CAE 463/524
Building Enclosure Design

Fall 2012

Lecture 6:
Moisture transport and management in enclosures

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Housekeeping

- HW 2
  - Graded
  - Solutions ready to post (waiting on one submission)
- HW 3 (THERM) due today
  - Any issues?
- Next class period – October 8
  - I will be at a conference in Minneapolis
  - It's Fall Break Day anyway (Columbus Day?)
    - No class on Monday October 8
  - BUT:
    - I will ask you to complete a short anonymous survey about the class so far and changes you'd like to see

Housekeeping

- There is a building façade conference coming to IIT
  - October 11th and 12th 2012
  - Day 1: Symposium
  - Day 2: Workshops
  - One day is $70 for students
    - Not clear how valuable this will be to us
    - I think the keynote presentation is free
- http://facade.archpaper.com/chi2012/

Campus project

- My expectations
  - Short "consulting" report
  - No in-class presentation
- Expectations document has been uploaded to BB
  - View in class
- Example reports to model yours after
  - Two sample assessment reports have been uploaded to BB
  - One from BEMCO, the other from CLI group
  - These provide good examples for what I'm looking for
  - View in class
- Note for camera check-out
  - I am out of town October 8-11 and October 27 - November 1
  - Will setup camera check-out process with CAEE front desk

Campus project

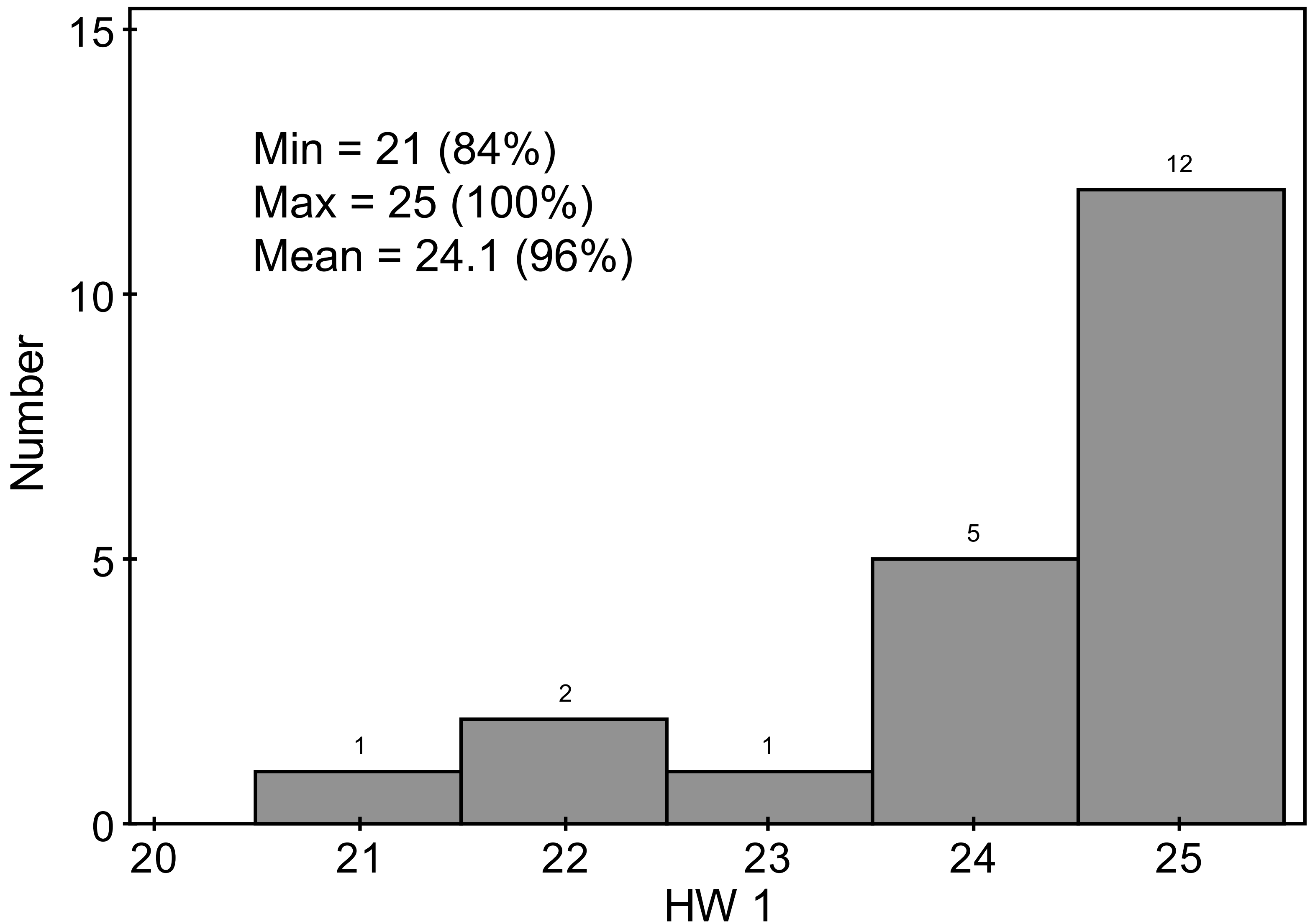
- Equipment checkout
- Thermal imaging camera will be in CAEE office while I'm gone next week
  - Alumni Hall 228
  - Ask the front desk receptionist to sign out

- Front desk:
  - Kimberly
    - Monday 8:30 am to 6:00 pm (lunch 12-1)
    - Wednesday 1:30 pm to 3:00 pm
  - Abigail
    - Tuesday 8:30 am to 11:15 am
    - Thursday 8:30 am to 11:15 am and 3:10 pm to 6 pm
    - Friday 11:20 am to 1:20 pm

HW updates

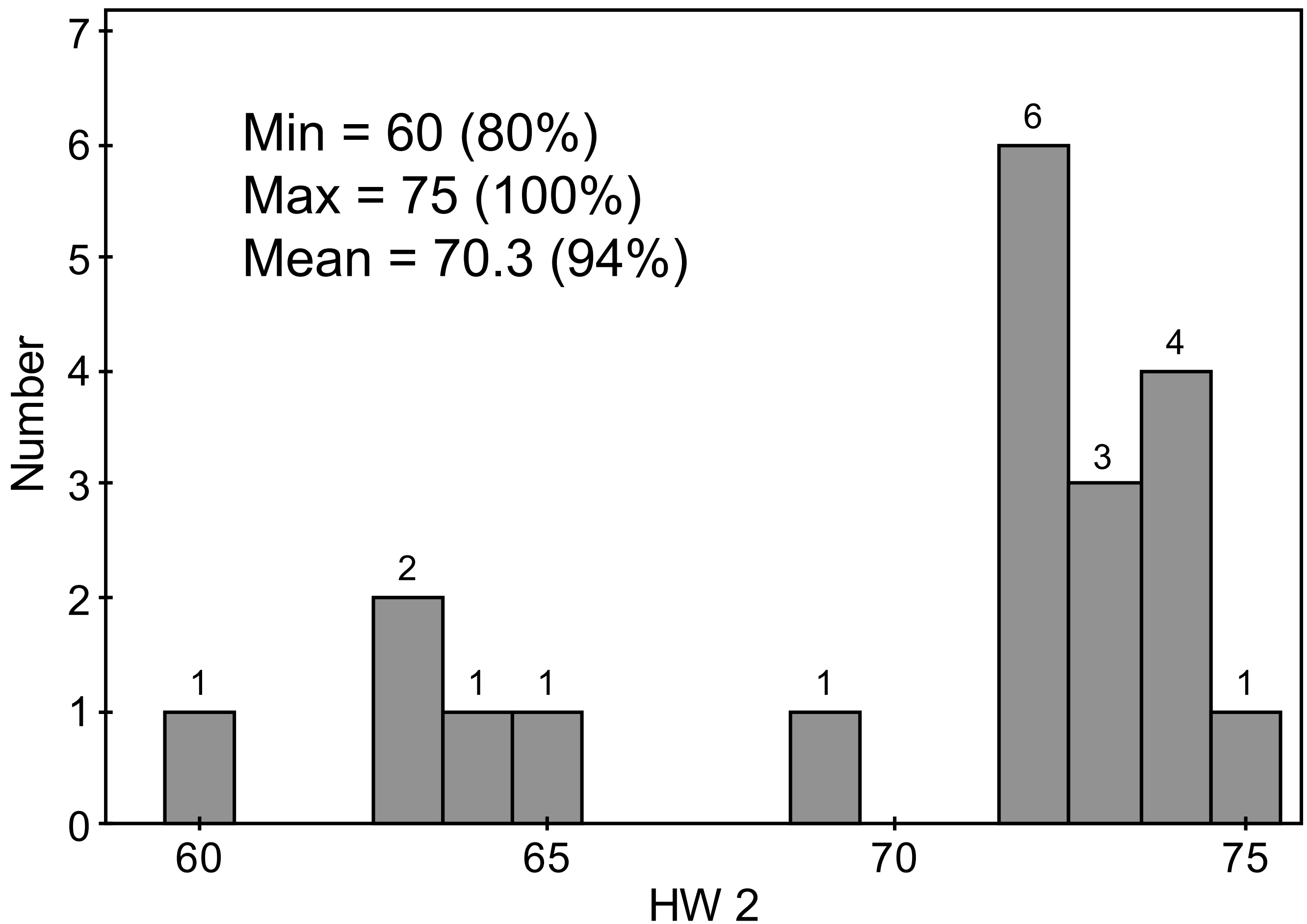
- HW 1 grade distribution
- HW 2 solutions and grade distribution
- HW 3 due today
- HW 4 will be assigned today
  - Due in 2 weeks
  - Your last HW!
- Final topic justification document
  - Would like to have it next week, **Monday October 8**
  - 0.5 to 1 pages showing me that you understand your topic
    - Will spend some time on my October 15 lecture describing project expectations

HW 1 grade summary



HW 2

- Grades posted on Blackboard
  - Will go over solutions (particularly #2) at the end of class if there's time

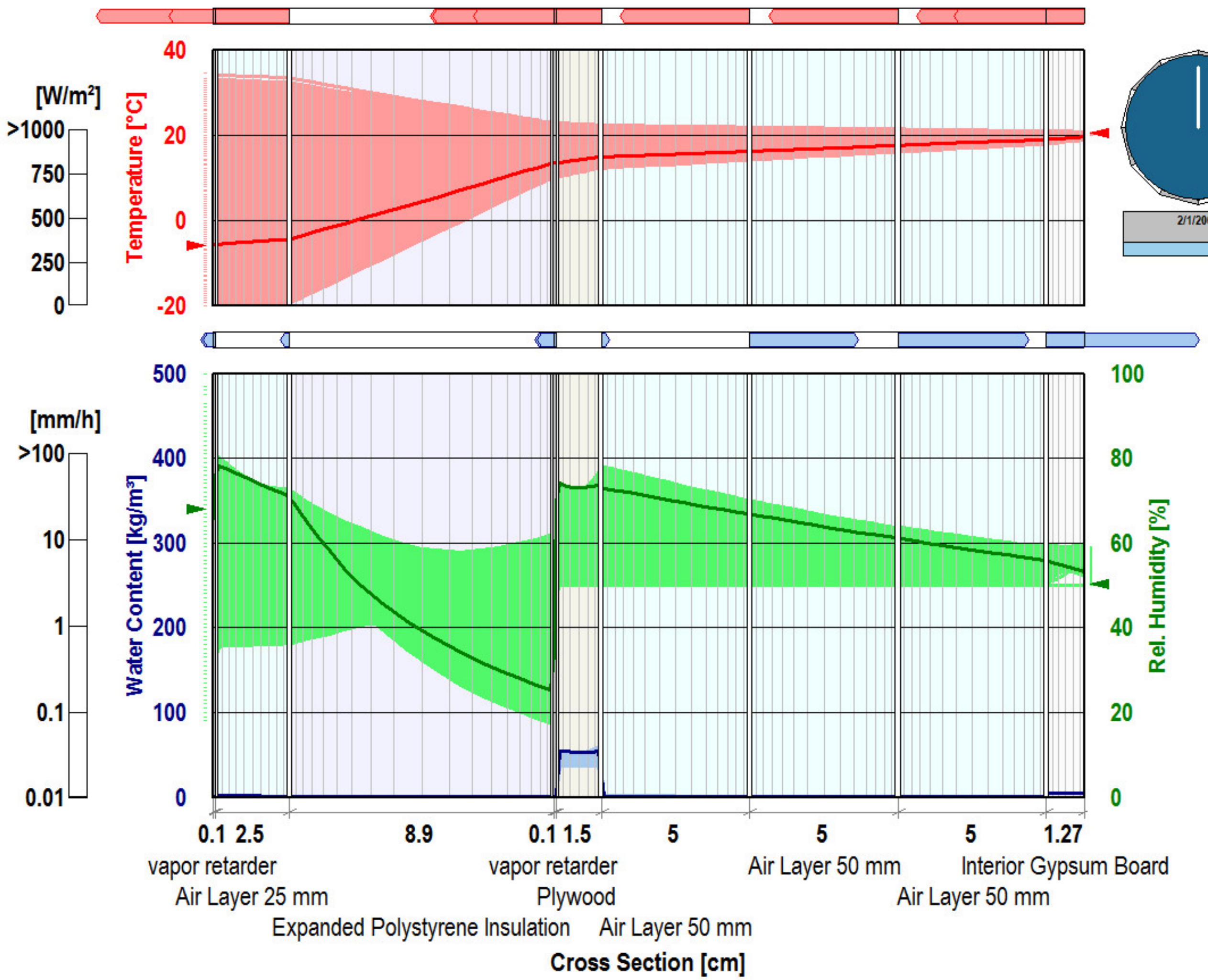


Last time

- Last time we covered water transport in enclosures
  - Briefly mentioned bulk liquid water
  - Focused on:
    - Vapor diffusion
    - Bulk water vapor convection (w/ air movement)
  - Performed some calculations
    - All with the purpose of finding potential areas for condensation
    - Even worked to estimate rate of condensation formation

Last time

WUFI – moisture modeling



This time

- We will finish water vapor transport
  - More examples
  - Different climates
  - Material influences

- We will address bulk liquid water transport
  - Examples

- Explore strategies to manage moisture issues

1. WATER VAPOR TRANSPORT

Water vapor transport

- Advection
  - Diffusion
  - Bulk convection

- Went over some examples in winter conditions
  - Showed that the rate of water vapor transport via bulk convection was typically **much** greater than by diffusion

- We will cover a few more examples from Straube and Burnett Ch. 6
  - Summer conditions
  - Materials that are already wet

Advection: Diffusion and convection

- Diffusion

$$Q_v = \frac{\mu}{L} A\left(p_{w,1} - p_{w,2}\right)$$

where

Q_v = rate of water vapor mass flow [ng/s]

A = area perpendicular to flow [m^2]

μ = average vapor permeability [ng/(m Pa s)]

L = length of material [m]

$p_{w,i}$ = vapor pressure on either side of material [Pa]

$$\Delta p_{w,j} = \frac{p_{w,interior} - p_{w,exterior}}{\sum_{j=0}^{n} R_{v,j}} R_{v,j}$$

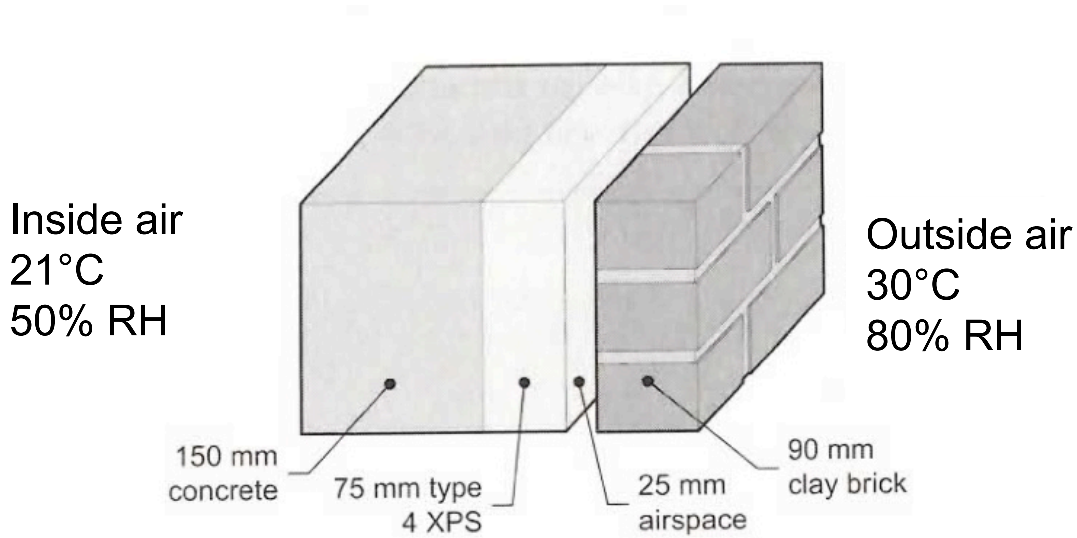
To find condensation:
Hunt for vapor pressure at a surface that is higher than the saturation vapor pressure at that surface temperature

- Convection

$$\dot{m}_v = \rho_{air} \dot{V}_{air} W$$

Advection: Diffusion and convection

- Summer conditions example:
  - Determine vapor and temperature distribution through the wall assembly from last time for a hot, humid, summer day with exterior conditions of 30 C and 80% RH



  - This time, water vapor is driven inward
    - Exterior is the high vapor pressure side

Summer conditions

	Permeability	Thickness	Permeance	Resistance
	μ	L	M_j	$R_{v,j}$
Layer material	**ng/(Pa-s-m)**	**m**	**ng/(Pa-s-m^2)**	**(Pa-s-m^2)/ng**
Indoors				
Interior film			15000	0.000067
Concrete	2.6	0.15	17.3	0.058
XPS	2.0	0.075	26.7	0.0375
Air space		0.025	7200	0.00014
Brick	10	0.09	1000	0.001
Exterior film			75000	0.000013
Outdoors				
			$R_{v,total}$	0.096

Summer conditions

	Conductivity, k	Thickness, L	Conductance, U	Resistance, R	ΔT	T	T	$P_{w,sat}$
Layer material	**W/mK**	**m**	**W/m^2K**	**m^2K/W**	**°C**	**°C**	**K**	**Pa**
Indoors						21	294.2	2487.7
Interior film			8.0	0.125				
					-0.4	21.4	294.5	2544.8
Concrete	1.8	0.15	12	0.083				
					-0.2	21.6	294.8	2583.5
XPS	0.029	0.075	0.39	2.564				
					-7.6	29.2	302.4	4055.9
Air space		0.025	n/a	0.17				
					-0.5	29.7	302.9	4175.2
Brick	1.3	0.09	14.4	0.069				
					-0.2	29.9	303.1	4224.9
Exterior film			34	0.029				
Outdoors					-0.1	30.0	303.2	4246.0
			R_{total} (m^2K/W)	3.04				
			U_{total} (W/m^2K)	0.33				

New outdoor temperature and saturation vapor pressures, $p_{w,sat}$

Summer conditions

	Permeability	Thickness	Permeance	Resistance				
	μ	L	M_j	$R_{v,j}$	$\Delta P_{w,j}$	$P_{w,j}$	$P_{w,sat}$	RH
Layer material	**ng/(Pa-s-m)**	**m**	**ng/(Pa-s-m^2)**	**(Pa-s-m^2)/ng**	**Pa**	**Pa**	**Pa**	**%**
Indoors						1244	2487.7	50%
Interior film			15000	0.000067	-1.5			
						1245.5	2544.8	49%
Concrete	2.6	0.15	17.3	0.058	-1288.4			
						2533.8	2583.5	98%
XPS	2.0	0.075	26.7	0.0375	-837.4			
						3371.3	4055.9	83%
Air space		0.025	7200	0.00014	-3.1			
						3374.4	4175.2	81%
Brick	10	0.09	1000	0.001	-22.3			
						3396.7	4224.9	80%
Exterior film			75000	0.000013	-0.3			
Outdoors						3397	4246.0	80%
			$R_{v,total}$	0.096				

$$\Delta p_{w,j} = \frac{p_{w,interior} - p_{w,exterior}}{\sum_{j=0}^{n} R_{v,j}} R_{v,j}$$

Summer conditions (more realistic)

- The last example ignores solar radiation
  - What if the same assembly is exposed to solar radiation?
  - Exterior surface temperature increases
    - We could estimate the surface temperature using the methods in HW 2
    - Or we could get a rough estimate using this table:

Table 5.5: Approximate extreme radiation-induced surface temperatures (°C)

Situation	**Thermally massive**	**Thermally lightweight**
Roofs: direct sun	$t_a + 42\,\alpha$	$t_a + 55\,\alpha$
Roof: sun + reflected /emitted radiation	$t_a + 55\,\alpha$	$t_a + 72\,\alpha$
Roof exposed to night sky	$t_a - 5\,\varepsilon$	$t_a - 10\,\varepsilon$
Walls: winter sun	$t_a + 35\,\alpha$	$t_a + 48\,\alpha$
Walls: summer sun	$t_a + 28\,\alpha$	$t_a + 40\,\alpha$
Walls exposed to night sky	$t_a - 2\,\varepsilon$	$t_a - 4\,\varepsilon$

Notes: t_a refers to the ambient air temperature, ε is the surface emittance, and α is the solar absorptance.

