Upgrading Below-Grade Spaces: Challenges & Opportunities

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
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- Prologue: Brief Introduction to Building America
- Act 1: Upgrade Below Grade
- Act 2: Challenges of Basement Insulation
  - Moisture Management Primer
- Act 3: Foundation Insulation for Existing Homes
  - Managing Risks
  - Best Practices
  - New Approaches

Building Technologies Program

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Building America

National Renewable Energy Lab

Introduction to Building America

- Focus is to reduce energy use by 50% in new houses and 30% in existing residential buildings.
- Promote building science solutions using a systems engineering and integrated design approach.
- “Do no harm” => we must ensure that safety, health, and durability are maintained or improved.
- Accelerate the adoption of high-performance technologies.

Building America
U.S. Department of Energy

Industry Research Teams

BA-PIRC

BARA
BUILDING AMERICA RETROFIT ALLIANCE

ARIES Collaborative

Alliance for Residential Building Innovation

NorthernSTAR

CARB
Consortium for Advanced Residential Buildings

bsc Building Science Corporation

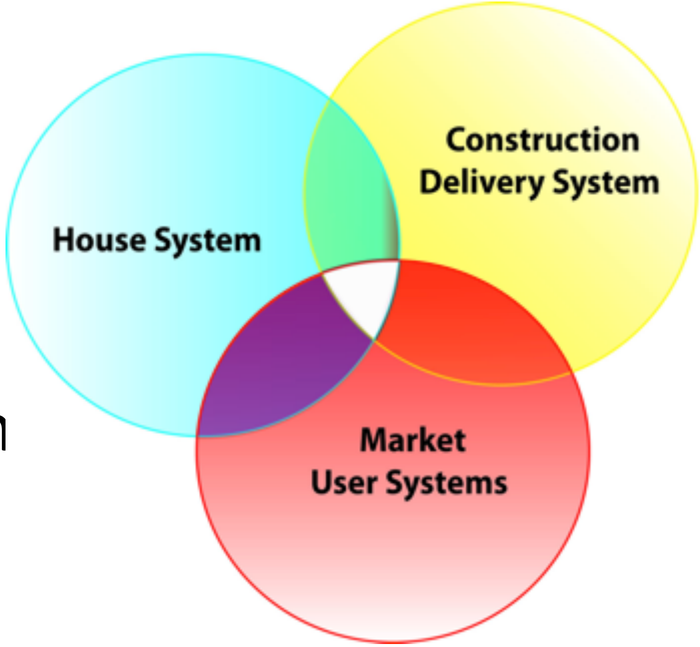
IBACOS
Home Quality + Performance

NAHB RESEARCH CENTER

PARR
The Partnership for Advanced Residential Retrofit

NorthernSTAR
A Building America partner in research, innovation, and real home solutions.

- Exploring the next generation of high performance homes for cold climates, using
  - building science as our compass
  - research as our guide



- Taking a total systems approach
  - House (physical) system
  - Construction delivery system
  - Market (consumer-user) system

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A Building America partner in research, innovation, and real home solutions.

- Research and deployment of a whole-house, systems engineered, integrated design approach to select the least cost and highest value features including:
  - Climate-specific designs
  - Highly-efficient walls, foundations, roofs
  - Super-efficient windows & doors
  - Passive solar space & water heating
  - State-of-the-art heating & cooling systems
  - Advanced hot water, appliances, lighting
  - Solar thermal and solar electric systems
  - Moisture resistant construction
  - Healthy indoor air

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- Research Team Lead: University of Minnesota
  - Cold Climate Housing Program – Pat Huelman
  - Center for Sustainable Building Research – John Carmody

- Research Team Partners
  - Center for Energy and Environment – David Bohac
  - Building Knowledge, Inc. – Ed VonThoma
  - Energy Center of Wisconsin – Dan Cautley

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- University Research Partners
  - Advanced Building Systems Group (BBE)
  - Initiative for Sustainable Enterprise (IonE/IREE)
  - Energy Systems Design Program (BBE)
  - Mechanical Engineering (CSE)
  - Clean Energy Resource Teams (CFANS)
  - Natural Resource Research Institute (UM-D)

- University Support
  - College of Food, Agricultural & Natural Resource Sciences
  - Initiative for Renewable Energy and Environment
  - University of Minnesota Extension

- External Research Partners
  - Building Green
  - Conservation Technologies
  - Hunt Utilities Group
  - McGregor Pearce
  - Verified Green
  - Wagner Zaun Architecture

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- Building Enclosure
  - CertainTeed
  - DuPont - Building Innovations
  - Johns Manville
  - BASF
  - Dow
- Windows and Fenestration
  - Andersen Corporation
  - Cardinal Corporation
  - Marvin Windows and Doors
- Mechanical Systems
  - AIM
  - A.O. Smith
  - Panasonic
  - RenewAire
  - Venmar Ventilation
- Builders/Remodelers/Suppliers
  - Christian Builders
  - JET Construction & Remodeling
  - Lumber Dealers Supply
  - Nor-Son Construction
  - Northway Construction
  - TDS Custom Construction
  - Thompson Homes
  - Wausau Supply Company
  - Cobblestone Homes
  - Amaris Custom Homes
  - Cocoon Home Performance Solutions
  - Lambert Lumber
- Professional/Community
  - MN Office of Energy Security
  - NARI

- Current Research Portfolio
  - Foundation Insulation Systems
    - Full-scale testing of interior systems at the CRRF
    - Exploring innovative retrofit options for masonry
  - Project Overcoat
    - Exterior insulation systems focused on airtightness of 1-1/2 story roof applications
  - Integrated Space & Water Heating Systems
    - In-situ monitoring in WX homes

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- Future Research Plans
  - Integrated Space & Water Heating
    - Laboratory optimization
  - Project Overcoat
    - Cost reduction (materials & labor)
  - Foundation Insulation for Existing Homes
    - Testing insulation system performance at the CRRF
    - Demonstrate "excavationless" method for exterior retrofit
  - Simplified Test Method for Combustion Safety

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Act 1. Upgrading Below Grade

- Basement Renovation Touches It All!
  - Combustion safety
  - Foundation moisture
  - Radon (& other soil gases)
  - Biologicals (mold, dust mites, etc.)
  - Garage gases (if attached)
- And front and center are uncontrolled…
  - negative pressures in basements
  - below grade moisture transport

Big, Bad, Boogie Men in the Basement

- Carpet on the slab
- Insulating the walls (from the interior)
- Egress windows
- Furnace change-out
- Ductwork changes
  - drywalling the ceiling
  - rim (or extended) joists to the garage
- Hot tub or sauna

