CAE 463/524
Building Enclosure Design
Spring 2016

Week 5: February 9, 2016
Conduction in building enclosures
(*Half-lecture, until ~6:30 pm*)

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Campus enclosure assessment projects

- Need to do thermal assessments by early/mid March
  - There are now 23 students in this class

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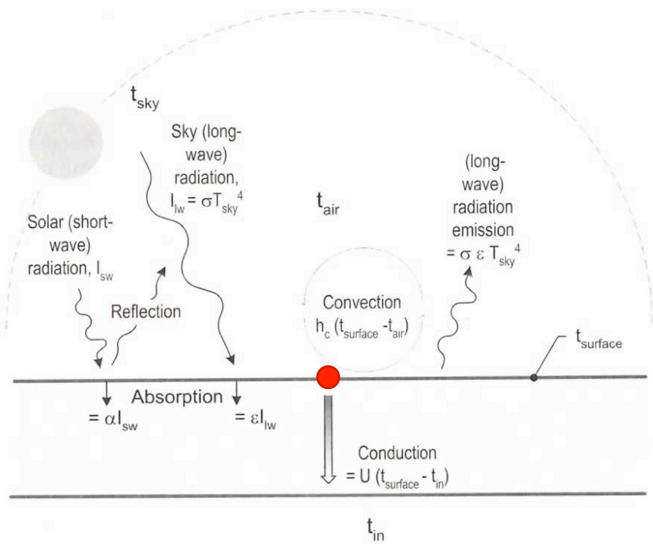
Campus enclosure assessment projects

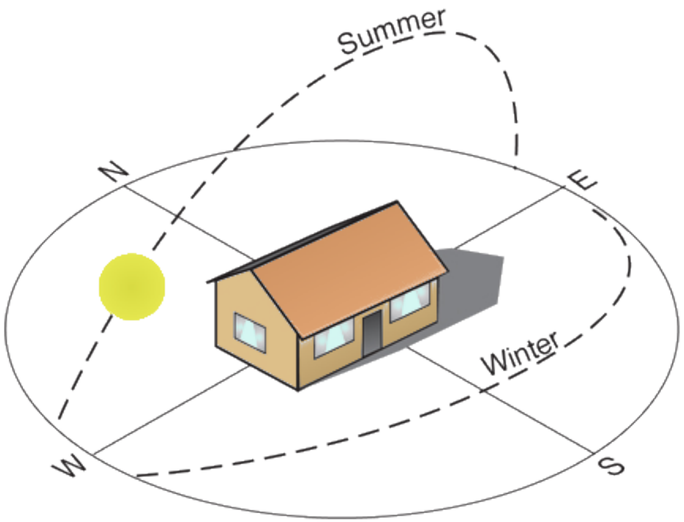
- Need to do thermal assessments by early/mid March
  - I suggest 5 teams of 4 or 5

Team #	Members	Building
1	Naveen, Julia, Xu, Luanzhizi	Alumni
2	Bianca, Al, Taylor, David	SSV
3	Nina, Dina, Lindsey, Salvatore	Vandercook
4	Andrea, Ben	Crown
5	Afshin, Ali, Mehdi, Jose, Kamal	

Last time

- Solar orientation and enclosures





- Assigned HW #1
  - HW #1 due today

This time and next time

- Conduction in building enclosures
  - Insulation materials and properties
  - Thermal bridges
  - Temperature profiles through enclosures
  - Layers with different materials
    - Parallel path vs. isothermal methods
  - 2-D and 3-D conduction analyses
  - THERM modeling
  - Floor-ground conduction

CONDUCTION IN BUILDING ENCLOSURES

Conduction

- **Conduction** follows Fourier's Law: $q = -k\nabla T$

$$q = -k\nabla T = -k\left(\frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} + \frac{\partial T}{\partial z}\right)$$

where:

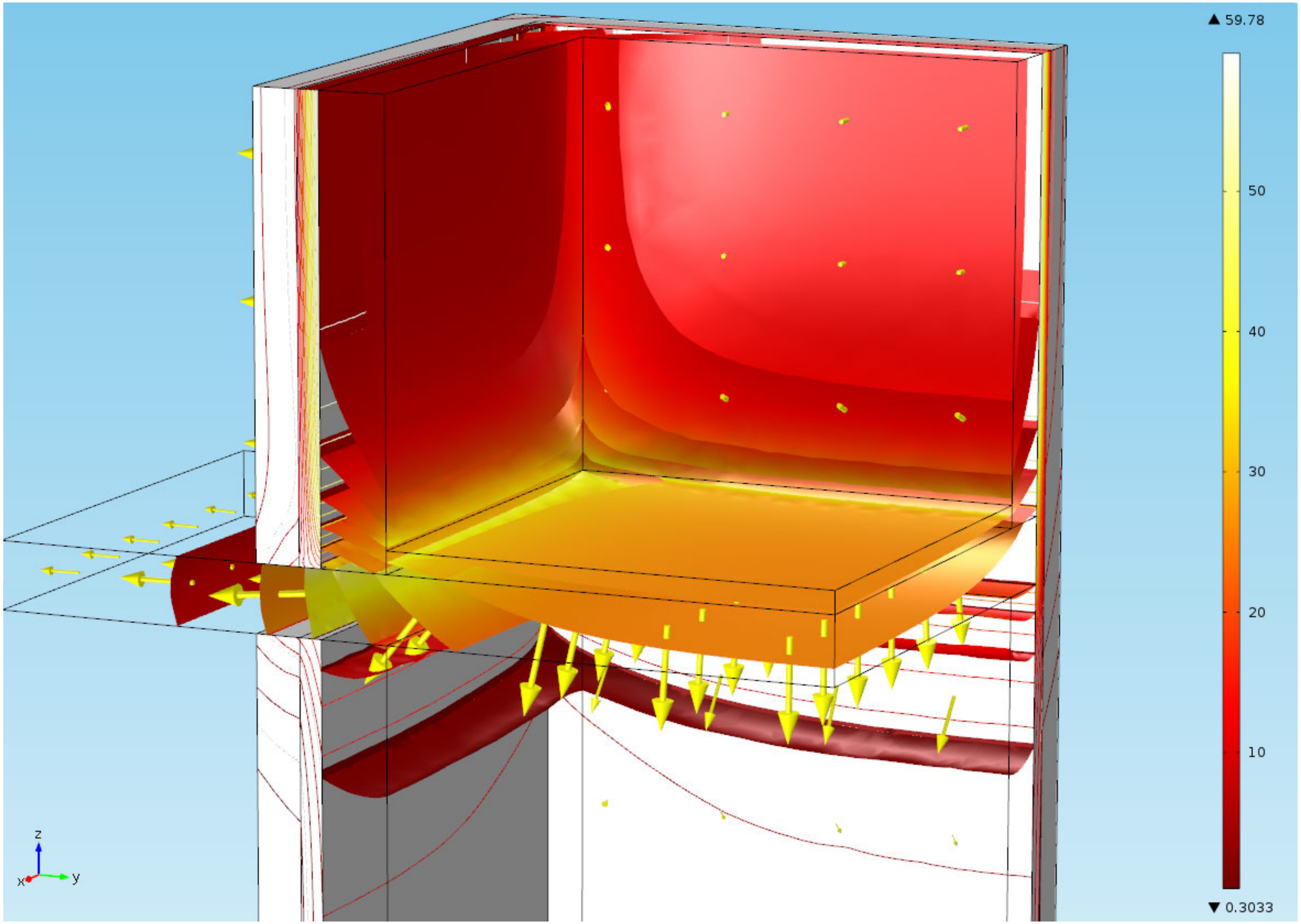
$q =$ heat flux per unit area [Btu/(h $\cdot$ ft^2) or W/m^2]

$k =$ thermal conducitivity [Btu/(h $\cdot$ ft $\cdot$ °F) or W/(m $\cdot$ K)]

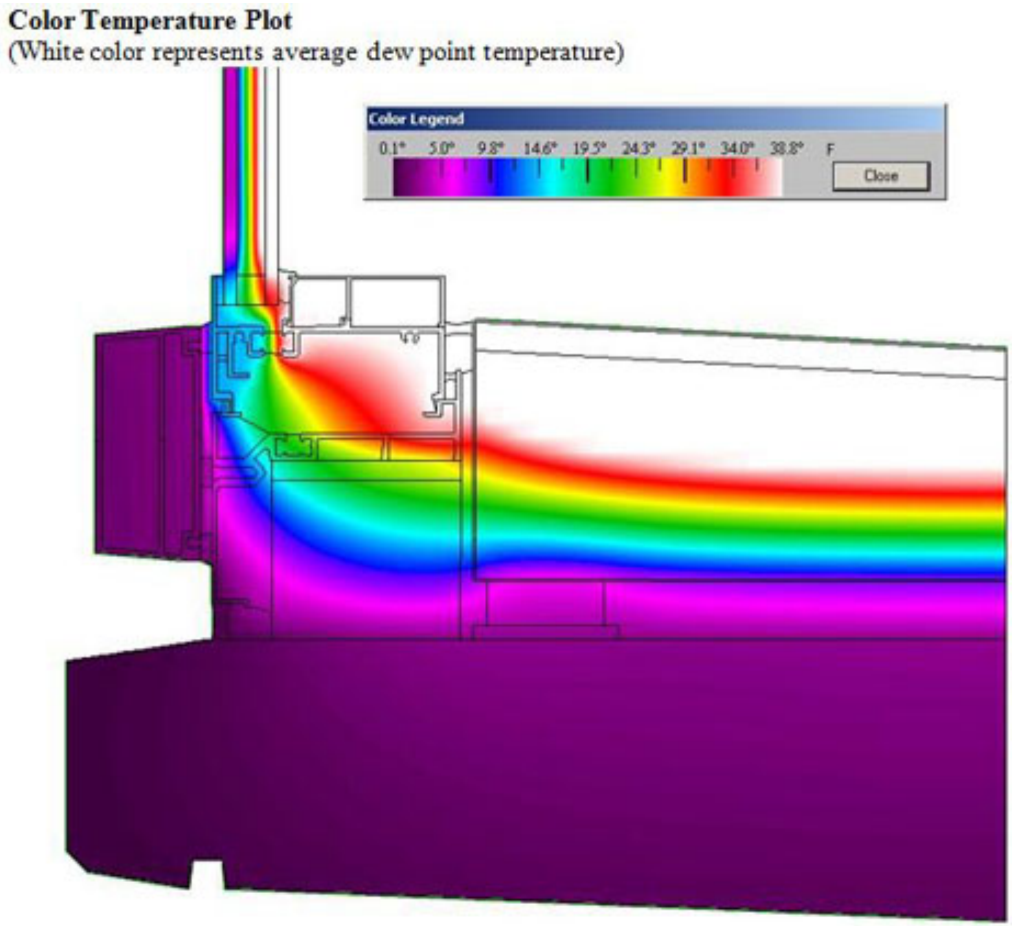
$T =$ temperature [°F or K]

- In 1-dimension, this becomes: $q = -k\dfrac{dT}{dx}$

3D conduction and enclosures

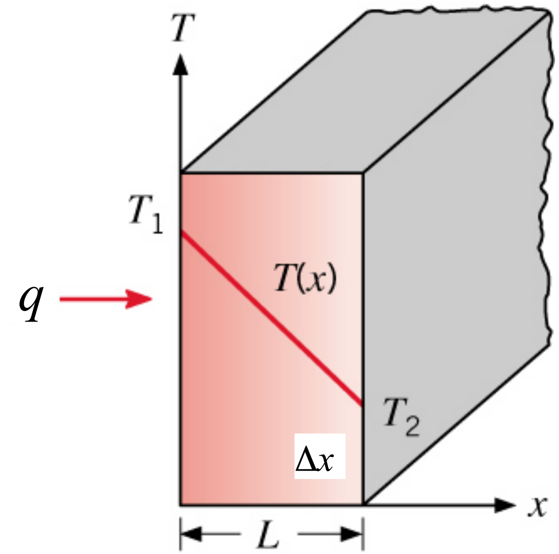


2D conduction and enclosures (simplified)



Even more simplified conduction: 1D

If a material has uniform thermal conductivity throughout & consists of parallel surfaces with uniform temperatures, then:



$\Delta x = L$

$$q = k\frac{\Delta T}{\Delta x} = k\frac{T_1 - T_2}{x_2 - x_1} = \frac{k}{L}\left(T_1 - T_2\right)$$

Here T_1 and T_2 are the surface temperatures at x_1 and x_2

Notice that this equation differs from the last by a minus sign

I suggest you use the $\Delta T/\Delta x$ formulation and note that heat will always flow from high to low temperature

Thermal conductance and resistance

- Conductivity and length can also be described in other terms

$$Q = A\boxed{\frac{k}{L}}\left(T_1 - T_2\right)$$

$$\frac{k}{L} = U \qquad \text{and} \qquad R = \frac{1}{U}$$

where:

U = unit thermal conductance [$\frac{\text{Btu}}{\text{h·ft}^2\text{·°F}}$] or [$\frac{\text{W}}{\text{m}^2\text{K}}$]

R = unit thermal resistance [$\frac{\text{h·ft}^2\text{·°F}}{\text{Btu}}$] or [$\frac{\text{m}^2\text{K}}{\text{W}}$]

Conductive heat flux: $q = \frac{k}{L}\left(T_1 - T_2\right) = U\left(T_1 - T_2\right) = \frac{1}{R}\left(T_1 - T_2\right)$

A note on materials and *k*, *U*, and *R* values

- It's important to have a good working knowledge of these values for common building materials (particularly **high conductivity** materials)
  - Pay special attention to metals, in addition to those values we already know
  - Thermal conductivity (*k*) of common materials
    - Insulation <0.05 W/mK
    - Wood ~0.1-0.2 W/mK
    - Rubber ~0.1 W/mK
    - Brick/stone/concrete ~0.5-2.0 W/mK
    - **Steel ~45 W/mK**
    - **Cast iron ~50 W/mK**
    - **Aluminum ~220 W/mK**

Increasing conductivity

Decreasing resistance (also depends on thickness)

Units of R and U-Value

- R values are typically used for insulating materials
  - For example: wall insulation materials
- U values are typically used for conductive materials
  - For example: windows
- SI units are easier for most to work with, but <u>most products in the US are sold in IP units</u>
  - Remember this conversion! R(IP) = R(SI) × 5.678

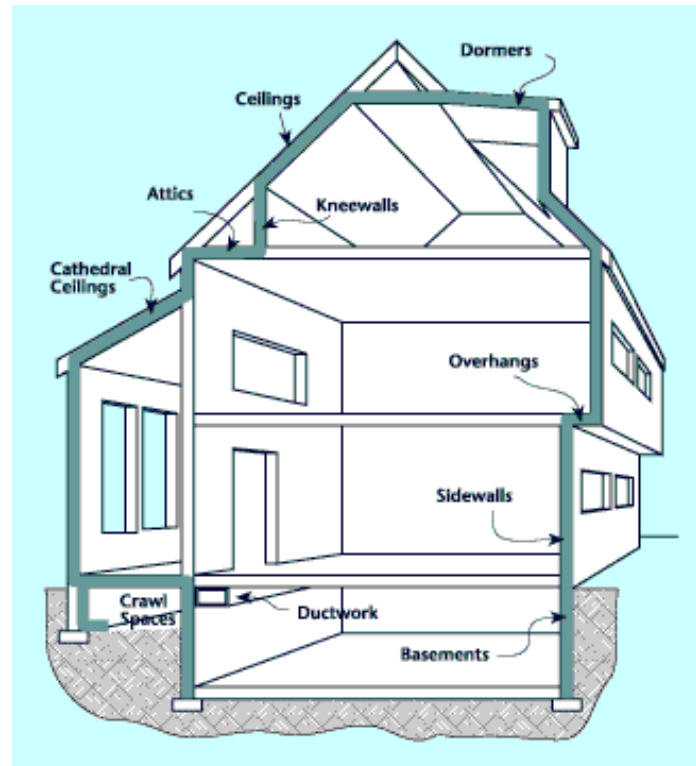
R-SI

$$1\,\frac{\mathrm{m^2K}}{\mathrm{W}} = 5.678\,\frac{\mathrm{h\cdot ft^2\cdot {}^\circ F}}{\mathrm{Btu}}$$

R-IP

Building insulation

- Insulation is necessary to control heat flow through enclosure
- All opaque external surfaces should have insulation
  - Walls
  - Ceilings
  - Roof
  - Basements
- We've discussed insulation in terms of thermal conductivity, U-values, and R-values



Actual building materials

- Materials with thermal conductivities (k) less than about 0.05 W/mK are used specifically for insulation
  - 0.05 W/mK divided by 3-inches of typical thickness (0.076 m) yields U-value of ~0.66 W/m^2K
  - R = 1/U = 1/0.66 = ~1.5 m^2K/W RSI (or ~R-9 in English units)

Example from product literature

Johns Manville

AVAILABLE FORMS*

Specification Compliance	R-Value ($hr•ft^2•°F/Btu$)	RSI-Value ($m^2•°C/Watts$)	Thickness** (in)	(mm)
ASTM C 665	38c	6.7	10 ¼	260
Kraft-Faced	38	6.7	13	330
Type II, Class C	30c	5.3	8 ¼	210
Category 1	30	5.3	10 ¼	260
	25	4.4	8 ½	216
	22	3.9	7 ½	191
	21	3.7	5 ½	140
	19	3.3	6 ½	165
	15	2.6	3 ½, 3 ⅝	89, 92
	13	2.3	3 ½, 3 ⅝	89, 92
	11	1.9	3 ½, 3 ⅝	89, 92

Notes for construction documents

- Conductivity of types of insulations can change from manufacturer to manufacturer
  - It is best to denote a required R value on the building drawings and in the specifications
  - Ensures that the required insulating value is installed

- When comparing insulations, it is better to compare ***R per inch*** or k values because they are basic material properties
  - Not dependent on thickness

Actual building materials: “R per inch”

- Insulation manufacturers often sell their products in terms of “R-value per inch”

PRODUCT OVERVIEW

FOAMULAR 150 extruded polystyrene (XPS) rigid foam insulation contains hundreds of millions of densely packed closed cells to provide exceptional thermal performance. It's also virtually impervious to moisture, unlike other plastic foam insulation products, preventing loss of R-value due to moisture penetration. FOAMULAR weighs considerably less than plywood, OSB or other non-insulation materials so it's easier, faster and safer to install. Plus, the product's built-in rigidity means it can be scored and snapped, cut, or sawed with common tools. Sagging and settling are never a problem. Retains it's long-term R-value year after year, even following prolonged exposure to water leakage, humidity, condensation, ground water and freeze/thaw cycling. Contains a minimum of 20% certified recycled content, certified GreenGuard Indoor Air Quality for Children and Schools, Energy Star Seal and Insulate Program, and NAHB Green approved. Owens Corning Foam Insulation, LLC now warrants a Lifetime Limited Warranty on FOAMULAR Extruded Polystyrene (XPS) Foam Insulation products. This new, enhanced warranty indicates that for the lifetime of the product, FOAMULAR XPS Insulation products are free from defects in material and/or workmanship that materially affect the performance of the product in a building installation.

