John Straube, Ph.D., P.Eng

Spray Foam

Thermal Control:
Insulation & Thermal Bridges

presented by www.buildingscience.com

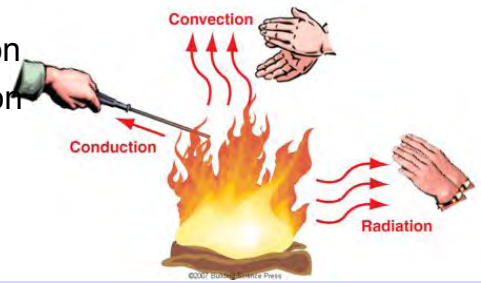
Why Control Heat flow?

1. Occupant Comfort
2. Control surface and interstitial condensation
3. Save energy, reduce operating cost & pollution
4. Save distribution & heating plant costs (capital)
5. Increase architectural options
6. Decrease load diversity
7. Meet codes and specs

How to Control Heat Flow?

Modes of heat transfer:

- Radiation
- Convection
- Conduction

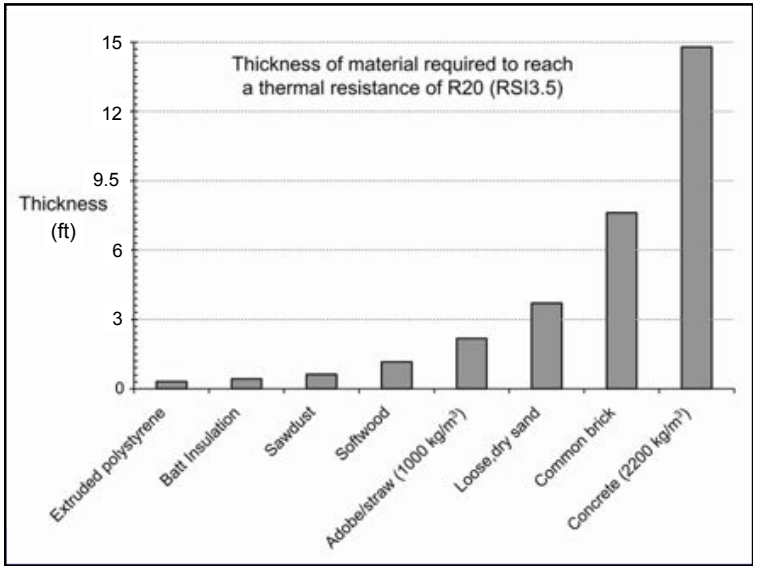


Thermal Performance

- Thermal Conductivity
  - Symbol is “k” or “λ”
- Conductance
  - C = k / thickness
- Resistance “R-value”
  - R = thickness / conductivity
- Measures conduction only
- “effective” conductivity includes other modes

Trends in materials

- Low density materials insulate better!
- High density materials are structural
- Past – relied on high density (but **thick**) structural materials to control heat, air, and moisture flow
  - Wood R 1.000 /inch
  - Clay Straw R 0.700 /inch
  - Old brick R 0.180 / inch
  - Concrete R 0.070 /inch
  - Steel R 0.004 / inch



Fibers

- Mineral Fiber Insulation (vs organic fibers)
  - glass fiber
  - rock fiber
  - slag fiber

  rockwool
- Glass vs rockwool
  - melts at a much lower temperature
  - has thinner fibers so can use lower density
  - Lower density means more air permeance, less strength, and low volume (less cost and energy) shipping

Blown/spray fibrous insulation

- Can use cellulose, glass, rockwool
- Net or adhesive holds sprayed fiber in cavity
- fills space and around obstructions
- avoids settling problems?
- May help control convection

- Are NOT vapour barriers

Cellulose Wall Spray Insulation

- Density 2.5 to 4+ pcf (> 3pcf is recommended)
- R value 3.5 +/- depending on density
- Helps controls convection (higher density=better)
- Can fill irregular cavity spaces
- Settling a concern with low density (< 3pcf)
- Built in moisture concerns (MC? at close in)
- Provides moisture storage
- Controls mold with borate salts (avoid ammonia)
- Is not part of an air barrier system!

