Building Science

Foundations

Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

presented by www.buildingscience.com
Expansion of Conditioned Space

- Conditioned space boundaries moving towards exterior surfaces of building
- Garage isolated from house by air barrier/pressure boundary
- Garage ventilated and conditioned independently of rest of conditioned spaces
Mechanisms of Flow

- Liquid: Gravitational Hydrostatic Pressure, Capillary Suction Pressure, Osmosis Solute Concentration
- Vapor: Diffusion Vapor Pressure, Convective Air Pressure
Roof overhang screens wall (deflects rain)

Site grading slopes ground away from building over entire perimeter
Rain water falling on roof is collected in gutters

Overhang protects the ground around the foundation from getting saturated

Down spouts carry rainwater from the roof away from the foundation

Capillary break under plate

Polyethylene vapor diffusion retarder in direct contact with concrete slab

Ground slopes away from the foundation

Granular drainage pad (coarse gravel, no fines)

- Keep rain water away from the foundation perimeter
- Do not place sand layer over polyethylene vapor diffusion retarder under concrete slab
- Where vinyl flooring is installed over slabs, a low water-to-cement (w/c) ratio (≤ 0.45 or less is recommended) to reduce water content in the concrete; alternatively, the slab should be allowed to dry (less than 0.3 grams/24 hrs/ft²) prior to flooring installation
Rain water falling on roof is collected in gutters.

Overhang protects the ground around the foundation from getting saturated.

Flash roof into gutter.

Down spouts carry rainwater from the roof away from the foundation.

Capillary break under plate.

Polyethylene ground cover acting as both an air barrier and a vapor barrier.

Ground slopes away from the foundation.

Conditioned space.

Interior grade of crawlspace higher than surrounding grade.

- Keep rain water away from the foundation perimeter.
- If the interior crawlspace is lower than the exterior grade, a sub-grade perimeter footing drain is necessary as in a basement foundation.
- The crawlspace is conditioned space; it is part of the "interior" of the building and should be heated, cooled and ventilated as part of the building's heating, cooling and ventilating strategy.
Rain water falling on roof is collected in gutters
Overhang protects the ground around the foundation from getting saturated
Flash roof into gutter
Down spouts carry rainwater from the roof away from the foundation
Ground slopes away from the foundation

Concrete foundation wall
Groundwater flow is downward (not horizontal) under the influence of gravity to the perimeter drainage system
Capillary break over footing
Slab isolation joint
Polyethylene vapor diffusion retarder
Granular drainage pad (coarse gravel, no fines)

- Keep rain water away from the foundation perimeter
- Drain groundwater away in sub-grade perimeter footing drains before it gets to the foundation wall
Roof flashing

Vent stack

Concrete slab

Polyethylene vapor barrier

Granular drainage pad (no fines)

Sealant at all slab penetrations

Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack
Roof flashing

Vent stack

Polyethylene vapor barrier

Concrete slab

Sealant at all penetrations in air barrier

Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack
Concrete Porch Slab with Housewrap

- Wood stud wall
- Subfloor
- Band joist
- Treated mudsill
- Foundation wall
- Exterior sheathing
- Housewrap, WRB or building paper
- Waterproof membrane
- Sealant
- Tar paper as bond break
- Concrete porch
- 4" stone pad (no fines)
- Undisturbed/compacted earth
**Concrete Porch Slab with Insulating Sheathing**

- Wood stud wall
- Subfloor
- Band joist
- Treated mudsill
- Foundation wall
- Exterior finish
- 1" insulating sheathing
- Waterproof membrane
- Tar paper as bond break
- Sealant
- Concrete porch
- 4" stone pad (no fines)
- Undisturbed/compacted earth
Control joint at steps in foundation wall

Control joints at corners

Control joints are sealed with flexible sealant at the exterior prior to backfilling

Control joints at window openings

Sealant

Diagonally cut 2 x 2's in forms provide goose neck joint

Saw cut joint
Garage foundation
(Isolated from basement foundation for frost heave protection)

