CAE 463/524
Building Enclosure Design
Spring 2016

Week 8: March 1, 2016
Moisture management and control

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Illinois Institute of Technology
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Campus enclosure assessment projects

- Need to do thermal assessments by early/mid March
  - Don't wait too long!
  - All teams have now been formed

Team #	Members	Building
1	Naveen, Julia, Xu, Luanzhizi, Steve	Alumni
2	Bianca, Al, Taylor, David	SSV
3	Nina, Dina, Lindsey, Salvatore, JiWan	Vandercook
4	Andrea, Ben, Keonho, Kevin	Crown
5	Afshin, Ali, Mehdi, Jose, Kamal	Siegel

- Email me (brent@iit.edu) and our TA Akram (aali21@hawk.iit.edu) when you're ready to check out the IR camera, IR thermometer, and air T/RH sensor

ASHRAE IL Spring Conference: March 8th

SPRING CONFERENCE RETURNS MARCH 8th

Get Back to the Basics of HVAC Design

ASHRAE YEA

2016 Spring Conference

HVAC Design Essentials

March 08, 2016
8:30 AM - 4:00 PM

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http://www.summitchicago.com

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ASHRAE Distinguished Lecturer

Victor W. Goldschmidt, Ph.D.

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United States
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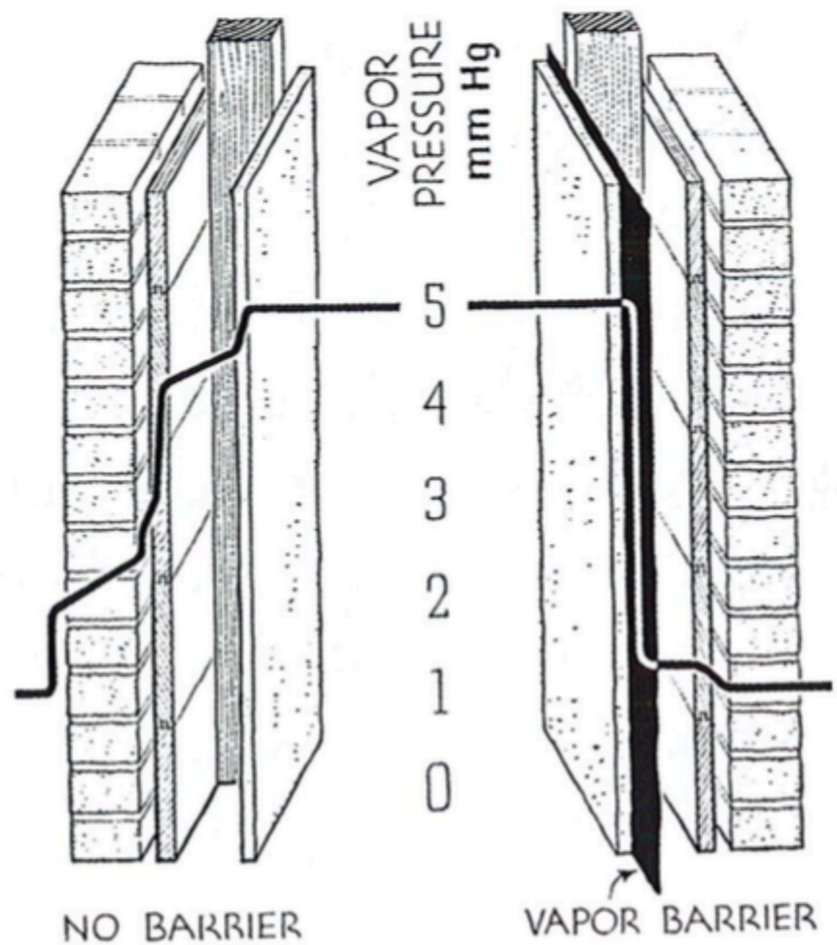
Region: V
Honorarium: None
creating2@earthlink.net

Victor W. Goldschmidt, Emeritus Mechanical Engineering Professor, served at Purdue University from 1964 through 2000. He is currently serving as a Leelanau County Planning Commissioner as well as a facilitator and engineering consultant. During his 36 years at Purdue University, Mr. Goldschmidt was responsible for educating mechanical engineering students, including the direction of graduate research in the HVAC area. Most of his service with graduate students was with the Ray W. Herrick Laboratories with heavy support from the HVAC industries. During early stages of his career, he served as Director of the Engineering Purdue Fellows in Latin America; during later stages he served as department head for Freshman Engineering. Prior to his academic involvement, he worked in Applications Engineering and Development Engineering with Honeywell. Mr. Goldschmidt has taught almost every course in thermal sciences offered at Purdue, as well as a special upper level technical course on the "Creative Process in Engineering." He is trained as a Synectics (special brainstorming) facilitator and is currently engaged in the development of strategic plans and problem solving sessions. A past ASHRAE Director-at-Large, he also has served as a member of Publishing and Technology Councils. He is an ASHRAE Distinguished Service Award recipient and Fellow, as well as Honorary Member of IIR, ACAIRE, ASURVAC and AAF. He resides in North Michigan, above Traverse City.

Review from last time

- Moisture problems/failures
  - Condensation potential
  - High RH or water content
- Types of moisture transport
  - Vapor diffusion
  - Moist air transport
  - Bulk liquid transport (today)
- Calculating 1-D vapor flow
  - Glaser method
  - Vapor pressure diagrams
  - Moisture storage
  - WUFI
    - HW 3 due next week



Review from last time

Moisture flows in building enclosures

Water vapor diffusion:

Permeability and permeance

$$\dot{M}_v = \frac{\mu}{L} A\left(p_{w,1} - p_{w,2}\right) = MA\left(p_{w,1} - p_{w,2}\right) = \frac{1}{R_v} A\left(p_{w,1} - p_{w,2}\right)$$

$$M = \frac{\mu}{L} \quad \text{and} \quad R_v = \frac{1}{M}$$

M = vapor permeance [ng/(s m^2 Pa)]

R_v = vapor resistance [(s m^2 Pa)/ng]

$\dot{M}_v$ = 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]

Bulk convection of moist air:

$$\dot{M}_{v,conv} = \rho_{air} \dot{V}_{air} \Delta W$$

Vapor pressure through assembly:
(Condensation potential)

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

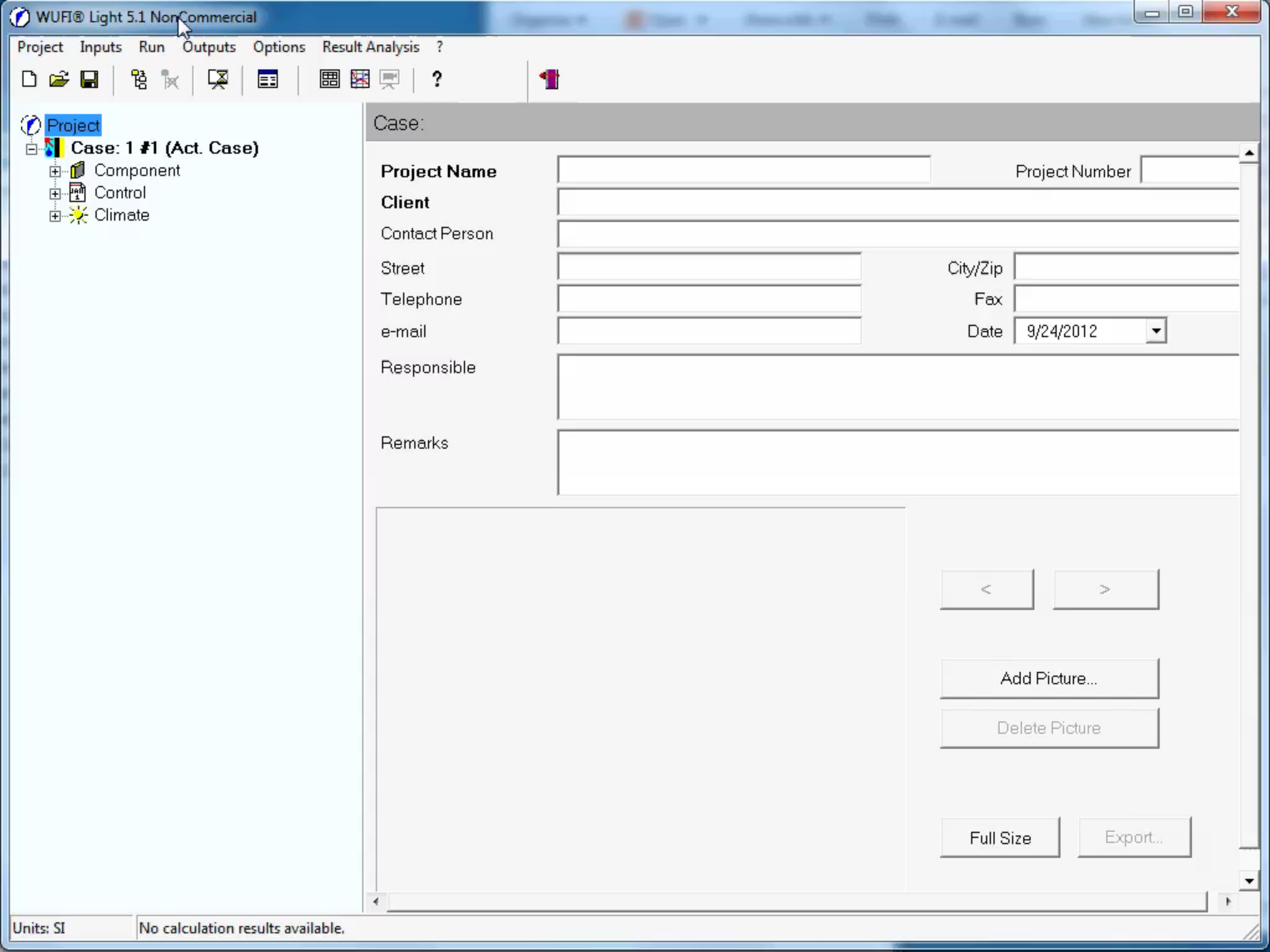
Units for M:
1 perm = 1 grain/(hr ft^2 inHg)
1 perm = 57.2 ng/(s m^2 Pa)

Today’s objectives

- Moisture management and control
  - Practical focus
  - When and where to use vapor barriers?
  - Managing bulk liquid transport
  - Building enclosure design details

VAPOR BARRIERS

Applications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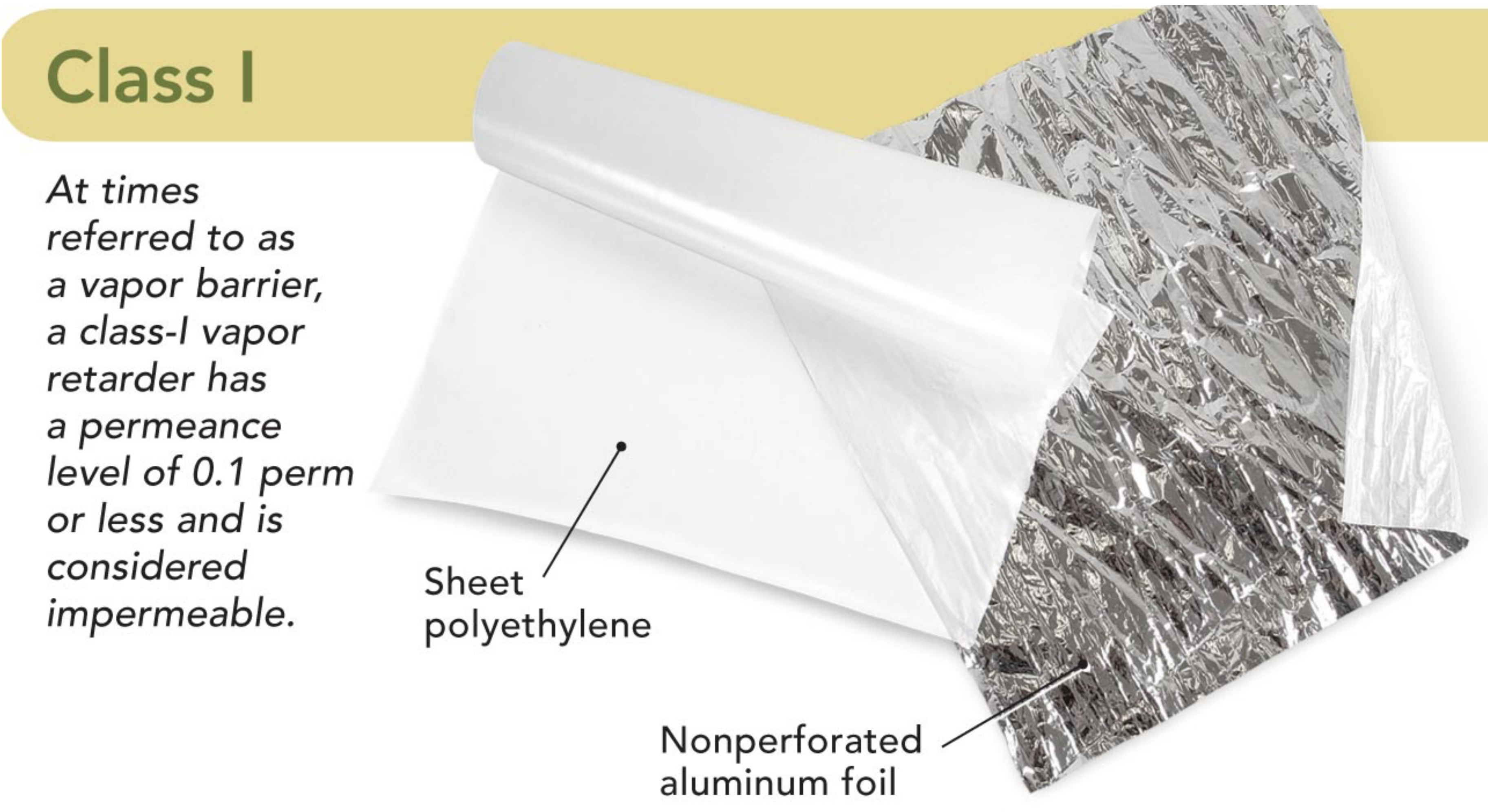
Materials: Vapor barriers and vapor retarders

- Vapor retarders slow the rate of vapor diffusion
  - But do not prevent it

- General rules for vapor permeance are as follows:

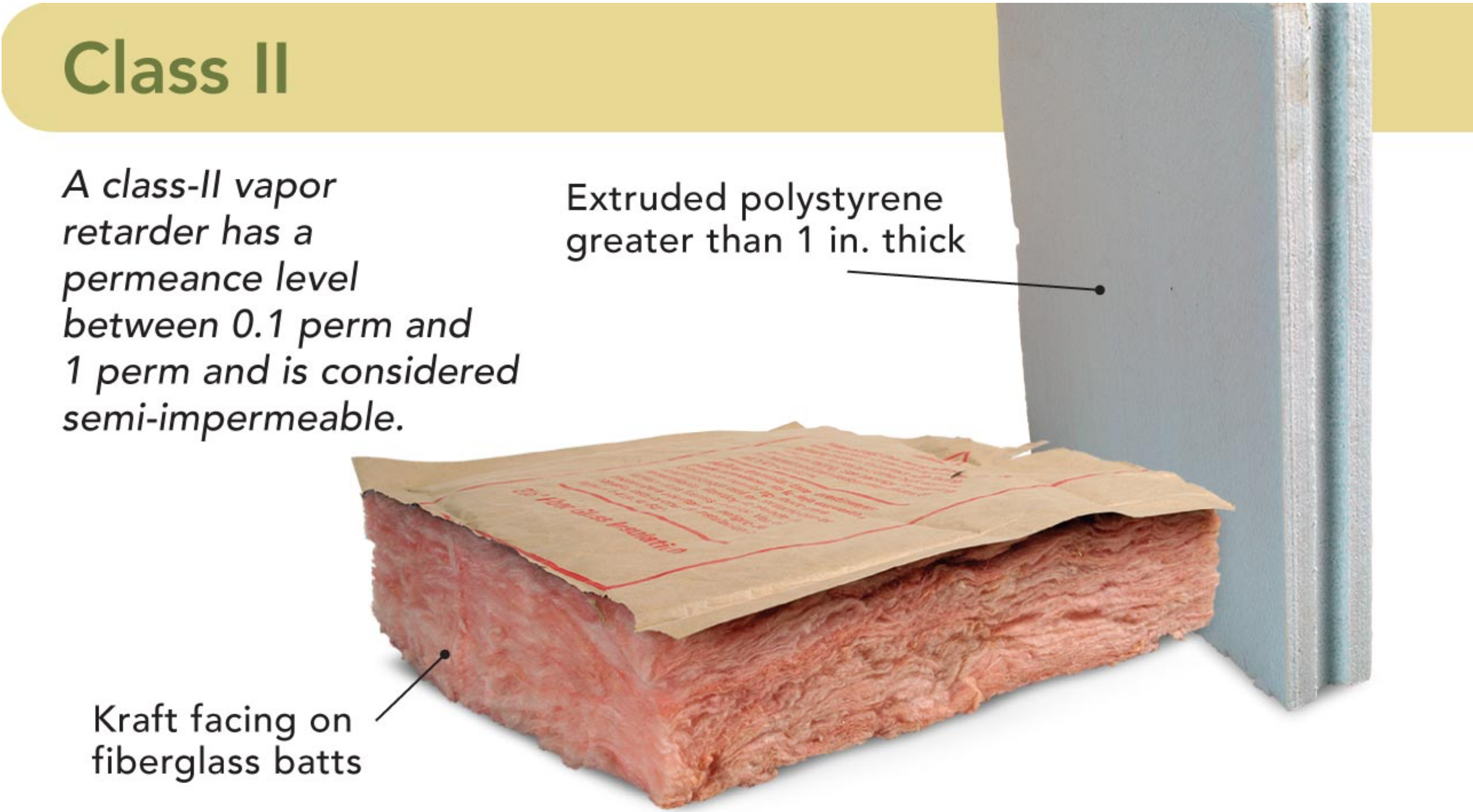
Type	Perms (IP units) [grains/(hr ft^2 inHg)]	SI units [ng/(s m^2 Pa)]	Example
Class I vapor retarder Vapor barrier Vapor impermeable	0.1 or less	5.7	Foil Polyethylene
Class II vapor retarder Vapor semi-impermeable	0.1-1	5.7-57	Brick XPS
Class III vapor retarder Vapor semi-permeable	1-10	57-570	Poly-iso EPS
Vapor permeable NOT a vapor retarder	10+	570+	Gypsum board

Class 1: Vapor barriers (impermeable)



http://www.finehomebuilding.com/item/5090/whats-the-difference-vapor-barriers-and-vapor-retarders

Class II vapor retarders (semi-impermeable)



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Class III vapor retarder (semi-permeable)

http://www.finehomebuilding.com/item/5090/whats-the-difference-vapor-barriers-and-vapor-retarders

Vapor barriers: Good or bad idea?

- While vapor barriers/retarders can reduce vapor diffusion regardless of where they are placed
  - They must be placed carefully in order to ensure that the potential for condensation is minimized
- Where should vapor barriers be placed?
- In hot and humid climates:
  - Vapor barriers go toward the outside of the enclosure
- In very cold climates:
  - Vapor barriers go toward the inside of the enclosure
- In mixed or cold environments:
  - V*apor retarders* should be used (not barriers), or you may have problems in the opposite seasons
- Vapor barrier selection largely depends on climate and order of material installation

Interior vapor barriers

- Insulation with Kraft Paper
  - Kraft paper is a barrier at low humidity and a retarder at high humidity
  - Kraft paper also holds some moisture so light condensation is not a problem
  - Not an air barrier as commonly installed (stapled)

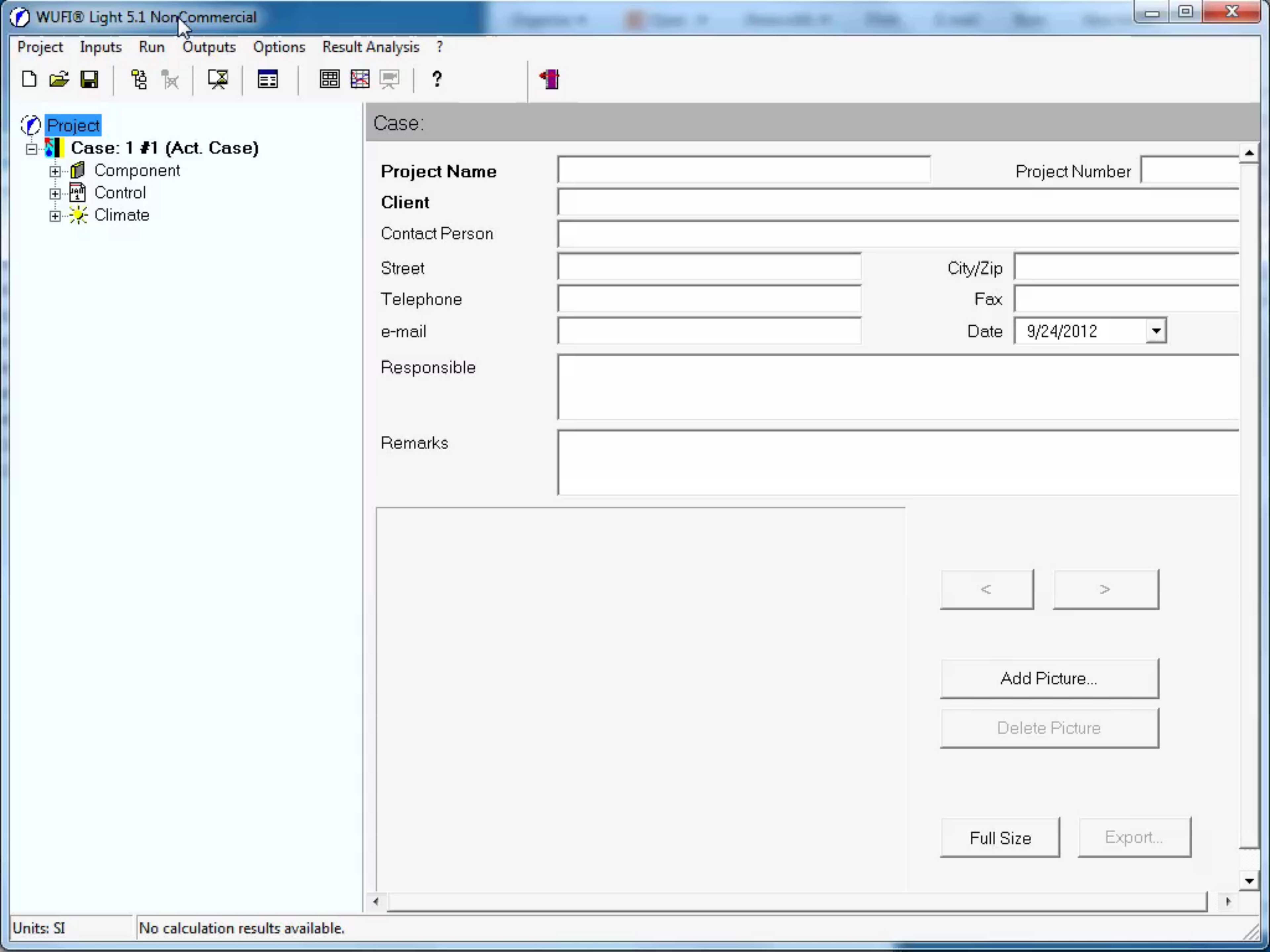
- Polyethylene sheet (discouraged)
  - This is a vapor barrier installed after insulation
  - Polyethylene holds no moisture so condensation results in standing water
  - Not an air barrier as commonly installed

Paints as vapor barriers/retarders

- Latex paints and primers are available in permeable, semi-permeable, or nearly impermeable forms
  - Typical latex paint has $5 < M < 10$ perm
  - Benjamin Moore Vapor Retardant Primer has $M \approx 0.4$ perm
  - These are especially useful when membrane vapor barriers cannot be installed

- Be careful to ensure that your paint is not acting as a vapor barrier or retarder unless you want it to act as a barrier or retarder

BULK LIQUID TRANSPORT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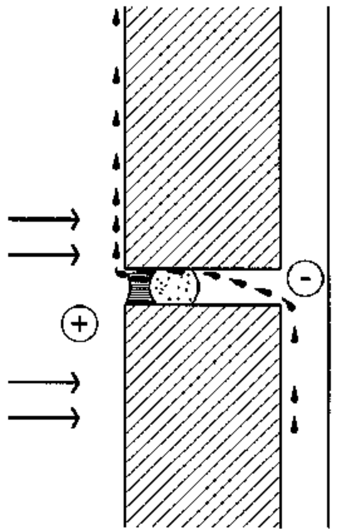
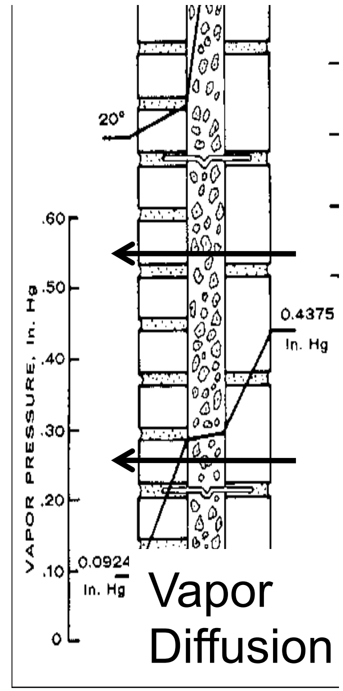
Moisture transport mechanisms

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



Air Leakage

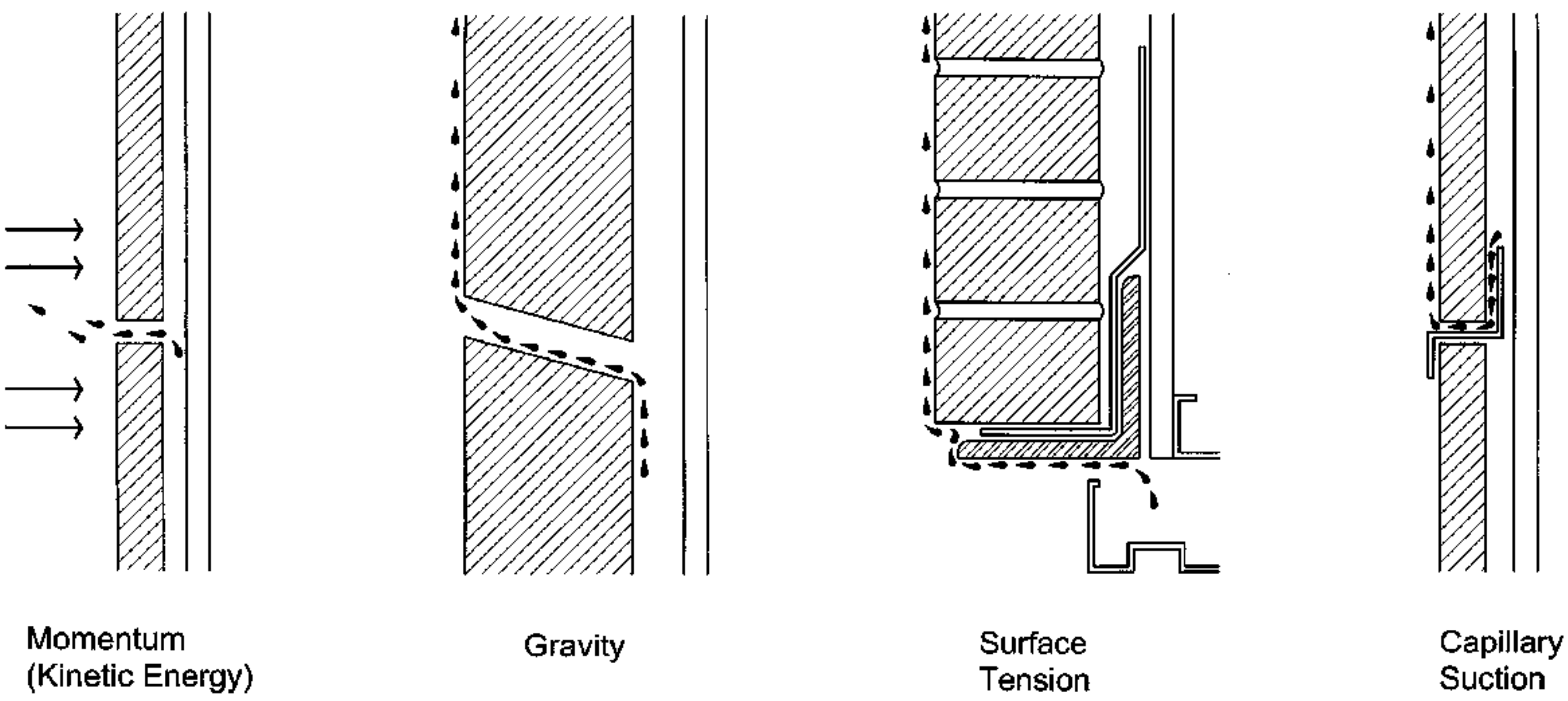


Vapor Diffusion

- 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 very difficult to control

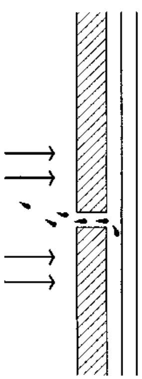
Condensed water (liquid) transport

- There are 4 main 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

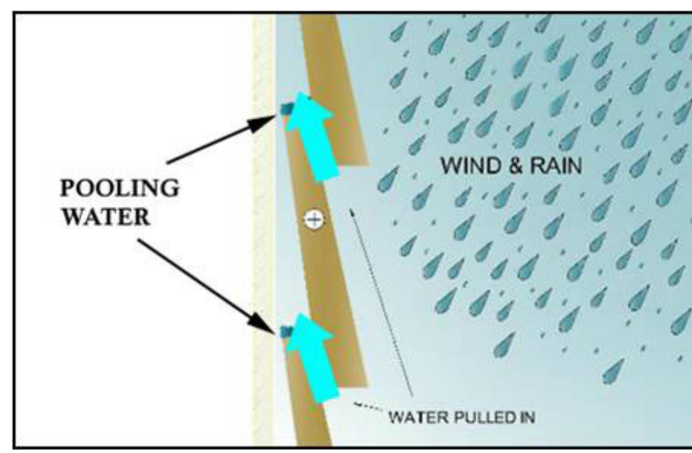
- Momentum of wind-driven raindrops
- Force will carry raindrops directly through openings of sufficient size
  - Recognize that rain doesn't fall straight down
  - Need to protect intentional openings from direct rain entry



Momentum (Kinetic Energy)

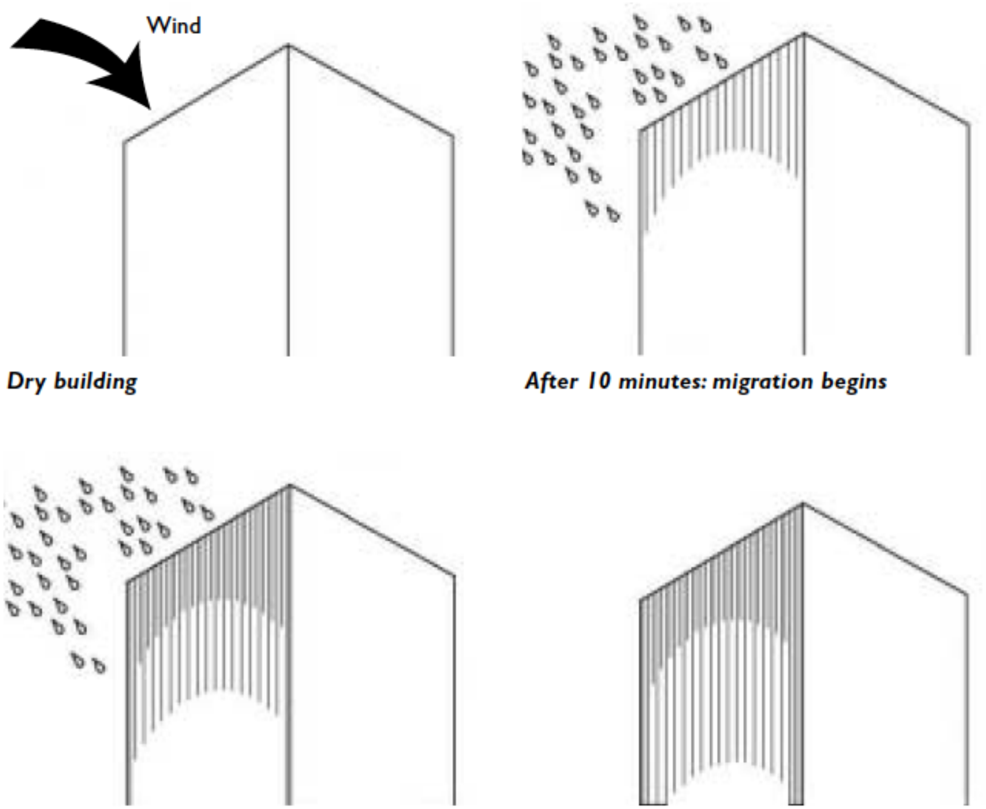
Pressure gradients (related to momentum driven rain)

