Design Implication of Glazing Ratio Restrictions

Medgar Marceau, PE
Member ASHRAE

Stéphane Hoffman, PE, PEng
Associate Member ASHRAE

ABSTRACT

The 2009 and 2012 International Energy Conservation Codes set the trend for significant improvements to the thermal performance of the building envelope. 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-factors and spandrel panel design will be presented, including a comparison of prescriptive versus performance-based approach to code compliance. Through a case study of a high-rise residential tower in the Pacific Northwest, this paper will present solutions involving both traditional glazing technology as well as emerging technologies that provide solutions that comply with one of the strictest energy codes in the nation. 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 includes multi-unit residential buildings over three stories. The scope is limited to the thermal performance of the building envelope. The case study is based on an analysis undertaken during the design of a multi-family high-rise residential building in western Washington state. Energy codes stipulate requirements for energy-efficient design and construction of commercial and residential buildings. In the United States there is no nation-wide energy code, except for federal buildings (CFR 10 Part 433 2012). So, code adoption and enforcement generally 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). A few states, including California, Oregon, and Washington, have their own "home-grown" energy codes (DOE 2013). 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 was permitted under the *2009 Washington State Energy Code* (WSEC), the paper will also discuss some of the requirements of the 2009 WSEC. At the time of writing, the state of Washington is in the process of switching to the IECC with state amendments.

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

Medgar Marceau *is a building science engineer and* ***Stéphane Hoffman*** *is a senior building science consultant at Morrison Hershfield, Bellevue, WA.*

(which is in climate zone Marine 4), exterior steel-framed walls enclosing a residential occupancy (other than single-family) are required to have fiberglass batt insulation with a minimum thermal resistance (R-value) of 3.3 $m^2 \cdot K/W$ (19 $h \cdot ft^2 \cdot °F/Btu$) plus continuous insulation with a minimum thermal resistance of 1.5 $m^2 \cdot K/W$ (8.5 $h \cdot ft^2 \cdot °F/Btu$) without thermal bridges other than fasteners (WSEC 2009). 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 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 90.1-2007 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 alternative," and "component performance building envelope option." 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 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. 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 also 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*).

Maximum Allowable Fenestration Area: 40%

With most states having implemented the 2009 IECC during the global financial crisis of 2007–2012, the so-called Great Recession (IMF 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 envelope. One of these new requirements is a 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 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 to 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 2009 WSEC is similar to the definition of fenestration in ASHRAE 90.1-2007 except that the 2009 WSEC does not specifically mention plastic panels and the threshold of glass in doors is not specified. 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 2009 WSEC—essentially comes down to a limit on the area of *vision* glass. Fenestration area is all areas (including frame) in the building envelope 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 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

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).

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-factor of the opaque wall area—be it spandrel glass or some other opaque cladding systems—meets or exceeds the overall U-factor 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—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 address 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. According to Johnson (1983), 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. These windows have thermal transmittance (U-factor) 3.41 $W/m^2 \cdot K$ (0.60 $Btu/h \cdot ft^2 \cdot °F$), solar heat gain coefficient (SHGC) 0.6, and visible transmittance (VT) 0.63. The U-factor of fenestration products includes the effects of framing but not the interface between framing and adjacent constructions. In the same cities, the optimum fenestration area jumps to 45% for triple-pane, clear low-e windows with overhang and daylighting controls. These windows have U-1.14 $W/m^2 \cdot K$ (0.20 $Btu/h \cdot ft^2 \cdot °F$), 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-factors significantly below the 2009 WSEC mandated value of 2.27 W/m^2·K (0.40 Btu/h·ft^2·°F). 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-factors 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 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 as shown in Figure 2. The gross wall area is 7786 m^2 (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 of forests, lakes and sound, mountain ranges, and snow-capped volcanoes, 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 m^2·K/W (R-19 h·ft^2·°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 envelope, 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 envelope 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. And even 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/m^2·K (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 for the vision glazing. Note that this glazing system already has a much better U-factor than the code maximum U-factor of 2.27 W/m^2·K (0.40 Btu/h·ft^2·°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 3. For example, to get to a 50% fenestration area, the glazed spandrel assembly would have to have an over-