- Exceptional thermal performance at r-5 per in.
- Virtually impervious to moisture penetration
- For exterior wall sheathing, wall furring, perimeter/foundation, cavity wall, crawlspace, pre-cast concrete, under slab and other applications
- Fast, easy installation
- Available in a wide range of sizes, thicknesses and edge trims
- Compressive strength of 15 psi; astm c578 type x
- Will retain at least 90 percent of their advertised r-value
- MFG Model # : 45W
- MFG Part # : 270895

Owens Corning FOAMULAR 2 inch x 48 inch x 8 feet foamboard
Extruded polystyrene rigid foam insulation – closed cell

Primary types of insulation materials

- Fiberglass
- Mineral fibers
- Cellulose
- Natural fibers
  - Cotton
  - Wool
- Spray-on foams
- Rigid foams
- Structure-integrated insulations
  - EIFS, ICFS, SIPS

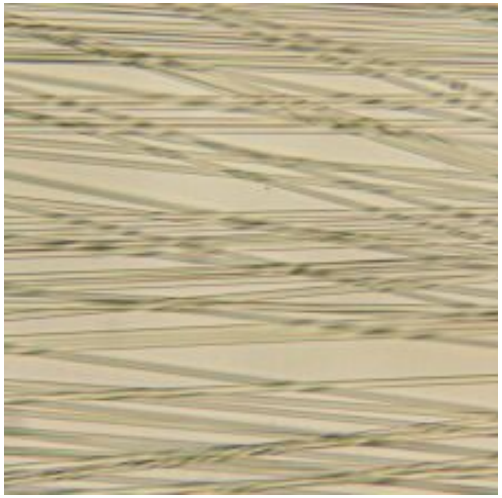
Another note on insulation materials

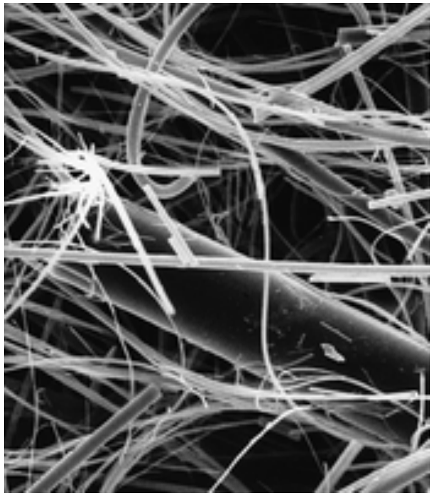
- **Still air** is also a low-cost insulator
  - Density ~1.2 kg/m^3
  - Conductivity, k ~ 0.03 W/mK
  - So many insulation materials rely on creating air voids

- Example: fiberglass insulation
  - Glass, with a density of 2500 kg/m^3 and k = 1 W/mK, is spun into fibers and made into a fiberglass insulation batt, which is ~99.4% air voids (~0.6% glass fibers) by volume
    - Yields a product with a density of 16 kg/m^3 and thermal conductivity of 0.043 W/mK
    - Both values are very close to that of **still** air

Fiberglass or glass wool insulation

- Fiberglass is made from thin filaments of glass
  - Also known as glass wool
- Fiberglass acts as an insulator by reducing internal convection and radiation
  - Glass fibers conduct heat better than still air, but the closely spaced fibers resist air motion and nearly eliminate convection
  - Radiation is absorbed and reradiated by fibers but each absorption and re-radiation reduces the energy transmission



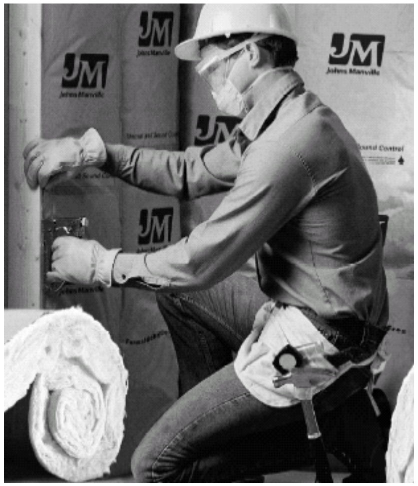


Forms of fiberglass insulation

- Blankets
  - Faced or Unfaced rolls and batts
    - Kraft paper facing provides some vapor resistance but reduces fire resistance
    - Foil facing provides vapor resistance, fire resistance, and a radiative reflective barrier
  - Encapsulated batts
    - Poly-encapsulation acts as a vapor barrier and makes it easier to install without contacting fibers
- Loose-fill
  - Blown-in to place
  - Fits into nooks and crannies in studs
- Rigid boards
  - Used for acoustic panels and external insulation boards

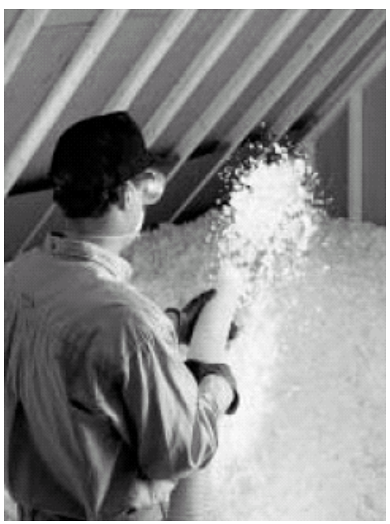
Types of fiberglass insulation

Kraft Faced



Poly Encapsulated

Rigid



Blown In

Foil Backed

Properties of fiberglass insulation

- $R \approx 3$ hr·ft^2·°F/Btu per inch with $2 < R < 3.7$ per inch
  - Starts a bit higher but usually drops as fiberglass settles
  - Must avoid compression to keep R-value high
    - A 6 inch fiberglass batt compressed to fit in a 2x6 stud has a lower R value than a 5 inch fiberglass batt undisturbed
- Usually sold according to its R-value
  - R-11, R-13, R-19, etc. (or R per inch)
- Vapor Resistance (IP)
  - 0.001 rep (bare), ~0.1-5 rep (Kraft faced), 20 rep (foil faced)
- Relatively low cost

Advantages and disadvantages of fiberglass

- Advantages
  - Low density
    - Easy storage and transport
  - Inexpensive (both material and installation costs)
  - Inorganic – fiberglass itself is fire and mold/bacteria growth resistant
- Disadvantages
  - Low density means surprisingly poor fire resistance
    - Material very difficult to ignite, but flame travels through air space fairly well
  - Fiberglass is a carcinogen
    - Very hazardous installation - must wear gloves, masks and goggles
    - Must keep fibers from getting airborne after installation
  - Can absorb moisture since there are no closed cells
    - R-value can decrease when wet

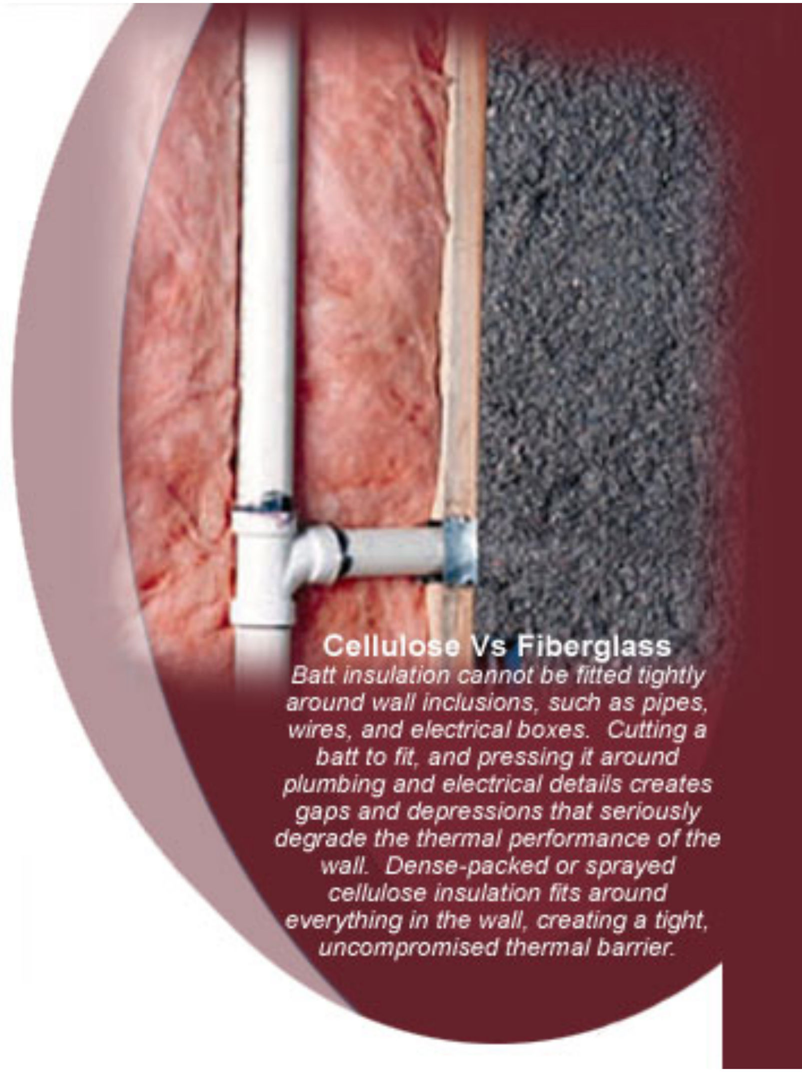
Rock and slag wool insulation (aka mineral wool)

- Rockwool
  - Made from basalt (a volcanic rock) and limestone
- Slagwool
  - Made from recycled blast furnace slag (byproduct of iron/steel)
- r usually a bit higher than fiberglass
  - R is 3.7 hr·ft^2·°F/Btu per inch for 2.5 pcf rock wool
  - R is 3.9 hr·ft^2·°F/Btu per inch for 4 pcf rock wool
- Higher fire resistance than fiberglass
- Does not absorb moisture well
- Installed costs a bit higher than fiberglass

Mineral wool insulation

Cellulose insulation

- Made from shredded newspaper and wood pulp
  - Chemically treated to increase fire resistance
  - Noncarcinogenic
- $r \approx 3.6$ hr·ft^2·°F/Btu per inch
- Cellulose is applied wet and sticks to wall and fills gaps
- Installed costs a bit higher than blanket fiberglass



Advantages and disadvantages of cellulose

- Advantages
  - Low embodied energy
    - 6x less energy than fiberglass to manufacture
    - 25 to 50x less embodied energy than other mineral fibers
  - Higher density than fiberglass can reduce air flow
    - May reduce heat transfer even with a lower R value
    - Less air space means flame spread characteristics can be better than fiberglass
- Disadvantages
  - Absorbs and retains moisture, which reduces R-Value
  - More susceptible to mold/fungus growth than mineral fibers
  - Lower innate fire resistance than mineral fibers
    - Wet applied clings to walls which means quicker ignition
  - Wet Applied Cellulose must dry before walls are closed – slows down construction time

Cotton fiber insulation

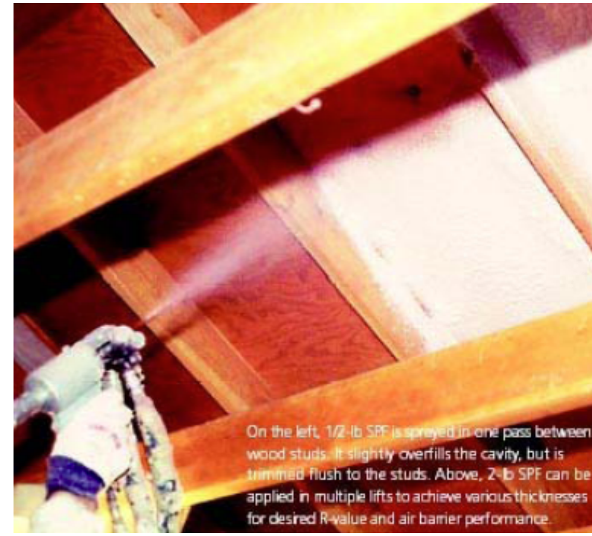
- Made mostly from recycled cotton fibers
- r value ≈ 3-4 $hr \cdot ft^2 \cdot {}^\circ F/Btu$ per inch
- Organic
  - Possible problems with mold/fire
  - Fire ratings are pretty good
- No problems with chemical emissions
  - Possible problems with allergies
- Low embodied energy
  - 100% recyclable
  - Low energy to manufacture
- Installed cost is comparable to mineral fibers and cellulose

Insulation made from recycled denim

Foam insulations

- Foam building insulations offer an alternative to fibrous materials
- Liquid foams are sprayed in and expand to fill cavities
  - Use in place of spray in fiberglass or cellulose
- Foam board is rigid and self supporting
  - Use in place of blanket, batt or rigid fiberglass insulation
  - Very useful for external and roof insulation

Spray-on expanding foam

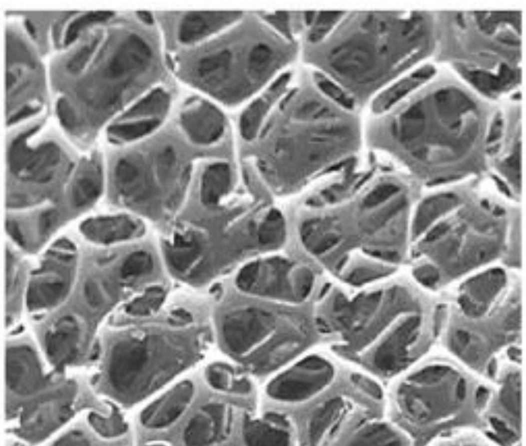


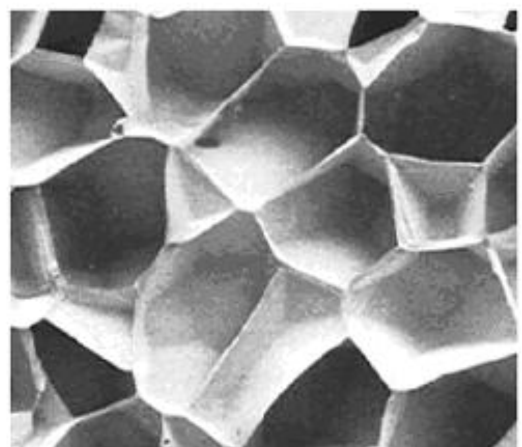
- Spray-on polyurethane material
- r ≈ 3-7 hr·ft^{2}·°F/Btu per inch
- Spray in expanding foam fills cracks and gaps
- Closed cell completely eliminates the need for taping/sealing and air barrier material
  - This is great for trying to insulate existing construction where it is hard to cut around framing and piping
    - Spray in foam can be sprayed around it
- Installed costs are higher
  - But you eliminate the cost to install an air barrier for closed cell foam

Open-cell:
r ~ 3.6 per inch

Closed-cell:
r ~ 6.5 per inch

Open-cell and closed-cell foams



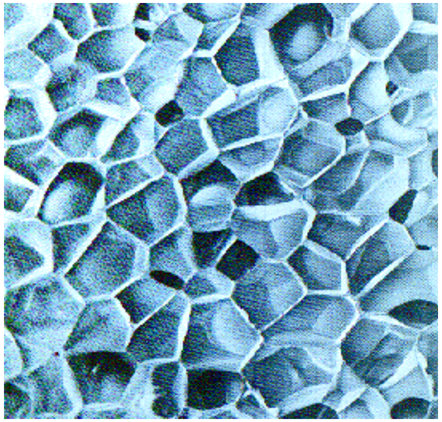


Expanded polystyrene (EPS)

- Also called styrofoam
- Polystyrene beads are heated in molds
  - Expands a gas (pentane) within
  - Resulting structure is touching spheres with gaps in between
- More easily molded to different thicknesses than XPS
- r ≈ 4 hr·ft^2·°F/Btu per inch
- Vapor Resistance ≈ 0.3-3 rep/in
- Compressive strength
  - Much higher than non-rigid fiberglass

Extruded-expanded polystyrene

- XEPS or **XPS**
- Polystyrene is melted and injected with a blowing agent forming gas bubbles
- Resulting structure is more like a honeycomb with closed or open cells
- Often used as structural insulating panels (SIPs) or insulating concrete forms (ICF)
- Because the cells are closed, it stores less moisture and is suitable for foundation insulation



XPS properties

- $r \approx 5.5$ hr·ft$^{2}\cdot{}^{\circ}$F/Btu per inch
  - A bit higher than EPS
- Density ≈ 1.5-5 lb/ft^3
- Vapor Resistance ≈ 0.4–2.2 rep/in
  - Compressive Strength: 20–100 PSI

Polyisocyanurate (“polyiso”)

- Low conductivity gas is injected to form bubbles
  - Decreases thermal conductivity
  - Increases thermal resistance
- Available in rigid board or as a spray on foam
- Foil backed boards repel water and reflect radiant energy

http://www.polyiso.org/

Polyiso insulation properties

- $r \approx$ 8-10 $\mathrm{hr \cdot ft^{2} \cdot {}^{\circ}F/Btu}$ per inch
  - Highest of all common building materials
- Vapor Resistance ≈ 0.5 reps/in
- Density ≈ 1.5 – 2 $\mathrm{lb/ft^3}$
- Compressive Strength: 16 – 40 PSI

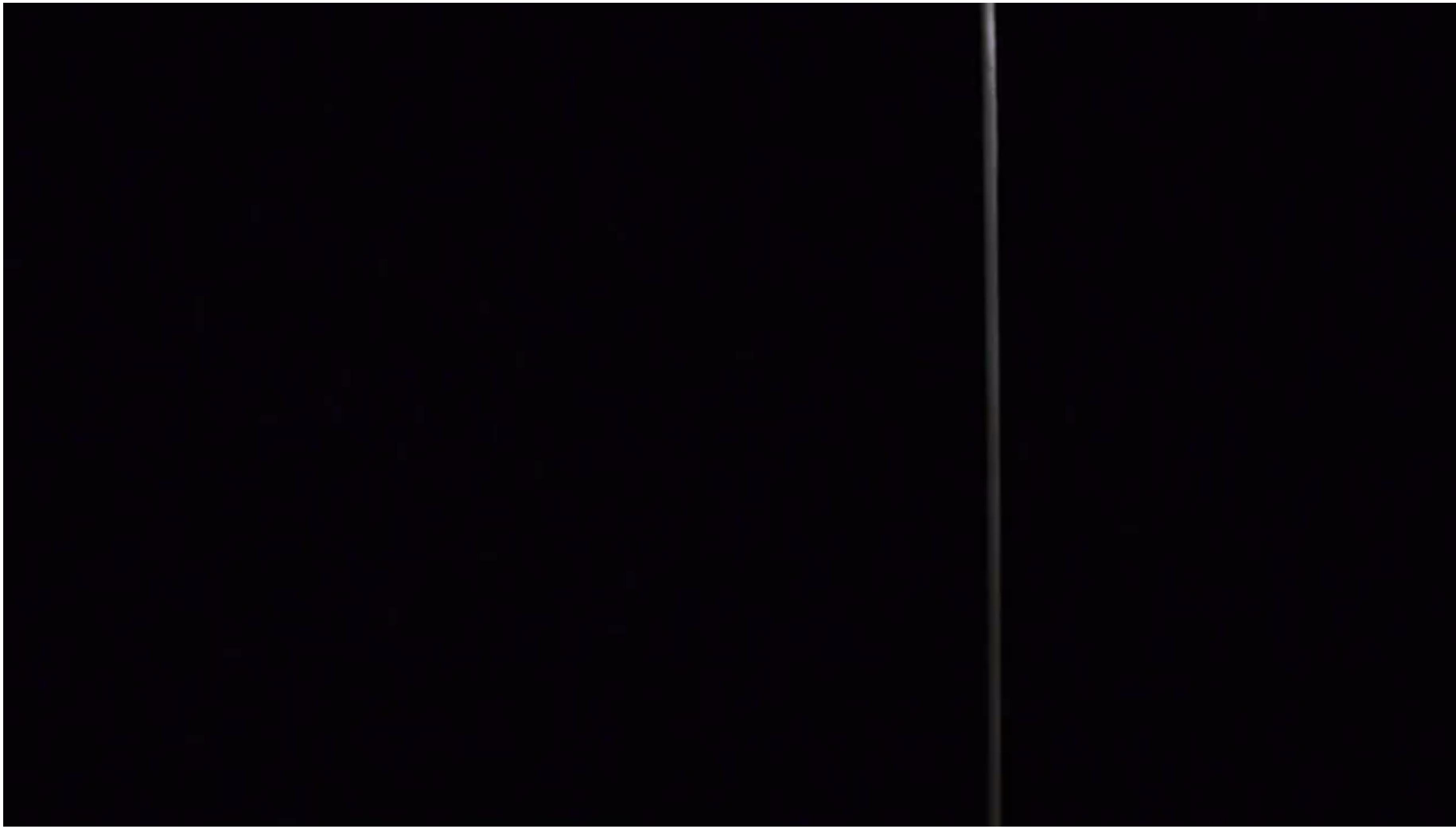
Advantages and disadvantages of foams

- Advantages
  - Highest R-values = best insulating capabilities
  - Easy storage, transport, and installation
  - Easily shaped and tapered
    - Important for designing drainage in roofs
- Disadvantages
  - Least environmentally friendly to manufacture
    - Made from plastics (oil and natural gas inputs)
    - Blowing agents in XPS and polyiso are still usually HCFCs or HFCs
  - Foams generally have lower fire resistances and are toxic when ignited
  - Does have some water absorption properties (especially EPS)
  - Possible VOC off-gassing problems

Question…

- How do you actually **measure** the conductivity or thermal resistance of building materials and assemblies?

