Principles of Rain Control for Enclosure Design

1. Introduction

In countries with cold climates, moisture is one of the most important agents leading to building envelope deterioration. Understanding and predicting moisture movement within and through the envelope is therefore of fundamental importance to predicting and improving performance, particularly durability. Since driving rain deposition on walls and roofs is quantitatively the largest single source of moisture, it is no surprise that controlling rain penetration is one of the most important parts of a successful moisture control strategy. In fact, failure to control rain is likely the oldest and most common serious building enclosure problem.

This document will consider rain control from a general to a specific level. The following sections will cover: basic moisture control principles that should be employed in the design of above-grade building envelopes; driving rain as a moisture load on walls; a classification system of the various rain control strategies available for walls; and finally, good design practises for walls.

1.2 Driving Rain

Driving rain is typically the largest source of moisture for the above-grade building enclosure. Hence, rain control is a fundamental function of the building enclosure, and a major part of moisture control. Despite thousands of years of experience, avoiding rain-related building damage is still one of the most difficult tasks designers and builders face. There are, however, means of providing rain control which are based on both traditional details and modern physical understanding. Regardless of the wall design approach taken, building shape and site design choices can reduce the amount of rain deposited on walls. Finally, despite our best efforts, some rain often is absorbed into materials or penetrates through imperfections so drying must be provided to remove this incidental moisture.

This Canadian holistic state-of-the-art approach to rain control can be described by the three-D's: **Deflection, Drainage, and Drying**. The next three sections of this report will investigate each in turn.

2. Deflection

The climate and the site play a large role in defining the rain exposure that a building is exposed to. Most parts of the world experience a significant amount of wind-driven rain, and those areas exposed to typhoons can have extreme exposure conditions. While this type of climate demands good rain control strategies for enclosure walls, the rain deposited on walls can be significantly reduced by good design and siting.

The first line of defence is the siting of the home – exposure to the prevailing driving rains can be defended against by planting, landscaping, and choosing lower building designs (i.e., bungalows).

The shape of the house roof and overhang also have a critical impact. Field measurements [1] and computer modelling [2] have shown that overhangs and peaked roofs reduce rain deposition by approximately 50%. A damage survey of wood frame buildings in British Columbia [3] found that the size of a buildings overhang correlated directly with the probability of rain-related damage. Peaked roofs and overhangs protect a wall from rain by shadowing and redirecting airflow (Figure 2). Hipped roofs provide an opportunity to shelter the walls from rain on all four sides of the building.

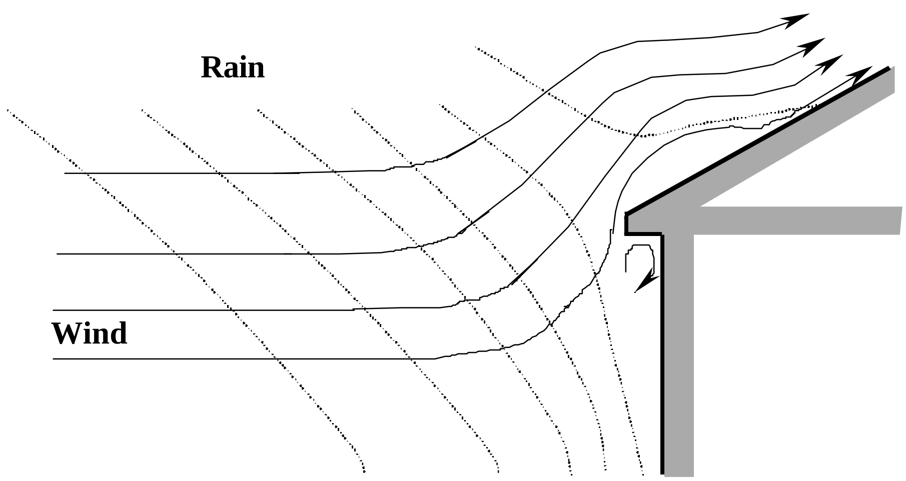

Figure 2: Influence of Overhangs and Pitched Roofs on Wind and Rain Flow

Field measurements [4,5,6,7], computer modelling [8,9], and wind tunnel testing [10] have provided an indication of the quantity of driving rain deposition that can be expected on vertical walls. For many housing situations, the amount of rain deposited is in the order of 10 to 20% of the product of wind speed and rainfall intensity. Thus the amount of rain deposited on the walls of houses erected on exposed Japanese sites could be in the order of hundreds of litres per square meter per year. Sheltered locations and single-storey houses with wide overhangs will be exposed to much less than this amount of rain.

Once water is on the wall it will form a film and begin flowing downward under the force of gravity. Wind flowing over the surface will tend to deflect the flow from this path and, in extreme cases, may even force water upward. Surface features such as trim, surface texture, and openings can greatly affect the flow paths of this surface drainage, either concentrating or dispersing surface flows.

Traditional surface details on old and vernacular buildings (Figure 3) often served the function of directing water away from sensitive areas (e.g., windows) and distributed surface water in such a way as to prevent the concentrated streams which cause staining. The copious use of drip edges and slopes also ensured that surface water was removed from the building surface as often as possible.

