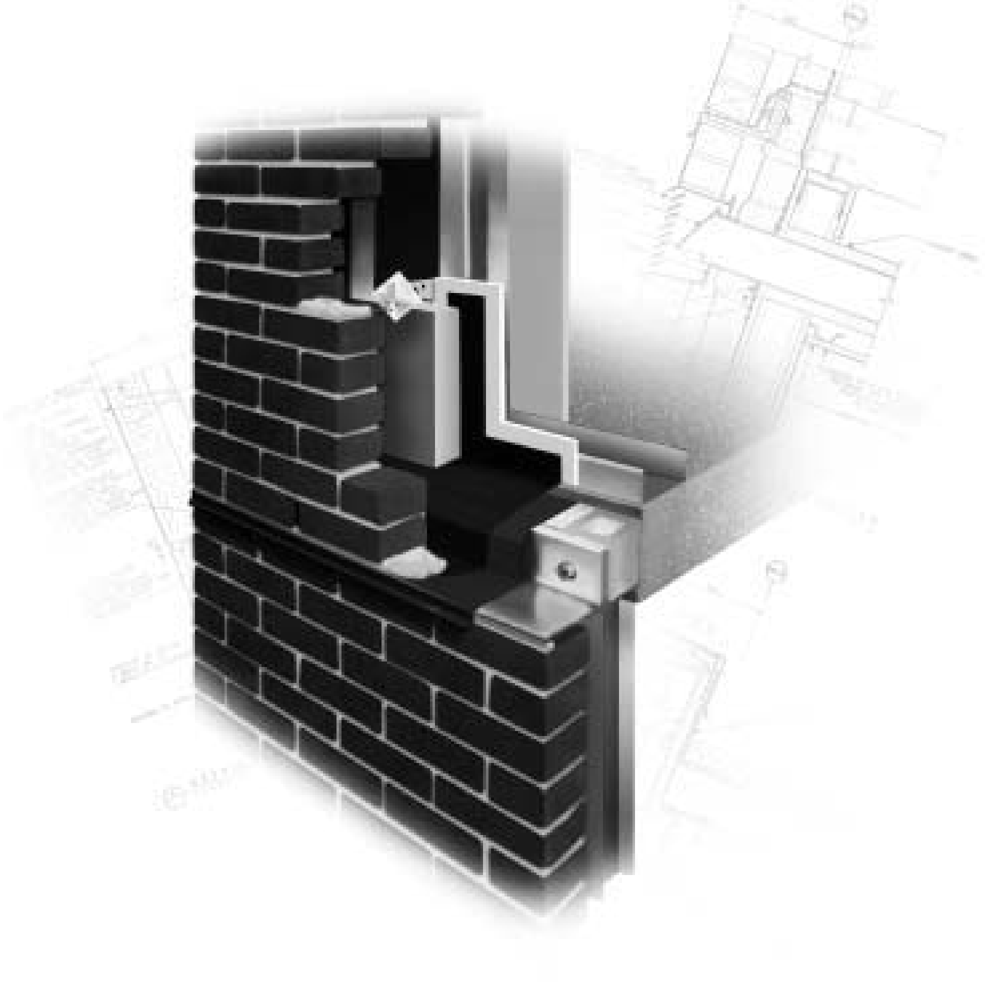
BRICK VENEER
STEEL STUD

BEST PRACTICE GUIDE
BUILDING TECHNOLOGY



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CHAPTER 1

INTRODUCTION

PURPOSE

Recent research has extended available knowledge of the performance of brick veneer steel stud (or BVSS) walls. The purpose of this guide is to distill the findings of recent research, with emphasis on building science issues and CMHC sponsored research, and to consolidate this information in an accessible form for building designers.

The guide does not attempt to address structural design of BVSS walls *per se*. Structural aspects are discussed only because structural decisions have impacts on architectural and building science aspects of wall design that might otherwise be overlooked. Readers whose primary interest is structural design should refer to the original research reports as well as sources of information on design procedures, such as the *CSSBI Lightweight Steel Framing Design Manual*. This guide places greater emphasis on traditionally architectural aspects of building science.

The *CSSBI Lightweight Steel Framing Manual* provides the following checklist of building science issues:

- rain screens;
- air spaces in walls free of debris;
- flashing and weep holes;
- insulation;
- protection from condensation and water penetration for exterior sheathings that deteriorate in strength and stiffness in the presence of moisture;
- insulation detailing to minimize thermal bridging;
- continuous air barrier systems incorporating well sealed joints;
- vapour retarders that may or may not be integral with the air barrier;
- fire resistance;
- detailing to minimize sound transmission;
- detailing to accommodate building frame movements;
- detailing to accommodate thermal movements of large panels;
- in masonry veneer construction, brick ties with corrosion protection, required stiffness and strength and with adequate connection to the steel studs.

These issues are addressed in this guide in greater detail, except for fire resistance and sound transmission. Insulation is dealt with only insofar as it affects durability of the wall, as opposed to energy consumption.

Chapter 6 provides sample details and master specifications to facilitate the application of suggested improvements.

The focus is on control of flows of moisture, air, and heat. These factors, if not addressed, will compromise durability and maintenance of satisfactory interior conditions. Where they interact with structural design, the guide discusses criteria to consider in structural design, to ensure satisfactory architectural performance. Questions about how much insulation to use for energy conservation or life cycle cost, fire resistance, acoustic control, and aesthetics are not addressed.

From the literature, it appears that some aspects of BVSS wall design are controversial, and that problems may exist for which there are no generally accepted and well-tried solutions. The guide does not pave a single path to good BVSS wall design. It provides new tools that designers can use to pave their own paths. Every project, with its own environmental loads, structure, and budget, will call for different design choices, and result in details different from the details illustrated. The issues raised, research results, and suggested analytical tools, however, will all apply to a broad spectrum of designs.

Steel stud exterior walls have received criticism, particularly as backup for masonry veneer. At the same time, their low cost, small footprint, and light weight are attractive characteristics.

The most common problems of steel stud exterior walls derive from an inability to exclude moisture and thereby prevent corrosion and other deterioration. Rain is the most obvious source. However, air leakage resulting in condensation is a common if less obvious cause. Thermal bridging and localized heat loss often result in discolouration, or even condensation, on interior surfaces at stud locations of walls insulated only within the stud space. Structural problems, when they occur, typically appear as distress in veneer and finishes. They may increase air leakage and rain penetration, or impair appearance, but rarely affect safety, except in the long term, when corrosion results.

The design conditions specified by codes seldom occur in service, and never occur during the useful lifetimes of many buildings. Subjecting full size samples of wall assemblies to the extremes of their design service conditions is the only way to hasten the discovery of unexpected design problems. The details in Chapter 6 take into account the experience gained from several CMHC sponsored test programs conducted to simulate extreme service conditions.

Some problems associated with BVSS walls have nothing to do with the steel stud framing. Brick spalling as a result of inadequate allowance for creep shortening and deflection of the building frame can happen with any backup wall. If tolerances are not coordinated to provide enough latitude for unavoidable dimensional inaccuracies, the builder will be forced to improvise alternative details. Any wall may suffer from condensation damage or rain penetration, if not designed to avoid them.

BACKGROUND

The components of a typical steel stud framed wall, designed to carry lateral loads and to permit frame shortening and deflection at the head of the wall are shown in *Figure 1-1*.

Steel stud framing has been used to support lateral loads for more than 40 years. Some authorities have questioned the suitability of the system, particularly as a support for stiff

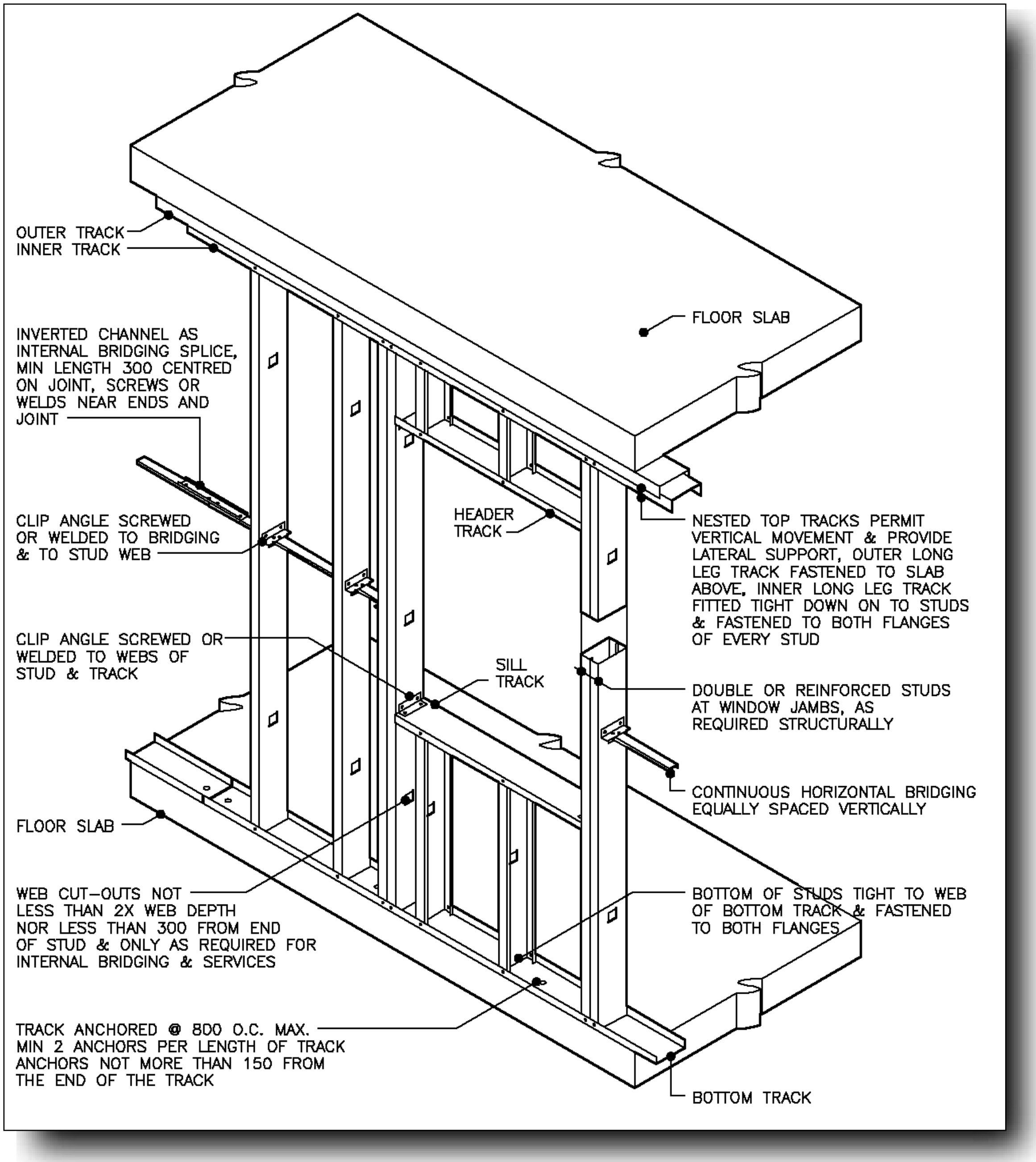

Figure 1-1: *Framing components of a typical lateral-load-bearing steel stud wall.*

exterior cladding. In a recent survey done for CMHC[1], respondents classified themselves as:

- users with reservations 60% (mostly designers);
- enthusiastic users 20% (mostly contractors);
- non-believers 10%;
- open minded non-users 10%.

While in retrospect it may seem that extensive use of steel studs preceded extensive analysis and research, steel studs were originally designed by applying familiar procedures. We should be surprised if 40 years of service and testing failed to reveal room for improvement.

Some modifications have become common as a result of published field and laboratory investigations. Other innovations have been introduced to save cost by eliminating seemingly useless features. Some people are sufficiently alarmed by reports of failure to recommend abandoning the system altogether. In response to growing criticism, researchers have gone back to look for hidden problems, and to verify the basis of design against performance of full scale assemblies subjected to the extremes of anticipated service conditions. CMHC has recently completed a series of studies, involving both investigation of existing buildings and laboratory observation under simulated service conditions. As part of this program, CMHC issued an advisory document on brick veneer for high-rise buildings[2].

In Chapters 2 and 3 building science principles, and the modes of failure observed in these studies, are discussed to illuminate BVSS wall design parameters. We could abandon steel stud framing instead of examining the problems in detail and correcting them; however, we would lose the advantages of low cost, light weight, and speed that made the system popular in the first place.

Advantages

Steel stud exterior walls are popular because of their light weight, ease and speed of construction, low cost, and small footprint. Properly designed and constructed steel stud exterior walls are as durable and as capable of sustaining extreme loading as are heavier systems.

In addition to reducing the cost of materials, both in the wall system and in the supporting structure, the light weight of steel stud systems suggests the possibility of reduced environmental impact.

Limitations

In the past, design procedures used in many instances were simple, and much of the detailing was done by rule of thumb, or left to the trades to do during construction. This casual approach to design has led to many of the difficulties observed in service. More detailed design attention is required for successful steel stud walls.

Steel stud framing members are of thin material in relation to their overall dimensions. Steel stud framing is

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[1] Keller, in *CMHC Seminar on Brick Veneer Wall Systems.*

[2] Drysdale and Suter, *Exterior Wall Construction in High Rise Buildings.*

inexpensive (hence likely to be perceived as not worthy of a lot of design effort), and yet it is at least as complicated to design on an analytical basis as structural steel framing. In the past, most connections and members other than the typical stud were not designed from first principles. Cutouts, point loads, and the possibility of localized damage were often neglected. A properly designed steel stud wall will not suffer from the resulting difficulties, although the amount of forethought per kilogram of material used may be greater than for other systems.

Because they are thin, it is important to ensure that steel stud framing and its connections do not corrode. Parent material thickness is not as important as galvanizing thickness for protection from loss of structural integrity due to corrosion. In heavy structural steel, corrosion can often be allowed for by a modest increase in thickness. A loss of 0.25 mm (0.01 in.) of material is only 5% of the original thickness of 5 mm (0.2 in.) member. It would be 25% of the thickness of a 0.91 mm (20 ga.) sheet steel member. Steel stud wall systems have little capacity for storing moisture for future evaporation, in contrast to the heavy masonry walls of the past. For these reasons, air leakage, component temperatures, and resulting condensation need careful consideration.

Historical Basis for Design

During preparation of working drawings, design has typically consisted of selecting a stud depth from a manufacturer’s table of maximum spans for various combinations of depth, thickness, load, and allowable deflection. In the 1986 CMHC survey, responding designers reported that they regarded deflection criteria of anywhere from L/240 to L/720 as being appropriate (55% opted for L/360, only 7% for L/720, and 10% felt that less than L/360 was adequate). Details received relatively little attention. Detailing was based on accepted reference standards or de facto standard trade practices, not on analysis. Specifications provided additional direction, but rarely differed from one project to another, despite different design parameters. Like the details on the drawings, they were based on accepted standards. The tables provided by manufacturers were derived in accordance with CSA S136; however, they were often based on uniform loads and simple bending. Some tables ignored secondary effects like web crippling, localized loads from ties or fasteners, lateral displacement at connections, and localized effects around web openings. Many tables also assumed bracing adequate to prevent rotation along the entire length of each member.

Designers gave no detailed consideration to the probability of wet service conditions. Although some form of galvanizing was almost always called for, the degree of protection provided often did not receive the attention it deserves.

Detailers rarely considered the possibility that floors and columns might vary from the exact positions indicated on the drawings, or the effects of such variations on wall framing, connections, and appearance of cladding. The builder was left to make *ad hoc* modifications of the details when the actual position of the structure did not allow for acceptable positioning of visible cladding surfaces, even though the structure met the tolerances of the applicable codes and specifications.

Evolution and Improvement

Some failures have been widely publicized and most designers who have used steel studs extensively probably know of other, less well known cases. Practices accepted at one time have gradually been modified as a result.

Welded truss studs have been eliminated, cost alone being sufficient cause. In addition, there were failures particular to the type.

A deflection limit of L/720 is more often accepted as necessary where studs support masonry veneer, and has recently become a standard requirement.

Use of double track at the wall head prevents unintended axial loading, where a single track with studs cut short was considered adequate at one time. It allows connection of both flanges of the stud to prevent twisting. In some markets, connectors are available to attach the web of each stud directly to the structure, providing a stiffer connection in addition to torsional restraint and relief from axial load.

Many designers recognize that bracing needs to be connected to the studs to be effective, and that gypsum interior and exterior cladding is not always reliable for preventing rotation, let alone for composite action. When metal bridging is used for bracing, manufacturers now recommended fastening it to the studs.

Some building designers now delegate detailed design of load bearing stud systems and conception of details to engineers who specialize in cold formed steel design. Often, this task is part of the contractor's work. Much of the decision making (sometimes including the thickness of studs) was always left to the contractor, but now the delegation is formalized, and the degree of care expected made more explicit.

Instances have occurred of extensive moisture damage to metal stud framing and gypsum board in metal stud framed exterior walls. Not all of the possible causes have been recognized, but most designers now provide what they consider to be a *rain screen* wall, and improved windows make leakage from window sills into the wall cavity less likely.

Thermal bridging is recognized as a problem, both for energy economy, and as an appearance problem in some instances, with dust marking at each stud location.

Simplifications, Shortcuts, and Oversights

Structural design of metal stud exterior walls is often an orphan. During the preparation of working drawings the structural engineer, the party most likely to have been trained for the task, regards this element as outside the scope of structural work and fees. Thus, the design of the system is left to the architect. Because it is uncommon for the architect to have personnel qualified in the structural design of sheet steel, reference to the stud manufacturer's load tables usually determines the size and thickness of the studs. The architect may have recourse to the advice of a manufacturer's representative, if good representation is available.

Some designers assume that sheathing on both sides of the studs is adequate lateral bracing, having observed that gypsum sheathing is stiff, if not strong, and that loads on bracing are generally low. Metal bridging, when specified, may still be omitted by builders who are unaccustomed to its use in some regions.

Modifications of the accepted system are sometimes made that are hard to explain on the assumption of good intentions and diligence. Interior studs, of 0.53 mm (26 ga.) or lighter material, with depth as indicated on the drawings, have been used despite the thickness called for by manufacturer's load tables or specified. Inappropriate fasteners, such as interior drywall screws, are used to secure track at head and sill. Spacing of fasteners used to attach track to structure, and sheathing to studs, is often much wider than the accepted written standards or specifications require. Studs may even be held in place only by friction, until attachment of the sheathing and interior finish, connecting the studs to the track. Denting or kinking of members is often ignored, although it reduces capacity.

Common construction deficiencies include studs fastened to the track only on the interior (accessible) side, or not at all; studs cut to a standard length, too short for some locations because of variation in actual jobsite dimensions; and bridging channels omitted. If provided, bridging is not always fastened together or overlapped at ends, or fastened to the studs.

False Alarms?

Encon Insurance Managers published a Loss Control Bulletin for architects and engineers insured by Simcoe and Erie with the headline, "An investigator of brick veneer/steel stud failures explains why he thinks the system should be avoided."[3] It cited three main reasons to avoid the system:

- vulnerability to structural failure from moisture;
- cracking of brick veneer under design wind loading;
- inadequacy of commercial wall ties.

Only the first of these three problems is one to which steel stud backup is particularly susceptible; the second and third are common to other masonry veneer systems. As an example, the bulletin goes on to cite the failure of steel stud walls in a 12-story apartment building in Dartmouth, N.S. in 1977 listing the following problems observed in that case:

- windows leaked water into the wall;
- brick veneer projected beyond the toe of the shelf angle because of alignment problems;
- shelf angles improperly installed and rusted;
- no soft joints below shelves, veneer bulging and cracking;
- inadequate, missing, and rusted ties;
- cavity bridged by mortar droppings, weep holes blocked;
- missing and improper flashings;
- extensive water damage of gypsum sheathing;
- rusted studs and track;
- wet insulation in stud space, sagging;
- extensive air leakage, evidence of condensation;
- interior foil backing of gypsum drywall damaged by rainwater.

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[3] Cowie, *The Failure of Steel Studs.*

Many of these defects are found in buildings with backup materials other than steel stud; only three are unique to steel stud construction. It is not necessary to abandon steel stud backup to solve this problem! It is clear, however, that there are issues to be addressed:

- control ingress of moisture into the wall, whether rain or condensation;
- materials that are not damaged or rendered dysfunctional by water, for those parts of the wall that cannot be kept dry;
- masonry veneer alignment, support, and protection from unintended stress (in common with all masonry veneer support systems).

This first Loss Control Bulletin did not pass without comment. Another bulletin, *The Success of Steel Studs*, followed shortly,[4] and was a succinct rebuttal of the first. It includes a summary of recent CMHC research and list of recommendations based on *rain screen* control of water penetration and air leakage control with an interior air barrier.

FUTURE DESIGN

The issues raised by the first Encon bulletin have been illuminated by recent research, and are addressed in the sections that follow. The details and specifications provided in Chapter 6 show incremental improvements on current practice that should result in better performance. The second Encon bulletin provides a starting point for development of alternative details using an interior air barrier. Much of the information provided here will be helpful to readers who wish to pursue this approach, although the details included here use an air barrier on the cold side of the studs. The details in this guide have yet to be built and tried in service to see if they work as well as it seems they should, but they do retain the proven features of past successful designs while adding new features where the research suggests that they will improve performance. To quote *The Success of Steel Stud/Brick Veneer Walls*,

> “The information is at hand to properly design and build BVSS wall systems. Designers can choose BVSS with confidence that they are providing building owners with an economical, well researched, robust, modern building technology.”

We need more research about tolerances. Little is known about tolerances possible in building construction, let alone what tolerances are economically optimal. A good discussion of the issue, and limited information about observed inaccuracies, is available in CBD 171. The design of the details in Chapter 6 assumes that the tolerances specified in applicable current standards can be achieved, although experience might suggest that they are sometimes not met by current construction practice.

Choosing the person who will do the detailed structural design is the most important decision the architect must make. Traditional architectural and structural fees do not allow much latitude for increased design effort, nor are all structural designers

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[4] Trestain, The Success of Steel Studs.

conversant with light gauge steel design. Master specifications often call for the builder to retain a specialist to do detailed wall framing design and prepare shop drawings. If the low bidder overlooks this requirement, the result is a cost for which no one has allowed, and the design may suffer as a result.

There are advantages to having the builder do the detailed design. An engineer who is well versed and who has specialized in light gauge steel design can do the work more effectively, at lower cost. Relieving the architect, or the structural consultant, of this cost makes steel stud more competitive with materials that require less design effort. On the other hand, completion of design before bidding would allow better coordination, more economical design, and tighter bidding. This is particularly true if the masonry veneer, ties, and stud framing are designed as an interactive structural system, since control of some of these elements is lost when the project is bid. A designer working for the steel stud sub-contractor cannot control the selection of some important elements, ties in particular. Ideally, the engineer doing the design prior to bidding would be a specialist structural sub-consultant, but the added fees are a strong disincentive, unless paid over and above the usual architectural fee.

CHAPTER 2

BUILDING SCIENCE ISSUES

EXCLUSION OF EXTERIOR WATER

Water can pass through a wall by missing the exterior surface completely and flying through a hole (as through an open window), by running down the surface until a passage that leads downhill through the wall is found, and by soaking into pores and fissures too small for surface tension to allow gravity flow. The addition of a difference in air pressure substantially increases the amount of water passing through a wall by these means. If the wall is monolithic, then even without an air pressure difference any of these three means of entry will sooner or later let water pass to the interior if water is available on the outside for long enough. With very thick walls able to soak up a large volume of water it may take a while. Thick walls are unusual, however; so many walls are built with a cavity separating the interior face from the exterior face of the wall. Holes in the outer wall are mostly not aligned with holes in the inner wall (excepting open windows), and water that passes through the exterior face by gravity or by air pressure against saturated pores and fissures tends to run down the back surface of the exterior face, where it can be intercepted and drained outside by flashings and weep holes. This reduces the amount of water that finds downward running paths leading to the interior, or that comes into contact with porous materials in the backup wall, and the amount of water eventually reaching the interior is also reduced. If nothing is done about the effects of air pressure differences, a wall with such a cavity has been aptly called a *drain screen* wall.[1] In more usual parlance it is a *two-stage* or *cavity wall*, but these terms encompass a broader set of possibilities. A wall designed to exclude water entirely at the exterior surface is a *face seal* wall.

A *drain screen* achieves some control over the entry of water without a perfect exterior surface. A less than perfect *face seal* wall admits water to the interior (unless it is thick and porous and can store the water until it has an opportunity to evaporate). *Figure 2-1* shows the amount of water passing into the cavities of 3 sample brick veneer *drain screens*, tested before and after cracking in load tests.

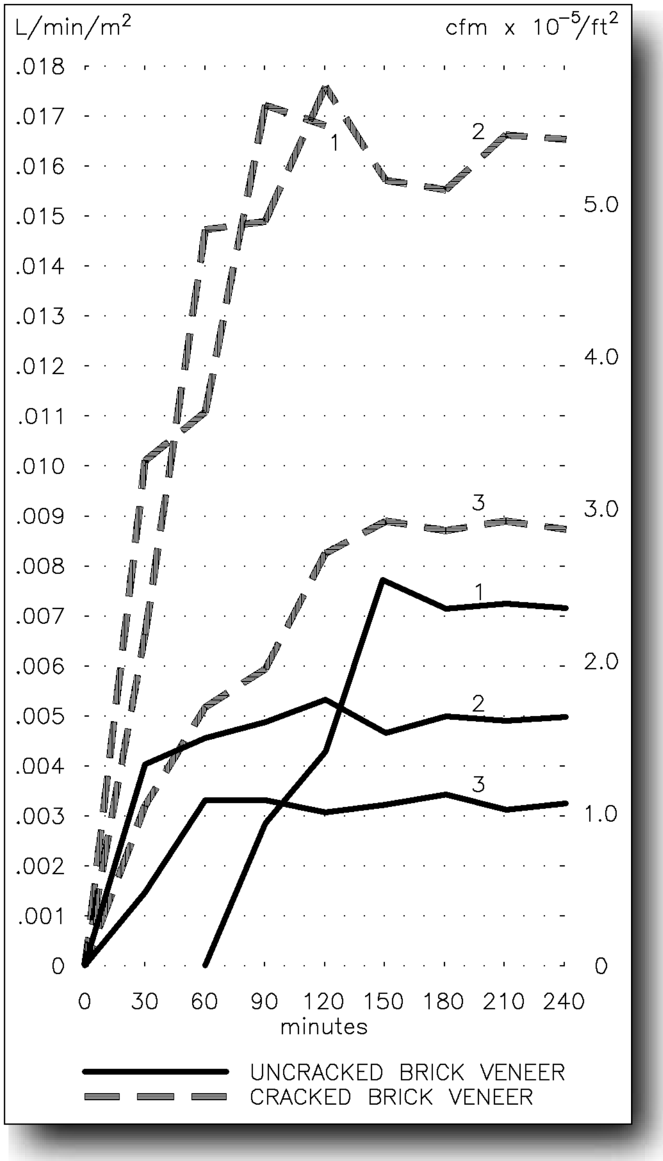

Figure 2-1: *Water leaking into cavities of brick veneer drain screens, with 0.5 kPa (20 lbf/ft²) air pressure difference.*[2]

The performance of a *drain screen* can be improved remarkably by introducing equalization of pressure between the air in the cavity and air on the exterior. When the air pressures are equal, there is no pressure to push water in small pores and cracks through the wall. Instead, it stops at the back of the exterior surface, arrested by

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[1] by Gustav O.P. Handegord.

[2] Drysdale & Wilson, McMaster Part 5, Fig. 4.5b.

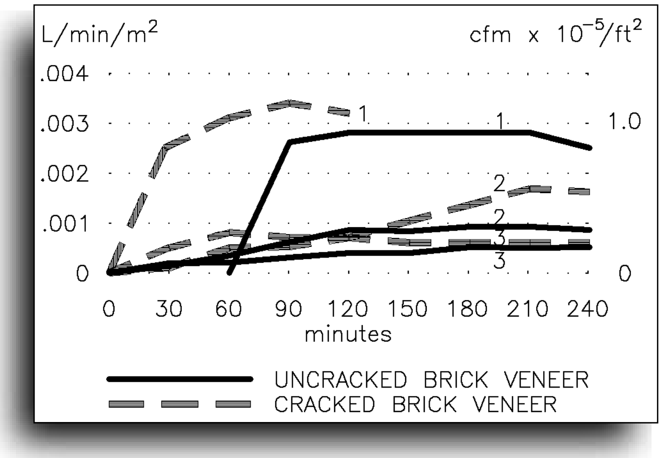

Figure 2-2: *Water leaking into cavities of brick veneer* rain screens, *with no air pressure difference.*[4]

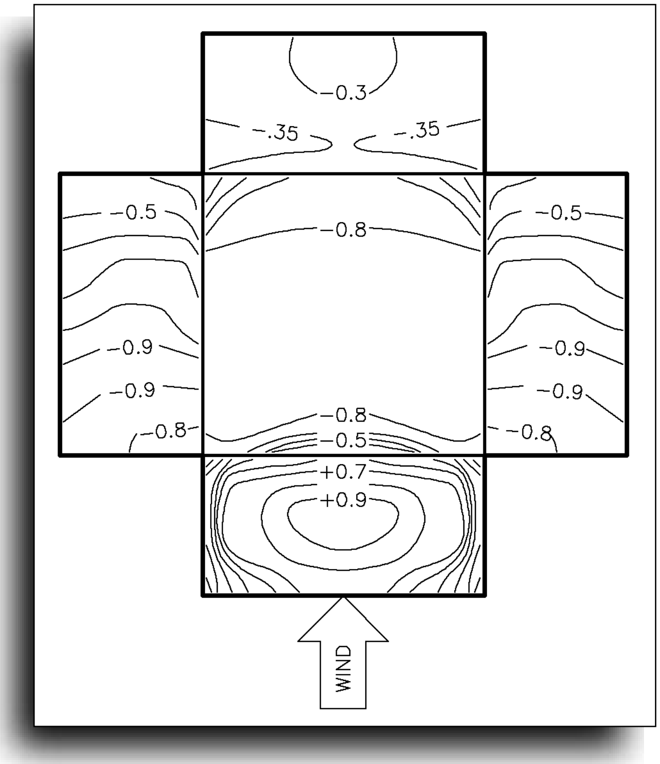

Figure 2-3: *Pressure distribution of head-on wind on building surfaces.*

surface tension (now the only force causing it to enter such small spaces in the first place). Water still flows in larger downward leading paths, where the weight of the water overcomes surface tension, but the absence of air flow or pressure reduces the flow of water, unless the passage is very large indeed. A wall with a pressure equalized cavity is a *pressure-equalized rain screen cavity wall*, or, for sake of simplicity, a *rain screen*. Compare *Figure 2-1* with *Figure 2-2*, both plotted to the same vertical scale, for a graphic impression of the difference between a *drain screen* and a *rain screen*, all other factors being equal.

Pressure Equalization

There are three basic requirements for equalizing cavity and exterior air pressures to achieve a *rain screen*:

- air flow into the cavity (or out of it) through openings to the exterior when the exterior pressure changes;
- negligible air flow between the cavity and the interior;
- barriers to air flow within the cavity between places where the exterior air pressures are different.