Summer conditions (more realistic)

- Taking a hypothetical exterior surface temperature in direct sunlight
  - Where $T_{surface,exterior}$ = 45°C
  - Change distribution of T and $p_{w,sat}$
    - But p_w distribution does not change

	Conductivity, k	Thickness, L	Conductance, U	Resistance, R	ΔT	T	T	$P_{w,sat}$
Layer material	**W/mK**	**m**	**W/m^2K**	**m^2K/W**	**°C**	**°C**	**K**	**Pa**
Indoors						21	294.2	2487.7
Interior film			8.0	0.125				
					-1.0	22.0	295.1	2642.6
Concrete	1.8	0.15	12	0.083				
					-0.7	22.6	295.8	2750.5
XPS	0.029	0.075	0.39	2.564				
					-20.2	42.9	316.0	8594.4
Air space		0.025	n/a	0.17				
					-1.3	44.2	317.4	9214.9
Brick	1.3	0.09	14.4	0.069				
					-0.5	44.8	317.9	9479.3
Exterior film			34	0.029				
Outdoors					-0.2	45.0	318.2	9593.2
			R_{total} (m^2K/W)	3.04				
			U_{total} (W/m^2K)	0.33				

Summer conditions (more realistic)

- Taking a hypothetical exterior surface temperature in direct sunlight
  - Where $T_{surface,exterior}$ = 45°C
  - Change distribution of T and $p_{w,sat}$
    - But pw distribution does not change

	Permeability	Thickness	Permeance	Resistance				
	μ	L	M_j	$R_{v,j}$	$\Delta P_{w,j}$	$P_{w,j}$	$P_{w,sat}$	RH
Layer material	ng/(Pa-s-m)	m	ng/(Pa-s-m^2)	(Pa-s-m^2)/ng	Pa	Pa	Pa	%
Indoors						1244	2487.7	50%
Interior film			15000	0.000067	-1.5			
						1245.5	2642.6	47%
Concrete	2.6	0.15	17.3	0.058	-1288.4			
						2533.8	2750.5	92%
XPS	2.0	0.075	26.7	0.0375	-837.4			
						3371.3	8594.4	39%
Air space		0.025	7200	0.00014	-3.1			
						3374.4	9214.9	37%
Brick	10	0.09	1000	0.001	-22.3			
						3396.7	9479.3	36%
Exterior film			75000	0.000013	-0.3			
Outdoors						3397	9593.2	35%
			$R_{v,total}$	0.096				

- Reduced chance of condensation because of warmer surface T

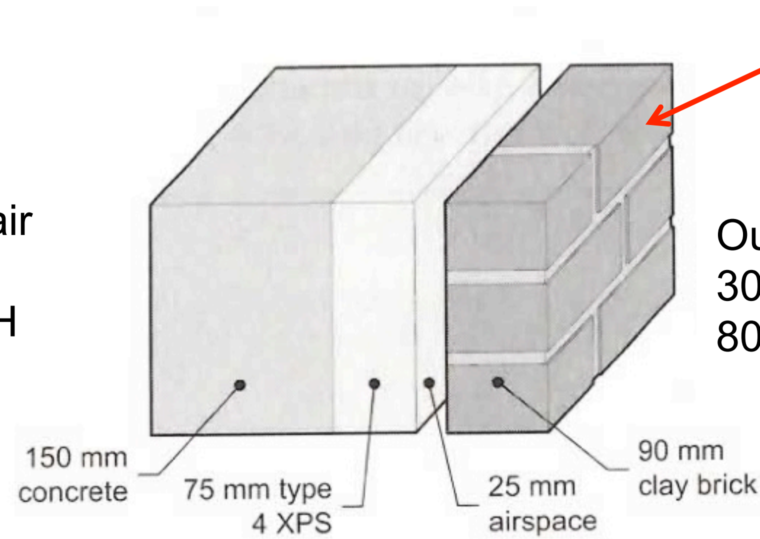
Water vapor transport: another condition

- What happens if the brick cladding was already wet?
  - From either previous rains, condensation, or built-in moisture (i.e., construction occurred with wet materials)

  - Let’s assume the same sun-heated wall assembly and summer conditions, but the brick cladding is wet (already saturated)

Brick saturated
w/ water vapor

Inside air
21°C
50% RH



Outside air
30°C
80% RH

Water vapor transport: wet brick

- Same solution procedure, but the back of the brickwork is assumed to be at RH 100%
  - That becomes the exterior boundary condition
    - Meaning we don’t use the outdoor humidity in this calculation

	Permeability	Thickness	Permeance	Resistance				
	μ	L	M_j	$R_{v,j}$	$\Delta P_{w,j}$	$P_{w,j}$	$P_{w,sat}$	RH
Layer material	ng/(Pa-s-m)	m	ng/(Pa-s-m^2)	(Pa-s-m^2)/ng	Pa	Pa	Pa	%
Indoors						1244	2487.7	50%
Interior film			15000	0.000067	-5.7			
						1249.7	2642.6	47%
Concrete	2.6	0.15	17.3	0.058	-4928.7			
						6178.4	2750.5	225%
XPS	2.0	0.075	26.7	0.0375	-3203.6			
						9382.0	8594.4	109%
Air space		0.025	7200	0.00014	-11.9			
						9393.9	9214.9	102%
Brick	10	0.09	1000	0.001	-85.4			
						9479.3	9479.3	100%
Exterior film								
Outdoors								
			$R_{v,total}$	0.096				

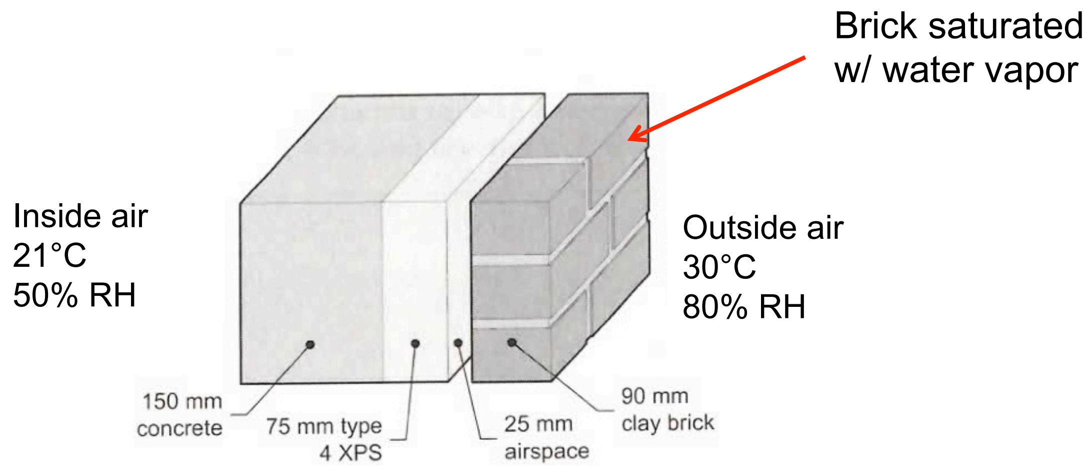
Brick set to 100% RH
Becomes new boundary condition

Condensation would occur at two interior surfaces

- Inward-driven water vapor can also condense in the interior wall assembly, given the right conditions

Water vapor transport: wet brick

- Does the condensation matter?

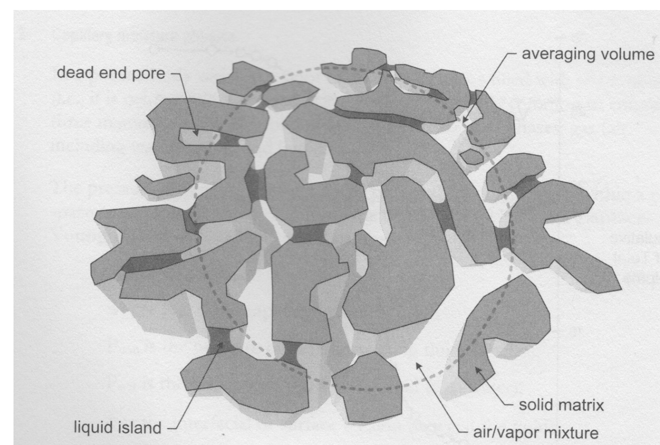


- Condensation would occur between air space and XPS, as well as between the concrete and XPS
  - Largest accumulation occurs at the XPS-air interface
  - What happens to the condensation?
    - **Concrete:** can store a lot of moisture; as long as it's dry by the time freeze-thaw could occur, moisture shouldn't be an issue
    - **XPS-air interface:** condensation can be harmlessly drained away
      - Or drain into the foundation and cause issues (not preferred!)

Moisture storage and transport in porous media

- Our textbook, Straube and Burnett, has an in depth chapter on moisture and porous materials
  - Focus is on the micro-scale physics of moisture storage, wetting, and drying
  - We will not go into this level of detail
  - Just a summary

- Most materials appear completely solid to the eye
  - But many natural building materials are very porous
  - Large fractions of the material are actually air volumes
    - Wood, brick, gypsum, stone, and concrete
  - Concrete and brick can be 50% air by volume
    - Metals and plastics have almost no porosity



Moisture contents and porosity of common materials

- Because of this porosity, building materials can hold moisture
  - In widely varying amounts

Table 8.1: Moisture contents of some common building materials

Material	Density (dry) kg/m^3	Open porosity (%)	MC @ ≅ 95%RH (M%)	w_{cap} (M%)
Concrete	2200	15-18	4-5	6-8
Brick	1600-2100	11-40	3-8	6-20
Cement mortar	1800-1900	20-30	5-7	14-20
Softwood	400-600	50-80	20-30	100-200
Fibreboard	240-380	60-80	20-25	100-200
Wood chipboard	700	50-70	15-20	100-150
Expanded polystyrene	32	95	5	> 300
Gypsum (exterior)	1000	70	10	50-100

Note: these values are approximate and from a variety of sources [e.g., Whitley *et al* 1977, Kumaran 1996, Lohmeyer 1996, Pel 1996, Kuenzel 1994]

Moisture storage and transport in porous media

- Capillary attraction
  - Occurs within porous bodies
  - Particularly when they are not saturated
    - Mixture of solid, air, water vapor, and liquid
- Capillary suction occurs in small pores under about 0.1 mm in diameter
  - Molecular attraction of water molecules and surfaces

$$s = \frac{2\sigma \cos\theta}{r}$$

s = capillary suction, Pa
σ = surface tension of H_2O, N/mm^2
r = equivalent radius, mm
θ = contact wetting angle, °

- A gradient in capillary suction will move liquid water
  - This could be from a variation in pore radius

$$m_l = -k_m \operatorname{grad}(s)$$

m_l = liquid flux, g/(s- m^2)
k_m = water permeability, g/(m^2 s Pa)

Pore size distribution

- Capillary action relates to pore size distribution
- Pore size distribution differs by material

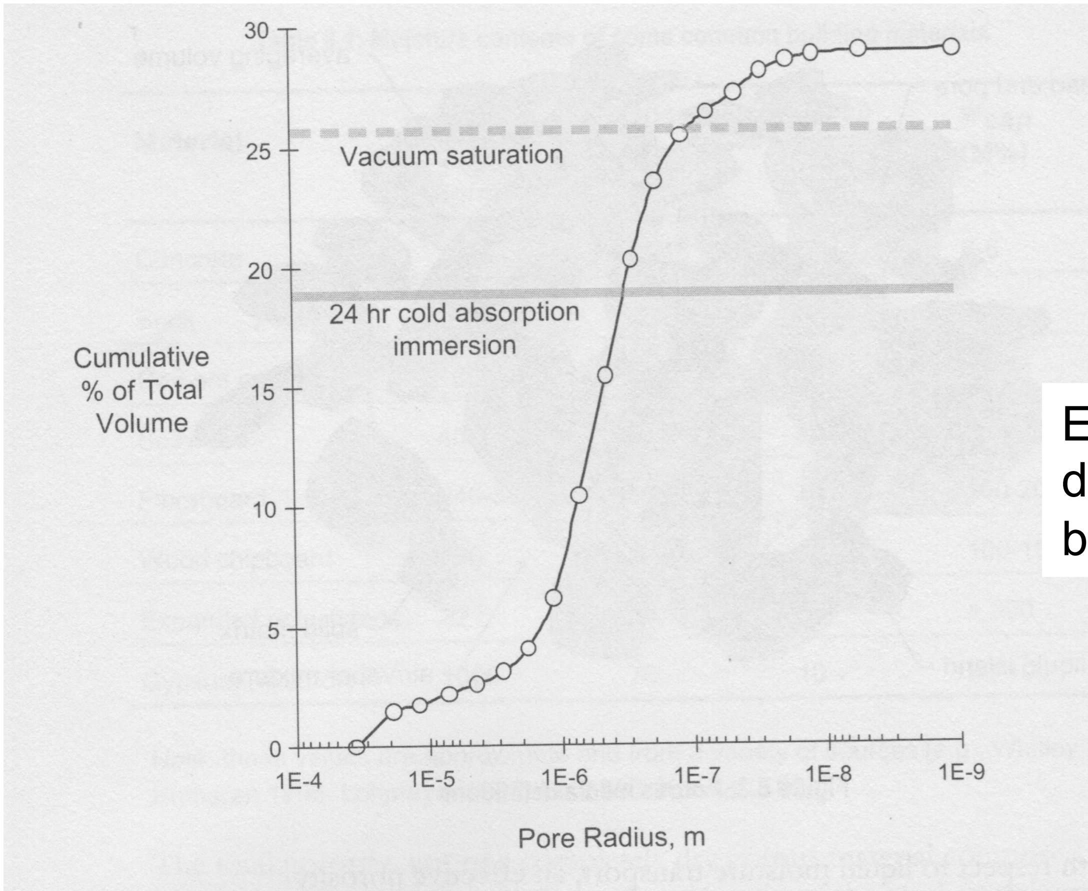


Figure 8.4: Pore size distribution of a representative clay brick [Arnott 1990]
Note: A water molecule is approximately 3×10^{-10} m in diameter

Example pore size distribution for clay brick

Moisture storage and transport in porous media

- Capillary suction in a tube

$$s = \frac{2\sigma\cos\theta}{r}$$

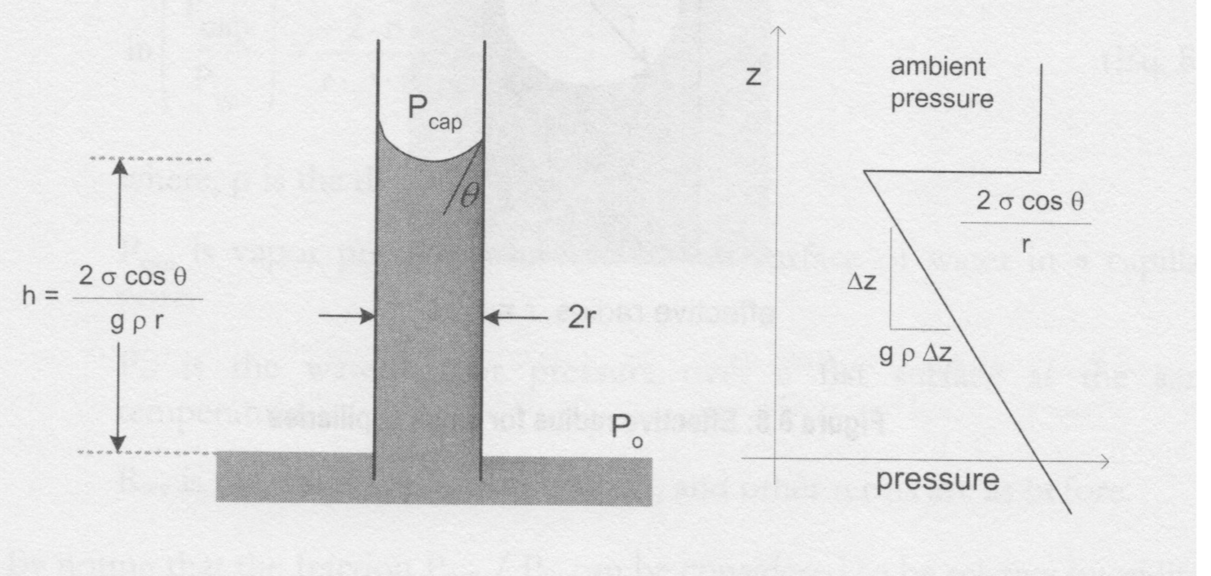
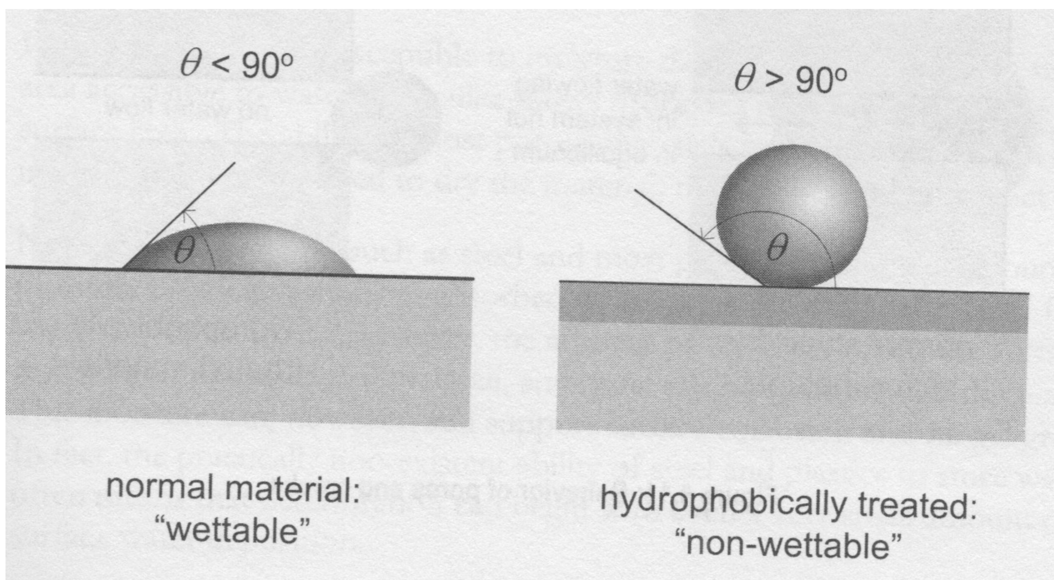


