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STRATEGIES FOR ENERGY-EFFICIENT AND FIRE-RESISTANT BUILDING ENCLOSURE DETAILS

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ABSTRACT

Energy conservation codes and sustainable building practices often require building enclosures to have continuous insulation for increased energy efficiency. Recent code updates also include more stringent fire-resistant requirements for many popular exterior wall products. This presentation will review requirements for continuous insulation, placement of a vapor retarder and air barriers, and effects of thermal bridges. The speakers will identify common paths of thermal loss through building enclosures and discuss mitigation of condensation-susceptible details, methods to improve enclosure details by use of thermal models, and strategies to achieve compliance with new fire-related building code requirements for building enclosures.

SPEAKERS

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STRATEGIES FOR ENERGY-EFFICIENT AND FIRE-RESISTANT BUILDING ENCLOSURE DETAILS

Current energy conservation codes and sustainable practices require building enclosures to have continuous insulation for increased energy efficiency and reduced thermal bridging, including inefficiencies created by steel stud framing and floor slabs. Addition of continuous insulation requires consideration of the placement of a vapor retarder and air barrier, and of the effect of thermal bridges created by cladding supports or other elements that penetrate the continuous insulation. Thermal bridges can create condensation risk, particularly in humidified buildings or where vapor-impermeable air-and-water-resistive barriers are used. Designers must also consider more-stringent fire-resistant requirements in recent code updates for water-resistive barriers, claddings, and insulation products that are popular architectural choices for energy-efficient exterior wall designs.

Designing building exteriors to improve energy efficiency and reduce condensation risk requires design solutions that both perform adequately and comply with building code requirements. The authors will identify common paths of thermal loss through building enclosures and discuss mitigation of condensation-susceptible details, methods to improve enclosure details by use of thermal models, and strategies to achieve compliance with new fire-related building code requirements for building enclosures.

Learning objectives:

1. Recognize prescriptive insulation and “continuous insulation” requirements of the energy codes and discuss methods for compliance.
2. Identify common enclosure construction details and deficiencies that cause thermal breaches and bridges, and potential consequences of these breaches.
3. Learn methods for mitigating effects of thermal bridges, reducing condensation potential, and improving thermal resistance.
4. Understand use of flammable insulating and air/water-resistive/vapor barrier materials with respect to fire-resistant construction and NFPA 285.

INTRODUCTION

Long behind us are the days when batt insulation in a light-gauge steel-stud-framed wall was considered a satisfactory means to insulate exterior building walls. Traditional construction that resulted in excessive thermal bridging in the building enclosure—thermally bridging wall studs, exposed slab edges, projecting structural steel, and other components that penetrate the building’s insulation—has given way to more thermally efficient construction that seeks to maximize the efficiency of wall insulation and reduce energy use in buildings. Minimizing thermal bridging requires a fundamental shift in the manner in which insulation is provided, and typically includes placing continuous insulation in the wall’s drainage cavity outside of the water-resistive barrier, where the insulation is exposed to water and where the insulation may not be protected against fire exposure by a thermal barrier.

Continuous insulation (CI) requirements for steel-stud-framed walls for both residential and commercial buildings began with the 2006 International Energy Conservation Code. This and other codes do, however, allow energy-use equivalency to be determined in some cases through whole-building energy modeling, component trade-off, or other analysis, allowing increased efficiency in energy use in other areas such as mechanical systems or lighting to offset inefficiencies in building enclosure thermal performance.

