K EEPING WALLS DRY

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ABSTRACT

Water is the most significant factor in the deterioration of buildings. But walls can be designed to stay dry, or at least to limit wetting through the "4-D" strategies of Deflection, Drainage, Drying and Durability to such an extent that deterioration does not become an issue.

This article examines the many considerations that must go into the design of walls that "stay dry," starting with the results of several CMHC studies that looked at the most common causes of building problems. The sources of moisture that can cause wetting of walls, including interior, exterior and construction moisture, are examined and methods of controlling each source are discussed. This article gives special emphasis to the penetration of rain, as rain is the leading cause of water problems in walls. Several design approaches are discussed for keeping walls dry, including drained cavity walls, simple rainscreen walls and pressure-equalized rainscreen walls.

Lastly, environmental data are presented that can be used to determine the severity of the environmental conditions to which the wall will be exposed; such data can be of use in determining what moisture control strategy should be employed.

Water damage at window-wall interface

Ontario Association of Architects

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OBJECTIVES

After reading this article, you should:

1. Understand the importance of buildable, durable and maintainable details and the importance of communication during construction, and know several ways to improve both.

2. Understand the three sources of moisture in walls and the strategies that can be employed to limit each source.

3. Understand the forces that push rain into buildings and the major ways building design influences rain penetration.

4. Understand the importance of designing buildings for the environmental conditions to which they will be exposed and know how to determine the severity of that environment.

1. INTRODUCTION

The cost of construction defects in high-rise residential buildings has escalated significantly over the past several years; this is particularly evident in British Columbia. There have been several studies commissioned by CMHC (CMHC *Research Highlights and Reports*) over the past decade to examine the most common causes of building failures, including: *Construction Problems in Multi-family Residential Buildings*, (Drysdale Report);[1] *Wall Moisture Problems in Alberta Dwellings* (Alberta Study);[2] *Survey of Building Envelope Failures in the Coastal Climate of British Columbia* (B. C. Survey)[3] and *2001 Building Failure Study*.[4]

Even though each study looked at residential construction in different parts of Canada and both low-rise and high-rise residential construction was examined, the reports have all come to similar conclusions: Water is the most significant factor in the premature deterioration of buildings. Not only can water damage materials directly, for example, causing corrosion of metal or the chemical breakdown of organic materials like wood or drywall, it can also reduce the effectiveness of materials (like insulation) and it is the major factor in the growth of mold.

The reports identified contributing factors to moisture problems in buildings as:

- Lack of sufficient detail in the drawings,

- Lack of inspection during construction, and

- Lack of understanding of building science principles.

The reports also identified some specific aspects of construction that are more prone to moisture problems, including:

- Windows, doors and skylights (including their installation),

- Saddle flashings (where a saddle is defined as the transition of small horizontal surfaces, such as the top of a balcony guard rail or parapet wall, with a vertical surface, such as a wall),

- The perimeter of decks, balconies and walkways, and

- Precast concrete walls.

1 Drysdale Engineering and Associates Limited. *Construction Problems in Multi-family Residential Buildings*. Canada Mortgage and Housing Corporation, 1991.

2 Building Envelope Engineering Inc. *Wall Moisture Problems in Alberta Dwellings*. Canada Mortgage and Housing Corporation, 1999.

3 Morrison Hershfield Limited. *Survey of Building Envelope Failures in the Coastal Climate of British Columbia*. Canada Mortgage and Housing Corporation, 1996.

4 R. J. Burnside & Associates Limited. *2001 Building Failure Study*. Canada Mortgage and Housing Corporation, unpublished.

Table 1 is a more detailed summary of the problem areas identified in the *B.C. Survey*. Similar results were found in the *Alberta Survey* with problems in which windows and penetrations accounted for a high percentage of the problem areas. *The B.C. Survey* found that 90 per cent of the problems investigated were related to interface details between wall components or at penetrations; only 10 per cent of problems were directly related to the basic wall assembly. All cladding types experienced performance problems, although the number of problems reported on stucco walls was substantially more than on other walls, and the cost of repairing damage to stucco walls is significantly higher on average. Again, the Alberta study had similar results. In general, buildings with simple details or those that contained fewer of the details associated with problems (such as exterior walkways or saddle connections) performed better.

In this paper, the recommendations of the CMHC studies will be examined. As well, the building science principles behind several moisture-control strategies will be examined.

Problem description	# of problems	% of total
Windows		
No sealants at frame/cladding joint	10	5.2%
No sealants at corner mitre joints	12	6.2%
Poor flashing at head or sill	16	8.3%
Poor building paper installation	7	3.6%
Subtotal—windows	45	23.3%
Deck/Walkway/Balcony		
Poor Deck/Walkway/Balcony Waterproofing: Field	16	8.3%
Poor Deck/Walkway/Balcony Waterproofing: Junction with walls	17	8.8%
Subtotal Deck/Walkway/Balcony	33	17.1%
Horizontal Surface Flashings		
Poor Guardrail Saddle Joints	22	11.4%
Poor Guardrail Cap Flashings	13	6.7%
Poor Parapet Cap Flashings	8	4.1%
Subtotal Horizontal Surface Flashings	43	22.3%
Other		
Poor Base/Transition/Control Joint Flashings	15	7.8%
Poor Roof/Wall Joint Flashings	3	1.6%
Poor Eavestroughs/Downspouts	5	2.6%
Poor Concrete Slab/Wall Joints	5	2.6%
Poor Dryer Vents: Lint Plugged, Leaking in Wall	8	4.1%
Poor Vents: No Sealing or Flashing at Hood	8	4.1%
Poor Other Details	12	6.2%
Material/Installation Defects: Cladding, Weather Barrier, Sheathing	16	8.3%
Subtotal Other	72	37.3%
TOTALS	193	100.0%

Table 1-Problems Identified in the B. C. Study (from *Survey of Building Envelope Failures in the Coastal Climate of British Columbia*)

1.1. The construction process

The *Drysdale Report* determined that most problems could be traced to a lack of sufficient detail in the drawings and specifications, and more specifically to poor detailing. He went further in his report, suggesting that better drawings should help minimize the incidence of construction defects. The drawings and specifications are key communication tools, so they must be readable and understandable. The following are some recommendations made in CMHC research to help improve the quality of the drawings and specifications and to generally improve the lines of communication on the job site.

- It is essential to provide complete details for those components of the building envelope that most often fail, such as window, door and skylight installations, saddles (wall penetrations), intersections of decks and balconies with walls, perimeters of decks, etc. (see Table 1).

- The architect must continually seek feedback from the contractor to understand which details tend to be problematic. The contractor must also take some responsibility in ensuring this information is promptly relayed to the architect.

- Key details should be provided in a larger scale—a minimum of 1:5, but preferably 1:2. The larger scale will help ensure that there are no misunderstandings in reading the detail. The use of three-dimensional (possibly cutaway) details for key details is also recommended. Both these recommendations are made to improve clarity in the requirements.

