Exterior Wall Assemblies in Extreme Climates

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ABSTRACT

Exterior wall assemblies in severe environments pose special problems and require unique solutions. The assemblies are affected by the speed of construction, the choice of structural systems, the use and occupancy and other factors such as tolerances and moisture movements. The choice of system and the arrangement of its components in many cases influence the durability and serviceability of the cladding. This paper provides an overview of factors which affect the performance of cladding systems in severe climatic conditions and provides some guidelines as to the importance of these factors to the structural engineer designing such assemblies.

INTRODUCTION

The main function of the exterior wall and its materials, components and assemblies, is to provide a level of environmental separation between environmentally dissimilar spaces; to provide acceptable resistance to environmental loads such as air leakage, vapour diffusion, the ingress of precipitation or moisture from the ground, and heat transfer. Concurrently, the wall must also perform as a safe and serviceable structure resisting or accommodating the impact of structural loads including wind and seismic loadings, accidental impact, thermal and moisture movements, and elastic and inelastic frame deflections and deformations.

For the purpose of this paper, extreme climates are defined as those climates where the ambient temperature is very high or very low for a prolonged period of time throughout the year, or where temperature variations between the seasons are high. The range in temperature for a geographic location is a function not only of latitude, but also of proximity to major bodies of water, and of prevailing winds. Most areas of Canada and the northern part of the United States are considered to have extreme climates. Extreme climates ranges impose unique problems where wall assemblies are required to provide a high level of environmental separation. In addition, the effects of extreme climates on wall components and assemblies may be exacerbated by high exposure to precipitation combined with driving rain, repeated freeze-thaw cycling, and corrosive environments resulting from industrial pollution. Corrosive environments are placing special demands on cladding systems. Careful consideration by the designer of the properties of the building materials and components is needed to ensure that wall components and assemblies meet their expected design service life under the service environment.

The choice of exterior wall system should be made only after careful consideration of many factors, including: budget; occupant use; construction schedule; macro- and micro-service environment; structural serviceability, fire, and health and safety considerations; predicted service life of the component and assemblies; the design service life of the building and its components and assemblies; and aesthetics. In general, construction costs are reduced for a system where an individual wall component can be relied upon to provide satisfactory resistance to multiple environmental loadings and structural loads, rather than provide resistance to a single environmental or structural load, and where the designer considers the ease of constructabililty of the wall. Repair and maintenance costs can be reduced through the selection of material and component types having a long service life, by effort to control the micro-environment to which the material or component will be subjected, and by appropriate location of components for ease of access for repair. Operation costs are reduced where the wall provides good resistance to heat transfer, air leakage, vapour diffusion, and moisture ingress.

In this paper, the factors which affect the performance of exterior walls with respect to durability, serviceability and buildability are examined, and recommendations are made as to the desirable features of these walls from the perspective of the structural engineer.

COMPONENTS OF THE WALL ASSEMBLY

To effectively resist or accommodate the imposed environmental and structural loads, a typical exterior wall, above grade, consists of the following components: an exposed, exterior weathering surface necessary to resist the effects of deterioration from precipitation and chemical/biological attack, and to protect the inner components from the affects of agents of deterioration; behind the weathering surface, and in direct contact with the air barrier system, sufficient thermal insulating materials to provide the appropriate level of conditioned interior space, to prevent or minimise condensation on and within components and assemblies located to the interior, and to minimise thermal movements of components within the wall assembly and of the structural frame; a continuous, air-tight, air barrier system resistant to the effects of wind loading (supported by the structural backing), to minimise movement of air through the building envelope which can affect HVAC and indoor air quality, and the amount of moisture deposition on wall components and assemblies; a structural backing to support all the components of the wall assembly; and a vapour barrier to resist the movement of vapour by diffusion through the wall assembly, positioned with respect to the insulation to minimise condensation within the wall assembly.