The increased use of CI outboard of the framing created concerns that were not

present when wall insulation was installed between wall studs. These concerns include the following:

- **Use of insulation that can withstand a wet environment where CI is needed.** The industry began widespread use of extruded polystyrene insulation (XPS) in the wall cavity to meet CI requirements, often without considering the fire resistance of the assembly as required by National Fire Protection Association (NFPA) 285 as referenced in model building codes and since the 2000 International Building Code (IBC) was introduced.
- **Outward movement of the vapor retarder plane.** In cold climates, CI in the wall cavity keeps the exterior sheathing warmer in winter as compared to a wall without CI. Many designs adopted a single membrane to function as the air, water-resistive, and vapor barriers (AWVB)

on sheathing behind the CI, omitting the vapor retarder from the inside face of the studs. When insulation is added between wall studs in this configuration, it will lower the sheathing temperature in the winter, and the sheathing is no longer protected from moisture by a vapor retarder on the inside face of the wall. If the sheathing tem-

perature, interior humidity levels, and hygrothermic performance of the assembly are not considered,

Continuous Insulation (CI): Insulation that is continuous across all structural members without thermal bridges other than fasteners and service openings. It is installed on the interior, exterior, or is integral to any opaque surface of the building envelope.

ASHRAE 90.1

the design may allow the sheathing temperature to fall below the dew point temperature of air inside the building, creating condensation risk at the sheathing plane. This risk may be offset by placement of a variable-permeance vapor retarder at the inboard side of the wall or use of vapor-retarding, closed-cell stud cavity insulation, but the resulting assembly with two vapor retarders must be carefully considered with respect to creating a “vapor trap” between the two vapor-retarding materials.

- **Effects of thermal bridging by cladding support systems.** Many designs fail to recognize that cladding systems create thermal bridges that can be as inefficient as the steel-stud framing for which the CI is intended to address. These ther-

mal bridges can locally lower the exterior sheathing and stud cavity temperatures well below the indoor dew point, even though analysis of the wall system shows it to be condensation-resistant when thermal bridging is not considered.

The inefficiency of only insulating between steel-stud framed walls should come as no surprise, given that thermal conductivity of steel is over one thousand times greater than glass fiber batt insulation. According to ASHRAE Standard 90.1, the effective R-value of a 6-in. steel stud wall with R-19 batt insulation is reduced to about R-9.

EXTERIOR WALL DESIGN CONSIDERATIONS

Designers can think of exterior wall function in terms of providing four barriers: air,

water, vapor, and thermal. In addition, exterior walls containing certain combustible components are required to meet fire performance criteria as specified in the building code. These five considerations are summarized as follows:

- **Air barrier:** The air barrier prevents movement of air between the indoor and outdoor environments. This helps prevent moisture-laden warmer air from traveling to cold surfaces within the assembly, where it can condense. Reducing air leakage through the building enclosure also reduces energy loss through the enclosure.
- **Water-resistive barrier:** The water-resistive barrier is necessary to protect the building from liquid water that could otherwise penetrate and damage water-sensitive components of a wall system or building, but must be placed in a manner that allows the water-resistive barrier to drain.
- **Vapor retarder:** The vapor retarder is needed in colder climates to protect cold components within the wall from condensation resulting from diffusion of moisture from indoor humidity, and may be needed in warmer climates to protect cold surfaces in air-conditioned



Figure 1A –
A thermal bridge leads to condensation on the interior of the window frame (arrow).

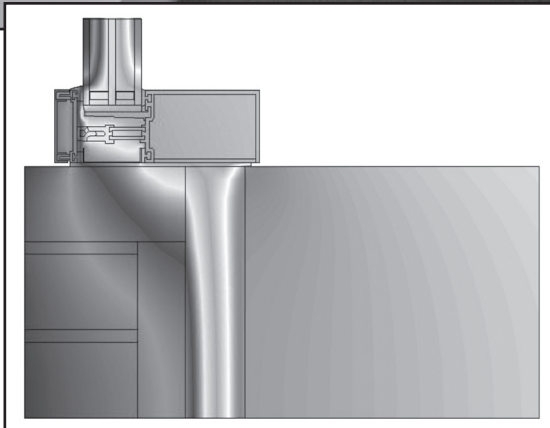


Figure 1B – Computer thermal model of the window shown in Figure 1A, placed directly on a masonry veneer. The window thermal break is offset from the continuous wall insulation.