- Drawings must be practical and reflect buildable details. For example, it is quite easy to draw a line that represents a membrane, indicating that the membrane should be used to air-seal a window to the wall. However, in real life, membranes only bend easily in two directions, not three, so it may be difficult or impossible for the actual material to do what is shown by the two-dimensional line on the drawing. Consider the example in Figure 1. The design intends that the peel-and-stick air barrier membrane that is sealed to the block backup be sealed to the window frame. These membranes are sticky on only one side. However, this fact seemed to be forgotten when the line was drawn.

- Designers should develop a bank of proven details that can be used on subsequent projects; however, that said, a one-size-fits-all approach should be avoided. Each detail in the bank must be reviewed and adapted as needed to ensure it is appropriate for each job and for the particular part of the building where it is to be used.

- It is not always sufficient to reference CSA or other standards on the drawings or in the specifications. Few contractors will be completely familiar with such standards and even fewer (if any) of the workers on site will have ever looked at a standard. So, to ensure that the work is completed in the expected manner, the pertinent issues with respect to the execution of the work, especially those related to details that most often fail, must be specifically stated in the documents. For materials, however, if
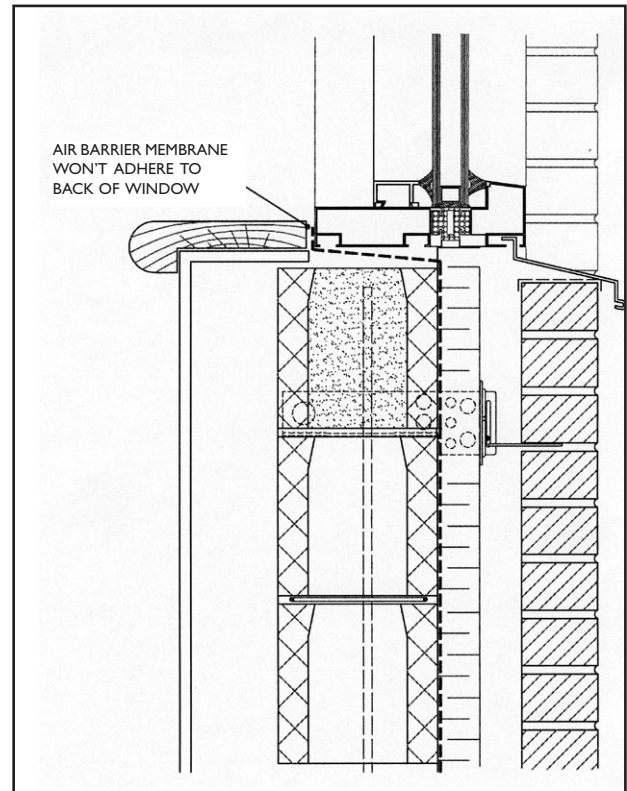

AIR BARRIER MEMBRANE WON'T ADHERE TO BACK OF WINDOW

Figure 1-Example of an impossible-to-build detail.

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compliance with a standard can be easily verified, reference to a standard is acceptable. For example, the specifications may state that a sealant to be used must comply with CAN/CGSB 19.24-M90, "Multi-component, Chemical-Curing Sealing Compound." This can be easily verified on site, as the sealant should state its compliance on its packaging.

- However, it would not be appropriate to state in the drawings that the spacing of masonry ties must conform to CSA Standard A370, "Connectors for Masonry." As another example, it would not be sufficient to state that window installation must be in accordance with CSA A440.4, "Window and Door Installation." That standard provides several different methods for air-sealing the window to the wall-air barrier system. The contractor could essentially install the window in the manner of his choosing if the installation method is not specified more thoroughly in the construction documents.

- Acceptable and non-acceptable product equivalents should be identified. Contractors often deal with a preferred material supplier and may be able to get volume discounts using their preferred supplier. However, the architect should maintain responsibility for material selection. If alternative products or suppliers are acceptable, the bid documents should specify this to allow the contractor to prepare his best bid.

- But more importantly, unacceptable materials must be noted, particularly if there are special circumstances on the particular project that make a normally fine alternative unacceptable. Listing unacceptable alternatives ensures that the contractor's bid is not accepted on products that cannot be used.

- The construction documents should provide an indication of the water penetration strategy being employed (see further in this document for a discussion of alternative water penetration strategies). For example, if the intent was to create a face-sealed building for control of rain penetration, the contractor must understand this so the appropriate level of care is taken to ensure all exterior seals are complete and the maintenance requirements must be spelled out for the owner–occupant. Similarly, if the interior drywall is to be the air barrier (for control of interior moisture), the contractor must know this to ensure that extraneous holes in the drywall (such as an electrician or plumber might make) are to be avoided or sealed.

- Once the project is tendered and the actual materials and components to be used are established, shop drawings or working drawings must be developed from the generic drawings used for tendering. Again, the use of working drawings will help avoid any confusion during construction.

- The construction of details, whether shown on the drawings or not, is also a significant contributor to the poor performance of the as-constructed details. This fact indicates that better communication during construction is needed. The use of mock-ups is recommended to communicate the design intent of details likely to be problematic, particularly as they relate to sealing of air barriers at connections, and joints of different materials, such as the window-to-wall interface. The construction of the mock-up offers the opportunity to identify potential construction problems or material incompatibility problems before construction is well underway. It also provides a training opportunity for the on-site personnel. Lastly, the mock-up provides a benchmark for comparing actual construction to expected results.

The above recommendations should help in all aspects of construction, not just preventing moisture penetration. To understand how to keep walls dry, an understanding of how walls get wet is first needed.

2. MOISTURE PENETRATION OF WALL ASSEMBLIES

There are three things required to move water through an assembly:

1. A source of water,

2. An opening for the water to enter the assembly, and

3. A force to drive the water through the opening.

2.1. Moisture sources

Water in a wall can come from three sources: construction moisture, interior moisture due to occupant use, or exterior moisture.

2.1.1. Construction moisture

Construction moisture is moisture that is given off by new construction materials. While wood is supposed to have a moisture content no greater than 19 per cent when installed, this is often not the case. After construction, this excess moisture leaves the wood and becomes available for absorption-deterioration of other wall materials. Initial evaporation of excess water in concrete is also a great source of moisture during the building's first years. The efflorescence that often occurs on the surface of a new masonry building is visible evidence of evaporating construction moisture.

Little can be done to totally eliminate construction moisture. However, consideration should be given to providing some time for construction materials to dry before being closed in by wall, ceiling or floor finishes. Consideration should also be given in the design to allowing the construction moisture to escape from the wall to the exterior. For example, wood studs should not be enclosed in a double vapour barrier, such as polyethylene film on one side and EPS insulation on the other. The polyethylene and EPS would limit the opportunity for the wood to dry, and if it can't dry, deterioration will occur.