- Air pressure differences across the building envelope can create suction
  - Draws water through available leakage paths
  - Air movement can also carry water droplets directly
- 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 can vary a lot within the same building



Pressure gradients acting on different parts of a building

- Wetting of a section of a tall building

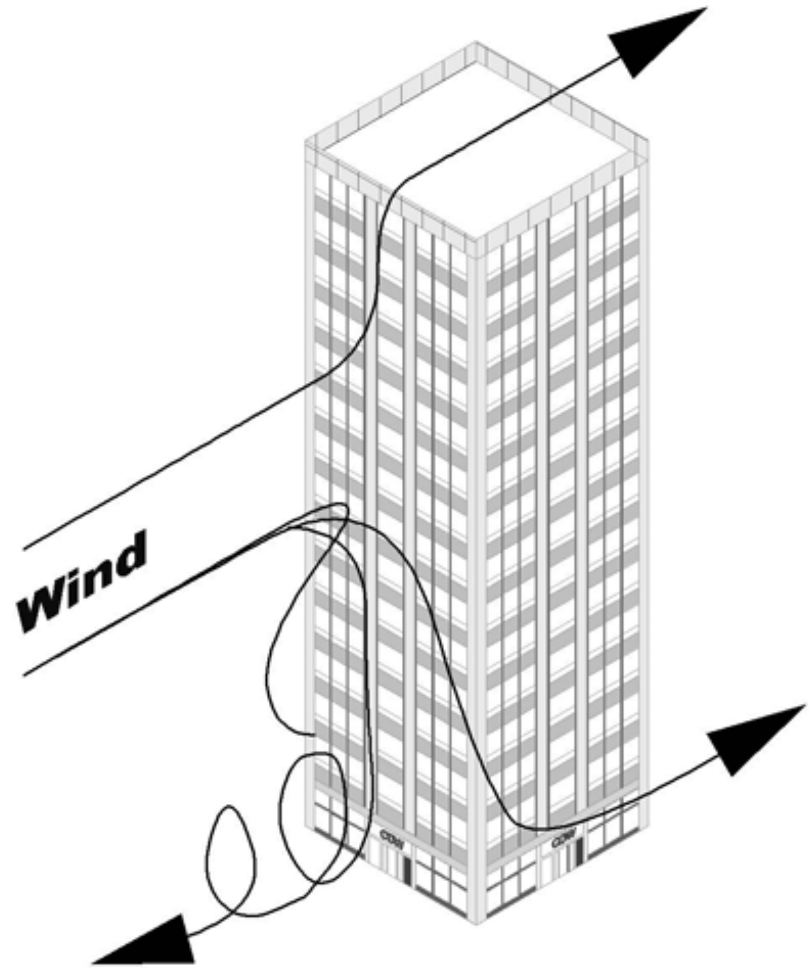


Dry building

After 10 minutes: migration begins

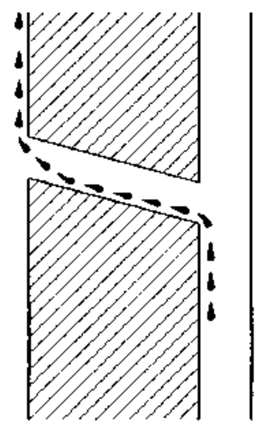
After 20 minutes: development of characteristic rain-wetting pattern

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



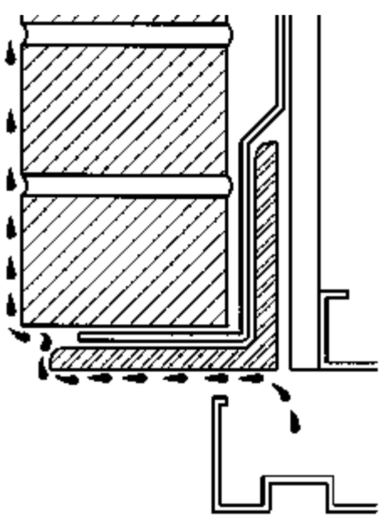
Gravity-driven water penetration

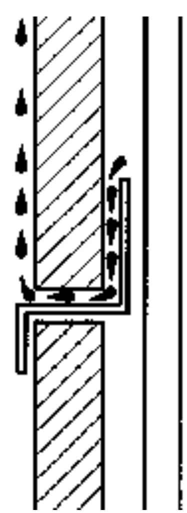
- Leakage due to gravity still occurs frequently in modern buildings
  – Particularly with near-horizontal or only moderately sloped building elements
- Gravity-driven water movement seems elementary to prevent
  – Problems can usually be traced to errors in the design or construction of elements
  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

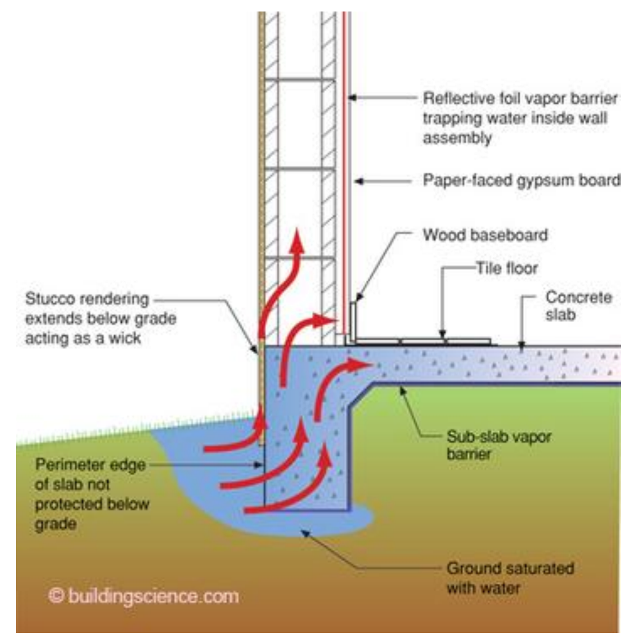


Capillary action and surface tension

- 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 action

- Capillary attraction
  - Occurs within porous bodies
  - Particularly when they are not saturated

- 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

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

m_l = liquid flux, $g/(s\text{-}\ m^2)$
k_m = water permeability, $g/(m^2\ s\ Pa)$

Capillary action

- Capillary suction in a tube

Units on surface tension:

$$1\ \frac{\text{dyn}}{\text{cm}} = 1\ \frac{\text{erg}}{\text{cm}^2} = 1\ \frac{\text{mN}}{\text{m}} = 0.001\ \frac{\text{N}}{\text{m}} = 0.001\ \frac{\text{J}}{\text{m}^2}$$

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

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

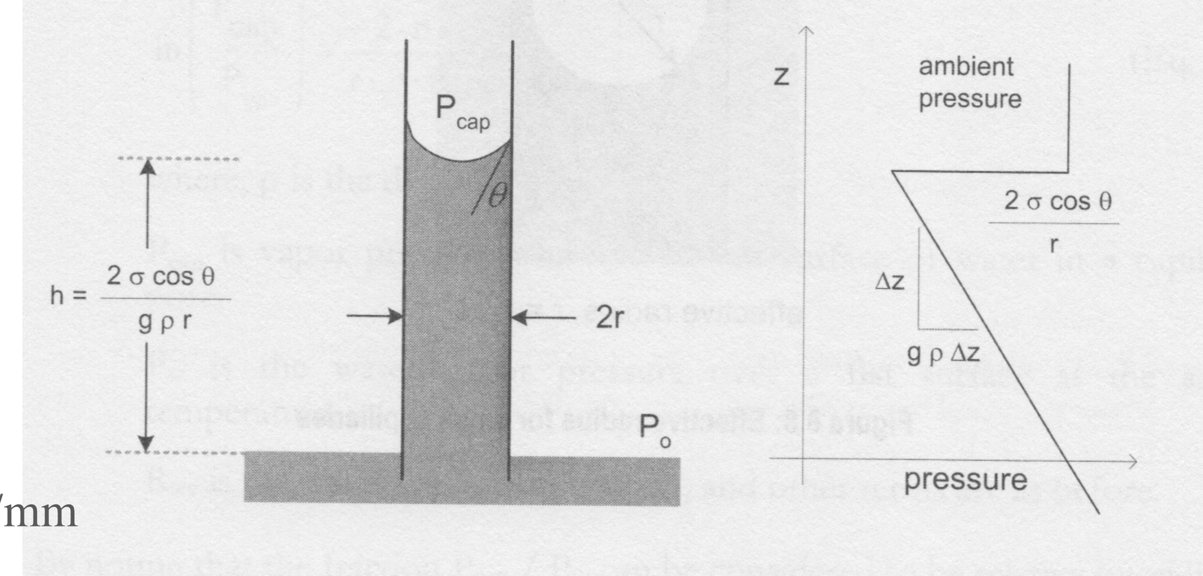
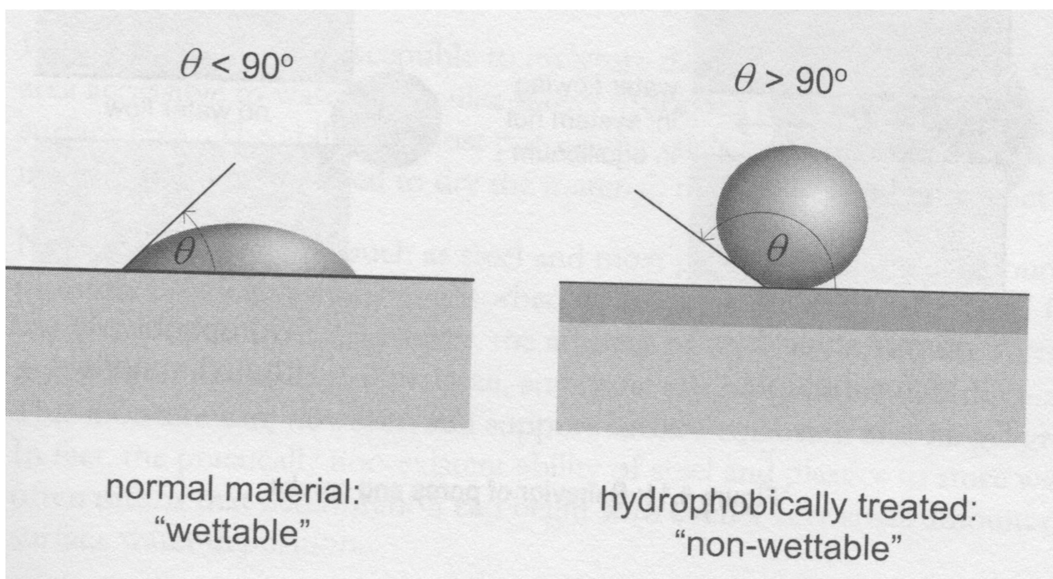


Figure 8.7: Capillary suction of water in a cylindrical tube

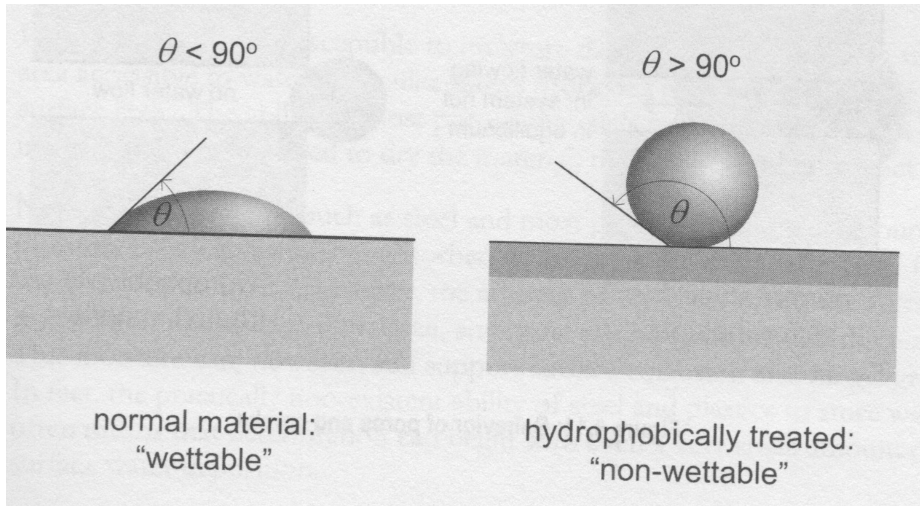
- The pressures involved with capillary suction in small pores (10-1000 nm) that make up a significant volume of concrete and wood generate large suction pressures (kPa to MPa)
  - Wicking water in small pores can be far greater than gravity forces or wind pressures

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”** 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

Examples of liquid water driven moisture damage

Figure 1-6 Blistering paint on split face concrete block. Wind-driven rain is the source of moisture contributing to the damage. Water wicks into the concrete masonry unit (CMU) through pin holes in the paint. The sun drives water vapor through the CMU. The assembly cannot dry to the interior because low-vapor-permeability foam board, taped at the joints, insulates the interior surface of the wall. The wall remains saturated throughout the spring, summer and fall. The same paint on areas of the wall sheltered from sun and rain shows no damage.

EPA **2013** Moisture Control Guidance for Building Design, Construction and Maintenance

Examples of liquid water driven moisture damage

Figure 1-8 Rainwater leaks in a rooftop parapet wall result in damaged plaster and peeling paint. Rainwater is drawn into this brick assembly by capillary action, and the moisture is aided in its downward migration by gravity. The peeling paint contains lead and results in an environmental hazard as well as physical damage to the plaster.

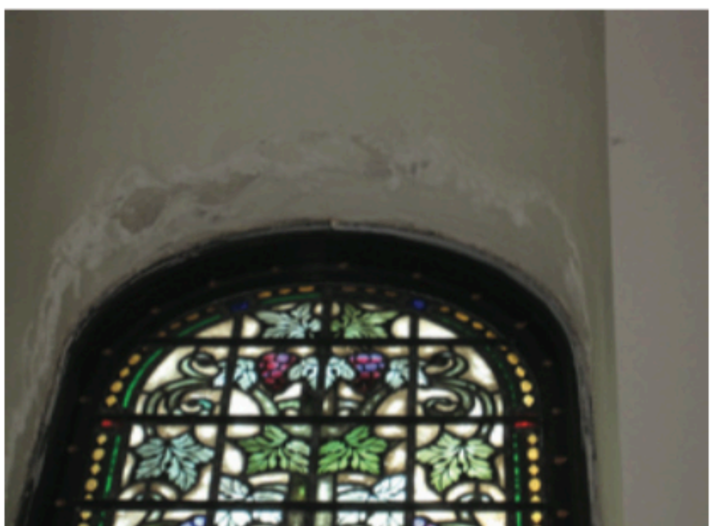


Figure 1-9 Interior plaster damaged by rain seeping around a window in a brick building. The inside of the exterior wall is insulated with closed-cell spray foam. Consequently, the wall cannot dry to the interior, so it retains excessive amounts of moisture. At the point where the plaster on the window return meets the brick wall, rainwater wicks into the plaster causing the damage seen in this photo.

EPA **2013** Moisture Control Guidance for Building Design, Construction and Maintenance

Examples of liquid water driven moisture damage

Figure 1-11 Gypsum board on the lower edge of a basement wall dissolved by seasonal flood waters. The water table is just below the basement floor during dry weather and rises several inches above the floor during heavy spring rains.

Figure 1-12 Hardwood gymnasium floor warped by moisture in the cavity below it. Water rises through the concrete sub-floor. The source of the moisture is rainwater that has not been drained away from the foundation of the building.

DEALING WITH WATER

Conceptually

Liquid water problems

- 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 a previous 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

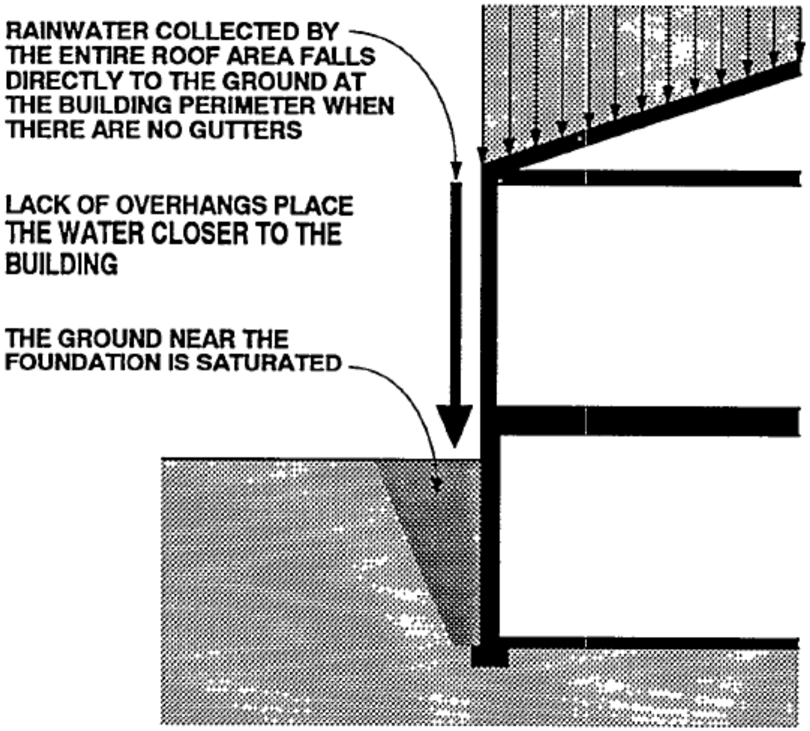


Figure 2-1A: Potential Surface Drainage Problems

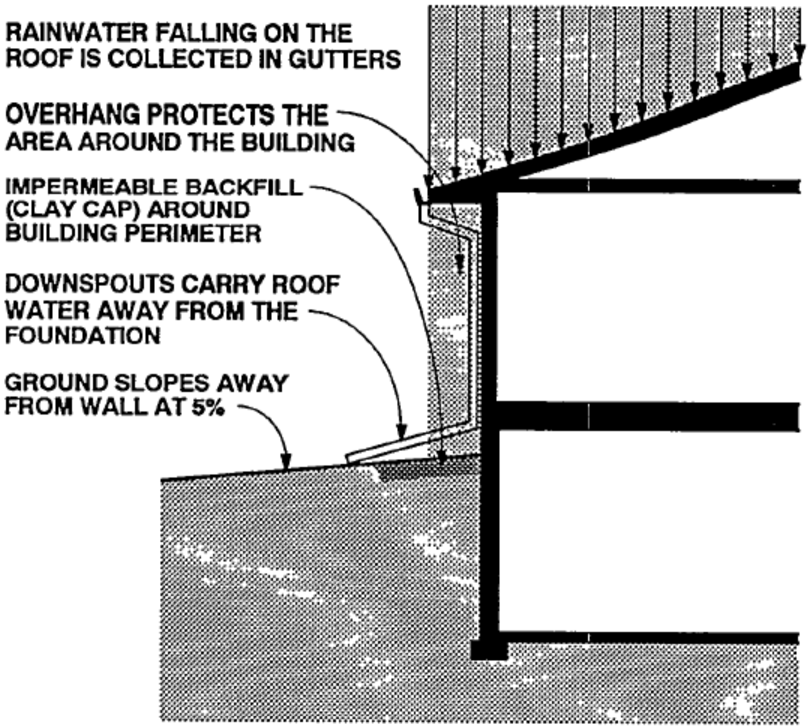


Figure 2-1B: Effective Surface Drainage Techniques

Good foundation design

Give water somewhere to go

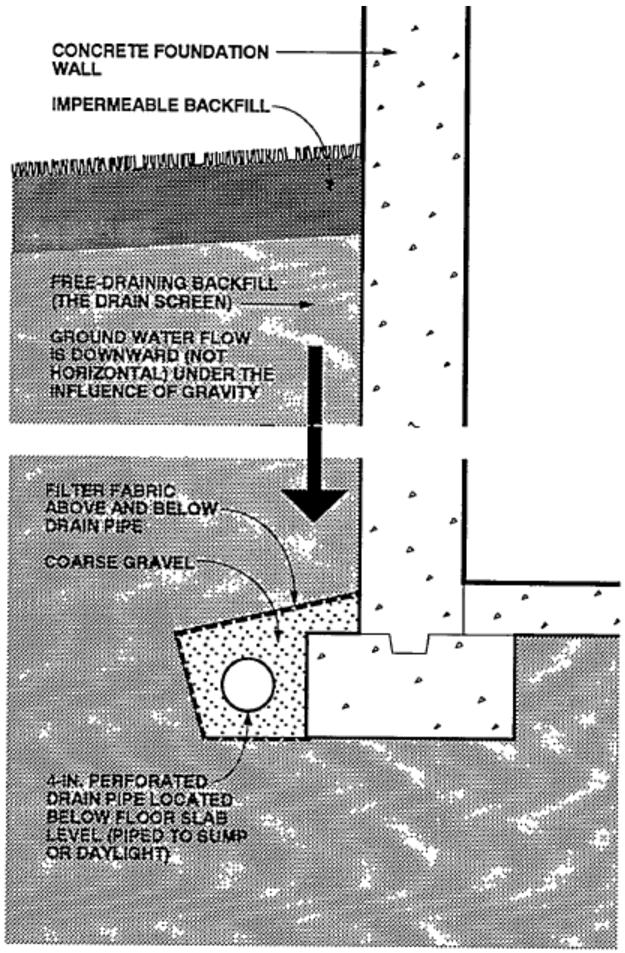


Figure 2-2: Drain Screen Concept Using Porous Backfill

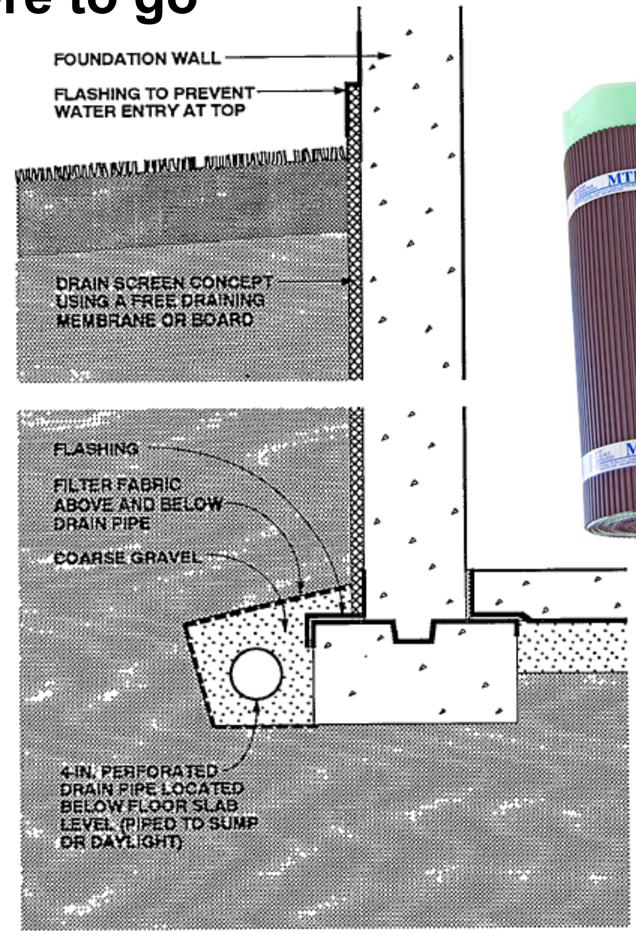


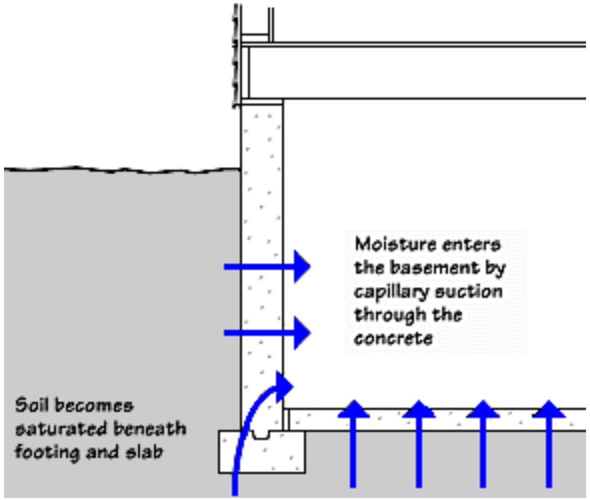
Figure 2-3: Drain Screen Concept Using a Free-Draining Board or Membrane

Porous backfill

Add a drainage plane

Capillary suction: Foundations

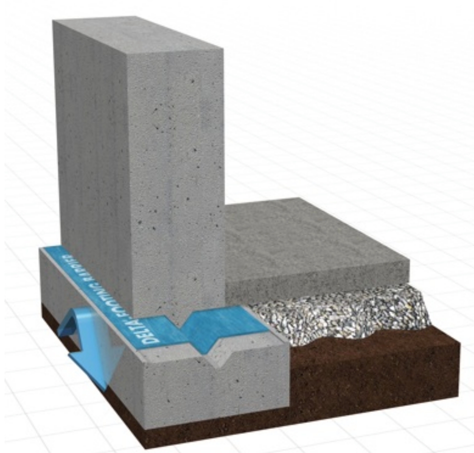
- Capillary suction draws water from saturated soil into the foundation and standing water through small cracks in brick, concrete and other materials
- To stop capillary suction we need to:
  - Keep moisture away from foundation
  - Seal pores or add barrier
  - Make pores larger or add separation plane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



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

Stopping capillary suction in foundations

- 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 Polyethylene sheet



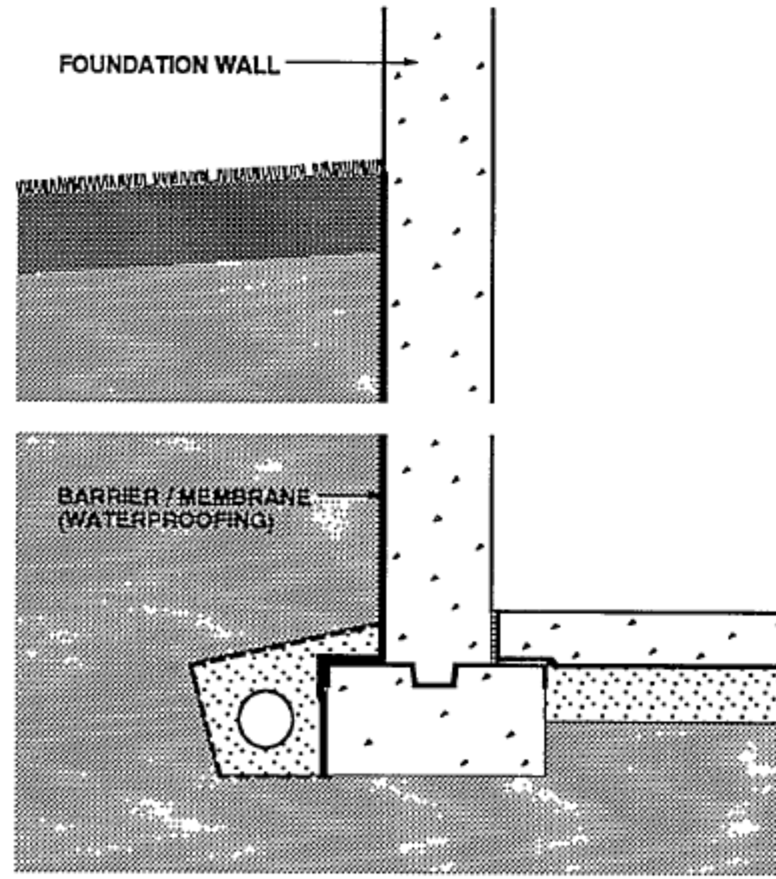
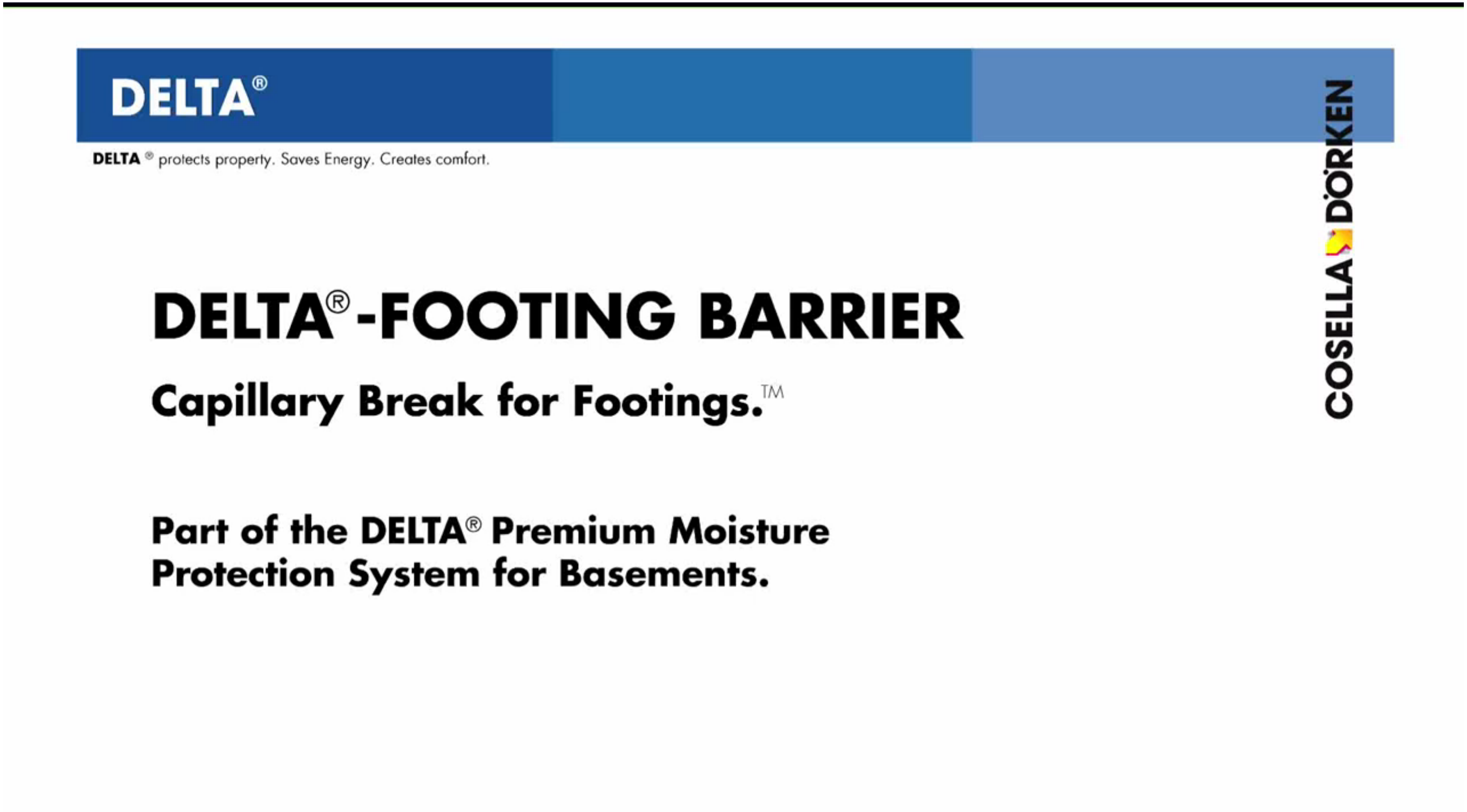


