Kohta Ueno

Introduction to Building Science

March 8, 2011

Building Science Corporation is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product. Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Copyright Materials

Learning Objectives

- Explain the benefits of the "perfect wall": a system that can be built in any climate, with any conditions inside, and not sustain damage (assuming that somebody will pay for it).
- Throw metaphorical stones at glass houses.
- Reduce your odds of running screaming when you see the psychrometric chart.

This Session: Limited Goals

- 3-hour class—can't fit much material
- "Hearing things a few times until they stick…"
- Scientific jargon?
  - Too complex (falling asleep)
  - Too simplistic (insulted?)
- Based on Joseph Lstiburek / John Straube "Building Science Fundamentals"—2 day class
- Or University of Waterloo one-semester class for engineering seniors
- Many topics we won't be able to cover

Enclosure Functions

Building Functions

- Human needs… more than shelter (e.g. Location, Shelter, Utility, Comfort & Delight)
- …function of a building:

"Provide the desired environment for human use and occupancy"

"Durability, Convenience, and Beauty"
Vitruvius, 70 BC

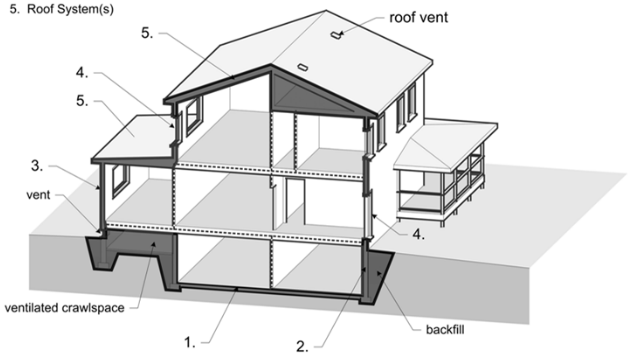
The Enclosure: Environmental Separator

- "Building envelope" and "building enclosure"
- The part of the building that physically ***separates*** the ***interior*** and ***exterior*** environments.
- Includes all of the parts that make up the wall, window, roof, floor, etc… from the innermost to the outermost layer.

Building Enclosure Components:

1. Basement Floor System(s)
2. Foundation Wall System(s)
3. Above Grade Wall System(s)
4. Windows and Doors
5. Roof System(s)

We will cover: roofs, walls, basements/slabs and windows



Importance of the Enclosure

- Image
  - People see it!
- Building problems
  - Often heat, moisture and the enclosure
- Energy consumption
  - Driven by enclosure performance

Building Science Corporation NESEA BE2011: Introduction to Building Science 10

Enclosure Loadings

- The separation function generates *loads*
- *Load*: any event, phenomenon or characteristic that can affect the enclosure
  - Heat, Air, Moisture
  - Fire, Sound
  - UV, Ozone
  - Gravity, impacts, abrasion
  - Insects
  - Etc…

Building Science Corporation NESEA BE2011: Introduction to Building Science 11

Loads: Climate / Site

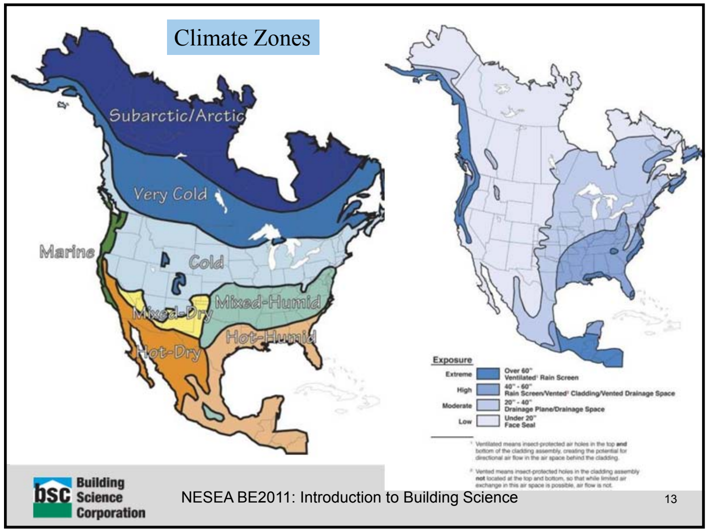
Seattle ≠ Sacramento
Miami ≠ Minneapolis
Edmonton ≠ Vancouver

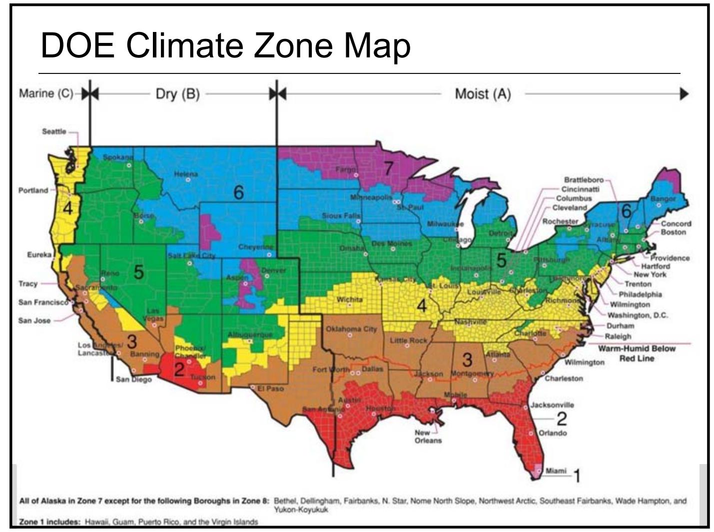
- Design for
  - Climate zone
  - Site
  - Building height, shape, complexity

Marcus Vitruvius Pollio

These are properly designed, when due regard is had to the country and climate in which they are erected. For the method of building which is suited to Egypt would be very improper in Spain, and that in use in Pontus would be absurd at Rome: so in other parts of the world **a style suitable to one climate, would be very unsuitable to another**: for one part of the world is under the sun's course, another is distant from it, and another, between the two, is temperate.

Building Science Corporation NESEA BE2011: Introduction to Building Science 12





Enclosure Failures

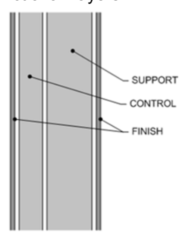
- Problem causes:
  - 1. Material/system does not fill function
  - 2. Layer doing function not designed for
  - 3. Not built according to design (workmanship)
- Avoidance requires understanding each

Building Science Corporation NESEA BE2011: Introduction to Building Science 16

Basic Functions of the Enclosure

- 1. Support
  - Resist and transfer physical forces from inside and out
- 2. Control
  - Control mass and energy flows
- 3. Finish
  - Interior and exterior surfaces for people
- Distribution – a building function

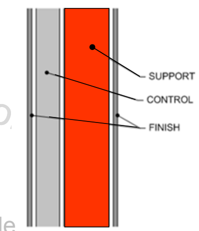
Functional Layers



Basic Enclosure Functions

- **Support**
  - **Resist & transfer physical forces from inside and out**
    - Lateral (wind, earthquake)
    - Gravity (snow, dead, use)
    - Rheological (shrink, swell)
    - Impact, wear, abrasion
- Control
  - Control mass and energy flows
- Finish
  - Interior and exterior surfaces for people

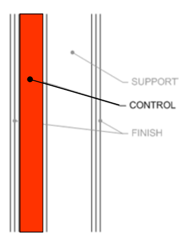
Functional Layers



Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- **Control**
  - **Control mass and energy flows**
    - **Rain** (and soil moisture)
      - Drainage plane, capillary break, etc.
    - **Air**
      - Continuous air barrier
    - **Heat**
      - Continuous layer of insulation
    - **Vapor**
      - Balance of wetting/drying
- Finish
  - Interior and exterior surfaces for people

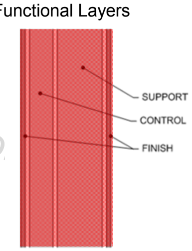
Functional Layers



Other Control . . .

- Support
- **Control**
  - **Fire**
    - **Penetration**
    - **Propagation**
  - **Sound**
    - **Penetration**
    - **Reflection**
  - **Light**
    - **Diffuse/glare**
    - **View**
- Finish

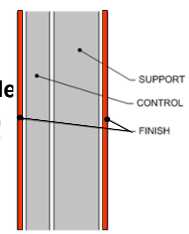
Functional Layers



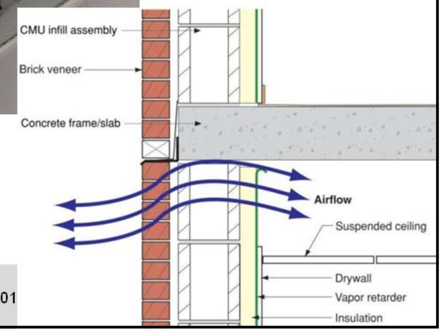
Basic Enclosure Functions

- Support
  - Resist & transfer physical forces from inside and out
- Control
  - Control mass and energy flows
- **Finish**
  - **Interior & exterior surfaces for people**
    - Color, speculance
    - Pattern, texture

Functional Layers



Finish vs. Control Confusion



Distribution

- A *Building* Function imposed on enclosure
- Distribute services or utilities to from through, within, the enclosure, e.g.,
  - Power
  - Communication
  - Water (Potable, sewage, etc.)
  - Gas
  - Conditioned air ←
  - Cold or hot water ←

Enclosure Design

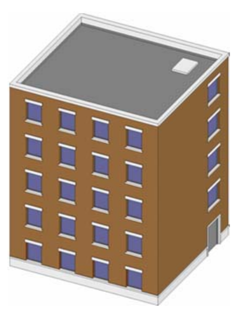
Enclosure Design Principles 1

- Design a complete structural load transfer path
  - Structure, windows, ties, etc.
  - All loads go to ground
- Respect the site and climate
  - Rain, sun, wind, hill, valley, high rise or low-rise
- Continuous rain control plane
  - Control with surface features and detailing
  - Drained, storage, or perfect barrier strategy
- Continuous plane of air barrier tightness
  - Fastidious attention to detail 3-D

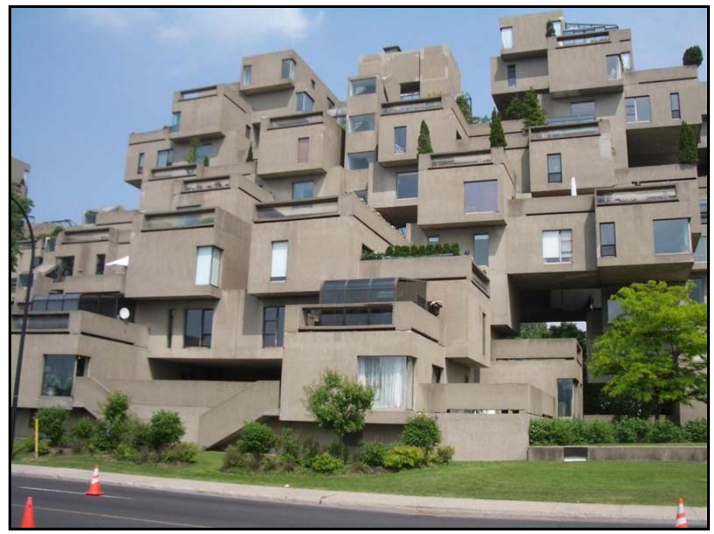
Enclosure Design Principles 2

- Provide a continuous plane of insulation
  - Ideally separate structure from enclosure
  - *Avoid thermal bridges*
- Provide a moisture tolerant design
  - Balance wetting, drying, and storage (matl's, climate)
  - Use appropriate levels of vapor control
    - No cold vapor barriers, allow drying
- Accommodate movements and tolerances
- Draw all of the Details!