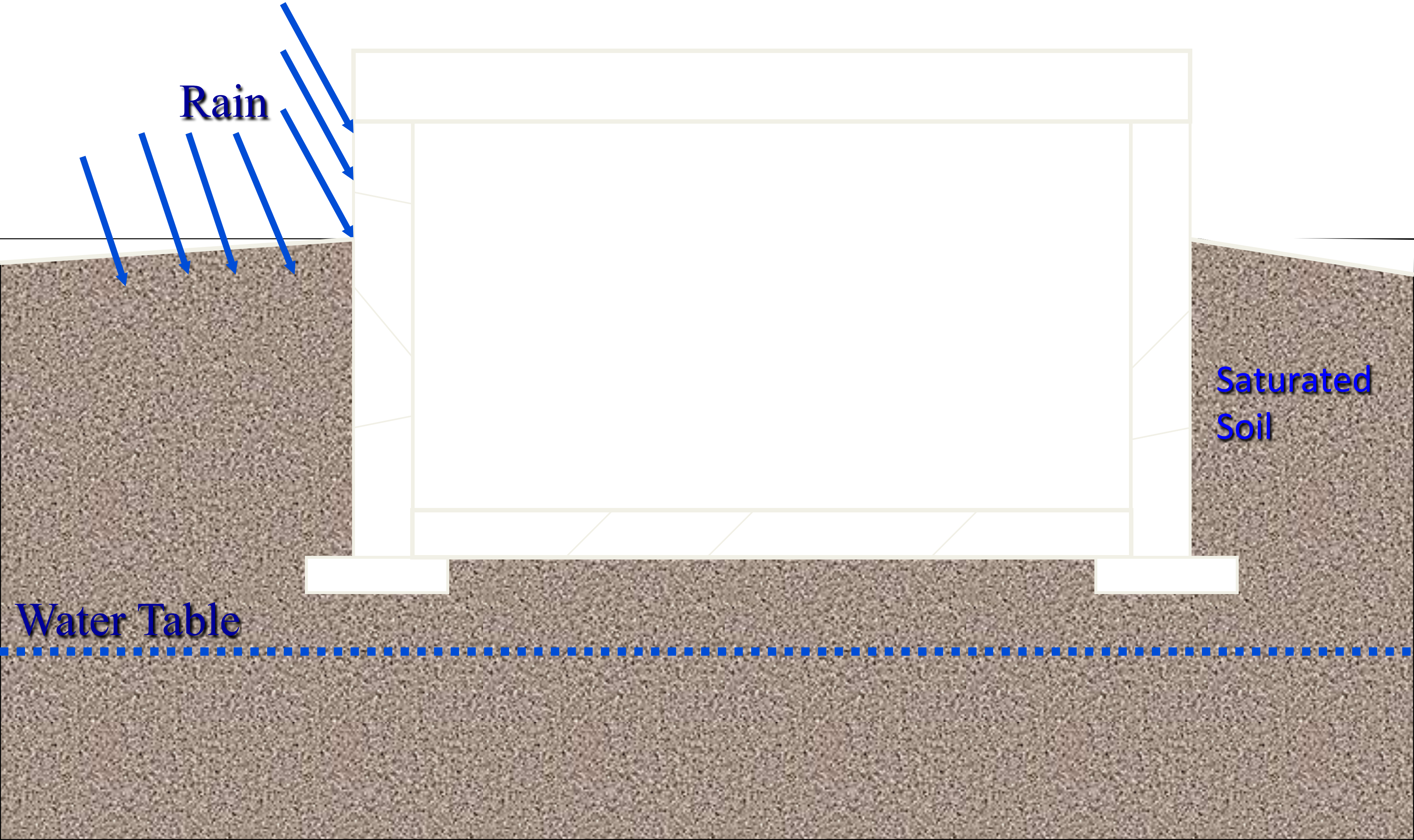
Basement Moisture Challenge

- Foundations get wet from four sides by all four moisture transport mechanisms.
  - bulk water, capillarity, diffusion, and air flow
- Foundations dry primarily to the inside.
  - generally by diffusion only
- So you must keep it dry from all four sides
  - or come up with an approach that promotes inward drying better than outward wetting.

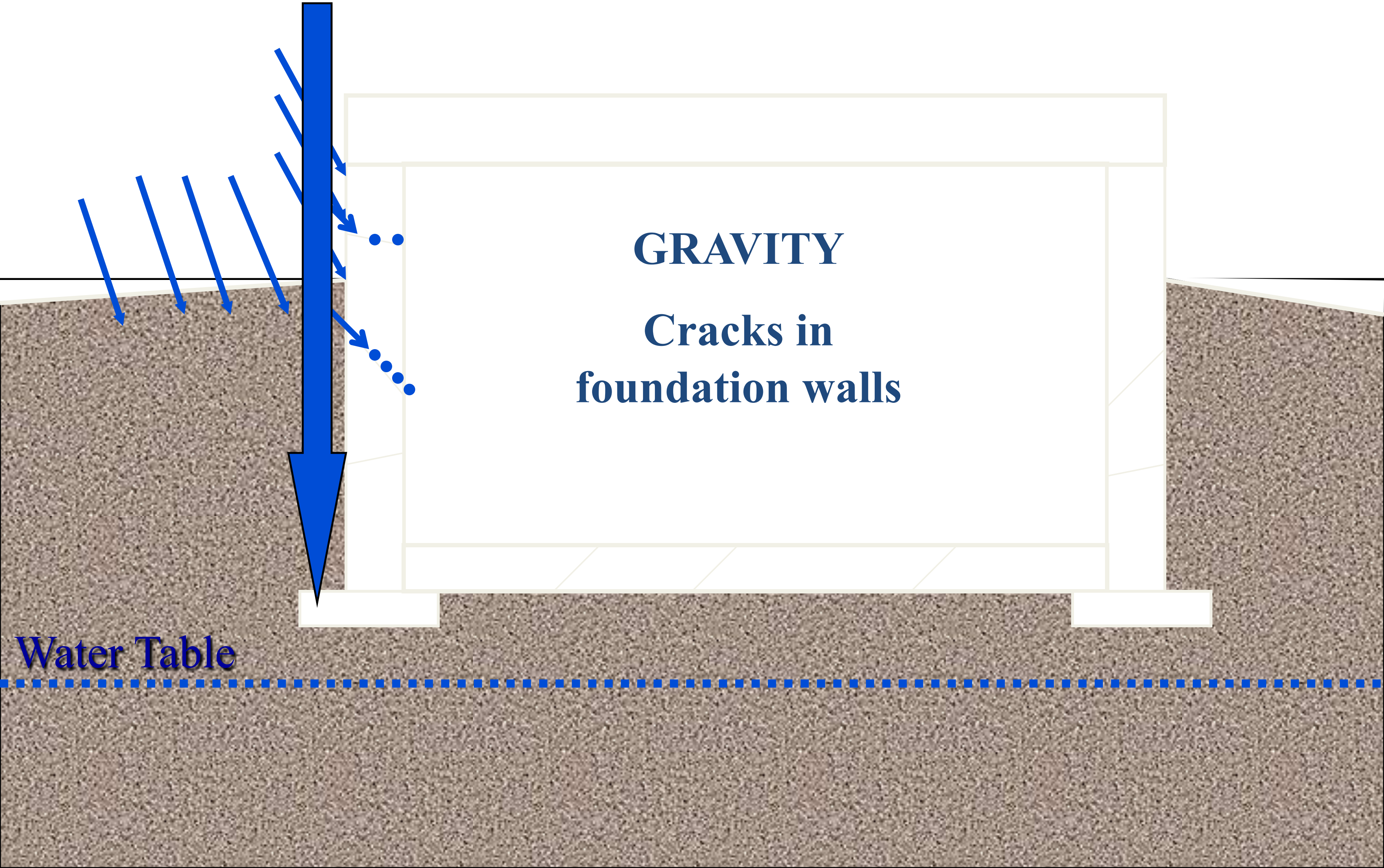
Basement Moisture Challenge

- Below Grade Moisture Transport is Complex
  - Liquid
    - gravity
    - capillarity
  - Vapor
    - air leakage
    - diffusion

