Troubleshooting in Design of Construction Details, Walls

Mark Lawton, P.Eng.
Morrison Hershfield Limited, Vancouver, BC

Most modern wall systems are constructed in a series of layers that perform one or more specific functions. Some of these layers are critical for the performance and durability of the wall systems and we have assigned functional names to them such as air barrier, vapour barrier/retarder or moisture barrier. For example, a common steel stud wall system could have the following layers.

Material layer	Roles	Functional Elements
Interior paint	• Aesthetic finish • Vapour diffusion control	Vapour control layer
Gypsum wall board	• Fire protection of structural elements • Fire separation between floors • Control of air leakage • Structural resistance to air pressures between frame members • Structural restraint against twisting of steel studs	Air control layer
Steel stud frame with Batt Insulation	• Resistance to lateral loads (air & seismic) • Provision for differential slab edge deflection • Control of heat flow • Sound damping	Thermal control layer
Gypsum sheathing	• Fire protection of structural elements • Structural restraint against twisting of steel studs	
Sheathing membrane	• Resistance to exterior water penetration	Moisture control layer
Exterior insulation	• Control of heat flow	Another thermal control layer
Air space with Cladding attachment	• Capillary break • Vent space for moisture removal • Drain space for water removal • Transfer of lateral loads to frame • Transfer of cladding gravity loads to structure	
Cladding	• Aesthetic finish • Primary resistance to exterior water penetration	Rain shedding surface

Each of the control layers has is own functional requirements with respect to continuity, location relative to other control layers and attachment to the structure. In other walls, the control layers can be provided by different material layers. In adjacent assemblies the material and the location of the control layers can be quite different. A high percentage of performance failures in wall assemblies can be attributed to insufficient continuity or incorrect connections of these control layers at the junction of different assemblies. This paper presentation will present a systematic approach to identifying potential performance problems at the design review stage.

Introduction

Like other cultures, building science communities seem to have their prophets and teachings that help bring enlightenment. In the Canadian building science community, one of the key scriptures is a paper by Dr. N.B. Hutcheon, presented to the Engineering Institute of Canada in 1953 entitled, “Fundamental Considerations in the Design of Exterior Walls for Buildings”. In this paper Hutcheon encouraged moving the basis of design of wall systems beyond historic practice to a more analytic approach based on applied science. He introduced the concept of an exterior wall as a separator of two different environments and listed nine major considerations or requirements for exterior walls:

- structural strength and rigidity
- control of heat flow
- control of air flow
- control of water vapour flow
- control of liquid water movement
- stability and durability of materials
- control of fire
- aesthetic considerations
- cost

One could argue that most of Canadian building science and building regulation with respect to the building enclosure is based on the concepts laid down by Hutcheon. Our intellectual constructs and our codes are based on the provision of control layers that address Hutcheon’s list with a few addition and tweaks added over the following decades. Terms such as “driving forces” and “barriers” to the flow of air, vapour, moisture, weather, heat, and fire have become part of the language we use to describe and understand how building enclosures function. These terms are direct extensions of concepts of controlling “flows” as espoused by Hutcheon.

The value of these mental constructs is not just intellectual. The process of reviewing and evaluating the design of a building enclosure (or building envelope if that is your culture’s language) is greatly simplified and enhanced by identifying what elements act as the control layers in each assembly, and confirming that each is appropriately placed in the assembly and appropriately interfaced to the same control layer (or barrier or retarder if that is your culture’s language) in adjacent assemblies. This design review method has evolved to a design review process that is so central to the author’s practice that is seems hard to understand that it is not well documented and universally applied. However, comments received following a presentation by the author at the inaugural BEST Conference in Minneapolis in 2008, suggest that a paper documenting the process would be useful.

The Enclosure Design Review Process

The purpose of the enclosure design review process is to identify concerns regarding performance, durability, code compliance and constructability concerns at the design stage and to help develop methods of resolving those concerns.

In our context the design review is typically an independent review of project design documents by someone other than the designer. The reviewer considers the interest of both the contractual client and other parties including future owners, regulatory bodies and insurers. The independence shapes the review because if a knowledgeable professional from outside the design team cannot extract design intent from the construction documents, the intent needs to be extracted from the design team and made evident in the documents.

The scope of the review can vary by contractual arrangements and understandings but generally considers:

- Environmental Separations
  - Roofs and decks over conditioned space
  - Opaque walls
  - Glazing
  - At grade waterproofing
  - Below grade walls
  - Slabs on grade
- Other Waterproofing
  - Balconies
  - Canopies
  - Suspended slabs on parkades

The review generally considers:

- Elements providing control of heat, air and moisture flows
- Allowance for relative movement of structure and enclosure element
- Durability
- Constructability

The design documents for a major project can be a weighty package with a huge volume of information. Only part of this information relates to the building enclosure but that part is a significant one and it is distributed widely in the plans and specifications. To carry out a comprehensive building enclosure review seems a daunting task. It requires a process – even for a seasoned expert. However with an appropriate process, it is amazing how quickly an understanding of a building can develop.

