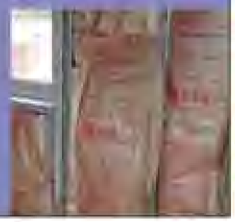
Building Science 2013

Thermal Control: Insulation & Thermal Bridges



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

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How to Control Heat Flow?

Modes of heat transfer:

- Radiation
- Convection
- Conduction

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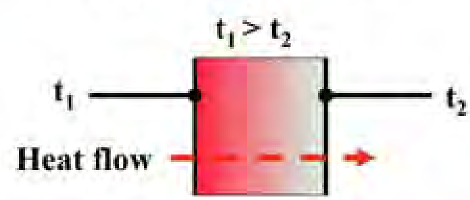
Conduction

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



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Thermal Performance

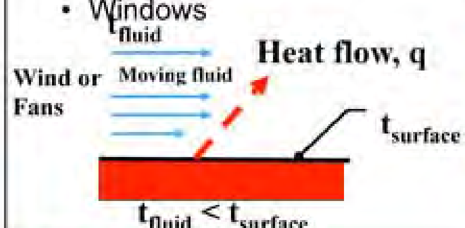
- Thermal Conductivity
  - Symbol is “k” or “λ”
- Conductance
  - C = k / thickness
- Resistance “R-value”
  - R = thickness / conductivity
- Measures conduction only
- “effective” conductivity includes other modes

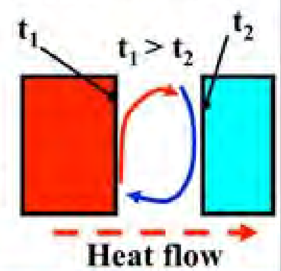
R Values

- An effective property including all heat flow modes

Convection

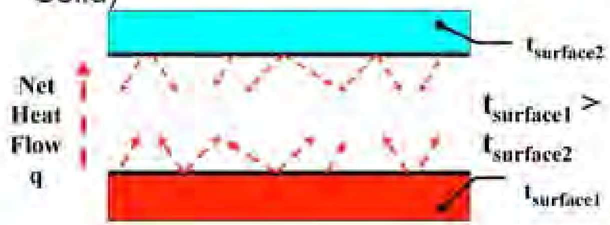
- Heat Flow by bulk movement of molecules
- Most important for liquids and gases
- Critical for surface heat transfer (e.g convectors, “radiant floors”
- Windows





Radiation

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



Radiation

- Important for surfaces, air spaces, voids
  - e.g. Thermos bottle
- Key for low-e Windows
- Foil faced insulation, radiant barriers only work when facing an air space
- Radiation within *pores* important for high void insulation (e.g., glass batt)
- Emissivity is the measure

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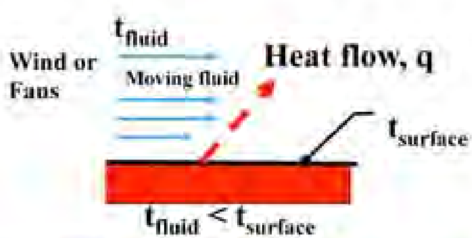
Forced Convection

- E.g. air flow (forced air furnace)
- Also heat flow from solid to liquid or gas



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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

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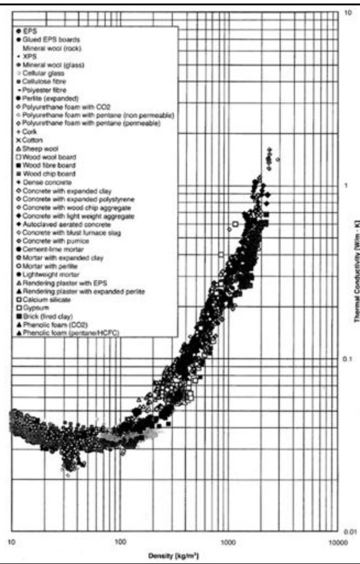
- Density vs R-value
- It's the law



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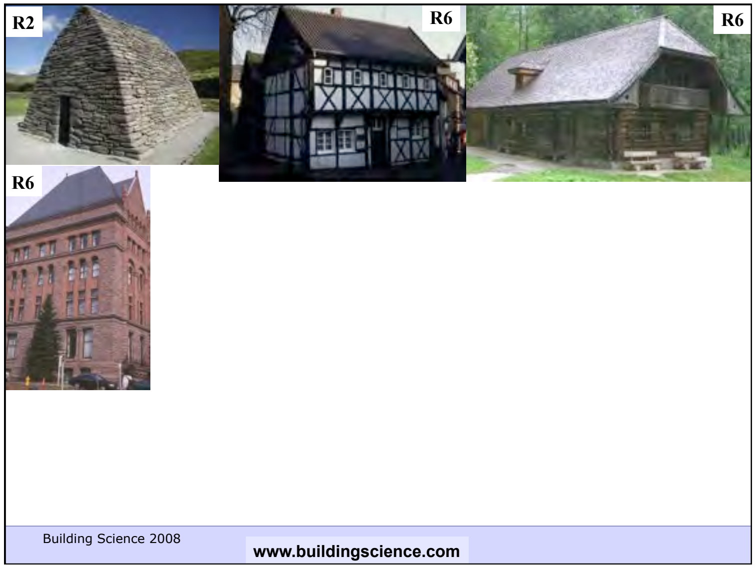
on - History


