Reconsidering the Approach towards Determining Overall Building Enclosure Thermal Performance for Code Compliance

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ABSTRACT

With each building code update and revision of ANSI/ASHRAE/IESNA Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings, *and* ANSI/ASHRAE Standard 90.2, Energy-Efficient Design of Low-Rise Residential Buildings, *building enclosure thermal performance criteria are becoming more stringent to reduce building energy consumption. It is well understood that two-dimensional heat transfer must be considered in determining the U-factor of certain building enclosure assemblies (e.g., steel-stud-framed walls with batt insulation). However, the current approach to energy code calculations lacks guidance and/or requirements for*

- *Whole-wall U-factors versus clear-wall U-factors (Kosny and Desjarlais 1994), including inside and outside corners, additional framing around windows and doors, and top and bottom track for framed walls*
- *Including two- and three-dimensional heat transfer effects between assemblies (e.g., the effect of a cantilevered concrete slab on the wall U-factor, steel shelf angles)*
- *U-factors of fenestration products as installed, rather than* NFRC Standard 100, Procedure for Determining Fenestration Product U-Factor, *values for standard-sized products, which is intended for side-by-side comparison of fenestration product, and are not typically representative of those actually used on most projects*

Such simplifications can result in overestimating building thermal performance. With the ultimate goal of analyzing and demonstrating realistic energy conservation, rather than conservation predicted by oversimplified models, it is imperative that designers consider whole-wall R-values, two- and three-dimensional (2D and 3D) interaction of assemblies, and actual glazing assembly U-factors. This paper discusses and presents how current methods for U-factor calculations are insufficient through the use of examples, and proposes more detailed methods for calculating U-factors that include recognition of construction practices to be considered future revisions of energy codes and ASHRAE standards. Previously, the lack of software and computing power made conducting more detailed calculations including 2- and 3D thermal analysis unrealistic. However, today the necessary software and computing power exists, making it feasible to require more detailed calculations.

INTRODUCTION

Energy conservation in buildings is at the forefront of our industry. Conservation goals continue to be adopted, target U-factors continue to be lowered, and jurisdictions having authority are looking more closely at enforcing their energy codes. This is good: people are paying attention.

Adopting energy conservation goals and enforcing them is certainly a significant step in the right direction. However, lowering target U-factors alone, without taking a closer look at current practices for calculating U-factors, is insufficient. In fact, "calculating U-factors" is actually a misnomer because, for the most part, assembly U-factors are selected from tables included within ANSI/ASHRAE/IESNA Standard 90.1,

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Energy Standard for Buildings Except Low-Rise Residential Buildings. As an example, in *ASHRAE Standard 90.1*, U-value tables, steel-stud-framed wall assembly U-factors are "clear-wall" U-factors (Kosny and Desjarlais 1994; Christian and Kosny 1996), where thermal bridging elements are considered at equal vertical spacing, but all the additional framing at corners, horizontal tracks, and bundled studs at window or door openings are ignored. Herein lies the problem: there is very little recognition in our energy codes that clear wall U-factors can significantly overestimate building thermal performance, and many U-factor calculations fail to consider actual building construction, or whole wall U-factor (Kosny and Desjarlais 1994; Christian and Kosny 1996). Essentially, two very different building constructions can have the same clear-wall U-factor, but significantly different whole-wall U-factors. Hence, building thermal performance can be significantly overestimated. Lowering target U-factors without providing better guidance on how to determine more realistic U-factors does not make sense. Ultimately, as practitioners are forced to undertake more detailed calculations, the obvious thermal shortcomings of many current construction practices will hopefully become more widely recognized and better thermally performing building details and construction practices will emerge as the minimum standard. Kosny and Desjarlais (1994) summarized it as follows:

> These techniques for quantifying the thermal performance of wall systems appear to have obvious shortcomings. Building envelope subsystems such as window and door frames, along with the additional structural support that these subsystems require, are ignored. The impact of construction details such as wall corners, and floor and ceiling interfaces with the wall system are overlooked. These simplifications can lead to errors in determining the energy efficiency of the building envelope. In addition, these techniques de-emphasize the importance of energy-efficient design of the wall details. Since envelope system designers cannot claim performance benefits due to innovative detailing, the building community is less likely to concern itself with novel detailing concepts.

The current approach of determining overall building thermal performance—essentially, how we calculate energy code compliance as implied in standards like *ASHRAE Standard 90.1*—is no longer sufficient. The purpose of this paper is twofold: first, demonstrate how current methods for U-factor calculations are insufficient through the use of examples; and second, propose more detailed methods for calculating U-factors that include recognition of construction practices. Hopefully, more detailed approaches for determining U-factors will soon be required, particularly for energy code trade-off compliance approaches.

