Capillarity
it sucks, and how

Dr John Straube, P.Eng.
Associate Professor, University of Waterloo
Principal, RDH Building Science

jfstraube@uwaterloo.ca

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Rough outlines

- How capillary forces act with respect to
  - Drainage of walls and weep holes
  - Lap siding, flashing, backdams
  - Rain penetration
- Focus is larger gaps (*not* porous materials)
  - 0.02” to 0.50”

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History

- **Geovanni Borelli** (1608-1675)
  - demonstrated experimentally that h ~ 1/r
- **Geminiano Montanari** (1633-87):
  - attributed circulation in plants to capillary rise
- **Francis Hauksbee** (1700s):
  - conducted an extensive series of capillary rise experiments reported by Newton in his Opticks but was left unattributed
- **James Jurin** (1684-1750):
  - independently confirmed h ~ 1/r; and creator of “Jurin’s Law”.

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BACKGROUND SCIENCE

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The Water Molecule

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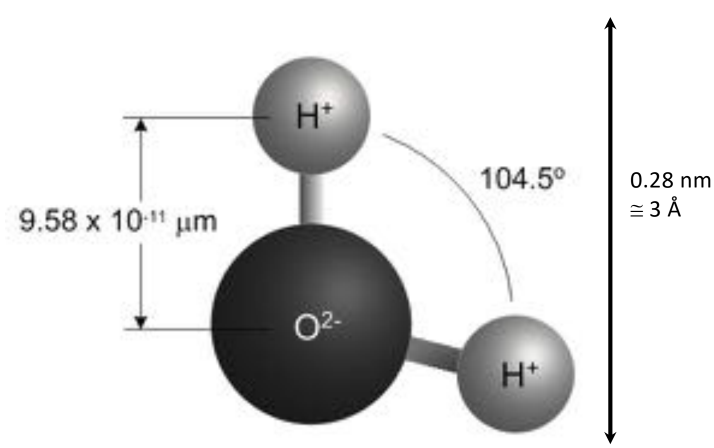
- Asymmetrical = polar



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The Polar Molecule

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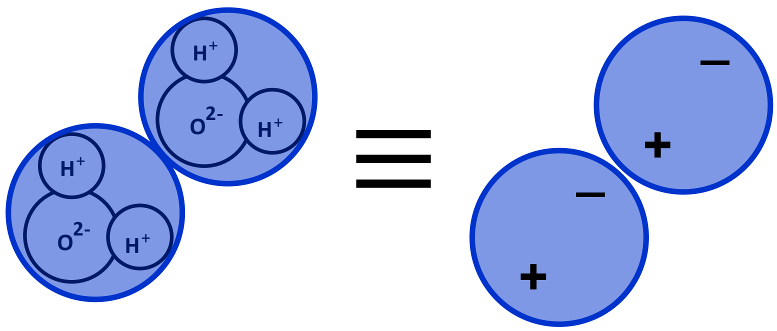
- Hydrogen end is “more” positive
- Oxygen end is “more” negative



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Cohesive

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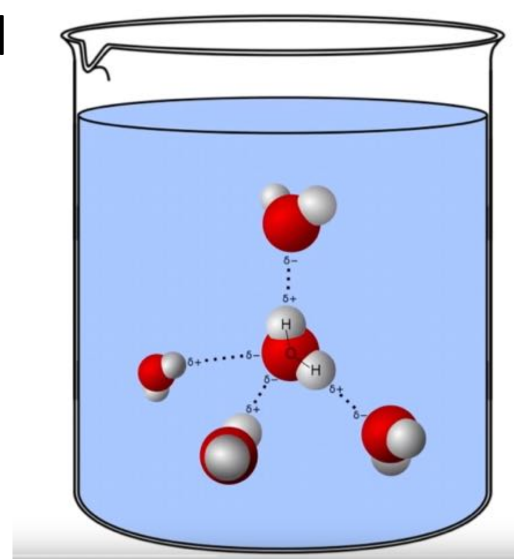
Water molecules are attracted *to each other*



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Surface tension

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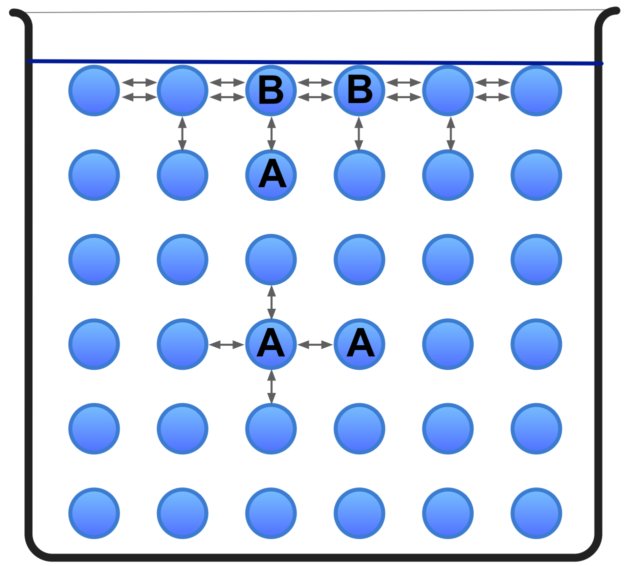
- Water molecules are attracted to each other
- At air-water interface unbalanced forces create a surface "film"
- B-B is stronger than A-A



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From: www.thenatureniche.com

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Wettable / hydrophobic

- Water is also attracted to some materials
  - Hydrophilic
- Water is repelled by some materials
  - hydrophobic

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Adhesive Forces

Water is attracted to vinyl siding… “adheres” to underside

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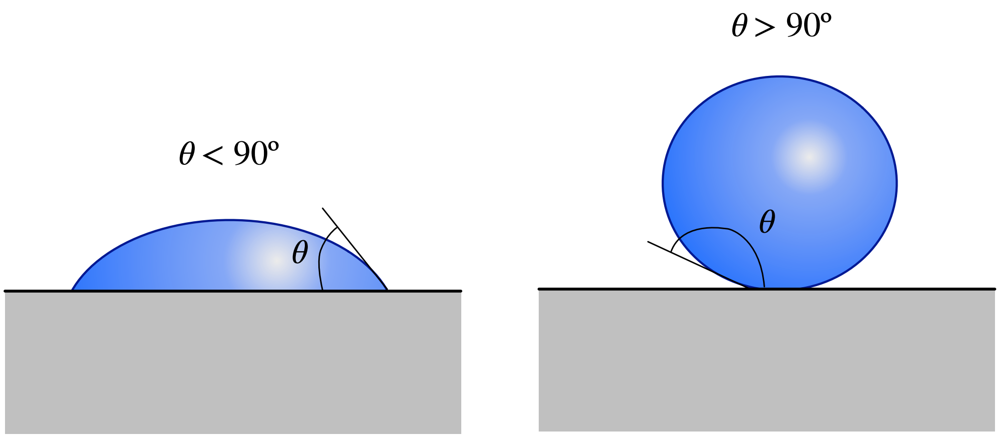
Wettable



hydrophilic, wettable

hydrophobic, non-wettable

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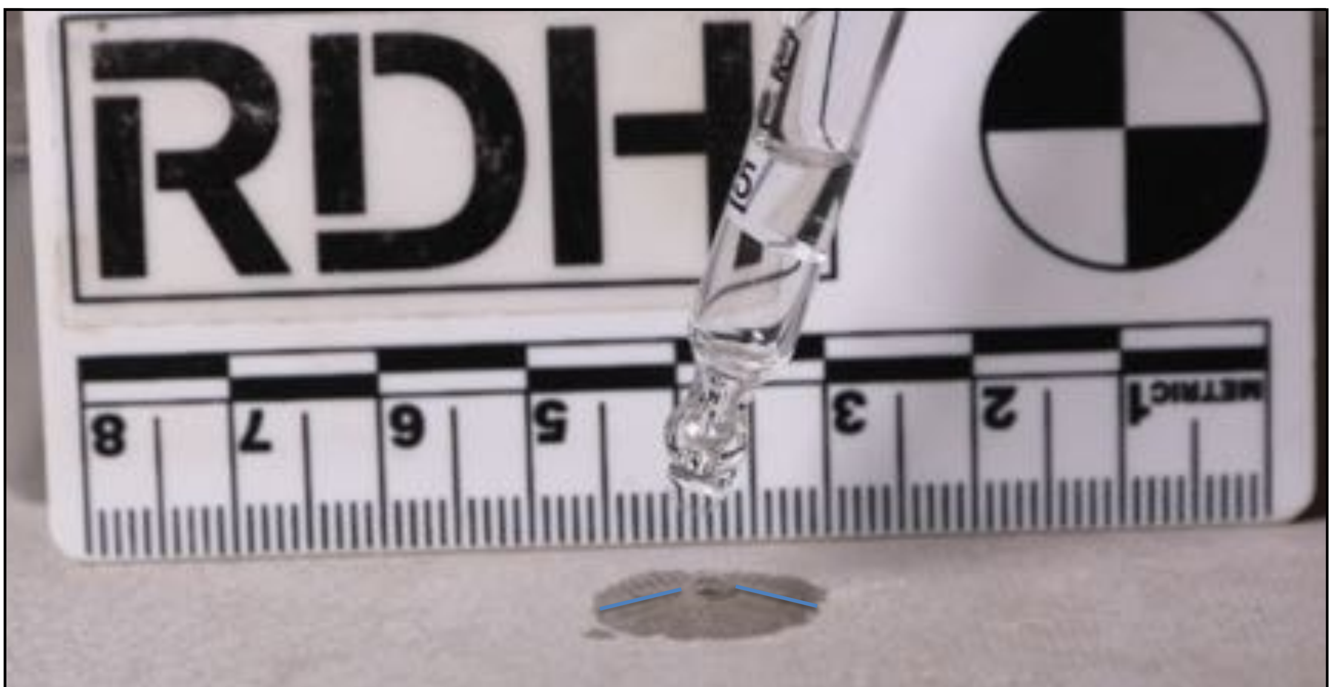

An absorptive cement-based material at the moment a water droplet contacts the surface

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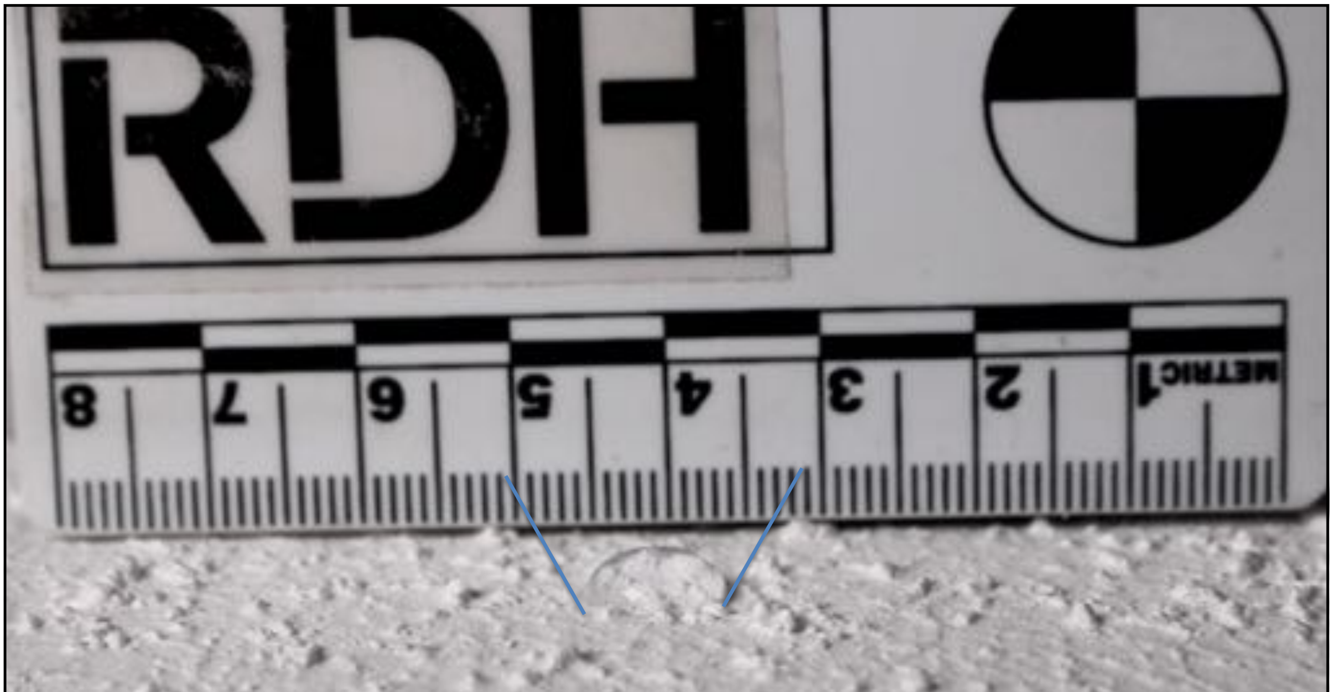

An textured acrylic-coating designed to repel water with droplet on surface

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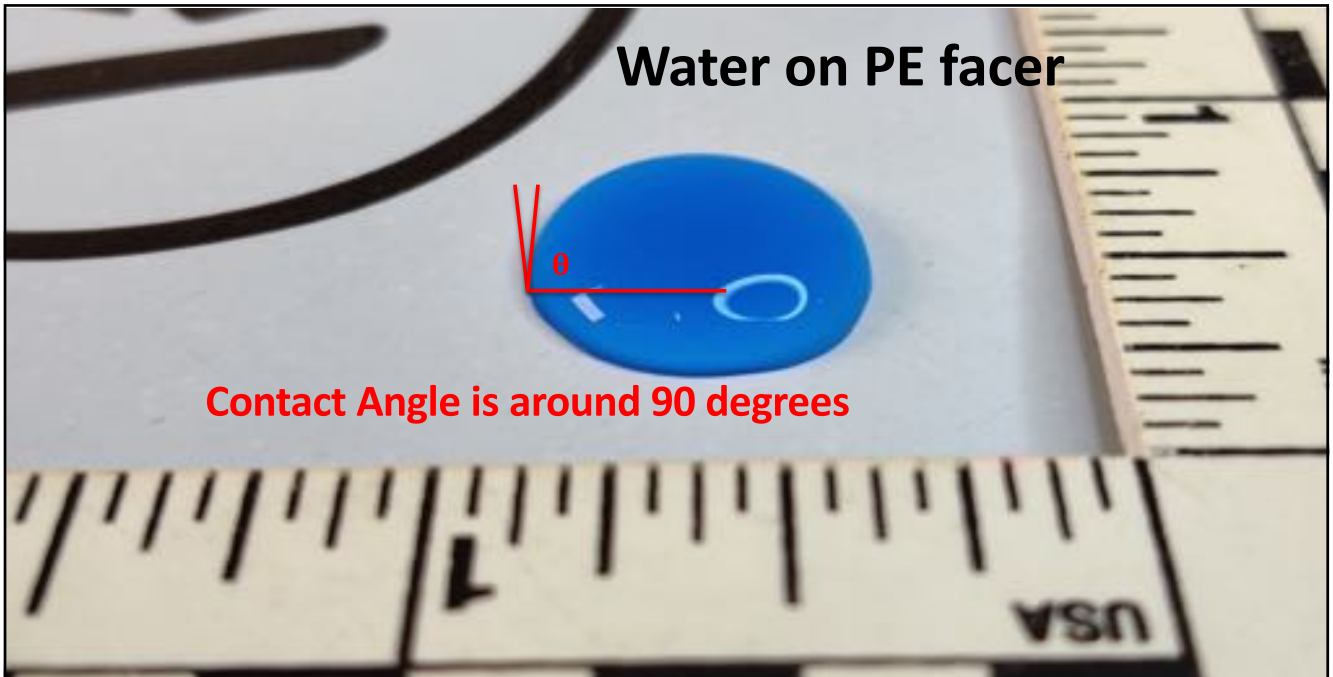