R2
R6
R6
R6
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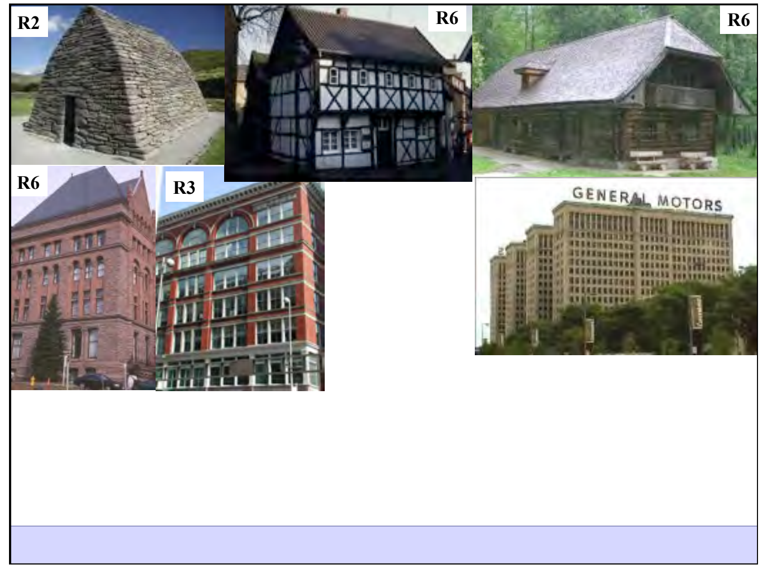
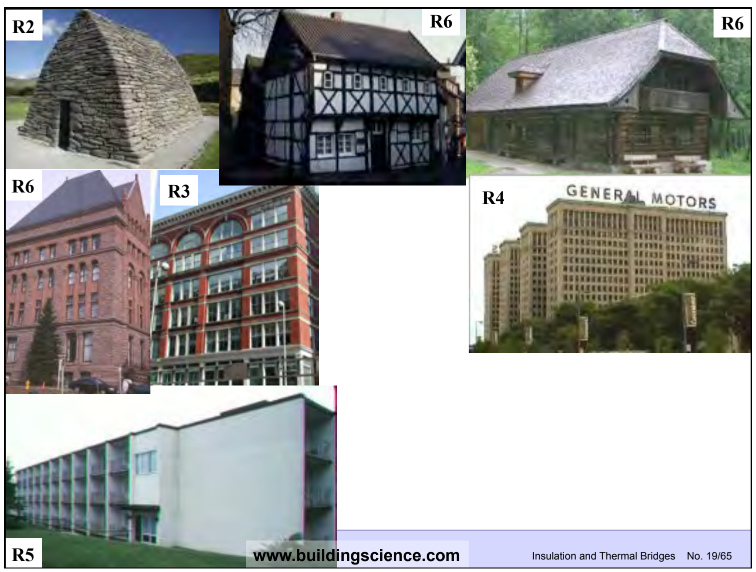
www.buildingscience.com


R2
R6
R6
R6
R3
GENERAL MOTORS


R2
R6
R6
R6
R3
R4
GENERAL MOTORS
R5
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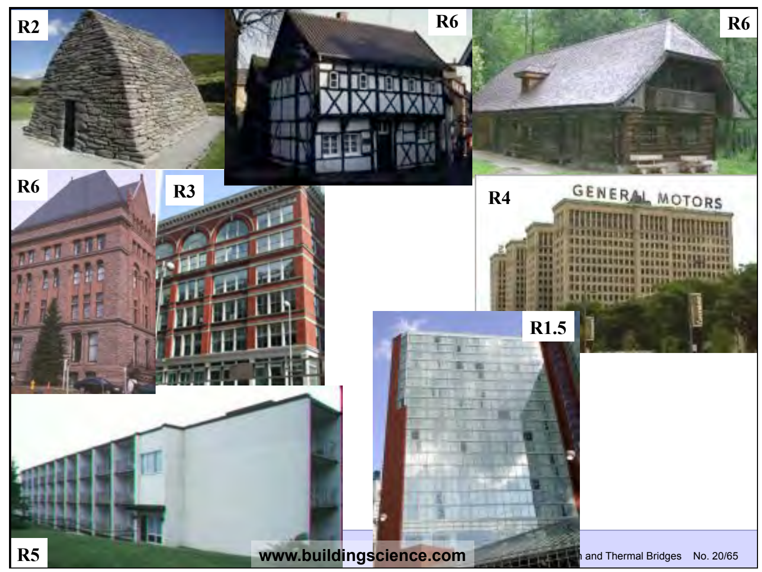
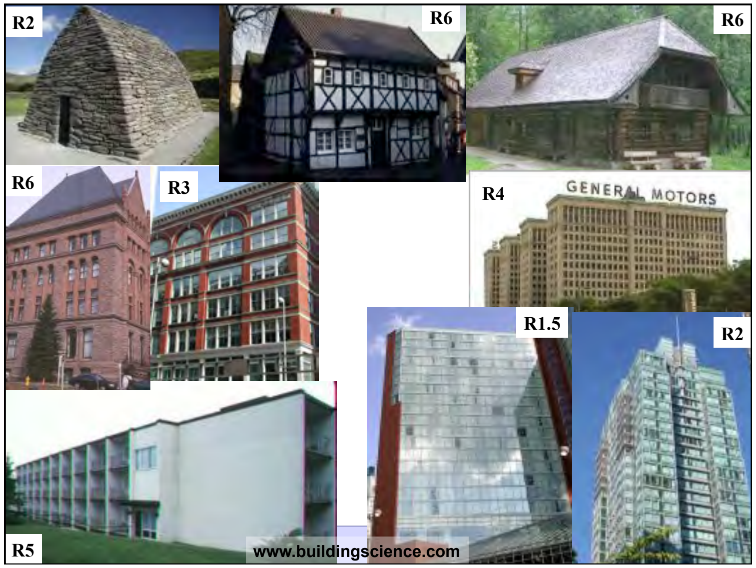
Insulation and Thermal Bridges No. 19/65


R2
R6
R6
R6
R3
R4
GENERAL MOTORS
R1.5
R5
www.buildingscience.com
and Thermal Bridges No. 20/65



Changing Needs

- Now and tomorrow
  - Better heat flow control required
  - More environmental concerns re: energy
  - More demanding comfort standards
  - Building materials & finishes are less resistant to condensation (& mold)

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Materials

- Thermal conductivity (& resistance) varies with
  - material type (conduction, radiation)
  - density and pore structure
  - moisture content
  - temperature difference
- Combination of insulation of air + material
- *Still* air is about R6/inch (k=0.024 W/mK)
- Only gas fills (e.g. HCFC) can improve this

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Insulation

- A brief survey . . .