The usual example of areas where exterior pressures are different is at corners when there is wind, but exterior wind pressures may vary over the face of a wall as well. *Figure 2-3* shows average pressures of steady wind on the four walls and roof of a simple building form for flow perpendicular to one wall. *Figure 2-4* shows them for flow at a 45° degree angle.[3]

An additional requirement arises from turbulence, which causes exterior wind pressures at any one spot to vary rapidly. If the volume of the cavity is too large, or if the separation between the interior and the cavity is too flexible, air may not be able to pass through small vents in the exterior rapidly enough to compress (or decompress) the air in the cavity and compensate for cavity volume change before the pressure on the exterior changes again.

In either a *drain screen*, or a *rain screen* wall, some water can enter the cavity from the exterior. In this respect the separation of the cavity from the building interior is different from a *face seal* wall only to the extent that it is exposed to less water. A separation at the inside of the cavity has the advantage of being less subject to UV degradation of materials and extremes of thermal movement, but it is also

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[3] Chien *et al*.
[4] Drysdale & Wilson, McMaster Part 5, Fig. 4.5a.

less accessible for maintenance. The less water enters the cavity the better, so the additional attention to detail required to convert a *drain screen* to a *rain screen* is likely to be worthwhile, particularly if the cladding is a type that admits some water by gravity flow (*e.g.*, brick veneer).

Those parts of the inner wall that are most likely to be exposed to water, such as flashings and supports for the cladding, and places where construction debris may accumulate (allowing gravity flow to bridge the cavity), require just as much care in selection of materials and in construction as parts in a *face seal* wall.

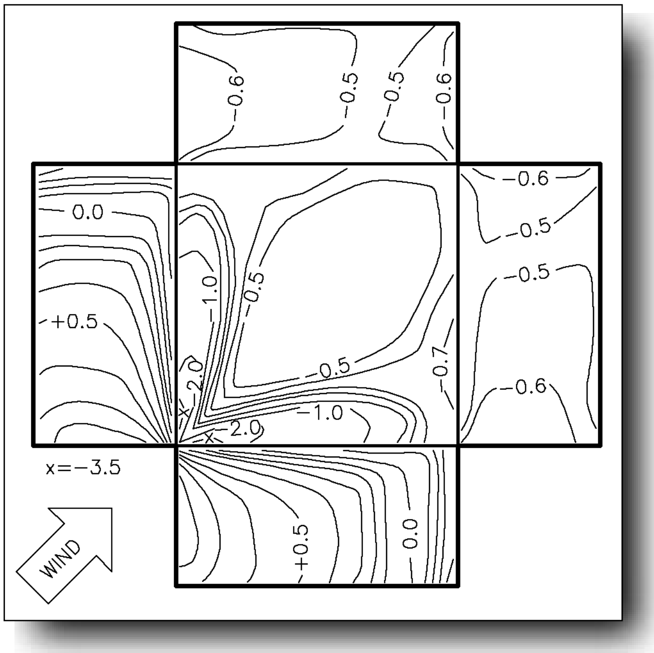

Figure 2-4: *Pressure distribution of diagonal wind on building surfaces.*

HEAT FLOW AND THERMAL BRIDGING

Outdoor winter conditions tend to be uncomfortable at best in most of Canada, and having a source of warmth in front is marginal comfort if you still have the cold at your back. Thus, we want walls with relatively warm surfaces, and in addition we expect them to keep out wind, rain, and snow. For fuel economy we want them to retard the escape of heat as well. Uninsulated walls can keep out wind, rain, and snow, and even allow us to maintain air at “room temperature” if we furnish enough heat, but they still tend to have cold interior surfaces that reduce comfort and attract condensation. Insulation reduces heat flow through the wall, raises the temperature of interior surfaces, and lowers the temperature of the outer parts of the wall. It is not possible to make all parts of the wall equally resistant to heat flow; metal studs in particular conduct heat much more than insulation does, thus forming *thermal bridges*. Slab edges and projecting supports for exterior cladding do the same thing. The temperature of the interior surface at a *thermal bridge* depends not only on the conductivity of the bridge, but also on its location relative to the insulation. Two differently located bridges, one with most of its mass and surface outward from the insulation, the other with most of its mass and surface inward, may well conduct the same amount of heat to the exterior, but will have different interior surface temperatures. The mostly outboard bridge will be distinctly cold, while a mostly inboard bridge may be only slightly cooler than adjacent surfaces of less conductive parts. The situation is reversed on the exterior. Since we cannot avoid having some *thermal bridges*, it is better that they should be warm than cold. Highly conductive elements, if they cannot be eliminated, should be located so that they present most of their mass and surface to the interior of the insulation. It is possible to design thermal bridges using two- or three-dimensional numeric models to predict heat flow and surface temperatures.[5]

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[5] Blomberg, HEAT2 & HEAT3, or DOE HEATING 7.2.

AIR LEAKAGE, VAPOUR DIFFUSION, AND CONDENSATION

The introduction of insulation and tighter wall construction caused hidden condensation to become a recognized problem. The absolute water vapour content of air, at a given relative humidity and comfort level, is much greater in warm interior air than it is in winter outdoor air. If you take indoor air outside in a sealed jar, as it cools the excess moisture condenses on the inside of the jar. Condensation stops when the water vapour content of the air in the jar corresponds to 100% relative humidity for the exterior temperature, and the air in the jar has cooled completely. Allow the same air to blow through a hole in the wall until it reaches a surface colder than its dew point temperature (the temperature at which its absolute water vapour content corresponds to 100% relative humidity) and the same thing happens, but in a location inside the wall that you can't see. Where there are cold *thermal bridges*, condensation may even occur on interior surfaces, and in hidden locations within a wall cavity it will occur on the coldest surfaces first. Warm *thermal bridges*, on the other hand, are protected from condensation where they pass through colder parts of the wall, while less conductive adjacent surfaces suffer.

When air moves rapidly enough through a wall it can get all the way outside before it loses enough heat for condensation to occur. However, in a wall deliberately constructed to be air tight, slow flow will probably ensure that cooling and condensation are complete before the leaking air gets outside. If the materials on which the condensation occurs are porous, and resistant to damage by water and ice, no harm will occur, as long as they dry out before the next winter and as long as the total amount of condensation is less than what is required for saturation (or for the onset of damage). Condensation on surfaces that cannot absorb the moisture is harmless, if the resulting water drains outside, not back to the interior. There are exceptions. Materials that can be damaged may get wet. Falling icicles can be a problem, even where no damage to the wall occurs because of melting or draining condensation. Some porous materials do not attract condensation, even when flow is slow and surfaces are below the dew point, as long as flow is not impeded on the cold side by less pervious materials.

Condensation often causes harm. In porous insulations it reduces thermal resistance, so that in extreme cases the insulation slowly becomes solid fibre reinforced ice, freezing from the outside inward. Brick, steel studs, and gypsum board are all materials condensation can damage in varying degrees. Brick is capable of storing more moisture without damage than many materials, but excessive moisture causes spalling. Subsequent evaporation causes deposition of soluble salts on surfaces or in pores of the material. Gypsum board can absorb large quantities of water, but not without permanent damage. Exterior sheathing in particular often swells and becomes fragile in walls where condensation occurs. On damaged protective surfaces, burrs and shavings around fasteners, unprotected fasteners, and cut edges, sheet steel can start to rust in the presence of small amounts of condensation. Galvanizing protects damaged areas by sacrificing zinc around the exposed steel, but oxidation of the zinc proceeds more rapidly at these locations, and the protective action of galvanizing lasts only as long as there is still zinc available. Although the relationship is difficult to quantify, thickness of galvanizing and time duration of wetting combine to determine service life where corrosion occurs.

When condensation was first perceived as a problem, vapour diffusion through materials, driven by the difference in the partial pressure of water vapour between interior and exterior, was initially identified as the culprit. This explanation, while very appealing, explains only a small portion of observed condensation. Vapour diffusion does occur, and causes condensation, but air leakage generally causes far more and can better explain the observed amounts of condensation. Even walls constructed with care by people who are well aware of the possibilities and strongly motivated to eliminate air leakage, are not sufficiently air tight that vapour diffusion can cause more condensation than air leakage.[6]

Various levels of airtightness have been recommended. NRC has recommended 0.15 (0.03), 0.10 (0.02), and 0.05 (0.01) L/s/m² (CFM/ft²) at 75 Pa (1.6 lbf/ft²) pressure difference, for low, average, and high humidity occupancies.[7] Many building sheathing and cladding materials are capable of meeting these requirements, if carefully fitted.[8] However, measurements of actual buildings have produced rates varying from 0.5 (0.1) to 3.0 (0.6) L/s/m² (0.6 CFM/ft²) at the same pressure.[9] Constant leakage of 1.0 L/s/m² (0.2 CFM/ft²) of air starting out at 22°C (72°F) and 30% relative humidity would carry 42 L/m² (1.1 US Gals/ft²) of water into a wall over a three-month period. Such an amount is unlikely to accumulate since the pressure difference is usually less than 75 Pa (1.6 lbf/ft²), pressure is not constant, and drying can occur during warmer weather. Still, it has been estimated that stack effect pressure for one story acting on a leakage area of 0.01% could result in accumulation and subsequent evaporation of 3 kg/m² (0.65 lbs/ft²) of moisture (a 3 mm (0.125 in.) layer of water) over a winter season, based on hourly weather data for Montreal.[10]

When wall materials are susceptible to damage from condensation, there are two ways to protect them: limit air leakage and vapour diffusion, or keep the materials above the dew point. Some materials can store moisture up to a point, without damage. In such cases a third option is to limit accumulated condensation to the amount that can safely be stored and reliably evaporated under summer conditions. To prevent any condensation whatever by limiting air leakage is very difficult in the lab, let alone on a construction site. The practical answer, for steel framing at least, is to keep the material warm. For gypsum board, some condensation may be tolerable, perhaps as much as 5 or 10% by weight accumulated over a full winter, a very small amount compared to the moisture that small amounts of air leakage can carry. A buildable air barrier, capable of resisting the sum of all the air pressures applied to it, and tight enough to ensure proper cavity pressure equalization in a *rain screen*, is difficult enough to build. Nevertheless, it will not be tight

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[6] Drysdale and Kluge, McMaster Part 3.

[7] *Building Science Insight '86*.

[8] *Bumbaru et al, Air Permeance of Building Materials*, and Brown and Poirier, *Testing of Air Barrier Systems for Wood Frame Walls*.

[9] Shaw and Tamara, "Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings."

[10] TROW Inc. Criteria for *The Air Leakage characteristics of Building Envelopes*.

enough to prevent condensation on the back of exterior gypsum board exposed to an uninsulated cavity behind veneer, or on steel studs that bridge the full thickness of the insulation. *Figure 2-5* shows temperatures, and dew points for different interior humidities, at the back surface of the gypsum sheathing in steel stud walls insulated in various ways. The peak in the centre of the graph shows the effect of the metal stud as a warm thermal bridge; condensation is less likely on the stud than on the sheathing between studs, with the studs protected by outboard insulation. Danger of condensation in the stud space is absent in only one instance, where there is 75 mm (3 in.) of cavity insulation and no insulation in the stud space. With the stud space insulated, 25 mm (1 in.) of cavity insulation suffices to prevent condensation on the studs, but not the sheathing, under the conditions tested.

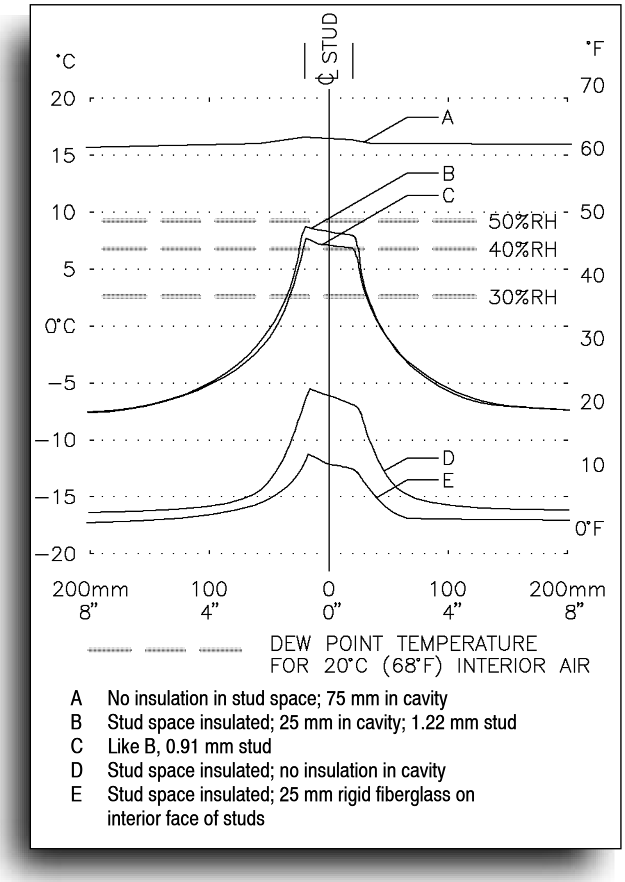

Figure 2-5: *Temperature at interior surface of exterior sheathing, for exterior temperature of -20°C (-4°F), & interior temperature of 20°C (68°F), at horizontal distances of 0 to 300 mm (12 in.) from stud centerline.*[11]

INACCURACY AND VARIATION IN POSITION

A last consideration that sometimes leads to unexpected difficulties in service is the coordination of dimensions and tolerances between components of the building. For example, reasonable efforts to place concrete members in the intended location result in variations that are visually unacceptable when reflected in finished exterior wall surfaces. Unless properly designed, taking permissible variations into account, steel stud wall framing and connections to the exterior cladding may end up bridging the gap in ways that compromise their serviceability. Details should still work when the components are at their permitted extremes of departure from intended position.

The whole question is more difficult because of the way the building industry generally treats tolerances. Statistical methods are rarely used, and little information is available about the variances to be found in dimensions of actual buildings. Canadian standards for concrete, steel, and masonry construction all refer to tolerances, but only the concrete standard uses statistical concepts.

Concrete

CSA A23.1-94 governs tolerances for concrete construction. In an appendix it briefly discusses tolerances in relation to probability and probability density distributions. It suggests that the Normal distribution probably describes the distribution of errors in concrete dimensions in most cases, and that tolerances should be specified as the intended dimension plus or minus an amount sufficient to encompass a 90% confidence interval (an amount that would result in a 10% reject rate, on average, with the expected variance). In order to specify tolerances in steps of equal difficulty of achievement, the following preferred ranges are

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[11] Drysdale and Suter, *Exterior Wall Construction in High Rise Buildings*.

suggested: ±3 (±0.12 in.), ±5 (±0.2 in.), ±8 (±0.3 in.), ±12 (±0.47 in.), ±20 (±0.8 in.), ±30 (±1.2 in.), and ±50 mm (±2 in.).

A23.1 specifies the following tolerances for alignment of members with intended locations:

Dimension, m (ft.)	Tolerance, mm (in.)
0 - 2.4 (0 - 8)	±5 (0.2)
2.4 - 4.8 (8 - 16)	±8 (0.3)
4.8 - 9.6 (16 - 32)	±12 (0.47)
9.6 - 14.4 (32 - 48)	±20 (0.8)
14.4 - 19.2 (48 - 64)	±30 (1.2)
19.2 - 57.6 (64 - 190)	±50 (2.0)
above 57.6 (190)	as specified

For thickness of columns and walls, and for floor to floor offsets the tolerances are:

Dimension, m (ft.)	Tolerance, mm (in.)
0 - 0.3 (0 - 1)	±8 (0.3)
0.3 - 1.0 (1 - 3.3)	±12 (0.47)
1.0 - & up (3.3 & up)	±20 (0.8)

Vertical surfaces and arrises must be plumb to 1:400, up to ±40 mm (±1.6 in.) maximum. Sloped surfaces must conform to slope within the same limits.

Ordinary floors are required to be level, in any 3 m (10 ft.), to within ±12 mm (±0.47 in.), but ±8 (±0.3 in.), ±5 (±0. 2 in.), or ±3 mm (±0.12 in.) can be specified optionally. This is one tolerance that has been studied extensively. The cost of construction rises rapidly as improvements on ±12 mm (±0.47 in.) are introduced.

Structural Steel

CAN/CSA S16.1-M89, *Limit States Design of Steel Structures*, defines tolerances for steel building structures. Exterior columns must be plumb to within 1:1000, to a cumulative total of up to -25 (-1 in.) or +50 mm (+2 in.) in the first 20 stories, with an additional allowance of 2 mm (0.08 in.) per story up to a maximum of -50 (-2 in.) or +75 mm (+3 in.) for taller structures. Horizontal members are aligned in plan to within 1:1000, except that ±3 mm (±0.12 in.) is always acceptable, no matter how short the member, and ±6 mm (±0.24 in.) is the maximum in any case. Horizontal members are at the correct elevation, if within ±10 mm (±0.4 in.), and must slope no more than 1:500. When connections are adjustable, members must be level to within 1:1000. Abutting ends are required to align within ±3 mm (±0.12 in.), or, if adjustable, within ±2 mm (±0.08 in.).

Masonry

CSA A371-94 *Masonry Construction for Buildings* restricts errors in position. It requires masonry construction to meet the following tolerances, unless otherwise specified. Previous editions of this standard suggested tolerances, but they were not mandatory.

- Vertical Alignment:
  - ±20 mm (±0.8 in.) in surface of wall
  - ±13 mm (±0.5 in.) in alignment of head joints
- Lateral Alignment:
  - ±13 mm (±0.5 in.) vertical members
- Level Alignment:
  - ±13 mm (±0.5 in.) for bed joints and exposed tops of walls
  - ±25 mm (±1 in.) not exposed
  - ±13 mm (±0.5 in.) top of wall used as a bearing surface
  - ±20 mm (±0.8 in.) top of wall, not bearing
- Cross-sectional Dimensions:
  - +13 mm (±0.5 in.), -6 mm (-0.24 in.)
- Joint thickness:
  - ±3 mm (±0.12 in.) for 10 mm (0.4 in.) nominal head and bed joints
  - 6 - 20 mm (0.24 - 0.8 in.) for bed joint of starting course
- Relative Alignment:
  - ±6 mm (±0.24 in.) over 3000 mm (120 in.) change in position relative to reference plane

Field Experience

Are tolerances specified in applicable codes and specifications actually achieved in the field? Experience suggests that they are exceeded relatively frequently.[12] The specified tolerances are difficult enough to deal with; one case has been observed where the actual wall cavity dimension varied from 0 (0 in.) to 75 mm (3 in.), as opposed to 50 mm (2 in.) shown on the drawings.[13]

Keller reported cavities as much as 17 mm (0.7 in.) smaller and 20 mm (0.8 in.) larger than the dimension detailed. The range from smallest to largest cavity dimension on a single building averaged 19 mm (0.75 in.). The range was never less than 10 mm (0.4 in.) (seen on two buildings), and on the worst building it was 37 mm (1.5 in.).[14]

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[12] Experience includes cases of tolerance for floor flatness exceeded by a factor of 10, and a column (in the worst case out of 100 measured) out of plumb by 75 mm (3 in.) in 2440 mm (100 in.).

[13] J. Vlooswyk, Building Envelope Engineering.

[14] Keller, H., *Field Investigation of Brick Veneer/Steel Stud Wall Systems.*

USER SURVEY AND FIELD OBSERVATIONS[1]

In 1986 Keller examined eight buildings in four cities from St. John's to Calgary, and sent out a questionnaire to people he expected were involved in BVSS construction. One hundred and eleven architects and engineers, 23 masonry contractors, 16 sheet steel framing contractors, and 21 building officials responded; 76% had some experience with BVSS. Most were from southern Ontario or Quebec. Collectively, he estimated that the response involved experience of some sort with over 1000 buildings, 66% of them four stories or less in height, 52% framed in steel, and 44% in reinforced concrete.

The architect usually designed the steel stud framing (65% of cases) mainly relying on manufacturer's literature for guidance, and to a lesser extent on CSA standards, the NBC, CMHC reports, and similar sources. Engineers acting as prime consultant (28%) relied on the same sources. Only 8% of all designers relied on the opinion of a structural engineer.

Shop drawings were required: never (33%); seldom (28%); sometimes (16%); often (7%); and, in some cases, always (16%). Framing was mechanically fastened more often than welded (74% vs. 6%). 95% were fabricated on site. A sliding top connection was provided 68% of the time. Explosive actuated fasteners were used for attachment to the structure 70% of the time. Stud spaces were more often insulated than not (64%). If rigid insulation was used, it was usually, but not always on the outside of the framing. The vapour barrier was almost always on the inside face of the framing (89%) and consisted of polyethylene film (84%).

Most of the designers had encountered problems in the field, most commonly air infiltration; 83% felt that not enough information was available, and that design fees do not allow for proper design. Contractors felt that construction documents provided too little guidance, and that responsibility for design, especially of details and connections, was left to them too often. BVSS systems had been in use in the areas sampled for an average of about eight years.

In the field study that followed the survey, Keller made a general visual examination of the veneer, did thermographic surveys, and made visual inspections of the stud space and the cavity behind the veneer through openings made from the interior.[2] Visual examination and thermographic survey from the exterior revealed nothing that might not have been seen in any masonry veneer building. Where there were problems with the framing, ties, or with air leakage, these methods did not reveal the locations.

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[1] Keller, *Brick Veneer/Steel Stud Wall Design and Construction Practices in Canada: Results of a 1986 Survey,* and Keller, Trestain, and Maurenbrecher, *The Durability of Steel Components in Brick Veneer/Steel Stud Wall Systems.*

[2] Keller, *Field Investigation of Brick Veneer/Steel Stud Wall Systems.*

He found that the steel stud framing, after four to 11 years of service, was in generally satisfactory condition, with little corrosion. However he also observed the following substandard aspects to be typical:

- no bridging;
- inadequate stud attachment;
- no provision for vertical movement;
- inadequate sheet steel thickness;
- inadequate protection from corrosion;
- black metal screws used in corrosive conditions.

Defects observed in the brick veneer were those that could typically be found with other commonly used backup systems:

- compression spalling at shelf angles;
- freeze spalling;
- excessive chlorides and efflorescence;
- corroded or otherwise ineffective ties;
- small cavities (25 mm (1 in.) or less) made ineffective by construction debris.

WALLS IN SERVICE

Keller reported that corrosion would render the framing unserviceable in as little as five years in some cases. But he expected 10 or more years typically. Brick ties did not fare so well, some were already in very poor condition, few were rated as having more than five years remaining.

Although the buildings were selected without advance knowledge of their condition, at least one authority who saw some of the buildings regards them all as “by and large” products of “gross neglect” in design, and regards Keller’s estimates of remaining service life as “too suspect to be quoted”.[3] The estimates of service life were subjective and not supported by any quantitative method of assessment. On the other hand, in five out of eight buildings the bottom track was extensively rusted, and rust also appeared on adjoining portions of the studs. Although it is not mentioned in the report, it has been said that in the worst instance of stud corrosion the bottom 50 mm (2 in.) of stud had rusted away completely.[4]

LABORATORY STUDIES

Tests of Strength and Stiffness of Components and Connections[5]

To complement the field survey observations, CMHC arranged for a series of laboratory studies. Drysdale and Breton looked at the structural behavior of typical steel stud wall framing members and connections in isolation, in the first study. Connections, full size wall panels with and without cladding, and individual studs were tested. A finite element program was written to investigate the effects of combined torsion and bending of studs.

Tests of connections between studs and track demonstrated that for a typical connection, with the stud nested in the track and attached flange to flange, the typical mode of failure of the

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[3] T.W.J. Trestain.
[4] J. Rousseau, at the ABEC/CMHC/CANMET *IDEAS Seminar*, Feb. ’94, Calgary.
[5] Drysdale and Breton, McMaster Part 1.

connection is crippling of the stud web. Experimental loads were safely in excess of the safe loads determined by current design procedures. The deformations resulting in failure were typically confined to the ends of studs, within a distance along the length less than the stud depth.

Most significant for design of other parts of a wall, connections of this type exhibited displacements before failure that were relatively large, compared to the displacement at mid-span of a stud designed for L/720 deflection. The rate of displacement varied considerably with the method of connecting the flanges, and how much gap there was between the stud end and the web of the track.

In addition to screws through the flanges, several other arrangements were tested:

- box track (stud blocked to prevent twisting, but not fastened);
- nested track (stud flanges screwed to inner track with minimum gap at end, 12 mm (0.5 in.) between the webs of the two tracks, outer track not fastened to inner);
- clip angle, securing the stud web directly to the support, with slotted fastener holes to accommodate 12 mm (0.5 in.) of movement;
- flexible clip, secured to stud web, and to the support, also allowing 12 mm (0.5 in.) of movement.

Connections that attached the web of the stud directly to the support with a sliding clip angle, or a flexible clip, tended to be very stiff, allowing relatively little displacement before failure. They also tended to fail suddenly by shearing fasteners or pulling them out of the support. Loads at failure were safely in excess of design loads for these connections as well.

RECOMMENDATIONS

- Verify that the design accounts for secondary torsional effects and web crippling.[6]
- Use metal bridging, spaced at 1220 mm (48 in.) maximum centres. For heavier studs, use through-the-cutout bridging fastened to studs with clip angles.[7]
- Make bridging continuous, and provide periodic anchorage.
- If ties are attached to stud flanges, take resulting reduction in stud capacity into account. Do not locate ties where there are web cutouts.
- If cutouts are located where there is no bridging, allow for resulting reduction in stud capacity. Best location for unbraced cutouts is between 300 (12 in.) and 400 mm (16 in.) from either end of stud.
- Consider the effect of displacement at supports on cladding and finish materials, in addition to evaluating ultimate capacity of the stud to structure connection.
- When cladding is used to provide bracing, specifically design the cladding and method of fastening for the purpose, and use more durable material than gypsum board.[8]

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[6] If design tables are used, verify that these effects were considered.

[7] Notched channel bridging, fastened to both faces of the studs, was also tested. Other research reportedly indicates that flat strap bridging can be as effective. Unbraced specimens performed poorly compared to those with any type of bridging.

[8] If steel bridging is attached to studs, interior gypsum board may reliably prevent translation of the bridging in the plane of the wall.

Prior to the onset of failure, the load displacement relationship was essentially linear for all connections. *Table 3-1*[9] shows the load-displacement ratio found for the connections tested:

Table 3-1: *Stiffness of Stud to Structure Connections*

Stud Size mm (in. x ga.)	Track mm (ga.)	Gap mm (in.)	Connection	Load/D N/mm (lbf/in.)
90 x 0.91 (3.5 x 20)	0.91 (20)	≤ 2 (≤ 0.082)	2 screws	555 (124)
	1.90 (14)	≤ 2 (≤ 0.082)	2 screws	1088 (242)
	1.22 outer 0.91 inner (18 outer 20 inner)	12 (0.48)	2 screws	517 (115)
	0.91 (20)	12 (0.48)	2 screws	247 (55)
	0.91 (20)	12 (0.48)	1 screw (t)	160 (36)
90 x 1.22 (3.5 x 18)	1.22 (18)	≤ 2 (≤ 0.082)	2 screws	964 (217)
	1.22 (18)	≤ 2 (≤ 0.082)	1 screw (t)	698 (157)
	1.22 (18)	≤ 2 (≤ 0.082)	welded	2142 (482)
	1.22 (18)	≤ 2 (≤ 0.082)	welded (r)	1844 (415)
	1.22 (18)	12 (0.48)	2 screws	479 (107)
	1.22 (18)	12 (0.48)	web clip	1825 (410)
	1.22 (18)	12 (0.48)	flex clip	2763 (620)
	1.22 (18)	12 (0.48)	box track	388 (87)
150 x 0.91 (6 x 20)	0.91 (20)	≤ 2 (≤ 0.082)	2 screws	623 (140)
	0.91 near end (20 near end)	≤ 2 (≤ 0.082)	2 screws	587 (132)
	0.91 (20)	≤ 2 (≤ 0.082)	1 screw (t)	535 (120)
	1.90 (14)	≤ 2 (≤ 0.082)	2 screws	764 (170)
	0.91 (20)	12 (0.48)	2 screws	235 (515)
	1.22 outer 0.91 inner (18 outer 20 inner)	12 (0.48)	2 screws	652 (146)
150 x 1.22 (6 x 18)	1.22 (18)	≤ 2 (≤ 0.082)	2 screws	1014 (227)
	1.22 (18)	≤ 2 (≤ 0.082)	1 screw (t)	781 (175)
	1.22 (18)	≤ 2 (≤ 0.082)	welded	4165 (937)
	1.22 (18)	12 (0.48)	2 screws	488 (110)

(t) = screw on tension side
(r) = same detail, load direction reversed

Wall panels tested in bending without cladding had interior steel bridging channels. Failure always occurred at a cutout hole, by twisting. These torsion failures typically occurred at one of the holes where there was no bridging (some manufacturer's design tables are calculated without taking cutouts or combined torsion and bending into

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[9] Drysdale and Breton, McMaster Part 1, pp 30-33.

account). The studs used were commercially available studs with cutouts at about 650 mm (26 in.) centres. Spans were tested with one row of metal bridging at mid-span in some cases, and with 2 rows of bridging. The ultimate load was strongly influenced by the attachment of the bridging to the studs. Clip angles fastened with screws were most effective with 4 screws, 2 into the bridging channel, and 2 into the stud web. Welded clip angles were equally effective. The ultimate moments in bending were typically less than allowable moments calculated using simple beam theory and the section modulus of the perforated section (at a cutout). Walls braced with cladding were also tested. Conditions included drywall with standard fastener spacing and reduced spacing, and wetted gypsum sheathing. The ratio of actual maximum moment sustained before failure to yield moment predicted by simple bending theory from the perforated section properties ranged from 0.57 to 1.03 over the full range of test conditions. It ranged from 0.81 to 0.98 for unclad specimens with metal bracing.[10]

The report also explores theoretical models for combined bending and torsion, and for combined action of brick veneer with steel stud backup.

Tests of Water Permeability of Cracked Masonry Veneer[11]

A preliminary series of leakage tests with small masonry specimens evaluated the effect of cracking isolated from other variables. The results were scattered and in any event, not very useful in predicting wall performance. They did indicate a degree of self-healing. The rate of leakage through cracked masonry decreases with time, with constant pressure.

Small Scale Tests with Temperature, Air Pressure, and Vapour Pressure Differentials[12]

Five BVSS wall specimens were tested. The air pressures used were intended not to test the structural adequacy of the walls (since the samples were only 830 (33 in.) x 1240 mm (50 in.)), but to provide typical driving forces for air leakage and rain penetration. They found that seemingly small construction flaws can result in service problems in some designs, but that other designs were relatively defect tolerant.

Walls tested include the following:

Wall 1

- taped and painted 12.7 mm (0.5 in.) gypsum board;
- 0.15 mm (6 mil) polyethylene vapour barrier;
- 92 mm (3.7 in.) studs and track of 0.91 mm (20 ga.) steel (studs at 406 mm (16 in.) centres);
- RSI 2.1 (R12) glass fibre batt in stud space;
- 12.7 mm (0.5 in.) exterior gypsum sheathing;
- 25 mm (1 in.) vented cavity;

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[10] Drysdale and Breton, McMaster Part 1, Tables 4.3, 4.5, & 4.6.
[11] Drysdale, Kluge and Roscoe, McMaster Part 2.
[12] Drysdale and Klauge, McMaster Part 3.