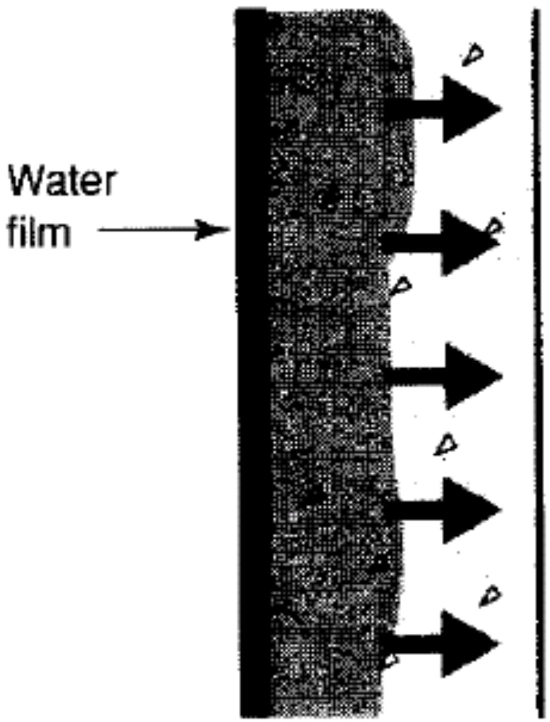
Figure 2-4: Barrier / Membrane Approach

Capillary break in foundation



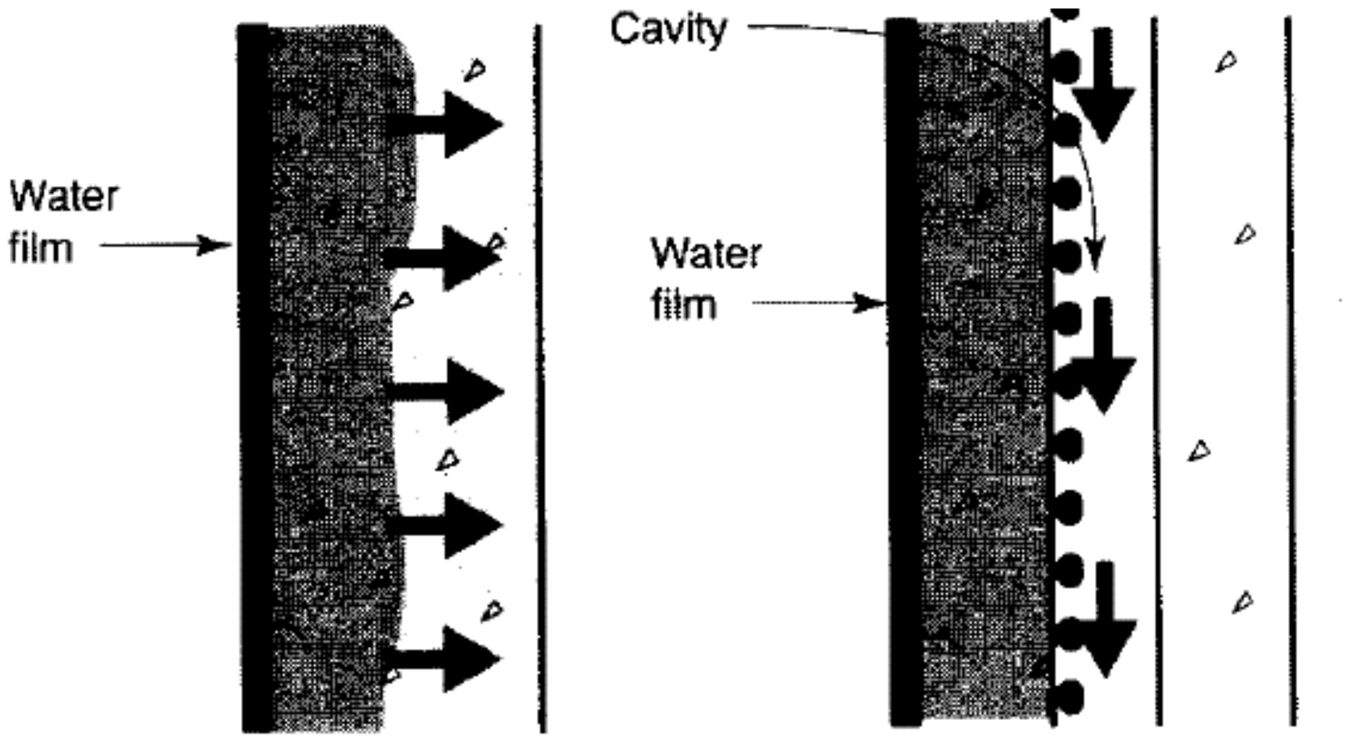
https://www.youtube.com/watch?v=wBhkI3sFfFA

Capillary suction (horizontal)



Capillary suction draws
water into porous material
and tiny cracks

Solution to capillary suction water movement

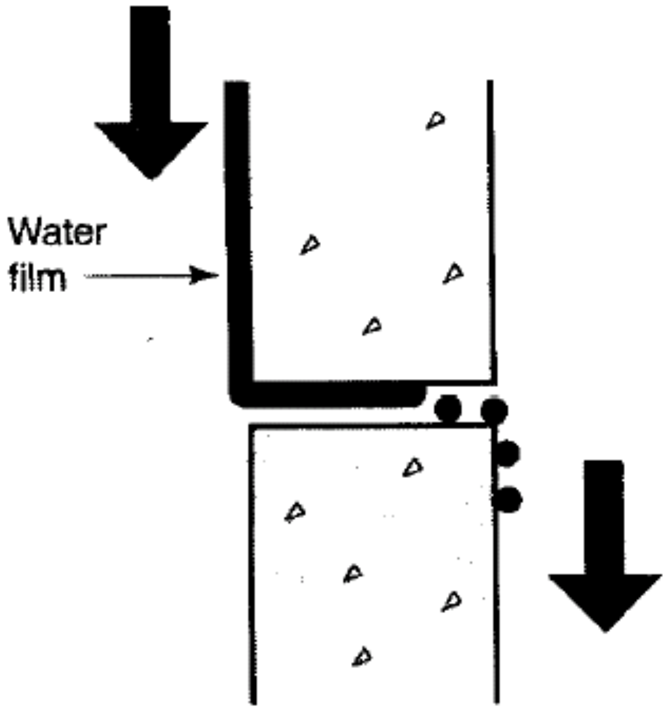


Capillary suction draws water into porous material and tiny cracks

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

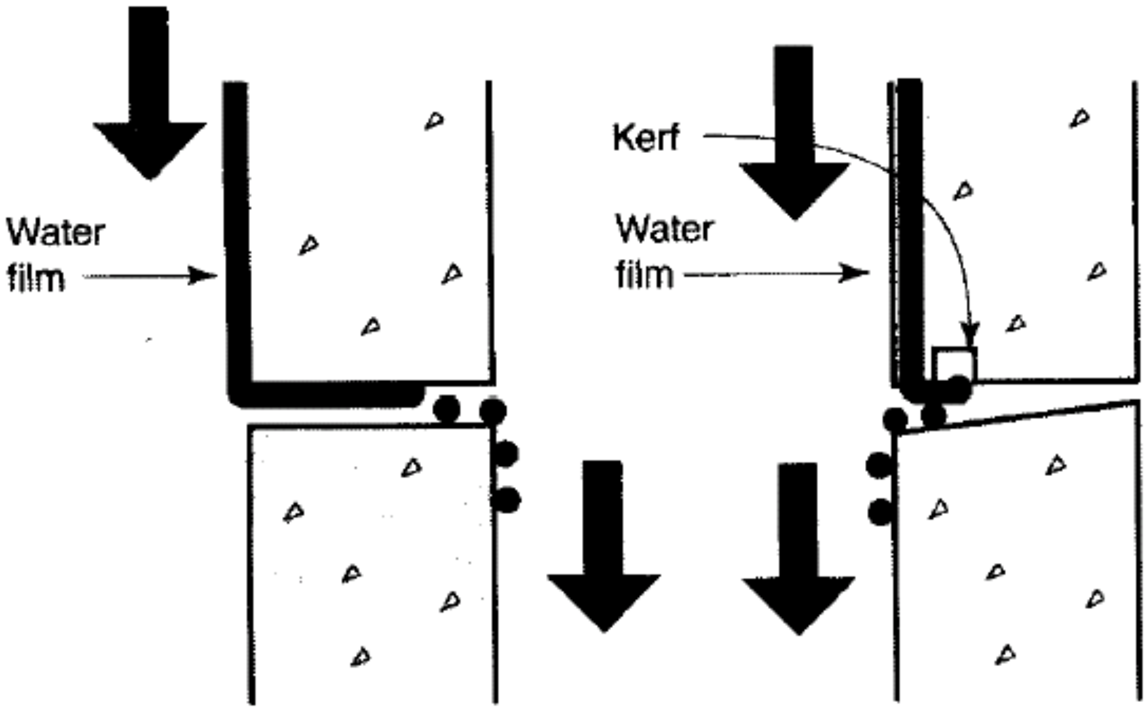
Add an air cavity

Surface tension



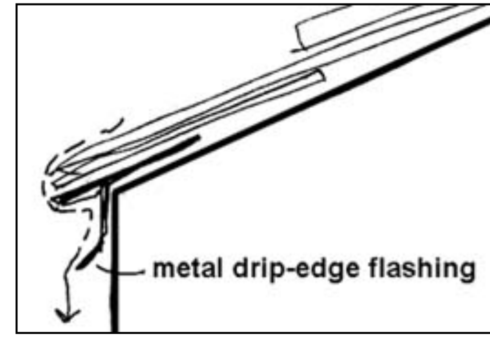
Rainwater can flow around a surface as a result of surface tension

Solution to surface tension water movement



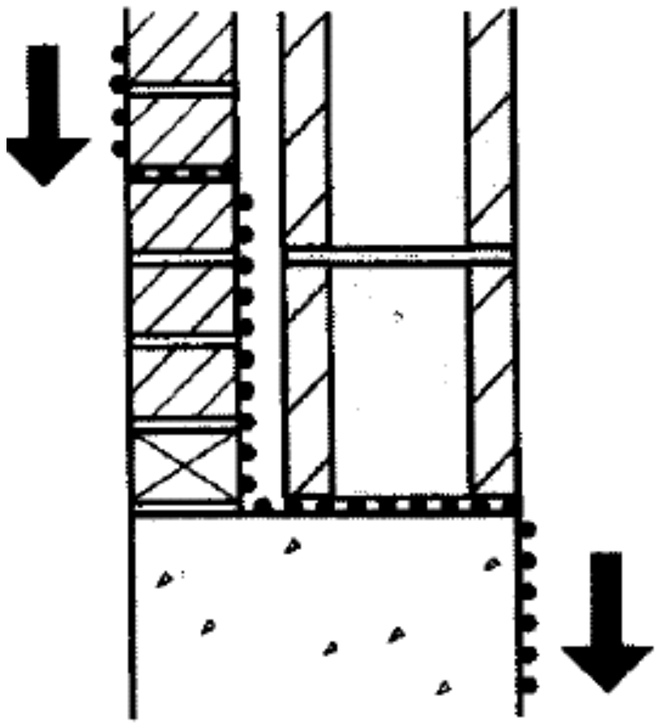
Rainwater can flow around a surface as a result of surface tension

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



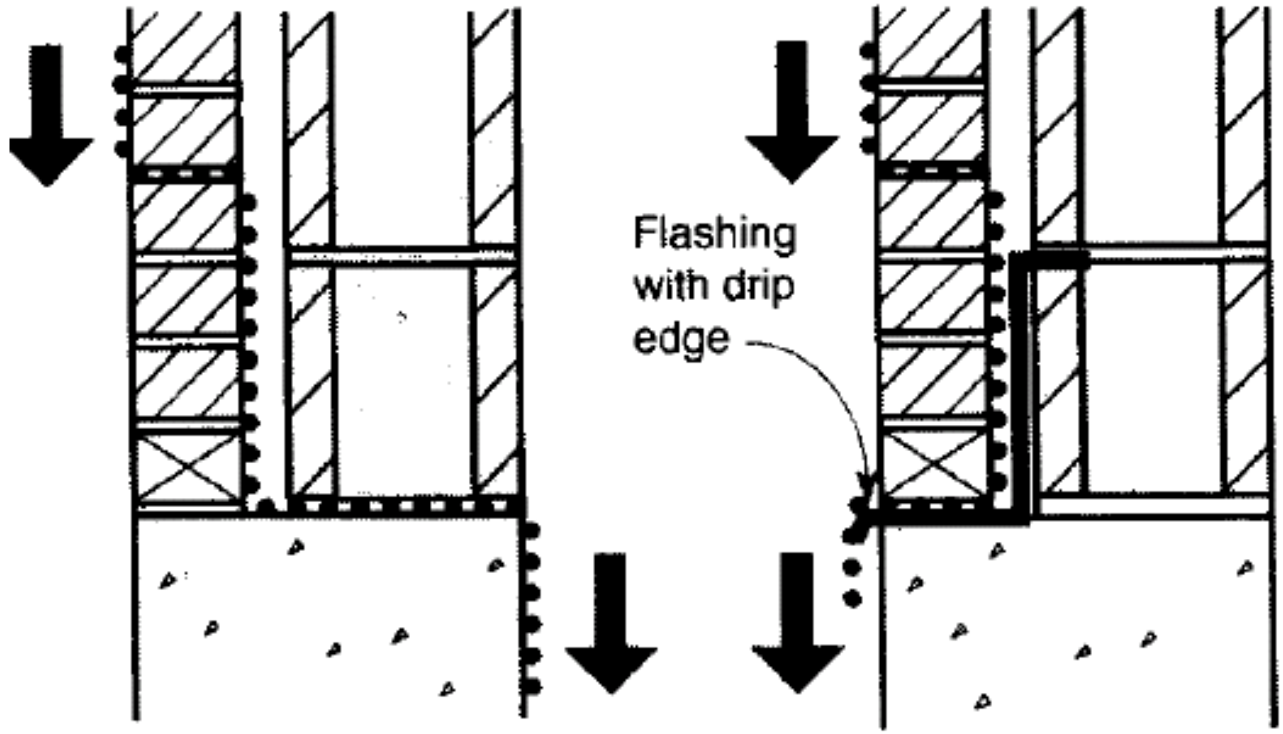
Provide a kerf or drip edge

Gravity



Rainwater can flow down surfaces and enter through openings and cavaties

Solution to gravity-driven water movement

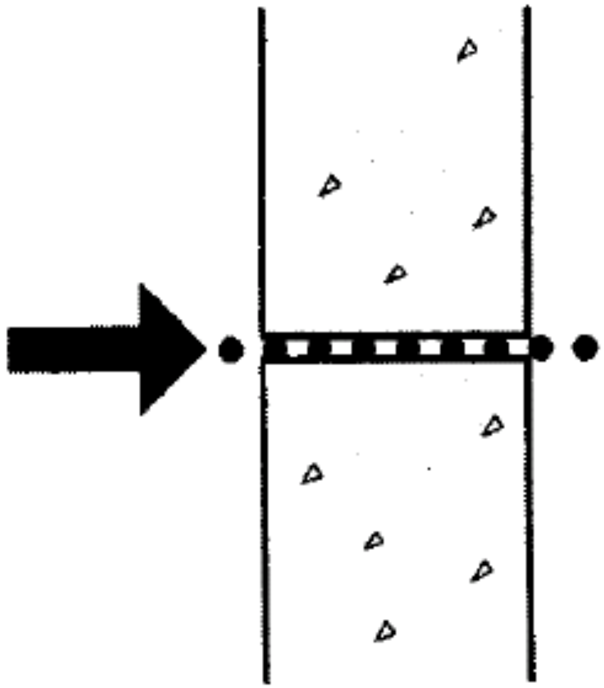


Rainwater can flow down surfaces and enter through openings and cavaties

Flashings direct gravity flow rainwater back toward the exterior

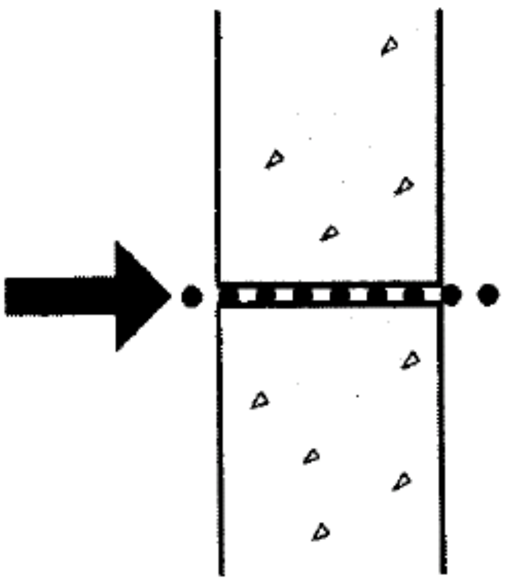
Flashing, flashing, flashing

Rain droplet momentum

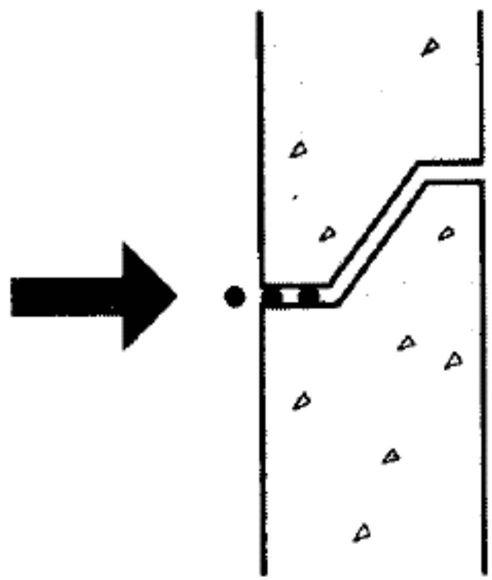


Rain droplets can be carried through a wall by their own momentum

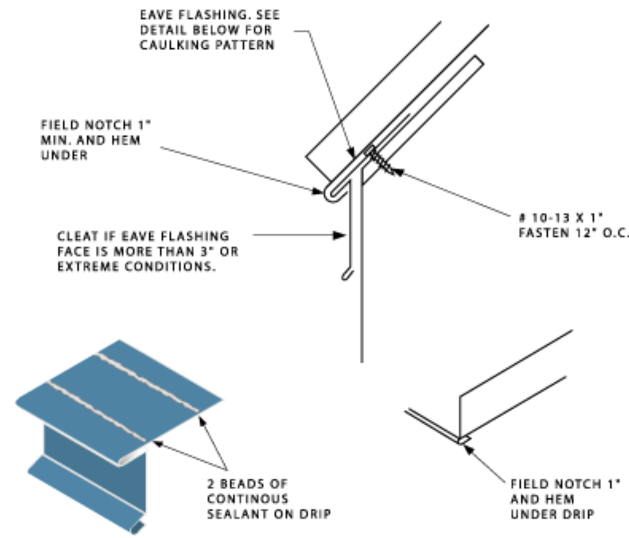
Solution to droplet momentum problems



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



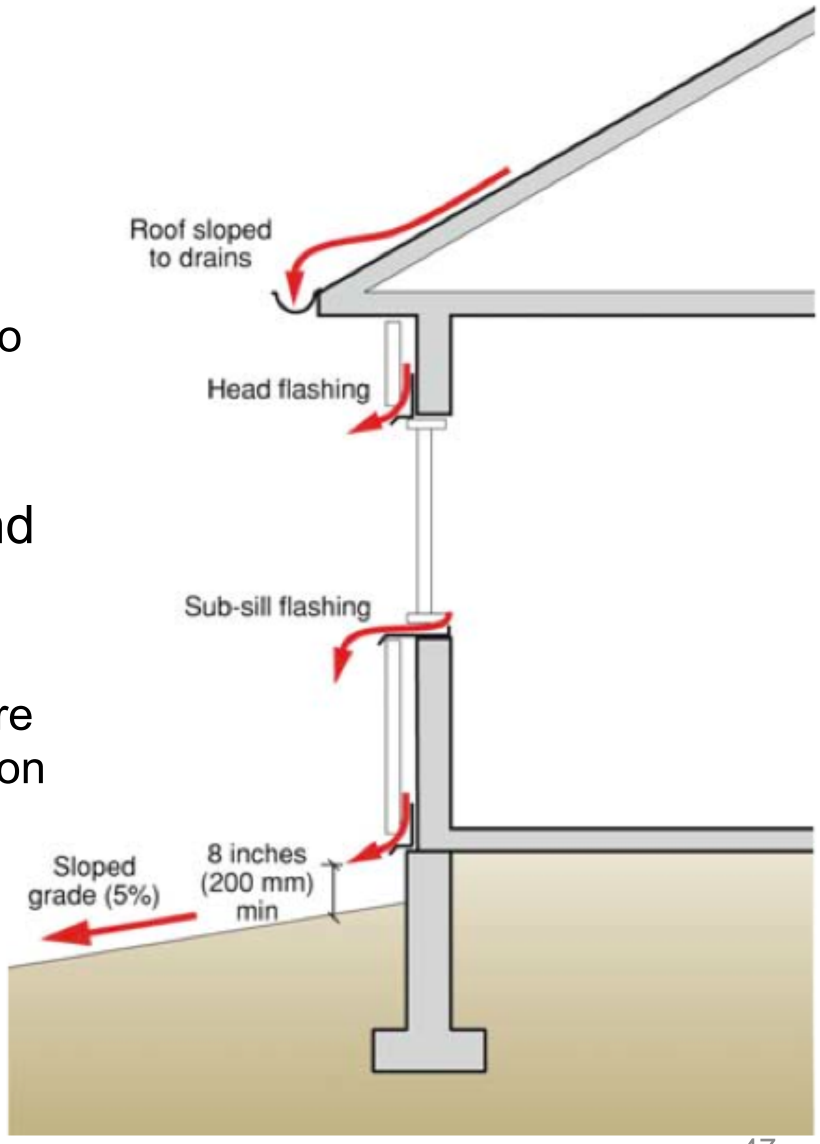
Rain entry by momentum can be prevented by designing wall systems with no straight through openings



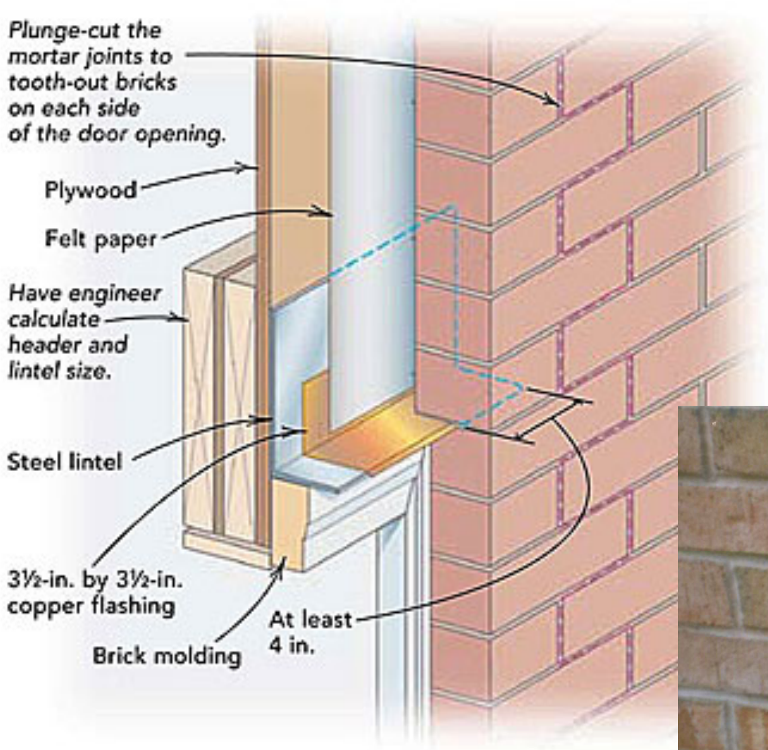
Also reduces gravity transport

Flashing: Extremely important architectural detail

- When we have liquid water, we must deal with it!
  - Major solution: **flashing**
- Flashing design is as much art as science
  - Good detailed construction documents need to be created and built as drawn
- ASTM E2112 Standard Practice for the Installation of Exterior Windows, Doors, and Skylights
  - Describes the proper flashing design, building wrap installation and sealing required to ensure watertight window, door, and skylight installation
- 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



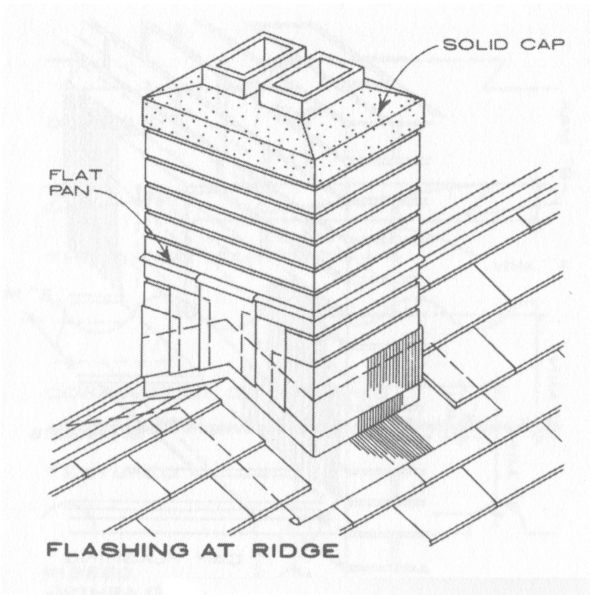
<u>Flashing</u>: Extremely important architectural detail

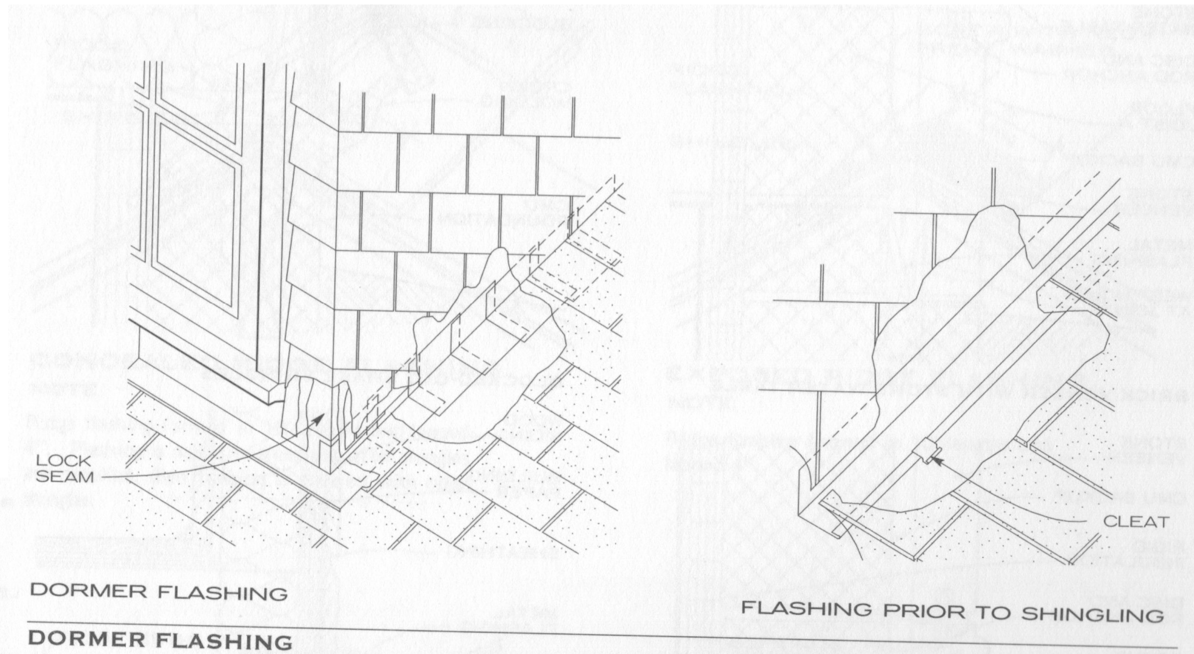


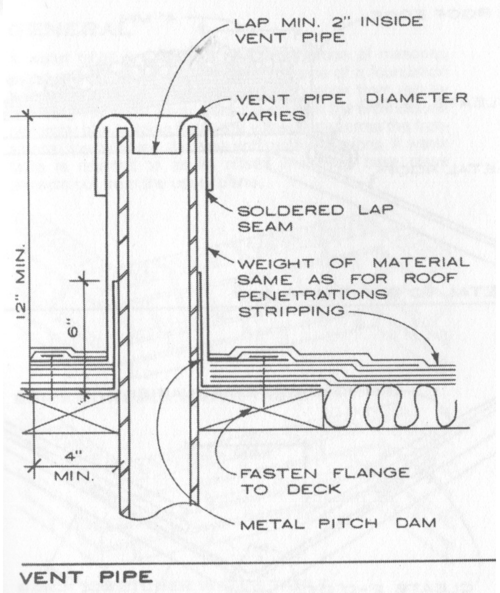
AIA provides good standard graphic details for flashing in residential construction

- Make sure your architect follows these!

Flashing details: roofs

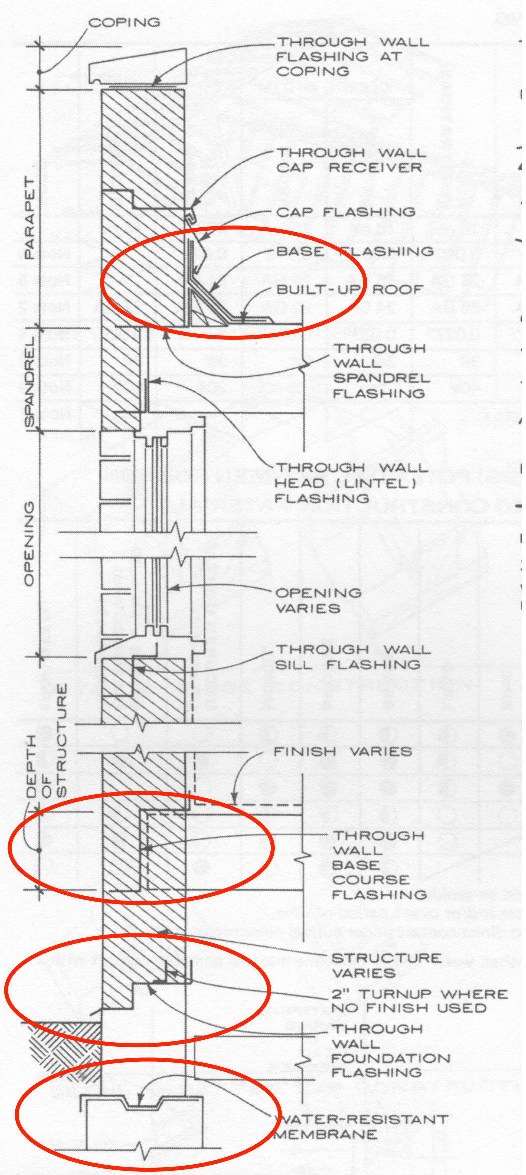




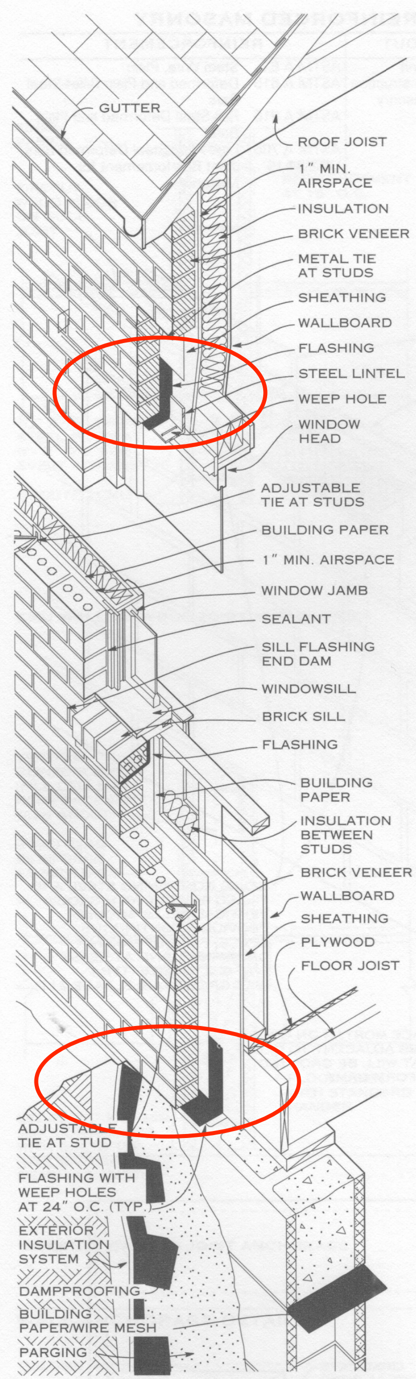


- Install prior to shingles
- Overlap in the correct direction for drainage

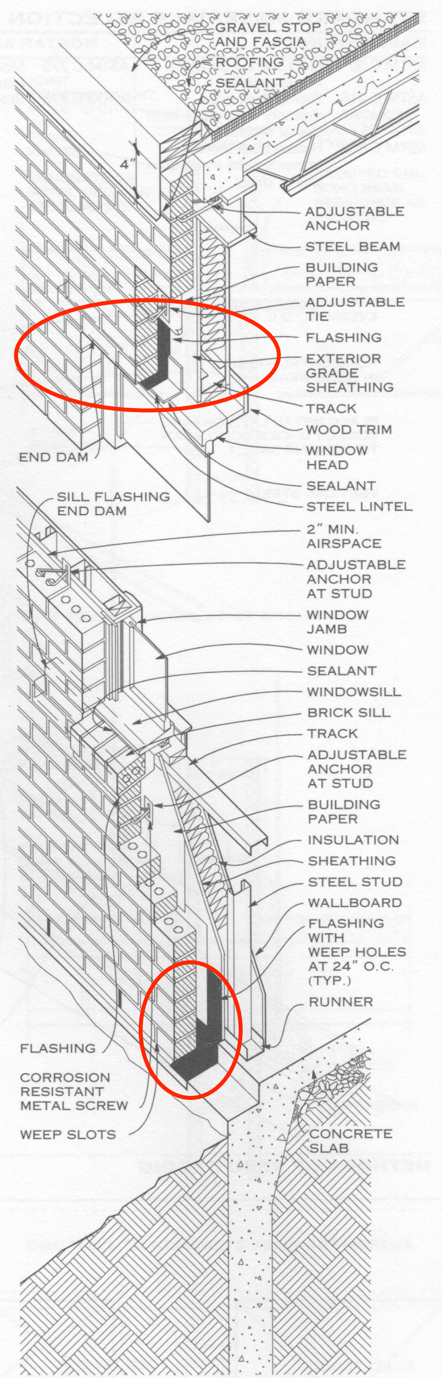
Flashing details: walls



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

CONDITIONS / MATERIALS	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#	2 1/2#	2 1/2#	2 1/2#	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.