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

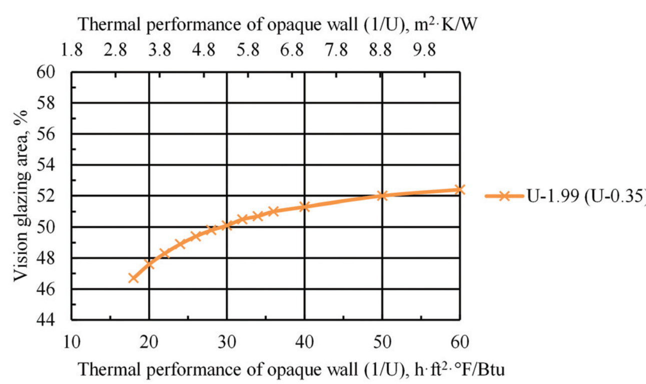

Figure 3 *For a given fenestration U-factor of 1.99 W/m^2·K (0.35 Btu/h·ft^2·°F), the maximum allowable fenestration area increases as the overall effective R-value of the opaque wall (that is, the glazed spandrel assembly) increases but it has diminishing returns after about 51% of the gross wall area.*

all effective R-value of about R-5.3 $m^2 \cdot K/W$ (R-30 $h \cdot ft^2 \cdot °F/Btu$). 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 envelope, 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 envelope shows that now 89% 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.

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 $W/m^2 \cdot K$ (0.31 to 0.35 $Btu/h \cdot ft^2 \cdot °F$) in 0.06 $W/m^2 \cdot K$ (0.01 $Btu/h \cdot ft^2 \cdot °F$) increments. The resulting required thermal performance of the glazed spandrel assembly for a given fenestration U-factor is shown in Figure 4. 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 1.76 $W/m^2 \cdot K$ (0.31 $Btu/h \cdot ft^2 \cdot °F$) and an overall effective R-value of R-5.3 $m^2 \cdot K/W$ (R-30 $h \cdot ft^2 \cdot °F/Btu$), the maximum allowable fenestration area is only about 57%. But based on the project's budget and technical constraints, 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 (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 as shown in Figure 6.

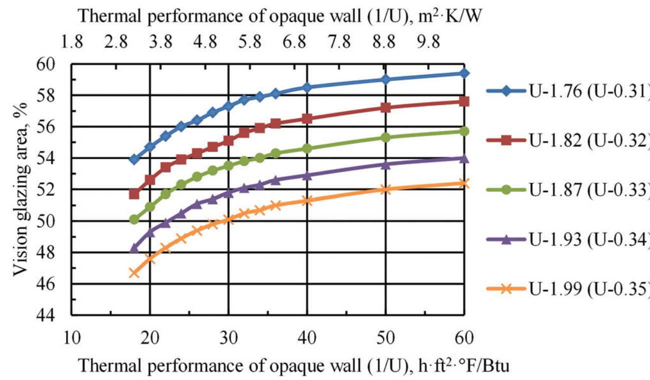

Figure 4 *Maximum allowable fenestration area for a given thermal performance of the opaque wall (that is, the glazed spandrel assembly) assuming fenestration U-factors in the range of 1.99 to 1.76* $W/m^2 \cdot K$ *(0.35 to 0.31* $Btu/h \cdot ft^2 \cdot °F$*).*