2.1.2. Interior moisture

Interior moisture comes from the people living in the building—from perspiration, respiration and activities, such as bathing, clothes washing, or cooking. Health Canada recommends an interior relative humidity between 30 per cent and 50 per cent to prevent occupant discomfort and drying of mucous membranes; however, at the higher end of that range, condensation will occur on exterior walls and windows in winter. As a rule, interior moisture, measured as relative humidity, should not exceed 25 per cent to 35 per cent during the heating season to prevent condensation on windows. CSA Standard A440.1-00, "User Selection Guide to CSA Standard A440-00, Windows" recommends the humidity levels shown in Table 2 to minimize condensation on windows.

Where possible, interior moisture should be handled at the source using ventilation fans, such as kitchen and bathroom fans. In fact, there are provisions in the 1995 National Building Code of Canada (NBC) for exhaust appliances that must serve kitchen and bathroom areas.

The control of interior moisture that cannot be removed at the source requires an effective air barrier and an effective vapour retarder. The function of the air barrier and the vapour retarder are sometimes confused, especially as a single material is often used for both functions.

Outside air temperature	Inside relative humidity
-29°C or below (-20°F or below)	Not over 15%
-29°C to -23°C (-20°F to -10°F)	Not over 20%
-23°C to -18°C (-10°F to -0°F)	Not over 25%
-18°C to -12°C (-0°F to 10°F)	Not over 30%
-12°C to -7°C (10°F to 20°F)	Not over 35%
-7°C to 4°C (20°F to 40°F)	Not over 40%

Table 2-Recommended interior relative humidity levels to avoid condensation on windows (from *User Selection Guide to CSA Standard A440-00, Windows*).

The function of the vapour retarder is to resist the flow of vapour caused by a vapour pressure differential. A vapour pressure differential exists if the air on one side of the building envelope contains more moisture than the air on the other side. Nature likes a balance, so the moisture tries to move across the materials in the building envelope to create this balance, until the air on both sides has an equal amount of moisture. Of course, the exterior environmental conditions differ from the controlled interior environmental conditions so such a balance is never effectively achieved and there is always an imbalance or vapour pressure difference that attempts to drive moisture through the building envelope.

The rate of this moisture movement can be slowed by installing materials within the wall assembly that resist the flow of vapour. Materials installed at the side having the greater vapour pressure (usually the inside in a cold climate), such as polyethylene, foil-backed gypsum board and even certain paints, are effective at slowing the movement of vapour. If the vapour retarder is installed at a location in the wall assembly that will be at a temperature lower than the dew point temperature of the air, condensation will occur on the vapour retarder. To prevent this, the vapour retarder must be installed on the warm side of the insulation. In a cold climate, this will be on the interior of the insulation. Caution must also be taken to avoid the *double vapour barrier*, whereby there is another material, also impermeable to water vapour, further to the exterior than the vapour retarder. An example of a common detail where such a situation exists is in a typical window–wall system (see Figure 2), with exterior metal panels that are very good at resisting the flow of vapour.

Moisture migration via vapour diffusion is much less significant than that via air movement. Preventing airflow into or across the building envelope is crucial in controlling interior moisture because of the moisture that is carried within the air.

Water vapour pressure

To understand the concept of water vapour pressure, think about an air molecule rapidly moving around inside a box. Every now and again, that air molecule will hit the side of the box, applying a pressure to the box. Now think of a huge number of air molecules doing the same thing. It is the molecules hitting the side of the box that creates the air pressure. Now add to that air some water molecules. Keep in mind that the molecules are very, very small compared to the size of the box and are very spread out within the box, so the air and water molecules act somewhat independently. The water molecules will hit the side of the box, just like the air molecules, and will create a pressure on the box, adding to the pressure created by the air molecules. The pressure created by just the water molecules is known as the partial pressure of the water vapour or just vapour pressure.

The function of the air barrier is to resist the flow of air across the building envelope, whether that flow is driven by wind, stack effect or fan pressurization. Air barriers must be designed to be airtight, continuous, structural (to resist wind loads) and durable, particularly if they are located within the wall assembly where they are not readily repairable.

For further information on the subject of air barriers see *Guidelines for Delivering Effective Air Barrier Systems,*[5] *Design Considerations for an Air Barrier*[6] and *Air Pressure and the Building Envelope.*[7]

Plumbing leaks are another source of interior moisture and the second most common source of water problems in buildings. Suggestions to avoid plumbing leaks in the building envelope include:

- Keeping pipes out of exterior walls where they may be subject to freezing,

- Designing to facilitate access for servicing, so leaks can be more readily discovered and more readily repaired, and

- Making use of watertight pans and drains (with adequately sized drainage holes) to control water leakage from equipment such as evaporation pans, washing machines or hot water tanks.
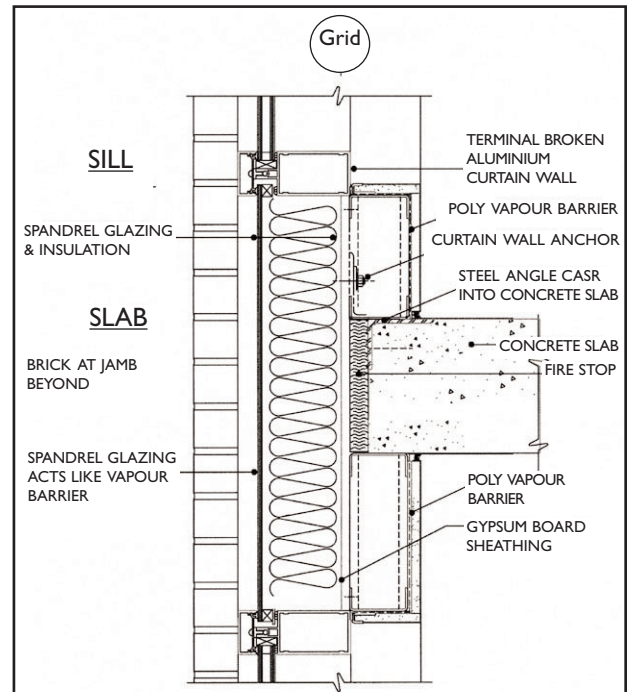
Figure 2-Example of a common detail resulting in a double vapour barrier.