Below Grade Moisture Sources



Below Grade Moisture Paths



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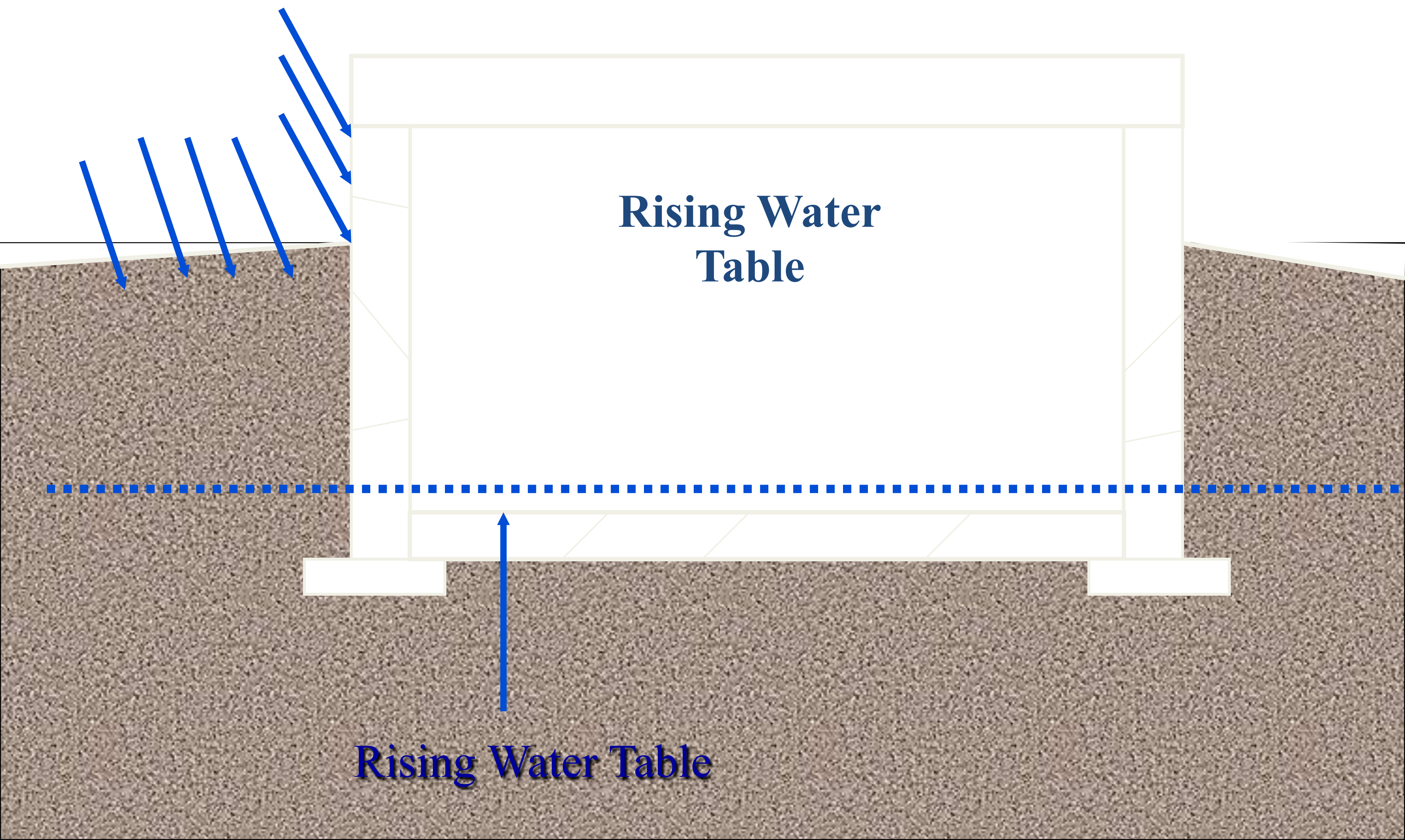
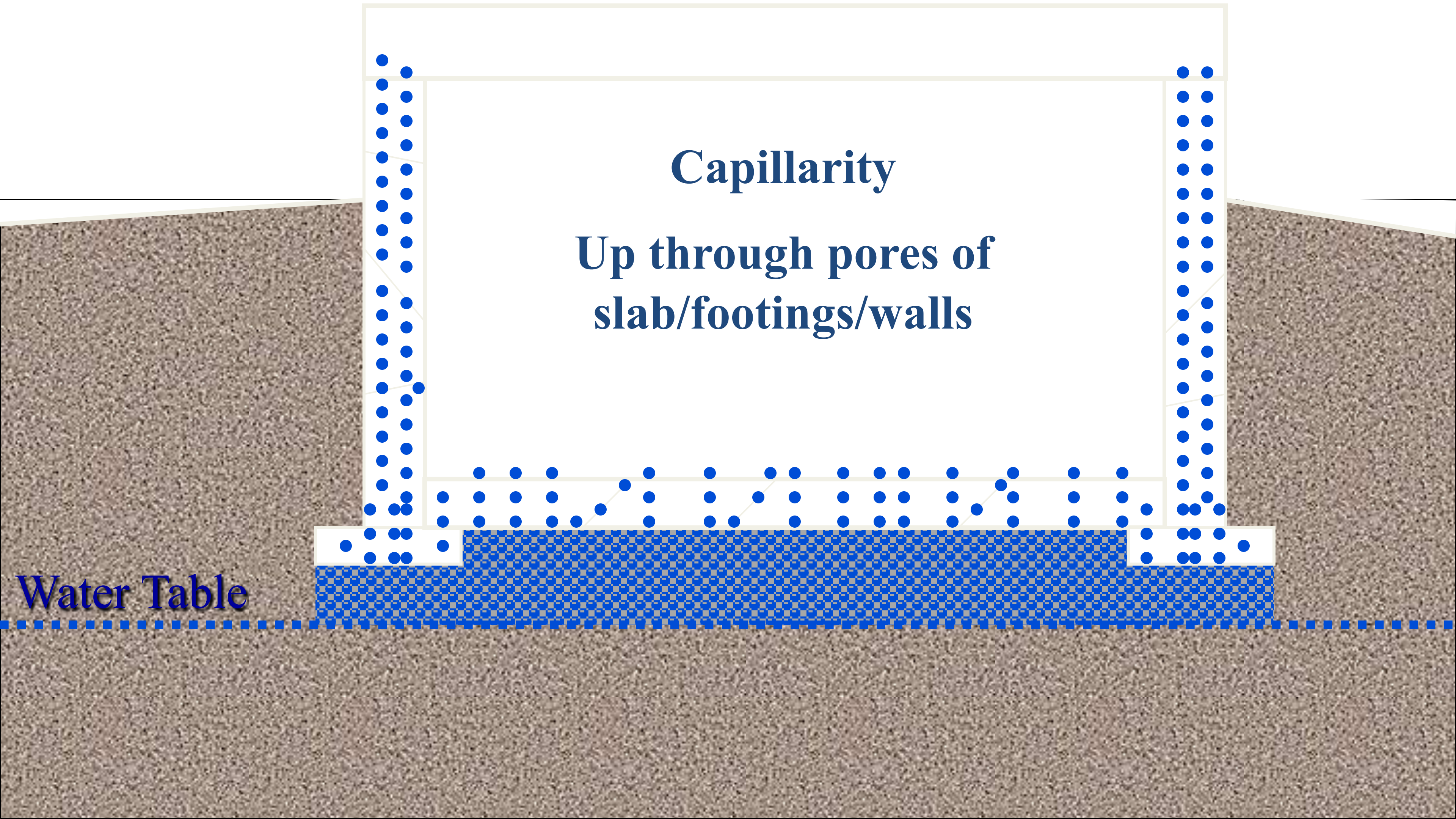
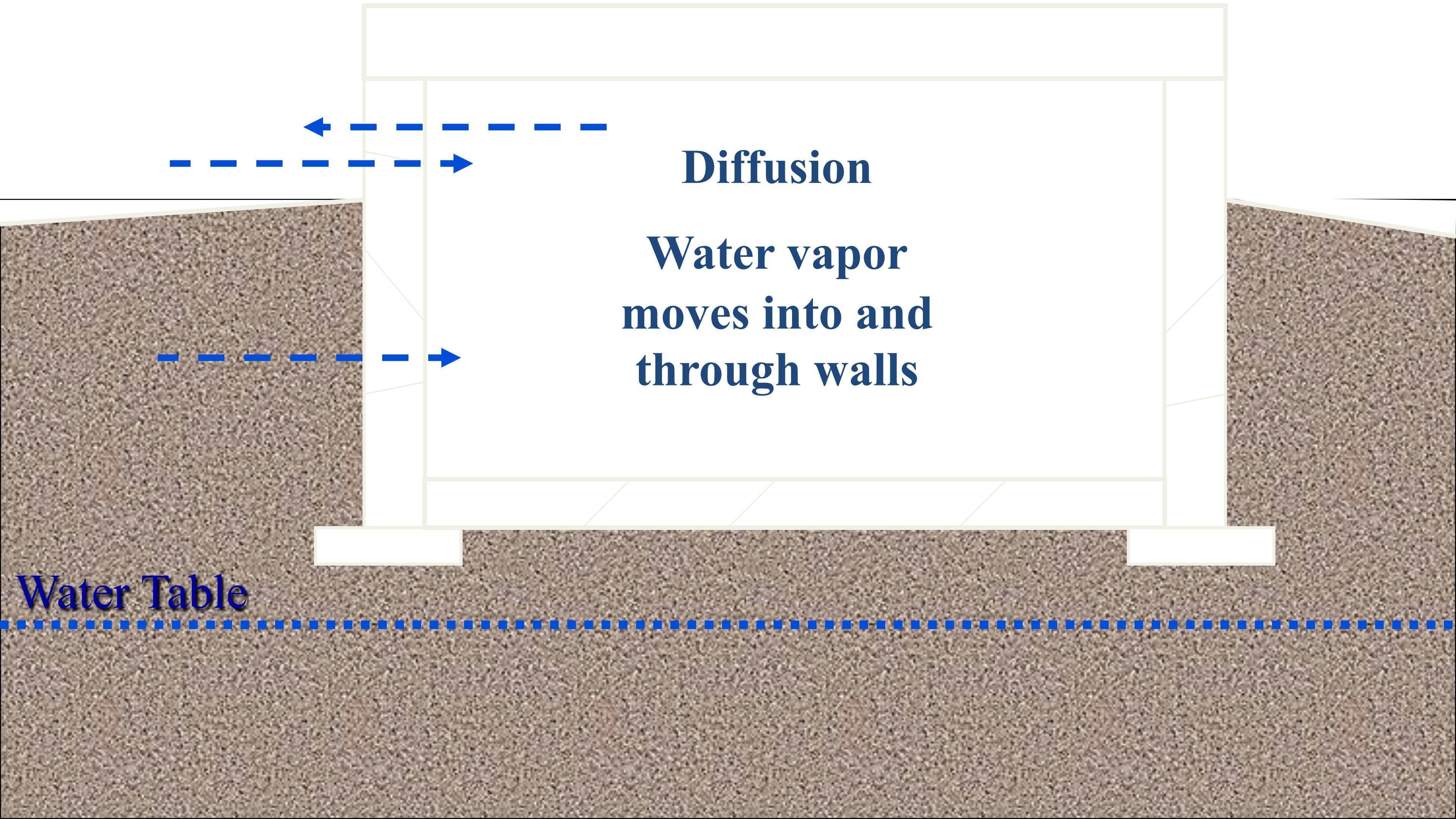