Flashing: An application of water barriers

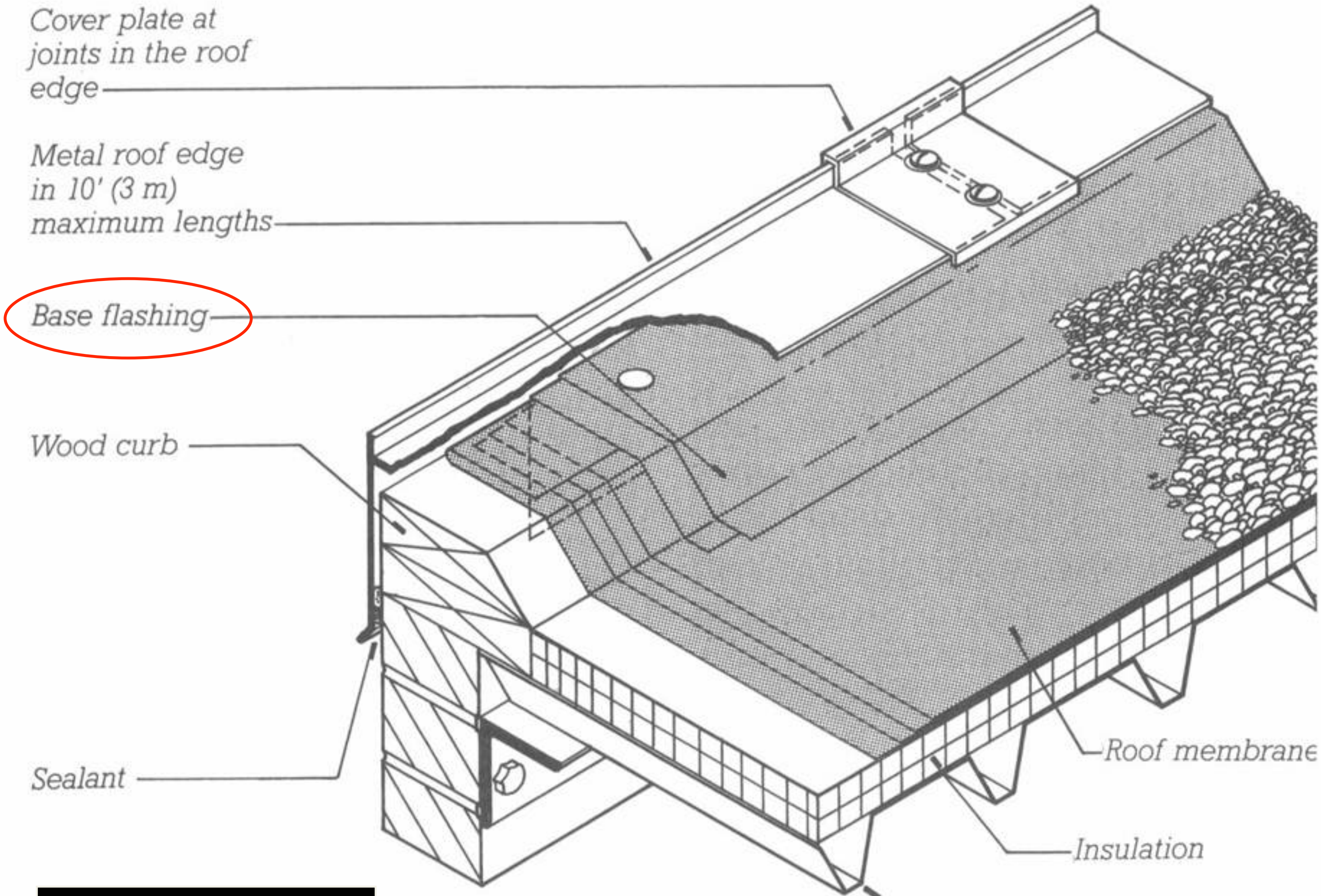
- A **water barrier** is a material that does not transport condensed water
  - It may allow air diffusion or vapor diffusion
  - It may not be completely sealed which allows direct and indirect air infiltration
- It is placed on the outside of a building to keep rainwater off the building wall components
- A water barrier need not be an air barrier or a vapor barrier
  - Shingles and building felt are good water barriers but poor air and vapor barriers

Flashing and joints on roofs

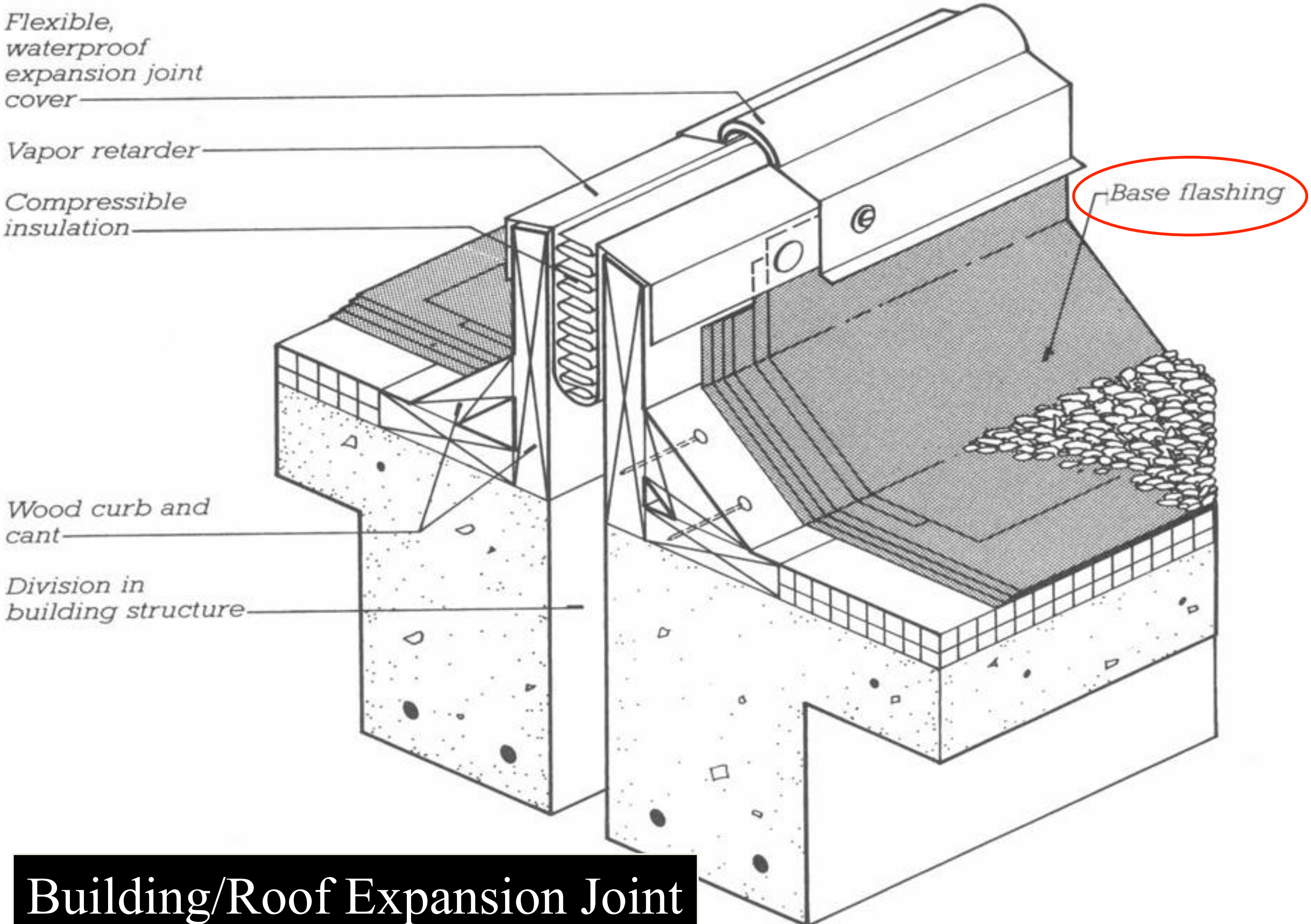
- Flashing is needed to maintain seals
  - Building edges and parapets
  - Expansion joints
  - Over top of cavity walls
  - Around drains
  - Around vents

- Usually metals or plastics over which membrane is fastened

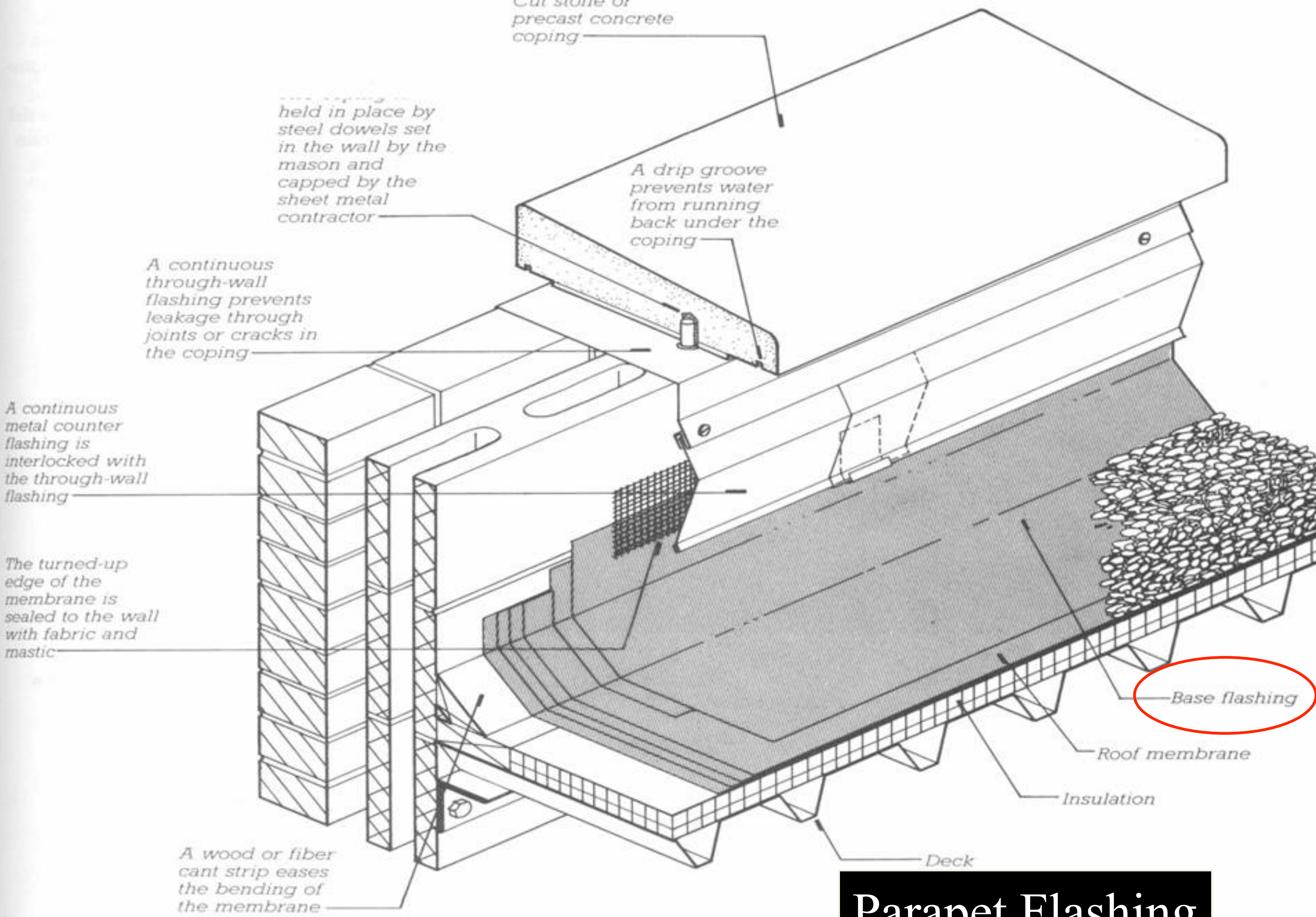
- Proper flashing is **absolutely essential** to avoid roof leaks



Edge Flashing



Building/Roof Expansion Joint



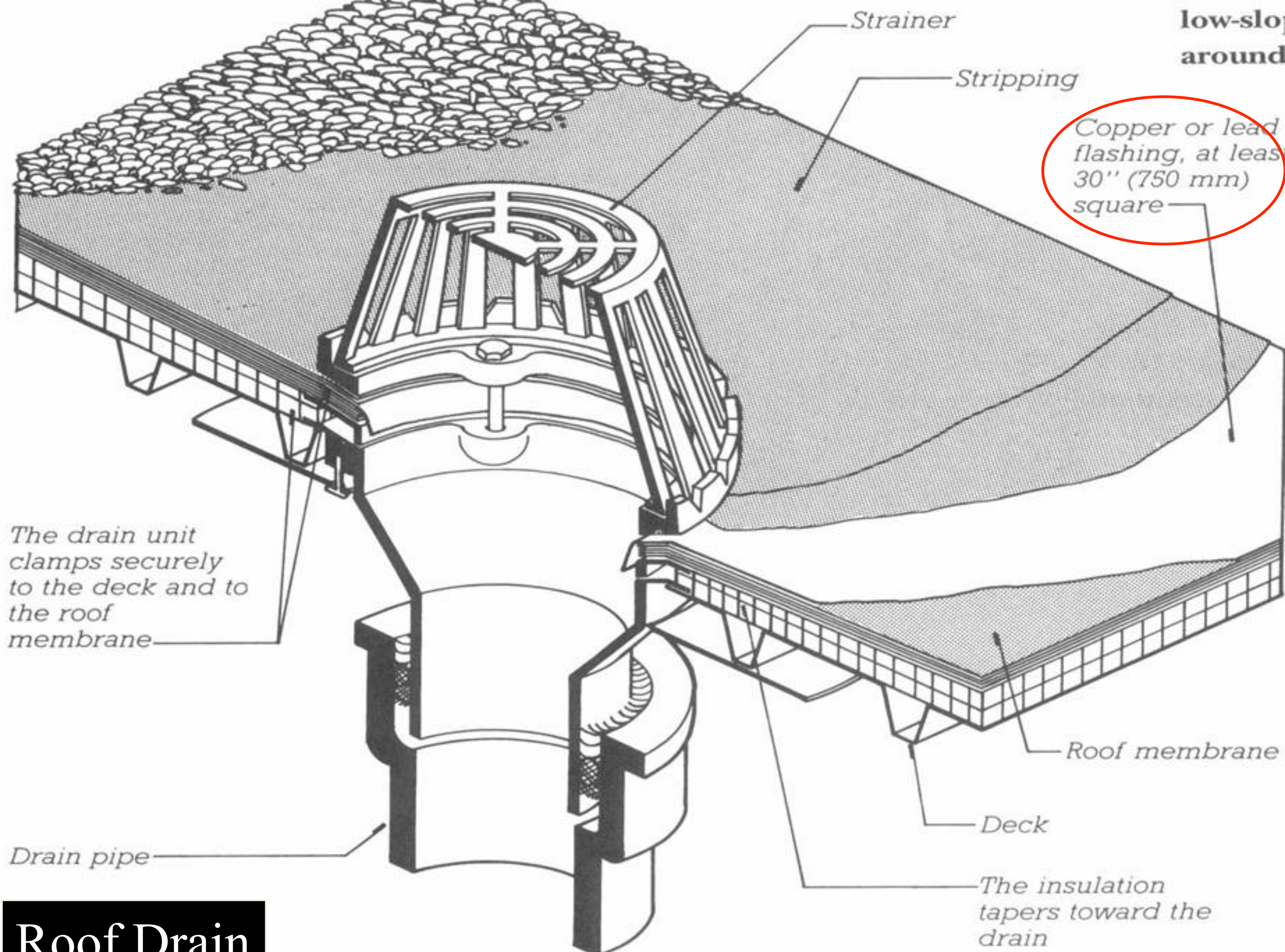
Parapet Flashing

FIGURE 16.30
A conventional parapet design.

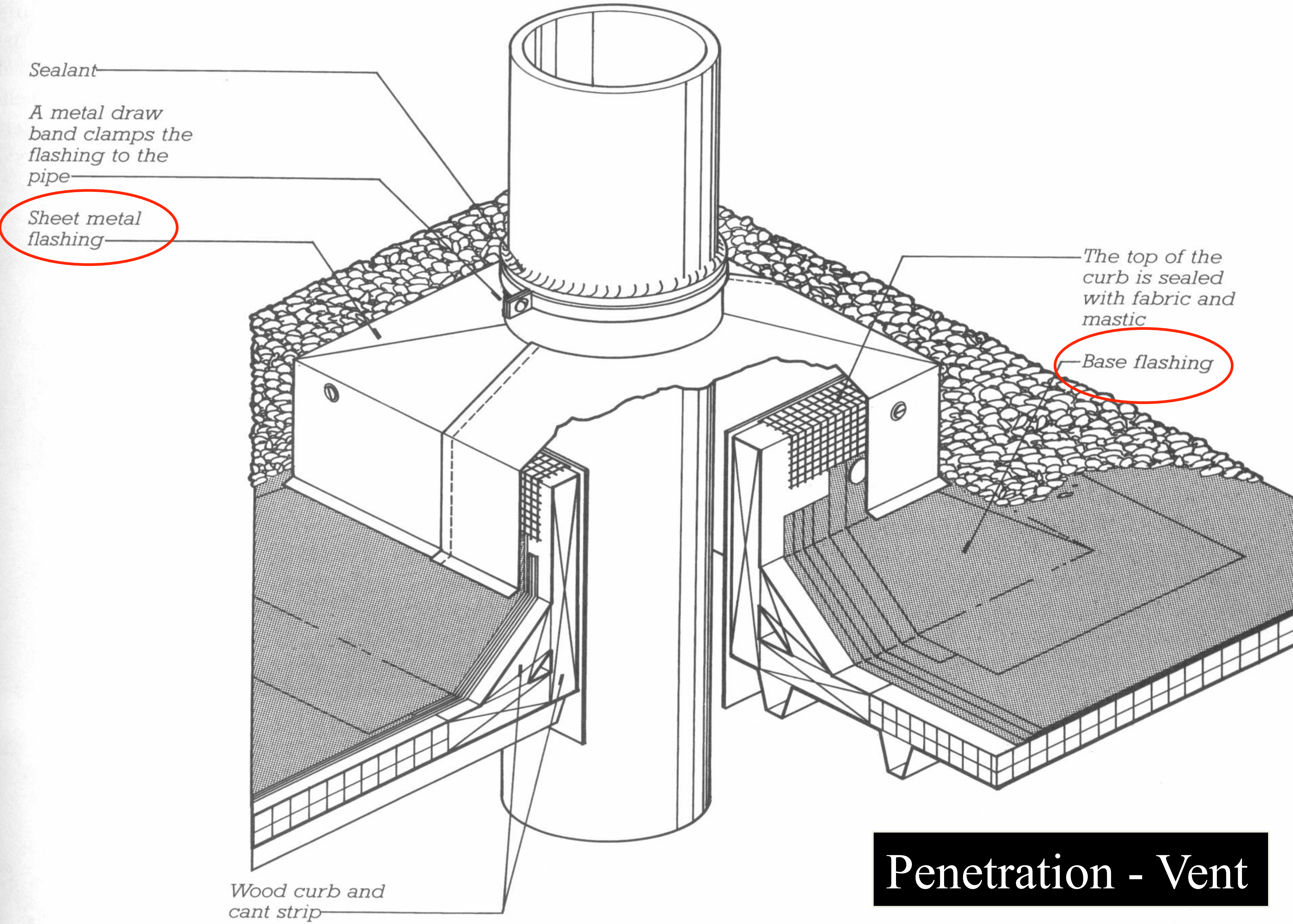
Roof drainage

- Drains need to be at low points of roofs to avoid water ponding
  - Drains near columns are at high points since there is no deflection

- Smaller and closer spaced drains preferred to larger but fewer


Strainer
low-slo
around
Stripping
Copper or lead
flashing, at leas
30'' (750 mm)
square
The drain unit
clamps securely
to the deck and to
the roof
membrane
Roof membrane
Deck
Drain pipe
The insulation
tapers toward the
drain

Roof Drain

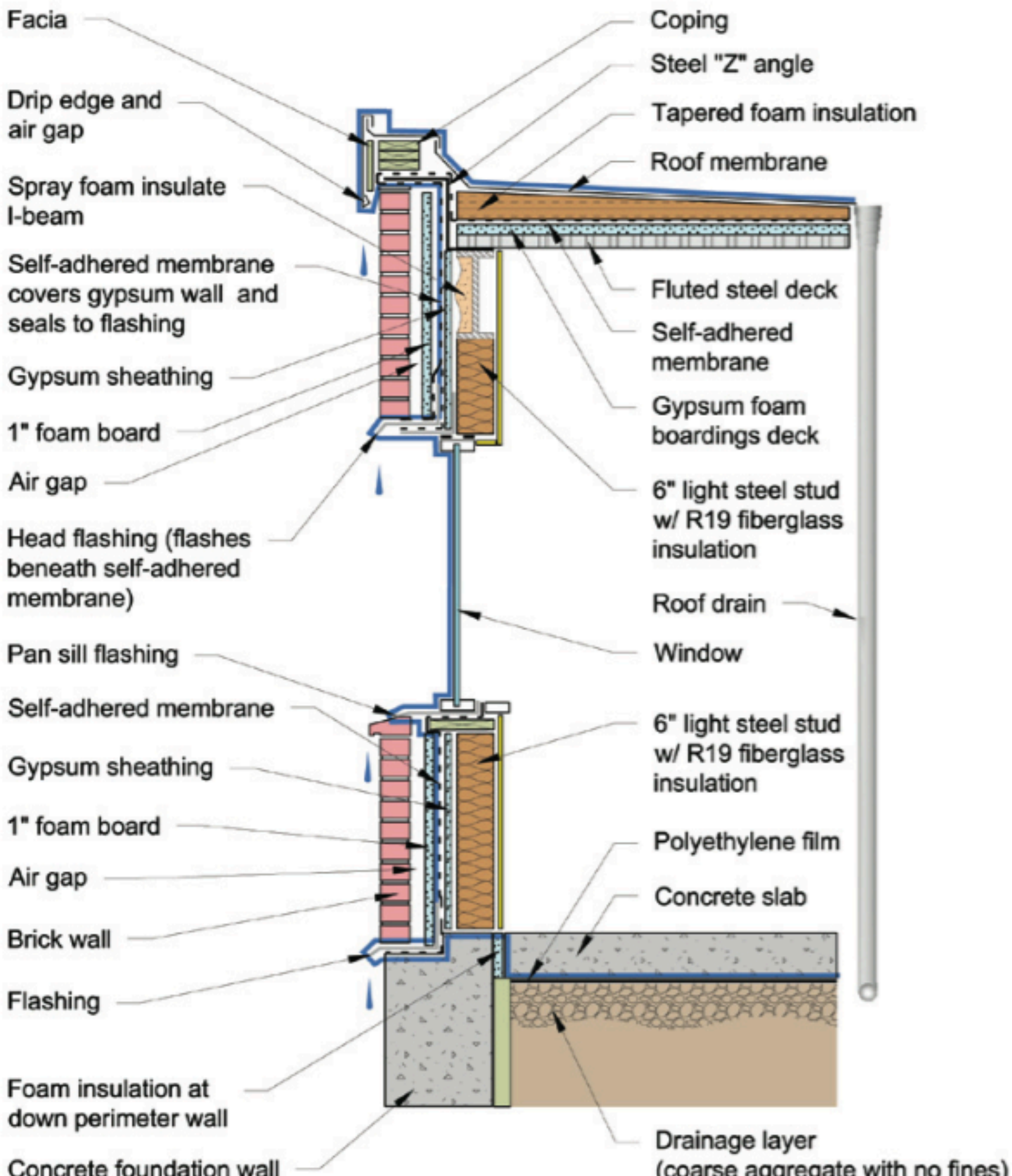


Penetration - Vent

The “pen test”

- We can use the “pen test” to trace the continuity of all materials for moisture control
  - Thermal and air barrier layers too

- Steps:
  - Place a pen on a material that forms a capillary break between the rain-control materials that get wet and the inner portion of the enclosure that must stay dry
  - Without lifting the pen off the paper, trace from the center of the roof around the walls, windows, and doors and along the foundation to the center of the foundation floor



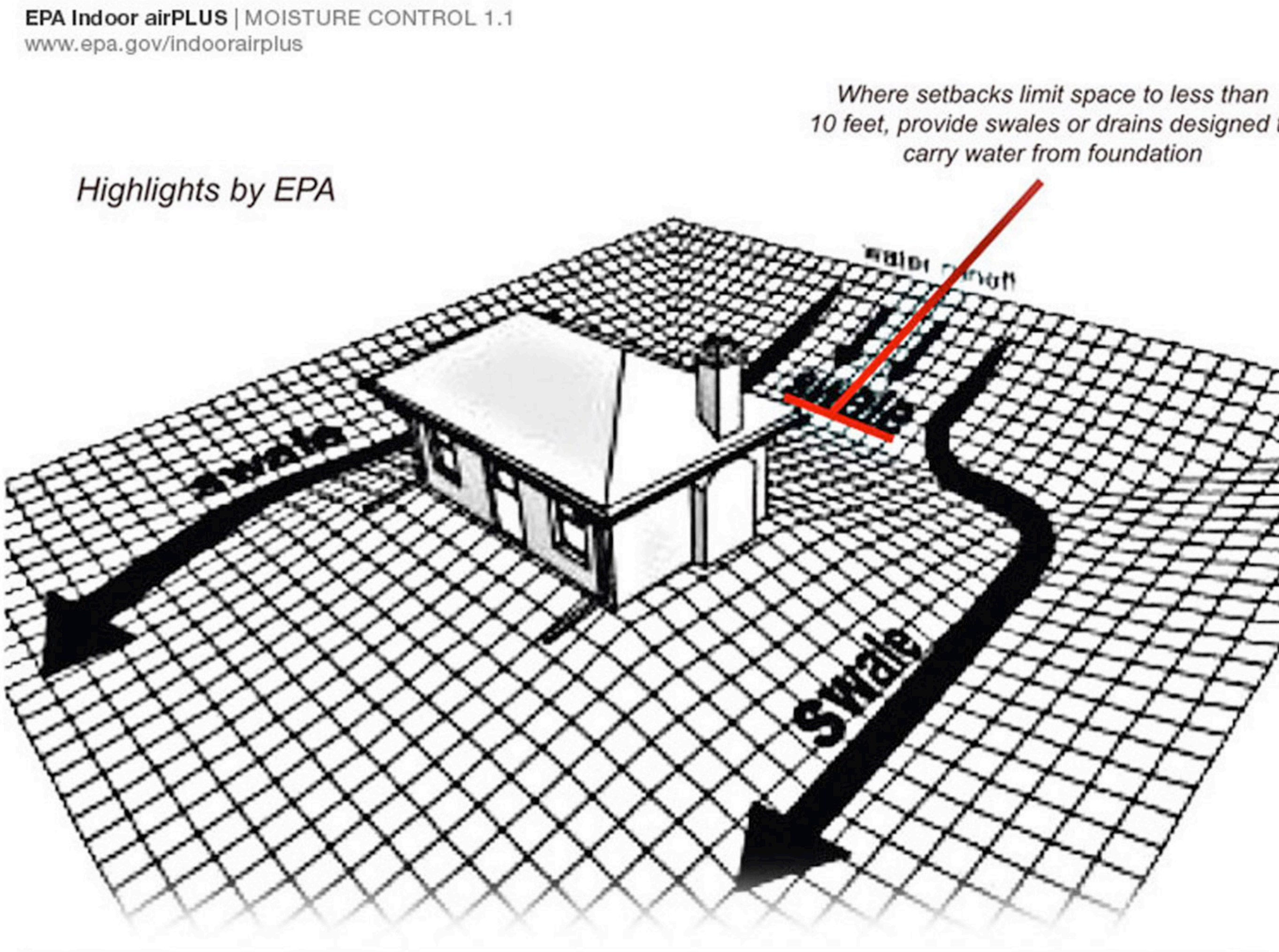
- The roofing membrane separates wet materials from the inner dry materials.
- Tracing to the edge of the roof, the roofing membrane flashes beneath a metal coping, this in turn flashes to a metal fascia.
- The fascia forms a drip edge, channeling water away from the cladding.
- An air gap between the drip edge and the brick veneer forms a capillary break protecting the materials beneath the metal coping from rainwater wicking from below.
- An air gap and water-resistant barrier behind the brick veneer form a capillary break between the damp brick and the inner walls.
- The water-resistant barrier shingles over a head flashing, protecting the window from rainwater with a drip edge and air gap.
- The window frame, sash and glazing form a capillary break system that sits in a pan sill flashing at the bottom of the rough opening.
- The pan sill flashing forms a capillary break protecting the wall beneath from seepage through the window system.
- The pan sill flashing shingles over the water-resistant barrier in the wall beneath.
- The water-resistant barrier shingles over a flashing that protects the bottom of the wall system where:
  - The foam sill seal makes a capillary break between the foundation and the bottom of the framed wall, connecting with:
    - One inch of extruded styrene foam insulation making a capillary break between the top of the foundation wall and the edge of the floor slab.
  - Polyethylene film immediately beneath the slab forms a capillary break between the bottom of the slab and the fill below. NOTE: If the bed of

EPA **2013** Moisture Control Guidance for Building Design, Construction and Maintenance

DEALING WITH WATER

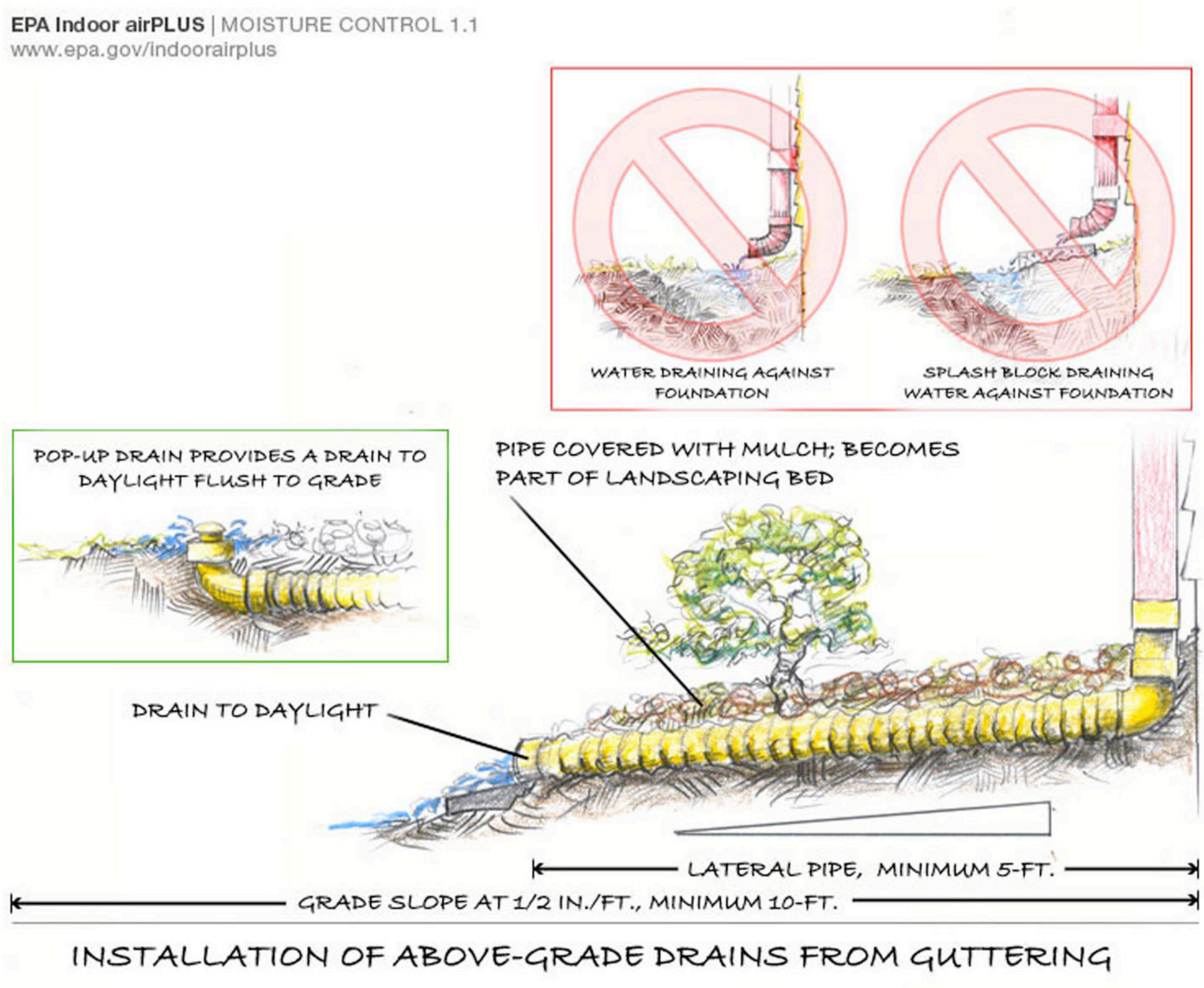
w/ drawings from US EPA Indoor Air Plus program guidelines

