Rainwater management on building facades: theories, principles and research

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Rainwater Management on Building Facades: Theories, Principles and Research

by

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National Research Council Canada, Ottawa

for

Building Enclosure Council Atlanta Feb. 19th, 2008

<u>" It is breezy this morning", the waiter said, shivering…</u>

"Tell them what you are going to tell them…"

4 Blocks:

1. Major building envelope damage in the 90s due to rain penetration
2. Review of wall design approaches for rain penetration control
3. Review of selected research findings
4. Wrap Up

Looks Great Here!

But What Happened?

Courtesy of Morrison Hershfield

Premature Deterioration of Sheathing Board

"Once Upon a Time… Some Leaky Condos

- Low rise residential buildings less than 10 years old
- Many types of claddings: traditional stucco, vinyl siding, wood siding
- Coastal climate of BC Lower Mainland

Field Survey of Building Envelope Failures in BC Lower Mainland

Commissioned by Canada Mortgage and Housing Corporation, conducted by Morrison-Hershfield

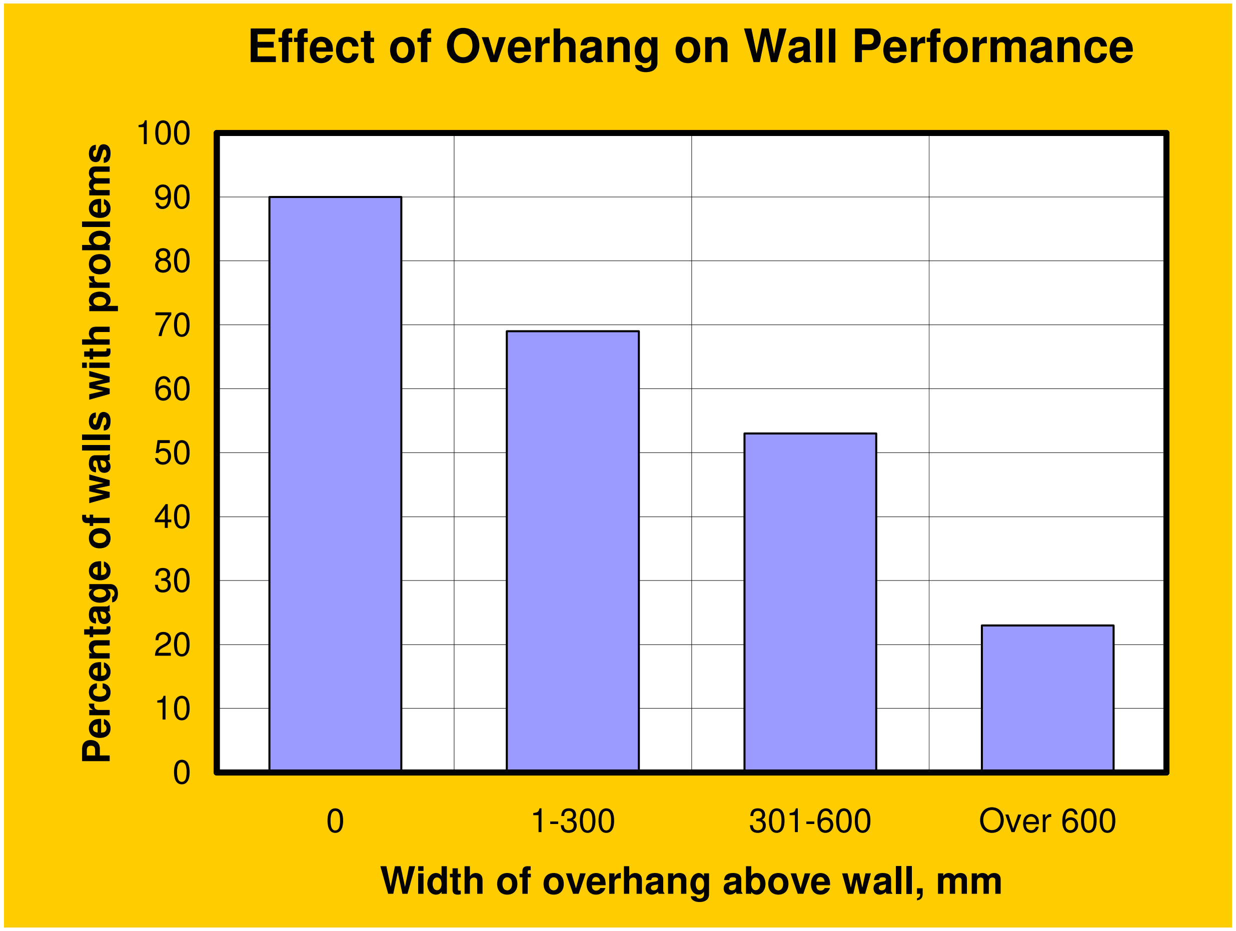
- 46 buildings surveyed; 37 buildings with problems
- Stucco, vinyl and wood siding
- Building paper and housewrap
- Plywood and OSB
- Polyethylene vapour barrier
- Windows: aluminum frames without thermal break, frame joints unsealed

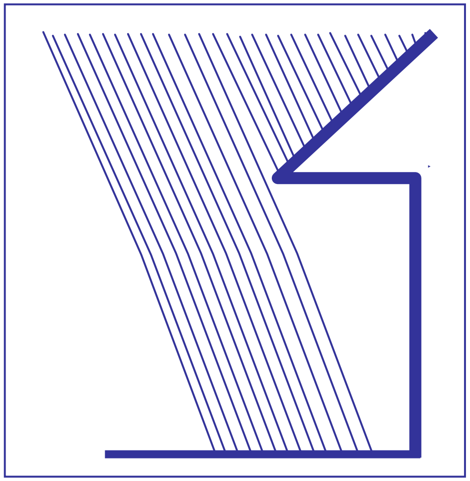
Observations

- Water came from outside (rain); not from inside (condensation)
- Problems related mostly to penetrations into the walls:
  - windows
  - decks; balconies
  - balcony railings
- Rain water bypassed the cladding and the second line of protection (WRB membrane), reached the moisture-sensitive materials of the assembly, and did not drain or dry fast enough to prevent initiation of deterioration

Details not designed and built by others...

Sheltering Effect of Overhangs





Windows and Window-Wall Junctions

- Window frames corners not sealed
- Wall/window interface not sealed
- Poor flashing installation at head or sill
- Poor sheathing membrane installation

Other Junctions

- Flashings
  - saddle flashing at guardrail/wall junction
  - parapet cap flashing
- Deck/balcony/walkways
  - interface between waterproof membrane of deck and wall

Observations

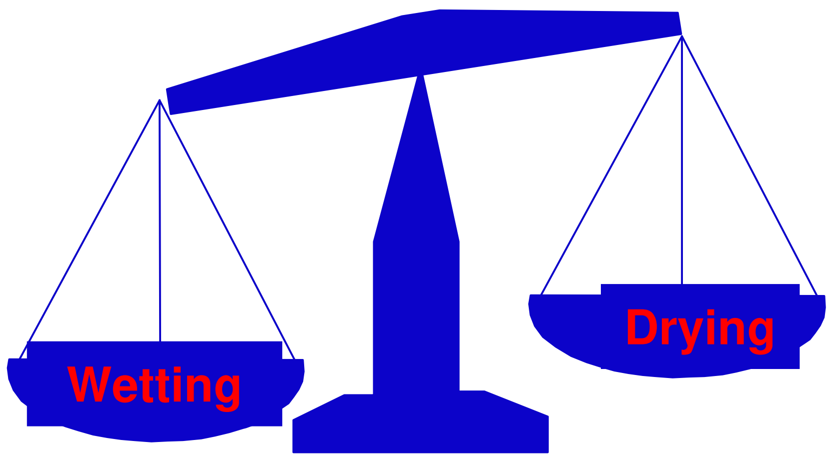
Stucco-clad walls had proportionally more defects than other systems

- face seal approach commonly used
- absorptive cladding

The CMHC Survey in BC- Why Did Walls Fail?

Inappropriate balance between wetting and drying mechanisms

- Exposure - walls got wet
- Details let water in
- Sensitivity of assemblies – inability to drain or dry



Rain Penetration Problems Occur in Less Wet Climates as Well

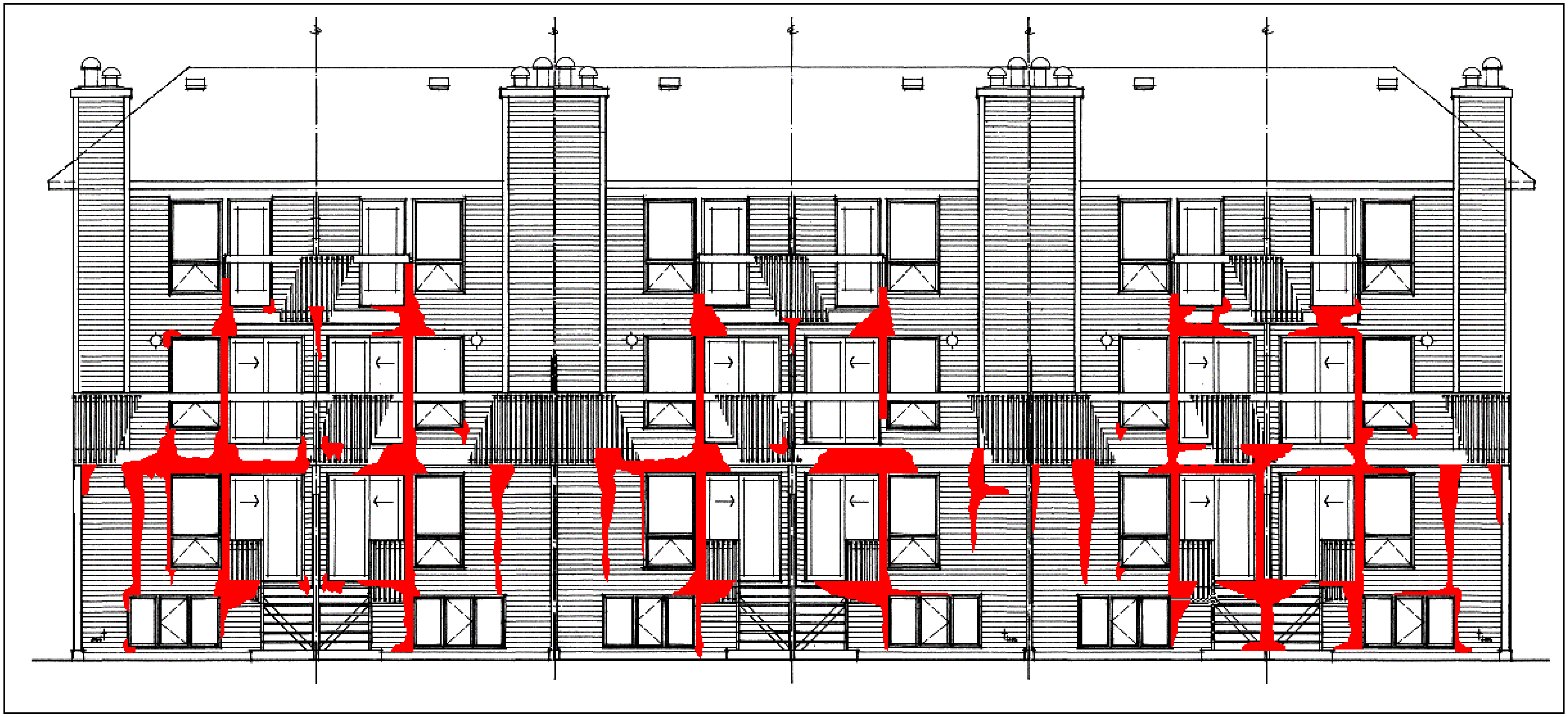
1999 (Vlooswyk et al.) – "Wall Moisture problems in Alberta Dwellings", CMHC Report

2001 (Chouinard, Lawton), "Rotting Wood Framed Apartments – Not Just a Vancouver Problem", 8th Building Science and Technology Conference, Toronto

"Unusually wet environments increase risk, however, where water passes the moisture barrier, extensive damage is likely to occur even in moderate climates"

Field Investigation in Ottawa area

Water Staining – Sheathing Survey



The "6 D" Approach to Rain Penetration Control in Walls

- The 6 D Approach
  - Deflect
  - Drain
  - Dry
  - Durable
  - "*Deal with air pressure difference*"

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Sequencing … Think 3D Think cross trading…

"Tell them what you are going to tell them…"

4 Blocks:

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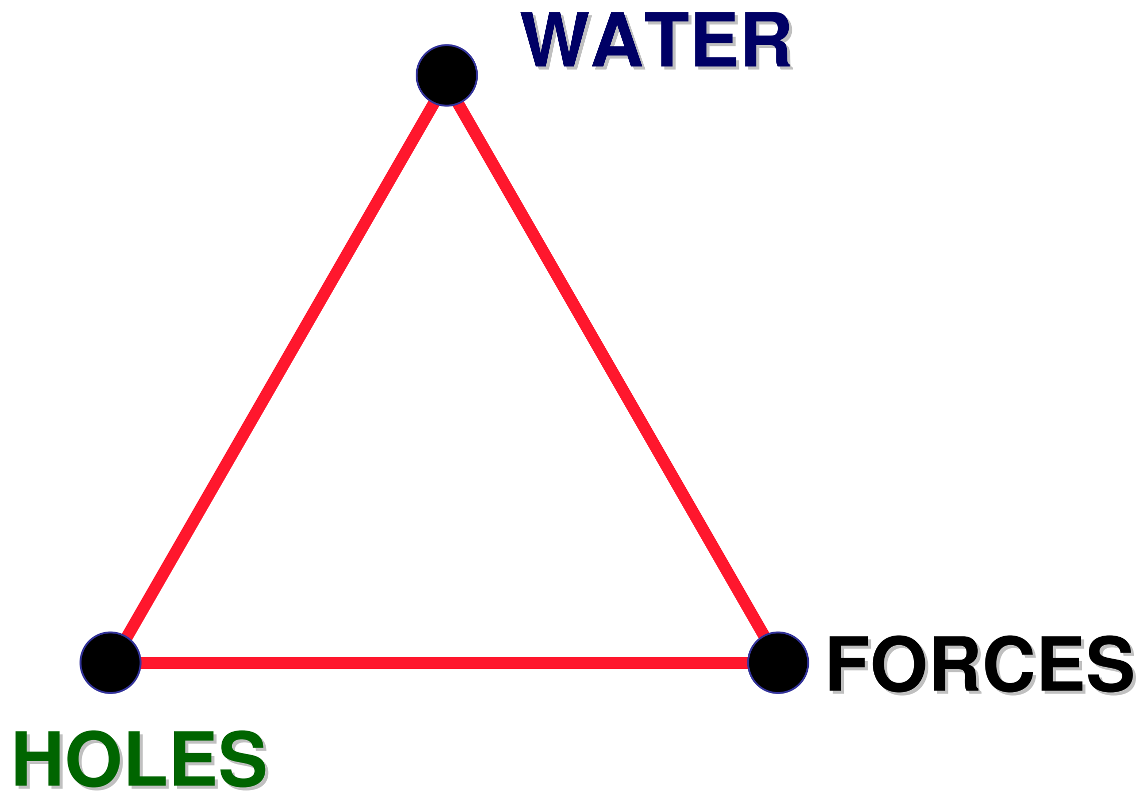
Three Conditions Required for Water Ingress



Over time, design strategies focused on the control of some of these conditions

Single Element Protection

Mass walls (masonry)

- Masonry is porous
- Thickness of masonry provides large storage capability and long path for water ingress
- Rain deflection on building facades was extensive (e.g. deep overhangs
- As structural design evolved toward non-load-bearing facades, masonry walls were built thinner and that prompted a change in design to control rain ingress (i.e. cavity walls)