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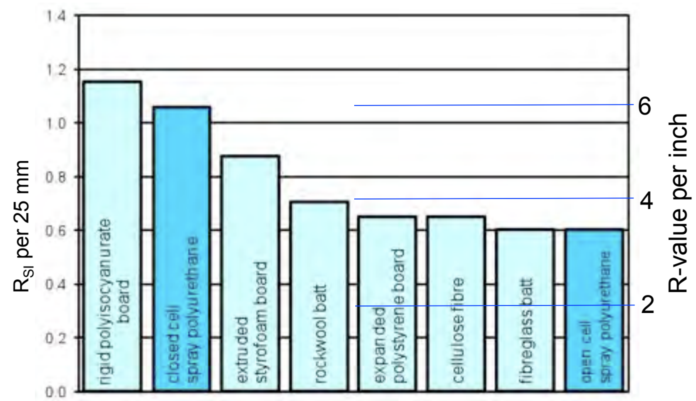

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Fibers

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

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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

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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 <u>not</u> part of an air barrier system!

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Blown Cellulose

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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

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Spray Foam

- Open cell
  - Most high vapor permeance
  - controls convection / wind washing
- Closed cell
  - air barrier and part vapor barrier
  - excellent air seal in difficult areas!
  - Beware: adhesion and movement/shrinkage cracks
- Both Expensive
- Neither solve air leakage outside of stud cavity

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Great for sealing/insulating difficult complex details

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

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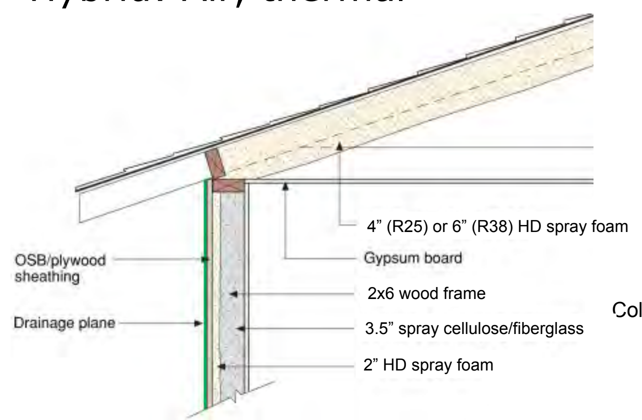
Residential – Air Sealing, Attics, Basements

Hybrid: Air, thermal



Cold Climate Zone

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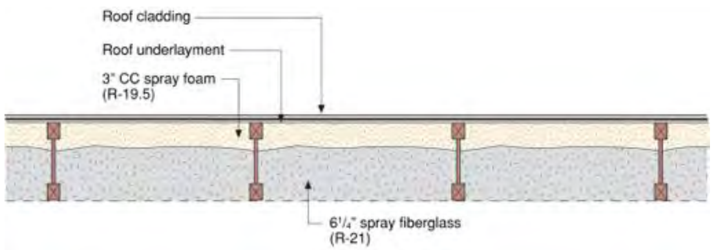
R40+ roof, fire protection



Cold Climate (Zone 5/6) Solution

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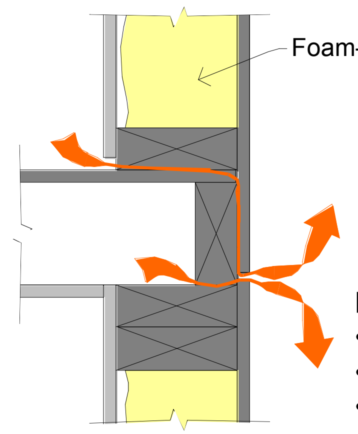

Air Sealing Framed Walls with Foam: foam the details!

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

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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"

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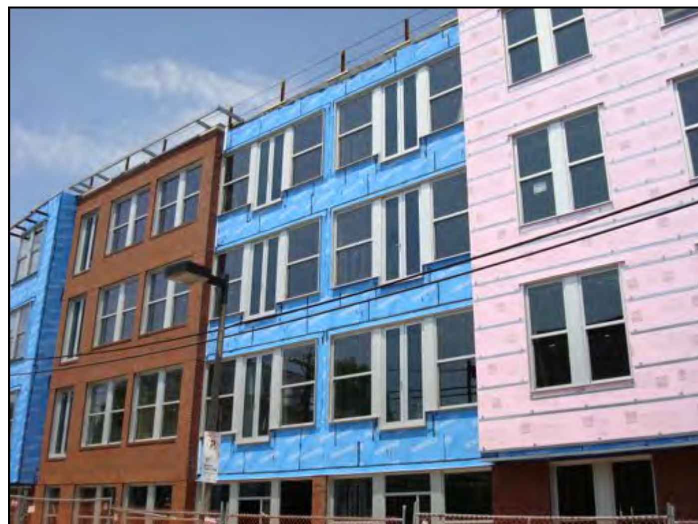
Insulation and Thermal Bridges No. 39/65



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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 (3.5”=R12, 5.5”=R20)
  - 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

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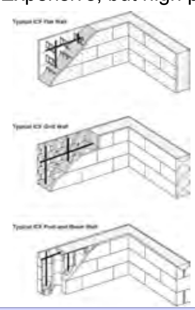
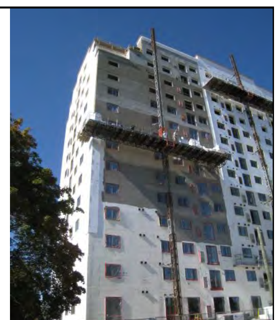
Insulated Concrete Forms

- Excellent enclosure system
- Concrete acts as air barrier
- No vapor barrier needed
- Expensive, but high performance (R20)





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Future products

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

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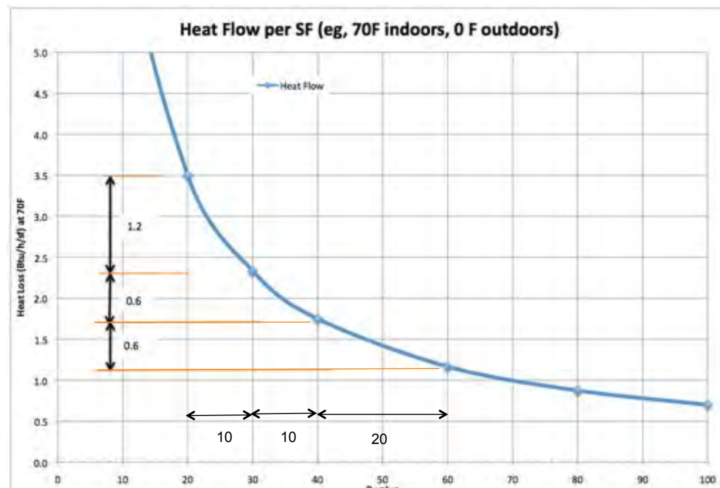
Radiant barriers

- 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?