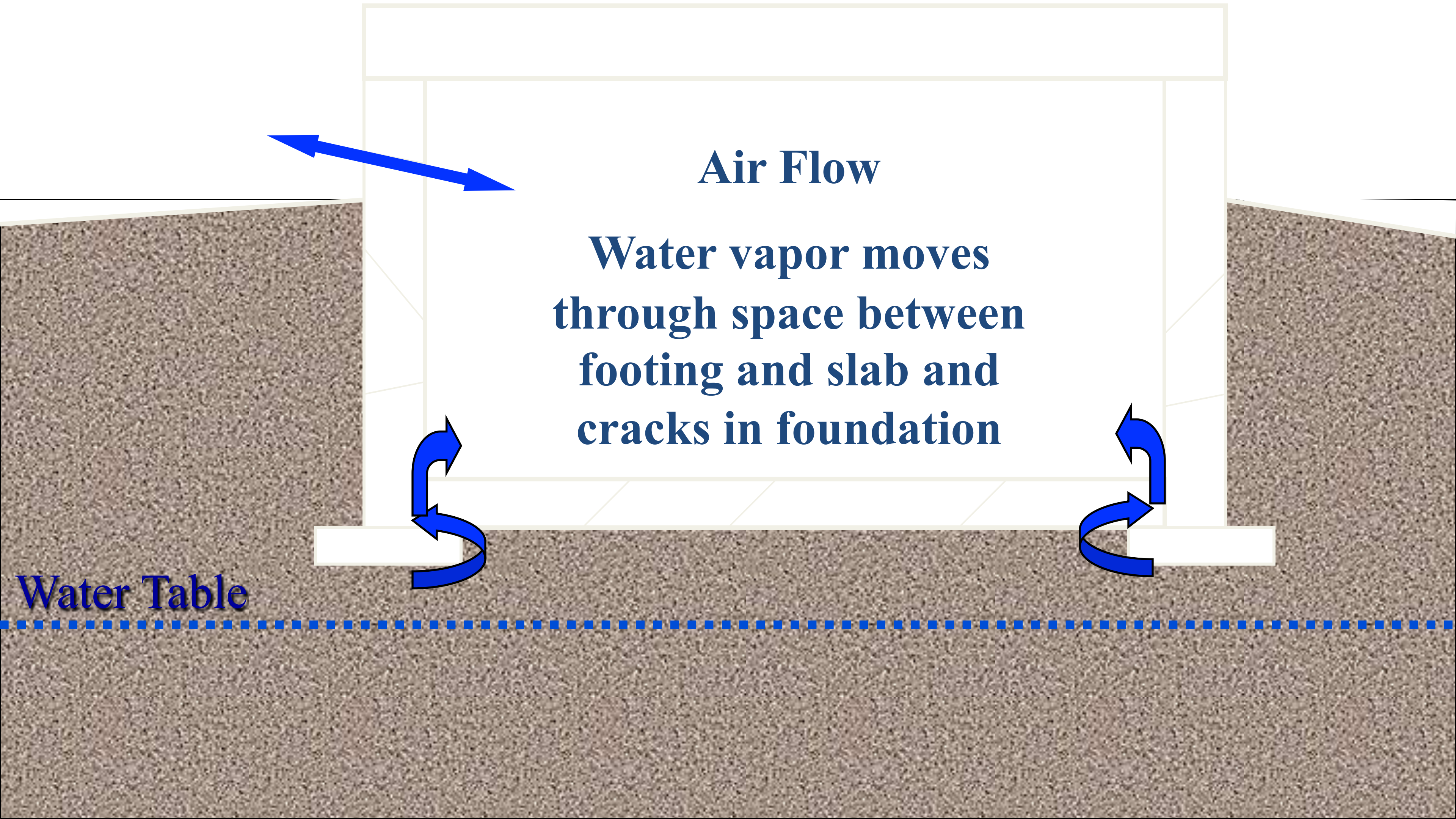
Below Grade Moisture Paths



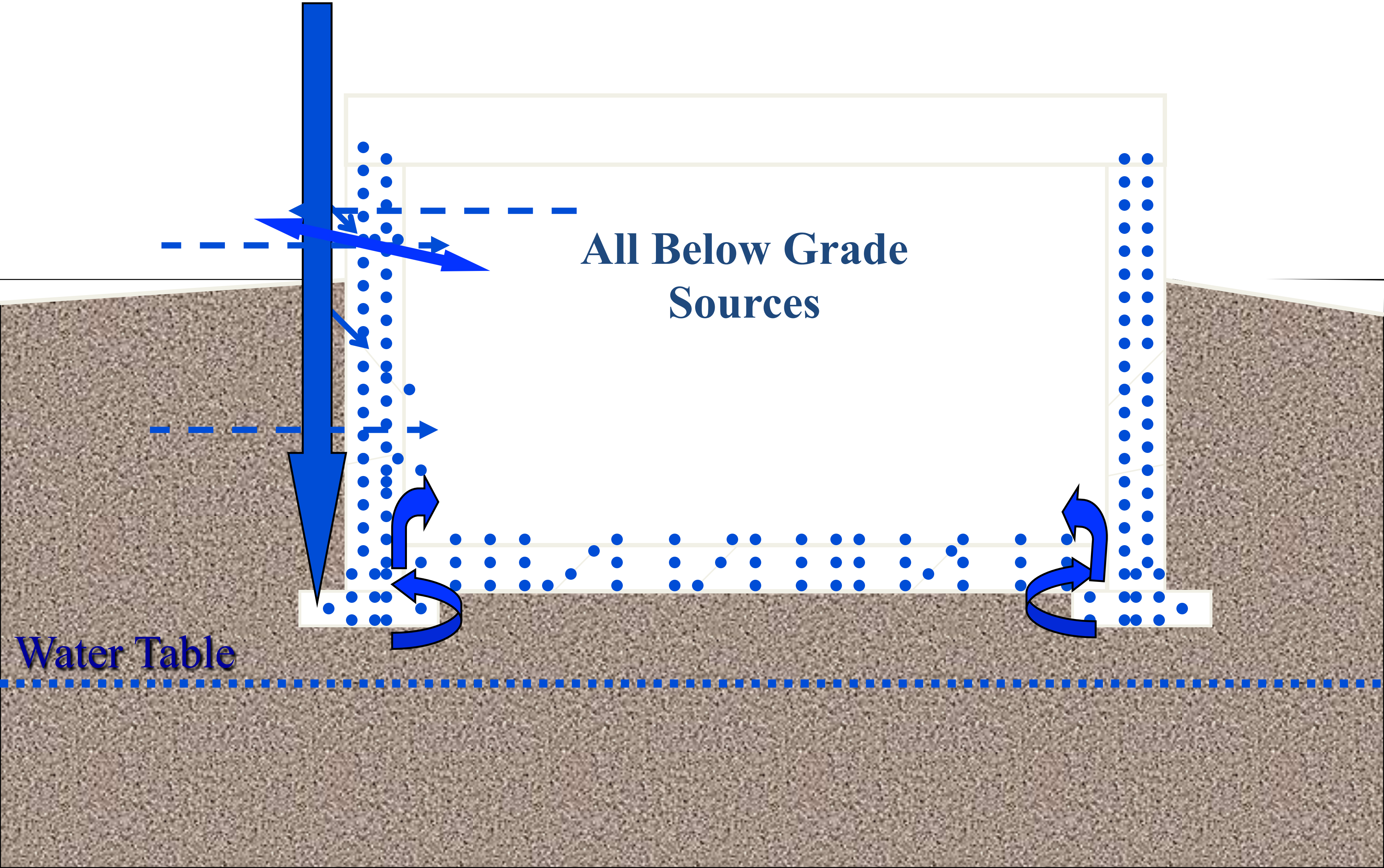
Below Grade Moisture Paths



Below Grade Moisture Paths



Below Grade Moisture Paths



Basement Remodeling – "Easy Button"

- Just say no to …
  - reverse grading, landscape irrigation, ponding, etc.
  - carpet on cold slabs
  - air-permeable interior wall insulation
  - chimney-vented combustion
- Just say yes to …
  - basement ventilation
  - aggressive humidity control (dehumidification or AC)
  - radon mitigation
  - paperless drywall (off the floor at least 1")

Act 2: Challenges of Basement Insulation

- Arguably the most challenging component of the building enclosure!
  - The physics is simple, but demanding
    - It starts out damp and cold and goes downhill from there, especially with interior insulation
  - Occupancy and expectations have changed
    - Basement use and finishing has increased dramatically.
  - A road less traveled
    - There is a serious lack of good and useful below-grade hygrothermal models and experimental data is limited.

So What is the Problem?

- Should we insulate basement walls of existing homes?
  - Energy => certainly
  - Moisture => probably
  - Indoor Air Quality => with caution
- How should we insulate basement walls?
  - It is a system.
  - It depends!

Basement Insulation: Benefits

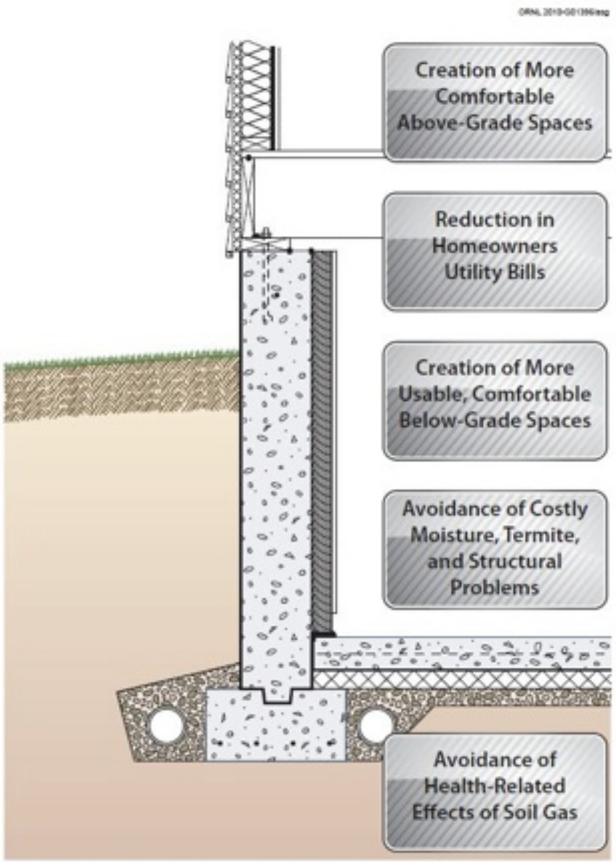
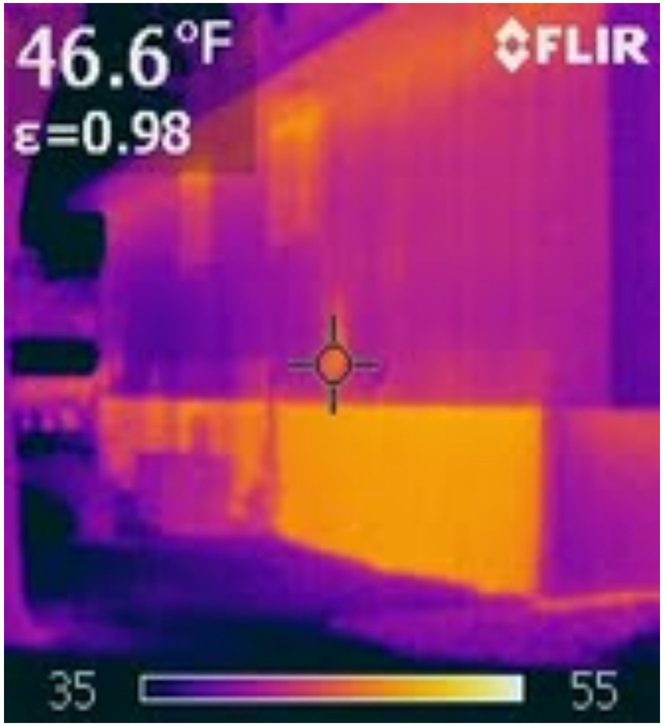


