UNIVERSITY OF MINNESOTA | EXTENSION

MAKING A DIFFERENCE IN MINNESOTA: ENVIRONMENT ✦ FOOD & AGRICULTURE ✦ COMMUNITIES ✦ FAMILIES ✦ YOUTH

Of Building Science:

Control Layers and High Performance Enclosures

Energy Design Conference
Duluth, MN

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University of Minnesota Extension

OF BUILDING SCIENCE: CONTROL LAYERS AND H-P ENCLOSURES

- In accordance with the Department of Labor and Industry's statute 326.0981, Subd. 11,

  "This educational offering is recognized by the Minnesota Department of Labor and Industry as satisfying **1.5 hours** of credit toward **Building Officials and Residential Contractors** continuing education requirements."

  For additional continuing education approvals, please see your credit tracking card.

OF BUILDING SCIENCE: CONTROL LAYERS AND H-P ENCLOSURES

- Part 1: Making a Case for High Performance
- Part 2: Brief Building Science Review
- Part 3: It is All About the Control Layers

=> Using building science to guide us towards more robust, high-performance enclosures!

OVERARCHING THEMES

- We can and must do better!
  - Challenge ourselves towards better performance
- Existing technology can get us there, but …
  - We need to reduce the focus on products.
  - We must embrace more robust systems.
  - We need improvement in design & execution.
- Together we must find more robust designs, technologies, and processes for the future.

Building Technologies Program

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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 technology.

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

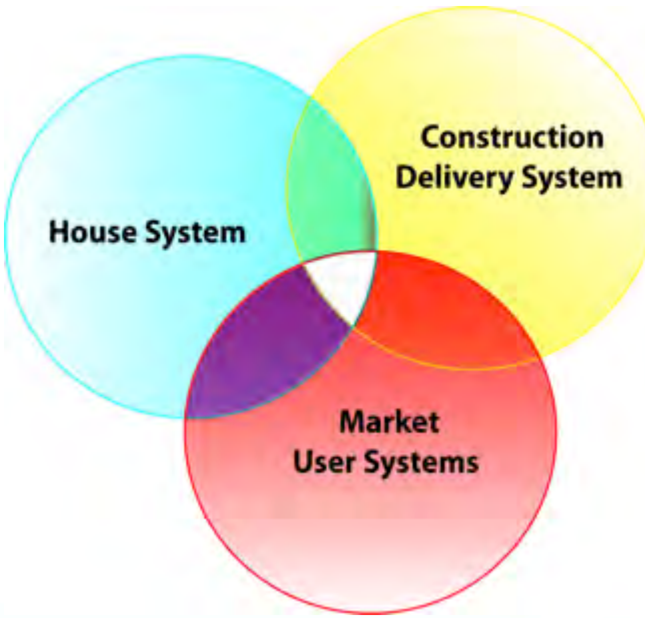
NAHB RESEARCH CENTER

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



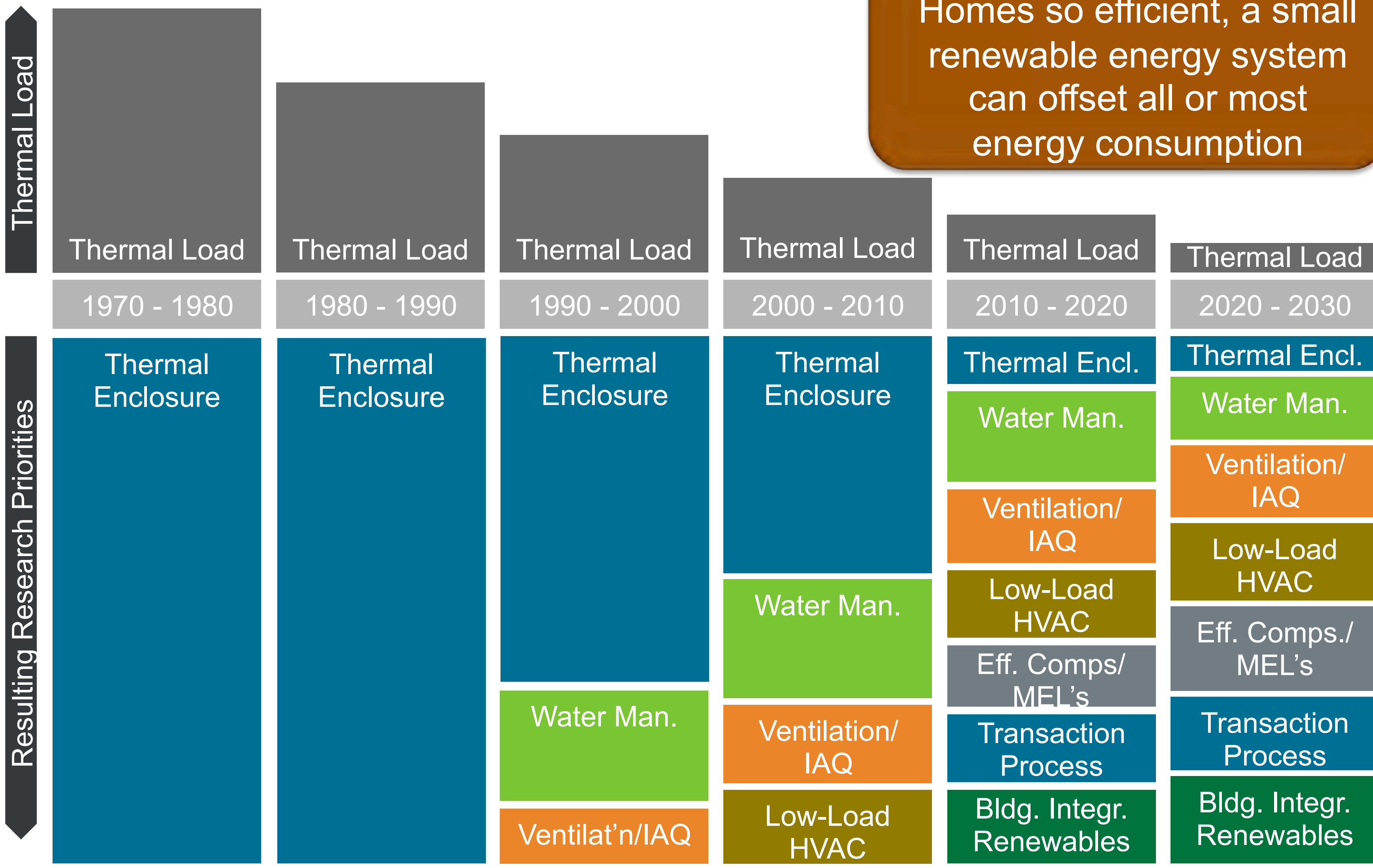
NorthernSTAR

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

Building America Strategy

Goal:
Homes so efficient, a small renewable energy system can offset all or most energy consumption