Perimeter drain pipe around exterior of garage foundation

Bond break material

See Figure 4.4
Isolation joint between garage foundation and basement foundation

The diamond shaped joints may be omitted if column footings are below floor level and the column is wrapped with two layers of sheathing membrane or joint filler to break the bond

Concrete foundation wall control joints

Slab control joints

Exterior insulation can act as garage foundation isolation joint

Column isolation joints

Column

Sump (airtight cover)

Bond break between slab and foundation wall at slab perimeter

Perimeter drain pipe connected to sump

Through footing pipes connect granular drainage pad under slab to perimeter drain pipe
Structure of house on foundation must be shifted outward to compensate for thickness of exterior insulation

Protection layer/system
Heat Loss
Calculating capillary rise

\[ h = \frac{2 \sigma \cos \theta}{g \rho r} \]
Capillary rise versus diameter

diameter [inch]
capillary rise [inch]
Capillary Flow

Siding laps
Continuous fillet bead of urethane sealant between 2” XPS bond break and foundation wall
Continuous fillet bead of urethane sealant between 2” XPS bond break and concrete slab
2” XPS bond break
4” concrete slab with welded wire mesh placed at mid-depth
6 mil polyethylene vapor barrier
2” XPS rigid foam slab insulation
Embedded hydronic tubing

Free-draining backfill
Liquid-applied capillary break (must dry tack-free) applied on top of footing prior to placing/casting concrete foundation wall
Keyway
Filter fabric placed under perimeter drain and wrapped around gravel
Coarse gravel (no fines)
4” PVC pipe through bottom of footing connecting interior and exterior gravel beds
4” perforated perimeter drain

4” gravel pad (no fines)
Filter fabric
Undisturbed native soil or engineered fill as determined by soil conditions
Continuous concrete footing 2’-0” wide and 10” deep
Sealant, adhesive or gasket (typ.)

Drainage plane

Sealant

Sill gasket (capillary break)

$\frac{3}{8}$ ” fibercement
3” spray polyurethane foam (2 lb/ft³ density)

1½” metal stud wall

Gypsum board thermal barrier

¾” drainage mat (filter fabric side facing up)

2” extruded polystyrene (XPS)

New concrete slab

Existing slab
Vapor semi-permeable assembly allows moisture to pass in a slow, controlled manner.
Vapor pressure on top of slab and under slab equalizes, thereby stopping capillary transfer of water and soluble mineral salts (moisture content in air space and under slab remains the same; i.e. "wet")
Rigid extruded polystyrene
Polymer based (PB) stucco
Plastic L-bracket for insect/rodent protection of rigid insulation
Weep screed/capillary break/termite shield for stucco rendering over polyethylene

For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Concrete slab

Granular capillary break and drainage pad (no fines)
Rigid insulation as bond break material
Concrete foundation wall
Concrete footing below frost depth
Perimeter edge of slab not protected below grade

Sub-slab vapor barrier

Ground saturated with water
Latex paint (vapor permeable, but water repellent)

Polyethylene "skirt" attached to form; remains in place after form is removed

Capillary break under framing (polyethylene strip)

Capillary break (plastic/polyethylene ground cover) extending under grade beam and upwards to grade
Wood floor

Felt slip sheet

Plywood

Two-ply felt set in mastic

Granular base
Wood floor
Topside fluid-applied vapor barrier
Concrete slab
Polyethylene vapor barrier
Granular base
Hollow Back
Scratch Back
Hollow or Scratch Back
Continuous exterior insulation

Cladding

Rodent protection for continuous rigid insulation

Cavity insulation

Gypsum board

Sealant, adhesive or gasket

Sill gasket

Masticed membrane strip

Polyethylene

Concrete slab

For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Dampproofing

Granular capillary break and drainage pad (no fines)

Rigid insulation as bond break material

Concrete foundation wall

Concrete footing below frost depth

Capillary break
Continuous exterior insulation

Cladding

Rodent protection for continuous rigid insulation

For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Dampproofing

Concrete foundation wall

Cavity insulation

Gypsum board

Sealant, adhesive or gasket

Sill gasket

Mastic membrane strip

Concrete slab

Granular capillary break and drainage pad (no fines)