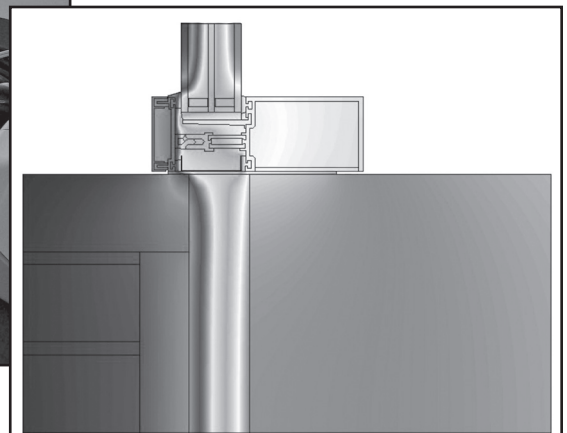


Figure 1C – Computer thermal model of a window thermal break aligned with continuous insulation in the wall to reduce thermal bridging and the potential for condensation shown in Figure 1A.

buildings from diffusion from outdoor humidity.

- **Insulation:** The thermal insulation layer reduces heat loss by conduction, but placement of insulation within the wall affects the temperature of wall materials and must be coordinated with the vapor barrier location.
- **Fire Performance:** The designer should consider requirements including fire blocking; flame spread and smoke-developed indices; NFPA 285 testing; and other requirements in Chapters 6, 7, 14, and 26 of the IBC.



Figure 2 – High-rise condominium building in Northeast U.S.

The air barrier and vapor retarder can be combined or can be separate layers. The vapor retarder should be located in an exterior wall to prevent moisture diffusion that can cause damage to sensitive materials. Building codes generally specify that a vapor retarder be placed on the “winter-warm side” of the wall in northern climates. Southern climates typically have vapor retarders on the exterior side of the insulation. Introducing CI outside of exterior sheathing may allow combining the vapor retarder and air barrier on exterior sheathing between the CI and stud cavity insulation.

In northern climates, this means the vapor retarder will be subjected to lower temperatures than it would see on the winter-warm side of the wall, with no insulation inboard of the vapor retarder. This may increase condensation risk on the interior side of the vapor retarder in northern climates. In this case, a hygrothermal analysis of the wall should be performed to check the vapor barrier location and determine stud cavity and CI thermal resistance to maintain the vapor retarder above the dew point.

Continuity of the air barrier and vapor retarder are essential. To identify breaches in the barriers, trace the barriers to check for continuity. Discontinuities in air- or

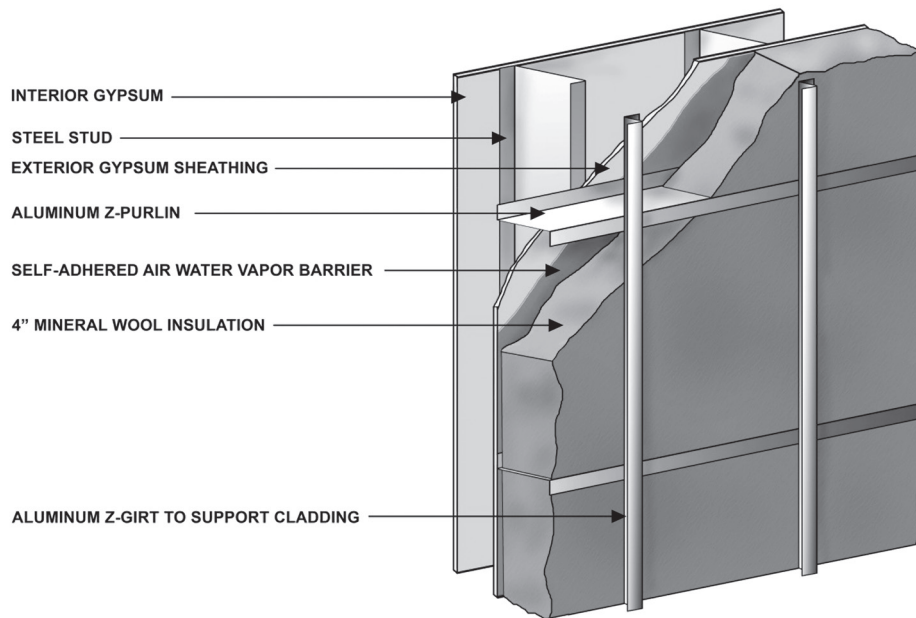
thermal-barrier layers can lead to energy loss. Thermal bridges through the insulation layer reduce the effectiveness of the insulation and create the potential for condensation. Similarly, breaches in the air barrier resulting in air leakage through walls can quickly transport large quantities of interior or exterior moisture to concealed locations where it can condense. Thermal bridging of insulation often occurs where the plane of the thermal barrier is offset at transitions or wall openings (*Figures 1A, 1B, and 1C*), and at metal structural components, such as steel relieving angles to support masonry, metal purlins that support cladding, wall studs, edges of floor slabs, and balconies. Because the R-value of common structural materials—including concrete, steel, and wood—is much lower than the R-value of the insulation layer it interrupts, these thermal bridges may have a large impact on the thermal performance of a structure. Maximizing the efficiency of insulation requires reducing or eliminating these thermal bridges wherever possible.