- brick ties;
- brick veneer.

Wall 2

- unfinished 12.7 mm (0.5 in.) gypsum board;
- 0.15 mm (6 mil) polyethylene vapour barrier;
- 92 mm (3.7 in.) studs and track of 0.91 mm (0.04 in.) steel (studs at 406 mm (16 in.) centres);
- RSI 2.1 (R12) glass fibre batt in stud space;
- RSI 0.88 (R5), 25 mm (1 in.) polystyrene sheathing;
- 25 mm (1 in.) vented cavity;
- brick ties;
- brick veneer.

Wall 3

- taped and painted 12.7 mm (0.5 in.) gypsum board;
- 25 mm (1 in.) steel hat channels;
- 0.15 mm (6 mil) polyethylene vapour barrier;
- 12.7 mm (0.5 in.) gypsum sheathing, joints caulked;
- back to back 1.21 mm (0.05 in.) thickness steel studs;
- RSI 2.2 (R12.5) glass fibre insulation;
- 38 mm (1.5 in.) polystyrene caps on stud flanges (rebated 13 mm (0.5 in.) deep to fit over studs and retain fiberglass insulation);
- 50 mm (2 in.) cavity (from face of studs);
- brick ties;
- brick veneer.

Corrosion of drywall screws occured in tests with no exterior insulation after relatively short exposures. The discussion observed that conventional drywall screws have a black oiled finish without corrosion resistant plating. During installation, the magnetized bit of the screw gun magnetizes the screws, so that fine particles cut from the stud as the screw is driven remain on the screw. With the cuttings, the minimally protected screw, and burrs from the stud at point of penetration, there is considerable scope for corrosion in moist conditions.

The second wall, with 25 mm (1 in.) of exterior polystyrene insulation, was tested with a deliberate imperfection equivalent to a 0.3 mm (0.01 in.) x 12 mm (0.48 in.) crack for every square meter. Interior relative humidity was 35 - 40% with 21°C (70°F) interior temperature and -17°C (1°F) exterior temperature. A pressure difference of 75 Pa (1.6 lbf/ft^2) resulted in leakage of 0.011 L/s/m^2 (0.002 CFM/ft^2). After 13 days there was no sign of any moisture having accumulated anywhere in the wall. Under more severe conditions with 50 - 55% interior relative humidity, condensation occurred on the inside surface of the polystyrene insulation, but not on any of the steel components.

Drysdale and Kluge observed that:

- even small openings in the air barrier can allow significant air leakage;
- the intended air barrier is not necessarily the only element in the wall that resists air flow;
- unpainted gypsum board is not airtight, but two coats of latex paint are enough to serve as a vapour barrier;
- even with great care taken in the lab, unexpected air leaks occur; they should be anticipated on construction sites and means of detection and repair should be provided;
- an outboard air barrier may also function as a vapour barrier, and trap condensation in between two vapour barriers;
- air leakage paths around insulation can short circuit the insulation and reduce its effectiveness;
- the steel framing of BVSS walls can be kept above the dew point temperature only by insulation in the cavity;
- the effects of studs as thermal bridges extend 50 (2 in.) to 100 mm (4 in.) to either side of the stud;
- large steel fasteners used to fasten rigid insulation from the exterior "affect the local thermal profile by less than 5%";[13]
- any air leakage, however small, can cause condensation somewhere within the wall; even leakage as low as 0.03 L/s/m² (0.006 CFM/ft²) results in significant accumulations;
- moisture accumulation due to vapour diffusion is so small it cannot be measured;
- unplated screws, burrs, and chips will quickly begin to rust if they are below the dew point temperature.

They concluded that air barriers should be included in all wall designs, but that they should not be assumed to be perfect. It should be taken for granted that condensation will occur somewhere; the important question is where will it occur, and will it cause any damage? If it will occur in the stud space or on the framing, have adequately moisture resistant materials been used? Air barriers should, if possible, be located where they can be inspected and repaired. Unintended air or vapour barriers should be avoided, to prevent accumulation of condensation or other moisture that cannot escape.

RECOMMENDATIONS

- Keep studs above the dew point temperature of the interior air, since small amounts of air leakage are difficult to prevent, yet can transport enough moisture to cause significant corrosion.
- Polystyrene sheathing significantly reduces the potential for condensation in an insulated stud space, but does not eliminate it. Condensation is eliminated on the framing, but may still occur on the back and in the joints of the sheathing.
- The best way to avoid condensation is to eliminate all insulation from the stud space and insulate only the cavity. From theory, with a design temperature of minus 30°C (-20°F) and interior relative humidity of 30%, 76 mm (3 in.) of Type 4 polystyrene with no insulation in the stud space is required to eliminate all condensation. If there is insulation in the stud space, condensation is eliminated on the framing, but not on the back of the exterior sheathing. It may damage gypsum sheathing, lead to wetting and sagging of the stud space insulation, and increase the frequency and time of wetness of the bottom track.

Tests of Brick Ties With Steel Studs[14]

This study tested 12 commonly used types of masonry tie with steel studs in various configurations to determine both stiffness and ultimate load carrying capacity in both tension and compression. Many ties were found

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[13] The actual temperature difference was not reported. McMaster Part 3, page 151.

[14] Drysdale and Wilson, McMaster Part 4.

wanting, particularly at the extremes of adjustment. Point loads applied by ties to studs were also found to be capable of compromising the performance of the studs, in some cases. The object of the tests was to find ties meeting the following criteria:

- strength and stiffness adequate for structural requirements;
- robustness and durability to survive job site conditions;
- tolerance for, or limitations on, adjustment and misalignment as needed to ensure structural performance;
- adequate corrosion protection, including attachments;
- compatibility with sheathing, air barrier, insulation and other adjoining material and installation procedures;
- cost and convenience of use, including ease of inspection.

A wide range of previous work was reviewed at the outset, including research, industry technical recommendations, and standards. Except for the corrugated strip tie, the ties selected appeared to have some merit.

A displacement of 4 mm (0.16 in.) between the centerline of the stud and the back of the veneer was used as a limit state criterion. Ties were attached to 0.91 mm (20 ga.) studs, 1.22 mm (18 ga.) studs, and rigid supports. The effect of positioning ties at different locations on the stud flange was also investigated. Most of the tests were done with 0.91 mm (20 ga.) studs, and ties attached either to the web, or 15 mm (0.6 in.) from the web on the flange, depending on type of tie. Sheathing was gypsum board, for types of tie normally attached through the sheathing. Tension tests were done on several types of screw fasteners used for tie to flange connections. Adjustable ties were tested at different positions, including the least favorable.

Ties that permit adjustment ranged widely in the effect various positions had on tie capacity and stiffness; in the worst case the load at 1.2 mm (0.05 in.) displacement was 10.5% of that which the same tie could carry in the most favorable position. Loads required to produce 1.2 mm (0.05 in.) displacement varied from 53 (12 lbf) to 1277N (290 lbf).

Ties that attach to the flange of the stud were very sensitive to their position on the flange relative to the web, and to crushing of the gypsum sheathing where they were bearing on it. Ties that adjust by sliding a wire into a hole were very weak at the extreme position. Ties that attach with screws loaded in tension when tie load is negative were found to pry against the screws, and to be susceptible to fatigue with repeated load reversal.

The best ties were those that attach directly to the web of the stud, using fasteners loaded in shear.

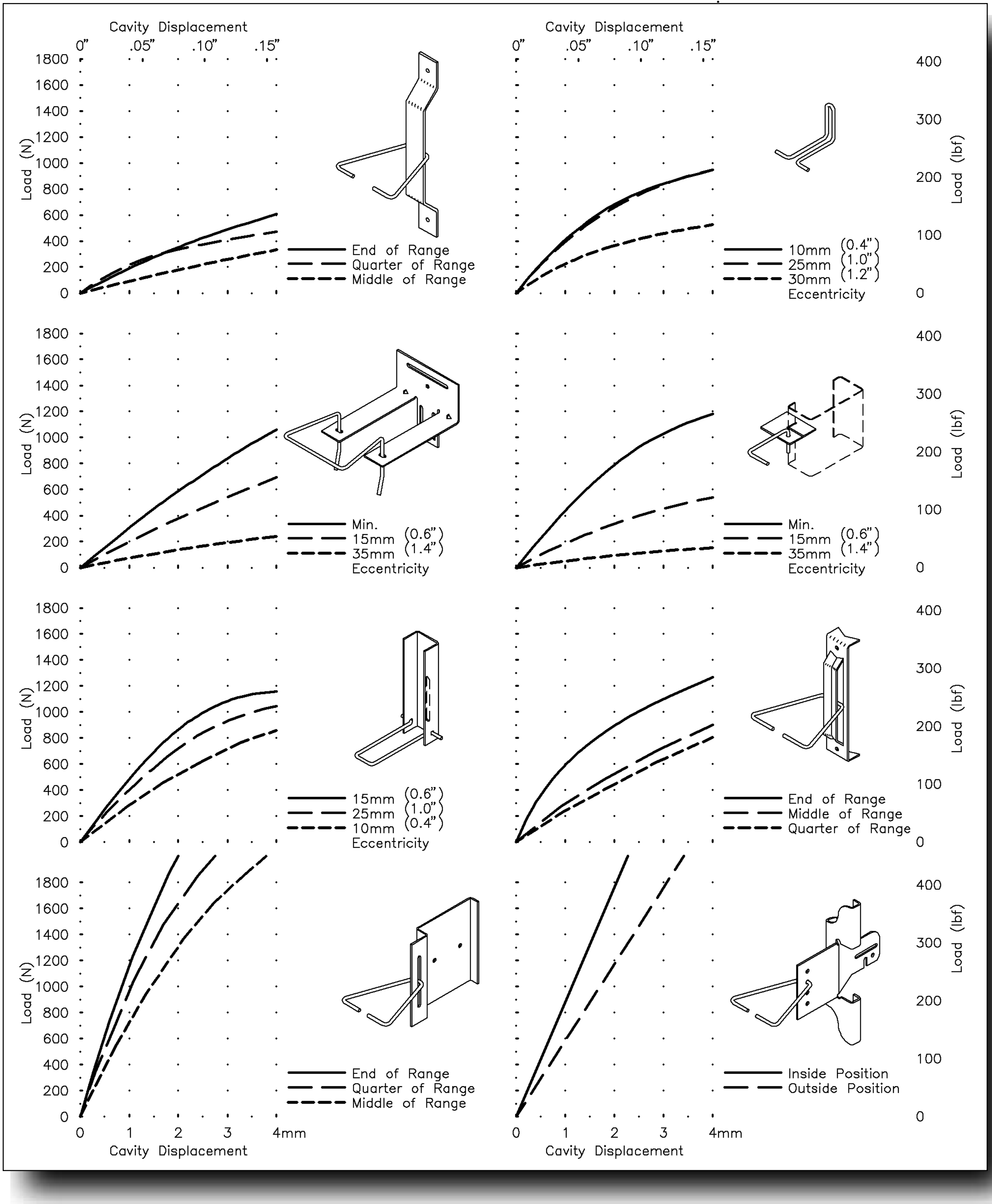

Figure 3-7: *Stiffness of various masonry veneer ties.*[15]

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[15] Based on Fig 21.7 of the *CMHC Seminar on Brick Veneer* and on Drysdale and Wilson, McMaster Part 5 tests.

FULL SCALE TEST FINDINGS

- Cavity pressurization reduces rain penetration into the cavity substantially, but cavity compartmentation is necessary to achieve it. A vented cavity is not enough.
- Conventional weep holes and spacings are sufficient for cavity pressurization, if the cavity is compartmented.
- Most water penetration through brick veneer occurs in the head joints. They should be filled when the masonry is laid.
- Unsealed joints at the top of the veneer can lead to very large volumes of rain penetration; unprotected vents at the top of the wall also allow substantial penetration.
- Cracked veneer has little impact on rain penetration, if the cavity is pressurized.
- Veneer ties are not loaded uniformly; very large forces occur at the top ties prior to cracking, and at ties adjacent to cracks after cracking.
- The critical load condition for veneer and for ties occurs when the load is being carried by the veneer, i.e. when the cavity is not pressurized, and before veneer cracking.
- Prior to cracking, the stiffness of the veneer prevents the studs from bending; the studs do not carry a uniformly distributed load.
- The air pressure required to cause cracking is determined more by the strength of the masonry alone than any other factor.
- Tight packing of the top joint provides a top support condition for the veneer (even sealant will provide restraint) which transfers part of the reaction at the top from the studs to the shelf angle.[19]
- Supporting the end studs of the backup wall along their length introduces two way bending behavior in the veneer, that reduces displacement of the wall and reduces secondary cracking.[20]

Full Scale Tests with Simulation of Wind and Rain[16]
Drysdale and Wilson tested five, full scale (2.75 (9 ft.) x 5.2 m (17 ft.)) brick veneer wall specimens, using a new test apparatus capable of simulating wind and rain simultaneously. Four of the specimens were BVSS. They looked at structural performance under varying loads, and at rain penetration performance of walls including both *drain screens* and *rain screens*. They observed that even carefully constructed drain screens are likely to experience excessive rain penetration under commonly occurring conditions, and that cracking of brick veneer occurs at loads somewhat more than the design load based on an L/720 deflection criterion for the studs. In summarizing they made the following “Good Practice Recommendations,” in addition to several more traditional recommendations:

- provide a 50 mm (2 in.) minimum clear air space in the cavity;
- divide the cavity into compartments; keep cutout holes in studs away from mid-height;[17]
- fasten bridging to studs with clip angles and four screws at each connection;[18]
- splice and fasten joints in bridging;
- screw studs to legs of track on both sides;
- provide at least double studs at openings;
- use ties with minimal free play and flexibility;
- place line of action of tie force as close to stud web as possible.

The steel stud walls tested had 25 mm (1 in.) cavities and all but one used the interior drywall as the air barrier (one wall had a peel and stick membrane applied to exterior sheathing). There was no insulation. Various ties were used, selected for average performance from a previous test program. All walls provided for vertical movement of the supporting structure, typically with a nested top track. One wall was unusual. It had studs placed back to back at twice the usual spacing, and hung from the top with provision for vertical deflection at the bottom. Except for this wall, all walls had mechanically fastened lateral bracing and studs spaced at 406 mm (16 in.) centres.

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[16] Drysdale and Wilson, McMaster Part 5.

[17] This is good advice in view of the location of maximum bending moment, but not practical for a 2400 mm (95 in.) high wall with one row of internal bridging. It is acceptable to include cutouts at mid height when the effect has been taken into account in the manufacturer’s load tables.

[18] There is nothing wrong with bridging on the faces of the studs; but the studs still have to be restrained from rotating in unison. Drysdale was unable to do this reliably in the McMaster Part 1 test setup.

[19] This may change the load at first crack and the pattern of cracking of the veneer.

[20] In practice, this effect varies with aspect ratio, a constant during the tests.

All of the steel stud walls used framing designed for maximum deflection of L/720 with a load of 0.96 kPa (20 lbf/ft²). The top and bottom track were selected without imposing a limit on the stiffness of the stud to track connections. In the tests, cracking of the veneer only occurred at higher loads (1.2 (25 lbf/ft²) to 1.6 kPa (33 lbf/ft²)). Prior to cracking of the veneer, lateral displacement due to bending alone was on the order of L/1800 to L/2500. This shows that the stiffness of the veneer restrained the studs, especially at mid-span. Significant lateral displacement occurred at the tops of the walls, and some displacement occurred at the bottoms, in addition to the bending. The top and bottom connections were of conventional design, with top nested track and screw attachment of stud flanges to track flanges. *Figure 3-8* shows all these displacements graphically. Ultimate loads required to produce failure of the masonry, ties, or studs ranged from 4 to 8 times the design load. Where the interior drywall served as the air barrier in all cases some distress showed in the drywall after application of the full design load. With the cavity pressurized, interior and exterior air barriers both failed completely in all cases, prior to failure of either the veneer or the framing. A sheet of plastic placed over the exterior face of the veneer was necessary to produce ultimate failure; otherwise, the equipment used to load the wall could not produce enough air pressure after failure of the gypsum board.

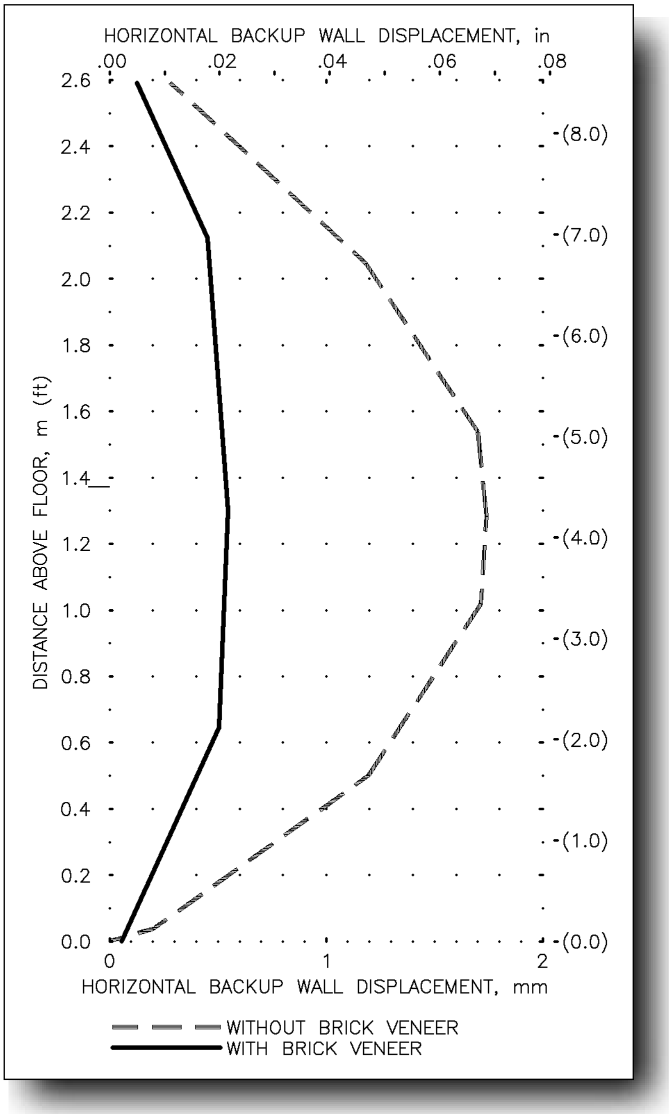

Figure 3-8: *Deflection of loaded steel stud backup wall, before and after construction of masonry veneer.*[21]

Summary of McMaster Results

At the conclusion of the series of laboratory projects at McMaster, Drysdale made the following conclusions:[22]

- Brick veneer is much stiffer than steel stud backup walls, increasing the stiffness of the backup to control cracking is not practical.
- Cracking will not occur in a stiff unbroken wall at ordinary loads. However, cracking will occur under ordinary service conditions because of openings, differential movements, and atypical conditions that occur in most buildings. The design of the wall has to assume that there will be cracks and deal with the additional potential rain penetration.
- A deflection limit of L/720 should be used to limit the size of cracks when the veneer has cracked, and the backup is carrying the full load.
- Stiff connections for the top of the backup wall reduce overall movement of the wall substantially.

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[21] Drysdale and Wilson, McMaster Part 5, Fig. 5.29.

[22] Drysdale, *Defining Better Cladding Systems.*

- Walls with large openings crack at much lower loads. Independent support for large windows and doors should be considered. Thin strips of veneer adjoining openings are susceptible to cracking.
- Double studs at openings have little effect on cracking load, but do limit subsequent deflection. If large openings do not have independent supports it may be necessary to double several studs in addition to those immediately adjacent to the opening.
- A soft joint at the top can significantly restrain the veneer, and effectively increase its vertical span, reducing cracking loads.
- A wall works better structurally when most of the pressure difference acts on the backup, rather than the face of the wall.
- Before cracking, the top tie transfers approximately half of the load from the veneer to the backup. After cracking, a tie near mid-height may carry the same load.
- More flexible ties can result in higher cracking loads and lower maximum tie forces. To avoid undue movement and distress in sealants and adjoining work, a load of 450 N (100 lbf) should result in a 2 mm (0.08 in.) maximum movement, including mechanical play and backup distortion.
- Condensation of moisture from air moving through walls is a serious concern.

CMHC Research Project Testing of Air Barriers Construction Details[23]
This and a succeeding report detail the results of testing several methods of using the interior finish as the air barrier, as well as a method of controlling air leakage with a vapour permeable exterior air barrier. The details apply primarily to wood frame construction, but might be helpful to develop a design with an insulated stud space and interior air barrier.

CONCEPTUAL STUDIES

Structural Requirements for Air Barriers[24]
An earlier study of the air permeance of various cladding and sheathing materials found gypsum board to be virtually airtight. However, tests to failure indicated that with conventional fastening, it would not be strong enough for some design wind loads. A conventionally fastened gypsum board air barrier failed at 1.6 kPa (33 lbf/ft^2), after having sustained a gust load of 1.8 kPa (38 lbf/ft^2) which pulled screw heads partly through the board.[25] This raised the question of what load an air barrier must support. McDonald used the NBC as a framework for determining design loads.

His findings include some that are not obvious:

- Building materials, including air barriers, do not have to be located on the exterior skin of the building to be subjected to exterior wind pressures.
- Air barriers should be designed for summation of exterior and interior wind pressures including gusting, and pressures due to stack effect and mechanical pressurization.

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[23] Quirouette, *CMHC Research Project Testing of Air Barriers Construction Details.*
[24] McDonald, *Structural Requirements for Air Barriers.*
[25] Brown and Poirier, *Testing of Air Barrier Systems for Wood Frame Walls.*

- Creep, fatigue, and ultimate loads need separate consideration in determining if an air barrier is strong enough.
- Materials that are relatively airtight, although not as tight as the air barrier, can be subjected to significant loads.

Static strength of the air barrier needs to be compared to loads resulting from extreme wind (including gust effects), restraint of thermal expansion and contraction, stack effect, and mechanical pressurization.

Fatigue strength of the air barrier needs to be compared to loads resulting from commonly occurring winds, and restraint of thermal expansion and contraction.

Creep strength of the air barrier needs to be compared to loads resulting from stack effect, mechanical pressurization, and restraint of thermal expansion and contraction.

For BVSS walls designed as *rain screens*, McDonald offers these comments and recommendations:

- Air barriers should be capable of transmitting total air pressure loads (wind + stack + mechanical) to the steel stud framing.
- Fastening of air barrier material or its substrate to steel studs by mechanical fasteners must hold air barrier to the studs when loads are outward, as well as inward.
- Rigid insulation can also be subjected to significant transient air pressure loads due to gusting. Air impermeable insulation and its fastening system should be structurally capable of resisting the gust portion of wind loads.

For gypsum board and gypsum-board supported air barriers, McDonald concludes that the standard screw spacing for gypsum board (300 mm (12 in.) at the perimeter and 400 mm (16 in.) for the interior) is inadequate in most cases. Not all structural designers will agree with McDonald's method of quantifying design loads. However, he does offer a framework within which they could determine their own loadings for a particular site and wall design. McDonald based his recommended fastener spacings on a $q_{1/10}$ of 0.65 kPa (15 lbf/ft^2), which he chose as adequate for all but the most severe wind zones in Canada. This approach has been criticized as being too conservative. Site specific loads would result in wider fastener spacings in almost all cases. At the same time his estimate of the bending strength of gypsum board may be too high, by a factor of as much as two.[26] Other structural designers might arrive at different recommendations, particularly for areas where wind loads are lower, but similar reasoning would apply, even if the resulting numbers were different. For a limit states design resistance factor of 0.5, given the unknown variability of screw pullout from average, and for general use anywhere in Canada, McDonald recommends the following, as shown in *Table 3-2*.

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[26] T.W.J. Trestain.

Table 3-2: *Spacing of fasteners on studs, mm (in.)*

	stud spacing, mm (in.)		
ht. above grade, m (ft.)	300 (12)	400 (16)	600 (24)
0 to 6 (0 to 20)	200 (8)	150 (6)	100 (4)
6 to 12 (20 to 40)	150 (6)	100 (4)	75 (3)
12 to 20 (40 to 65)	150 (6)	100 (4)	75 (3)
20 to 30 (65 to 100)	150 (6)	100 (4)	75 (3)
30 to 44 (100 to 150)	100 (4)	100 (4)	75 (3)
44 to 64 (150 to 220)	100 (4)	100 (4)	50 (2)

He also recommends minimum board thickness and orientation (gypsum board is stronger when applied horizontally) as shown in *Table 3-3*.

Table 3-3*: Gypsum board thickness, mm (in.), and orientation.*

	stud spacing, mm (in.)		
ht above grade, m (ft.)	300 (12)	400 (16)	600 (24)
0 to 6 (0 to 20)	12.7 (0.5)	12.7 (0.5)	12.7 H (0.5H)
6 to 12 (20 to 40)	12.7 (0.5)	12.7 H (0.5 H)	12.7 H (0.5 H)
12 to 20 (40 to 65)	12.7 (0.5)	12.7 H (0.5 H)	12.7 H (0.5 H)
20 to 30 (65 to 100)	12.7 (0.5)	12.7 H (0.5 H)	12.7 H (0.5 H)
30 to 44 (100 to 150)	12.7 (0.5)	12.7 H (0.5 H)	12.7 H (0.5 H)
44 to 64 (150 to 220)	12.7 (0.5)	12.7 H (0.5 H)	15.9 H (0.6 H)

Where gypsum sheathing on the outside of the studs, instead of gypsum drywall on the inside, functions as the air barrier, the same reasoning applies. However, the direction of net loading is different with respect to the screws for suction, and the possibility of repair is more remote, so a smaller limit states design factor is appropriate than for an interior drywall air barrier.

McDonald provides further recommendations for fastening and minimum thickness of various rigid insulations in cavities.

Finite Element Models

In conjunction with the laboratory testing of full scale walls, Drysdale and Chidiac[27] prepared analytical models of several possible ways of looking at brick veneer and steel studs as 2 dimensional structural systems, including:

- using the veneer as a wind-load bearing element in itself; in this case the function of the steel studs is to carry the wind load from cavity pressurization through the ties to the veneer, that would span from floor to floor;
- letting the veneer and studs act independently, without ties; in this case, if cavity pressure equalization can be relied upon, the veneer is not subject to wind load;
- constructing the veneer with only the studs in place; allowing the cavity to be inspected and cleaned prior to adding insulation and interior cladding (variations of this concept were tested in the laboratory).

They also developed a three-dimensional finite element structural model to predict the behavior of systems in which all elements interact to carry the load. The veneer is modeled as a plate bending element, supported on all 4 edges as well as by ties. The studs and bracing are modeled as a grid, and the ties as springs. The model, written in FORTRAN 77, runs on an IBM-PC with 640K RAM and 10 Megs of disk storage. The model would be useful only to an experienced structural analyst; however, it predicts the behavior of full scale samples observed in the lab reasonably well, and provides the following insights:

- doubling the stiffness of the steel studs has only a modest influence on the behavior of the veneer until after the first crack appears;
- increasing both the strength and stiffness of the veneer increases cracking load. Doubling the stiffness causes it to attract more of the load, but does not change the load at first crack very much;
- doubling the tie stiffness causes a slight decrease in cracking load;
- preventing lateral translation at the top (i.e. deflection perpendicular to the plane of the wall), by using a stiff top track or connection, is very beneficial;
- tie loads near the top are very high prior to cracking and loads on ties elsewhere quite low (the tributary area concept and the assumption of uniform load distribution on which codes have been based are far from accurate. The top row of ties carries more load than the codes anticipate);
- increasing veneer thickness to 140 mm (5.5 in.) more than doubles the load at first crack (1.43 kN (320 lbf) vs. 3.20 kN (660 lbf));
- when walls have openings (*e.g.*, windows) the load at which cracking occurs is substantially reduced (0.5 kN (110 lbf) vs. 1.43 kN (320 lbf)), and is nearly independent of the stiffness of the backup wall. Stiffer backup does serve to limit the size of the cracks.

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[27] Drysdale and Chidiac, “Defining Better Cladding Systems - Theoretical Work.”

RAIN[28]

RAIN is an IBM PC compatible computer program that grew out of research investigating the pressure equalization of wall cavities under changing pressure conditions in both a test chamber and a wind tunnel. The program is based on the gas laws, and takes cavity depth and area (hence compartment volume), backup wall flexibility and leakage, and cladding flexibility and vent area all into account as inputs. When these variables are specified by the user, the program calculates the cavity pressure as a function of time assuming a sawtooth function to describe the exterior pressure. The program then presents the percentage of load carried by the cladding, the percentage carried by the backup, and the cavity pressure on a graph. It tabulates exterior pressure, cavity pressure, cladding load, air barrier load, cavity volume, flow through the vents, and flow through the air barrier for a time period from 0 to 1.5 seconds (3 sawtooth cycles) in 0.05 second intervals. RAIN was validated with the results of the work conducted in the test chamber. Its predictions agree reasonably well with measured cavity pressures in the exterior *rain screen* wall of one tall building.[29] The sawtooth frequency chosen simulates typical rates of load and gust amplitude measured with pressure taps on actual buildings. The program comes with excellent documentation and is easy to understand and operate.

By adjusting the inputs and examining the results, the user quickly gets an appreciation for how sensitive the equalization of the cavity pressure is to different variables. If the cavity fails to track exterior pressure well, should one reduce the cavity volume, or increase the exterior vent area? If the air barrier leaks twice as much as expected, what happens to the load on the cladding? These are questions that, without this program, are almost imponderable given ordinary design office resources. They are easy to explore with RAIN, permitting identification of the best design options, and the construction defects most likely to cause problems. For instance, RAIN shows a performance difference between open fibrous and closed cell insulation materials of equivalent RSI (R value). Since air can move freely in and out of fibrous insulation, its volume becomes part of the cavity volume, potentially reducing cavity pressure equalization.

Better tools may become available, as testing underway at CMHC and NRC/IRC proceeds. Meanwhile, this program is easy to apply to the design of walls intended to function as *rain screens*. It will provide improved quantification of important variables, such as the effect of compartment volume.

EMPTIED[30]

To establish a criterion for air leakage that was both buildable and adequate, CMHC and TROW developed EMPTIED, an IBM-PC compatible computer program, to calculate condensation accumulated in a wall over the course of several seasons. The program uses hourly BIN data for each month to determine temperatures of selected surfaces inside the

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[28] Morrison Hershfield, *Rainscreen Concept Applied to Cladding Systems on Wood Frame Walls.*

[29] Place Air Canada, Montreal.

[30] TROW Inc. Criteria for *The Air Leakage Characteristics of Building Envelopes.*

wall. It allows the user to specify a BIN data file (from files provided for major Canadian cities), interior conditions of temperature and humidity (which the user can specify for each month), the thermal properties of the wall, a leakage area, and the maximum amounts of moisture that two user-specified condensation planes in the wall can store.

EMPTIED bases its calculations on theory, and makes several simplifying assumptions that may limit accuracy. It is better for comparing two different designs, or climates, than for predicting absolute amounts of condensation. It assumes that the driving pressure for air leaking into the wall is the stack effect for a single floor height determined hourly BIN by hourly BIN from the exterior temperature. It also assumes that the path through the wall is sufficiently long that air reaches moisture equilibrium before exiting. For each month, the program calculates amounts of condensation, evaporation, and moisture stored at the two selected surfaces, and thereby determines how much must either drain out or remain in the wall as water or ice not absorbed in materials.