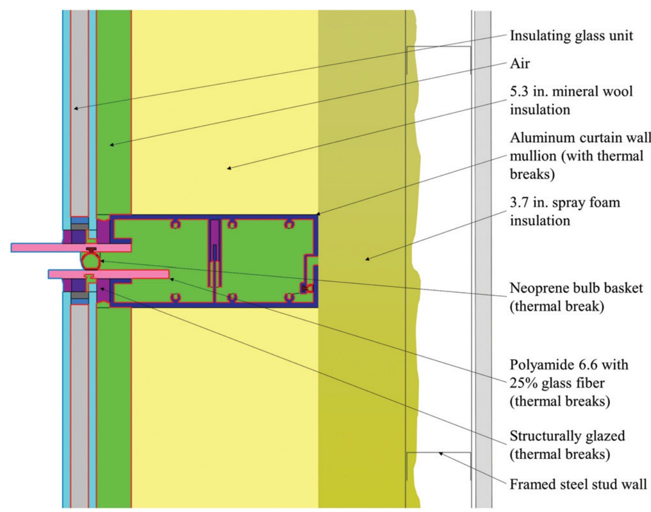

Figure 5 *The glazed spandrel assembly has a 2D overall effective R-value (1/U) of 5.8* $m^2 \cdot K/W$ *(33* $h \cdot ft^2 \cdot °F/Btu$*). The figure shows a horizontal cross-section through a vertical mullion.*

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 Standard 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 envelope 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 close 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 are no longer sufficient energy savings to allow for a significant increase in glazing area. Going forward on most projects the building envelope 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.

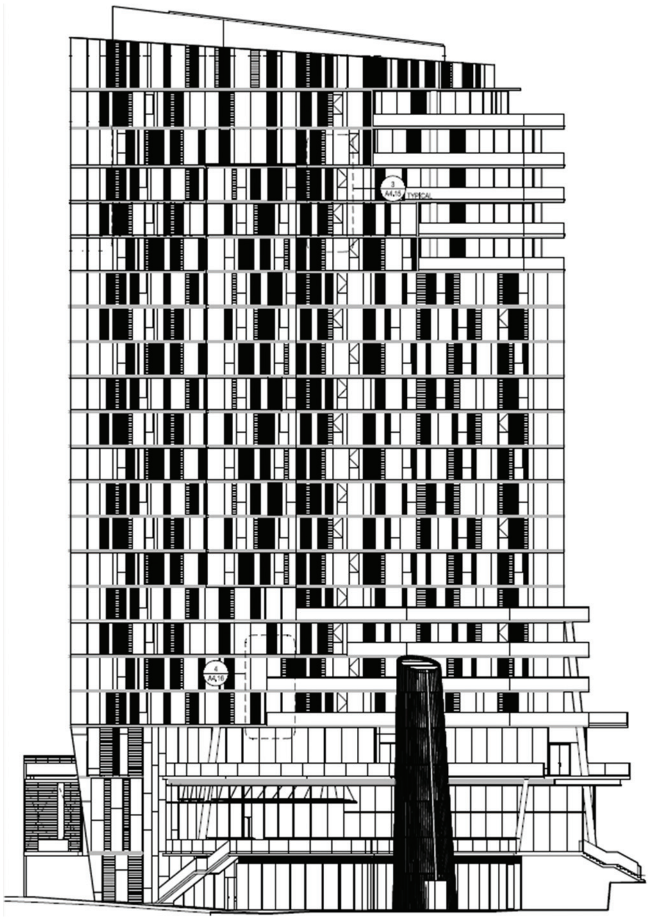

Figure 6 *The final design will consist of a combination of vertical vision and opaque glazing to meet the calculated maximum fenestration area of 51%.*

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 is 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-factor of 1.82 $W/m^2 \cdot K$ (0.32 $Btu/h \cdot ft^2 \cdot °F$) 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-factor of 2.38 $W/m^2 \cdot K$ (0.42 $Btu/h \cdot ft^2 \cdot °F$). The opaque spandrel areas had a better than code U-factor of 0.27 $W/m^2 \cdot K$ (0.048 $Btu/h \cdot ft^2 \cdot °F$) based on an insulated backpan design with 100 cm (4 in.) of spray foam insulation applied across the interior face of the system. The U-factor of insulated slab-edge covers was 0.50 $W/m^2 \cdot K$ (0.089 $Btu/h \cdot ft^2 \cdot °F$). 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.