In the following section, examples of various conditions that are not typically considered or addressed are presented. Specifically, examples related to (1) steel-stud-framed walls assemblies, (2) wall-to-floor interaction, (3) cladding attachment and support, and (4) fenestration are presented. In our
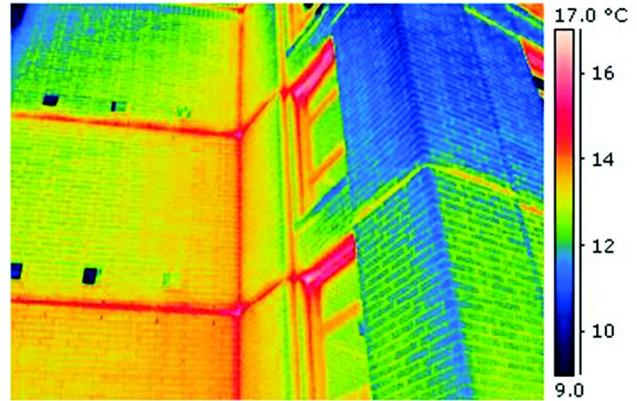
Figure 1 *Thermographic image of building.*

experience, these conditions are overlooked either due to a lack of understanding of building thermal performance or due to lack of guidance in our codes and standards on how to consider these conditions in calculating U-factors.

U-FACTOR CALCULATIONS OF CONSTRUCTION REALITIES

Not surprisingly, many buildings include significant, repetitive thermal bridges that undoubtedly have a negative impact thermal performance and energy use (Kosny and Desjarlais 1994). Using a thermographic camera, it is easy to quickly identify these areas on constructed buildings. For example, Figure 1 is a thermographic scan of the exterior of a brick veneer wall. Evident in the scan are thermal bridges at floors, window deflection heads, brick veneer shelf angles, the inside corner, etc.

Thermal bridges across the building enclosure are not a new topic. In fact, much research and publications on the topic exist (Kosny and Desjarlais 1994; Barbour and Goodrow 1995; Christian and Kosny 1996; Ullet et al. 1995; Kosny et al. 1997; McGowan and Desjarlais 1997; *NFRC Standard 100, Procedure for Determining Fenestration Product U-Factor*). However, we do not see the knowledge transferred into our codes and standards for energy conservation.

The impact of construction realities on U-factors is demonstrated through seven examples listed below under the following subsections:

- Steel-stud wall assemblies
  - Example 1: Steel-stud-framed infill walls
  - Example 2: Load-bearing steel-stud-framed walls
- Wall-to-floor interfaces
  - Example 3: Exposed floor slab edge at steel-stud-framed wall

- Example 4: Insulated floor slab edge at steel-stud-framed wall
- Cladding attachment and support
  - Example 5: Brick veneer shelf angle
- Fenestration assemblies
  - Example 6: Window size and configuration
  - Example 7: Curtain-wall spandrel panel

Steel-Stud Wall Assemblies

Steel-stud wall assemblies are a very common construction used for both infill and load bearing assemblies. In almost all cases, these walls are sheathed with gypsum board on both the interior and exterior and insulated in one of three ways: (1) stud cavity insulation only, (2) combination of stud cavity insulation and continuous exterior insulation, or (3) empty stud cavity and only continuous exterior insulation. Also note that, depending on the cladding, the "continuous" exterior insulation is often also bridged by additional framing or support, and in fact is not truly continuous.

Thermal performance of steel-stud-framed wall assemblies, including the effect of thermal bridging of steel studs, is recognized and well documented in various publications including *ASHRAE Standard 90.1*. Specifically, Table A3.3 in *ASHRAE Standard 90.1* includes the U-factor of various configurations of steel-stud-framed assemblies with varying R-values of stud cavity insulation (R-0 to R-21) and continuous exterior insulation (R-0 to R-40), as well as various stud depths (nominal 3 1/2 in. and 6 in.) and spacing (16 in. and 24 in. on center). Note, however, that additional framing at corners, door and window rough openings, or horizontal tracks are not considered in the clear-wall U-factor presented in *ASHRAE Standard 90.1*'s Table 3.3.

In Table A3.3, a nominal 2 × 6 framed steel-stud wall assembly with studs at 16 in. on center and R-21 glass fiber batt insulation has a U-factor of 0.109 Btu/h·ft^2·F (R-9.2 h·ft^2·F/Btu); with the studs spaced at 24 in. on center, the U-factor is 0.090 (R-11.1). It is worthwhile to point out the significant reduction from R-21 because the steel studs create a thermal bridge, which is well documented in the literature (Barbour and Goodrow 1995; Ullet et al. 1995; Kosny and Christian 1997; McGowan and Desjarlais 1997). It is also well known that stud spacing has a significant impact on the U-factor of steel-stud wall assemblies that do not include continuous insulation, as is evident in the difference in U-factor between walls with studs at 16 in. versus 24 in. spacing. However, for calculating wall assembly U-factors for energy code compliance purposes, very little guidance is provided in *ASHRAE Standard 90.1* to account for the fact that walls include far more studs than simply those at regular spacing, except that other calculation methods are permitted for conditions not represented in the tables (e.g., those presented in other ASHRAE publications such as ASHRAE [2009]). The following two examples demonstrate this significant oversight.

Example 1: Steel-Stud-Framed Infill Walls. Infill walls are defined as non–vertical-load-bearing and are typical for buildings with concrete- or steel-framed superstructures. In this application, studs spaced at 16 or 24 in. on center are very typical. However, most buildings do not have long expanses of walls without windows, doors, corners, or interior walls that intersect exterior walls, and all these conditions require additional framing. The additional framing at each opening, each inside and outside corner, interior wall intersection, and top and bottom tracks can further reduce the overall U-factor of the wall assembly, depending on the insulating strategy. In our experience, however, the additional framing is rarely, if ever, considered in energy code calculations. We find that most practitioners conducting energy code compliance calculations simply assume that studs are spaced at 16 or 24 in. and ignore the additional framing. It is not clear whether the additional framing is not considered because (1) those conducting the calculations are not aware of the additional framing or its impact or (2) codes and standards are relatively silent on the need to consider the additional framing. We believe the latter is the case, since a detailed calculation of the building's whole-wall R-value would likely demonstrate the buildings are not energy code compliant in a strict sense.