Figure 1-2: Benefits of Foundation Insulation and Other Design Improvements

Source: Oak Ridge National Laboratory

Basement Insulation: Opportunities

- Foundation heat loss can be significant in existing buildings.
- While below grade temperature differences might be smaller,
  - the surface area can be fairly large
  - the above grade portion is substantial, especially in older homes.
- There are a lot of uninsulated foundations in cold climates.



Basement Insulation: Obstacles

- Most existing foundations do not have waterproofing or capillary break at the footing.
- When you insulate the interior
  - the top of the wall is extremely cold in the winter and
  - the bottom can be below the dew point in the summer.
- The foundation wall must dry inward; interior insulation generally limits the drying potential.

Basement Insulation: Heat Transfer

- Below grade heat loss is always out
  - Winter heat loss is highest at the top and gets progressively less as depth increases.
  - Summer heat loss is higher at the bottom.
    - colder soil conditions & footing connection
- However, the above grade portion has similar issues to other above grade construction.
  - But not identical, due to vertical coupling.

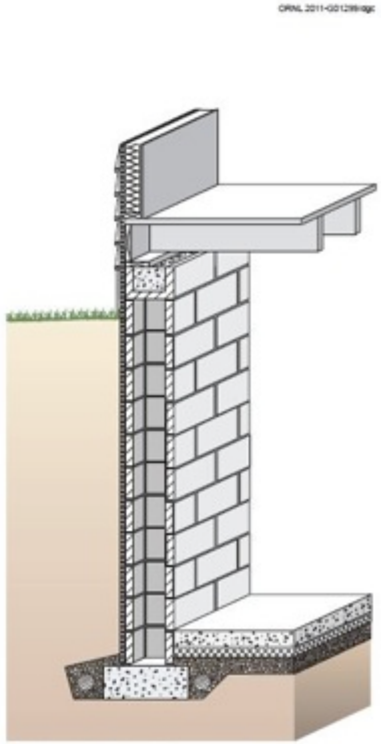


Figure 2-1: Concrete Masonry Basement Wall with Exterior Insulation

Source: Oak Ridge National Laboratory

Basement Insulation: Vapor Flow

- Below grade vapor flow is almost always inward.
- However, the above grade portion has similar issues to other above grade construction.
  - above grade can be outward in winter and inward in the summer
  - vertical coupling is huge, especially with concrete masonry

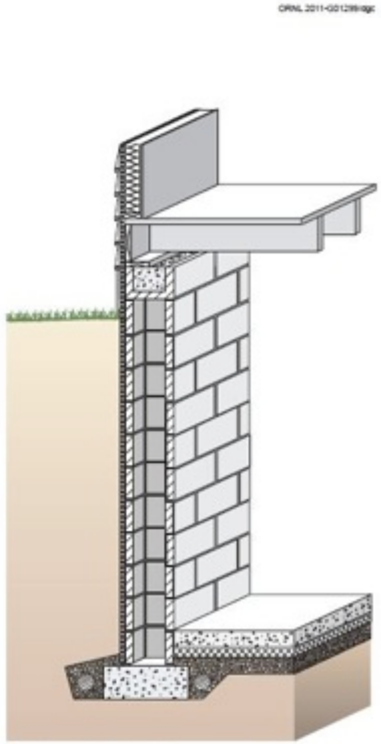


Figure 2-1: Concrete Masonry Basement Wall with Exterior Insulation

Source: Oak Ridge National Laboratory

Basement Insulation: Condensation

- Condensation Potential
  - Without insulation
    - condensation is limited.
  - With exterior insulation
    - condensation is virtually nil.
  - With interior insulation …
    - condensation may occur at the top in the winter and
    - condensation may occur at the bottom in the summer.

Basement Insulation: Drying

- Drying Potential
  - Without insulation
    - heat and moisture move freely.
  - With exterior insulation
    - drying to the inside is strong.
  - With interior insulation
    - outward warming is slowed and interior drying is severely limited.

Basement Insulation: Current Wisdom

- Exterior insulation is almost always preferable.
- If interior insulation is used,
  - must have a very dry foundation
    - quality dampproofing in very dry, free-draining soils
    - waterproofing in moderate soils
    - waterproofing and drainage in tight, wet soils
  - must have a capillary break
  - must have an interior air barrier
  - must use basement dehumidification.

A Reality Check

A Reality Check

A Reality Check

A Reality Check

A Reality Check

A Reality Check

A Reality Check

Basement Assessment

- A Holistic Approach to Walls and Floors
  - Assessment of Site Conditions
  - Assessment of Basement Conditions
  - Assessment of Critical Foundation Details
  - Assessment of Interior Conditions
  - Identify Moisture Potential and Risk
  - Select Appropriate Wall and Floor System

Basement Assessment

- Key Assessment Tools
  - Blower door; infrared camera; thermometer
  - Moisture meter & hygrometer or psychrometer
  - Testing: radon, vapor emissions, mold, etc.
  - Digital pressure gages
    - Including sub-slab pressure mapping
  - Fiber optic camera / borescope
  - Core drilling

Basement Assessment

- Assessment of Site Conditions
  - Common warning signs
    - tight soils
    - high water table
    - poor site drainage
  - Other considerations
    - roof drainage
    - landscaping plans
    - irrigation system

Basement Assessment

- Assessment of Basement Conditions
  - Distance of basement floor to water table
  - Exterior drainage
    - type of backfill
    - exterior drainage system
    - slope and drainage
    - gutters, downspouts and extensions
  - Interior drainage
  - Foundation exposure above grade

Basement Assessment

- Assessment of Critical Foundation Details
  - Type of foundation
    - block vs. poured concrete
  - Type of drainage system
    - drainage level
  - Step footing location
    - block vs. poured concrete
  - Underslab conditions
    - horizontal drainage
  - Presence and location of capillary breaks

Basement Assessment

- Assessment of Interior Conditions
  - Interior condensation
    - slab/foundation wall temperatures
    - humidity control
  - Ventilation (for winter moisture control)
    - type of ventilation
    - quantity of ventilation available
  - Dehumidification (for summer moisture control)
    - air-conditioning (including set-up and use)
    - dedicated dehumidification

Basement Assessment

- Identify Moisture Potential => Very High Risk
  - Tight soils or high water table
  - Block walls
    - with step down footings below drainage
  - Uncertain dampproofing / waterproofing
  - Poor indoor humidity control

Basement Assessment

- Identify Moisture Potential => High Risk
  - Generally dry soils
  - Block walls
    - With no step footings below drainage
  - Concrete
    - with step down footings below drainage
  - Uncertain underslab drainage
  - Uncertain capillary break

Basement Assessment

- Identify Moisture Potential => Moderate Risk
  - Very dry, free-draining soils
    - or verifable dampproofing and drainage
  - Concrete walls
    - no step footings
  - Good underslab drainage layer

Basement Assessment

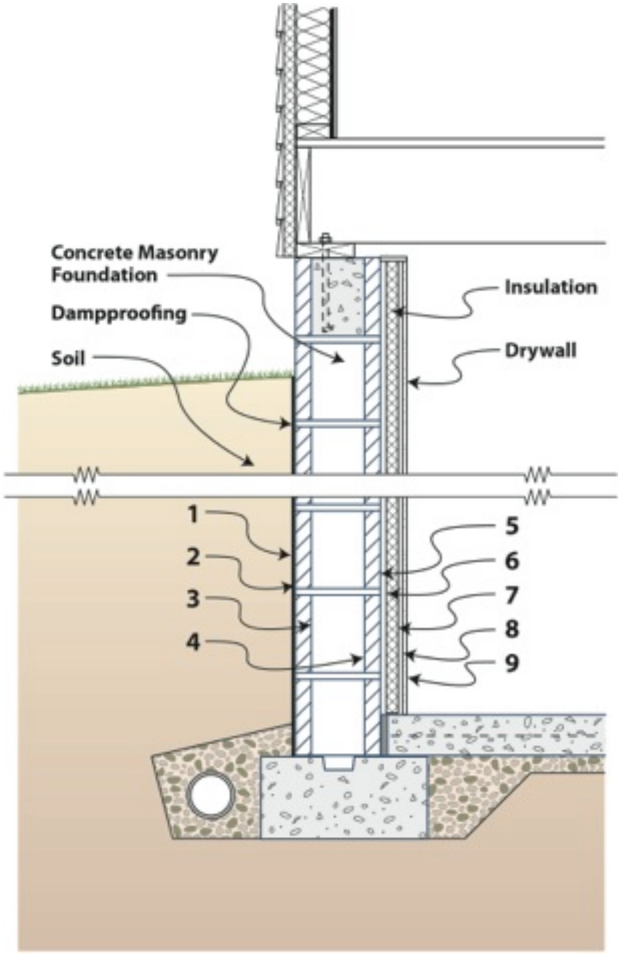
- Identify Moisture Potential => Low Risk
  - Extremely dry soils
    - or verifiable waterproofing, drainage, and capillary break
  - Concrete walls
    - no step footings
  - Good underslab drainage layer with vapor retarder
  - Good indoor humidity control