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 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:

1. 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.
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 (Morrison Hershfield LTD 2011). 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-5.8 (R-33) results in an assembly with an overall effective R-value of about R-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 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-0.9 to R-1.6 (R-5 to R-9). However, with new materials such as vacuum insulated panels—about R-7 (R-40) per inch—and non-metal curtain wall framing, the authors are beginning to see these limitations be exceeded.

THE NEED FOR ALTERNATIVE ASSEMBLIES

As demonstrated by the two case studies, glazing ratios in the range of 50% (that is, ten percentage points above the code prescriptive maximum of 40%) can be achieved using the current nominally thermally-broken frames and good quality dual glazed units combined with highly insulated opaque wall assemblies. However, those projects seeking even higher glazing areas or those seeking energy savings exceeding the code baseline will have to turn to higher performing assemblies.

There are existing high performance technologies on the market that have been used on projects where extreme climates or extreme interior environmental conditions dictated a high performance system. These include 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 coatings in and on glazing units. Combined, these technologies can deliver a U-factor below 1.70 $W/m^2 \cdot K$ (0.30 $Btu/h \cdot ft^2 \cdot °F$). To date the cost premiums associated with these assemblies has limited their applications. With the demands of the new energy code 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 that 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: traditionally 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 photochromic glass can be used to significantly reduce solar heat gain beyond what can be

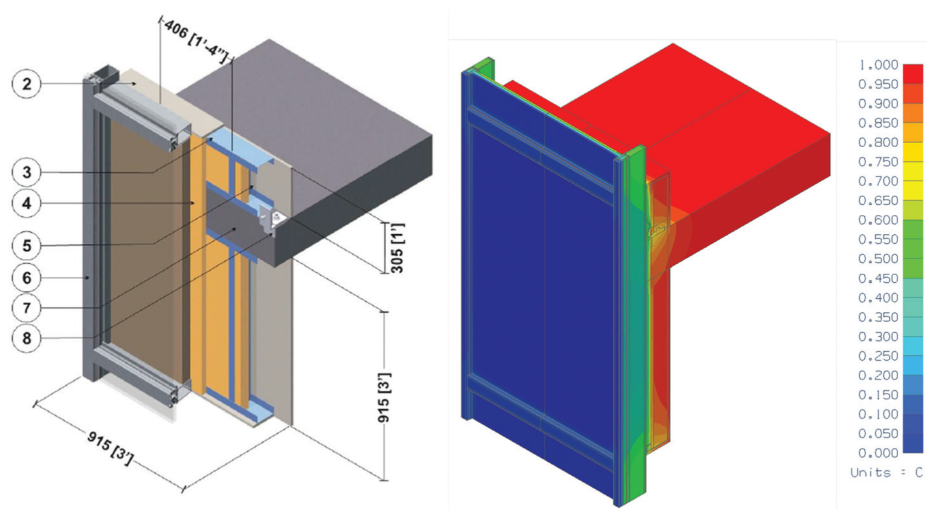

Figure 7 *On the left, a typical opaque spandrel area of curtain wall with insulation in the backpan and spray foam insulation applied to the inside face of the backpan (through the steel framed wall). On the right, the same detail showing the typical pattern of temperature distribution (normalized temperature index) as a result of three-dimensional heat loss (Morrison Hershfield LTD 2011).*

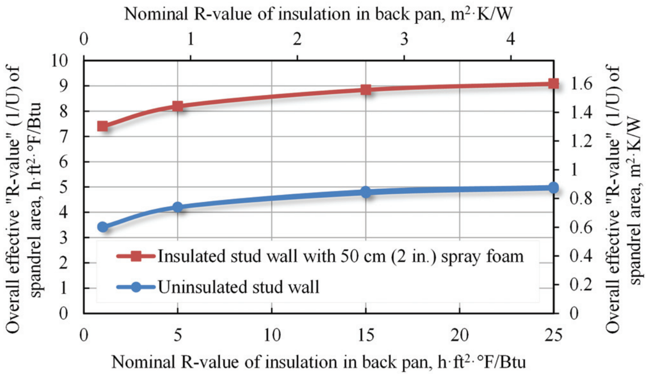

Figure 8 *Overall effective R-value (1/U) of spandrel areas of curtain wall with a range of insulation in the backpan and either no insulation in the stud wall cavity or 2 in. of spray foam insulation in the stud wall cavity applied to the inside surface of the backpan (Morrison Hershfield LTD 2011).*

achieved with fixed shading devices. Lastly, innovative integrated photovoltaic systems are generating electricity on-site 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