The Enclosure: Adding the Layers

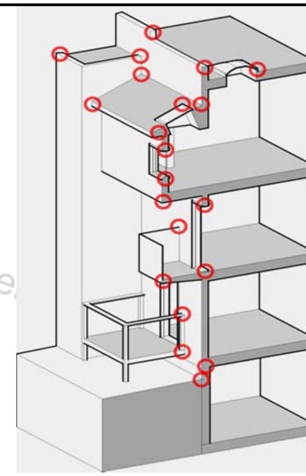


- Structure
- Air-Rain Barrier
- Insulation
- Finish



Enclosure Design: Details

- Details demand the same approach as the enclosure.
- Scaled drawings required at ○



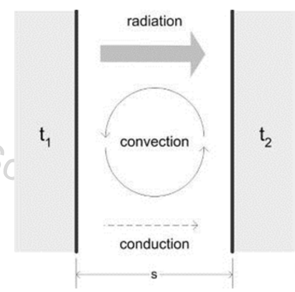
Heat Flow and Control

Basic Heat Flow

Conduction

Convection

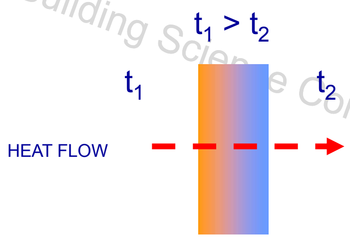
Radiation



Basic Heat Flow

Conduction

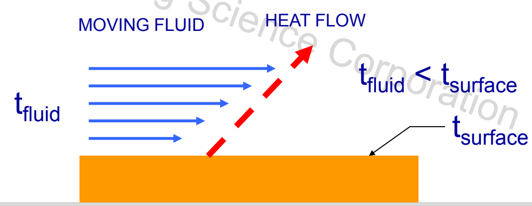
- *Heat Flow by direct contact*
- *Vibrating molecules*
- *Most important for solids*



Basic Heat Flow

Forced Convection

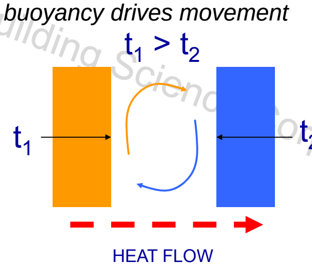
- *Heat Flow by bulk movement of molecules*
- *Most important for liquids and gases*
- *Movement driven by fans or wind*



Basic Heat Flow

Natural Convection

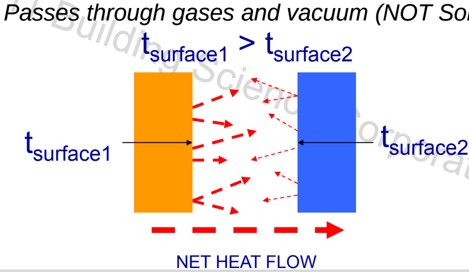
- *Heat Flow by bulk movement of molecules*
- *Most important for liquids and gases*
- *Natural buoyancy drives movement*



Basic Heat Flow

Radiation

- *Heat flow by electromagnetic waves*
- *Heat radiates from all materials, e.g. campfire*
- *Passes through gases and vacuum (NOT Solid)*



Heat Flow In Materials

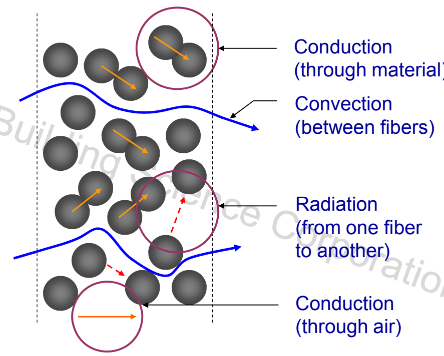
Function of:

- *Material Type*
- *Density and pore structure*
- *Moisture content*
- *Temperature difference*

Combination of:

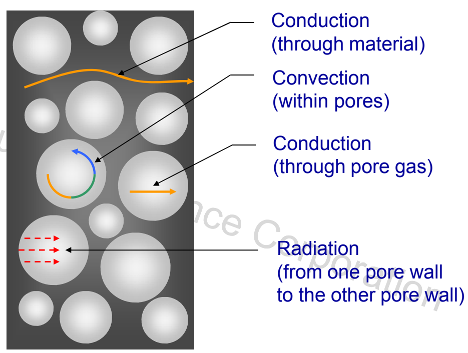
- *Conduction through material and air (or other gas)*
- *Convection in pores*
- *Radiation through pores*

Heat Flow In Materials



HYPOTHETICAL FIBEROUS MATERIAL

Heat Flow In Materials



HYPOTHETICAL POROUS MATERIAL

Heat Flow In Materials

Thermal Conductivity (k)

- *Material property*
- *Time rate of heat flow through a unit thickness and unit area of material under a unit temperature difference*

Units: Btu•in/(ft^2•hr•° F) *or* W/(m•K)

Heat Flow In Materials

Thermal Conductance (C)

- *Layer property*
- *Time rate of heat flow through a unit area of a material layer (or the conductivity of a material for a given thickness)*

Formula: C = k/L

Units: Btu/(ft²•hr•° F) *or* W/(m²•K)

Heat Flow In Materials

Thermal Resistance

- *Layer property*
- *Reciprocal of conductance*
- *A measure of how well a material resists heat flow*

Formula: Resistance = 1/C

Units: ft²•hr•° F/ Btu *or* m²•K/W

Heat Flow In Materials

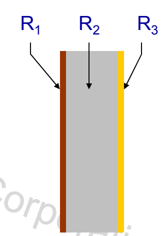
R-Value or RSI

- *Gives heat flow as "equivalent conductance"*
- *Includes all three modes of heat transfer*
- *Rarely includes thermal bridging or three dimensional heat flow*
- *Never intended to include airtightness or thermal mass*

Conductance through the enclosure

Total thermal resistance R_T is a sum of the thermal resistance of all the materials in the enclosure assembly.

Materials such as gypsum, plywood, OSB, wood studs, metal studs all contribute to the overall thermal resistance.

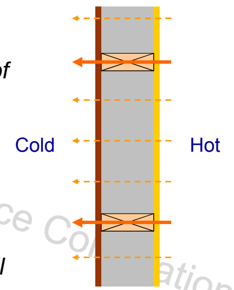


$R_T = R_1 + R_2 + R_3$

Conductance through the enclosure

Materials of lower thermal resistance create pathways of increased conductance losses, or "thermal bridges" through layers of greater thermal resistance

Thermal bridging can reduce the effective R-value of a wall assembly.

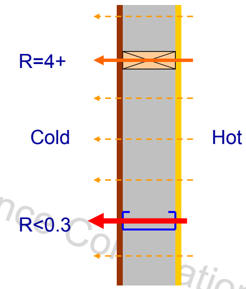


A 2x6 wood stud wall 16" OC with R-19 Fiberglass Batt = effective R-13 wall assembly.

Conductance through the enclosure

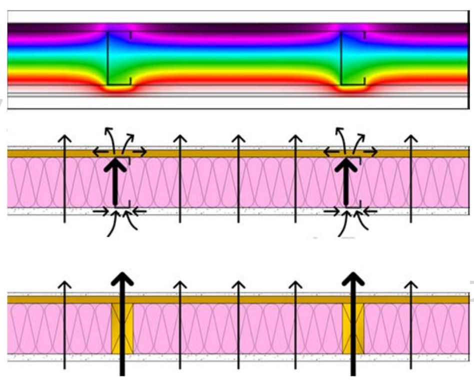
Steel is 400 times more conductive than wood

Steel studs are about 40 times thinner



A 2x6 steel stud wall 16" OC with R-19 Fiberglass Batt = effective R-9 wall assembly.

Conductance through the enclosure



Conductance through the enclosure

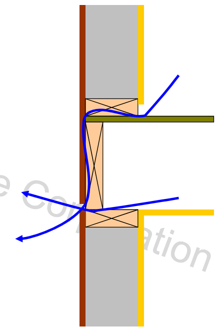
Eliminating the Thermal Bridge

Convection through the enclosure

Commonly referred to as "Air Leakage"

Driven by air pressure differences
- *wind*
- *mechanical*
- *stack effect*

Large energy impacts (can account for 30% of the heating and cooling energy)



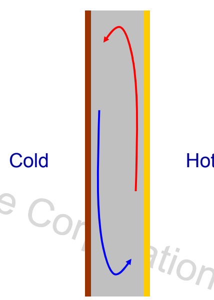
Convection within the assemblies

Commonly referred to as "Convective Loops"

Driven by natural buoyancy - warm air will rise

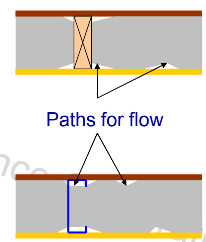
Short circuits insulation

R-value does not take into account the potential of movement of air within an assembly.



Convection within the assemblies

Spaces for flow from:
- *Compressing batts*
- *Inset stapling*
- *Difficulty in filling steel studs*



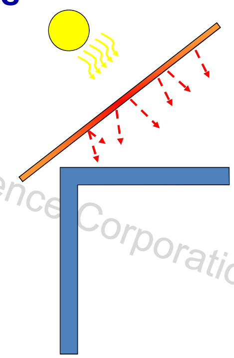
Convection within the assemblies

Radiation from surfaces within the enclosure assemblies

Net radiant flow across a clear cavity

Emissivity: how much radiation comes off the material

Low emissivity material: common in attics



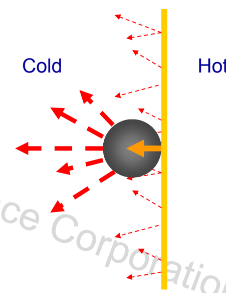
Radiation from surfaces within the enclosure assemblies

Radiation from surfaces within the enclosure assemblies

Must have an airspace for radiant products to work

While low emitting, radiant products are often highly conductive

Energy will be conducted to other materials in contact with radiant product (framing, dirt)



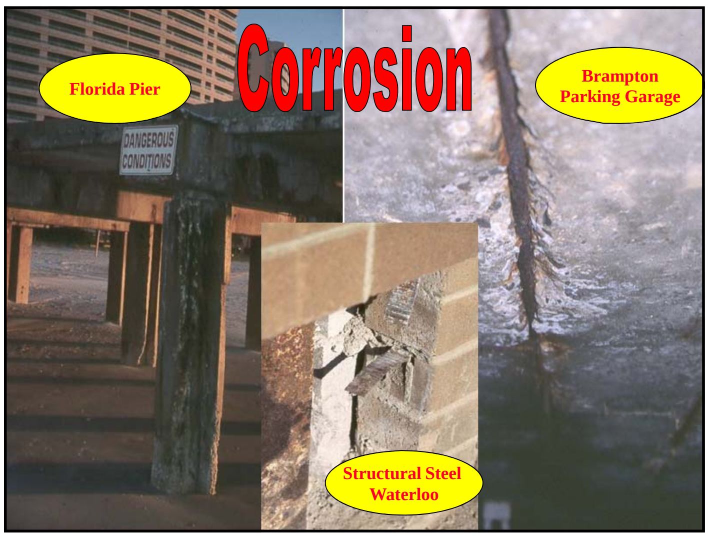
Moisture and Buildings

Moisture and Buildings

- Moisture is involved in almost all building envelope performance problems
  - In-service .... Durability
- Examples:
  - rot,
  - corrosion,
  - mold (IAQ)
  - termites, (!),
  - staining
  - etc.

