Considerations in the Design of Cladding Systems with Continuous Exterior Thermal Insulation

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ABSTRACT
This paper addresses specific and seldom discussed details of cladding systems and the impact continuous exterior insulation and other common building practices today has had on their design.
The primary issue is how the desire to increase any one aspect in the design of the building envelope, in this case thermal insulation, impacts the performance of all the other components of the design – namely, the weather-resistive element, the air control element, the vapor control element and the support element.
A large amount of the discussion concerns what I believe to be most needed by the design team today – guidelines for cladding support or sub-framing design.
Topics include:
1. Proper orientation of sub-framing
2. Providing the proper load path
3. How cladding systems accommodate building movement
4. The placement tolerances of primary structure materials and the need for girt space
By address of these issues, the author hopes to re-establish the fundamentals needed in any good cladding design and spur development in areas where the present design is lacking.

KEYWORDS: cladding, support framing, deflection, continuous insulation

1. Introduction

Creating a proper building envelope is not easy; yet all we need to work with is five components:

1. Weather-resistive element (cladding, et.al.)
2. Air control element
3. Support element(s) (wall stud framing, et.al.)
4. Thermal control element(s)
5. Vapor control element(s) (including the interior finish)

With only five components to work with, what could go wrong?
Often mistakes arise when we assemble the components to meet individual requirements and not consider their assemblage as a system: We add insulation to retard the flow of heat, we add an air barrier to control unwanted air leakage and we use the supports to hold the other components

in place against external forces. We then place the weather-resistive element to the exterior to protect all the other components and finally we add the vapor control element to protect the other components from possible damage caused by the insulation.

Walls designed in this piece-wise fashion can have problems; yet that is precisely how they are often specified by building and energy codes. The building code requires a weather-resistive barrier and cladding designed to meet structural and fire-resistive requirements. The energy code requires a vapor barrier, sufficient sealing to reduce air leakage and thermal insulation in ever increasing amounts to decrease the heat transfer through the envelope. Meeting these individual requirements does not produce a resilient wall nor does it ensure the health of its occupants or necessarily serve the best interest of the owner's investment. That is where the building design team earns their pay.

The storm that was the early adoptions of regulatory requirements for building envelope performance by the federal, state and local jurisdictions has become commonplace, and we are not surprised by the adoption of further, more restrictive regulations. We do know that they are coming; however, with each change, the means to design a functional building envelope becomes surprisingly more difficult. In many cases wall systems that have worked in the past no longer work properly with additional insulation requirements or placements.

This paper serves to give one manufacturer's perspective on the daily challenges to meet or exceed the building and energy code requirements. To do this, the author has chosen to illustrate the issues in a few less traveled areas of design that may be of interest to Architects, Engineers, and construction managers as well as those who have chosen to participate in the process of code development.

6. Continuous Exterior Insulation and Anchored Cladding

Continuous exterior insulation over the past few years has become standard in many areas for residential construction and also with many commercial wall constructions as well. But just what is it and how do we know if we meet the prescriptive requirements of the energy code? The three definitions listed below will serve to help discuss the issue:

Continuous Insulation (CI): *Insulation that runs continuously over structural members and is free of significant thermal bridging; such as rigid foam insulation above the ceiling deck. It is installed on the interior, exterior, or is integral to any opaque surface of the building envelope.*[4]
{Building Energy Codes Resource Center}
continuous insulation (c.i.): *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.*[1]
{ASHRAE Standard 90.1-2004}

. . .*"Continuous insulation" means insulation which is installed continuously across structural members with its effectiveness undiminished by compression or bridging, except for fasteners.*[5] *{Section 7676.0700, Subparagraph 8, Minnesota Rules}*

Can one design a commercial cladding system faithful to these definitions?
Not very often. These definitions create a problem because they ignore the fact that something has to carry the weight of the cladding and adequately convey lateral wind and seismic forces to the main frame. The *Exterior Walls* and *Structural Design* sections of the building code[3] have not been replaced by the energy code. The insurance provider will have difficulty turning a blind eye to cladding failures in the name of reduced dependency on foreign oil. Using the ASHRAE or Minnesota language, it is clear that we cannot use rigid exterior foam board and comply with the definition if anything other than fasteners bridge the continuity of the insulation. Are then shelf angles at each floor used in the commercial building application of masonry veneer in compliance with the prescriptive application of cavity plus continuous insulation?

Conservatively speaking the answer is no – it does not comply with the intent of the prescriptive requirements. Similarly neither would sub-framing positioned between insulation sheets at 24-inch or 48-inch spacing to act as a proper path for the cladding loads. Each detail affects sufficient area to reduce the average effectiveness of the insulation by more than 5%.

So to meet the intent of the energy code tables, we must only bridge the insulation with fasteners. What are the roadblocks to such a design concept? The reason why fasteners cannot simply cantilever from the stud framing and continue through the rigid foam insulation is because they are inadequate to do so. Carbon steel self-tapping screws are hardened to resist thread rollover or stripping when driven. In doing so, the exterior surface and part way into the steel core of the screw is made to resist plastic behavior. This lack of flexibility desired to make carbon steel screws an adequate fastening device consequently makes them unable to take repeated bending as a cantilevered object. Installed into stud framing of 16GA or less, as they would be more often than not, the screw tilts and enlarges the hole, thereby reducing its pullout value and allowing the cladding system to drift downward under its own weight. Additional screw bending is necessary to tie the differing degrees of stiffness between the main structure and the cladding as well as the different applied loads in plane and perpendicular to the plane of the wall. This application is unworkable. Remember – one cannot sufficiently preload a self-tapping screw to eliminate bending or tilting as you might a cap screw or bolt.