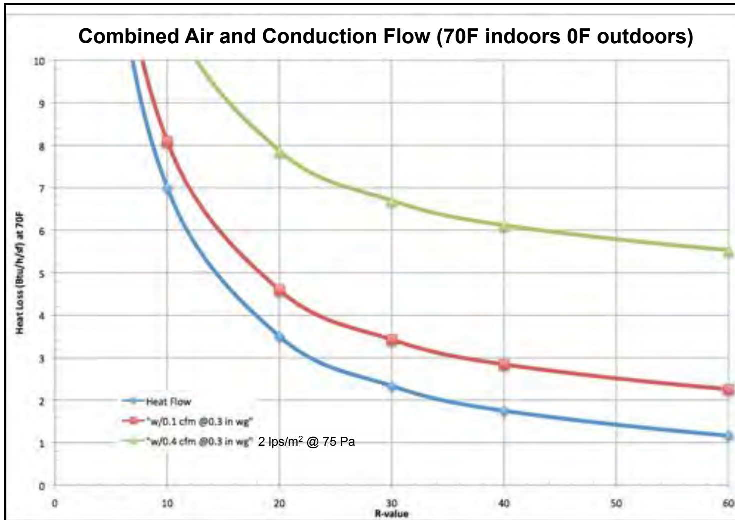
How much insulation?

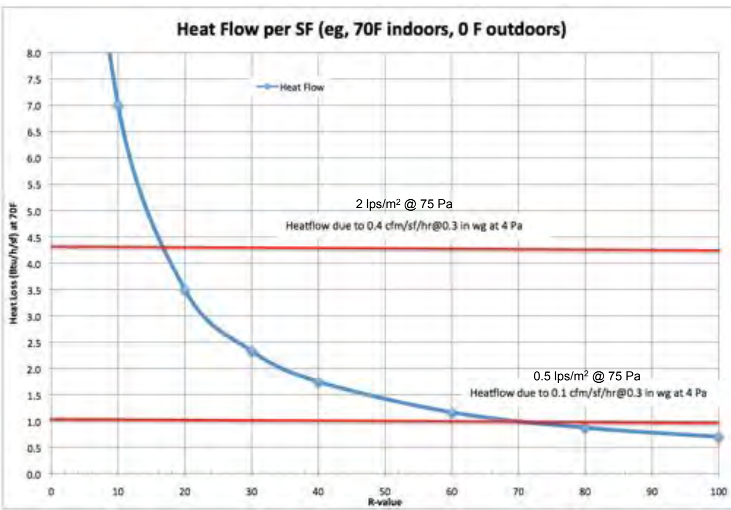
- Regardless of type, use *more*
- Comfort & moisture –
  - **True** R5-10 is usually enough, but …..
- For energy / environment
  - As much as practical
- Practical constraints likely the limit
  - How much space available in studs?
  - Exterior sheathing of 1.5"/4"
- Increased insulation should reduce 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
  - o **Air Leakage**
  - o **Thermal Bridges**
  - o **Thermal Mass**



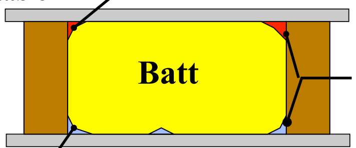


The Meaning of R-value

- 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

- Gaps in batt insulation on both sides
- Wrinkles inevitable

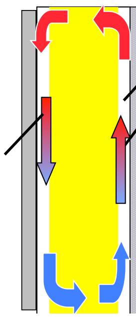


Common problem

Internal Stack Effect

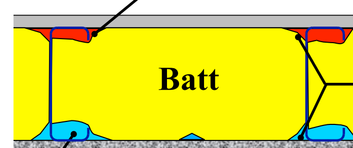
- Gaps in batt insulation on both sides
- closed circuit
- energy cost
- cold surfaces