Polyethylene facer on a "peel-and-stick" almost hydrophobic

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Contact angle

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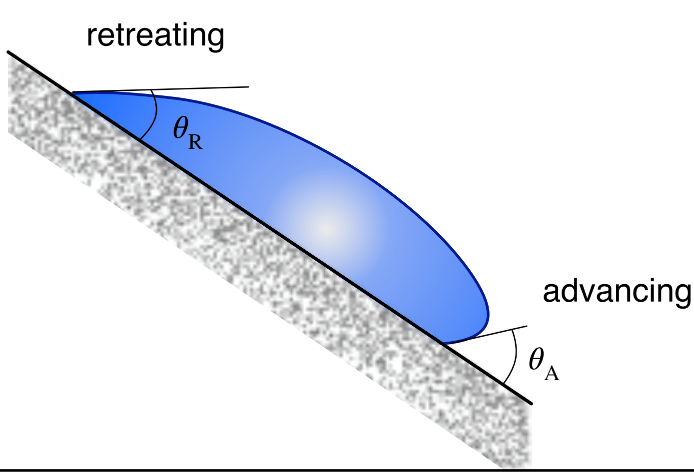
- Angle varies dynamically, with surface texture and with small impurities



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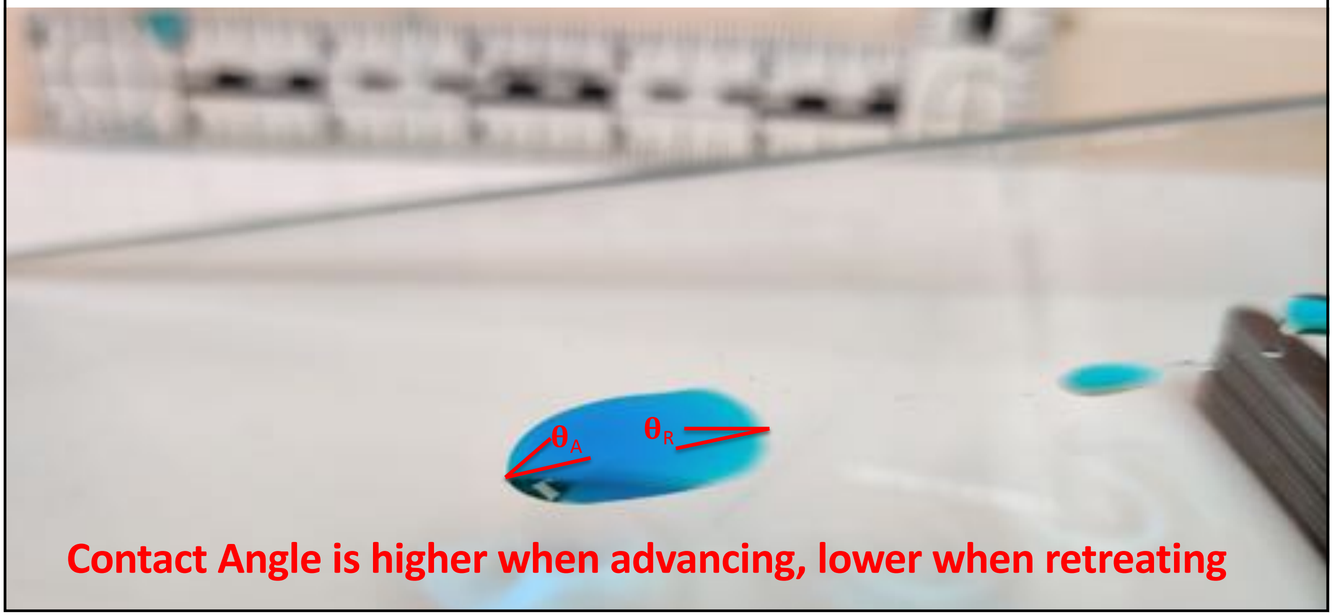
Droplet on sloped glass



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Advancing / retreating angle

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Long history

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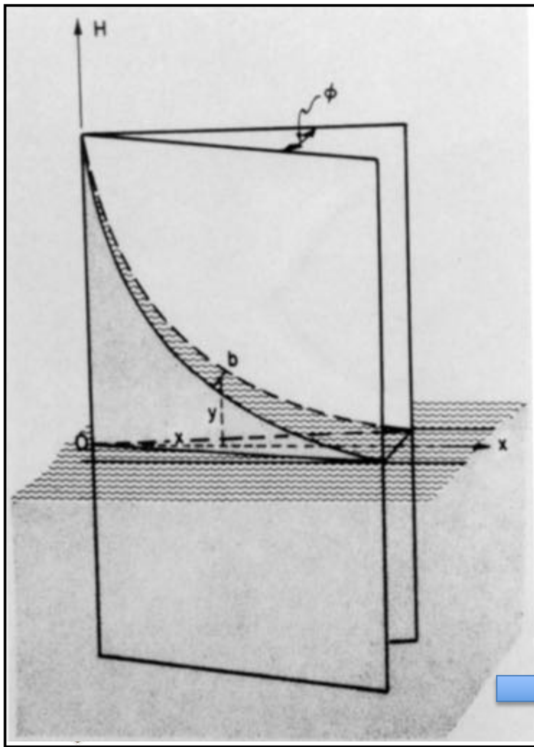

Journal of Colloid and Interface Science, Vol. 26, No. 4, April 1968

Capillary Penetration between Dissimilar Solids[1]

W. J. O'BRIEN, R. G. CRAIG, AND F. A. PEYTON

School of Dentistry, Marquette University, Milwaukee, Wisconsin, and University of Michigan, Ann Arbor, Michigan

Received October 2, 1967

(*See page 507 for Summary*)

The mathematical formulas derived by Young and Laplace (1) cannot be readily applied to the penetration of a liquid between dissimilar solids. Their equation,

$$h = \frac{2\gamma_{LV}}{\ldots}, \quad [1]$$

ferent properties. The Young-Dupré equation gives

$$(F_{SV} - F_{SL}) = \gamma_{LV} \cos \theta. \quad [3]$$

Here γ_{LV} refers to surface tension of the liquid, θ is the liquid-solid contact angle,

TABLE II

CONTACT ANGLES OF LIQUIDS ON VARIOUS SOLIDS AT 27°C

Solid	Liquid	θ_A (degrees)	θ_R (degrees)	n
Acrylic	Water	74	54	5
Teflon	Water	110	82	4
Glass	Water	14	11	6
Desicote	Water	91	65	6

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Water Resistant Barrier Materials

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- WRB materials are hydrophobic-ish

Table 1. Contact angles distilled water on sheathing membranes

No. Sample	Description	$\theta_{C,\ static}$	$\theta_{C,\ advancing}$	$\theta_{C,\ receding}$
0	Polycarbonate	79.1 ± 1.5	83.3 ± 1.5	48.7 ± 1.5
1	Cross-woven polyolefin wrap	77.7 ± 5.8	85.1 ± 4.0	50.8 ± 4.7
Tyvek DrainWrap?	Spun-bonded polyethylene, grooved	84.2 ± 4.0	88.4 ± 1.8	57.3 ± 3.6
Tyvek?	Spun-bonded polyethylene, continuous	90.4 ± 2.1	96.5 ± 3.3	73.1 ± 2.7
4	Asphalt saturated Kraft building paper	105.4 ± 6.4	111.3 ± 2.1	74.9 ± 2.1
	Glass about 10 deg			

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From Dr Nathan Van der Bossche, 2018

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Capillary Suction

- Attraction to surfaces if hydrophyllic
  - That is angle <90°
- Tubes / cracks / pores have a lot of surface area to attract water

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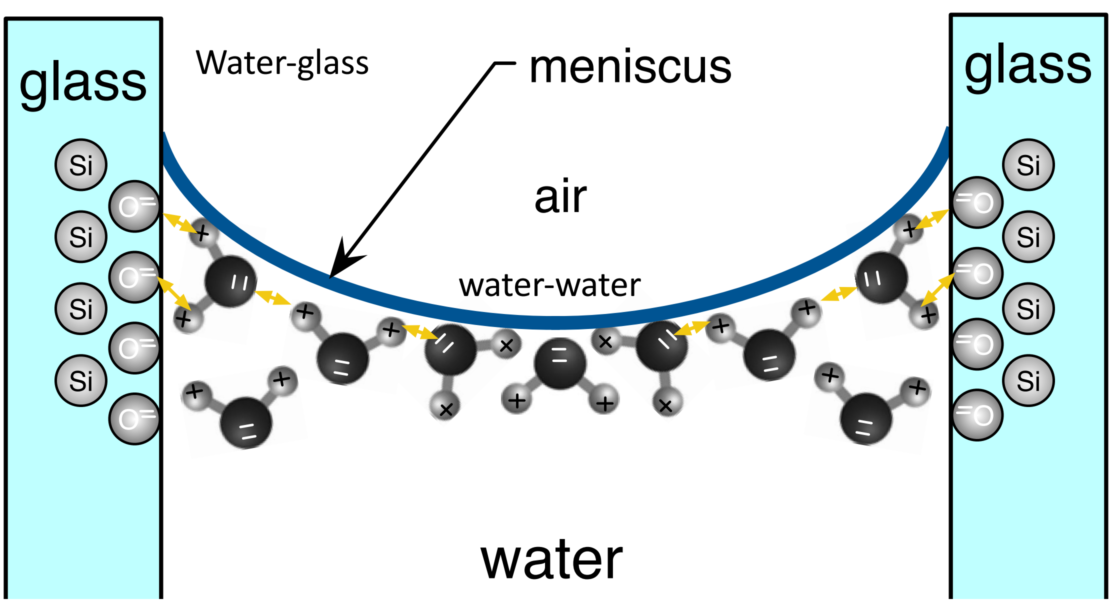
Water between two sheets of glass



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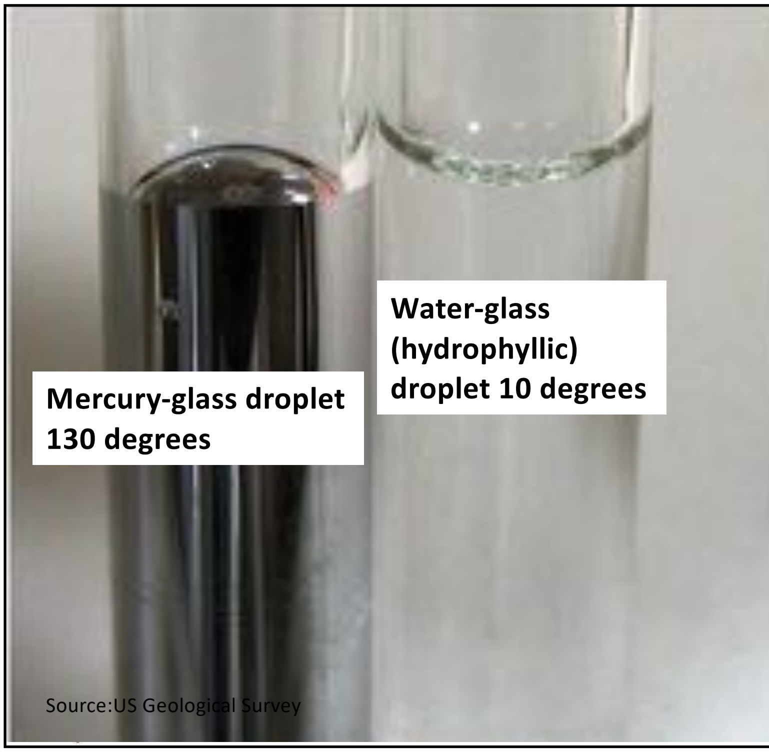

Source:US Geological Survey

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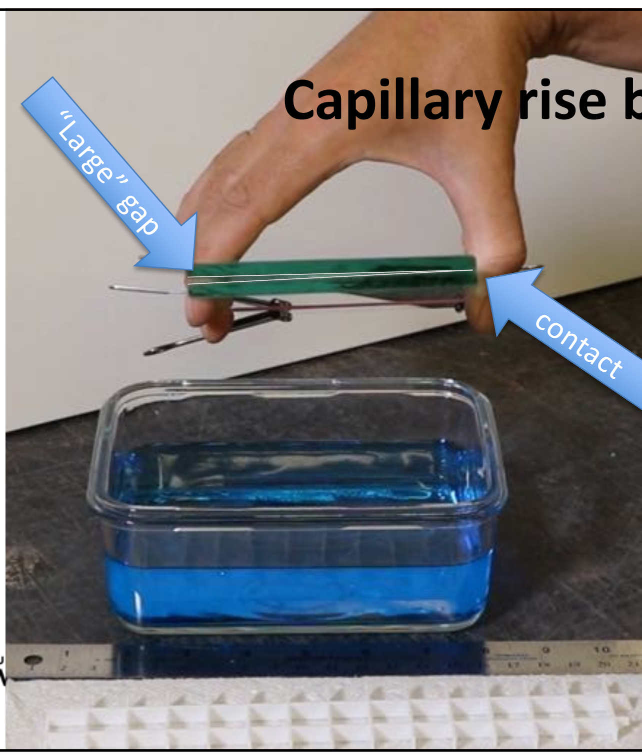
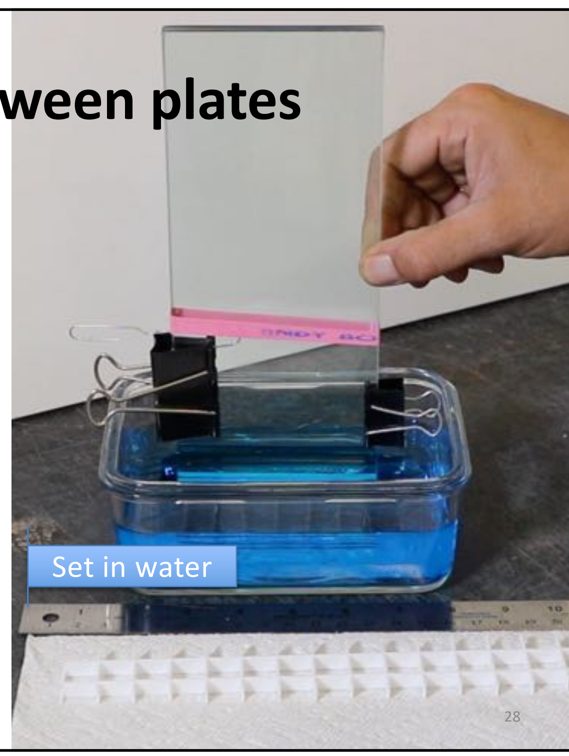
Capillary rise between plates