Site drainage

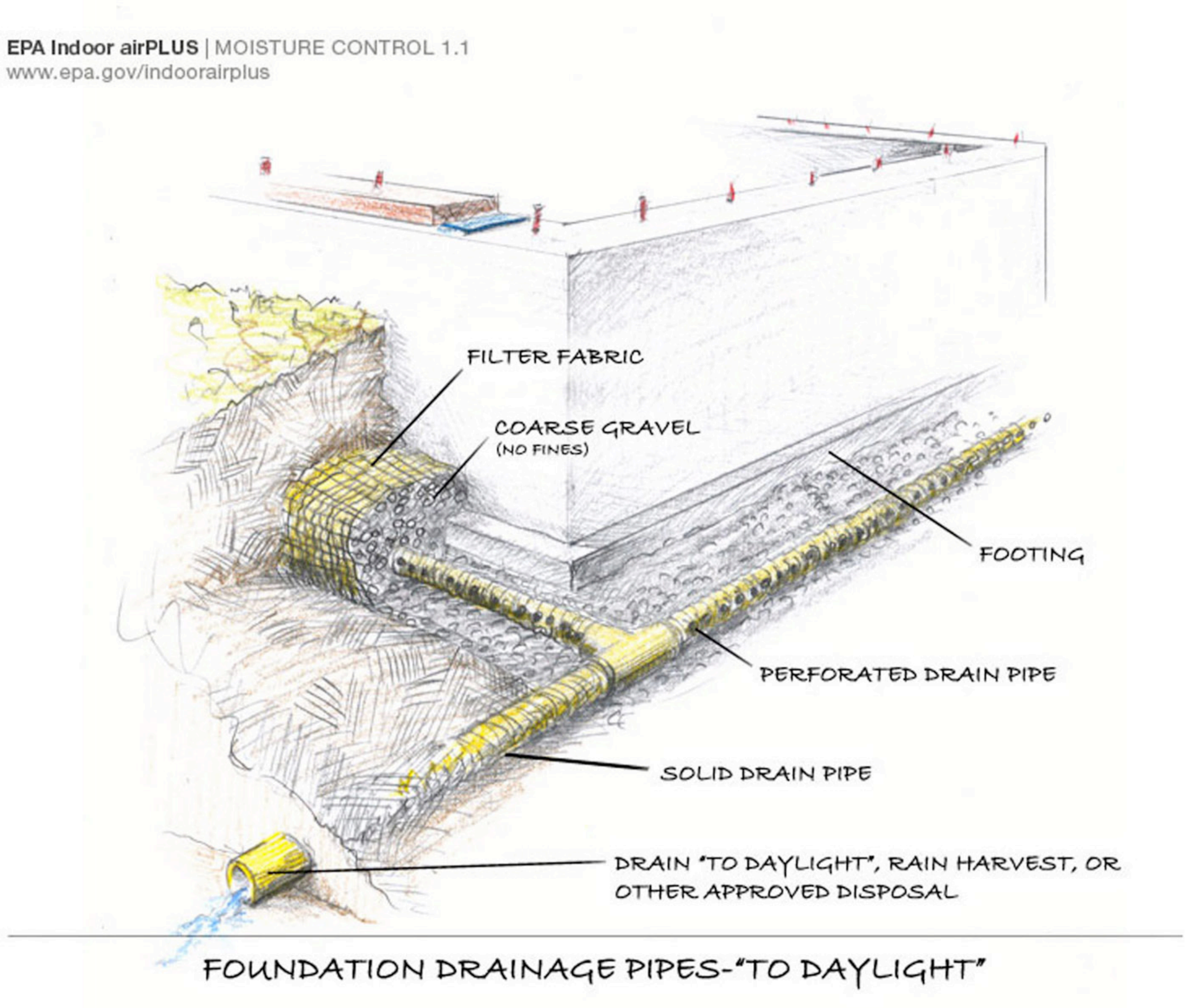


BUILDING SITE DRAINAGE

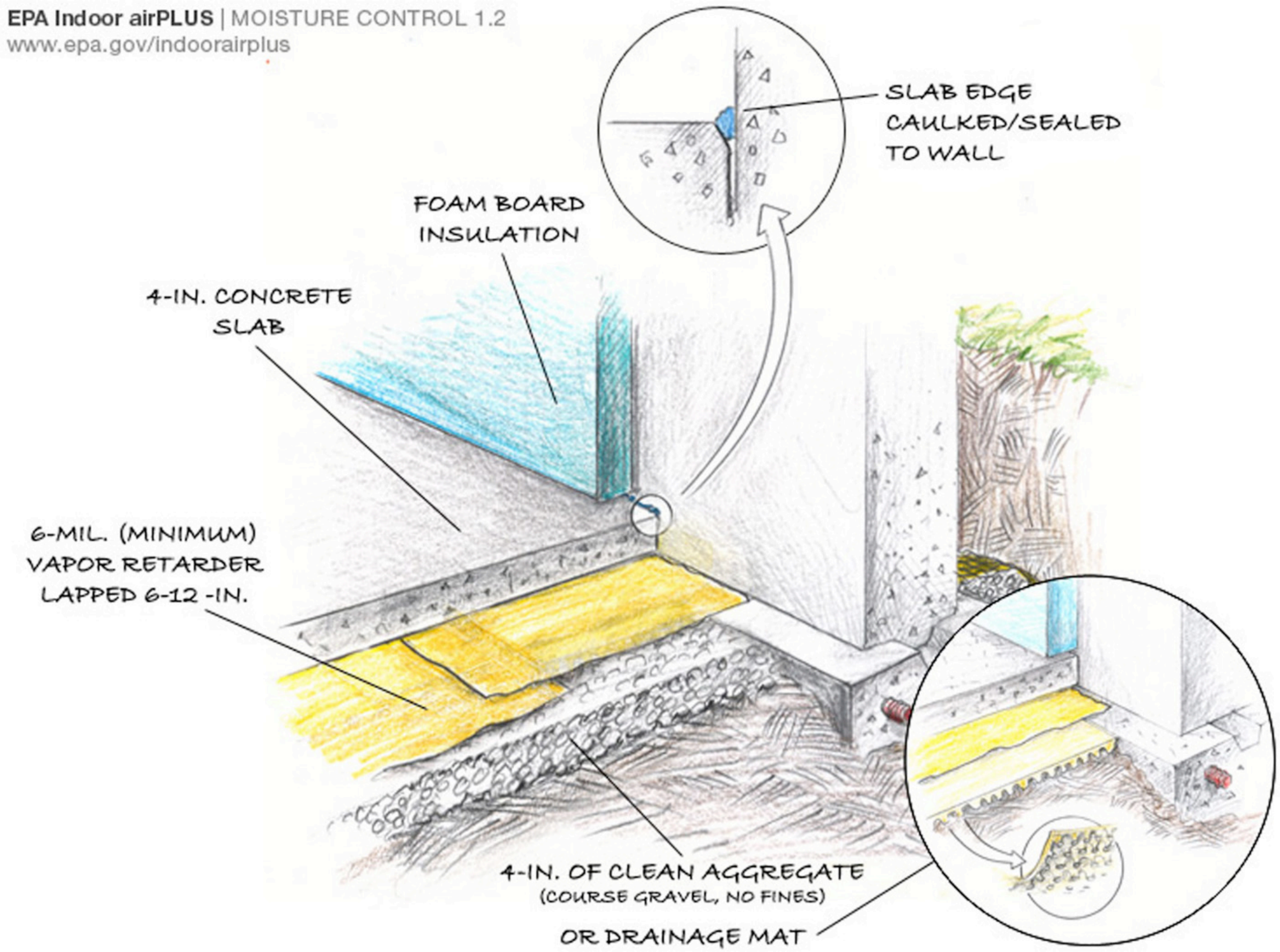
Site drainage



Good foundation design

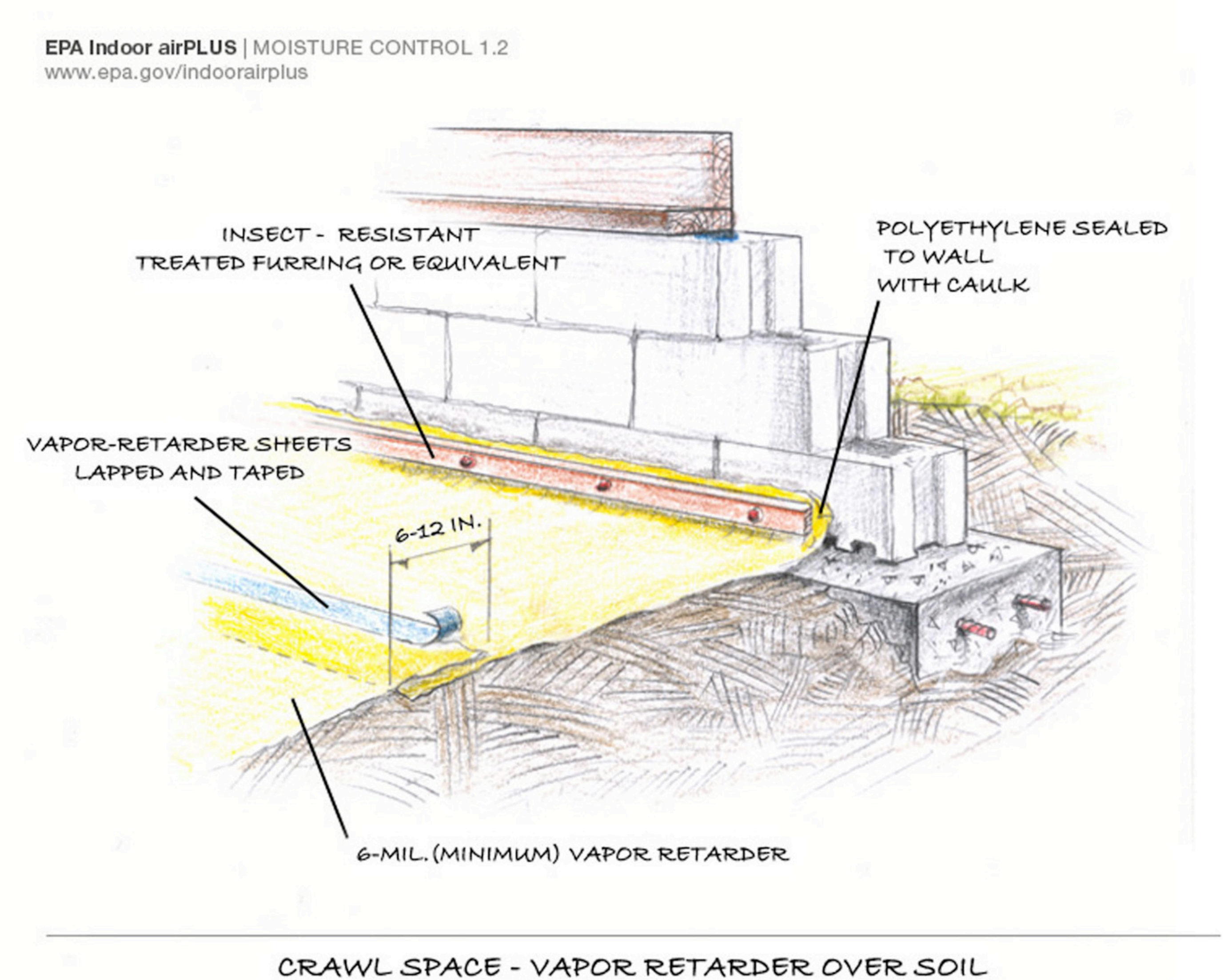


Basement slab with capillary break

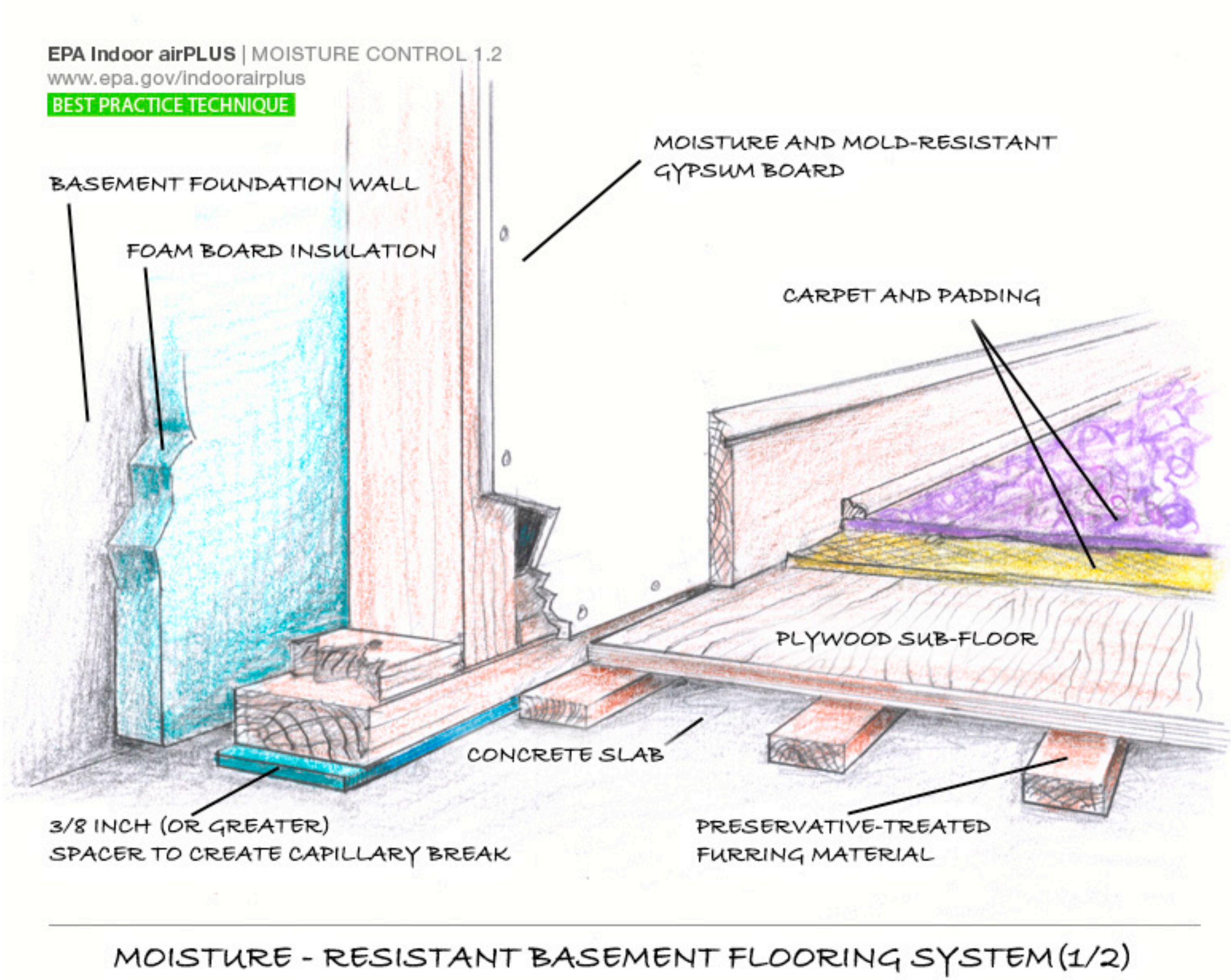


BASEMENT SLAB W/ CAPILLARY BREAK - GRAVEL AND GEOTEXTILE MAT (INSET)