STRUCTURAL DESIGN REQUIREMENTS

The structural design of the wall assemblies requires the consideration of the many factors, which if not appropriately addressed, can directly result in serious and structural distress to the wall assembly, but most often, will weaken the effective resistance to environmental loads of components and assemblies within the wall, change the anticipated micro-environment of the component or assembly or of adjacent components and assemblies, reduce the service life of the component or assembly, and thereby cause premature deterioration of the wall. At the time of construction, the exterior wall system generally accounts for about 15 to 18% of the cost of the building. Improper design can result in premature deterioration with associated maintenance and repair costs many times the initial costs. Factors affecting the structural design of the wall assembly include:

i) frame shortening and deflections of the supporting elements
ii) lateral loads
iii) thermal movements
iv) tolerances
v) moisture migration

I. Frame Shortening and Deflection of Support Elements

The effects of frame shortening and the deflection of the supporting elements should be accommodated by the connections between the structural frame and the exterior wall assembly. With a concrete frame structure, for example, it is not unusual to expect the frame to be shortened under elastic, shrinkage, and creep effects by 3 to 5 mm per storey, and to expect edge beam and slab deflections (long-term + short-term) in the order of 12 to 16 mm over a span of 5 m.

Figure 1 shows an exterior wall assembly which incorporates a deflection accommodating connection to the supporting concrete slab. The deflection space between the underside of the brick shelf angle and the top of the brick panel wall beneath is provided with sufficient width to accommodate frame shortening, moisture and temperature movements in the brick panel wall, and the movement capabilities of the type of the physical properties of the materials employed in the structural frame and the wall assembly, imposed structural loadings, and the sequence of construction (which affects the magnitude of "residual" deformations and deflections). Connections must not only satisfy structural requirements, but effectively resist, or minimise the impact on other components which are intended to resist, environmental loads.