Figure 8.7: Capillary suction of water in a cylindrical tube

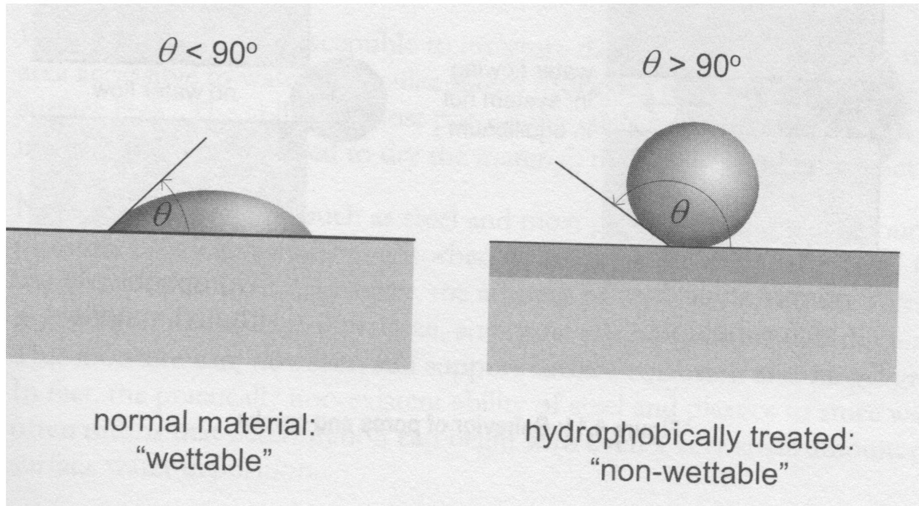
- The pressures involved with capillary suction in small pores (10-1000 nm) that make up a significant volume of concrete and wood generate large suction pressures (kPa to MPa)
  - Wicking water in small pores can be far greater than gravity forces or wind pressures

Wettable materials and hydrophobicity

- Capillary suction is driven in part by contact angle
  - Contact angle describes the angle of contact between water and a surface
  - "Wettable" materials have a surface structure that strongly attracts polar water molecules
    - Have a small contact angle (< 90 degrees)
  - "Hydrophobic" or "non-wettable" surfaces have a higher contact angle



Wettable materials and hydrophobicity



- Materials can be designed with pore radii and contact angles in mind to make them more or less water repellent
  - Waxes, oils, and silicone are all more hydrophobic than wood, brick, and stone
  - Greater contact angles
- Can apply treatments to surfaces of materials to change their wetting potential
  - Sometimes penetrating sealers for porous bodies
  - Sometimes just hydrophobic exterior coatings

Moisture storage

- At a macro scale, basic/ fundamental parameters act in intuitive ways
- Sorption isotherms can inform how much moisture materials can or will store at various environmental conditions

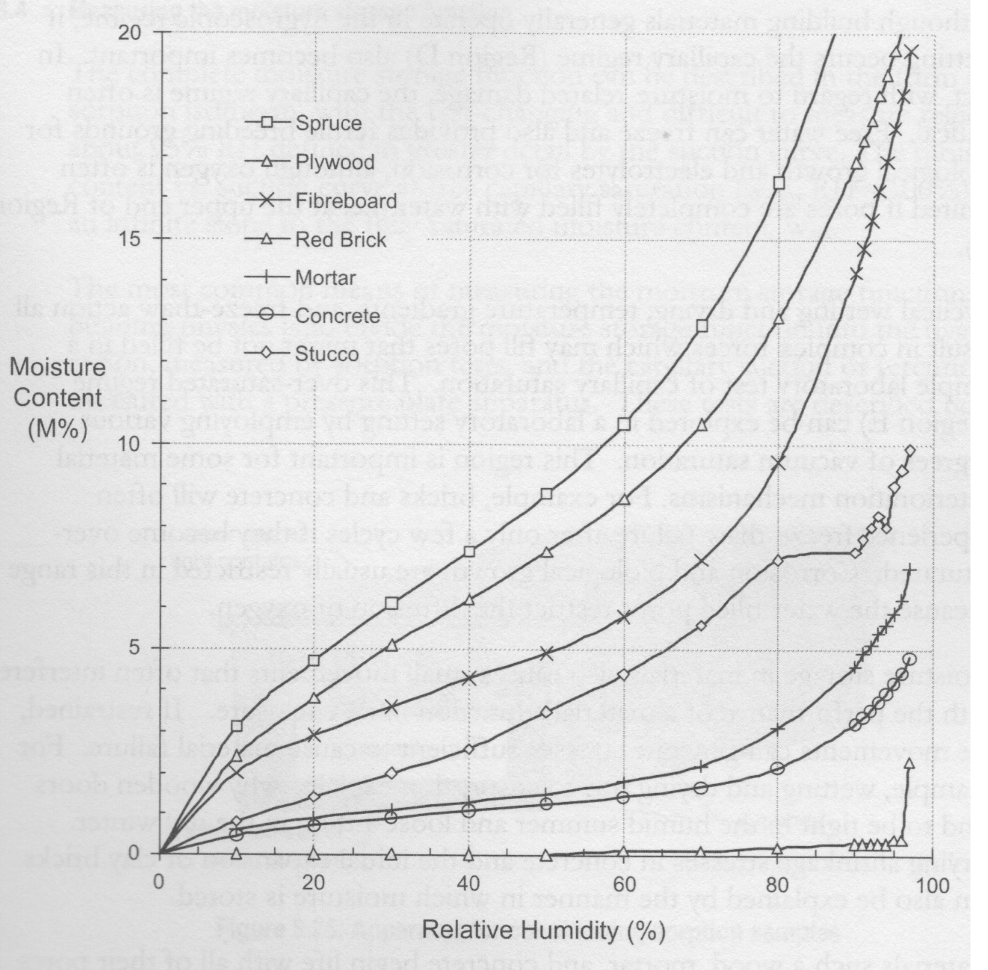


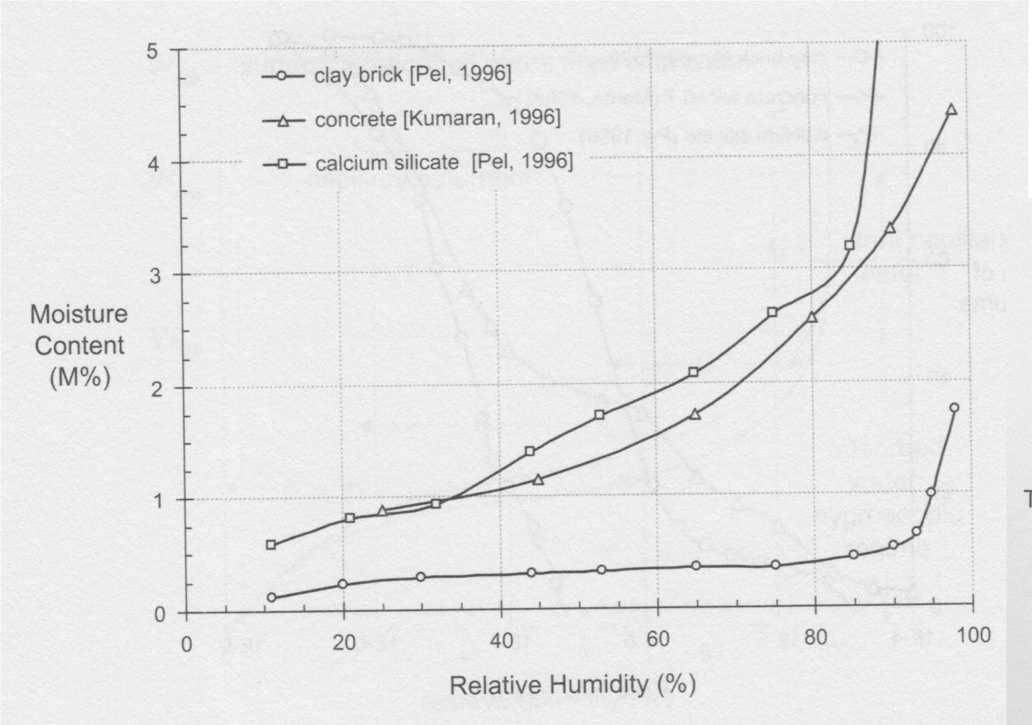
Figure 8.24: Sorption isotherm for several building materials [Kumaran 2002]

Notice the different regimes:

- Hygroscopic/absorbent regime
- Saturated/supersaturated regime

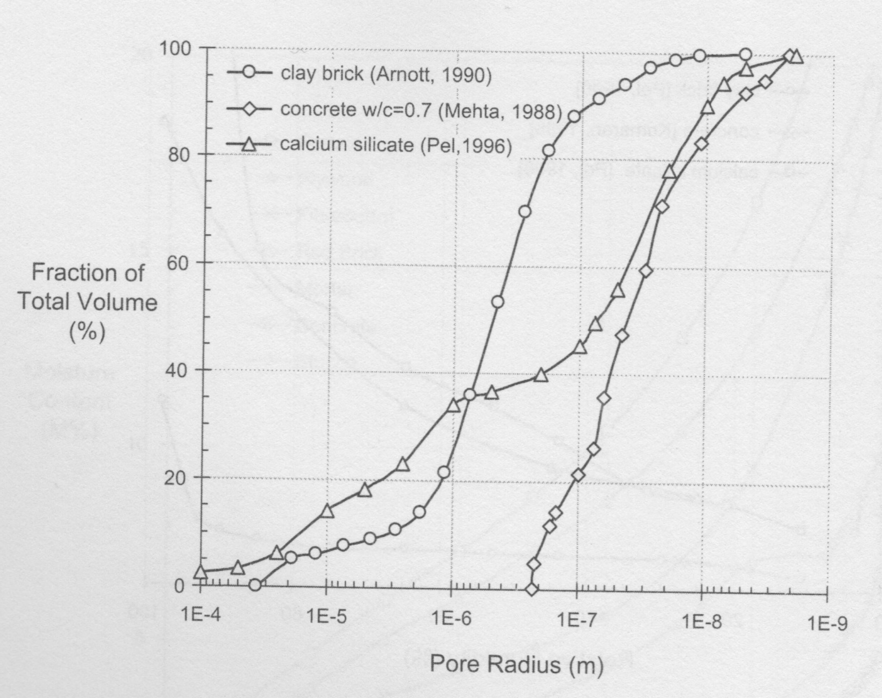
Moisture storage

- Sorption isotherms fundamentally relate back to pore size distribution of a material



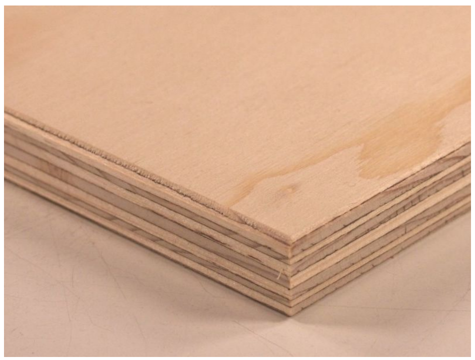
Sorption isotherm for three materials

Pore size distribution for three materials



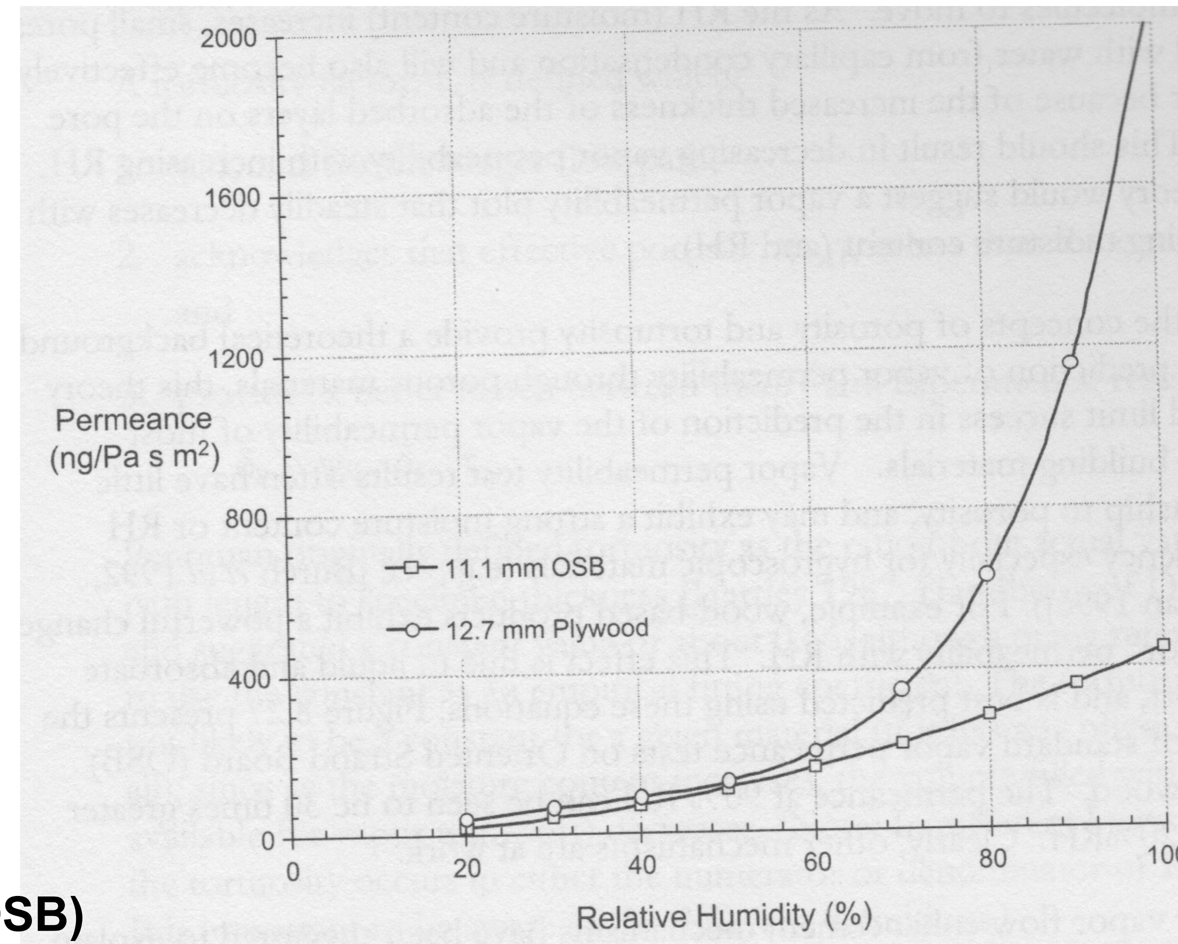
More material influences

- Remember I said that vapor permeability (μ), permeance (M), and resistance (R_v) can vary with RH?
  - This is because increasing RH increases capillary transport in small pores
  - Makes mass flow of water vapor easier ("water canal" effect)



Plywood

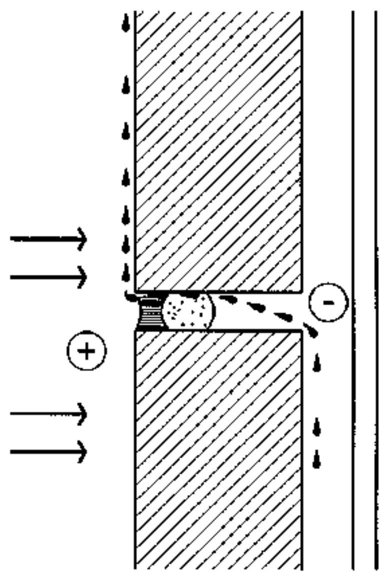
Oriented strand board (OSB)



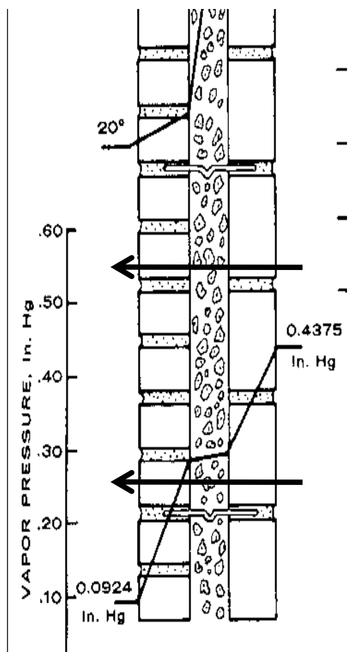
2. BULK LIQUID TRANSPORT

Moisture transport mechanisms

- So far, we've talked mostly about water vapor, either in terms of diffusion or water vapor associated with air leakage



Air Leakage

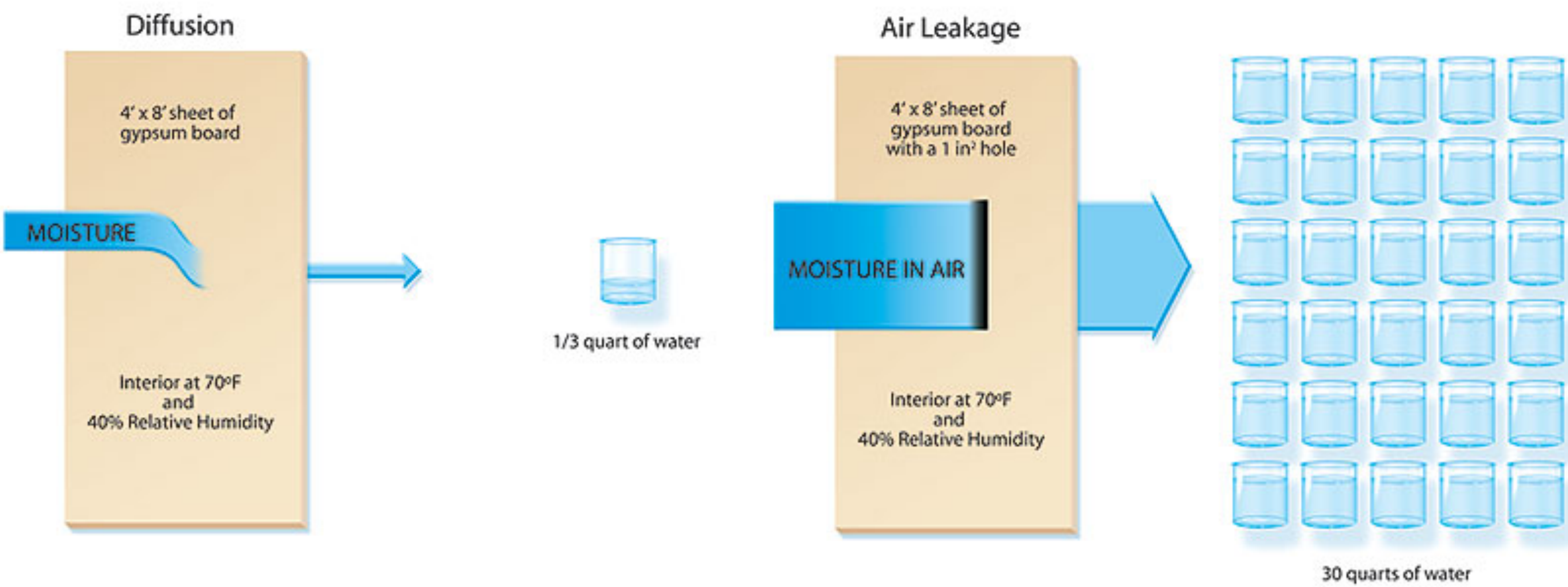


Vapor Diffusion

- We showed that water vapor due to air leakage is usually larger than that due to diffusion
  - It turns out that liquid water can be even more important
  - Liquid water can be difficult to control