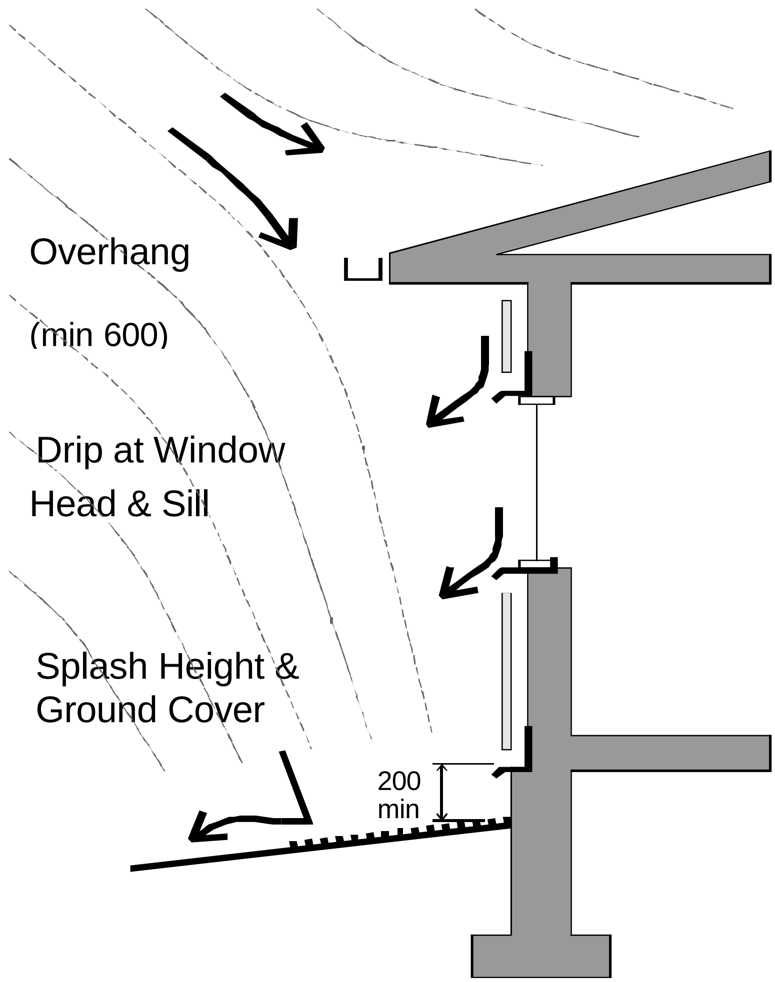

Figure 3: Principles of Rain Deflection

3. Rain Control Strategies and Drainage

Siting, building shape, and surface rainwater control rarely provide sufficient rain control in rainy climates. Hence, some strategy to deal with the rainwater that penetrates the surface of the wall must be employed. There are three fundamental rain control strategies available to the designer [11]:

1. storage or mass walls,
2. perfect barrier walls, and
3. drained and screened walls.

This categorisation is independent of materials or design intent and is based solely on the method by which a wall system controls rain penetration.

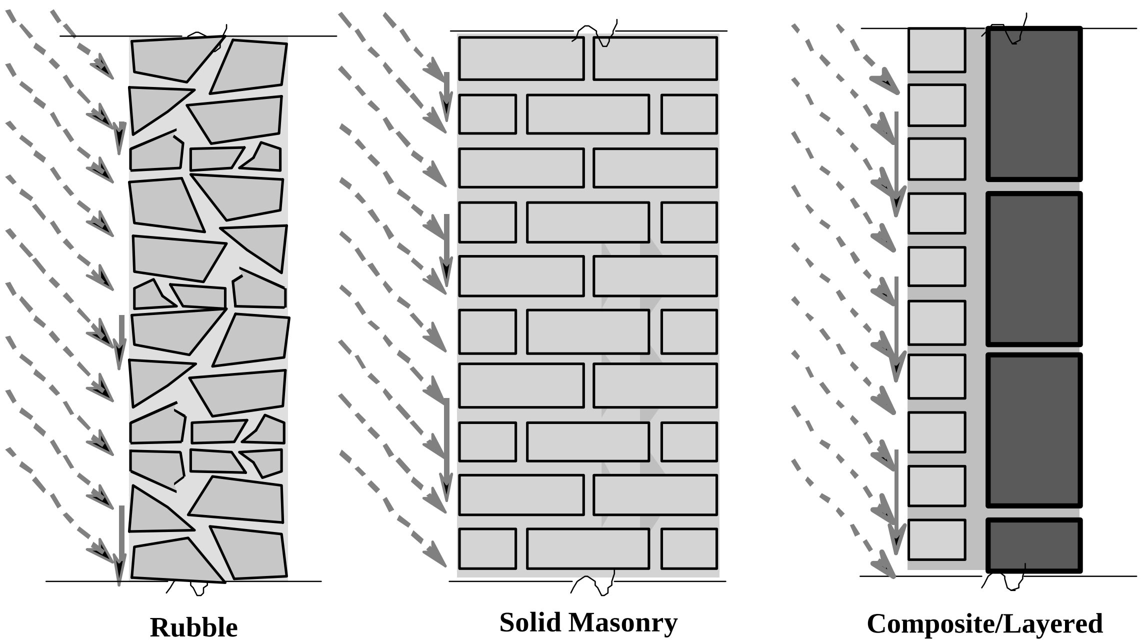

Figure 4: Examples of Mass or Storage Wall Systems

Storage or mass walls are the oldest strategy. This approach requires the use of an assembly with enough storage mass to absorb all rainwater that is not drained or otherwise removed from the outer surface. In a functional mass or storage wall this moisture is eventually removed by evaporative drying before it reaches the inner surface of the wall. Although envelopes employing this strategy might be best termed "moisture storage" systems, "mass" is often used because a large quantity of material is required to provide sufficient storage. The maximum quantity of rain that can be controlled is limited by the storage capacity available relative to drying conditions. Some examples of mass walls include adobe, solid multi-wythe brick masonry, and single-wythe block masonry.

Perfect barriers stop all water penetration at a single plane. Such perfect control required the advent of modern materials. Some examples of perfect barrier walls are some window frames, and some metal and glass curtain wall systems (Figure 5). Because it is very difficult to build and maintain a perfect barrier wall, most walls are designed as, or perform as, imperfect barrier wall systems of either the mass type or the screened type. The joints between perfect barrier elements may be also designed as perfect barriers (e.g. a single line of caulking). Such joints have a poor record of performance and should not be used to control rain entry .