Moisture Damage

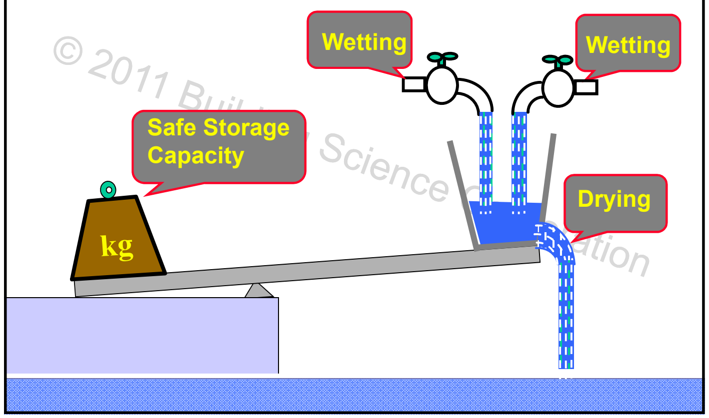
- Damage caused by
  - Very high humidity for a long time
  - Wet (100%RH) for a shorter time
- Time required depends
  - on material
  - Temperature
    - Higher temperature accelerates process



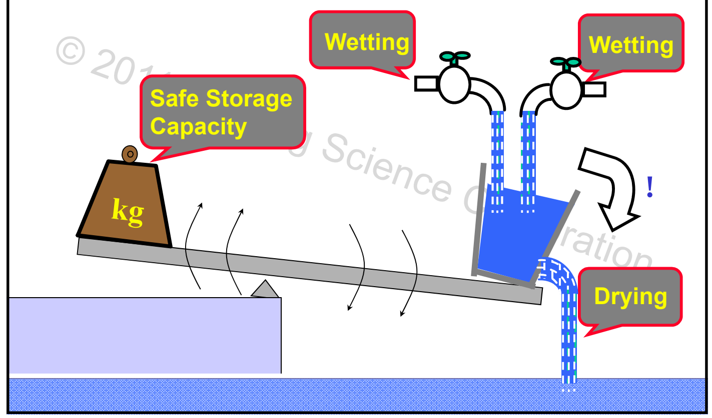
Moisture Control

- Moisture-related Problems
  1. **Moisture** must be available
  2. There must be a route or **path**
  3. There must be a **force** to cause movement
  4. The material must be **susceptible** to damage
- Theory:
  - eliminate any one for complete control
- Practice:
  - control as many as possible

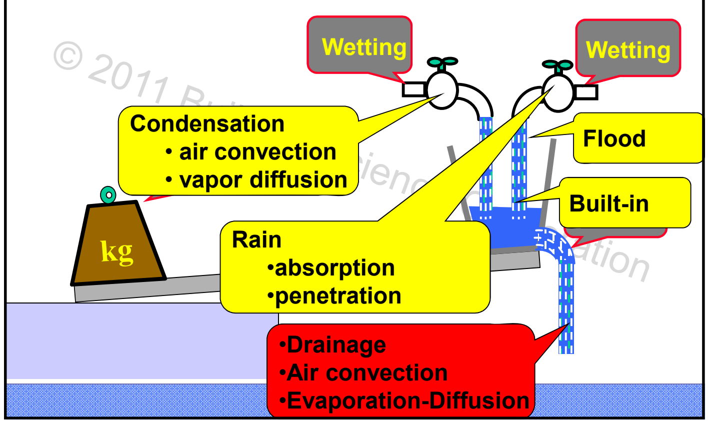
Moisture Balance



Moisture Balance: Accumulation



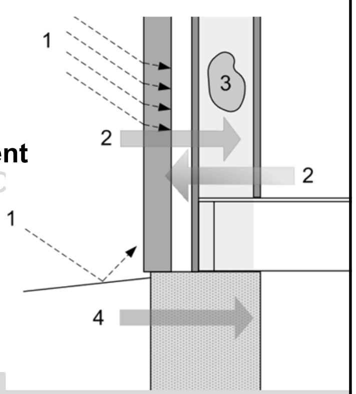
Moisture Balance



Wall + Roof Wetting

Sources/ Mechanisms

1. **Rain**
   - absorption
   - penetration
   - splash and drips
2. **Water Vapor Movement**
   - Diffusion
   - Convection (air leaks)
3. **Built in**
4. **Ground**
   - Capillary (wicking)
   - Gravity
   - Diffusion

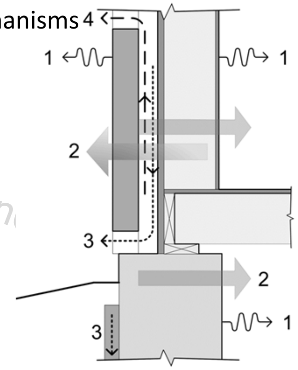


bsc Building Science Corporation NESEA BE2011: Introduction to Building Science 68

Wall + Roof Drying

Sinks and Mechanisms

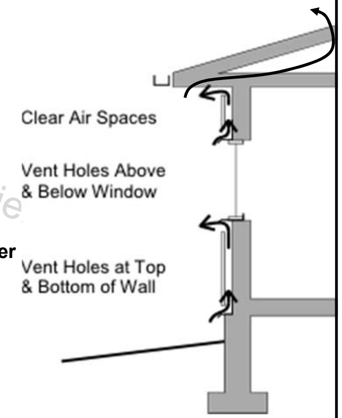
1. **Surface Evaporation**
   - Wicking to surface
2. **Vapor Movement**
   - i) Diffusion
   - ii) Convection
3. **Drainage**
4. **Intentional Convection** = Ventilation Drying



Note above and below grade

Ventilation Drying

- **Ventilation provides drying to the exterior**
- Can be important for:
  1. **vapor impermeable cladding**
     - metal panels
     - most roofing
  2. **systems which retain rainwater**
     - Improves survivability of small rain leaks and condensation



Storage

- Bridges gap in time between wetting and drying
- How much moisture for how long before damage
- *Safe* storage: safe against what?
  - mold, rot, freeze-thaw, corrosion

Design Choices

- Either avoid wetting
- Or, provide enough drying to accommodate wetting
- Depending on the storage provided

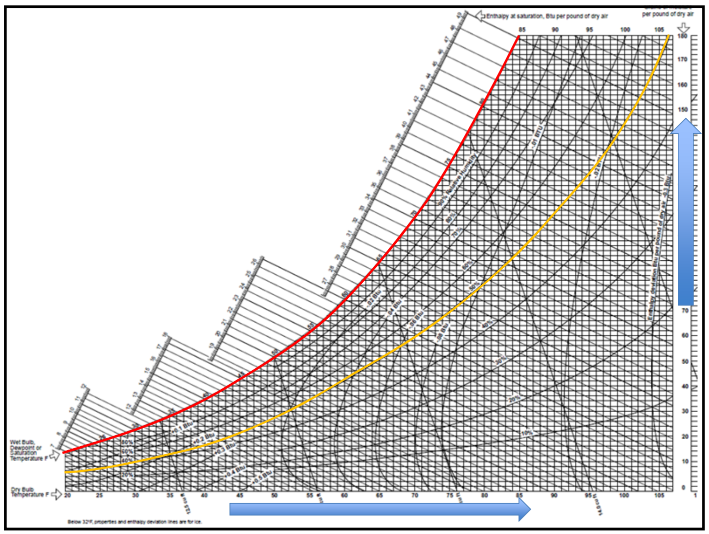
The balance has shifted over time

- *Amount* of storage has changed over last 100 yrs
  - e.g. steel stud, vs wood stud vs concrete block
  - 1: 10 : 100+
- Wetting is usually less
- Drying is often much less

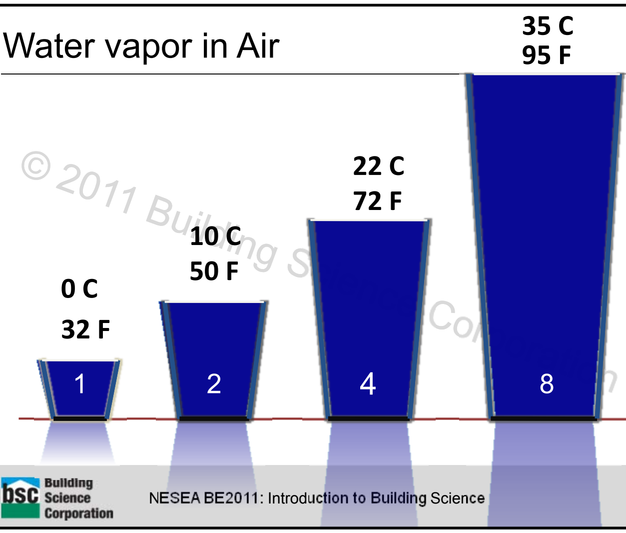
Design Solutions

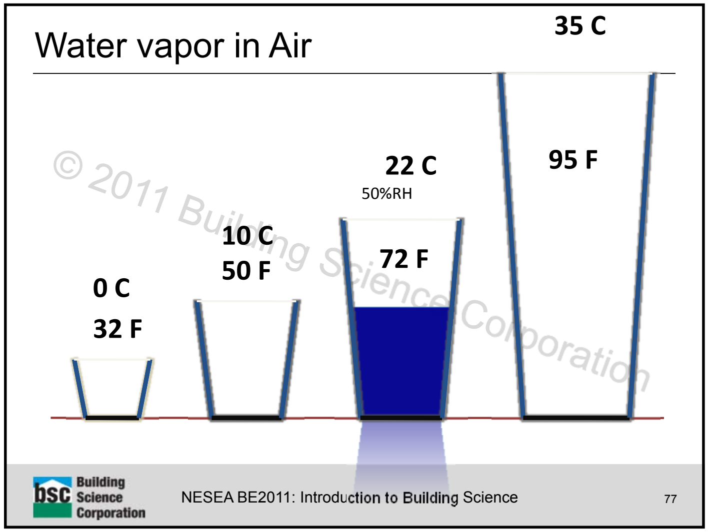
- Balance wetting, drying, and storage
- Practical Rules
  - Provide a continuous plane of rain control including each enclosure detail
  - Provide continuous air barriers and insulation to control condensation problems
  - Allow drying of built-in and accidental moisture – beware drying retarders