Act 3: Foundation Insulation for Existing Homes

- Challenges of adding interior insulation on existing foundation walls.
  - We have limited experimental data sets.
  - Existing modeling tools are crude and poorly validated.
  - Existing material properties and boundary conditions are highly variable and unknown, so we must focus on …
    - developing a liquid water management approach,
    - balancing R-value and vapor diffusion characteristics,
    - evaluating safe moisture storage,
    - identifying risk and risk tolerance.

Perception of Risk

- Which surfaces or layers can be:
  - Saturated?
  - Frozen?
  - Moldy?



Foundation Insulation
(high risk)

- Alternatives for Existing Basements
  - Frame wall with batt insulation system
    - Vapor retarder needed on both sides
    - Interior air barrier is critical
    - Very limited drying potential if wetting occurs
    - Moisture accumulation on foundation wall is almost certain at typical insulation levels

Foundation Insulation
(very low risk)

- Alternatives for Existing Basements
  - Dig to the footings,
  - Install proper perimeter drainage,
  - Add exterior waterproofing,
  - Install thermal insulation,
    - ideally covering the rim joist, as well
  - Install protective coating
    - including 6” to 18” below grade
  - Backfill with free-draining material and impermeable cap.

Foundation Insulation
(very low risk)

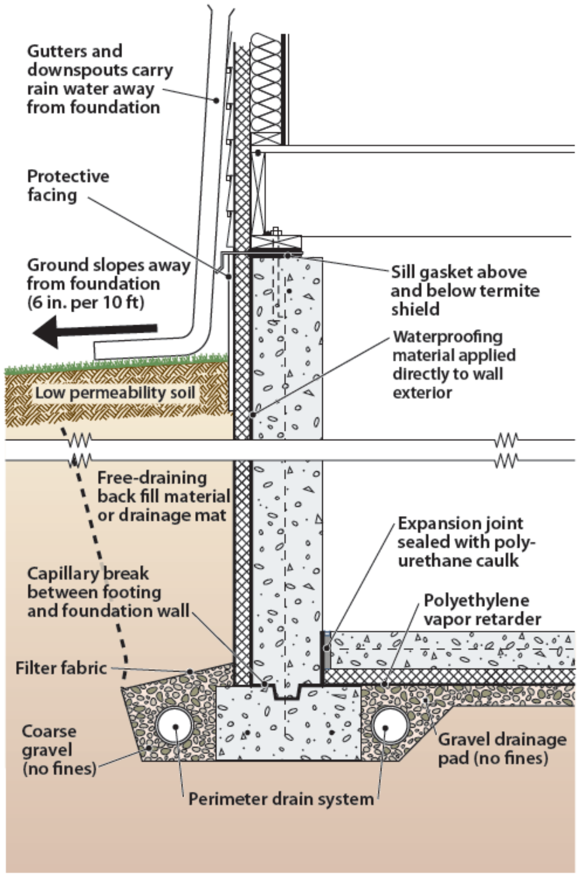


Figure 2-3: Components of Basement Drainage and Waterproofing System

Source: Oak Ridge National Laboratory









W. R. MEADOWS
SEALTIGHT

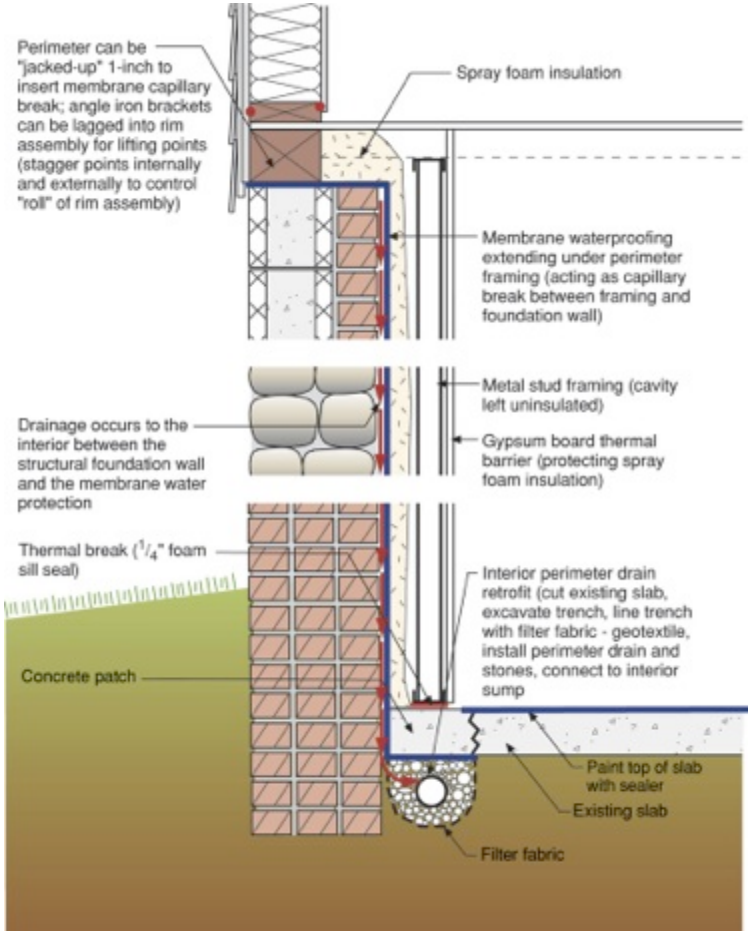

Foundation Insulation
(very low risk)

- Alternatives for Existing Basements
  - Interior finish without insulation or carpet
    - empty stud wall, paperless drywall, latex paint
    - aggressive interior humidity control

Foundation Insulation
(low risk)

- Alternatives for Existing Basements
  - Barrier system with interior finishes
    - sealed interior liner with concealed drainage
      - and possibly active drying
    - use semi-permeable continuous insulation and appropriate interior finishes
    - must be very cautious of top condition
      - recommended to insert capillary break between foundation wall and sill plate

Foundation Insulation
(low risk)



Source: Building Science Corporation

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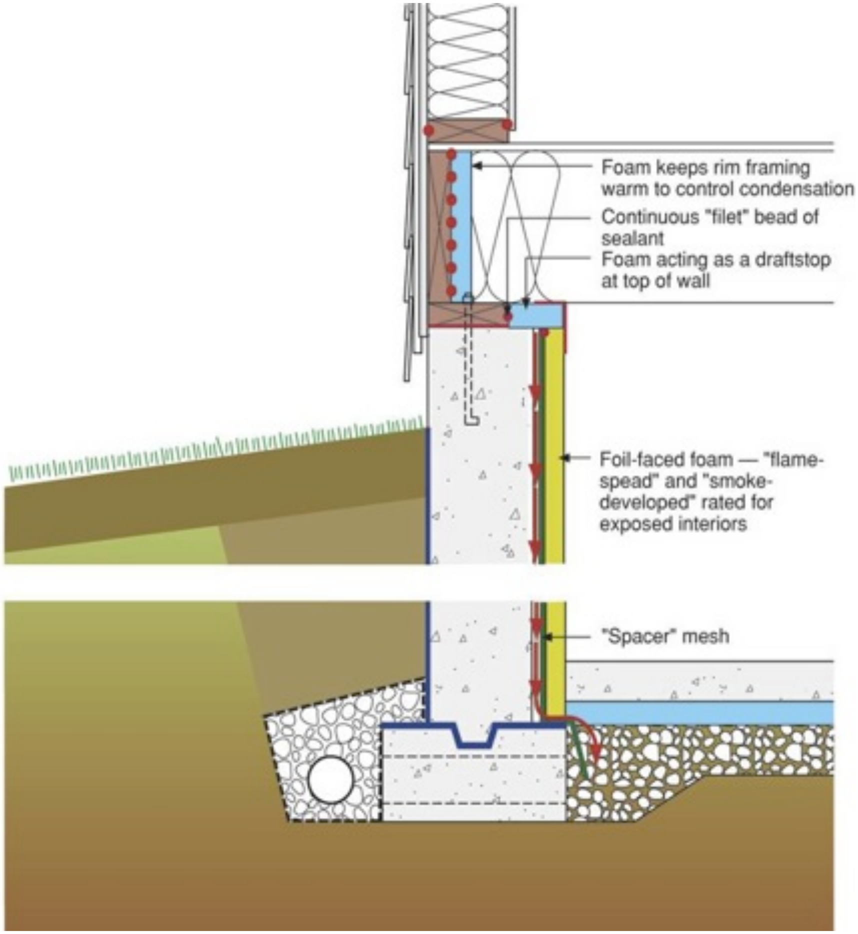
Foundation Insulation
(low risk)