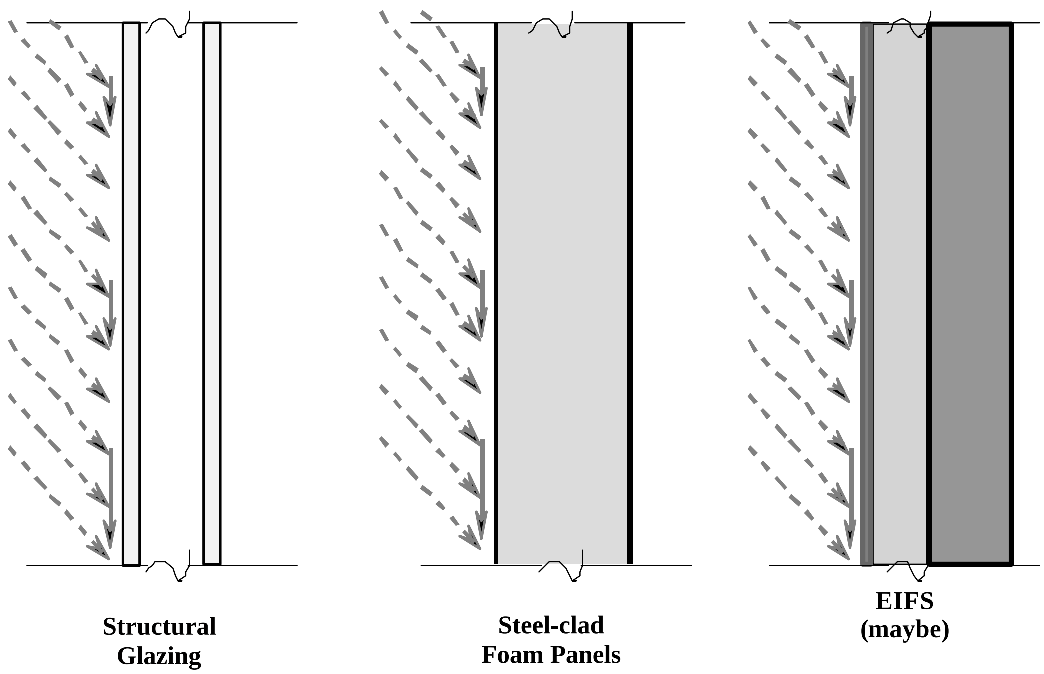

Figure 5: Examples of Perfect Barrier Wall Systems

Screened-drained walls assume some rain water will penetrate the outer surface (hence the cladding “screens” rain) *and* remove this water by designing an assembly that provides drainage within the wall. Since it has often been shown that lap siding and brick veneer leak significant amounts of water, this design approach is the most realistic and practical for such walls.

Supplementary mechanisms, such as a capillary break and a water barrier, are usually employed to resist further inward movement of water that penetrates the inevitably imperfect cladding. Some examples of screened wall systems include cavity walls, brick and stone veneer, vinyl siding, two-stage joints, and drained EIFS (Figure 6). It should be noted that the screen is much more than a rainscreen; it must also resist wind, snow, solar radiation, impact, flame spread etc.

An air space is usually provided to facilitate drainage and act as a capillary break between the cladding and the remainder of the wall. This air space becomes more important as the rain loading increases since more water will drain within this space more often in high exposure locations. The drainage space should be at least 6 to 8 mm wide, since this is approximately the size of a gap that can be spanned by water. However, since dimensional tolerances must be accounted for, a dimension of 10 mm is usually quoted. The size of the airspace must be larger to allow for ventilation air flow (see Drying).

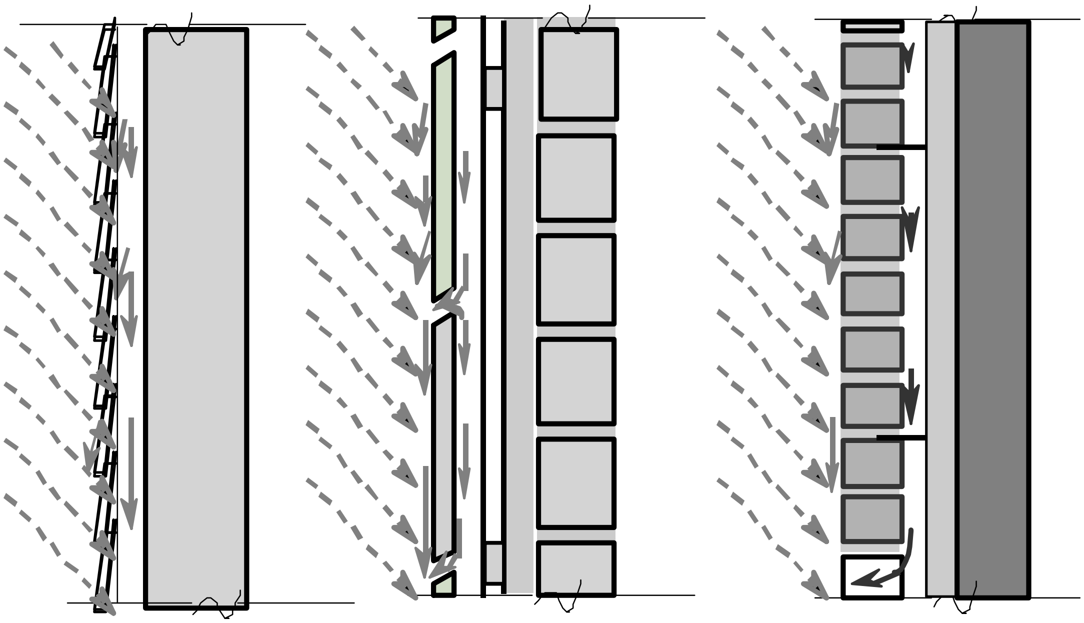

Figure 6: Examples of Drained-Screened Wall Systems

A vented airspace also allows for both some degree of pressure moderation and ventilation. Pressure moderation is the term given to the mechanism whereby wind pressure differences across the cladding are reduced by connecting an air space behind the cladding with the wind-induced pressure acting on the exterior (Figure 7). By reducing air pressure differences across the cladding, rain will not be forced across openings by this force, while the standard features of capillary break, drainage, and flashing deal with the other rain penetration forces. If the air pressure is completely eliminated (not practical in the field [12,13,14]), the process is termed pressure equalisation.