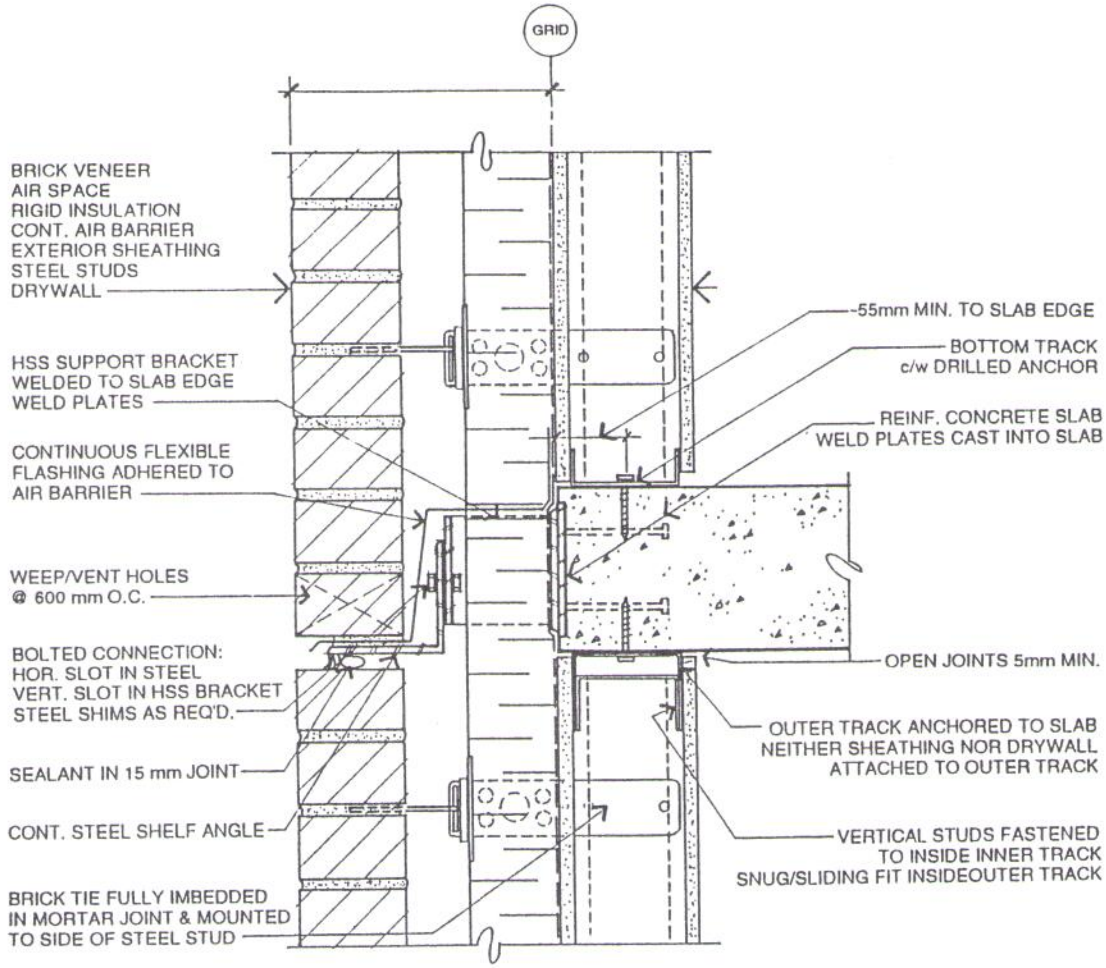

Figure 1. Brick Veneer/Steel Stud Detail At Slab Edge

In severe climates, and because of cost consideration, it is desirable to close in the structure as quickly as possible. The installation of the cladding often begins as soon as floors are structurally able to receive the structural loads from the exterior walls. The speed and schedule of construction thus affects the deformation which must be accommodated by the exterior and interiors walls. Incorporation of horizontal control joints at regular intervals along the height of the building are designed with structural input to safeguard against accidental loading due to deformation and deflection.

II. Lateral Loads

Laterals loads acting on the wall are transferred to the main structural elements by means of connectors, (anchors, ties, and fasteners) the design of which requires due consideration of the limitations of the assembly as it relates to the number of penetrations of the air barrier and the location of fasteners in relation to the structure. Factors such as edge distance and location influence the choice of connectors used to secure the assemblies.

Figure 1 shows a drilled in insert structurally connecting the outer track of a steel stud backup wall to a concrete slab.

III Thermal Movements

Thermal movements become more important in extreme climates because of the extreme temperature fluctuation and the resulting difference between the interior and the exterior environments. Variations as high as 45° to 50° C. can be expected. The effect of large temperature fluctuations is more detrimental when the components are acting in shear and are not separated by an air space and have no provisions in the design to accommodate these movements or to restrain them.

Figure 2 shows a wall assembly partially restrained to resist differential movements between the exterior wythe and the interior wythe. This assembly and the one shown in Figure 1 incorporate air space which allows for the weathering surface to provide resistance to moisture and allow for dry drainage.