The program always starts Year 1 with perfectly dry materials, so the effects of building with wet material cannot be examined. Consecutive years can be run to see if surplus moisture is likely to carry over from year to year. Version 2.0 allows superimposition of a constant pressure on stack effect, which is otherwise the only force causing air to pass into the wall, with flow governed by the leakage area of the tightest layer. Convective flow into and out of the wall on the same side is not included. The program should be applied with these assumptions in mind. Nevertheless, it provides an interesting means of exploring the potential influence of different designs on potential for accumulated condensation in a wall.

OTHER SOURCES OF INFORMATION

The references listed at the end of this guide include more sources of detailed information than have been already mentioned. *The Canadian Building Digests*, issued periodically for many years by the Division of Building Research (now the IRC) of NRC are a basic source of building technology information in Canada. *IRC's Building Practice Notes* are also helpful. A good basic textbook for building technologists is *Walls Windows & Roofs for the Canadian Climate*.[31] A more advanced text, that will be of greater interest to engineers, or to architects who have kept up their mathematics, is *Building Science for a Cold Climate*.[32]

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[31] Latta.

[32] Hutcheon & Handegord.

FACE SEAL SYSTEMS

Experience and laboratory testing both strongly suggest that exclusion of exterior water by *face seal* systems should not be expected. Steel stud framing and fastening, cladding, corrosion protection, and insulation for such systems should therefore be selected on the assumption that moisture will be present. This may require difficult judgements, since both the amounts of moisture and lifetime of the selected corrosion protection are difficult to estimate. Brick veneer walls with steel stud backup are unlikely to function successfully as *face seal* systems.

DRAIN SCREEN SYSTEMS

Since cavity compartmentation has not been common, the walls Keller examined probably were functioning as *drain screen* systems, not pressure equalized *rain screens*. A wall designed to exclude wind-driven rain and prevent condensation should show less corrosion than he observed. Predicting service life of sacrificial metallic coatings is difficult, especially when the service conditions cannot be related to standard test conditions, but the following relationships are clear:

- Conditions in a wall cavity are more severe than outdoor conditions.
- Conditions in a *drain screen* cavity are more severe than in a *rain screen* cavity.
- Conditions in an insulated stud space are more severe than in an uninsulated stud space.
- Conditions inward from the air barrier are less severe than outside the air barrier.
- The risk of periodic wetting in the stud space of an exterior wall is greater than for an interior partition.
- Coatings used on masonry ties in the past (typically Z275 (G90) or less) have been inadequate for a reasonable service life in the wall cavity.

For *drain screen* systems, without compartmentation and pressure equalization, care should be taken in selecting corrosion protection, particularly in areas of high wind and rainfall, and coastal areas. Selection should be based on the assumption that rain penetration will reach the stud space, unless the stud space is uninsulated and separated from the wall cavity by a waterproof barrier.

As a starting point, Keller's observations suggest that electogalvanizing is not adequate for studs, and that Z275 (G90) hot dip zinc is not enough for the bottom track, when building paper over gypsum sheathing is the separation between the stud space and the cavity. At the other extreme, protection equivalent to that required for masonry ties should more than suffice, since the ties Keller observed were typically in worse condition than other galvanized metal parts of the same walls. The new requirement[1] for stainless steel ties for some locations, based on driving rain index, presumably assumes that most walls will continue to function as *drain screens*, not *rain screens*.

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[1] CSA A370-94 *Connectors for Masonry.*

There should be no overdesign of sheet steel members to allow for rust. Once sacrificial corrosion protection is lost, the useful life of the protected member has come to an end.

RAIN SCREEN SYSTEMS

For a *rain screen* to function, an air barrier capable of resisting the pressure differences between the interior and the cavity is necessary. In addition, it must be stiff enough, and sufficiently airtight and continuous in relation to cavity volume and vent area to ensure equalization of the cavity pressure to the exterior pressure. If the air barrier is gypsum sheathing on steel studs, or interior drywall, the accustomed fasteners and fastener spacings of the drywall trade are probably inadequate. In addition to closer spacings, corrosion protected fasteners are required for exterior sheathing. Gypsum board supporting an air barrier that is not accessible should be fastened more securely than one that can easily be repaired.

A *rain screen* is probably a better defense than increased thickness of metallic protection alone, since it substantially reduces, or even eliminates exterior water entering the wall. In climates where wind-driven rain is common, and on the aspects of a building most exposed to severe storms, the effectiveness of a *rain screen* increases. Carefully chosen protection is still needed in the wall cavity, and where condensation can occur in insulated stud spaces. If the air barrier is on the outside of the stud space, and the space is uninsulated, available information, though limited, suggests that Z275 (G90) zinc coating is probably enough. It would make sense to use the same protection as for interior studs, Z180 (G60), except that lateral loads are greater, and consequences of failure more severe.

To ensure that a wall will function as a *rain screen*, RAIN can evaluate cavity pressure equalization. Sheathing, insulation, and cladding materials should all be selected and fastened to withstand wind loads combined with other air pressure differences. An air barrier supported inaccessibly requires more caution than one that could be repaired if damaged.

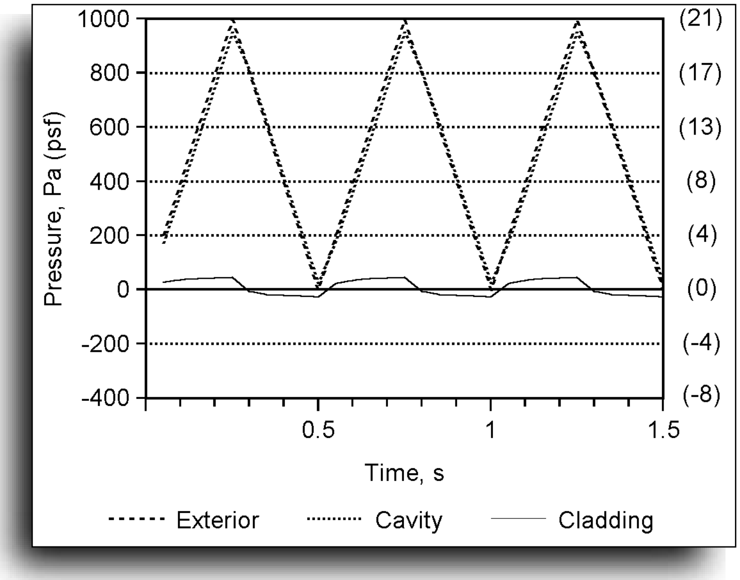

Figure 4-1: *Pressure equalization evaluation of BVSS details, with 50 mm (2 in.) Type 4 polystyrene insulation & air barrier on sheathing.*

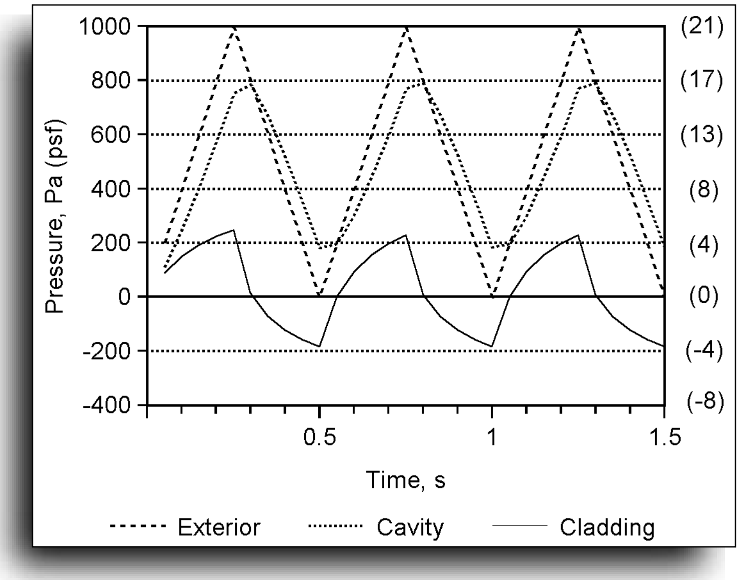

Figure 4-2: *Pressure equalization evaluation of BVSS details, with 75 mm (3 in.) rigid glass fiber cavity insulation & air barrier on sheathing.*

Figures 4-1, 4-2, and *4-3* show RAIN's graphical output for different conditions, all similar to the details in this guide. As the cavity volume increases, by adding the volume of the cavity insulation, and then the volume of the stud space, the maximum cladding load increases from 48 Pa (1.0 lbf/ft²) to 248 Pa (5.2 lbf/ft²), and then to 370 Pa (7.7 lbf/ft²). All three cases assume that the cavity is 2.6 m (100 in.) high, with compartments 10 m (400 in.) long. The flexibility of the cladding and the air barrier are both taken as zero, since they are tied together. Free play in the ties is assumed to have been taken up by a constant pressure base on which the sawtooth gusting is superimposed. The vent area is 0.012 m² (0.13 ft²) per compartment; 0.01 m² (0.11 ft²) as open joints at 600 mm (24 in.) spacing plus 0.002 m² (0.02 ft²), a 0.2 mm (0.008 in.) average gap behind the flashing. The leakage area of the air barrier is 0.00060 m² (0.006 ft²) per compartment. This corresponds to 0.15 L/s/m² (0.03 CFM/ft²) @ 75 Pa (1.6 lbf/ft²), the highest rate of leakage recommended by Lux and Brown.[3] Although the average gap behind the flashing might be larger, some of the brick vents might be obstructed, and the air barrier is not likely to be so tight. Similar pressure difference results could be obtained with vent and leakage areas both increased.

To illustrate the effect of air barrier leakage, *Figure 4-4* shows what happens to the best of the three previous conditions when the leakage area is increased to correspond to the best of the existing buildings measured by Shaw[4] - 0.0019 m² (0.019 ft²) per compartment (roughly equivalent to 0.5 L/s/m² (0.1 CFM/ft²) @ 75 Pa (1.6 lbf/ft²)). This is still quite tight compared to many existing buildings where air tightness has been measured.[5] Pressure equalization is somewhat compromised, with maximum cladding load increasing from 48 (1.0 lbf/ft²) to 98 Pa (2.0 lbf/ft²), but not dramatically compared to the effect of increasing cavity volume. Condensation from air leakage is another matter.

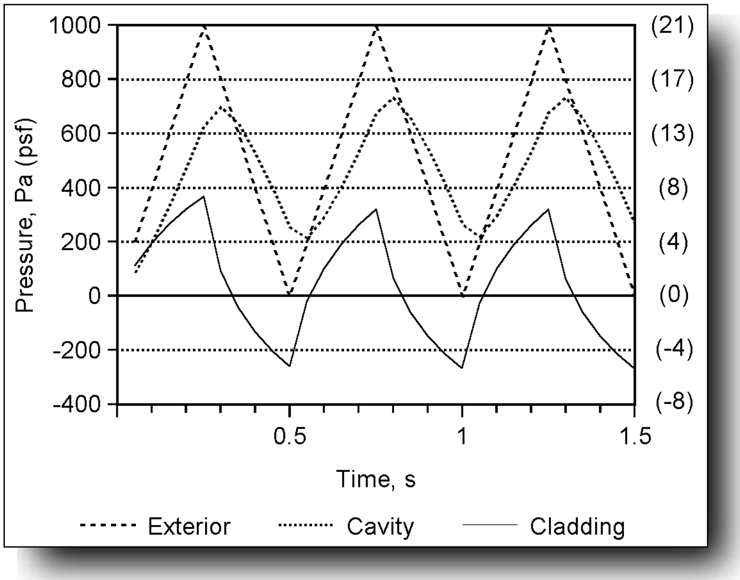

Figure 4-3: *Pressure equalization evaluation of BVSS details, with 75 mm (3 in.) rigid glass fiber cavity insulation, glass fiber insulated 90 mm (3.5 in.) stud space, & airtight drywall air barrier.*

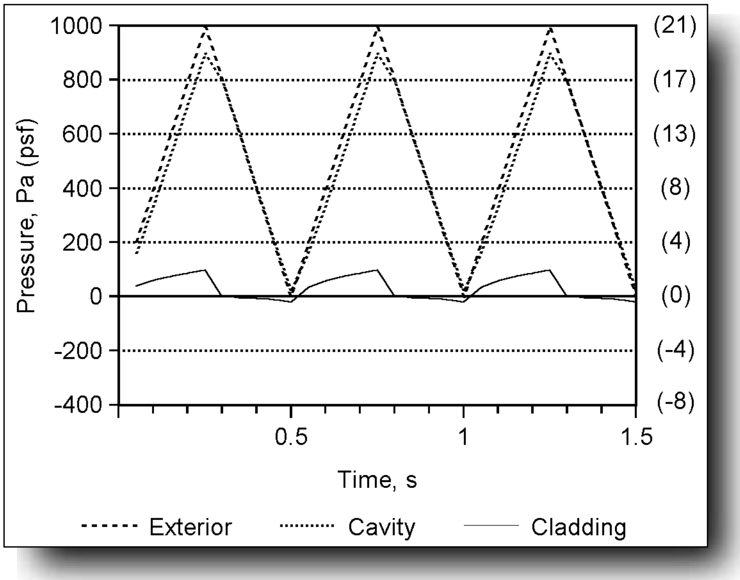

Figure 4-4: *Pressure equalization evaluation of BVSS details, with 50 mm (2 in.) type 4 polystyrene insulation & tightly fitted sheathing as air barrier.*

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[2] The formula for approximate conversion of flow to equivalent area, from *Building Science Insight '83*, is: $A = 1/780 * F/(\Delta P)^{0.5}$, where Area (A) is in m², Flow (F) is in L/s, and pressure difference (ΔP) is in Pa. (Change 1/780 to 1/1058 for A in ft², F in CFM and ΔP in lbf/ft².) EMPTIED uses a different formula in which the 1/780 factor is varied as a function of air density, with ΔP raised to an exponent of 0.7. EMPTIED's calculations are a more accurate function of actual leakage area, assuming you have accurate area measurements to begin with. Hence, a straightforward conversion is not to be expected, nor are results from the two programs or field tests of leakage comparable, beyond the first order of magnatude.

[3] *Building Science Insight '86*.

[4] Shaw and Tamara, *Studies on Exterior Wall Tightness.*

[5] Values of 2.10 (0.42 CFM/ft²) to 3.15 L/s m² (0.63 CFM/ft²) @ 50 Pa (1.0 lbf/ft²) were reported by Gulay, Stewart and Foley, in *Field Investigation Survey of Airtightness*.

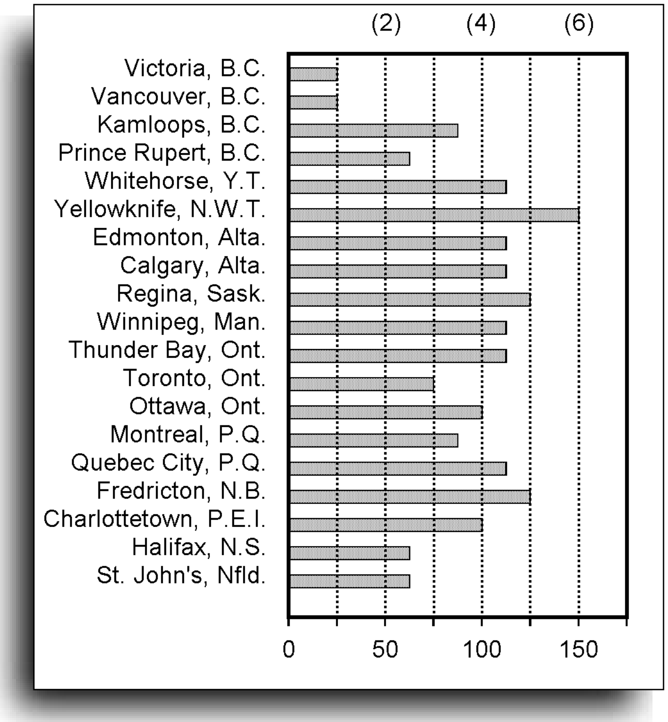

***Figure 4-5:** Cavity insulation (mm (in.)) required to prevent condensation in sheathing with stud space insulated.*

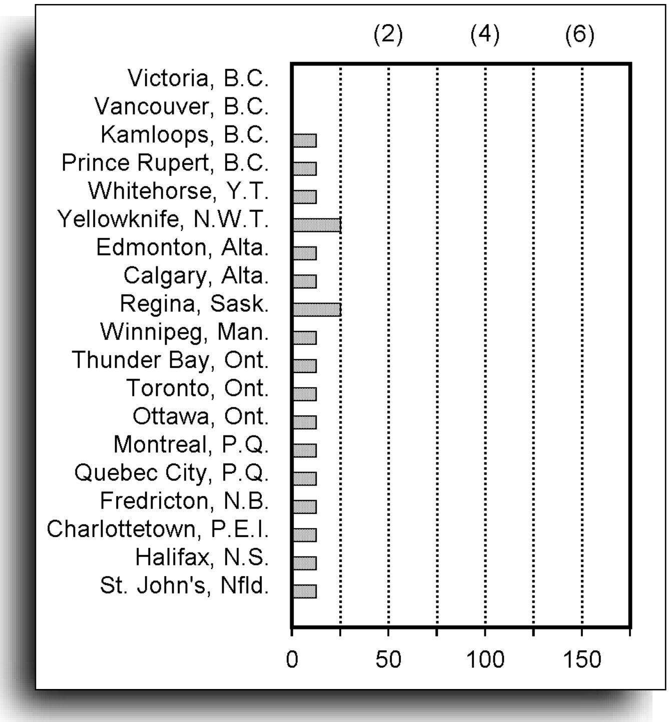

***Figure 4-6:** Cavity insulation (mm (in.)) required to prevent condensation in sheathing with uninsulated study space.*

Condensation in Sheathing

An air barrier adequate for proper *rain screen* pressure equalization is not so airtight that it will exclude warm moist air from the stud space. This consideration is enough to dictate elimination of stud space insulation in some climates of Canada, and with moist building interiors, without substantial amounts of cavity insulation. Alternatively, metal stud systems, fasteners, and cladding materials can be selected that are capable of sustaining periodic wetting without damage over a reasonable service life. However, it is difficult to decide how to match expected levels and duration of moisture to appropriate materials.

With EMPTIED it is possible to compare differences in potential condensation between two wall systems, or the performance of identical designs in different climates. Although EMPTIED is not necessary for the purpose, it can also determine what level of cavity insulation will ensure that no winter condensation occurs at a particular layer of the wall by keeping that layer above the interior dew point at all times. EMPTIED can also determine required amounts of cavity insulation for particular combinations of equivalent leakage area and absorbed condensation, if a criterion of acceptability can be chosen by other means.

Figure 4-5 shows the amount of Type 4 polystyrene cavity insulation, in 12.5 mm (0.5 in.) increments, which EMPTIED predicts will prevent winter condensation in the exterior sheathing of a wall with 90 mm (3.5 in.) of fibrous insulation in the stud space. The model wall used is similar to the walls detailed in Chapter 6, except that interior drywall is the air barrier, with a polyethylene vapour barrier, and nothing separates the sheathing from the cavity insulation. The interior temperature is 22°C (72°F), and interior relative humidity is 30%. Leakage area should not have any influence in this case, since the sheathing is above the interior dew point (0.75 cm^2/m^2 (0.012 in^2/ft^2) was used, and condensation amounts of less than 0.0009 kg/m^2 (0.021 lb/ft^2) are rounded down to zero).

Figure 4-6 shows, for the same locations, the corresponding amount of insulation required to prevent condensation in the sheathing with no insulation in the stud space. Except for thickness of insulation, these walls are like those detailed in Chapter 6. The other parameters are the same.

Clearly, with the stud space not insulated, the amount of cavity insulation required is governed by energy consumption, not condensation or comfort.

If the designer decides that some condensation is tolerable, then the equivalent leakage area and the driving pressures, in addition to the indoor conditions, affect the amounts of condensation reported by EMPTIED. For all of these examples, the only pressures considered are the partial pressure of water vapour (for diffusion), and the stack effect created over one story by the difference in air density between interior and exterior conditions (for moisture transported by air leakage). EMPTIED permits superimposing a constant pressure on the stack effect pressure, if desired.

Figure 4-7 shows what happens to the cavity insulation requirement if condensation in the sheathing of 0.25 kg/m² (0.05 lb/ft²) (equilibrium with 100% RH) is acceptable for the wall with 90 mm (3.5 in.) of insulation in the stud space, with the same interior conditions, and 0.75 cm²/m² (0.01 in²/ft²) equivalent leakage area.

Different rates of air leakage, or different interior humidity, would require different levels of cavity insulation to limit condensation to a particular maximum amount.

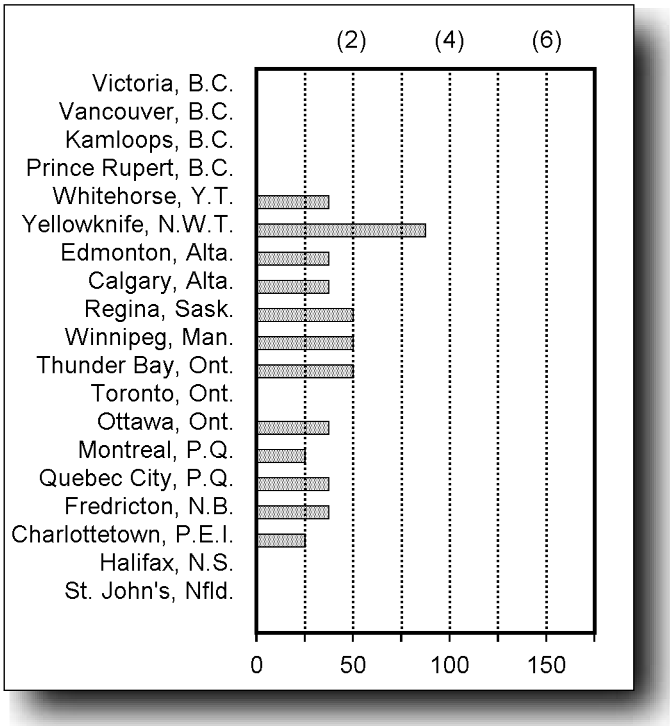

Figure 4-7: *Cavity insulation (mm (in.)) required to limit condensation in sheathing to equilibrium with 100% RH, with insulated stud space.*

If cavity insulation is less than required to prevent condensation in the sheathing altogether, small differences in leakage area make dramatic differences in the risk of saturation. *Figure 4-8* shows, for Yellowknife, N.W.T., the equivalent leakage area at which EMPTIED predicts 0.25 kg/m² (0.05 lb/ft²) condensation in the sheathing, for varying amounts of cavity insulation. Note that leakage areas are expressed in mm²/m² (in²/ft²), not cm²/m² (ft²/ft²)! When the level of cavity insulation will not prevent condensation altogether, the amount of air leakage that can be tolerated may be very small. While Yellowknife is an extreme case, the climate influences the insulation thickness at the transition more than the abruptness of the transition.

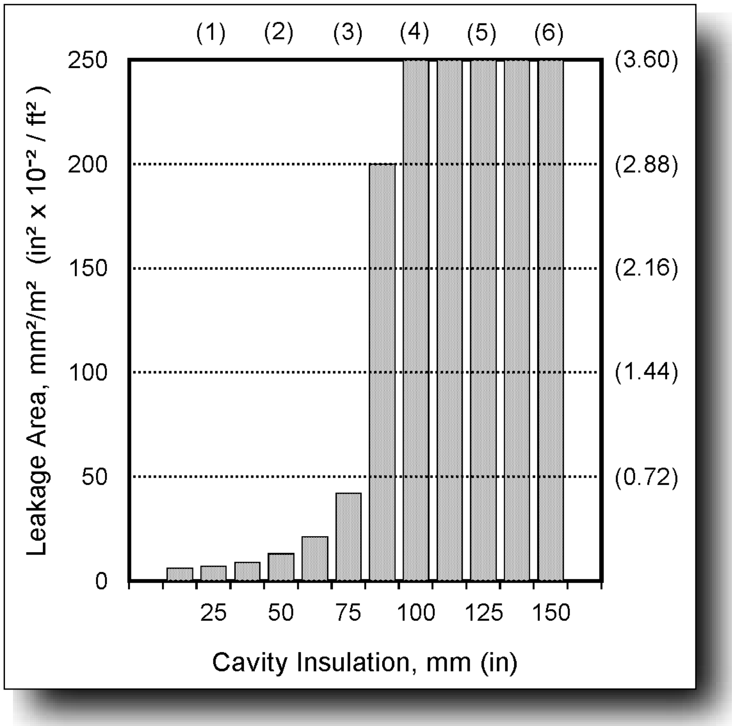

Figure 4-8: *Leakage area for which EMPTIED predicts 0.25 kg/m² (0.05 lb/ft²) condensation in gypsum sheathing, with insulated stud space and varying levels of cavity insulation, for Yellowknife, N.W.T.*

Wall designs are also sensitive to changes in interior conditions. A wall adequate for housing may not serve equally well for a museum or swimming pool. *Figure 4-9* shows, for a leakage area of 0.75 cm²/m² (0.01 in²/ft²), the interior relative humidity that will result in 0.25 kg/m² (0.05 lb/ft²) condensation in the sheathing, for varying amounts of cavity insulation, again for Yellowknife. Unlike the relationship between cavity insulation and tolerable leakage area, this relationship is nearly linear.

In all the preceding examples, interior temperature is 22°C (72°F), interior relative humidity is 30%, and leakage area is 0.75 cm²/m² (0.01 in²/ft²) (roughly equivalent to 0.5 L/s/m² (0.1 CFM/ft²) @ 75 Pa (1.6 lbf/ft²)), unless stated otherwise.

All of the examples consider only winter condensation. EMPTIED also reports condensation occurring in sheathing cooled by interior air conditioning, from moisture in exterior air in summer months.

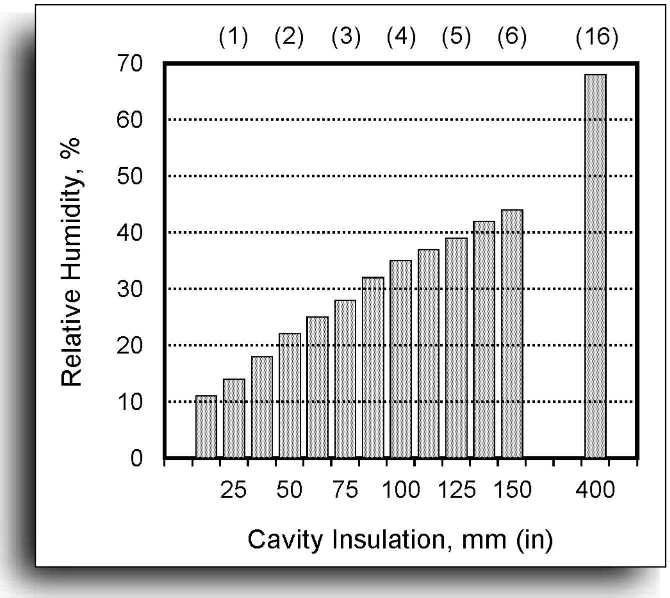

Figure 4-9: *Level of interior relative humidity that EMPTIED predicts will result in 0.25 kg/m² (0.05 lb/ft²) condensation in gypsum sheathing.*

Condensation in Brick Veneer

Adding cavity insulation decreases the potential for condensation in the sheathing; however, it increases winter condensation in the cladding, since the brick becomes colder as a result of the increased insulation.

While the amounts of condensation predicted by EMPTIED may not be what would actually occur, since wind, solar radiation, and other drying factors are not included in the calculations, EMPTIED does allow comparison of different designs, and assessment of the relative danger of accumulated moisture, efflorescence, and frost damage. In conjunction with the amount of accumulated condensation, EMPTIED shows the number of hours above and below freezing for the selected condensation planes. For the same conditions as in *Figures 4-5* and *4-6*, *Table 4-1* shows predicted maximum condensation in the brick veneer, in the first year. In all cases, moisture will accumulate in the brick from year to year unless solar heating, outdoor air circulation through the cavity, wind, or other factors not considered by EMPTIED come into play. With insulated stud spaces, if there is enough insulation to prevent wetting the sheathing, the increases in condensation and hours below freezing caused by additional insulation are almost negligible.

Table 4-2 shows, for Winnipeg, that if there is enough insulation to protect the gypsum sheathing, air leakage must be very low to control condensation in the brick. It also shows that, in contrast to leakage, the amount of insulation makes only a modest difference. The shaded areas of the table indicate leakage areas for which EMPTIED predicts annual increases in condensation.

What about Toronto? You could use EMPTIED to generate a book larger than this guide, filled with tables answering such questions. Further exploration would reveal that for most buildings in Winnipeg or Regina, a good air barrier, humidity reduction in the winter, and higher interior temperatures in summer are all required for well insulated walls to avoid condensation altogether. In Montreal and Toronto, no amount of cavity insulation will prevent condensation from exterior air in summer, with or without insulation in the stud space.[6] As insulation is increased, the period of constant presence of condensation from outside increases. This can be prevented by allowing interior temperatures to rise

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[6] Because of the way EMPTIED handles the user specified condensing planes, errors probably occur in calculating condensation from reversed airflows induced by low interior temperatures or negative fan pressures.

in summer. In Vancouver and Victoria an air barrier is needed mainly for rain screen cavity pressurization, rather than control of condensation.

Condensation is not the only source of water in a wall. Before assuming that the framing in a rain screen wall will be perfectly dry all the time, consider unexpected sources of water. Leaking window frames, plumbing, parapet flashings, and floor spillage are all possible, and have all caused enough damage to necessitate more or less extensive repairs to steel stud framed exterior walls in specific instances where they occurred.