2.1.3. Exterior moisture

The control of exterior moisture requires an effective water-shedding surface and an effective moisture barrier. The term *water shedding surface* refers to the surface of assemblies, interfaces and details that deflect and/or shed the vast majority of water impacting on the wall. The moisture barrier (or water-resistive barrier) is the surface furthest into the wall from the exterior that can accommodate some exterior water without causing damage to interior finishes or materials within the assemblies

Walls at or below grade
Exterior moisture is predominantly rain. However, other sources of exterior moisture include groundwater, surface runoff and melting snow. Most often, these sources affect walls at or below grade. These other sources can be minimized by:

- Keeping the basement above the water table,

- Ensuring the grade around the perimeter of the building slopes away (a five per cent or greater slope is recommended),

- Capping the backfill adjacent to the building with a low-permeability (high-clay content) soil extending 1.5 to 2.0 m (5 to 6.5 ft.)from the foundation to reduce water infiltration adjacent to the foundation,

- Ensuring there is adequate foundation drainage, including a drainage layer or drainage fabric adjacent to the foundation wall tied to a properly designed weeping tile and sump or storm system,

- Using the ability of the soil to absorb water and thus keep the water away from the wall, by minimizing paved areas, which do not absorb water,

- Directing runoff from eavestroughs and downspouts away from the building,

- Keeping wood materials at least 150 mm (6 in.) above grade, and

5 Knight, Kevin D. and Boyle, Bryan J. *Guidelines for Delivering Effective Air Barrier Systems*. Canada Mortgage and Housing Corporation, date unknown.
6 Quirouette, Rick, Marshall, Sandra and Rousseau, Jacques. *Design Considerations for an Air Barrier System*. Canada Mortgage and Housing Corporation, 2000.
7 Quirouette, Rick. *Air Pressure and the Building Envelope*. Canada Mortgage and Housing Corporation, to be published 2004.

- Placing a moisture barrier (asphalt coating, asphalt-impregnated building paper or closed-cell gasket) between wood framing and concrete or masonry and/or ensuring all wood in contact with concrete is pressure-treated.

Where hydrostatic pressure may develop in the soil (i.e., the groundwater table is above the level of the footings), it will be necessary to waterproof the foundation wall. Waterproofing is distinct from dampproofing, which only resists the diffusion of water vapour; waterproofing resists the movement of liquid water.

2.1.4. Ice dams

Melting snow does not only affect walls at or below grade. Sometimes melting snow on the roof can affect walls. This most often happens when ice dams form.

Snow
Thin ice slab under snow
Trapped water
Eave protection run 12" (300 mm) beyond inside face of stud line
Melted snow runnig down underside of sheathing
Melted snow
Water carried to cavestrough
Ice
Ice in eavestrough
Inside face of wall
Insulation
36" (900mm) min.
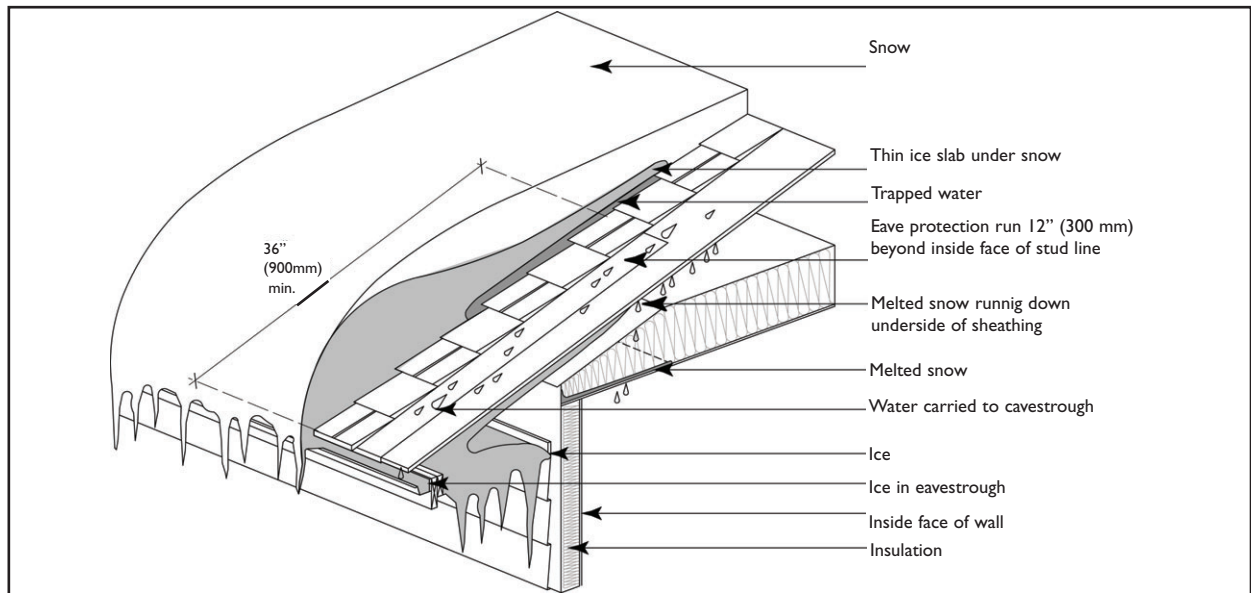
Figure 3-Formation of an ice dam (from *Air Quality in Interior Environments*)

Ice dams are formed when heat from inside the building (and to a lesser extent heat from solar radiation) causes snow on the roof to melt. The melted snow runs down the roof to the cold edge, where it freezes again. As the process continues, layers of ice are built up, forming an ice dam. It is called an ice dam because the ice blocks further melt water from reaching the eavestrough. As a result, a pool of water can build up behind the ice, eventually backing up under the shingles, causing water damage to the roof and possibly to the interior walls (see Figure 3). Ice dams can be prevented by keeping the space below the roof as cool as possible, by adding insulation and especially by preventing warm air from leaking into the attic space.

The damage caused by ice dams can be minimized by installing an ice and water shield around the perimeter of the roof. In fact, the National Building Code requires eave protection to extend a minimum of 900 mm (3 ft.) up the roof slope from the roof edge for any roof constructed with shingles, shakes or tiles. Further, the extent of the eave protection must be at least 300 mm (12 in.) inside the inner face of the exterior wall.

There are exceptions where eave protection is not required, including over unheated spaces, where the roof overhang to the inner face of the exterior wall exceeds 900 mm, on roofs with a slope of 1:1.5 or greater and in regions with 3,500 or fewer degree-days. Heating cables can also be used to help melt the ice and create a clear drainage path to the eavestrough. However, this approach is only recommended as a remedial measure.

The removal of ice once it has formed is not an easy task.[8] It is far better to prevent the buildup of ice on the roof in the first place.