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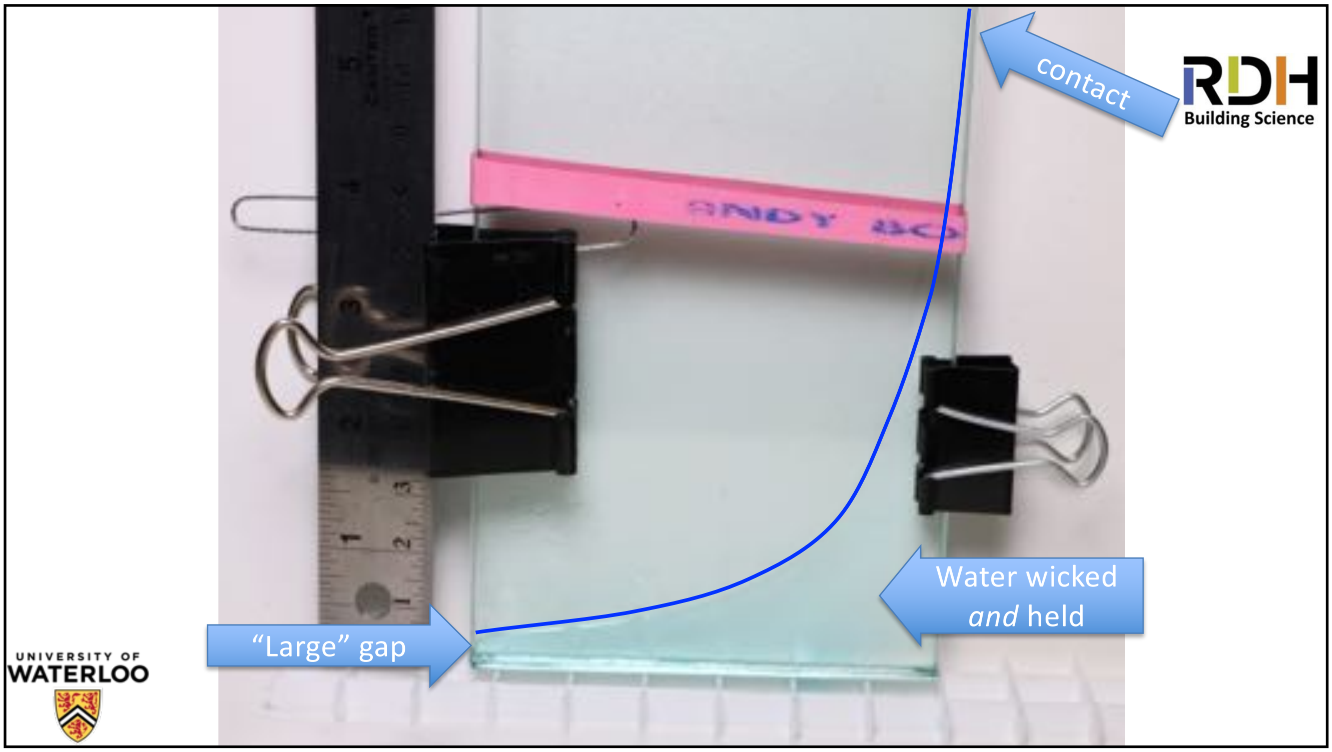

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How much does is wick?

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- We can predict with calculations!
- Suction is reported as a **pressure** (Pa, psi)
- BUT, suction can be reported as **head** (mm, inch) that capillarity will draw water up against gravity
  - Capillary **rise** is another term

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Laplace-Young, etc.

$$h = \frac{2 \cdot \sigma \cdot \cos\theta}{\rho \cdot g \cdot w}$$

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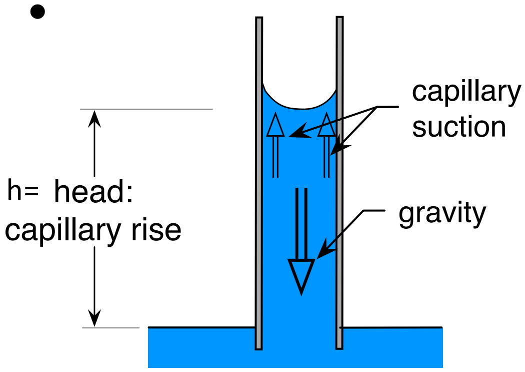

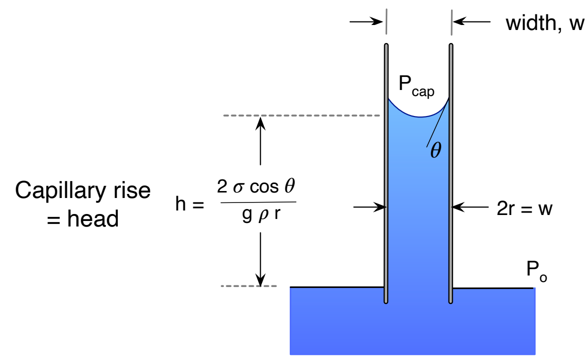

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Where, σ is the surface tension of water, 0.072 N/m, and θ is the contact angle of liquid-solid

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Small Pores .. Capillary suction

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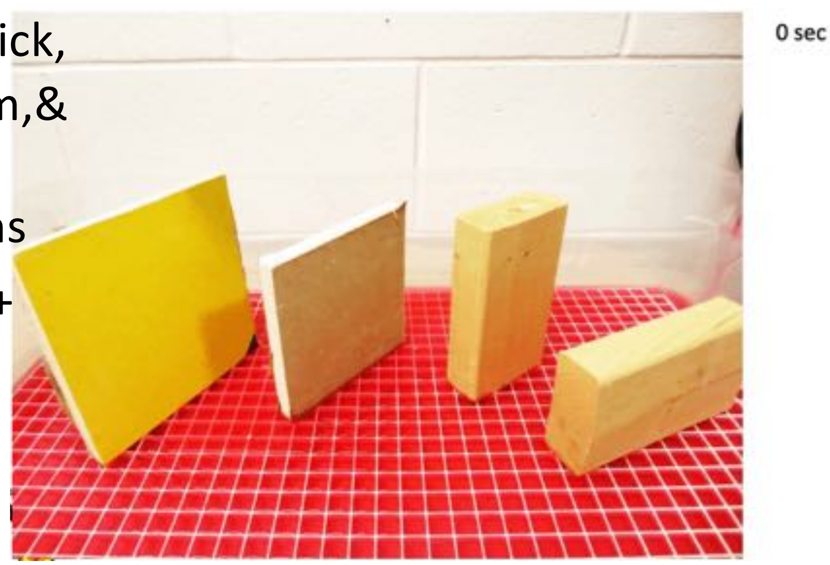
- small pores in brick, concrete, gypsum,& wood have very high suctions
- 1 000-10 000 Pa+
- Heads many feet



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Capillary vs Wind Pressure

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Capillary | Wind pressure

Crack width / pore radius			Capillary Suction (Hydrophilic surfaces 90°)				Windspeed
			Pressure	head	Pressure	head	stagnation
[inch]	[inch]	[mm]	[Pa]	[mm]	[psf]	[inch w.c.]	[mph]
0.5	1/2	12.7	11.3	1.15	0.24	0.05	10
0.125	1/8	3.2	45.1	4.60	0.94	0.18	19
0.063	1/16	1.6	90.2	9.21	1.88	0.36	27
0.020	1/50	0.50	286	29.2	5.98	1.15	48
0.01	1/100	0.25	564	57.5	11.8	2.27	68
0.001	1/1000	0.025	5640	575	118	22.7	214
0.0001	1/10000	0.0025	57 600	5750	1180	227	678

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CAPILLARY BREAKS

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Capillary Breaks

- Q. What is a capillary break?
- A. A feature of an assembly that interrupts capillary flow

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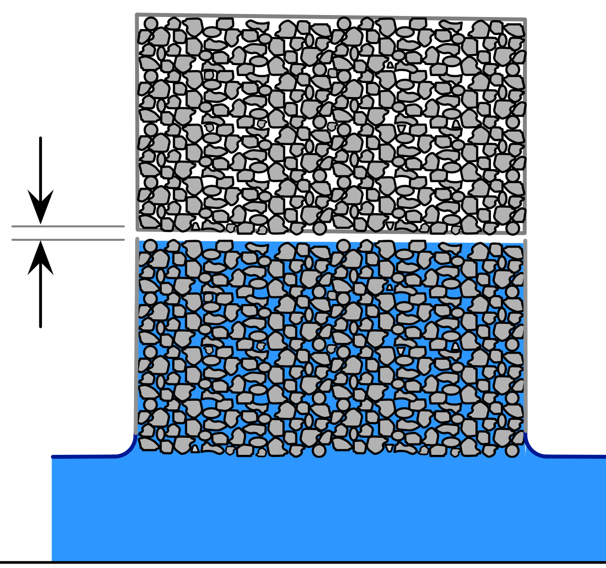
A gap

- A gap is a large pore.. Therefore no wicking

Gap size > pore size =capillary break



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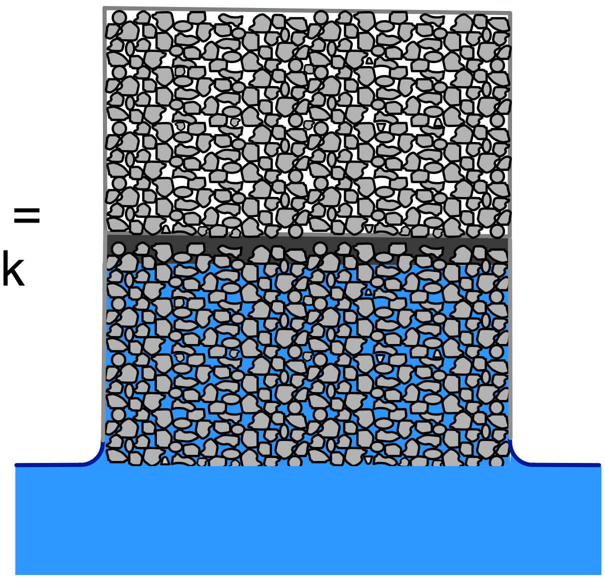
A layer

- Blocked pores can't wick water



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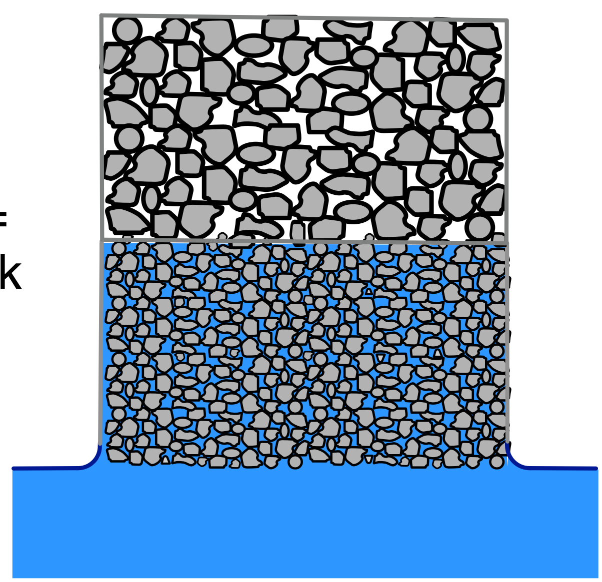
- large pores don't wick as strongly as small pores



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Capillary Breaks

- Q What is a capillary break?
  - A feature of an assembly that interrupt capillary flow
  - Impervious material (no pores)
  - Hydrophobic material (no attraction)
  - Large voids (low capillary suction)

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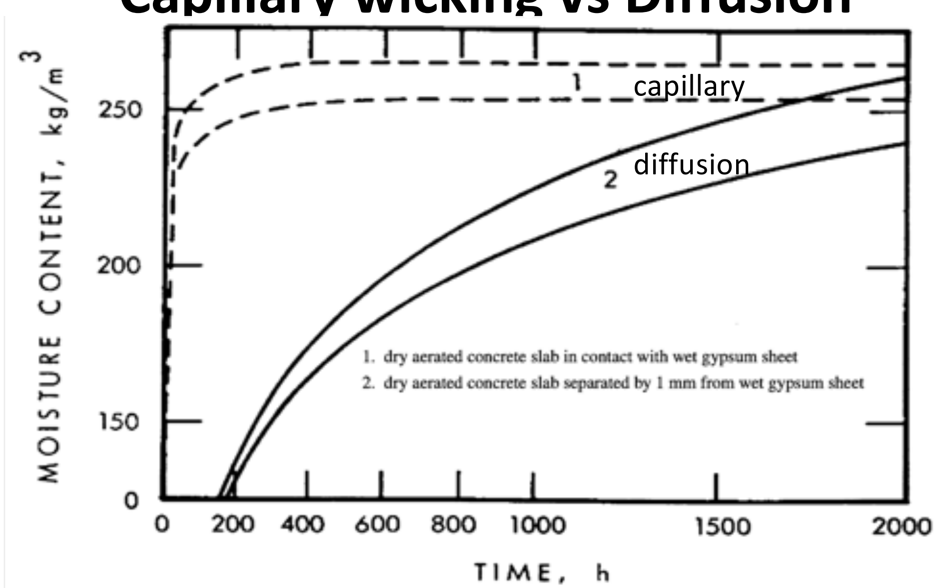
Capillary wicking vs Diffusion



(From Bomberg, M. 1974. *Moisture flow through porous building materials*. Lund Institute of Technology,Lund Sweden.