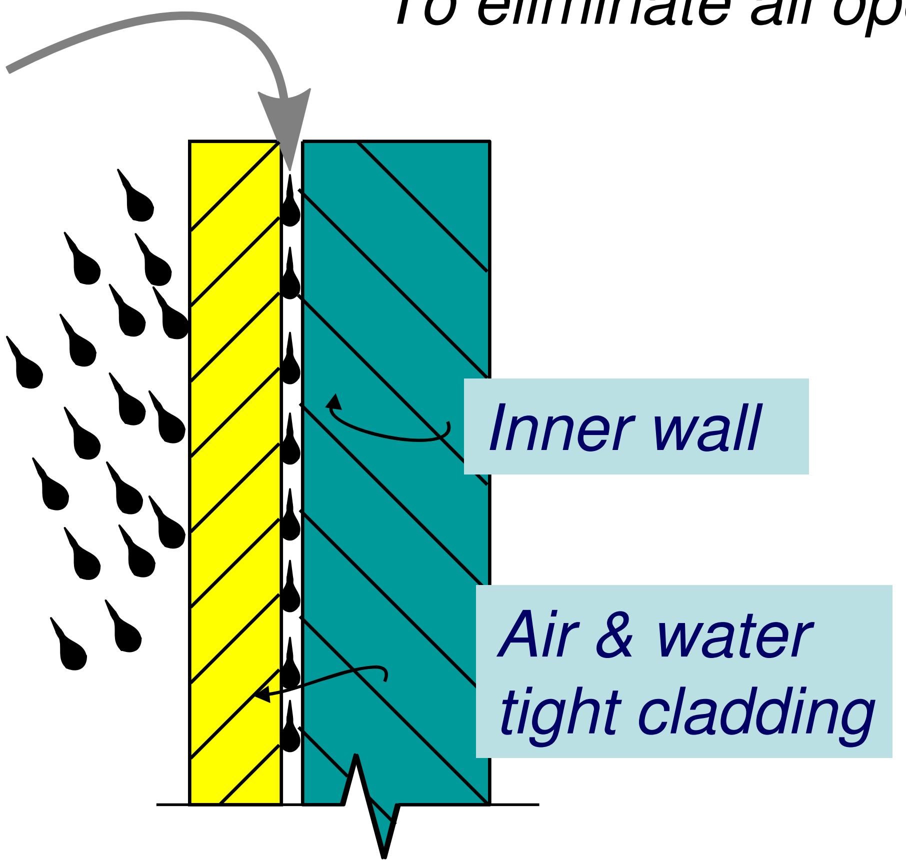
Parliament building Ottawa

Single Element Protection

Face Seal Approach: Control the Holes

Barrier wall; Surface seal barrier wall; face seal wall

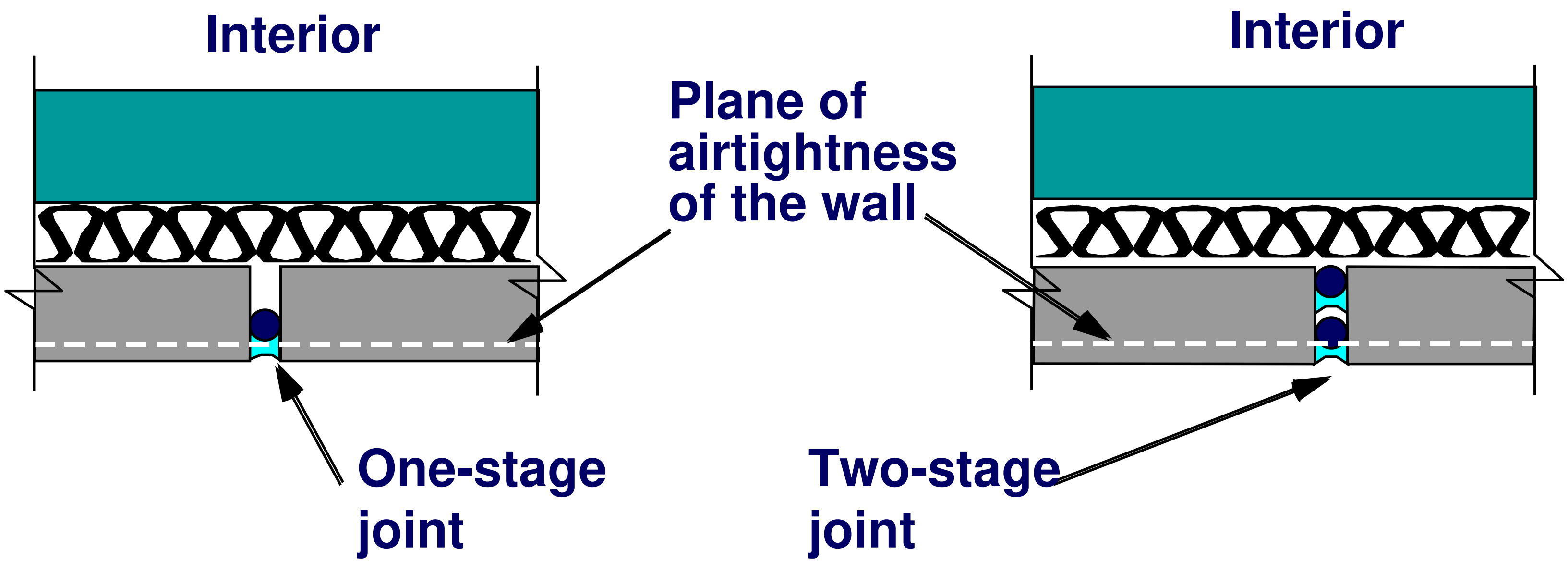
Goal: PERFECTION
To eliminate all openings in the cladding system



- *Cladding assembly is the ONLY line of defense against rain penetration (and air leakage)*
- *No provision for water evacuation once it gets in.*
- *High on-going maintenance; reliance on exterior seals*

Face-seal Approach

Face-seal approach applied to a precast concrete panel cladding wall

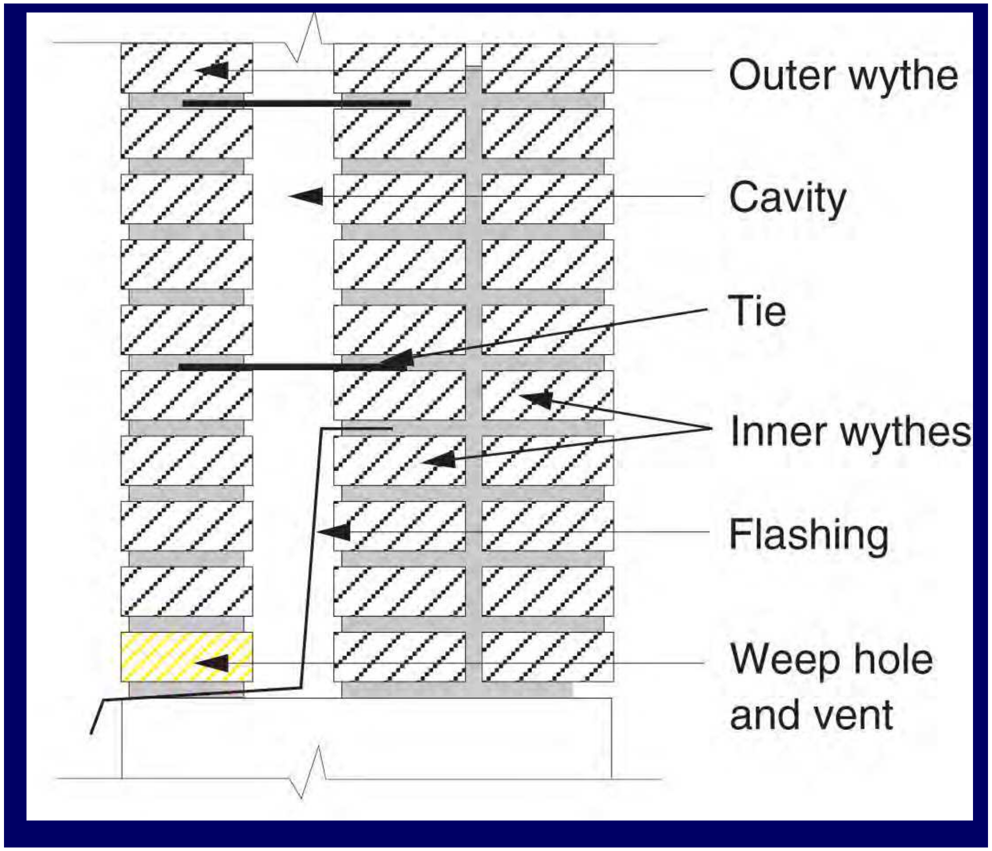


Horizontal section

Multiple –Elements of Protection

Cavity walls

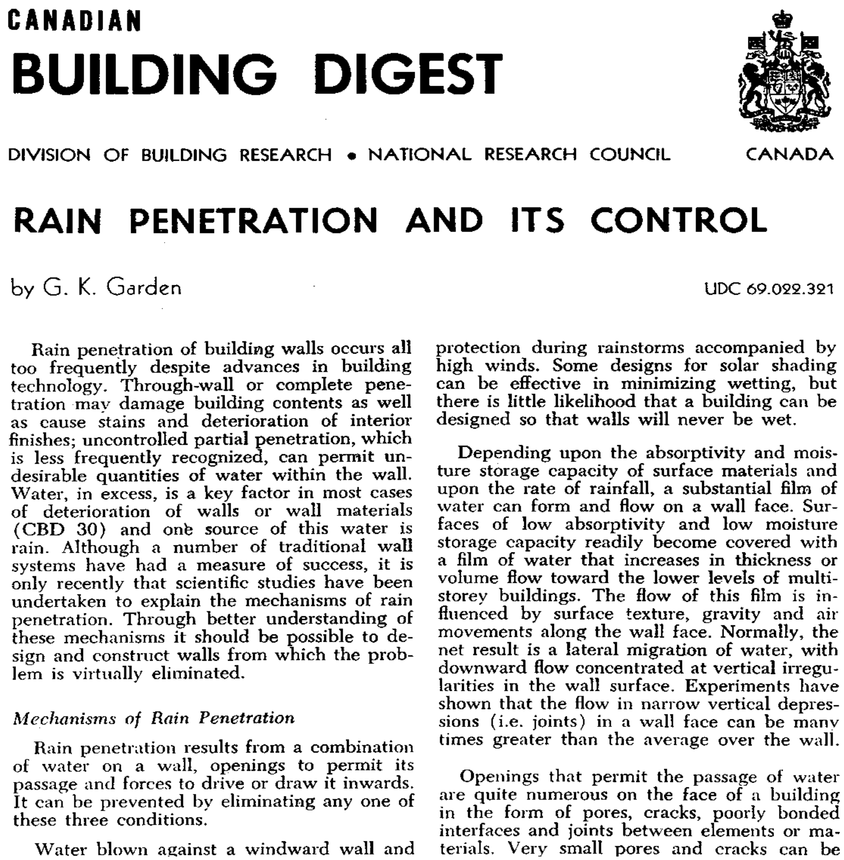
- Started with masonry, where two layers of masonry were separated by a large air space, flashed and drained at bottom
- Brick veneer with a 1 in. air space, moisture barrier, flashing and weepholes
- Siding installed on vertical furring strips over a moisture barrier, with flashing drained outside
- Includes a drainage space, a capillary break and a moisture barrier
- Includes some redundancy, and control some of the forces



Then the Open Rain Screen was Born…

- In 1962 Norwegian Building Research Institute published *Curtain Walls*, in which Mr. Birkeland wrote:
  - "*The only practical solution (to the problem of water leakage) is to design the exterior rain-proof finishing so open that no super-pressure can be created over the joints… The surges of pressure created by the gusts of wind will then be equalized on both sides of the exterior finishing.*"
- In 1963 Kirby Garden at NRC Canada wrote Canadian Building Digest *Rain Penetration and its Control*.
  - Control of ALL FORCES acting on exterior wall
  - Importance of air leakage control to gain rain penetration control and pressure equalization
- In 1971 the Architectural Aluminum Manufacturers Association published "The Rain screen Principle and Pressure-equalized wall design

Rain Screen Walls



CANADIAN

BUILDING DIGEST

DIVISION OF BUILDING RESEARCH • NATIONAL RESEARCH COUNCIL CANADA

RAIN PENETRATION AND ITS CONTROL

by G. K. Garden UDC 69.022.321

Rain penetration of building walls occurs all too frequently despite advances in building technology. Through-wall or complete penetration may damage building contents as well as cause stains and deterioration of interior finishes; uncontrolled partial penetration, which is less frequently recognized, can permit undesirable quantities of water within the wall. Water, in excess, is a key factor in most cases of deterioration of walls or wall materials (CBD 30) and one source of this water is rain. Although a number of traditional wall systems have had a measure of success, it is only recently that scientific studies have been undertaken to explain the mechanisms of rain penetration. Through better understanding of these mechanisms it should be possible to design and construct walls from which the problem is virtually eliminated.

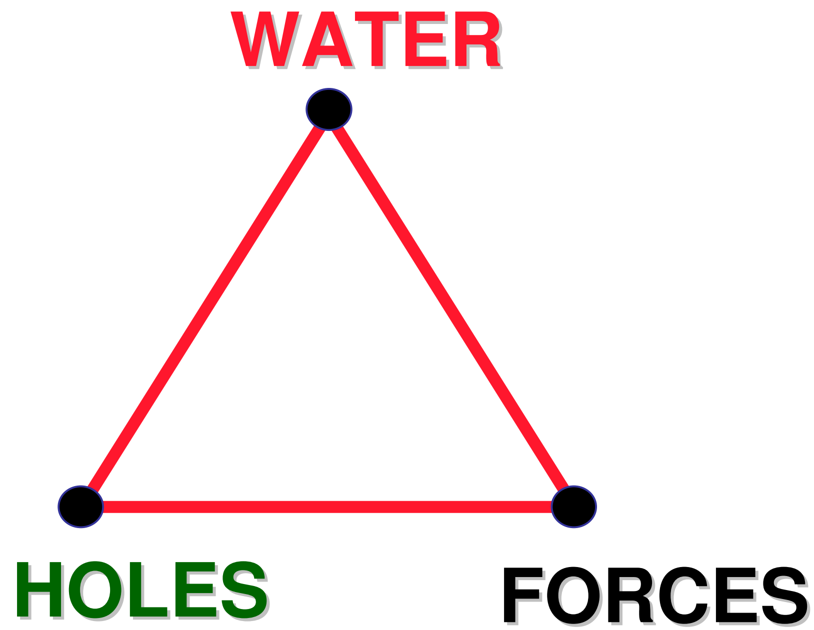
Mechanisms of Rain Penetration

Rain penetration results from a combination of water on a wall, openings to permit its passage and forces to drive or draw it inwards. It can be prevented by eliminating any one of these three conditions.

Water blown against a windward wall and protection during rainstorms accompanied by high winds. Some designs for solar shading can be effective in minimizing wetting, but there is little likelihood that a building can be designed so that walls will never be wet.

Depending upon the absorptivity and moisture storage capacity of surface materials and upon the rate of rainfall, a substantial film of water can form and flow on a wall face. Surfaces of low absorptivity and low moisture storage capacity readily become covered with a film of water that increases in thickness or volume flow toward the lower levels of multistorey buildings. The flow of this film is influenced by surface texture, gravity and air movements along the wall face. Normally, the net result is a lateral migration of water, with downward flow concentrated at vertical irregularities in the wall surface. 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.