Building America Strategy

Ultra-High Efficiency + High-Performance

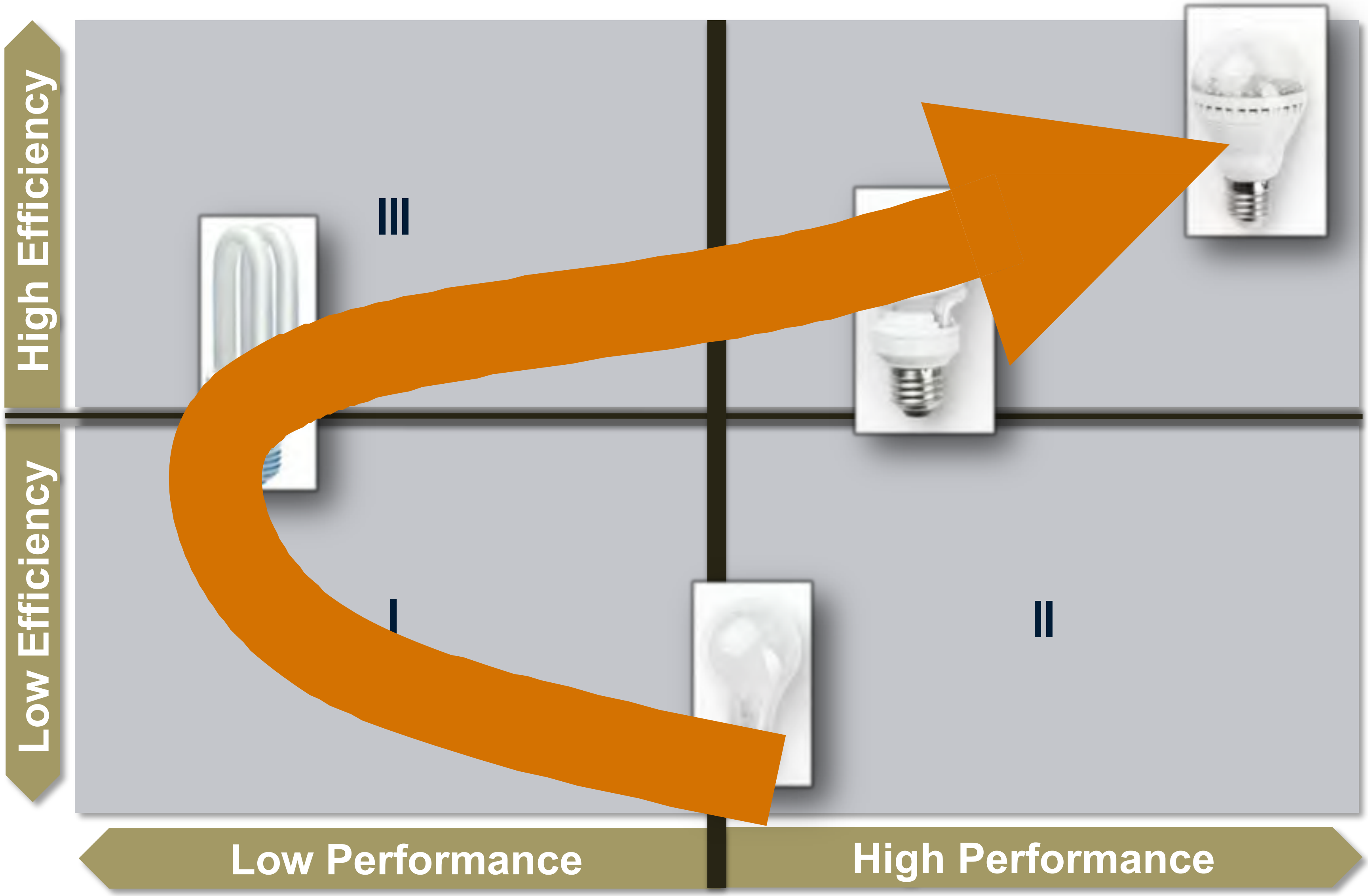
Ultra-High Efficiency

- Enclosure
- Low-Load HVAC
- Components

High-Performance

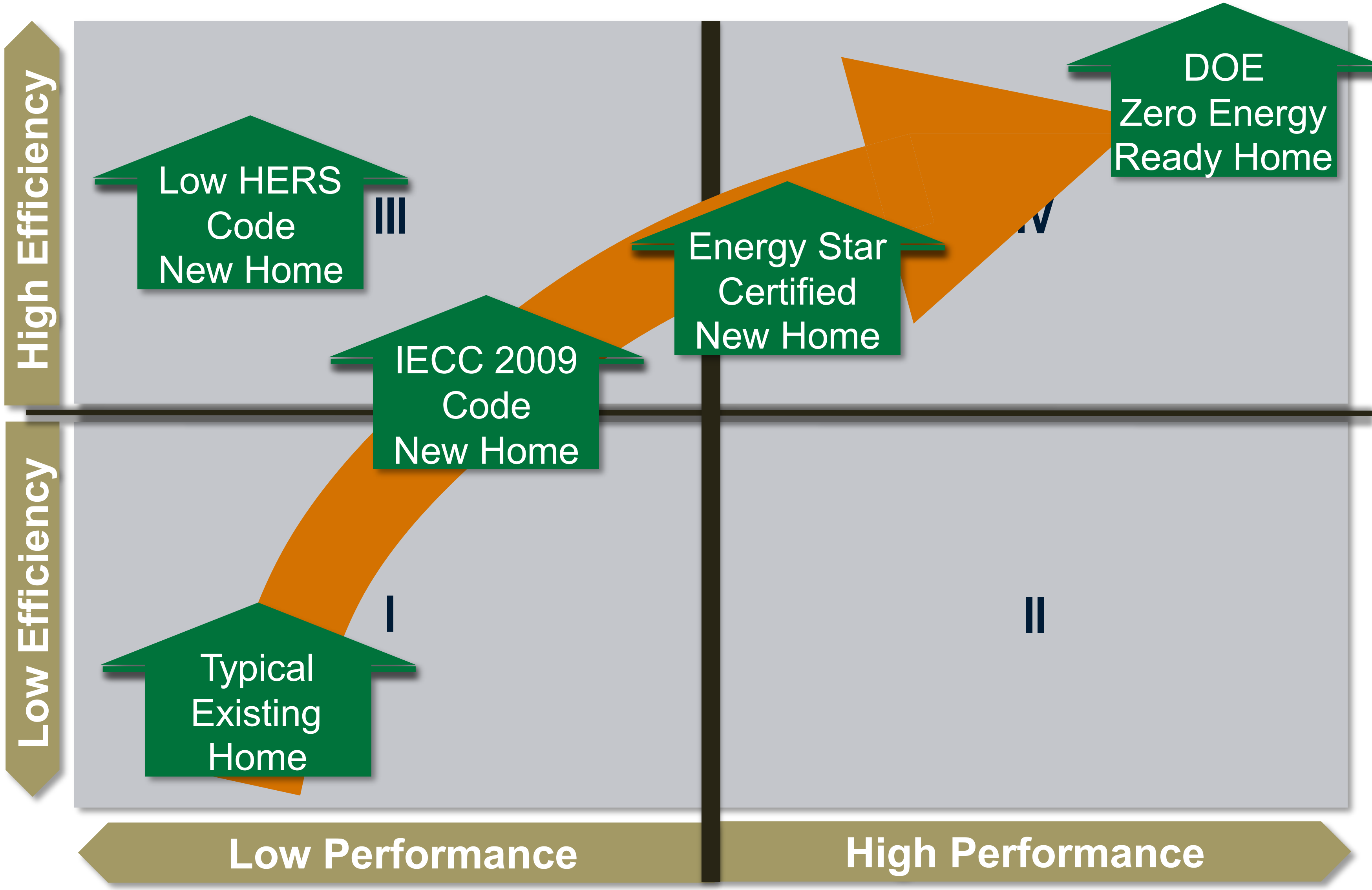
- Affordable
- Comfort
- Health
- Durability
- Renewable Readiness
- Water Conservation
- Disaster Resistance

Efficiency + Performance Example



DOE Zero Energy Ready Home Path

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



KEEPING OUR EYE ON THE BALL

- How is high-performance – especially health and safety, long-term energy efficiency, and building durability – built into our current game plan?

- Reminder: In the past, excessive energy consumption provided forgiveness at many different levels of building performance.

KEEPING OUR EYE ON THE BALL

- Is it possible that we are putting our "eggs into a very fragile basket" or

- Is our basket getting more fragile with changes in the industry?
  – It appears that some of the designs, systems, materials, and operations are falling short of our performance expectations.

KEEPING OUR EYE ON THE BALL

- Is it possible that we have over-invested in things and under-invested in good design and proper execution?
- Perhaps, but how many times have you heard that we no longer have a qualified, skill work force in construction?
    - If that is true, then it is even more important that we find designs, systems, materials, and methods that are not as installation sensitive.

KEEPING OUR EYE ON THE BALL

- Are we not being realistic about the process?
  - Are we investing in risky designs, systems, and materials and hoping for perfect execution?
  - Are we counting on perfect homeowner operation and maintenance?

A GROWING EPIDEMIC: NOTMYJOBITIS

HIGH-PERFORMANCE HOUSING: MAKING THE CASE FOR ROBUST

- We must ensure our high-performance houses meet our expectations today and in the future?

- High-performance houses will push the envelope (mechanical systems, occupants, etc).
  - This will require more robust designs
  - It will demand systems with forgiveness/tolerance
  - We must have a more predictable delivery system
  - The owners/occupants will need to be in the loop

HIGH-PERFORMANCE HOUSING: MAKING THE CASE FOR ROBUST

- What must we do to move away from the fragile edge and move towards more robust

HIGH-PERFORMANCE HOUSING: MAKING THE CASE FOR ROBUST

- Designs
  - House
  - Mechanicals
- Systems
  - Envelope
  - Equipment
- Materials/Products
  - Components
  - Assemblies
- Methods (Execution)
  - Techniques
  - Process/Sequence
  - Delivery system
- Operation & Maintenance
  - Normal operation
  - Preventative maintenance
  - Emergency response
  - Repair & replacement

HIGH-PERFORMANCE HOUSING: MAKING THE CASE FOR ROBUST

- When push comes to shove; will your home's response be one of robustness or fragility?
  - Climate extremes
  - Abnormal interior conditions
  - Execution errors
  - Unusual operations
  - Neglected maintenance

HIGH-PERFORMANCE HOUSING: MAKING THE CASE FOR ROBUST

- Robust: Don't think of it as a thing, but more of a conceptual way of evaluating new designs, systems, materials, execution, and operation.

- There are a number of ways to think of robust.
  - It is idiot proof, bullet proof, and unlikely to fail.
  - If it fails, it won't hurt anything else.
  - If it fails, it will be easy to repair or replace.
  - If it fails, there is a planned back-up or redundancy.

BUILDING SCIENCE REVIEW => HAM

- Heat
- Air
- Moisture

HEAT: FUNDAMENTALS

- Heat always goes from hot (more energy) to cold (less energy)

- Modes of Heat Transfer
  - Conduction
  - Convection
  - Radiation

BASICS OF HEAT LOSS/GAIN

- Enclosure Losses/Gains (Loads)
  - Transmission
  - Air exchange
  - Solar gains
  - Internal gains

BASICS OF HEAT LOSS/GAIN

- Heat moves through the building enclosure in two distinct ways:
  - Transmission losses/gains
    - through the opaque ceilings, walls, floors
    - through windows and doors
  - Air exchange losses/gains
    - infiltration & exfiltration
    - exhaust devices
    - combustion equipment
    - ventilation

BASICS OF HEAT LOSS/GAIN

- Using the appropriate formulas, we can calculate the heat (energy) losses from a building.
  - There are separate calculations to find heat loss through the building envelope
    - we call these **transmission losses**,
  - and the heat loss from air movement in and out of the building
    - we call these **air exchange losses**.

MOISTURE: OVERVIEW

- States of moisture
  - Solid
  - Liquid
  - Gas
  - Adsorbed
- Moisture transfer
  - Liquid
  - Vapor
- Wetting vs. Drying

MOISTURE: THE BASICS

- Moisture States

Solid

Liquid => Absorbed

Vapor => Adsorbed

MOISTURE STATES: SOLID

- Ice is generally not an issue in residential construction, except for:
  - wind-driven snow in attics,
  - attic frost,
  - water entry resulting from ice dams, and
  - freeze-thaw action in absorbent materials.