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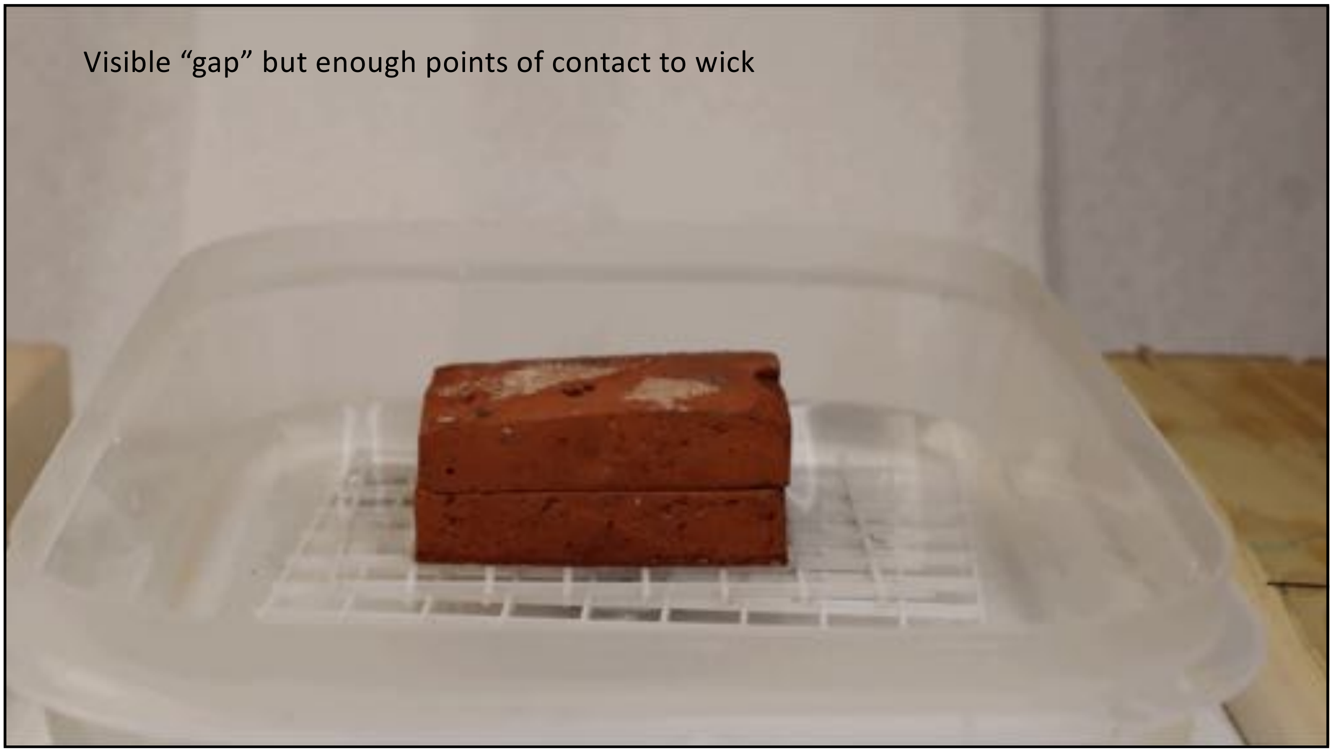

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Insert a small gap, < 1/25” = 1 mm

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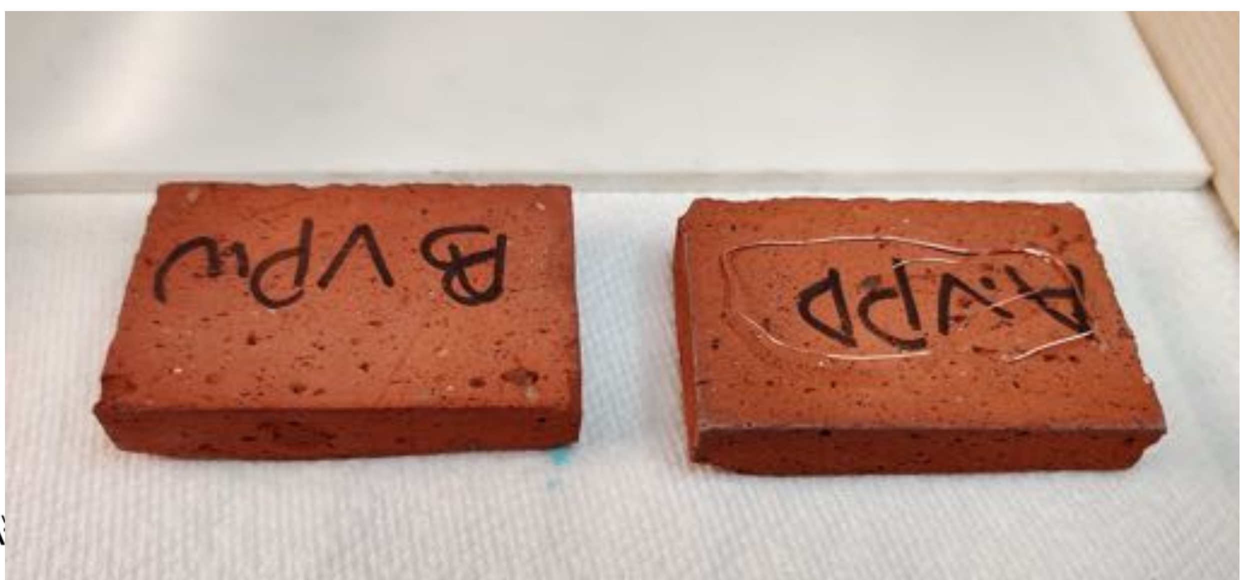

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Brick samples stacked on top of each other

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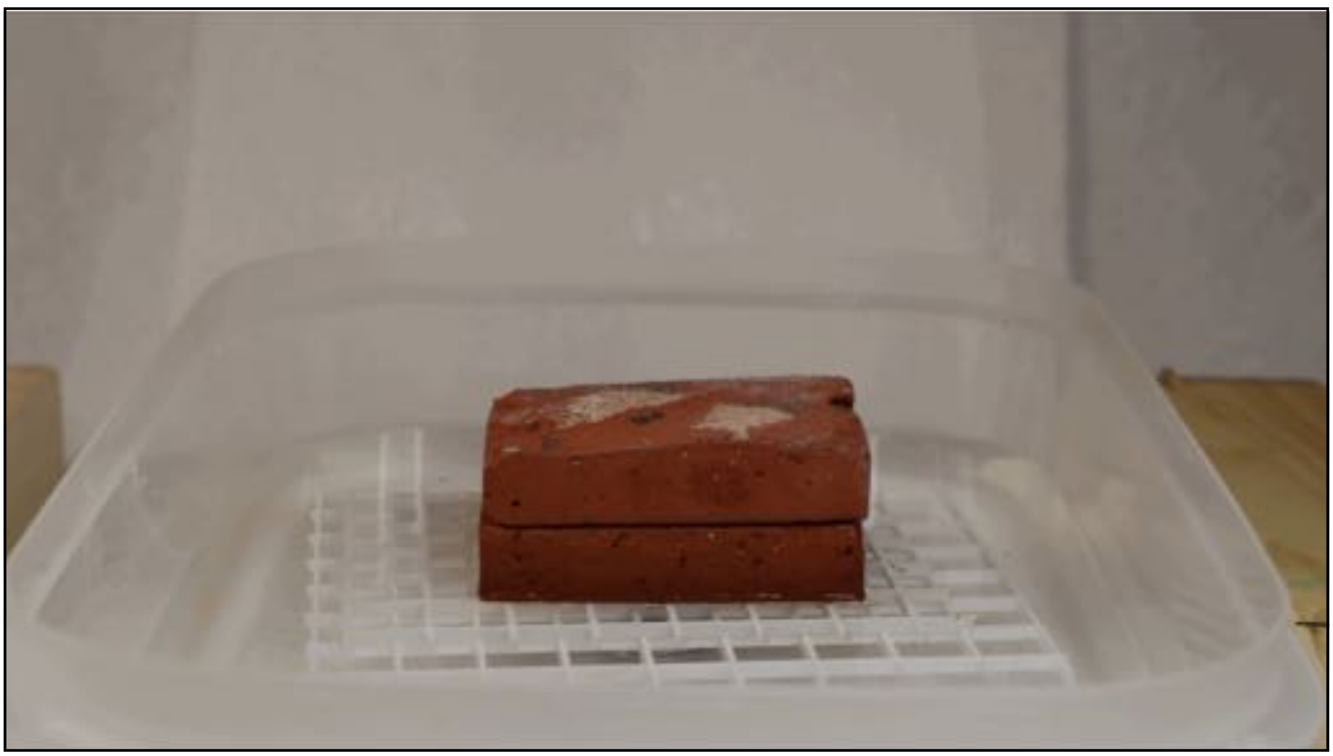

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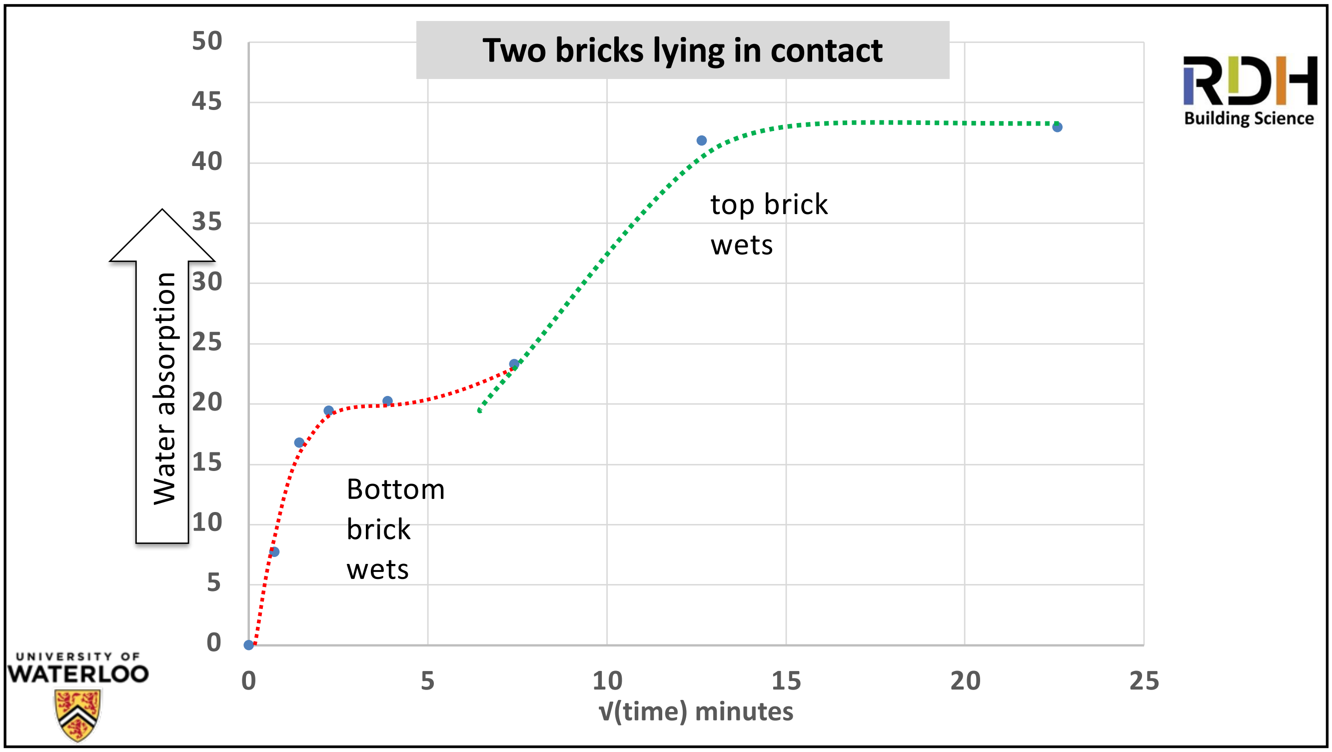
Two bricks lying in contact
Water absorption
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
√(time) minutes
top brick
wets
Bottom
brick
wets
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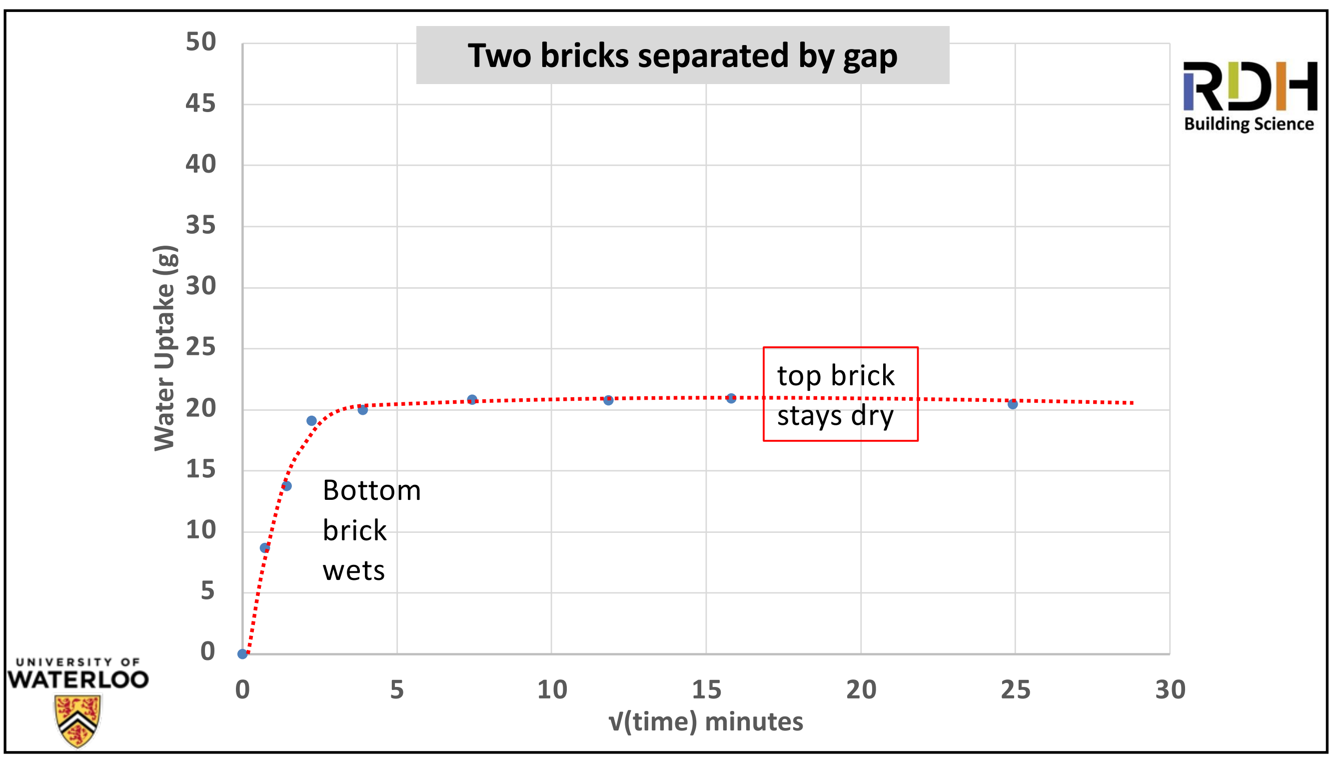
Two bricks separated by gap
Water Uptake (g)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
√(time) minutes
top brick
stays dry
Bottom
brick
wets
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What did we learn?