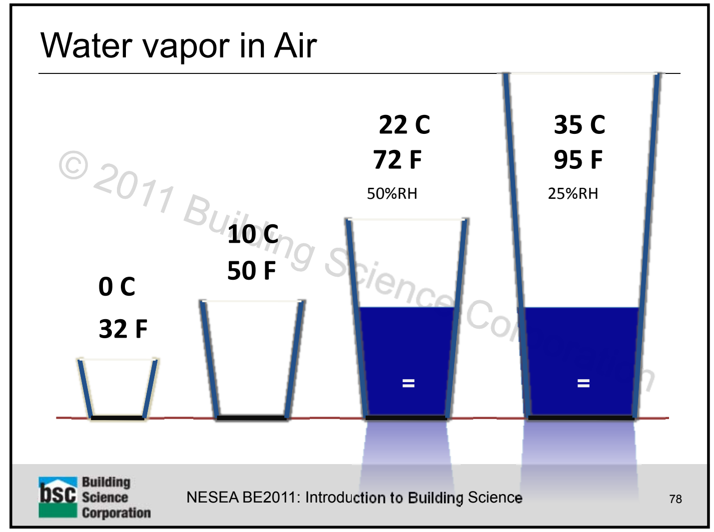
Psychrometrics (and Condensation)

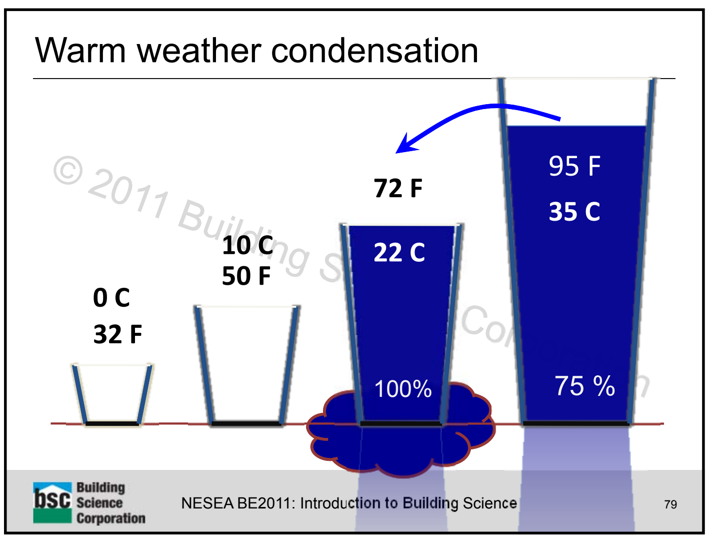


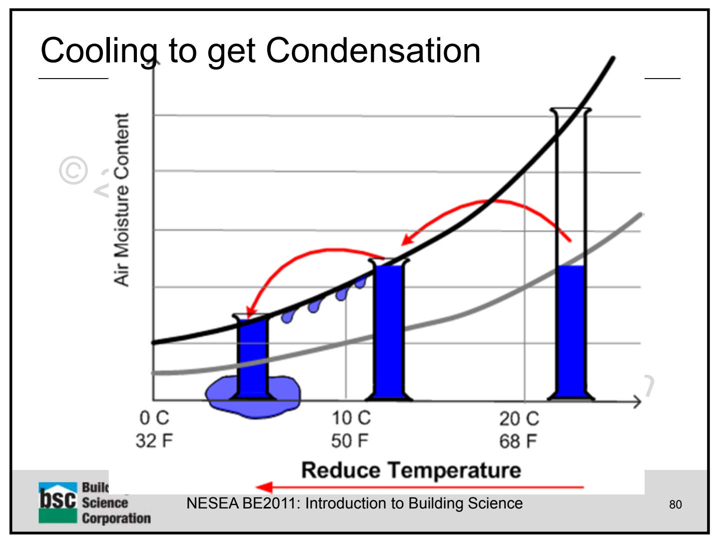
Water vapor in Air



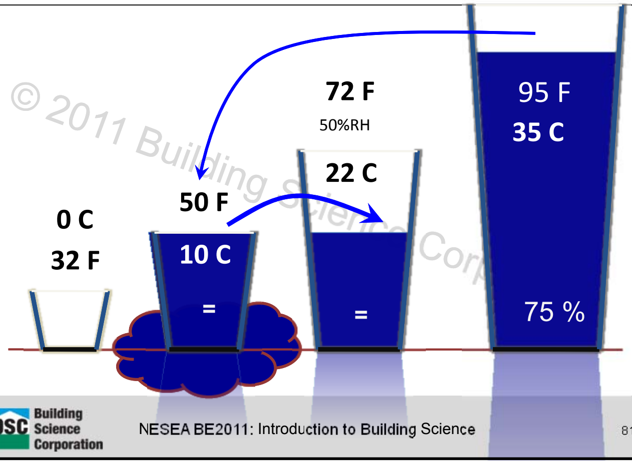

Water vapor in Air
0 C
32 F
10 C
50 F
22 C
50%RH
72 F
35 C
95 F
Building Science Corporation
NESEA BE2011: Introduction to Building Science
77


Water vapor in Air
0 C
32 F
10 C
50 F
22 C
72 F
50%RH
35 C
95 F
25%RH
=
=
Building Science Corporation
NESEA BE2011: Introduction to Building Science
78


Warm weather condensation
0 C
32 F
10 C
50 F
72 F
22 C
100%
95 F
35 C
75 %
Building Science Corporation
NESEA BE2011: Introduction to Building Science
79


Cooling to get Condensation
Air Moisture Content
0 C
32 F
10 C
50 F
20 C
68 F
Reduce Temperature
Building Science Corporation
NESEA BE2011: Introduction to Building Science
80

Dehumidification



Air Flow

Airflow Control: Why

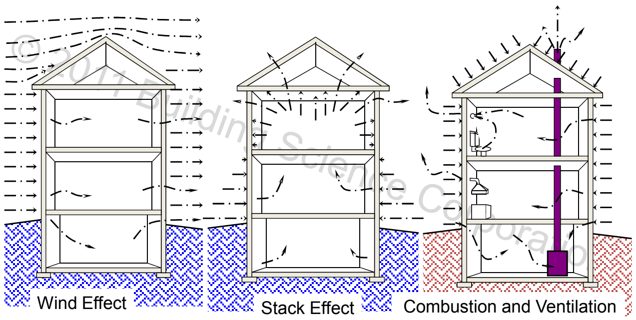
- Moisture control
  - air leakage condensation
- Comfort and Health
  - Drafts
  - Odors, particles, gases
- Energy
  - Heat transferred with air
- Sound
- Required by some codes

If you can't enclose air, you can't condition it

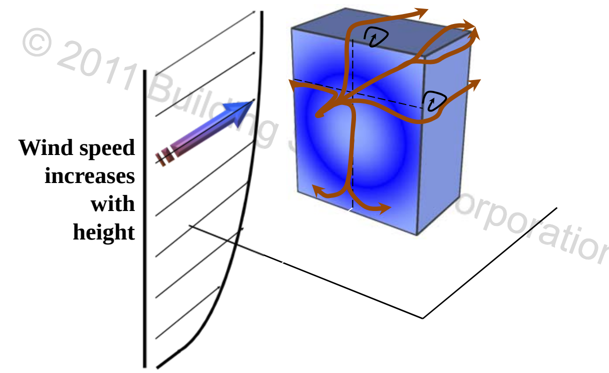
Driving Forces

- 1. Wind Pressures
- 2. Buoyancy (or stack effect)
- 3. HVAC

Driving Forces

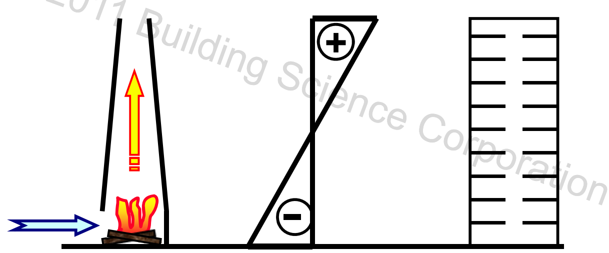


Wind Flow Patterns



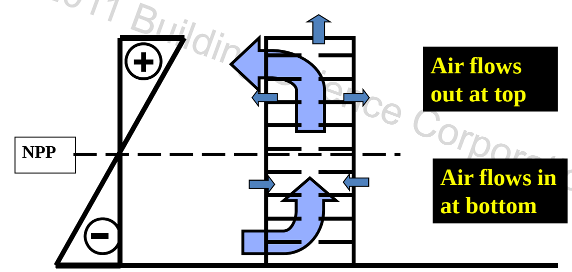
2. Stack Effect: Cold Weather

- Hot air rises
- Tall Building in Winter = Heavy Balloon



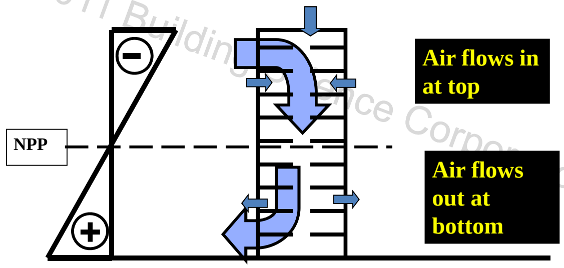
Stack Effect: Cold Weather

- “Perfect” Building equally leaky everywhere
- Neutral Pressure Plane at mid-height



Stack Effect: Warm Weather

- "Perfect" Building equally leaky everywhere
- Neutral Pressure Plane at mid-height

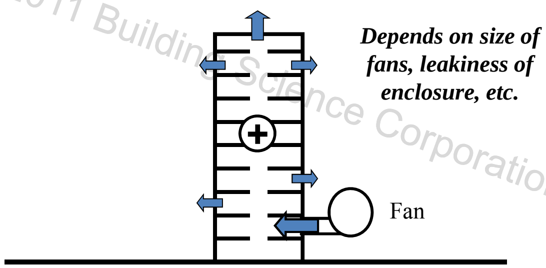


Stack Effect

- When cold (20 F) outside
  - About 4 Pa per storey (10') of height
- When hot (95 F) outside
  - About 1.5 Pa per storey (10') of height
- Result
  - Revolving doors
  - We suck air from below in cold weather

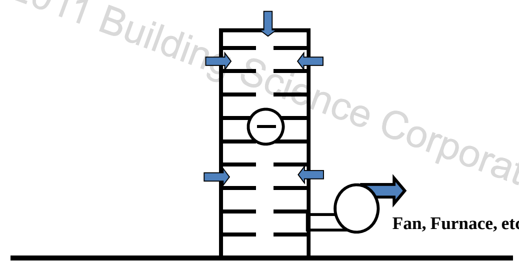
3. HVAC Pressurization

- More airflow forced into building than sucked out of building = Pressurization



De-Pressurization

- More airflow forced out of building than forced into building = De-Pressurization



Driving Forces

- Wind
  - Taller buildings see high pressures!
  - 2-10 Pa low bldgs, 30-200+ Pa tall buildings
- Stack Effect
  - Pressure increases directly with temperature difference and height
- HVAC
  - Depends on design and operation

Building Science Corporation NESEA BE2011: Introduction to Building Science 93

Air Leakage Condensation

- Controlling interstitial condensation is a major reason to control airflow
- If moist air contacts cool surface: Condensation occurs
- When
  - winter: cold outside surfaces
  - summer: cold inside surfaces
- Damaging airflow direction:
  - cold weather inside to outside
  - warm weather outside to inside

Building Science Corporation NESEA BE2011: Introduction to Building Science 94

Summer condensation

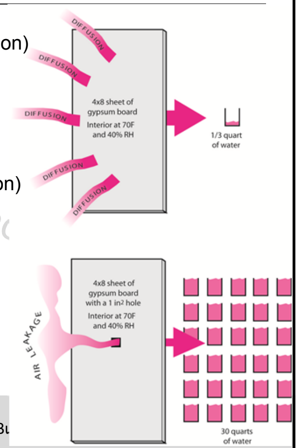
Air Leakage Condensation at top stories
- Wind +
- Stack +
- (Rain)