Measuring thermal resistance of materials



ASTM C1114-00 Heat flow apparatus (small sample) & ASTM C1363-05 Hot box (full sample)
https://www.youtube.com/watch?v=PjfznDPOeDA

Hot box apparatus

Thermal transmittance measurements with the hot box method: Calibration, experimental procedures, and uncertainty analyses of three different approaches

F. Asdrubali*, G. Baldinelli

Energy and Buildings 43 (2011) 1618–1626

Contents lists available at ScienceDirect

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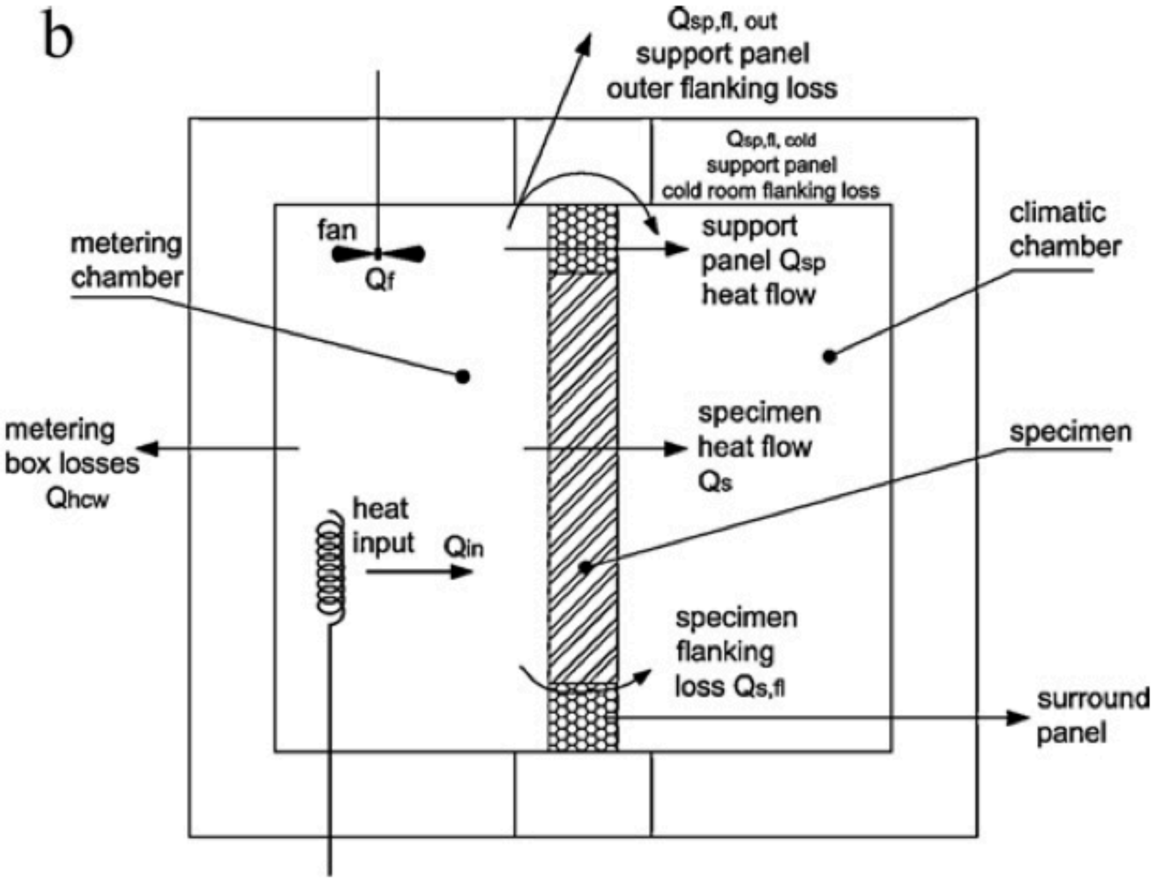

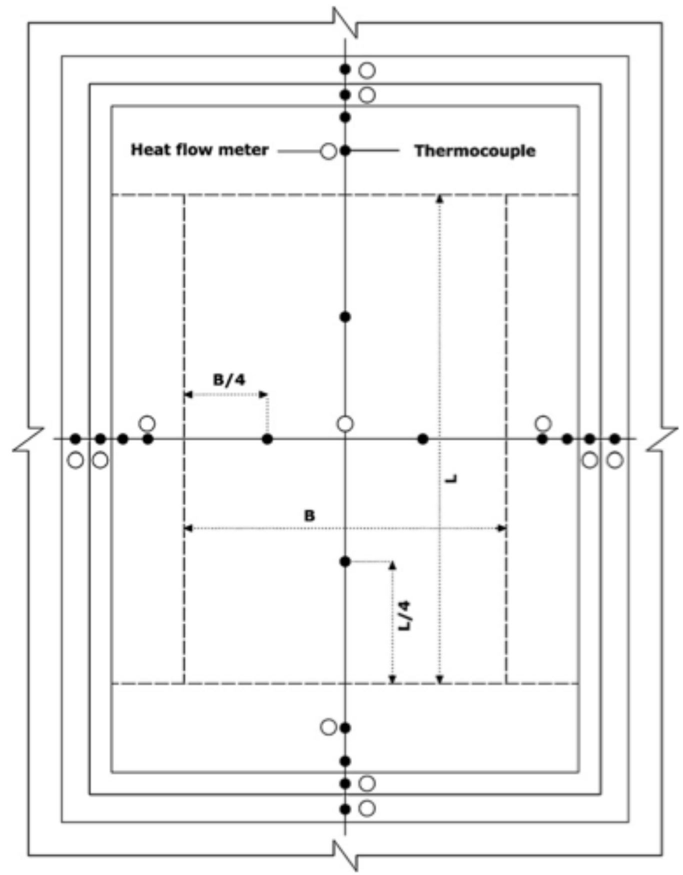

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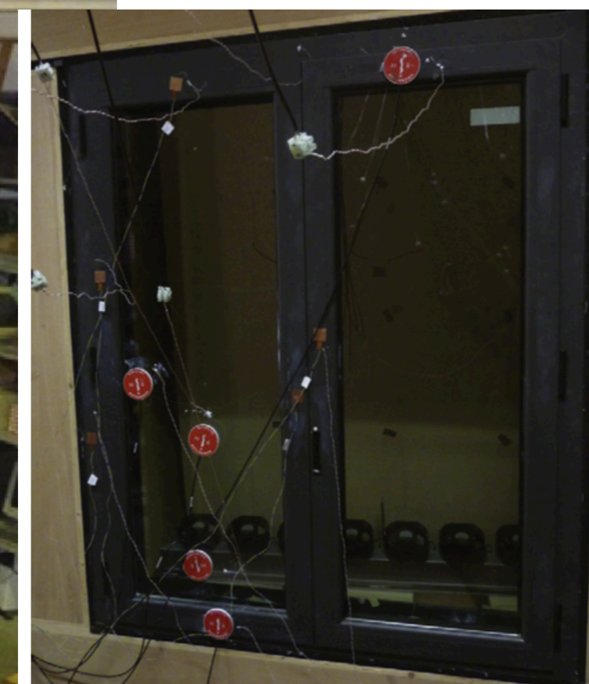


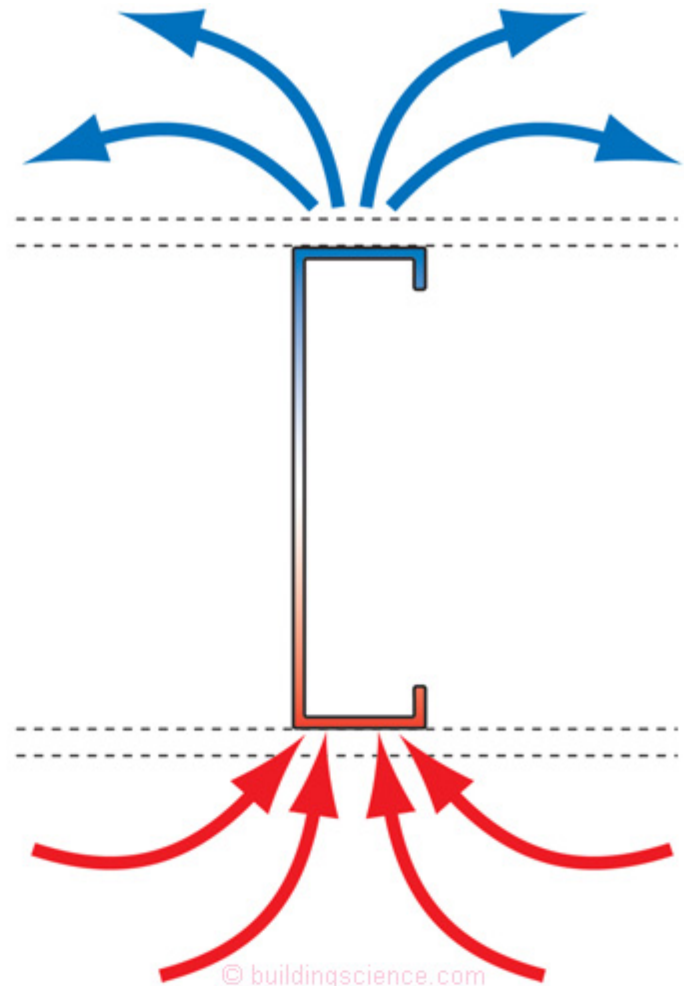
THERMAL BRIDGES

In building enclosure assemblies

Thermal bridges

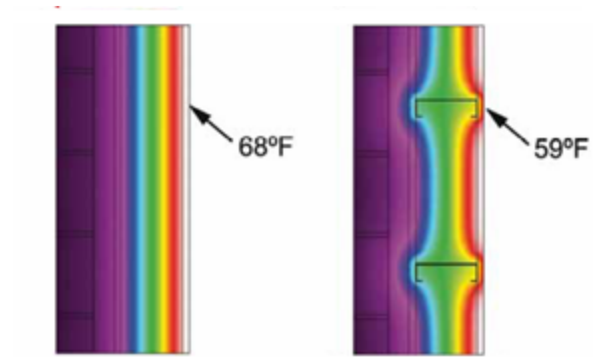
- A thermal bridge is a high conductivity portion of an assembly that penetrates insulating layers and significantly reduces the overall R value of the assembly

- These bridges act as thermal “short circuits”

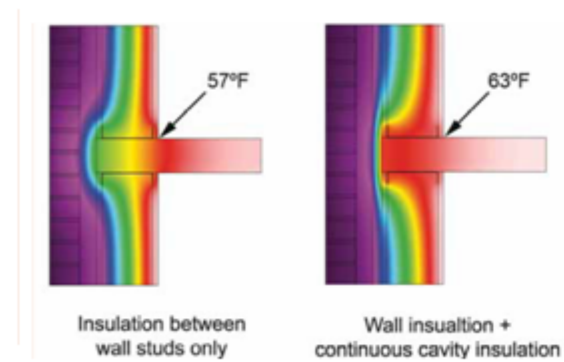


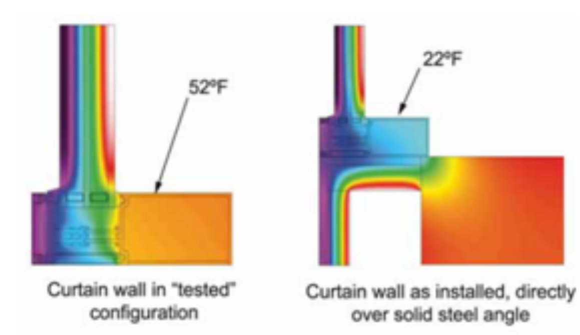
Common thermal bridges

- Metal studs in insulated walls without external insulation
- Floor planks without continuous external insulation
- Curtain walls in contact with steel framing



Thermal Bridging through Light Gauge Steel Studs





Thermal Bridging at Curtain Wall Connection

Identifying thermal bridges

We can identify thermal bridges in many ways:

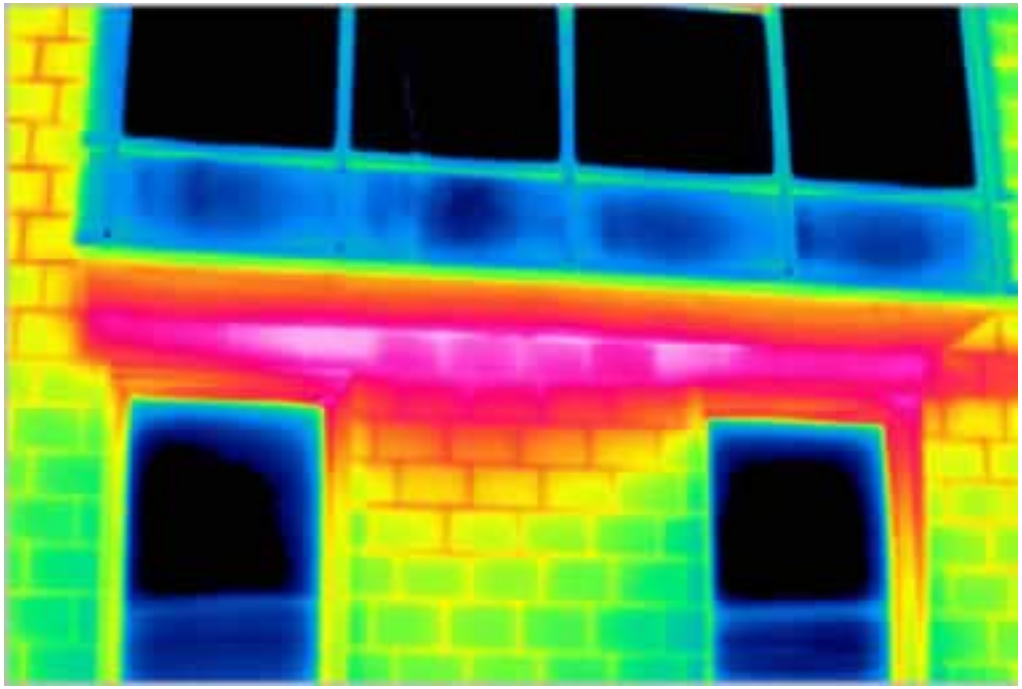
- Inspection of detail drawings
  - Use this to identify potential problems
- Thermal analysis of detail drawings
  - Use to quantify the extent of thermal bridging
- Thermal imaging
  - Useful way to find bridges in existing construction
- Visually without tools

Thermal imaging

- One way to find existing thermal bridges in buildings is to use thermal imaging
  - Particularly when the inside-outside temperature difference is large

- Regions around thermal bridges will have very different temperatures than the rest of the wall
  - This will be visible to IR

$$q = \varepsilon T^4$$

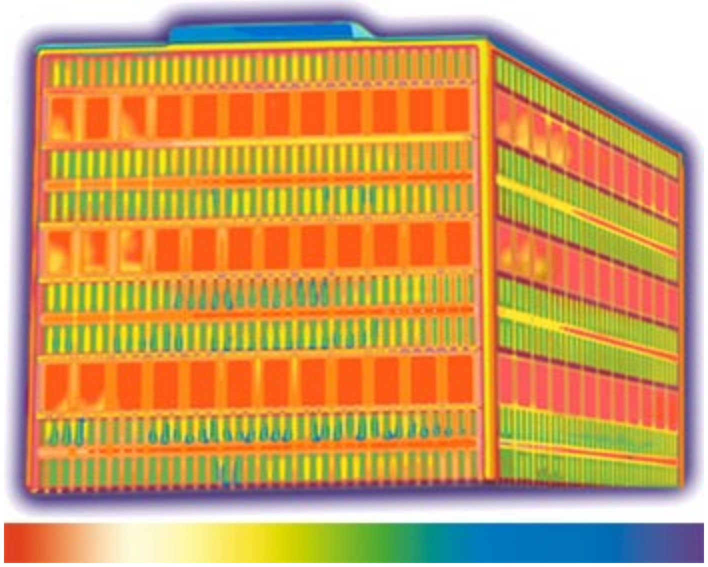


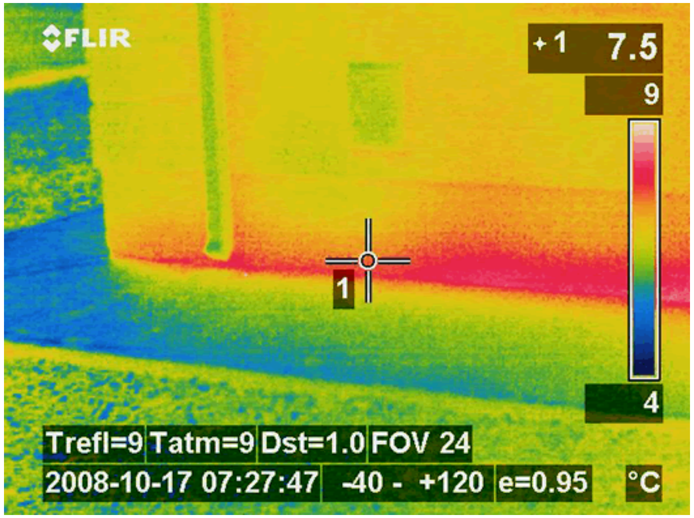
The red here indicates a thermal bridge created by a structural beam below the window

Cold outside, hot inside

More thermal imaging

- These figures show hot spots in red
- The windows, frames, and locations where the floor meets the walls are clearly visible bridges in the top figure
- The floor/foundation junction in the bottom has clear thermal bridges



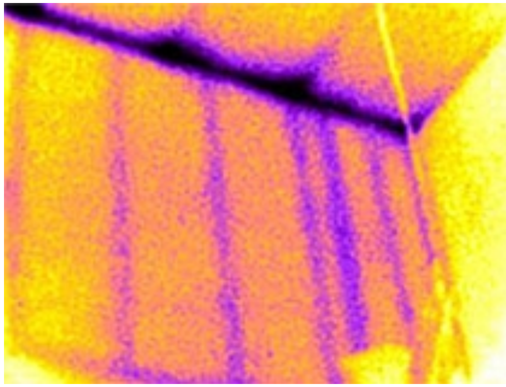


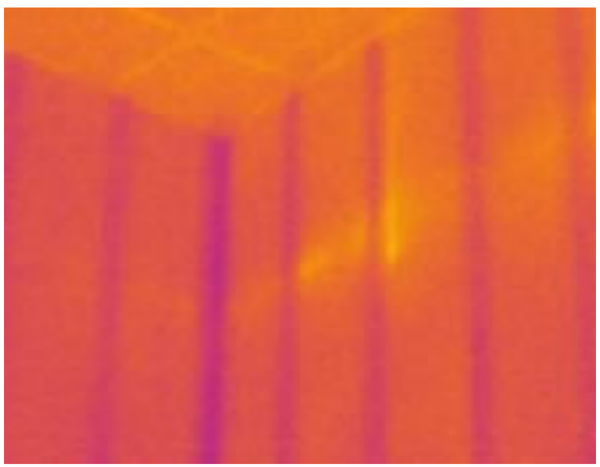
Framing effect

- The "framing effect" is a term used to denote the reduction in R-value from thermal bridging of the framing
  - Steel stud walls commonly have a framing effect of 40-50%

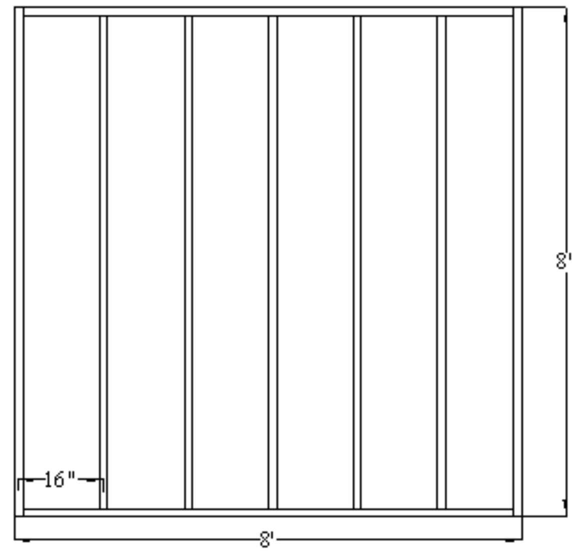
- A reduction in the framing effect means an increase in the effective R-value of a wall