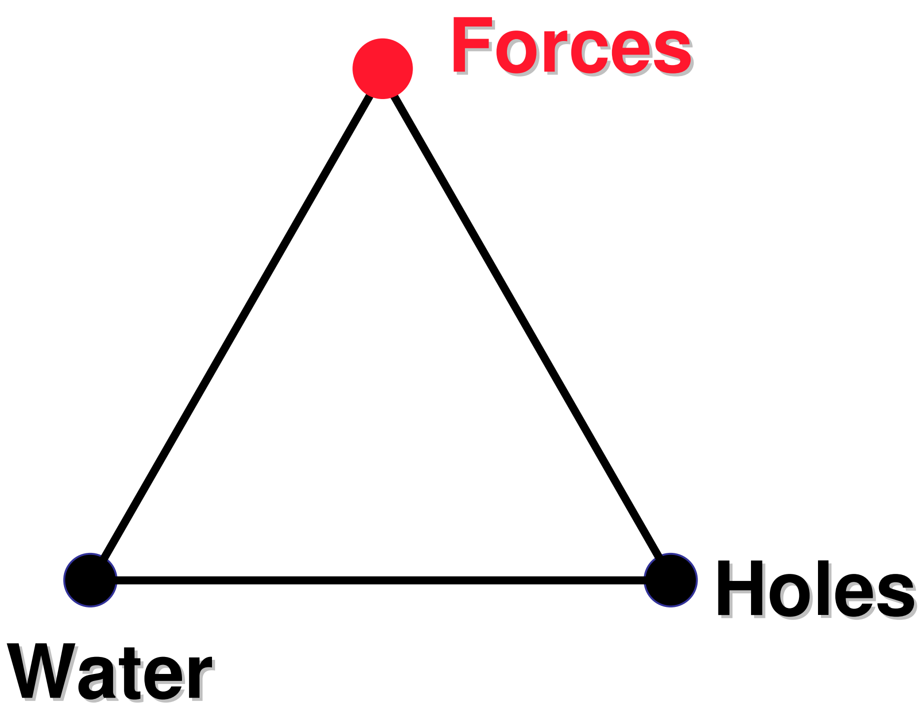
Openings that permit the passage of water are quite numerous on the face of a building in the form of pores, cracks, poorly bonded interfaces and joints between elements or materials. Very small pores and cracks can be



Premises:

- ***All holes cannot be eliminated***
- ***Water may enter past the cladding***
- ***Need to manage all forces, and need for a second protection***

Reduce Forces Acting on Cladding



- Gravity
- Surface tension
- Capillarity
- Rain drop momentum
- *Air Pressure Difference*

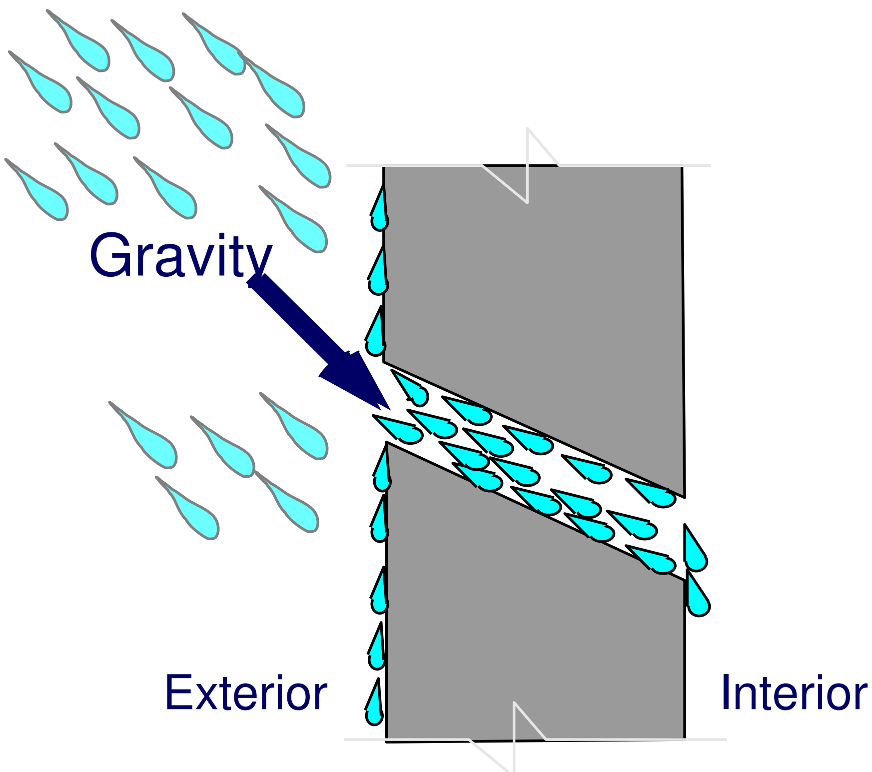
•Cavity wall

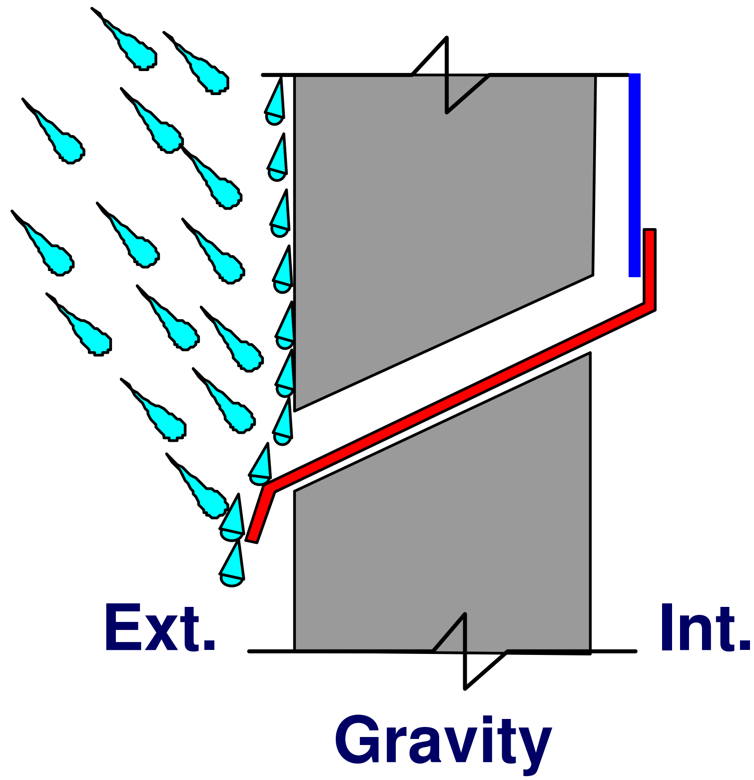
•Rain screen; Drain screen

•Pressure-equalized; Pressure-modulated; Pressure-moderated;Pressurized rain screen

•Ventilated rain screen

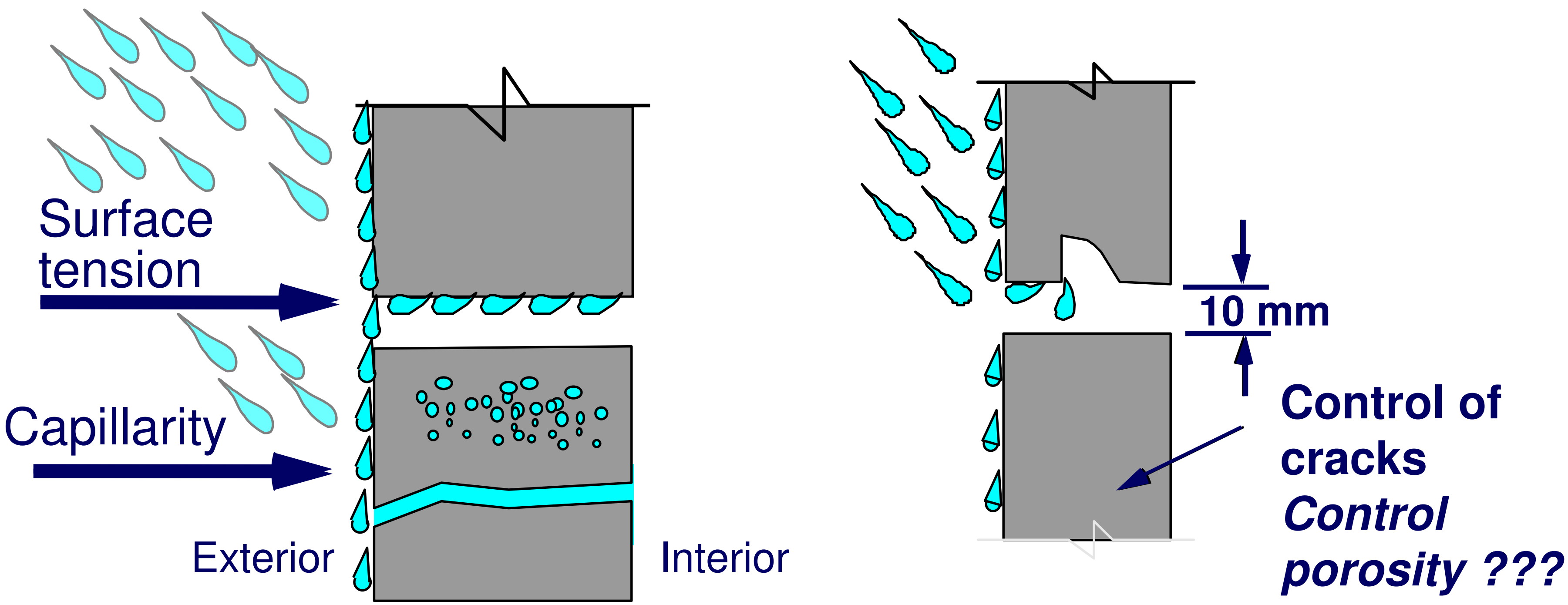
Forces Acting on Cladding- Gravity



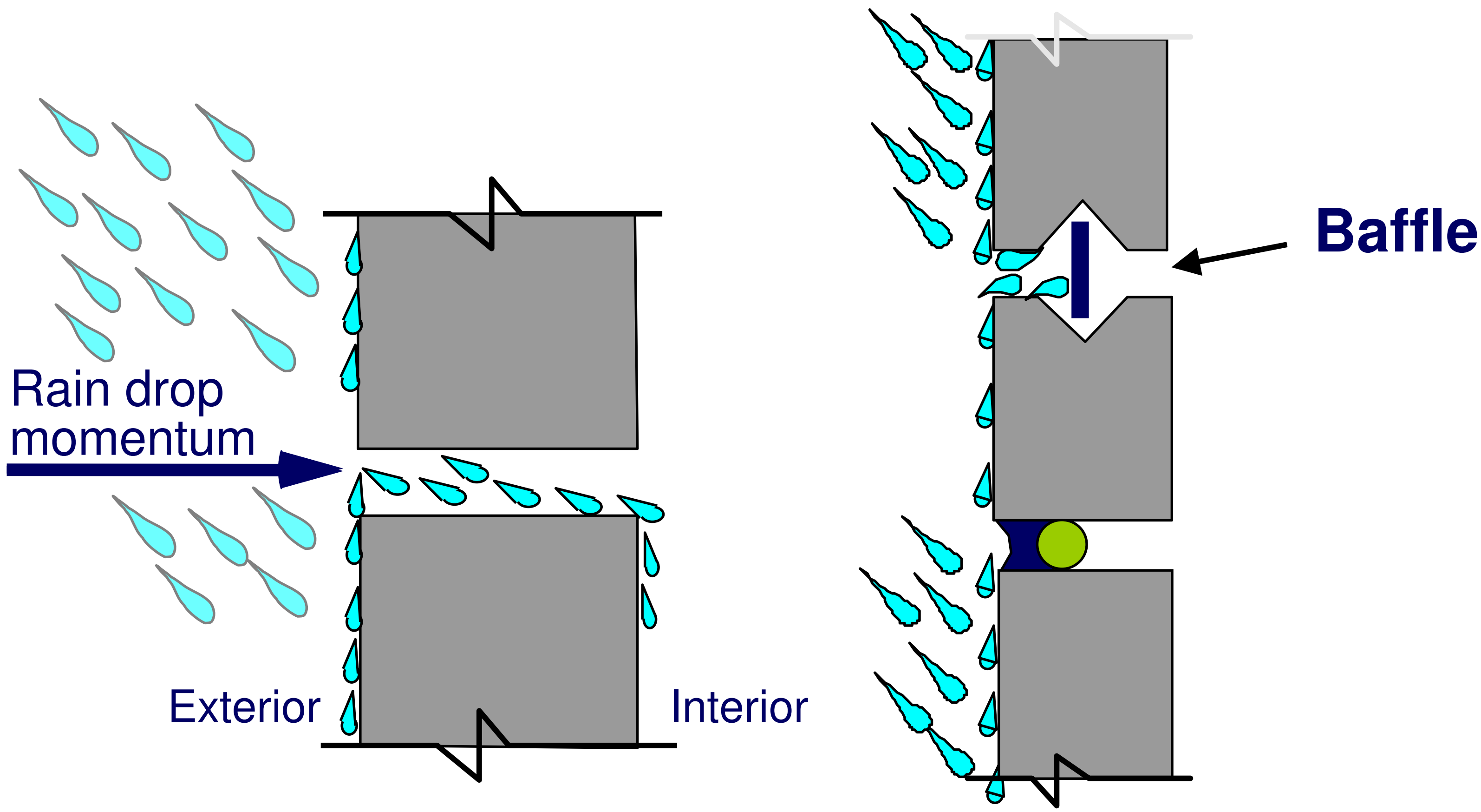


Horizontal Joint

Forces Acting on Cladding- Surface Tension & Capillarity

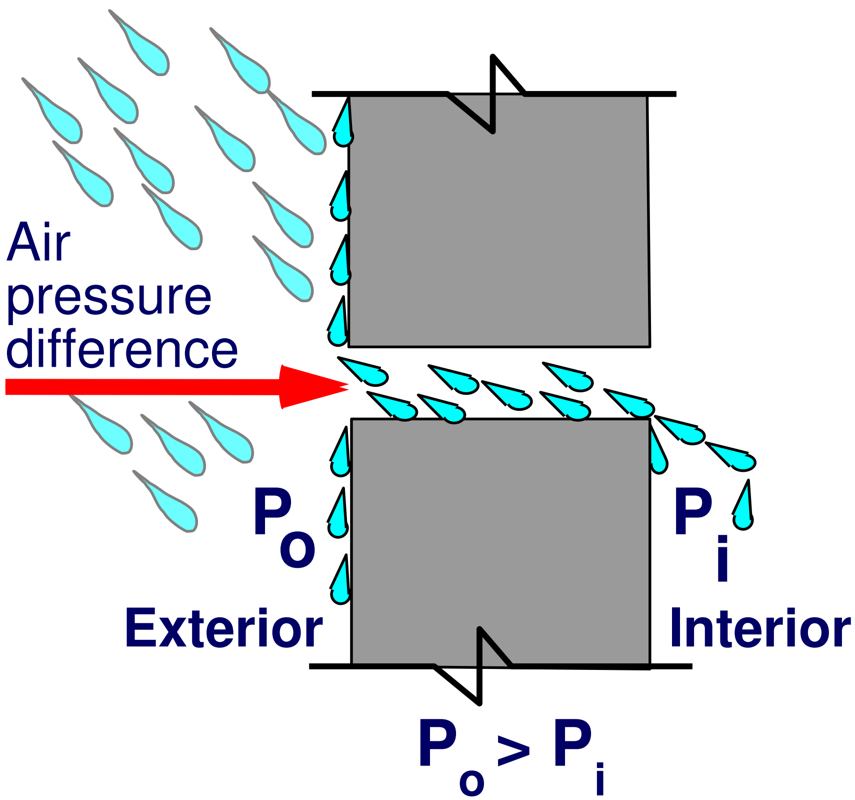


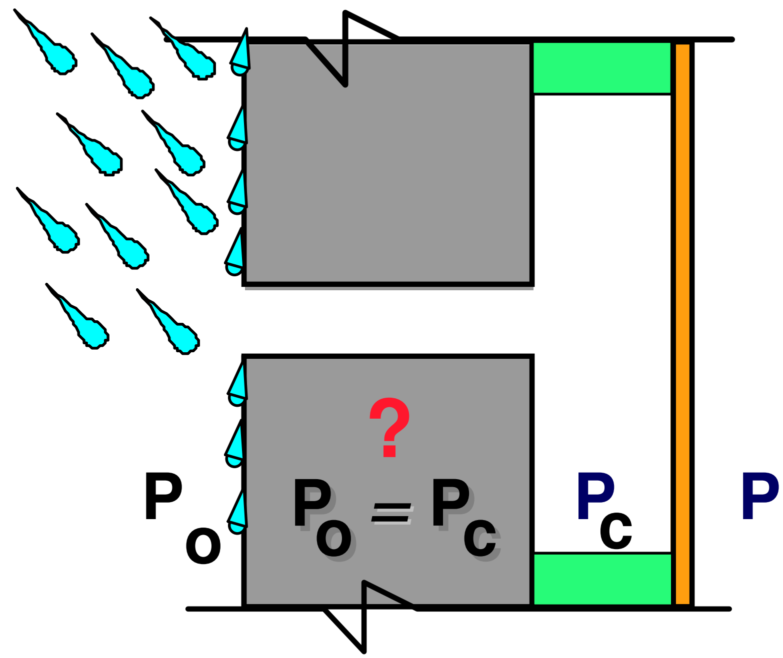
Forces Forces Acting on Cladding - Rain Drop Momentum