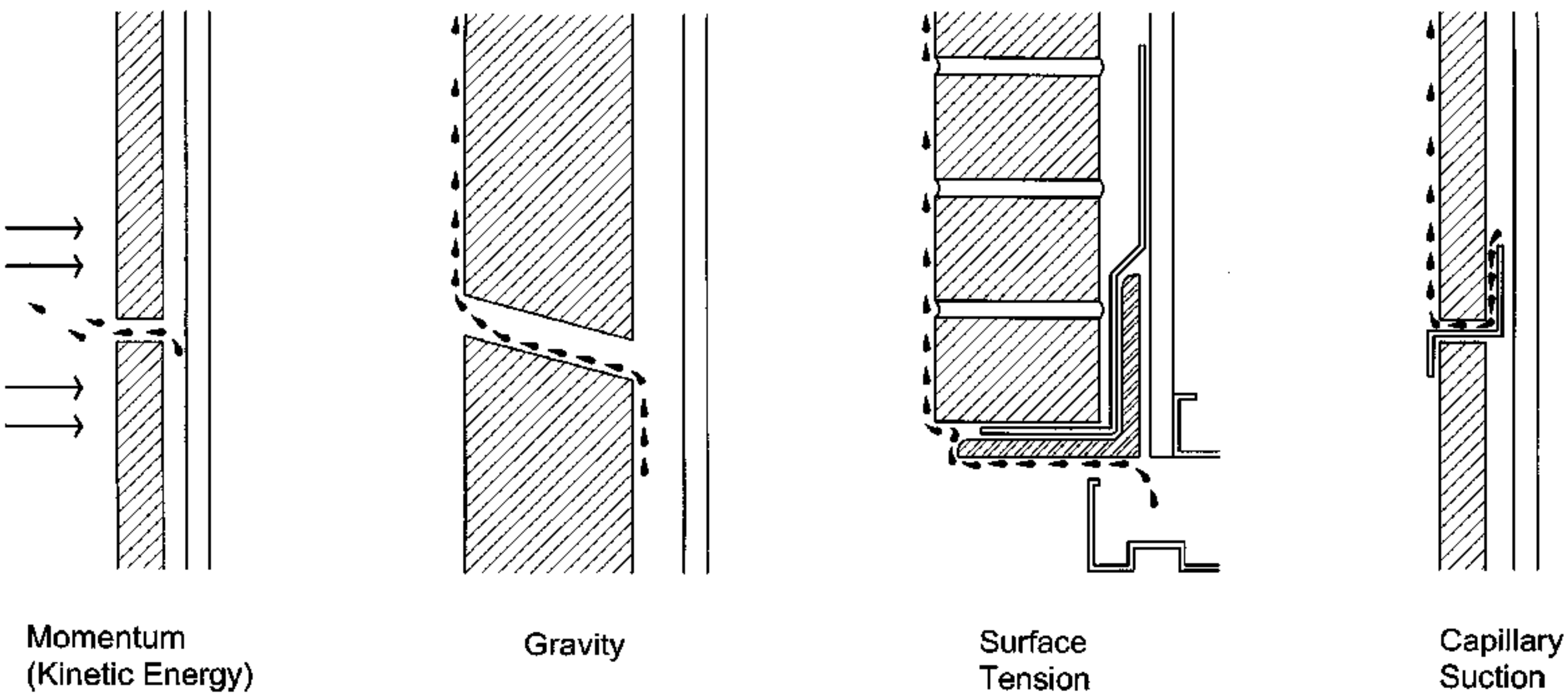
Leakage (bulk convection) versus Diffusion

- Air Leakage, particularly in older buildings, usually dwarfs diffusion but it is harder to model and control



Condensed water transport

- Four mechanisms for condensed moisture or rain to enter into wall cavities or directly inside buildings
  - These can be stopped fairly easily with simple design ideas



Momentum (kinetic) driven rain penetration

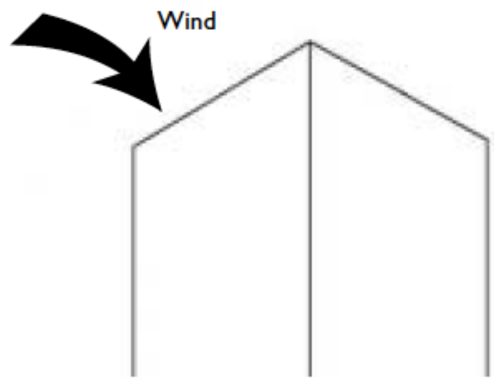
- Momentum of wind-driven raindrops
- Force will carry raindrops directly through openings of sufficient size
  - Recognize that rain doesn't fall straight down
  - Need to protect intentional openings from direct rain entry

Pressure gradients (related to momentum driven rain)

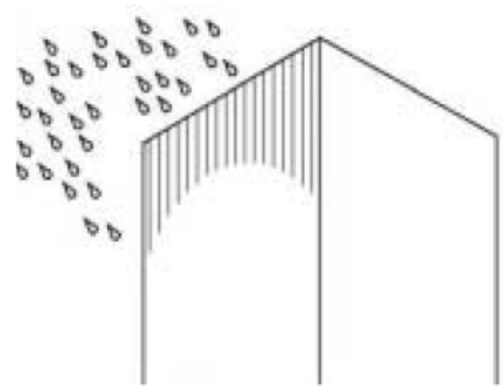
- Air pressure differences across the building envelope can create suction
  - Draws water through available leakage paths
  - Air movement can also carry water droplets directly
- Will learn more about these pressure differences next lecture
  - Pressure due to wind is a big concern for water penetration
  - In wall systems with impervious outer cladding, pressure differences can be the most significant source of driving rain into a building
    - e.g., curtain walls
      - Where outer walls are non-structural
- Pressure driven rain penetration varies a lot within the same building

Pressure gradients acting on different parts of a building

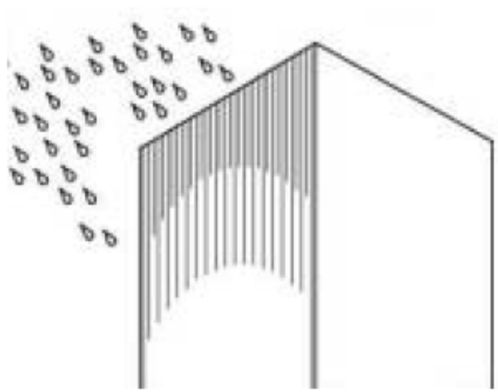
- Wetting of a section of a tall building



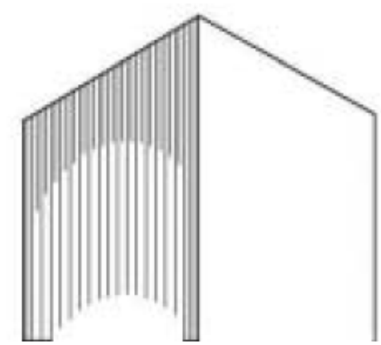
Dry building



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

Gravity driven water penetration

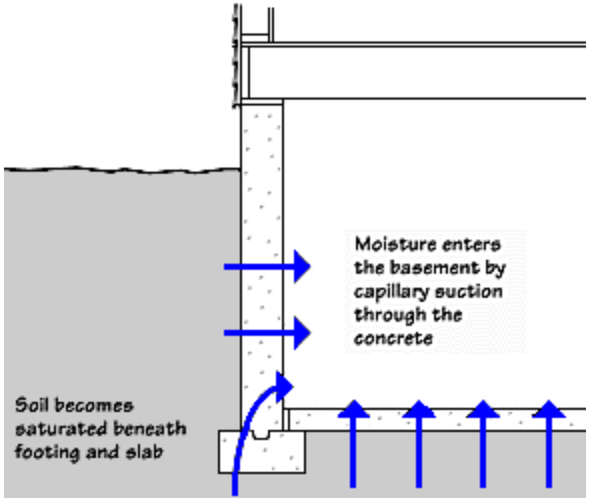
- Gravity driven water movement seems elementary to prevent
  - Leakage due to gravity still occurs frequently in modern buildings
  - Particularly with near-horizontal or moderately sloped building elements
  - Problems can usually be traced to errors in the design or construction of elements
    - Particularly flashings
    - Also restricted/clogged drainage paths after construction
  - Take care to avoid inward-sloping leakage paths and areas where water can pond

Capillary action and surface tension

- Cohesive forces allow water to cling and flow along horizontal surfaces
  - Can move against gravity
  - The force with which capillary action can work against gravity is inversely proportional to the size of openings
    - Small cracks allow more capillary action
  - Also depends on material affinity for water
  - More important in porous materials

Capillary suction

- Capillary suction draws water from saturated soil into the foundation and standing water through small cracks in brick, concrete and other materials
- To stop capillary suction we need to
  - Keep moisture away from foundation
  - Seal pores or add barrier
  - Make pores larger or add separation plane
  - Provide a receptor for moisture



Soil Type	Capillary Rise
Gravel	Inches
Sand	1-8 ft
Silt	12-16 ft
Clay	12-20 ft

Liquid water problem

- When we have rain
  - Liquid water directly impacts our roofs and walls
- Without proper design, that water will get into the roof and wall assembly
  - Can lead to the problems we discussed in the last lecture
- We need to divert that water away from our enclosure

Keeping moisture away

- A proper gutter system diverts rain on building to sewer or away from foundation

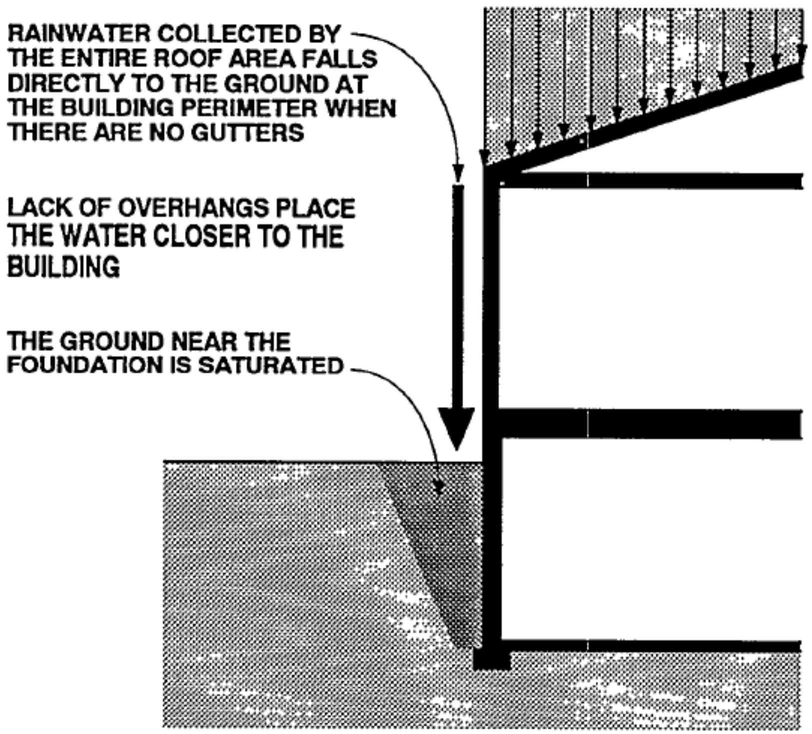


Figure 2-1A: Potential Surface Drainage Problems

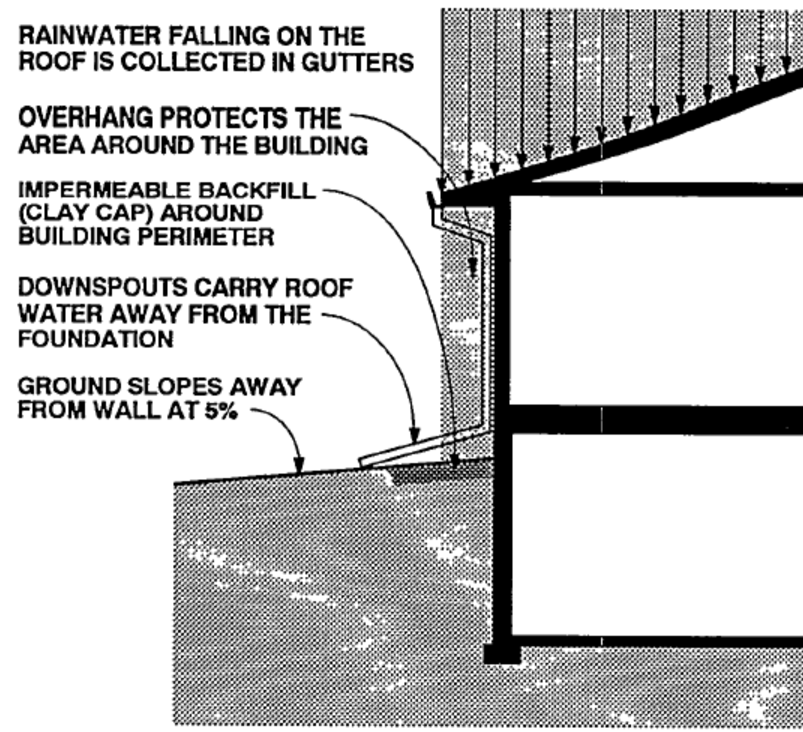


Figure 2-1B: Effective Surface Drainage Techniques

Good foundation design

Give water somewhere to go!

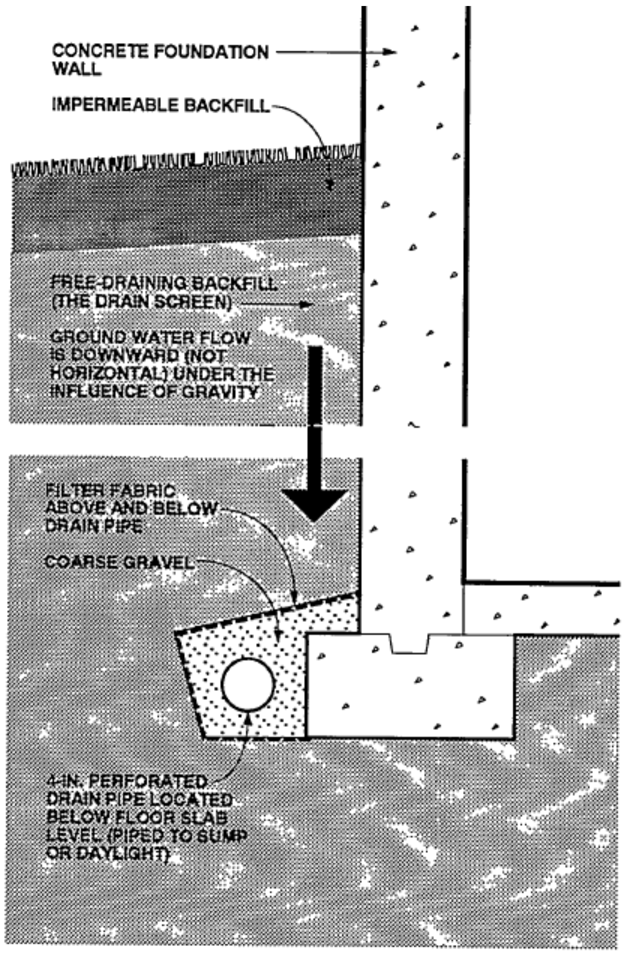


Figure 2-2: Drain Screen Concept Using Porous Backfill

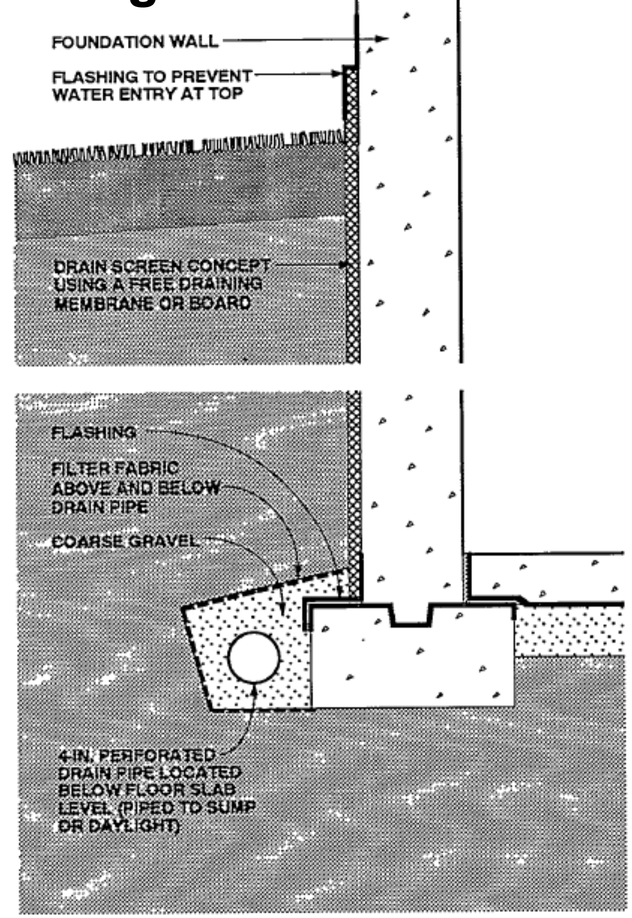


Figure 2-3: Drain Screen Concept Using a Free-Draining Board or Membrane

Porous backfill

Add a drainage plane

Stopping capillary suction

- Put concrete floor slab over large pore gravel
- Coat masonry block foundation with mortar and fluid applied sealant
- Capillary breaks (barriers) over concrete footing
  - Fluid applied sealant or Polyethelene sheet