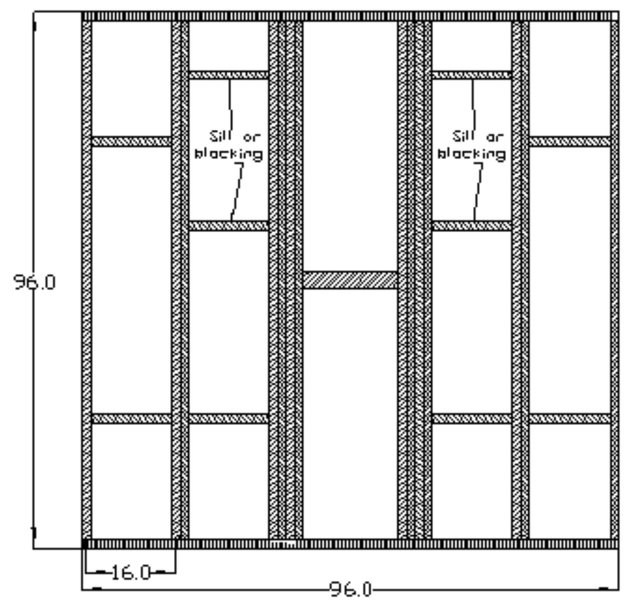
Framing effect



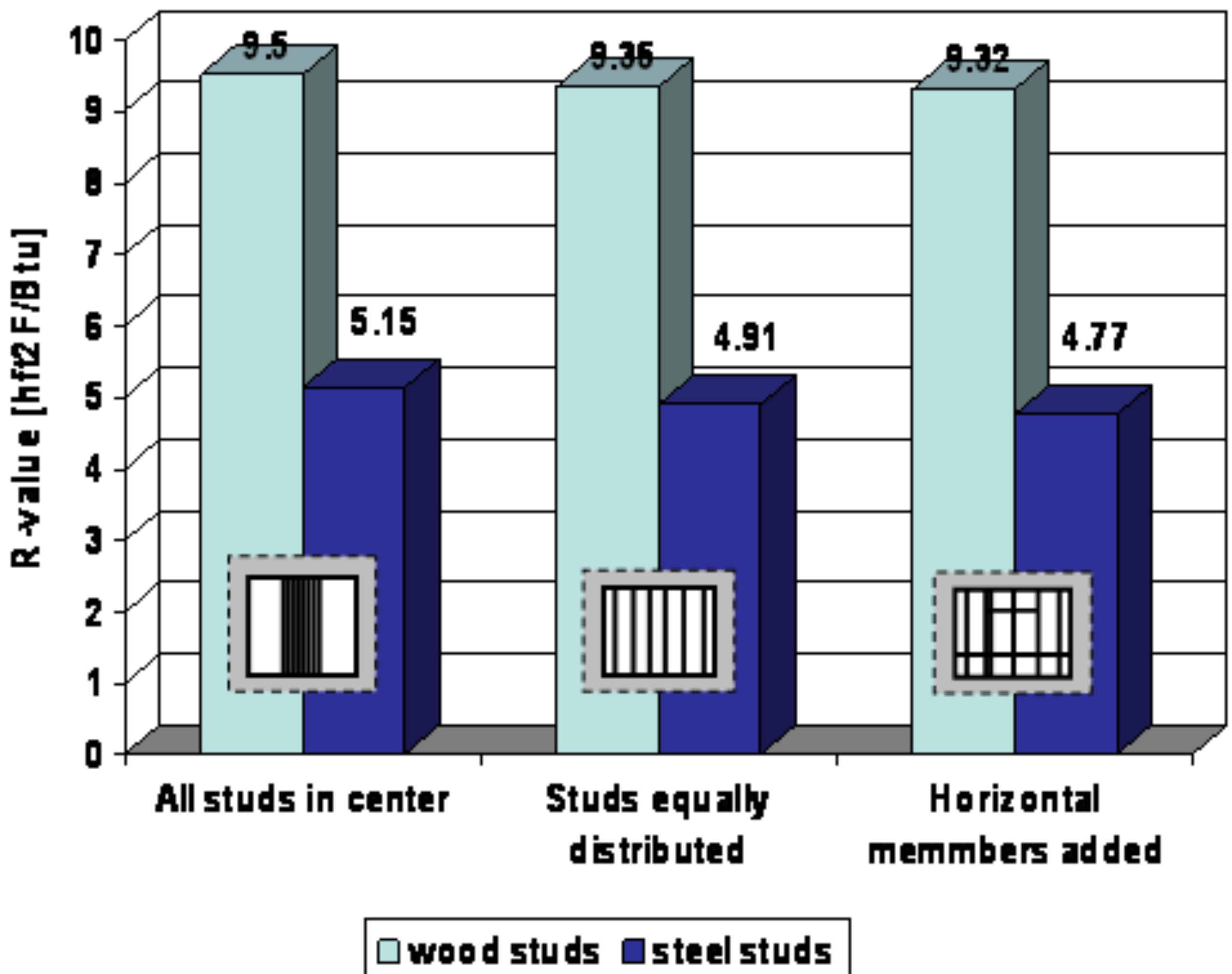


Thermal bridges show up in blue on these figures. Notice that corners seem to have the worst thermal bridges





Framing effect



http://web.ornl.gov/sci/roofs+walls/research/detailed_papers/thermal_frame/

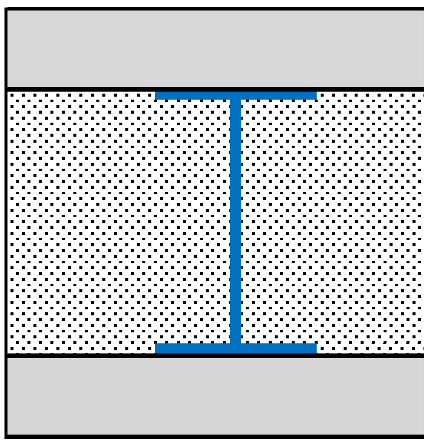
Framing effect

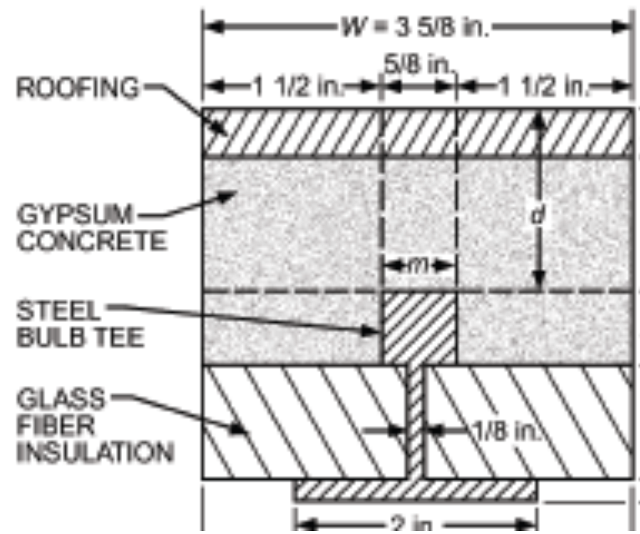
Thermal bridging in the uninsulated roof framed with steel (R-value of around 0.04-IP per inch) means bare roof at the rafter lines

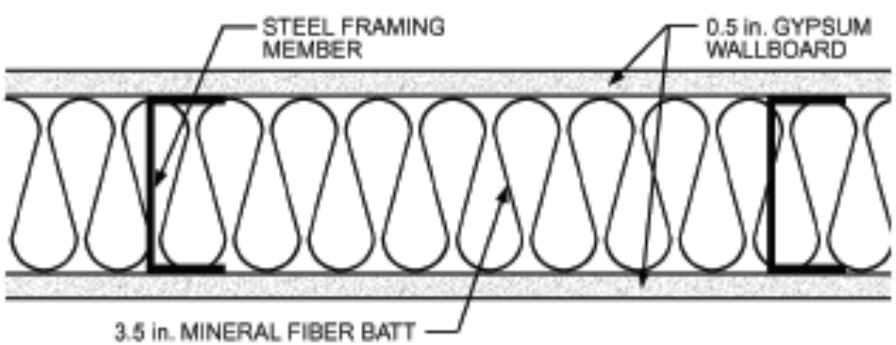
http://www.greenbuildingadvisor.com/blogs/dept/building-science/thermal-bridging

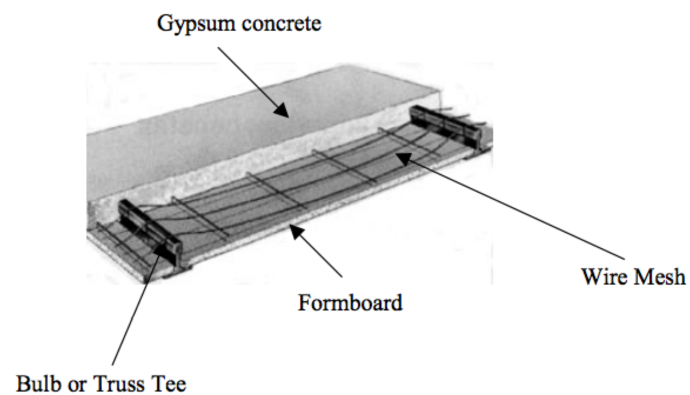
Metal thermal bridge examples

- I-beams sandwiched between sheathing
- Metal stud walls
- Metal embedded in concrete



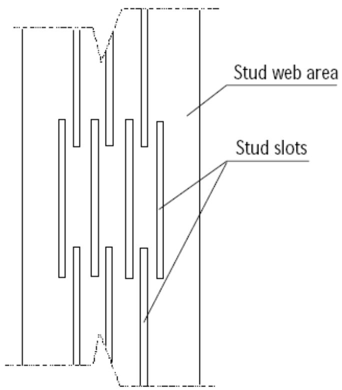




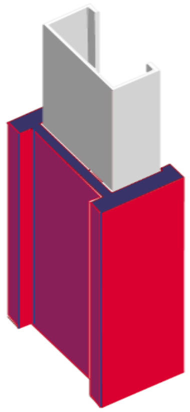


Reducing framing effects: Modified steel studs

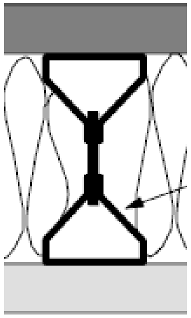
Slotted Studs



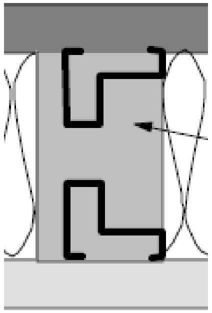
Insulated Studs



Triangular Studs



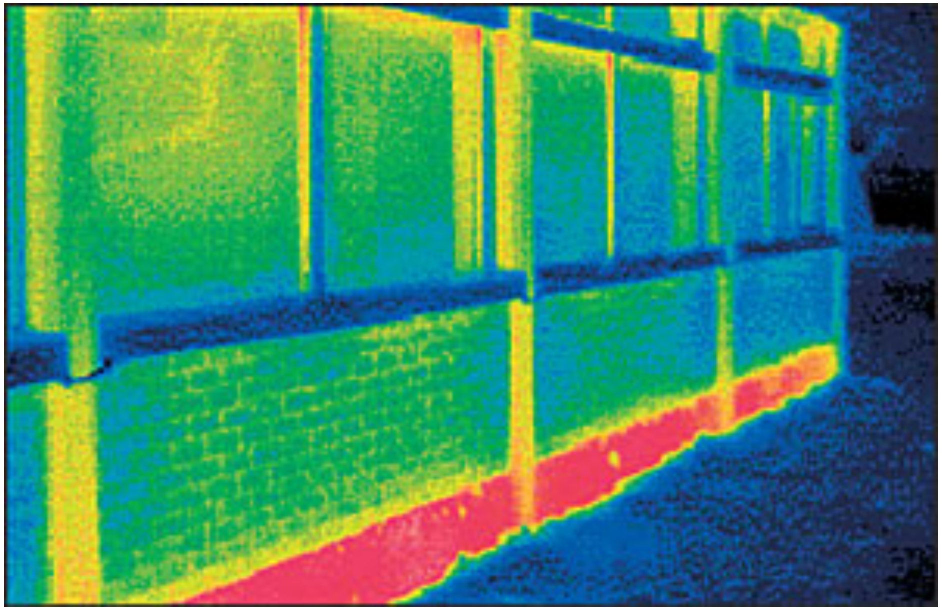
Small Studs + Foam Binder



AISI/DOE report from 2003 on alternative steel options with better insulation: http://steeltrp.com/finalreports/finalreports/9703NonPropFinalReport.pdf

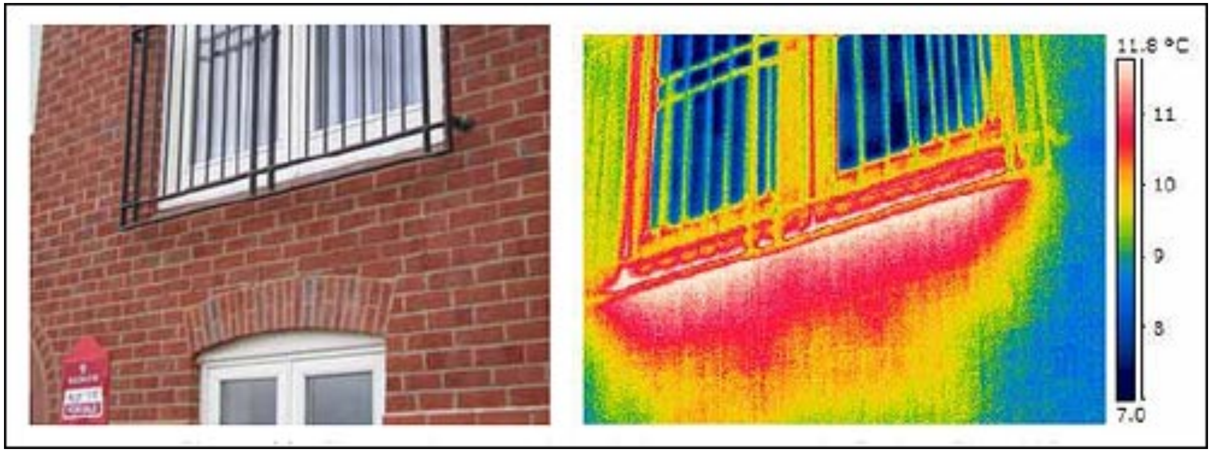
Foundation thermal bridges

Here are some thermal images showing thermal bridges where a slab floor or foundation meets a wall



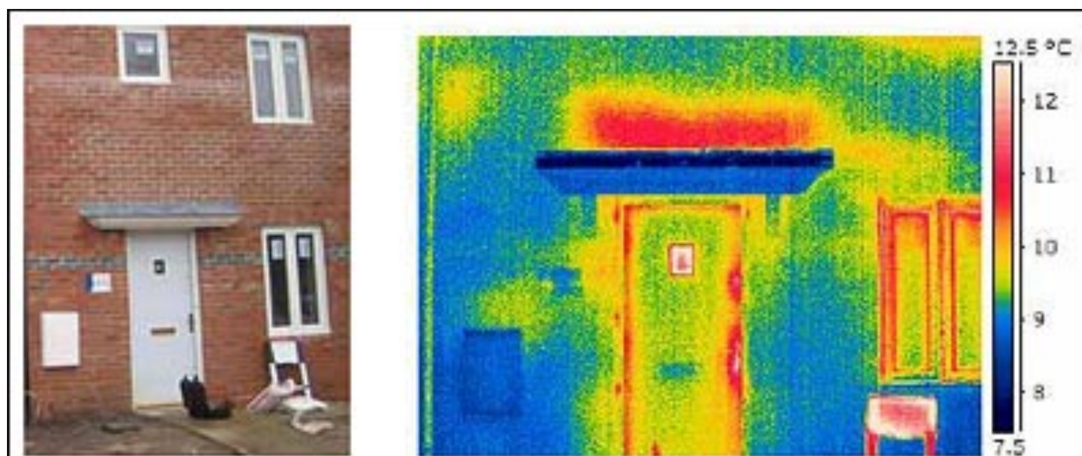
Wall-floor thermal bridges

Here are some examples of thermal bridges where interior floors and supports meet with exterior walls



Thermal bridge for support under the window

Thermal bridge from lintel over the door



Reducing thermal bridging

Basic concept:

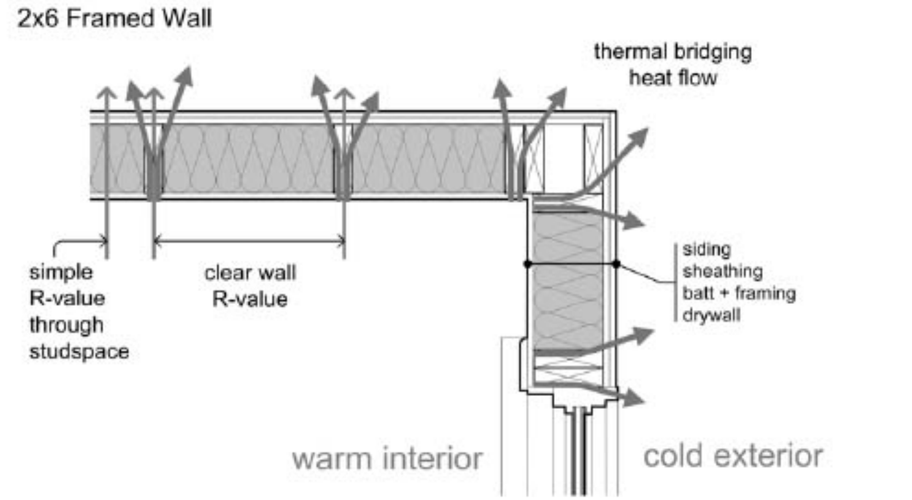
- To reduce thermal bridging we need to provide a thermal break in the high-conductivity heat transfer path

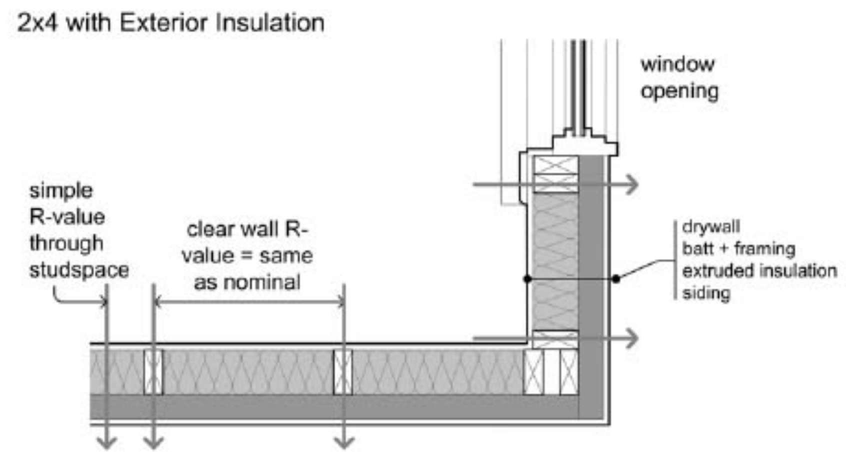
Basic solution:

- Add insulation to the path to reduce direct heat flow

An important solution: External insulation

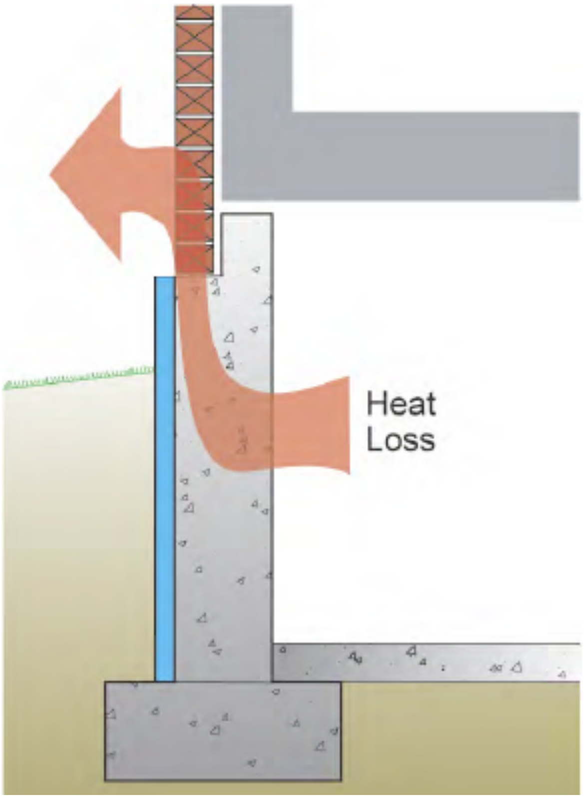
- The use of external insulation is a very effective way of reducing the bridging effects
  - It also increases the R value of the non-bridge areas
    - A 2x4 wall with 2 inches external insulation is much better than a 2x6 wall with 6 inches interior insulation
  - Need a continuous (or near continuous) layer of external insulation to break the path of high-conductivity material
    - Add to the exterior to ensure as much continuity as possible





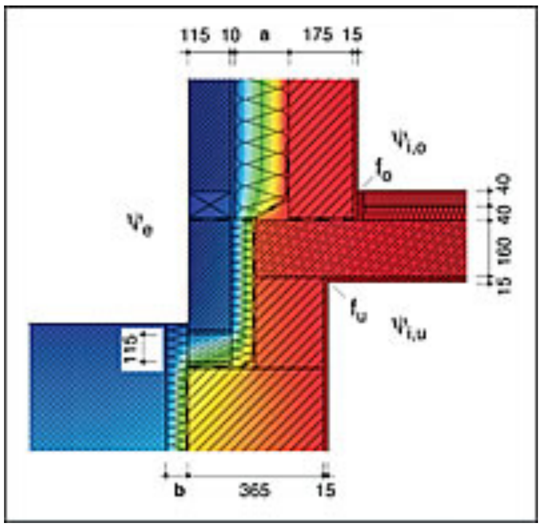
Foundation thermal bridges

Thermal bridges between brick veneer and foundation are common

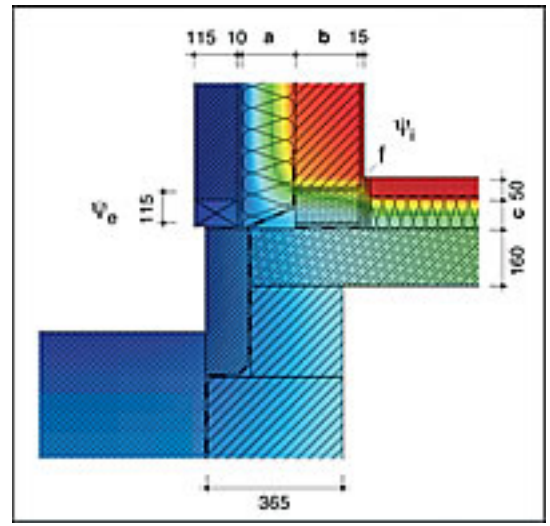


Fixing wall-floor bridges

To correct this problem we need to break the heat flow path:



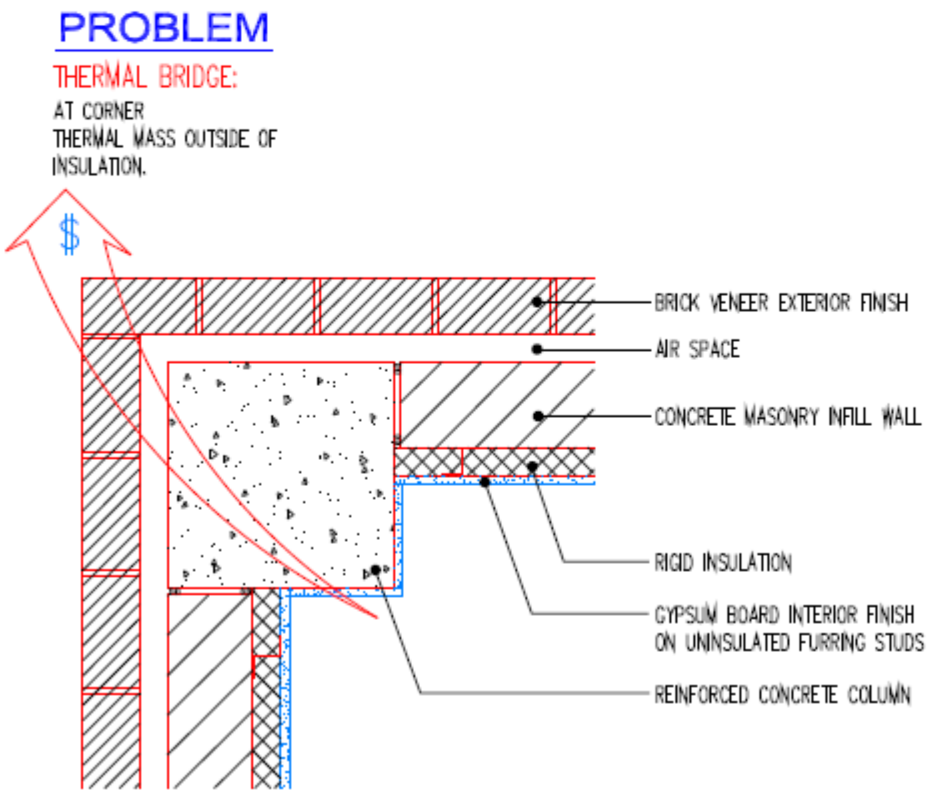
External insulation added down along the foundation breaks the thermal bridge



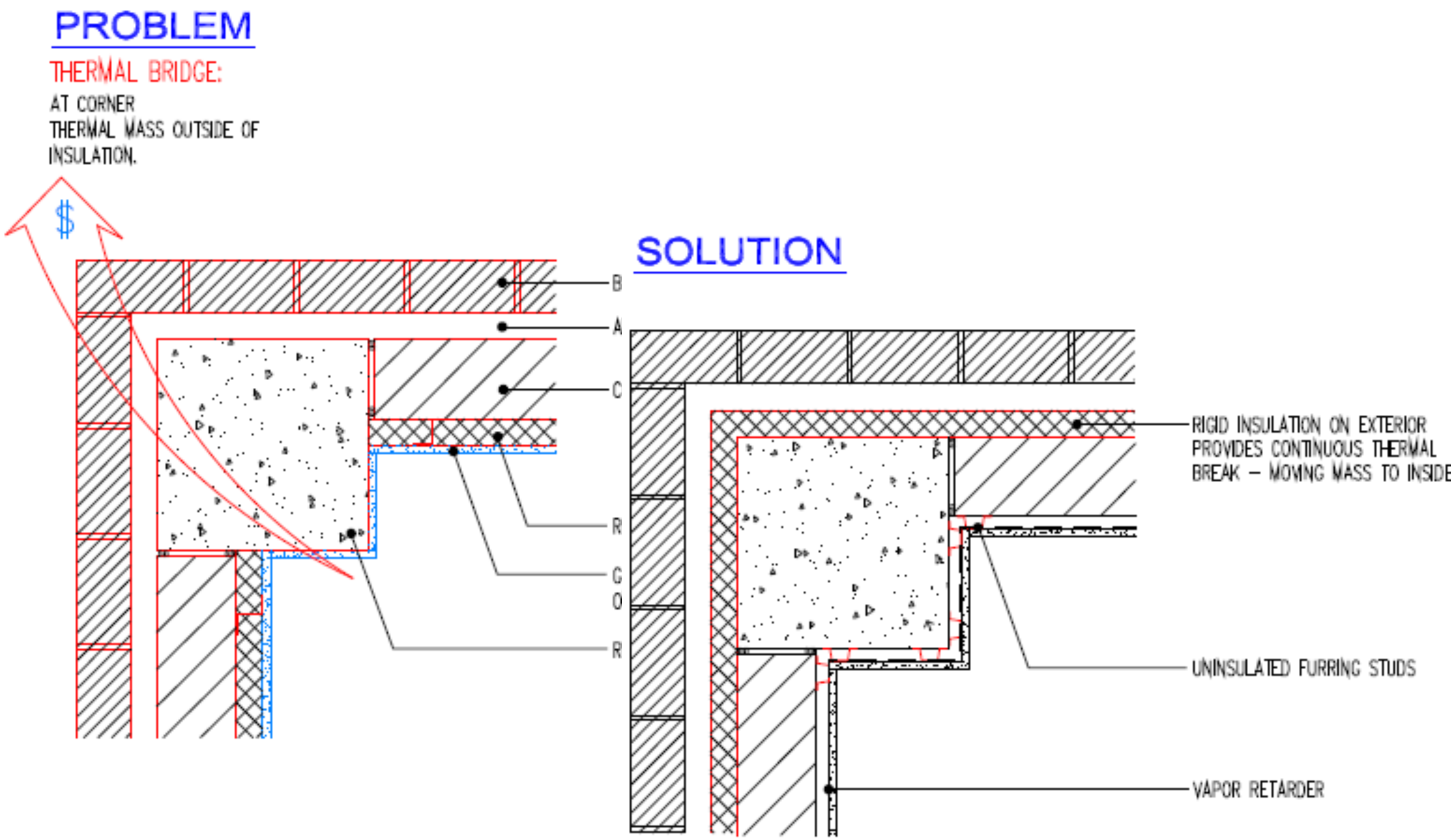
Insulation added to the floor also breaks the thermal bridge