Table 4-1: *Winter condensation in brick veneer and hours below freezing, as a function of insulation, for the worst month.*

City	**Insulation Stud + Cavity, mm (in.)**	**Hours Below 0 deg C (32°F)**	**Condensation in Brick kg/m^2 (lb/ft^2)**
Winnipeg Man.	0 + 13 (0 + 0.5)	389	4.16 (0.9)
	0 + 25 (0 + 1.0)	496	4.43 (0.97)
	0 + 37 (0 + 1.5)	496	4.58 (1.0)
	0 + 50 (0 + 2.0)	496	4.67 (1.02)
	0 + 63 (0 + 2.5)	496	4.73 (1.04)
	0 + 75 (0 + 3.0)	496	4.78 (1.05)
	90 + 50 (3.5 + 2.0)	496	4.78 (1.05)[7]
	90 + 63 (3.5 + 2.5)	496	4.47 (0.98)
	90 + 75 (3.5 + 3.0)	496	4.77 (1.045)
	90 + 87 (3.5 + 3.5)	496	4.85 (1.05)
	90 + 10 (3.5 + 4.0)	496	4.92 (1.07)
	90 + 113 (3.5 + 4.5)	496	4.94 (1.08)
Fredericton N.B.	0 + 0 (0 + 0)	337	2.11 (0.46)
	0 + 13 (0 + 0.5)	337	2.61 (0.57)
	0 + 25 (0 + 1.0)	410	2.84 (0.62)
	0 + 37 (0 + 1.5)	410	3.03 (0.66)
	0 + 50 (0 + 2.0)	410	3.13 (0.68)
	0 + 63 (0 + 2.5)	410	3.19 (0.70)
	0 + 75 (0 + 3.0)	410	3.24 (0.71)
	90 + 37 (3.5 + 1.5)	410	3.03 (0.66)
	90 + 50 (3.5 + 2.0)	410	3.01 (0.65)
	90 + 63 (3.5 + 2.5)	410	3.18 (0.70)
	90 + 75 (3.5 + 3.0)	410	3.29 (0.72)
	90 + 87 (3.5 + 3.5)	410	3.35 (0.74)
	90 + 100 (3.5 + 4.0)	410	3.38 (0.75)
	90 + 113 (3.5 + 4.5)	410	3.40 (0.76)
	90 + 125 (3.5 + 5.0)	410	3.41 (0.77)

DISPLACEMENT AT SUPPORTS

Part of the structural design of the wall should include design of connections of the studs to the structure to meet an acceptable displacement criterion. Welded connections, heavy gauge nested track, and stud web connectors are all possible and were tested at McMaster. For brick veneer, stud to structure displacement at the top connection is not very significant, unless the veneer is caulked or wedged to the underside of a shelf angle. In this case a flexible top stud connection may not carry the load until the restraint of frictional resistance or sealant between the veneer and the shelf angle is overcome, or until the veneer cracks. For interior finishes, and for exterior finishes such as EIFS, or face-sealed stucco in close contact with the insulation, otherwise normal displacements of flexible connections are likely to result in damage to the finish. Allowing for tolerances, the gap required at the end of the studs may be larger than the 12 mm (0.5 in.) used in the McMaster tests. As the required gap increases, the difference between the lateral deflection of web connectors and that of equally strong double track also increases. The amount of displacement that the cladding and finishes can tolerate should be estimated and considered in the structural design of the connection. If the connection design is delegated to the contractor, then the maximum displacement at full design load should be specified as part of the design requirements.

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[7] This is the value that EMPTIED reports, although in context it appears incongruous.

Table 4-2: *Winter condensation in brick veneer, as a function of air leakage, for the worst month.*

City	Insulation mm (in.)	Leakage Area cm^2/m^2 (in^2/ft^2)	Condensation in Brick kg/m^2 (lb/ft^2)
Winnipeg Man.	0 + 13 (0 + 0.5)	0.75 (0.012)	4.16 (0.9)
	0 + 13 (0 + 0.5)	0.37 (0.006)	1.98 (0.43)
	0 + 13 (0 + 0.5)	0.19 (0.003)	0.95 (0.21)
	0 + 13 (0 + 0.5)	0.09 (0.0014)	0.37 (0.08)
	0 + 13 (0 + 0.5)	0.05 (0.0008)	0.14 (0.03)
	0 + 13 (0 + 0.5)	0.02 (0.0003)	0.03 (0.007)
	90 + 50 (3.5 + 2.0)	0.75 (0.012)	4.78 (1.05)
	90 + 50 (3.5 + 2.0)	0.37 (0.006)	2.06 (0.45)
	90 + 50 (3.5 + 2.0)	0.19 (0.003)	0.96 (0.22)
	90 + 50 (3.5 + 2.0)	0.09 (0.0014)	0.42 (0.09)
	90 + 50 (3.5 + 2.0)	0.05 (0.0008)	0.20 (0.04)
	90 + 50 (3.5 + 2.0)	0.02 (0.0003)	0.05 (0.008)
	90 + 113 (3.5 + 4.5)	0.75 (0.012)	4.94 (1.08)
	90 + 113 (3.5 + 4.5)	0.37 (0.006)	2.39 (0.52)
	90 + 113 (3.5 + 4.5)	0.19 (0.003)	1.18 (0.26)
	90 + 113 (3.5 + 4.5)	0.09 (0.0014)	0.51 (0.101)
	90 + 113 (3.5 + 4.5)	0.05 (0.0008)	0.24 (0.05)
	90 + 113 (3.5 + 4.5)	0.02 (0.0003)	0.08 (0.009)

TOLERANCES

Concrete

For concrete construction, it may be easier to specify and enforce tighter dimensional control than to accommodate the variation allowed in the standards.

Steel and Miscellaneous Metal

To meet the accuracy of position required by standards for structural steel, steel elements require adjustable connectors when they are supported by concrete.

Masonry

The tolerance specified by code should be coordinated with the tolerances for concrete, steel, and steel studs to be sure that what the mason is required to accomplish is possible.

Steel Studs

The structural designer should determine the minimum gap to allow for vertical movement of the building structure without transfer of axial load to the wall, allowing for the cumulative effects of:

- inaccuracy of precut vs. custom cut studs;
- variation in opening height and stud length due to allowed tolerances;
- live and dead load deflection of the spandrel or slab edge;
- long term creep deflection of the spandrel or slab edge;
- movements due to postensioning.

Much smaller movements will also occur due to:

- elastic shortening of columns (taking construction sequence into account since the wall may be built before full dead load is applied);
- long term creep shortening of columns.

In buildings of more than one story, however, the latter effects are unlikely to be significant.

THE LAST WORD?

Research at CMHC and elsewhere is ongoing. The final say on design implications of knowledge gained from research and from observation of performance of existing buildings will never be heard. There is always room for more information.

Current prospects include research on wetting patterns on buildings during wind-driven rain, suggested by observations published in the 1970s by NRC.[8] Better understanding of where wind-driven rain strikes buildings may make it possible to fine tune efforts to keep rain out of various parts of the enclosure, depending on location. Some parts of walls may not need to be *rain screens* because they never get wet. Other parts may require more attention than they get today, because of the extent of their exposure.

Investigation of design and performance of *rain screens* is also ongoing. While changes of exterior pressure with time have been considered here, the frequency with which such changes occur could be considered in more detail, and spatial variation of exterior pressure over the building surface could be taken into account. Future laboratory tests, wind measurements, and pressure measurements in cavities of buildings in service will give a clearer picture of the extent to which cavity pressure equalization can be achieved in practice, and of the compartment sizes required on various parts of a building. A better knowledge of the spatial and temporal distribution of transient pressures may reveal a need for smaller compartments than would be selected based on time-averaged pressure distributions.

Tolerances, both usual and economically possible, are another area in which more knowledge would be helpful.

APPLICATION

Chapter 6 presents details and discussion showing how these design implications can be applied to design a wall for a particular set of environmental and structural circumstances.

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[8] Robinson and Baker, *Wind-Driven Rain and Buildings.*

CHAPTER 5

QUALITY ASSURANCE

COMMISSIONING

Detailing and specifying a carefully designed wall is not enough to ensure that it will perform as expected when built. Measurement of material thicknesses, zinc coating weights, brick and mortar properties, and visual inspection for missing parts or improper assembly procedures are all reasonably well understood aspects of quality assurance. Standards for the materials establish test procedures for acceptance or rejection of suspect parts or materials, and shop drawings or contract documents show how to assemble them. There are no widely accepted procedures for verification of air leakage performance of an assembled wall, yet this factor is critical to satisfactory performance and durability. All the following precautions should be considered as means of ensuring expected performance.

Prototype

Testing a prototype of the wall for air leakage at the pressure used to specify acceptable performance will ensure that unrealistic goals are not built into a contract. The test pressure should be 50 (1.0 lbf/ft^2) or 75 Pa (1.6 lbf/ft^2), depending on available equipment, and on how acceptable leakage will be specified. Fifty Pascals (1.0 lbf/ft^2) is the reference pressure used for evaluation of R2000 homes, so fan door equipment is available designed for use at this pressure. While 75 Pa (1.6 lbf/ft^2) may be difficult to maintain, it has the advantage of being the reference pressure for requirements proposed for the 1995 edition of the NBC. The ability of the prototype to withstand design wind loads without distress should also be tested if possible without substantial added expense. People who have used steel stud construction for plenums know that unexpected problems can arise when the fans are turned on and the full design load is applied. Wall builders may have to wait many years to discover their errors, unless a prototype is tested. Construction difficulties may appear that were not evident on the drawings or in specifications. They can be corrected without undue expense at this stage. The inspector for the construction phase should be involved in the test, to take advantage of experience building and testing the prototype during the construction phase. If a prototype is tested before working drawings are completed and put out to bid, the designer can be assured that the design is capable of being constructed and performing as anticipated, and bidders for the project need not fear having to meet an impossible performance requirement. Prior experience building and testing projects with essentially the same design, if it is available, may be better than testing a prototype.

Mock-up

Once a builder is selected, a jobsite mock-up provides opportunity for the contractor to evaluate adequacy of chosen construction methods, and train personnel to be able to meet the performance requirement. If there are no prototype tests or prior experience with the same design, the mock-up can serve the purpose of verifying the design, but any required adjustments may be expensive at this stage, if they involve changes to the contract. Extensive failures to meet performance requirements can be avoided if the workers and supervisors who will be responsible for the rest of the project build the mock-up, observed by the design personnel who participated in testing the prototype. Building the mock-up permits fine tuning of construction procedures. Testing it allows the contractor to verify that the required performance is possible.

Ongoing Inspection
Periodic inspection of ongoing work will catch any drift away from the tested construction procedures and materials, and deal with any unanticipated special conditions. Accuracy of location of studs and shelf angles, attachment and connections, and provisions for movement should be checked periodically before the drywaller can conceal errors or omissions, and before the mason discovers inaccuracies the hard way.

Final Inspection
A qualitative check of all completed work is necessary to verify that no significant air leaks have been overlooked. Smoke generators, smoke pencils, acoustics, thermography, or a combination can locate significant problems that random selection of areas for quantitative testing might miss. Experienced inspection personnel will have a good feel for what works best. Detection, not measurement, of unusual air leakage is the object. The methods used are only as important as their effectiveness at pinpointing leaks of a different order of magnitude from the required overall performance.

Compliance Testing
Full testing to measure air leakage performance of randomly selected areas is the most reliable way to verify compliance. The tested areas should be representative, not selected on the basis of expectations about particular areas. Ideally, enough samples should be tested to allow statistical evaluation of the variance. The contractor should not have the opportunity to police an area specifically designated for testing. Neither should the designer take the liberty of testing a suspect area. Unusually leaky areas should be found by qualitative testing and corrected before this final phase. If the floors of the building are not subdivided into rooms, then test a whole floor.

A procedure for this last test, which serves to verify that the contractor has matched the air leakage performance of the prototype, is suggested by Gulay *et al*.[1]

In an apartment building with identical plans on successive floors, a single apartment can be tested by using one fan to pressurize (or depressurize) the test suite, with measured air flow, while using additional fans and pressure sensors to maintain matching pressures in the adjoining suites, left, right, above, and below, and in the hallway. If there are no unknown paths leading to other parts of the building, the flow required to maintain test suite pressure is the flow through the exterior wall. Before the test is done all ducted supply and exhaust vents are sealed. Depending on how the performance criterion is specified, it may be necessary to seal the windows, taking care not to seal the juncture between the window frame and the wall, if leakage at that location is regarded as part of the wall leakage. While the test suite and adjacent spaces are equalized, use of a smoke pencil will detect possible paths to non-equalized spaces, so that they can be sealed.

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[1] Gulay, Stewart and Foley, *Field Investigation Survey of Airtightness.*

CAD DRAWING FILES

The details presented here are included as CAD drawing files on the accompanying CD-ROM.

The wall shown was conceived as a *rain screen*. The details are intended to illustrate responses to the issues discussed in Chapters 2, 3, and 4. The particular design parameters are arbitrary. An actual building design would differ in response to some other unique set of conditions, since different buildings have different interior environments, exterior environments, and structural frames, all of which affect the BVSS design.

BUILDING FRAME

The building frame is reinforced concrete. Around the perimeter of the building the distance between columns is about 2.4 m (8 ft.). The floor to underside of slab height is 2440 mm (8 ft.), and the soffit of the structural slab forms the finished ceiling adjacent to the exterior wall. The structural designer says that the total vertical movement to be accommodated by the wall framing is 5 mm (0.2 in.), at mid-span. The floors are not post-tensioned, so no access is required to the edges of the structural slabs. This set of conditions falls near the lower limit of vertical movement that steel stud wall connections might need to accommodate. The alternative slab edge in Detail 2 would allow for 15 mm (0.6 in.) of vertical slab edge deflection, permitting wider column spacing.

THERMAL AND MOISTURE PROTECTION

At the building location, 75 mm (3 in.) of cavity insulation is required to avoid condensation on the sheathing of an uninsulated stud space. Exterior temperatures of -30°C (-20°F) are possible but not frequent. This is more than enough insulation to provide thermal comfort, but energy conservation might require more. Interior relative humidity is expected to be 30% or less, with normal interior temperature of 22°C (72°F). A peel and stick (modified asphalt and polyethylene) membrane serves as air barrier, vapour barrier, and cavity flashing. With this air barrier on the outside, low air leakage is expected. Sealing the barrier around the brick ties will be important to ensure this. The success of this approach needs to be confirmed by building and testing a prototype before extensive use of the details. Reducing the cavity volume ensures cavity pressure equalization, compared to an airtight drywall approach. Use of extruded polystyrene foam insulation further limits the cavity volume.

Drywall sheathing supports the air barrier membrane. Normal fastening of the sheathing will not be enough to ensure attachment for the life of the building. If a major windstorm dislodges the sheathing, it is more serious than with an interior air barrier, since access for repair would require dismantling the wall. Hence, plated fasteners at 100 mm (4 in.) o.c. secure the sheathing along each stud, to ensure that the air barrier remains in place under design wind + stack + fan loading.

Because the insulation is a closed cell foam, it is fastened more securely than usual, to ensure that changes in air pressure in the cavity do not create temporary pressures behind the insulation capable of dislodging it. Air pervious insulation would not require as much fastening, but would require other adjustments to the design, because of increased cavity volume. In any case, fastening must be capable of pulling the insulation into uniform contact with the insulated surface to minimize gaps between the insulation and the air barrier.

Proprietary plastic washers on the brick ties hold the rigid insulation against the sheathing so that it spans from tie to tie. In a milder climate, with thinner insulation, the brick ties might be too far apart for this to work. Mechanical fasteners into the sheathing, tested to ensure they would not cause leaks in the air barrier, would be an alternative.

There will rarely be any potential for condensation on the back of the exterior sheathing. Hence, Z275 (G90) zinc coating is enough for sheet steel components, other than masonry ties, and steel fasteners are zinc plated. There is no polyethylene behind the interior drywall, and no special effort to seal the interior drywall. The air barrier also serves as vapour barrier. If windows or plumbing leak, or if there is water on the floor, water that finds its way into the stud space will have an opportunity to evaporate. The bottom track might be made of more heavily galvanized material, to allow for moisture collecting there. The usual variable gap is left undisturbed at the bottom of the interior drywall, and joints are taped only as required for decorative and fire resistive purposes. Interior drywall is omitted where partitions intersect the exterior wall, and in service spaces, except when required for fire-resistance. The interior drywall is fastened with screws at standard spacing.

PROVISION FOR MOVEMENT

There is less provision for movement than is usually required. The 10 mm (0.4 in.) clear joint beneath the shelf angle will provide for 5 mm (0.2 in.) of combined column creep shortening and slab deflection, corresponding to perimeter column spacing and floor to floor dimensions of about 2.5 m (100 in.), plus 1.5 mm (0.06 in.) of brick expansion with aging, and 3.5 mm (0.138 in.) for good measure. Allowing for the full 5 mm (0.2 in.) in every case takes into account the possibility that one floor might carry the full live load while adjoining floors remain unloaded. In order to use sealant instead of flashing, a joint of 20 mm (0.8 in.) or more would be required between the shelf angle and the top of brick, depending on the compression the selected sealant could accommodate.

The 5 mm (0.2 in.) minimum gap between the top edge of the drywall and the soffit, and also between the leg of the outer track and the highest screw heads where the studs are secured to the inner track, allows for movement of the structural frame. The air barrier manufacturer has advised that the membrane can span such a gap and accommodate the expected movement.

If studs are pre-cut to length to accommodate indicated tolerances in the slab position, then in addition to structural movement, a gap from end of stud to slab of up to

45 mm (1.8 in.) would be required. This does not include a tolerance for cutting the studs. The nested track arrangement shown cannot accommodate so large a gap, unless the outer track is quite heavy. Too light a track would allow excessive inward movement under full wind load. Hence, the studs will be pre-cut to the most extreme length, requiring many studs to be cut shorter as they are installed.

The open joint between the top of the veneer and the underside of the shelf angle, behind flashing, provides additional cavity ventilation sheltered from water on the surface, and avoids restraining lateral deflection of the veneer. There are no open head joints for ventilation, since lab tests have demonstrated that they allow water to enter the cavity, even with pressure equalization, under conditions of wind driven rain. Water entering the joints during rain is a greater threat than failure of water vapour to leave by the same route under drying conditions.

SHELF ANGLE

The shelf angle is aligned with the nominal slab soffit elevation, allowing ceiling-high windows without lintels or brickwork between the window head and the shelf angle. The shelf could be inverted to avoid difficulties with the flashings at connections, and, if required, to permit access to postensioning anchorages.

The attachment shown for the shelf angle allows location accurate enough to avoid unsightly undulations in the masonry, while accommodating all slab edge positions permitted by the tolerances. The shelf angle tolerance is the usual tolerance specified for adjustable steel framing members. This location also provides thermal separation from the slab edge. Detail 2 shows a shimmed and grouted shelf angle without thermal separation.

The face of the exterior sheathing is nominally in line with the slab edge, to allow a bit of extra room for adjustment in cases where the slab edge is at the inward extreme position. When the slab is fully retracted, the bottom track projects somewhat, but the minimum fastener to slab edge distance is still available for drilled concrete screws.

At corners the shelf angle is mitred and welded. Shelf angle joints are located at control joint/compartment locations near corners, and at intervals along the wall, to minimize field welding. For humid, rainy, or coastal locations, where it might be necessary to galvanize the shelf angle, bolted connections should be used in place of welded connections.

BRICK TIES

The brick ties are attached to the sides of the studs, with fasteners acting in shear (stronger than fasteners acting in tension). The ties will not cause local bending of the stud flanges, and twisting of studs is minimized. Where the ties penetrate the sheathing, the air barrier is patched with pieces of peel-and-stick membrane. The ties are galvanized after fabrication, because there will be more moisture in the cavity than in the stud space. For coastal climates, they would be stainless steel. The ties provide maximum stiffness over a range of adjustment, and transfer load directly to the web of the stud. The ties are spaced in accordance with CAN3-A371[1], but designed so that the top row of ties will carry 50% of the wind load for one floor, to ensure that they will not be overloaded before the veneer cracks.[2] Additional ties at openings and edges are kept 200 mm (8 in.) away from the edge of the veneer. Extra studs are provided at these locations, to support the added ties.

CAVITY

Since the cladding is brick veneer, the nominal cavity width is 50 mm (2 in.), and some exterior water will get into the cavity by gravity, despite the *rain screen*. To minimize this possibility, vents into the cavity are located only at the shelf angle; the joint below the shelf angle is sheltered by the flashing above. In Drysdale's tests, vents located above the bottom of the cavity admitted substantial amounts of water.[3] Alternatively, the joint could be caulked, in which case open joints or vents might be added to encourage ventilation, but these openings would have to be sheltered. A stiffer top connection for the studs might be necessary as well since the sealant would accommodate less lateral movement. Either way, water running down the exterior face will not have much opportunity to enter the top of the cavity by gravity flow. Where it enters the vents at the shelf angle, it will meet flashing that has to be fully sealed in any event.

To avoid a cavity plugged with fallen mortar and debris, the bottom of the cavity could be filled for the first few courses with free-draining gravel. This method is one of several recommended by Drysdale and Suter[4], and has been in use in some cases for several years without evident adverse effects. Several other methods commonly specified in the past are less satisfactory. Pulling a board up through the cavity might work if ties were installed progressively, and if the cavity was always the same size, but this is not the case. Pulling ropes out of the vents suffers from a timing difficulty; if they are pulled out when the mortar is plastic, subsequent plugging of the holes is possible. When a story of brickwork is completed, the mortar at the bottom has set and the rope is trapped. Another method that is reported to work well is leaving out every third brick in the first course, until after all mortar has been cleaned out through the resulting openings. This permits inspection of the cavity just prior to closure of the openings.

At corners, and at 10 m (33 ft.) intervals (coinciding with every other brick expansion joint) vertical baffles are installed to limit cavity volume and ensure pressure equalization is maintained. RAIN was used to evaluate the spacing. Larger or more frequent brick vents would be required, perhaps along with more compartments, if fibrous insulation were used, since its volume is mostly air, or if an airtight drywall approach had been taken that would add the

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[1] CAN3-A371, *Masonry Construction for Buildings.*

[2] Under CAN/CSA S304 *Masonry Design for Buildings*, every tie is required to be able to carry a load equal to 40% of the tributary load on an area equal to wall height x stud spacing. Making the top row of ties stronger is an option for the building structural designer to consider as part of a detailed stiffness analysis.

[3] Drysdale and Wilson, McMaster, Part 5.

[4] Drysdale and Suter, *Exterior Wall Construction in High Rise Buildings.*

volume of the stud space to the cavity. The shelf angles act as horizontal baffles. The shelf angle at the roof line and the double baffles at corners create smaller compartments at points where exterior pressures vary substantially over short distances, and where wind-driven rain impinges with greater intensity, compared to the rest of the facade.

STRUCTURAL CONSIDERATIONS

Welded connections are worth considering, if welders experienced in sheet steel welding and the proper equipment are both available.

The minimum stud thickness specified will be 1.22 mm (18 ga.), or that selected from the manufacturer's table for the L/720 deflection criterion, if thicker. The thicknesses and attachments of all of the components will receive the detailed attention of a structural engineer at the shop drawing stage. Where there are no openings, the veneer will crack at about the design wind load. If this happens, crack width and additional ingress of water into the cavity will be acceptable provided the *rain screen* pressure equalization is effective. The engineer responsible for the shop drawings will design and detail the head connection and additional reinforcement at openings, but is not likely to use a heavier stud than the minimum specified.

DETAIL 1 - SLAB EDGE

Most of the features of this detail have been mentioned already. Notes describing parts that are repeated in other details generally appear only here, and are not repeated in the other details.

Tolerances

The detail can be built, without compromising function, when the components are located within the ranges indicated. All components are shown in their nominal position. In specific instances, the face of stud might be 22.7 mm (0.9 in.) inward from the grid, with the edge of slab a further 2.3 mm (0.09 in.) inward, or projecting 47.7 mm (1.9 in.) outward from the face of stud. The air space, shown as 54 mm (2.1 in.), might actually be anywhere from 39 mm (1.5 in.) to 69 mm (2.7 in.). These extremes are consistent with the tolerances specified in the applicable standards, except that the concrete structure has been given more latitude, based on experience and the reject rate implied in the Appendix to CSA A23.1. The shelf angles should be carefully adjusted and secured before the metal stud framing is installed, so that the toe of the shelf angle can serve as a reference for the location of the framing. An assortment of wire tie sizes accommodates the full range of cavity dimensions. Installing the stud framing by measuring from the slab edge, rather than the toe of the adjusted shelf angle, would make it impossible to maintain both a reasonable air space and a visually flat exterior wall surface.

Slab Edge Insulation

The insulation behind the shelf angle cannot be a continuation of the wall insulation, because the space is variable and not necessarily aligned with the sheathing. If firestopping is required, it could be RTV silicone foam. Otherwise, batt insulation could be stuffed into the space to fill it, rather than the foam insulation shown. However, urethane foam would provide the best thermal insulation, since it would fill the space intimately, and provide almost as much R value as the insulation on the wall, even when the gap was smaller than average.

Ties

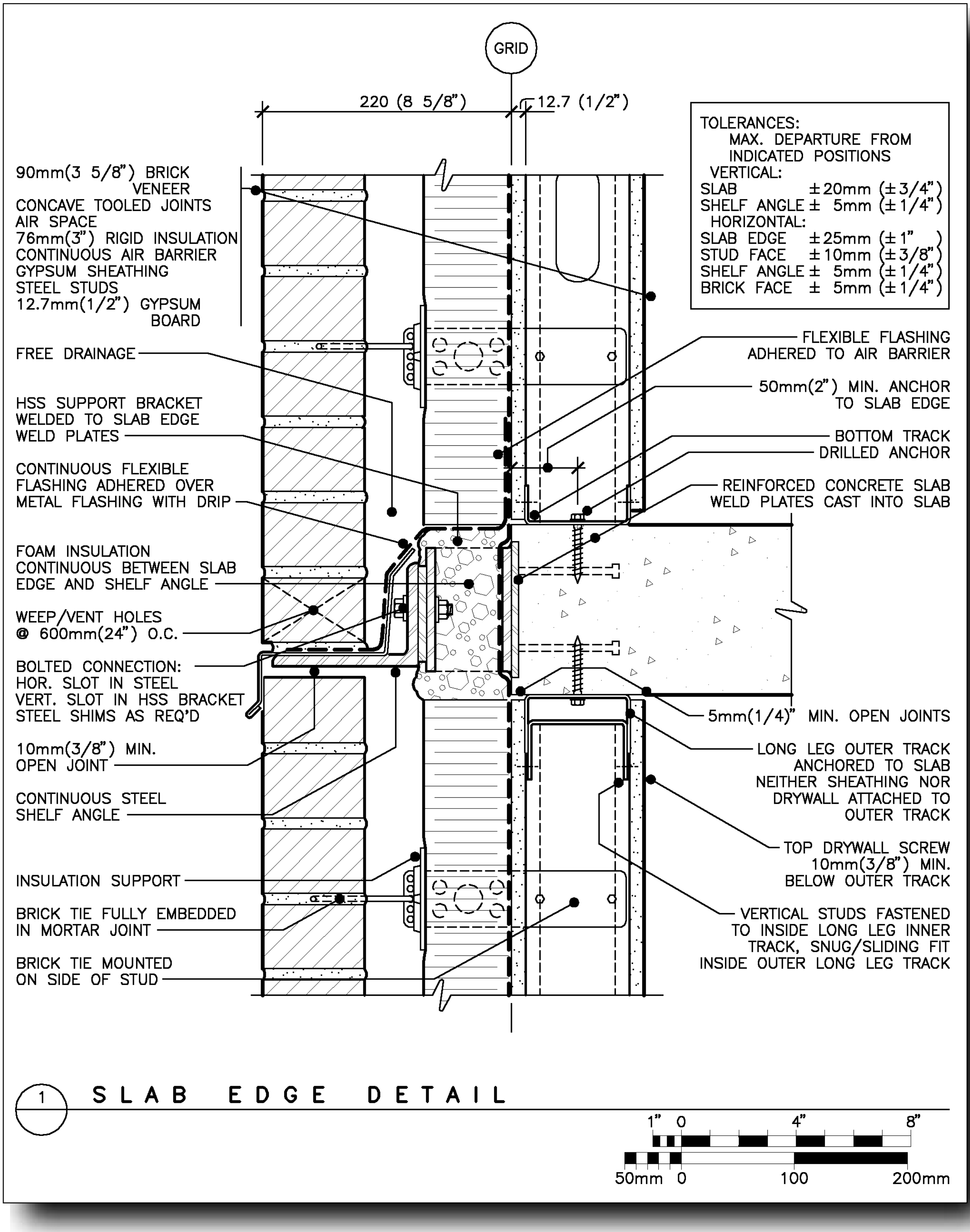
The ties shown have two advantages. Ties fastened to the stud web performed best in Drysdale’s structural tests. Thermally, they have more mass and surface inside than outside. Since heat flow through the thermal bridge is determined by cross section and temperature difference, it makes little difference whether the bridge is warm or cold. The temperature is determined by where most of the mass and surface area are located, on the warm or cold side. These ties will be relatively warm, compared to ties with more exterior material and surface area, although heat flow might be equal. Their main disadvantage is that each tie is a potential breach of the air barrier, making some possible types of air barrier difficult or impossible to install.

Flashing

The metal flashing supports the flexible flashing where it bridges the cavity. The joints are lapped, and not sealed, since the flexible flashing performs the water shedding function. On the exterior, the metal provides a drip and shelters the open joint at the head of the veneer below, preventing water running on the face of the building from entering the cavity. Near the top of the building, where rain entrained in moving air may be moving upward, a flashing more like the parapet cap flashing shown in Detail 6 should be considered, with more overlap onto the brick, and a sealed joint behind the drip.

Fastening of Stud Track

The fasteners to attach the track to the structure should be selected by the engineer designing the stud framing, in consultation with the supplier. Stud anchors or concrete screws are the types most likely to perform satisfactorily so close to the slab edge. The 50 mm (2 in.) edge distance shown is valid for a particular fastener size and type. Fasteners should be selected so as to work with the edge distance remaining in the worst case combination of allowed slab and stud locations.



Detail 1: *Slab Edge*

DETAIL 2 - WARM LEDGER & STUD CONNECTOR

This detail illustrates two alternatives that do not have to go together: a warm shelf angle, and a stud top connection providing greater movement capacity and lateral stiffness.

Shelf Angle

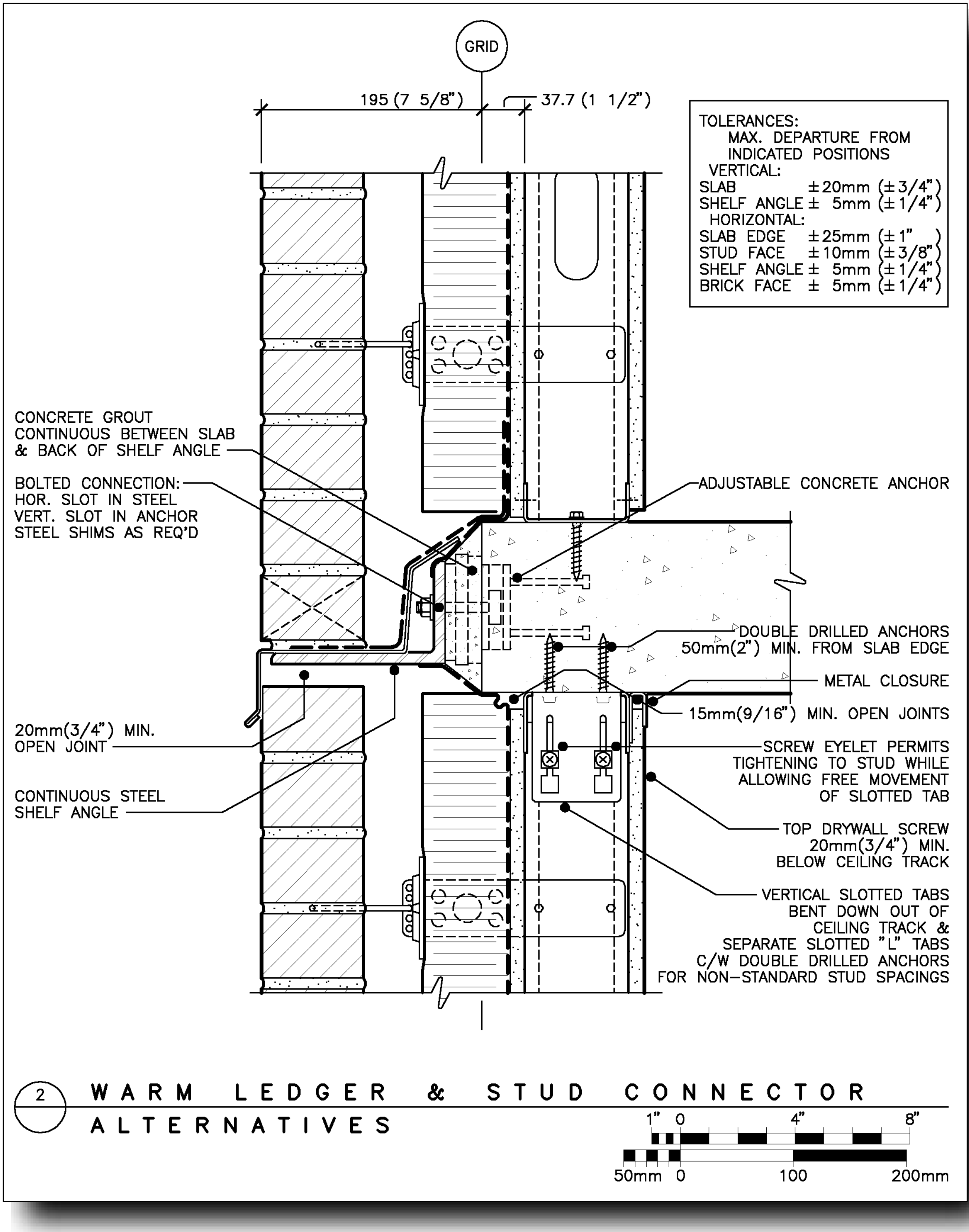
Some means of adjusting the position of the shelf angle relative to the variable slab edge position is required to ensure alignment of the exterior masonry, but an insulated space behind the shelf angle may not be desired. If the energy budget of the building permits, heat loss at the shelf angle will help to avoid freezing at the bottom of the cavity and promote drainage, although in cold climates it will result in cold floors. The shim space shown provides for adjustment. The grout provides thermal contact, and resists rotation of the shelf angle. As with the previous detail, an inverted shelf angle could be used.