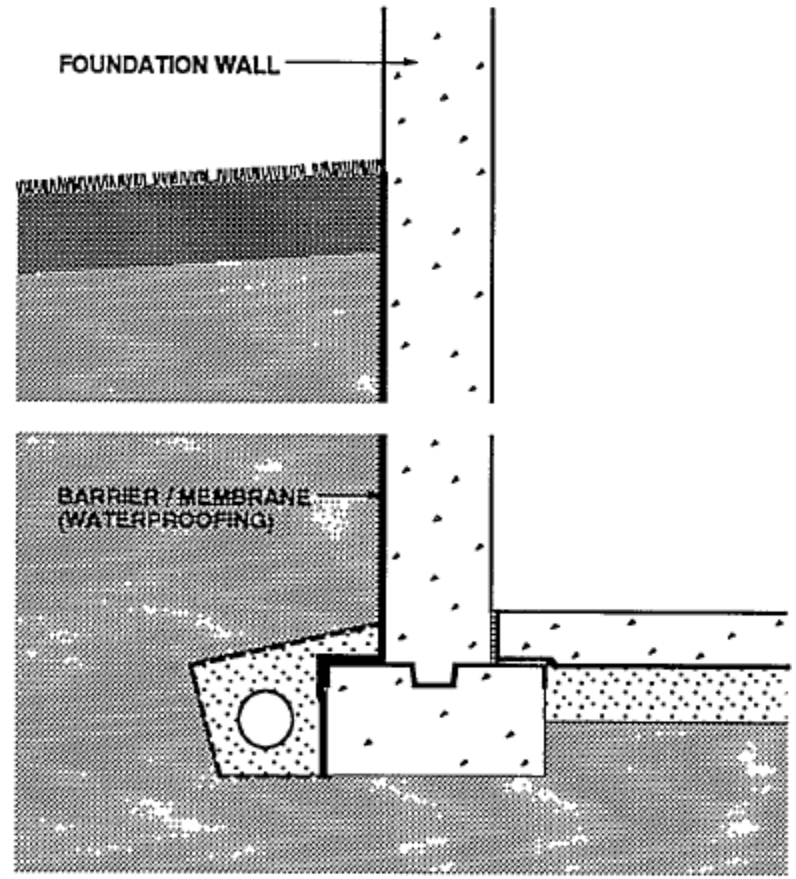
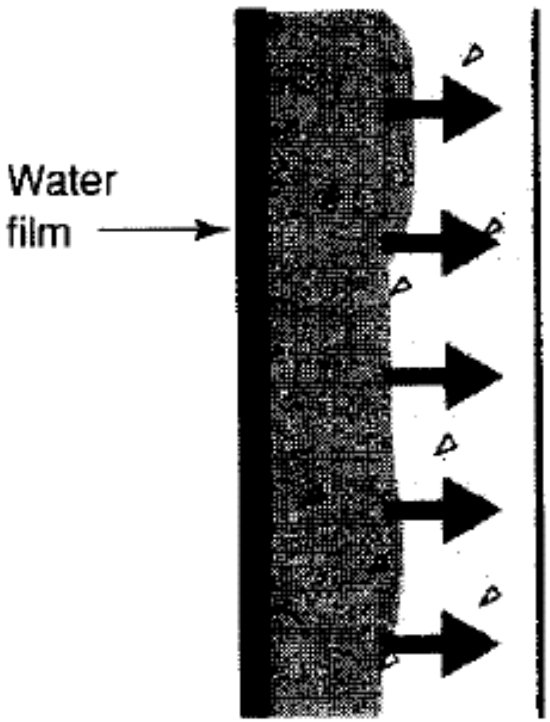


Figure 2-4: Barrier / Membrane Approach

Reducing moisture transport

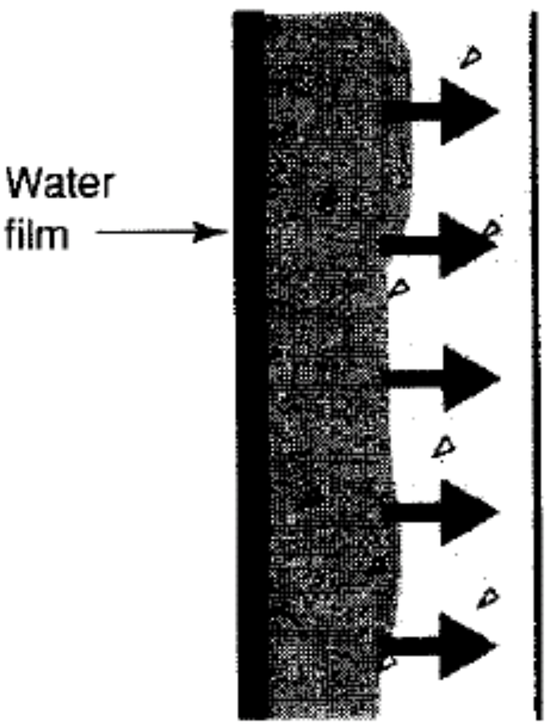
- One way to reduce moisture transport to/from the walls and building is to keep water from ever getting to the main structure to begin with
  - Here are some ideas on how to achieve that

Capillary suction

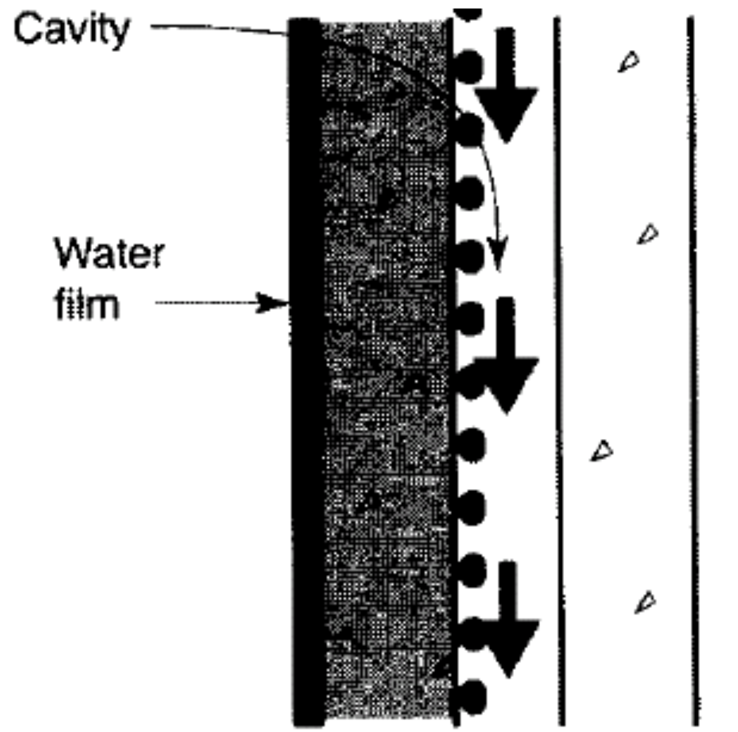


Capillary suction draws water into porous material and tiny cracks

Solution to capillary suction



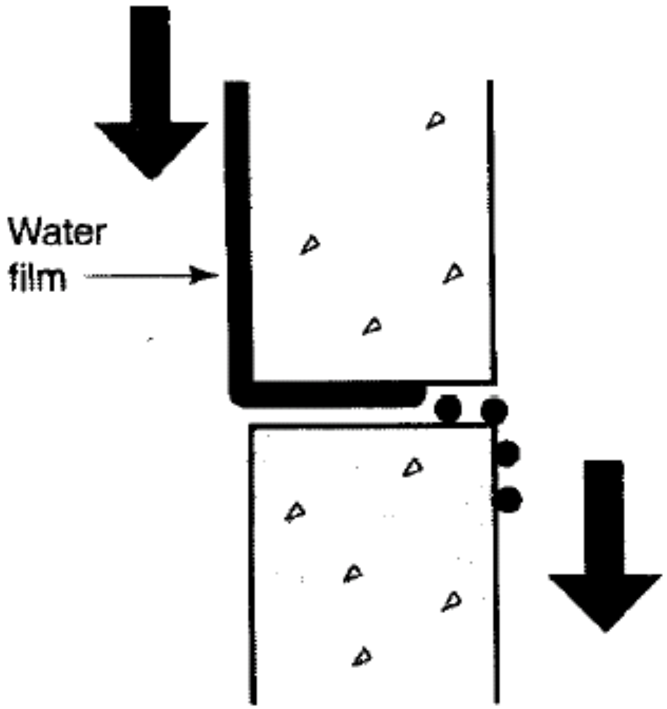
Capillary suction draws water into porous material and tiny cracks



Cavity acts as capillary break and receptor for capillary water interrupting flow

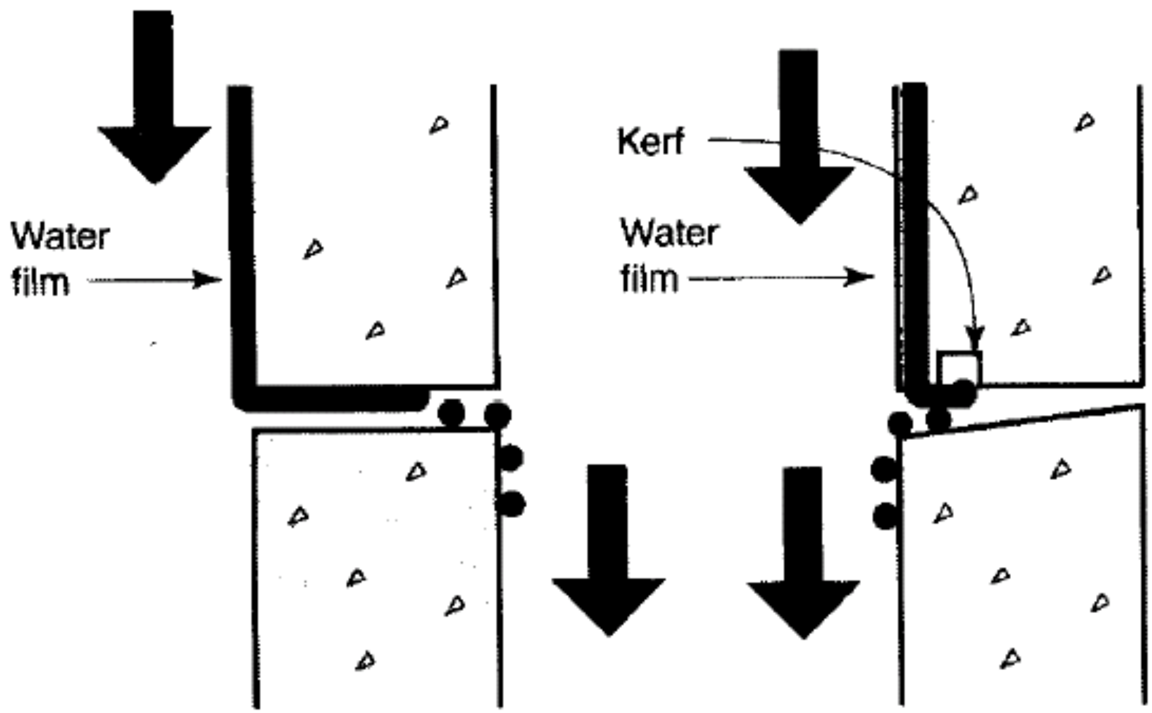
Add an air cavity

Surface tension



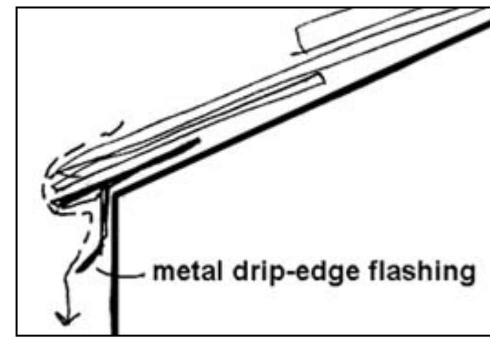
Rainwater can flow around a surface as a result of surface tension

Solution to surface tension

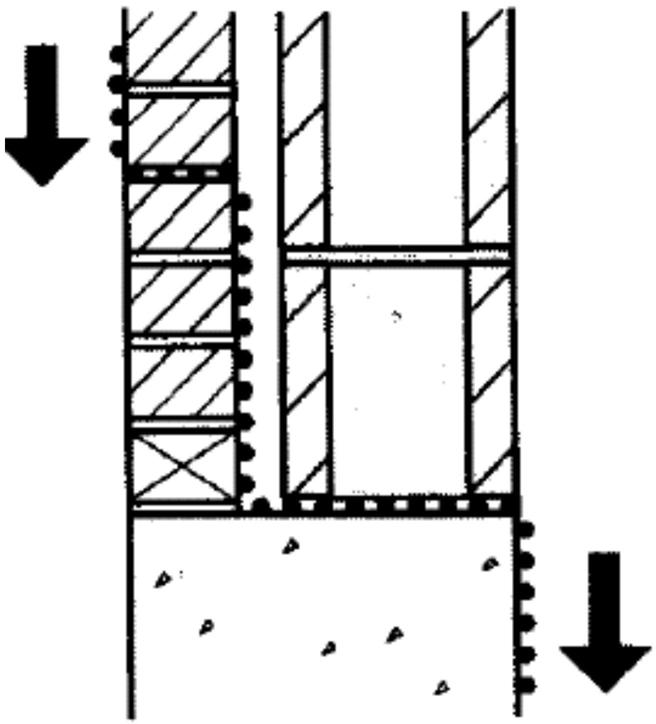


Rainwater can flow around a surface as a result of surface tension

Providing a kerf or drip edge will promote the formation of a water droplet and interrupt flow

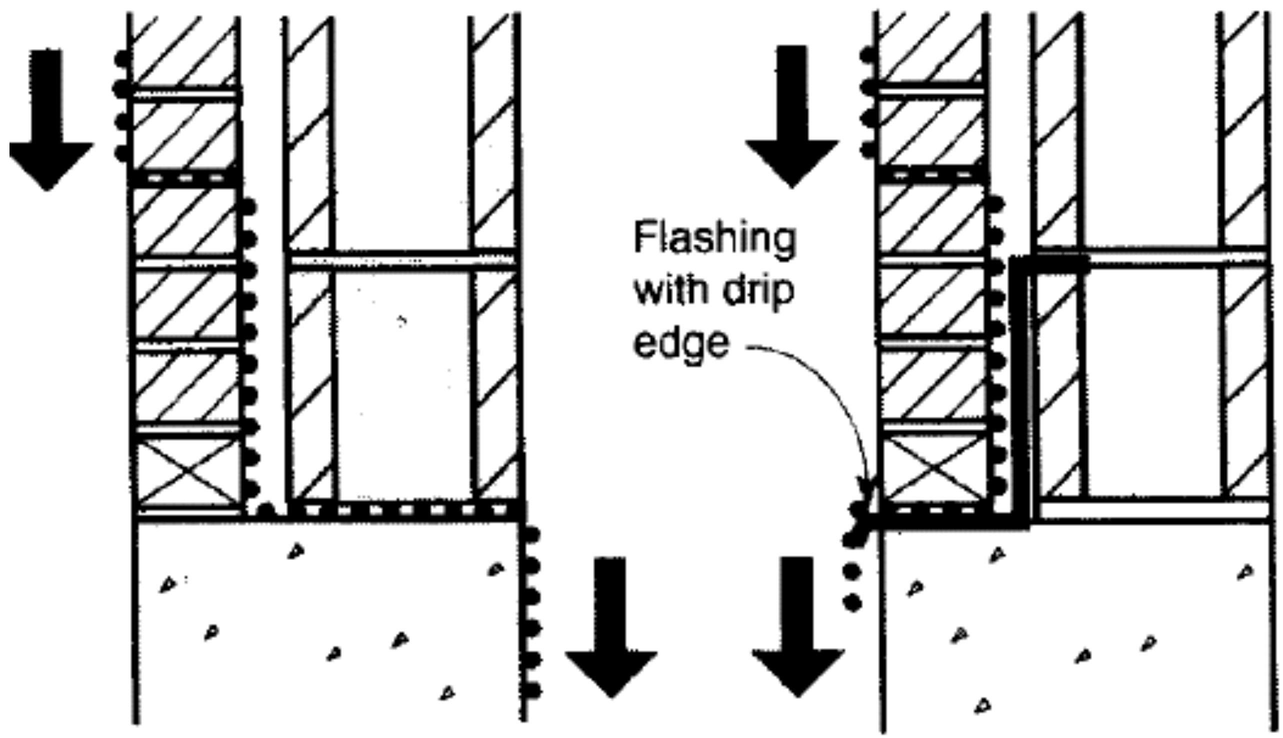


Gravity



Rainwater can flow down surfaces and enter through openings and cavaties

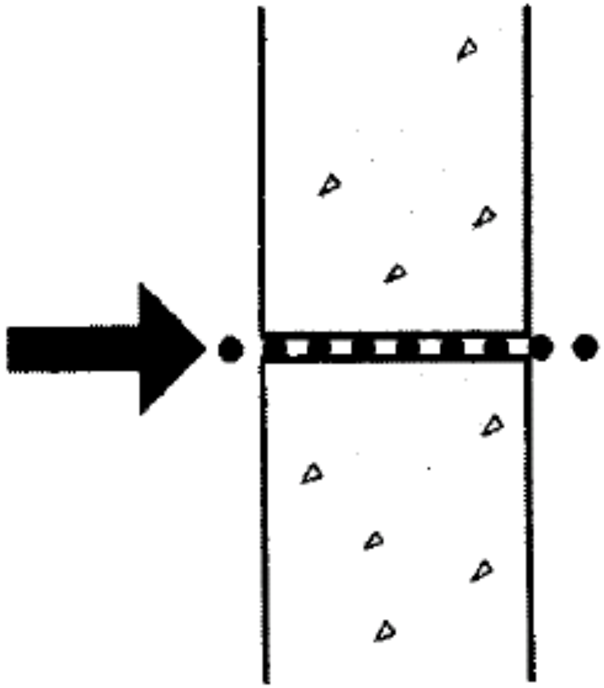
Solution to gravity



Rainwater can flow down surfaces and enter through openings and cavaties

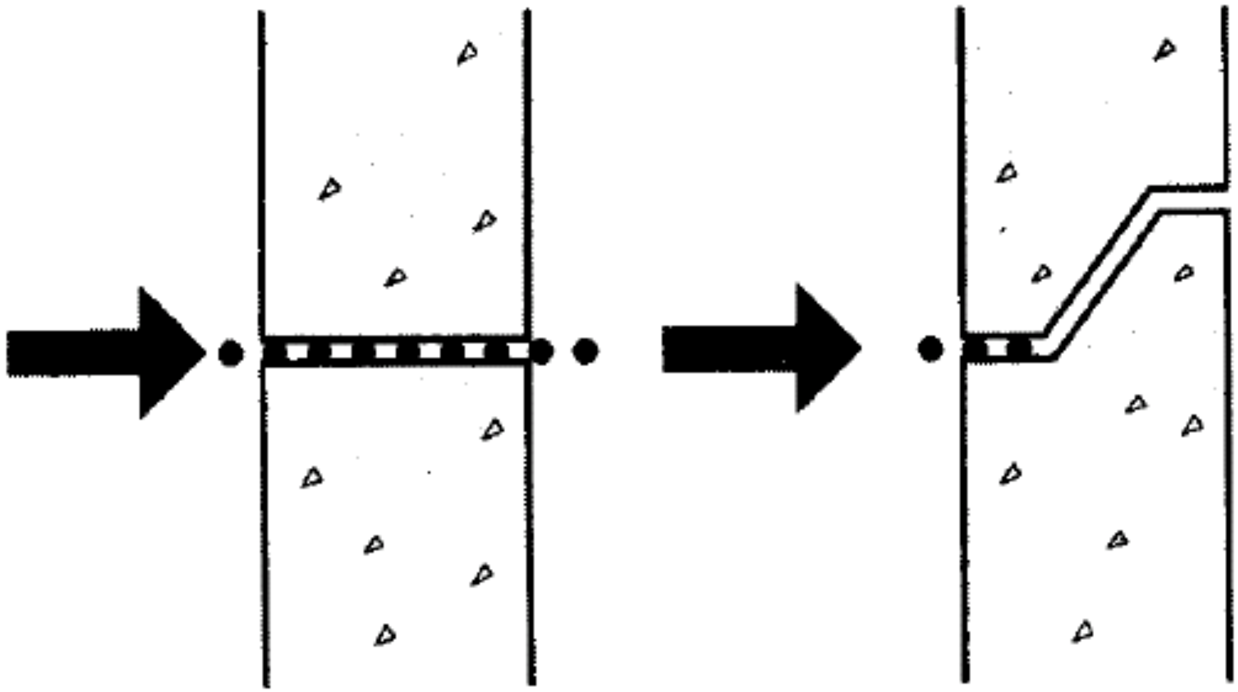
Flashings direct gravity flow rainwater back toward the exterior