Experience with wood-frame housing from coast-to-coast in Canada [15] and in the hurricane-prone regions of the south-eastern US [16] has shown that drained and screened cladding systems are the preferred approach to reliably provide rain control. Drainage within the wall complements the drainage approach on the exterior surface while pressure moderation reduces the amount of rain that penetrates.

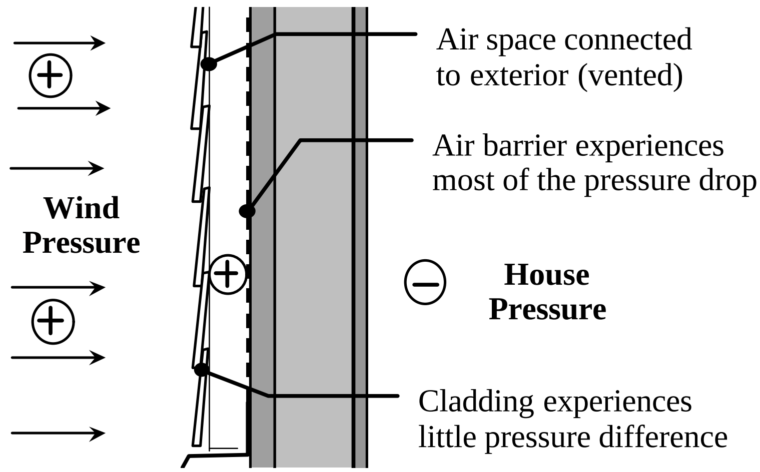

Figure 7: Pressure Moderated Air Space

Although drained-screened walls provide excellent rain penetration control, problems can still develop at interruptions in the plane of the wall. Windows, decks, and the termination of walls at grade all create conditions where rain can penetrate. Flashing must be provided at these penetrations to direct water in the drainage cavity to the exterior.

Flashing must be made of a waterproof material[1] since it is installed in a nearly horizontal manner [17]. Flashing must be installed in a continuous manner with an outward slope. Leaks often occur at the laps between lengths of flashing, so these should be sealed, not just lapped. Windows and especially mulled window joints and window corners often leak rain water into the wall. To deal with this eventuality, sub-sill flashing should be installed. Since the joint between the wall and the window is sensitive to workmanship, the head of the window should be well protected with. This flashing directs water on the surface of the wall and in the drainage space behind the cladding safely back out. The flashing should extend past the window by at least 50 mm so that water flowing laterally on the flashing does not concentrate at the jamb but runs down the drainage space.

[1] Building paper is not waterproof when exposed to standing water. Materials such as heavy PVC, metal, peel and stick membranes, special tapes, etc are more appropriate choices for flashing.

Essentially the rough window should be prepared in such a way as to make it water resistant (see also construction drawings later in the report).

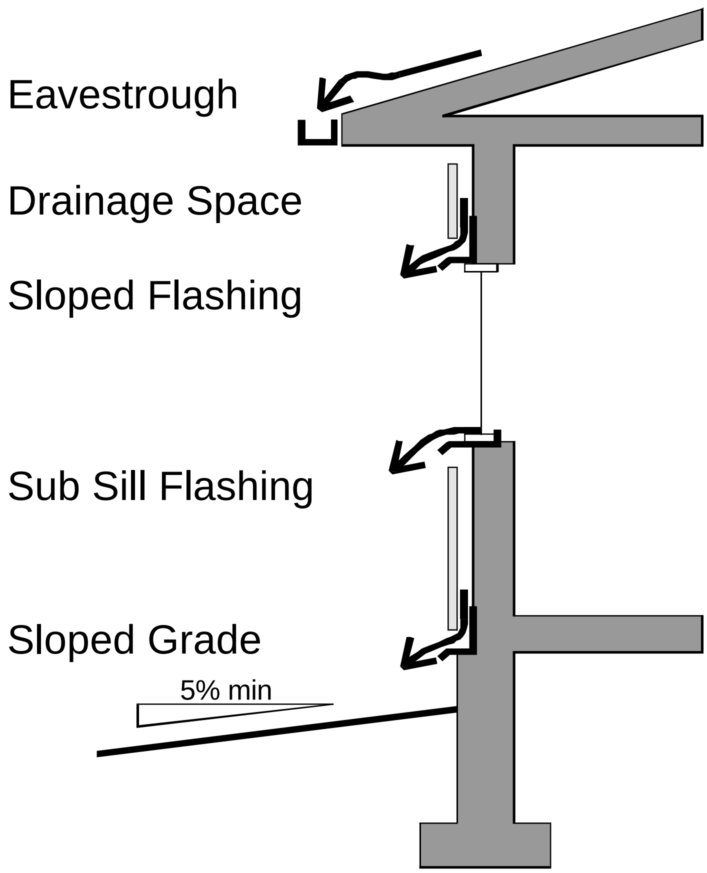

Figure 8: Drainage and Flashing Concepts

4. Drying

Despite all attempts to resist and drain water, field experience has shown that some water may still penetrate or be built in during construction. Drying of this moisture must be provided for.

Moisture can be removed from a wood framed wall clad with drained siding by (Figure 9):

1. evaporation from the inside or outside surfaces,
2. vapour transport by diffusion, air leakage, or both, either outward or inward; and
3. drainage, driven by gravity,
4. ventilation, if provided for.