Returning to our original case study demonstrates the impact of some of these technologies. Assuming the project budget could have afforded a triple glazed system with high performance thermal breaks U-factor of 1.42 W/m^2·K (0.25 Btu/h·ft^2·°F) compared to the code maximum U-factor of 2.27 W/m^2·K (0.40 Btu/h·ft^2·°F), we determined a maximum allowable glazing ratio of 72% would have been attainable with the same R-5.8 (R-33) spandrel assembly. This demonstrates that improving the thermal performance of the glazing system has the single biggest impact for increasing the glazing ratio above the prescriptive requirement.

Alternatively, using the case study's glazing assembly with a U-factor of 1.99 W/m^2 K (0.35 Btu/h·ft^2·°F) and introducing a vacuum insulated spandrel panel in the glazing pocket of the spandrel area would have replaced the backpan insulation and stud cavity insulation. Alternatively it could have raised the opaque wall value to R-12.3 m^2·K/W (R-70 Btu/h·ft^2·°F) allowing a glazing ratio of 54%. This demonstrates that the super insulated spandrel assembly developed for the case study can be more efficiently achieved; however, even with highly insulating materials, increasing the thermal performance of the opaque wall has limited impact in terms of increasing the glazing ratios.

Finally, one must consider what is the goal in increasing the glazing ratio? If increase daylighting potential is the goal, there may be more efficient ways to achieve it. Combining the case study's glazing assembly with a U-factor of 1.99 W/m^2·K (0.35 Btu/h·ft^2·°F) in a 60/40 split with a translucent insulated fiberglass panels insulated with nanogel infill with a U-factor of 0.11 W/m^2·K (0.02 Btu/h·ft^2·°F) would have allowed an 82% glazing ratio with the same opaque wall R-value of 5.8 m^2·K/W(33 h·ft^2·°F/Btu).

CONCLUSION: 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 ASHRAE 90.1-2010 and the 2012 IECC have 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. We expect that these stricter requirements in the energy code will eventually trickle down to LEED. One of the proposed changes for the next version of LEED for New Construction is to reference ASHRAE Standard 90.1-2010 as the baseline design (LEED 2013). 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 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 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 buildings where 50% or more of the floor plate benefits from daylighting. 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.

REFERENCES

ASHRAE. 2007. *ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings except Low-Rise Residential Buildings*. Atlanta: ASHRAE.

ASHRAE. 2010. *ANSI/ASHRAE/IESNA Standard 90.1-2010, Energy Standard for Buildings except Low-Rise Residential Buildings*. Atlanta: ASHRAE.

CFR 10 Part 433. 2012. Code of federal regulations, Energy efficiency standards for the design and construction of new federal commercial and multi-family high rise residential buildings, Title 10, CFR Part 433. Washington: U.S. National Archives and Records Administration. http://www.ecfr.gov/. Retrieved 19 February 2013.

DOE. 2013. Status of state energy code adoption maps, U.S. Department of Energy Building Energy Codes Program, http://www.energycodes.gov/status-state-energy-code-adoption. Retrieved 21 February 2013.

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

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

IMF. 2012. *World economic outlook: a survey by the staff of the International Monetary Fund*. Washington: International Monetary Fund. http://www.imf.org/external/pubs/ft/weo/2012/01/pdf/text.pdf. Retrieved 19 February 2013.

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*. Richland, WA: Battelle Pacific Northwest Laboratories.

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.

Morrison Hershfield Ltd. 2011. *Thermal Performance of Building Envelope Construction Details for Mid- and High-Rise Buildings*. ASHRAE RP-1365. Atlanta: ASHRAE.

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