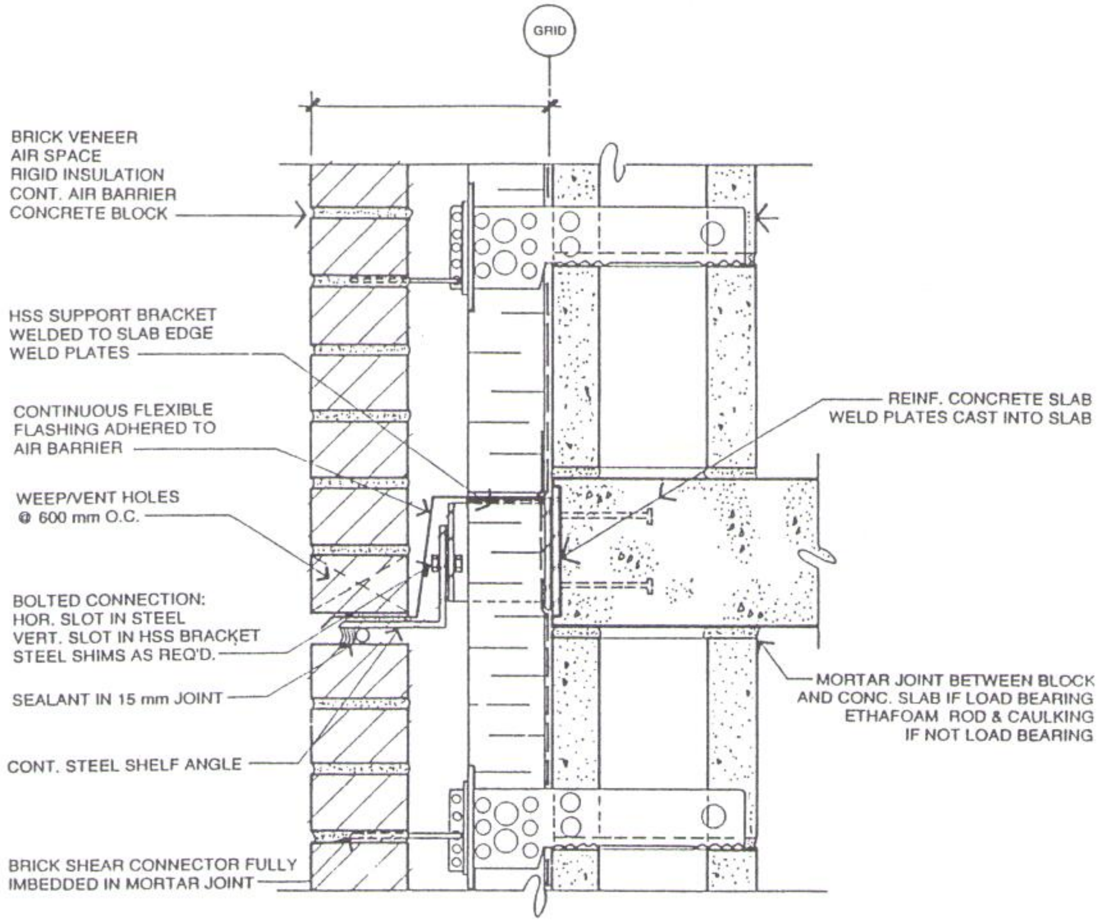

Figure 2. Brick Veneer/Concrete Block Detail At Slab Edge

IV. Tolerances

Tolerances affect the performance of exterior wall assemblies because in order to be accommodated, the construction of the wall as designed is made in many cases impossible.

Tolerance values, specified by code authorities, set the deviation of particular dimensions to be within certain allowable boundaries. Tolerance values are set for individual member dimensions and dimensions of constructed buildings for variations from plumb and level, and for variations from grid and elevation.

It is realistic to expect some deviation from dimensions set by designers on their drawings when a structure is erected. Designers must bear in mind that such deviations could affect the design strength of a system and components of the system. The designer must also be prepared for the situation when the tolerance values specified by the codes are exceeded when a particular member is manufactured and erected. Also, in a system such as an exterior wall assembly, is there correlation between the specified tolerance values for the different components of the assembly? These issues or concerns must be considered by the designers during design and construction of the exterior walls.

The effects of construction tolerances on the exterior wall assemblies are summarised as follows:

a) Increasing or decreasing the cavity with
b) Reducing the insulation thickness
c) Reducing thickness of the veneer and cutting of the shelf angle
d) Increasing the eccentricity on the shelf angle
e) Contouring the wall, resulting in exceeding the specified wall tolerance
f) Changing the behaviour of the tie system
g) Reducing the life expectancy of the wall assembly

V. Moisture Migration

In extreme climates, moisture migration through the exterior wall assemblies requires careful evaluation. In Canada it is safe to assume that in most buildings there is more moisture trying to get out from the interior than entering the closure from the outside. The performance of the assembly can be enhanced by providing for resistance to moisture from entering from the exterior. Incorporation of an air space between the weathering component and the insulation and the installation of flashing at floor levels (as shown in Figures 1 and 2) will ensure that the interior portion of the assembly is pre-treated from the rain.

Evaluation of the due point and ensuring that no condensation will occur in the backup assembly will safeguard against corrosion and deterioration of interior finishes. Since the due point is a function of the difference in temperature between the exterior and interior and the relative humidity, it is impossible to design an exterior wall assembly without having condensation occur at times within the wall. Provided that the material can discharge the moisture back into the space within a reasonable time (at least once a year) and it is not greatly affected by the pressure of such moisture, the wall is considered adequate. When condensation is expected to cause deterioration then appropriate materials must be chosen.