We must also consider the fact that wind load acts towards the elevation as well as away from it. How are these positive loads conveyed? The masonry veneer industry has realized that positive loads should be directed straight to the steel stud framing and not through the foam or sheathing. More recent clip designs use a pair of back legs to penetrate the foam insulation and sheathing and seat on the face of the steel stud. The overriding concern in any cladding design be it masonry veneer or metal is that a solidly constructed load path be established for both positive and negative wind loads. The screw applied framing used to attach cladding systems is not designed to withstand the hammering caused by loose connections thrust to and fro by the action of wind. The screw engagement will fail. More importantly the foam surface is inadequate to bear localized loads from contact of sub-framing and shims and tends to lose its properties in time when harshly exposed to heat such as that behind a metal wall cladding or longer than expected exposure to the sun during construction.

The bottom line: an experienced structural cladding engineer will not design a wall without a positive and stable mechanism of conveying external forces through to the primary building frame.

Review the photographs of simple laboratory testing below. They reveal the downward displacement of the exterior sub-framing under load and the enlargement of the stud flange hole as the hardened screw tilts and cuts through it.

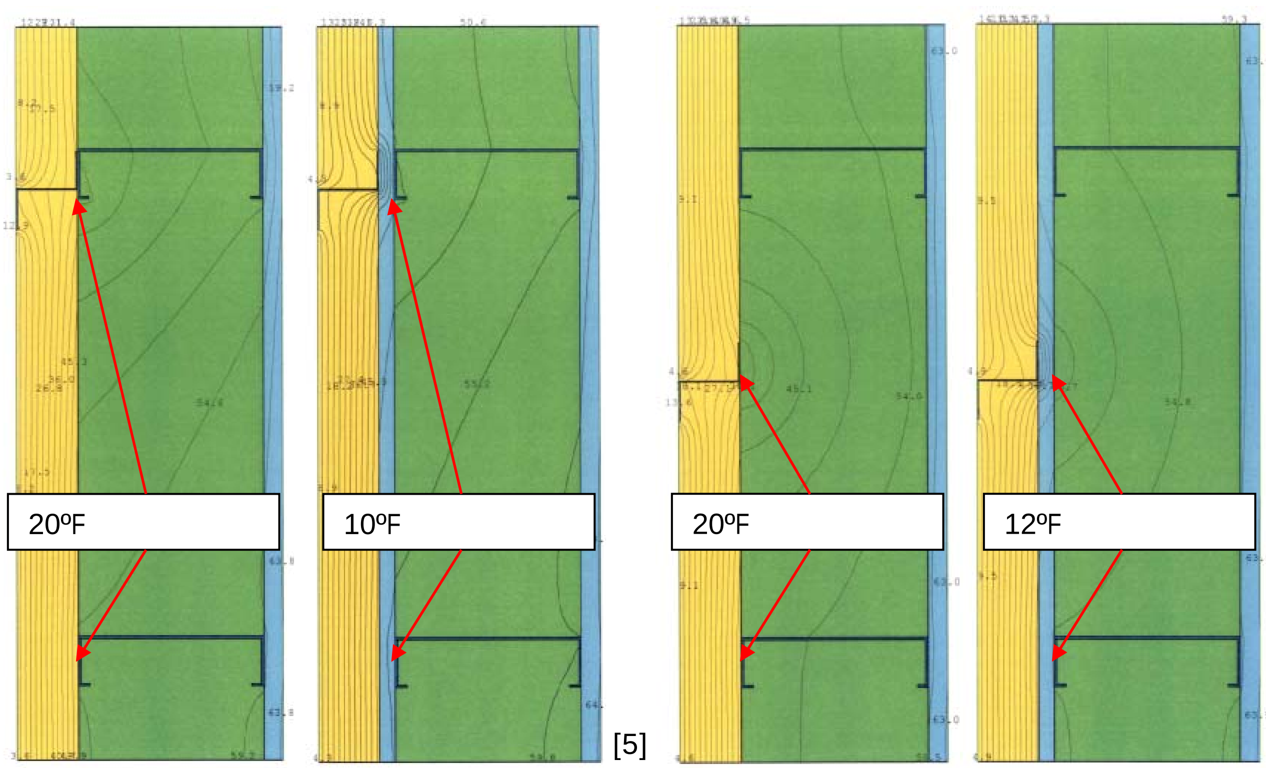
SCREW TILTING AT 50LB VERTICAL LOAD FASTENED TO 16GA STUD THROUGH 1-1/2” XPS AND GYPSUM. NOTE VERY LITTLE BENDING IN SCREW, BUT NEARLY 1/2” DEFLECTION. NOTE: FOAM REMOVED FOR PHOTO AFTER LOADING.