With studs spaced at 24 in. on center, the framing represents approximately 7% of the wall area, whereas with studs spaced at 16 in., the framing represents approximately 10% of the wall area. In both cases, these values do not including top and bottom tracks, since an assumption for the wall height is required to include the tracks into the wall area calculation. Consider a hypothetical concrete framed building with 10 ft floor-to-ceiling height and 4 ft by 4 ft punched windows spaced at a regular interval of 8 ft. Assuming studs at 24 in. in the field of walls, a double top track under floor slabs to accommodate deflection, a single bottom track, double studs at each window jamb, a double nested stud at window sills and window heads, we calculate the following:

- Total wall area of 80 ft^2 (10 ft × 8 ft)
- Total window area of 16 ft^2 (4 ft × 4 ft)
- Total opaque wall area of 64 ft^2
- Total framing area of 36.8 ft^2
- Percentage of framing of opaque wall area of 57.6%

Including additional corners or interior wall intersections obviously will increase the percentage of framing.

Assuming the wall assembly includes only interior gypsum wall board and exterior gypsum board sheathing, we estimate the wall U-factor to be 0.155 (R-6.5) using an area-weighted calculation of the various 2-D U-factor calculations (center stud, double jamb stud, bottom track, top track, nested studs at head and sill). If we modeled a wall section where the stud width represented 57% of the wall width modeled in 2-D, the effective U-factor would be in the range 0.255 (R-3.9). Either approach is significantly lower than the ASHRAE tables indicate. We should note that *ASHRAE Standard 90.1* does include an option in section 9 to use other means to calculate the U-factor of wall assemblies that are not represented in the appendices, such as 2- and 3D thermal analysis, but

Figure 2 *Photo of equinox wall assembly.*

provides no guidance on how to approach the analysis, leaving much room for interpretation or worse, oversight.

Example 2: Load-Bearing Steel-Stud-Framed Walls. Where steel-stud-framed walls are vertical-load-bearing, the actual amount of framing can be significant. Figure 2 is a photo of an insulated load bearing steel stud wall for a 6-story building. We count 21 studs in approximately 4 ft of wall area between two windows. We estimate the vertical stud framing accounts for approximately 71% of the wall area, not including the steel rim joist at each floor line or top and bottom tracks. Obviously, the U-factor of the wall shown in Figure 2 is affected by the quantity of framing. However, the effect of the additional framing on the wall U-factor is a function of the insulating strategy for these types of walls.

Referring to the wall depicted in Figure 2, the assembly consists, from interior to exterior, of

- 1/2 in. gypsum wallboard
- R-21 glass fiber batt insulation between 2 × 6 steel studs, where possible
- 5/8 in. thick gypsum board sheathing
- R-10 extruded polystyrene insulation
- Air space
- Brick veneer

For this project, the architectural drawings depict the stud spacing at 16 in. on center in the field of the wall, except where modified per the structural drawings. Assuming studs at 16 in. on center, the wall U-factor is 0.051 (R-19.6) per table A3.3 in *ASHRAE Standard 90.1*. Using THERM 5.2 (Finlayson et al. 2003), the wall assembly U-factor is 0.08 (R-12.5). Obviously, the unaccounted framing has a significant effect, even for walls with some continuous exterior rigid insulation. If the above-noted stud wall were empty (i.e., no batt insulation), the U-factor of the wall would be essentially the same given just the two gypsum layers, the empty stud space, the rigid insulation layer, and the surface films, which is in the order of R-12 (R-10 for the insulation, R-0.5 for each of the gypsum layers, and about R-1.0 total for the surface films). Thus, the batt insulation between the studs essentially provides no additional R-value for the above-noted wall, since the wall assembly U-factor is essentially the same without the batt insulation.

If the wall assembly did not include the continuous rigid insulation, the U-factor would be in the range of 0.255 (R-3.9), including the actual percentage of framing, as opposed to a U-factor of 0.109 (R-9.2), as listed in Table A3.3 for a wall with studs at 16 in. on center.

Wall-to-Floor Interaction

A portion of the opaque wall of multistory buildings is actually the edge of a floor slab assembly. Floor edges can represent a significant thermal bridge across the building enclosure, so it is critical to consider their thermal performance when evaluating whole-building performance. Although floor edges are often included in whole-building calculations, we find that little guidance exists on how to calculate the U-factor of floor edges. One method is to consider the floor edge as an independent element that does not have any thermal interaction with the wall assembly above or below and calculate the U-factor in one dimension. Alternatively, the thermal interaction of the floor edge with the wall assembly above and below can be considered. In the following two examples, both methods are demonstrated.

Example 3: Exposed Floor Slab Edge at Steel-Framed Wall. Consider the wall assembly in Example 1, with a clear floor height of 10 ft and an 8 in. thick concrete slab, depicted in Figure 3, ignoring any cladding. The slab edge represents 6.25% of the overall building wall area. Left uninsulated, the floor slab edge can significantly reduce the overall thermal performance of the building as demonstrated below.