- Capillary wicking is stopped by a capillary break
- Even a small gap (0.04”) is a perfect capillary break

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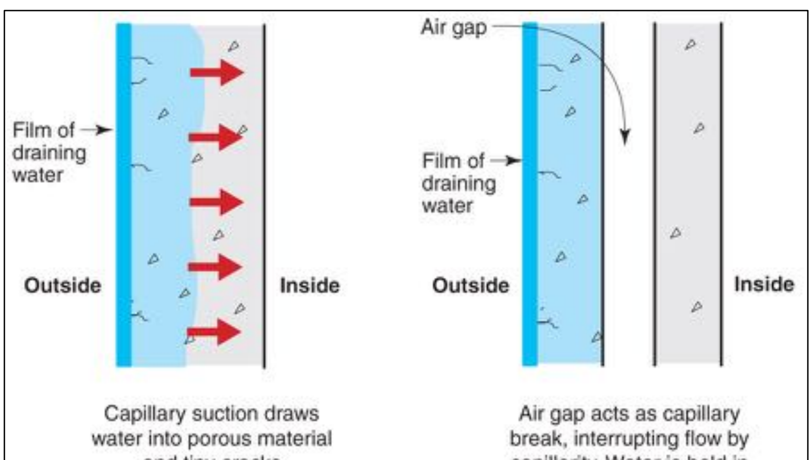
Capillary break



Source: Building Science Corp

Air gaps are used to stop water wicking
from porous cladding (stucco, brick) to
moisture sensitive backing (wood, etc)

Such a gap can be
very small!
<1/32”

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Q: Why bigger gaps?

A: not to make a capillary break

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Why bigger gaps?

- Avoid **Bridging** of the "cavity"
- Drainage of water
- Accommodate **Tolerances**
- Allow **Ventilation** drying

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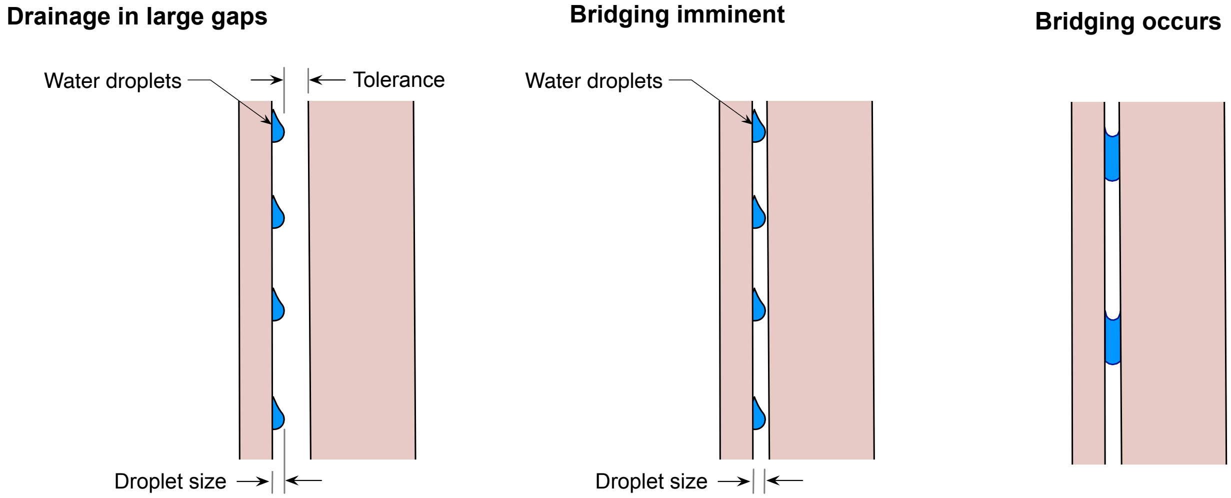
Droplet size & bridging



When does bridging start?
What is the size of a droplet?

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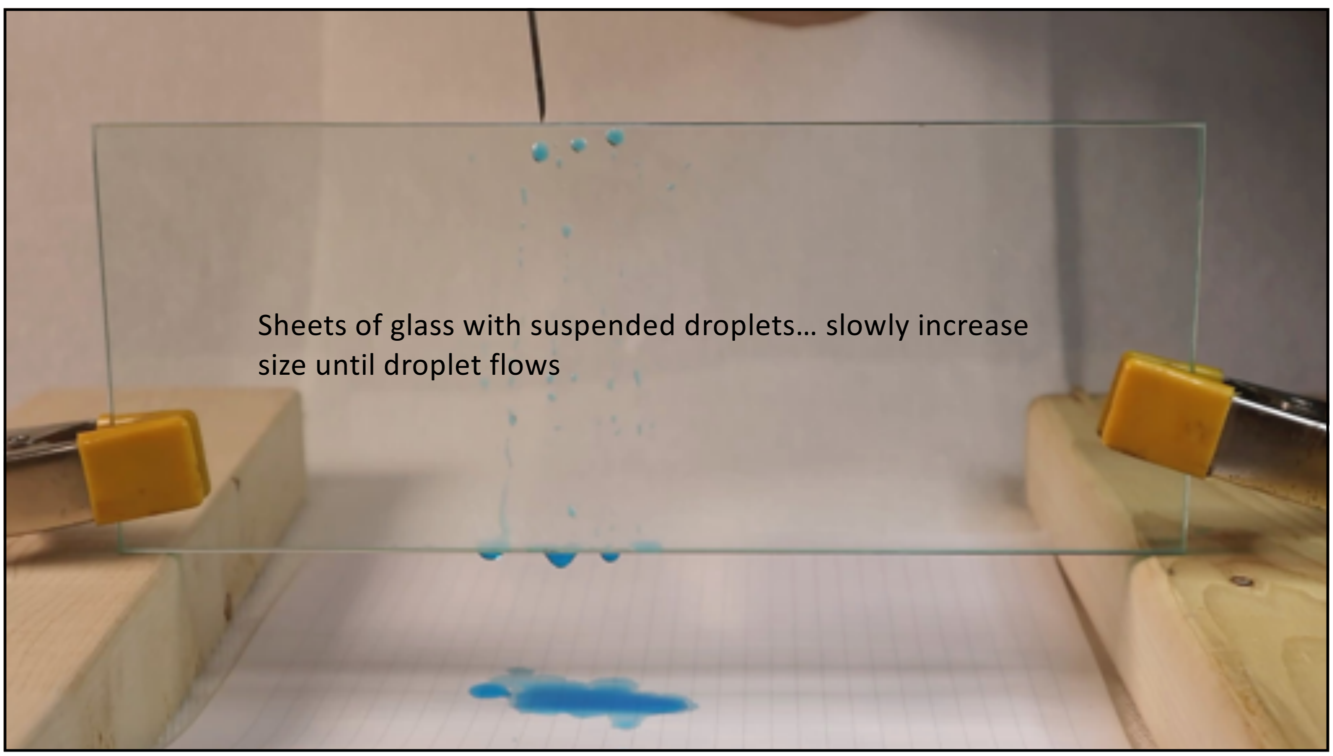

Sheets of glass with suspended droplets… slowly increase size until droplet flows

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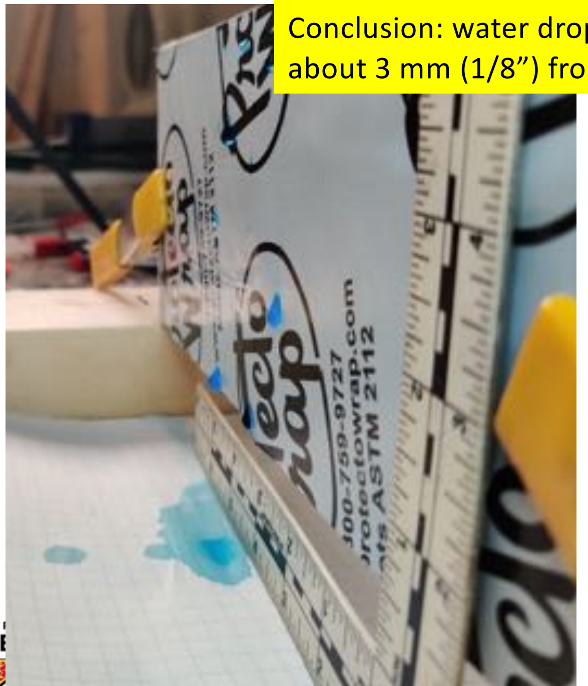
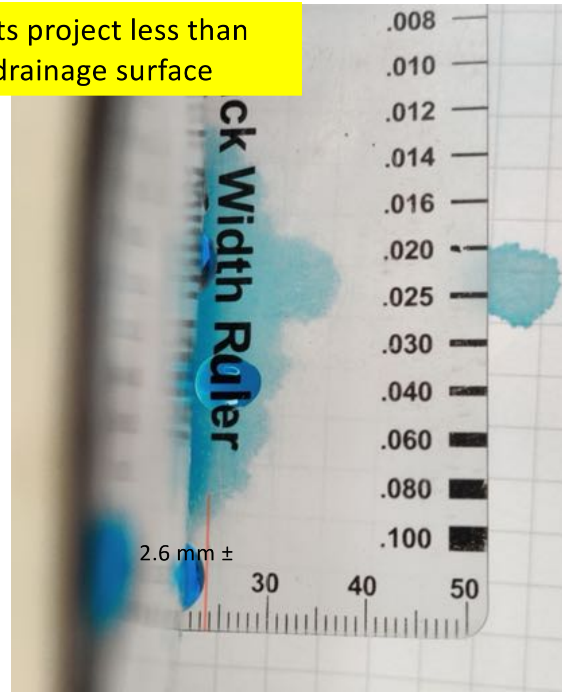
Conclusion: water droplets project less than about 3 mm (1/8”) from drainage surface





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What do we learn?

- A true gap of over 1/8” wont ”bridge”
- Why do you want to prevent bridging?
- If you have a WRB, then not a great reason

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Gaps under metal roofs

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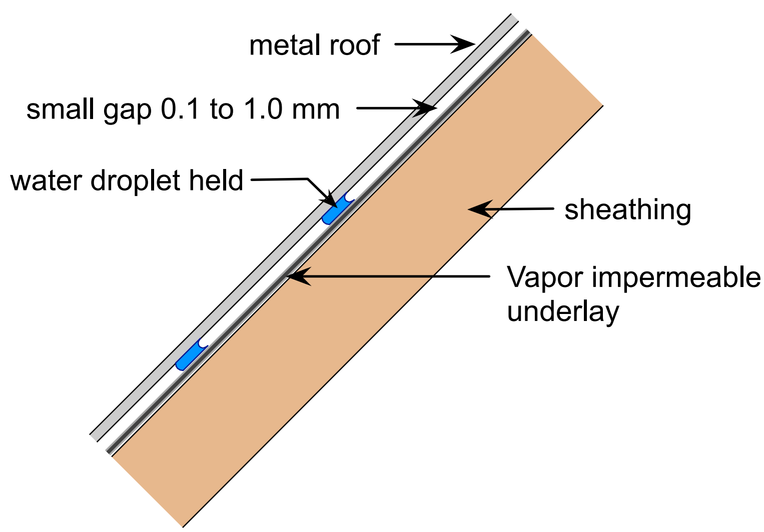
Gaps under metal roofs

- Some metal roofs (zinc, copper) can experience local corrosion from droplets on underside
- Small gaps hold drops in contact with the underside



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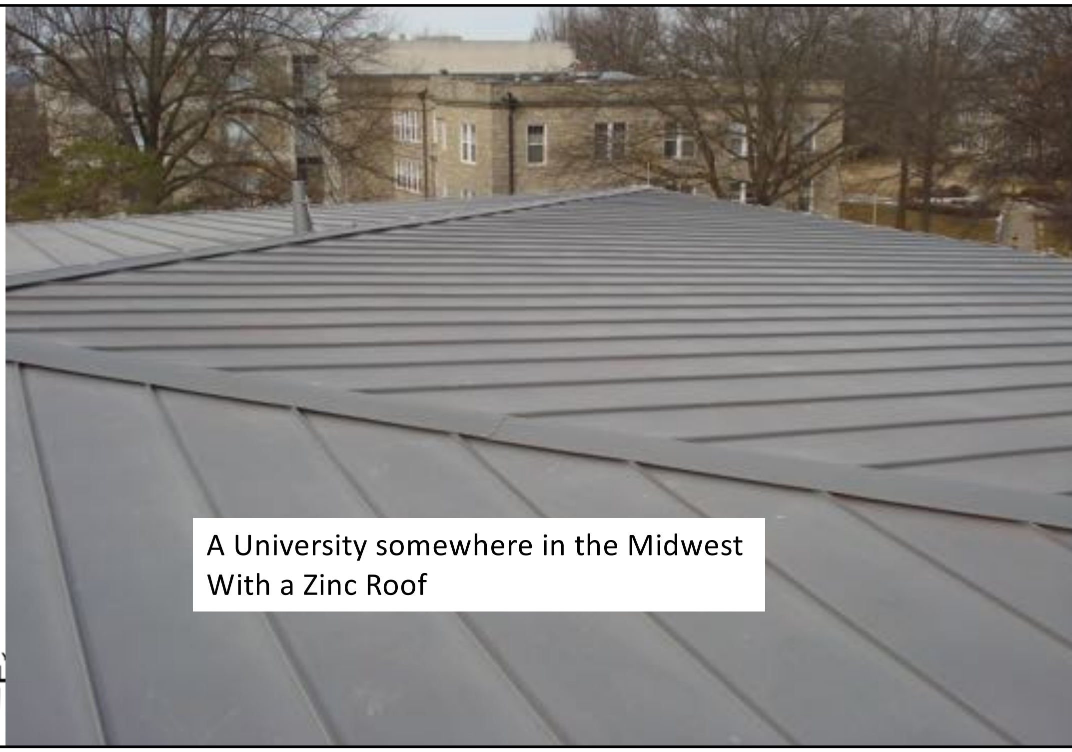
A University somewhere in the Midwest
With a Zinc Roof

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After about 2 years …

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An RPH somewhere in Texas. Zinc roof

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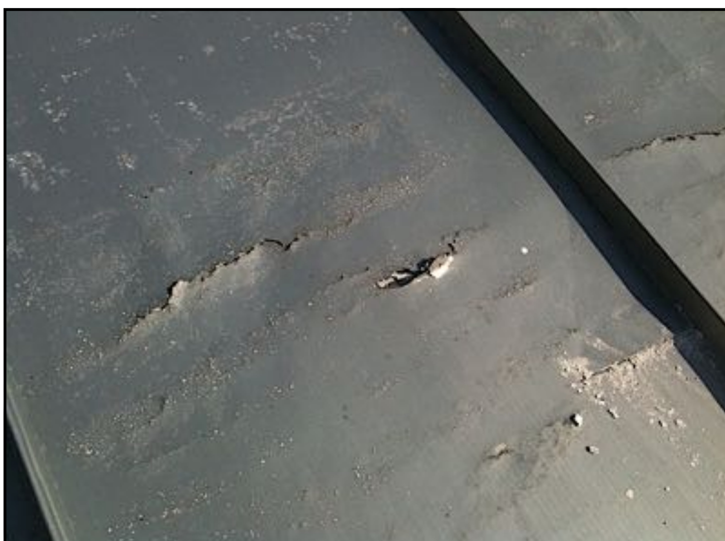