Rain droplet momentum



Rain droplets can be carried through a wall by their own momentum

Solution to momentum

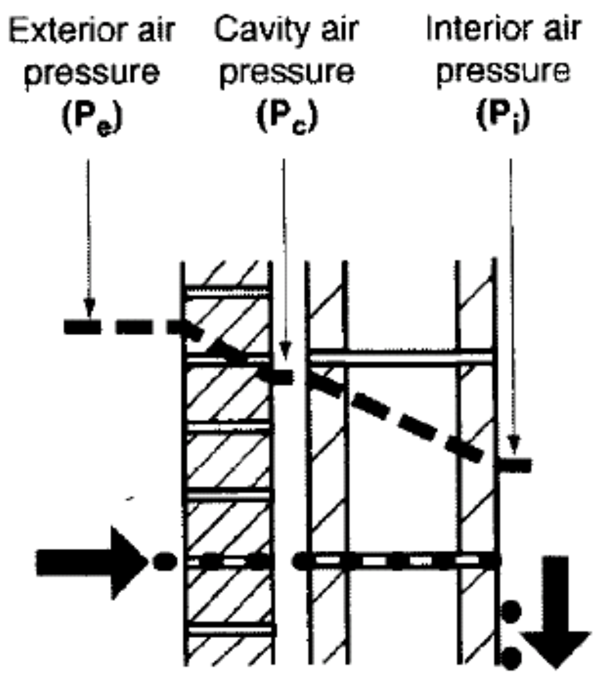


Rain droplets can be carried through a wall by their own momentum

Rain entry by momentum can be prevented by designing wall systems with no straight through openings

This also reduces gravity transport

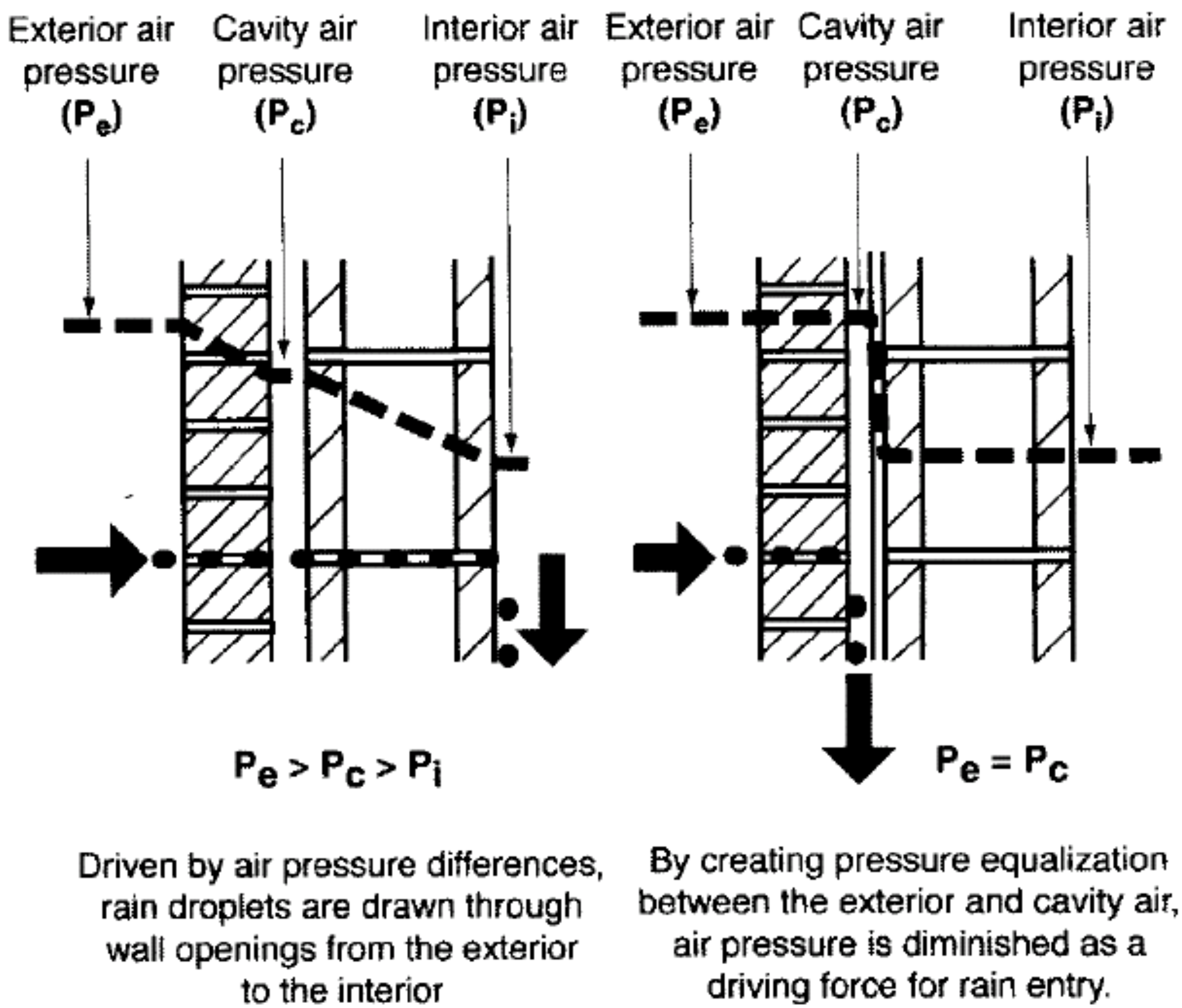
Pressure difference



$P_e > P_c > P_i$

Driven by air pressure differences rain droplets are drawn through wall openings from the exterior to the interior

Solution to pressure difference



Air cavities

- Air cavities can provide beneficial breaks to:
  - Stop capillary suction
  - Allow flashings to direct gravity flow to exterior
  - Allow for pressure equalization to force rain back to exterior

- Intentionally “screen-drained” walls
- “Rain screen” walls

Screen-drained walls

- A screen-drained wall allows some water to penetrate the outer layer of a wall assembly
  - But uses the air cavity to break most water transport
  - Uses that air space for drainage
    - Air space should be at least 5 mm wide, although 10 mm is a better minimum to allow for normal construction tolerances

- The screen-drained wall then uses properly designed and installed flashing to redirect water from the drainage plane back outside the cavity

Screen-drained walls

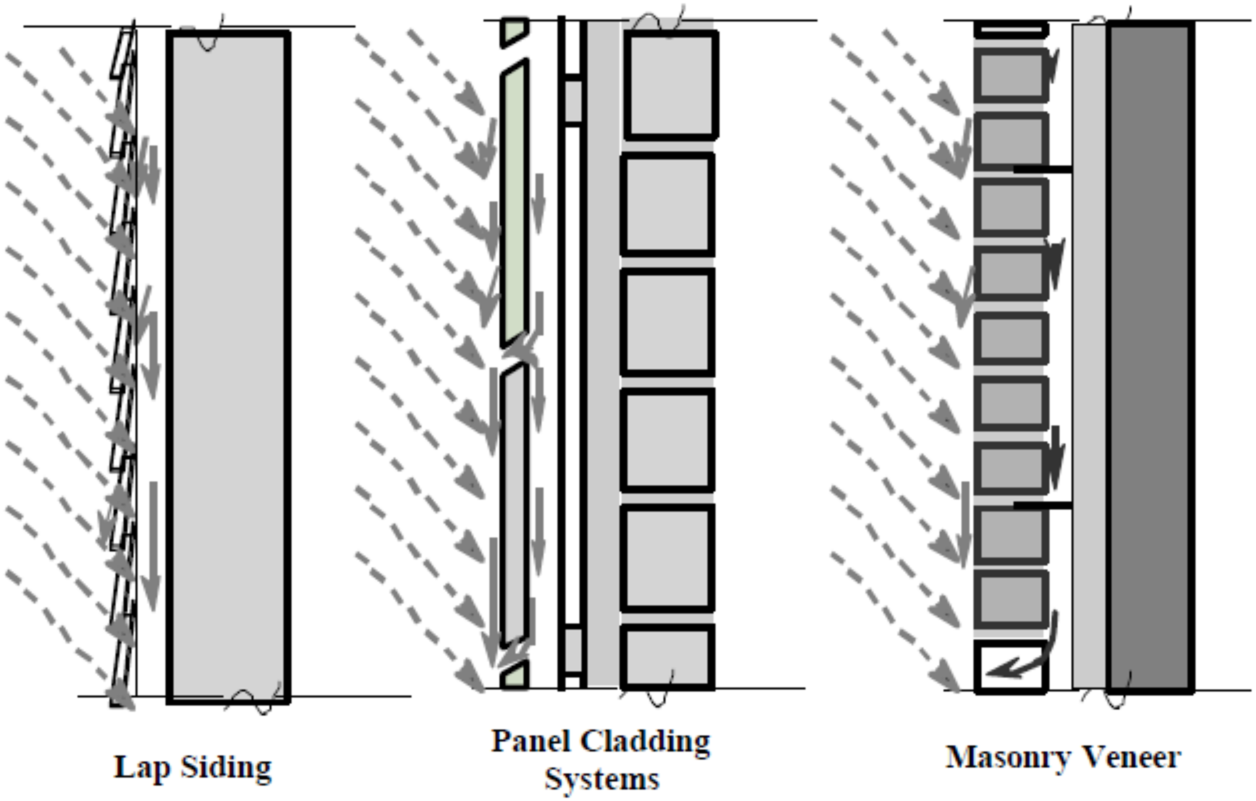


Figure 7: Examples of Drained-Screened Wall Systems

Rain-Screen Wall

- If we are a little more careful in the design of the air cavity between the outer layer and inner layers we can improve performance

- If the cavity has holes to the outside and the inside layer has an air barrier
  - The cavity will actually be pressurized to a pressure similar to outside
  - This will keep water from being driven into the cavity with by the pressure difference
  - We call this wall design a rain screen wall

Rain screen wall: Basic idea

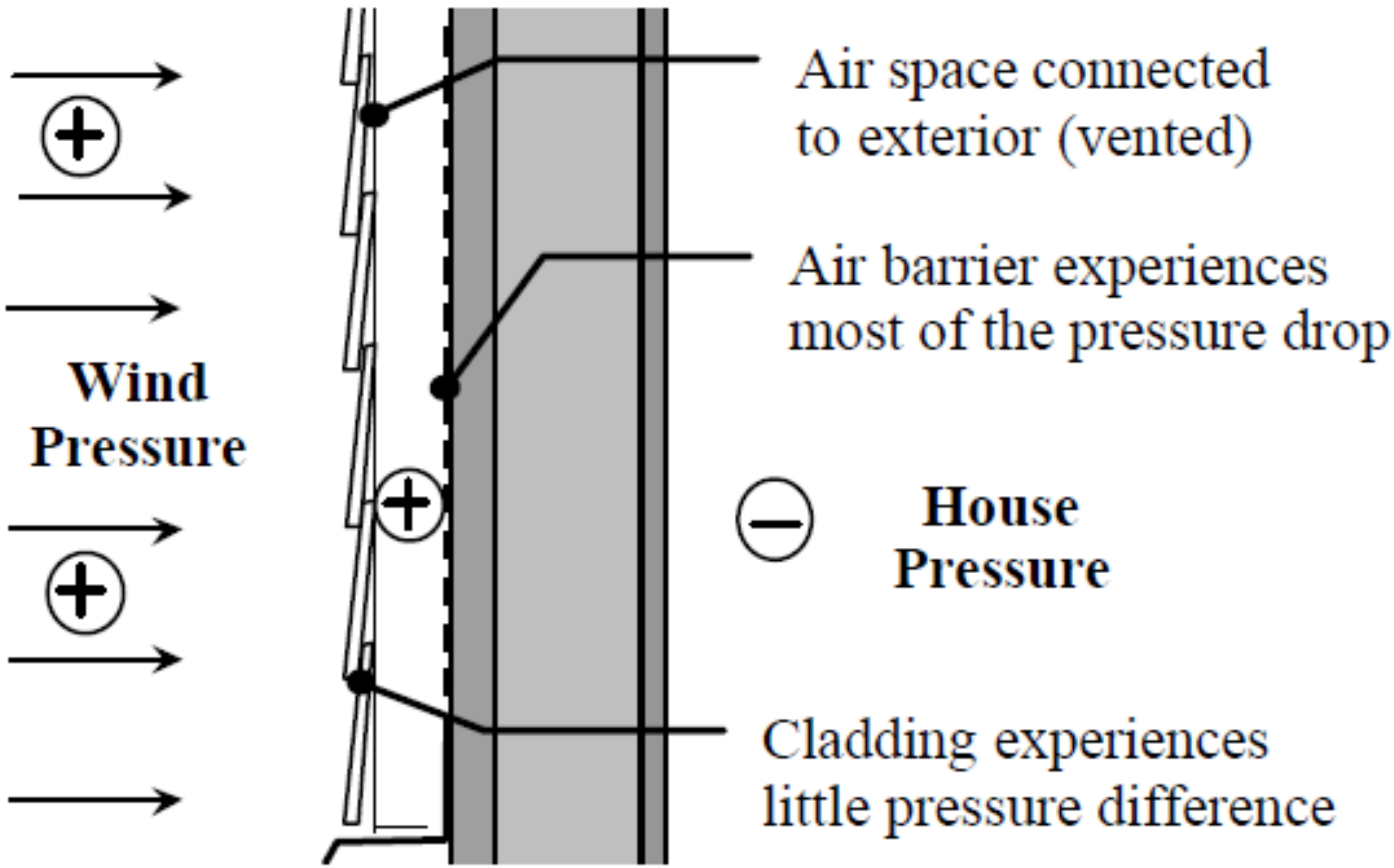
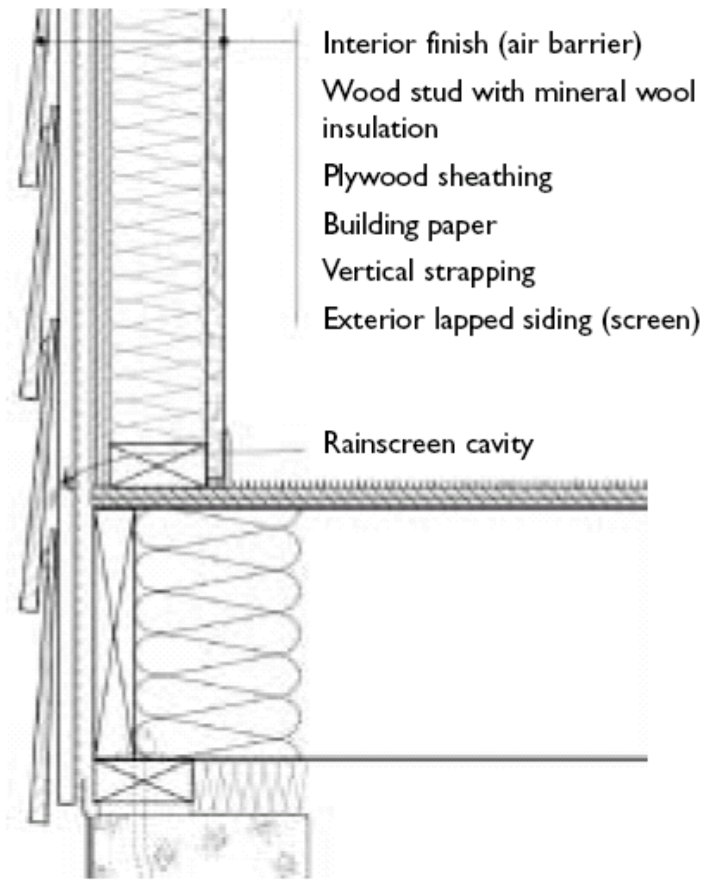


Figure 8: Pressure Moderated Air Space

Open Rain Screen



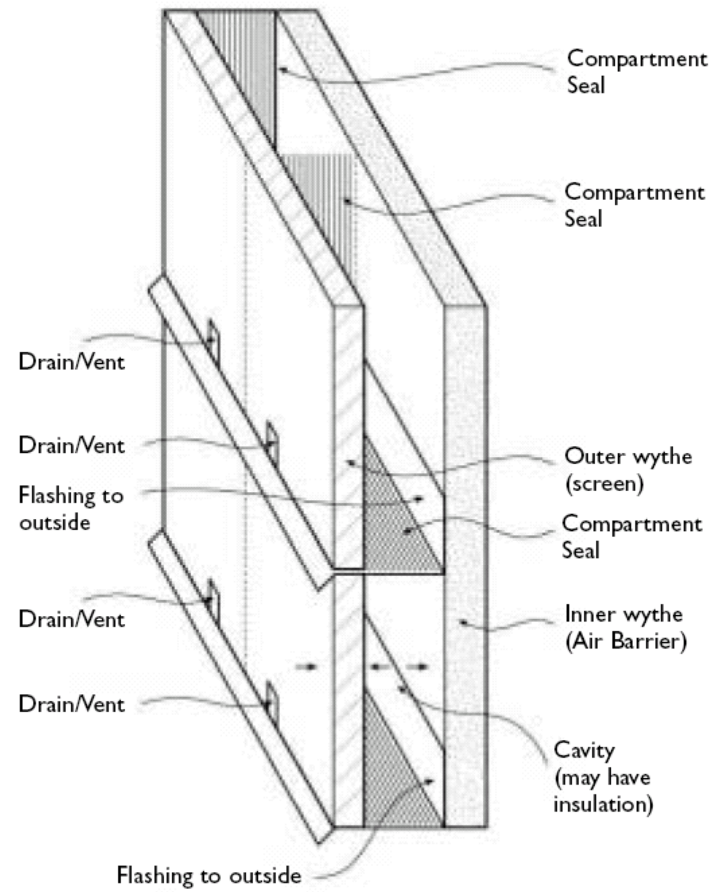
- A wall with siding will have natural air gaps
- Siding gaps act as a vent opening for drainage and drying
- Must have an air barrier somewhere on interior wall

Pressure Equalized Rain screen (PER)

- If we design the cavity openings and volume very carefully
  - We can make the pressure in the air cavity actually track outside air pressure
  - Which means that we stop the rain from even entering the cavity (if driven by pressure difference)
- We call such a design a Pressure Equalized Rain screen wall
  - PER
- PER are useful in high rain areas but are too expensive for general wall design

Basic PER Design

- Flashing
  - Directs dripping water to the exterior drains
- Drain/Vents
  - Act as openings for pressure equalization
  - Allow rain that enters cavity to drain out
- Compartmental Seals
  - Breaks the interior cavity into smaller sections