AFTER TEST PHOTOS REVEAL FASTENER HOLE SLOTTED VERTICALLY, BUT SCREW

7. Continuous Exterior Insulation and Exterior Sheathing

Exterior sheathing placed inside the exterior continuous insulation in commercial construction may be required to provide limited lateral bracing to the stud framing, to provide a proper “dried in” interior space to reduce the project schedule and allow electricians, interior finish contractors, etc. to begin, and to provide a sufficiently rigid plane for which to attach the air barrier or weather-resistive barrier. The air control element and weather-resistive element are two of the five components of the wall envelope. Both of these components are best applied as large membranes or in situ films to minimize the effect of edge discontinuities. The support provided by exterior sheathing in multi-component cladding systems is essential to the resiliency of these components. Remember, the whole idea of placing continuous insulation outboard of the framing is to position it outboard of the air barrier as well. The achievable continuity of the air barrier is afforded by the considerably less interrupted plane of the exterior sheathing. Placing continuous insulation outboard of the framing without sheathing only satisfies half the equation.

Consequently, the author sees no application for foam board “structural sheathing” in mid-to-large scale commercial construction. It lacks the resilience to assure that it will be installed and sealed adequately and remain as it appears after it is covered. Use the same as exterior insulation intermingled with sub-framing and positioned outboard of a resilient air barrier supported by exterior sheathing and a more durable and functional system is created.



[5]

ALL MODELS USE 0ºF EXTERIOR AND 70ºF INTERIOR

The thermal models on the preceding page illustrate one additional function of exterior sheathing. Exterior sheathing serves to provide some thermal isolation to the stud cavity from the sub-framing necessary to attach commercial cladding. Without it, the crosswise intersection or continuous contact of the metal sub-framing to the metal stud framing and the exposed flange create a larger temperature depression in the cavity then what is desired or necessary. The exterior sheathing acts then as a thermal break similar to that found in window extrusions. This thermal isolation or thermal break is important to the effectiveness of the exterior insulation and is an added benefit to the primary role of exterior sheathing – to establish or support the air barrier.

In most cases of envelope design, the final form is arrived at in a circular, somewhat iterative process. Continuous exterior insulation is the most efficient way to decrease the thermal transmittance of the wall envelope. However, by direct result of its application in commercial construction, there is usually a need for exterior sheathing because the foam or mineral wool insulation is inadequate to properly support the air and weather-resistive elements and for sub-framing to convey the cladding loads to the wall stud framing. This raises the question we began with — can continuous insulation be properly applied to most commercial construction at the simple prescriptive R-value amounts listed in the energy code and still provide the listed overall thermal transmittance requirements? Not Likely. The decision is yours.

8. Cladding Support Framing

Hopefully, now that the requirements of cladding support framing has been established in the discussion of continuous insulation, it would be the right time to discuss in further detail the proper application of this necessary component of commercial construction.

First and foremost, with rare exception, framing must be oriented perpendicular to the orientation of the cladding. If a panelized cladding element is desired to have its long dimension horizontal, then the supports that it makes direct attachment to must be oriented vertically. Sounds like a simple concept, right? Add continuous exterior insulation and this point is often lost.

Stud framing is designed in most cases for uniform lateral load. In this way each stud conveys an equal loading that is uniform from top to bottom of its span. When sub-framing is added to nest between stock widths of rigid exterior insulation at 16-inch, 24-inch or 48-inch on center, they are best applied horizontal to result in a loading as similar as possible to the original stud design. The wall is then ready for vertical cladding. Horizontal cladding requires one more layer of sub-framing applied crosswise to the first. Each subgirt layer must be designed against limits of bending and fastener pullout in the light gage steel. Very rarely are the spans or the spacings greater than 48-inch; no matter how stout the cladding.

But how then are the cladding support framing members attached to the main building frame? How do they accommodate the building movement such as floor and roof deflection and sway?

From a façade engineer's perspective, the number one cause for concern in any design today is building movement – especially interstory differential live load deflection of the slab edge. The present model building code, 2006 IBC, Table 1604.3[3] limits live load floor deflection to L/360. That is 1-inch for a 30-foot bay when most architectural panels can accommodate about 1/8-inch without special design. However, the Brick Institute of America (BIA), the American Concrete Institute (ACI), the American Society of Civil Engineers (ASCE) and the American Institute of Steel Construction (AISC) state additional recommendations.

The ACI 530 Standard[6] recommends the lesser of a vertical deflection ratio of L/600 or a deflection limit of 0.3-inch due to total (dead + live) load when a slab edge supports masonry cladding.

The ASCE reference is found in Standard 7-05, Appendix C, "Serviceability Considerations"[7]. A recommended limit of 3/8-inch is given that if exceeded as a result of either vertical deflection or wind drift, may cause damage to non-structural partitions, cladding and glazing.

The AISC publication, "Serviceability Design Considerations for Steel Buildings"[8] suggests that unless the cladding system is ground or column supported the limit on live load deflection should be the lesser of L/360 or ¼-inch to ½-inch depending on the details.

None of these references other than the AISC publication speaks of differential deflection. Most are referring to damage caused by distortion or tension-side cracking of brittle or weak nonstructural elements. Differential deflection is a primary cause of serviceability issues. It causes racking of vertical joints and opening or crushing of horizontal ones. The resultant seal failures can lead to costly water damage and deterioration of building components as well as water-related occupant health issues.