Polyethylene

Rigid insulation as bond break material

Concrete footing below frost depth

Capillary break
Continuous exterior insulation

Cladding

Rodent protection for continuous rigid insulation

Gypsum board

Sealant, adhesive or gasket

Sill gasket

Masticed membrane strip

Polyethylene

Concrete slab

For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Dampproofing

Concrete foundation wall

Geotextile (filter fabric)

Granular capillary break and drainage pad (no fines)

Rigid insulation as bond break material

Concrete footing below frost depth

Capillary break
Continuous exterior insulation

Cladding

Rodent protection for continuous rigid insulation

Cellular PVC protection board

For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Rigid insulation

Cavity insulation

Gypsum board

Flashing set in mastic sealed to slab

Sealant, adhesive or gasket

Sill gasket

4" concrete slab

4" granular capillary break and drainage pad (no fines)

Concrete grade beam

Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break
Continuous exterior insulation

Cladding

Rodent protection for continuous rigid insulation

Cellular PVC protection board

For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Dampproofing

Rigid insulation

Cavity insulation

Gypsum board

Flashing set in mastic sealed to slab

Sealant, adhesive or gasket

Sill gasket

4" concrete slab

4" granular capillary break and drainage pad (no fines)

Concrete grade beam

Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break
Building wrap
Sealant, adhesive or gasket (typ.)
2x4
Capillary break
Rodent protection for continuous rigid insulation
For insect protection provide 3’-0” of mulch and then drought-resistant plants

T&G subfloor
1 1/2” rigid insulation
Plate under load bearing walls only

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Polyethylene
Building wrap
Sealant, adhesive or gasket (typ.)
2x4 Capillary break
Rodent protection for continuous rigid insulation
For insect protection provide 3'-0" of mulch and then drought-resistant plants

Ground slopes away from wall at 5% (6 in. per 10 ft.)

T&G subfloor
1 1/2" rigid insulation
Plate under load bearing walls only

Polyethylene
For insect protection provide 3'-0" of mulch and then drought-resistant plants.

Ground slopes away from wall at 5% (6 in. per 10 ft.)

Polyethylene
From the US Army Corps Engineers Extreme Frost Penetration (in inches) based on state averages.
Frost Line
Snow cover

Insulated and heated; frost heave protected
Capillarity + Salt = Osmosis

- Mineral salts carried in solution by capillary water
- When water evaporates from a surface the salts left behind form crystals in process called efflorescence
- When water evaporated beneath a surface the salts crystallize within the pore structure of the material in called sub-efflorescence
- The salt crystallization causes expansive forces that can exceed the cohesive strength of the material leading to spalling
1. Evaporation

Water with salt in solution travels in porous material via capillary flow to surface where evaporation occurs.

2. Salt is left behind as water evaporates; process leads to an ever-increasing concentration of salt as evaporation continues.

3. Water rushes to dilute concentration of salt leading to potential huge hydrostatic pressures.

4. "Spalling"

Surface breaks apart and flakes when hydrostatic pressure due to "osmosis" exceeds cohesive strength of material.
Diffusion + Capillarity + Osmosis = Problem

- Diffusion Vapor Pressure: 3 to 5 psi
- Capillary Pressure: 300 to 500 psi
- Osmosis Pressure: 3,000 to 5,000 psi
Mortar “eaten” away as drying happens from within the mortar matrix

Salts left behind on surface in the form of crystals ("efflorescence")

Evaporation from surface film of water

Capillary flow of salts in solution
Lime mortar “eaten” away over time “sacrificing” itself to protect brick and masonry units.

Evaporation from thick lime-based mortar rendering.

Capillary flow of salts in solution.
Wood floor framing embedded into masonry wall

Stainless steel cap flashing regletted into exterior wythe

Vapor permeable layer to prevent evaporation or drying inward

1.5 χ

Sacrificial layer

χ

Wood floor framing embedded into masonry wall

Stainless steel cap flashing regletted into exterior wythe

Stainless steel capillary break regletted 1/3 of wall thickness

Vapor permeable layer to prevent evaporation or drying inward

3/4 χ

Sacrificial layer

χ
16 Million Gallons are Pumped Out of the Tunnels Each Year....