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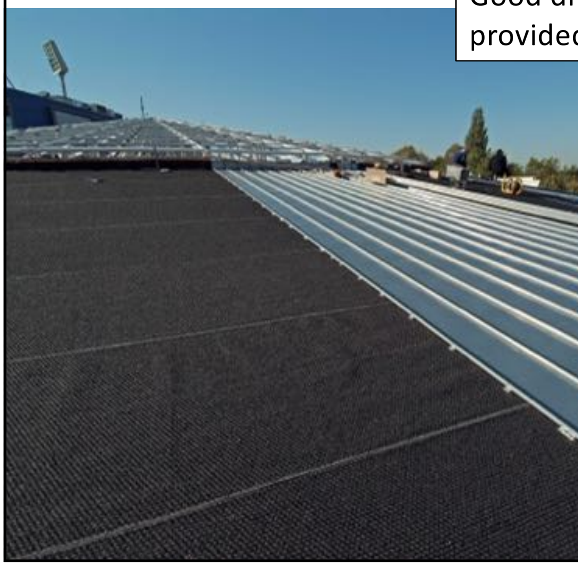
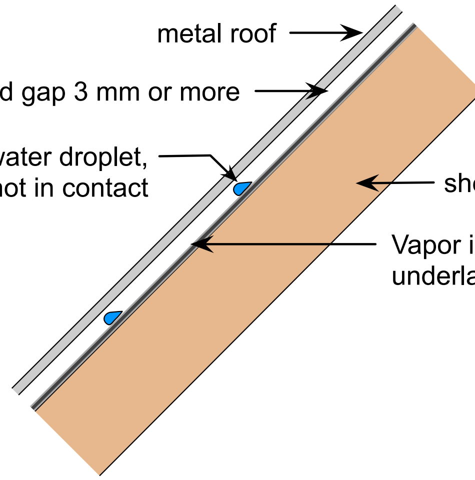
Gap membrane below Zinc

Good drainage is also ensured, but usually provided in direct applications anyway





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How big does the gap need to be to allow drainage

DRAINAGE IN SMALL GAPS

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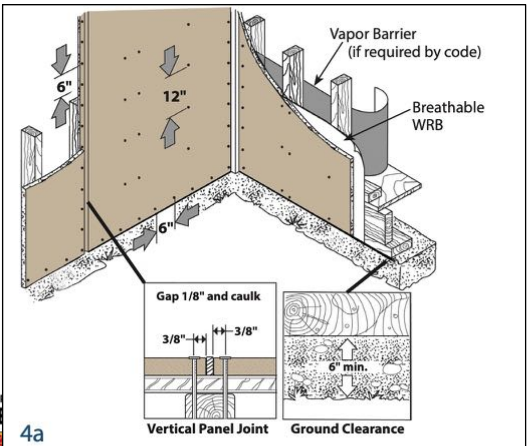
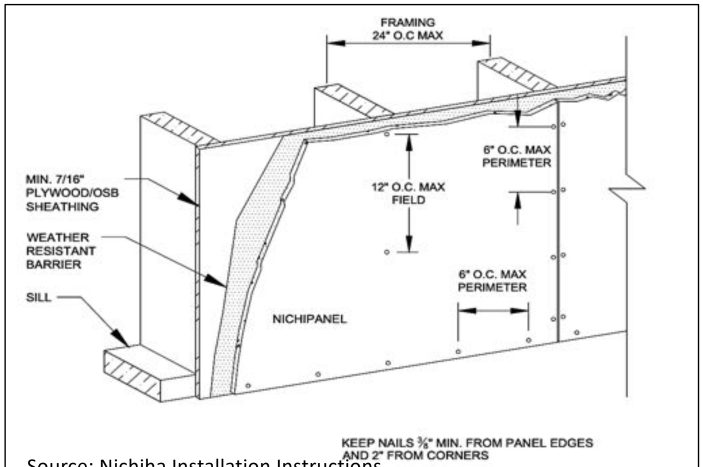
Many enclosure systems rely on small gaps for drainage

- E.g. T-111, LP Smartside (OSB), Nichiha Fibercement



Source: LP Smartside Installation Instructions



Source: Nichiha Installation Instructions

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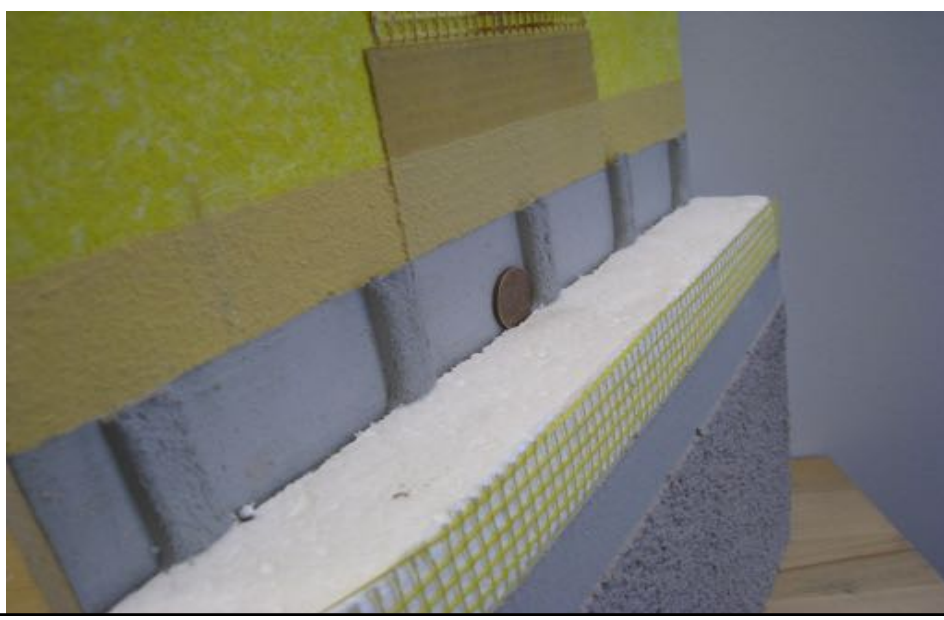
Drained EIFS



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History of Research

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- B Brown 1999 (EIFS)
- T Weston 2001 (stucco)
- JJAC Test hut 2004
- J Smegal thesis, 2006

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JJAC 2004

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Drainage rate between building paper sheets was astonishing

Drainage between stucco and paper was zero where stuck

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Experiment

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- Demonstrate that drainage occurs in small gaps
- Quantify water held in gap

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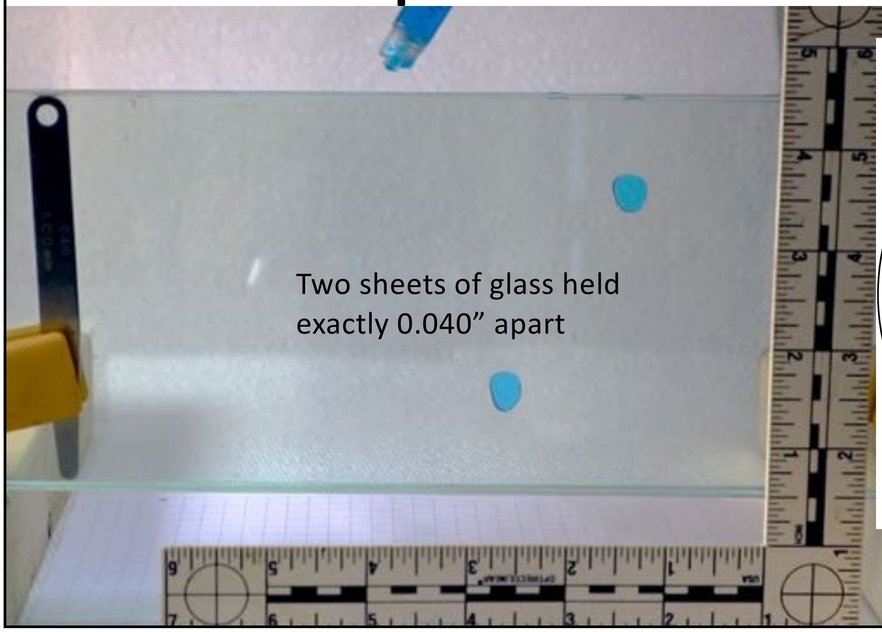
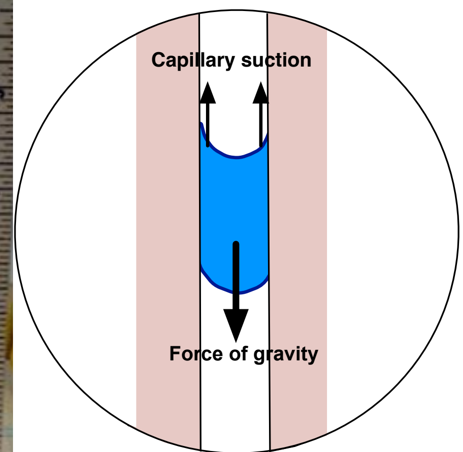
Water droplets held in 1.0mm (1/25") gap



Two sheets of glass held exactly 0.040" apart



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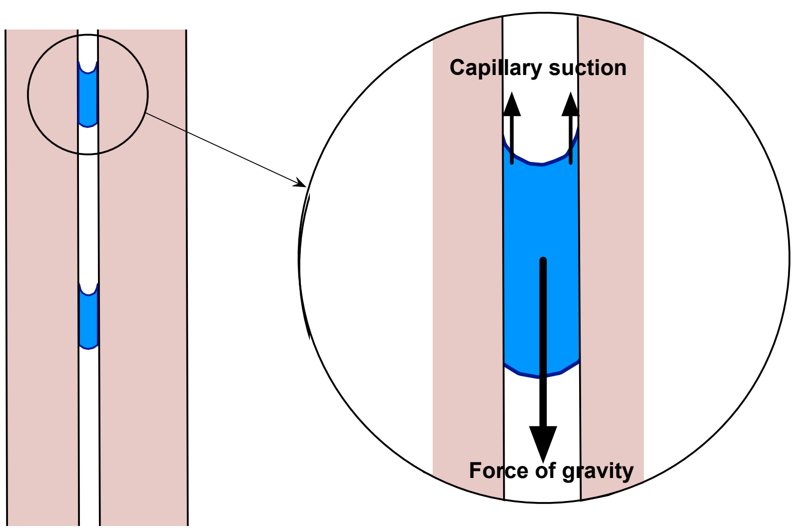
Drainage is the unbalanced state

-



Gravity **exceeds** capillary = Drainage flow begins

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Reminder

Gap Width	Suction Pressure	Head (if glass-glass)
0.25 mm = 0.01”	564 Pa	57.5 mm = 2.26”
0.50 mm = 0.02”	286 Pa	29.2 mm = 1.15”
1.00 mm = 0.04”	141 Pa	14.4 mm = 0.56”
1.60 mm = 1/16”	90 Pa	9.2 mm = 3/8”

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Drainage videos

- Glass sheets both sides
  – 1.0 mm gap

Movie 1

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Drainage videos

- Glass sheets both sides
  - –1.0 mm gap (0.040”)
- Results: Drains and Retains less than ¼”
- WRB’s are not made of glass….

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Video: Glass over HDPE

- Use HDPE to mimic facers and housewrap
- 1.5 mm (≈$^{1}/_{16}$”) gap …

- Movie 2

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Video: Glass over HDPE

- Use HDPE to mimic facers and housewrap
- Results 1.5 mm (≈$^1/_{16}$”) gap …
  - it drains. Retains a little, about ¼”

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Video: Glass over HDPE

- Use HDPE to mimic peel ’n stick & housewrap
- Results 1.5 mm (≈$^1/_{16}$”) gap …
  - it drains. Retains a little, about ¼”
- 0.5 mm (0.02”) gap
  - 290 Pa, > 25 mm head
  - Movie 3

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0.5 mm gap = 0.02" gap

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- Capillary theory… gap = 290 Pa of suction
- 1" = 25 mm head = 250 Pa
- Movie 3…

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Video: Glass over HDPE

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- Use HDPE to mimic peel 'n stick & housewrap
- Results 1.5 mm (≈$^{1}/_{16}$") gap …
  - it drains. Retains a little, about ¼"
- 0.5 mm (0.02") gap
  - It drains. Retains a little, over ½"

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What did we learn?

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- Drainage can occur in very small gaps
  - Gravity-driven leaks inward also occur in small gaps of sufficient height
- Small gaps will retain water
  - Not a large quantity of water, but height 1” or so practical

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Air gap size vs function

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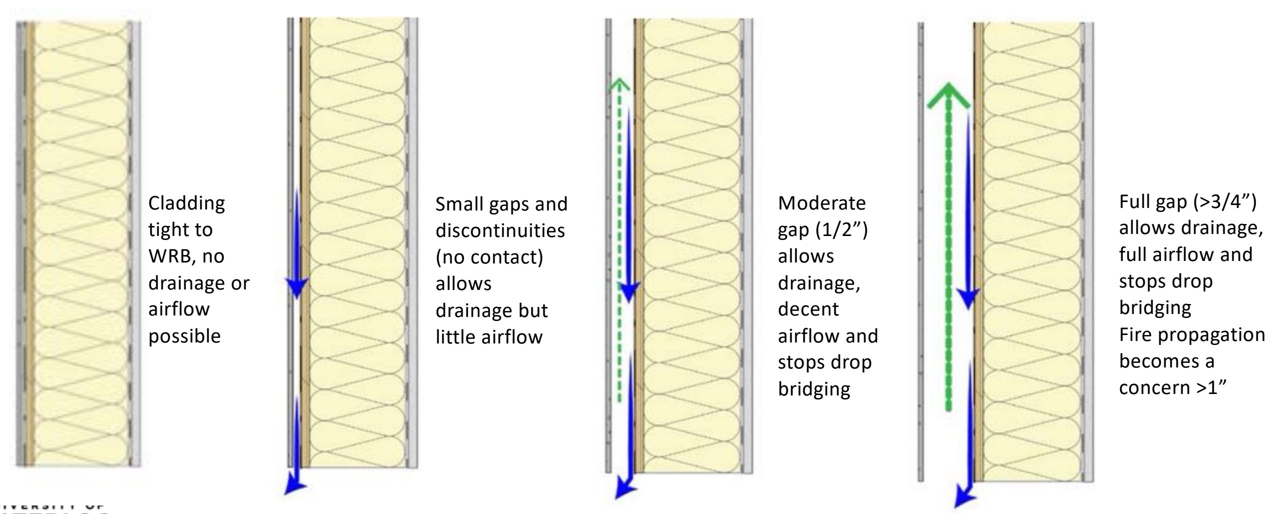

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Small gap drainage

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Drainage in practise

- Dimple sheets used below grade
- 6-10 mm gaps
  - –Could be much less
- Incredibly effective

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Stucco "drainage"

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- New IRC code requirements

2510.6.2 Moist or marine climates. In moist (A) or marine (C) climate zones, water-resistive barrier shall comply with of one of the following:

In addition to complying with Item 1 or 2 of Section 2510.6.1, a minimum 3/16 inch (4.8 mm) space shall be added to the exterior side of the water-resistive barrier.

In addition to complying with Item 2 of Section 2510.6.1, a space with a minimum drainage efficiency of 90% as measured in accordance with ASTM E2273 or Annex A2 of ASTM E2925 is added to the exterior side of the water-resistive barrier.