Blown Cellulose

Can act as thermal (fire) control layer over foam

Spray Foam

- Primarily polyurethane foam
- open cell (CO_2 blown) e.g., Icynene
  - about R3.7/inch (R13/3.5", R20/5.5")
  - moderate to high vapour permeance (>10 perms)
  - Airtight <0.01 lps/m² @ 75 Pa
- closed cell (gas blown)
  - R6+/inch
  - 1 - 2 US perms (don't need vapour barrier)
  - Airtight <0.01 lps/m² @ 75 Pa

Depends on skin

Spray Foam

- "Open cell" ½ pcf +/-
  - Most high vapor permeance
- "Closed cell" 2 pcf +/-
  - Vapor retarder
  - Beware: adhesion and movement/shrinkage cracks
- "Tweenie" foam (0.9-2)
  - Mixture of properties
- Both Expensive
- Neither solve air leakage outside of stud cavity

Building Science

Insulation and Thermal Bridges No. 31/65

Great for sealing/insulating difficult complex details

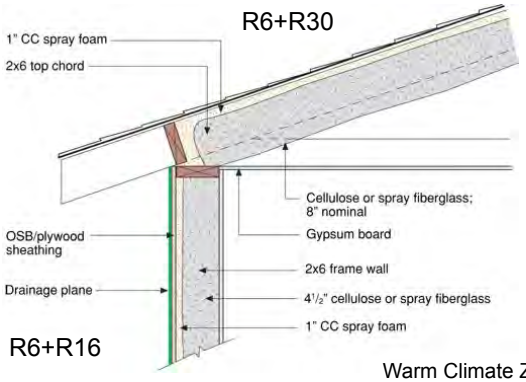
Building Science 2008

•Complete air-vapour -water barrier solution
•Requires transition membranes

Building Science 2008

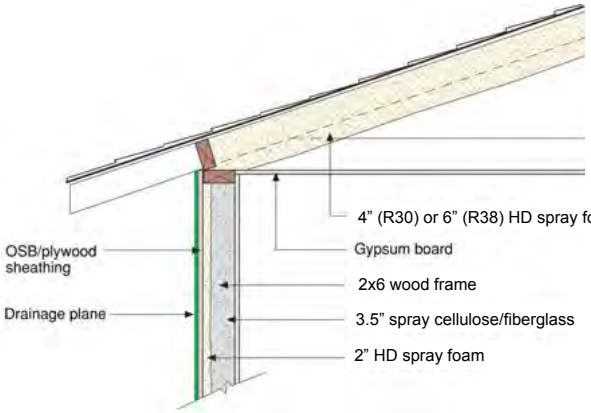
Residential – Air Sealing, Attics, Basements

Hybrid: Air, thermal, fire



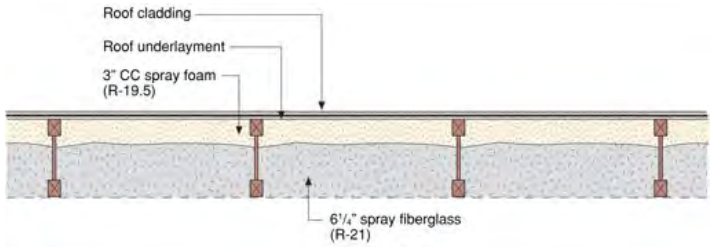
Warm Climate Zone

Hybrid: Air, thermal

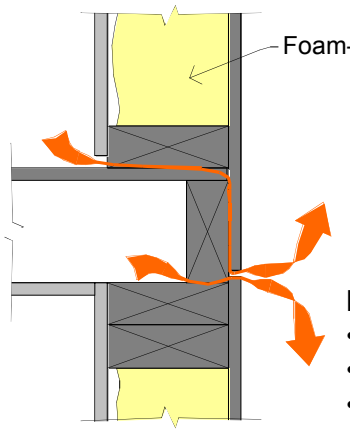


Cold Climate Zone

R40+ roof, fire protection



Cold Climate (Zone 5/6) Solution



Air Sealing Framed Walls with Foam: foam the details!