Drainage is capable of removing the greatest volume of water in the shortest period of time. Hence, as described above, it is a very important mechanism for moisture control. Provided a clear drainage path exists (e.g. cavities, slopes, drainage openings), a large proportion of rain water penetration[2] can flow out of a wall.

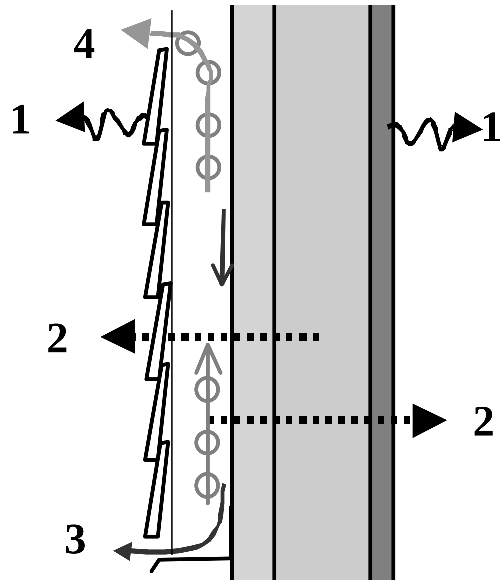

Figure 9: Moisture Removal Mechanism in Drained and Screened Walls

A small but significant amount of water will usually remain attached to surfaces by surface tension and held in materials by capillary forces even in walls with excellent drainage. Sidings of wood and cement will also absorb and store moisture. This moisture can only be removed from a wall system by either diffusion or air flow.

Diffusive drying can dry in either direction, depending on the wall system and the climate. In colder climates the vapour flow is often outwards, and inward drying only occurs during warm weather or when the sun shines on a wall. In hot humid climates water vapour will be driven inward for most of the time and this drying mechanism should be encouraged.

Hence, in cold climates like Edmonton, a vapour barrier of polyethylene may be acceptable. In warmer climates (e.g. Toronto) normal latex paint with a permeance of less than 200 ng/Pa•s•m^2 will provide sufficient vapour control in cold weather in many walls while still allowing vapour to flow inward during warm weather.

[2] Drainage is also useful for removing cold weather air leakage condensation that can form on the back side of the siding.

In hot-humid climates, such as Atlanta, a vapour barrier on the interior must not be used, and only latex paint on drywall will allow sufficient vapour to pass through to the interior. With few exceptions, any material with low permeance (e.g., oil paint, aluminium foil, vinyl wallpaper, epoxy) must be avoided on the interior.

Air movement (or leakage) through the envelope can, under the proper conditions, move a large quantity of moisture. While both cold weather air leakage outward and warm weather air leakage inward can cause condensation and hence wetting, the opposite conditions (e.g. inward flow in cold weather) will provide some drying. In some cases, this drying can be significant. Because air leakage through the enclosure is difficult to control, expensive in terms of energy, and potentially dangerous for indoor air quality, the modern approach is to limit airflow through the wall to nearly zero. This also eliminates the potential for airflow drying, so drying must be secured by other means.

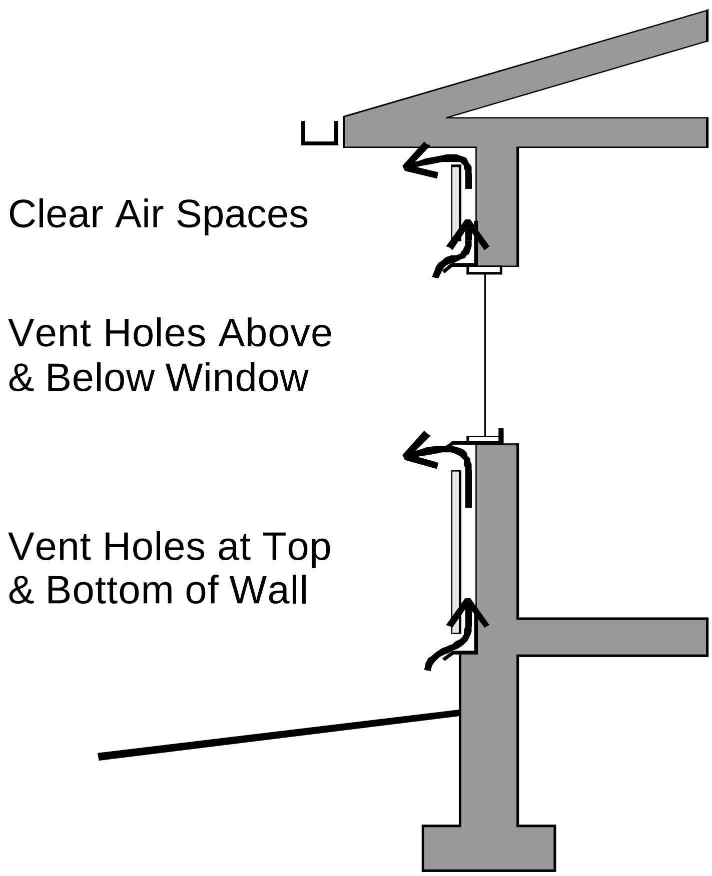

Figure 10: Ventilation Concepts

Ventilation, or exterior air flow behind the cladding driven by wind pressure differences on the face of the building or solar heated air rising, is useful since it accelerates drying. Ventilation bypasses the high vapour resistance of claddings such as vinyl siding, metal panels, and cement board, thereby allowing outward drying. A recent Canadian study [18] and previous European research [19] has shown that ventilation drying occurs and explore the influence of various design variables. This research shows that a clear space of at least 19 mm should be provided behind lap siding to encourage ventilation, and that clear vents must be placed at the top and bottom for the most effective ventilation.