Cold or Hot Weather



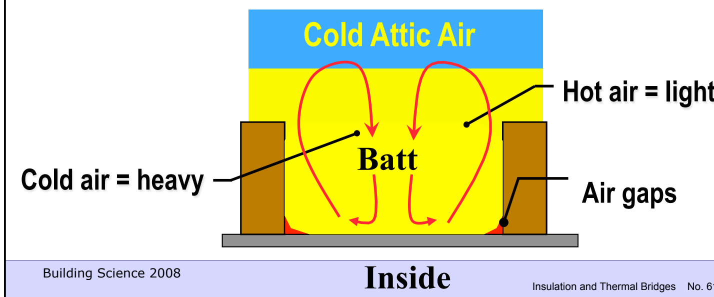
Steel studs provide conduits

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



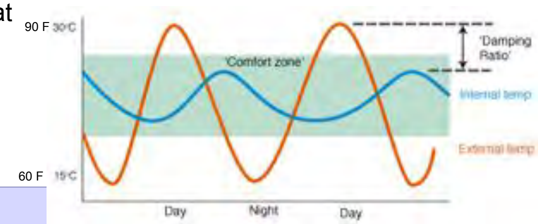
Attics

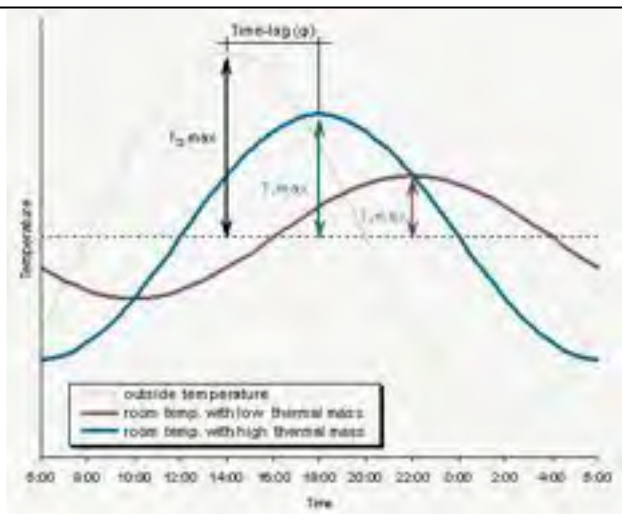
- Large temp differences in winter & summer (large temp diffs cause probs)
- One side open to air



Thermal mass

- A heat capacitor, stores heat or cold
- Smooths variations
  – Reduces peak loads (Title24)
- Can reduce energy if
  – Daily temps vary above/below interior temp
  – Energy flows can be stored, eg solar energy or office waste heat





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

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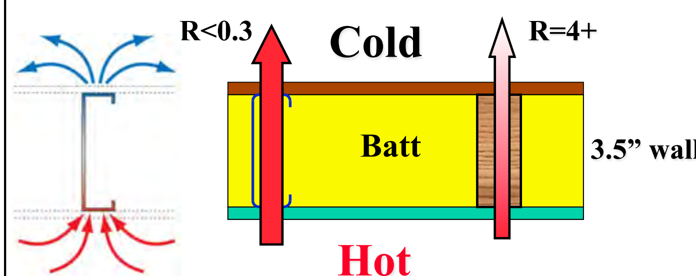
Insulation and Thermal Bridges No. 66/65

It's More Than Insulation!

Thermal Bridging

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



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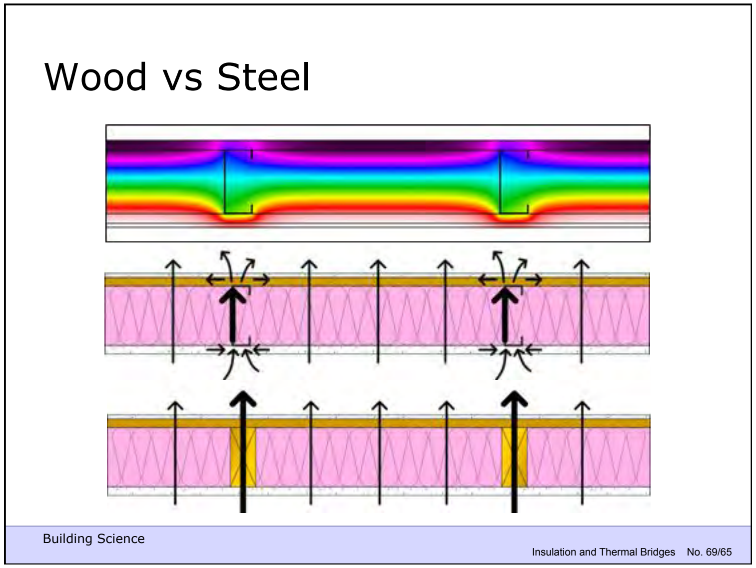
Insulation and Thermal Bridges No. 68/65


Wood vs Steel
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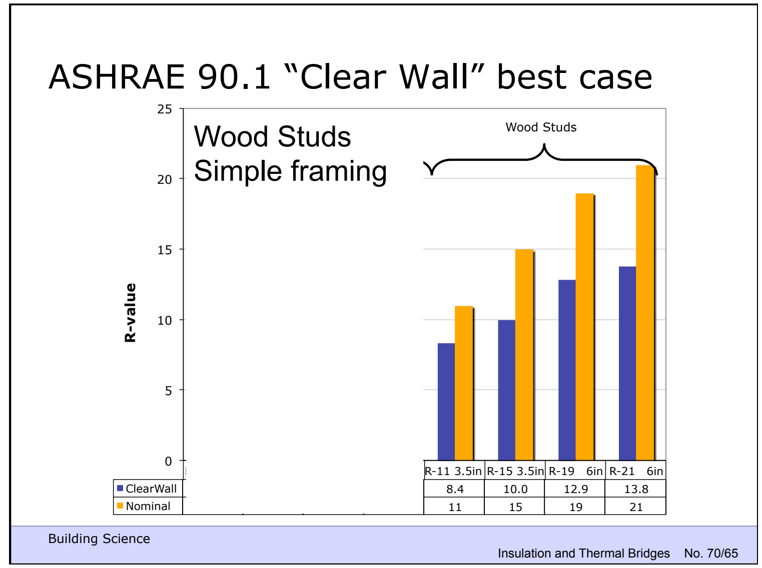
Insulation and Thermal Bridges No. 69/65


ASHRAE 90.1 "Clear Wall" best case
Wood Studs
Simple framing
Wood Studs
R-value
25
20
15
10
5
0
R-11 3.5in R-15 3.5in R-19 6in R-21 6in
ClearWall 8.4 10.0 12.9 13.8
Nominal 11 15 19 21
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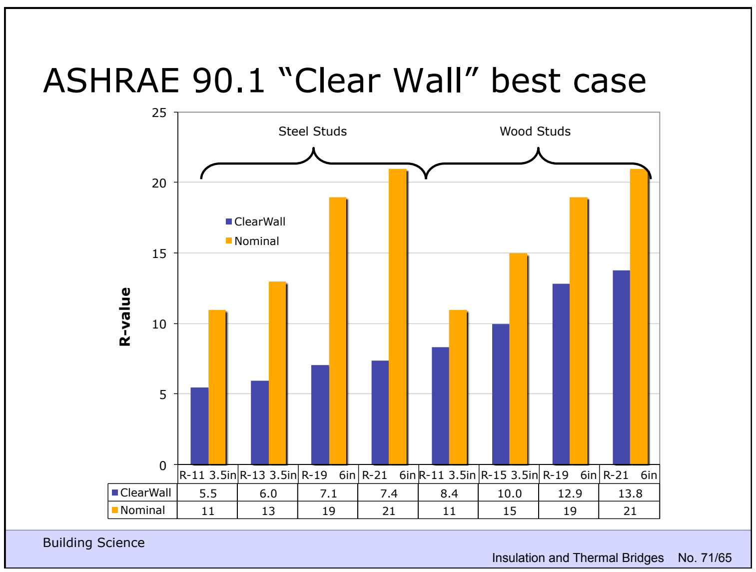
Insulation and Thermal Bridges No. 70/65