Using an area-weighted 1D calculation and ignoring slab-to-wall thermal interaction, the composite U-factor of the wall and slab is 0.148 (R-6.8) assuming the steel-stud wall assembly U-factor is 0.109 (R-9.2), accounting for studs at 24 in. on center, and the slab edge U-factor is 0.73 (R-1.4).

Using THERM to include the slab-to-wall thermal interaction (2D calculation), the composite U-factor of the wall and slab is 0.152 (R-6.6) when we model the wall assembly above the floor as solid insulation with an equivalent U-factor, which includes the vertical framing (0.109) (similar to an effective conductivity or Keff approach [Enermodal Engineering Limited 1996]), the bottom track, and half the slab edge. Considering the slab-to-wall interaction, the composite U-factor increases approximately 3% over the area-weighted approach: not a significant difference. However, the impact of the floor slab in general is an increase in U-factor of approximately 36%, which is very significant.

Example 4: Insulated Slab Edge at Steel-Framed Wall. Uninsulated floor slab edges are relatively well recognized as an area of the building enclosure that requires consideration when
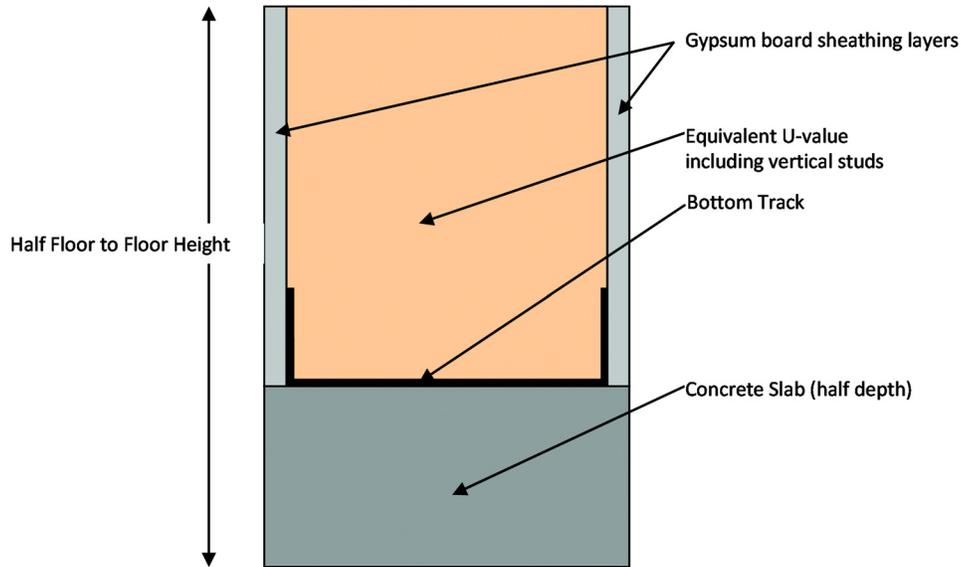
**Figure 3** *Typical uninsulated slab edge: floor-to-wall section.*
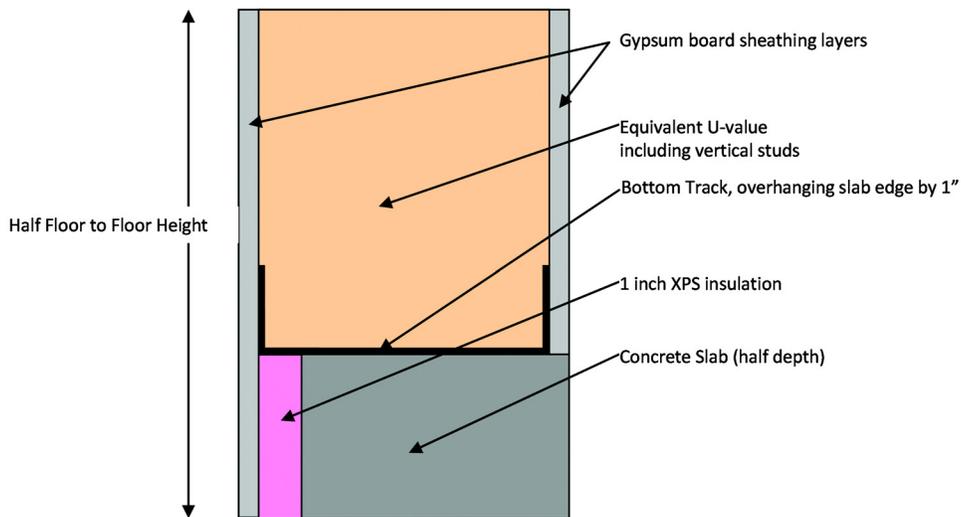
Figure 4 *Typical insulated slab edge: floor-to-wall section.*

looking at overall building thermal performance. As such, slab edges are sometimes insulated. Typically, the stud-framed wall is constructed to overhang the slab edge by 1 in., such that the edge of slab can be insulated and the exterior sheathing is run continuous over the slab edge, as depicted in Figure 4. Similar to Example 3, the composite slab and wall U-factor is calculated both with and without slab to wall interaction.

In this example, the stud-framed wall overhangs the slab edge by 1 in., the edge of slab is insulated with 1 in. of extruded polystyrene insulation (R-5), and the exterior sheathing is run continuous over the insulation.