Most air leakage at
- rim joist
- windows
- penetrations
- bath rooms

Rigid Boards (sheathing)

- Expanded Polystyrene (EPS)
  - R-value of 3.6 to 4.2
- Extruded Polystyrene (XPS)
  - higher R-value, usually 5/inch or higher
  - usually more strength
- Polyisocyanurate (PIC)
  - Highest temp resistance. Long term R6
- all have fire “issues”

Mineral Fiber Sheathing

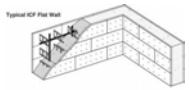
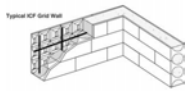
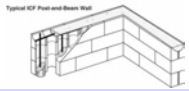
- Semi-rigid MFI (mineral fiber insulation)
- Rockwool and Fiberglass
  - Air permeable
  - Vapor permeable
  - Allows drainage (provides gap)
- R values of 4 to 4.4/inch

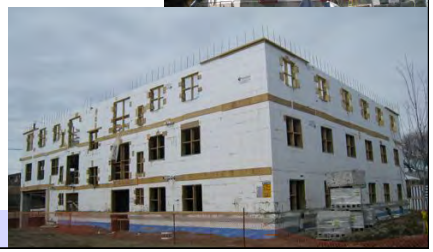
Structural Insulated Panels

- Advantages
  - Superior blanket of insulation
  - if no voids then no convection or windwashing
  - May seal OSB joints for excellent air barrier system
- Therefore, done right = excellent
- Small air leaks at joints in roofs can cause problems
- Don’t get them too wet from rain
  - Low perm layers means limited drying

Insulated Concrete Forms

- Excellent enclosure system
- Concrete acts as air barrier
- No vapor barrier needed
- Expensive, but high performance



Radiant barriers

- Often misunderstood
- Must have an air space!!! (below slabs?)
- Performance depends on temperature difference
  - better at high temperatures, e.g., roof, South
- Can be useful (R5 or so) if low cost
- Most effective at high temperatures (radiation ∞ T^4)
  How reflective is the material over time?
  Are dust and corrosion avoided?

Future products

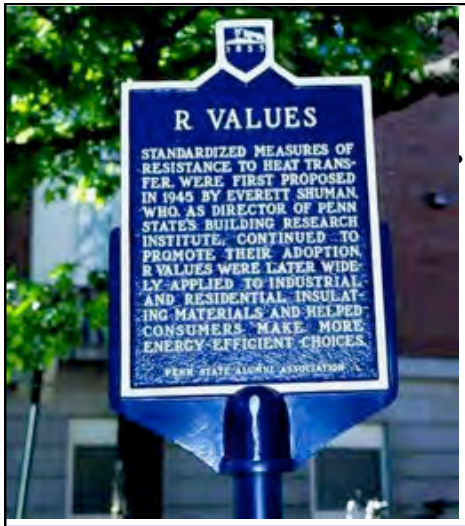
- Vaccum panels: Depends on vacuum
  - R20-30/inch
  - VacuPor (Porextherm)
- Nanogel/aerogel
  - R12-20/inch
  - AspenAerogel

How much insulation?

- Regardless of type, use *more*
- Comfort & moisture –
  - **True** R5-10 is usually enough, but …..
- For energy / environment
  - As much as practical
- Practical constraints likely the limit
  - How much space available in studs?
  - Exterior sheathing of 1.5”/4”
- Increased insulation should reduce HVAC capital as well as operating!

But there are Complications

- Add up the R-values of the layers to get the total R-value of the assembly
- **BUT** the actual thermal resistance of an assembly is affected by
  - **Thermal Bridges**
  - **Thermal Mass**
  - **Air Leakage**