Claddings such as wood and cement-board absorb water. When these materials are heated by the sun during warm weather very large inward vapour drives develop (which accelerate drying of the cladding), even in predominately heating climates like Sapporo. These inward drives can cause dangerous summertime condensation within wood framed walls, especially if a low-permeance vapour barrier (e.g., polyethylene) is used on the interior [20, 21, 22]. Ventilation is important since it can reduce or control these inward vapour drives, by safely redirecting the vapour to the exterior even in hot-humid conditions [23]. Additional control is usually required in hot-humid climates, and an outer layer with moderate vapour permeance (permeance less than about 200 ng/Pa•s•m^2) is recommended. A layer of extruded (not expanded) polystyrene insulation is ideal for this application. Expanded foam can be used in mixed and cool climates.

5. Recommendations for Practise

Moisture control in above-grade walls is best achieved by the proper selection of materials and design of assemblies so that both storage and a drying potential higher than the wetting potential are provided. Because of the magnitude of driving rain deposition, rain control should be an important part of a moisture control strategy for the above-grade building enclosure. A designer must have a well conceived strategy for rain control for each enclosure type, and joint type, for the entire project.

Regardless of which strategy or assembly is considered, reducing the amount of rain deposited (i.e., controlling exposure by the judicious choice of site and building shape) and increasing the fraction shed from the exterior face will reduce the moisture load on the assembly. Controlling water by the use of generous overhangs, proper window sills, and other surface drainage features should almost always be the first and most important step in designing for the control of rainwater penetration.

5.1 Storage Systems

Storage (sometimes called mass or reservoir systems) walls are often used in low-rise commercial buildings (in the form of single-wythe concrete block), and some high-rise residential buildings (in the form of exposed concrete shear walls). Provided the absorbency and safe storage capacity are well matched to the local exposure and climatic conditions, storage walls may be a reasonable choice. Deflect as much rain from the building as possible with good details, and beware warm weather inward vapour diffusion.

Mass walls are sometimes prohibitively expensive (in materials, structural weight, or floor space). Failure of joints (designed as perfect barriers) between wall elements or the interface with windows, doors, balconies, etc. are often the cause rain penetration, even when the wall element itself is functional. If a sufficient amount of storage is provided for the exposure conditions and absorbency of the material, performance of a mass wall system will depend on the performance of joints and interfaces.

5.2 Perfect Barrier Systems

Perfect barrier systems, especially face-sealed versions, often fail to perform as designed, if not initially, then after many years of exposure. The perfect barrier systems that appear to function in the field usually lend their performance to the fact that other layers are providing drainage and/or storage: in effect these "perfect barrier systems" are acting as screened systems or mass systems. Perfect barrier wall elements built with tight quality control in factory conditions and connected in the field with drained-screened-types of joints may be able to provide good performance for a long service life. In almost all cases, screened systems with the same amount of material and labour will provide better, longer-lasting rain control.

If you must use a perfectly sealed system, pay extra attention to surface drainage, joints, and buildable details. Quality control is essential on site, and maintenance important. Use these systems under low exposure conditions, and/or in situations in which a rain leak will not be catastrophic (e.g., there are no moisture sensitive materials). Consider a redundant backup system to deal with the possibility of local failures.

5.3 Drained-Screened Systems

Screened wall systems are inherently more forgiving than either mass or perfect barrier systems. Properly designed and built screened wall systems will provide economical and durable rain penetration control. Failures in screened systems tend to occur because drainage was not provided (either through a design or construction failure). So long as sufficient drainage is provided, the combination of the number of layers, their absorbencies, and their penetration fraction will define a screened systems ability to control rain water.

The most reliable and widely applicable approach is to follow the mantra: “Deflection, Drainage, and Drying”.

Proper siting of the building and the use of sloped hip roofs and generous overhangs deflect driving rain, even for tall buildings. Water on the surface of the wall is deflected from openings by surface features, drip edges, and protruding flashing. Water is removed from the base of the wall by sloping the grade, and siding is kept at least 200 mm above grade to protect it from splashes.

Rain water will penetrate the cladding at joints, laps and penetrations. This water should be removed by drainage through a drainage space and redirected to the exterior by the use of waterproof flashing with all lap joints sealed.

Water will remain within the drainage cavity, will be absorbed into the cladding, and may even penetrate into the structural sheathing or studspace. This water should be removed by drying to the exterior and the interior by ventilating the space behind the cavity

This design approach can be achieved if the building design and construction:

1. controls exposure by proper siting and the use of sloped hip roofs with overhangs (at least 400 mm for buildings in rainy locations), and slope and drain surface water at the base of the wall;
2. controls the flow of water draining on the exterior surface by using surface features, slopes, protruding flashing, and drip edges, (this is especially important for high-rise buildings);
3. provides a clear airspace of at least 19 mm thickness behind the cladding to aid drainage of water that penetrates (larger tolerances if masonry is used);
4. ensures that waterproof flashing (lapped and sealed at joints) is used at every penetration and at the base of the wall system, to safely remove drained water to the exterior;
5. vents the top and bottom of the wall through openings of at least 10 mm width to allow ventilation air flow through an unobstructed air space of at least 19 mm and thereby encourage drying of the drainage space and cladding, and

6. places vapour retardant layers (vapour permeance of less than 200 ng/Pa•s•m^2) behind cladding in hot humid climates to control inward vapour drives
7. avoids the use of vapour barrier materials (vapour permeance of less than 60 ng/Pa•s•m^2) on the interior in warm and hot climates.

Pressure equalized screened systems offer only marginal benefits in most situations. So long as drainage and capillary breaks are provided, the reduced water penetration that may (and in many cases may not) result from pressure equalisation does not aid rain control -- failure will still be by a failure to drain.

6. Example Detailed Drawings

The recommendations developed above are embodied in the wall design shown Figure 11. This drawing is only one example of how these principles can be achieved in practise since many other combinations of materials and wall assemblies are acceptable alternatives. The drawing assumes a wood framed house with cement-board or wood siding, metal clad wood windows, and rigid foam insulated sheathing over a housewrap. The foam insulation is an important component of the moisture control strategy, not merely an energy saving feature. The wood stud walls are sheathed with OSB and plywood to provide lateral resistance, although this is not always necessary. The stud walls could be either 90 mm or 140 mm thick depending on the required energy efficiency and structural loads.