MOISTURE STATES: LIQUID

- Liquid water sources and transport are usually the most damaging in residential construction, both above and below grade, and can cause:
  - initiation of biological deterioration,
  - initiation of mold/mildew growth,
  - staining, leaching, efflorescence,
  - dimensional changes in materials, and
  - enhanced freeze-thaw damage.

MOISTURE STATES: VAPOR

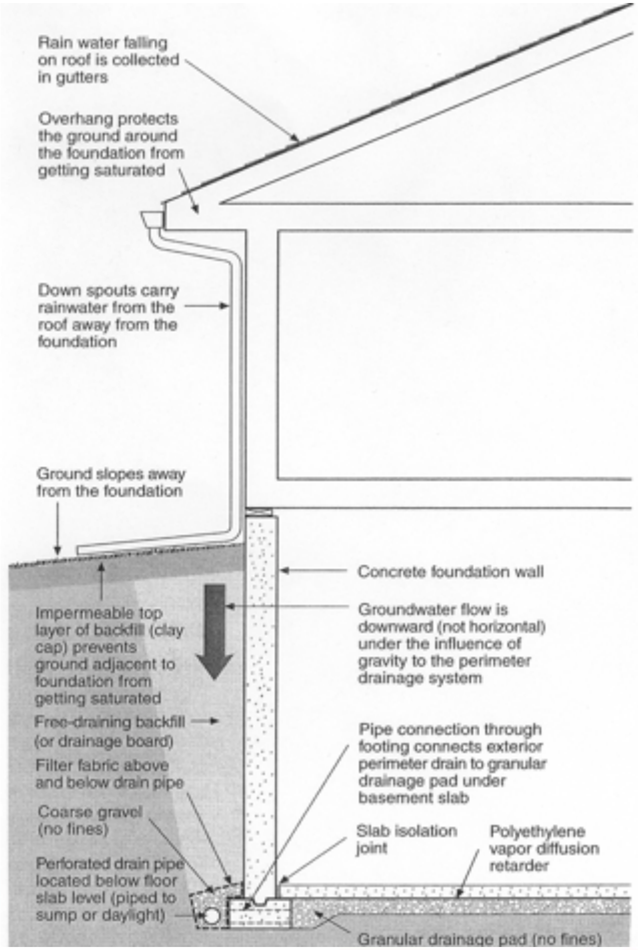
- Water vapor will rarely create a problem, as long as it stays in the vapor state.
- However,
  - it frequently contributes to durability and indoor air quality problems when it migrates and condenses on susceptible materials,
  - it can raise the moisture content of materials by adsorption and cause dimensional changes
  - at very high RH it can sustain mold growth.

MOISTURE STATES: VAPOR

- But don’t forget,
  - vapor drying is the main method of removing moisture from materials.

MOISTURE TRANSPORT: LIQUID

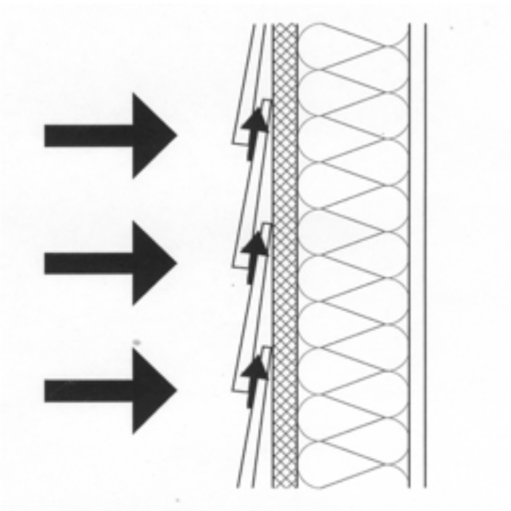
- Gravity (Bulk Water)
  - Above Grade
    - roof leaks
    - window/door leaks
    - wall penetrations
    - saturated materials
  - Below Grade
    - surface drainage
    - saturated soils

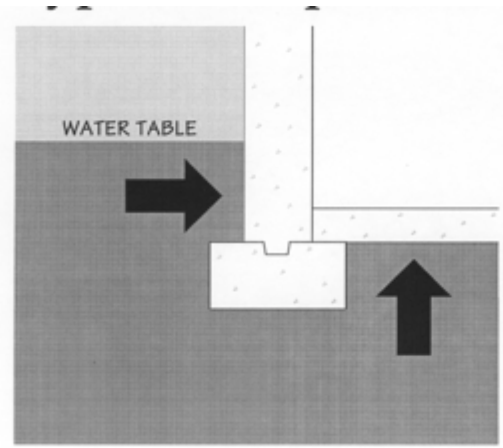


Courtesy of Building Science Corporation

MOISTURE TRANSPORT: LIQUID

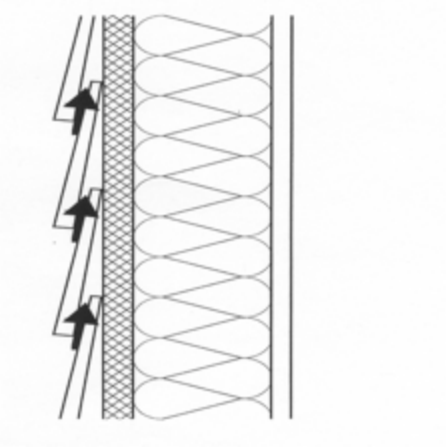
- Pressure Driven Flow
  - Above grade
    - wind-driven rain
  - Below grade
    - rising water table

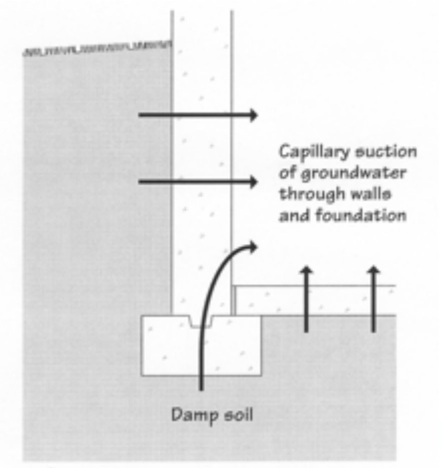




MOISTURE TRANSPORT: LIQUID

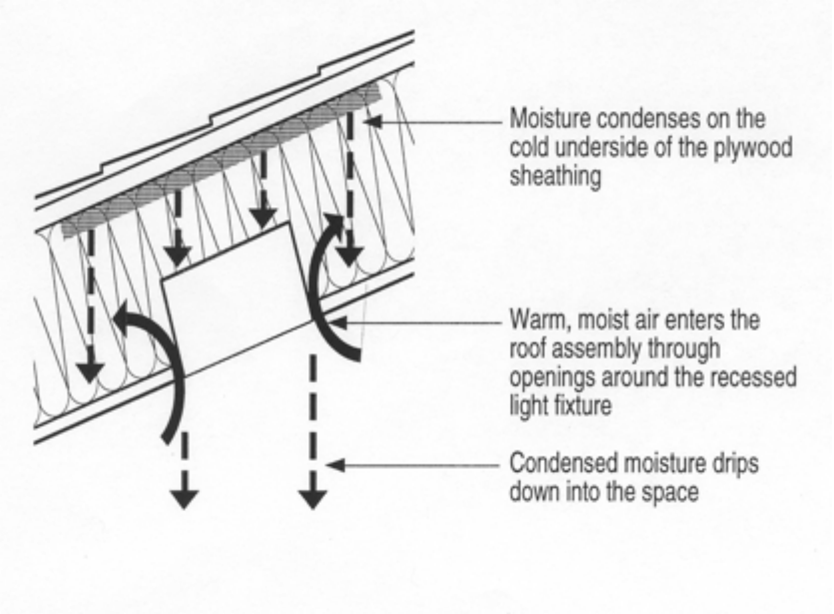
- Capillary Action
  - Above grade
    - seams/joints
    - flashing
  - Below grade
    - soils
    - footing/foundation
    - slab





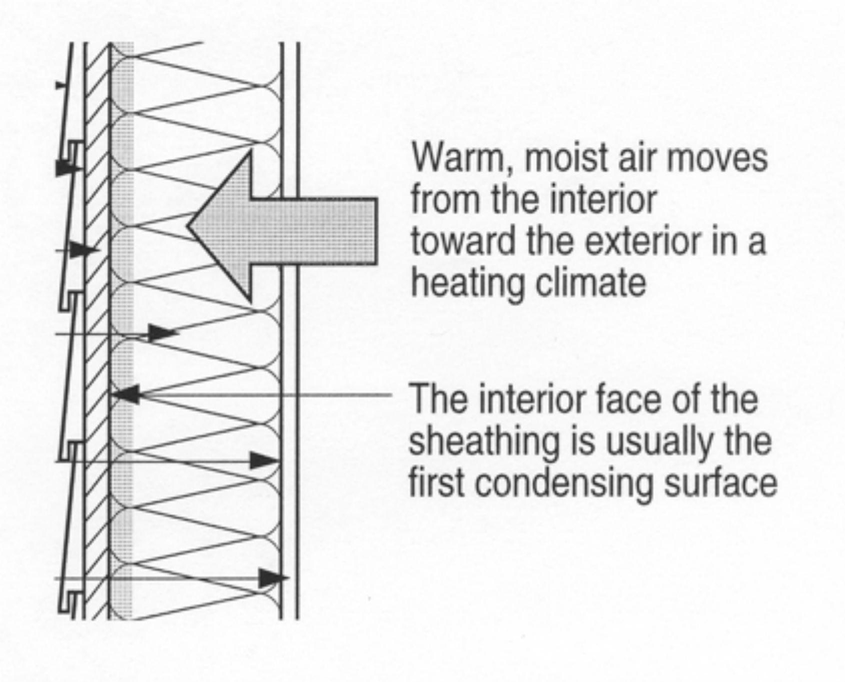
MOISTURE TRANSPORT: VAPOR

- Air Flow
  - Above grade
    - interior/exterior moisture
    - air barrier integrity
    - indoor-outdoor pressures
  - Below Grade
    - interior & soil moisture
    - air barrier integrity
    - basement-outdoor pressures