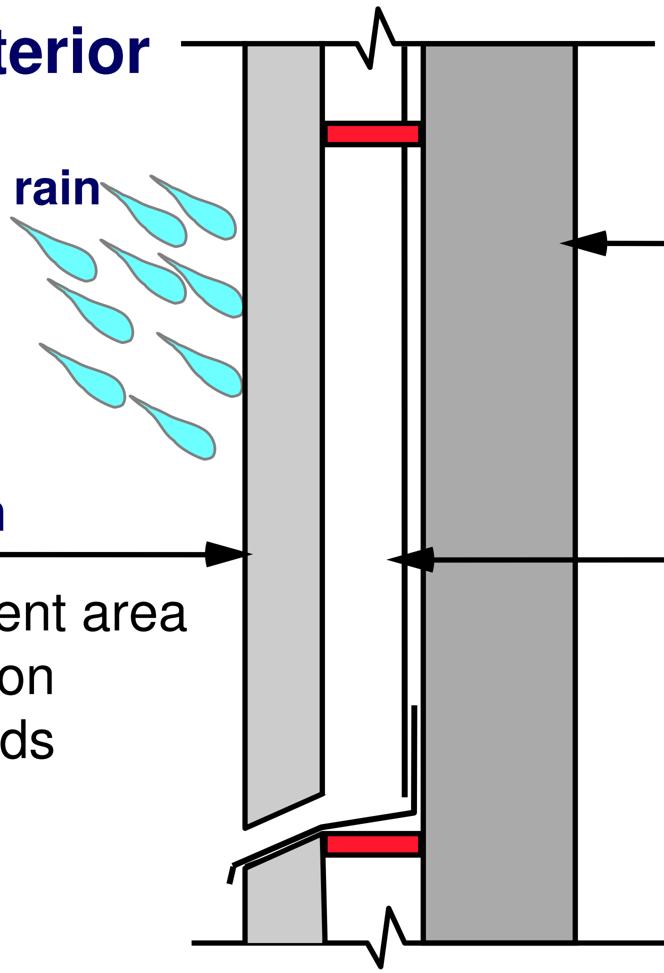
Vertical joint

Control of Forces- Air Pressure Difference





Features of a Pressure-equalized Rain Screen Wall



Rain screen

- Effective vent area
- Vent location
- Design loads
- Stiffness

Air Barrier System

- Effective leakage area
- Design loads
- Stiffness

Chamber

- Depth & Volume
- Air permeability
- Drainage (flashing & drainage holes)
- Delimiters
- Water resistance of inner boundary

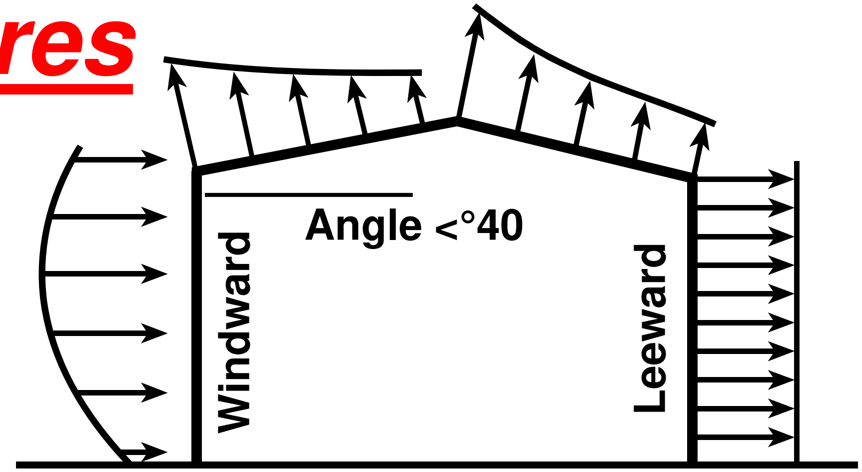
What is an Air Barrier?

- Why talk about it in a rain penetration talk? Wind-driven rain is about air flow
- Is it like a vapour barrier? No.
- Can air barrier materials have low vapour permeance? Yes
- Can vapour barriers have low air permeance? Yes
- Then what is the difference?
  - Air barrier have to be designed as a SYSTEM- Continuity is a critical issue, and
  - Air barrier is designed to sustain the wind load---- air pressure.

Air Barrier Requirements

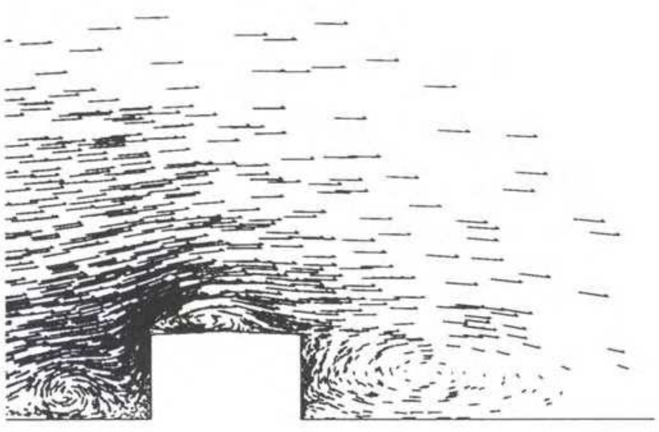
- **It is a SYSTEM made of SEVERAL materials over the building envelope**
- **Materials of low air permeance**
- **Rigid assembly, for small deformations**
- **Structural strength, to sustain wind loads**
- **Most challenging: Continuity at joints and interfaces. Look for the holes…Think Detailing**

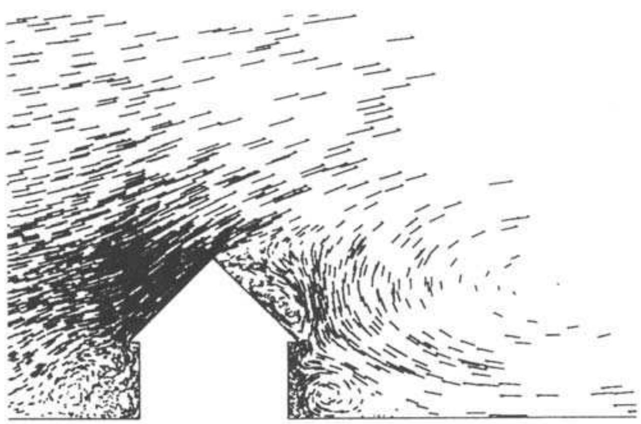
Wind Flow & Pressures

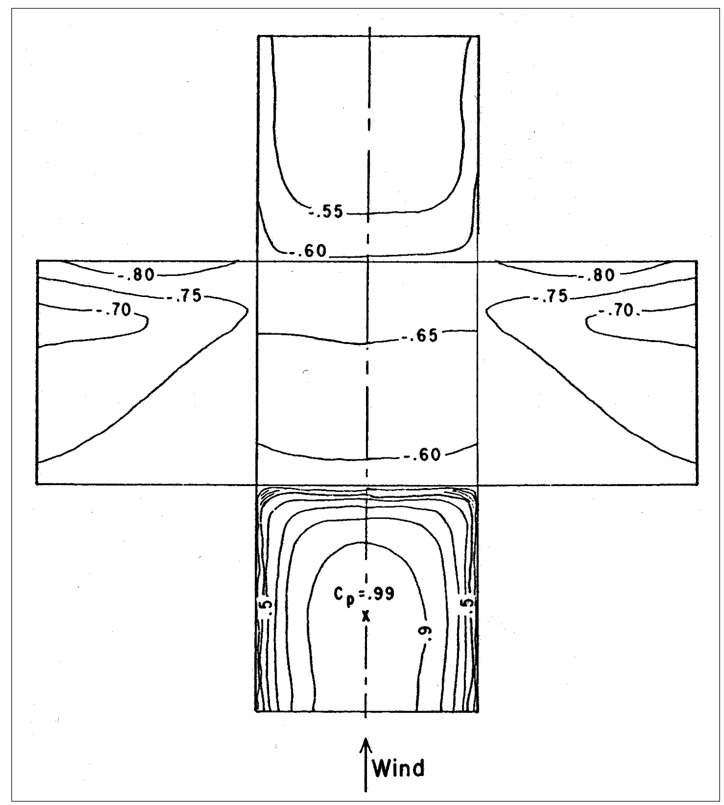


Section

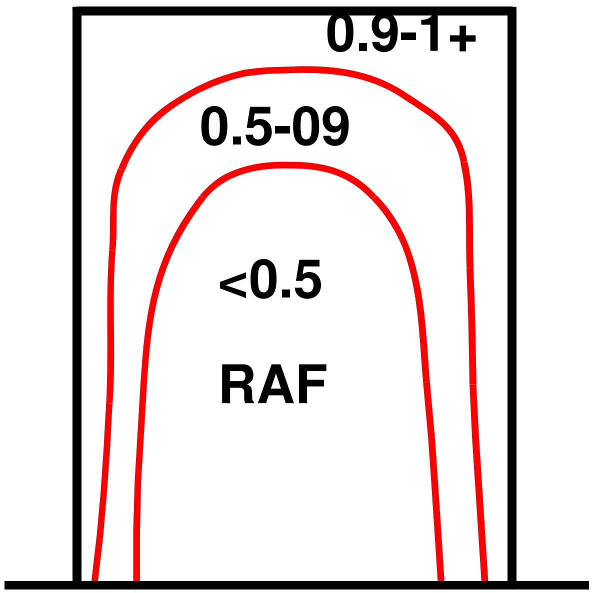
Wind flow around obstructions

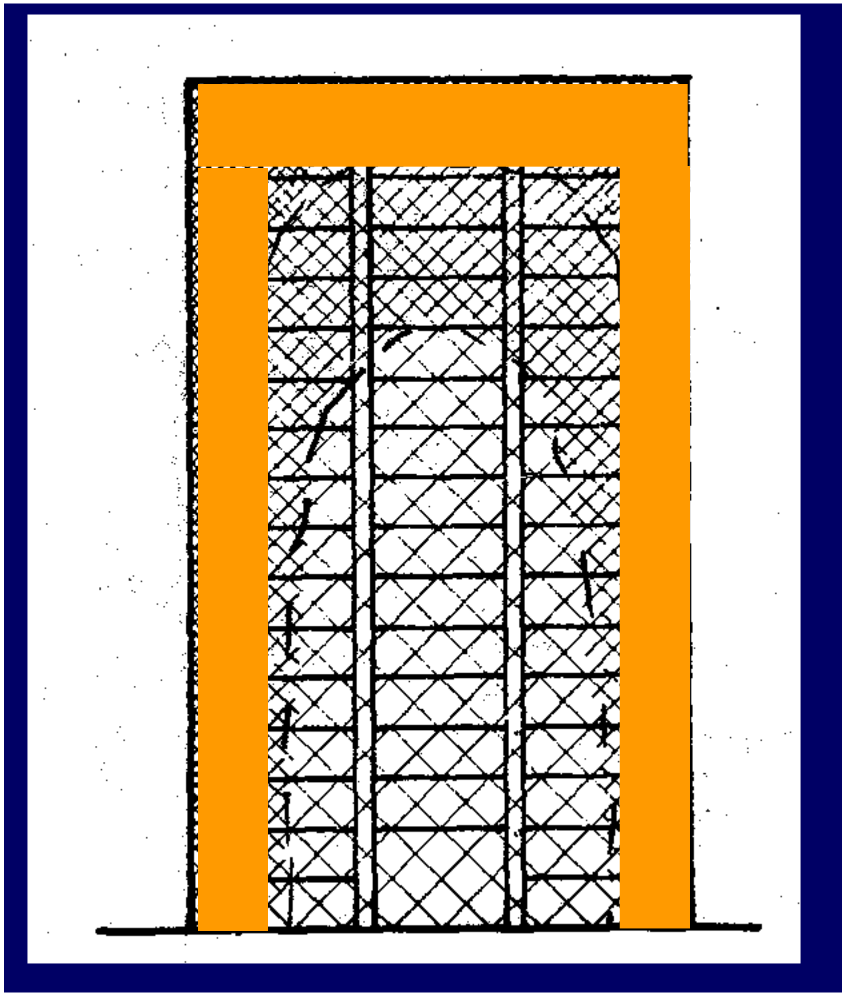






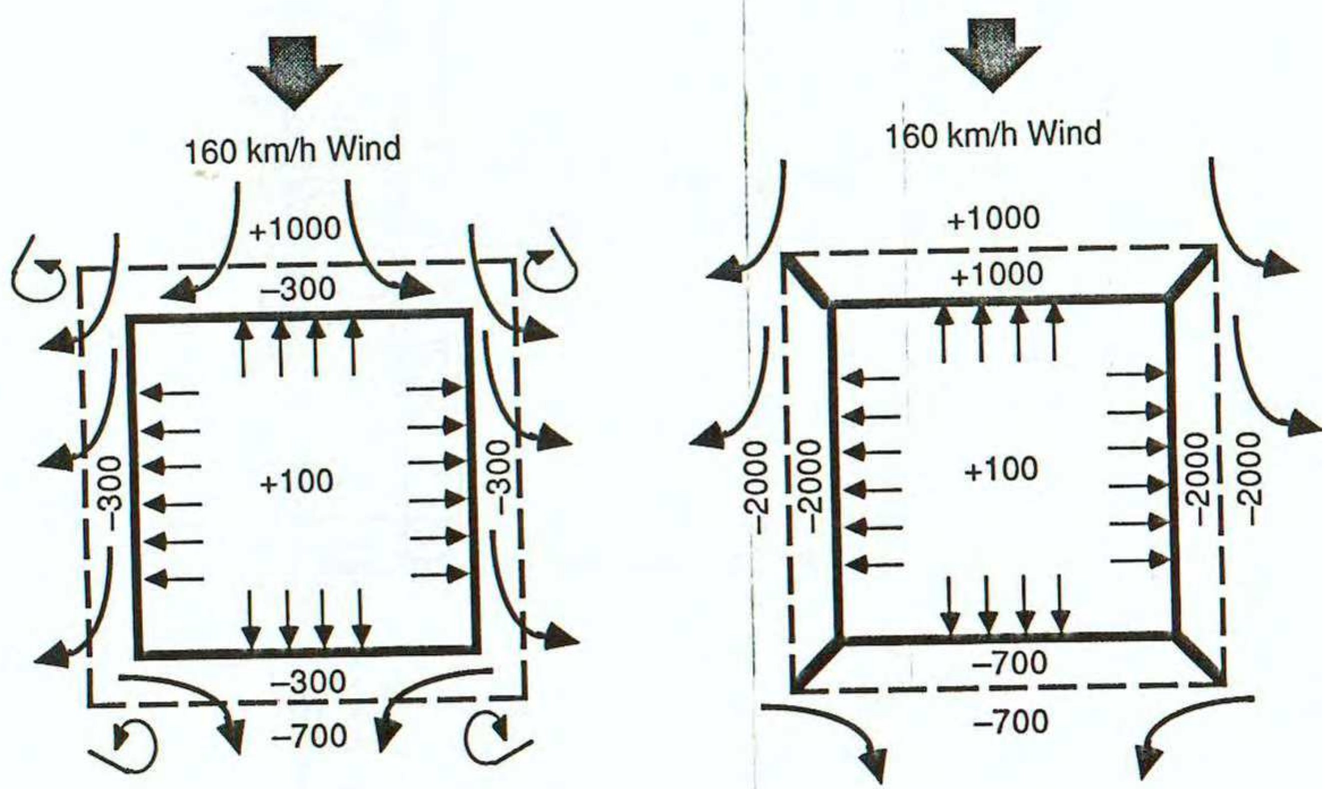
Wetting patterns, and air pressure on facades