Air movement and vapour diffusion control systems are required for all building enclosures -- these systems have not always been shown in the drawing (since rain control is the emphasis here).

Notes

1. Based on the need to reduce the potential for cold weather air leakage condensation, a minimum thickness of 25 to 38 mm is required for 90 and 140 mm stud walls respectively. All extruded polystyrene insulation will provide sufficient vapour resistance for hot-humid climates in thickness of 25 mm and greater. If expanded polystyrene is chosen (EPS has greater vapour permeance), a minimum thickness of 38 mm is recommended for hot-humid climates to control inward vapour flow. A rigid outboard drainage plane can be made by taping the joints in the rigid sheathing.
2. The furring strips used to create the drainage and ventilation space should be treated to resist decay, and fasteners should be corrosion resistant.
3. Exterior siding can be a range of products. All cement board and wood siding must be primed on all six sides to reduce water absorption thereby reducing the potential for swelling, staining, and inward vapour drives.

4. Sealant is shown in many locations as part of both air barrier and rain control functions. The location of sealant beads should always consider the potential that the sealant performs both functions.
5. The sheathing membrane is assumed to be comprised of a synthetic housewrap with taped and sealed joints over the structural sheathing. By sandwiching the housewrap between the foam sheathing and the OSB, the housewrap is well supported and unlikely to billow when it is windy, rip at fasteners, etc. Tar-impregnated building paper can also be used if properly installed shingle fashion over the structural sheathing (it also performs better when sandwiched).
6. Metal flashing is shown since this material is both rigid and waterproof. The rigid nature is important since it allows the flashing to extend beyond the face of the wall. Building paper is not waterproof when exposed to standing water. Materials such as heavy PVC, metal, peel and stick membranes, special tapes, etc are more appropriate choices for flashing. Laps in materials, especially rigid plastic and metal, must be sealed to prevent lateral flow under the flashing.
7. The vent openings should be at least 10 mm in size and run the full length of the siding. A stainless steel mesh with thin wires and large openings will resist insect entry while allowing air flow.. In the case of brick veneers, every other head joint should be left open in the bottom course, and a 10 mm gap left at the soffit. Commercially available brick vent inserts dramatically reduce ventilation and drainage and are not recommended.
8. The air stop at the top of the cavity is intended to prevent moist air from flowing directly into the attic.
9. A peel and stick membrane has been specified so that the sill is protected from leaking windows. The membranes are also self-sealing if fasteners penetrate (unlike sheathing membranes and metal flashing). The peel and stick interrupts the thermal bridges of the metal flashing.
10. The sealant on the sub sill between the window and the peel and stick is intended to prevent both the flow of air and water. It could be replaced with a bead of expanding polyurethane foam. Alternatively, an upstand or sloped sill can be installed to resist water flow, but an air seal would still be required.
11. The head flashing ver windows, doors, and other penetrations should be flashed with metal flashing that projects from the wall about 20 mm. Peel and stick membrane should be used to connect the upstand leg of the flashing to the face of the sheathing membrane.