The process we have developed can be summarized as follows:

1. Understand the design intent(s) of the spaces in the building and each enclosure system used in the building
2. Understand the geometry of the building and use of each enclosure system. Identify areas of high concern.
3. Review all transition details using a rational approach thinking first in two dimensions and then in three dimensions.
4. Review the plans and elevations with the intent of identifying missing details
5. Transmit information to design team

Initial Drawing Review

The first step in any enclosure review is to develop an understanding of what enclosure systems are proposed and what "boundary conditions" they will be subjected to. This requires knowledge of the exterior climate including long term and peak condition for:

- Temperature
- Vapour pressure
- Peak wind pressure
- Wind pressure coincident with rain

One needs to determine indoor environmental expectations, whether these conditions are controlled or coincidental to activities in the space. For example a high indoor vapour could be due to intentional humidification or due to moisture generating activities of a family living in a residential unit. A building may have several zones with different environmental expectations. This may require internal environmental separations. Conditions one should consider include:

- Temperature
- Vapour pressure
- Air pressure created by mechanical systems
- Air pressure created by stack forces
- Acoustic separation from outdoors
- Any special requirements related to use of the space (i.e. stability of temperature and RH in museum display areas)

The next step is to review what enclosure assemblies are proposed and assess whether they are generally appropriate for the environments to which they will be exposed. Most architectural plan sets provide wall, roof and floor schedules that provide this information. For each enclosure assembly one should identify:

- Air control layer (plane of air tightness)
- Rain shedding approach
- Moisture control layer (last line of defense against moisture entry)
- Mechanism for removal of incidental moisture
- Location of vapour control layer (vapour barrier, intentional or otherwise) relative to the thermal control layer (insulation), and temperature drive

If it is not clear which element provides each of these functions, the construction documents must be corrected to eliminate any uncertainty.

Assemblies of questionable appropriateness for the application and possible alternatives need to be brought to the attention of the designers as soon a possible.

We suggest that the next step is to review the floor plans, elevations, and sections marking the environmental separations with a highlighter. As you do this and compare the outlines from floor to floor and through the section it is relatively easy to note:

- Where different enclosure assemblies are used and what they transition to

- Changes in floor plan creating horizontal enclosure elements
- Slopes on all horizontal surfaces
- Location of drains, scuppers, and weep holes and elements that may restrict drainage paths
- Doors with no overhead protection
- Problematic locations where specific details should to be provided
    - Balcony edges
    - Curbs into walls
    - Parapets
    - Through wall flashing and shelf-angles
    - Expansion and control joints
    - At grade to below grade transitions

At the end of this initial review one should have a good understanding of where are the environmental separations, what enclosure assemblies provide the separation, how these assemblies connect to each other and where are the "danger zones" that warrant particular attention during detailed review.

There may very well be locations where it is not clear where the designers intended the environmental separation to be located. For example:

- Which slab(s) are intended to be the separation between an unconditioned parkade and fully conditioned space. Are utility rooms on the cusp conditioned or not?
- Are exterior stairwells intended to be conditioned space or not?
- Are proposed high humidity zones (e.g. pool enclosures, data centers, historical archives) isolated enough that adjacent space will remain at "normal" vapour pressure?

If there are such uncertainties, the construction documents must be corrected to eliminate any uncertainty.

Review of Details – Order

To a large extent the architectural details document the junctions of the building assemblies in plan or section. Details can only be rationally reviewed in their specific context. We, therefore, recommend against paging though the detail pages or detail book on their own. We suggest a systematic approach of:

- Follow references from plan, to section, to detail, to further referenced detail, to the end of the chain of references.
- After reviewing the last referenced detail in the chain, "check off" its reference number and go back one step and follow the next reference. Repeat until all references are checked off.
- Follow this procedure until all references on the sections and then the plans are checked off.
- When all the details on a sheet are reviewed check off the title block
- Repeat above process for until all references checked off

Clearly, the initial stages of the above process are tedious and require a lot of flipping through the drawings but you end up knowing exactly where each detail is applied and as you move through the drawing set you find that references become repetitive and you have already reviewed referenced details then sheets. When you finish you will have found most occurrences where the drawings related to the enclosure were not properly coordinated, and orphaned details that are not referenced to.

Review of Details – Process

The recommended method of reviewing each detail is to trace the functional element with a highlighter and confirm that the technical requirements of each functional element are met.

Glazing systems warrant a special note. Glazing systems, and some other manufacturer supplied assemblies, are proprietary products that are selected by tender. The designer may not know what products will be used so that their design details may only be representative. The final review may have to wait until the shop drawing stage. However, the architectural drawings should provide a clear intent of how glazing systems are to be integrated into adjacent assemblies.