Ignoring slab-to-wall interaction in an area-weighted calculation, the composite U-factor is 0.111 (R-9.0), assuming the slab edge U-factor is 0.142 (R-7.04) and the wall U-factor is 0.109 (R-9.2). In this example, insulating the floor slab edge results in a composite U-factor much closer to the wall U-factor using a 1D, area-weighted approach.

Using THERM to include the slab-to-wall thermal interaction, the composite U-factor of the wall and slab is 0.125 (R-8.0) when we model the wall assembly above the floor as solid insulation with an equivalent U-factor that includes the verti-
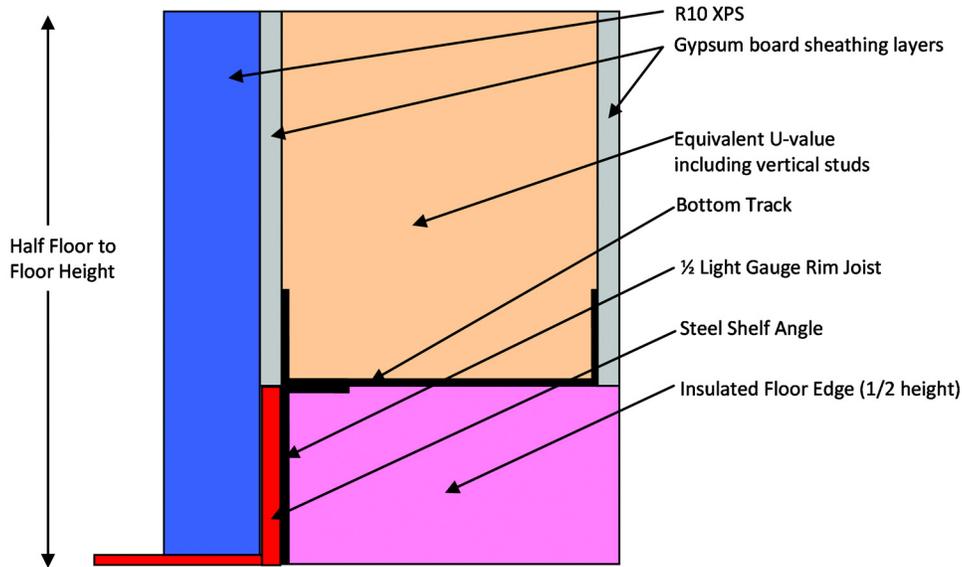
Figure 5 *Typical shelf angle at floor line.*

cal framing (0.109) (similar to a Keff approach), the bottom track, and half the slab edge with rigid insulation.

Including the slab to wall interaction, the composite U-factor increases by approximately 12% over the area-weighted approach U-factor of 0.111 (R-9). The slab-to-wall thermal interaction, even in an insulated slab edge condition, has a significant impact on the composite wall U-factor. In this scenario, the more detailed calculation method resulted in a higher U-factor, demonstrating the simplified approach is an overestimation. Note that we have also performed this calculation with 3D analysis software (HEAT 3D) and found similar results.

Cladding Attachment and Support

As previously mentioned, cladding attachment and support can also have an impact on the thermal performance of building walls and as such, must be considered in composite wall U-factor calculations. In Example 5, the effects of steel shelf angles that support brick veneer are considered.

Example 5: Brick Veneer Shelf Angle. Referring back to the wall assembly depicted in Example 2, the brick veneer is supported at each floor line with a steel angle, welded to the light-gage steel rim joist. Floor-to-floor height is 10 ft. Although the assembly includes continuous exterior rigid insulation, the insulation is interrupted at each floor line by the 1/2 in. thick horizontal leg of the steel angle, as depicted in Figure 5. Using THERM, we modeled the stud-framed wall assembly above the floor as solid insulation with an equivalent U-factor that includes the vertical framing (0.109) (similar to a Keff approach), the bottom track, half the rim joist, half the shelf angle horizontal leg, and the rigid insulation. Recall the U-factor for this wall assembly listed in *ASHRAE Standard 90.1* is 0.051 (R-19.6).

Including the floor line assembly and shelf angle, the composite U-factor is 0.069 (R-14.4), an increase of 35% over the ASHRAE 90.1 value of 0.051 (R-19.6).

We modeled the wall assembly above the floor with an equivalent U-factor of 0.40 (R-2.5) to account for the additional framing noted in Example 2. Recall that, with the additional framing, the wall U-factor is 0.080 (R-12.5). Including the floor line assembly and shelf angle, the composite U-factor is 0.095 (R-10.5), or 19% higher than without shelf angle effects. Essentially, Examples 2 and 5 demonstrate the composite wall U-factor is realistically 0.095 (R-10.5) versus 0.051 (R-19.6), an increase of 86% over the *ASHRAE Standard 90.1* value.

Interestingly enough, there are very good solutions to address thermal bridging at brick veneer shelf angles. In our practice, we often support the shelf angle on steel brackets space at 3 ft to 4 ft intervals, effectively holding the angle off the wall such that the rigid insulation can be continuous (except for at the bracket anchor points) behind the shelf angle. This could be a simple prescriptive requirement for all wall assemblies. The brackets effectively increase the composite wall U-factor by approximately 5% to 10%, depending on various factors.

Fenestration Assemblies

Fenestration generally represents the poorest thermally performing element of the building enclosure. Any increase or decrease in the fenestration U-factor can have a significant effect on the overall thermal performance of a building, especially for buildings with large glazing areas.