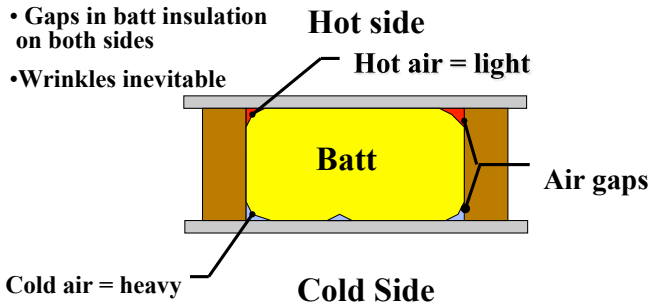
R Values

- An effective property including all heat flow modes

The Meaning of R-value

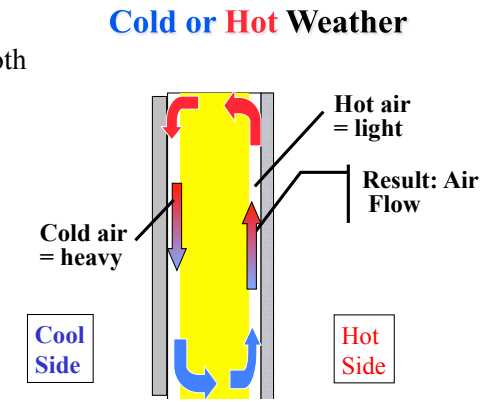
- Thermal Resistance
  - R-value (material property, not system)
  - Thermal Bridging
- Airtightness and Air Looping
  - About 10-40 % of energy loss
- Mass
  - smooths peaks and valleys
  - takes advantage of heat within (sun, equipment)
- Buildability / Inspectability
  - do you get what you spec/design?

Internal Stack Effect & Insulation



Internal Stack Effect

- Gaps in batt insulation on both sides
- closed circuit
- energy cost
- cold surfaces



Steel studs provide conduits

- Hard to fill steel studs
- Results in gaps in batt insulation on both sides

Hot

Hot air = light

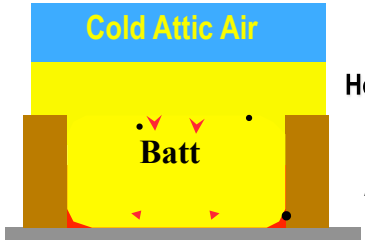
Air gaps

Cold air = heavy

Cold

Attics

- Large temp differences in winter & summer (large temp diffs cause probs)
- One side open to air



Hot air = light

Cold air = heavy

Air gaps

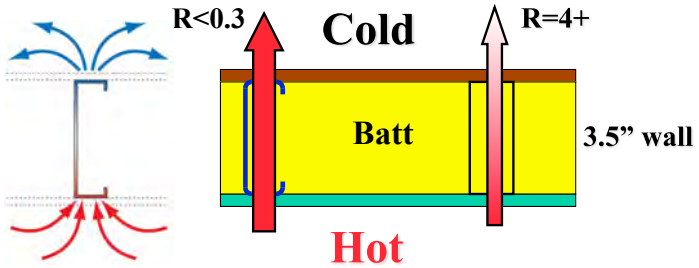
Inside

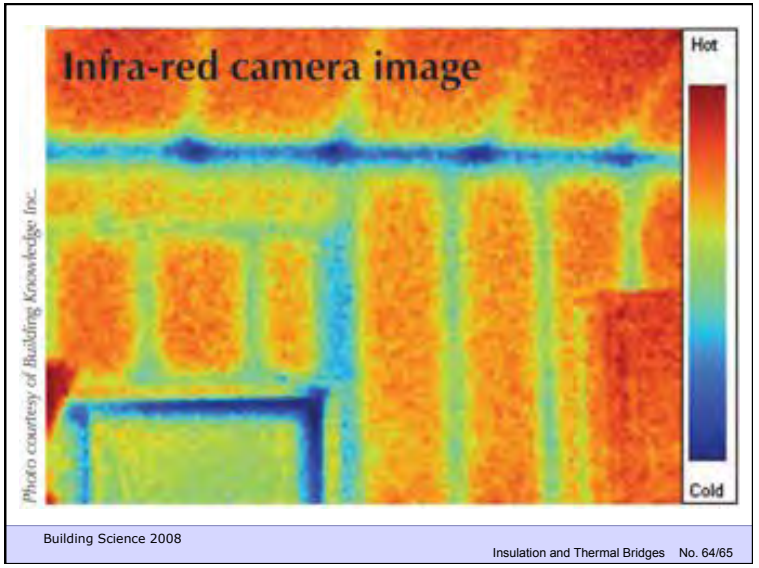
It's More Than Insulation!