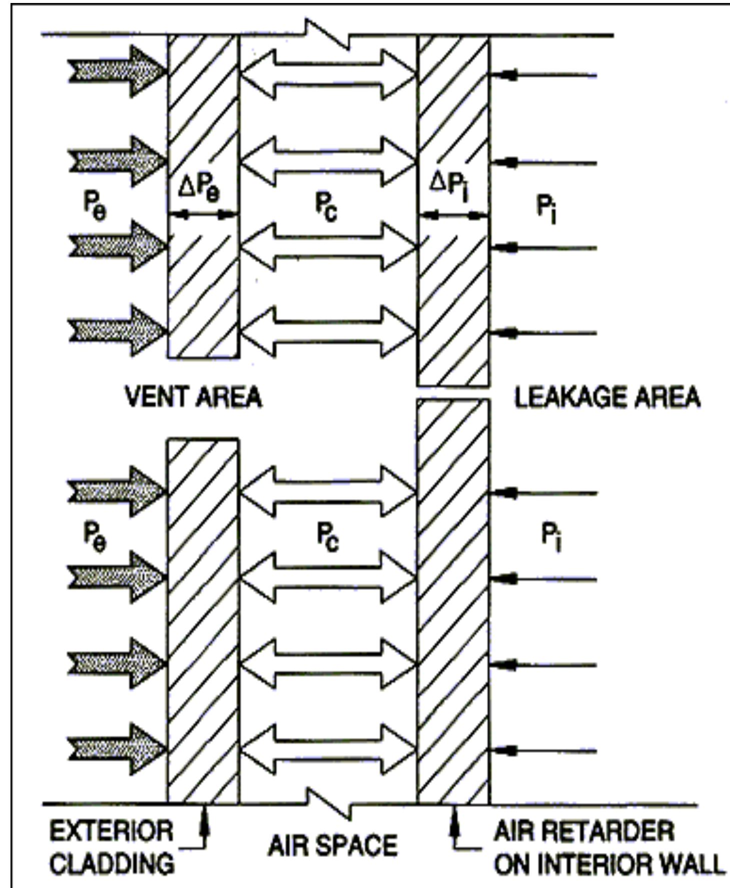
Pressure Equalized Rain Screen (PER)

- Large opening in exterior cladding increases cavity pressure equal to that of exterior so rain doesn't enter

  $P_c \approx P_e, \Delta P_e \rightarrow 0$

- Interior wall must have an air barrier to ensure that high cavity pressure is maintained

  $P_c > P_i, \Delta P_i > 0$



Flashing

- Drain screens work well except fenestration interrupts the drain screen cavity which then requires proper flashing

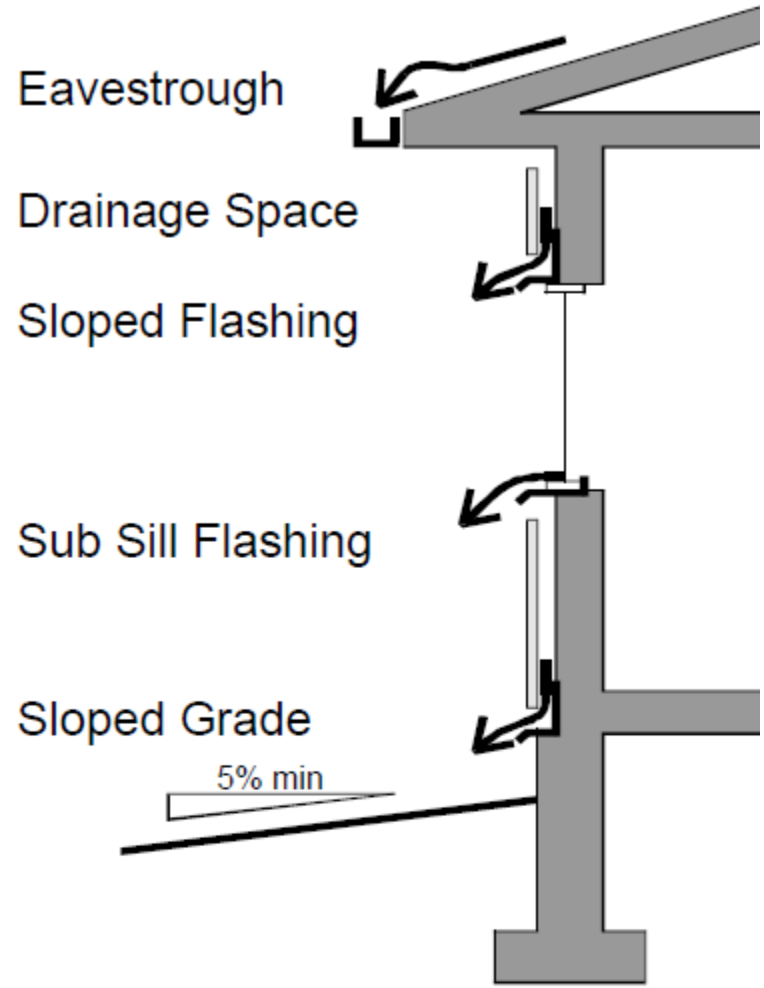


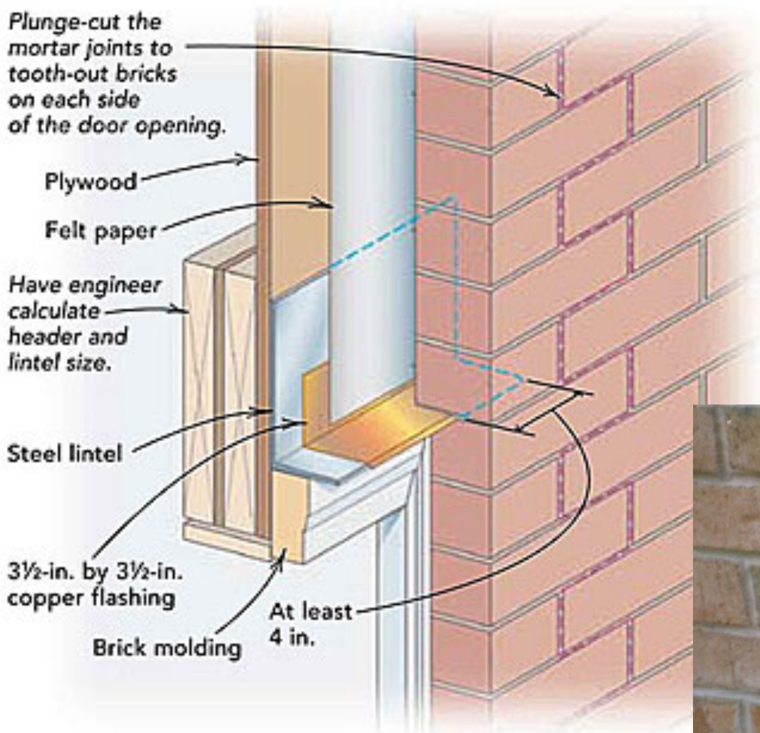
Figure 9: Drainage and Flashing Concepts

Flashing design

- Flashing design is not an art
  - The problem is ensuring that good detail construction documents are created and built as drawn

- Some help: ASTM E2112 Standard Practice for the Installation of Exterior Windows, Doors, and Skylights
  - This standard describes the proper flashing design, building wrap installation and sealing required to ensure watertight window, door, and skylight installation

Flashing

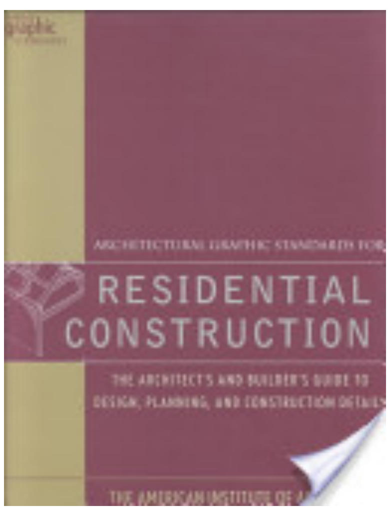


Plunge-cut the mortar joints to tooth-out bricks on each side of the door opening.
Plywood
Felt paper
Have engineer calculate header and lintel size.
Steel lintel
3½-in. by 3½-in. copper flashing
Brick molding
At least 4 in.

PERM-A-BARRIE

Flashing: Extremely important architectural detail

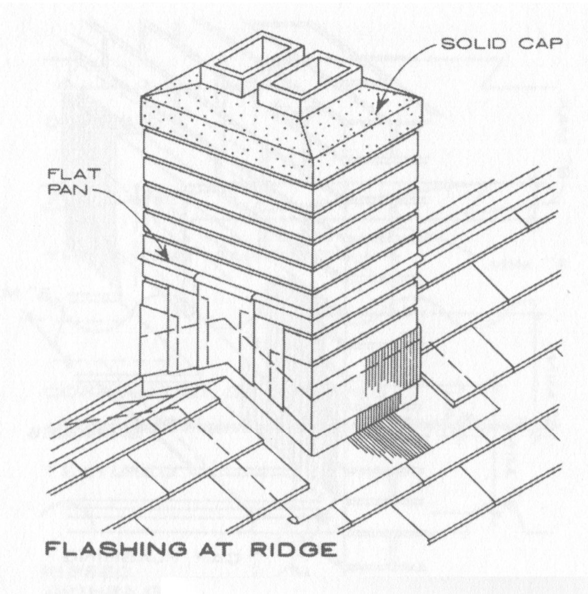
- Most of us are engineers
  - The architect is typically in charge of construction details
  - Then passed on to the contractor for construction
    - Sometimes no interaction with engineer
    - Many places to miss important flashing details

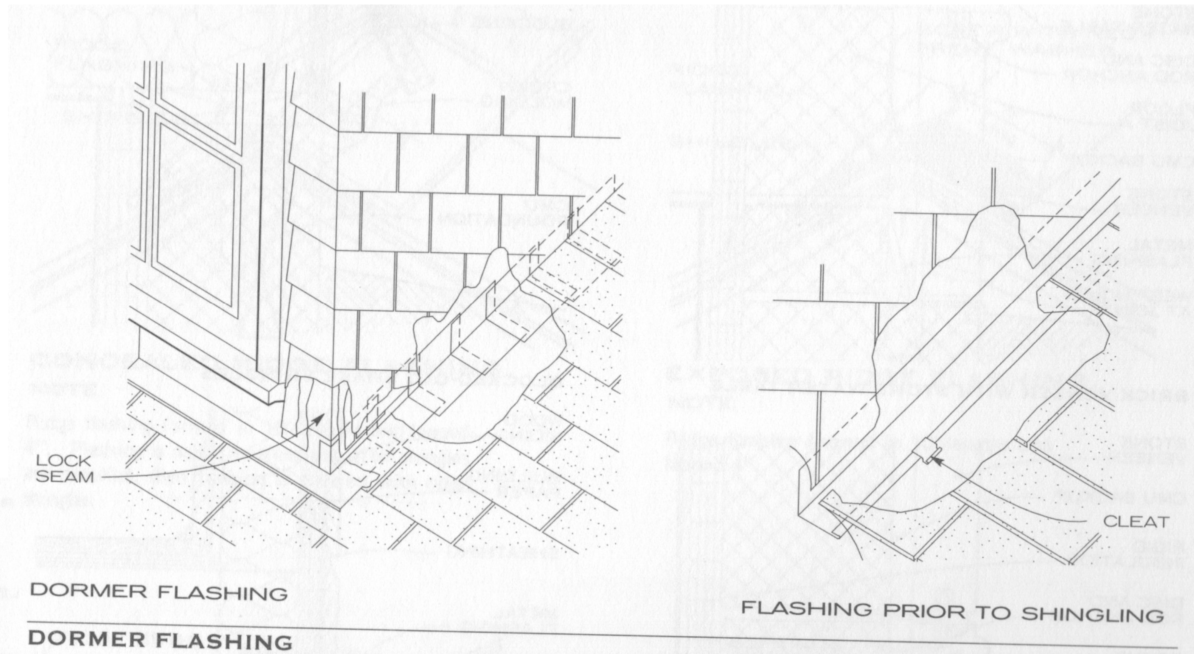


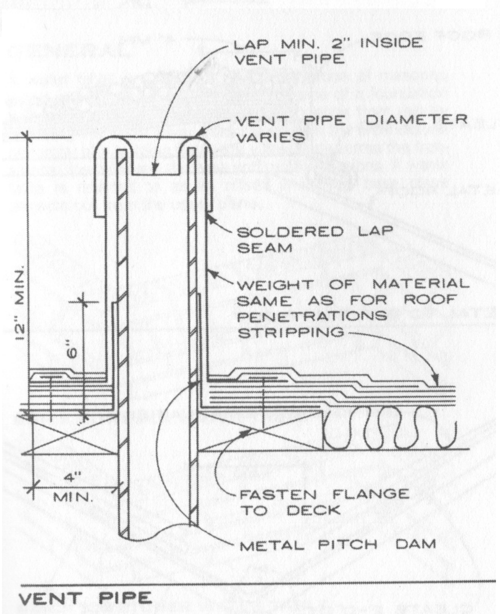
Next I will provide some flashing details taken from an AIA publication on standard graphic details for residential construction

- Make sure your architect follows these!

Flashing details: roofs

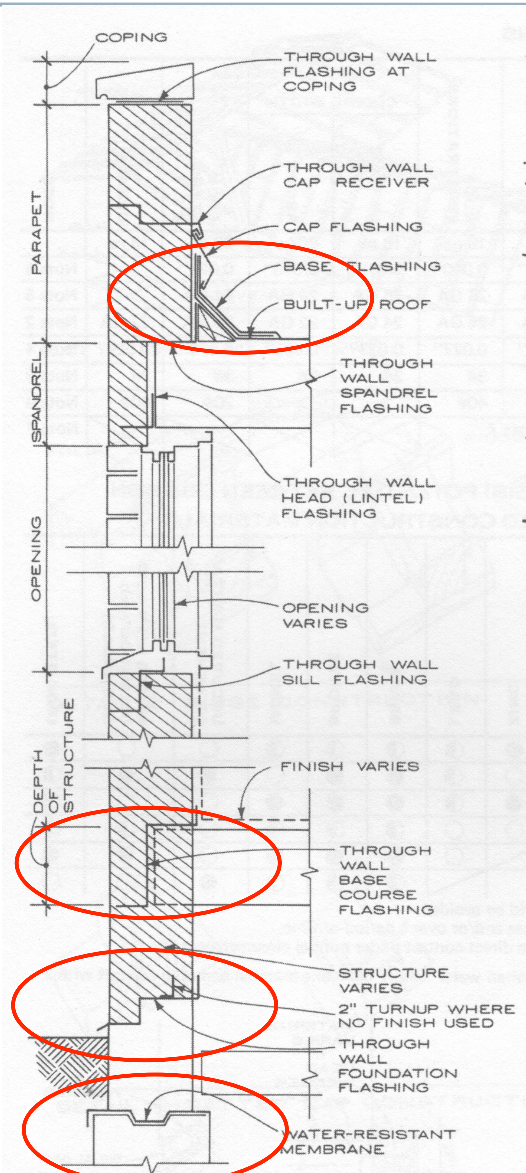




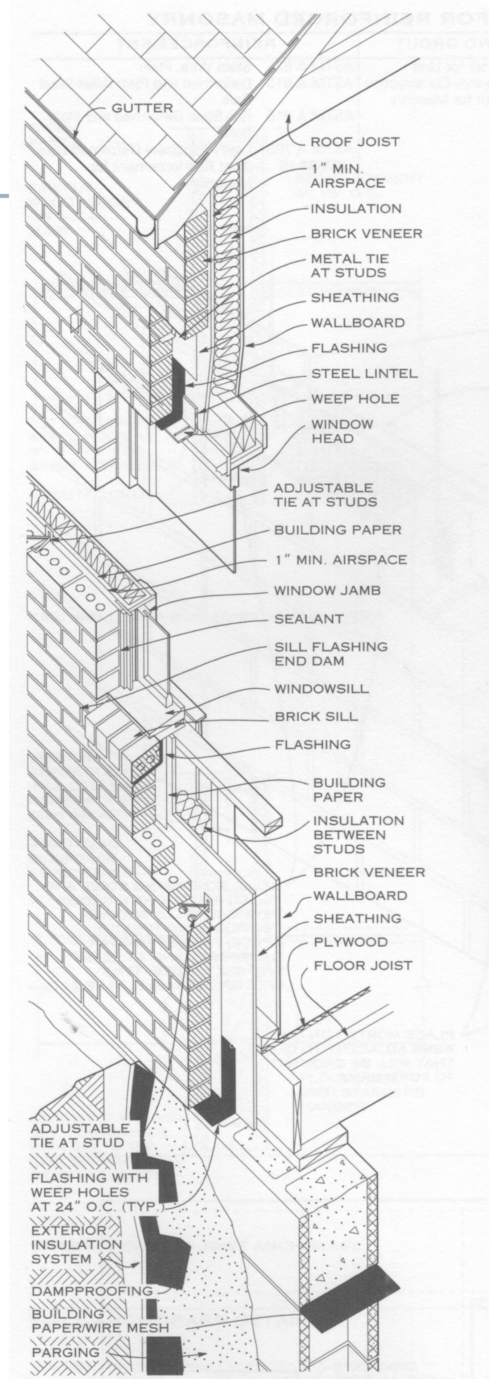


- Install prior to shingles
- Overlap in the correct direction for drainage

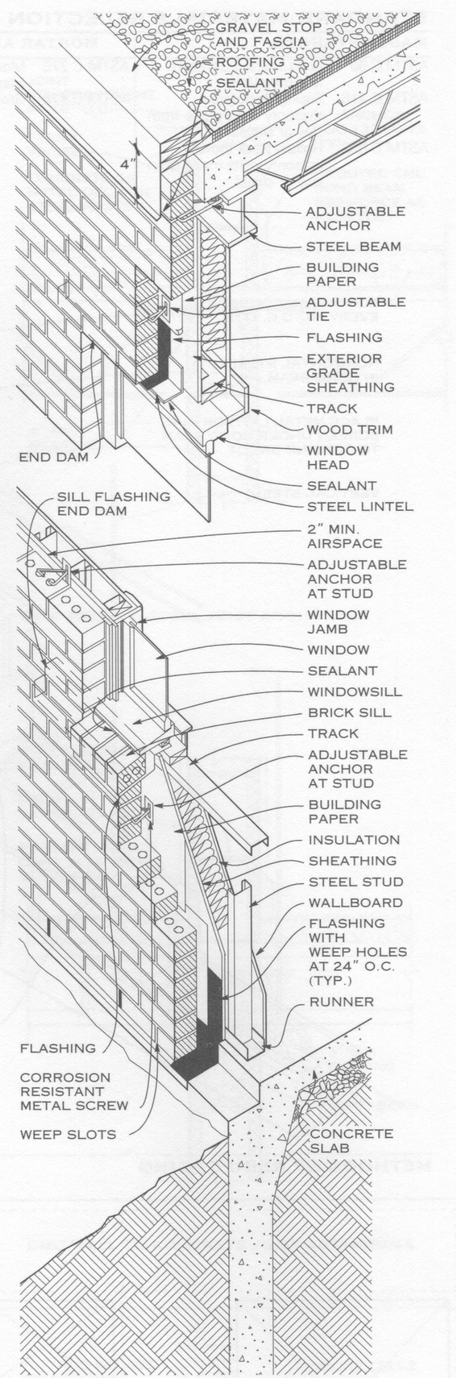
Flashing details: walls



TYPICAL THROUGH WALL FLASHING AT WALL SECTION



BRICK VENEER ON WOOD STUD BACKUP



BRICK VENEER ON STEEL STUD BACKUP

Flashing details: materials

- Some flashing materials are more compatible with your building materials than others