=Re-cladding

Air Barriers vs. Vapor Barriers

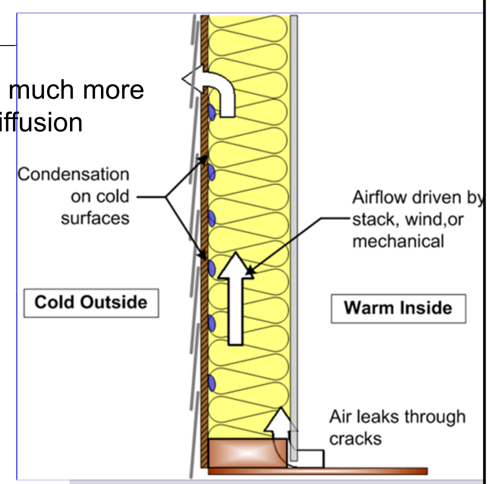
Water Vapor Transport

- Vapor Diffusion (like heat conduction)
  - more to less vapor
  - No air flow
  - Flow through tiny pores
- Air Convection (like heat convection)
  - more to less air pressure
  - flow through visible cracks and holes
  - vapor is just along for the ride

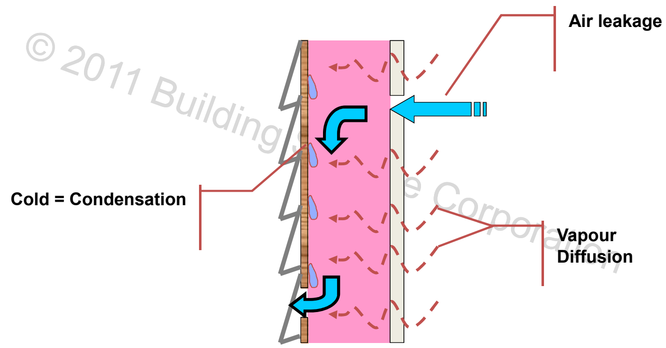


- Air leakage is much more critical than diffusion

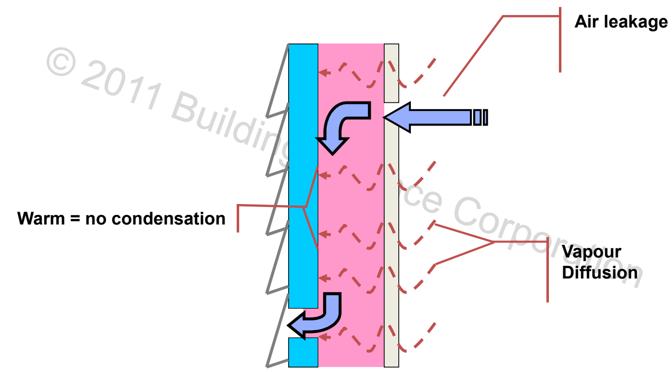
Beware
- Parapets
- Hollow walls
- Canopies
- Penetrations



Wall w/o Insulated Sheathing



Wall with Insulated Sheathing



Vapor Barriers and the Code

- Class I: 0.1 perm or less (polyethylene)
- Class II: 0.1 < perm ≤ 1.0 perm (Kraft facing, VB paint)
- Class III: 1.0 < perm ≤ 10 perm (Latex paint)
- More open vapor control allows greater drying—more "forgiveness" in wall

Vapor Barriers and the Code

TABLE N1102.5.1
CLASS III VAPOR RETARDERS

Zone	Class III vapor retarders permitted for:
Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 2.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 3.75 over 2x6 wall
5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 5 over 2x4 wall Insulated sheathing with *R*-value ≥ 7.5 over 2x6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 7.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 11.25 over 2x6 wall
7 and 8	Insulated sheathing with *R*-value ≥ 10 over 2x4 wall Insulated sheathing with *R*-value ≥ 15 over 2x6 wall

Can just use latex paint (no vapor barrier) if you add enough insulation outside of the stud bay insulation. Safer -> controls diffusion and air leakage moisture

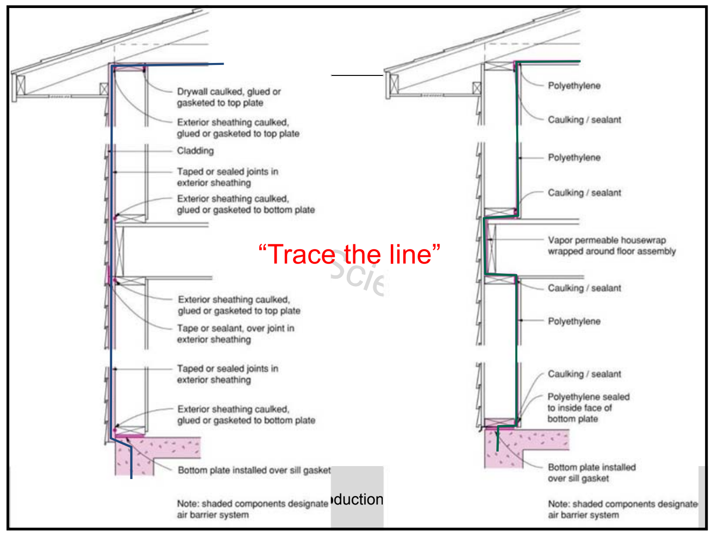
Air Barriers

Air Barrier Systems

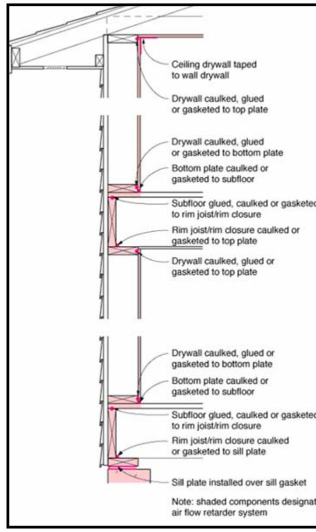
- Function: to stop airflow through enclosure
- ABS can be placed anywhere in the enclosure
- Must be strong enough to take wind gusts (code requirement)
- Many materials are air impermeable, but most systems are not airtight

Air Barrier Systems: Requirements

- Continuous
  - primary need, common failure
- Strong
  - designed for full wind load
- Durable
  - critical component - repair, replacement
- Stiff
  - control billowing, pumping
- Air Impermeable
  - (may be vapour permeable)



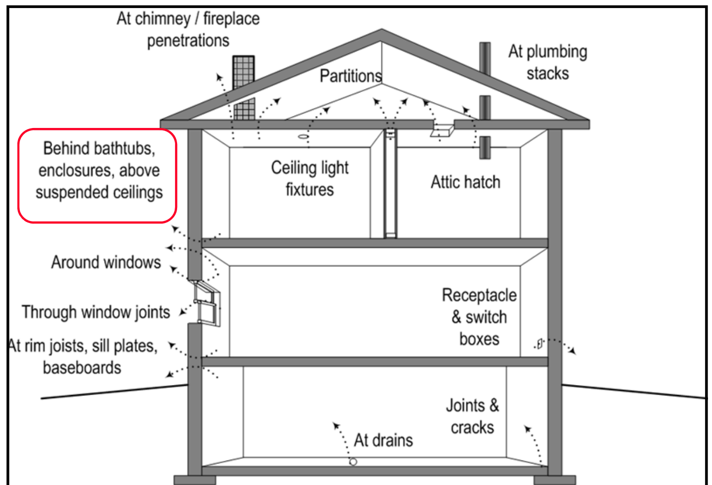
Poly can be (?) an air *and* vapour barrier
But
BEWARE when Air Conditioning
Definitely not in South



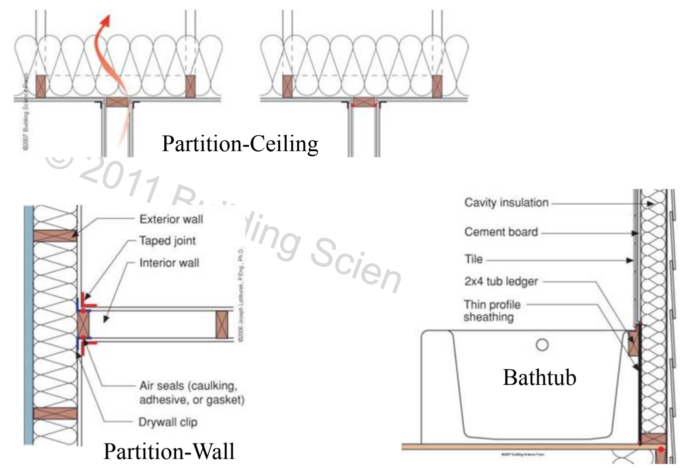
The Airtight Drywall Approach

Use drywall, framing members
- **Seal with sealant, gaskets, etc.**
- **Is stiff, strong**
- **Often easier to ensure quality**
- **Widely applicable to all forms of commercial, residential**
- **Allows choice of vapor permeance**

Air sealing around components:
e.g., windows and walls
other Openings and penetrations