Smaller compartments where wind pressure is higher

Compartimentation at corners most beneficial



(a) CONTINUOUS CAVITY

(b) COMPARTMENTALIZED CAVITY

Variation on a Theme

- **Cavity wall**
- **Rain screen; Drain screen**
- ***Pressure-equalized; Pressure-modulated; Pressure-moderated;Pressurized rain screen***
- ***Ventilated rain screen***

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Research on Rain Penetration Control

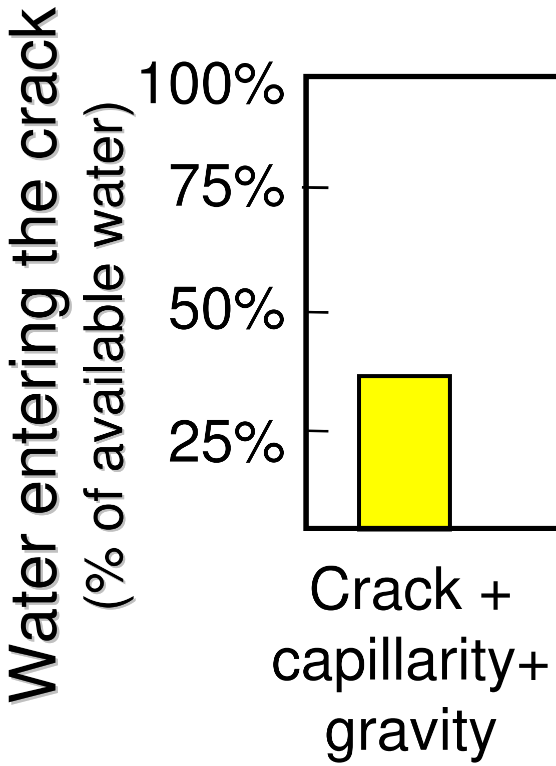
- Lots of research published!
- Pressure equalization performance
  - Static and dynamic loads; venting requirements
- Detailing of wall/window junctions

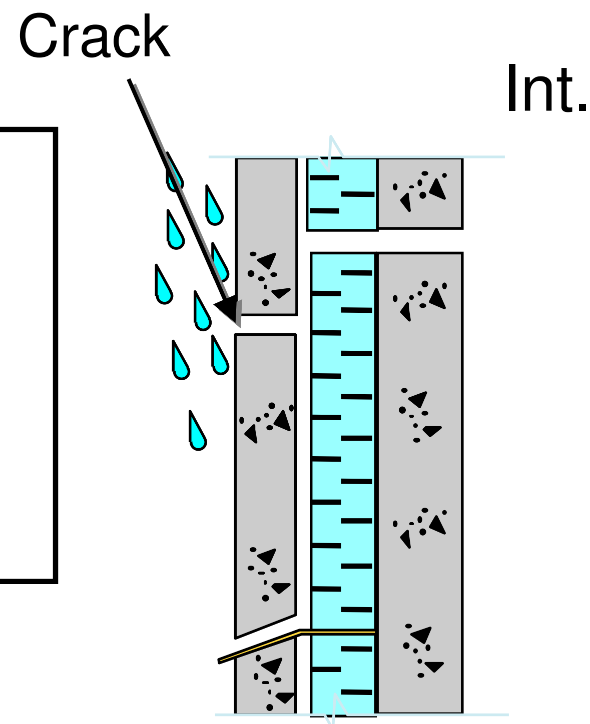
NRC/CMHC joint Research in 1990s

Focus

- The static and dynamic pressure equalization response of wall assemblies
- The water penetration performance of:
  - a sandwich precast concrete wall assembly with a deficiency, in face-seal and rainscreen fashion
  - More flexible system with brick veneer on steel stud