- Thermal bridges provide shortcut for heat through insulation
- Heat passes through the structural members
- Common offenders
  - Floor and balcony slabs
  - Shear walls
  - Window frames
  - Steel studs

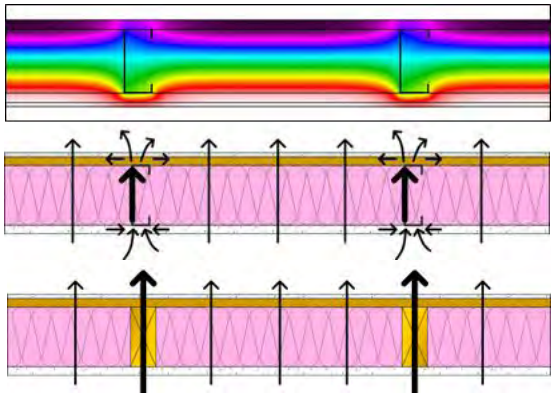
Thermal Bridging

- **Steel is 400 times more conductive than wood**
- **Steel studs are about 40 times thinner**

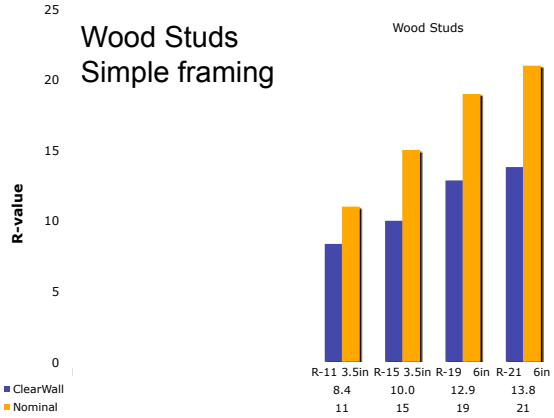




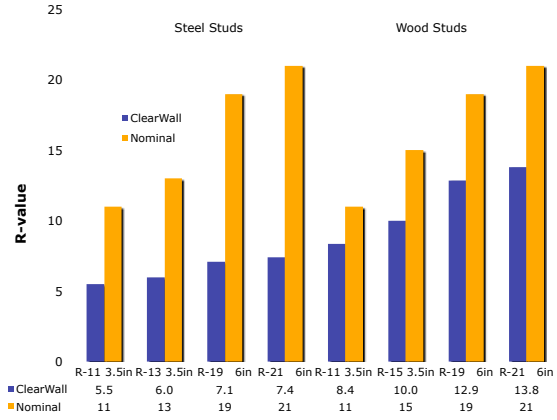
Wood vs Steel



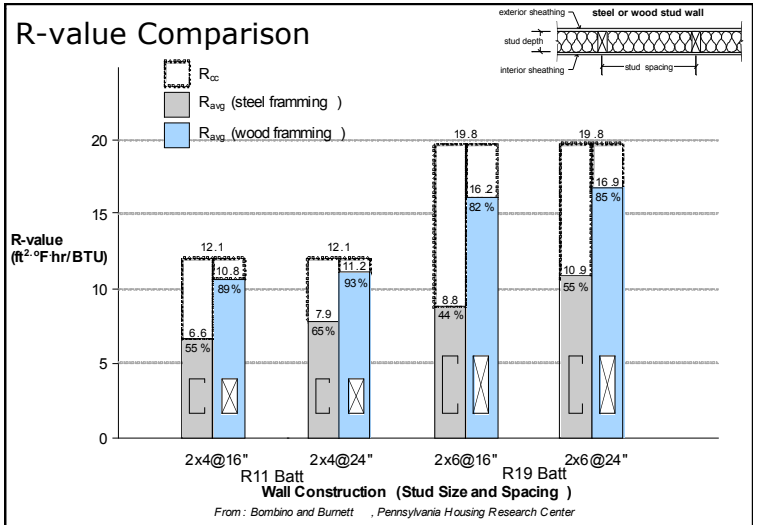
ASHRAE 90.1 "Clear Wall" best case



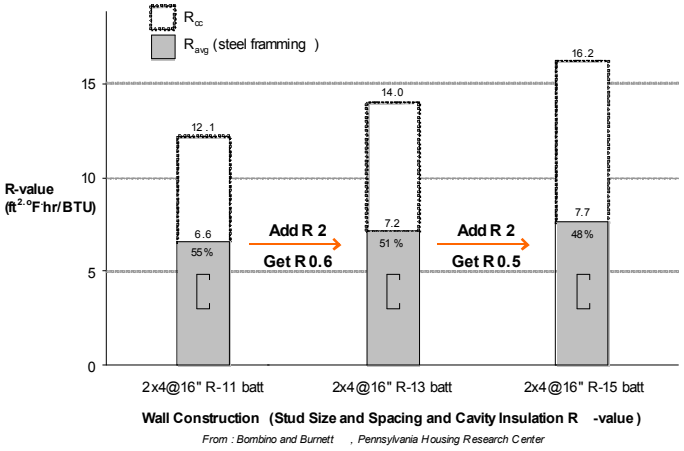
ASHRAE 90.1 "Clear Wall" best case



R-value Comparison

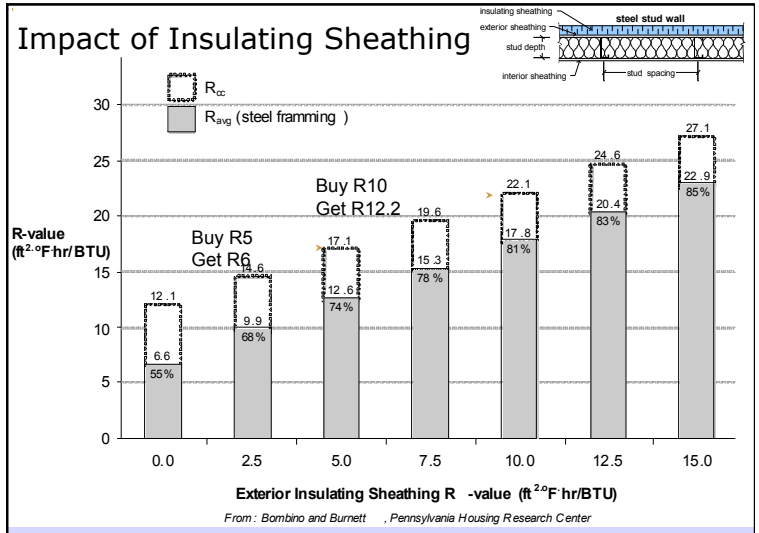


Adding studspace insulation is not helpful!