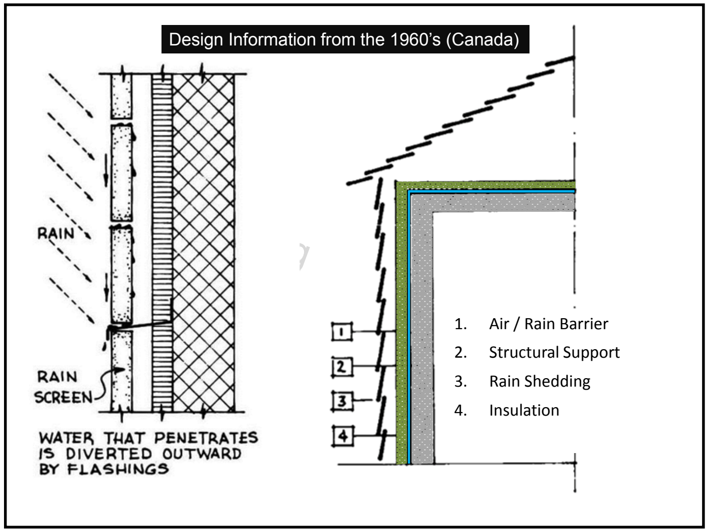
Typical Air Leakage Points

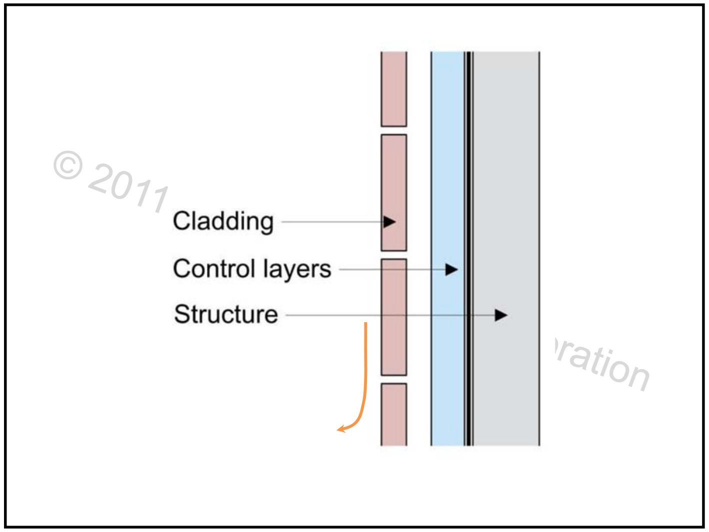


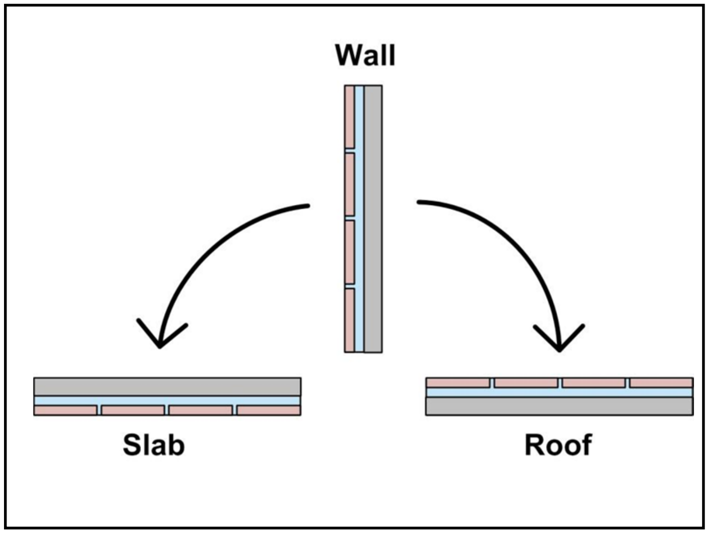
Big holes

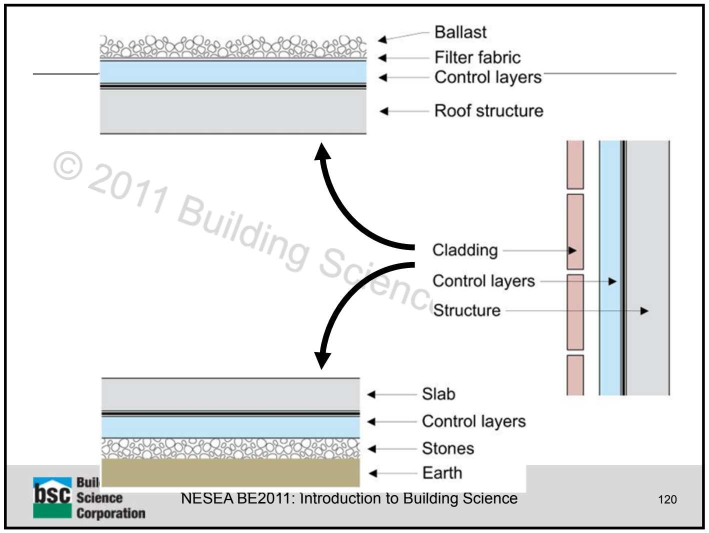
The “Perfect Wall”

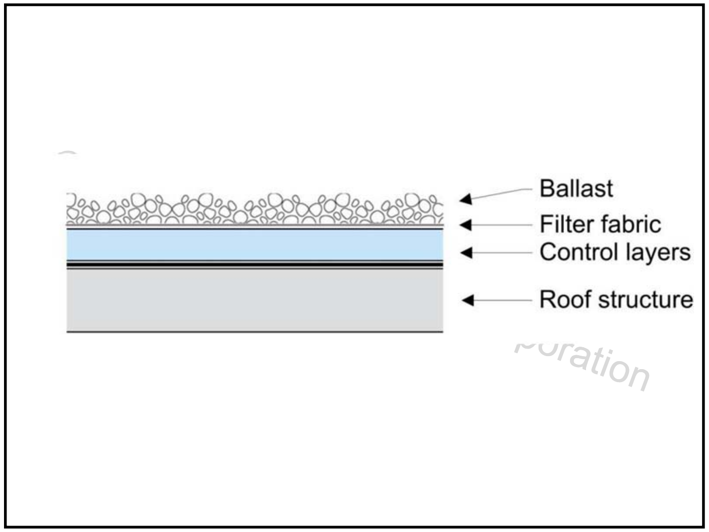
Building Science Corporation NESEA BE2011: Introduction to Building Science 116

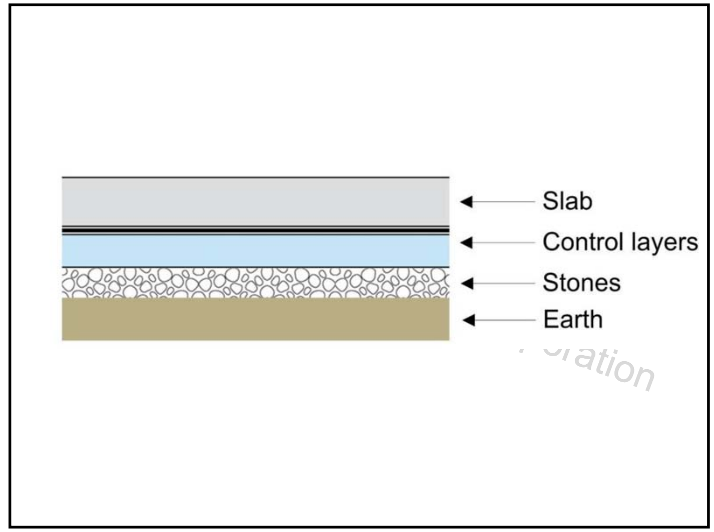

Design Information from the 1960's (Canada)
RAIN
RAIN SCREEN
WATER THAT PENETRATES IS DIVERTED OUTWARD BY FLASHINGS
1. Air / Rain Barrier
2. Structural Support
3. Rain Shedding
4. Insulation

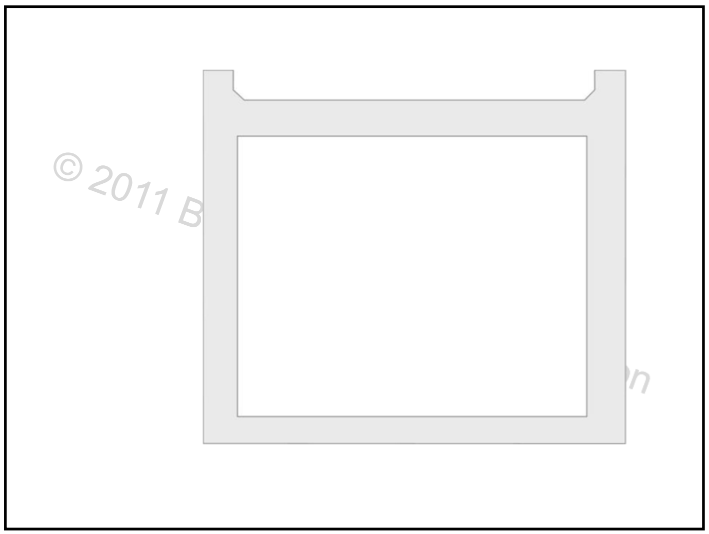

Cladding
Control layers
Structure

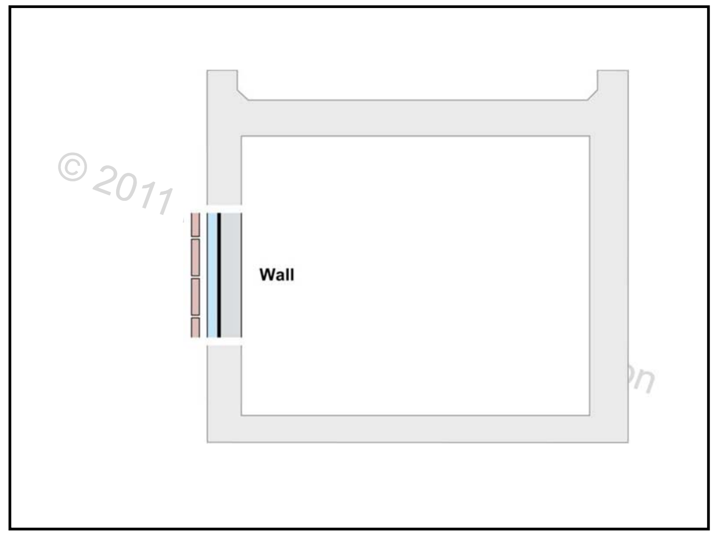

Wall
Slab
Roof

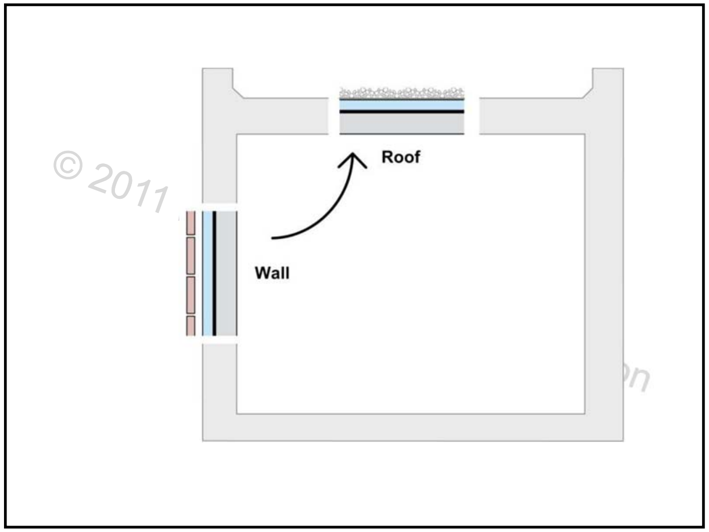

Ballast
Filter fabric
Control layers
Roof structure
Cladding
Control layers
Structure
Slab
Control layers
Stones
Earth
NESEA BE2011: Introduction to Building Science
120