Stud Top Connector

The connector shown is one of several available proprietary connectors that provide greater lateral stiffness than nested track. This connector provides a stiff connection because it attaches to the web of the stud. Each stud connects directly to the structure. Slotted holes provide for vertical movement and make it easier to pre-cut the studs without encountering situations where they are too long or too short. In this case a provision for 15 mm (0.6 in.) of structural movement is shown. To provide for 5 mm (0.2 in.) of brick expansion, a 20 mm (0.8 in.) open joint is required behind the flashing. A 40 (1.6 in.) to 60 mm (2.4 in.) caulked joint, depending on sealant selection, could be used instead.

Flashing

Flashings to cover the joint below the shelf angle, whatever one may think of their appearance, have some advantages. The joint at the head of the veneer is reduced, from at least 40 mm (1.6 in.) to only 20 mm (0.8 in.) in this case, and it provides access to the cavity for pressure equalization and ventilation. It prevents water running on the face of the wall from entering the cavity. One disadvantage is that on the top of the building, when wind and rain combine, the direction of flow on the surface can be upward, potentially driving water under the flashing. Above the stagnation point, this problem can be addressed with sealant behind the flashing, and increased vent/drain hole frequency, or reduced cavity size.



Detail 2: *Warm Ledger & Stud Connector Alternatives*

DETAIL 3 - WINDOW HEAD AND SILL

This is a punched window. Openings in stud framing affect the structural performance of the wall. To optimize design, the structural designer should consider all exterior wall panels, each with its own pattern of opening sizes and locations. In Drysdale's tests the load to first crack was much lower with a window than without, and the extent of cracking at design load was greater with a window than without, even with double studs at window jambs. Chidiac's program provides the structural engineer with a tool for considering each case on its own merits, designing the veneer, ties, and studs for each typical panel to act together.

Lintel

A loose lintel supports the veneer above the opening.

Window Position

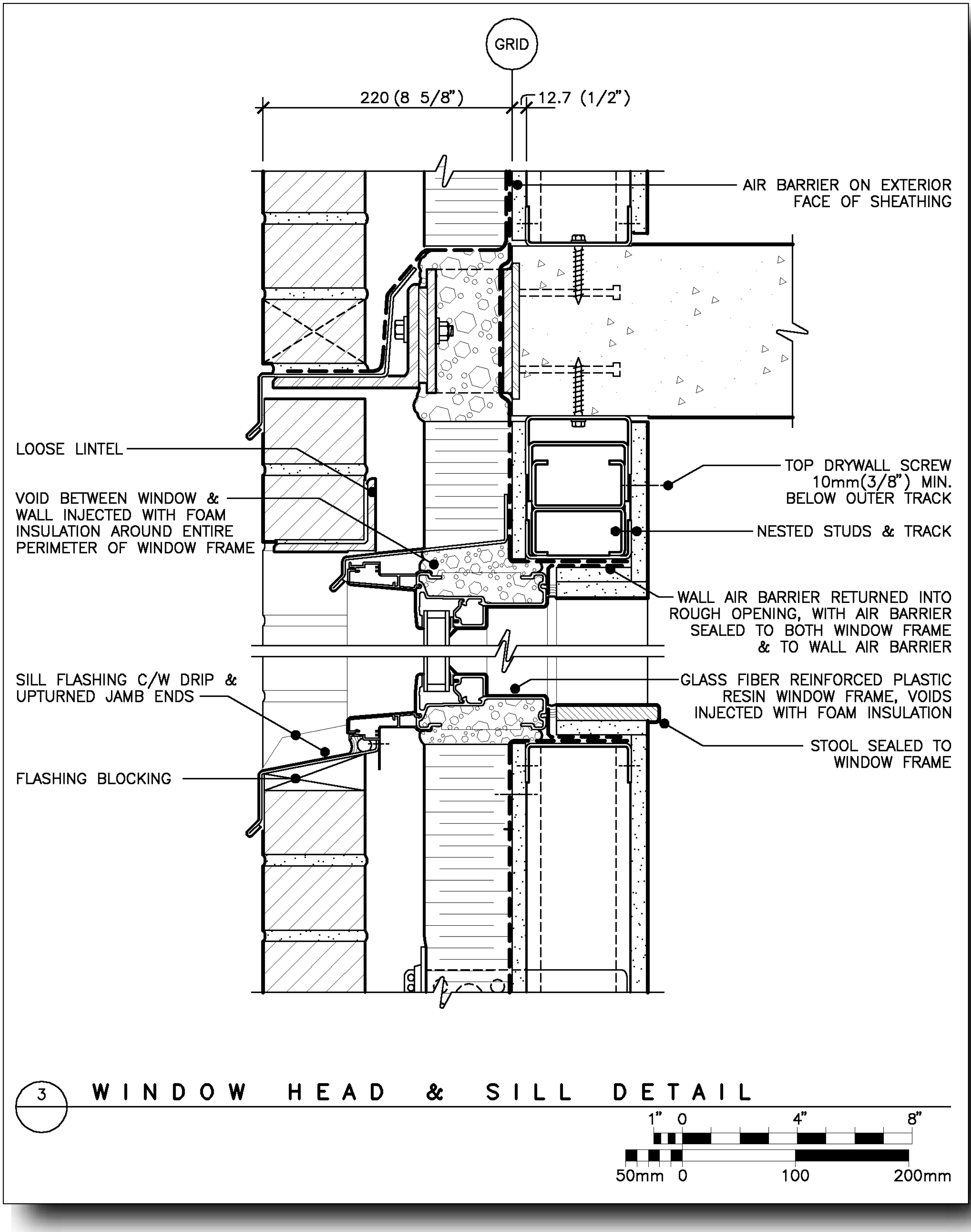
Most residential windows are designed for an insulated wood frame stud wall, without exterior insulation. The window aligns with the insulation when the nailing flange is nailed to the exterior sheathing. To position the window in line with the insulation in this detail requires projecting it beyond the studs, with brackets to attach it to the jambs. Perhaps a window manufacturer will someday design a window with a nailing flange properly located for this condition. With most available windows, the air barrier has to be wrapped into the opening, to permit sealing to the frame from the inside after the window perimeter is insulated. The corner detail of this window frame would need to be examined to be sure that any cavity moisture reaching the window head would drip off the sides, not run into the framing at the jambs or into the interior. The standard brick mold at the head is modified so that the flashing can be installed, to intercept cavity moisture and drain it at the window head.

Sill

The sill flashing turned up at the ends, behind the brick mold at the jamb, prevents water draining off the end and under the flashing. The flashing is a single piece, prefabricated to leave a mortar joint sized allowance at each end, to accommodate both tolerance and a sealant bead between it and the brickwork.

Stool

If windows are properly selected to avoid condensation, a water resistant stool is needed only to accommodate over-watered potted plants.

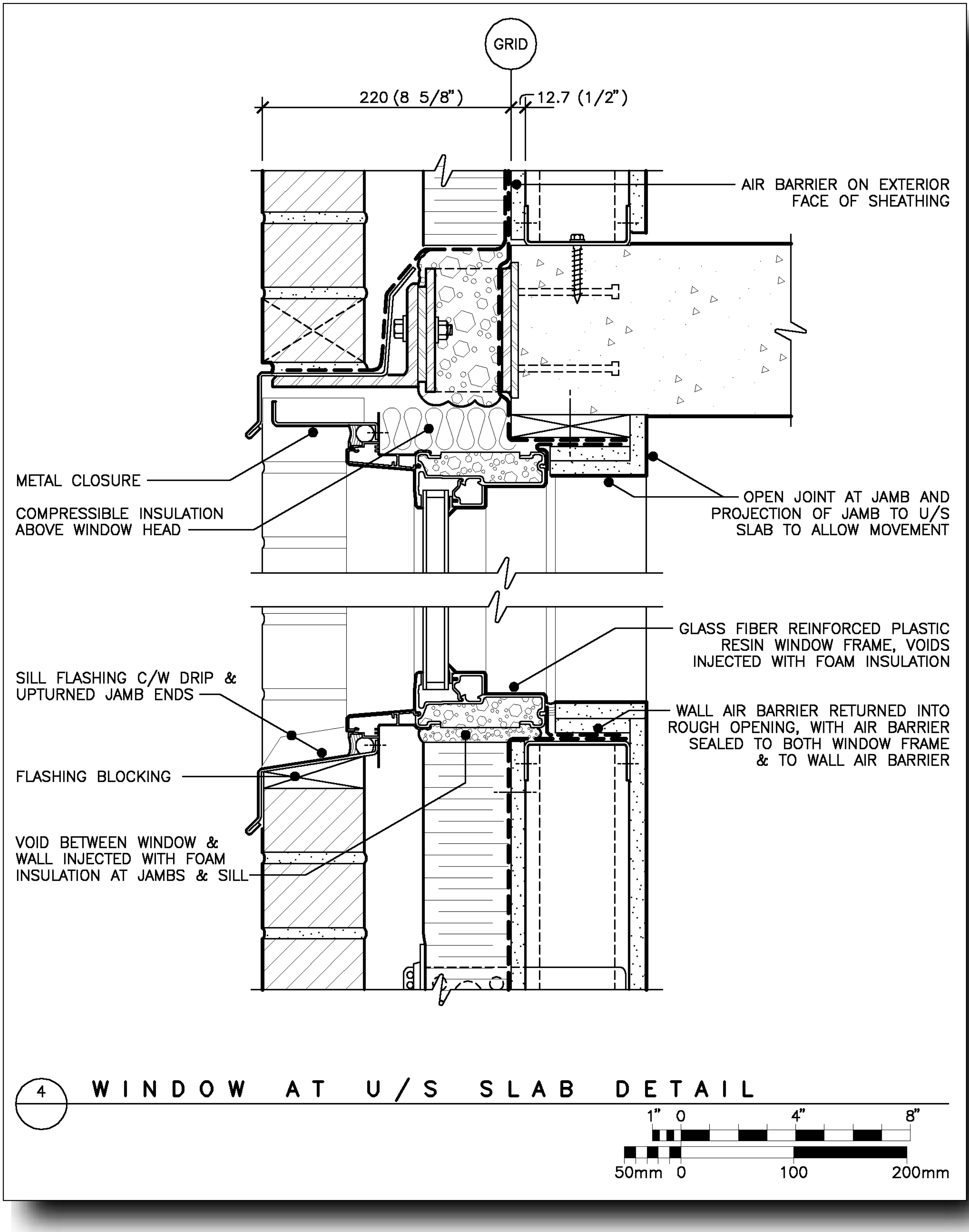


Detail 3: *Window Head & Sill*

DETAIL 4 - WINDOW AT U/S SLAB

This is still a punched window, but placed as close to the ceiling as possible. A strip window would require structural supports spanning from column to column below the sill, or hot rolled members cantilevered from the floor slab, with different provisions for structural movement and window attachment, and an additional shelf angle in line with the sill for any panels of brick between windows.

The window is attached to the wall, but the drywall at the window head is attached to the slab. Therefore, joints are required in line with both jambs, extending to underside of slab, and at the window head, between the window frame and the drywall, to provide for movement of the ceiling and drywall attached to it relative to the wall and window frame.



Detail 4: *Window at U/S Slab*

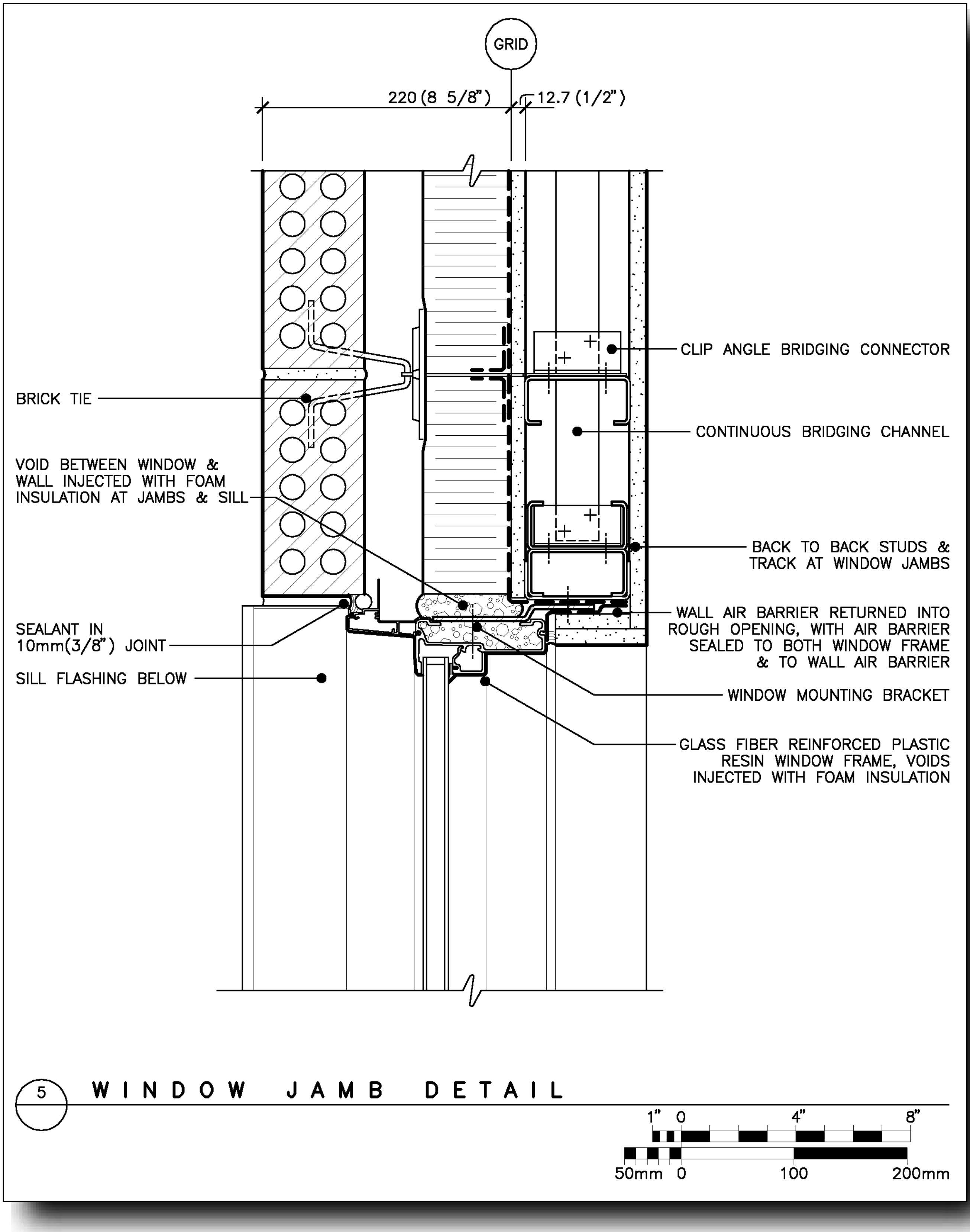
DETAIL 5 - WINDOW JAMB

The window is supported by metal brackets attached to the window jamb, and to doubled studs at the jamb of the opening. (Structural design might dictate something other than double studs.) The window is installed after the air barrier has been wrapped into the opening. Connection to the window is made with additional strips of air barrier applied from the interior, over the support brackets.

An additional stud and ties support the edge of the veneer at both sides of the opening, 200 mm (8 in.) away from the opening. Air leakage at ties is prevented by using Band-Aids of air barrier material sealed to each tie, to the air barrier, and to each other above and below the tie.

Bridging in the stud space is mechanically attached, or welded, to the studs.

Foam insulation around the window could be replaced with batt insulation stuffed into the space between the window frame and the cavity insulation; however, the higher thermal conductivity of fibrous insulation might result in glass edge temperatures lower than the interior dew point.



Detail 5: *Window Jamb*

DETAIL 6 - LOW PARAPET

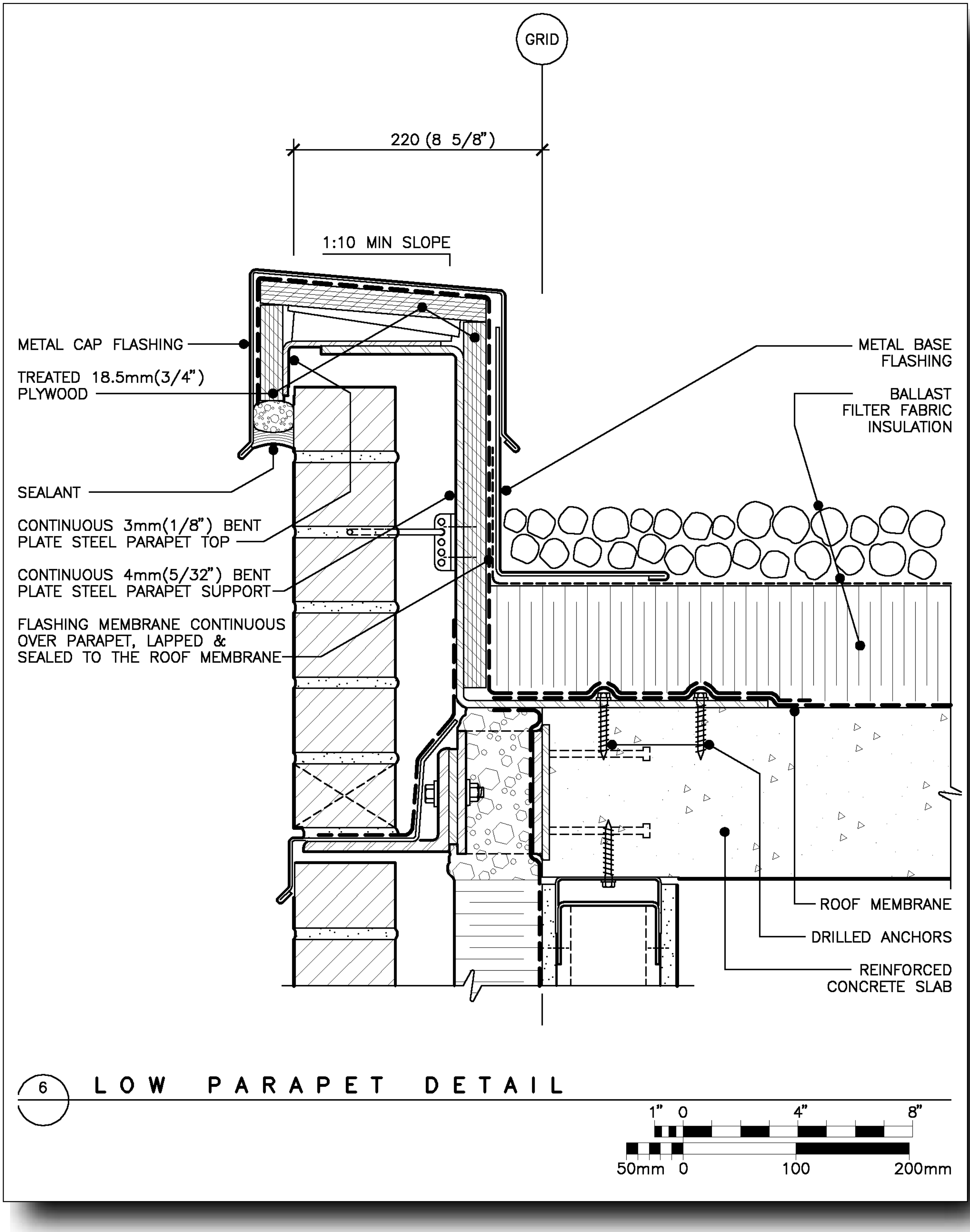
Shelf Angle
There is a shelf angle at the roof line for two reasons. If there were no shelf angle, the brick veneer would be attached to both the top of the stud wall and to the parapet. These two elements deflect differently in response to both wind and snow loadings. The top of stud connection is where lateral deflection in response to wind is normally at its maximum. If the shelf angle is omitted, a detailed structural analysis would be needed to be sure excessive cracking of the veneer would not occur. The shelf angle also separates the cavity into two regions with different thermal and moisture regimes. In the parapet the cavity is unheated, and does not receive condensed moisture from air leakage. In the wall cavity there is some heat loss from the wall, as well as air leakage. If the two cavities are connected, a convection current in the air space is likely to transport moisture into the parapet, and concentrate condensation there.

Insulation
With insulated parapets, where the insulation goes up and over the parapet, designers assume that the structure of the parapet will be warm as a result of the insulation. A two-dimensional heat flow analysis will probably show that this is not true, unless the parapet is very low or made of very conductive material. In this case, the edge of the roof slab will still be cold, because the plate supporting the parapet acts as a thermal bridge, but not colder than it would be with a conventional hollow framed insulated parapet. An alternative connection might be devised to provide a thermal break if slab temperature remains a concern.

Support
The bent plate support shown for the parapet is robust enough to survive impacts from gravel buggies, and to allow swing stage outriggers to rest on top. A hollow parapet framed in steel stud cannot withstand these forces, or even wind loads, unless structurally supported along the top by steel or concrete supports attached to the roof slab. This narrow parapet requires less flashing material, and can be positioned to accommodate the tolerance allowed for the location of the slab edge, in addition to being self supporting.

Compartmentation
Like the wall cavities, the parapet cavity needs to be compartmented, particularly at corners, to ensure pressure equalization and reduce rain penetration. The same compartment spacing used in the wall should extend through the parapet cavity.

Flashing
The top of the parapet is sloped to prevent puddles on top. Waterproof bituminous flashings underneath make caulking of joints in the metal neither necessary nor desirable. Metal flashings should be fabricated in sections short enough that fastening is only required in the S-lock joints at the ends, without clips in the hem that are often difficult to install, and omitted as a result. Caulking between the back of the flashing and the face of the wall will prevent entry of wind-driven rain, usually traveling upward



Detail 6: *Low Parapet*

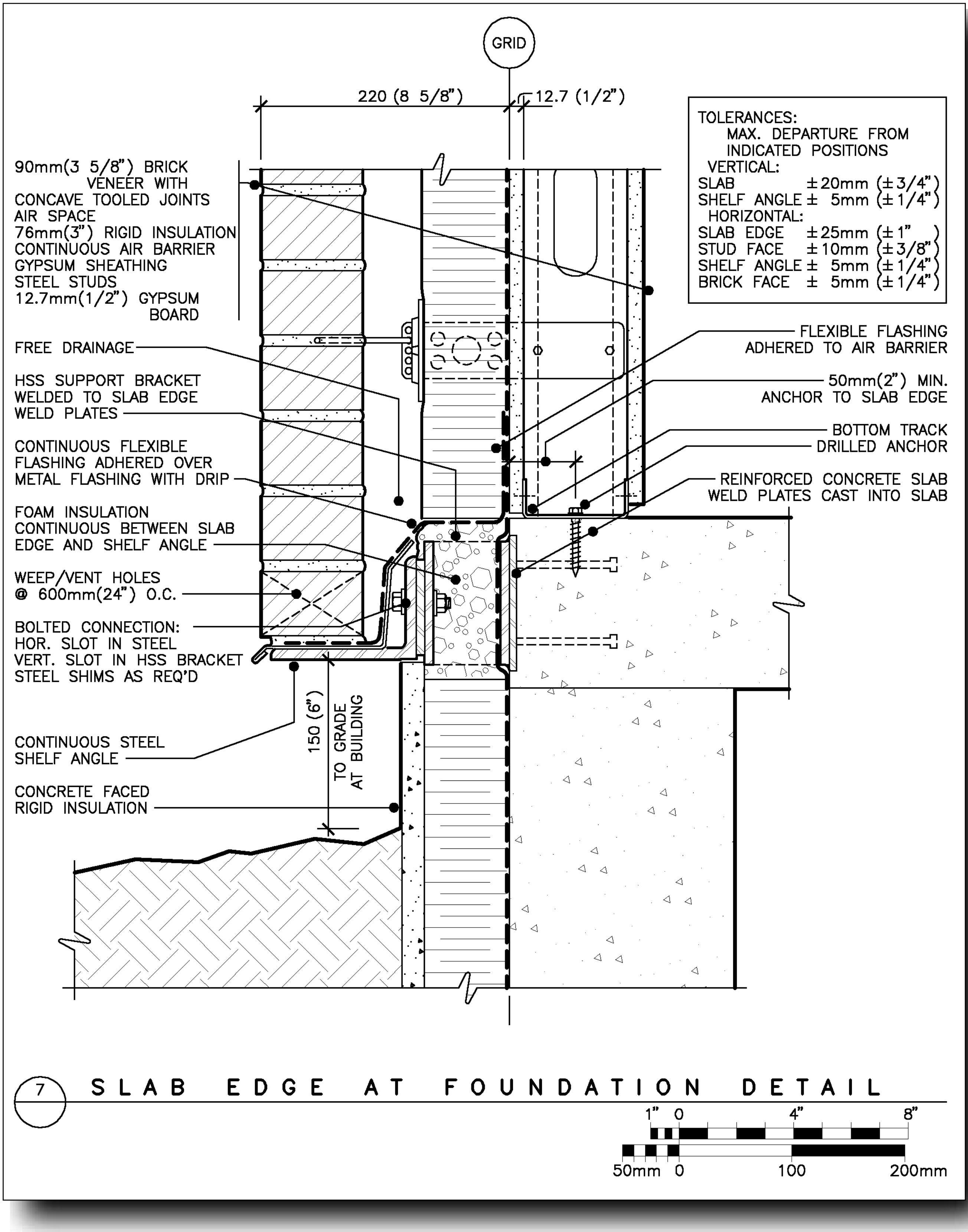
at the top of a building. The sealant will tear at the joints in the flashing unless it is discontinuous at each joint, or debonded from the flashing for an interval.

Roofing

Each roofing type will require different detailing. This roof is hot-melt rubberized asphalt, inverted, and reinforced with EPDM sheet embedded in the membrane over the joint with the parapet support and over joints in the parapet support.

DETAIL 7 - SLAB EDGE AT FOUNDATION

This detail provides continuity of insulation between the wall and the foundation wall. If the grade is sloping, coordinate steps in the shelf angle with brick expansion joint/cavity compartment locations. A metal closure at sides of steps can close the cavity. In some geographic localities, corbels or thick foundations are often used to support brickwork at grade. Except for the resulting thermal bridge, this is a perfectly acceptable alternative that may avoid an unusual recess at grade, and allow a sloping grade to be followed more evenly by the bottom of the brickwork. The difference between tolerances possible in concrete and those required in brickwork needs to be considered in this case, to ensure that steps and corbels are aligned with the brick coursing. Thick bed joints or awkwardly cut brick or both will result if normal concrete tolerances are applied.



Detail 7: *Slab Edge at Foundation*

DETAIL 8 - BALCONY AT PATIO DOOR

This detail shows how to eliminate some of the problems that often occur with the common cantilevered balcony, without radical change. An ideal balcony would avoid the cantilevered slab altogether. For some owners this is a requirement. This would eliminate the thermal bridge of the slab itself. A space between the two slabs would allow continuous insulation. Elimination of the perimeter radiation would allow elimination of the curb at the threshold, permitting wheelchair access and making pedestrian access much more convenient.

Curb

The curb extends for the full width of the cantilevered slab, and supports waterproofing as well as the patio door. Because of the large size of the door, it is better to provide different cladding above and below the opening, rather than having a punched opening in the brickwork. Perimeter hot water radiation is kept simple by running it past the door on the inside of the curb, eliminating either additional risers, or the need for a drop ceiling on the floor below, with an offset in the piping. With door and walls designed for high thermal efficiency, it might be possible to eliminate the perimeter radiation altogether.

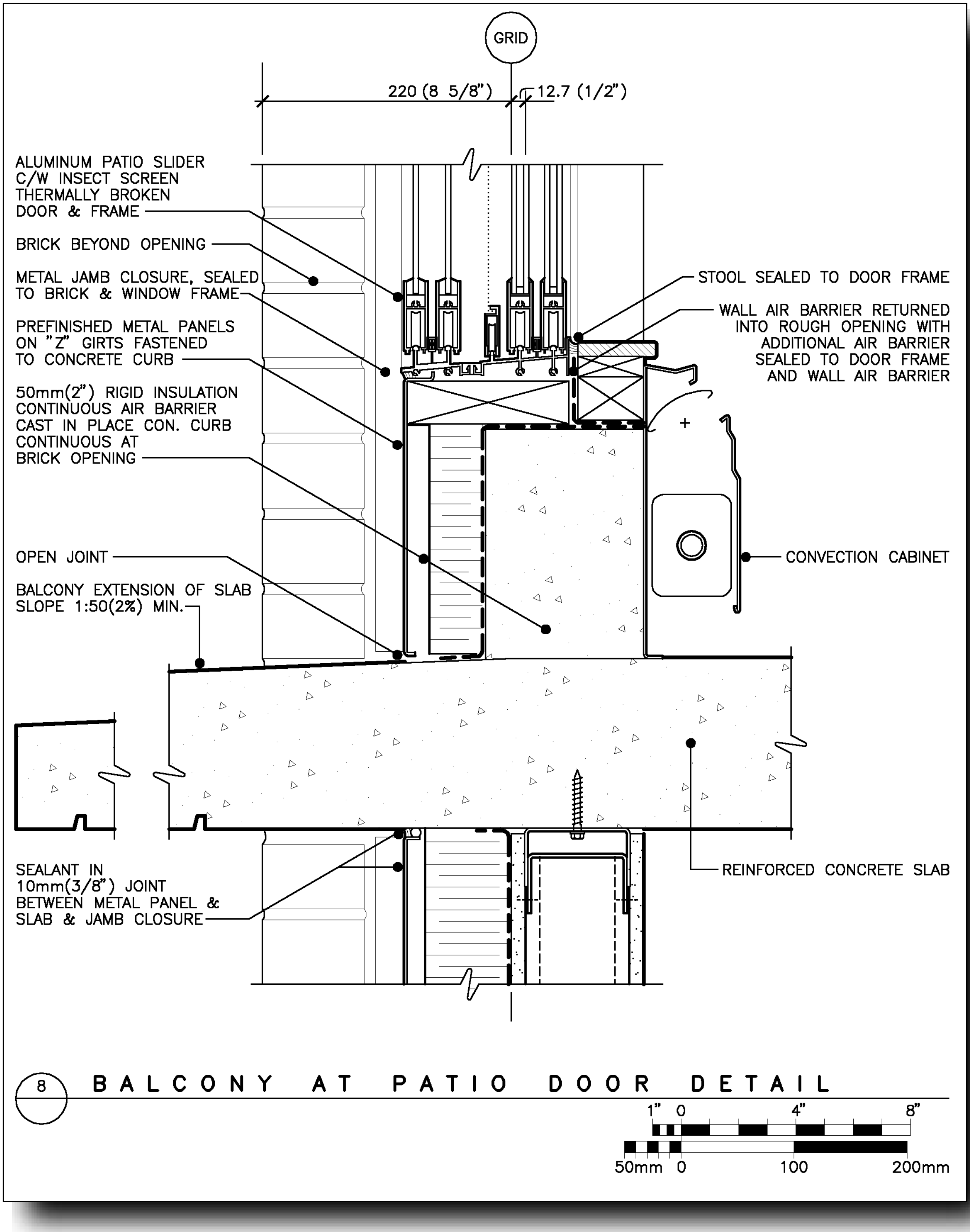
Instead of the concrete curb shown, the curb could be built of metal stud, with the top channel designed as a beam to carry lateral loads across the width of the opening. Metal stud framing is unlikely to be adequate unless specifically designed for the loads transferred from the door to the curb.