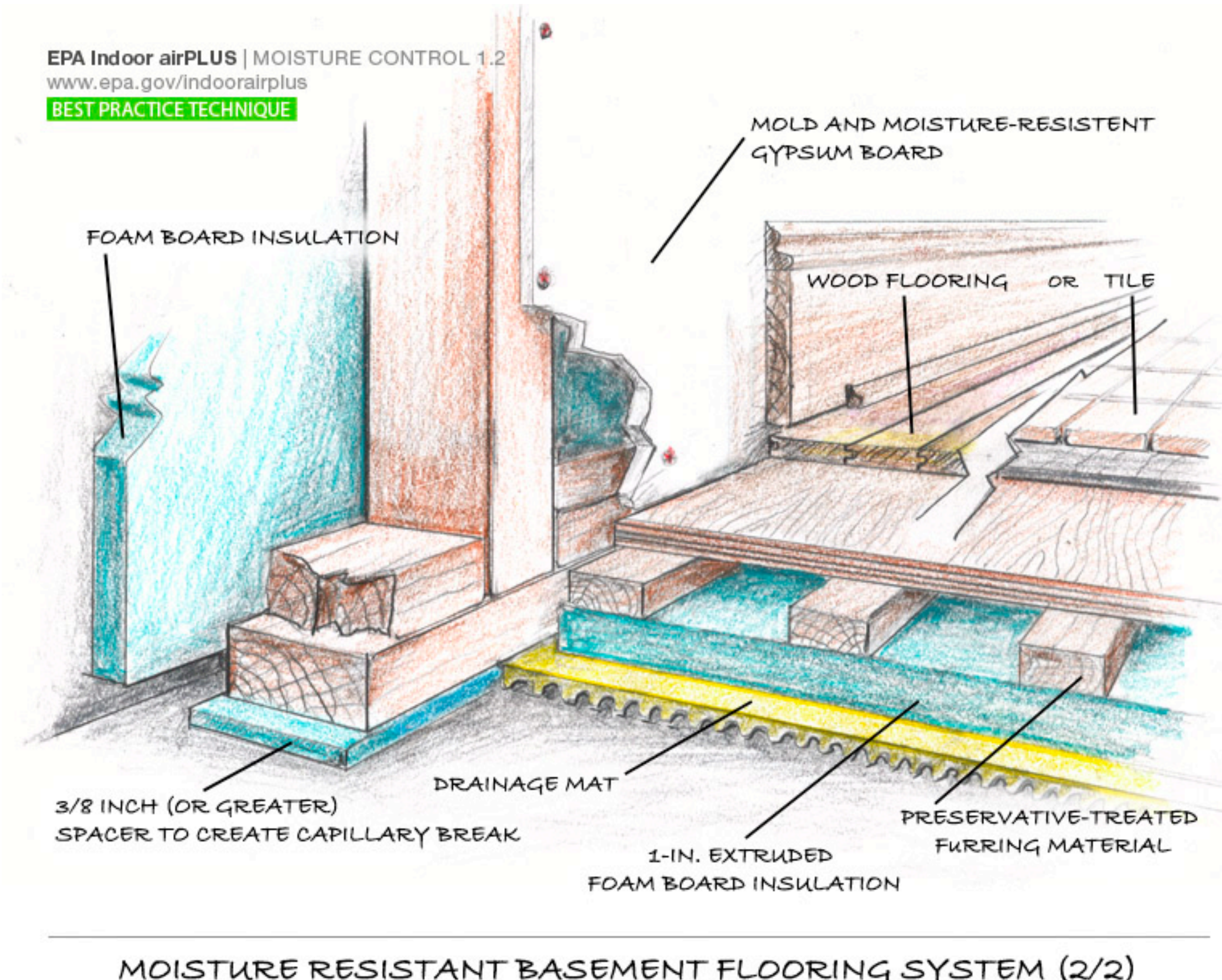
Crawl spaces and vapor retarders



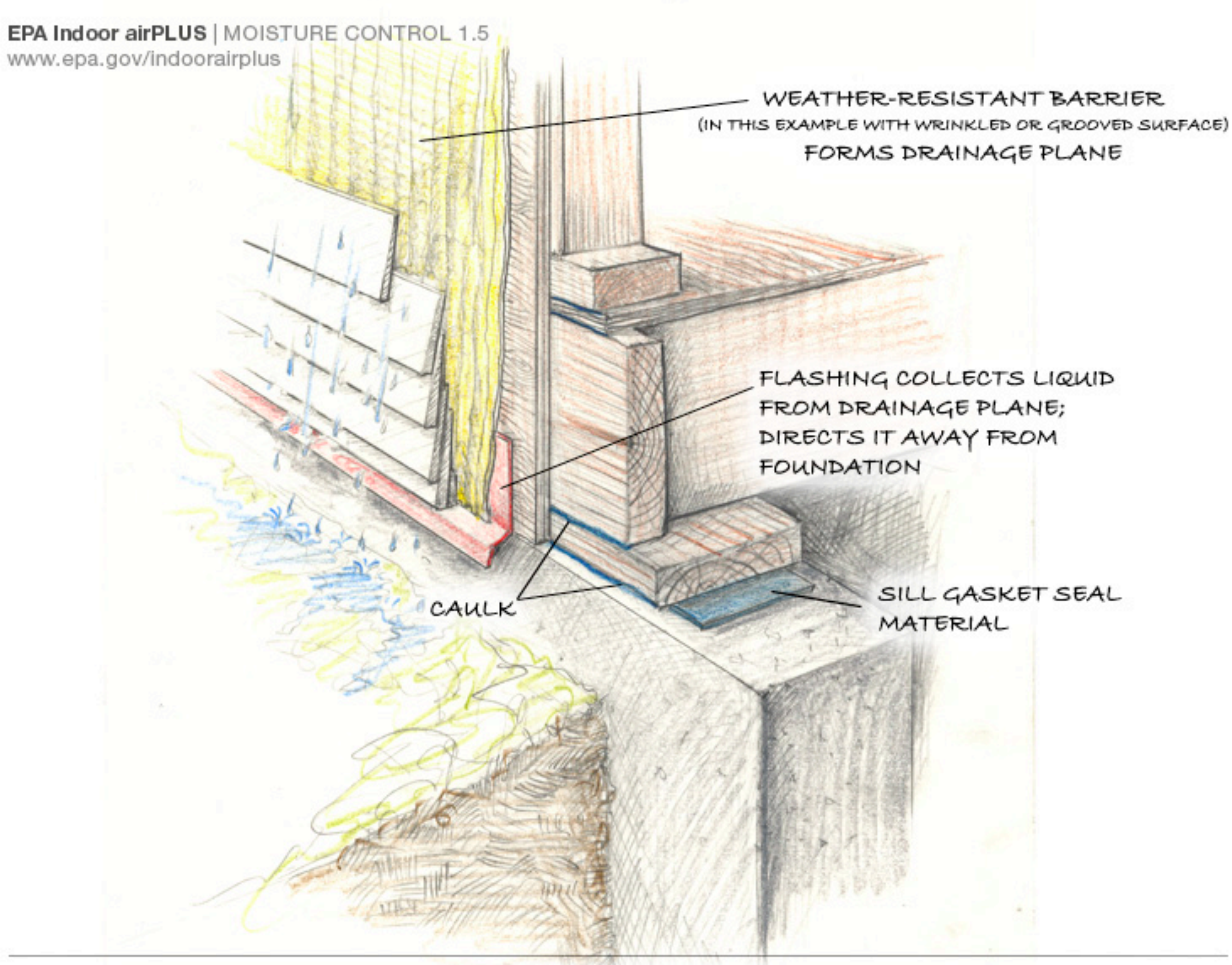
Moisture resistant basement floors



Moisture resistant basement floors

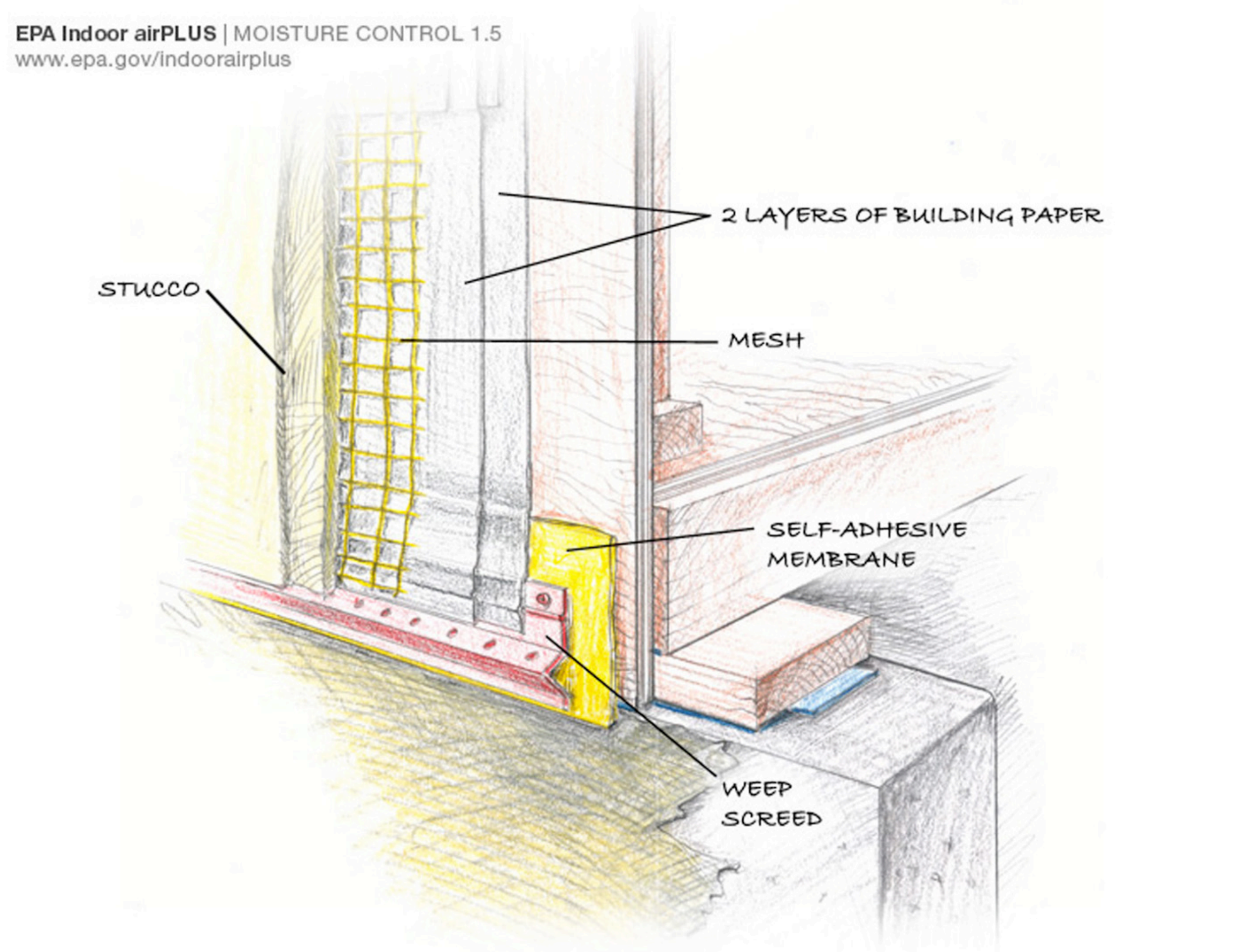


Drainage planes and drip edges: Siding



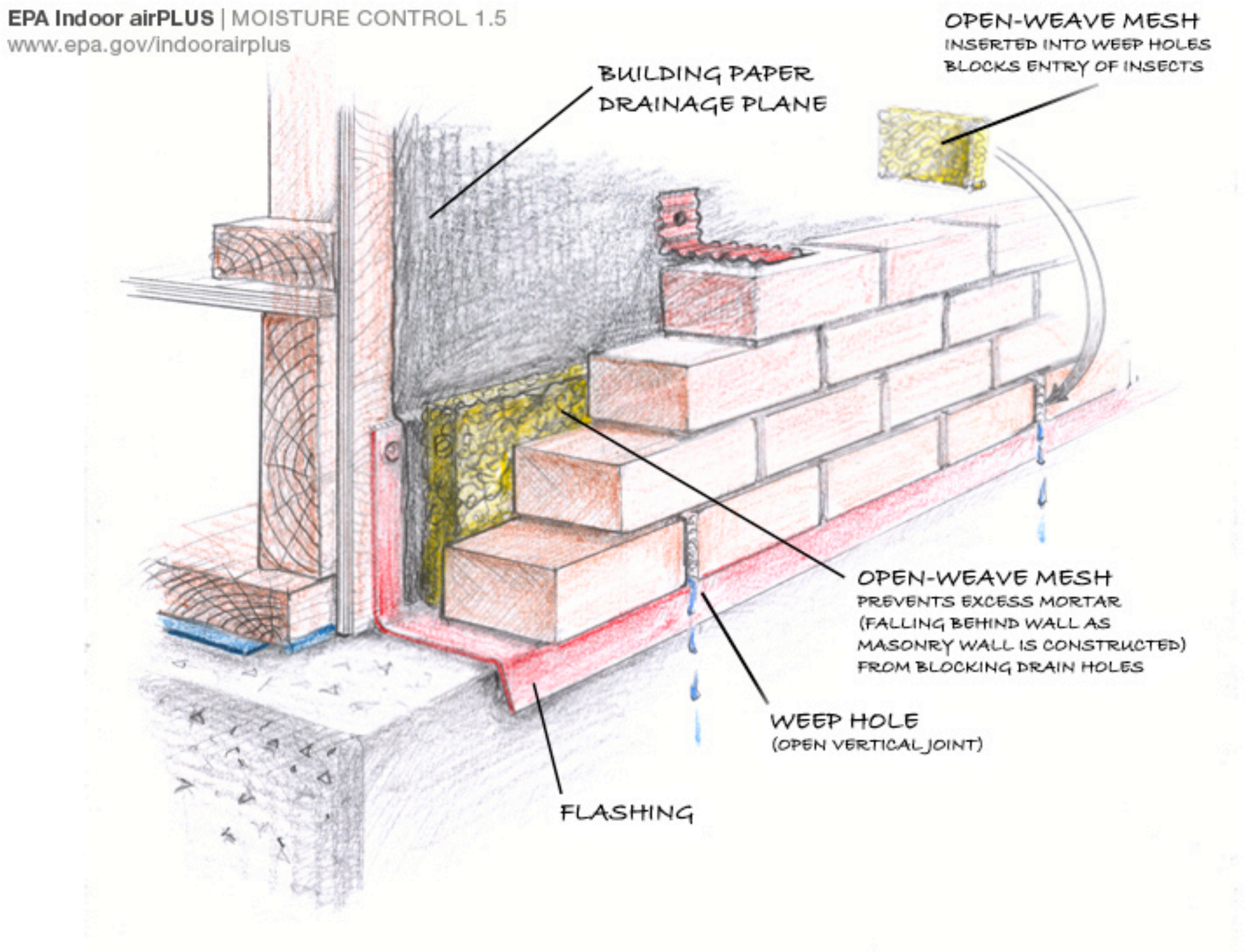
DRAINAGE PLANE AND DRIP-EDGE FLASHING WITH WOOD HORIZONTAL SIDING

Drainage planes and drip edges: Stucco



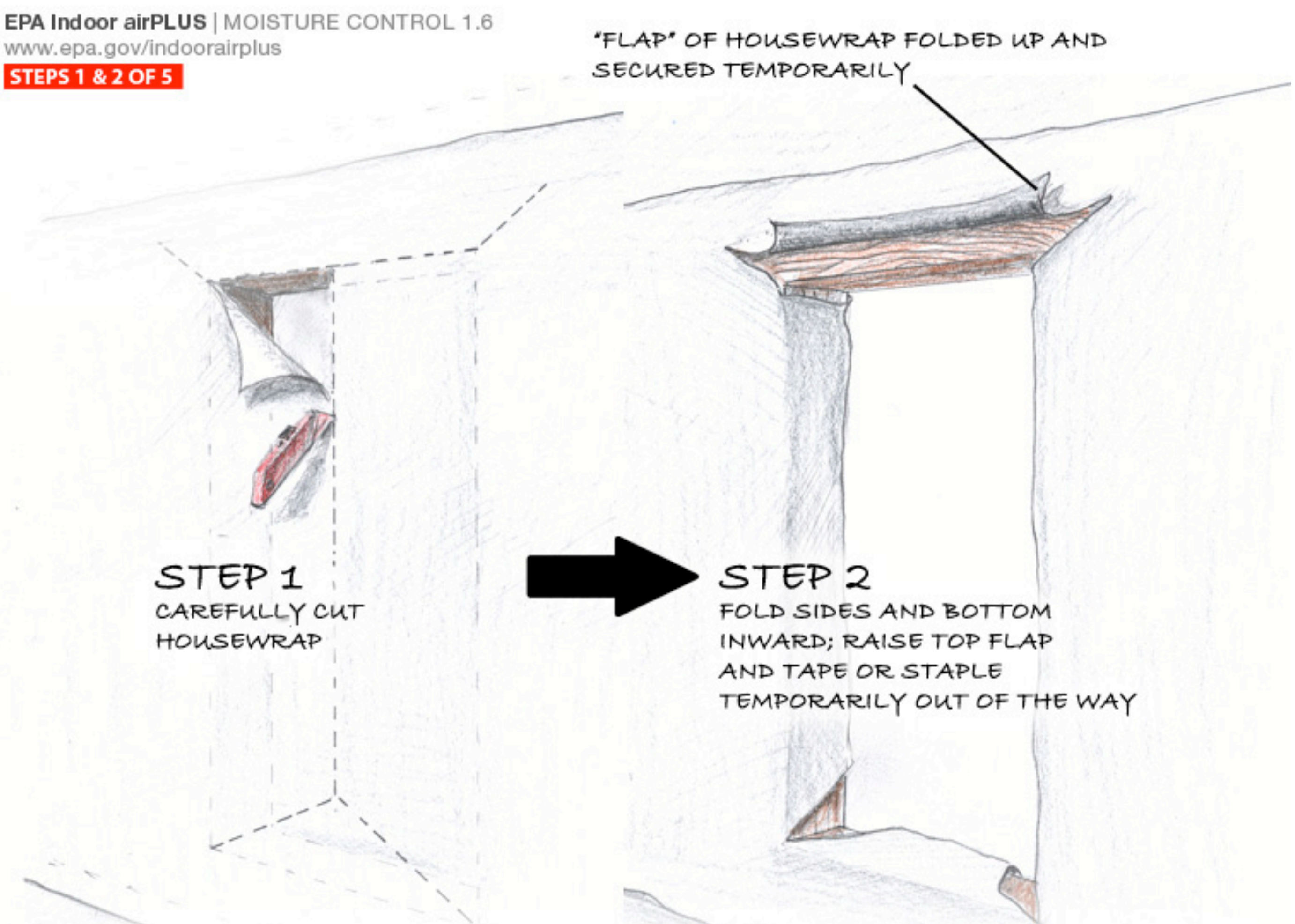
TWO LAYERS OF BUILDING PAPER FORM DRAINAGE PLANE BENEATH STUCCO

Drainage planes and drip edges: Masonry



MASONRY WALL WITH DRAINAGE PLANE, FLASHING, AND WEEP HOLES

Window flashing: Housewrap

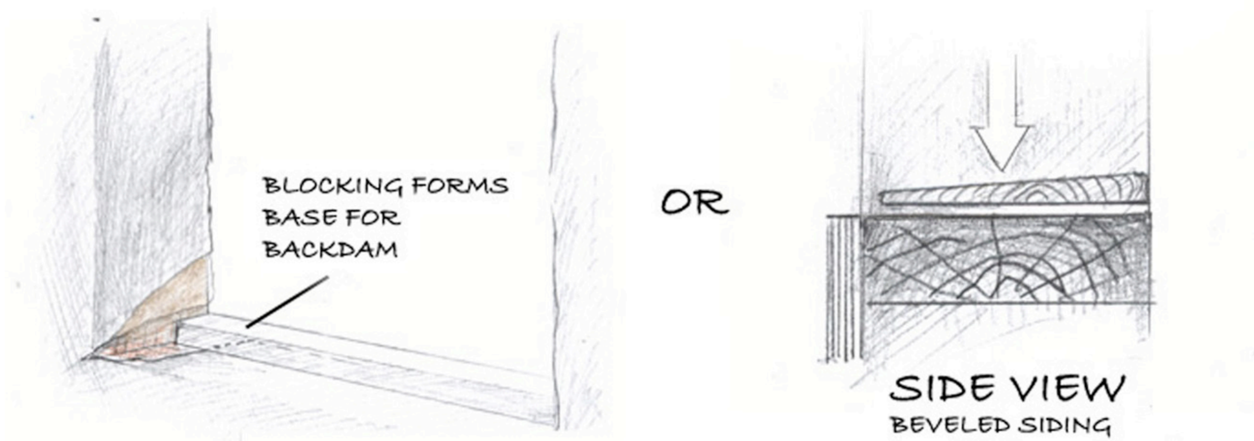


WINDOW FLASHING - HOUSEWRAP DRAINAGE PLANE - 5 STEPS
STEPS 1 AND 2 - CUTTING AND FOLDING HOUSEWRAP

Window flashing: Housewrap + slope

EPA Indoor airPLUS | MOISTURE CONTROL 1.6
www.epa.gov/indoorairplus
STEP 3 OF 5

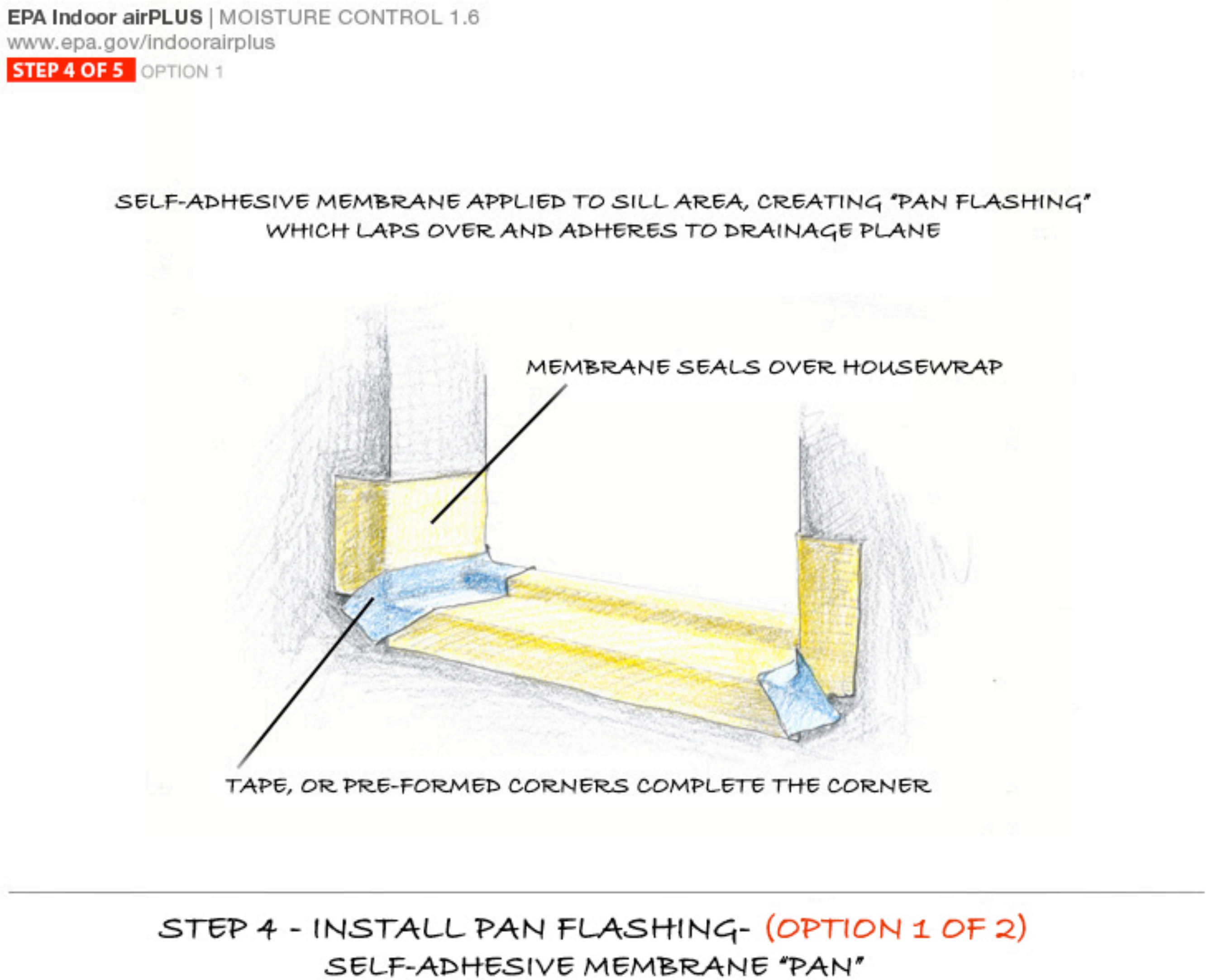
CREATE BACK-DAM OR SLOPE TO DIRECT ANY WATER THAT DRAINS TO THE SILL AREA OUTWARD AND ONTO THE DRAINAGE PLANE (HOUSEWRAP)



SIDE VIEW
BEVELED SIDING
ATTACHED TO ROUGH
SILL FRAMING

STEP 3 - CREATE BACK DAM OR SLOPE

Window flashing: Housewrap + pan flashing



Window flashing: Housewrap + flashing

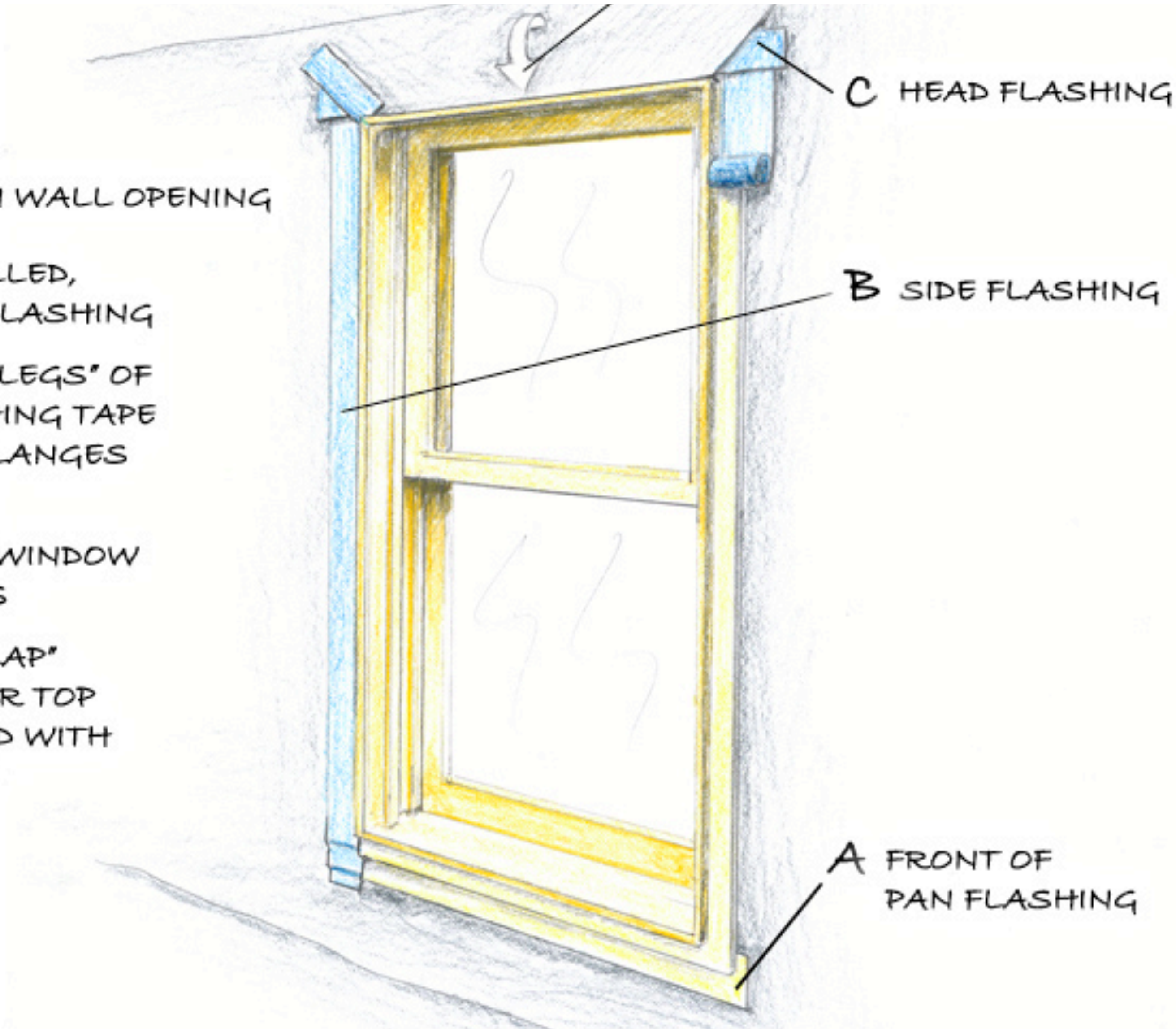
WINDOW PLACED IN WALL OPENING

A: WINDOW INSTALLED, RESTING ON PAN FLASHING

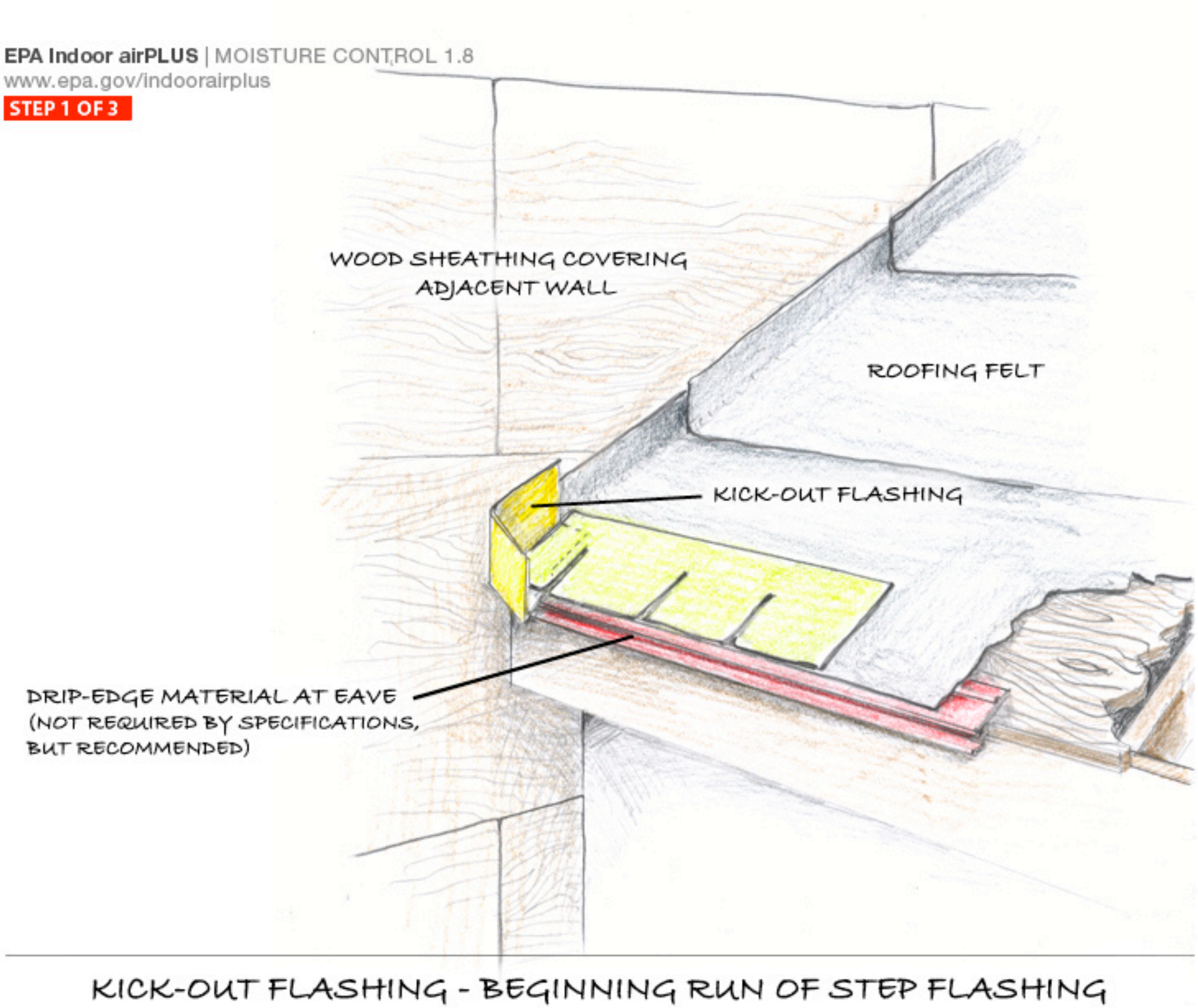
B: VERTICAL "SIDE-LEGS" OF MEMBRANE FLASHING TAPE SEAL OVER SIDE FLANGES OF WINDOW UNIT