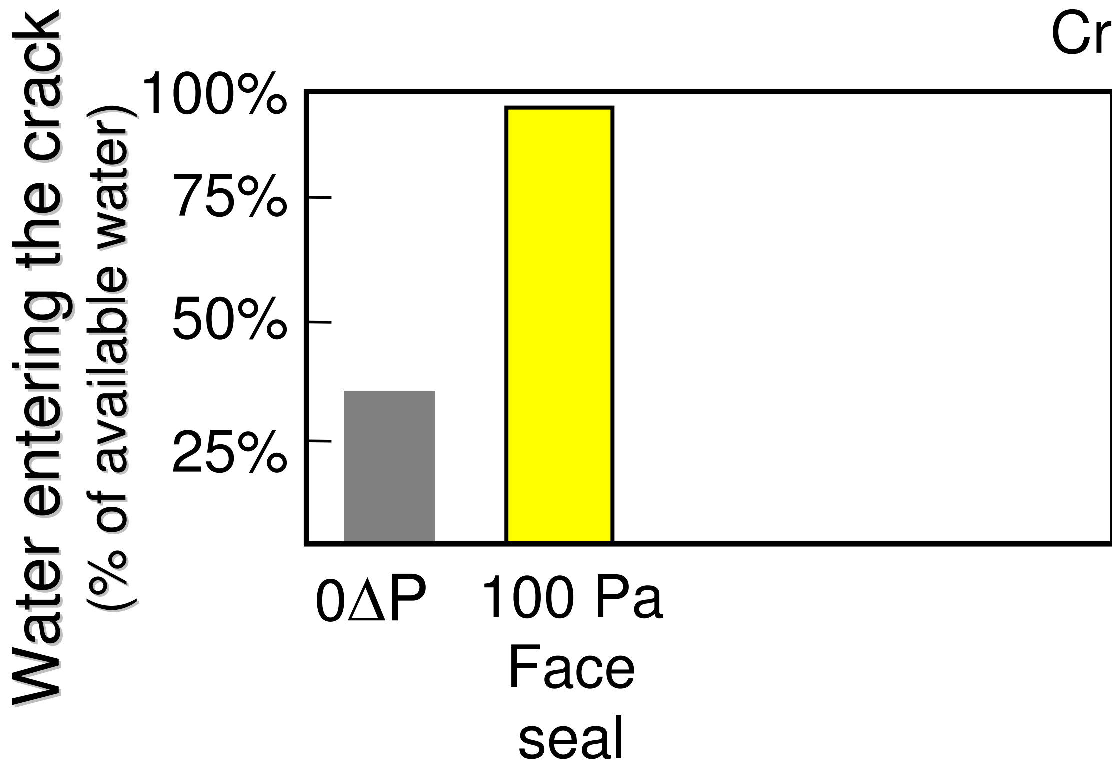
Effect of Gravity & Capillarity

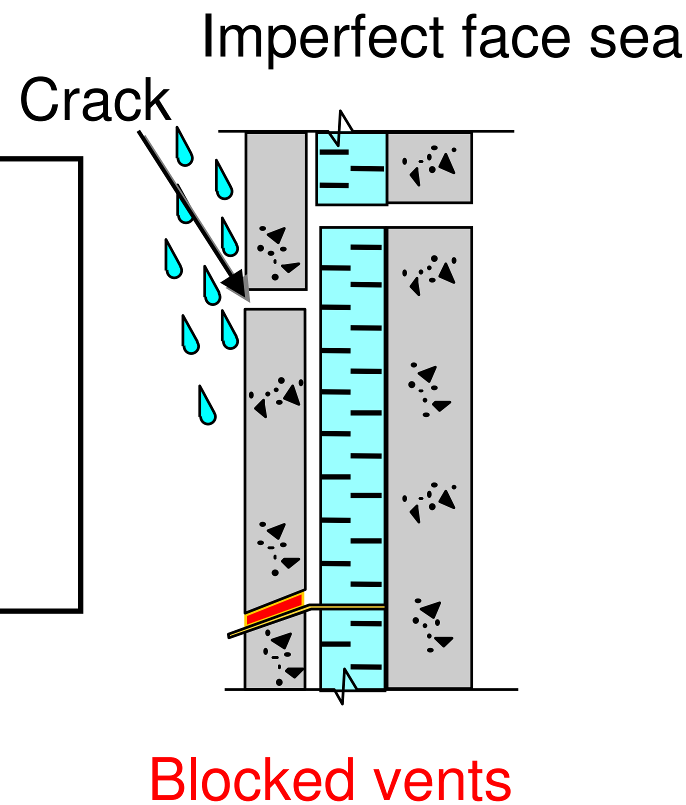




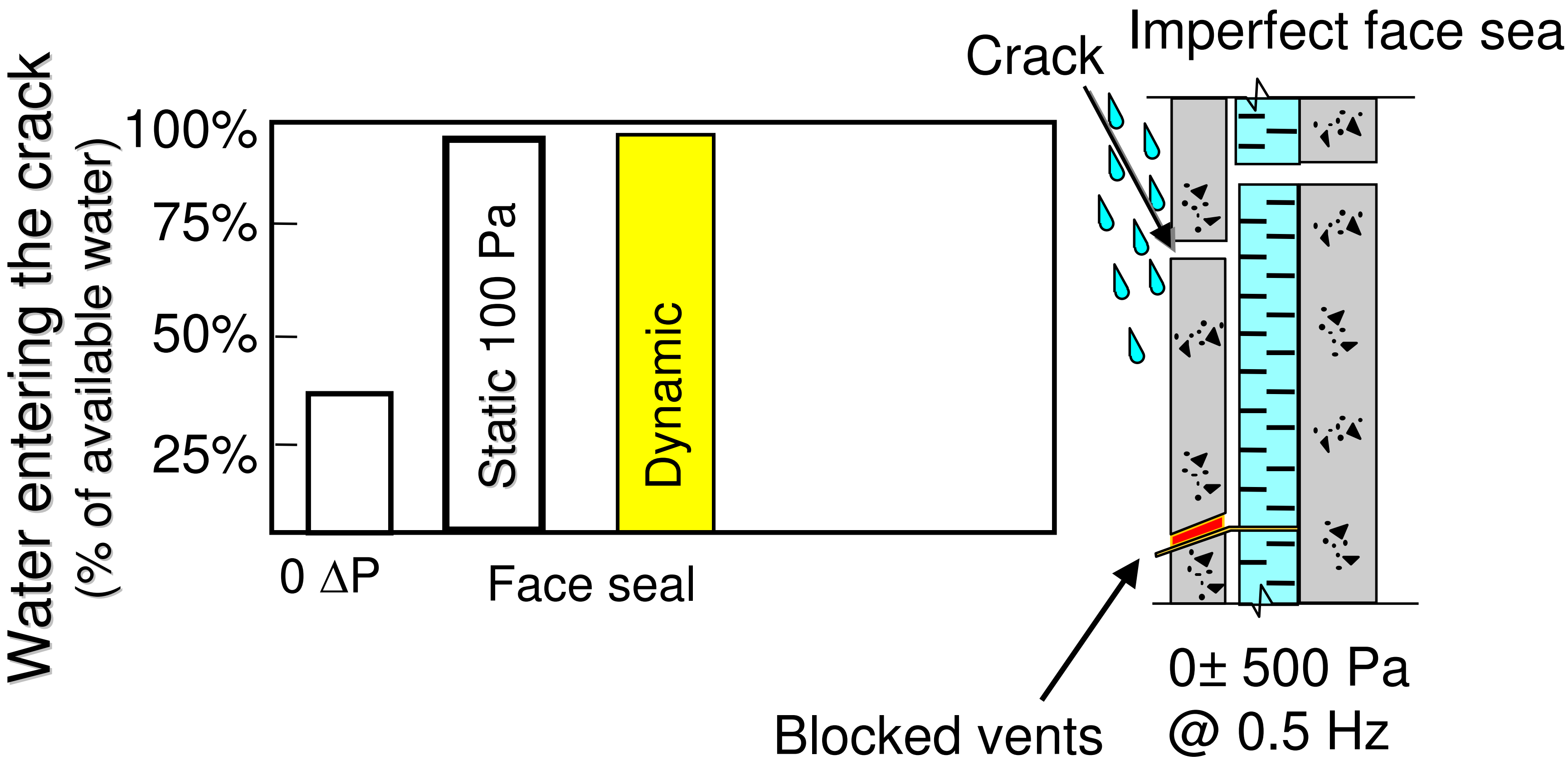
No ΔP_{air}
across specimen

Face Seal under Static Pressure Differential

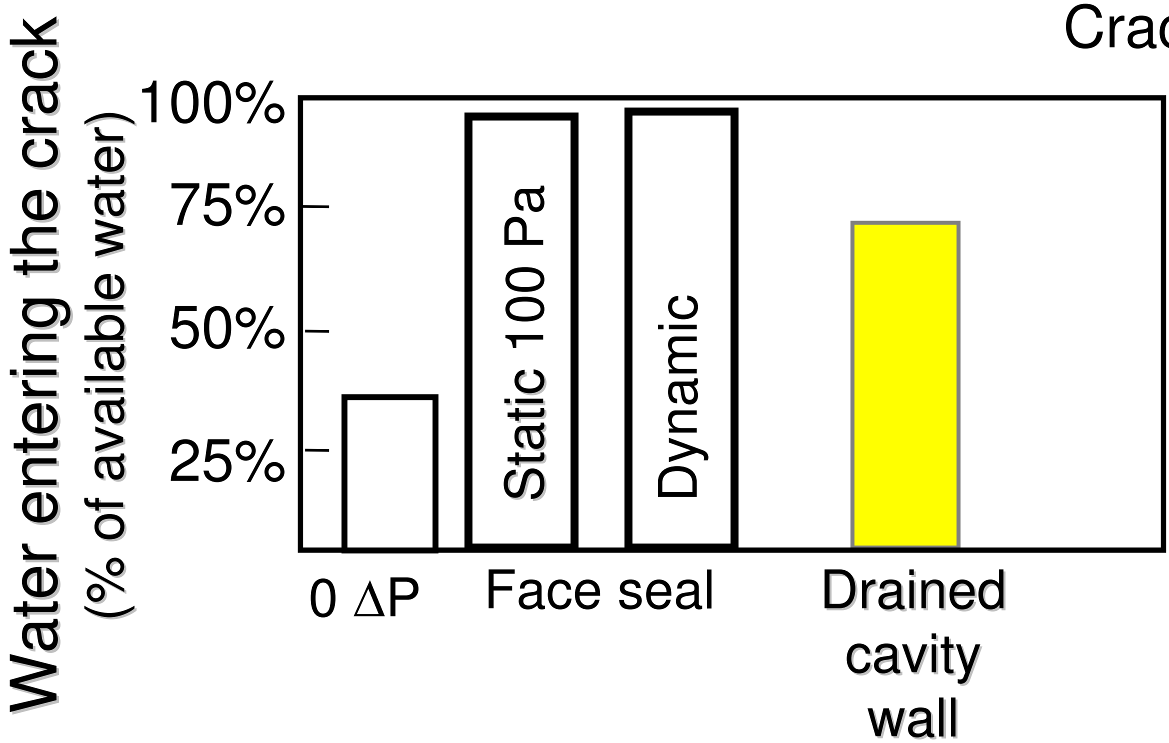


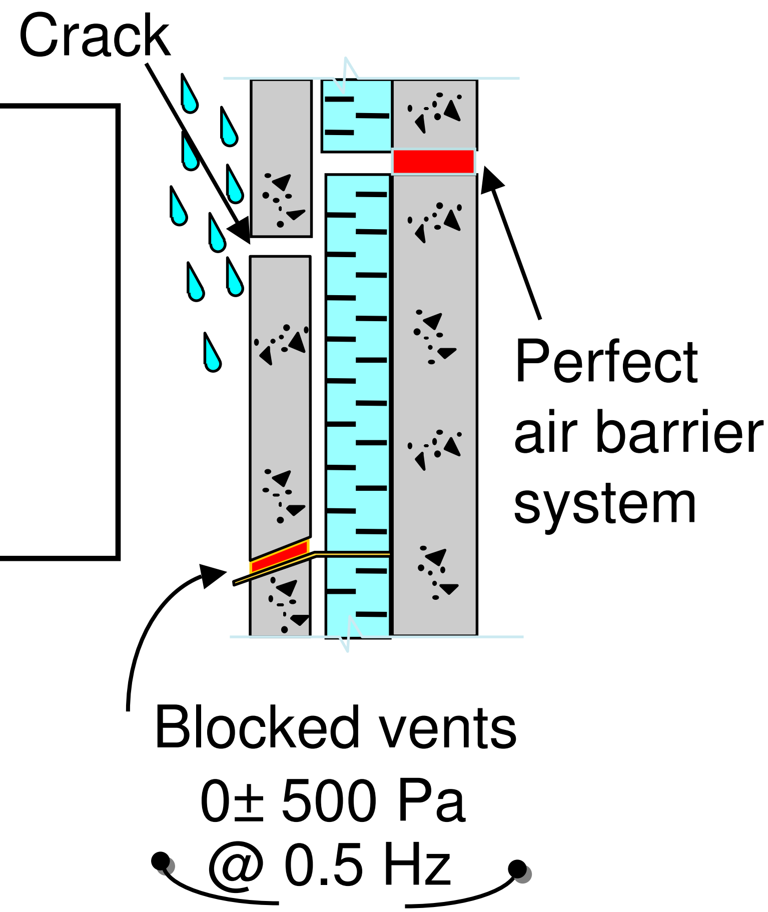


Face Seal under Dynamic Pressure Differential

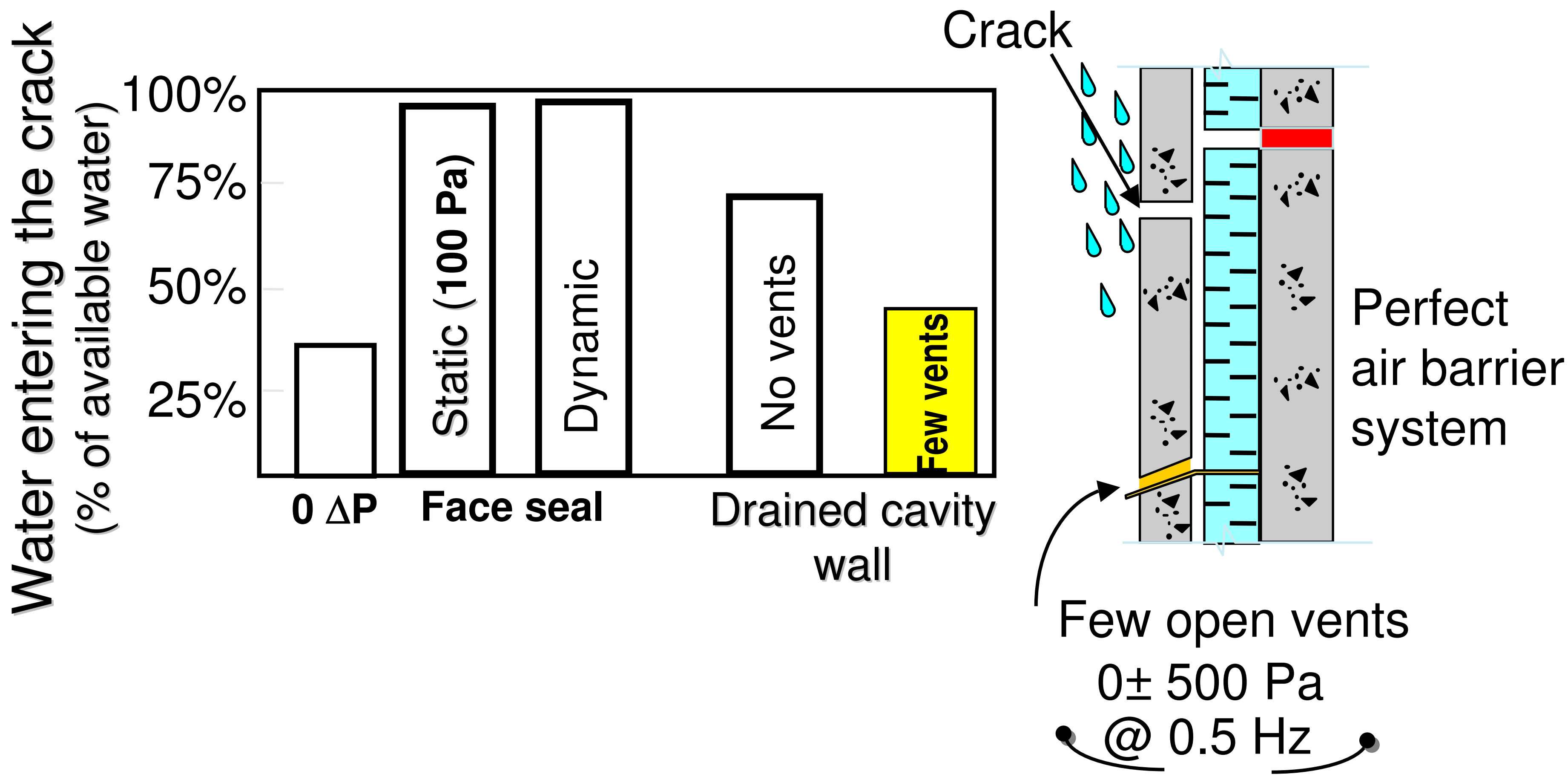


Drained Cavity Wall under Dynamic Pressure Differential

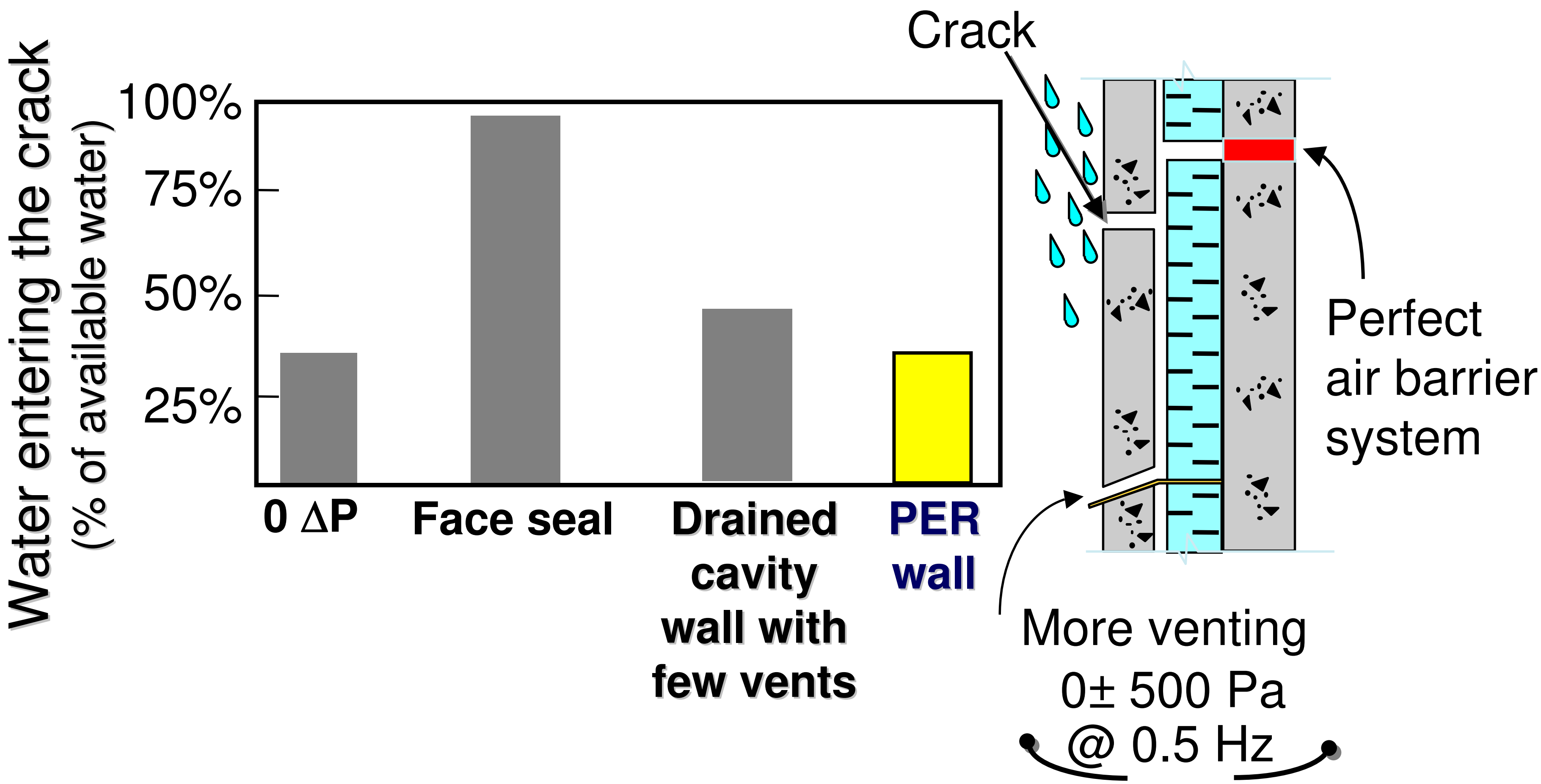




Drained Cavity Wall under Dynamic Pressure Differential



Pressure Equalized Rain Screen Walls under Dynamic Conditions



NRC/CMHC Joint Research

Highlights

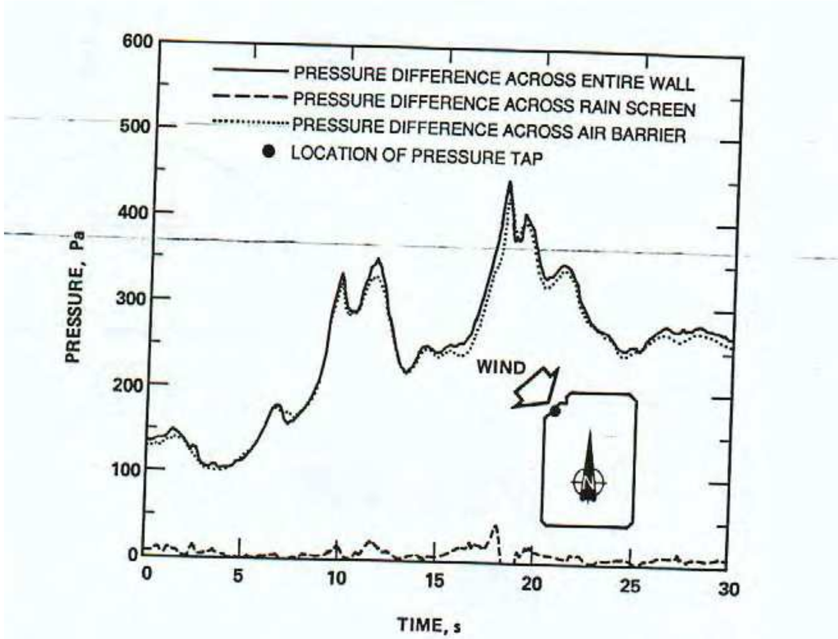
- The more rigid the cladding and air barrier system, the less venting required to obtain pressure equalization across the cladding
- Gravity and air pressure differentials are dominant forces

IRC/CMHC joint research (cont'd)

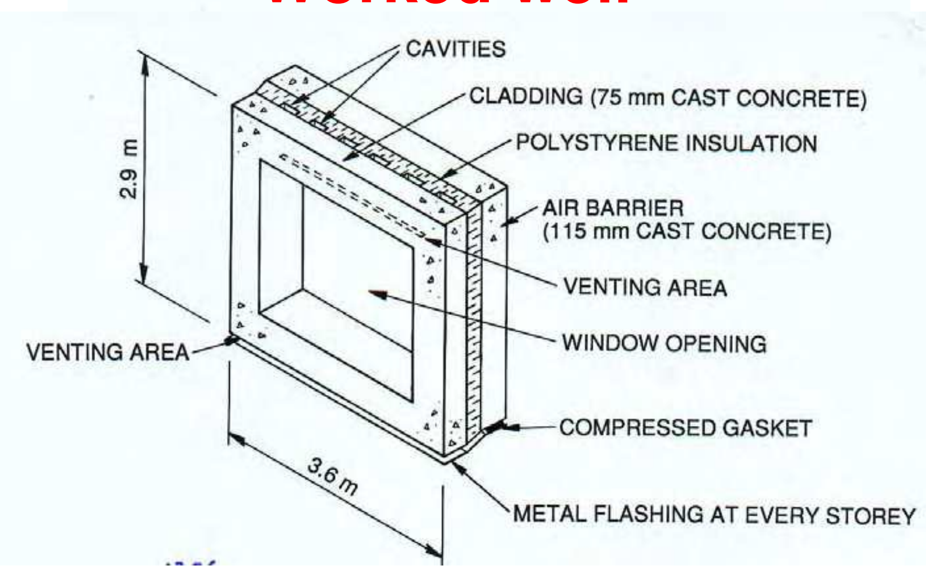
Highlights

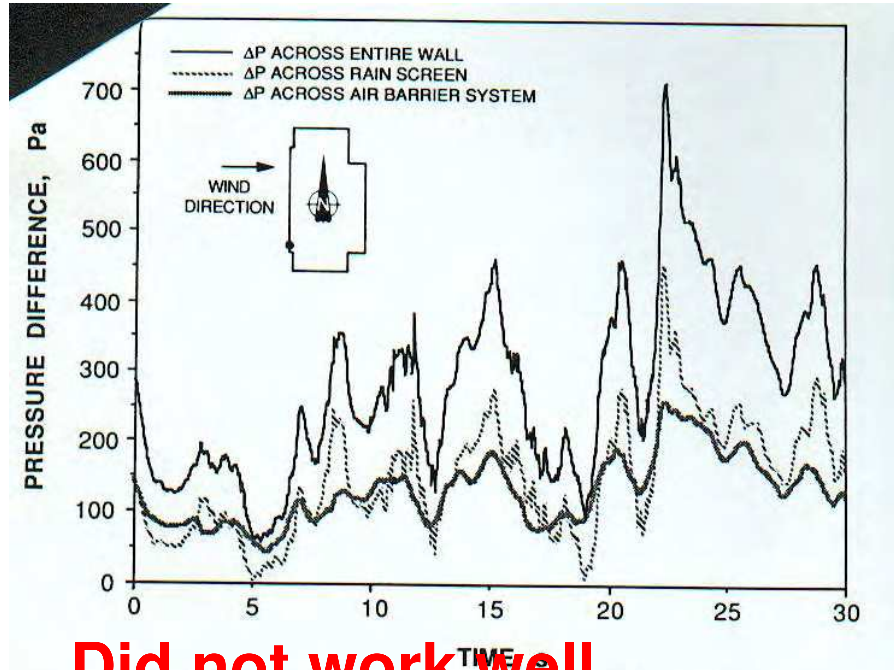
- Precast concrete sandwich assembly with a crack experienced a higher level of water penetration when designed as a face-seal system than a rainscreen wall
- The dynamic pressure equalization response of wall assemblies can be very specific to their design

Field monitoring of 2 large buildings

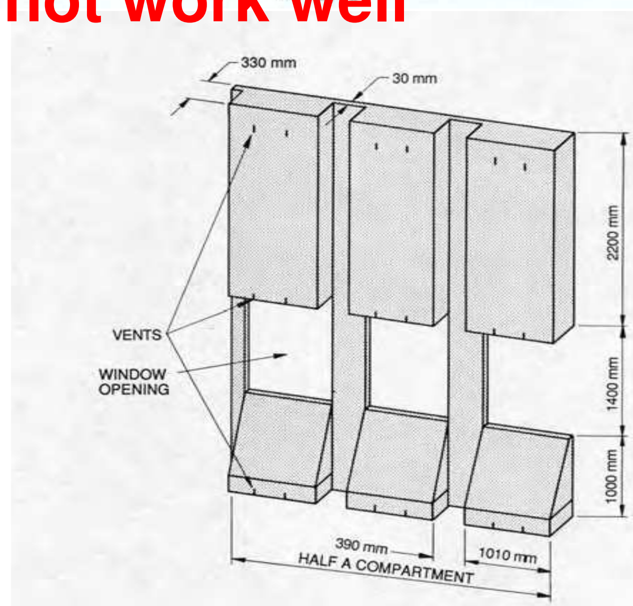


Worked well





Did not work well



Venting Requirements

Goal: aim for maximum reduction of pressure difference across cladding

How much?