CONTINUITY REQUIREMENTS

The exterior wall assembly in severe climates must be integrated with the other components and functions of the structure. The connections details to the roof, the parapets and the foundation details require understanding of the concepts of building physics. Figure 3 shows a parapet detail which illustrates the continuity of the air barrier and its connection to the roof. For a high parapet (more than 600 mm) this detail may not be appropriate in buildings with high humidity levels, as moisture may condense at the top of the cold parapet and cause failure. Figure 4 shows an appropriate detail for high parapets.

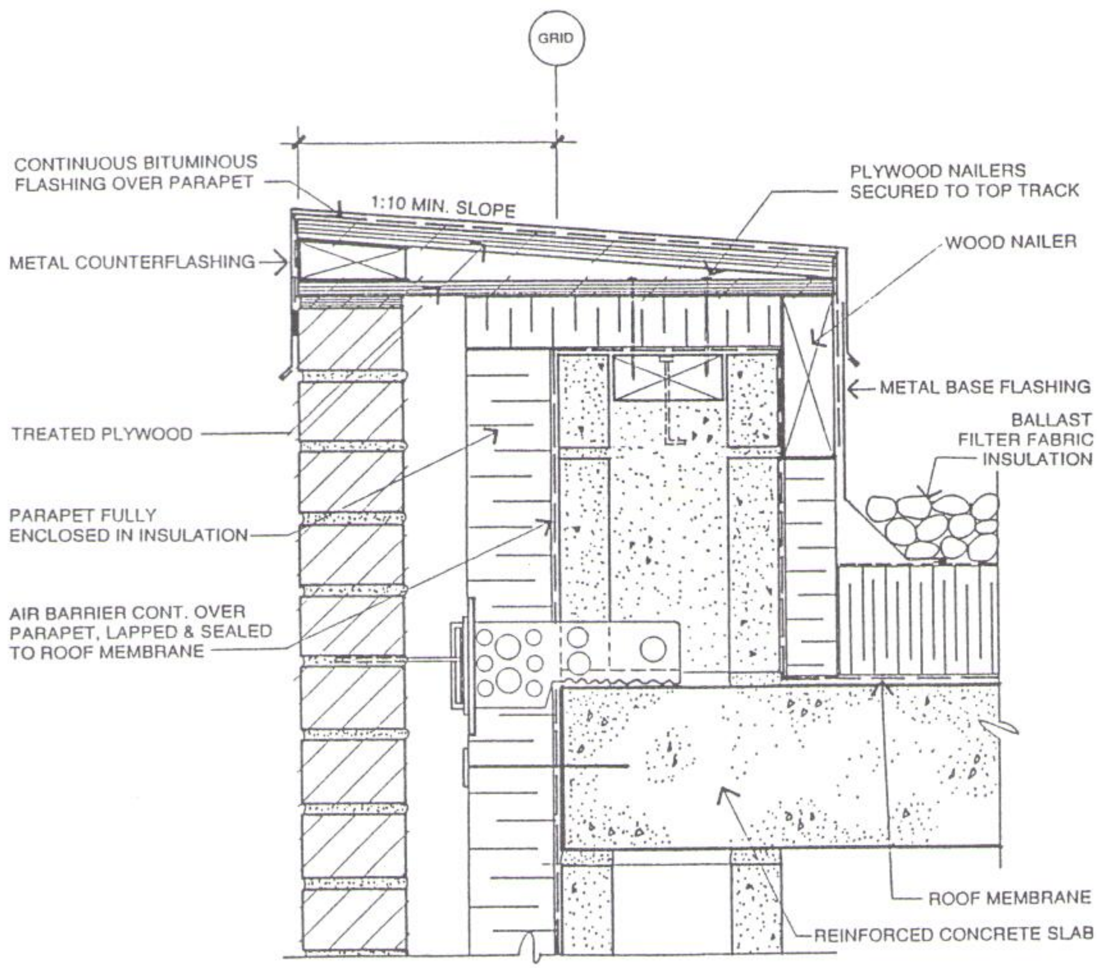

Figure 3. Brick Veneer/Concrete Block Detail At Low Parapet

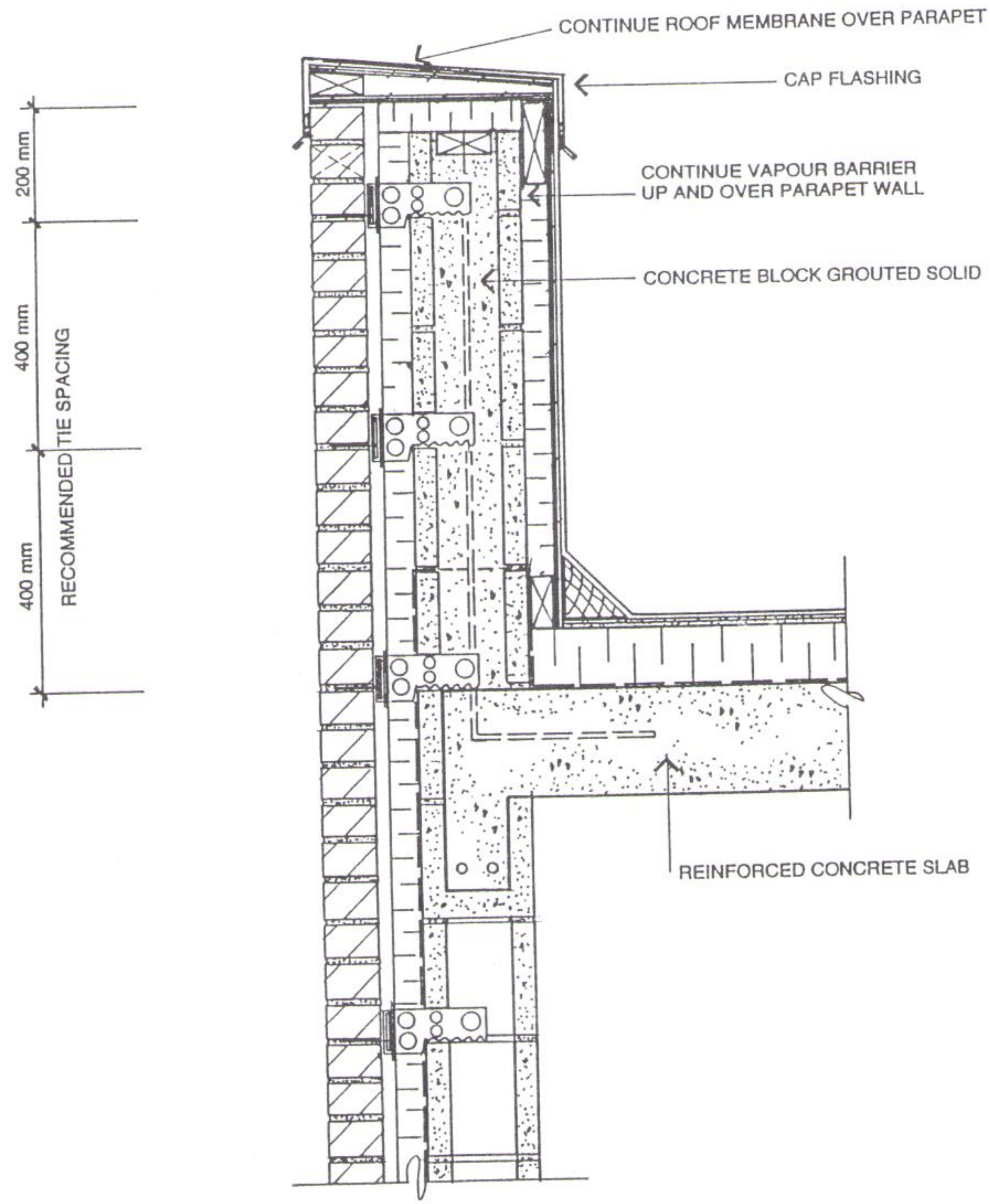

Figure 4. Brick Veneer/Concrete Block Detail At High Parapet

The support of the cladding at intermediate floor level requires details designed to facilitate the continuity of the insulation and the air vapour barrier (shown in Figure 1 and 2). The details at the termination of the exterior wall at the main floor are provided with similar provisions as those at floor levels to ensure continuity of the air barrier and the installation.

Figure 5 shows a detail at the foundation level which incorporates the requirement set above.