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Capillary impacts

RAIN PENETRATION

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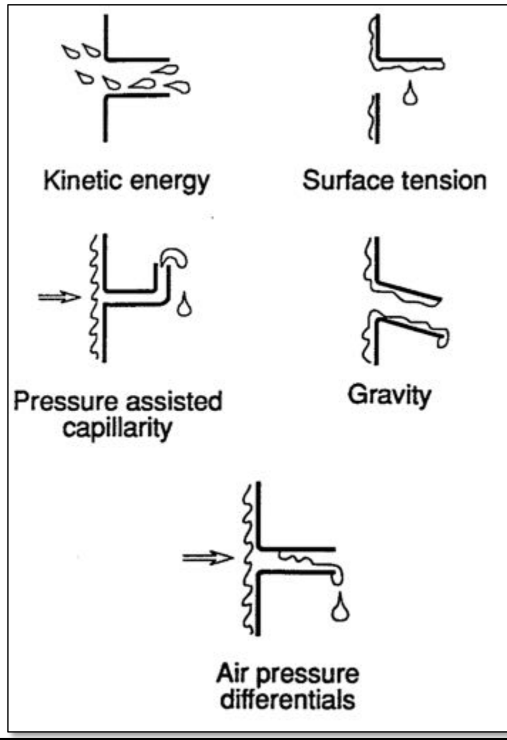
Capillarity as a rain penetration force

- How does capillarity play a role in rain penetration?



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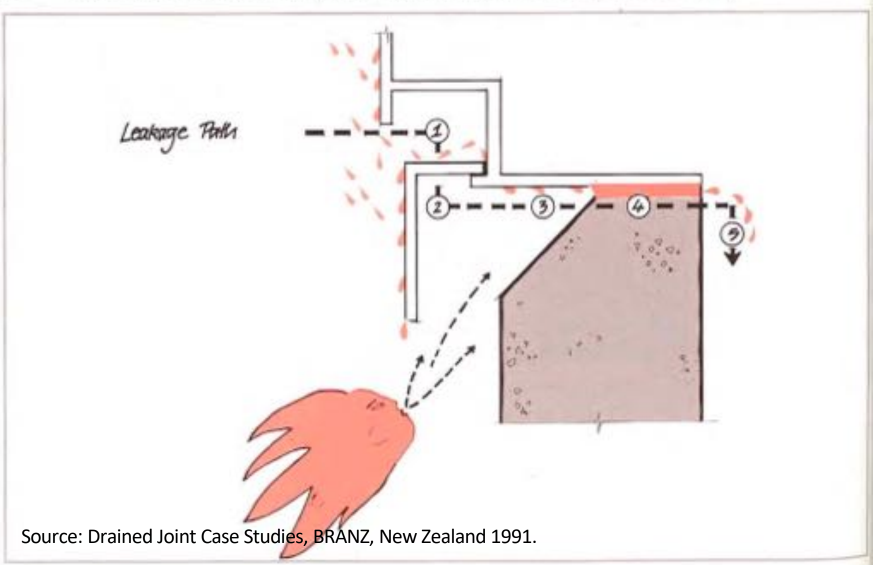
Source: Baskaran, B.A. 1992. *Review of design guidelines for pressure equalized rainscreen walls*. National Research Council of Canada.

85

(1) the kinetic energy of wind-driven raindrops carries them into the wall, through an opening in the rainscreen,
(2) gravity drainage causes the water to flow downward through a gap,
(3) surface tension allows water to flow sideways along an overhanging joint surface,
(4) capillary suction makes this water fill the gap between two elements, and
(5) wind pressure forces the water in that gap through to the inside of the building.



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Source: Drained Joint Case Studies, BRANZ, New Zealand 1991.

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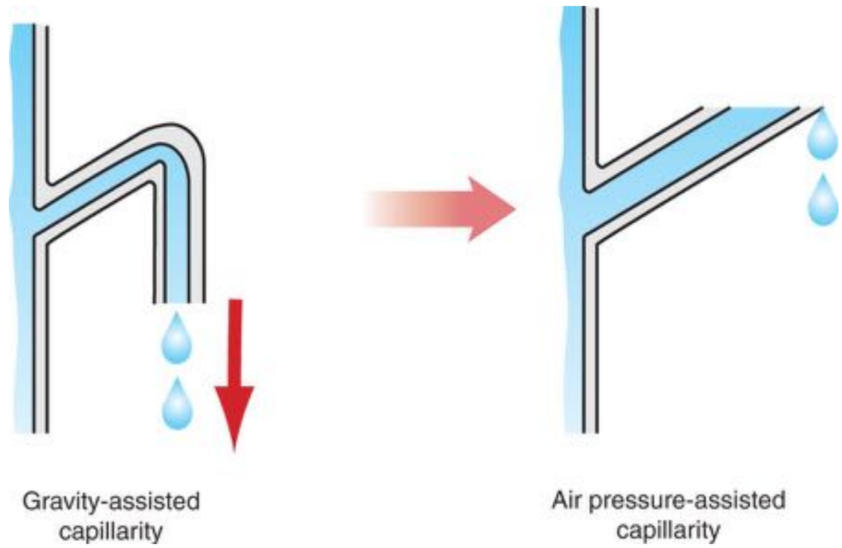
Capillary + other force



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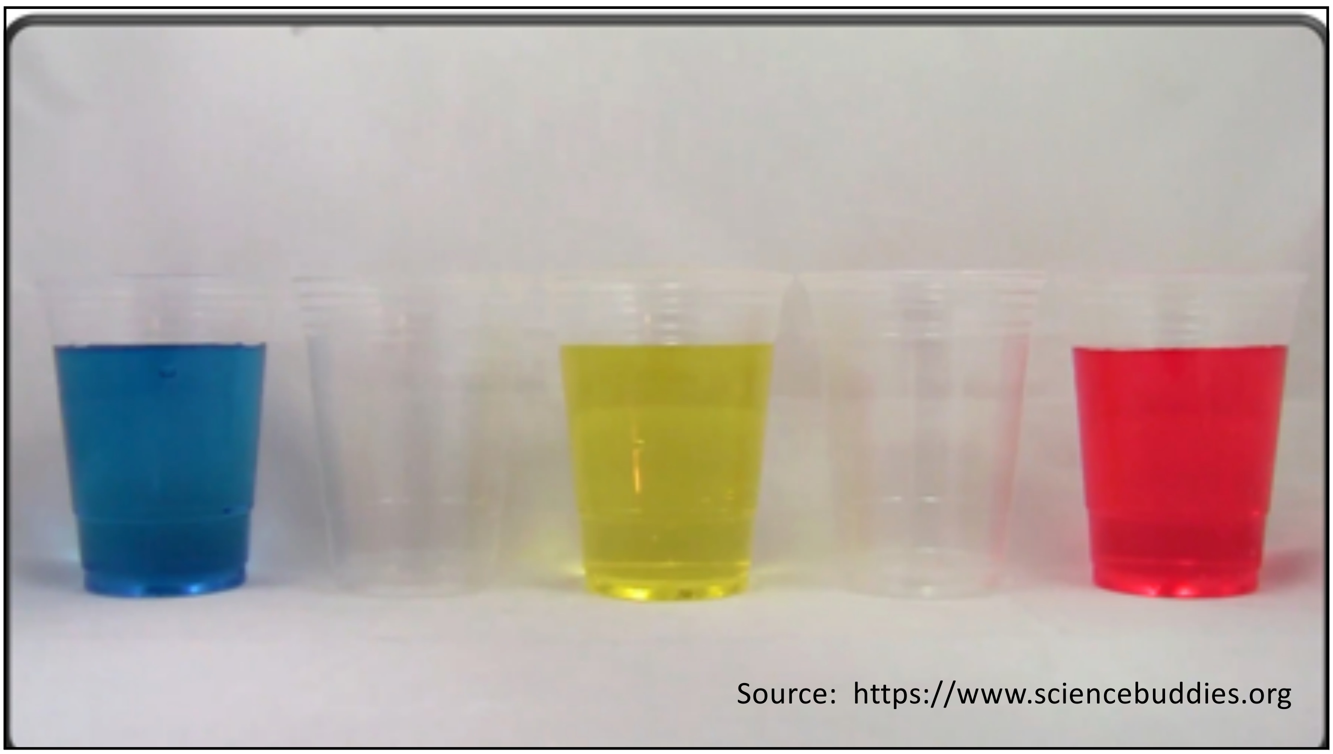

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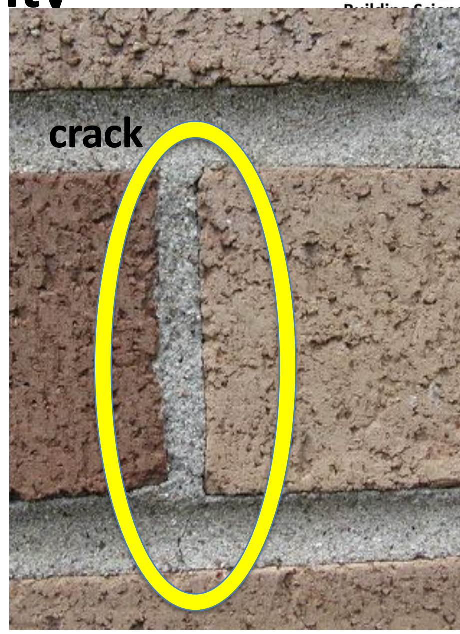
Gravity + capillarity



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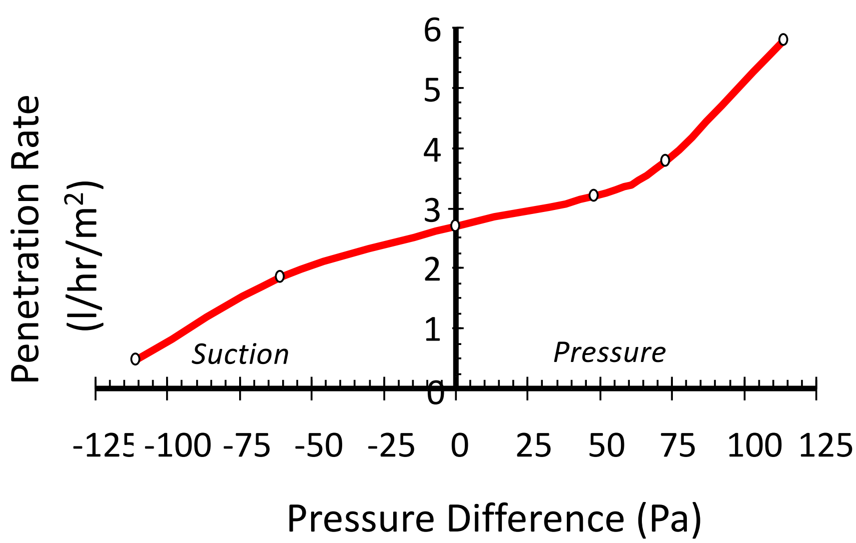
Pressure and Masonry Permeance



ASTM E514:
Application Rate:
200 l/m² /hr

90

Water Penetration Mechanism

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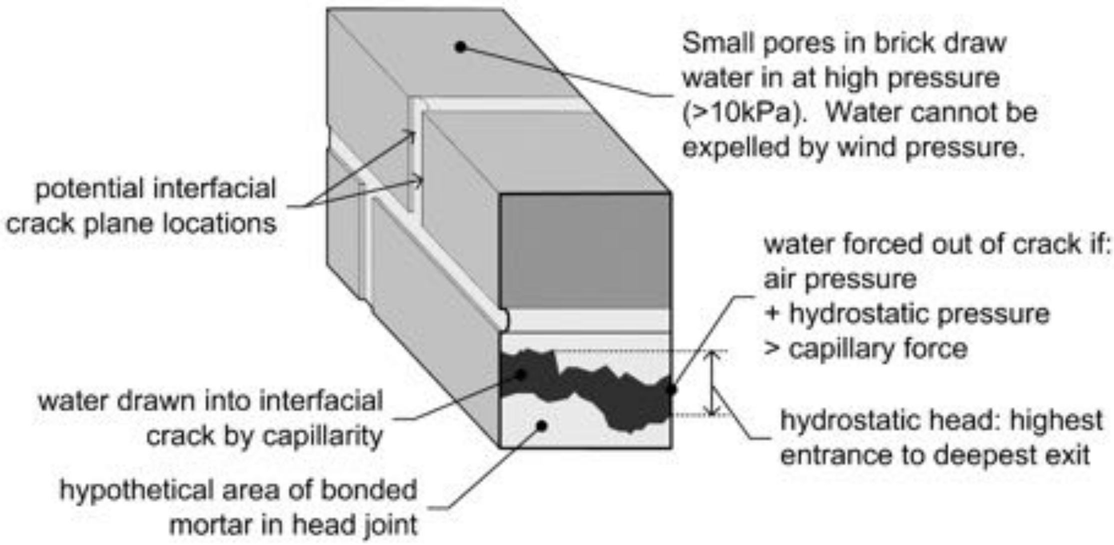

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Capillary vs Wind Pressure

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Capillary | Wind pressure

Crack width / pore radius			**Capillary Suction** (Hydrophilic surfaces 90°)				**Windspeed**
			Pressure	head	Pressure	head	**stagnation**
[inch]	*[inch]*	*[mm]*	*[Pa]*	*[mm]*	*[psf]*	*[inch w.c.]*	*[mph]*
0.5	1/2	12.7	11.3	1.15	0.24	0.05	10
0.25	1/4	6.4	22.6	2.30	0.47	0.09	14
0.125	1/8	3.2	45.1	4.60	0.94	0.18	19
0.063	1/16	1.6	90.2	9.21	1.88	0.36	27
0.040	1/25	1.0	141	14.4	2.94	0.57	34
0.020	1/50	0.50	286	29.2	5.98	1.15	48
0.01	1/100	0.25	564	57.5	11.8	2.27	68
0.001	1/1000	0.025	5638	575	118	22.7	214

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Lap siding

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Wicking behind laps
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Cleveland, 1986
Source: Dr Joe Lstiburek, P.Eng.

94


incipient decay
Source: Dr Joe Lstiburek, P.Eng.