Recognizing the importance of realistic U-factor for fenestration, codes are moving towards requiring NFRC-certified values for fenestration products. Briefly, NFRC-certified products are required to have their thermal perfor-

mance measured in a full-scale test by an independent agency, and then a separate independent agency models the thermal performance using 2D analysis software and an area-weighted calculation using values from the 2D analysis. If the results of the physical testing and the modeling are within a prescribed limit, the window can then be NFRC certified. Additional thermal performance calculations of the certified fenestration product with different glazing packages need only be modeled to calculate the NFRC certified U-factor (i.e., no additional physical testing is required). Depending on the fenestration type (fixed, casement, window wall, etc), each fenestration product is tested and modeled at a specific size and configuration. For example, a curtain wall assembly is tested and modeled at 79 in. by 79 in. with one vertical intermediate mullion. The NFRC-certified values allow for a side-by-side comparison of window products. Although the certification process has significant benefits, there are still several areas that require improvements. As such, it is worth reviewing a few examples of where fenestration U-factors used for energy code compliance are often overestimates.

Example 6: Window Size and Configuration. Often fenestration assemblies are not simple configurations as tested or modeled for NFRC certification, but are combination configurations and almost always different in sizes than the certified standard size.

At the most basic level, a window that is smaller than the standard NFRC size will have more framing to glass area, which will increase the window U-factor, often significantly for poorly thermally performing frames. Also, windows are often coupled together with additional coupler mullions, or intermediate mullions, which also increase the frame-to-glass ratio and similarly increasing the window U-factor. In a positive example, using larger windows will decrease the frame-to-glass ratio, which will decrease the window U-factor.

Since window U-factors are based on an area-weighted calculation of typical 2D analysis of all glass-to-frame intersections (sill, jamb, head, and intermediate framing), determining the U-factor of larger, smaller, or combination units is straightforward. There is no reason why the actual U-factors of windows should not be used for energy code compliance.

For many high-rise residential projects, and commercial projects that are trying to take advantage of natural ventilation, operable vents and doors are often integrated into curtain walls with fixed glazing. Typically, the U-factor of an operable window or door that is inserted into a fixed glazing assembly is considered as a separate area from the fixed area, rather than considering it as installed and detailed in reality. In reality, the operable vent and door add significantly more framing. These assemblies are almost exclusively aluminum-framed, and even with thermal breaks have relatively poor thermal performance as compared to other window frame materials. As such, additional aluminum framing can increase the building composite U-factor. In addition, in some instances we find the thermal break in the curtain wall and the operable vents are not aligned, resulting thermal bridging due to the installation.

For curtain wall and window walls that incorporate operable vents and doors, the composite U-factor should be determined accounting for the additional, doubled-up framing when one system is integrated into another.

Example 7: Curtain-Wall Spandrel Panels. Many high-rise commercial and residential buildings have glass/metal curtain walls that include both vision and opaque spandrel areas. For energy code compliance, vision areas are governed by fenestration requirements and spandrel areas are governed by opaque-wall requirements. Moreover, vision areas are often required to have NFRC-certified values. Consider the glass/metal curtain-wall assembly depicted in Figure 6. The upper portion is vision glass, and the lower portion is an insulated spandrel. Assuming the upper vision area is required to be NFRC-certified, all the horizontal mullions shown in the section are technically included as part of the vision area certified U-factor. For the curtain-wall system in this example, the NFRC100 U-factor for the standard 79 1/2 in. × 79 1/2 in. panel with an intermediate vertical mullion is 0.46 (R-2.17). For the actual size and configuration of the vision panel as depicted in Figure 6, the U-factor is 0.39 (R-2.56). The actual vision-area U-factor is lower than the NFRC value because the standard NFRC size and configuration is approximately 10% framing, while the actual project conditions are 8.7% framing.

To calculate the U-factor of the spandrel area, either the horizontal mullions (or some portion of them) are included, or the horizontal mullions are ignored entirely because technically they are part of the vision area.

For this particular example, the spandrel-area U-factor is 0.17 (R-5.88) without the influence of the horizontal mullions, and 0.27 (R-3.70) including the influence of the horizontal mullions. Including the influence of the horizontal mullions, the U-factor of the spandrel area increases by 59%. Considering that the spandrel in this example consists of an insulated glass unit with a U-factor of 0.24 (R-4.2) and 4 in. of mineral fiber insulation that is approximately R-16.8, the net result of a U-factor of 0.17 (R-5.9) in a best-case scenario, and 0.27 (R3.9) in a worst-case scenario (only 23% of the effective insulation value) is very significant and often overlooked.

Unfortunately, in many instances the actual installed units and installation methods are very different than the NFRC standard size and configuration used for certifying U-factors. Also, there is very little guidance, if any, on how to determine the U-factor of opaque spandrels, and whether to include 2- and 3D heat transfer effects between the insulated spandrels and the vision areas. Again, the U-factors used in the energy code compliance calculations are not representative of real construction practices.