In both of these two designs the continuous insulation breaks the thermal bridge

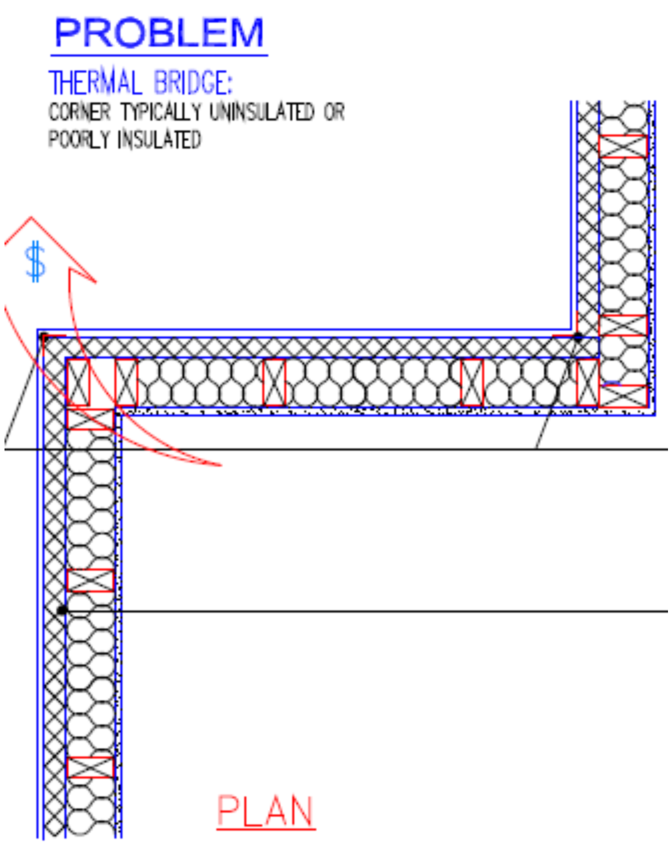
Corner columns

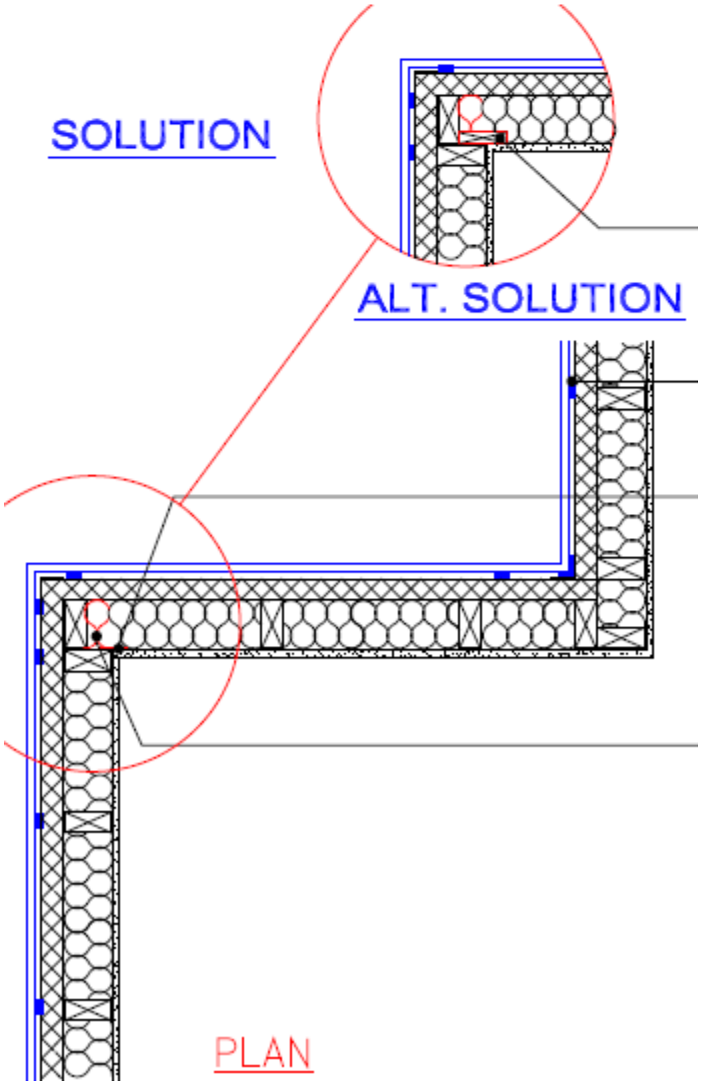


Corner columns

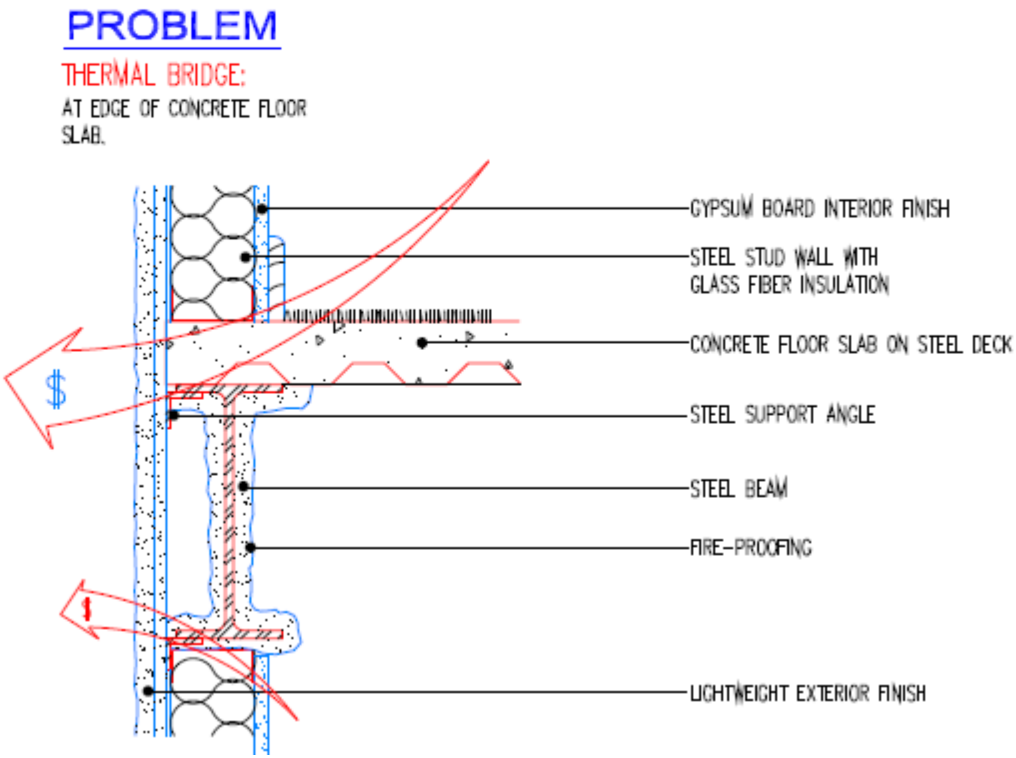


Wood stud corners

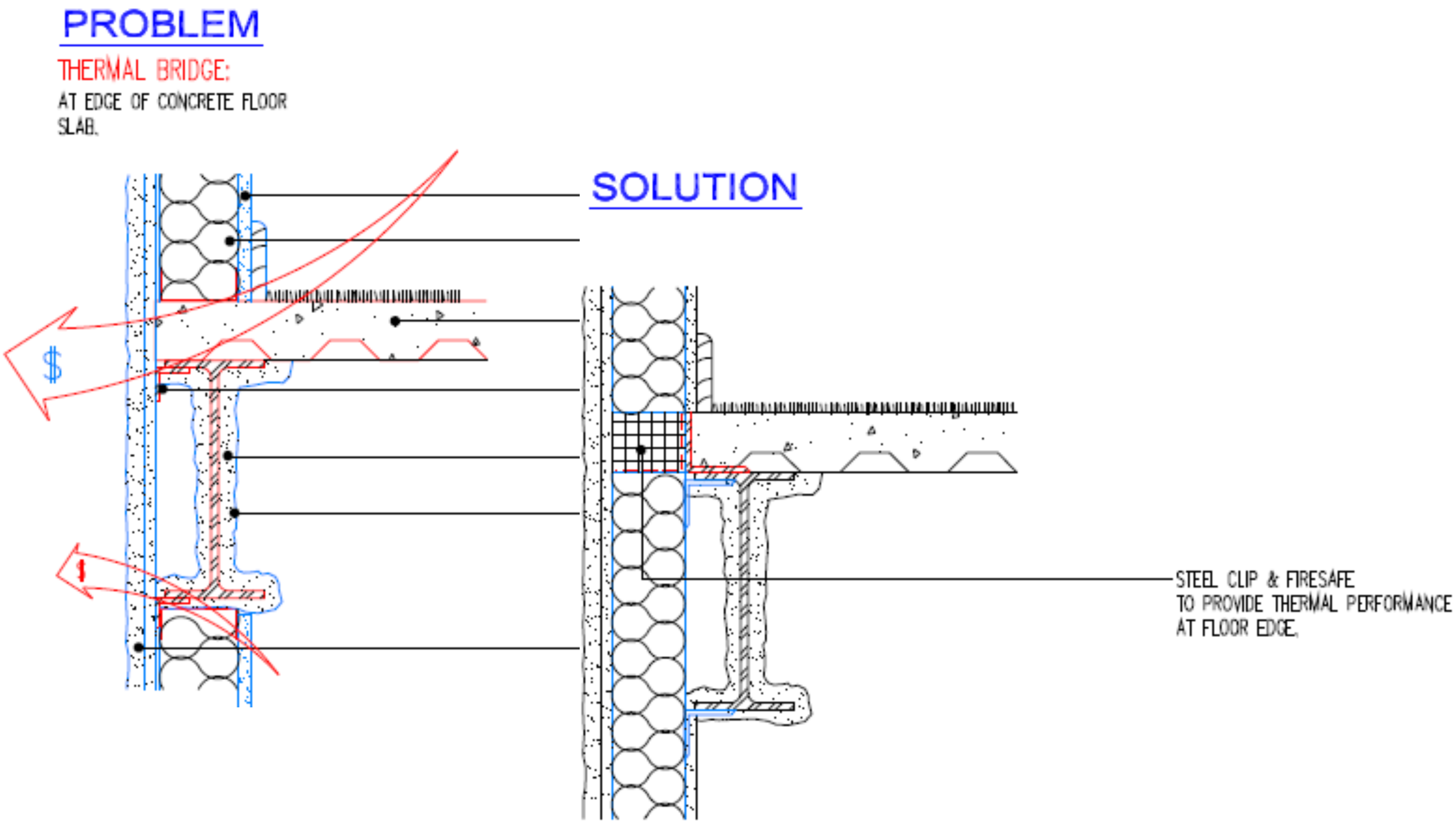




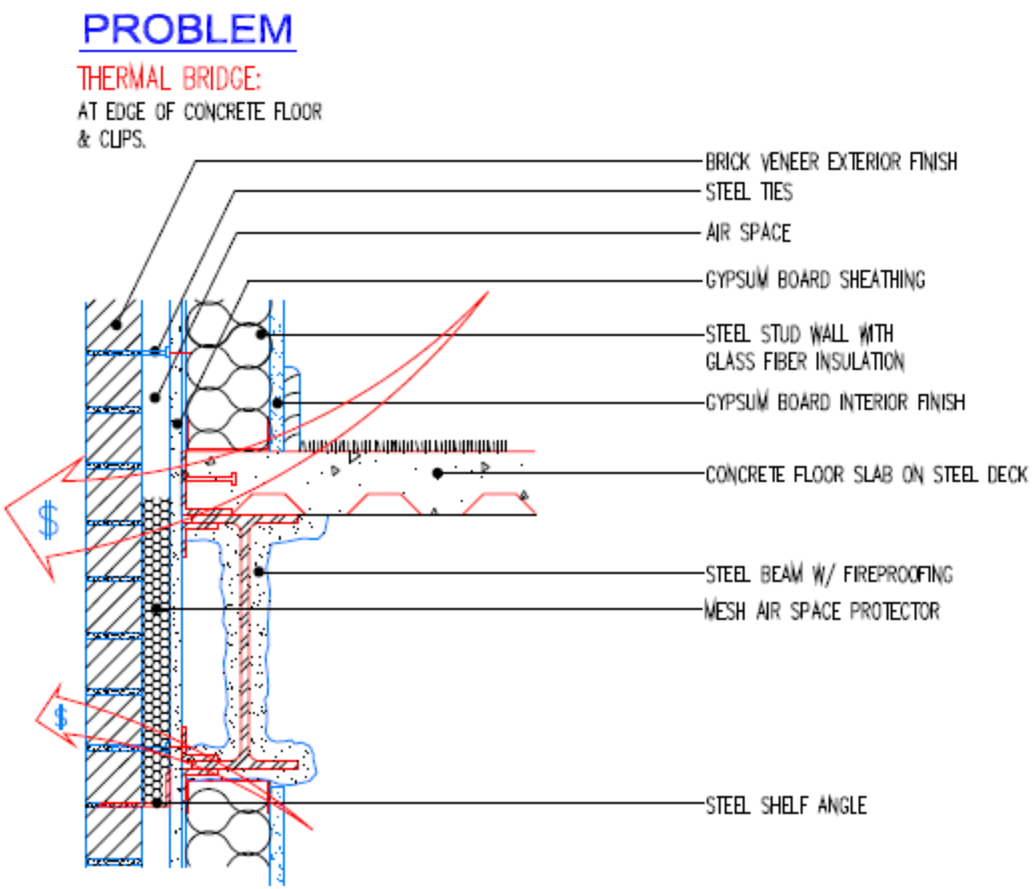
Slab edge stud wall



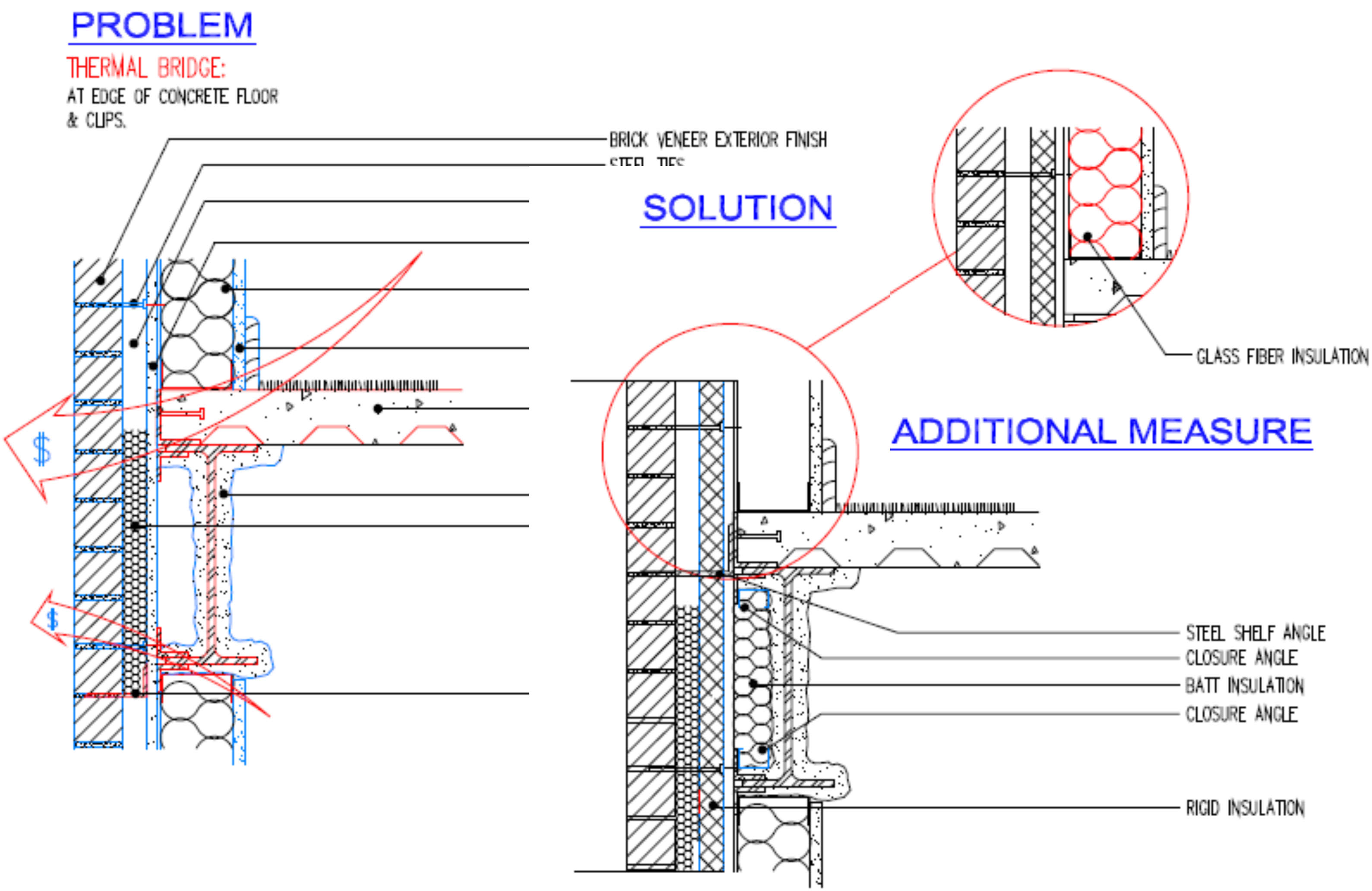
Slab edge stud wall



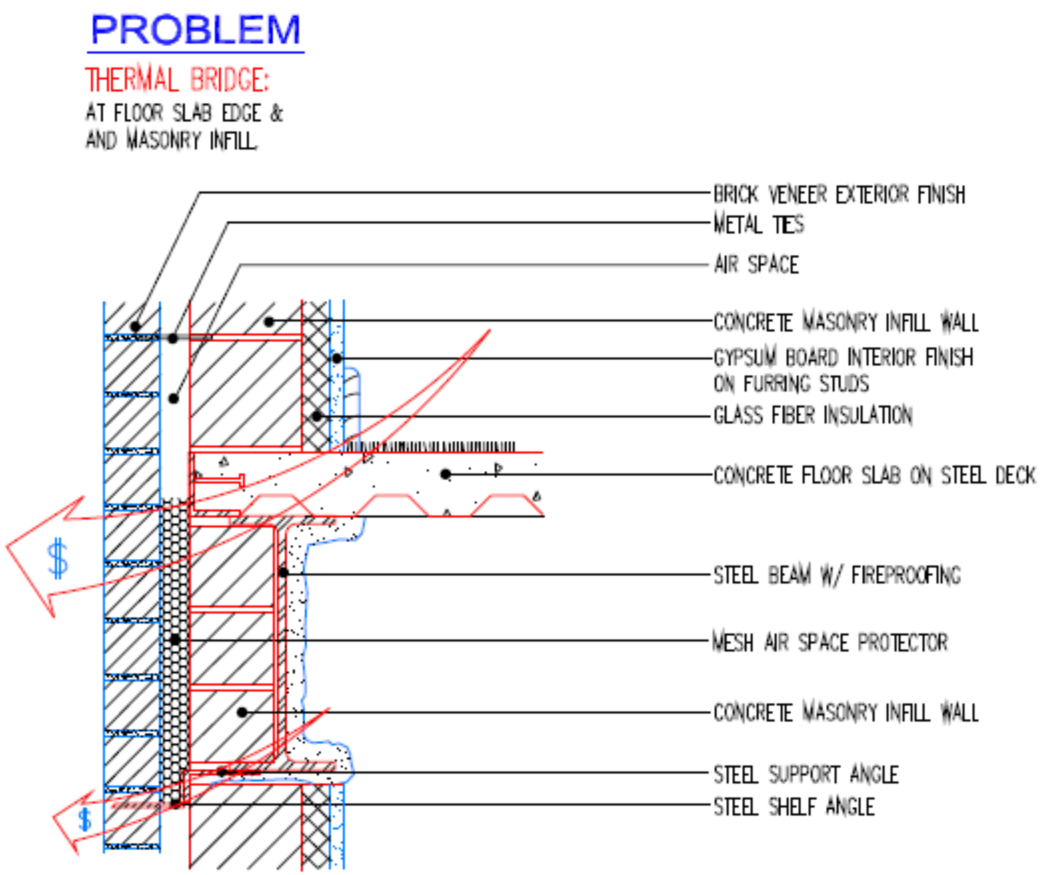
Slab edge brick/stud wall



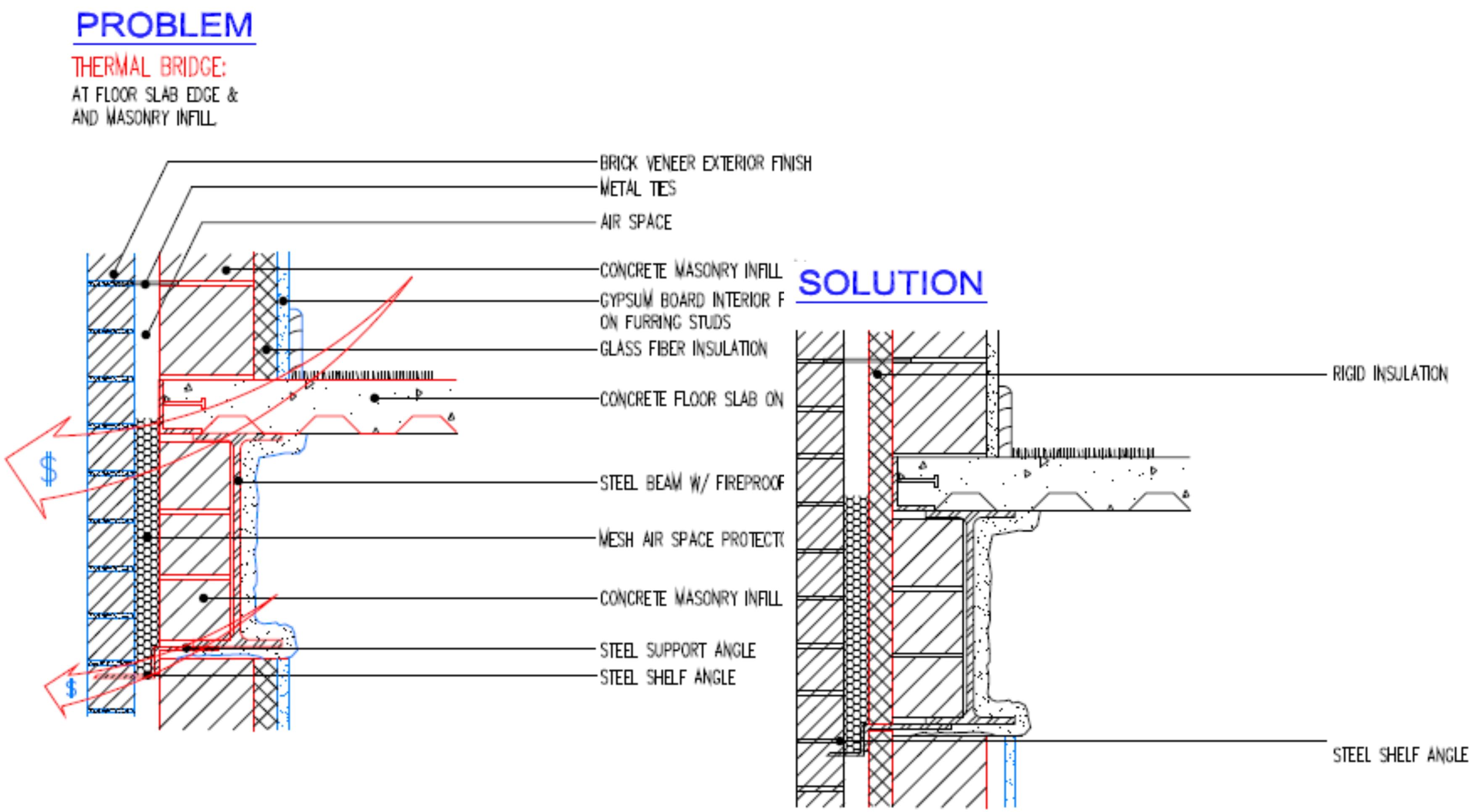
Slab edge brick/stud wall



Slab edge masonry wall

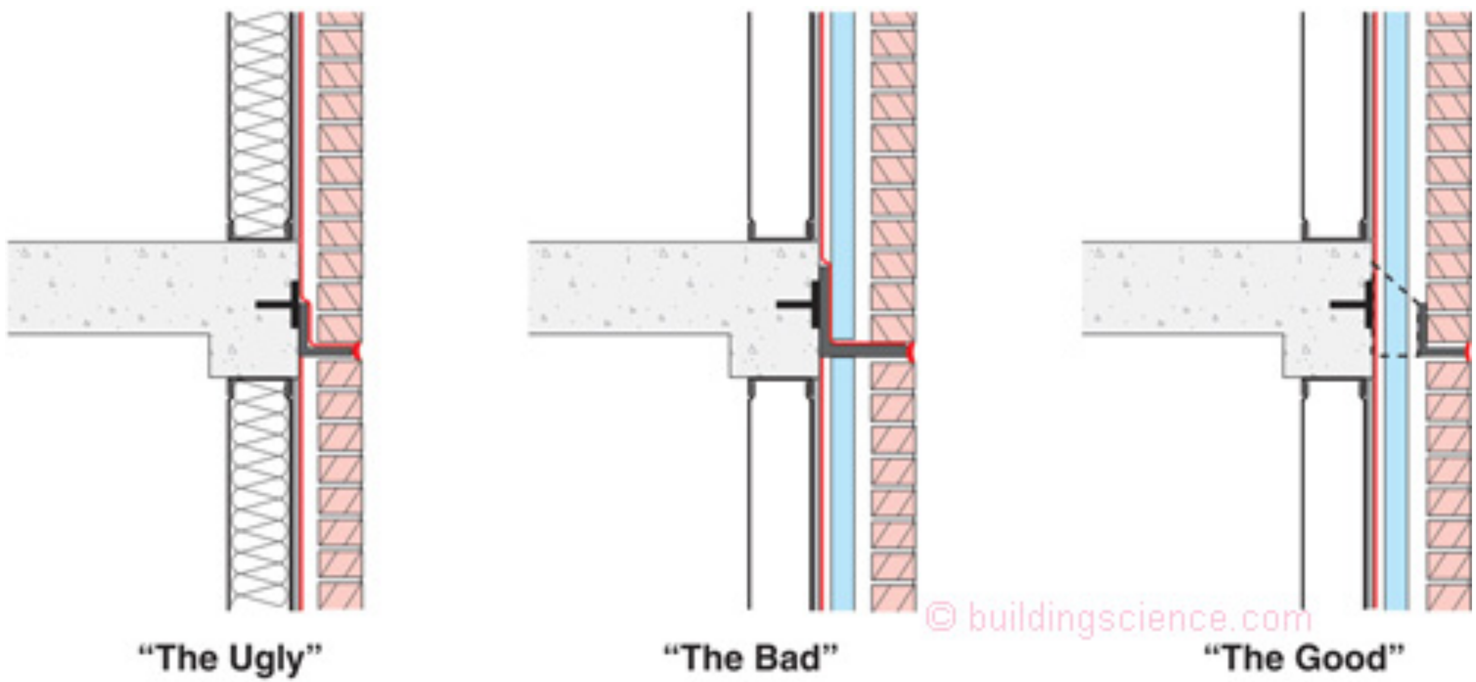


Slab edge masonry wall

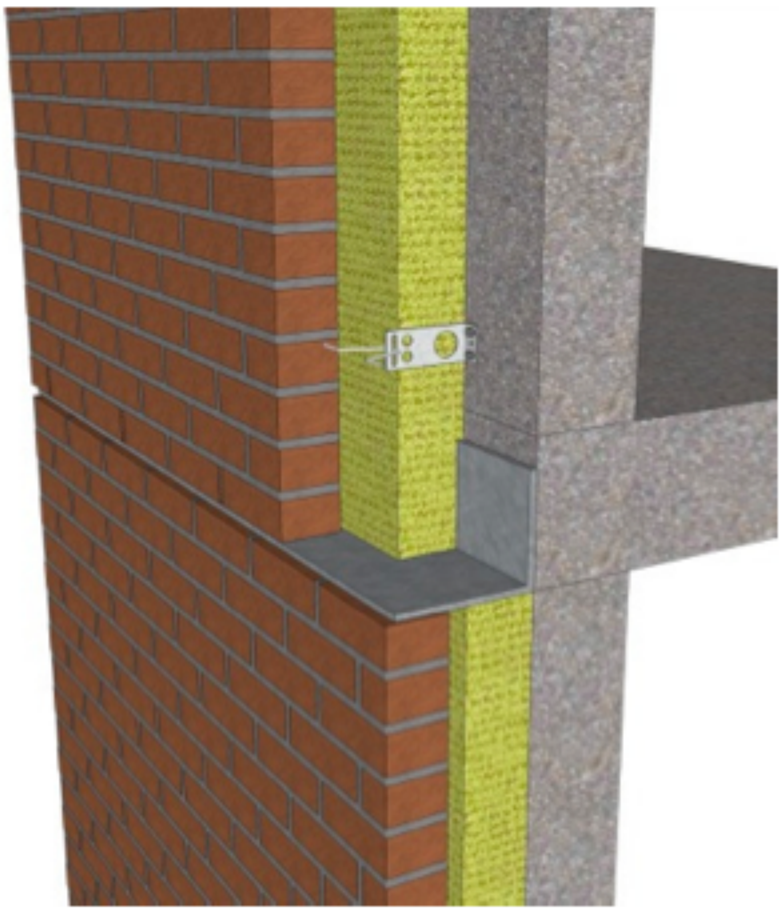


Slab edges and exterior wall connections

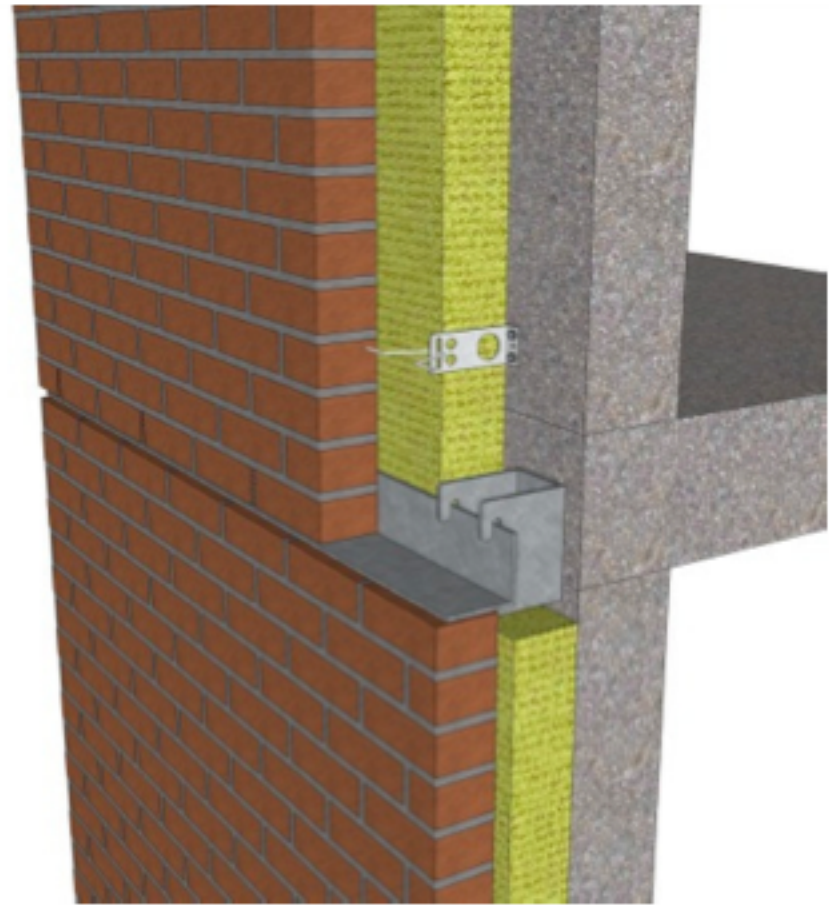
- Exterior veneer connections can be significant thermal bridges
  - Here are three different design examples:



Exterior wall connections



Standard slab attached shelf angle

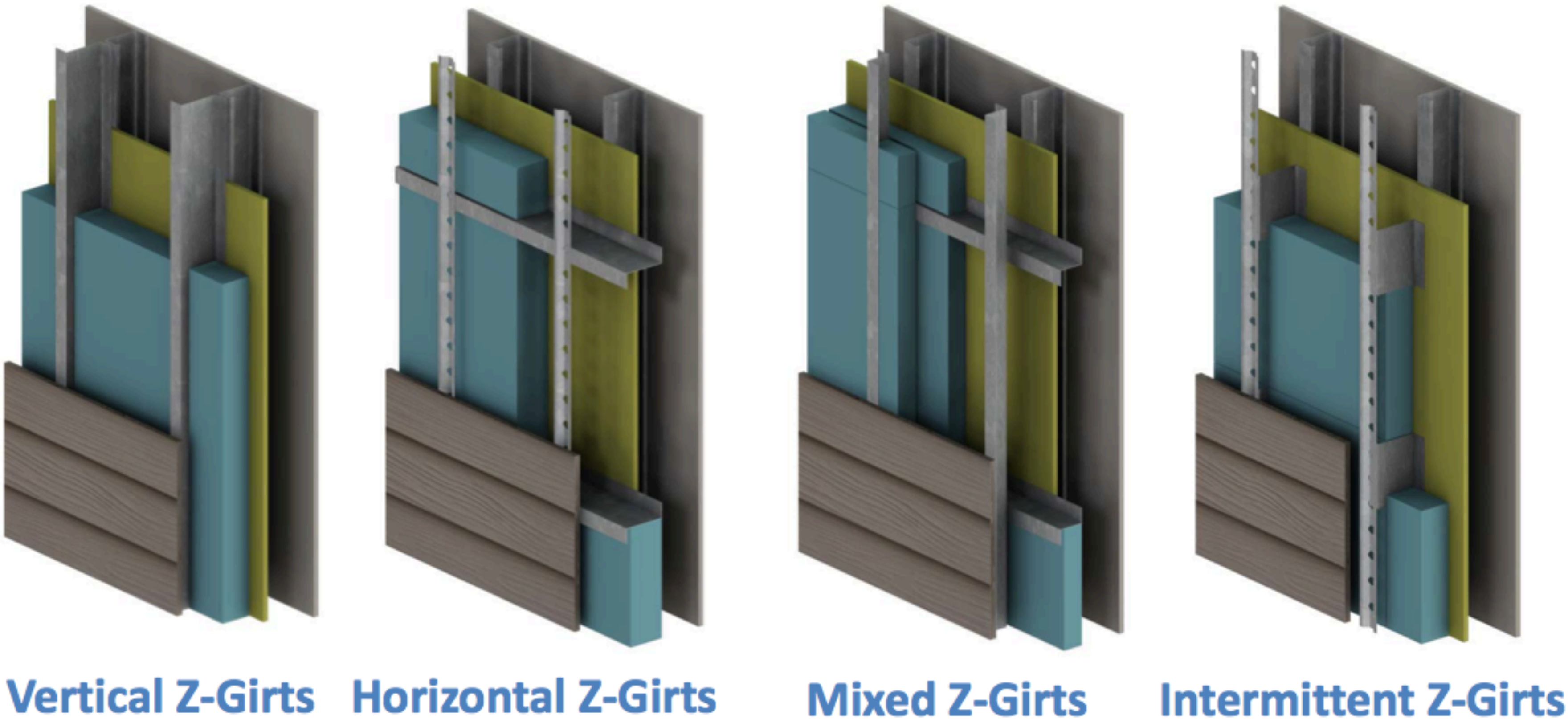


Intermittent shelf angle support

Improved thermal performance

Finch et al. 2013, 12th Canadian Masonry Symposium

Exterior wall connections: Diminishing R value of external insulation



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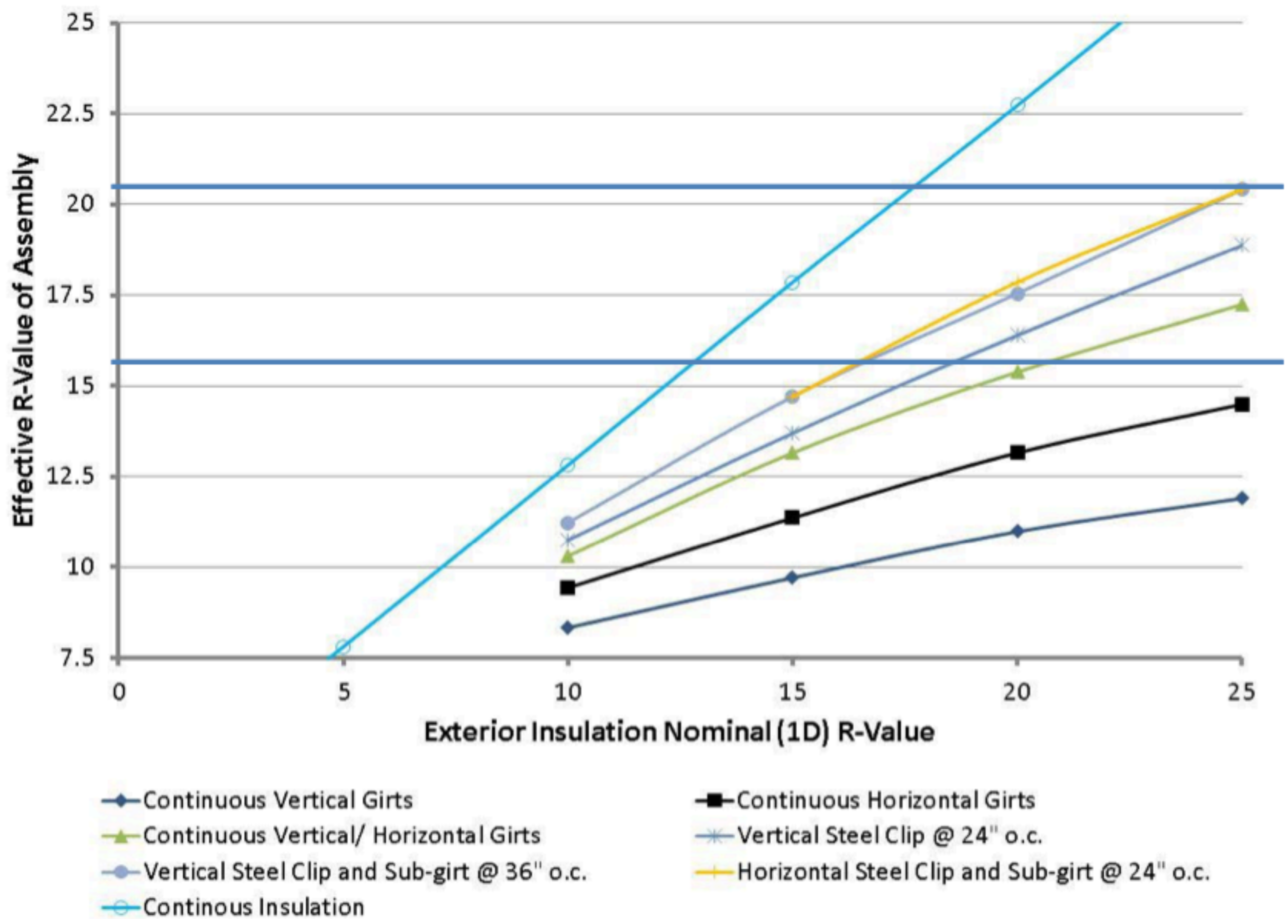
BC Hydro: Building Envelope Thermal Bridging Guide

https://www.bchydro.com/powersmart/business/programs/new-construction.html

Exterior wall connections: Diminishing R value of external insulation



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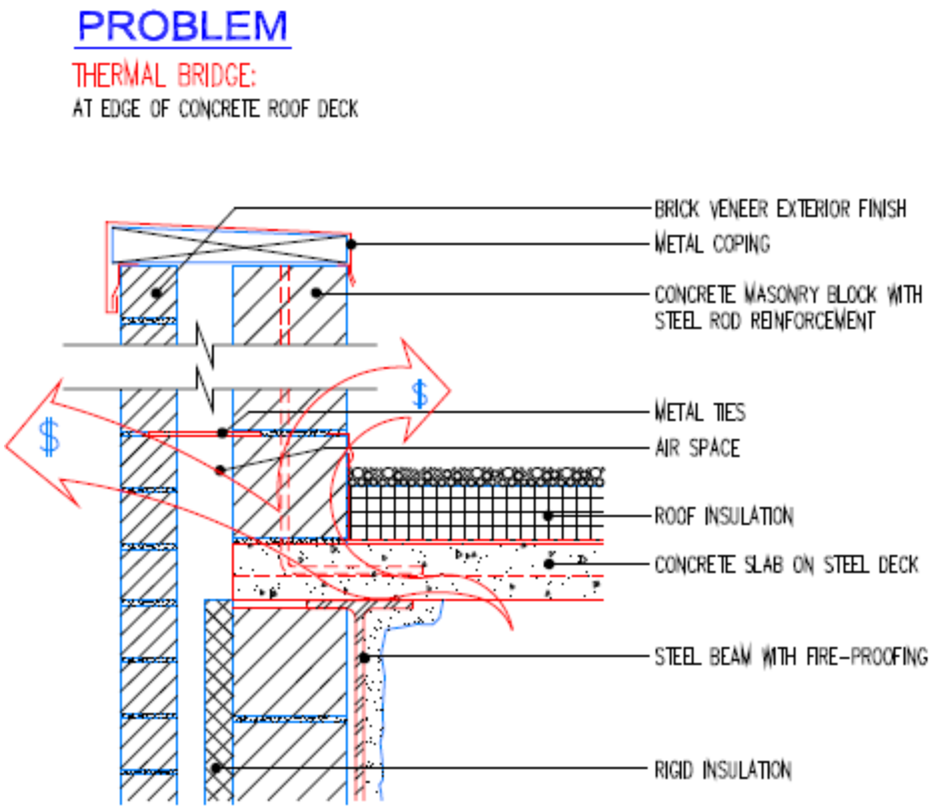
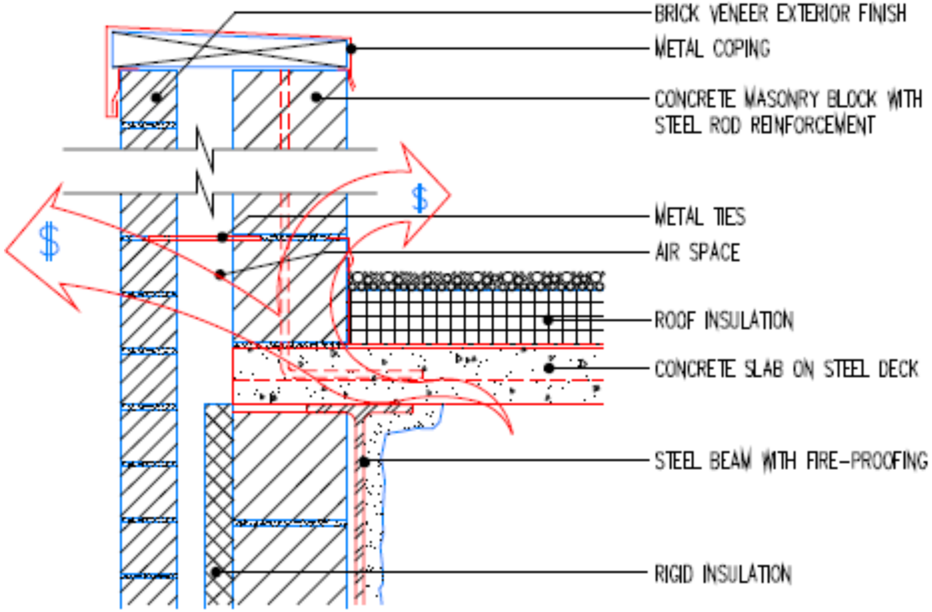
Roof parapet



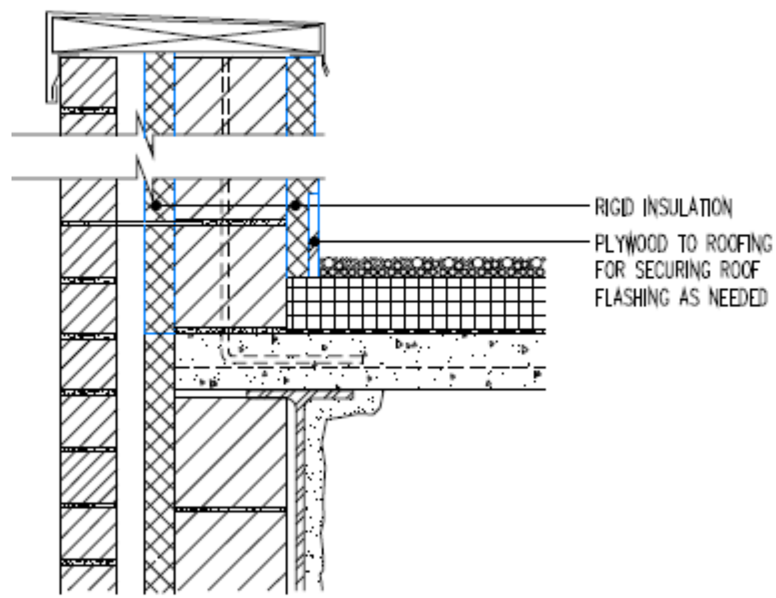
Roof parapet

PROBLEM

THERMAL BRIDGE:
AT EDGE OF CONCRETE ROOF DECK



SOLUTION



Roof parapet

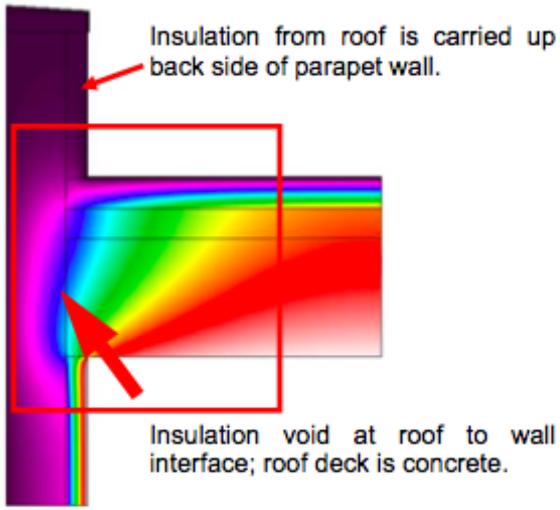


Figure 2

Results of a THERM model showing a thermal bridge at the roof to wall interface of a precast wall where roof insulation is not tied to wall insulation; although insulation now carries up the backside of the parapet wall, there is still no major effect on the bridge.

$T_{interior}$ = 72°F
$T_{exterior}$ = 7°F

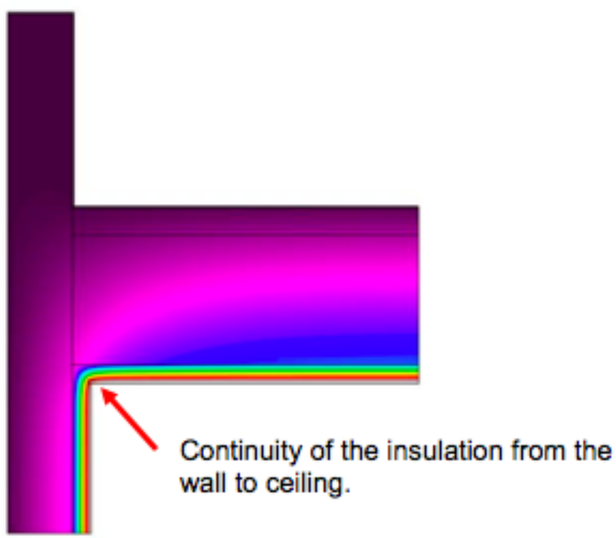


Figure 3

Results of a THERM model shows continuity of insulation below the roof deck; another option not shown here is to carry the wall insulation up by the roof deck and tie it into the roof insulation; structural considerations must be evaluated for this option. Window head below either option also requires careful evaluation.

$T_{interior}$ = 72°F
$T_{exterior}$ = 7°F

Finch et al. 2013, 12th Canadian Masonry Symposium

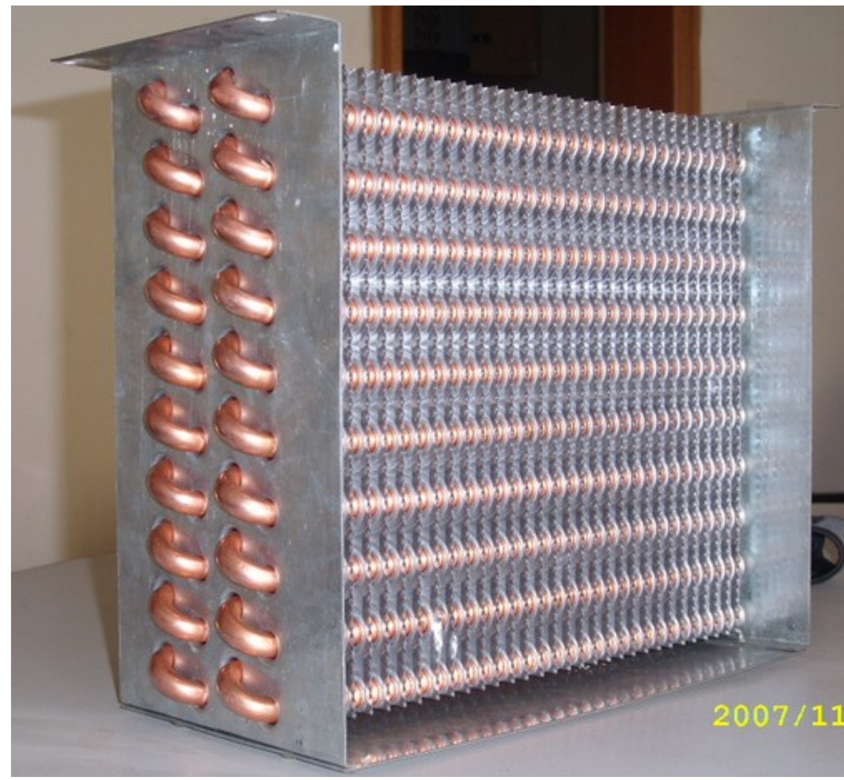
Ultimate thermal bridge?

- This **cantilevered balcony** design provides a thermal connection from the interior to an exterior heating/cooling fin

- The balcony makes a fantastic heat exchanger!

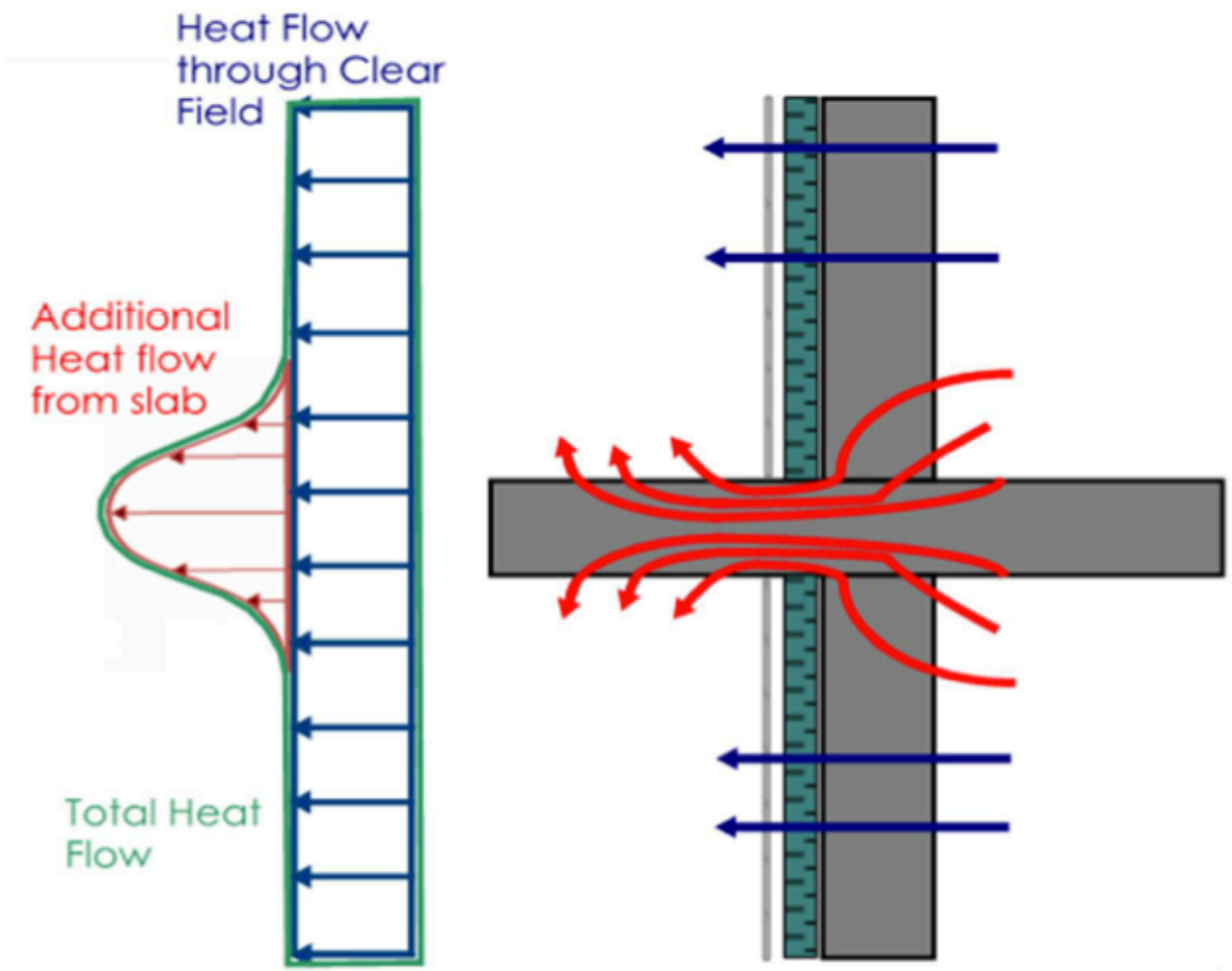
Ultimate thermal bridge?

=



Balconies can act as a heat exchanger – heat exchangers are specifically designed to use fins to increase surface area for heat transfer (increasing UA)

Ultimate thermal bridge: Balconies



https://www.bchydro.com/powersmart/business/programs/new-construction.html

What about this building?