Use of CI reduces substantially the thermal bridging from wall framing. Common choices for continuous wall insulation include extruded polystyrene (XPS) and mineral wool. Advantages of XPS CI include its high R-value per inch (about R-5 per inch), which is generally unaffected by moisture found in the wall drainage cavity.

However, foam plastics such as XPS are made from flammable, petroleum-based chemicals that can release toxic smoke when burned. Building codes contain limits for flame spread, combustibility, and smoke development values for materials. Codes also contain requirements for full-scale fire-resistance testing of entire wall assemblies with foam plastic insulation. Mineral wool is made from basalt rock and slag and is not flammable. However, the typical insulating values of dry mineral wool are about 15 to 20% less than XPS foam plastics for a given thickness (about R-4 per inch).

CASE 1: ANALYSIS OF ENERGY-EFFICIENT ENCLOSURE ON AN EXISTING BUILDING

We analyzed the thermal performance of an existing high-rise condominium building in the northeastern U.S. constructed in the late 1980s (*Figure 2*), with 24% of the exterior wall area consisting of glazed areas (window U-value of 0.50), R-19 batt insulation in 6-in. steel stud framing (no CI), uninsulated floor-slab edges, cantilevered concrete floors forming balcony slabs, and a brick masonry veneer. When the influences of thermal bridging of studs without CI, inefficient windows, uninsulated slab edges, parapets, curbs at roofs, cantilevered balconies, and other systemic thermal bridges are considered for this case study,



NOTE: CLADDING NOT SHOWN FOR CLARITY

Figure 3 – 3-D view of exterior wall assembly.

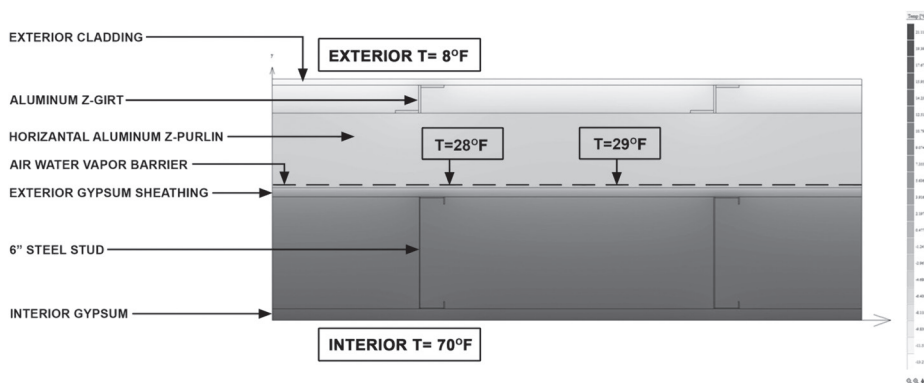


Figure 4 – Computer model showing influence of thermal bridging at the horizontal purlin to sheathing interface for the wall assembly shown in Figure 3.

the reduction in the overall wall and enclosure R-value (increase in U-value) becomes apparent.