ASHRAE 90.1 "Clear Wall" best case
Steel Studs
Wood Studs
ClearWall
Nominal
R-value
25
20
15
10
5
0
R-11 3.5in R-13 3.5in R-19 6in R-21 6in R-11 3.5in R-15 3.5in R-19 6in R-21 6in
ClearWall 5.5 6.0 7.1 7.4 8.4 10.0 12.9 13.8
Nominal 11 13 19 21 11 15 19 21
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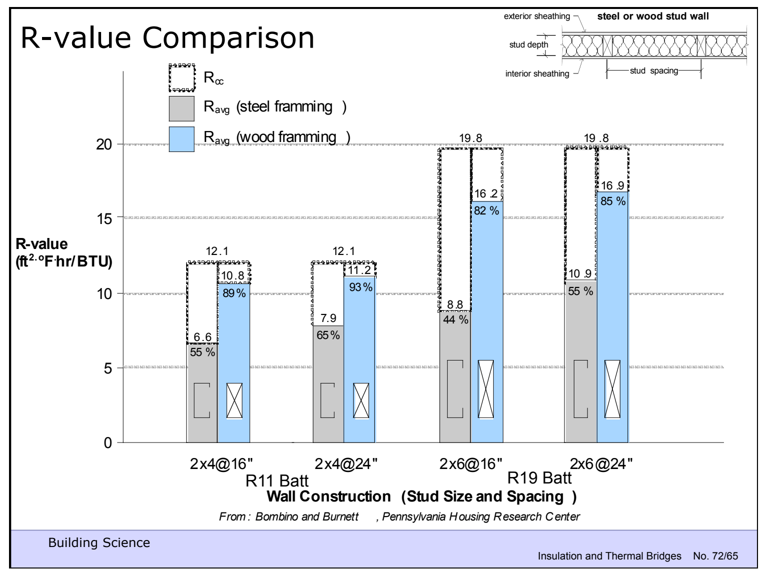
Insulation and Thermal Bridges No. 71/65


R-value Comparison
exterior sheathing
steel or wood stud wall
stud depth
interior sheathing
stud spacing
R
R avg (steel framming)
R avg (wood framming)
R-value
(ft²·°F·hr/BTU)
20
15
10
5
0
12.1
6.6
55 %
10.8
89 %
12.1
7.9
65 %
11.2
93 %
19.8
8.8
44 %
16.2
82 %
19.8
10.9
55 %
16.9
85 %
2x4@16"
2x4@24"
R11 Batt
2x6@16"
2x6@24"
R19 Batt
Wall Construction (Stud Size and Spacing)
From: Bombino and Burnett , Pennsylvania Housing Research Center
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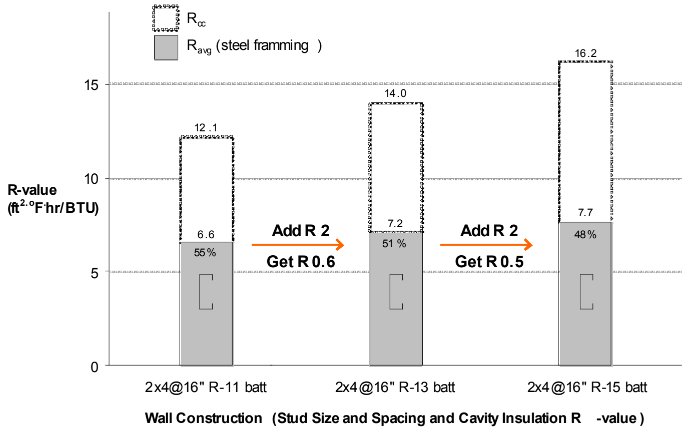
Insulation and Thermal Bridges No. 72/65

Adding studspace insulation is not helpful!



From : Bombino and Burnett , Pennsylvania Housing Research Center

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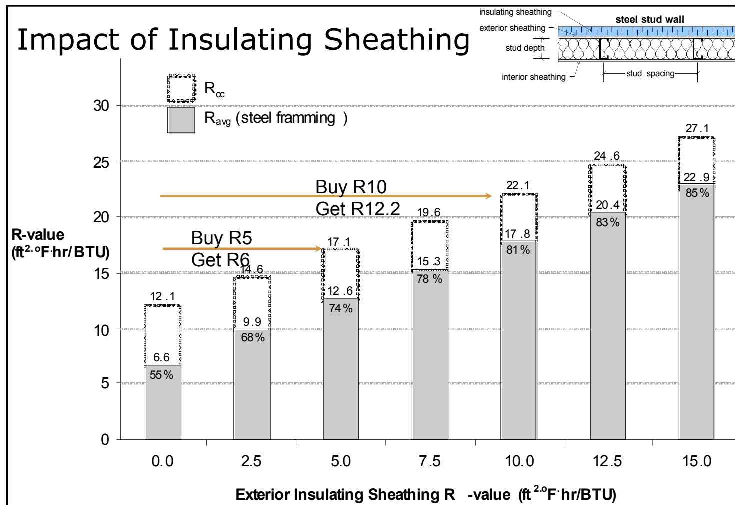
Insulation and Thermal Bridges No. 73/65