Drips

A drip is needed not only at the edge of the balcony, but also near the wall line, since concrete balconies often leak through cracks, with water sometimes running along the underside of the slab, adhered by surface tension, and then into the wall.

Perimeter Fastening of Air Barrier

Free edges of the waterproofing/air barrier should be mechanically fastened through metal battens. In this case they would be described in the specifications for the air barrier.



Detail 8: *Balcony at Patio Door*

DETAIL 9 - CORNER

Corner Compartments

Wind loads on cavity dividers are greatest at corners, because the most severe gradients in pressure occur at corners. By using two dividers similar to the those used in mid-wall, the load is divided and the corner appears symmetrical. The barriers shown are 400 mm (16 in.) from the corner. They could be up to 600 mm (24 in.) away from the corner, particularly if the building is large. The brickwork at the corner is supported by its own shelf angle, mitred and welded at the corner, with a joint, if required, located at one of the vertical expansion joints.

Fastening at Sides

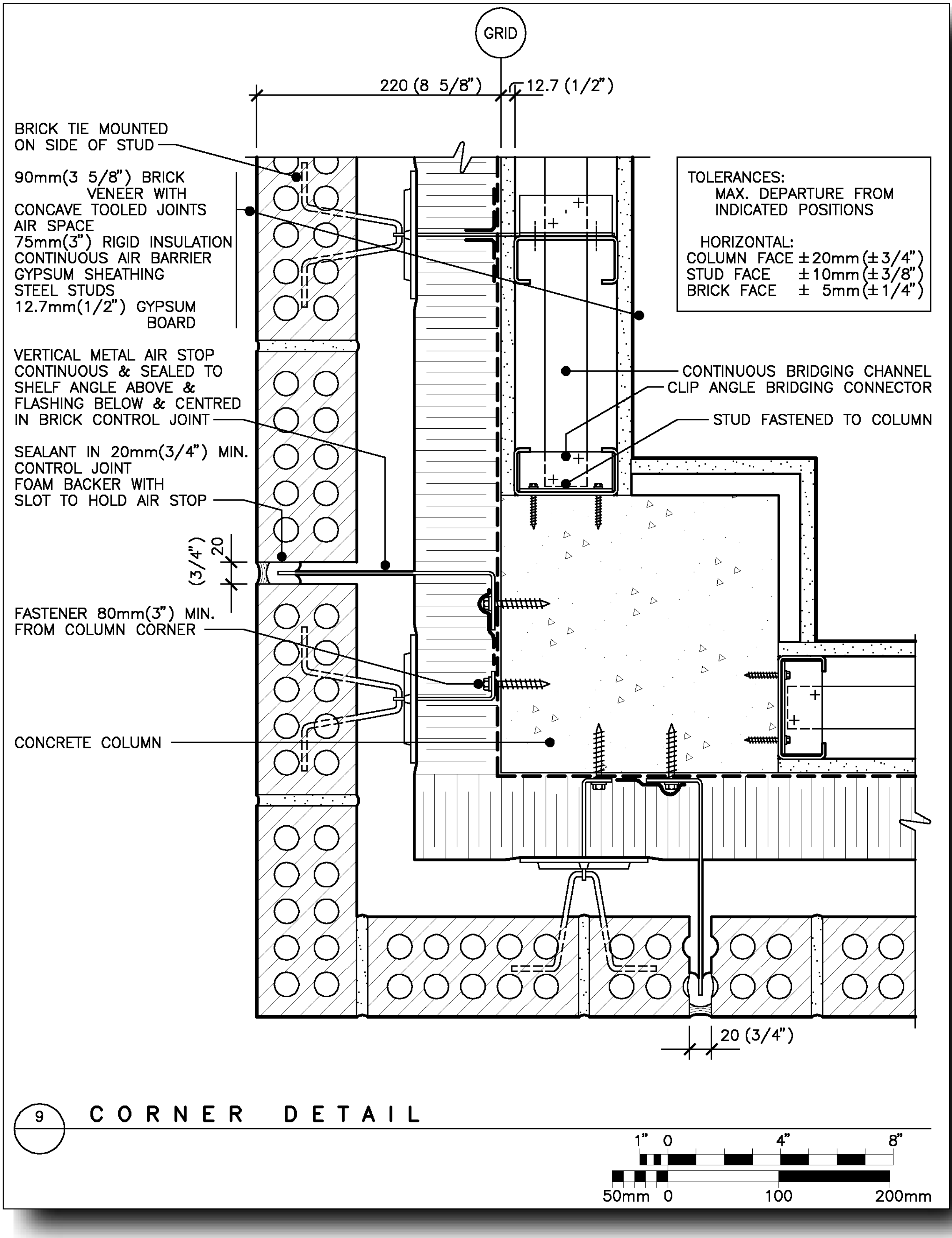
The studs, bracing, and inner top track of the wall framing are all fastened to the column. This provides redundancy, protects the interior finish from being crushed or cracked, and protects the air barrier from movement between adjoining substrata. The connection of the inner top track to the column will also prevent racking in the plane of the wall framing.

Alignment

The column will not always be in line with the sheathing. A 30 mm (1.2 in.) misalignment is possible within tolerance. In most cases there will be a step and joint in the insulation as a result, and the compartment dividers will have to be trimmed to suit the dimensions of each case.

Sealing Dividers

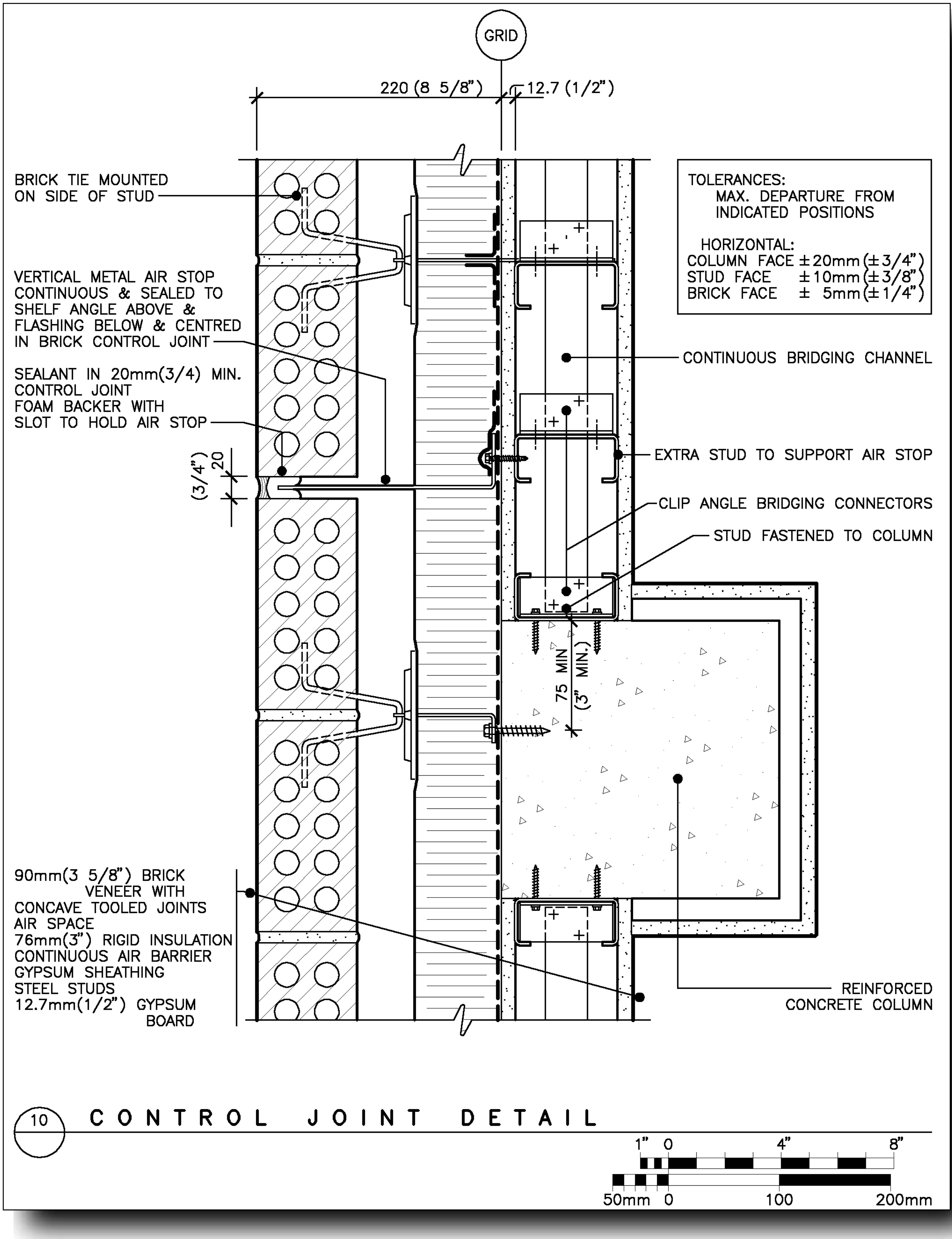
No *de facto* standard based on satisfactory experience has yet evolved for sealing compartment dividers. At the wall surface an added strip of peel-and-stick membrane does the job well. The same material can be used to seal the ends to the shelf angles; remember to leave room for movement. The slotted foam joint backer shown would be custom made from billets of polyethylene foam. Alternatives that have been suggested are to provide two caulked joints, so the edge of the divider is visible at the wall surface, or to fasten the divider mechanically to the edge of the brickwork on one side of the joint, with sealant or a gasket to seal the divider to the brick. Each suggestion has potential difficulties, such as misalignment with the wall face, rusty edges, or unwanted restraint of the brickwork. However the divider is sealed, it needs to be reasonably airtight although not perhaps as air tight as the air barrier. Just projecting it into the joint with a gap between the divider and the back of the joint sealant would allow air to do an end run between compartments and defeat the purpose of the divider.



Detail 9: *Corner*

DETAIL 10 - CONTROL JOINT

Here the compartment barrier fastens to the stud framing, rather than to the concrete frame. An additional stud is required at this location for attachment. To provide redundancy, and prevent differential lateral deflection, the stud framing should always be fastened to the structure at abutments like this column. If the barrier is mechanically attached to the brick, rather than as in this detail, the structural effect on the veneer should be considered.

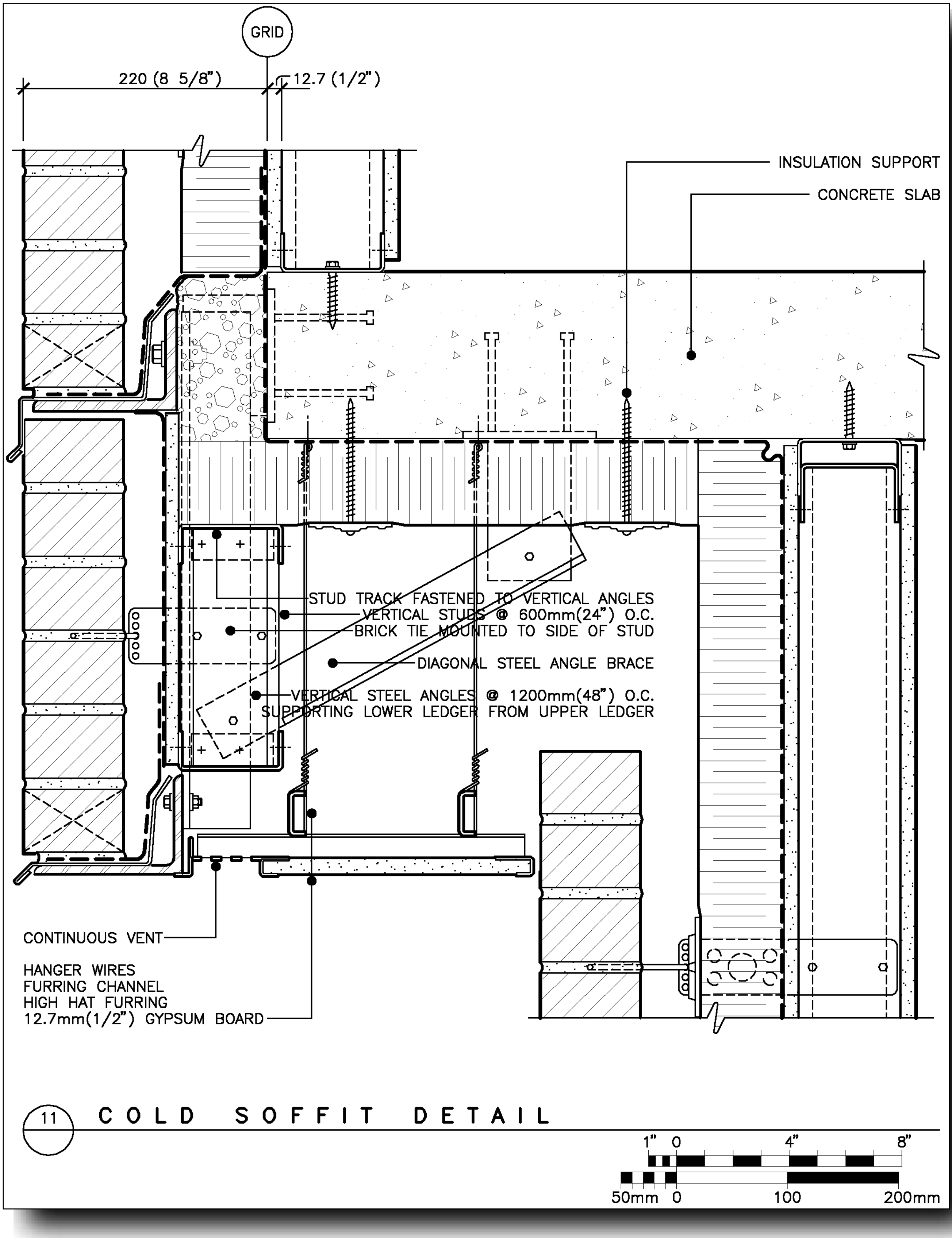


Detail 10: *Control Joint*

DETAIL 11 - COLD SOFFIT

Warm soffits are difficult to build so that they are airtight. They make expensive places to put water piping in danger of freezing. Except when there is no option, the insulation of a soffit should be attached directly to the underside of the floor structure.

The large volume of the soffit, added to the wall cavity volume below, would be likely to prevent pressure equalization of the cavity in the recessed wall. In this case, the dimensions of the recess provide shelter and eliminate the need for a *rain screen* in the recess. Otherwise, a horizontal compartment barrier is required between the wall cavity and the soffit cavity.



Detail 11: *Cold Soffit*

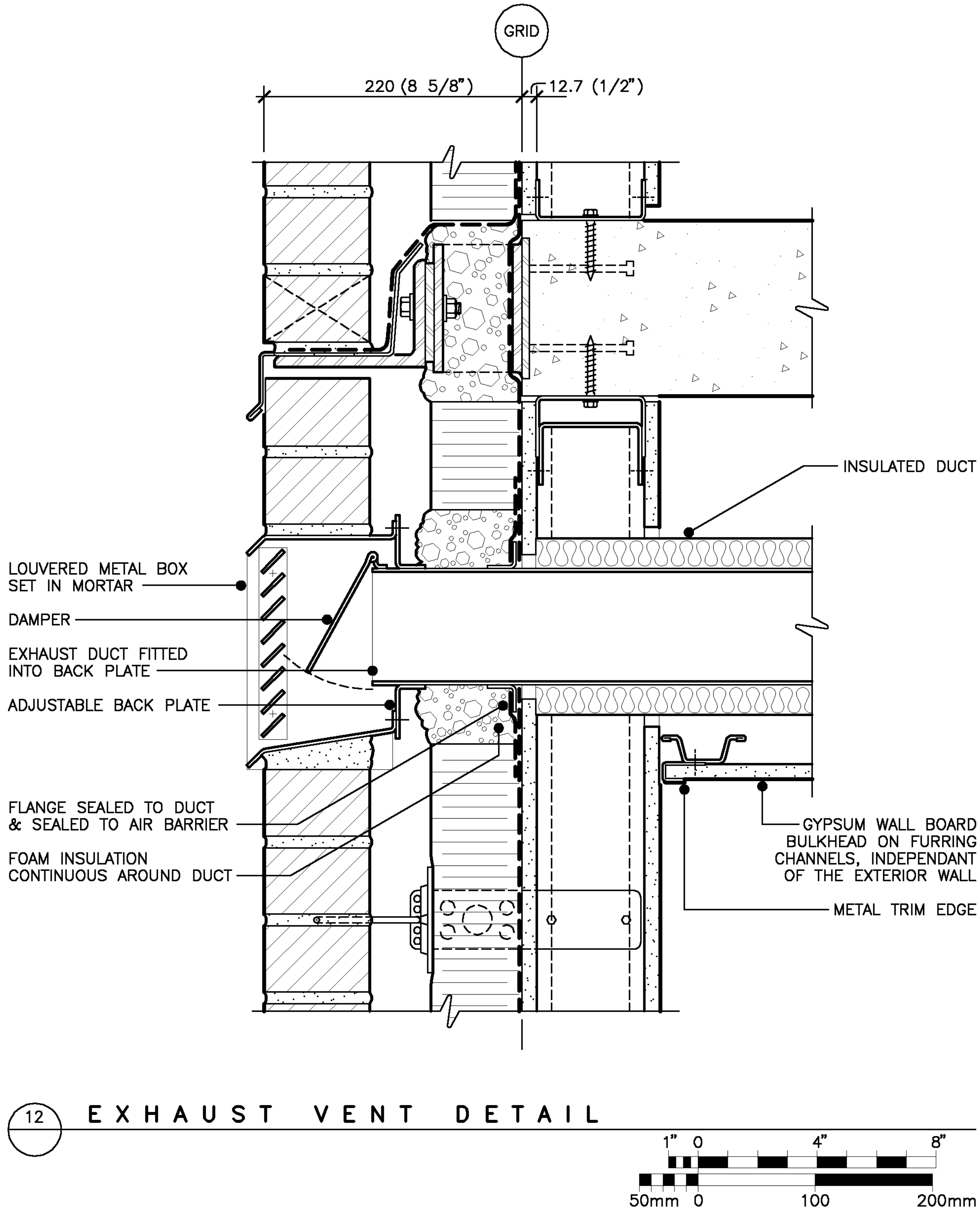
DETAIL 12 - EXHAUST VENT

This detail should be avoided in many cases, especially in colder climates. Unless the building is horizontally compartmented on the interior to prevent cumulative stack effect, air will exhaust on upper floors whether the fan is working or not. Centralized exhaust with heat recovery may be a more effective solution.

This detail illustrates two useful features. The box built into the veneer provides a shelter for the vent. If the duct extends to the face of the wall, with a conventional flanged hood and damper, then water running down the face of the wall commonly runs behind the flange and along the top of the duct. The box also provides for adjusting alignment of the duct with the brick coursing, and the adjustable backplate can serve as a round to rectangular adapter. The flange on the duct provides for continuity of the air barrier.

The damper location is not ideal. Some condensation will occur in the uninsulated portion of the duct as well as on the back of the damper, but a damper at the line of the insulation would not be accessible for service, and a damper inside the building would make it difficult to decide where to put a vapour barrier for the duct insulation, since the duct could be either cold or warm, depending on operation of the fan.

If the duct alignment interferes with a stud, provide a structurally framed opening.



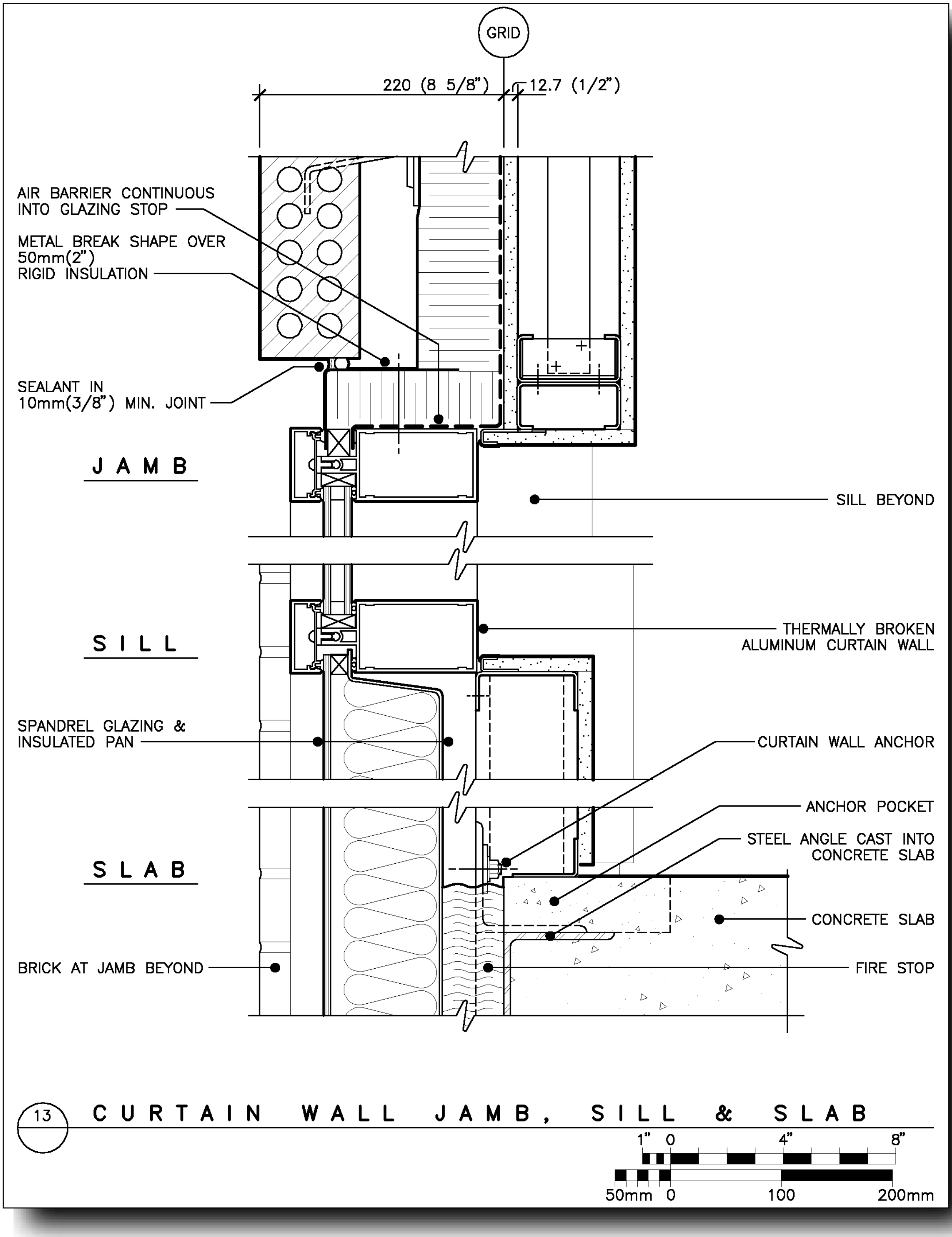
***Detail 12:** Exhaust Vent*

DETAIL 13 - CURTAIN WALL JAMB, SILL AND SLAB

The curtain wall continues past the edge of the slab, with an insulated backpan for the spandrel. Glass edge and spandrel pan cavities are another area where RAIN can help to evaluate pressure equalization. In many cases, for pressure equalization to occur, larger than usual vents and stiffer backpans are required.

Aluminum framing discontinuous at the floor slabs could be located further inward, possibly with the back of the throat in line with the air barrier. In any case, the mass of the frame needs to be kept warm, and it should be possible to remove the pressure plate and cap adjoining the brickwork without cutting sealant.

If construction sequence is a concern, a more complicated detail would allow the aluminum framing to be installed after the brickwork, whereas this detail requires it to be installed first: provide a sheet metal angle, like a compartment seal, 25 mm (1 in.) or so from the side of the curtainwall, and seal the air barrier to it. Insulate this angle, instead of the side of the aluminum framing. After installation of the brick, install a second metal angle, formed with an S-lock pocket filled with sealant and slid onto the edge of the first angle, and seal it to the back of the glazing rebate to complete the air barrier connection.



Detail 13: *Curtain Wall Jamb, Sill & Slab*

SPECIFICATIONS

Division 4 Masonry
Masonry veneer for use with steel studs is no different from masonry veneer for other back-up systems, with the possible exception of tie selection. If the design of the steel framing is to be done by the contractor, pick ties that are known to be stiff and to interact appropriately with the framing, since the designer needs to take the ties into account but has no influence on their selection. CSA S304.1-94 requires each tie to be designed to carry 40% of the tributary load on a vertical strip of masonry one stud spacing in width, and so that deflection under a 0.45 kN (100 lbf) load does not exceed 1.0 mm (0.04 in.), unless a detailed stiffness analysis is done of the composite structure comprising the framing, ties, and veneer. The ties least likely to cause problems in service attach directly to the web of the stud, rather than to the flange or through the sheathing. They also have substantial interior mass and surface, and are nearly equally stiff at all possible adjustments. Consideration should be given to strengthening the top row of ties, however, since actual loads, based on the McMaster tests and theoretical models, can be about 50% of the tributary load.[5] If the wall is designed in detail, and documented in the working drawings and specifications, then the designer of the stud framing should design the brickwork and ties as well.

Choice of brick and mortar for veneer are dealt with in the *CMHC Best Practice Guide for Brick Veneer, Concrete Masonry Backup*[6]. The NMS provides appropriate master specifications.[7]

Division 7 Thermal and Moisture Protection
CSC's *TEK•AID*[8] on air barriers provides background information and guide specifications for air barriers. The mock-up requirements, and performance requirements for the air barrier should be correlated with the air flows that the designer expects to be tolerable, and specified. Specific materials and methods of application can be specified in conjunction with performance requirements, provided that reports are available to show bidders that a prototype has been tested successfully.

Section 05410 Lateral Load-bearing Steel Stud Framing
A guide specification for this section is included, both in the Appendix and on disk.

The specification can be applied more generally than the details. It should be useful for any building where engineering of the steel studs is delegated to the contractor, with design and details to be delineated on shop drawings. In conjunction with the guide and the SPEC NOTES it should be self-explanatory.

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[5] Drysdale, *Defining Better Cladding Systems.*
[6] Hallsall and Otto + Bryden, *Best Practice Guide, Building Envelope Design, Masonry Veneer/Concrete Block Construction.*
[7] *National Master Specification*, Division 4.
[8] CSC *TEK•AID Reference 07195 - Air barriers.*

Section 09250 Gypsum Board

If either interior gypsum board, or exterior gypsum sheathing supports the air barrier, it is likely that specific requirements for fastening and direction of span of the board will need to be added to most master specifications. Otherwise, specifications like the NMS should suffice.

Coordination of Specification Sections

The sections specifying cash allowances, testing, concrete, masonry, metal fabrications, air barrier, insulation, metal flashing, and gypsum board in a project specification are all affected by the design of the steel stud exterior walls.

- Describe testing and inspection required for steel studs, and provide for the cost.
- Describe testing procedures for detecting air leaks, and provide for the cost.
- Coordinate tolerances specified for masonry, concrete, and steel to ensure that inaccuracies within the tolerances specified will never make the details impossible to build, even at the extremes.
- Specify adequate fastening of insulation to avoid wind gust displacement, corrosion, and damage to the air barrier.
- Ensure that the air barrier will accommodate the ties and supports used for cladding, that it will function as flashing where required, and accommodate movement at joints. If movement is large, butyl rubber sheets might be needed to supplement a modified bituminous air barrier, for instance.
- Specify fasteners, fastener spacing, and board orientation required for interior drywall and gypsum sheathing.

FILES ON CD-ROM

Drawing Files
The details included in the guide are also included in this CD as AutoCAD release 10 DWG files, and as DXF files. All are provided in SI (Metric) versions at 1:5 scale with layers offering a choice of English or French notes and titles. There are also both DXF and DWG versions in inches and feet, at 3"=1'0" scale. Refer to README.TXT on CD for further information.

This CD contains the following directories and their sub-directories:

- METRIC (Drawing files scaled at 1:5 in metric units)
- IMPERIAL (Drawing files scaled at 3"=1'0" in imperial units)
- PDF (Complete set of the documentation in PDF format)
- SPEC (Complete specification in various file formats)

In addition to the above directories, the CD contains the following files:

AR16E301.EXE : Installs Acrobat Reader for Windows 3.1x
AR32E301.EXE : Installs Acrobat Reader for Windows 95
LIC_RDR.PDF : A licence agreement for the Acrobat Reader
README.TXT : The README file
LISEZMOI.TXT : Same as the README file but in French

To install the Acrobat Reader on Windows 3.1x:

1. From Program Manager, Select **File** then **Run**
2. Browse and Select AR16E301.EXE
3. Click on OK

Follow the instructions on the screen.

To install the Acrobat Reader on Windows 95:

1. From **START** menu, Select **Run**
2. Browse and Select AR32E301.EXE
3. Click on OK

Follow the instructions on the screen.

Specification Files
The guide specification, section 05410, is included in this CD in five different formats: WP5, SAM, TXT, RTF and MSWord. It is provided in both English and French, in SI (Metric) units and refers to applicable Canadian standards. Refer to README.TXT on CD for further information.

REFERENCES

Blomberg, Thomas. *HEAT2, A Heat Transfer PC-Program*. Lund, Sweden: The Department of Building Physics, Lund University, April 1991.

–—. *HEAT2 (v2.53)*. Lund: The Department of Building Physics, Lund University, August 1995.