We performed an area-weighted R-value analysis of the effective enclosure thermal

resistance and found that the substantial degradation in overall thermal resistance is due to thermally inefficient glazing and inefficiencies in the overall enclosure that significantly reduce the enclosure's thermal

effectiveness. By improving the existing building with CI, modern, thermally efficient windows, and eliminating structural thermal bridges, we calculated the potential incremental R-value gains (decrease in overall U-value) as follows (see Table 1):

- Existing whole-building-envelope effective R-value, no CI: overall R-5.3 (U-0.19)
- Add CI to meet current code U-value of 0.064: overall R-6.3 (U-0.16)
- Add CI mentioned above, plus thermally efficient windows and doors (U-0.35): overall R-7.3 (U-0.14)
- Add CI mentioned above and windows, plus eliminate thermal bridges at slabs and balconies: overall R-9.3 (U-0.11)

Our analysis considers information published in ASHRAE RP-1365, *Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings*, prepared for ASHRAE Committee 4.4 by Morrison Hershfield in 2011. The publication contains computer-simulated thermal performance data for many wall sections and details found on such buildings, and discusses application of these data. Once considered, it is clear to see that use of CI improves overall thermal performance of the enclosure. Similarly, thermal bridges at slab edges, balconies, roof curbs, and other linear thermal bridges can have significant influence on the thermal performance of the enclosure. Thermal bridging of these components is often ignored, but they warrant consideration. In the case of the high-rise building above, where the wall area is much greater than roof area, the overall thermal resistance of the wall assembly controls, and increasing roof insulation thickness has little effect on overall enclosure thermal resistance. On low-rise buildings with large roof areas as compared to wall areas, the reverse is true. In these cases, improving

	Area-Weighted Whole-Building R-Value	Area-Weighted Whole Building U-Value	Improvement in Thermal Performance From Existing Building
Existing Building	5.3	0.19	-
With CI to meet current code	6.3	0.16	16%
With CI + new windows	7.3	0.14	26%
With CI + new windows + thermal bridge elimination	9.3	0.11	42%

Table 1

performance of a thermally inefficient wall system may not substantially affect the overall thermal resistance of the enclosure.

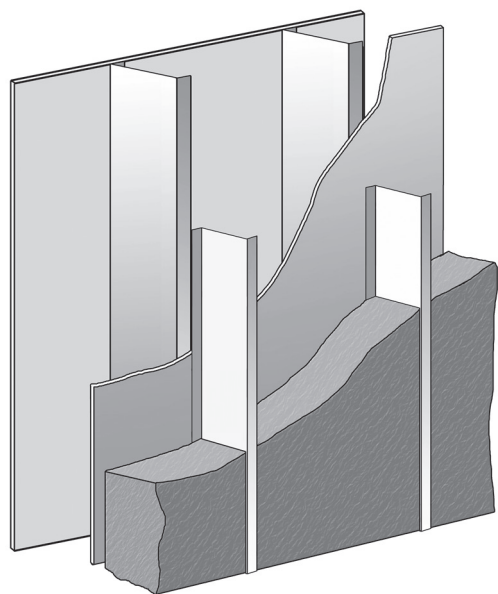
CASE 2: CONSIDERING CONDENSATION IN MODERN ASSEMBLIES

In theory, achieving the required R-value of the wall by using only CI in the drainage cavity behind the cladding keeps the wall sheathing and framing warmer in winter than a wall assembly only insulated in the stud cavity. As discussed above, this may allow use of a vapor-retarding, air- and water-resistive barrier (AWVB) on the