MINIMUM THICKNESS (GAUGES OR WEIGHT) FOR COMMON FLASHING CONDITIONS

MATERIALS \ CONDITIONS	BASE COURSE	WALL OPENINGS HEAD AND SILL	THROUGH WALL AND SPANDREL	CAP AND BASE FLASHING	VERTICAL AND HORIZONTAL SURFACES	ROOF EDGE RIDGES AND HIPS	CRICKETS VALLEY OR GUTTER	CHIMNEY PAN	LEDGE FLASHING	ROOF PENETRATIONS	COPING WIDTH: UP TO 12″	COPING WIDTH: ABOVE 12″	EDGE STRIPS	CLEATS	NOTE
Copper	10 oz	10 oz	10 oz	16 oz	16 oz	16 oz	16 oz	16 oz	16 oz	16 oz	16 oz	20 oz	20 oz	16 oz	
Aluminum	0.019″	0.019″	0.019″	0.019″	0.019″	0.019″	0.019″	0.019″	0.019″	0.040″	0.032″	0.040″	0.024″	☒	Note 6
Stainless steel	30 GA	30 GA	30 GA	26 GA	30 GA	26 GA	26 GA	30 GA	26 GA	26 GA	26 GA	24 GA	24 GA	☒	Note 5
Galvanized steel	26 GA	26 GA	26 GA	26 GA	26 GA	24 GA	24 GA	26 GA	24 GA	24 GA	24 GA	22 GA	26 GA	22 GA	Note 2
Zinc alloy	0.027″	0.027″	0.027″	0.027″	0.027″	0.027″	0.027″	0.027″	0.027″	0.027″	0.027″	0.032″	0.040″	0.027″	Note 4
Lead	3#	2½#	2½#	2½#	3#	3#	3#	3#	3#	3#	3#	3#	3#	3#	Note 3
Painted terne	40#	40#	40#	20#	40#	20#	40#	20#	40#	40#	☒	☒	20#	40#	Note 8
elastomeric sheet; fabric-coated metal	See Note 7			☒	☒	☒	☒	☒	See Note 7		☒	☒	☒	☒	Note 7

GENERAL NOTES

1. All sizes and weights of material given in chart are minimum. Actual conditions may require greater strength.
2. All galvanized steel must be painted.
3. With lead flashing use 16 oz copper cleats. If any part is exposed, use 3# lead cleats.
4. Coat zinc with asphaltum paint when in contact with redwood or cedar. High acid content (in these woods only) develops stains.
5. Type 302 stainless steel is an all purpose flashing type.
6. Use only aluminum manufactured for the purpose of flashing.
7. See manufacturer's literature for use and types of flashing.
8. In general, cleats will be of the same material as flashing, but heavier weight or thicker gauge.
9. In selecting metal flashing, precaution must be taken not to place flashing in direct contact with dissimilar metals that cause electrolysis.
10. Spaces marked ☒ in the table are uses not recommended for that material.

GALVANIC CORROSION (ELECTROLYSIS) POTENTIAL BETWEEN COMMON FLASHING MATERIALS AND SELECTED CONSTRUCTION MATERIALS

FLASHING MATERIALS \ CONSTRUCTION MATERIALS	COPPER	ALUMINUM	STAINLESS STEEL	GALVANIZED STEEL	ZINC	LEAD	BRASS	BRONZE	MONEL	UNCURED MORTAR OR CEMENT	WOODS WITH ACID (REDWOOD AND RED CEDAR)	IRON/STEEL
Copper		●	●	◑	●	◑	◑	◑	◑	○	○	●
Aluminum			○	○	○	◑	●	●	○	●	●	◑
Stainless steel				◑	●	◑	●	●	●	○	○	◑
Galvanized steel					○	○	◑	◑	◑	○	◑	◑
Zinc alloy						○	●	●	●	○	●	●
Lead							◑	◑	◑	●	○	○

● Galvanic action will occur, hence direct contact should be avoided.
◑ Galvanic action may occur under certain circumstances and/or over a period of time.
○ Galvanic action is insignificant, metals may come into direct contact under normal circumstances.

GENERAL NOTE: Galvanic corrosion is apt to occur when water runoff from one material comes in contact with a potentially reactive material.

What happens when you don’t address these?

- Michaels Engineering report on construction defects and resultant water damage in a Wisconsin condominium
  - Confidential
  - Names have been changed/erased to protect the innocent (and I suppose the guilty as well)
  - Just show in class (can’t provide as a handout)

Moisture management guidelines

- Philosophy and concepts used in the design of building enclosures to obtain desired moisture performance

- Remember, we manage moisture to control:
  - Leakage of water into a building
  - Freeze-thaw deterioration of concrete, stone, and masonry
  - Corrosion of metal components
  - Biological growth
  - Deterioration and dissolution of materials
  - Volume changes (expansion/shrinkage)
  - Discoloration

Moisture management

- Remember:
  - For a moisture problem to occur
    - There must a source
    - There must be a route
    - There must be a driving force
    - The materials involved must be susceptible
  - Eliminate any one will avoid a problem, in theory
  - In practice, difficult to:
    - Remove all moisture sources
    - Build walls with no imperfections
    - Remove all driving forces for moisture movement
    - So, if you can address two of these
      - You will reduce the likelihood of having a problem

Susceptibility and vulnerability

- As we've seen, different materials and assemblies vary in their susceptibility to moisture-related damage
- Standards, codes, and industry criteria help assess susceptibility of materials
- Susceptible materials are susceptible only in a vulnerable environment
  - Responsibility of designers and builders to ensure that a material or assembly are used in appropriate manners
  - Location is a primary determinant of exposure
    - The location of the relevant portion of material on the wall
      - The wall on the building
        - The building on the site
          - And of the geographical region of the site

Moisture management

- “This is a durable, high-performance wall assembly”
  - Means nothing without context of climate and purpose
  - Is the enclosure expected to separate an operating room from the Antarctic winter?
    - Or a warehouse from the Saharan desert?
  - Using a material that is not supposedly susceptible to moisture damage in locations with high wetting potential often leads to a problem
    - Good quality face brick in window sills

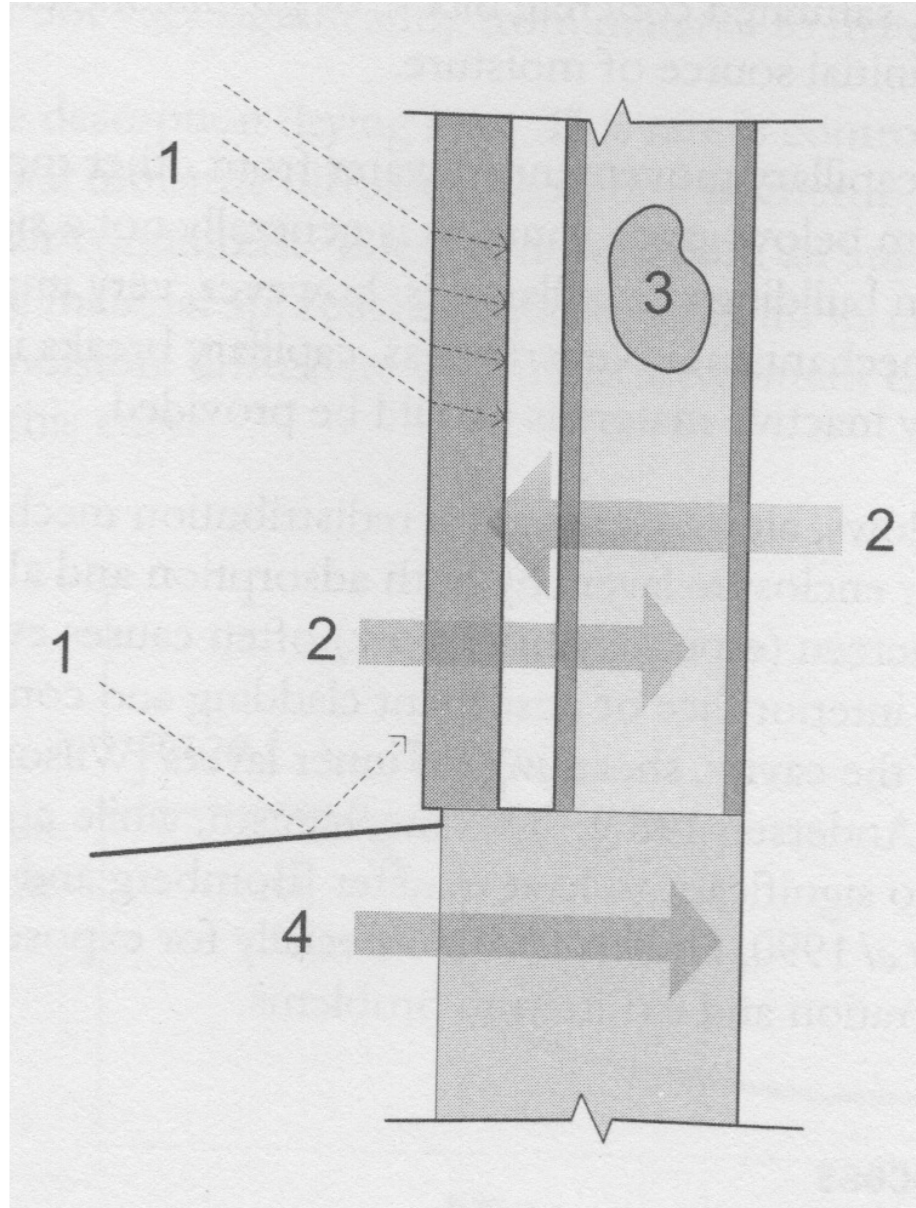
Moisture control

- If a balance between wetting and drying is maintained
  - Moisture will not accumulate over time
    - Moisture problems would then be unlikely

- Need to be cognizant of:
  - Moisture sources
  - Moisture removal mechanisms
  - Moisture storage

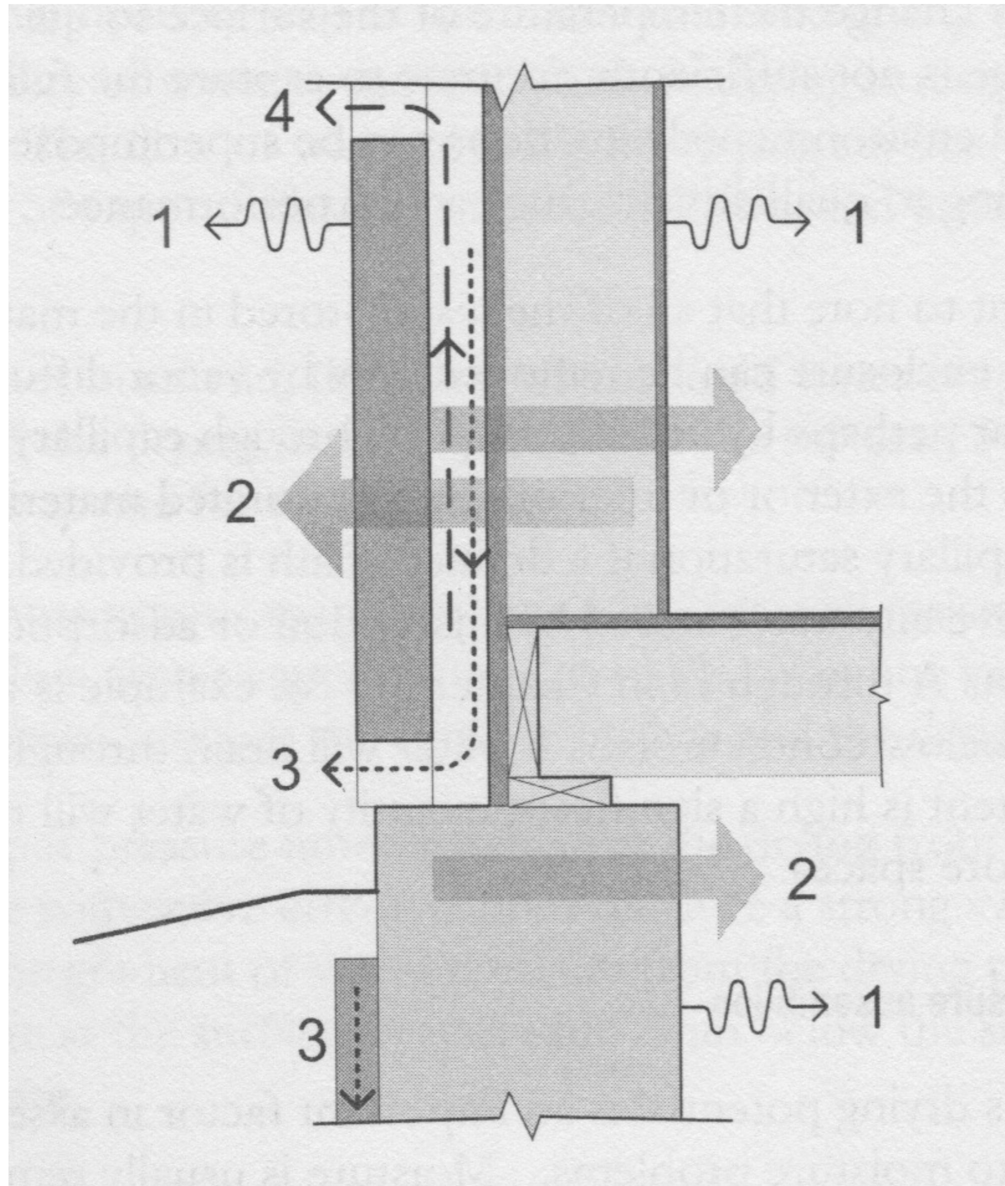
Wetting process (sources)

1. Precipitation
   – Driving rain
2. Water vapor transport
   – Diffusion
   – Air leakage
3. Built-in and stored moisture
   – During construction
4. Ground water



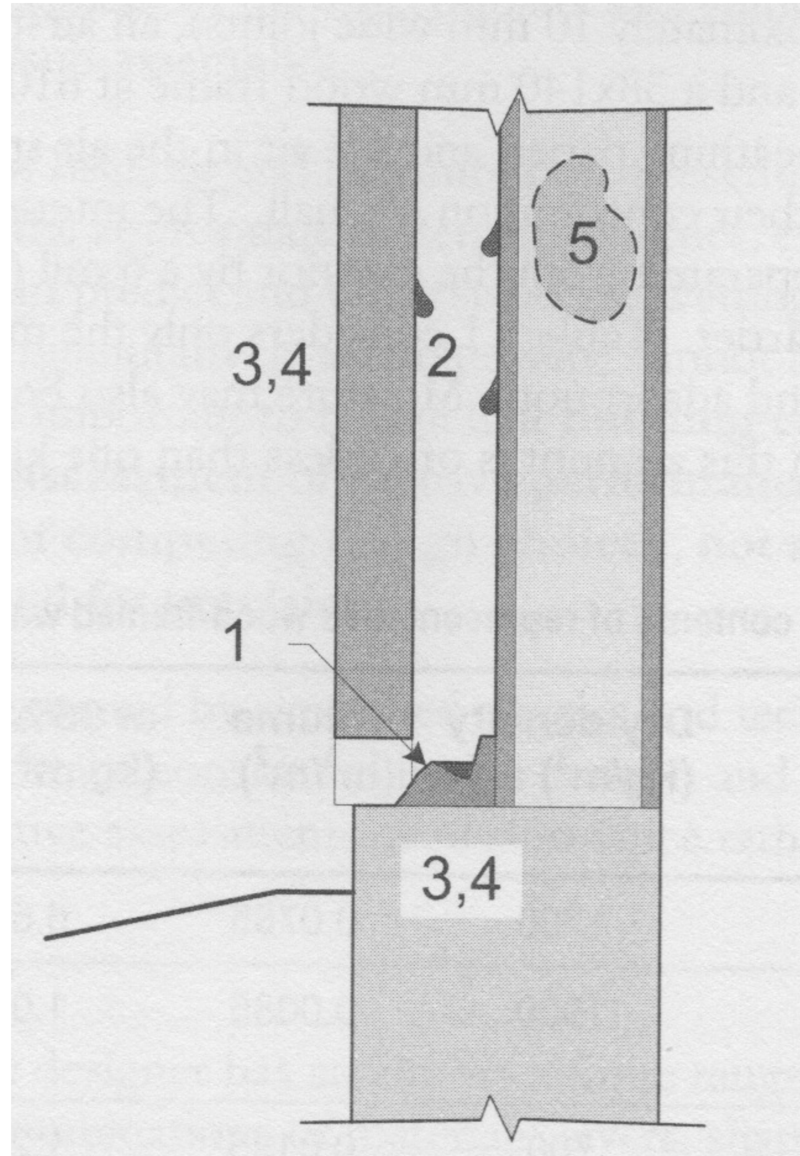
Drying mechanisms

1. Evaporation
2. Vapor transport
   - Diffusion
   - Air leakage
   - Outward or inward
3. Drainage
   - Driven by gravity
4. Ventilation drying



Moisture storage

1. Trapped in small depressions
   - Poorly drained portions of assemblies
2. Adhered by surface tension to materials
   - Droplets
   - Or even frost or ice
3. Adsorbed in or on hygroscopic building materials
   - Brick, wood, fibrous insulation, paper
4. Retained by capillarity (absorbed) in porous material
5. Stored in the air as vapor



Condensation control

- Two types that must be considered
  - Interior surface condensation
  - Interstitial (within enclosure) condensation
    - Just as important in hot-humid climates as in cold climates

- Like we’ve discusses, condensation on building surfaces is undesirable
  - On interior surfaces:
    - Moisture will damage moisture-sensitive finishes (wallpaper, paint, wood, gypsum wallboard)
    - Provides moisture for mold growth

Condensation control

- Surface condensation is often the result of dynamic/ short-term variations in temperature or absolute humidity
  - Cold windy night
  - Cool morning
  - After a shower
  - During cooking

  - Need to consider these events

Condensation control

- Most modern enclosure walls and roofs are well insulated such that interior surface condensation in winter shouldn’t be a problem
  - In winter, interior surface temperature is high enough to not be below indoor air dew point
- Surface condensation becomes a problem when:
  - Thermal resistance of the enclosure is low (i.e., at thermal bridges)
  - Surface film has an unusually high value
  - Interior humidity is very high

Designing enclosures for moisture control

- Building enclosure design usually involves the assessment of relative performance, pass-fail assessments, or the ranking of competing design choices
  - Not absolute values
  - Rarely a need for absolute precision

- Results generated by the simplified physics and solution techniques so far should be considered
  - Applied to arrive at reliable relative assessments
    - Rather than precise quantities

Designing enclosures for moisture control

- Material choices
  - You have an almost infinite range of choices considering possible combinations of
    - Materials
    - Layers
    - Shape
    - Orientation
  - There are no universally “good” materials

More information/resources

InspectAPedia®

Free Encyclopedia of Building & Environmental Inspection, Testing, Diagnosis, Repair

- Inspect A Pedia
  - http://www.inspectapedia.com/index.htm

- Building Science Corporation
  - http://www.buildingscience.com/index_html

Questions?

- HW 2 solutions
- Campus project
- Final project