From : Bombino and Burnett , Pennsylvania Housing Research Center

Impact of Insulating Sheathing

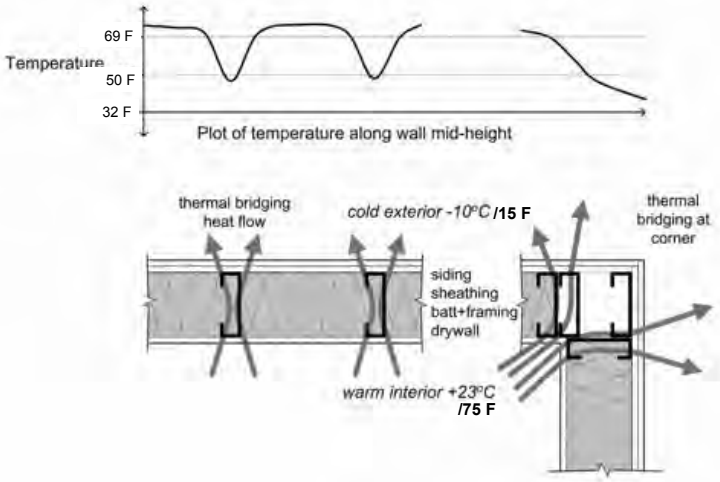


From : Bombino and Burnett , Pennsylvania Housing Research Center

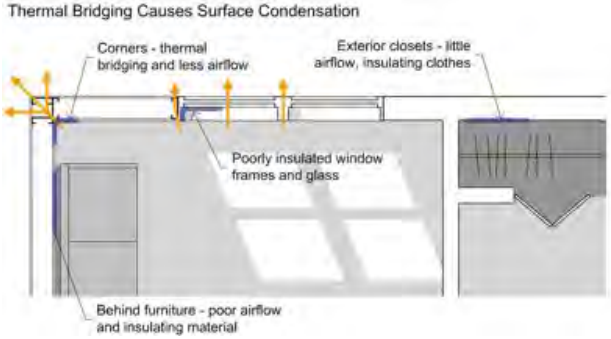
Thermal Bridge Examples

- Balcony, etc
- Exposed slab edge,

Cold surfaces where R<5



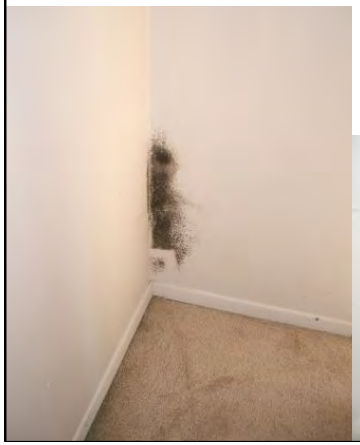
Thermal Bridging: Common Problems

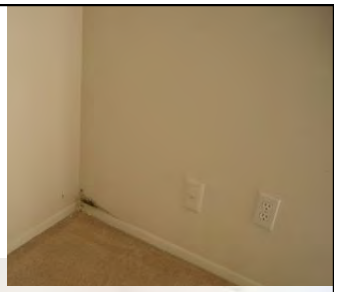


Building Science 2008

Insulation and Thermal Bridges No. 77/65

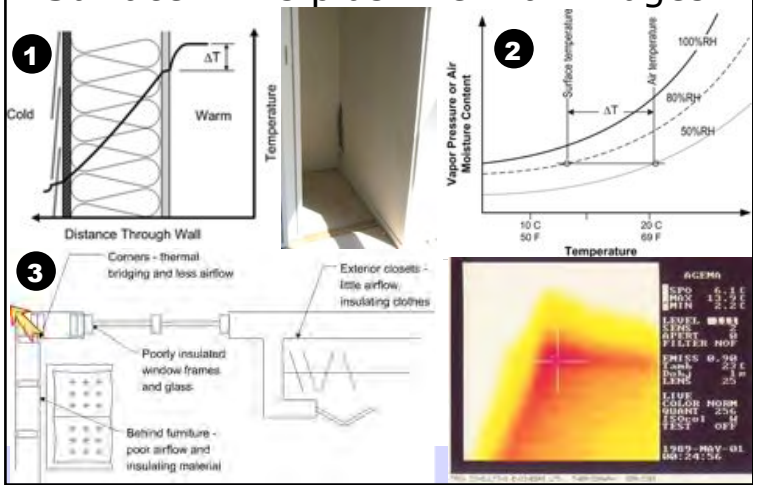
High RH / Low R





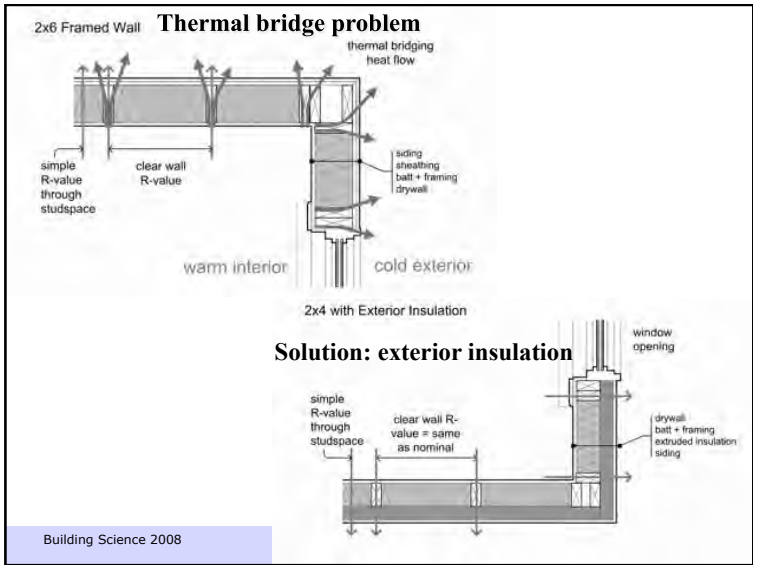
Insulation and Thermal Bridges No. 78/65