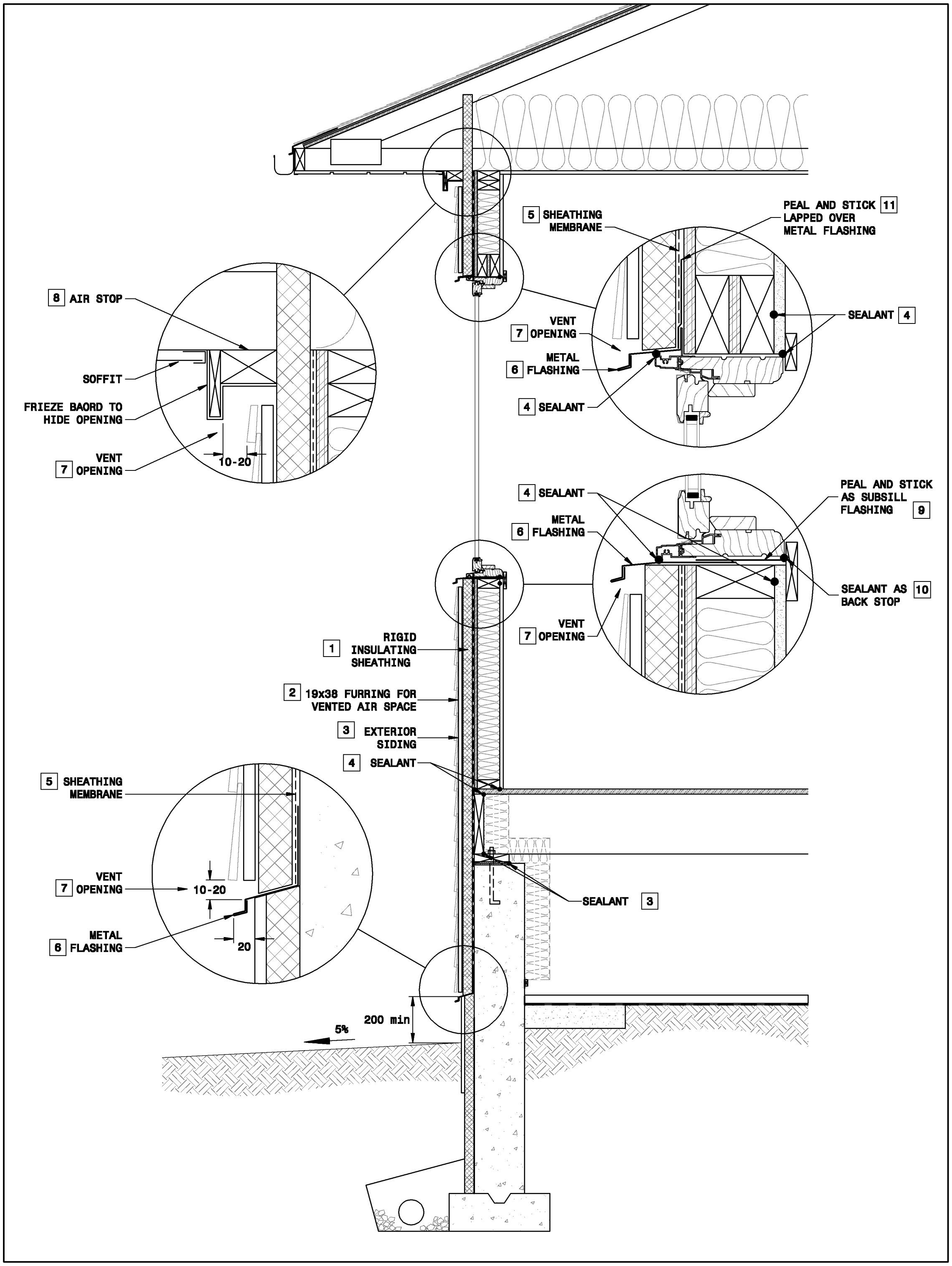

Figure 11: Detailed Wall Section - All Climate Zones

7. References

[1] Straube, J.F., *Moisture Control and Enclosure Wall Systems*. Ph.D. Thesis, Civil Engineering Department, University of Waterloo, April, 1998.

[2] Blocken, B., Carmeliet, J., “Driving Rain on Building Envelopes—I. Numerical Estimation and Full-Scale Experimental Verification", *J. of Thermal Insulation and Bldg Envelopes*, Vol 24, No 4, 2000, pp. 61-110.

[3] *Survey of Building Envelope Failures in the Coastal Climate of BC*. Report by Morrison-Hershfield for CMHC, Ottawa, Nov. 1996.

[4] Lacy, R.E., *Driving-Rain Maps and the Onslaught of Rain on Buildings.* Building Research Station Current Paper 54, HMSO Garston, U.K., 1965.

[5] Straube, J.F., and Burnett, E.F.P.,"Driving Rain and Masonry Veneer", *Water Leakage Through Building Facades, ASTM STP 1314*, R. Kudder and J.L. Erdly, Eds., American Society for Testing and Materials, Philadelphia, 1997, pp. 73-87.

[6] Künzel, H.M., Regendaten für Berechnung des Feuchtetransports, Fraunhofer Institut für Bauphysik, Mitteilung 265, 1994.

[7] Frank, W. *Entwicklung von Regen and Wind auf Gebaeudefassaden*, Verlag Ernst & Sohn, Bertichte aus der Bauforschung, 1973, Vol 86, pp. 17-40.

[8] Choi, E.C.C., "Determination of the wind-driven-rain intensity on building faces", J. *of Wind Engnrng and Industrial Aerodynamics*, Vol 51, 1994, pp. 55-69.

[9] Karagiozis, A., and Hadjisophocieous, G., "Wind-Driven Rain on High-Rise Buildings",*Proceedings of BETEC/ASHRAE/DOE Thermal Performance of Building Envelopes VI*, Dec., 1995, pp. 399-406.

[10] Inculet, D.R., Surry, D., "Simulation of Wind-Driven Rain and Wetting Patterns on Buildings," Report BLWT-SS30-1994, U. of West. Ontario, London, Nov, 1994.

[11] Straube, J.F. and Burnett, E.F.P., "Rain Control and Design Strategies". *J. Of Thermal Insulation and Building Envelopes*, July 1999, pp. 41-56

[12] Quirouette, R., *Laboratory Investigation and Field Monitoring of Pressure-Equalized Rainscreen Walls,* CMHC Research Report, September, 1996.

[13] Inculet, D., Surry, D., *The Influence of Unsteady Pressure Gradients on Compartmentalization Requirements for Pressure-Equalized Rainscreens*, CMHC Research Report by the Boundary Layer Wind Tunnel, University of Western Ontario, June, 1996.

[14] Laviolette, S., and Keller, H., *Performance Monitoring of a Brick Veneer / Steel Stud Wall System*, CMHC Research Report by Keller Engineering, June, 1993.

[15] Rain Control Report by CMHC

[16] Lstiburek, J., *Builders Guide for Mixed Climates,* Building Science Corporation, Westford, MA, 1999.

[17] CMHC Best Practise Guide for Flashing

[18] Straube, J.F. Burnett, E.F.P., *Vents, Ventilation Drying, and Pressure Moderation*. Building Engineering Group report for CMHC., Ottawa, 1995.

[19] Popp, W., Mayer, E., Künzel, H., 1980. *Untersuchungen über die Belüftung des Luftraumes hinter vorgesetzten Fassadenbekleidung aus kleinformatigen Elementen*. Forschungsbericht B Ho 22/80: Fraunhofer Institut für Bauphysik, , Holzkirchen, Germany.

[20] Wilson, A.G., "Condensation in Insulated Masonry Walls in the Summer", *Proc. Of RILEM/CIB Symposium*, Helsinki, 1965, pp. 2-7.

[21] Sandin, K., 1991. *Skalmurskonstruktionens fukt- och temperaturbetingelser*. Rapport R43:1991 Byggforskningsrådet, Stockholm, Sweden.

[22] Andersen, N.E.,"Summer Condensation in an Unheated Building", *Proc. of Symposium and Day of Building Physics,* Lund University, August 24-27, 1987, Swedish Council for Building Research, 1988, pp. 164-165.

[23] Straube, J.F. and Burnett, E.F.P., "Drainage, Ventilation Drying, and Enclosure Performance", *Proceedings of Thermal Performance of Building EnvelopesVII*, Clearwater Beach Florida, December 4-7, 1998, pp 189-198.