Cladding systems accommodate building movement in two ways: by isolating it from the in-plane behavior of the primary frame and by reducing its in-plane stiffness in relation to the same. Isolation is achieved by detachment of the weight of the cladding from the deflecting elements of the primary frame. The in-plane stiffness of a cladding is reduced by division of the cladding horizontally and vertically into separate panels, thereby allowing vertical sliding like a deck of cards when racked and some gathering and opening of joints like a group of blocks tied together by a string when deflected. Division into smaller panels in both height and length reduces the joint crowding resulting when the straight lines of the cladding panels, attempting to remain rectangular as the blocks in the analogy above, are forced to adjust to the curved line of the deflected member to which they are attached. Problems occur if panel joints crowd until the corners contact; glass may break, brittle claddings may spall or more resilient claddings may overstress fastenings.

Division of the cladding into individual panels does not alleviate the problem of differential floor or roof movement; anything rigidly attached to a deflecting primary frame member will attract loads that will attempt to deflect it as well. Similarly, one cannot choose to either isolate or reduce stiffness in the successful design of a cladding system. Absolute isolation is not achievable; even foundations settle. And unless the cladding material is rubber, it would be difficult to cover great areas without some vertical and horizontal relief joints to accommodate movement. So a combination of both makes for a successful design. Resolving where and how the weight of the cladding is supported should be the first step. Listed below are four methods to support the cladding weight, each more difficult to design successfully than the one preceding it:

1. Use a panelized stud system where the external framing supports the floor and roof dead and live loads and all other lateral (wind) and in-plane (shear) loads applied; often used in the hospitality industry.
2. Support the weight of the cladding system on the foundation or by one or more suitably stiffened floors and bypass the deflecting floor and roof lines; sometimes called a bypass or through-tube system.
3. Direct the weight of the cladding system solely to the columns by use of the panel strength or a separate outboard truss-like support frame with vertically-slotted intermediate (wind) connections to permit the floor and roof lines to deflect; sometimes called a strongback or truss system.
4. Support the weight of the cladding system on the horizontal perimeter (floor and roof) or spandrel framing and design a means of accommodating movement into the cladding itself; sometimes called a spandrel support system.

The figure on the next page describes the differences between one system and the next.

Panelized stud framing systems, described in method #1, are erected similar to residential kit homes. Wall sections are unloaded, erected and linked together. Temporary bracing is added to stabilize them to accept precast floor planks or concrete deck and formwork. Once the floor is completed, the next story is assembled in the same fashion. Because the exterior framing is load-bearing, it is usually suitable for cladding attachment and there is no differential deflection or measureable settling/shrinkage with which to contend. Additional framing for cladding joints and details should be coordinated in advance because strap bracing and bridging interferes with their later placement.

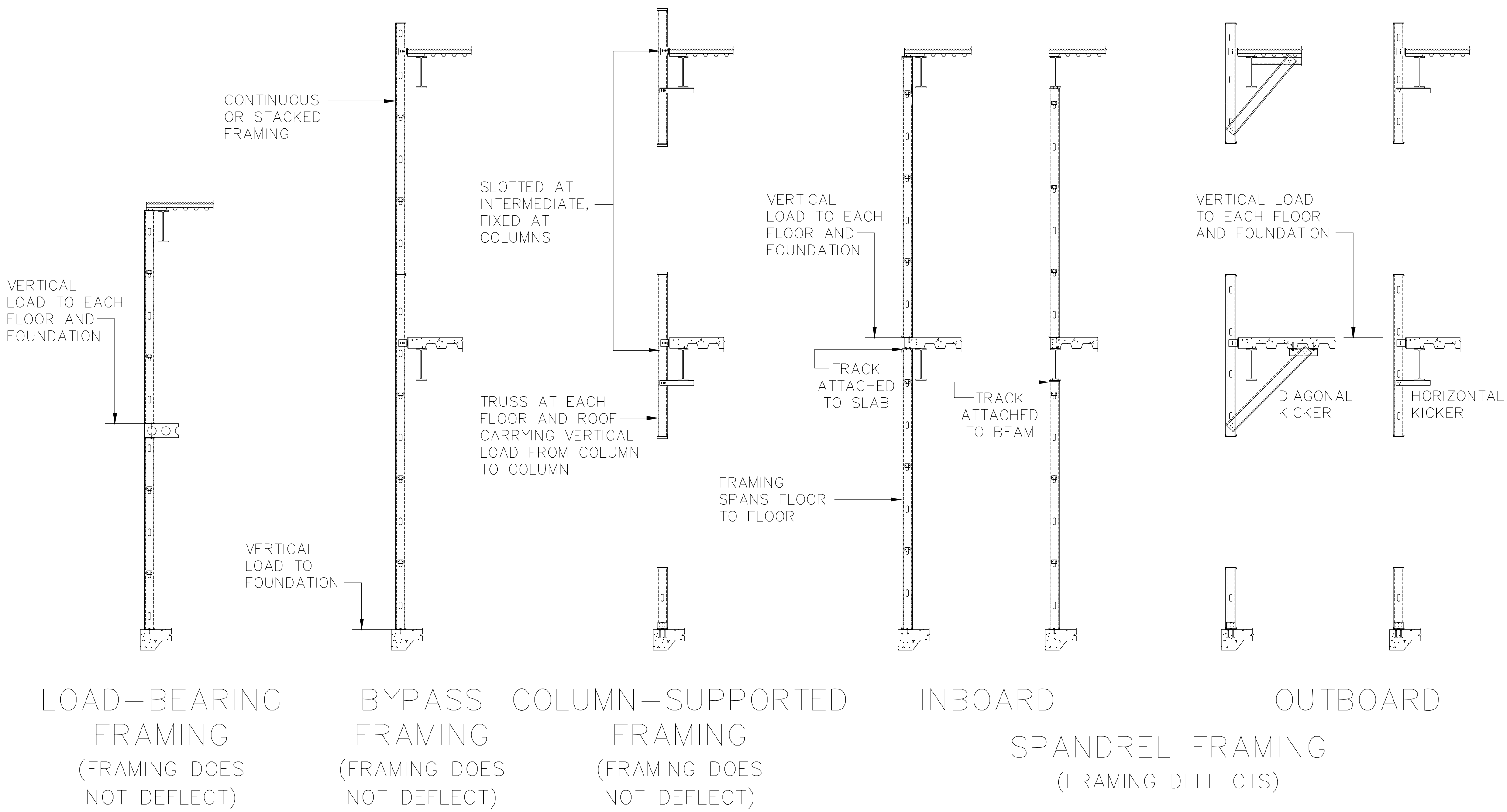
Bypass framing (method #2) used to support the cladding system has more than a few benefits over the systems that follow it:

1. The plane of the wall is established somewhat independent of the main steel or concrete frame tolerances.

2. Both vertical and horizontal panel joints, accent details and material transitions can be positioned without regard to the column or floor lines of the structure.

3. Minimal thermal and air barrier interruption occurs because there is no need for transitional deflection details and protruding slab edges.

It adds, however, by the consequence of its use the need for two other components: a fire and smoke containment system comprised of semi-rigid mineral wool insulation applied between the exterior cladding system and slab edge, or safing insulation, and a smoke sealant compound and



CLADDING SUPPORT FRAMING CATEGORIES

independent Division 9 interior finish support framing constructed on each floor. Many designers and construction managers view this to add unneeded cost to the construction. They often realize too late the cost associated with leaving this issue unresolved until the eleventh hour. In most instances it is both a monetary and a visual one involving a $20+ per foot deflection detail at each floor. Worse yet, if left unresolved entirely – cladding leakage or failure. The savings assumed to exist by the elimination of the need for fire safing and additional framing is often unrealized in the final analysis.

Column supported systems (method #3) are less used than foundation or spandrel supported systems. Because vertical cladding loads are applied only to the columns, the panel or secondary framing must span the distance from column to column outboard of the slab to collect the vertical loads from the cladding. Intermediate slab and roof edge connections are used to transfer lateral forces due to wind and add panel stability and are vertically slotted to isolate deflection.

There are two ways to transfer vertical load to the columns –through the use of the inherent strength of the cladding panel, or through the use of a strongback or truss support frame. For example, insulated metal composite and precast concrete panels exhibit sufficient stiffness in their strong axis and are able to be manufactured in sufficiently long lengths to apply them without a strongback. The designer must, however, accept bay length panels with vertical joints coincident to column lines and place additional vertical framing elements attached to the perimeter framing with slotted clips or brackets to stiffen them against wind forces.

When the panel length is broken into many panels across the length of a column bay, or when the panel stiffness is insufficient for span of its weight and possibly the weight of glazing above, a strongback or truss framing system is then required to convey the vertical load to the columns. Panelized façade systems are typically column supported systems and therefore achieve isolation from vertical live load deflection issues. Column supported systems work well but are less chosen because of the cost to design and detail, fabricate and install the tubular or light-gage truss frames and panels or completed panelized wall sections.

Spandrel supported systems (method #4) transfer the load of the cladding uniformly along the perimeter floor or roof framing. Spandrel supported framing can be positioned inboard or outboard of the floor slab. When positioned outboard, it often creates a continuous opening for strip windows. When positioned inboard, the glazed openings are typically intermixed with solid wall areas. One type of spandrel supported system, inboard or floor-to-floor stud framing, has gained broader appeal in the last few years. Through the acceptance and use of exterior fiberglass faced gypsum products, the responsibilities of the exterior framing contractor (Division 5) have merged with those of the Division 9 (interior finishes) contract who provides similar non-load bearing support framing. The exterior framing is now applied in the same cost-effective manner that they are accustomed to installing finish material – while standing on the floor. The result is gypsum-sheathed floor-to-floor stud framing. The appeal is in how quickly and cost-effectively the building can be enclosed and “dried-in” against weather; thereby permitting other trades to work more consistently.

Unfortunately in this case, which is common with all spandrel supported systems, as a direct result of the framing simplicity, there is a more than equivalent complexity passed along to the application of the cladding. The reason is that perimeter framing, whether floor or roof, deflects in response to load. This movement is not designed to be transferred as axial load to the stud framing. The typical solution is a slip track located between the top of the stud framing and the underside of the slab extension. The slip track unloads the non-bearing exterior stud framing from vertical live load. The detail of a PVC deflection joint or gunnable sealant appears to complete the detail by bridging the discontinuity of the sheathing. The façade problem, however, is just beginning. The cladding now must extend this line of movement through to the exterior without compromising its weather integrity, longevity and the aesthetic intent of the architect.