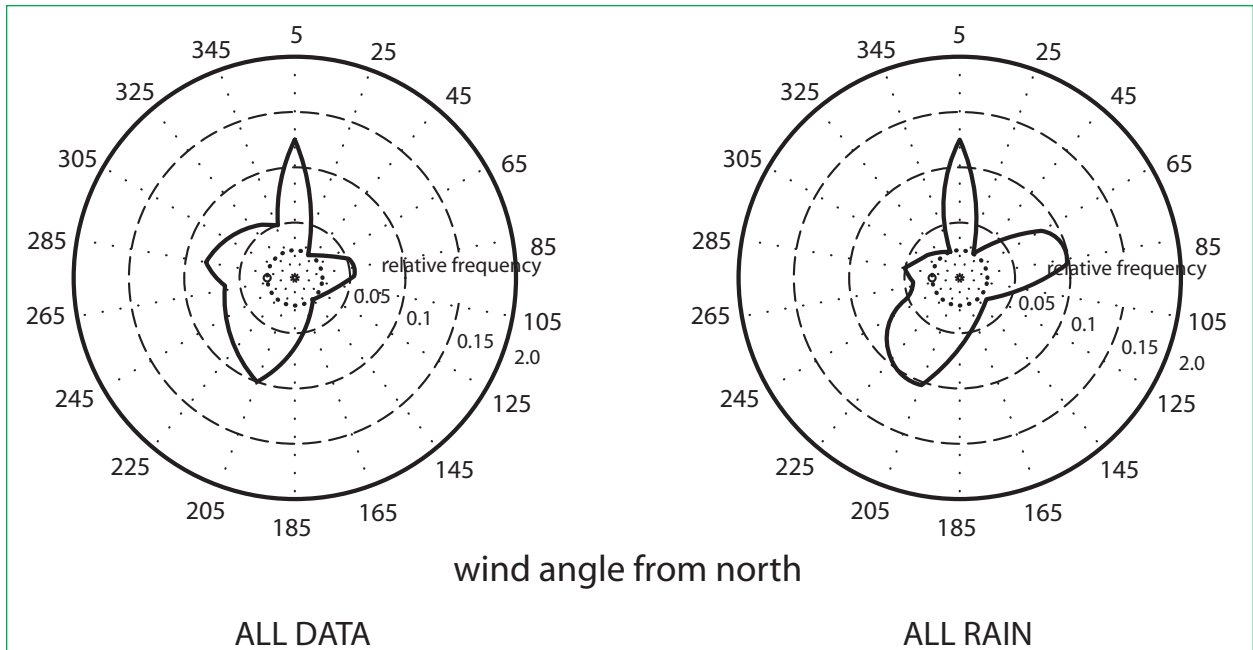8 "Removing Ice on Roofs", *About Your House*.

Figure 4-Wind roses for Ottawa, Ont. showing wind direction for all wind data and for wind during rain

3. RAIN

All the CMHC *studies* mentioned earlier identified rain as the major source of moisture problems in buildings, particularly within the first few years of occupancy. Before different rain-penetration control strategies can be developed, it is necessary to understand some of the physics behind rainfall, particularly since the amount of rain that actually hits a building varies over its surface.

The wind-flow pattern around a building affects how much rain is deposited at any location on the building. Wind direction is a factor, as windward-facing walls will be subject to more driving rain, while leeward walls will be protected.

Wind will typically blow most often from the same direction. Often, the preferred direction of strong winds accompanying rain is significantly different than the general prevailing wind direction. The wind roses in Figure 4 illustrate this phenomenon. The wind rose shows the relative frequency of wind from the cardinal directions. The further the line from the centre of the rose, the more frequent is the wind from that direction. Note the differences between the wind rose for all winds (including wind during rain) and for only the winds accompanying rain. Designers may want to consider the direction of wind, particularly wind during rain, and perhaps adjust their sophisticated designs using strategies more tolerant of wetting on certain building orientations. Unfortunately, wind roses are not routinely published by Environment Canada and are not available for many cities, so such information is not always readily available.

Mean, or average, wind speeds are also consistently greater during rainy hours than during all hours. This indicates that the designer should not base design considerations solely on published mean wind speeds; instead, the designer should consider the mean wind speed during rain. On the other hand, extreme wind speeds are consistently smaller for rainy hours than for all hours. This is likely because there are more hours when it is not raining than when it is raining. An "extreme" is a rare event; therefore an extreme wind speed is statistically more likely to happen when it is not raining. While extreme wind speeds should be considered in structural design, designers should not base decisions about controlling rain penetration on extreme wind speeds.

The aerodynamics of wind flow around buildings also cause different areas of a single wall to be subject to different wind forces, especially in larger buildings. As wind parts to flow around and over a building, a cushion of high-pressure, but relatively still, air is created at the centre of the wall. This "dead spot" protects this area of the wall from driving rain. Wind accelerates around the side and top edges of the building, driving rain more forcefully against these parts of the wall, even driving rain upwards at the parapet. Figure 5 shows a typical wetting pattern for a multi-storey building. Studies have shown that these edges can receive more than 20 times and as much as 50 times more rain than the centre of the wall. This discrepancy in wetting intensity is greater for taller and narrower buildings.

Rain-wetting patterns on a building face also depend on the finishes used. Porous surfaces, such as masonry, absorb much of the water that strikes them and they release this water more slowly, through diffusion. Impervious claddings, such as metal and glass curtain walls, readily become covered with a film of water that flows down the wall surface. The accumulated flow can be significant by the time it reaches the bottom of a tall building. The downward flow is concentrated at vertical irregularities.
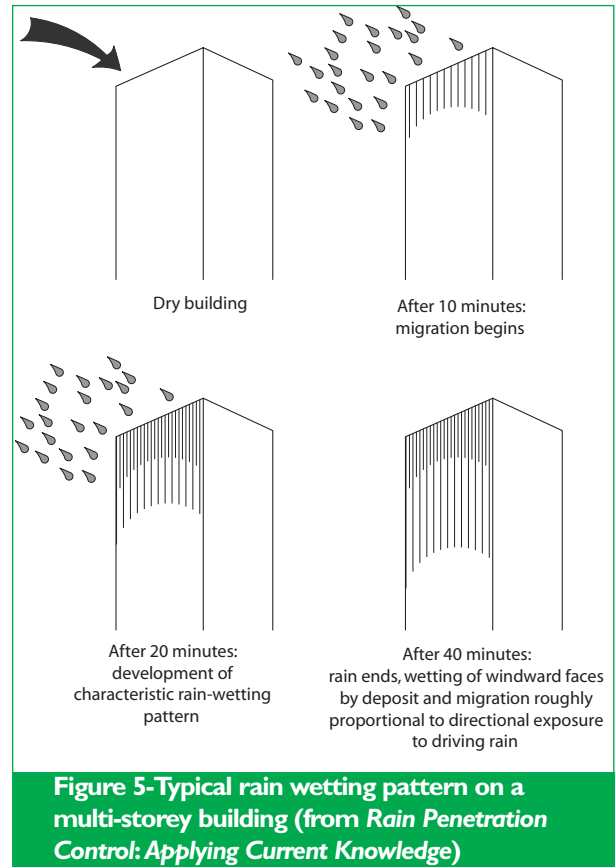
Dry building

After 10 minutes: migration begins

After 20 minutes: development of characteristic rain-wetting pattern

After 40 minutes: rain ends, wetting of windward faces by deposit and migration roughly proportional to directional exposure to driving rain

Figure 5-Typical rain wetting pattern on a multi-storey building (from *Rain Penetration Control: Applying Current Knowledge*)

Experiments have shown that the flow in narrow vertical depressions (i.e., joints) in a wall face can be many times greater than the average over the wall. Wind flow around corners and parapets can also draw water laterally and even upwards. This lateral flow can bring water to vertical joints, which are often quite vulnerable to leakage.