Impact of Insulating Sheathing



From : Bombino and Burnett , Pennsylvania Housing Research Center

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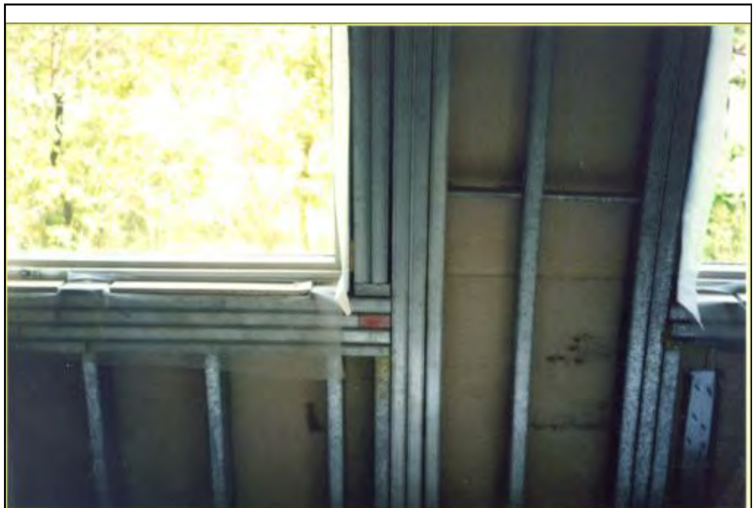
Insulation and Thermal Bridges No. 74/65



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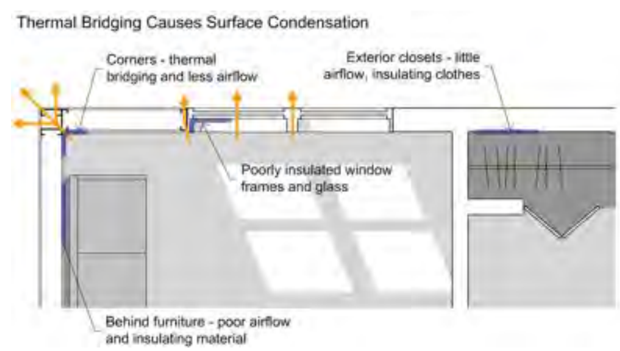
Insulation and Thermal Bridges No. 75/65

Thermal Bridging: Common Problems



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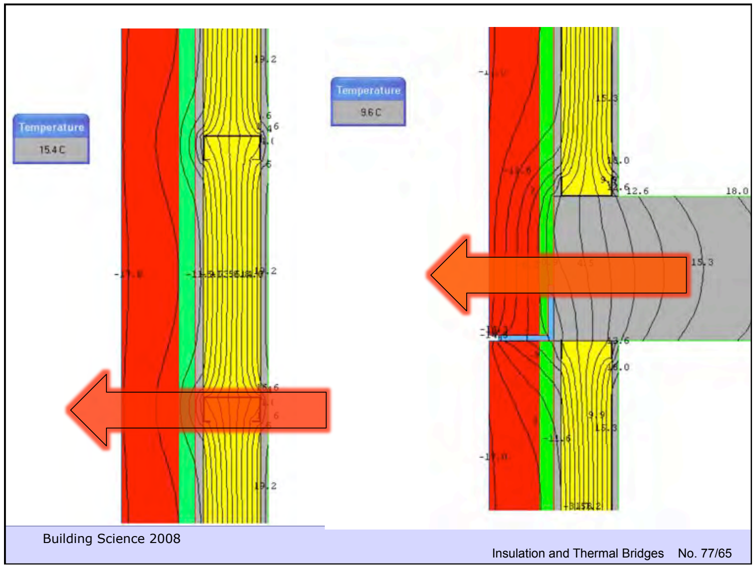
Insulation and Thermal Bridges No. 76/65


Temperature
15.4 C
Temperature
9.6 C
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Insulation and Thermal Bridges No. 77/65


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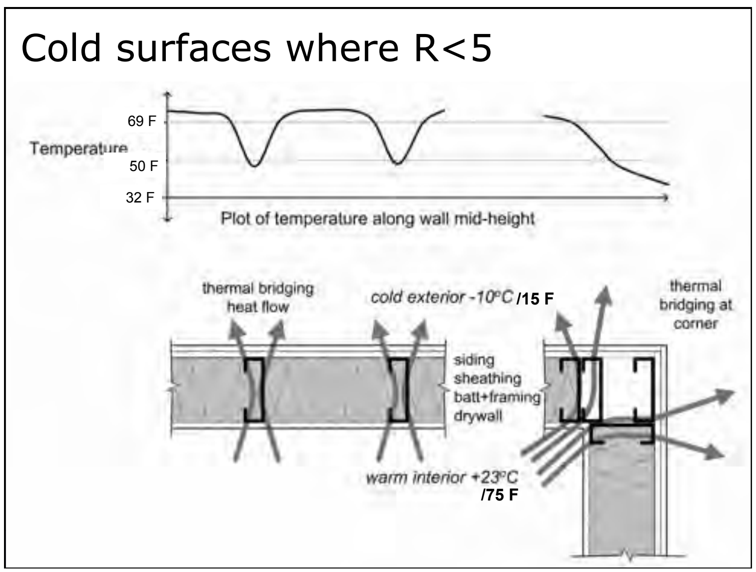
Insulation and Thermal Bridges No. 78/65


Cold surfaces where R<5
69 F
Temperature
50 F
32 F
Plot of temperature along wall mid-height
thermal bridging heat flow
cold exterior -10°C /15 F
thermal bridging at corner
siding
sheathing
batt+framing
drywall
warm interior +23°C /75 F