A similar problem may occur with outboard spandrel framing intended for strip windows.   The line of movement in this case is typically at the head of the glazing system. Glazing systems typically accommodate this movement by providing slip at the window head in the form of some sort of receiver pocket that allows for differential movement. A problem often arises when an intersecting or opaque wall section is desired in other than the movement-limited zone near the column. Slip head transitions from the window to the opaque panel are left unresolved and nearly impossible to satisfactorily detail after contract award.

One solution to the spandrel deflection problem is frequently overlooked. It is one that does not necessarily isolate the primary framing from the secondary framing, but instead makes it compatible with the cladding. By increasing the stiffness of the slab edge, the live load deflection can be reduced to an amount that is manageable by the joinery of the cladding or by a simple and less conspicuous movement joint. Movement due to live load of 0.250-inch or less typically falls into such a category. For the common spans today of 25-foot to 35-foot, the idea that the live load deflection should be reduced fourfold from the minimum of L/360 or 0.833-inch to 1.167-inch to 0.250-inch or less seems absurd at first. However, the cost of specifying a deeper structural steel shape to the full or partial composite stiffness of the concrete and steel section is usually less than the cost to apply a column supported façade system or to add lines of horizontal movement joints to the exterior cladding.

When all other means to partially or completely isolate the façade from the frame have been exhausted, all that remains is to continue this movement through the cladding to the outside.   To flex without tearing, the connecting material must generally be wider than the movement dimension required. Typically the location of the joint can be translated very little vertically from the source of movement. Panel joints must be placed near the slip track. Additionally, the depth of the slip track leg and an amount equal to the anticipated deflection must be left clear from cladding fasteners so as not to disable its function. The consequence of providing means of attachment, longevity of connective material and bridging the stud framing components is that the visible width of the movement joint is greatly increased. A ¾-inch movement joint often becomes a three or four inch wide horizontal stripe.

A product that allows the cladding to accommodate floor movement can be specified and purchased separately or can be designed, fabricated and purchased through the cladding manufacturer. The latter case has its advantages. One designed by the cladding manufacturer directs the responsibility to the manufacturer and its erector. It allows for any difficulty in making an attachment or bond to the cladding panel edge; an edge that typically lacks the strength and geometry to make a proper connection. An integral design is preferred if no other means of isolation can be achieved; however, it is often wise to be seated when handed the price and the thermal performance qualifications.

4. Structural Steel, Concrete & Masonry Placement Tolerances and The Need For Girt Space

Erection of secondary wall support members, or girts, to a toleranced plane both vertically and horizontally is substantially dependent upon the placement of the primary structural members and the allowance for adjustment that is afforded to the secondary attachments. To design allowance for these tolerances, the trade accepted values must be known. They differ with each substrate and therefore will be addressed individually as follows.

Primary Structure Placement Tolerances[9,10,11]

Primary Structure Type	Tolerance Origin	Variation in Plumb	Variation in Building Line	Recommended Design Value
Load-Bearing Stud Framing	ASTM C-1007	L/960 or 1/8-inch in 10-feet	none stated	1/4-inch
Concrete	ACI 347	1/4-inch in 10-feet, 1-inch maximum	1-inch	1-inch
Masonry	unknown	1/4-inch in 10-feet, 3/8-inch in 20-feet/story; or 1/2-inch in 40-feet	1/2-inch in any bay/20-feet; or 1/2-inch in 40-feet	1-inch
Structural Steel	AISC "Code of Standard Practice for Steel Buildings and Bridges"	1:500 slope	1/4-inch anchor bolt placement	1-inch

With respect to masonry, these tolerances are seldom held due little to any fault of the masonry contractor. Instead, concrete masonry installed in conjunction with concrete grade walls and steel framework requiring shear stabilization, many times is laid to the best line established by these trades, and not control lines which may or may not agree with this same work. Similarly with concrete, bent plates used at elevated slab edges are shop fabricated and set by the steel erector to adequate AISC tolerances but can warp outward due to the hydrostatic pressure of the concrete.

For any basic construction material, the owner or his representative is responsible for determining if the erected material is acceptable within the recommended tolerances stated. If no effort is made to verify or correct the state of erected material upon completion of work, the different code guidelines may prove very conservative to the actual field tolerances encountered by the wall contractor. The author always suggests arranging for the construction manager to provide a survey crew to establish and mark control lines prior to the erection of cladding support framing. In this way, out-of-tolerance issues can be resolved independently before the work of other trades makes it more difficult to correct.

5. Continuous Insulation Applications, Design-Build and Mixed Claddings

Now that we have discussed general requirements of the cladding and its supports such as:

1. the need for a load path for the cladding to convey external forces to the frame
2. the need for adequate girt space required to account for tolerances in the frame
3. the linkage between the cladding framing design and floor deflection
4. the difficulties in providing "continuous insulation" in agreement with the basic prescriptive language of the energy regulations

Let us broaden the discussion to include the other forms of continuous insulation and the interaction between each and other types of building envelope components.
EIFS, metal/foam composite panels, insulated concrete and to some extent metal building draped low-density fiberglass are all various forms of continuous insulation for above grade walls. Each has their advantages and disadvantages. Any prefabricated insulated cladding panel must have means to continue its thermal and weather and sometimes air control plane to its perimeter and to other cladding or fenestration components. Those built piecewise allow for greater flexibility but in turn often require greater care of the scope issues between trades. Today, few installers wish to touch materials that are not in their scope of work. The design-build process has not helped the situation. Fifteen years ago, the design of major projects included loads of preliminary work with manufacturers to ensure the tie-ins of one material to another, which was included in the scope and was agreeable in detail to both parties. These days the bidders, quite often the installers of the manufactured material and not the manufacturer, are asked to estimate material and labor based upon a preliminary drawing set similar to those we began discussions with in

past years. It is a sign of the times. But an adjustment in the process is warranted to ensure that the exterior façade resembles what was sold and functions without problem. Establish relationships with the primary material suppliers. Ask questions. Ask them early in the design process.