Understanding wetting and wind patterns, therefore, suggests some design solutions and precautions regarding rain penetration. Particular care should be paid to providing rain-resistant assemblies at the upper edge and corners of multi-storey buildings, and employing features such as cornices to direct rain off the building face. The design and construction of joints is critical in preventing rain penetration. Roof overhangs have long been effective in reducing rain exposure of low buildings, as shown by the B. C. Survey, which found a strong relationship between the width of eave overhangs and decreased frequency of rain penetration. Sloped roofs also ease windward wall wetting by reducing lateral wind, and hence water movement, at the wall–roof intersection.

3.1. Openings

Openings that permit the passage of water exist throughout the face of the building envelope—material pores, cracks, joints between materials or elements, etc. One approach to management of rain penetration is to locate both the water-shedding surface and the moisture barrier at the exterior of the wall. This approach, the *face-seal approach*, attempts to eliminate all openings at the exterior surface of the wall. The word attempt is used because it is impossible to completely eliminate all openings, especially over the long term. For all openings to be eliminated, the workmanship must be perfect, which is difficult to achieve given fabrication or job site inaccuracies and environmental conditions during construction. Further, even a perfectly constructed joint will suffer degradation over time due to thermal stresses, ultraviolet radiation, acid rain, etc.

Instead, better approaches to the design of the building envelope look to control the forces causing rain penetration.

3.2. Forces causing rain penetration

The forces that can move rainwater on the surface of a wall through openings are:

- Kinetic energy

- Capillarity and surface tension

- Gravity

- Pressure differences

Figure 6-Rain penetration due to the kinetic energy of the raindrops.

3.2.1 Kinetic energy

Kinetic energy refers to the momentum of wind-driven raindrops. This force will carry raindrops directly through openings of sufficient size (see Figure 6). The raindrops can even be carried upwards. However, if there is no through path, rain cannot penetrate deeply into the wall by this mechanism alone. Thus, the use of cover battens, splines or internal baffles can protect intentional openings, such as drains and vents, from rain penetration by kinetic energy of the raindrops.
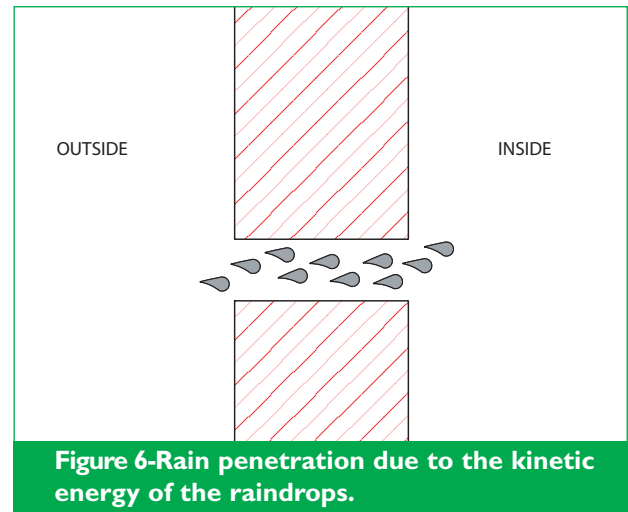
3.2.2. Surface tension and capillarity

Water molecules are attracted to each other and to the surfaces near them. Cohesion refers to the molecular forces within the water and adhesion refers to the attraction of the water to adjacent materials (which varies with different materials). When water is dropped onto a surface, cohesion, adhesion, air pressure and gravity combine to determine the shape of water droplets or the thickness of the water film.

Figure 7-Water will progress within the crack until it reaches the capillary-rise height (DH) (from *Migration of Water by Capillarity*)

The forces of cohesion and adhesion also cause water to be drawn into a tube, crack or capillary, such as is found in porous materials like masonry. These forces can even draw water in an upward direction against the force of gravity. This phenomenon is referred to as capillary suction, capillary action or just "capillarity." The height to which the water will rise depends on the diameter of the capillary (the smaller the diameter, the greater the rise) and the material of which it is made (smooth materials, such as glass and aluminum, show the greatest rise).
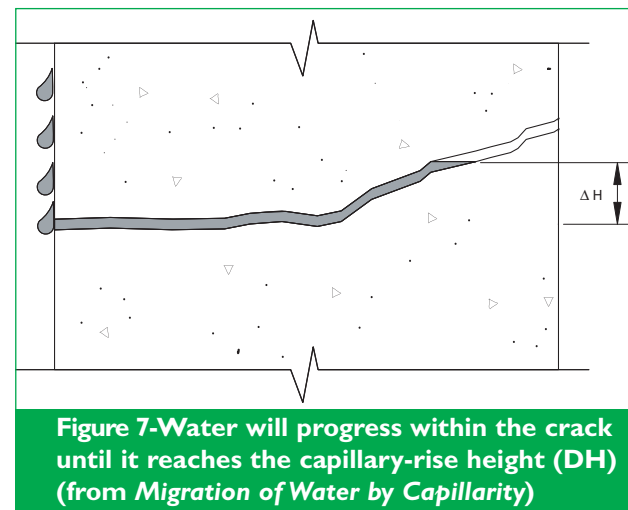
Water will be drawn into a crack or joint until it reaches the capillary-rise height for the given crack width and material (as shown in Figure 7). As long as there is a source of water, water will travel the full length of a horizontal capillary. The capillarity force is broken when the crack meets a much wider transverse space, such as the air space behind the masonry in a veneer wall or a capillary break (see Figure 8). A 10-mm (0.4 in.) gap is sufficient to interrupt capillarity in all common construction materials.[9]

9 Patenaude, Armand. *Migration of Water by Capillarity*, Canada Mortgage and Housing Corporation, 1993.

The adhesive and cohesive forces even allow water to cling to and flow along the underside of horizontal surfaces, such as soffits. Providing a drip on the underside of projections and overhangs is a common detail to break surface tension and prevent water from collecting or reaching the building face (see Figure 9).