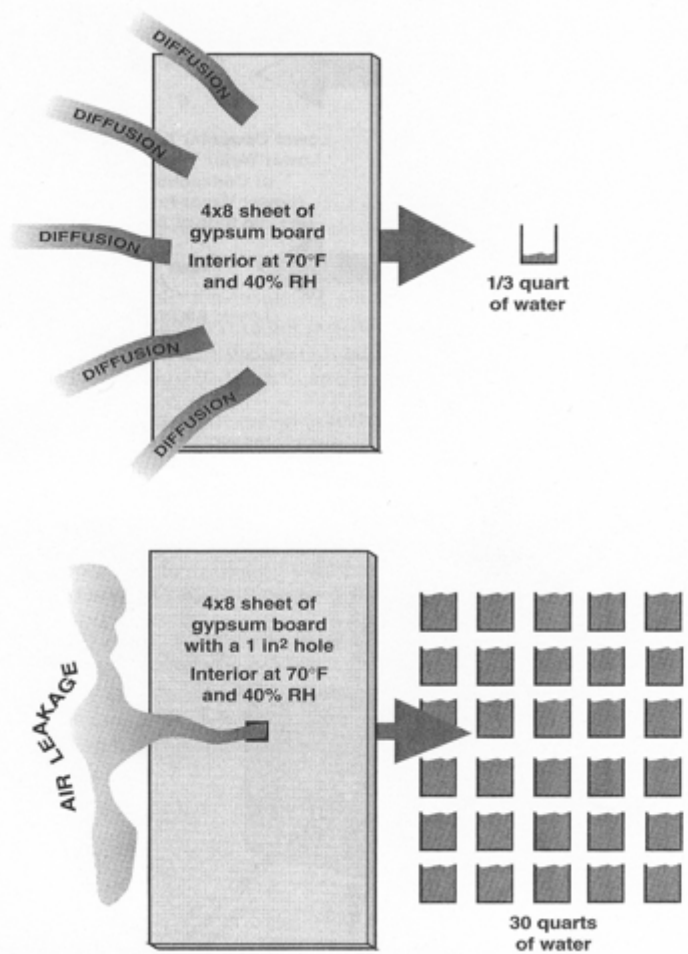


MOISTURE TRANSPORT: VAPOR

- Diffusion
  - Above grade
    - vapor pressure gradient
      - outward in heating
      - inward in cooling
    - permeability
  - Below grade
    - vapor pressure gradient
      - lower wall and slab is usually inward
      - upper wall is similar to above grade
    - permeability



MOISTURE TRANSPORT: VAPOR



Courtesy of
Building Science
Corporation

MOISTURE CONTROL: GENERAL

- Over some critical period
  - drying must exceed wetting
  - material storage provides the buffer

MOISTURE: STORAGE

- Storage as a Buffer
  - Because a perfect envelope is not realistic, wetting will occur. Ample storage must be provided until drying can be completed.
    - concrete/masonry walls provide a lot of storage
      - original EIFS was over mass walls and it worked
    - steel frame and fiberglass provide almost no storage
    - wood framing and sheathing provide limited storage
    - some evidence that cellulose board or insulation can act as a hygric buffer for short wetting periods
  - But remember, water stored (adsorbed or absorbed) must leave as a vapor!

AIRFLOW: THE BASICS

- Pathways
  - Unintentional – leaks and holes
  - Intentional – windows, ports, & ducts
- Pressures
  - Natural
    - wind
    - stack
  - Mechanical
    - combustion venting
    - exhaust fans/devices
    - supply fans/devices
    - forced air systems

BUILDING SCIENCE REVIEW

- Heat Flows
  - Transmission losses/gains
  - Air exchange losses/gains
  - Solar gains
  - Internal gains
- Air Flows
  - Paths
  - Pressures
- Moisture Flows
  - Liquid
    - gravity
    - capillarity
  - Vapor
    - diffusion
    - air transport

BUILDING SCIENCE REVIEW

- **Key Building Science Principles**
  - Heat goes from ______ to ______ .
  - Water vapor goes from ______ to ______ .
  - Water vapor goes from ______ to ______ .
  - Air in ______ ______ air out (and vice versa).
  - Air must have a ______ and a ______ to flow.
  - _____ the rain (and the soil)
  - Most of the action is at ______ and ______ .
  - Gas concentration (pollutants, water vapor, etc.) is a function of ________ ________ and ________ ________ .

- **In the end -- ______ , ______ , and ______ flows will drive the performance of the system!**

HIGH-PERFORMANCE HOUSING: MAKING THE CASE FOR ROBUST

- A Call for High-Performance Homes

- But it will demand a new approach. We must
  - design and engineer (not just build) our homes.
  - build forgiveness/tolerance into all systems.
  - build redundancy into critical materials.
    - or make it easy to repair and/or replace key components
  - develop a more predictable delivery system.
  - provide continuous feedback to the occupant.

FOCUS: HIGH PERFORMANCE ENCLOSURES

- Four Control Layers
  - Water
  - Air
  - Thermal
  - Vapor

- Essential for all enclosure elements!

HIGH PERFORMANCE HOUSES

- The “Ten Key Components” that will ensure …
  – Energy efficiency
  – Moisture control & durability
  – Good indoor air quality

- A formula for …
  – How to have your cake and eat it too!!!

The Ten Key Components

Components	Energy	Moisture	IAQ
1. Full coverage optimal thermal insulation	■	□	□
2. Continuous warm-side air barrier	□	■	□
3. Full-coverage warm-side vapor retarder	□	■	□
4. Continuous exterior-side weather barrier	□	■	□
5. Energy efficient, condensation resistant windows	■	□	□
6. Effective ground moisture / soil gas control	□	■	□
7. Low toxicity materials, finishes, and furnishings	□	□	■
8. Safe, efficient space heating and cooling	■	□	■
9. Managed mechanical ventilation	□	■	■
10. Efficient and safe appliances and lighting	■	□	□

THE 4 CONTROL LAYERS

- Every enclosure element must have four control layers!
- In rank order, they are:
  - Thermal control (???)
  - Water control
  - Air control
  - Vapor control

THERMAL CONTROL LAYER(S)

- General Overview
  - The intent is to slow the transmission of heat energy going from warm to cold.
    - Driver is the temperature difference
    - Primarily set by indoor and outdoor conditions

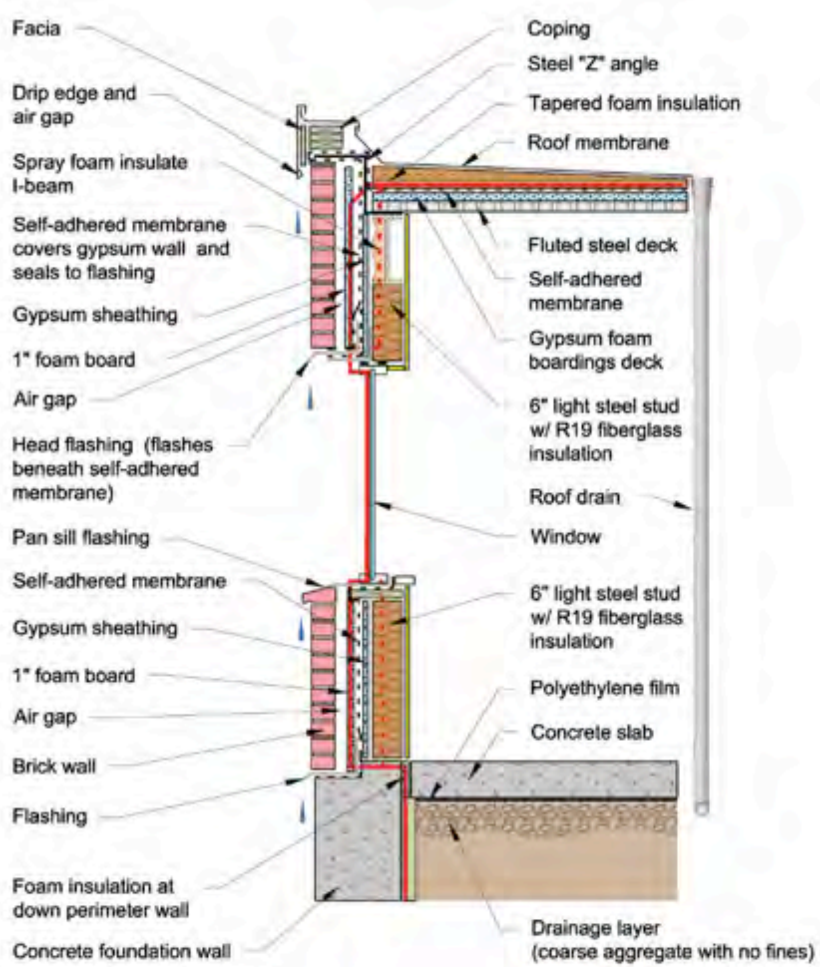
- This is the easy one!
    - How much?
    - Where?
    - What type?