All the various forms of continuous insulation/cladding systems can be designed properly to function. Some have greater thermal mass, some have reduced weight and capacity to span and some are able to be easily shaped to great detail. Furthermore, we often see more than one type of continuous insulation and cladding on an elevation mixed with other forms of cladding assumed to require cavity insulation. This is where the designer must be careful. He must possess a clear understanding of the issues and possible pitfalls; preferably before the construction manager proposes value engineering to the owner.

Let us use an example to illustrate this. A design using 2-inch XPS exterior insulation over a modified bitumen air/weather barrier on fiberglass-faced gypsum exterior sheathing supported by 6-inch open cavity studs has been used successfully from Philadelphia to St. Louis and your firm sees no reason to stop recommending its use. However, a project in Minnesota requires a lower thermal transmittance than this wall can provide because of either prescriptive requirements or to trade-off other less efficient fenestration. Would it be better to:

1. Add insulation in the cavity, or
2. Increase the thickness of the foam board

Although option A is suggested more often than not, it is not necessarily the right answer. Because cavity insulation is applied in depths that fill the cavity, the temperature in the cavity with an R19 or R21 batt will be below the dew point for a time during the colder months. Now we must consider mechanisms that dry the cavity and ensure they are not defeated by later alterations, or exasperated by harsher building uses, etc. Bottom line: the performance of option A is subjective to its input parameters; option B is not, therefore it is the better solution.

What if the same client is opening an office in Florida, will the same wall function properly? Yes, but a slight improvement will make it better. A change to a backside drained insulation board or the addition of a drainable membrane similar to that used behind exterior cement stucco will allow possible summer condensation to form and drain more readily to exterior weeps.

Does the choice of cladding affect your selection of the five envelope components? Let us review the two extremes: brick veneer and metal siding.

Brick veneer has the potential to absorb great amounts of moisture on its exterior face and present it for release to the interior face. In doing so the vapor pressure in the air space behind it raises considerably. Because the driving mechanism is often the sun, the increase in pressure is from both a temperature and a concentration gradient. Ventilation behind the veneer is required to limit the “rainforest effect” there. Yes, the modified bitumen should protect the stud cavity and exterior sheathing, however, one should also be concerned how long the galvanized coating of the brick ties and fasteners will last under such extreme conditions. The ventilation exchanges the humid veneer cavity air with less humid outside air. The concentration gradient portion of the vapor pressure is then reduced. Add a drainable plane behind the foam insulation and a workable and durable design is the result.

Metal siding is durable, but impermeable to vapor as a material. Only its joints and details present materials that may be more permeable, yet they account for too small an area to be of any effect. This impermeability may be defeated by providing a drained and ventilated space behind the siding. Some people prefer to specify a "rainscreen". Others try to distinguish on merit a drained and back-ventilated (DBV) space from a pressure-equalized rainscreen. There is a difference, but not in the context of providing necessary ventilation. The pressure-equalized rainscreen design can reduce the penetration of driving rains and therefore the requirement of a more robust air/weather barrier material. Some believe that it reduces the wind loading on the siding. Unfortunately, although true in theory, there is no proper method to account for this in structural design. What is needed in most mixed and cold climates is the ventilation to allow for outward drying in the colder months to complement the needed inward drying in the warmer months. Either a DBV or pressure-equalized wall will provide this ventilation. In every case, providing both inward and outward drying potential will prove to create the most successful assembly.

Yes, when properly designed, a continuous exterior insulated wall assembly is quite versatile. It can be used successfully in most all climates with most all claddings and building usages. What about the standard 6-inch steel stud, cavity insulated and sheathed wall?

It meets the prescriptive thermal insulation requirements for Climate Zones (CZ) 1-4 and with the piecewise addition of a spun-bonded polyolefin membrane, it can satisfy the remainder of the building and energy codes as far north as Virginia. In commercial applications, however, in these hot-humid and mixed-humid climates its function relies heavily upon drying mechanisms towards the interior and in CZ 4, the ability to retain excess moisture for brief periods without damage. Yet a cavity insulation system is indeed workable in these climates.

Therein lies the rub. Both continuous and cavity insulation systems are code worthy for a large part of the country. A designer wishes to interweave a medley of different materials on the exterior façade. He conducts sufficient internet research and includes manufacturer details into his bid set of drawings. Some suggest cavity insulation; others include or indicate details with continuous insulation. Nevertheless, is each adjoining cladding system compatible? Is a design using cladding with exterior insulation compatible with one using cavity insulation?