C: TAPE AT TOP OF WINDOW COVERS SIDE-LEGS

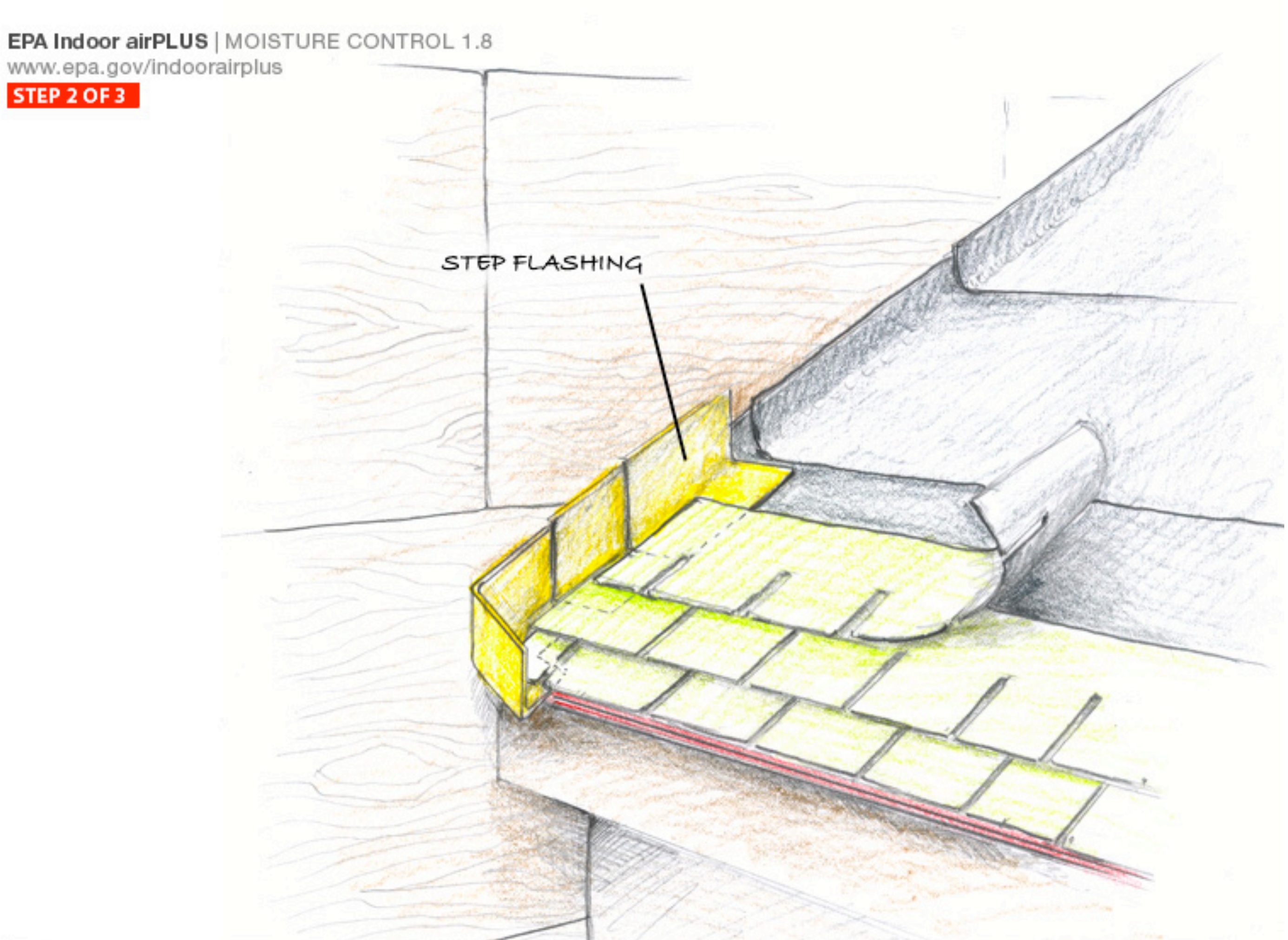
D: HOUSEWRAP "FLAP" LOWERED TO COVER TOP TAPE AND SECURED WITH TAPE AT CORNERS



Roof flashing

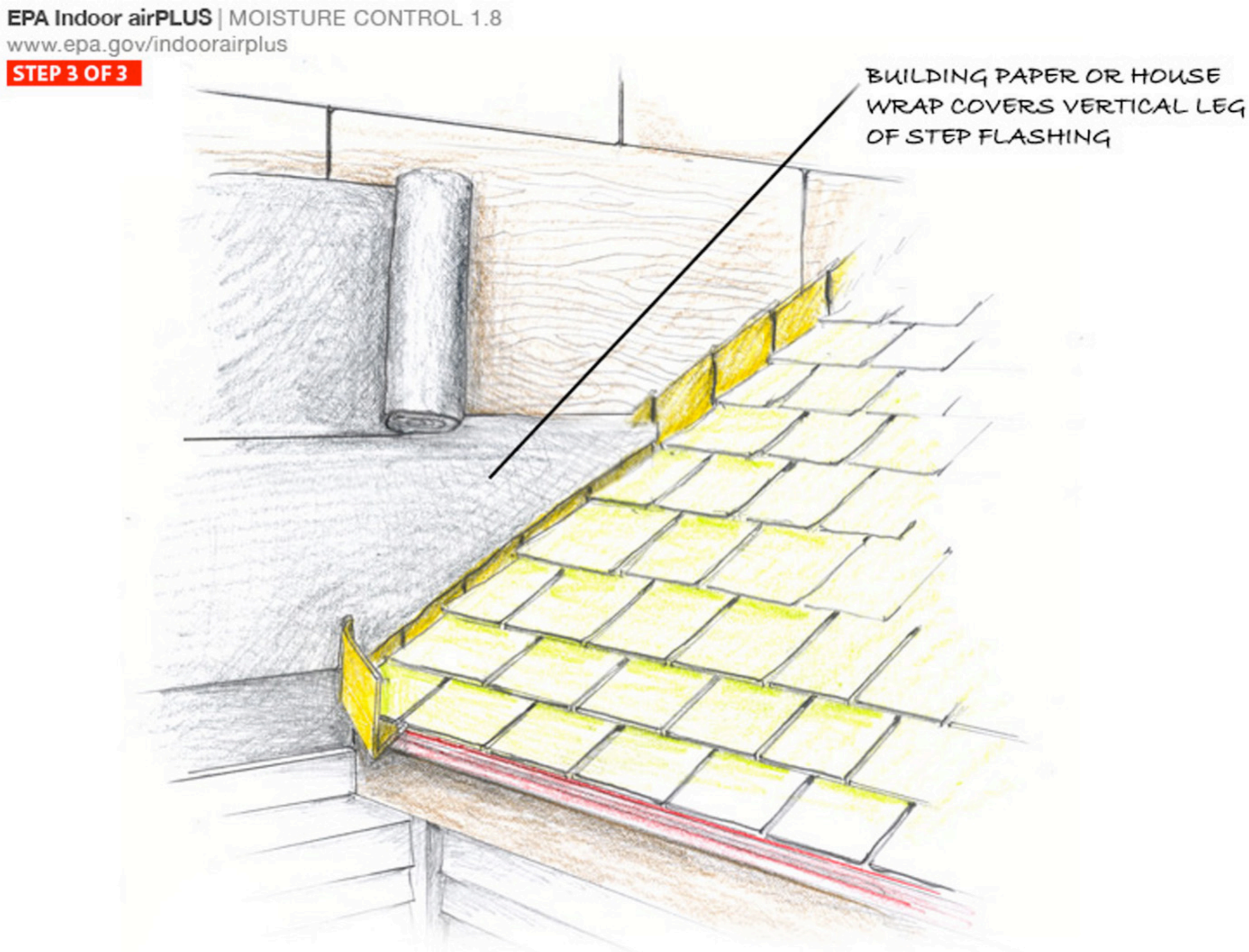


Roof flashing



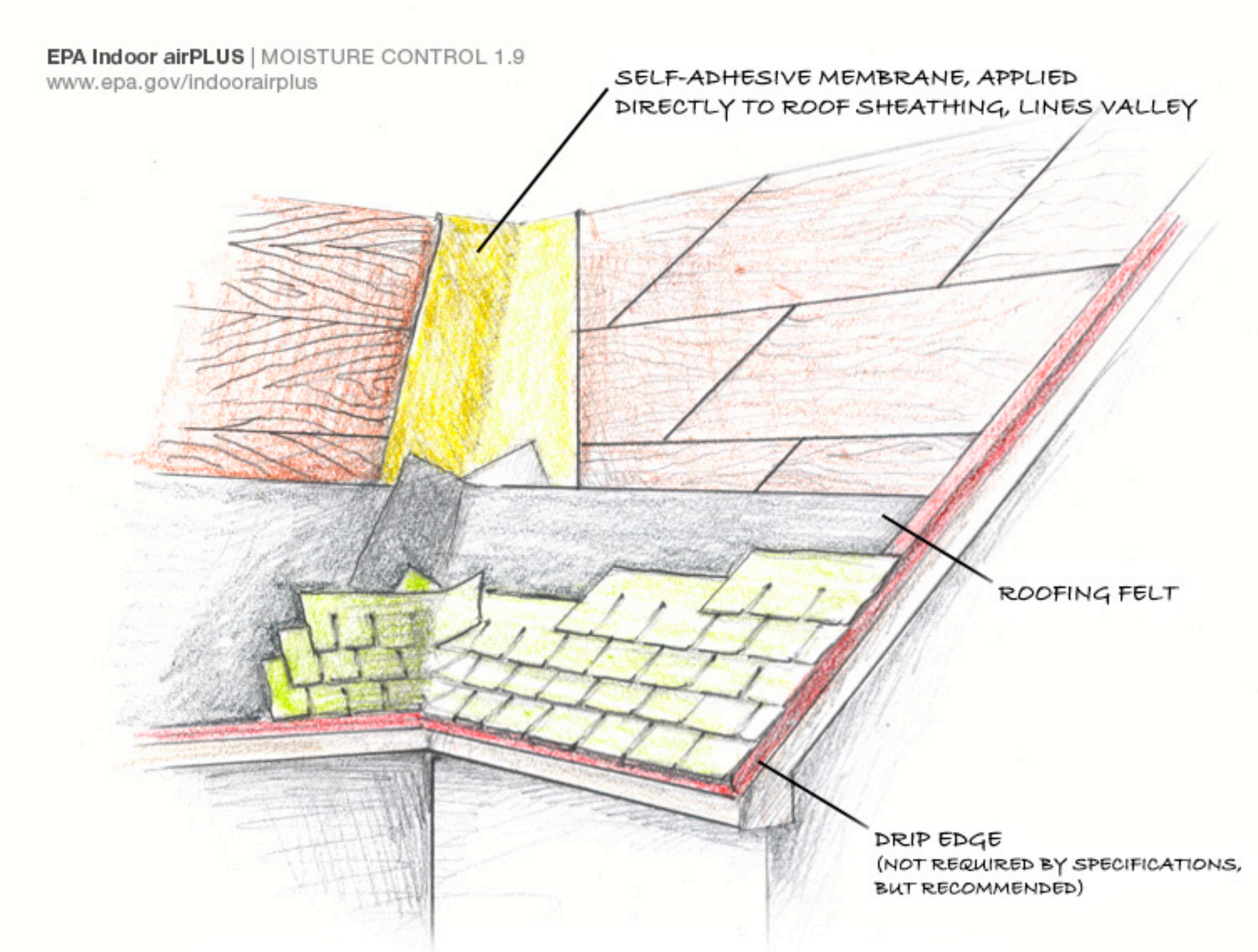
SUCCESSIVE SECTIONS OF STEP FLASHING INTEGRATED
WITH COURSES OF SHINGLES

Roof flashing



DRAINAGE PLANE MATERIAL COVERS STEP FLASHING

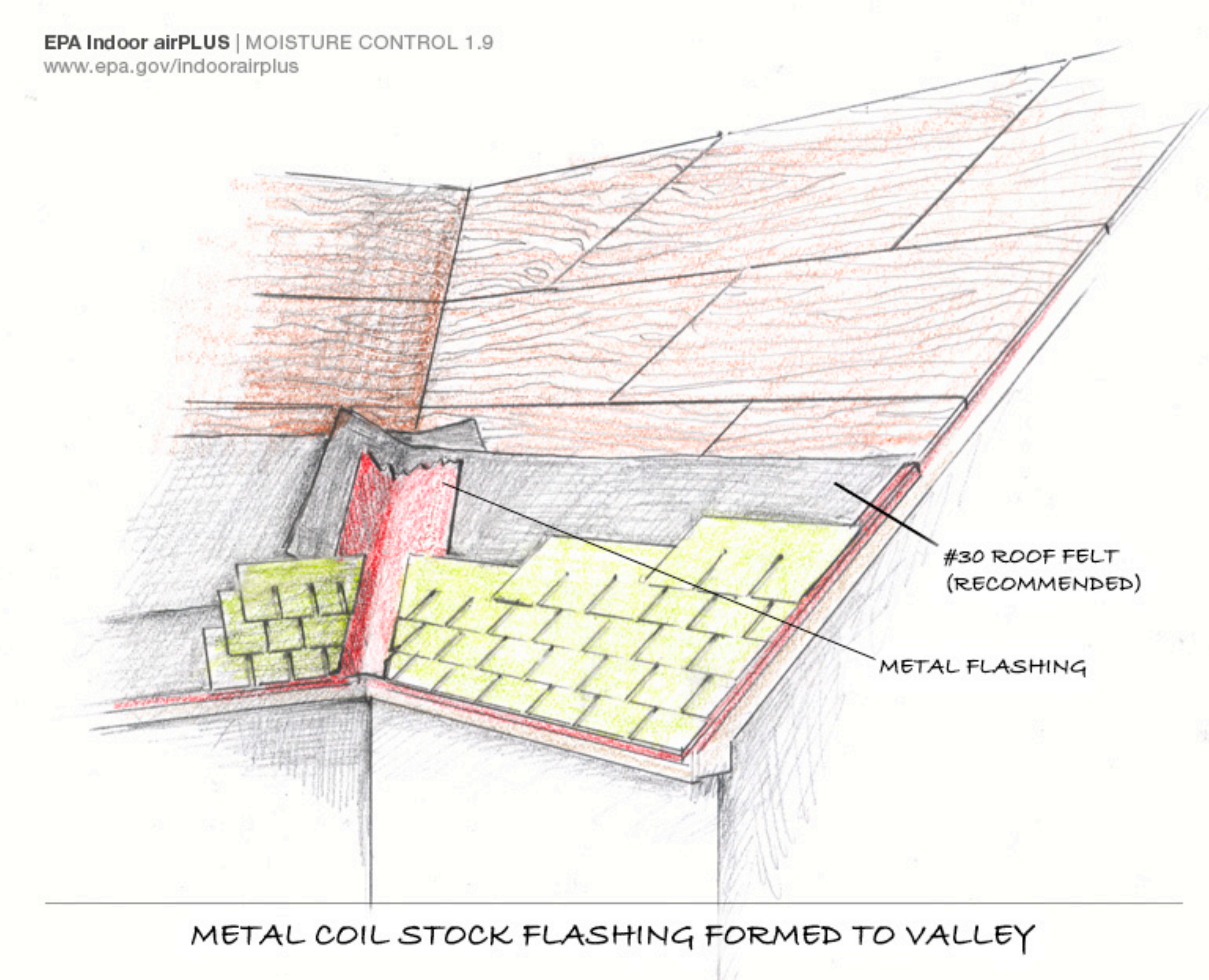
Membrane protection of roof valleys



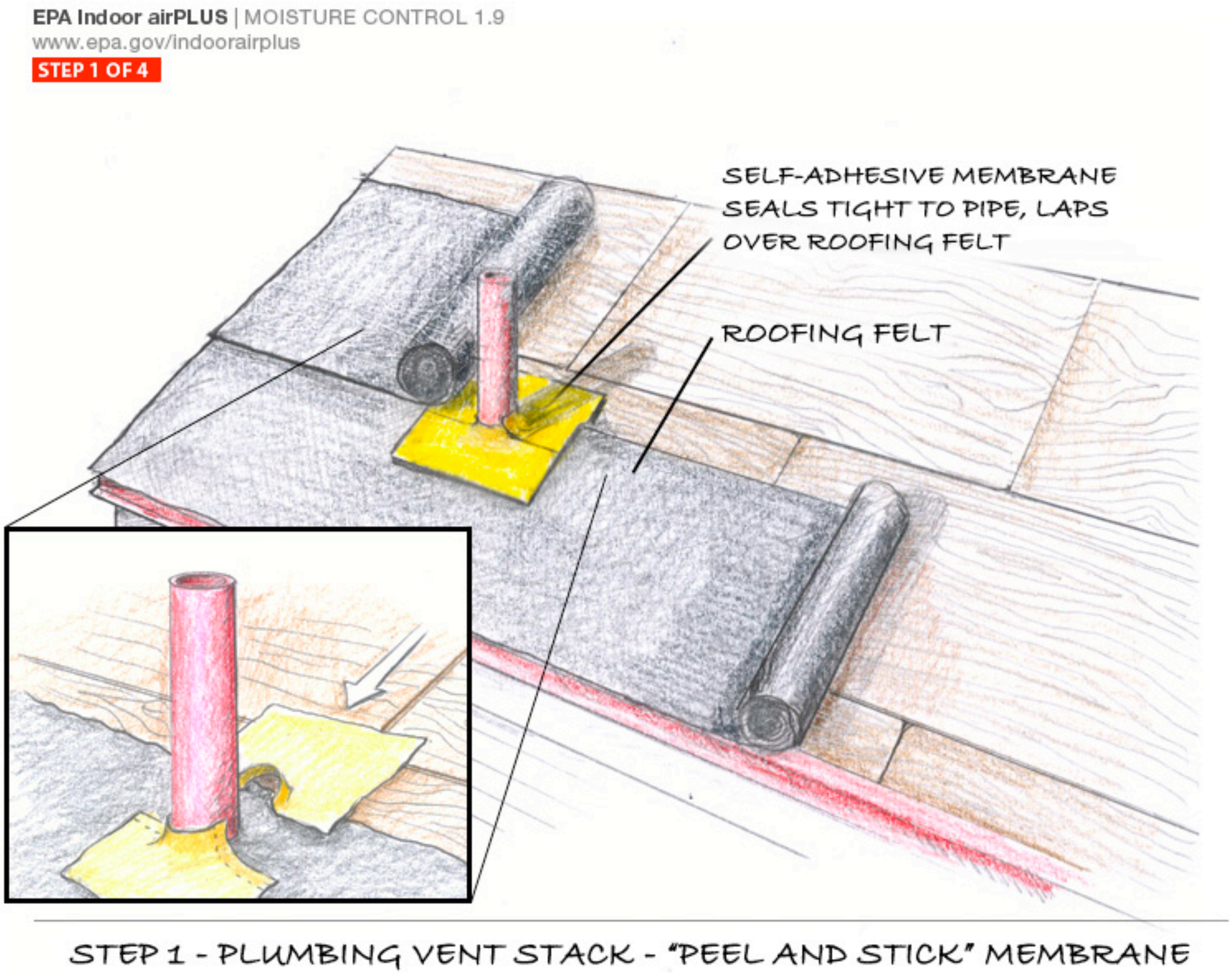
MEMBRANE PROTECTION OF ROOF VALLEY

Membrane protection of roof valleys

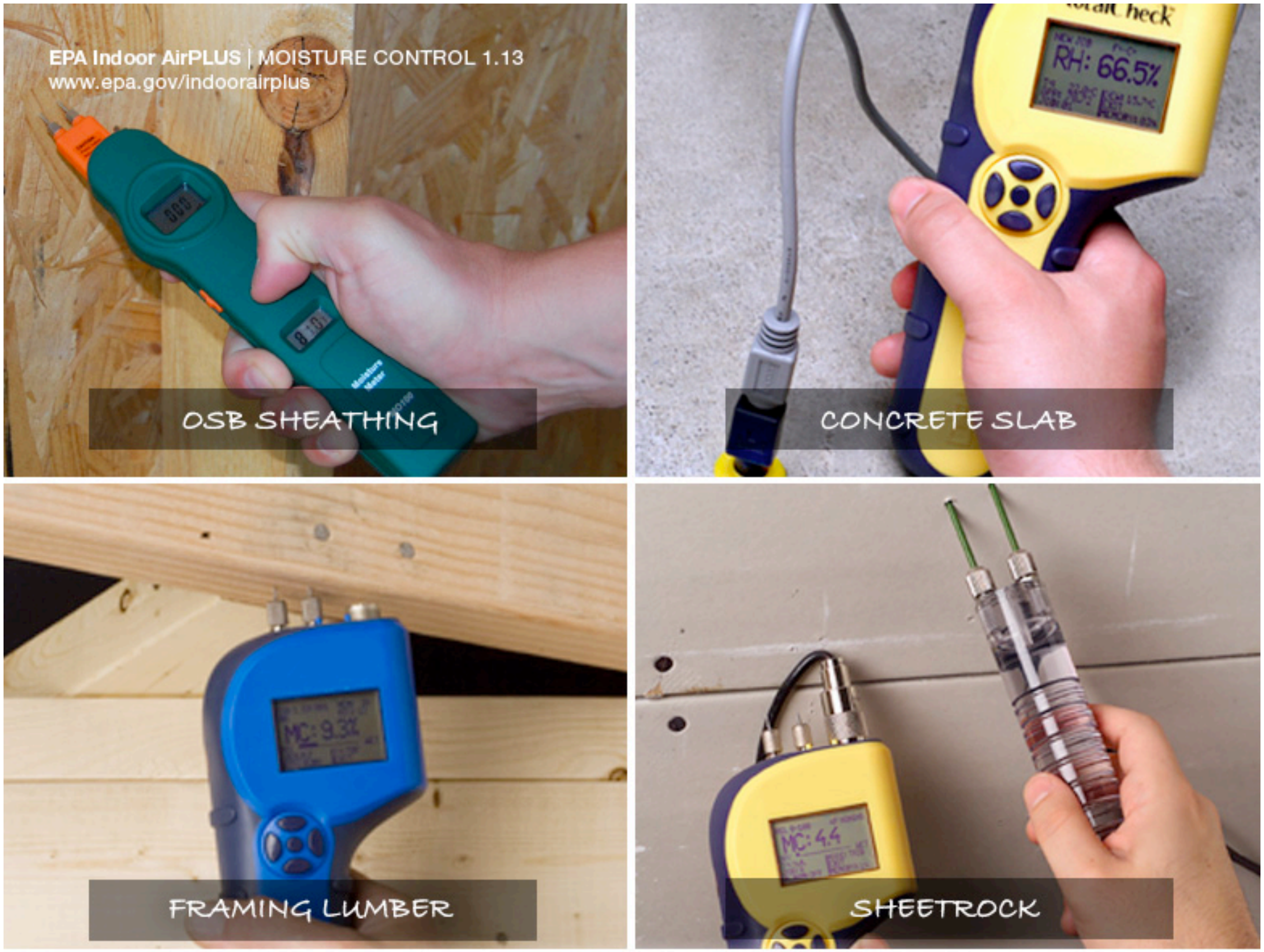
Metal flashing and roof valleys



Membranes and roof vents



Don’t install wet materials!



MEASURING MOISTURE IN VARIOUS BUILDING MATERIALS

What happens when you don't address these?

Photograph 2: Interior Frame Wall With Plastic Vapor Barrier
- Plastic vapor barrier prevents inward drying
- Common outcome are odor, mold, decay and corrosion problems

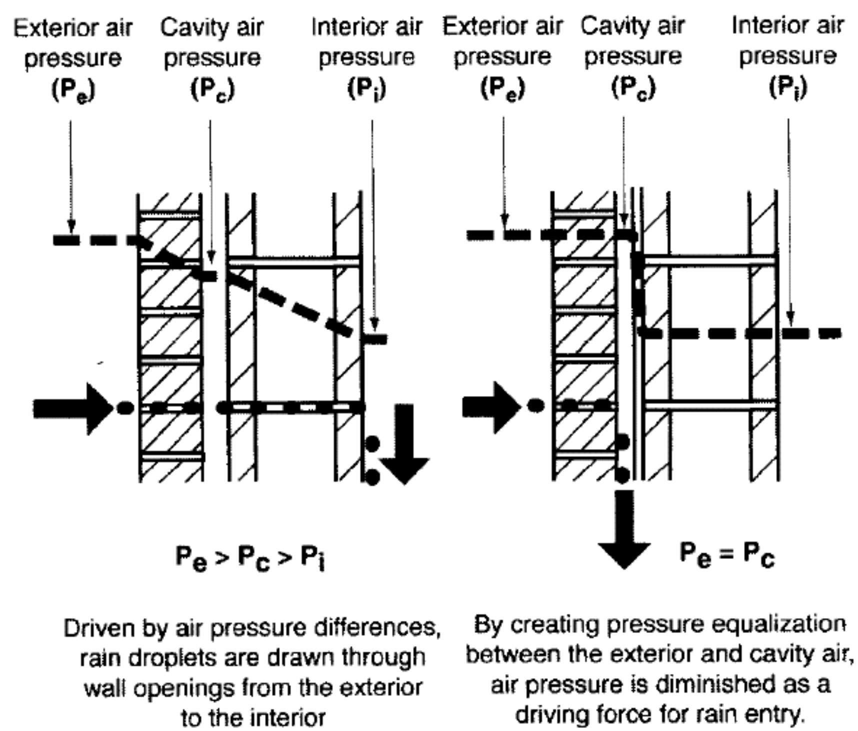
What happens when you don’t address these?

- 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)

AIR CAVITIES FOR MOISTURE MANAGEMENT

Use of air cavities in moisture management

- Air cavities can provide beneficial breaks to:
  - Stop capillary suction and reduce momentum driven rain entry
  - Allow flashing to direct gravity flow to exterior
  - Allow for pressure equalization to force rain back to exterior
- Intentional "**drain-screen**" walls and "**rain screen**" walls



Pressure equalization: Cavity ventilation

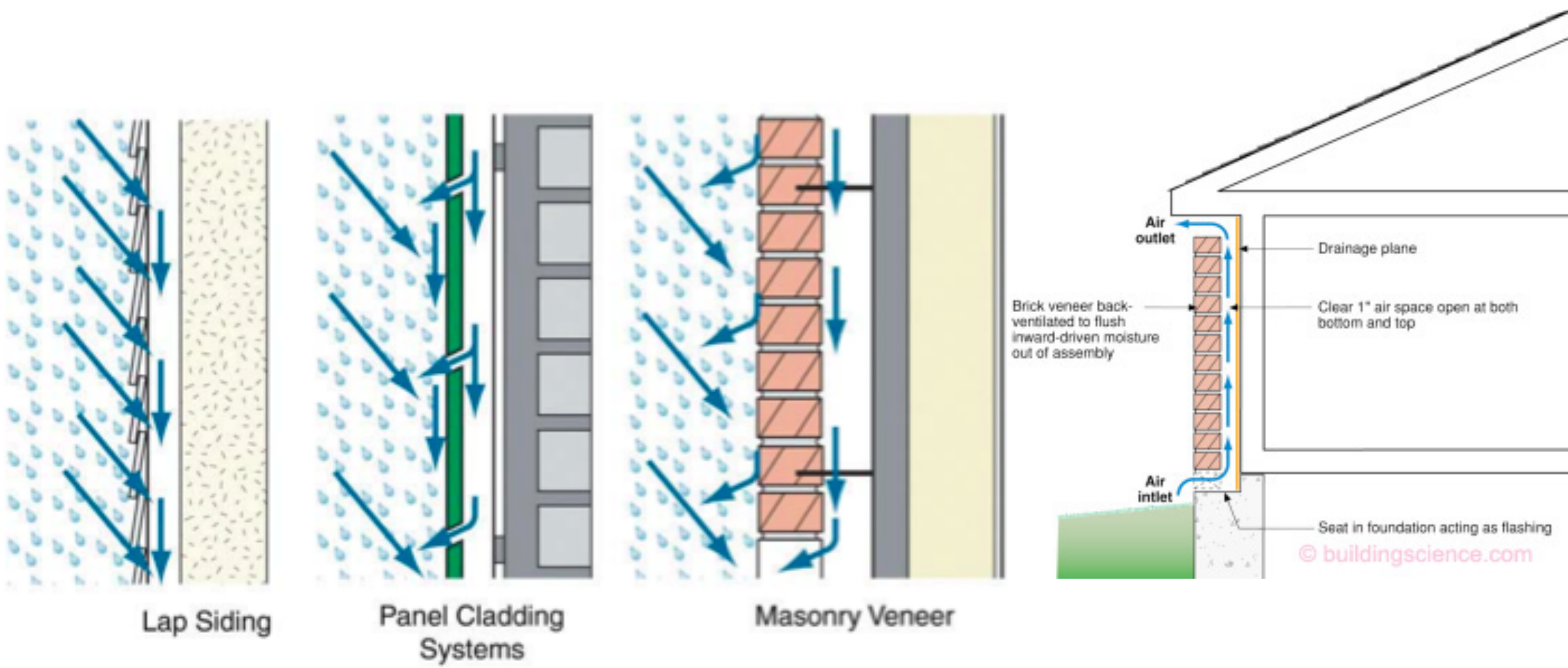
Drain-screen walls

- A **drain-screen** wall allows some water to penetrate the outer layer of a wall assembly
  - But uses the air cavity to break most water transport and provide drainage
    - Air space should be at least 5 mm (~1/4”) wide, although 10 mm (~3/8”) 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

- Examples include cavity walls, brick and stone veneer, vinyl siding, and drained EIFS (synthetic stucco)

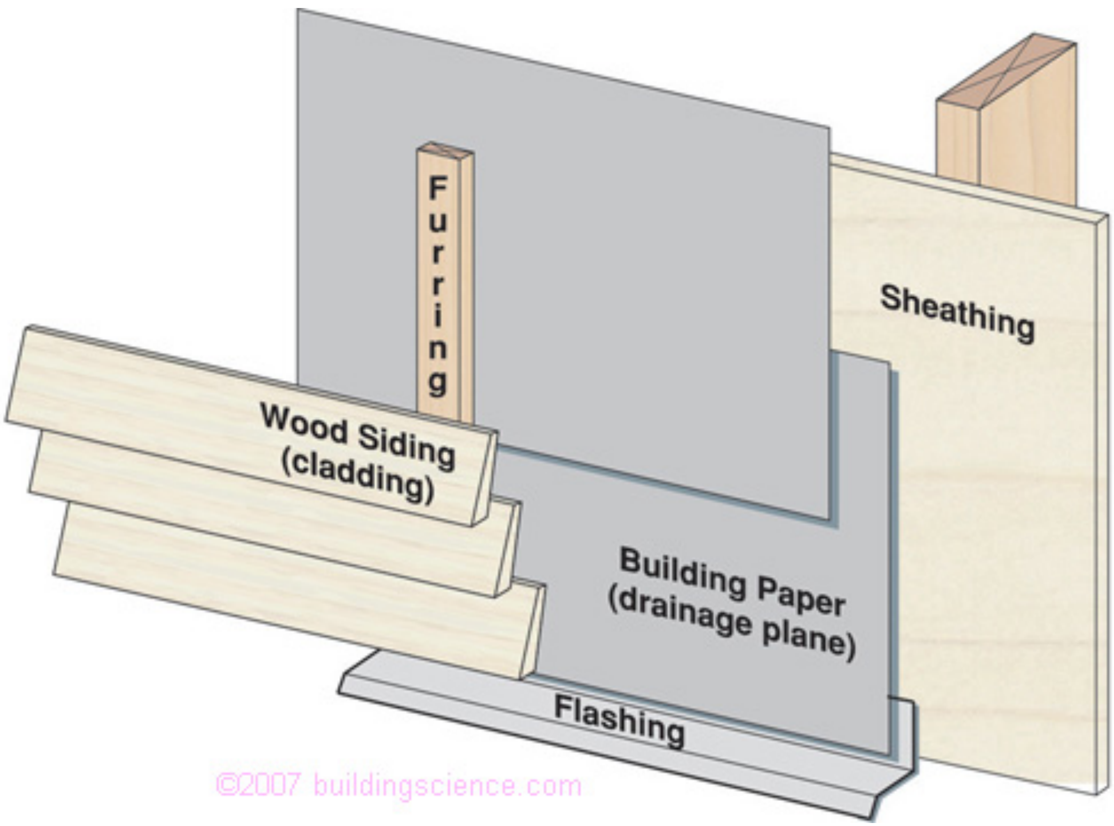
Drain-screen walls: Cavity ventilation



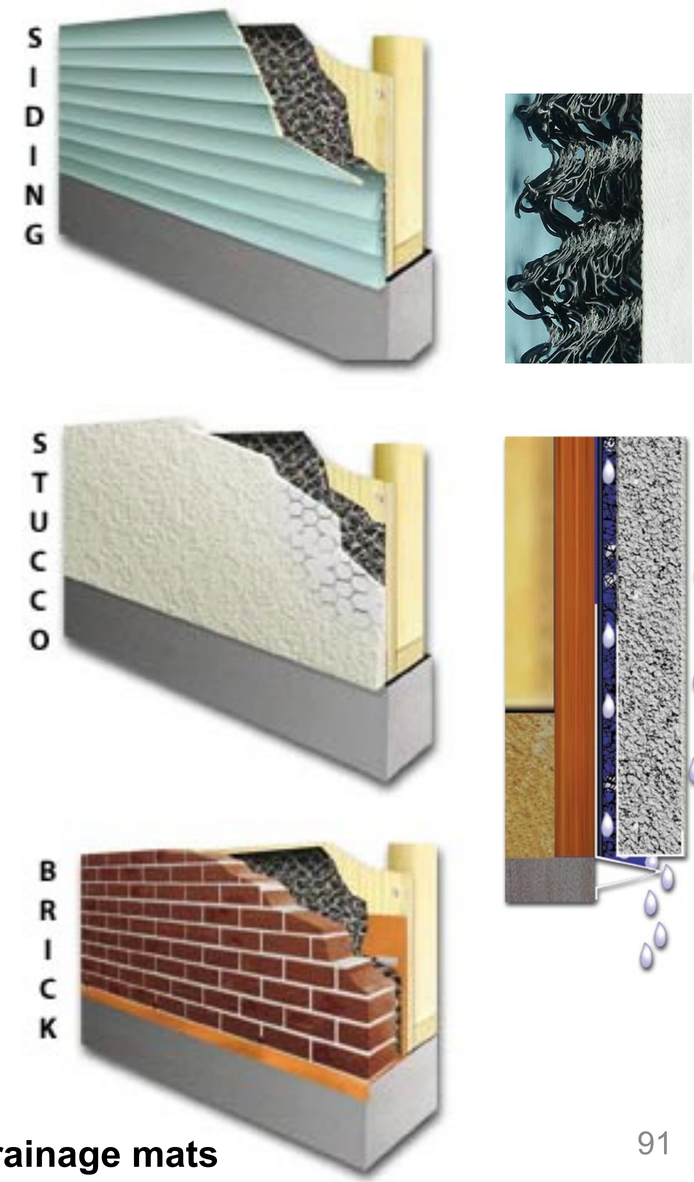
Each requires: (1) screen or cladding; (2) drainage gap; (3) drainage plane; (4) flashing at the base to direct water outwards; and (5) drain holes or weep holes to allow water out

Straube 2006

Drain-screen walls: Cavity ventilation



Furring and cavity ventilation



Drainage mats

Straube 2006

Rain screen walls

- 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 design a **rain screen** wall

Rain screen wall: Prevent momentum driven rain

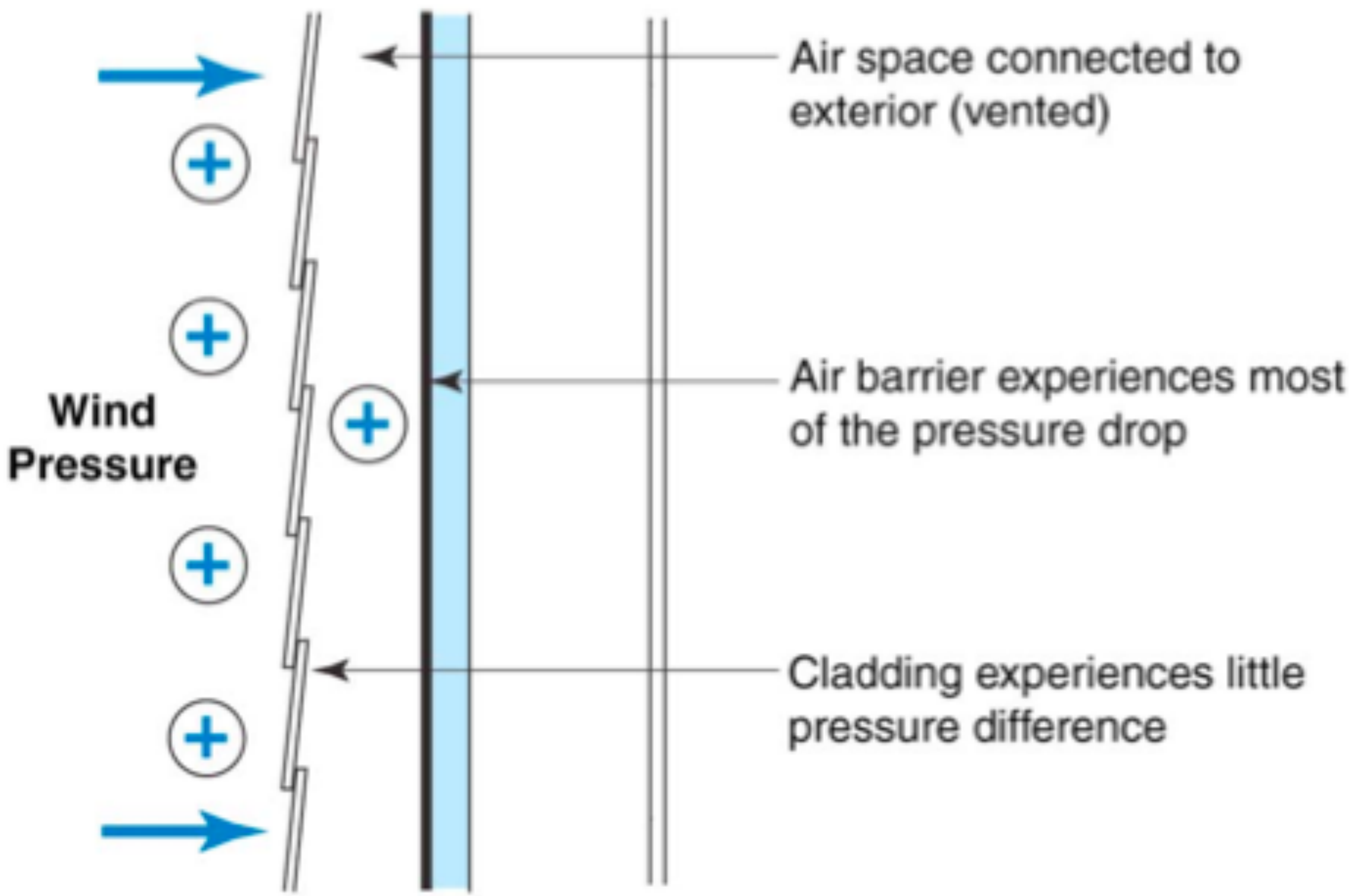
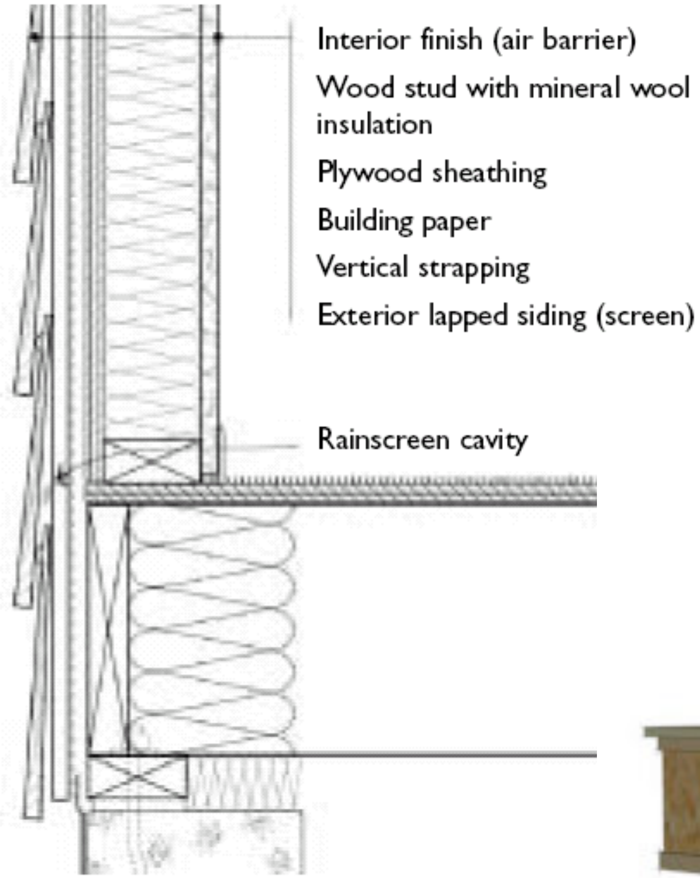


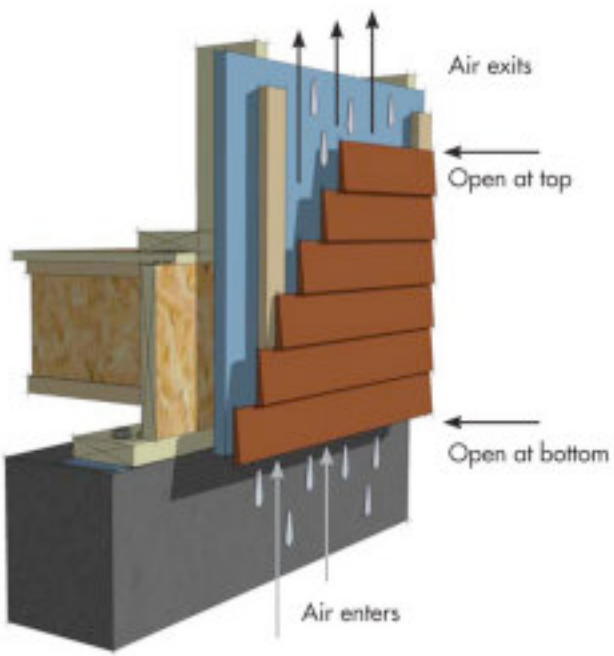
Figure 7: Pressure Moderated Air Space

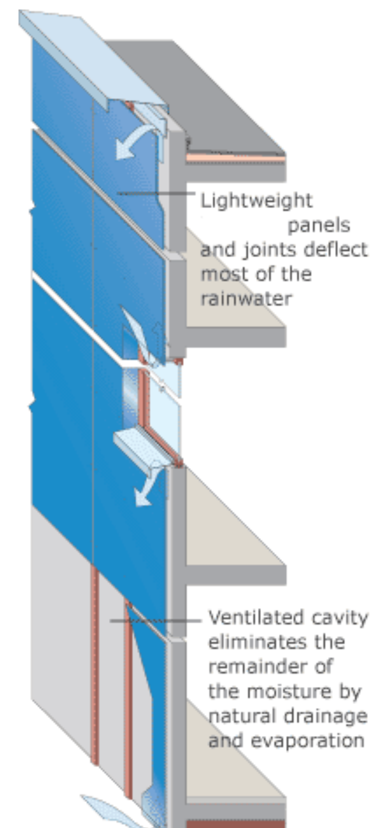
Straube 2006

Open (ventilated) 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





Open rain screen video

https://www.youtube.com/watch?v=78KKx2Nx2m4

Pressure equalized rain screen (PER)

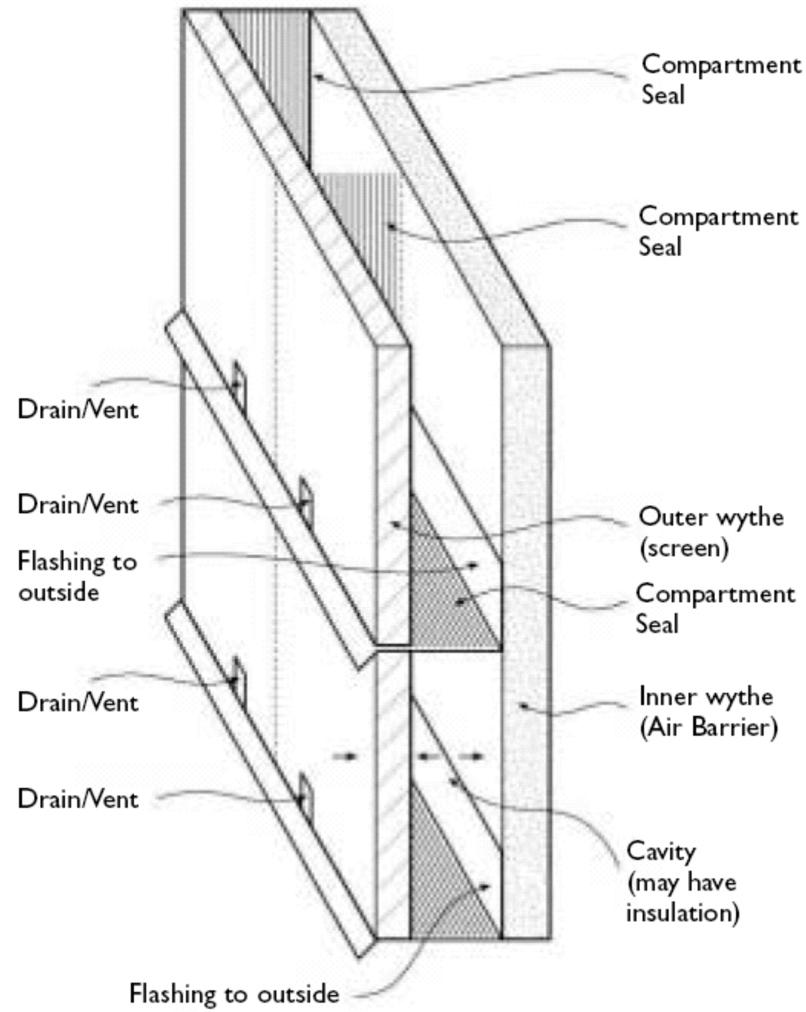
- Another type of rain screen is **pressure equalized**
  - Used more for tall buildings

- Allows compartmentalization of façade into chambers
  - Makes the pressure in the air cavity track outside air pressure
  - Stops the rain from even entering the cavity (if driven by pressure difference)

- PER screens are useful in high rain areas but are usually 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



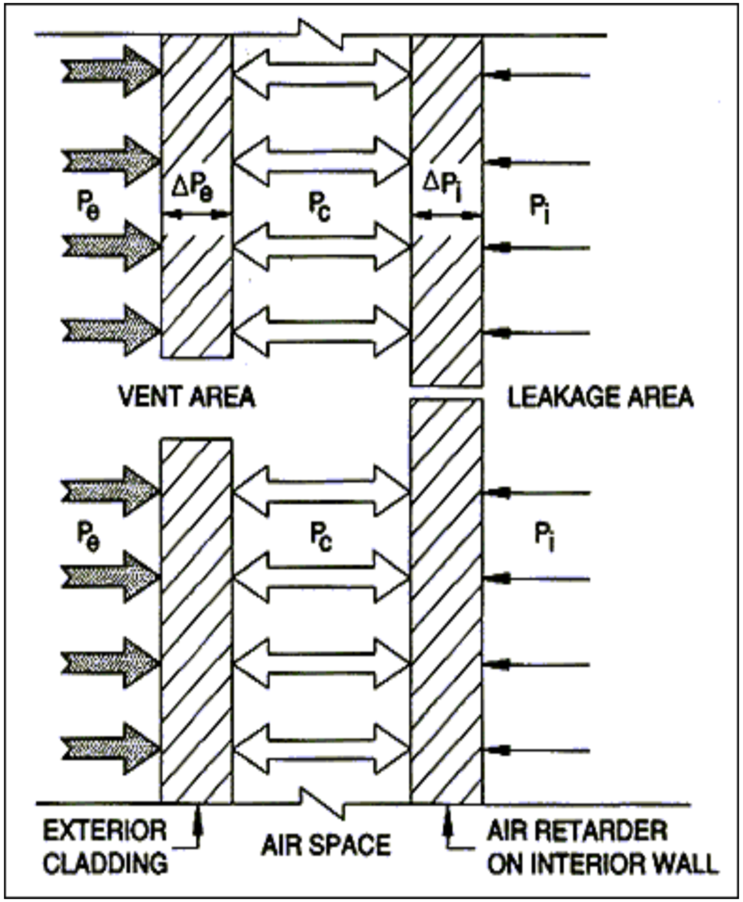
Pressure Equalized Rain Screen (PER)

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

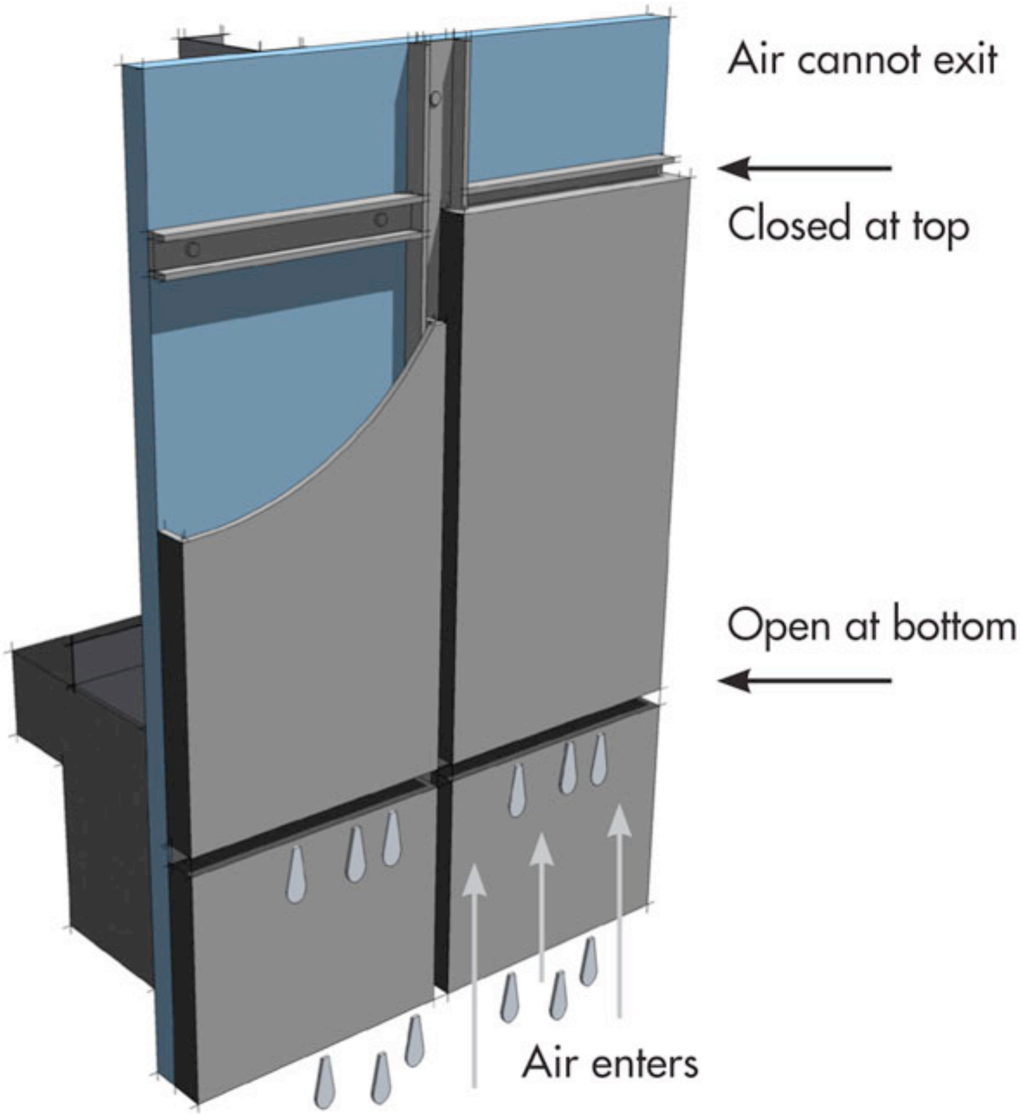
  $P_c \approx P_e,\ \Delta P_e \rightarrow 0$