The first step is to identify the **air control layer** (plane of air tightness). Considerations for the line you trace:

- Must be continuous and sealed through each assembly and through the junctions between assemblies,
- Supported back to the structural components of the assembly in both inward and outward direction,
- Have provision for movement at the points where the structure provided for movement.
- How vapour tight the air control layer can be depends on their location relative to the thermal control layer and the climate. In cold climates, low permeability materials can be used inboard of the majority of insulation. Air barrier materials outboard of insulation need to be permeable. In hot humid climates low permeability materials outboard of insulation is advantageous.

Next trace out the **moisture control layer** (moisture barrier or drainage plane in some culture's languages). This surface divides the assembly into a zone where incidental water is accommodated and the zone where it is not.

- One must be able to confirm that gravity moves water arriving at the moisture barrier down and eventually back out to the outdoors.
- The moisture barrier does not necessarily need to be sealed; as a shedding surface it can rely on joints that are lapped so that gravity moves water down and out (if is not sealed there needs to be an air control layer in the assembly inboard of the moisture control layer).
- How "waterproof" the moisture control layer is expected to be depends on how much moisture is expected to arrive at its location and how easily moisture can drain and dry off its face.
- Similar to the air control layer, the permeability of material forming the moisture control layer needs to consider their location relative to the thermal control layer and the climate.

The **rain shedding surface** is usually the outer surface of the assembly. As one traces it consider:

- Lapping of elements
- Use of projections and drips directing water off the face of walls and to stop surface tension bringing water back to the wall on the underside of horizontal surfaces
- How does water runoff horizontal elements?

The **thermal control layer** (insulation, thermal barrier) in each assembly is usually, but not always obvious. There can be more than one thermal control layer. As one traces the thermal control layer(s) through the assemblies consider:

- Continuity of insulating material in assemblies and the size and frequency of thermal bridges through them
- Whether the thermal control layers in each assembly are kept in the same general plane. If there is a jog, it generally implies a thermal bridge.
- Whether the insulation is located so that low permeability and indoor surfaces are kept above dew point of indoor air
- Is it possible to keep the thermal control layer outside the structure?

Specific **vapour diffusion control layers** (vapour barrier/retarder) may or may not be required. In general the material(s) providing the majority of vapour diffusion resistance should be identified in each assembly. In doing this, consider:

- low permeability layers should be located on the high vapour pressure side of insulation,
- vapour barriers should be reasonably continuous but do not necessarily need to be sealed (Quiroette).

As one traces the control layers identified above, one may find that one material layer may be expected to perform two, three, or even four of the functions. One has to consider the requirements to perform each role.

Once the control layers are identified, traced though each assembly, and assessed in a two-dimensional drawing, whether that be in section or plan, it is then necessary to consider the third dimension. This generally requires reviewing the plan and section detail together – if one is lucky enough to have both provided. Regardless, the reviewer should imagine moving up and down the plane of the drawn section and consider what happens at transitions to adjacent assemblies. This is a skill that develops with experience. One should pay particular attention to what happens where the plane of the air and moisture barriers change. What seems to "work" in section, may not work in the corners.

This paper cannot attempt to address all factors that need to be considered. We suggest, however, that the described process leads to the understanding of overall and specific requirements.

The focus of this paper is on the elements controlling heat, air and moisture flow, it is necessary to understand structural aspects of enclosure design. Enclosure assemblies must support and will deflect under dead and live loads. The enclosure must also accommodate movement of the building structure. The functional elements, particularly the air barrier, must accommodate these movements whether they are perpendicular to the plane of the enclosure or in plane, both vertically and under racking. Assessment of the structural loading and capacity of the enclosure assemblies may or may not be in the scope of an enclosure review assignment. But an understanding of the type and magnitude of structural deflection is critical to assessing the durability of the functional elements.

Each material may have special requirements to provide durable performance within the assembly (i.e. protection from UV radiation, level of corrosion protection, incompatibility with adjacent materials or special installation requirements). The reviewer also needs to consider whether it is possible to construct the assemblies as they are shown on the drawings and whether future maintenance and renewals can be carried out with a reasonable level of ease and cost. This requires knowledge of what materials are specified, their characteristics and of construction process and sequencing.

Regrouping

Having reviewed all the details, the reviewer's attention should turn back to the smaller scale drawings. The reviewer should go over them with several key questions:

- Do the plans and details actually show how all elements are to be constructed? What details are missing?
- Considering the problematic areas and danger zone identified in the initial review, have the identified concerns been appropriately addressed?
- Imagining how water runs down the building, where are water concentration points and how is water moved off the walls? Are there ways of limiting concentration points?

Transmitting Findings to the Design Team

Review comments are typically transmitted back to the designer using marked up drawings and a review memo that outlines key observations and recommendations. The memo should:

- State assumptions regarding
  - indoor and outdoor environments
  - functional elements in each major enclosure assembly
- Identify and explain design issues with reference to specific drawings and details
- Provide recommendations making it clear what is required, recommended or suggested for consideration.

We strongly recommend that the reviewer also meet the design team to expand on and explain review comments, clear up any misunderstandings and explore alternatives to meet the design intent.

References

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