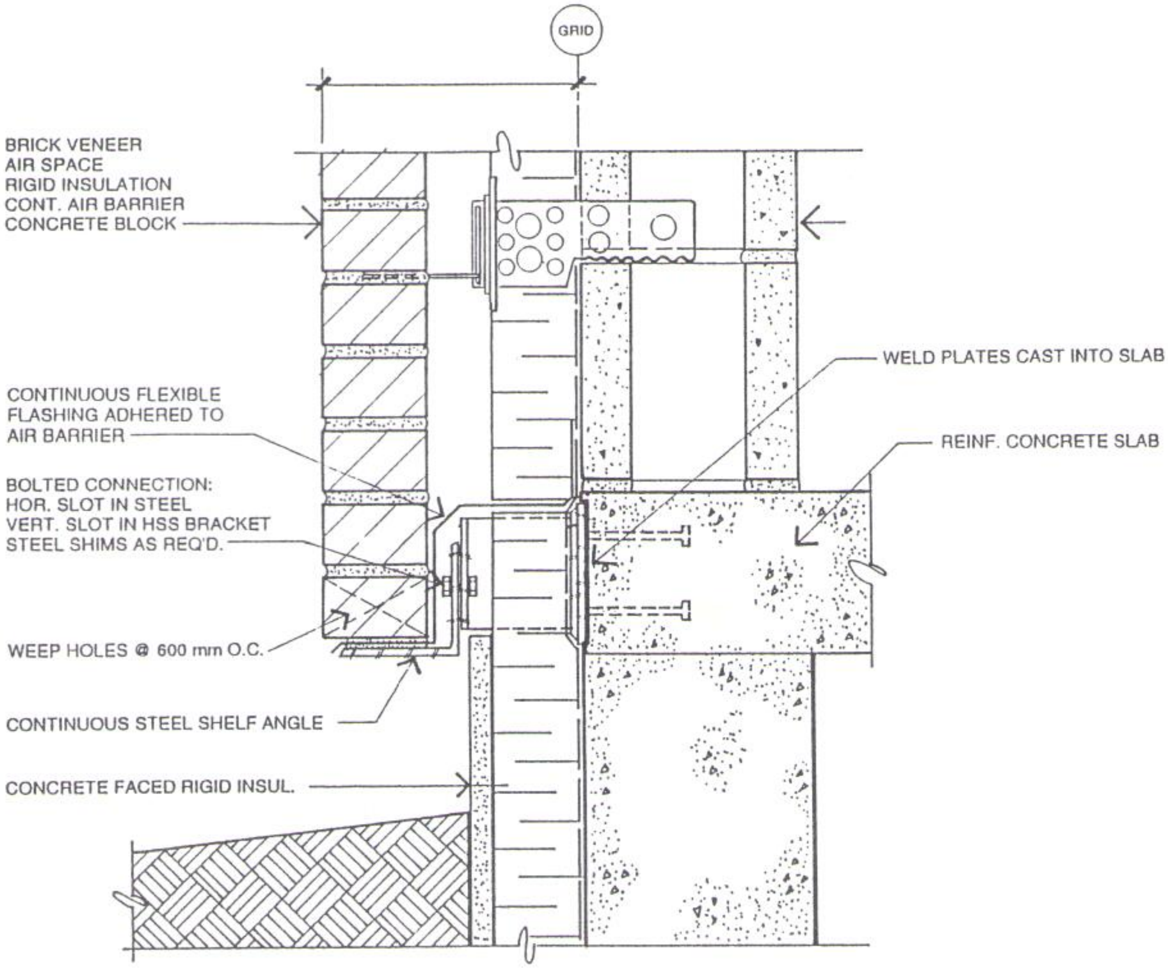

Figure 5. Brick Veneer/Concrete Block Detail At Foundation

Penetrations through the exterior walls is a major source of potential problems. Proper installation of vents requires careful examination of the sequence of construction and due consideration of air leakage through the assembly. Discharge of conditioned air into the cavity can be very detrimental to the system.

Figure 6 shows a typical venting detail of an exterior wall assembly.