Source: Building Science Corporation

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Foundation Insulation
(low to moderate risk)

- Alternatives for Existing Basements
  - Semi-vapor permeable, air impermeable insulation with permeable finish
    - low R-value, semi-permeable, airtight foam
    - aggressive interior humidity control

Foundation Insulation
(low to moderate risk)

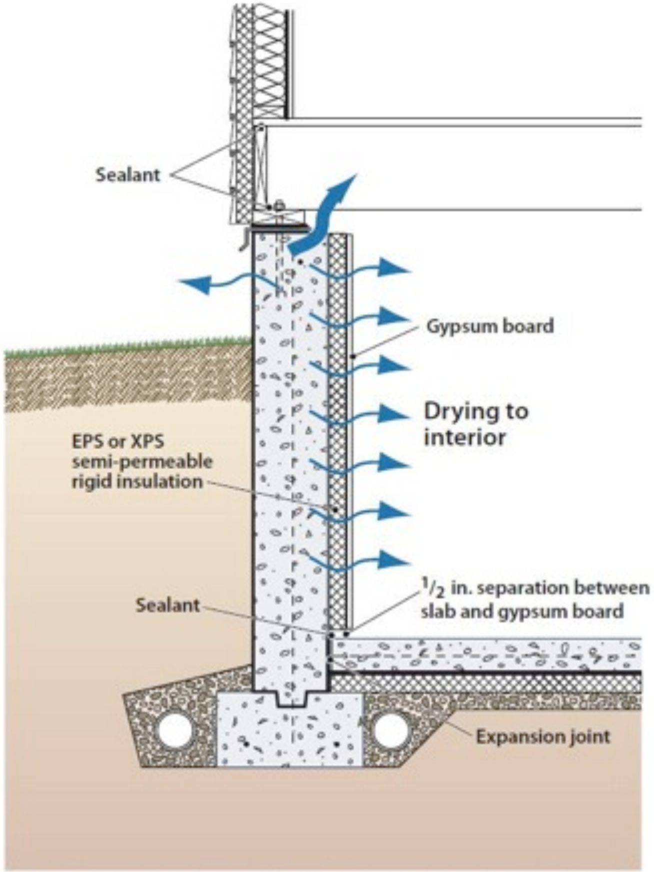


Figure 2-7: Basement Interior Insulation with EPS or XPS Semi-permeable Insulation on Inside Wall

Source: Oak Ridge National Laboratory

Foundation Insulation
(low to moderate risk)

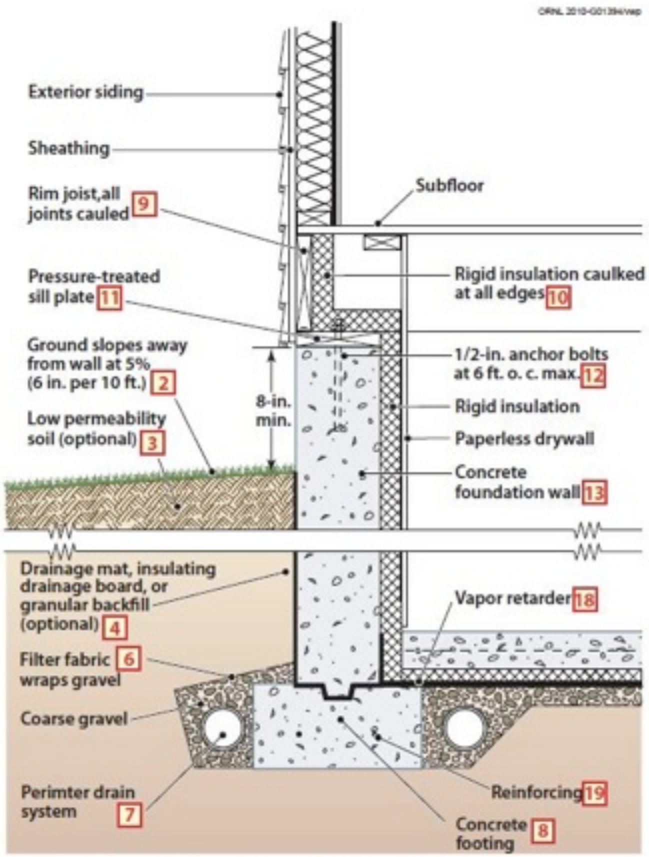
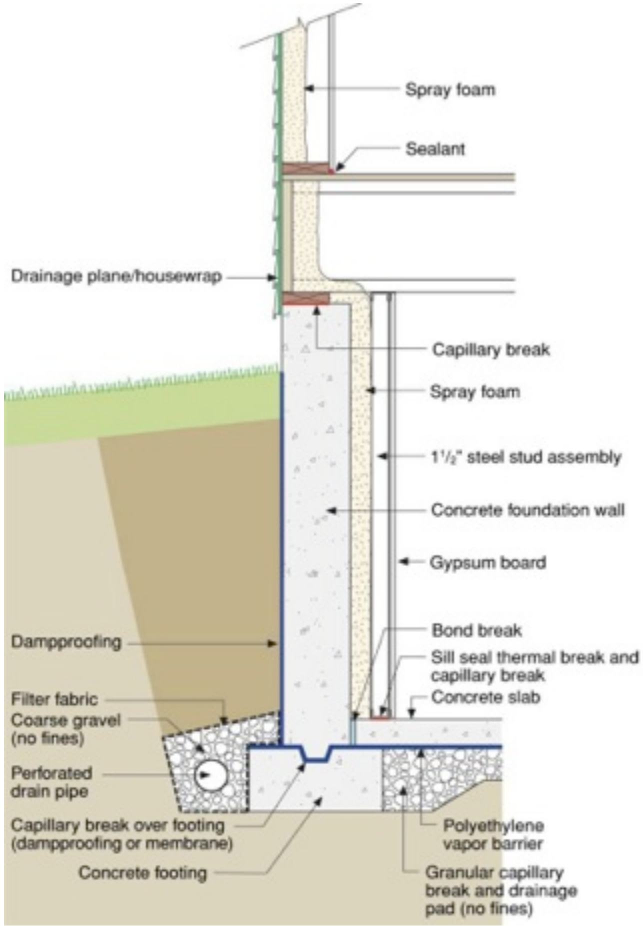


Figure 2-15: Basement Wall with Interior Insulation

Foundation Insulation
(low to moderate risk)



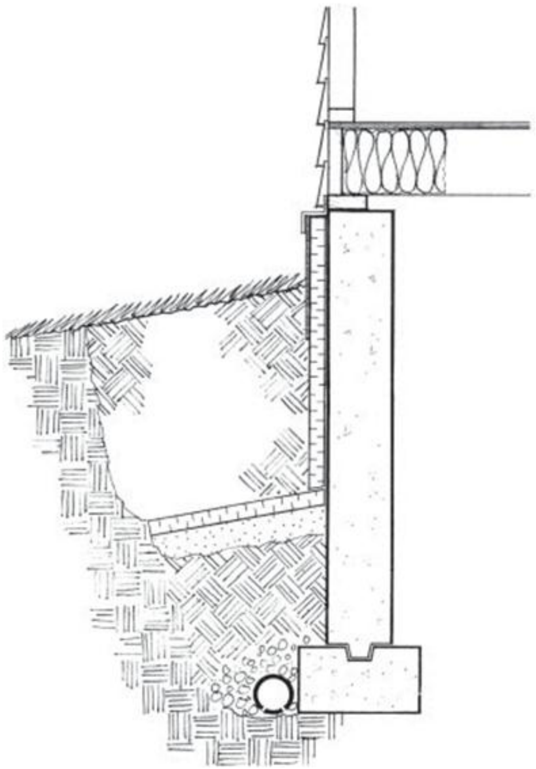
Source: Building Science Corporation

Foundation Insulation
(??? risk)

- Alternatives for Existing Basements
  - Hybrid or split insulation system
    - top and bottom could have different insulation strategies (r-value, permeability, etc.)
    - top could be on outside and bottom on inside

Foundation Insulation
(??? risk)

- Alternatives for Existing Basements
  - Partial exterior insulation systems
    - Partial depth
    - With or without skirt
  - Current cautions
    - Material choices
    - Moisture impacts



Foundation Insulation for Existing Homes

- Cautionary Note: If a Basement Floods …
  - Floor coverings must be removed to facilitate clean-up and improve drying.
  - Interior insulation systems must be fully removed because they are contaminated and retard drying.
  - From field experience, exterior foam plastic insulation systems appear to recover with little deterioration in performance.