THERMAL CONTROL LAYER(S)

Insulation	Code	ZERH	NZE*
– Ceiling (flat)	50	50	60
– Walls	20	25	40
– Fenestration	3	4	5
– Floor (frame)	30	40(30)	50
– Foundation	15(10+)	15	20
– Slab	0	0	10

* From "Zeroing In" by Joseph Lstiburek

PEN TEST: RED LINE FOR INSULATION



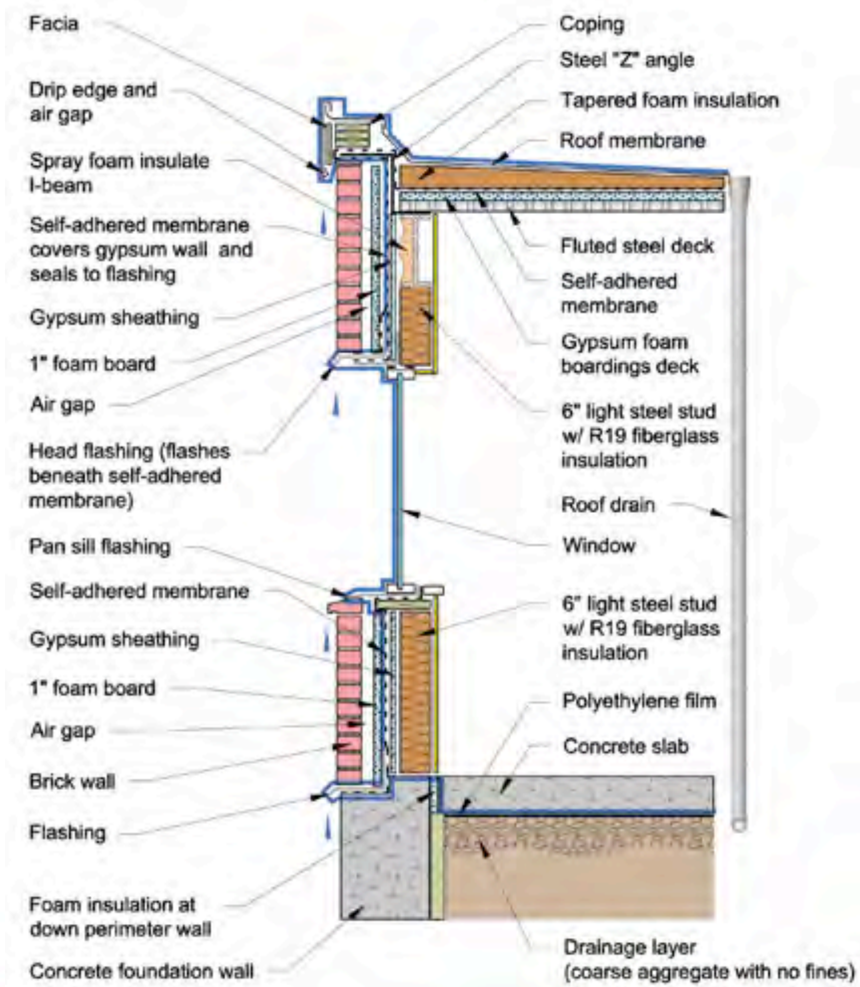
WATER CONTROL LAYER(S)

- General Overview
  - The intent is to keep water from reaching any moisture susceptible layers.
    - Primary drivers are gravity, wind, capillarity
    - You can (should) take steps to reduce the drivers
- This is absolutely critical,
  - especially as we remove drying potential with increased insulation, reduced air flow, and multiple vapor retarders!

WATER CONTROL LAYER(S)

- Theoretical Framework: 3 D's
  - Deflect
  - Drain
  - Dry

PEN TEST: BLUE LINE FOR WATER



AIR CONTROL LAYER(S)

- General Overview
  - The intent is to keep air from moving across the building enclosure carrying heat and moisture to locations that can create problems.
    - Primary driver is air pressures
    - You can (must) manage the pressure difference
- This is absolutely essential in modern construction.

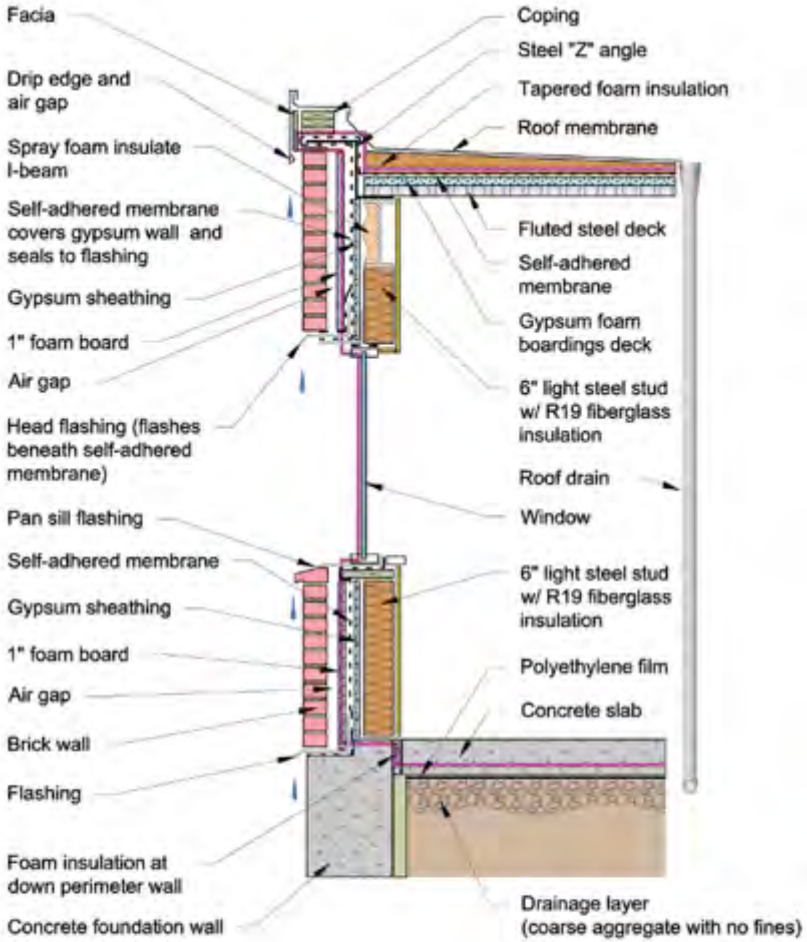
AIR CONTROL LAYER(S)

- Theoretical Framework
  - Material = 0.02 $l/s\text{-}m^2$ @75Pa
  - Assembly = 0.20 $l/s\text{-}m^2$ @75Pa
  - Building = 2.0 $l/s\text{-}m^2$ @75Pa
- Where does it belong?
  - Inside
  - Outside
  - In between
  - Both

AIR CONTROL LAYER(S)

	Code	ZERH	NZE
▪ Airtightness			
– ACH @ 50PA	3 ACH	2 ACH	1 ACH

PEN TEST: PURPLE LINE FOR AIR



VAPOR CONTROL LAYER(S)

- General Overview
  - The intent is to control vapor diffusion across a vapor pressure or thermal gradient.
    - Primary driver is vapor pressure
    - That vapor pressure can (should) be managed
- While perhaps not as critical as the other layers, it can’t be ignored in …
    - Very cold climates
    - Hot humid climates
    - High humidity environments

VAPOR CONTROL LAYER(S)

- General Overview (continued)
  - As the thermal insulation increases the vapor permeance must decrease.
  - Today (due to air-conditioning) you must manage vapor from both directions.
  - And if anything gets wet, generally the only drying potential is by vapor diffusion so there must be a clear drying direction.
  - So, this is more or a strategy rather than a specific layer.

VAPOR CONTROL LAYER(S)

- Theoretical Framework
  - Class 1 = < 0.1 perm — impermeable
  - Class 2 = 0.1 to 1.0 perm — semi-impermeable
  - Class 3 = 1.0 to 10 perm — semi-permeable
  - Class 4 = > 10 perm — permeable

VAPOR CONTROL LAYER(S)

- Current building code (since 1991) requires a Class 1 or 2 vapor retarder
  - 1 perm or less on the warm side in winter.
- Code doesn't address exterior vapor retarders for summer conditions.
  - but inward vapor pressure is real depending on cladding choices
  - and best practice would suggest you must design for inward protection

VAPOR CONTROL LAYER(S)

- 1 is an interesting (but not lonely) number!
  - ½” OSB (dry cup)
  - smart vapor retarder (dry cup)
  - 1” extruded polystyrene
  - Several coats of oil-based paint

THE MODERN ENCLOSURE CONUNDRUM

- It gets wet from inside out and outside in!
  - In general, they will wet outward in winter and inward in summer
- Things will get wet at some point due to imperfect design, execution, or operation.
- Therefore, all moisture susceptible materials must be able to dry out
  - In general, that can be outward in the winter or inward in the summer

THE MODERN ENCLOSURE CONUNDRUM

- Is air and vapor permeable cavity insulation dead?
- How about air and vapor impermeable cavity insulation?

