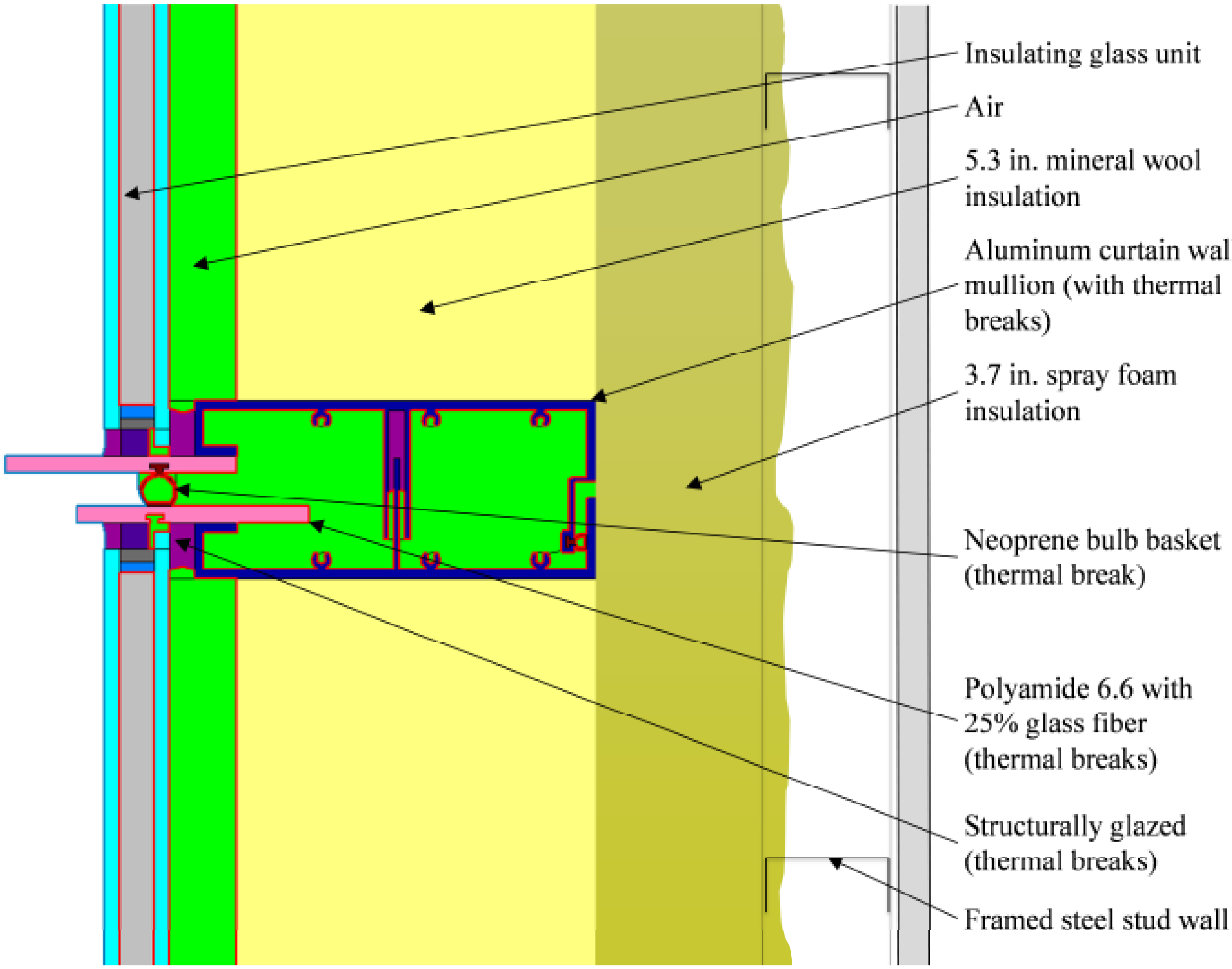

Figure 5. The glazed spandrel assembly has a 2D overall effective R-value (1/U) of 33 h·ft^2·°F/Btu (the figure shows a horizontal cross-section through a vertical mullion).