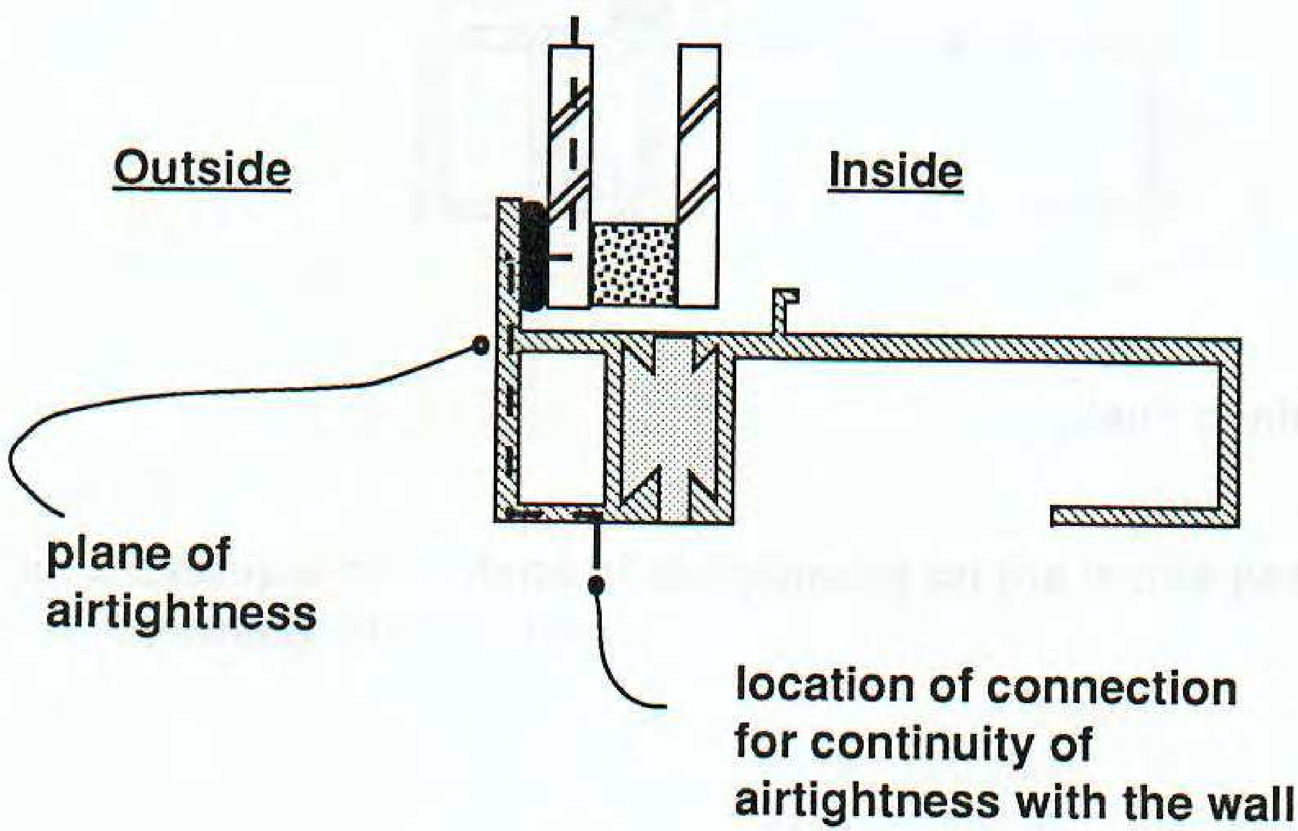
- Old rule of thumb (calculations) was 10 -40 times more venting than leakage of ABS
- Experimental: static and dynamic reqs different
  - Static loads: Venting RS ≥20 times Leakage ABS
  - Dynamic loads:
    - Rigid and small chamber: venting (m2) >volume of compartment(m3)/50 m
    - Flexible & larger chamber: venting (m2) >volume of compartment(m3)/25m

Where?

- Distributed at the bottom of the compartment, where vents can provide drainage as well
- Wind tunnel study investigated pressurizing the compartment by placing all the vents furthest from the edge of building
- Other research aims for ventilation of the cavity behind the cladding for drying purposes, and top and bottom venting was advocated

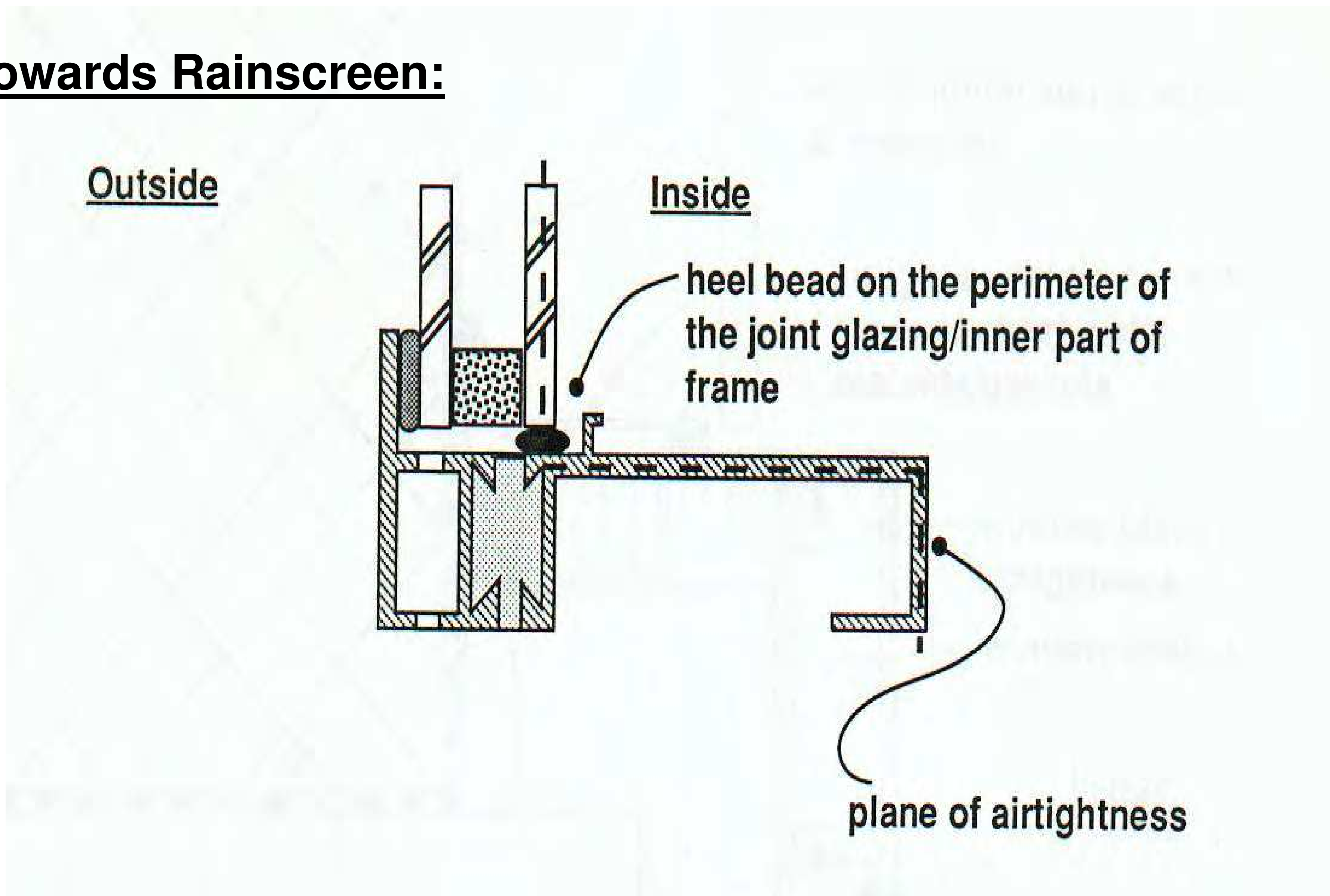
Rain Screen Principle: for Walls Only?

Face Seal Design:



Rain Screen Principle : for Walls only?

Towards Rainscreen:



Rain Screen Principle : for Walls only? Of course not!

Rainscreen:

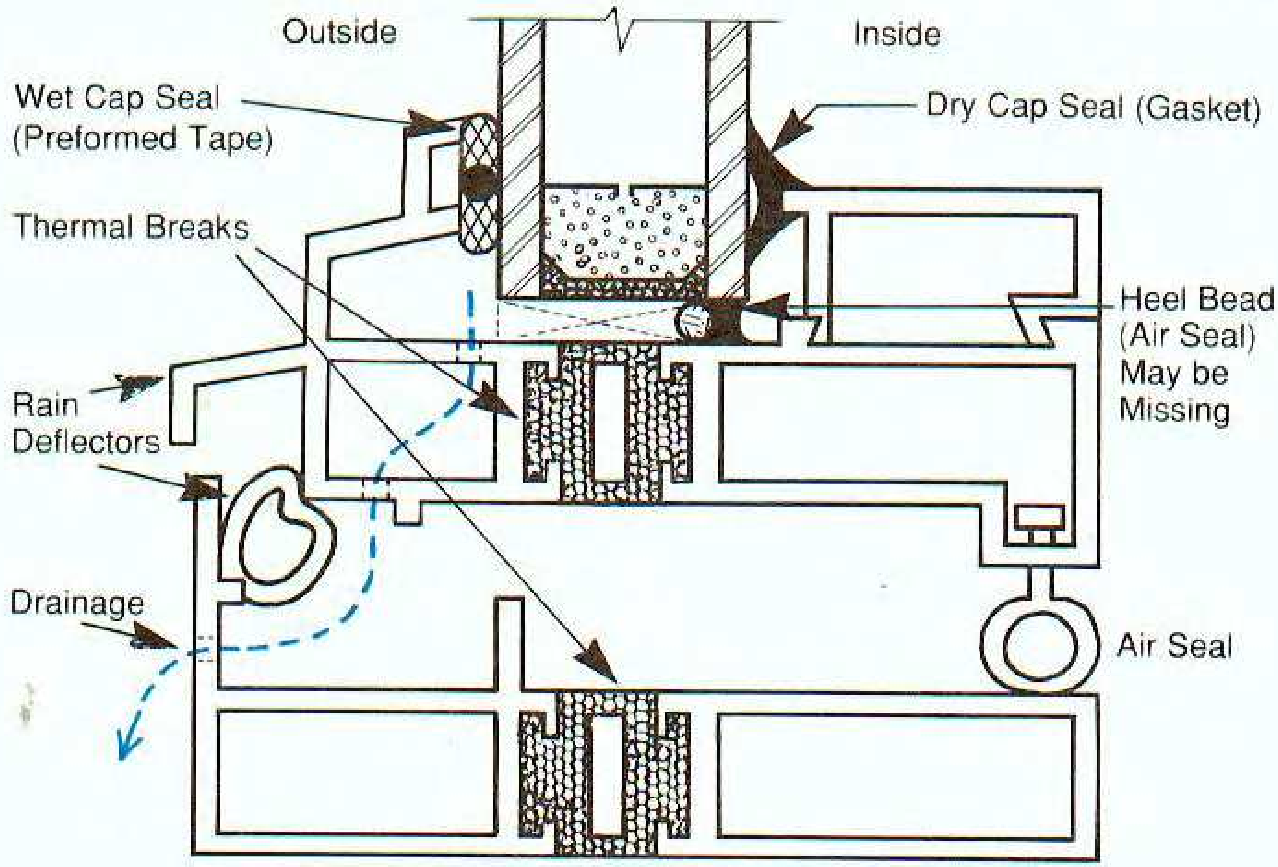
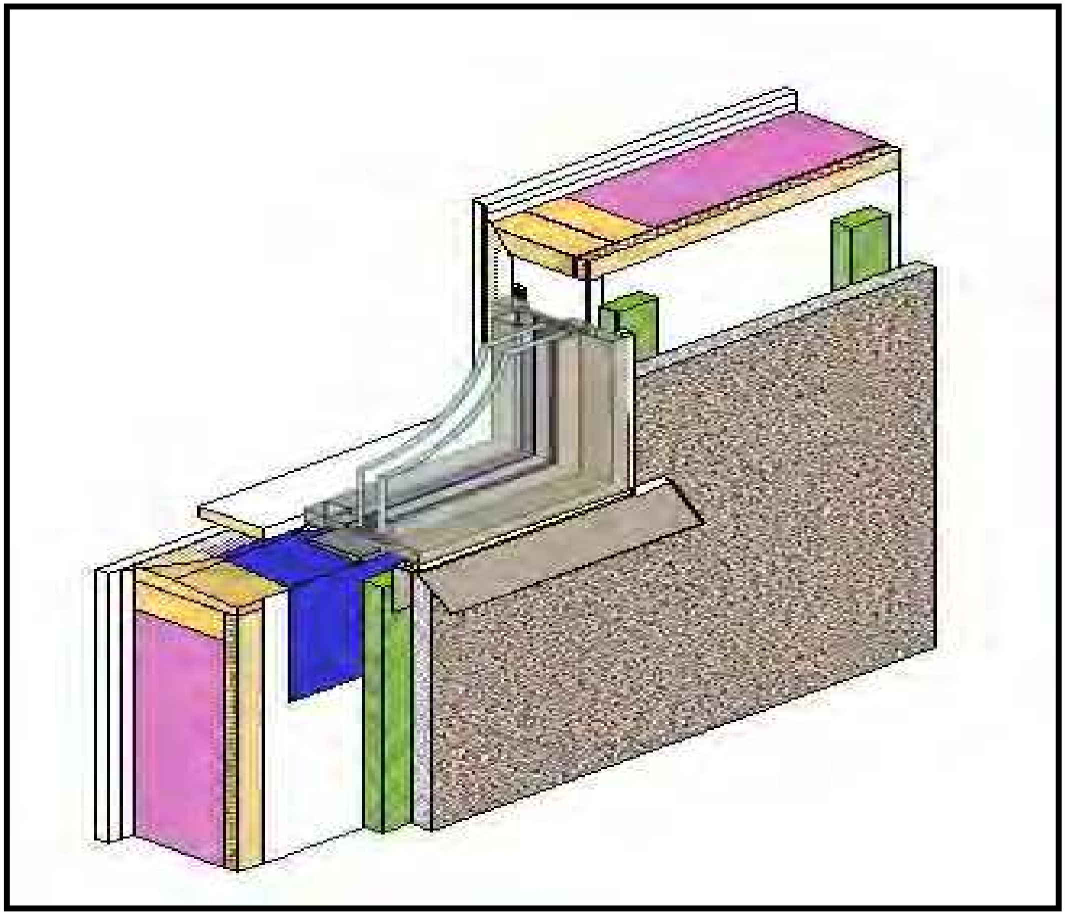


Figure 14. Cross–section of aluminum frame of inside awning window.

Rain Screen Principle- applicable to wall/window interface?

Absolutely!