PROPOSED METHODS OF U-FACTOR CALCULATIONS

The following discussion focuses on the conditions identified and discussed in this paper, and is far from being comprehensive enough for all buildings, conditions, and details. However, this should be considered as a starting point
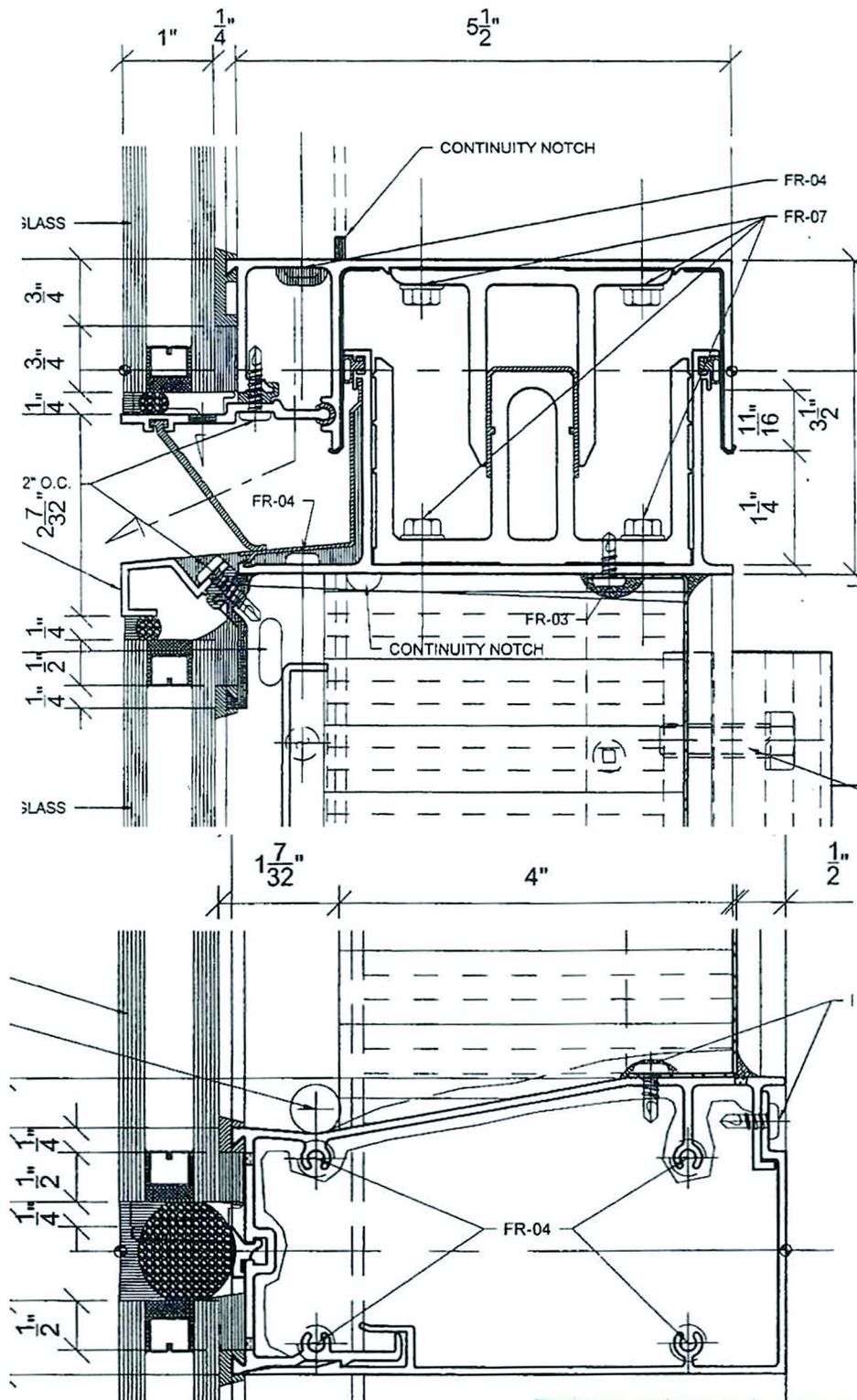
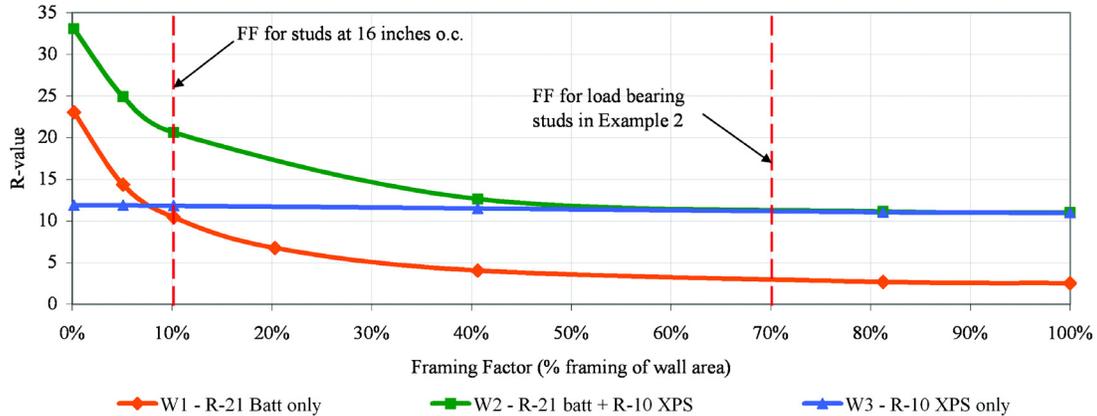***Figure 6*** *Curtain wall section.*

Figure 7 *R-value versus percent framing of wall area.*

for identifying shortcomings in the current approach towards U-factor calculation and energy conservation in general. It should also be noted that by requiring more detailed calculations, we may find that some of the current U-factor targets are not practically attainable. However, the hope is that more detailed calculation methods better recognize thermal bridge effects and that the industry will improve building enclosure detailing in terms of thermal performance.