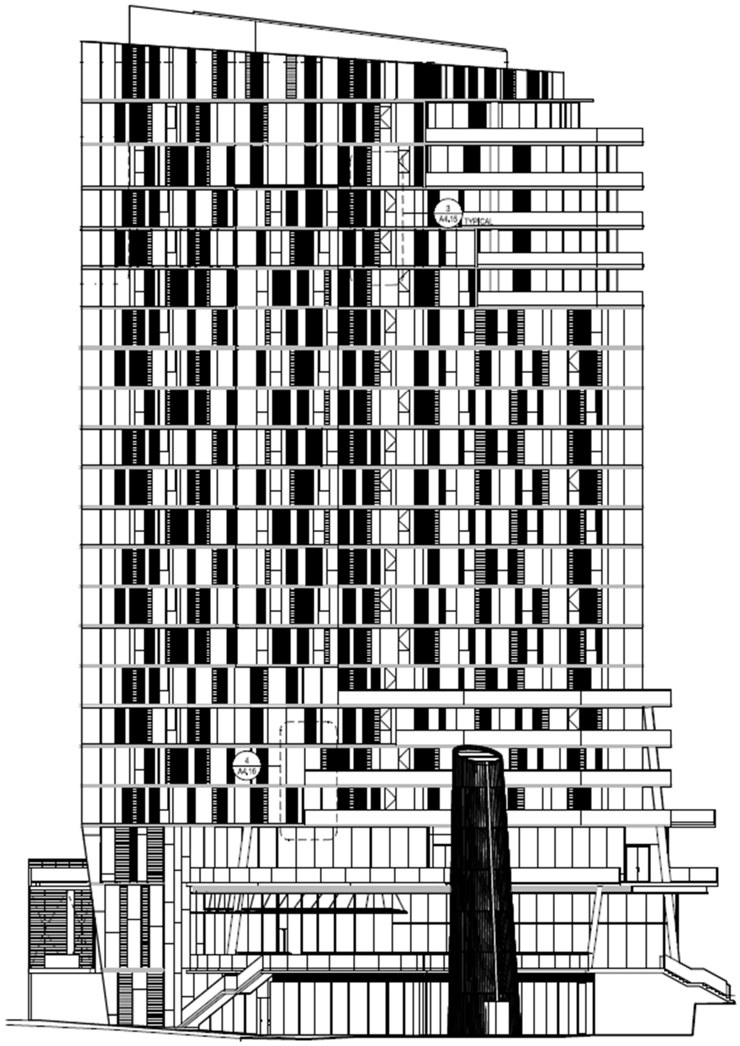

Figure 6. The final design will consist of a combination of vertical vision and opaque glazing to meet the calculated maximum fenestration area of 51%.

ENERGY CODES AND REALITY

The case-study above was based on overall effective R-values and accounted for thermal bridging as required by energy code. Standard practice in North America to account for thermal bridging within the building envelope 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:

- The belief that details do not have a significant impact on the overall building envelope performance and on whole building energy use because they comprise a small area compared to the total envelope area.
- 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.
- The lack of comprehensive thermal transmittance data for standard details.

However, recent work[10] accounting for 3D heat flow through details 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 (refer to footnote 10 for reference). Realistic expectations of building envelope performance are necessary to make informed decisions related to building energy efficiency.

3D heat loss through curtain wall systems is very significant and should not be ignored. For example, using the results of 3D thermal modeling such as that shown in **Figure 7**, installed insulation with a nominal R-value of R-33 results in an assembly with an overall effective R-value of about 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 8**. With conventional materials and a typical "good" thermally broken curtain wall system, the overall effective R-value will be in the range of R-5 to R-9. However, with new materials such as vacuum insulated panels (about R-40 per inch) and non-metal curtain wall framing, we are starting to see this limitation be exceeded.