Three issues concerning thermal insulation may occur when mixing continuous and cavity insulation systems:

1. An inappropriate or unbalanced use of additional insulation in the cavity
2. A lack of continuity of the thermal control plane

3. Thermal depression and condensation due to thermal bridging

The first potential issue follows the adage: some is good, even more is better. When a designer chooses to ignore that a "universal wall" constructed of steel studs with cavity insulation, exterior gypsum sheathing and spun-bonded polyolefin may not properly function in a hospital in New England with the addition of metal/foam composite panels, it usually comes as a surprise. More insulation is better, right?

Not in this case. The issue is the potential for damaging condensation with an unbalanced ratio of cavity insulation to exterior insulation enclosing high humidity operating rooms and patient recovery areas where resilient, insufficiently permeable or multiple layer interior finishes are often applied. The addition of exterior insulation with sealed metal facings exasperates the issue. Not by the use of the insulated metal panel, but instead by the lack of "system thinking" needed to provide a complete, resilient cladding system. The exterior insulation lowers the cavity dew point and the sealed metal limits the drying of accumulated moisture to the exterior. The wall only can dry to the interior, where walls are repeatedly painted and moisture levels are often at their highest permissible level. The simple answer: remove the cavity insulation and eliminate the potential problem. The more complete answer: consider the consequences of additional cavity insulation carefully before adding it behind a possible concealed condensing surface. Ask yourself: have I incorporated an effective, long-term mechanism to provide a moisture balance to the concealed space?

Lack of insulation continuity is another issue. Do not assume insulation effectiveness is equal to the area ratio with which it is installed. It is not. Consider an uninsulated 6-inch feature band of 0.125-inch aluminum located at 10-foot on center in a field of metal/foam insulated panels. The assembly is placed outboard of the same "universal wall" described above, however, this time without the cavity insulation. The tested thermal conductance of the foam panels is 0.077 Btu/h·ft^{2}·°F. The thermal conductivity of aluminum is about 100 Btu/h·ft·°F. Combined, it may surprise one to know that the overall U-factor is approximately 0.105 Btu/h·ft^{2}·°F or 68% of the assembly without the feature. Without the insulation provided by the stud air space and gypsum, the result would have been far worse. This assembly cannot meet the prescriptive insulation requirements for Climate Zone 5 without trade-off even though over 95% of the exterior is insulated in excess of the energy code requirements. The addition of a band of cavity insulation behind the feature is difficult to detail and coordinate. It might help to consider an analogy between the application of varying degrees of thermal insulation and a team of horses that is restrained by the weakest member the next time less insulated features are suggested.

One last issue of design to investigate before it is considered complete is to review areas of thermal bridging and make improvements to limit heat loss or account for the release of any condensation generated. Even insulated architectural precast concrete and insulated metal sandwich panels must tie together or bring their exterior and interior faces near to one another in order to convey external loads to their attachment locations. In doing so, thermal bridges, or less thermally efficient areas, are created. This is why full-scale thermal testing is important for panel assemblies. Likewise exterior insulation details at the window perimeter, material transitions, movement joints and the base are usually less thermally efficient to permit their attachment and the air barrier and flashing tie-ins. These details are many times improved simply by adding a return of exterior gypsum at a window jamb to act as a thermal break or the shingling of exterior insulation over the exposed slab at the base to limit heat flow. In areas such as these, keep in mind the hierarchy of the principles of good cladding system design: keep it on the building, keep the water out, and keep the climate inside the building separate from that outside the building. One principle usually acts to compromise the other and if not the other the cost.

Properly detailing exterior insulation systems can be challenging. My recommendation is to resist the temptation to add additional cavity insulation in a "belt & suspenders" manner to commercial building envelopes with continuous exterior insulation systems. More is not always better and installed in a disproportionate manner, cavity insulation can cause problems. Consider that although the net effect of insulation installed between steel framing may be near 50% of the thermal resistance of the insulation, as all well-read Architects and Engineers in building construction may know, the condensing surface at the interior face of the exterior sheathing, however, experiences the temperature depression from nearly the full effect of the insulation at the center of cavity. In other words, figure the potential for condensation with R-18 or R-21 in the cavity behind that R-10 exterior foam or R-13 metal panel. The decision, therefore, to add cavity insulation must always partner with an adequate drying mechanism. If the building finish and usage is not compatible with providing this drying mechanism it is then not compatible with cavity insulation.

4. Conclusion

Building envelope design is not as easy as it used to be when all that was needed to be successful was to keep the water out and the cladding on the building. The energy codes have seen to that. This author's recommendation to all involved in the specification, design and construction of building envelope systems is to expand your general knowledge of these subjects and ask suitable questions of the technical staff of the manufacturer. Advice and assistance from consultants is welcome but it too comes with limitations; their knowledge is often specialized in the field in which they worked. Some are great with envelope construction while others ensure the basics – that seal tie-ins are made and material is provided and installed to specification.

Exterior insulation is a necessary part of the solution for commercial construction. Its application, as part of a plan to make continuous the other components of the building envelope, can remove roadblocks to creative façade design by providing a sound means to employ various cladding materials without fear of condensation damage or construction surprises. Exterior insulation must be applied, however, with the understanding that the cladding must convey the external loads it attracts to the primary structure in an equally sound manner. This may often preclude the use of simple code referenced amounts of continuous insulation and the lowest cost framing system to achieve the prescriptive envelope requirements and overall design success.

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