High RH / Low R
Insulation and Thermal Bridges No. 80/65

Thermal Bridge Examples

- Balcony, etc
- Exposed slab edge,

Solving Thermal Bridging

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

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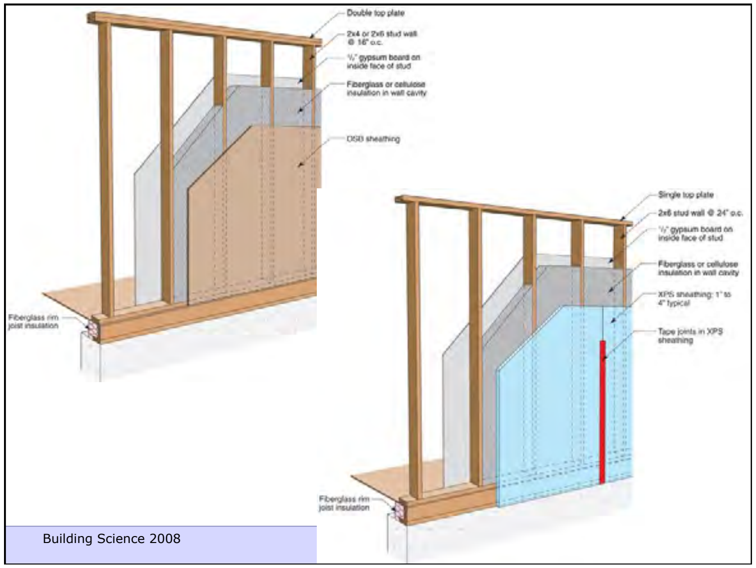
Insulation and Thermal Bridges No. 82/65



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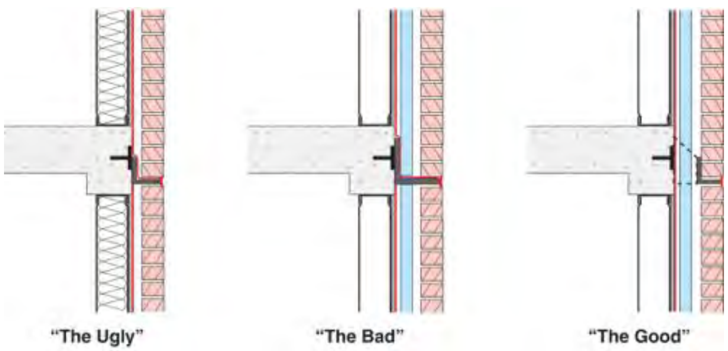
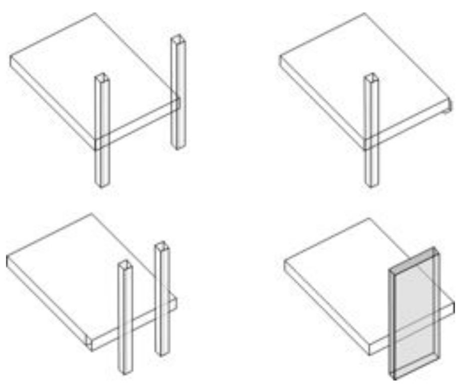


Balconies



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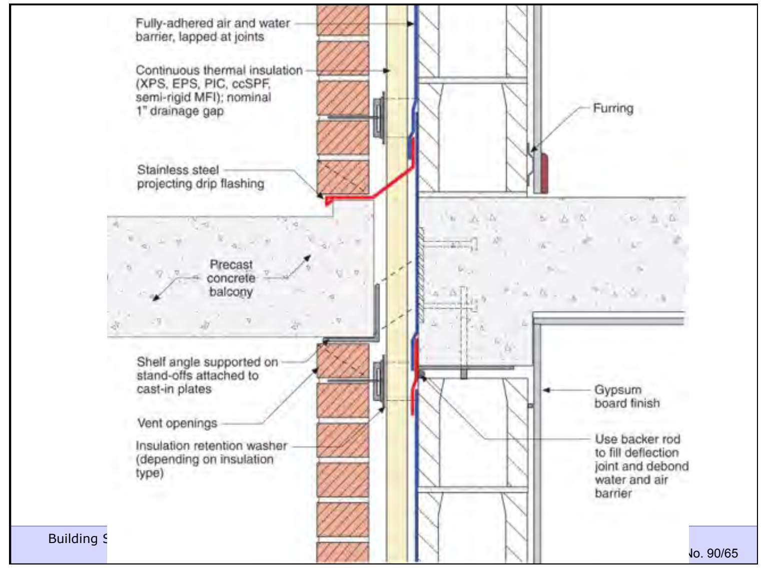
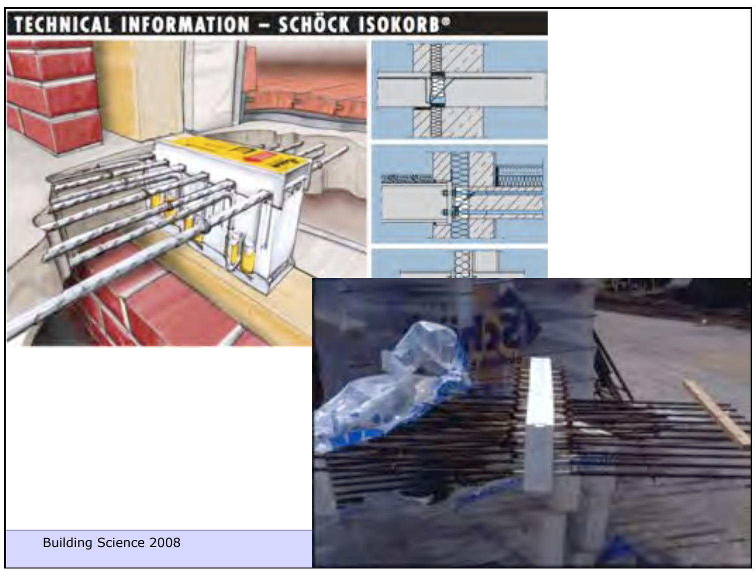
Insulation and Thermal Bridges No. 88/65


Fully-adhered air and water barrier, lapped at joints
Continuous thermal insulation (XPS, EPS, PIC, ccSPF, semi-rigid MFI); nominal 1" drainage gap
Stainless steel projecting drip flashing
Precast concrete balcony
Shelf angle supported on stand-offs attached to cast-in plates
Vent openings
Insulation retention washer (depending on insulation type)
Furring
Gypsum board finish
Use backer rod to fill deflection joint and debond water and air barrier


TECHNICAL INFORMATION – SCHÖCK ISOKORB®
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Precast balcony supported on knife edge supports to limit thermal losses

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

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