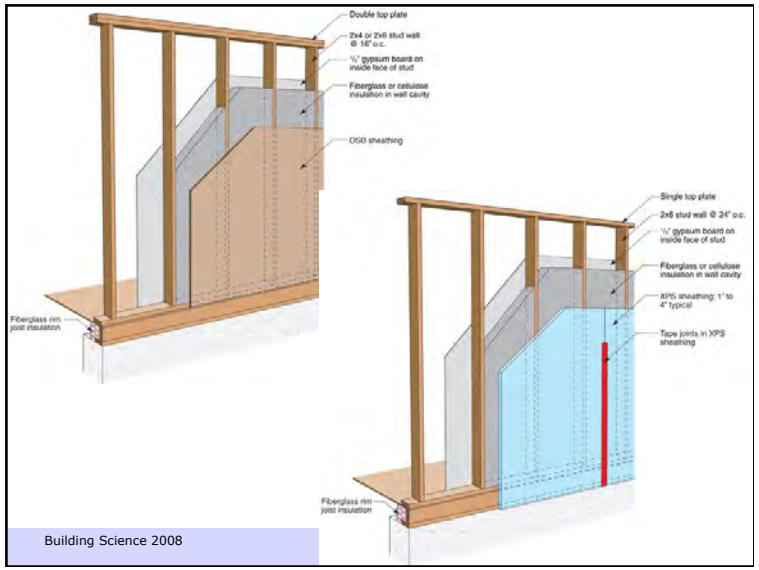
Surface Films plus Thermal Bridges



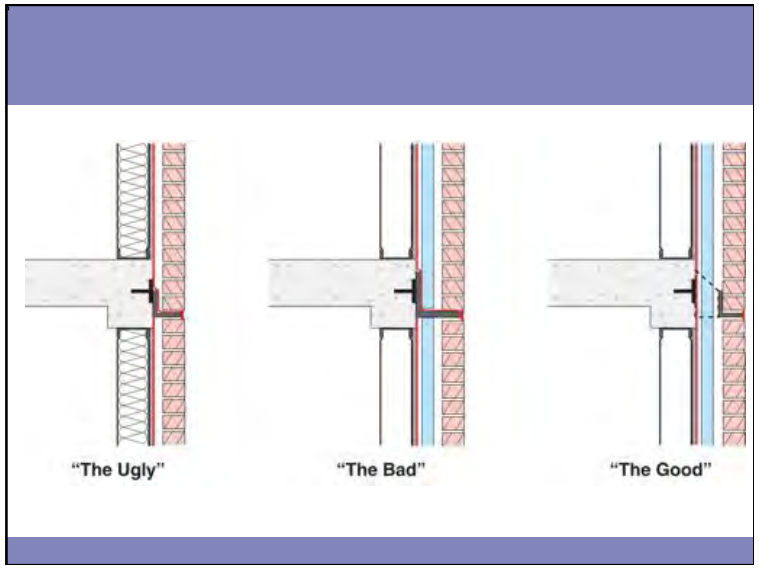
Solving Thermal Bridging

- Exterior insulation can solve most thermal bridges
  - Inside works, but hard to cover structural penetrations
- Lower interior RH to stop condensation



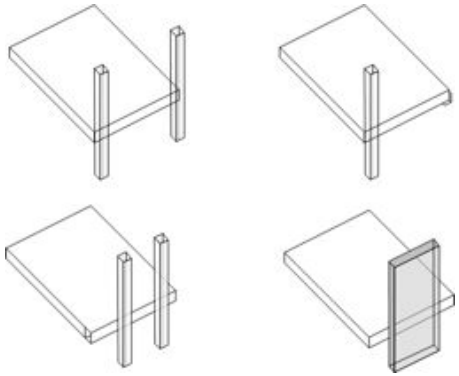

Double top plate
2x4 or 2x6 stud wall @ 16" o.c.
½" gypsum board on inside face of stud
Fiberglass or cellulose insulation in wall cavity
OSB sheathing
Fiberglass rim joist insulation
Single top plate
2x6 stud wall @ 24" o.c.
½" gypsum board on inside face of stud
Fiberglass or cellulose insulation in wall cavity
XPS sheathing: 1" to 4" typical
Tape joints in XPS sheathing
Fiberglass rim joist insulation
Building Science 2008


All on the exterior


"The Ugly"
"The Bad"
"The Good"


Small metal clips dramatically reduce thermal bridging

Balconies



Summary: Heat flow control

- A *continuous* layer of only R5-10 is key
  - Exterior is easiest to get continuous
  - Should provide much more for energy efficiency
- Heat flow control is not just about R-value!
  - Control of airflow
  - Thermal bridging must be managed
  - Thermal mass can play a role
  - Solar Gain can dominate
    - Window area, shading, low SHGC windows
    - Overhangs, light colors for walls and roofs