–—. *HEAT3, A PC-Program for Heat Transfer in Three Dimensions*. Lund: Group for Computational Building Physics, Lund University, November 1995.

Brown, W.C. and Poirier, G.F. *Testing of Air Barrier Systems for Wood Frame Walls* (Report No. CR5505.1). Ottawa: NRC Institute for Research in Construction (IRC), June 3, 1988.

Bumbaru, D., Jutras, R., and Patenaude, A. *Air Permeance of Building Materials, Summary Report* (AIR-INS Inc). Ottawa: CMHC, June 17, 1988.

The Canadian Sheet Steel Building Institute. *Lightweight Steel Framing Manual* (CSSBI 50M-91). Cambridge: CSSBI, August 1988.

–—. *Lightweight Steel Framing Design Manual* (CSSBI 51M-91). Cambridge: CSSBI, July 1991.

–—. *Guide Specification for Wind Bearing Steel Studs* (CSSBI S5-90). Cambridge: CSSBI, December 1990.

Canadian Standards Association. *Masonry Design for Buildings (Limit States Design)* (CAN/CSA-S304-94). Rexdale, CSA, 1994.

–—. *Connectors for Masonry* (CSA A370-94). Rexdale, CSA, 1994.

–—. *Masonry Construction for Buildings* (CSA A371-94). Rexdale, CSA, 1994.

Chien, N., Feng, Y., Wang, H, and Siao, T. *Wind-Tunnel Studies of Pressure Distribution on Elementary Building Forms*. Iowa City: The Iowa Institute of Hydraulic Research, State University of Iowa, 1951.

Cowie, J.W. *The Failure of Steel Stud*s (ENCON Loss Control Bulletin #89). Ottawa: ENCON Insurance Managers, September 1990.

Construction Specifications Canada. *TEK•AID Reference 07195 - Air Barriers*. Toronto: CSC, March 1990.

Drysdale, Robert G. *Defining Better Cladding Systems - Theoretical Work*. Ottawa: CMHC, July 1991.

–—, and Breton, N. *Strength and Stiffness Characteristics of Steel Stud Backup Walls Designed to Support Brick Veneer* (McMaster University test program on BV/SS wall systems, Part 1). Ottawa: CMHC, March 1989.

–—, Kluge, A., and Roscoe, Peter. *A Report on Water Leakage Characteristics of Bricks and Brick Assemblages* (McMaster University test program on BV/SS wall systems, Part 2). Ottawa: CMHC, May 1990.

–—, and Kluge, A. *Performance of Brick Veneer/Steel Stud Wall Systems Subject to Temperature, Air Pressure and Vapour Pressure Differentials* (McMaster University test program on BV/SS wall systems, Part 3). Ottawa: CMHC, May 1990.

–—, and Wilson, Michael J. *Behaviour of Brick Veneer/Steel Stud Tie Systems* (McMaster University test program on BV/SS wall systems, Part 4). Ottawa: CMHC, March 1989.

—–, and Wilson, Michael J. *Tests of Full Scale Brick Veneer/Steel Stud Walls to Determine Strength and Rain Penetration Characteristics* (McMaster University test program on BV/SS wall systems, Part 5). Ottawa: CMHC, July 1990.

—–, and Chidiac, S.E. “Defining Better Cladding Systems - Theoretical Work”, *Seminar on Brick Veneer Wall Systems*. Ottawa: CMHC, 1989.

—–, and Suter, G.T. *Exterior Wall Construction in High-Rise Buildings, Brick Veneer on Concrete Masonry or Steel Stud Wall Systems* (ISBN 0-660-13759-3, DSS NH15-20/1991E). Ottawa: CMHC, 1991.

Ganguli, U., and Dalgliesh W.A. “Wind Pressures on Open Rain Screen Walls: Place Air Canada.” *ASCE Journal of Structural Engineering*, Vol. 114, No. 3, March, 1988. (Reprint available as IRC Paper No. 1525, NRCC 28859).

Garden, G.K., *Control of Air Leakage is Important* (CBD 72). Ottawa: NRC Division of Building Research (DBR), 1965.

Gulay, B.W., Stewart, C.D., Foley, G.J. *Field Investigation Survey of Airtightness, Air Movement and Indoor Air Quality in High Rise Buildings, Summary Report* (Wardrop Engineering). Ottawa: CMHC, July 1993.

Halsall, R., and Otto + Bryden Architects. *Best Practice Guide, Building Envelope Design, Masonry Veneer/Concrete Block Construction*. Ottawa: CMHC, (unpublished, work in progress).

Handegord, G.O., *The Need for Improved Air Tightness in Buildings* (Building Research Note 151). Ottawa: NRC DBR, 1979

Hansen, A.T., *Moisture Problems in Houses* (CBD 231). Ottawa: NRC DBR, 1984.

Hatzinikolas, M.A., Lee, R., and Warwaruk, J. *Factors Affecting the Performance of Metal Stud Walls used as a Backup System to Masonry Veneer*. Edmonton: Prairie Masonry Research Institute, December 1987.

—–, Elwi, A.E..; and Warwaruk, J. *Connecting Cavity Walls*. Edmonton: Prairie Masonry Research Institute, 1991.

Hutcheon N.B. *Humidity in Canadian Buildings* (CBD 1). Ottawa: NRC DBR, 1960, revised 1968.

—–. *Requirements for Exterior Walls* (CBD 48). Ottawa NRC DBR, 1963.

—–, and Handegord, G.O. *Building Science for a Cold Climate* (ISBN 0-471-79763-4). Toronto: John Wiley & Sons, 1983

Keller, H. *Brick Veneer/Steel Stud Wall Design and Construction Practices in Canada: Results of a 1986 Survey*. Ottawa: CMHC, 1986.

Keller, H. *Field Investigation of Brick Veneer/Steel Stud Wall Systems* (Suter Keller Inc). Ottawa: CMHC, 1989.

—–, Trestain T.W.J., and Maurenbrecher A.H.P.; “The Durability of Steel Components in Brick Veneer/Steel Stud Wall Systems.” *Proceedings of the Sixth Conference on Building Science and Technology*. Waterloo: University of Waterloo and CSCE, 1992.

Latta, J.K. *Inaccuracies in Construction* (CBD 171). Ottawa: NRC DBR, 1975.

—–. Vapour Barriers *What are They? How are they Effective?* (CBD 175). Ottawa NRC DBR, 1976.

——. *Walls Windows and Roofs for the Canadian Climate* (NRC DBR Special Technical Publication No. 1, NRCC 13487). Ottawa NRC DBR, 1973.

McDonald, D. *Structural Requirements for Air Barriers* (Morrison Hershfield Report No. 30133.OR1). Ottawa: CMHC, August 13, 1991.

Morrison Hershfield Limited. *A Study of the Rainscreen Concept applied to Cladding Systems on Wood Frame Walls*. Ottawa: CMHC, August 3, 1990.

Oak Ridge National Laboratory, DOE. *Heating 7.2* (PSR-199). Oak Ridge, TN: Radiation Shielding Information Center, Oak Ridge National Laboratory, February 1993.

Public Works Canada. *National Master Specification*. Toronto: Construction Specifications Canada, and Spencerville: Royal Architectural Institute of Canada, updated periodically.

Quirouette, R.L. *The Difference Between a Vapour Barrier and an Air Barrier* (Building Practice Note No. 54). Ottawa: NRC DBR, 1985.

——. *CMHC Research Project Testing of Air Barriers Construction Details* (Morrison Hershfield Report No. 30132.OR/2). Ottawa: CMHC, Aug. 26, 1991.

——. *CMHC Research Project Testing of Air Barriers Construction Details II* (Morrison Hershfield Report No. 32173.03/1). Ottawa: CMHC, Mar. 31, 1993.

——, Ganguli, U., Lux, M.E., Brown, W.C., and Perreault, J.C. “An Air Barrier for the Building Envelope” *Building Science Insight ’86* (NRC DBR Proceedings No. 13, NRCC 29943, ISSN 0835-653X). Ottawa: NRC DBR, January 1989.

Reginato, R., and Handegord, G. *A Procedure for Estimating the Moisture Performance of Building Envelopes*. Brampton: TROW, ca. 1990.

Robinson, G., and Baker M.C. *Wind-Driven Rain and Buildings* (Technical Paper No. 445, NRCC 14792). Ottawa: NRC DBR, 1975.

Rousseau, J., Keller H., Drysdale R., and Suter, G. *Seminar on Brick Veneer Wall Systems*. Ottawa: CMHC/CCRB/ABEC/MBEC/OBEC, June 1989.

——, Rousseau, M.Z., Quirouette, R.L., and Handegord, G.O. “Humidity, Condenstation, and Ventilation in Houses” Building Science Insight ’83 (NRC DBR Proceedings No. 7, NRCC 23293). Ottawa: NRC DBR, May 1984.

Shaw, C.Y., and Tamara, G.T. “Studies on Exterior Wall Air Tightness and Air Infiltration of Tall Buildings” *ASHRAE Transactions*, Vol. 82, Part I, 1976.

Trestain, T.W.J. *The Success of Steel Studs* (ENCON Loss Control Bulletin #90). Ottawa: ENCON Insurance Managers, June 1991.

TROW Inc. *Criteria for The Air Leakage Characteristics of Building Envelopes* (Project No. B-03499-A). Ottawa: CMHC, December 1989.

1996.03.28
Project No. [___]
(Project Name)

05410
Lateral Load-bearing Steel Stud Framing

SPEC NOTE: Lateral load-bearing steel stud framing is wall framing of cold formed steel studs designed to support lateral loads, such as wind, but not axial or dead loads other than self-weight. It is usually used for exterior walls, but sometimes for plenums or shafts. Lightweight cladding or finishes may be supported, but the weight of exterior cladding like masonry veneer is supported independently. This section is written on the assumption that structural design of the framing is part of the Work, to be done by an engineer directly or indirectly responsible to the contractor. It also assumes that division of work between subcontractors is the responsibility of the contractor alone, and done without reliance on the specifications.

1. General

1.1 RELATED SECTIONS

1.1.1 Section 01020 Allowances

SPEC NOTE: If an allowance is provided that covers the cost of independent inspection or testing, list the section in which the amount of the allowance is specified.

1.1.2 Section 04200 Unit Masonry

SPEC NOTE: List the section in which ties for masonry veneer attached to steel stud framing are specified.

1.1.3 Section 072[ ] [_________] Insulation

SPEC NOTE: List the section(s) where insulation in stud space and insulation in wall cavity are specified.

1.1.4 Section [______] [___________________________]

SPEC NOTE: List section(s) where other exterior cladding or finishes attached to the framing are specified.

1.1.5 Section [09250] Gypsum Board

SPEC NOTE: List the section(s) where gypsum board finish attached to framing and gypsum sheathing are specified. Check to see if screw spacing, board thickness, and orientation required by wind loads have been covered there.

1.2 REFERENCES

1.2.1 ASTM A591/591M-89(1994), “Steel Sheet, Electrolytic Zinc-Coated, for Light Coating Mass Applications.”

1.2.2 ASTM A780-93a, “Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.”

1.2.3 ASTM A792M-85a, “Steel Sheet, Aluminum-Zinc Alloy Coated by the Hot-Dip Process, General Requirements (Metric).”

1.2.4 [CAN/CGSB-1.181-92, “Ready-Mixed Organic Zinc-Rich Coating.”]

1.2.5 CAN/CGSB-7.1-M86, “Cold Formed Steel Framing Components.”

1.2.6 [CSA W59-M1989, “Welded Steel Construction (Metal Arc Welding).”]

1.2.7 [CSA W47.1-92, “Certification of Companies for Fusion Welding of Steel Structures.”]

1.2.8 CAN/CSA-S136-94, “Cold Formed Steel Structural Members.”

1.2.9 [CAN/ULC-S101-M89, “Standard Methods of Fire Endurance Tests of Building Construction and Materials.”]

1.2.10 [ANSI/AWS D1.3-89, “Structural Welding Code - Sheet Steel.”]

SPEC NOTE: List standards used as references elsewhere in this section by designation, date or edition, and title.

1.3 QUALITY ASSURANCE

1.3.1 Employ a professional engineer registered in the place of the work to design metal stud systems; to prepare, seal, and sign all shop drawings; and to perform field reviews.

1.3.2 [Do welding in accordance with [CSA S136 and CSA W59] [for 0.70 mm and thicker material] [and][/or] [ANSI/AWS D1.3]].

SPEC NOTE: Under S136, most welds involving materials less than 0.70 mm are considered to have negligible structural value. D1.3 covers welding of thinner material. Review the standards before deciding to use welded connections.

1.3.3 [Companies engaged in welding: certified by the Canadian Welding Bureau to CSA W47.1, with welding procedures approved and welders qualified for the base material types and thicknesses that are to be welded.]

SPEC NOTE: Welding of steel studs requires experience and proper equipment. Verify that both are available in the locality of the project. Welded areas exposed to moisture are susceptible to rusting, unless properly prepared and touched-up with zinc-rich coating. Preparation sufficient to permit good metal-to-metal contact between the particles of zinc in the paint and the steel is necessary for effective protection. Corrosion protection of welds and availability of qualified welders may be disadvantages, but welded connections have the advantage of being much stronger and less flexible than mechanical connections.

1.4 DESIGN CRITERIA

1.4.1 Calculate structural properties in accordance with CAN/CSA-S136, limit states design principles using factored loads and resistances.

1.4.2 Calculate loads and load factors in accordance with the [National Building Code] [________________________].

1.4.3 Determine resistances and resistance factors in accordance with the [National Building Code] [________________________] and CSA-S136.

1.4.4 Conform to the requirements of fire rated assemblies [indicated] [which have been tested in accordance with CAN/ULC-S101-M and provide a fire resistance rating of [____________]].

1.4.5 Select studs which will deflect under specified lateral loads not more than [L/240] [L/360] for wall studs supporting [metal cladding] [stucco] and [L/720] [_____] for wall studs supporting masonry veneer cladding. Limit free play and movement in connections perpendicular to the plane of the framing to [0.5] [1] [__] mm relative to the building structure.

SPEC NOTE: More needs to be considered than stiffness of the studs. The deflection experienced by the cladding depends not only on bending of the studs, but also on take-up of free play and lateral displacement in connections under load. Localized deformations can also contribute where the cladding is connected to the studs. CSA S304.1 requires that the combination of all these effects be less than L/600, if the stiffness (EI) of the backup wall is less than 2.5 times that of uncracked veneer. This requirement is deemed to be met if the deflection of the framing is not more than L/720, and if half of the free play in the ties plus the deflection resulting from a load of 0.45 kN does not exceed 1.0 mm. These deflections will not eliminate cracking, but rain screen design of the wall should limit resulting water penetration to acceptable levels. Design attention and money will be better expended on reinforcement around openings and detailing, rather than on selection of stiffer studs. Where comprehensive structural investigation of the interaction between wall framing, connections, ties, opening sizes and locations, and masonry veneer is done, other deflection limits may be appropriate. Other claddings, while able to accommodate more bending than masonry veneer, may be less able to accommodate displacement at connections, depending on details. Brick veneer tends to be supported at the bottom by the shelf angle, and to rotate without distress when the top connection is flexible. Regardless of cladding, L/360 is the least restrictive limit allowable if there is gypsum board cladding or interior finish.

1.4.6 Space wall studs at [300] [400] [_____] mm maximum intervals [in back to back pairs].

SPEC NOTE: If stud spacing required is less than 300 mm, placing studs back to back may be more efficient structurally and may permit elimination of bracing. Specify stud spacing required to support cladding and finishes.

1.4.7 Stud depth is shown on the drawings. Adjust stud material thickness, stud spacing, or both as required by design criteria. Use greater or lesser stud depths only if approved by the [Engineer] [Consultant].

1.4.8 Design metal stud systems and attachments to accommodate the full range of tolerances permitted in adjoining materials.

SPEC NOTE: Coordinate tolerances specified for adjoining materials with details on drawings to be sure the details are workable over the full range of possible positions of each element. Specify tighter tolerances if needed.

1.4.9 Design stud end connections to accommodate structural deflections, frame shortening, and vertical tolerances permitted in structure such that studs are not loaded axially. [Provide for [____] mm differential in floor to head height for all effects combined.]

SPEC NOTE: Consult the designer of the building structure to determine possible structural movement during and after construction, and add an additional amount for tolerance depending on tolerances allowed in the structure. If studs are to be pre-cut, consider how accurately this can be done. Less allowance may be required for tolerance than the sum of the allowable extremes, since the probability of 2 or more worst cases occurring at the same place is low.

1.4.10 Take into account local loadings due to anchorage of cladding and interior wall mounted fixtures where shown.

1.4.11 Design bridging to prevent member rotation and member translation perpendicular to the minor axis for lateral load bearing studs. Provide for secondary stress effects due to torsion between lines of bridging. [Sheathing may be used to help restrain member rotation and translation perpendicular to the minor axis for wind bearing studs] [Do not rely on cladding, sheathing, or insulation for lateral bracing]. Provide metal bridging at [1500 mm o.c.][1220 mm o.c. for brick veneer] maximum. Use closer spacing if required by structural design.

SPEC NOTE: Allow use of gypsum sheathing as bracing only in dry conditions. Standard fastening may not be adequate if gypsum sheathing is used as bracing; coordinate fastening requirements in Section [09250] to ensure that cyclic loading will not render the sheathing ineffective as bracing.

1.5 SUBMITTALS

1.5.1 Make submittals in accordance with [Section [01340] [01300]] [Division 1].

SPEC NOTE: Refer to Section 01340 for Federal Government projects. Otherwise, refer to Section 01300 or to Division 1, or omit this paragraph.

1.5.2 Submit shop drawings indicating design loads, member sizes and spacings, materials, thicknesses exclusive of coatings, section properties, coating specifications, connection and bridging details, types, sizes, and spacing of fasteners [or welds], and tolerances. Indicate locations, dimensions, openings, tolerances, and requirements for coordination of adjoining work.

1.5.3 [Show nominal weld leg sizes for materials less than 3 mm thick. For such welds the throats shall not be less than the thickness of the thinnest connected part.]

1.5.4 Show coordination with [masonry connectors] [exterior cladding], and other attachments including windows, door frames, louvres, woodwork, plumbing fixtures, and electrical fixtures and panels.

> SPEC NOTE: This is an onerous task. The size and complexity of the job should be considered, and this requirement simplified accordingly. The more times a particular detail will be repeated, the more important it is to work it out carefully in advance. But, for smaller projects, shop drawings should be considerably simplified.

1.5.5 Submit two (2) certified copies of mill reports covering chemical and mechanical properties, and coating designation of steel used in the work.

1.5.6 Submit product data for mechanical fasteners, indicating sizes, load capacities, and type of corrosion protection.

1.5.7 Submit samples of all framing components and fasteners if requested.

1.5.8 Do not construct work until review of submittals [other than field review reports] is completed.

1.5.9 Submit two (2) copies of field review reports.

2. Products

2.1 MATERIALS

2.1.1 Steel sheet: to CAN/CSA-S136, with [electrolytic Zinc] [hot-dip Zinc (galvanized)] [Aluminum-Zinc] metallic coating.

> SPEC NOTE: For federal projects, the NMS contains additional requirements which are otherwise adequately covered by S136.

2.1.2 Electrolytic Zinc coating: to ASTM A591/591M, Class [__] [C]

> SPEC NOTE: Class A coating has no minimum thickness, Class B requires 24 g/m^2 of Zinc, Class C requires 48 g/m^2 of Zinc. None are suitable for exterior exposure. Class C is recommended for interior framing. Use hot-dip galvanized framing for exterior walls.

2.1.3 Hot-dip Zinc (galvanized) coating: to ASTM A653M, designation [________] [ZF75] [Z180] [Z275] [Z350].

> SPEC NOTE: Common coating weight designations under A653M are listed above in order of increasing thickness; check with manufacturers for available coatings. ZF75 is used for interior framing. Z180 is often used for exterior walls, but not recommended unless air barrier is outside, with no insulation in stud space. Z275 (the metric equivalent of G90) is the current most commonly available material. Additional possible designations are listed below. Coatings thicker than Z350 are difficult to fabricate into cold-formed framing. As zinc thickness and yield strength increase, larger minimum bend radii are required. Coatings thicker than Z275 are not available in less than 20-tonne coils.

Designation	Description
ZF001	Zn-Fe alloy, no minimum thickness
ZF75	Zn-Fe alloy, 75 g/m² of Zinc
Z001	Zinc, no minimum thickness
Z120	Zinc, 120 g/m²
Z180	Zinc, 180 g/m²
> Z275	Zinc, 275 g/m² <
Z350	Zinc, 350 g/m²
Z450	Zinc, 450 g/m²
Z600	Zinc, 600 g/m²
Z700	Zinc, 700 g/m²
Z900	Zinc, 900 g/m²
Z1100	Zinc, 1100 g/m²

2.1.4 Aluminum-Zinc coated steel sheet: to ASTM A792M, with [AZ150] [AZ165] [AZ180] designation Aluminum-Zinc alloy coating.

SPEC NOTE: Fabricators prefer not to use Aluminum-Zinc coated material because the coating tends to peel off and stick to the rolls during forming. Consult with supplier before using.

2.1.5 [Welding materials: to CSA W59.]

2.1.6 [Welding electrodes: 480 MPa minimum tensile strength series (e.g. E480XX, E480S-X).]

2.1.7 [Primer: zinc-rich organic, to CAN/CGSB-1.181.]

SPEC NOTE: To be fully effective this primer must be applied to surfaces prepared to SSPC-10, or preferably SSPC-5. Both are difficult for light steel field welds.

2.2 FRAMING

2.2.1 Member configurations and cutouts: to CAN/CGSB-7.1.

2.2.2 Steel studs: roll-formed of [electrolytic Zinc coated] [galvanized] [Aluminum-Zinc coated] steel sheet of thickness, material, and profile dictated by design, identified as to thickness by indelible markings or colour coded by thickness as follows:

Colour Code	Nominal Base Metal Thickness, mm
White	0.91
Yellow	1.22
Green	1.52
Orange	1.91

SPEC NOTE: A minimum thickness of 1.22 mm should be required to prevent local deformation during handling and erection, and where masonry anchors are attached.

2.2.3 Tracks: cold-formed of same kind of steel sheet as studs, of same or greater thickness, identified or colour coded in the same manner.

2.2.4 Bridging channels: [38.1 x 12.7 x 1.22] [38.1 x 12.7 x 1.52] [38.1 x 19 x 1.52] mm min. cold-formed of galvanized steel sheet.

2.2.5 Bridging clips: angles of 1.52 mm min. galvanized steel sheet, with 38 mm legs and length less than stud depth by up to 13 mm, [prepunched for screw attachment to studs and bridging].

2.2.6 Cutouts: provide cutouts to fit bridging at intervals of [600] [610] [1200] [1220] [_______] mm o.c.; centre cutouts on web of studs; limit unreinforced cutouts to the following dimensions (in mm):

Member Depth	Max. Across Member Depth	Max. Along Member Length	Min. Centre to Centre Spacing	Min. from End*
92	40	105	600	300
102	40	105	600	300
152	65	115	600	300
203	65	115	600	400

* to cutout centreline

2.3 FASTENERS

2.3.1 Concrete anchors: threaded fasteners designed to screw into in pre-drilled holes in concrete, expansion anchors, or drilled adhesive-set stud anchors; with minimum shank diameter of 5 mm, [of steel with 0.008 mm zinc or cadmium coating], [or] [of 400 series stainless steel coated with zinc and a dichromate conversion coating], [or] [of hot dip galvanized steel].

SPEC NOTE: Powder-actuated fasteners should not be used near the edge of a concrete member, and are structurally unreliable. Expansion stud anchors require minimum edge distances. Determine safe edge distance from the worst case combination of permitted tolerances. Expansion shields are not practical, because the hole in the concrete has to be larger than the hole in the track.

2.3.2 Bolts and nuts: to ASTM A307, with large flat washers, hot dip galvanized steel.

2.3.3 Screws: hex, pan, or wafer head, self-drilling, self-tapping sheet metal screws, zinc or cadmium plated with 0.008 mm minimum coating. Select fasteners known not to strip with the combination of material thicknesses being fastened and tools to be used.

SPEC NOTE: For service conditions of extended or frequently repeated exposure to moisture, more corrosion protection may be required. Consider use of 400 series stainless steel fasteners coated with zinc or cadmium and a dichromate conversion coating. Note also that it is sometimes difficult to use self-drilling or self-tapping fasteners to fasten through a heavy material into a lighter one.

3. Execution

3.1 WORKMANSHIP

3.1.1 [Fabricate and erect metal stud systems in accordance with reviewed shop drawings.] Where conditions other than minor dimensional changes are encountered which are not covered by the shop drawings, obtain direction from the engineer responsible for steel stud design.

SPEC NOTE: For non-federal specifications the first sentence can be omitted if it serves only to repeat requirements contained in the front end.

3.1.2 Cut members using saw or shears.

3.2 Erection

3.2.1 Construct framing piece by piece (stick-built), or by fabricating into panels either on or off site.

3.2.2 Erect framing true and plumb within specified tolerances. Take actual built dimensions of previously constructed work into account and accommodate them by adjusting position of framing. Make all field measurements necessary to ensure fit of all members.

3.2.3 Provide temporary bracing, if required for framing to sustain loads applied during erection and subsequent construction.

3.2.4 Anchor tracks securely to structure at [______] [800 mm] o.c. maximum. Place one additional anchor within [150][100] mm of each end of each piece of track, and additionally as required by structural design.

SPEC NOTE: In some cases 800 mm is too far apart. Determine anchor size and spacing from the load carried by each anchor in relation to anchor capacity and the maximum acceptable deflection of track between anchors.

3.2.5 Erect studs plumb and in alignment, and attach both flanges to legs of top and bottom tracks with one screw, No. 8 minimum diameter, at each connection (4 per stud). Do not splice studs.

3.2.6 Reinforce cutouts which occur within 300 mm of the end of a stud. [Align stud cutouts horizontally.] Do not allow additional cutouts to be made in the field, except as approved by the engineer responsible for preparation of shop drawings.

SPEC NOTE: Stud cutouts near end connections can substantially reduce the load carrying capacity of the whole stud. If studs are only available with cutouts near the ends, reinforcements should be designed and appear on the shop drawings. Cutouts need to be aligned both for through-the-cutout bridging and for service installations.

3.2.7 [Use nested inner and outer track for attachment to overhead structures.] [Use flexible stud clips to attach studs to overhead structures.] [Use sliding stud clips to attach studs to overhead structures.] Leave a minimum gap of [12 mm] [______] to accommodate structural movement. Design end connections for maximum take-up of play plus lateral deflection under full design load of [_____][1.0] mm at bottom connection and [______] mm at top connection.

3.2.8 [Install additional studs at not more than 50 mm from abutting walls, openings, terminations against other materials, and on each side at corners.]

SPEC NOTE: This requirement is common in current specifications and appropriate for interior walls where no engineering is done. It is not necessary if these conditions are considered by the engineer responsible for the design.

3.2.9 Frame all openings in stud walls, except openings less than [100 mm] in any dimension, and provide framing at points of attachment of wall mounted fixtures to adequately carry loads by using additional framing members and bracing as required structurally.

SPEC NOTE: Review sizes of openings to ensure that loads on windows, doors, and other closures are adequately supported. The shop drawings should show additional support for wider openings (usually 3 stud or more spacings). For large openings additional steel stud framing may not be practical. In such cases detail separate support systems (hot rolled steel framing, for instance) in the contract documents.

3.2.10 Brace steel studs with [horizontal bridging channels through stud cutouts] [flat strap bridging] at maximum vertical centres of [1500 mm] [1220 mm for brick veneer]. [Fasten horizontal bridging channels to each stud with bridging clips using four (4) No. 8 min. diameter screws [or by welding].

SPEC NOTE: Include an isometric detail of this connection in the contract documents. Both the strength and stiffness of steel stud framing depend on this connection.

3.2.11 Install bridging in longest practical lengths. Where splices are required, make them more than one stud space long, with each end fastened at a stud, [or reinforce splices with inverted channel bridging pieces 300 mm long, centred on the joint, and fastened at ends (4 screws or welds, 1 at each end of reinforcement, 1 at end of each spliced piece)].

3.2.12 Coordinate erection of studs with installation of service lines.

3.2.13 Use screws long enough to penetrate beyond joined materials by more than three (3) exposed threads. Use wafer-head fasteners [or welds] where panel products will be installed against the attachment.

3.2.14 Use screws with drilling and holding capabilities recommended by the manufacturer for the materials being fastened. Select different screws if initial selection fails to drill effectively, or tends to strip out.

3.2.15 Repair damaged zinc coating [and all welds] using zinc-rich primer in accordance with ASTM A780.

3.3 ERECTION TOLERANCES

3.3.1 Plumb: 1/500 of member length maximum.

3.3.2 Straightness (camber and sweep): 1/1000 of member length, maximum. Replace members with local buckling or bends.

3.3.3 Spacing: not more than 3 mm from design spacing, non-cumulative.

3.3.4 Location: within 10 mm of indicated alignment, and within 5 mm where alignment of structure permits.

3.3.5 Gap between end of stud and web of track (when connected): 4 mm maximum.

3.3.6 Alignment of adjoining or abutting members in the same plane, where supporting continuous cladding or sheathing: 1 mm maximum.

SPEC NOTE: These tolerances have been in master specifications for several years. They may be unrealistically and needlessly restrictive.

3.4 FIELD QUALITY CONTROL

3.4.1 The engineer responsible for design of the metal stud system, and preparation of the shop drawings, shall review the work in progress at the site regularly during construction and submit field reports to the [Engineer] [Consultant] for each visit.

3.4.2 [These field reviews shall include review of mill test reports, welded connections, member sizes and material thickness, coating thickness, screwed connections, erection tolerances, and all field cutting, including cutting and patching for other trades.]

SPEC NOTE: Use this paragraph for projects where independent inspection is deemed unwarranted.

3.4.3 Additional inspection and testing of materials and workmanship shall be carried out by an independent inspection agency appointed by the [Consultant] [Engineer]. It will include:

1. checking that mill test reports are properly correlated to materials;
2. sampling fabrication and erection procedures for general conformity to shop drawing and contract requirements;
3. [checking that welding conforms to shop drawings, specification, and specified standards;]
4. checking fabricated shapes and profiles of members;
5. [checking samples of joint preparation and fit-up of welded connections;]
6. [visual inspection of all welded connections;]
7. sample checking of [screwed and bolted joints, and] anchorages to structure;
8. sample checking that tolerances are not exceeded during fit-up or erection;
9. general inspection of field cutting and fitting to accommodate other parts of the work; and

10. submission of reports to the [Consultant] [Engineer], the engineer responsible for preparation of the shop drawings, and the Contractor, covering the work inspected and details of any deficiencies discovered.

SPEC NOTE: Check for the following requirements usually covered in the general conditions or general requirements: Contractor must provide access and cooperate with inspection; inspection does not relieve him of responsibility, nor can he rely on timely discovery and reporting; defective materials and workmanship can be ordered removed, even if contractor has to destroy and rebuild other work as a result; and contractor pays for additional inspection or testing deemed necessary to reveal full extent of discovered defects.

3.4.4 The cost of field reviews is included in the contract price. The cost of inspection is included in [the cash allowance for testing] [____________________].

End of Section

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