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

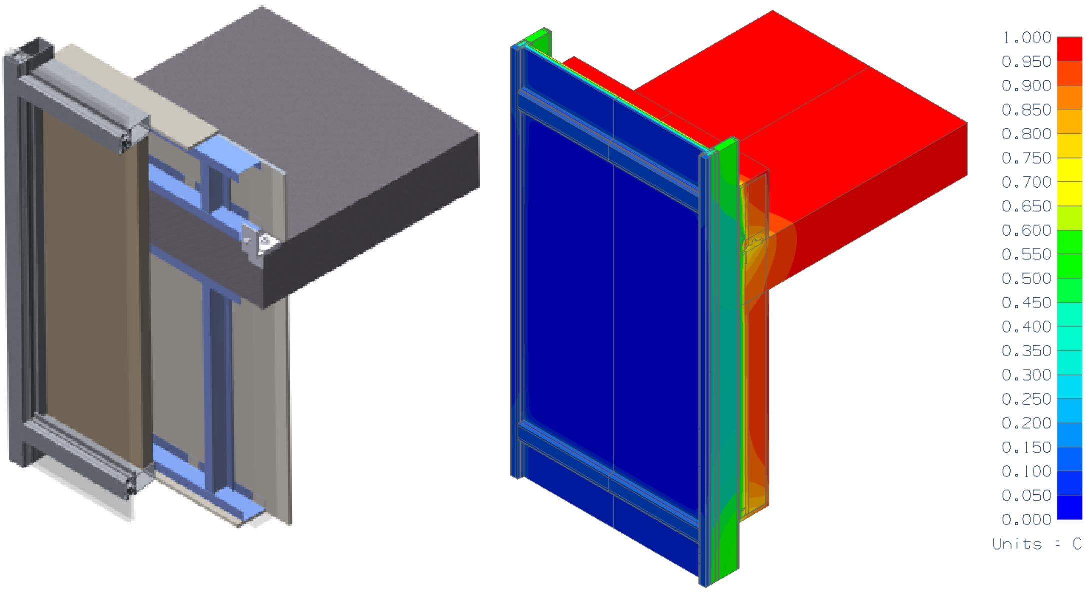

Figure 7. On the left, a typical opaque spandrel area of curtain wall with insulation in the back pan and spray foam insulation applied to the inside face of the backpan (through the steel framed stud wall). On the right the same detail showing the typical pattern of temperature distribution (normalized temperature index) as a results of three-dimensional heat loss (refer to footnote 10 for reference).

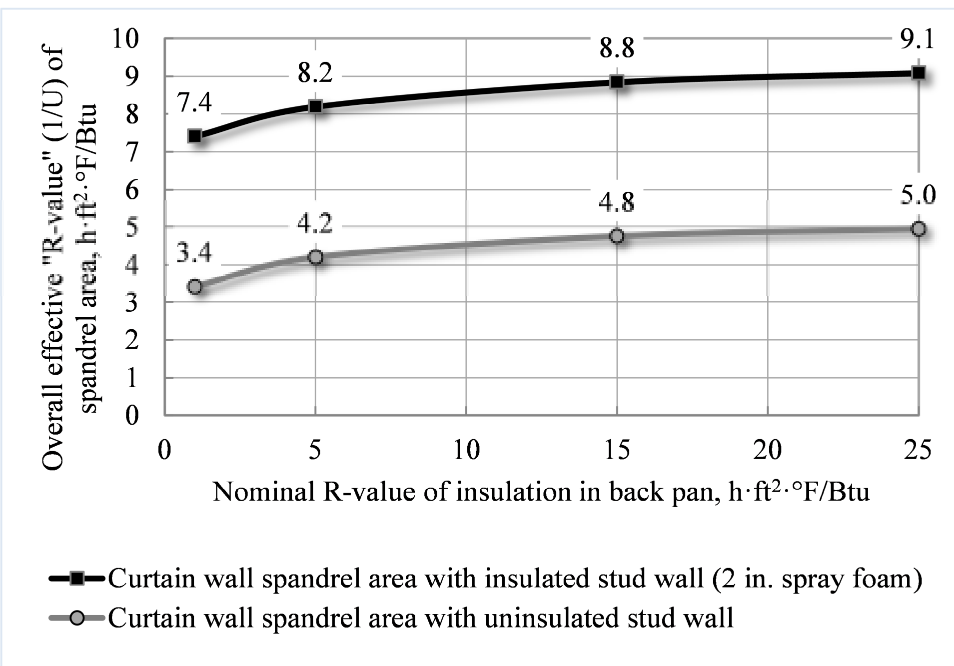

Figure 8. Overall effective "R-value" (1/U) of spandrel areas of curtain wall with a range of insulation in the backpan and either no insulation in the stud wall cavity or 2 in. of spray foam insulation in the stud wall cavity applied to the inside surface of the backpan (see footnote 7 for reference).

THE FUTURE OF ENERGY CODES

As challenging as the maximum fenestration area is, it will be even more challenging once the new 2010/2012 codes are adopted. Both the 2010 version of ASHRAE 90.1 and the 2012 version of the IECC have decreased the maximum fenestration area to 30% of the gross wall area[11]. 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. We expect that these stricter requirements in the energy code will eventually trickle down to LEED. Presently, to earn more than three points under Energy and Atmosphere Credit 1,[12] 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. One of the proposed changes for the next version of LEED (to be balloted June 1, 2013[13]) is to reference ASHRAE 90.1-2010 as the baseline. 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 Credit 1, exceeding 30% fenestration area will require even higher performing envelope 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 such as vacuum insulated glazing, vacuum insulated panels, electro-chromic glass, 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 envelope consultants will be even more crucial on these projects.

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[11] 2012 IECC, Section C402.3.1, *Maximum area*. However, the maximum allowable area is increased to 40% if certain exceptions are taken, such as using automatic daylighting controls.

[12] *LEED 2009 for New Construction and Major Renovations*. 2012. U.S. Green Building Council, Washington, DC.

[13] From a letter by the USGBG president, *Important News About LEED 2012: A Message from Rick Fedrizzi*. http://usgbcblog.blogspot.com/2012/06/important-news-about-leed-2012-message.html.