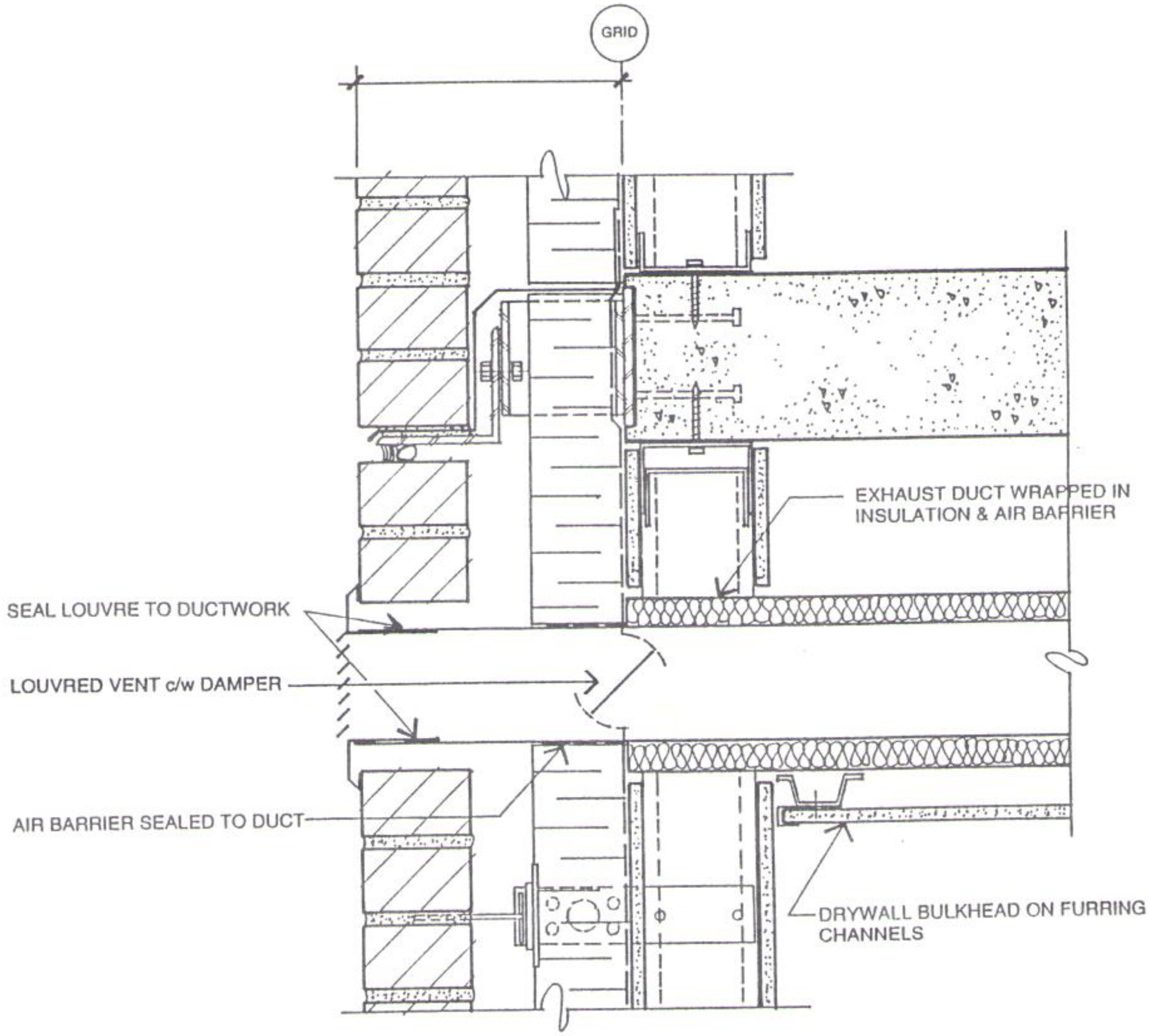

Figure 6. Brick Veneer/Steel Stud Exhaust Vent Detail

CONCLUSIONS

Exterior wall assemblies in severe climates require special design consideration. Failure to address issues such as frame shortening, deflection of supporting elements, effects of loads, thermal movements, tolerances and moisture migration can result in expensive repairs.

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