APPLICATIONS

- Floors over unconditioned space
- Foundations/Rims/Walls
- Ceilings

FLOORS OVER UNCONDITIONED SPACE

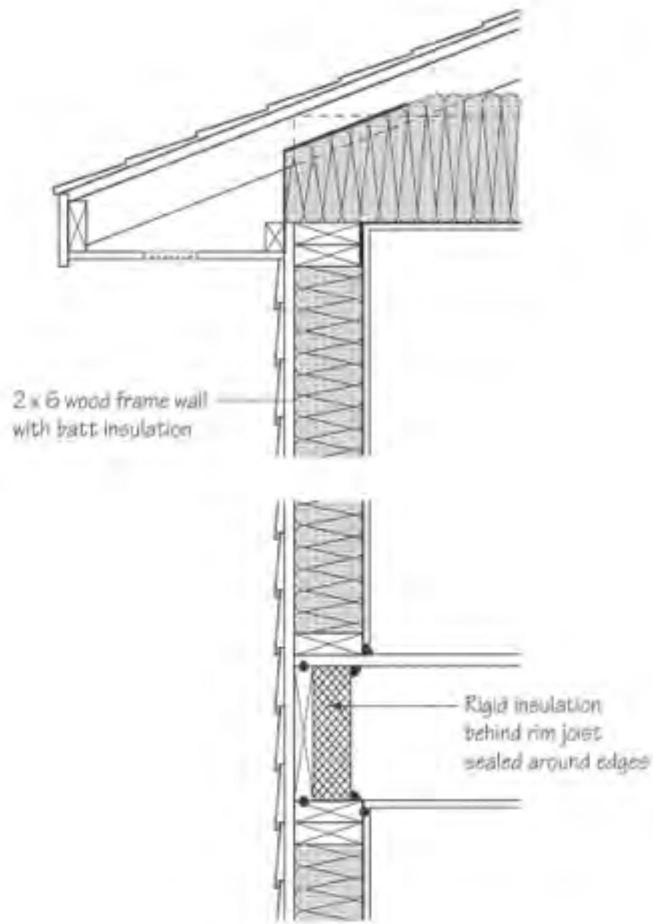
- Water Control Layer
- Air Control Layer
- Thermal Control Layer
- Vapor Control Strategy

FLOORS OVER UNCONDITIONED SPACE WITH DUCTWORK

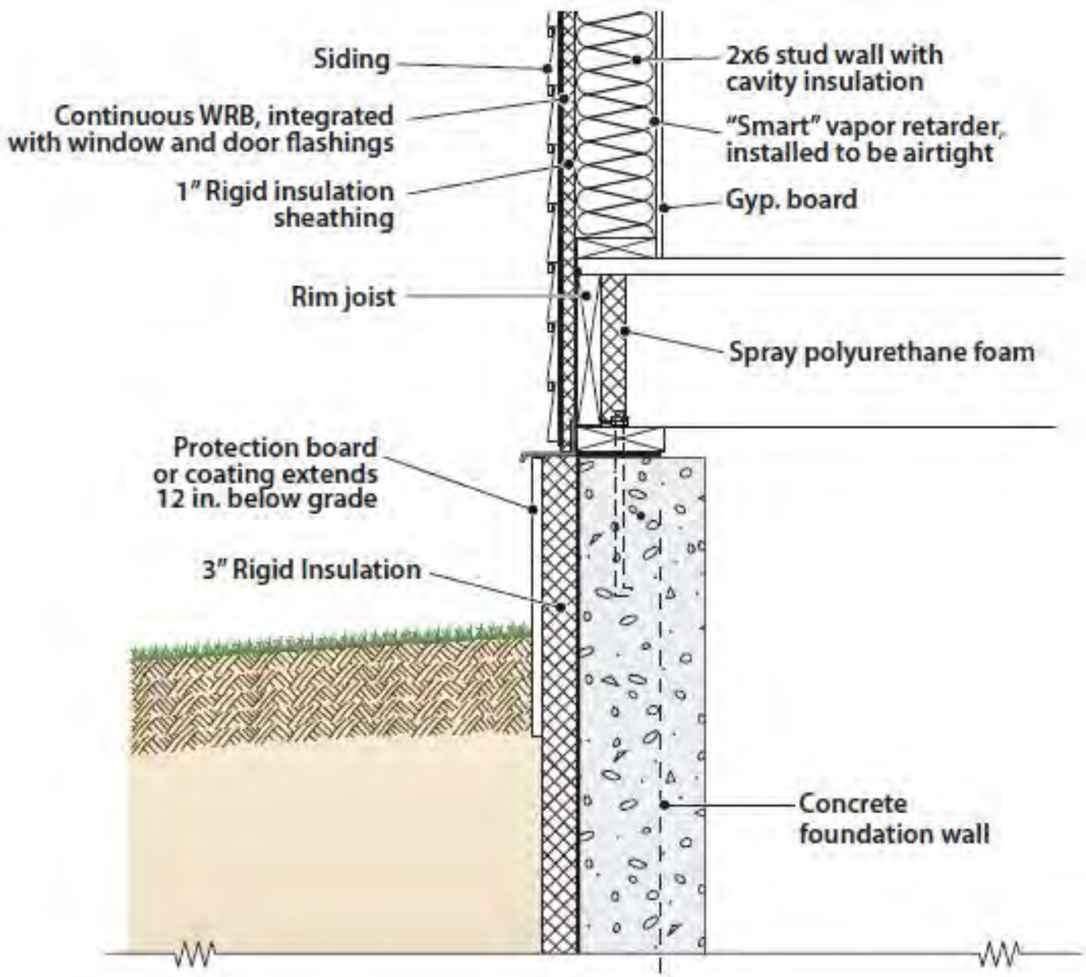
- What if the ductwork breaks through the air control and vapor control layer?

- Unless the duct is absolutely airtight, you must reconfigure the control layers …
  - and the air and vapor control layers must be outside of the ductwork.