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

  $P_c > P_i\ ,\ \Delta P_i > 0$



PER detail



MOISTURE MANAGEMENT AND CONTROL: SUMMARY

Moisture management rules

- 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

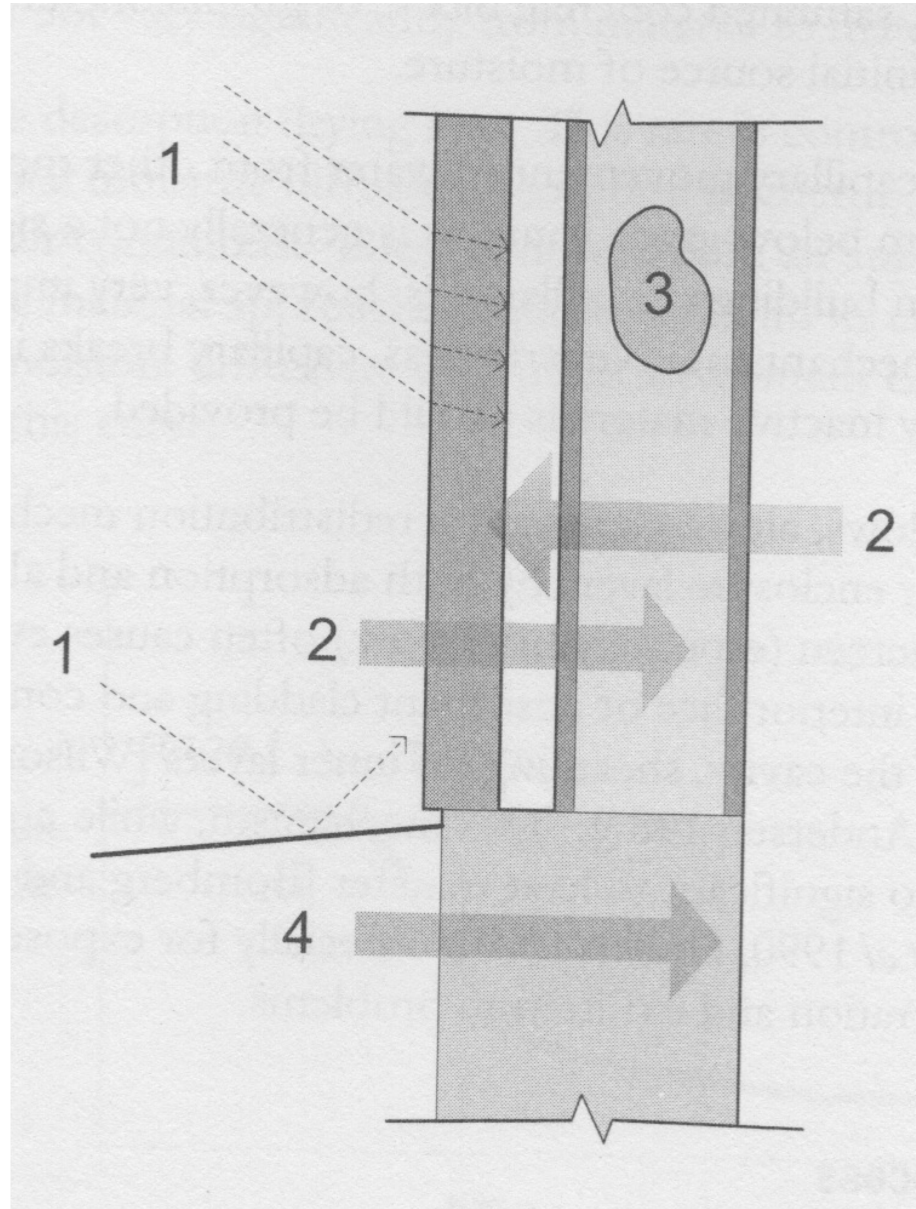
Moisture control

- 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
- Two main principles for moisture management:
  1. Control liquid water
  2. Manage condensation

  EPA **2013** Moisture Control Guidance for Building Design, Construction and Maintenance

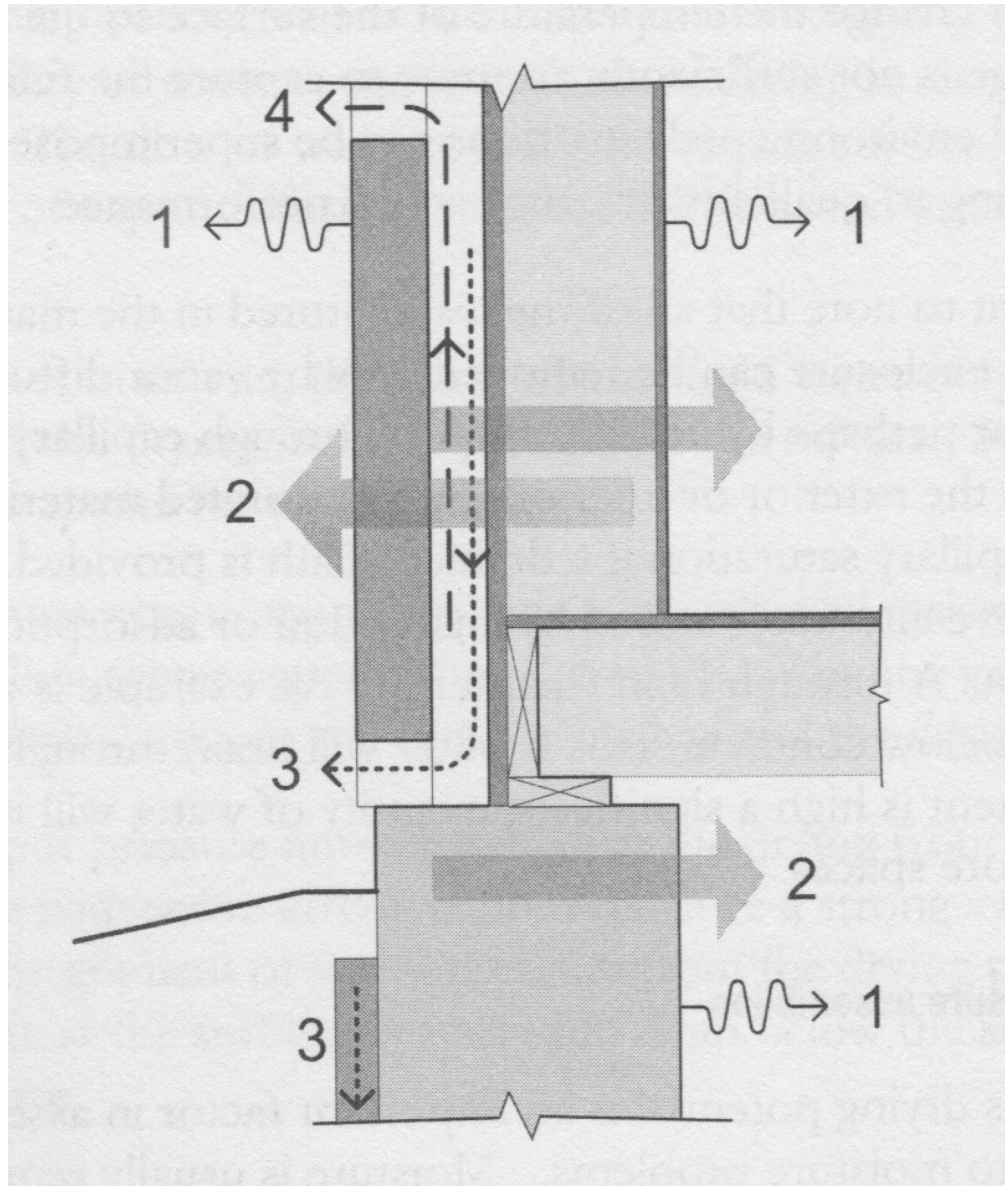
Wetting process (sources)

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



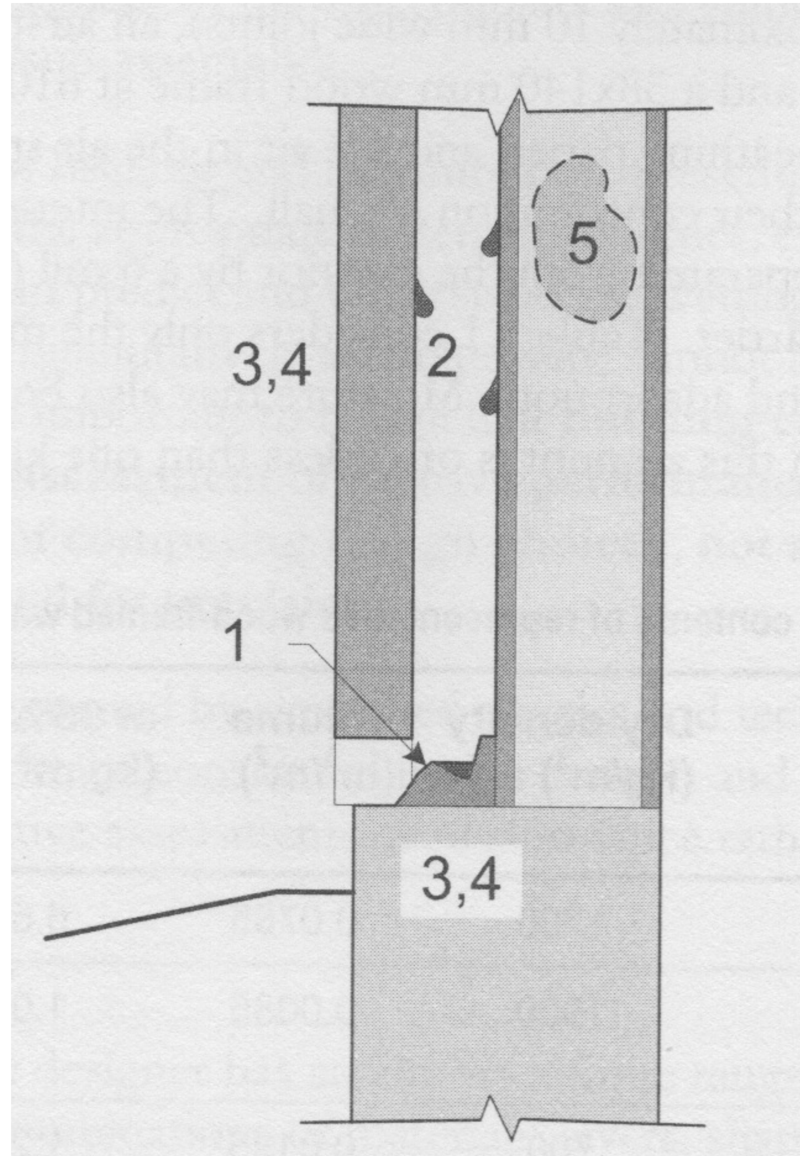
Drying mechanisms

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 discussed, 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

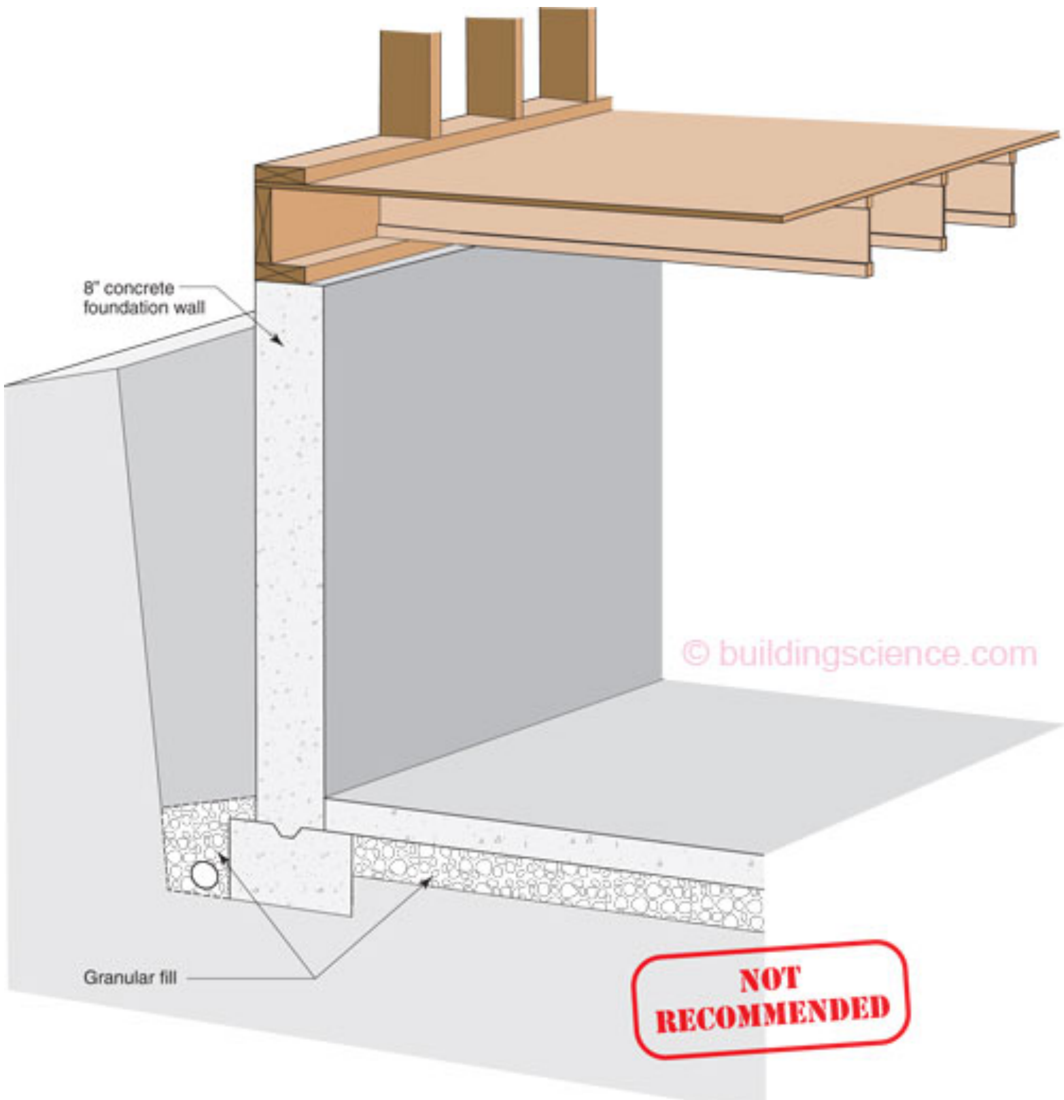
- Material choices
  - You have an almost infinite range of choices considering possible combinations of
    - Materials
    - Layers
    - Shape
    - Orientation
  - There are no universally “good” materials

Refer to Building Science Corp's website for more info

- "Enclosures that work"
  - http://www.buildingscience.com/doctypes/enclosures-that-work
- "Designs that work"
  - http://www.buildingscience.com/doctypes/designs-that-work
- "Understanding vapor barriers"
  - http://www.buildingscience.com/documents/digests/bsd-106-understanding-vapor-barriers

Below-grade enclosures (residential)

Uninsulated concrete foundation wall and slab

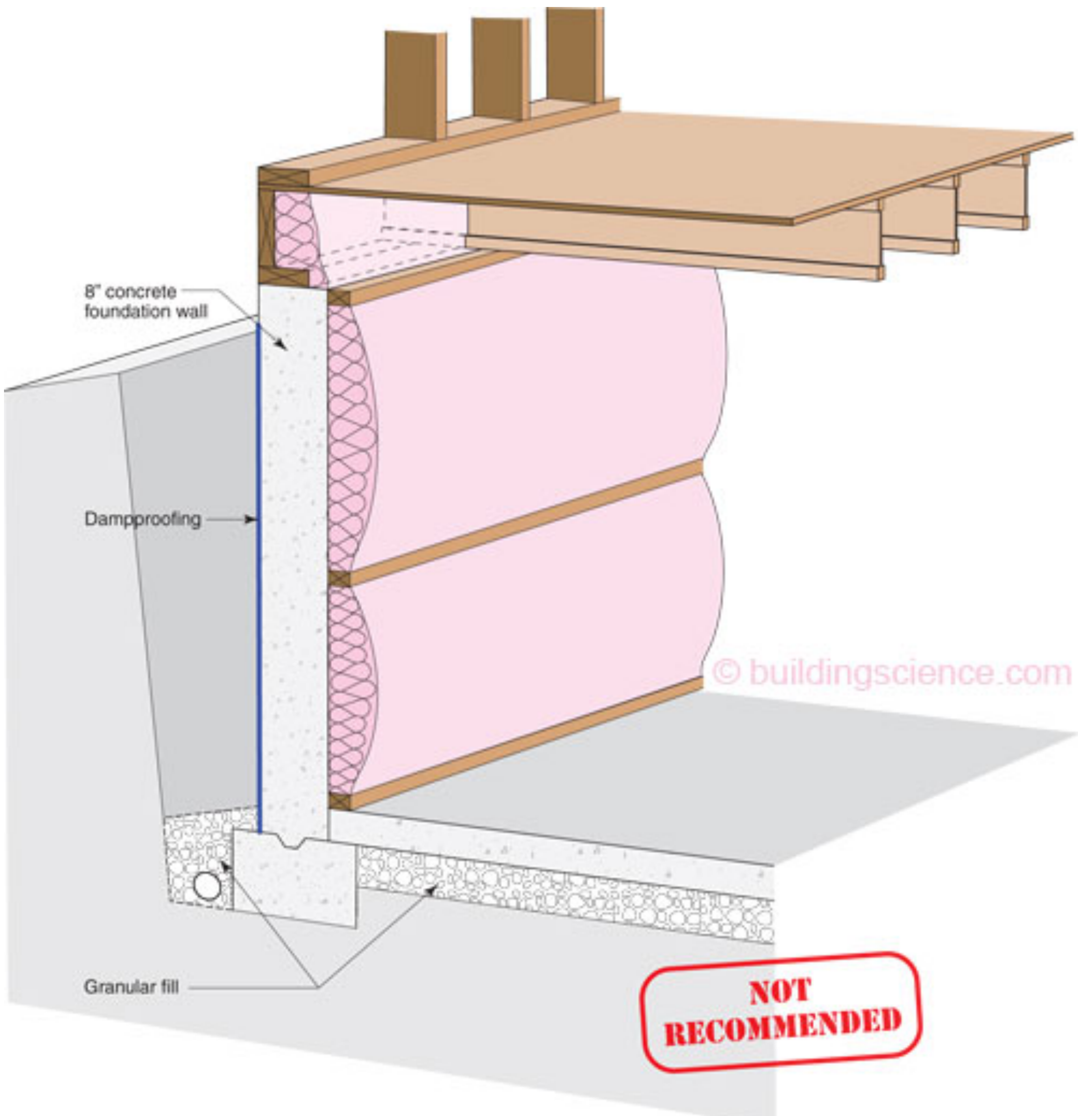


- No thermal control
- Not even allowed by code if basement is conditioned
- No moisture control
- Water vapor diffusion and capillary action are near-constant moisture sources

http://www.buildingscience.com/

Below-grade enclosures (residential)

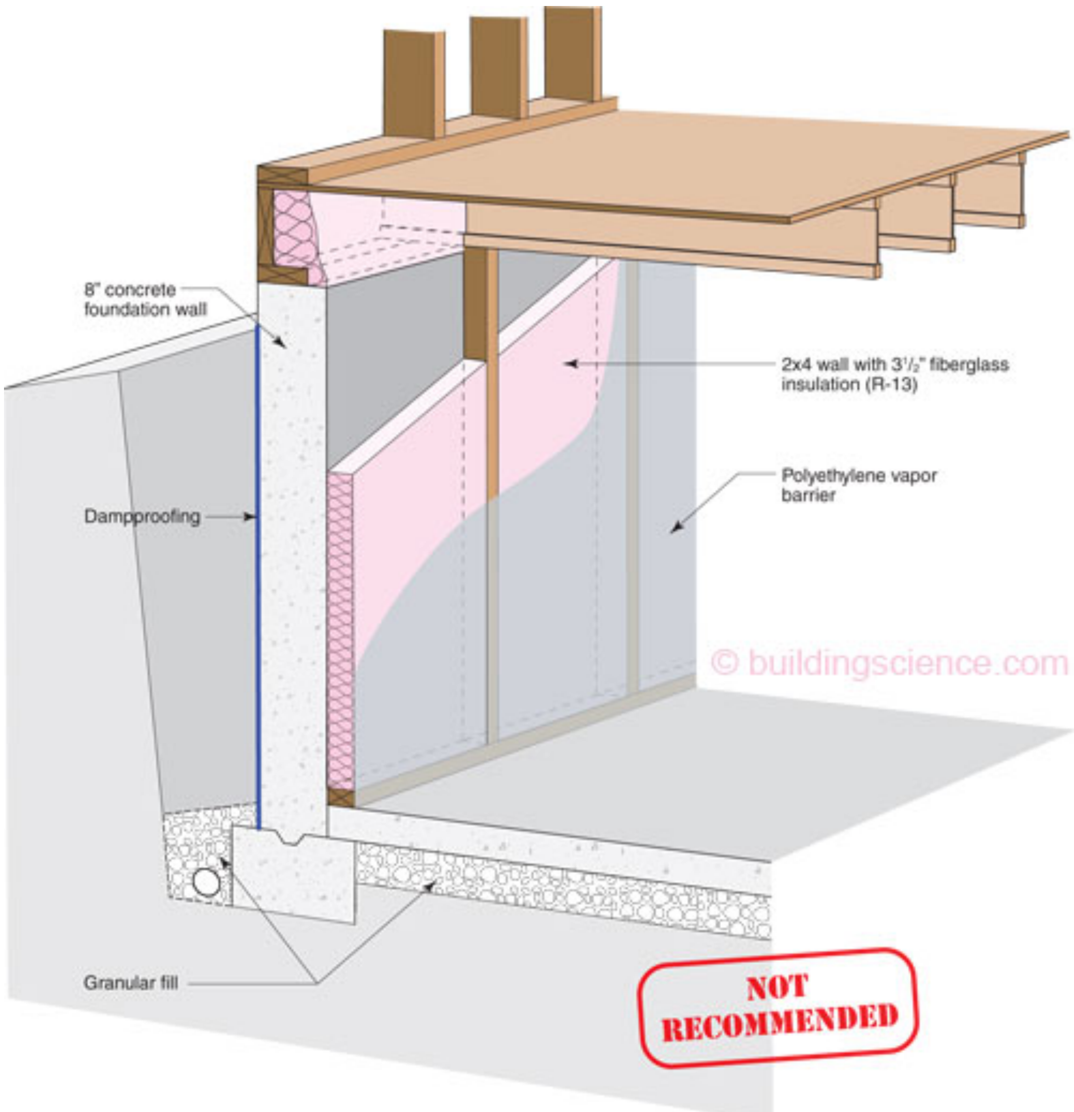
Code minimum R-10 (IP) continuous insulation in a framed wall



- Slab not insulated
- Better thermal control
- Inexpensive
- Sometimes wall insulation batt is covered with vapor barrier
- Moisture issues (batt is air and vapor permeable)
- High RH at concrete wall most of the year

Below-grade enclosures (residential)

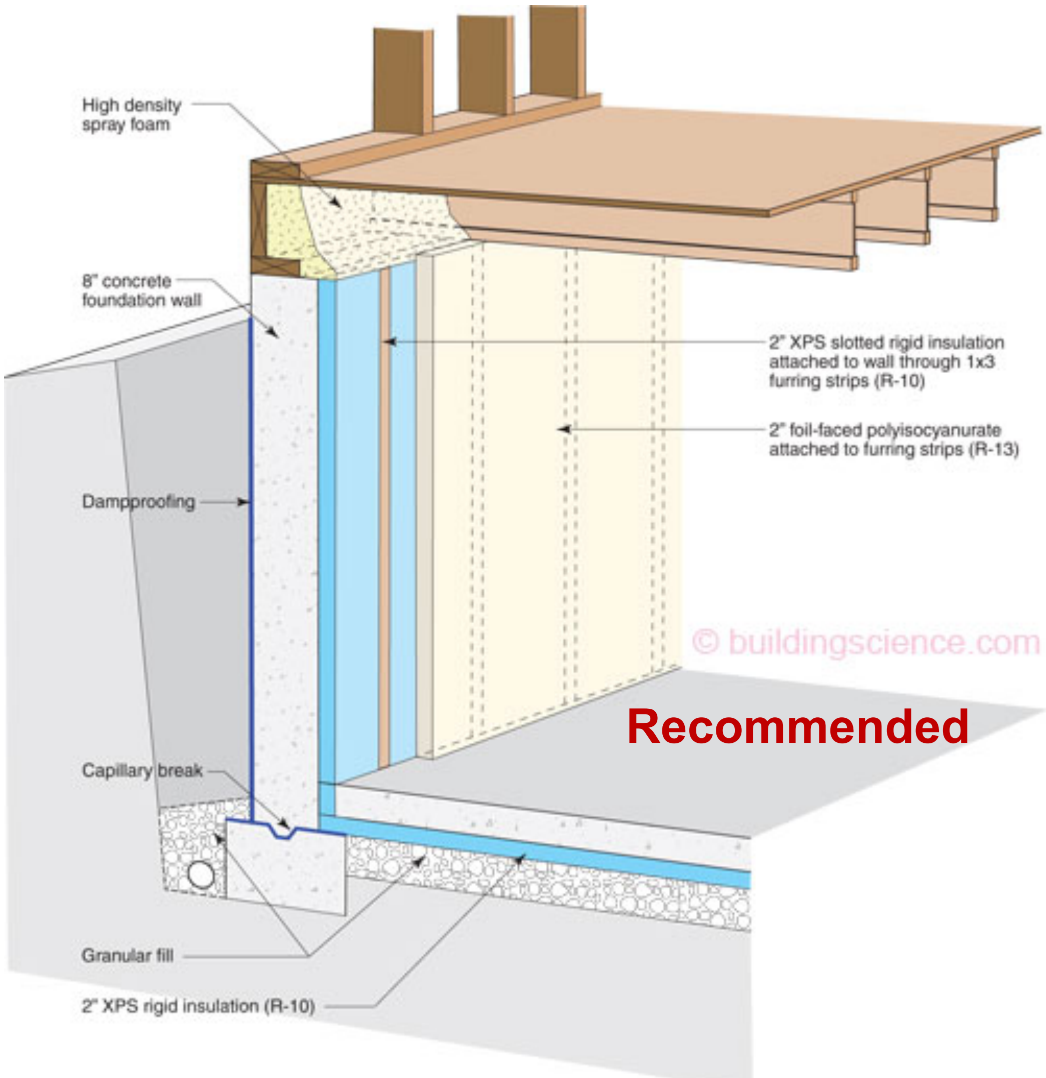
R-13 (IP) insulation w/ polyethylene vapor barrier in a 2x4 framed wall

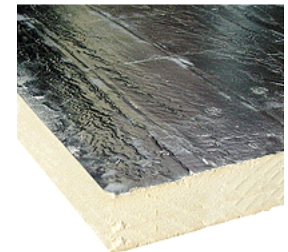


- Similar to last construction
- Moisture issues
- High RH at concrete wall most of the year
- Particularly a problem if there is any air leakage

Below-grade enclosures (residential)

2” XPS rigid insulation + 2” foil-face polyisocyanurate foam board

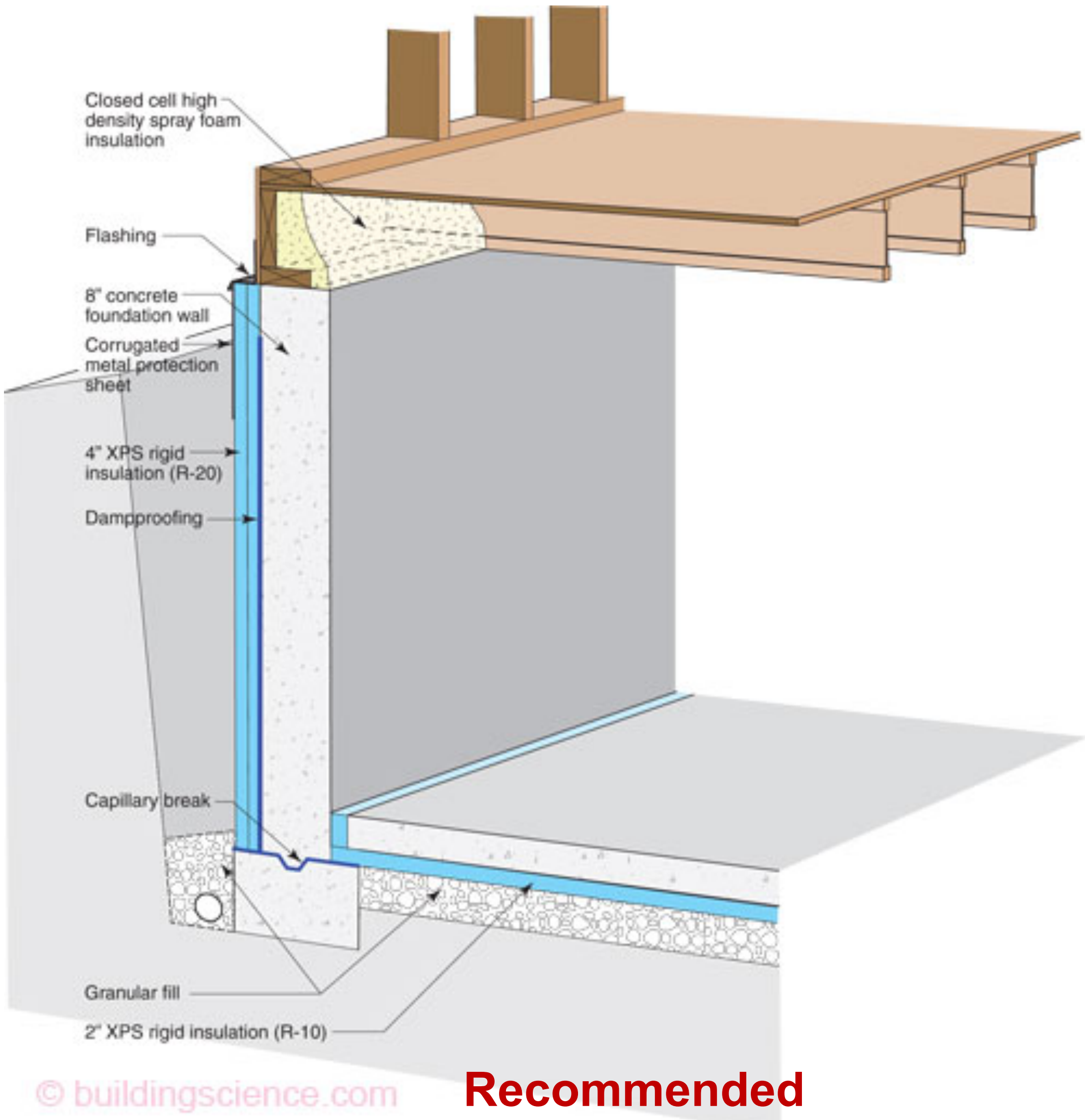




- Very good thermal control (R-23 walls)
- Water vapor diffusion is prevented
- Capillary action is prevented by the thermal/capillary break at the edge of the slab and top of footing

Below-grade enclosures (residential)

Rigid XPS exterior insulation



Recommended

- Very good thermal control (R-20 walls)
- Exterior insulation can be joined with first floor insulation
- Excellent resistance to vapor diffusion
- Capillary action is a potential problem (through the footing)
  - Need a break
- Exposed concrete provides moisture buffer after it dries
- May be hard to construct