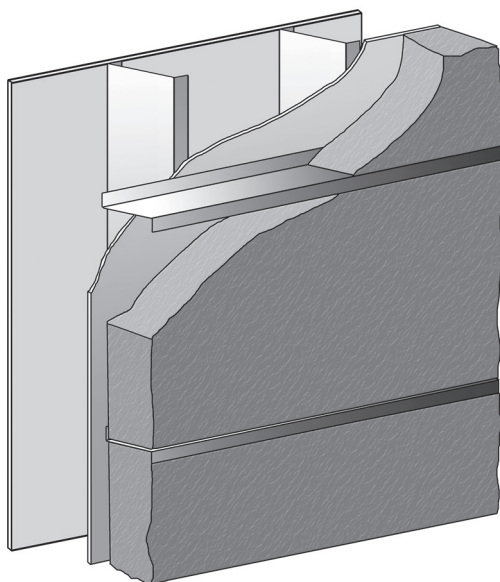
exterior face of the wall sheathing. For wall assemblies with no thermal bridges through the CI, there is generally little condensation risk inboard of the insulation, since the vapor-impermeable barrier remains warm. In practice, thermal bridges created by components such as cladding support purlins or lintels are often unavoidable, making these areas locally susceptible to condensation when cooled below the interior dew point temperature. These local effects need to be considered if high indoor humidity levels will create a concern for condensation.

Consider the case below, where unitized, steel-framed exterior wall panels are constructed using an impermeable AWVB over gypsum sheathing behind a single layer of R-17 CI, with no insulation in the stud cavity (Figure 3). The wall supports a rainscreen cladding system using continuous horizontal aluminum purlins that create thermal breaks in the CI. Design wintertime conditions specify an outdoor temperature of 8°F and indoor temperature of 70°F at an indoor relative humidity of 40% (indoor dew point temperature of 45°F).

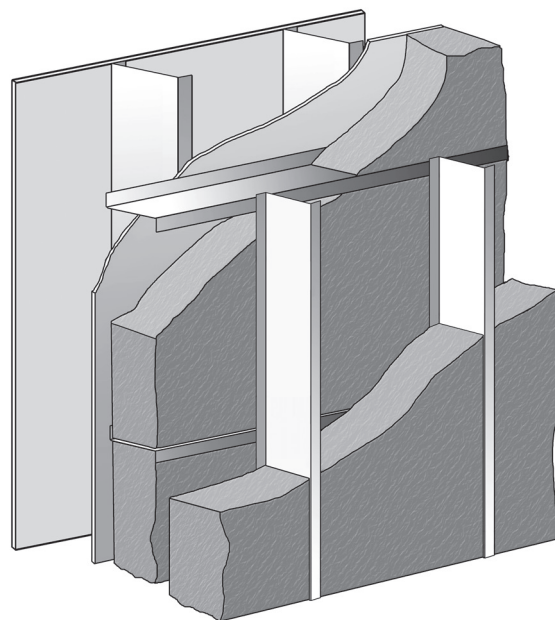
Figure 5 – Details 1, 2, and 3 based on ASHRAE RP-1365.



Detail 1 – Vertical Z purlins aligned with wall studs with insulation between purlins.



Detail 2 – Horizontal Z purlins perpendicular to wall studs with insulation between purlins.



Detail 3 – Horizontal Z purlins perpendicular to wall studs and vertical Z purlins to support claddings with insulation split between horizontal and vertical purlins.

If the effects of purlins are ignored, the R-17 CI is fully effective, and the sheathing temperature at the plane of the impermeable AWVB is about 57°F—well above the anticipated indoor dew point temperature under design conditions. However, we also considered thermal bridging by the purlins using the three-dimensional thermal-modeling program, HEAT3. The model calculates much lower sheathing temperatures behind purlins due to the local effects of thermal bridges at the aluminum purlins (Figure 4).