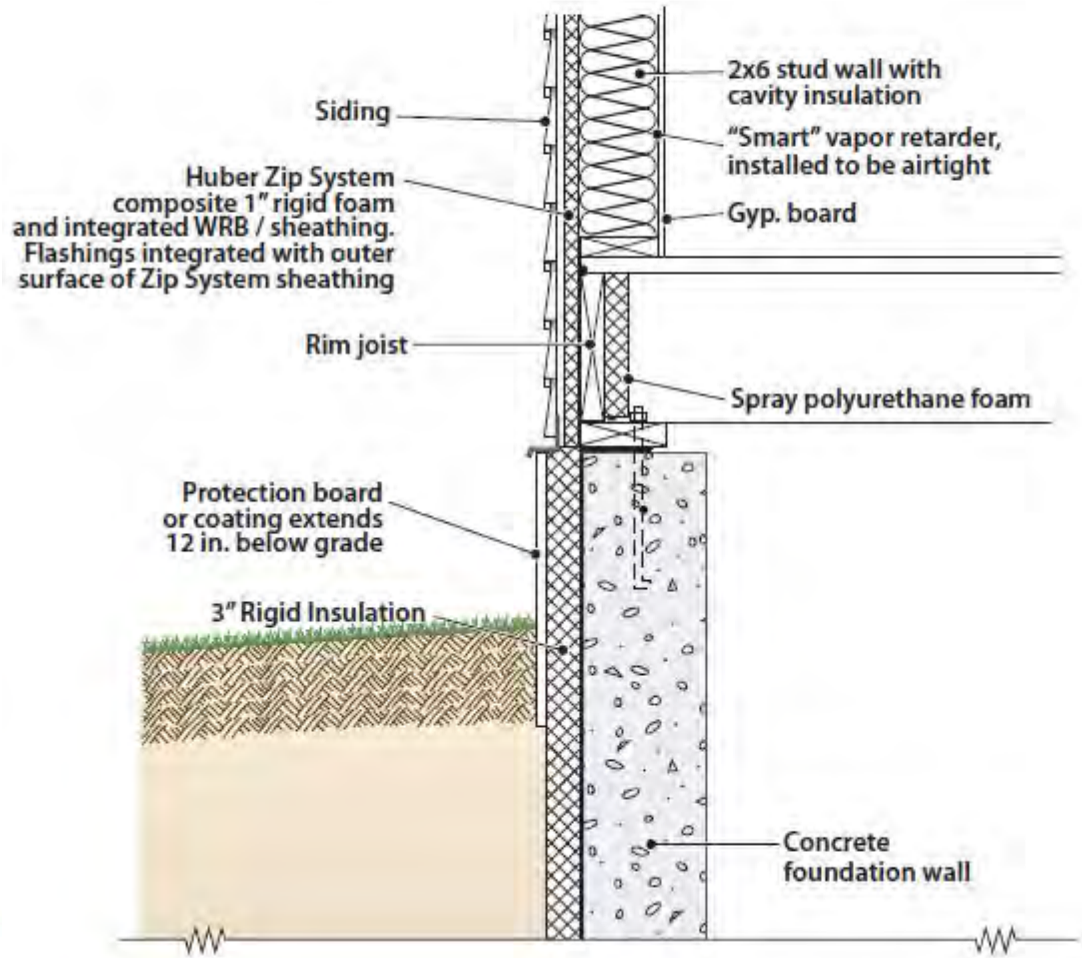
CONTROL LAYERS – BASE CASE



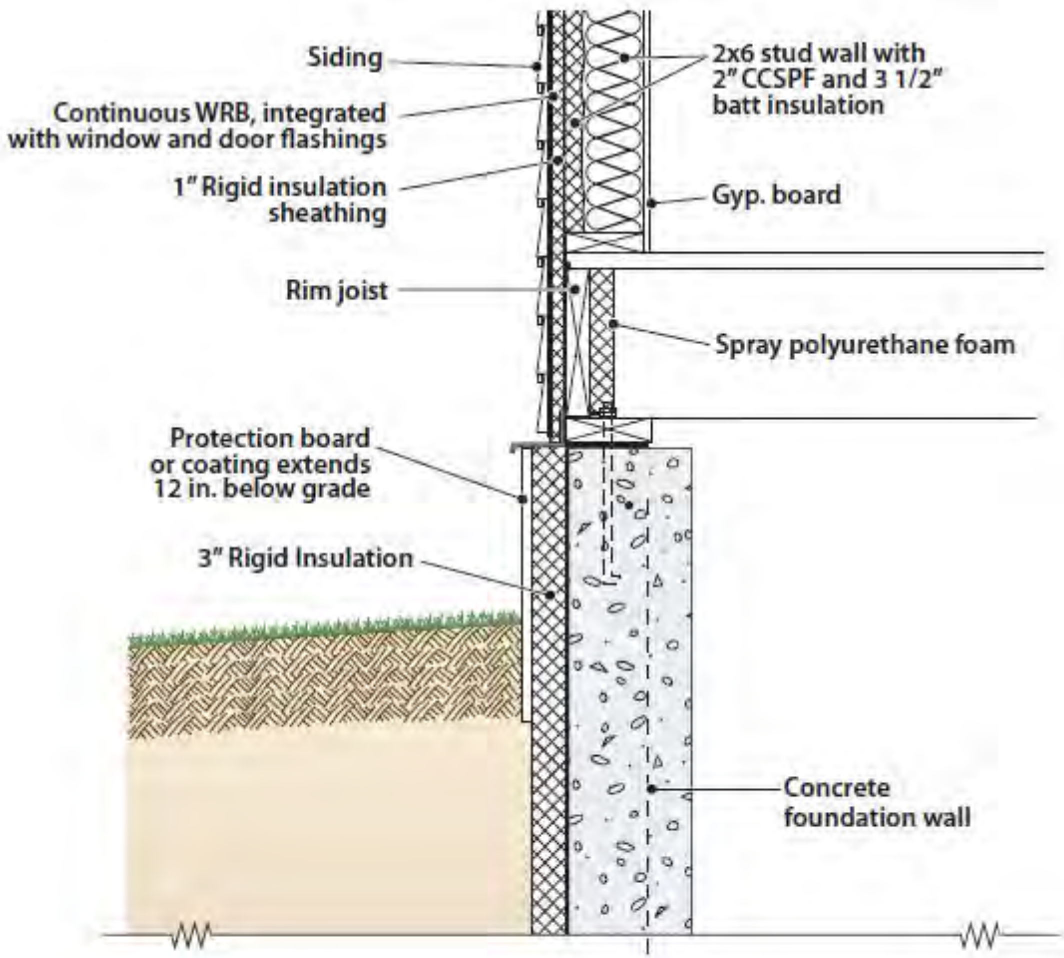
CONTROL LAYERS – EXAMPLE 1



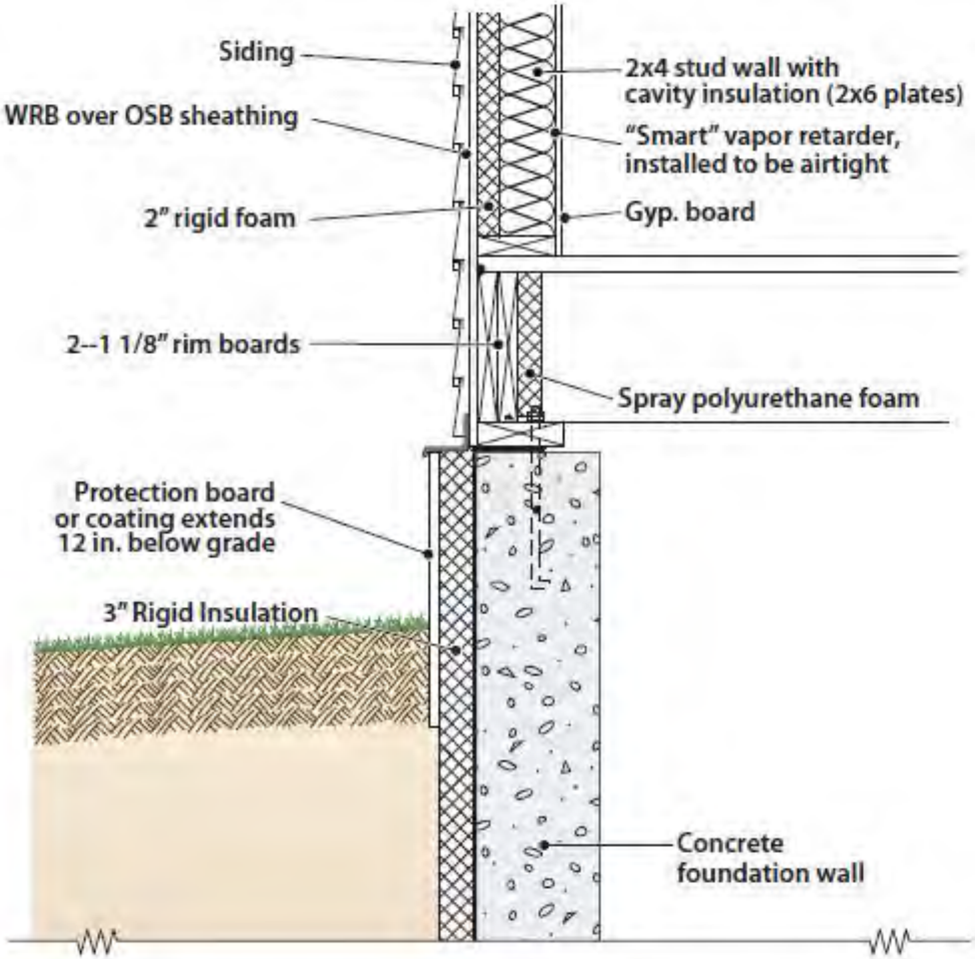
CONTROL LAYERS – EXAMPLE 2



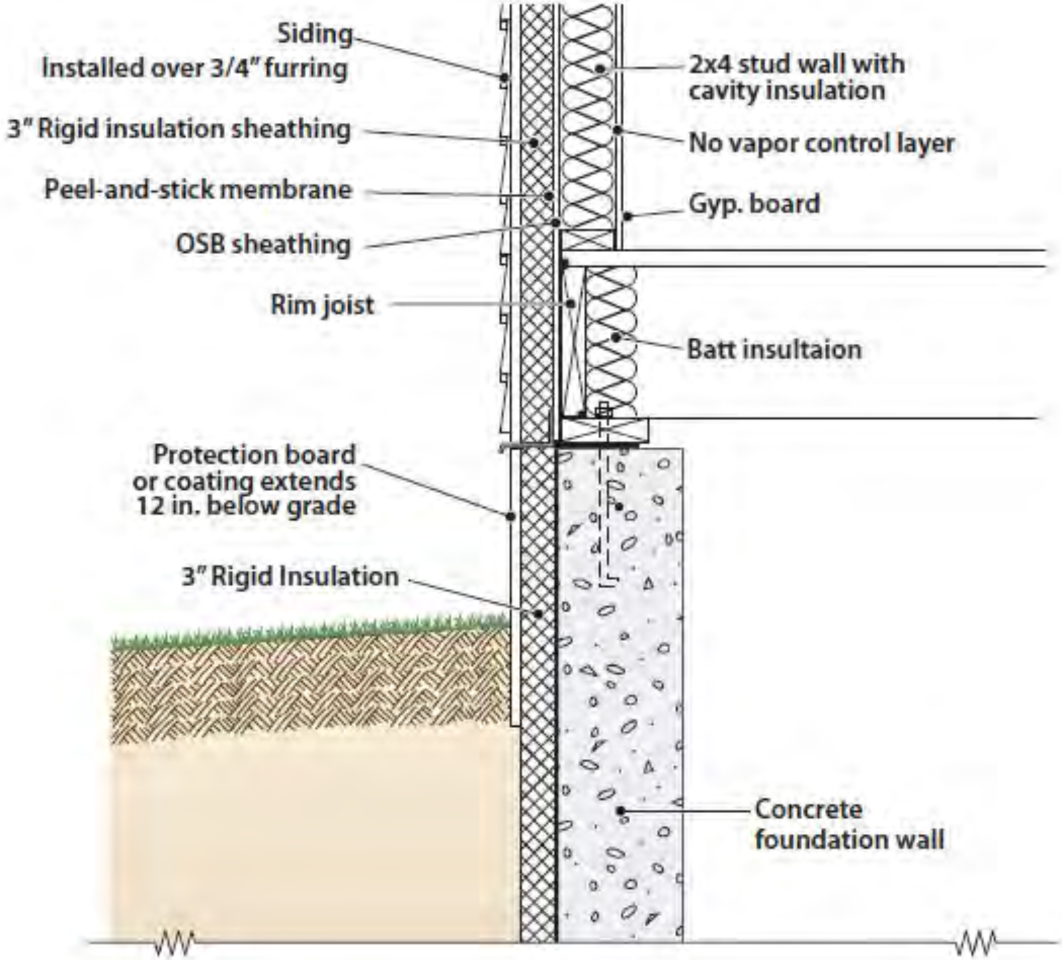
CONTROL LAYERS – EXAMPLE 3



CONTROL LAYERS – EXAMPLE 4



CONTROL LAYERS – EXAMPLE 5



STATE FAIR ECO-EXPERIENCE EXHIBIT

STATE FAIR ECO-EXPERIENCE EXHIBIT

- Building Enclosure 1: ICF Passive House
  - High level of insulation
  - Minimal thermal bridging
  - Resilient to wind & water

STATE FAIR ECO-EXPERIENCE EXHIBIT

- Building Enclosure 2: Low-Environmental Impact
  - Natural materials (limited materials from fossil fuels)
  - High overall R-value
  - Limit thermal bridging
  - High moisture storage and drying potential

STATE FAIR ECO-EXPERIENCE EXHIBIT

- Building Enclosure 3: Team Opti-MN
  - Developed by the U of MN Race to Zero Student Team
  - Robust, high performance wall optimized for current construction methods
  - Single water, air, and vapor barrier
  - Two-way drying potential

STATE FAIR ECO-EXPERIENCE EXHIBIT

- Building Enclosure 4: Innovative & Affordable
  - Based on the perfect wall, using a “studless” structural engineered panel
  - Single water, air, and vapor control layer
  - Recent experience has demonstrated that it can be built for less than a standard wood-frame wall system

FOCUS: HIGH PERFORMANCE ENCLOSURES

- Where does structure belong relative to the thermal insulation? You have 5 choices …
  - Outside
  - Both sides
  - Middle
  - In-between
  - Inside
- What if your structural materials
  - Change dimensionally with temperature / humidity and
  - Are subject to deterioration, if kept moist over time?