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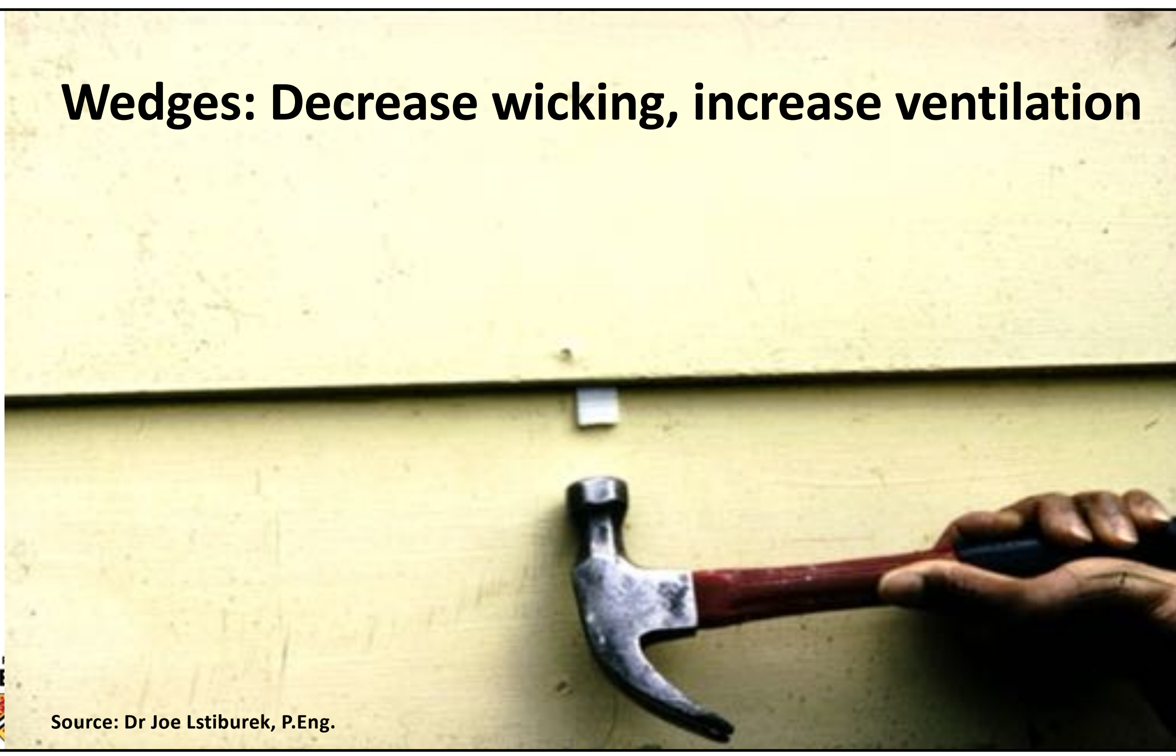
Wedges: Decrease wicking, increase ventilation
Source: Dr Joe Lstiburek, P.Eng.

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Apply air pressure and draining water

LAP DRAINAGE EXPERIMENTS

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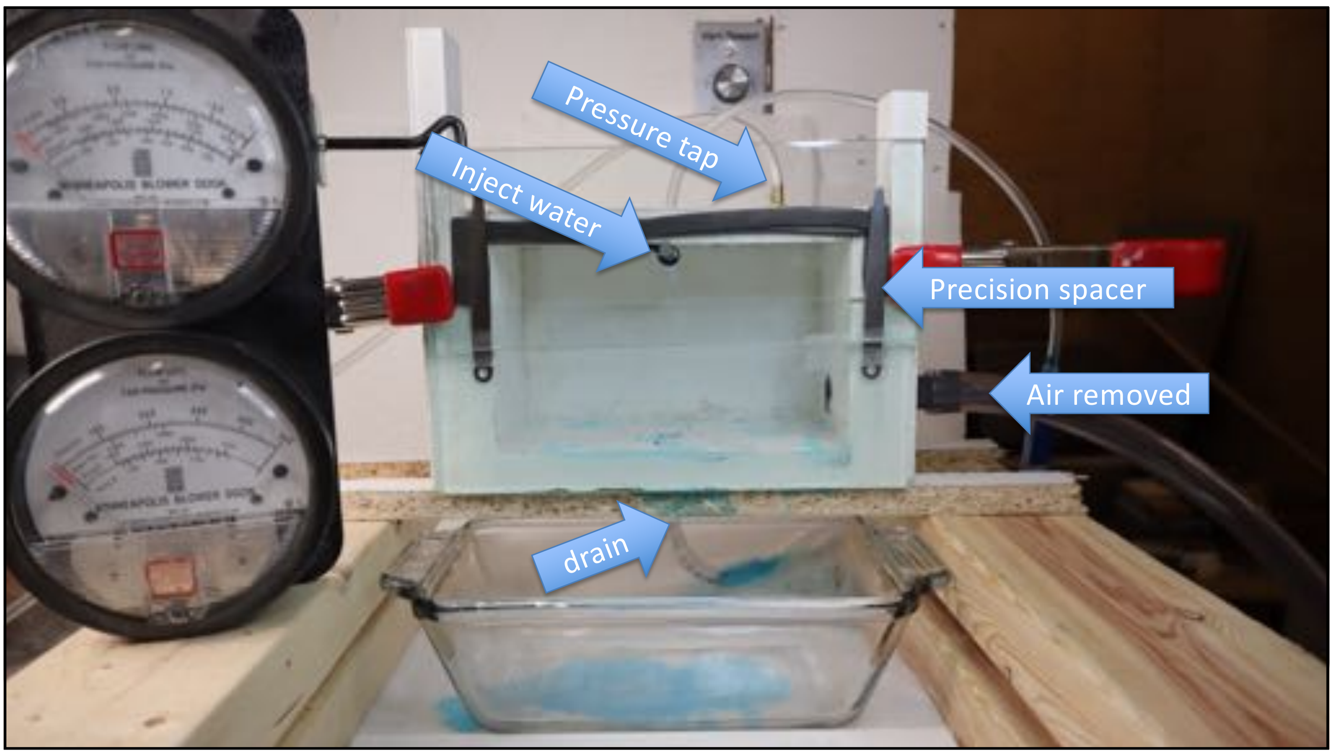

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Reminder

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Gap Width	Suction Pressure	Head
0.25 mm = 0.01”	564 Pa	57.5 mm = 2.26”
0.50 mm = 0.02”	286 Pa	29.2 mm = 1.15”
1.00 mm = 0.04”	141 Pa	14.4 mm = 0.56”
1.60 mm = 1/16”	90 Pa	9.2 mm = 3/8”

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- 0.50 mm = 0.02” size gap
- 25 mm = 1” overlap

- Movie 5

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- 1.50 mm ≈ 1/16” size gap
  - –About 100 Pa
- 25 mm = 1” overlap
- Movie 6

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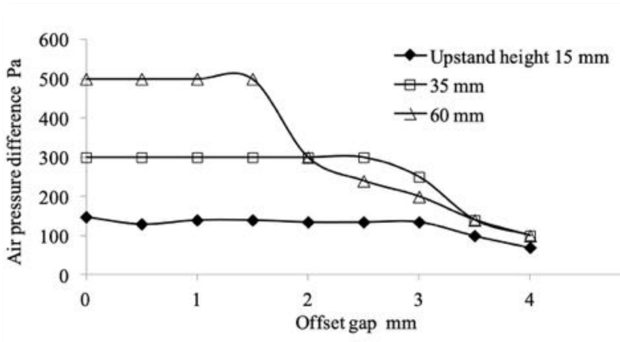
Research by others

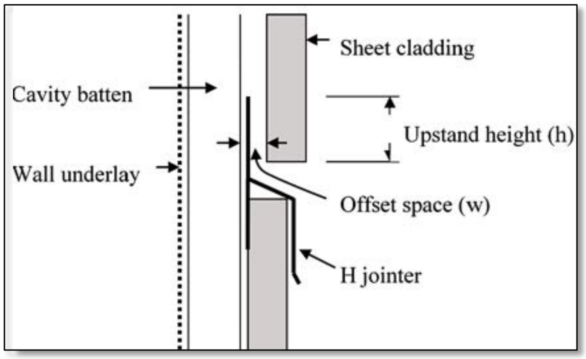
Measuring the Weathertight Performance of Flashings

Mark Bassett *,† and Greg Overton †

BRANZ Ltd., P.O. Box 50908, Porirua City 5240, New Zealand; E-Mail: greg.overton@branz.co.nz

buildings
ISSN 2075-5309
Buildings **2015**, Vol. *5*, pp. 130-148.





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Panel cladding over furring

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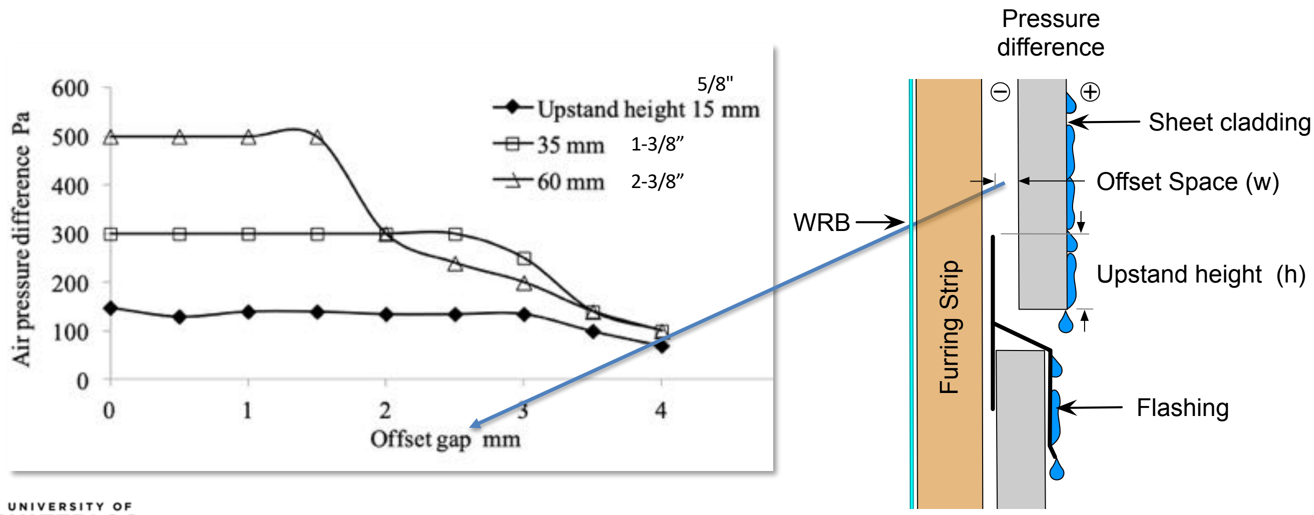

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Large pressure differences across the cladding for more than a few seconds are unlikely! Airflow will drag water

Pressure required to push plug upward is predictable

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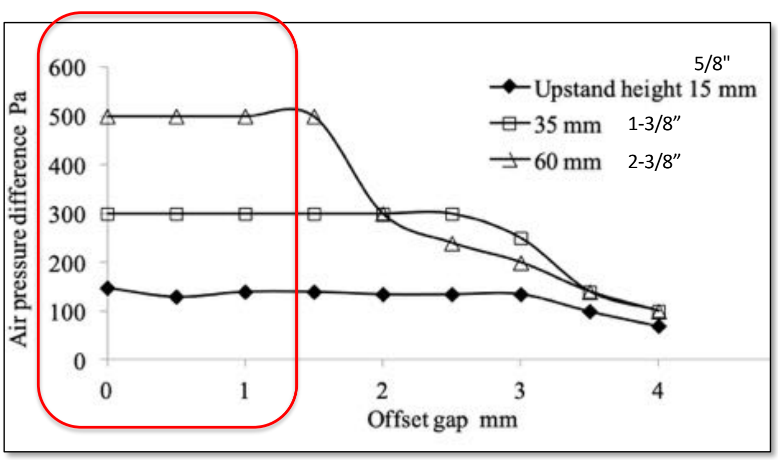

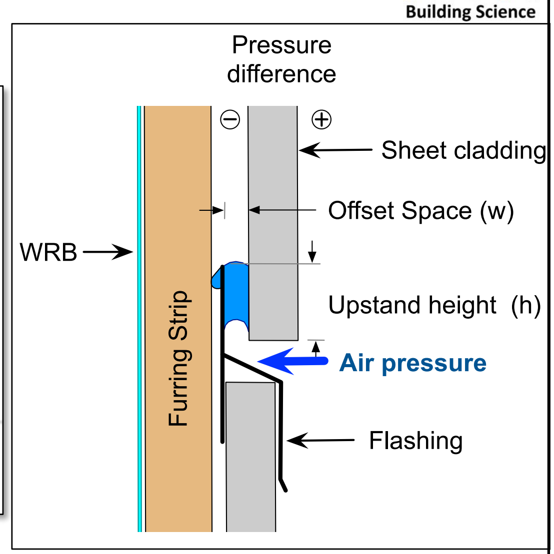

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With large airflows, water is dragged in

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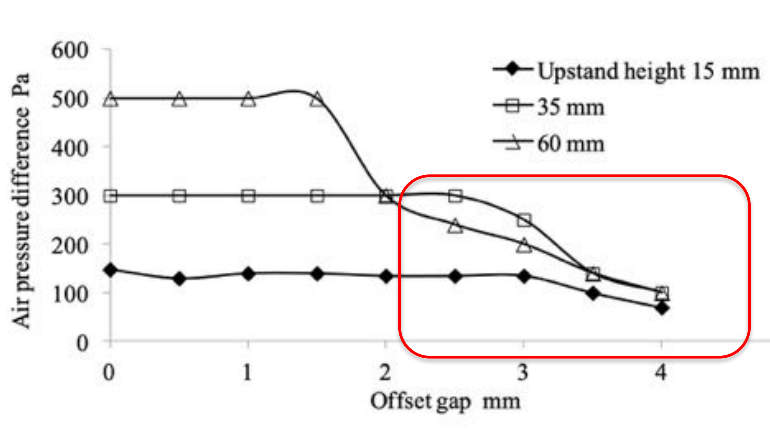

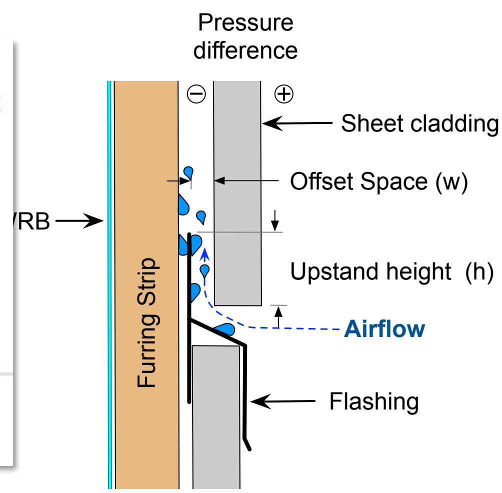

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What do we learn?

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- Air pressure can overcome drainage
- Airflow "aspiration" occurs at high pressure
  - But for a small gap, pressure is very high
  - 290 Pa = 48 MPH w/ no air barrier
- Not just siding lapped WRB, flashing, etc…
  - But hydrophobic pressures are different

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Conclusions

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- Very small gaps act as capillary breaks
- 3 mm = $^1/_8$" gaps prevent water drop bridging
- Very small gaps allow drainage / penetration
- Upstands work .. But airtightness helps
  - –Subtle point– air blows air over top

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Conclusions

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- This presentation is NOT ABOUT how big the gap behind your cladding should be
- Ventilation drying and practical installation requirements OFTEN result in larger recommended gap sizes
- This presentation aimed to show that larger gap sizes are NOT required to if providing drainage, a capillary break, or resistance to drop bridging are the only goals

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