Under design conditions, the sheathing temperature beneath the aluminum purlins and behind the impermeable AWVB falls to about 28°F, creating the risk of condensation. Several approaches were investigated to mitigate the condensation risk:

- Use of ¼-in.-thick plastic shims behind purlins. This raised the sheathing temperature by about 3°F, which is not enough to reduce condensation risk.
- Replace aluminum purlins with 18-ga. steel. Steel is less thermally conductive than aluminum, and thinner sections can be used to provide the same strength. Therefore, using steel instead of aluminum results in less heat transfer. This raised the design sheathing temperature to 36°F. This helps, but is not enough to eliminate condensation risk. Steel purlins also have potential for long-term corrosion, particularly in a marine environment.

- Provide continuous insulation behind aluminum purlins. R-2 insulation raises the sheathing temperature to about 45°F, equivalent to the indoor dew point temperature. R-4 rigid insulation raises the sheathing temperature to about 50°F behind the purlins. Reducing these thermal bridges also raises the sheathing temperature away from the purlins to about 60°F because of the improved overall thermal performance of the wall. Placing insulation behind purlins requires additional structural considerations of the purlin attachment, including cladding weight and rigidity of the insulation to resist rotation of the purlin.

The effect of differing orientations and configurations of metal cladding support purlins can also be estimated by using ASHRAE RP-1365. Details 1, 2, and 3 (Figure 5) depict an exterior wall with continuous steel purlins oriented vertically over studs, oriented horizontally, and with vertical purlins over horizontal purlins

and offset between stud-framing members, respectively. Detail 3 is presented using 5-in. insulation between vertical purlins, with varying insulation thickness between horizontal purlins. For the case above and using R-16 insulation outboard of the wall sheathing (no insulation in the stud cavity), we can compare the resulting effective clear-wall U-value to the nominal insulation value, which yields the following:

- Detail 1, vertical steel purlins: R-9 (U-0.11). The insulation's effective R-value is reduced about 44%.
- Detail 2, horizontal steel purlins: (R-10.5) U-0.095. The insulation's effective R-value is reduced about 34%.
- Detail 3, vertical purlins (R-5 insulation) over horizontal (R-11 insulation): R-12 (U-0.083). The insulation's effective R-value is reduced about 25%.

For simplicity, we have not considered the insulating value of the sheathing, wall-board, or air film thickness.

Attaching claddings using thermally

unbroken purlins through the “continuous” insulation sacrifices much of the benefit of continuous insulation, and it can no longer be considered CI. Breaking the insulation into two layers to allow use of vertical purlins over the horizontal purlins and offset from the studs improves thermal performance, but does not completely eliminate thermal bridging. Equating the effective U-value of walls incorporating metal purlin cladding supports to the nominal insulation value grossly overestimates the wall R-value, which could result in non-compliance with energy codes.

CASE STUDY 3: FLAMMABILITY CONCERNS WITH CONTINUOUSLY INSULATED WALL ASSEMBLY

As described above, the types and locations of four barrier layers in the exterior wall assembly are critical to managing condensation, energy loss, and drainage. Now let us consider fire performance of exterior wall assemblies. Some common materials used to create thermal and AWVBs—such as foam plastic insulation and rubberized asphalt membranes—are flammable, as are

some forms of composite claddings that use flammable plastic, such as composite-aluminum panels. The placement of these layers outboard of the exterior wall has increased the hazard for exterior building façade fires (Figure 6). Designers need to remember that the code invokes full-scale fire testing for exterior wall assemblies with combustible components in Types I, II, III, and IV construction. The full-scale fire test is performed in accordance with NFPA 285, *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components*. The 2012 IBC also introduces NFPA 285 testing



Figure 6 – Fire consumes exterior façade of 44-story Television Cultural Center (TVCC) high-rise building in Beijing (February 2009). Photo by WiNG.

requirements for all combustible water-resistive barriers installed 40 ft. or more above grade, regardless of the insulation and cladding. This requirement applies to commonly used AWVB membranes.

The NFPA 285 fire test is a two-story test apparatus to which an exterior wall test specimen is affixed. The test simulates a fire in the first story breaking out of a window in the exterior wall and exposing the façade to flames. Criteria for a successful test wall include limited vertical and horizontal flame propagation along the face of the wall or through the wall cavities and limited temperature rise measured in the specimen for 40 minutes. The NFPA 285 fire test is an assembly test, meaning that all components of the exterior wall assembly should be represented in the test specimen.