Study of Wall/Window interface

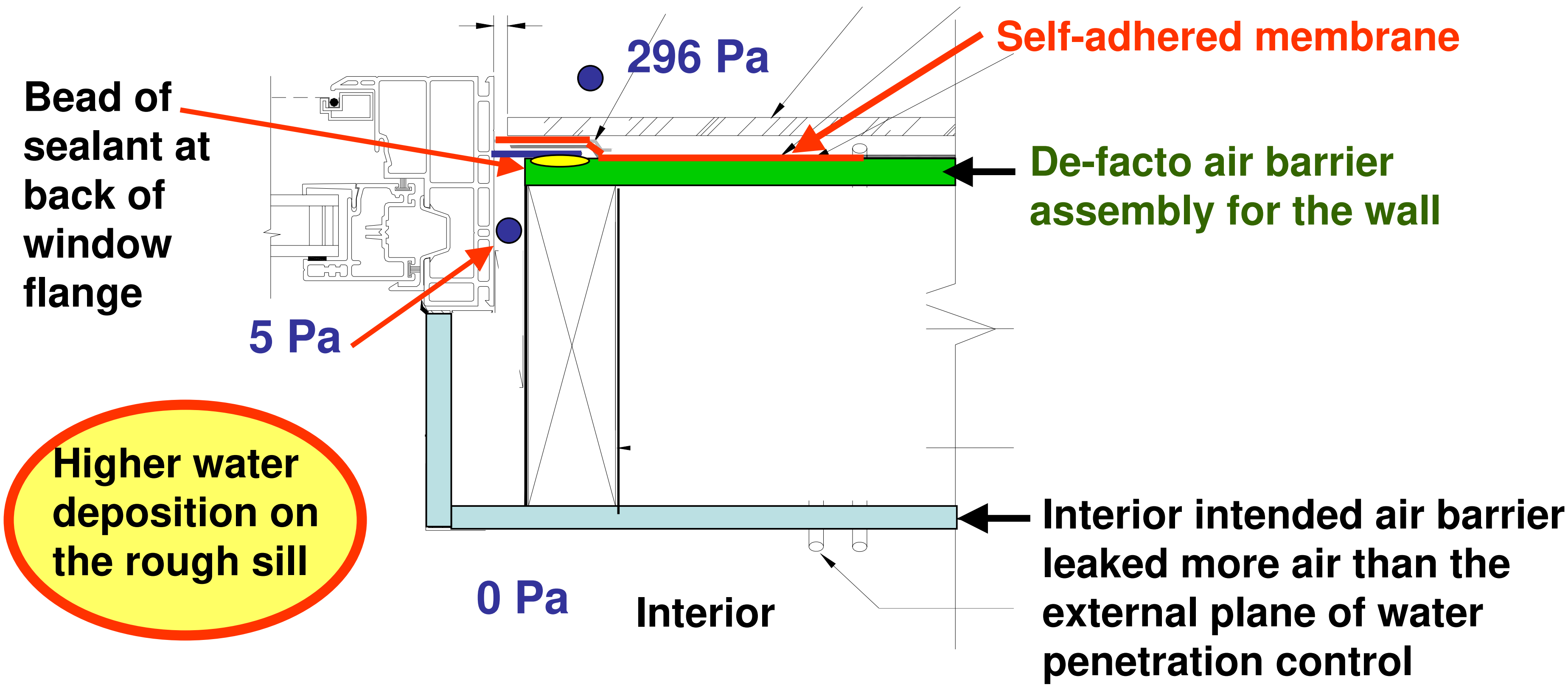
Effect of Air Pressure Difference

Effect on water accumulation on rough sill as related to:

- ***Location of tightest element of the wall (not necessarily the intended air barrier)***
- ***Air leakage rate of an interior air barrier***

Effects of Pressure Distribution

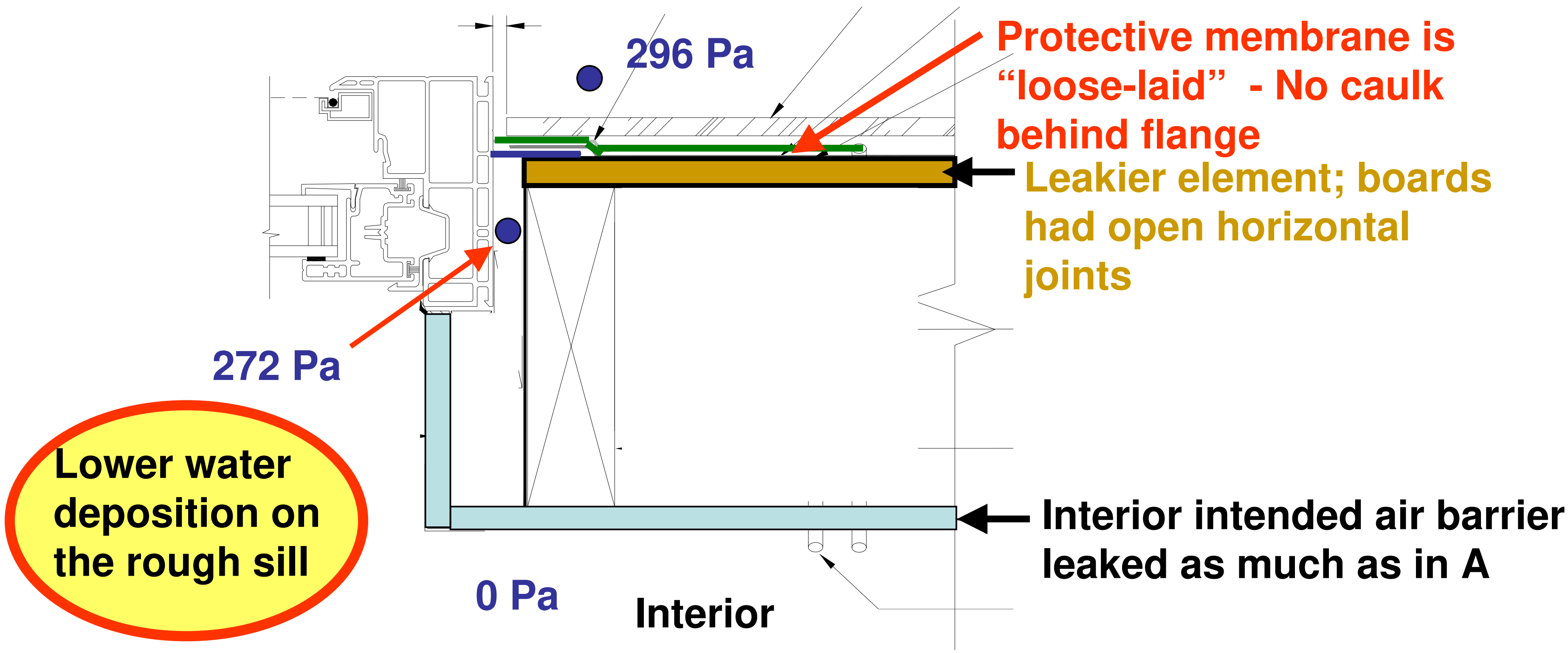
Specimen A: High pressure drop across wetted airtight external plane



Jamb detail (plan view)

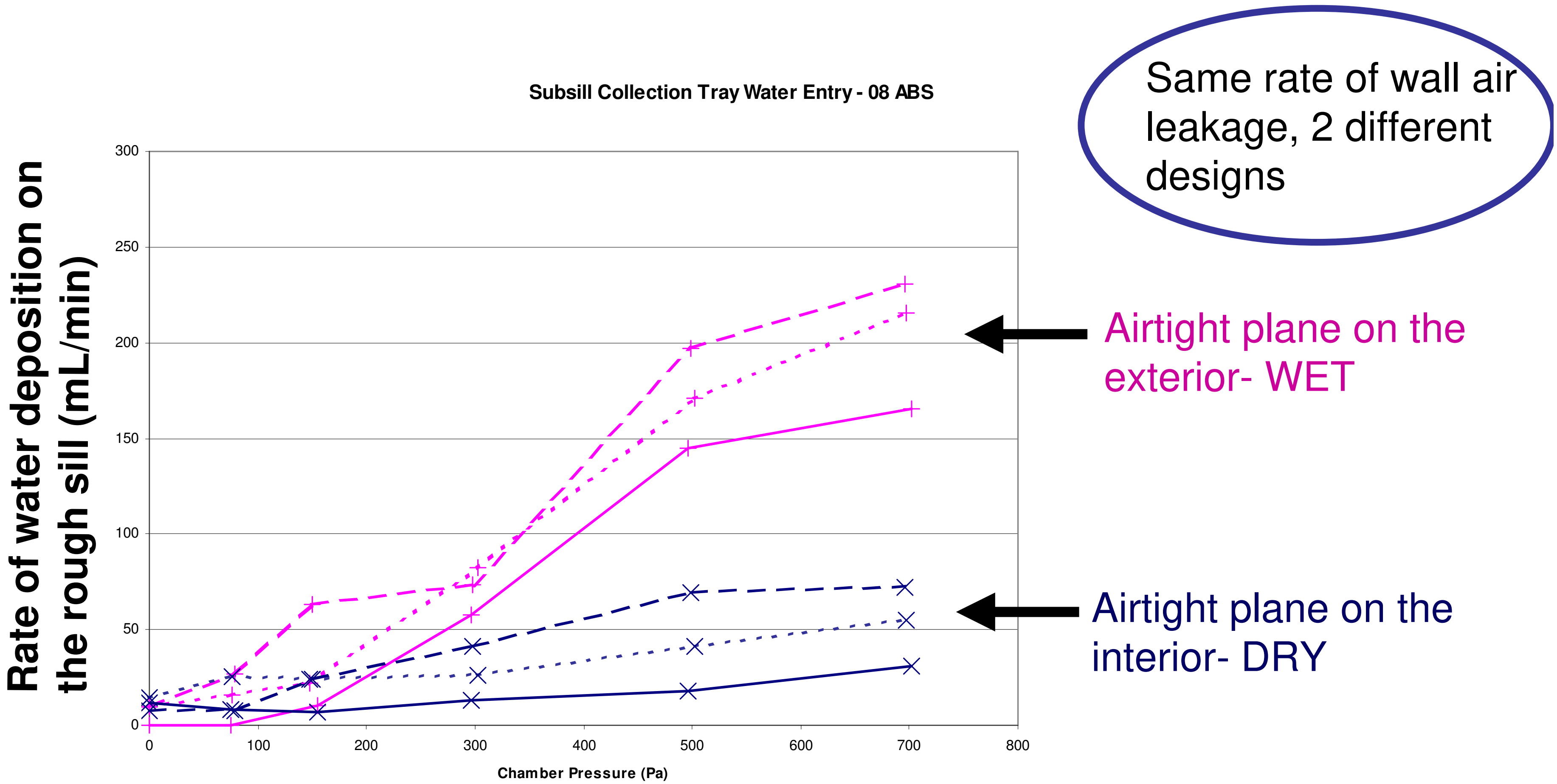
Effects of Air Pressure Distribution

Specimen B:
Low pressure drop across wetted "vented" external plane



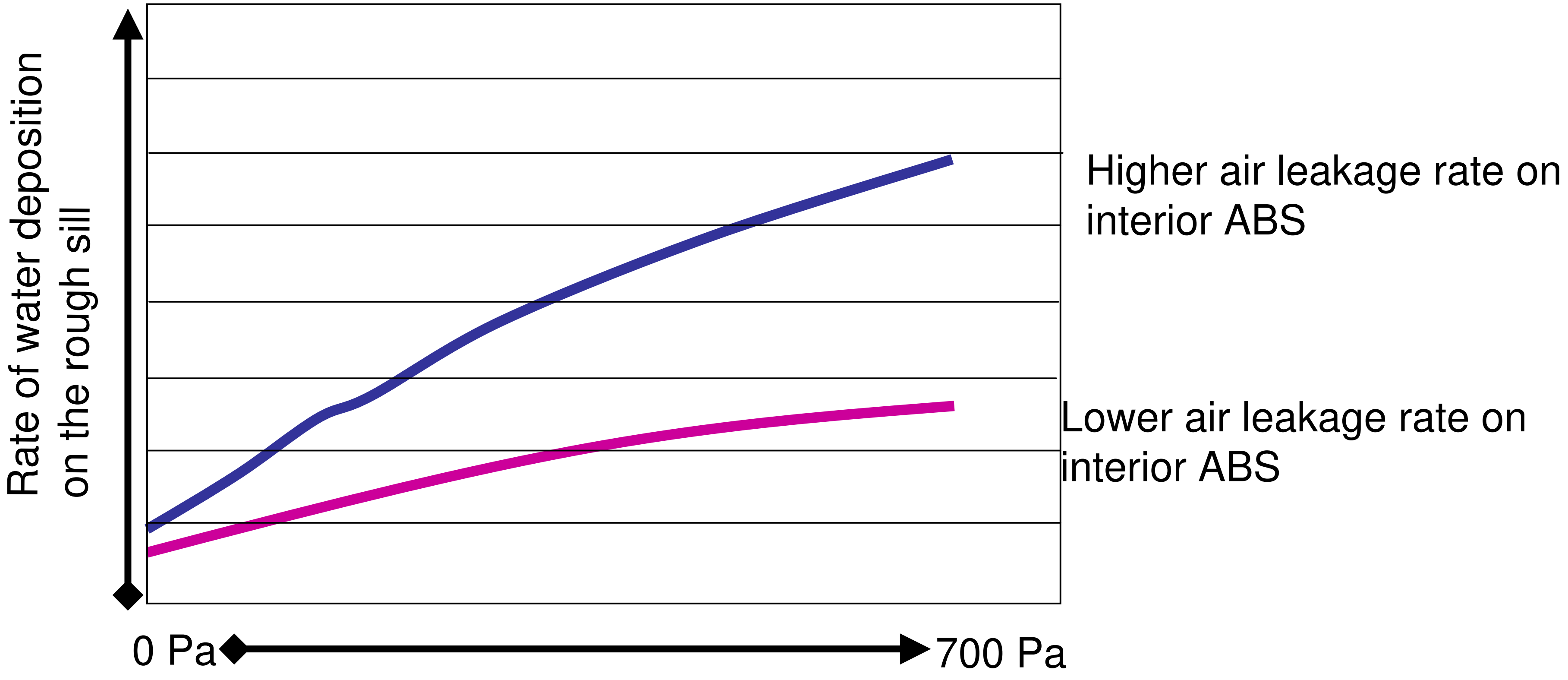
Jamb detail (plan view)

Effect of Location of Plane of Airtightness



Effect of Leakage Rate of Interior ABS

Leakier intended air barrier system resulted in higher water deposition on rough sill (exterior plane sealed)



Lesson #2: Keep Air Barrier Tight and Dry

- ***Current practice aims at sealing joints that can get wet: the joint between window frame (flange) and sheathing membrane***
- ***Imperfect seals at which both water and higher pressure differences coexist drive water through seal imperfections***
- ***Plane of higher pressure drop (Air Barrier System) should be in dry location, towards interior of joint***

Anymore here curious what was Lesson #1?

Lesson #1: The Rough Opening Will Get Wet: Drain it Out

Flash and drain the rough opening

- *Protect moisture-sensitive materials from water absorption*
- *Provide drainage path to outside, i.e. include*
  - *Sloped rough sill*
  - *Back dam*
  - *Water impermeable rough sill; up 150 mm on jambs*
  - *Provide ease of drainage from rough sill - out of wall assembly*
  - *Integrate with other elements that contribute to control of rainwater ingress (i.e. shingle lapping, sequencing)*

ROUGH SILL FLASHING SYSTEM

“Tell them what you are going to tell them…”

4 Blocks:

1. Major building envelope damage in the 90s due to rain penetration
2. Review of wall design approaches for rain penetration control
3. Review of selected research findings
4. Wrap Up

Wrap Up 1/4

- **Barrier walls**: Single protection without any redundancy. Watertightness based on perfection of exterior seals. Once exterior seals fail, water cannot get out. High maintenance costs for sealants, too often triggered by water damage
- **Mass walls:** single protection but with some redundancy. Weatherproofing based on absorptive property of large mass of masonry or concrete and evaporative drying. Problems tend to be corrosion of metals embedded in masonry, freeze thaw damage or rain ingress at joints

Wrap Up 2/4

- **Cavity walls:** dual protection by means of a drained and flashed clear cavity behind cladding and second line of defense (moisture barrier). Has been successful when combined with careful detailing and where wind-driven rain pressures were not high
- Variation: **Ventilated cavity walls**, which provide the dual protection of cavity walls, with the addition of vents top and bottom of compartment to promote drying of wall. Several modelling studies underway in this area

Wrap Up 3/4

- **Rain Screen walls**: Multiple protection & redundancy of the cavity wall, with addition of the control of air flow .
  - Requires an effective air barrier system inside the wall.
  - Requires more venting than typically provided in cavity walls.
  - Requires control of lateral air flow behind the cladding with compartment separators
- Has been used successfully in panelized wall systems and curtain walls exposed to high wind-driven rain pressures. Can reduce wind loads on cladding.
- Several terms used in industry:

  Pressure-equalized; pressure-moderated ; pressure-compartimentalized

Wrap-up 4/4

Adopt The 6 D Approach

- **D**eflect
- **D**rain
- **D**ry
- **D**urable
- "***D**eal with air pressure difference*"

→ **DETAILING** →

Sequencing,
Design intent
Communication
Proof of concept

Additional resources

NRC website www.nrc.ca/irc

- Construction Technology Update no 9, 17 and 34
- Canadian Building Digest no 40
- Electronic newsletter

Canada Mortgage and Housing Corporation

- Best Practice Guides
- Research highlights
- Electronic newsletter

Homeowner Protection Office (HPO) in British Columbia

- Practice documents

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Thank You!

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