Capillarity is usually the dominant force in water penetration of masonry. Capillarity will cause water to be drawn into masonry, even against gravity and an air pressure gradient, until the material is saturated. Other forces, such as wind pressure, gravity or kinetic energy may drive this absorbed water further through the wall. While capillary forces can act all through brick, testing of brick walls shows that most water penetration occurs at mortar joints, primarily through cracks at the mortar–brick interface. The water that has penetrated to the back of the masonry can be projected across the air space due to air pressure differences. Therefore, the air space must be of sufficient width to prevent this problem; however, further research is needed to determine scientifically what is the minimum acceptable air space width to prevent this. Adhesive forces can also cause water that penetrates masonry to flow across brick ties (or mortar droppings) to the inner wythe (possibly the air barrier).
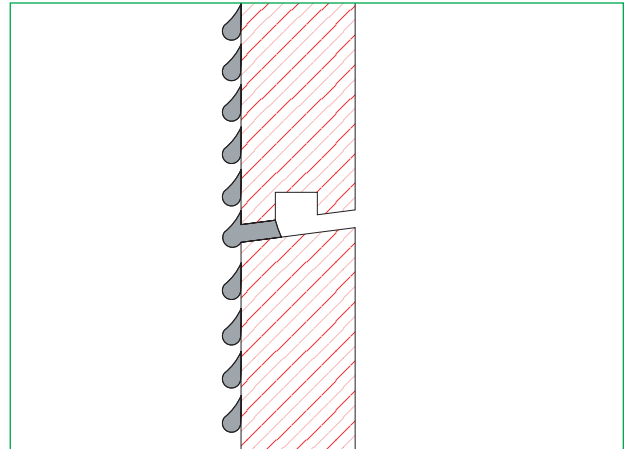

Figure 8-Example of a capillary break in a joint.

Capillarity is also a factor in the design of windows. Consider this example (see Figure 10). The height of water in its natural state on a piece of pine is 3.4 mm (0.13 in.). The gap between the sash and frame of a pine window, therefore, should be at least 6.7 mm (0.26 in.) to avoid pine/pine adhesion. If the distance is greater than 6.7 mm and the space is filled with water, as soon as the water supply ceases, the water will drain off and it will attain its natural height of 3.4 mm. If the distance is less than 6.7 mm, capillarity forces will retain that water in the space and no drainage will occur; such prolonged wetting will lead to deterioration.
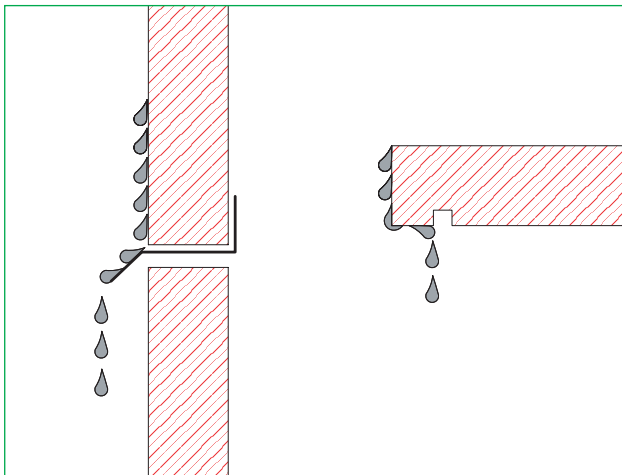

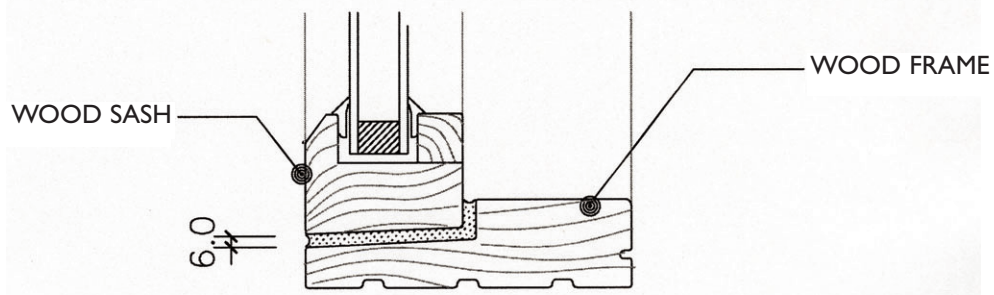**Figure 9-Two examples of drip edges.**

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Figure 10-Example of water trapped between the sash and frame of a wood window due to capillarity (from *Migration of Water by Capillarity*)

As another example, consider the thickness of shims beneath a sealed glazing unit in a vinyl window (see Figure 11). The maximum vertical distance allowing adhesion between glass and PVC is 6.8 mm. Therefore if the shims are 6.8 mm or thinner, water will not drain out of the glazing cavity and will cause failure of the sealed unit. Note that the typical thickness of shims is 1/4 in, or 6.4 mm. This problem might be avoided by specifying a thicker shim. A similar phenomenon may occur if the window's weep holes are not large enough. The distance allowing adhesion between two aluminum surfaces (natural finish) is 6.7 mm. If the weep hole is smaller than this, drainage will not occur naturally (i.e., without the application of another force to overcome the capillarity). Again, specifying a minimum size of weep hole may help prevent this problem.
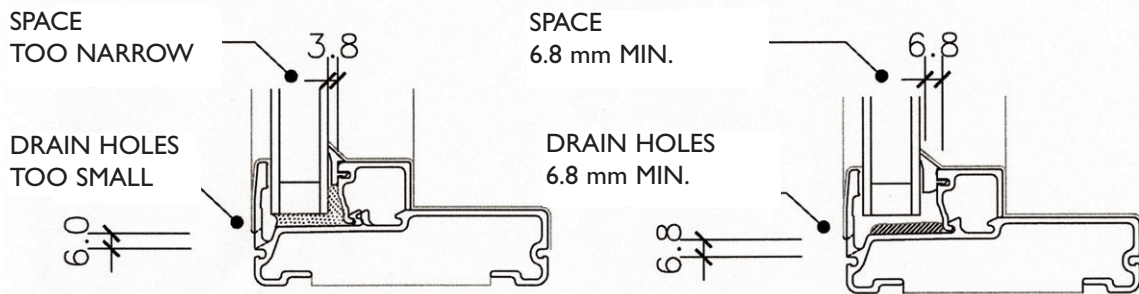

Figure 11-Window shim thickness and size of weephole can affect drainage of glazing cavity (from *Migration of Water by Capillarity*)
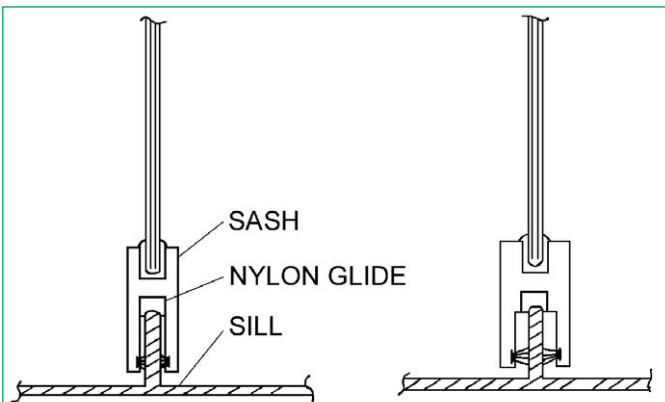

Figure 12-A wider sash track will help reduce capillary rise and water infiltration of sliding windows (from *Migration of Water by Capillarity*)

As windows have been identified as one of the key causes of water penetration of walls, consider one last window example. The bottom rail of a sliding window should be designed to minimize capillarity, as shown in Figure 12. With most current window designs, water infiltration in sliding windows is often generated by capillarity due to inadequate gap dimensions. Review window shop drawings carefully before accepting a manufacturer's product.