Not all combinations of exterior wall components have successfully passed NFPA 285. Consider the case below, where a conceptual wall design had to be modified to comply with building code and fire testing requirements. The exterior wall design was comprised of the following exterior wall assembly, from exterior to interior:

- Aluminum composite metal (ACM) cladding panels
- Air space
- 3-in. extruded polystyrene insulation (XPS), providing the thermal barrier
- Rubberized asphalt AWVB membrane with polyethylene facer—providing barriers to air, vapor, and water
- Gypsum sheathing on steel studs

Several wall assemblies with ACM panels have been successfully tested per NFPA 285, and several wall assemblies have been successfully tested with XPS insulation. However, a review of tested systems showed that there is not a tested system that includes ACM, XPS, and rubberized-asphalt membrane in the same system. Therefore, the proposed design did not comply with the code.

The designer was left considering the following design modification options:

1. An assembly using noncombustible mineral wool insulation in lieu of the XPS, keeping the rubberized-asphalt AWVB and ACM. This option is dependent on the interpretation of the MCM/ACM requirements of the code as to whether the AWVB is

required to be included in the NFPA 285 test. As stated above, under the 2012 IBC, the assembly would require testing due to presence of the rubberized asphalt AWVB if installed above 40 ft.

2. A tested assembly using ACM, polyisocyanurate insulation (in lieu of the XPS), and a fire-resistant, foil-faced AWVB membrane.
3. A tested assembly using noncombustible cladding, XPS, and a fire-resistant, foil-faced AWVB membrane.
4. An assembly using a non-combustible cladding, mineral wool, and a fluid-applied AWVB. This option is dependent on the applicable code.

Each of these options represents a functional compromise or cost increase to the conceptual design. In Options 1 and 4, mineral wool has a lower R-value per inch than XPS insulation, such that a greater total insulation thickness is required to achieve an equivalent total R-value. Depending on the dimensional restraints within the wall assembly, this may or may not be feasible.

In Option 2, polyisocyanurate insulation has comparable or better R-value to XPS. However, the foil-faced membrane, being relatively new to the market, does not have an established track record of performance.

In Option 3, the design aesthetic of the wall may change by using a different cladding. Concerns about the use of the newly introduced foil-faced AWVB as discussed above also warrant consideration.

Option 4 potentially eliminates NFPA 285 testing requirements altogether (depending on the applicable version of the IBC), but with the reduced R-value of mineral wool. In this case study, the system also required a fluid-applied AWVB, for which we have concerns regarding long-term performance due to high water absorption and degradation in wet environments with some products.


In the end, the designer chose Option 3. However, such decisions will vary from project to project, based on the design vision, project budget, the designer's comfort level with the robustness of wall materials, and local code requirements.

CONCLUSION

More stringent energy conservation codes and sustainable building practices have increased the use of CI in contempo-

rary walls. The type, placement, thickness, and continuity of insulation in the building enclosure will have long-term impacts on heating and cooling costs of a building structure. Identifying and reducing thermal bridges can significantly improve thermal performance. Reduction in thermal bridges requires careful consideration of cladding-support systems, and the thermal influence of structural or other elements that penetrate the building insulation.

Condensation resistance of wall assemblies using continuous insulation should be considered. This becomes more critical in cold climates or in buildings where anticipated interior humidity levels are high, and where locating vapor retarders inboard of the continuous insulation (particularly where the vapor retarder lies in the proximity of thermal bridges, which may locally lower the vapor retarder temperature and create conditions having condensation risk). Special detailing of insulation or vapor retarders in local areas of thermal bridging may be needed.

Fire-resistance code requirements limit exterior wall assemblies that can be constructed with combustible claddings, insulation, or AWVBs. Designers must consider fire-resistance requirements of materials in addition to meeting energy conservation code requirements. 

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