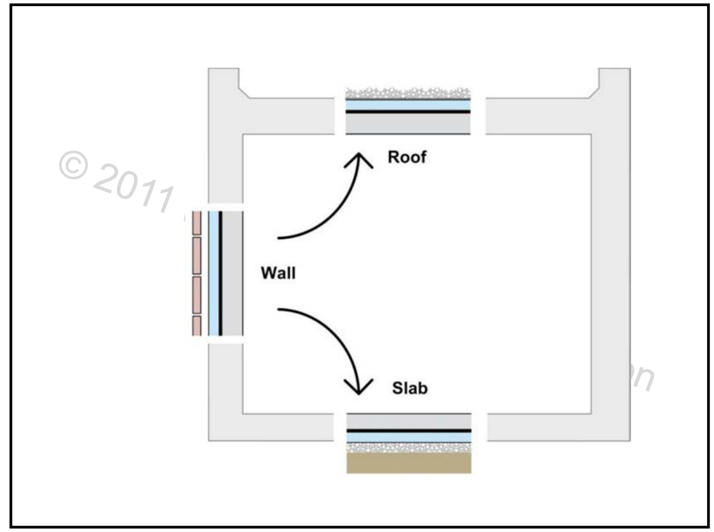

Ballast
Filter fabric
Control layers
Roof structure

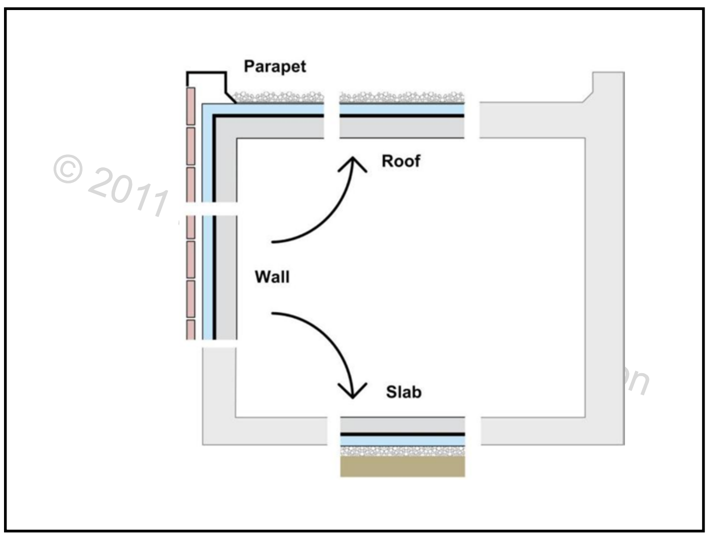

Slab
Control layers
Stones
Earth

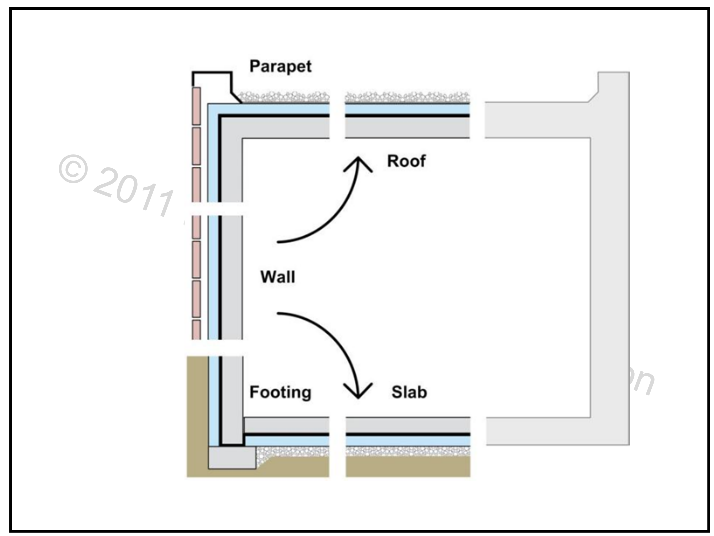


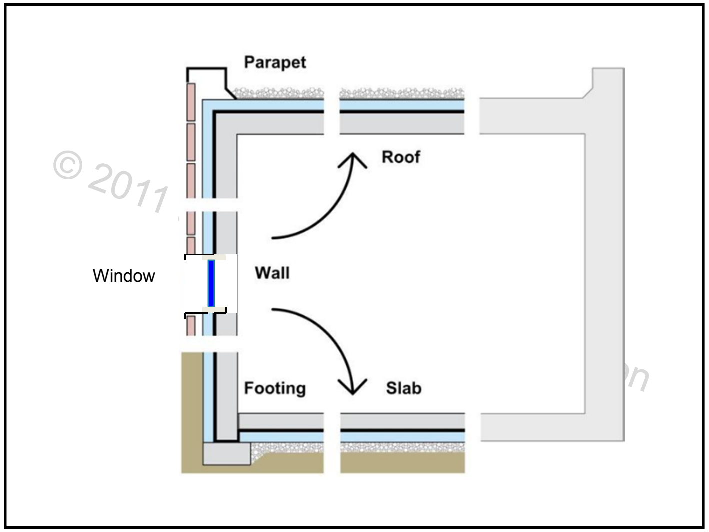

Wall

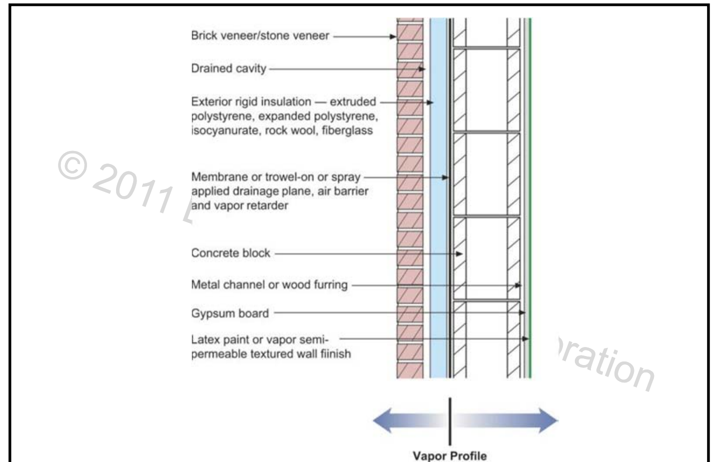

Roof
Wall


Roof
Wall
Slab


Parapet
Roof
Wall
Slab

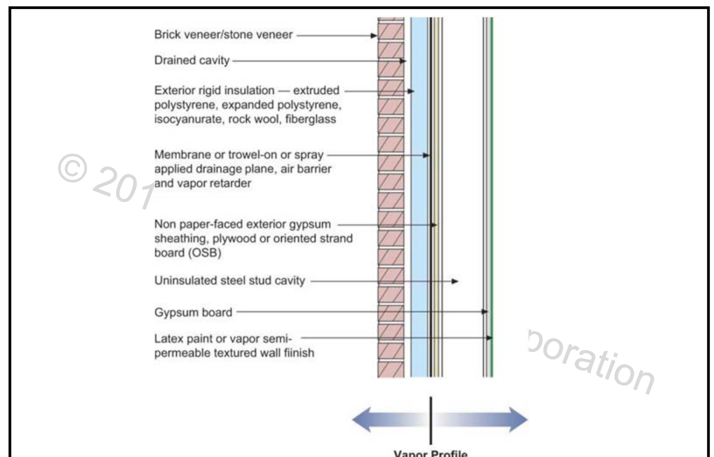

Parapet
Roof
Wall
Footing
Slab





The “Perfect” wall: Higher Performance


Asphalt Drainage Plane Air Barrier
Rockwool Insulation



The Commercial Steel Frame High Performance wall

"Perfect Wall" Example

133

All Four Control Layers

Spray foam= air barrier drainage plane insulation vapor control

Transitions, Continuity, Penetrations

"Perfect Wall" Advantages

- Very robust enclosure—"500 year building"
  - Structural portion in "interior" conditions
- Institutional/long term buildings
- No risk of interstitial condensation
- Continuity of control layers
- Any interior condition
- Any exterior condition

NESEA BE2011: Introduction to Building Science 135

Fenestration

NESEA BE2011: Introduction to Building Science 136

Windows & Curtainwalls

- A major element in modern architecture
- Must apply the usual building enclosure design principles
  - Support, Control, Finish, Distribute
- Must also consider
  - Control of solar radiation and light
  - Allowance for ventilation/emergency egress

Windows

- Functions: Same as wall - *plus*
  - transparent and allow ventilation
  - not easy, hence expensive and compromise
- Structure - transfer loads
- Rain control
- Heat control
- Airflow control – tight / ventilation
- Solar control – gain / reject

Why Good Windows/Curtainwalls?

- Major impact on:
  - energy performance, e.g. HVAC equip
  - view and light
  - comfort (warm, no drafts)
  - condensation resistance
  - rain penetration resistance
  - sound control (airtight)

Window vs. Wall Performance

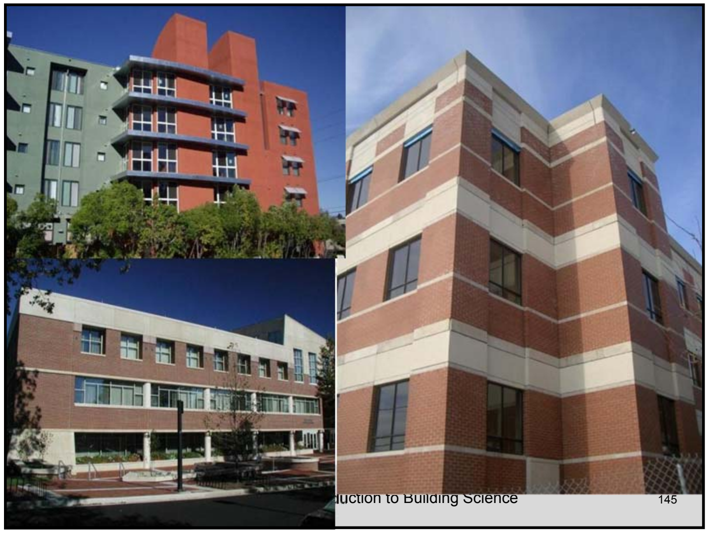
	Window	Wall	Ratio
Conduction: **Q_c=U ΔT**	**U=0.33 / R3**	**U=0.05 / R20**	
T_{in}=70 F **T_{out}=10 F**	**Q_c= 20** Btu/sf/hr	**Q_c= 3** Btu/sf/hr	**6.6**
Solar: **Q_s = SHGC I**	**SHGC=0.60**	**SHGC=0.015**	
I_s= 250 Btu/sf/hr (bright sun)	**Q_s= 150** Btu/sf/hr	**Q_s=3.5** Btu/sf/hr	**42**
Alternate: solar control glazing	SHGC=0.3 Q_s= 75 Btu/sf/hr	U=0.125 / R8 Q_c= 7.5	10

Windows

- Same functions as rest of enclosure
  - Support, control, finish
- Critical design element
  - Image, comfort, energy, durability, daylight
- New windows are often poorly insulated and air leaky
  - Must specify frames, spacers, fills, coatings

Performance Issues and Metrics

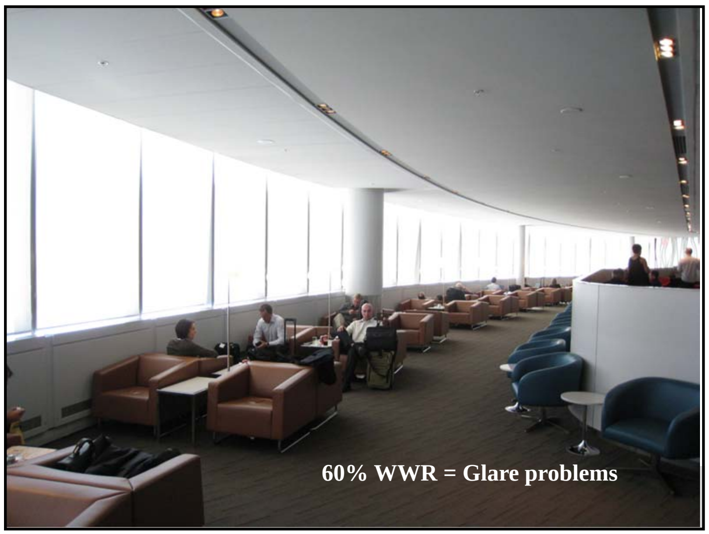
- Primary Metrics
  - Heat Loss / Gain (R,U)
  - Solar Heat Gain Coefficient (SHGC)
  - Visual Transmittance (VT)
- Other Important
  - Condensation resistance (CRI)
  - Air Leakage (AL)
  - Water penetration
  - Impact and Blast