Building America: 2011-12 Projects

Retrofit Interior Options

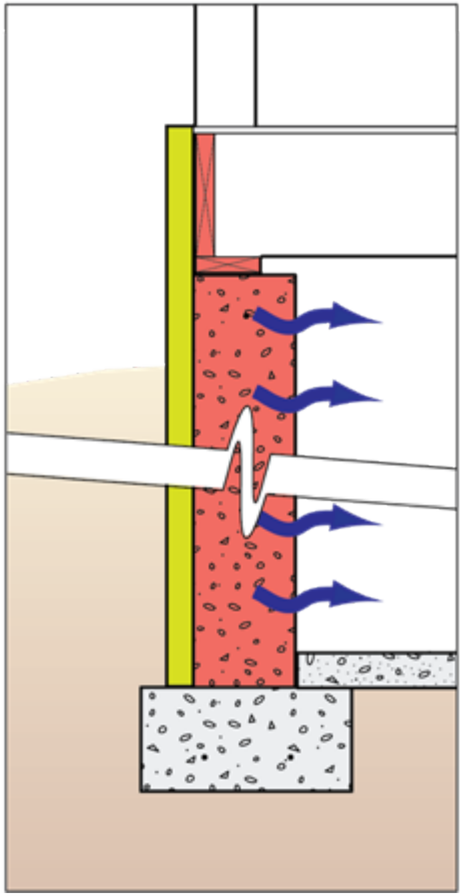
- In 2011, we explored 4 configurations for interior insulation.
  - 4 insulation levels in 3 climate locations
  - This initial investigation was limited to the use of existing below grade energy models and minimal hygrothermal evaluation.
- In 2012, full-scale, in-situ testing began at the Cloquet Residential Research Facility.
  - 3 interior options and 1 exterior option

Building America: 2011-12 Projects

Retrofit Exterior Options

- Exploration of methods to insulate the exterior of existing homes.
  - Identify approaches that could be used
  - Investigate means and methods
  - Determine how many homes would be conducive to each approach
- Exploration of innovative methods to insulate hollow concrete masonry block foundations.
  - Using existing models for energy/hygrothermal benefits

The Ins and Outs of the Outside Approach



- Exterior foundation insulation confers multiple hygrothermal benefits
- Missing moisture control materials can be added, or their importance is diminished because the wall is warm and can dry readily to the interior.
- Typical exterior approaches are costly, destructive to the landscape, and disruptive to homeowners.
- A cost-competitive, minimally-invasive technique is needed!

An Innovative Retrofit Exterior Option

- Possible Approaches
  - Full depth insulation
    - with waterproofing & drainage
    - without waterproofing
  - Partial depth
    - with waterproofing
    - without waterproofing
  - Upper foundation
    - vertical only
    - vertical with horizontal skirt

An Innovative Retrofit Exterior Option

- Means and Methods
  - Equipment and techniques
    - narrow trench
    - vibratory knife
    - air or water blade
  - Evaluate insulation formulations
    - installation
    - properties
    - durability

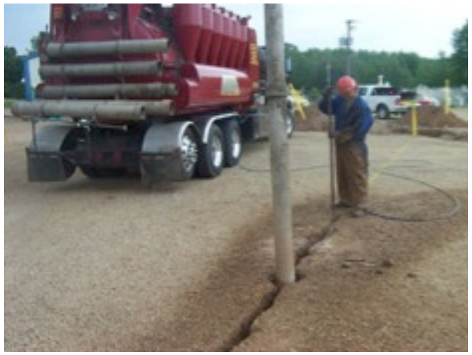
Technical Approach

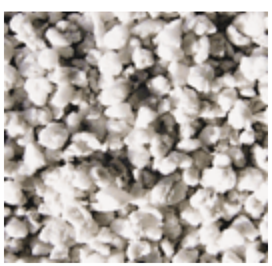
- To find an “excavationless” exterior foundation insulation upgrade that is cost-competitive with current methods and involves little impact to existing landscape and site features.
  – Literature review to establish the building science case for the advantages of exterior foundation insulation vs. interior insulation.
  – Survey of five typical Twin Cities neighborhoods to categorize and quantify typical obstructions.

Technical Approach

- Identify potential technologies, costs, & savings
  - Web-based search to identify available means and materials having promise for this application.
  - Interviews with industry representatives from down selected products and technologies to establish their suitability, along with cost.
  - Analysis of two exterior, full-excavation insulation upgrades to establish a base case for costs.
  - BEOpt analysis to establish energy savings potential.

Recommended Guidance





- Cut a narrow slot trench using air/hydro-vac.
- Backfill with one of three potential materials:
  - 4” pourable polyurethane (R-26)
  - 6” cellular concrete (R-9 to R-11)
  - 6” perlite aggregate concrete (R-9 to R-11)
- Above-grade foundation and rim techniques are under consideration.
  - rigid insulation application is one possibility.
- Potential for moisture mitigation
  - drape waterproofing membranes into the trench prior to installation or backfill.
  - for cementitious or foam materials, admixtures can make them more hygrophobic.

Cost Comparison Table *

Product	Insulation Type	Total R-value (h ft² °F/Btu)	Material cost	Labor cost	Excavation technology	Excavation cost	Total cost
Rigid mineral wool	Rigid board	10 (2.38" thick)	$689	$3198	Traditional power shovel	$2920	$6807
Extruded polystyrene	Rigid board	10 (2" thick)	$630	$3198	Traditional power shovel	$2920	$6748
Expanded polystyrene	Rigid board	8 (2" thick)	$336	$3198	Traditional power shovel	$2920	$6454
Cellular concrete	Cast in place	9 (6" thick)	$3000	included	Hydro-vac	$2600	$5600
Perlite Concrete	Cast in place	11 (6" thick)	$3529	included	Hydro-vac	$2600	$6129
Polyurethane foam	Cast in place	26 (4" thick)	$3360	included	Hydro-vac	$2000	$5360

* Cost does not include landscaping remediation, which will likely be higher for "traditional" methods

Market Potential

- Survey selected neighborhoods to evaluate constructability issues
- House constraints
  - steps, stoops & porches
  - attached garage
  - sidewalks & landscaping
  - cantilevers
- Access issues
  - equipment limitations

Market Potential

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Market Potential

Minneapolis - 1.5 story bungalow

Aerial Map Key		Sidewalk/patio abutting foundation	Sidewalk adjacent to foundation	Concrete Stoop/Steps	Wood Steps	Covered Porch	Deck	Driveway	Attached Garage	Bay without foundation	Addition without foundation	Vegetation	Chimney	% of perimeter that is easily accessible	Additional Notes
1		1		1								1	1	70	
2		1		1			1						1	55	
3		1		1		1	1					1		65	
4			1	1			1	1						50	
5		1		1		1	1					1	1	60	
6		1		1			1							70	
7			1	1			1				1			65	
8			1	1			1				1	1		65	
9			1	1					1					75	
10			1	1					1			1		70	
11			1	1					1					70	
12			1	1					1		1			75	
13			1	1			1		1		1			80	
14					1	1					1			0	appears to be slab on grade
15			1	1								1		95	
16			1	1			1							65	
17			1	1			1					1		65	
18			1	1								1		70	
19		1		1			1							65	
20		1		1							1			70	
21			1	1		1					1			70	
22			1	1		1	1				1			85	
23		1		1			1					1		65	
24		1		1							1	1		75	
25		1		1										75	
26		1		1		1	1				1	1		65	
27		1		1								1		75	
28			1	1										90	
	28 Houses														
# of occurrences		12	15	27	1	6	14	1	5	0	10	12	3		
% of occurrences		42.86%	53.57%	96.43%	3.57%	21.43%	50.00%	3.57%	17.86%	0.00%	35.71%	42.86%	10.71%		

"Excavationless" Pros

- Exterior insulation can be forgiving of existing defects.
- Vacuum excavation methods reduce landscape impact.
- Many landscape features (walks, stoops, decks, etc.) can remain in place with vacuum excavation.
- Process is quick
  - estimated at 2 to 3 days for a simple home.
- Pourable insulation materials can be made relatively waterproof, potentially reducing bulk water intrusion.
- Cost competitive with, and likely cheaper than, current methods of exterior insulation upgrades.

"Excavationless" Cons

- Method does not address moisture loading from sources such as capillarity from the footing or through the slab.
- More expensive than typical interior insulation methods
  - though most of these increase risk of moisture problems.
- Long-term thermal properties of materials are unknown
  - potential for moisture accumulation within pore spaces may cause thermal degradation.
- Large obstructions (patio slabs, sidewalks) may need to be sawcut to the trench width or removed and replaced.
- Extent of waterproofing ability, and durability of that solution are not well-characterized.

Market Readiness

- Foundation insulation has a significant impact on energy
  - and perhaps more importantly comfort.
- Exterior insulation confers many hygrothermal benefits
  - compared to typical interior approaches.
- Homeowners who understand these benefits currently choose exterior insulation upgrades
  - despite the inconvenience, cost, and landscape damage.
- Technologies evaluated are in current use in other sectors.
- Estimates indicate the method is cost competitive
  - with current exterior insulation upgrade methods and
  - replacement of landscape features was not included.

Building America Resources

- Excavationless Exterior Foundation Insulation
  - http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/excavationless_exterior_found.pdf
- Hybrid Foundation Insulation Retrofit
  - http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_hybrid_found.pdf
- High R-Value Foundations
  - http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high-r_foundations_report.pdf
- Basement Insulation Guide
  - http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/measure_guide_basement_insul.pdf%20

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Upgrading Below Grade Spaces: Challenges and Opportunities

- Questions?

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