FOCUS: HIGH PERFORMANCE ENCLOSURES

- In a heated and air-conditioned building with air/vapor permeable cavity insulation, where do the moisture control layers belong relative to the thermal control layer?
- You have 4 choices
  - Outside
  - Inside
  - Both sides
  - Middle

FOCUS: HIGH PERFORMANCE ENCLOSURES

- Two-sided vs. one-sided walls
- Is it possible to use a single material in a single plane as the air barrier, vapor retarder, and moisture barrier (or WRB)?
  - Absolutely
  - And with the right material selections, it can be a universal wall for all climates.

FOCUS: HIGH PERFORMANCE ENCLOSURES

- The "Perfect" Approach
  - Walls
  - Roof
  - Slab

- Move the structure to the inside and the control layers to the outside …
  - It simply works and works everywhere!!!

A BETTER WAY TO BUILD

- Step 1: Put the structure on the inside
  - Light-frame construction
  - Timber frame
  - Concrete masonry
  - SEP = Structural Engineered Panel (studless construction)

A BETTER WAY TO BUILD

- Step 2: Put the thermal and moisture control layers on the outside.
  - Perfect Wall
    - (Lstiburek, w/ credit to bright Canadians in CBDs)
  - PERSIST (Makepeace)
  - REMOTE (Alaskans)
  - PERFORM (Texans)
  - Out-sulation (???)
  - Exterior Thermal & Moisture Management System (ETMMS)

ETMMS: FOUNDATION, WALLS, & ROOF

- Build the entire structure;
  - foundation, floor systems, walls, and roof
- Wrap the entire envelope with a “peel & stick” membrane integrated with openings / penetrations
- Add rigid foam insulation
  - 2 to 3” on foundation
  - 3 to 4” on walls
  - 6 to 8” on the roof
- Add furring strips, overhangs, etc.
- Install trim; siding; roof sheathing and roofing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METROPOLITAN

IS IT POSSIBLE TO GET MORE FOR LESS?

		Performance		
		Poorer	Same	Better
Costs	More	very bad	bad	likely
	Same	bad	*	good
	Less	likely	good	possible

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  - Home Energy Raters
  - Home Performance Consultants
  - Other Resources
    - Building America

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- Building America Resources
  - General Energy Information (EERE)
  - Top Innovations "Hall of Fame"
  - Building America Solution Center
  - DOE Zero Energy Ready Home

BA Top Innovations “Hall of Fame”

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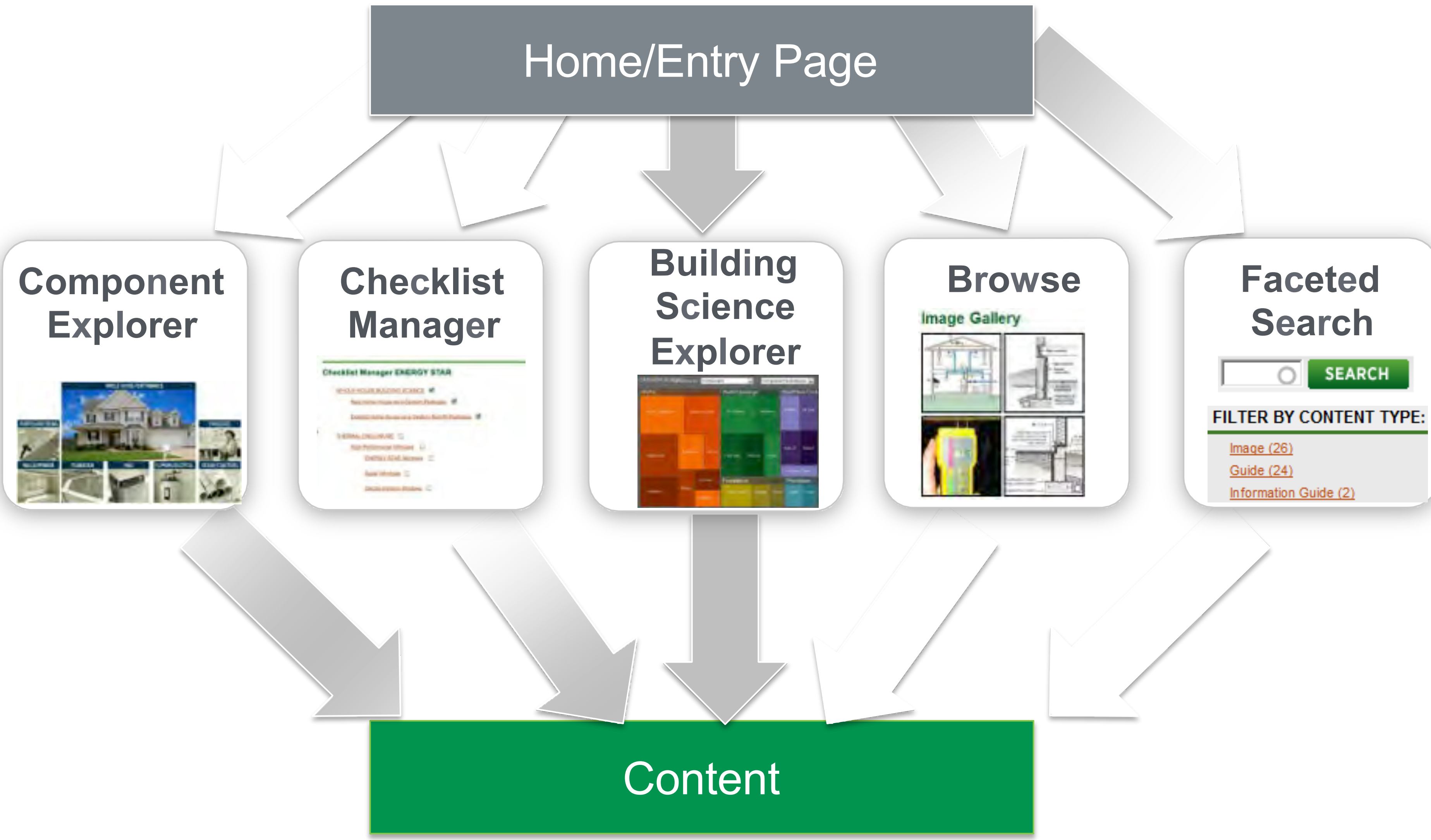

Quick Tour: Component Explorer

Walls/Openings

- Water Managed Walls
- Minimum Thermal Bridging
- Insulation
- Air Sealing
- Fully Aligned Air Barriers

Fully Aligned Air Barriers

- Behind Showers and Tubs
- Behind Fireplaces
- Attic Knee Walls
- Skylight Shaft
- Walls Adjoining Porch
- Double Walls
- Garage Rim/Band Joist

Quick Tour: Guides

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- Solution Center Home
- Component Explorer
- Checklist Manager
- Building Science Explorer
- Browser
  - Guides
  - CAD Files
  - Case Studies
  - Image Gallery
  - References

Attic Knee Walls

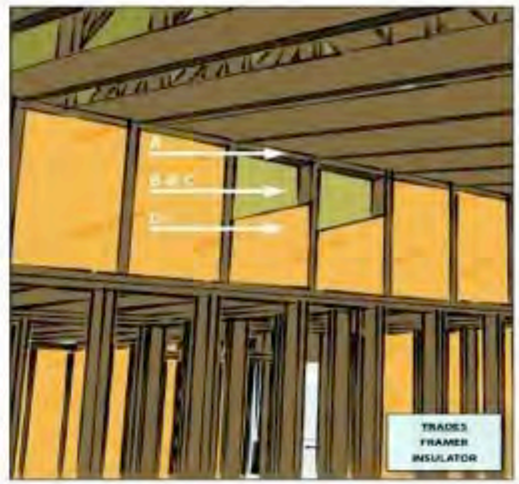
Please Register or Login to Provide Feedback.

Scope | Description | Ensuring Success | Climate | Training | CAD | Compliance | More Info.

Scope

Fully Aligned Air Barrier

A. Install a top and bottom plate or blocking at the top and bottom of all knee wall cavities.
B. Back attic knee walls with a rigid air barrier or other supporting material to prevent insulation from sagging and create a continuous thermal barrier*
C. Seal all seams, gaps, and holes of the air barrier with caulk or foam.
D. Install insulation without misalignments, compressions, gaps, or voids in all knee wall cavities.



* ENERGY STAR recommends using a rigid air barrier, but it is not a requirement.

Notes:

An air barrier is defined as any durable solid material that blocks air flow between conditioned space and unconditioned space, including necessary sealing to block excessive air flow at edges and seams

diameter unless otherwise indicated by the manufacturer. Flexible air barriers shall not be made of kraft

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Scope: Clearly defines and bounds the topic in a way builders and remodelers can contractually obligate their subcontractors.

- Discussion & Questions

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