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As another example of the effect of capillarity, consider a finished basement, with a wood-framed wall on the interior of the basement foundation wall. Tests conducted at the Alberta Home Heating Research Facility[10] have shown that standing wood-framed walls off the floor by a small amount reduced the amount of moisture absorbed by the bottom plate and allowed moisture (perhaps due to a crack in the basement wall) to escape from behind the panel more easily.

3.2.3. Gravity

Dealing with water movement due to gravity may seem elementary—simply avoid creating inward- and downward-sloping leakage paths or areas where water can pond or overflow drainage paths (see Figure 13). However, leakage due to gravity action still occurs all too frequently, sometimes due to errors in design or construction and sometimes due to cracks or other openings that develop after construction. However, gravity can be used to advantage in controlling rain penetration of walls. An air space immediately behind the wetted surface prevents water from flowing further inwards. Water reaching this space will cling to the inner face of the outer wythe and will run down the surface. Flashings can then be used to intercept and direct the flow of water to designed drainage paths.
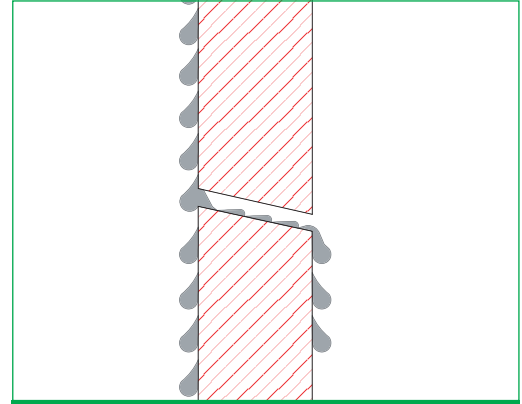
Figure 13-Gravity causing water infiltration.

It is also important to keep the concept of shingling in mind when designing to resist water penetration due to gravity; that is, overlapping construction materials so that the upper layer is overlapped on top of the lower layer. This is the way roof shingles work. One area where the concept of shingling is often forgotten is window installation. Most windows, particularly in Western Canada, now incorporate nailing flanges, rather than brick molds and drip caps. Typically, a wide strip of building paper is installed on the sheathing around the window openings, folded over at corners to speed and simplify installation. The folds create troughs that collect water. After the windows are installed, the building paper is lapped over the flanges and over the paper strip. This is appropriate at head and jambs, but at the sill, the lap leads water behind the building paper and into the wall. In some cases, flanges are taped or caulked to the paper strip with a corner bead along the edge.

10 Forest, Tom W. and Ackerman, Mark Y. *Basement Walls That Dry*. Canada Mortgage and Housing Corporation, 1999.

Figure 14 shows a better installation approach. Sheathing paper is installed under the window opening and then the sill of the window opening is covered with a sill membrane to prevent water that might leak through the window from entering the wall system below. This sub-sill drainage is a key benefit in preventing possible wetting of walls.

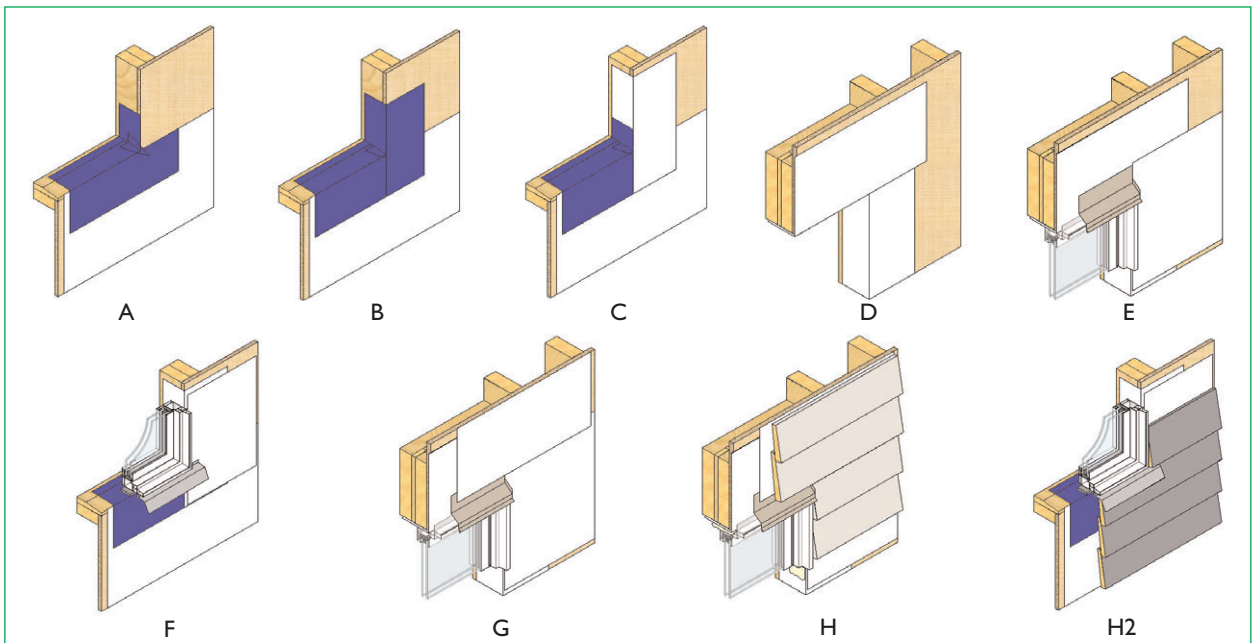A separate *corner membrane* is used to ensure the corner is watertight.

Figure 14-Window installation with nailing flange showing proper overlapping of sheathing paper and flashing (from *Water Penetration Resistance of Windows*.)
A
A separate *corner membrane* is used to ensure the corner is watertight.
B
Next, the jamb membrane is added such that it overlaps the sill membrane creating a shedding surface over the sill membrane.
C
Sheathing paper that extends to the head of the window is then added over the jamb membrane.
D
A strip of sheathing is added at the head of the window overlapping the jamb sheathing again to create a shedding surface.
E, F
The window is then set into the opening on shims ans secured into the opening by nailing through the nailing flange. Sheathing paper is installed at the jambs, overlapping the nailing flange, extending from the above the window head to below the windowsill. Flashings (or drip edges) are then installed at both the head and sill.
G
Another strip of sheathing paper is required at the head of the window to ensure water penetration to the sheathing paper is directed to the front of the drip edge.
H, H2
Lastly, the siding can be installed