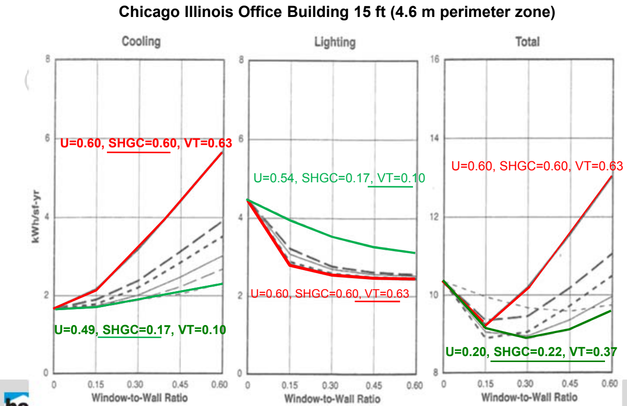
Daylighting

- Natural light can offset artificial lights
- Natural light almost always preferred
- BUT,
  - Must use daylight *controls* and sensors to capture energy savings
  - Need to control glare and solar heating caused by too much glass on sunny days
  - Cooling costs often overwhelm lighting savings
    - New efficient lighting technologies

Building Science Corporation NESEA BE2011: Introduction to Building Science 146



Balance Cooling & Lighting

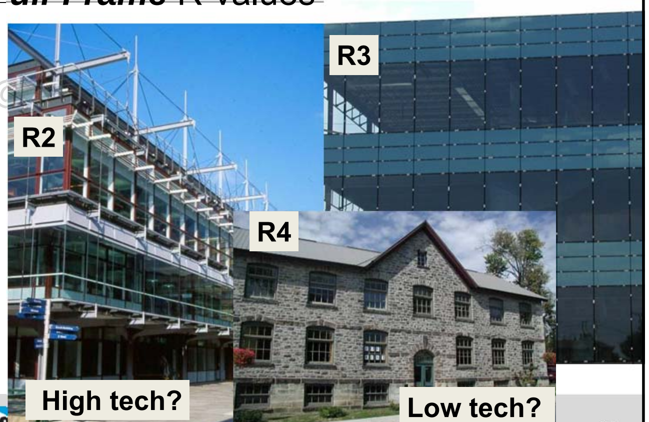


Controlling Heat (U/R)

- Windows usually have the lowest thermal performance of all parts of the enclosure
- Must control heat for
  - Comfort
  - Energy
  - Health
  - Durability

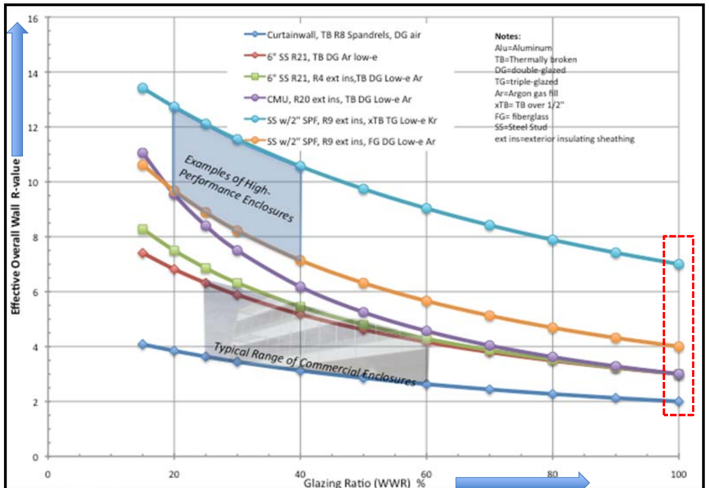
Prevent Condensation (Health, Durability)

Full-Frame R-values



High Performance

Getting better . .



NESEA BE2011: Introduction to Building Science 153

Solar Heat Gain

- Glazing ratio dominates size of AC equipment and ducts in all climates
- Solar Heat Gain Coefficient: SHGC
  - Ratio of solar gain on window that enters room as heat
  - Lower controls better
  - Typically below 0.5

NESEA BE2011: Introduction to Building Science 154

Impact of SHGC on AC sizing

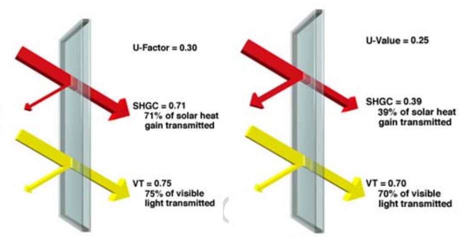
- Both have identical Enclosure Elements *except* Glass

Standard Clear Double Glazed
U= 0.79
SHGC = 0.68
3.5 Ton AC unit

Double Glazed Low-e, Low SHGC
U= 0.60
SHGC = 0.38
2.5 Ton AC unit

All Glazing is not the Same

What do you want?
Solar heating, or
Reduced cooling



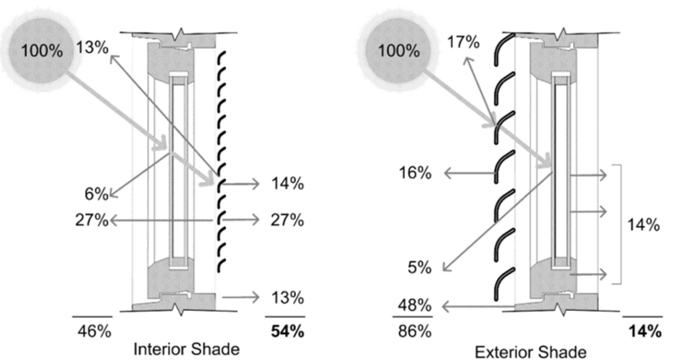
Double Glazed Low-e High SHGC

Double Glazed Low-e Low SHGC

Images © Efficient Windows Collaborative Website, www.efficientwindows.org

8 of 12

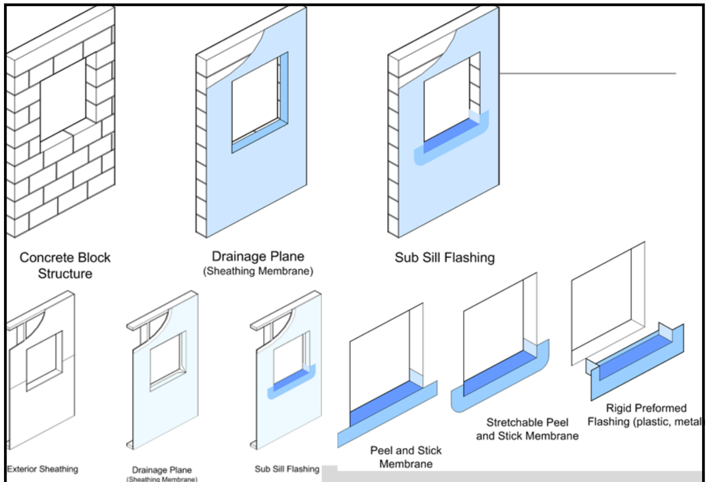
Interior vs. Exterior Shading



Windows and Rain

EIFS & Windows - Oops

Leaks



Building Science Corporation NESEA BE2011: Introduction to Building Science 161

Subsill

Building Science Corporation NESEA BE2011: Introduction to Building Science 162

Formable Sub-sill Flashing

Basements/Foundations

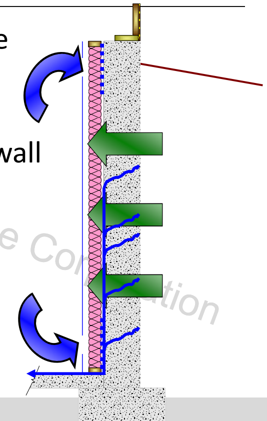
Building Science Corporation NESEA BE2011: Introduction to Building Science 164

Background

- Used increasingly as finished space
- Energy use of basements (insulation)
- Moisture-related failures of basement wall systems
- Known solutions (e.g., exterior insulation, ICFs)

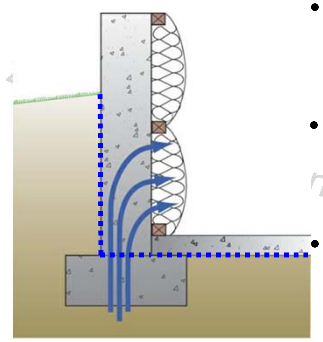
Basement Insulation Problems

- Wintertime interior moisture condensation (like above-grade walls)
- Condensation at bottom of wall (thermal lag of soil)
- Lack of drying of assembly (moisture from concrete and soil); soil is at 100% RH
- Liquid water through wall



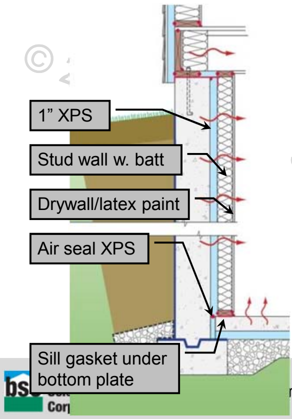
Control Liquid Water (e.g., drainage mat)

Control Capillary Water

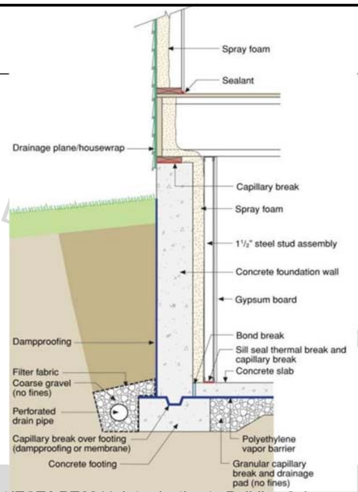


- Polyethylene under floor slab (over free-draining fill)
- Capillary break between soil & basement wall
- Dampproofing at footing-wall connection

Recommended Wall Assembly



- Wintertime condensation controlled
- Summertime (bottom of wall) condensation controlled
- Concrete can dry through XPS at a safe rate
- XPS is moisture tolerant



Spray foam basement insulation

- Open cell
  - Climate specific
- Closed cell

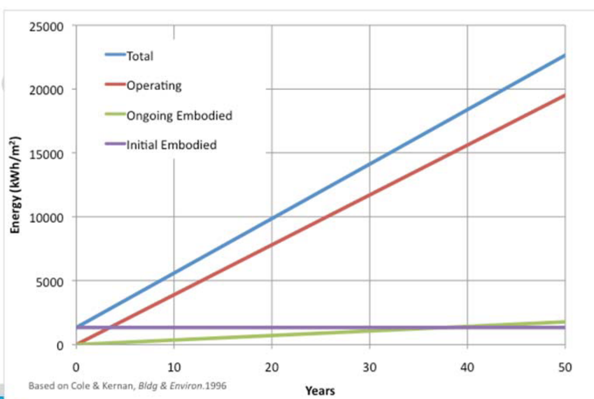
Embodied Energy

Damage Components due to Building

- Resource Extraction
  - Cutting trees, mining, drilling oil, etc.
- Processing
  - Refining, melting, etc. Pollutants and energy
- Transportation
  - Mass and Mode (ship/truck) and Mileage
- Construction
  - Energy, worker transport
- Operational Energy

The Majority of Impact

Office Building Example



Thank you for your time!

QUESTIONS??

This concludes The American Institute of Architects Continuing Education Systems Program

Building America U.S. Department of Energy

Building Science Corporation

Kohta Ueno
kohta@buildingscience.com