Steel-Framed Wall Assemblies

To demonstrate the effects of the framing factor on the thermal performance of a range of steel-stud wall assemblies, we determined the U-factor of three wall configurations, each with a different insulating strategy, and no framing (0% framing) to solid framing (100%). A description of the wall assemblies is as follows:

Wall Type 1 (W1)

- 1/2 in. gypsum wallboard
- R-21 glass fiber batt insulation between 2 × 6 steel studs
- 5/8 in. thick gypsum sheathing

Wall Type 2 (W2)

- 1/2 in. gypsum wallboard
- R-21 glass fiber batt insulation between 2 × 6 steel studs
- 5/8 in. thick gypsum sheathing
- R-10 extruded polystyrene (XPS) insulation

Wall Type 3 (W3)

- 1/2 in. gypsum wallboard
- 2 × 6 steel studs, empty cavity
- 5/8 in. thick gypsum sheathing
- R-10 XPS

Using THERM 5.2, we determined the U-factors for walls with studs spaced at 1 5/8 in., 2 in., 4 in., 8 in., 16 in., 32 in., and 128 in. on center, and plotted the results on an *x–y* curve,

presented in Figure 7 as R-value versus percent framing area, or framing factor (FF).

Note that W1 is significantly affected by the framing factor, W2 is somewhat affected, and W3 is essentially unaffected. Our method of using the framing spacing to represent framing factors is a simplified approach, but is useful for demonstrating how the different insulating strategies affected the framing factor assumptions. Essentially, W3 is not really affected, and thus determining the actual percent framing area (framing factor) is not important. However, for W1, determining a realistic percentage of framing area is critical. The percent-framing assumptions for W2, or walls like W2, depend on the ratio of stud cavity insulation to exterior continuous insulation. As you approach W1, framing assumptions are important, and as you approach W3, the framing assumptions are not important.

U-factor tables in *ASHRAE Standard 90.1* do not capture actual construction practices, and thus are in many instances not representative of the actual assembly performance. Although alternative calculation methods are permitted, guidance on how to approach the calculation is necessary. We propose the following:

- Estimate the percentage of framing, considering addition framing at corners, openings, and for structural-load-bearing conditions. For steel-framed walls where the framing exceeds 10%, continuous insulation should be required.
- For estimating wall U-factors with various additional framing, use either a 3D analysis or a 2D analysis combined with an area-weighted approach, similar to the approach used for determining U-factors of fenestration using 2D analysis outlined in *NFRC Standard 100*.

Wall-Floor Interaction

Much like the steel studs have an effect larger than their area due to 2D heat transfer effects, intermediate floor slabs also have a 2D thermal interaction effect on wall U-factors.

Floor-to-wall interactions require at minimum 2D analysis, and in some instances 3D dimensional thermal analysis, to capture the thermal interaction between assemblies.

As demonstrated in Example 4, even floors insulated at their edges can be a thermal bridge across a wall assembly, analogous to a steel stud in an insulated wall assembly. Without considering the thermal interaction, the composite U-factor of the wall area, which includes the floor edges area, can be an underestimate.

We propose that composite wall U-factors include, at minimum the 2D thermal interaction of floor edges.

Fenestration

NFRC-certified values are for standard sizes and configurations. This is useful for comparing one fenestration product to another, but does not necessarily make sense for energy code compliance. The analysis software and computer power available permit the U-factor calculation of the actual assemblies intended to be installed on the buildings we construct. Each fenestration assembly on a window schedule should have a composite U-factor calculated and represented in energy code calculations. The composite U-factors should also include attachment and installation details that are often overlooked. Some typical oversights are additional extrusions used to accommodate deflection at heads of window below floors, as well as at jambs used to accommodate seismic drift, and when glazing assemblies form inside and outside corners.

For glazed wall assemblies, certified U-factors need be determined from the shop drawings, and also include the U-factor of the insulated spandrels that account for the 2D and 3D interaction between the vision areas and the spandrel areas. The U-factor of each area can then be used for compliance per the fenestration requirements and the opaque wall requirements.

CONCLUSIONS AND CLOSURE

Better detailing of the building enclosure is required to improve thermal performance of buildings. Lowering target U-values alone will not likely result in improved thermal performance. Many typical construction practices have significant negative effects on building thermal performance, and without providing guidance to include these thermal bridges, we will not significantly improve building thermal performance.

To conclude, further revisions of energy codes and standards need to focus on better definition, guidance, and calculations methods for determining building component composite U-factors. Key areas of focus should include

- Requiring whole-wall U-factor calculations rather than clear-wall U-factors
- Requiring more detailed calculation methods for floor slabs and cantilevered building components such as balconies

- Consideration for 2D and 3D interaction of components and using current and past ASHRAE TRP publications on the topic of the building component thermal performance
- Requiring more detailed U-factor calculation methods for fenestration products that are representative of the actual size, configuration, and installation

Hopefully, requiring more detailed calculations and inclusion of known thermal bridges will raise awareness of the importance of better design and construction practices, resulting in energy conservation.

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