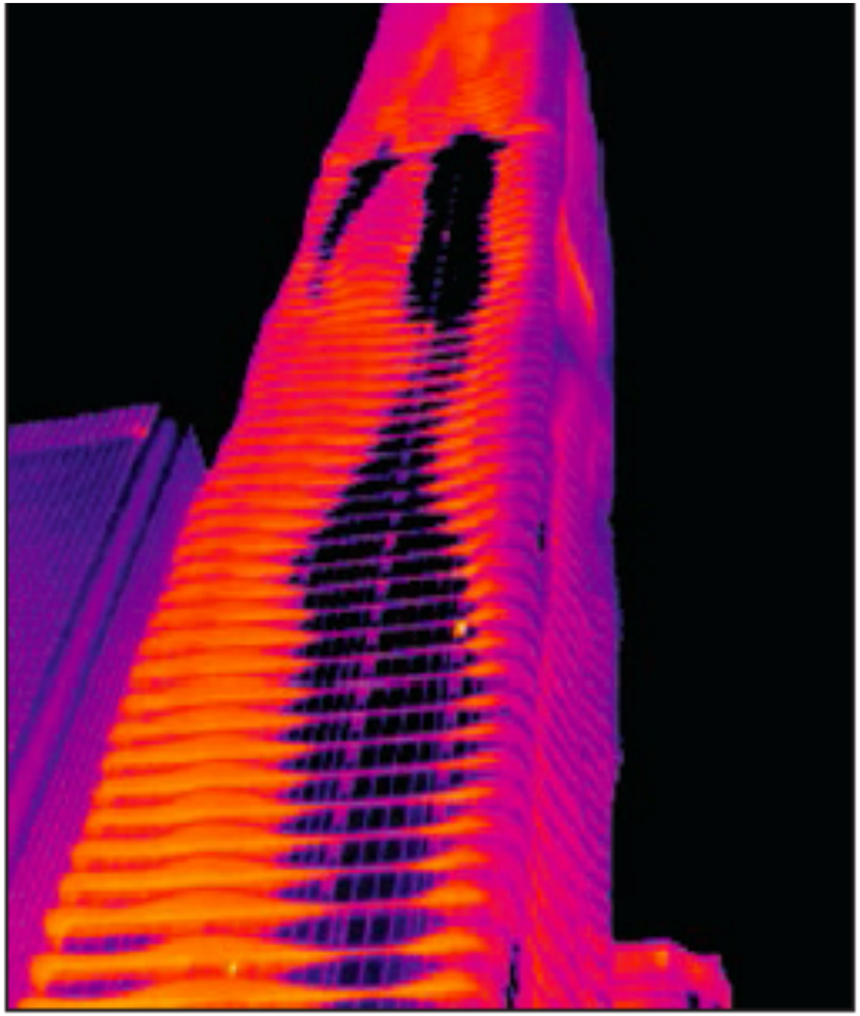
Aqua Tower

- Designed by Jeanne Gang, of Studio Gang

- This design has won many awards but it consists of many cantilevered concrete slabs

- They did NOT use insulated cantilevers
  - Used “insulating paint” which isn’t insulating – it just changes the reflectivity/emissivity/absorptivity
  - May help solar gains in summer but does nothing for conduction, particularly in the winter

“Thermal Bridge Redux” by J. Lstiburek, ASHRAE Journal July 2012



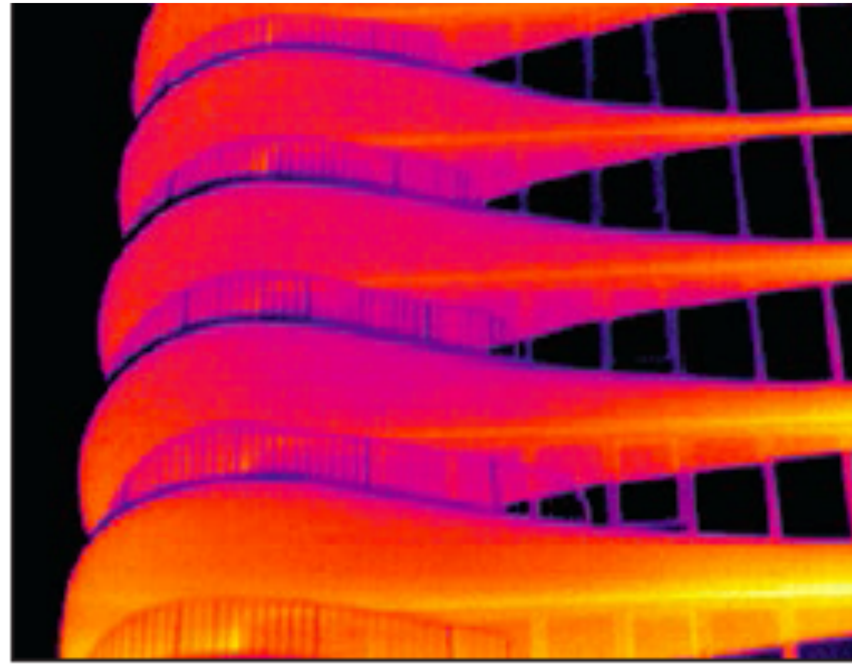


Photo 1f (left): Infrared of Aqua Tower. **Photo 1g (right):** Infrared of Aqua Tower Balcony.

Thermographic images courtesy of Dave Robley, Thermographer, Fluke

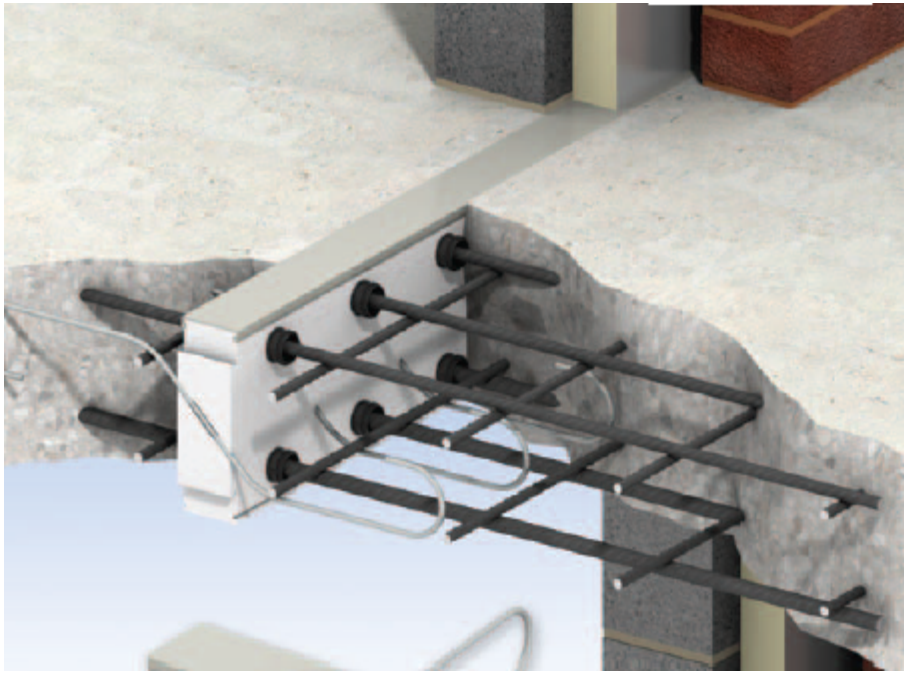
Solution 1: Hanging balconies

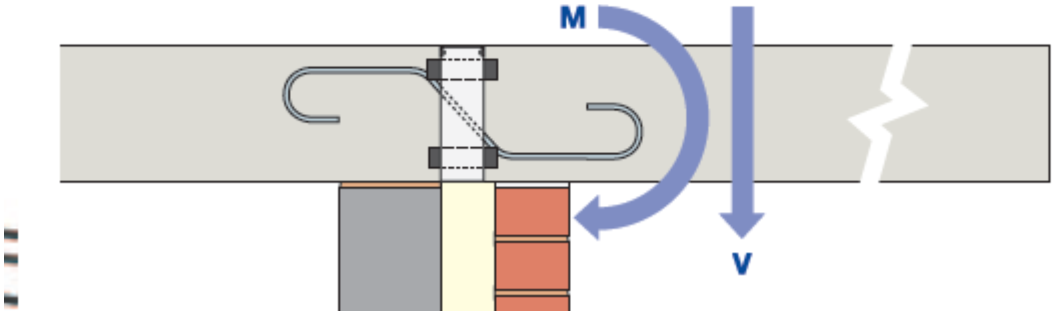
- These balconies are precast concrete that is connected with offset point supports and tie rods
- A foam thermal break is easily incorporated into this design
- Of course, this wouldn't work for the Aqua aesthetic

Solution 2: Insulated cantilever

- Insulated connectors for balcony cantilevers are now available on the market and used throughout Europe

- Search for: Ancon, Egcobox, Halfen





Solution 2: Insulated cantilever

k (carbon steel) ~36-54 W/mK
k (stainless steel) ~16-24 W/mK

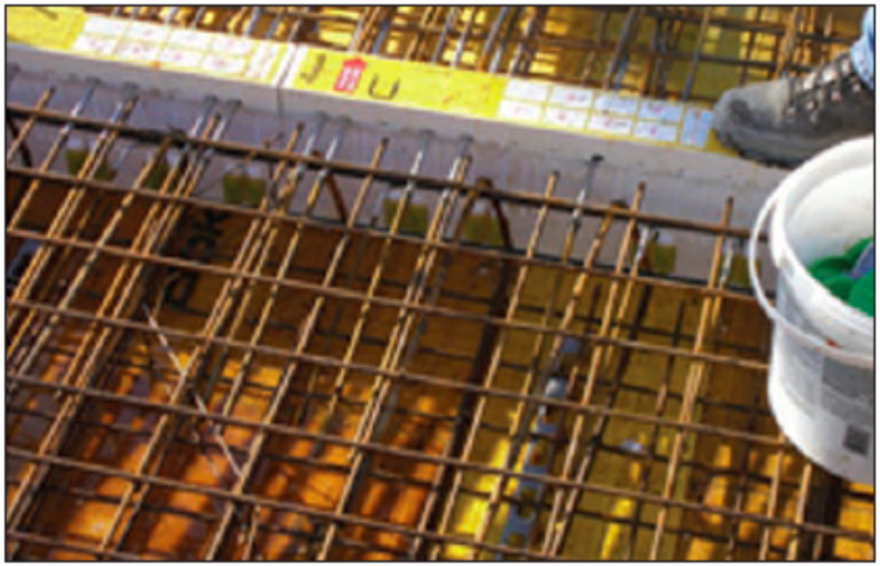


Photo 2: Premanufactured Thermal Break. High density graphite enhanced expanded polystyrene. Note the reinforcing rods penetrating the foam are stainless steel not carbon steel. Stainless steel has less than half the thermal conductivity of carbon steel. Neat, eh? Image courtesy of Schoeck Canada, Inc.

Photo 3: Belgrade Balcony. Nice view of the Danube River from a thermally broken balcony. OK, the river is out there somewhere. I have not been to Serbia recently, but apparently they can afford more efficiency than Chicago. Image courtesy of Beodom, Inc., Belgrade, Serbia.

“Thermal Bridge Redux” by J. Lstiburek, ASHRAE Journal July 2012

Solution 2: Insulated cantilever

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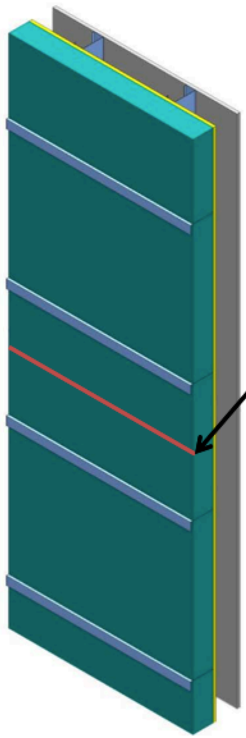

Concept of linear transmittance:

$$\Psi = Q_{slab} / L$$

- The linear transmittance represents the additional heat flow because of the slab, but with area set to zero

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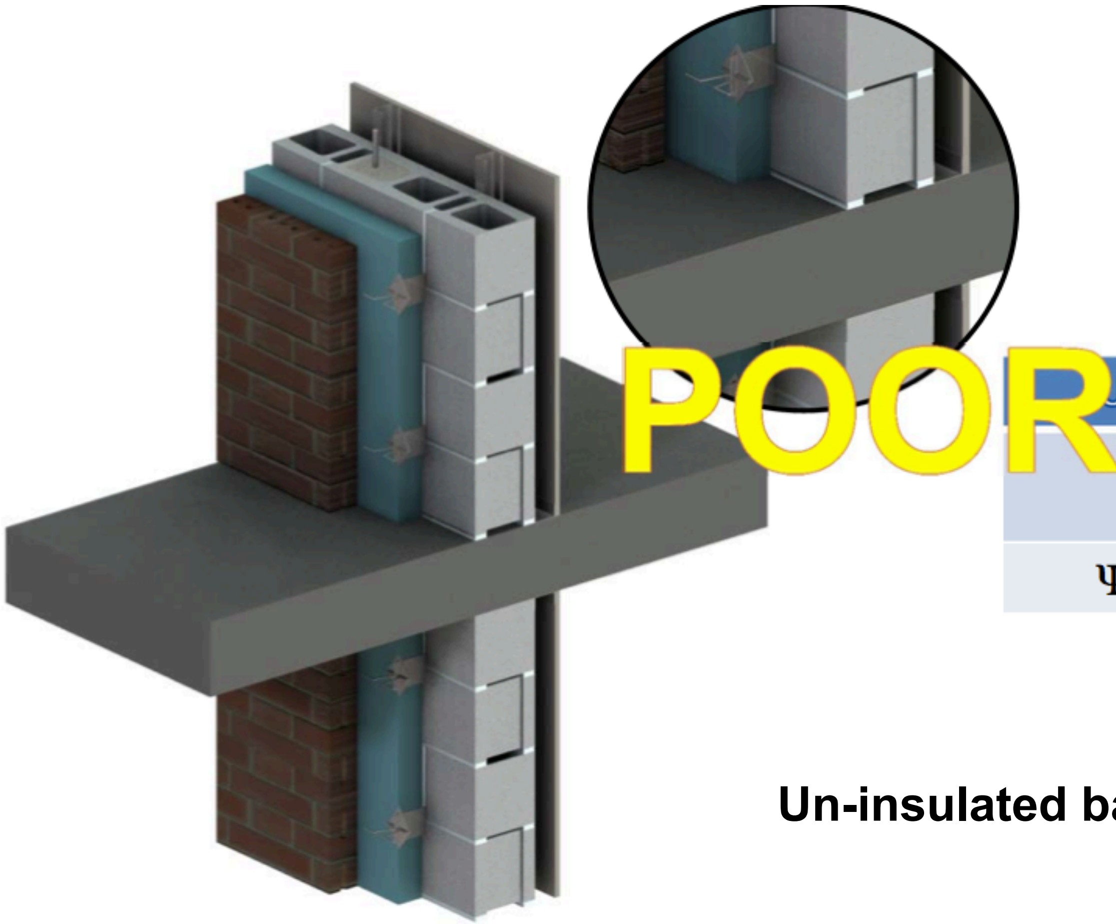
https://www.bchydro.com/powersmart/business/programs/new-construction.html

BC Hydro: Building Envelope Thermal Bridging Guide



Un-Insulated Balcony Slab		
	SI (W/m·K)	**IP** (BTU/hr·ft°F)
Ψ	0.59	0.34

Un-insulated balcony

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https://www.bchydro.com/powersmart/business/programs/new-construction.html

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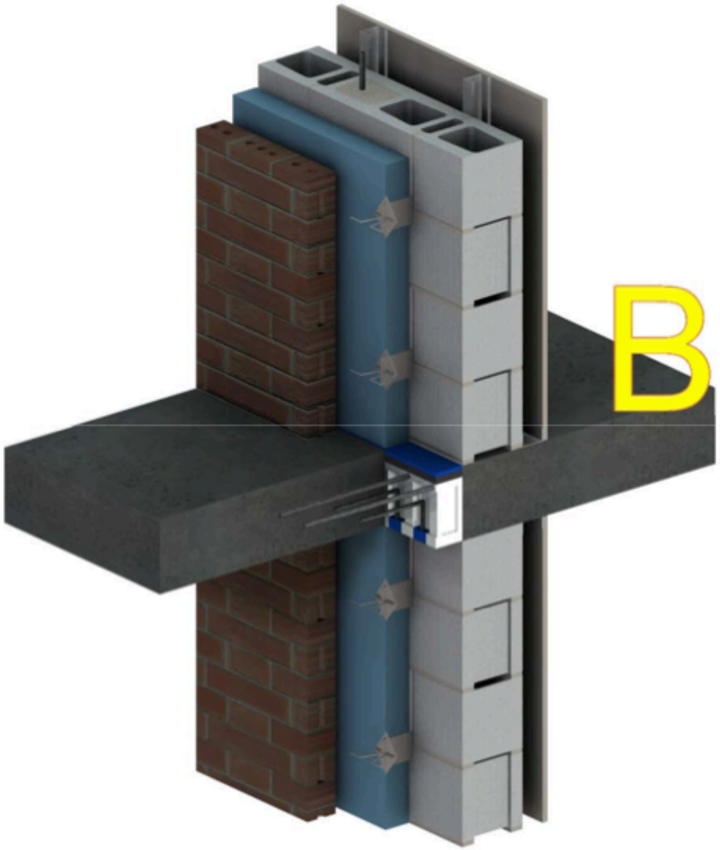

Structural thermal breaks

BEST

Thermally Broken Balcony Slab		
	SI (W/m·K)	**IP** (BTU/hr·ft°F)
Ψ	0.21	0.12

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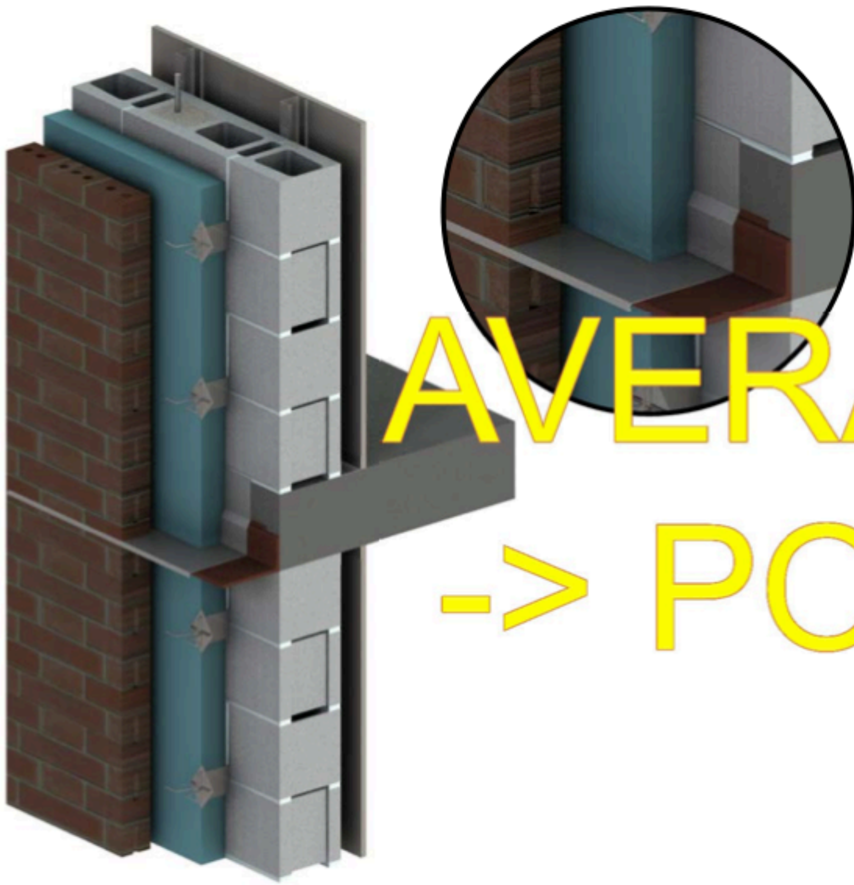
https://www.bchydro.com/powersmart/business/programs/new-construction.html

BC Hydro: Building Envelope Thermal Bridging Guide



AVERAGE

-> POOR

Shelf Angle		
	SI (W/m·K)	**IP** (BTU/hr·ft°F)
Ψ	0.47	0.27

Basic shelf angle

MORRISON HERSHFIELD

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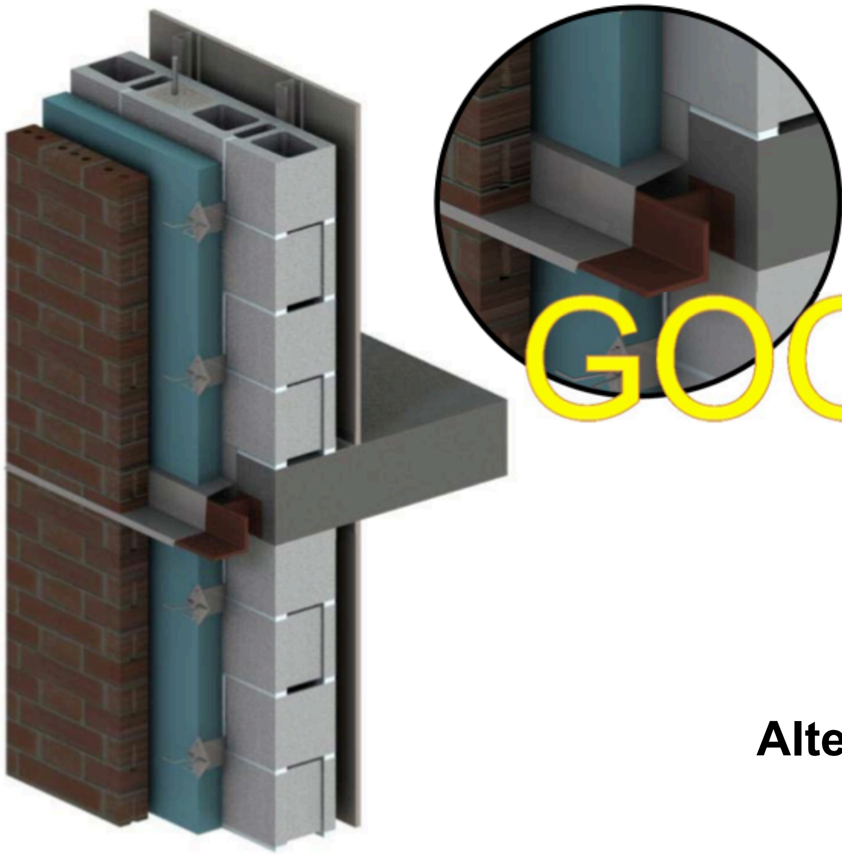
BC Hydro: Building Envelope Thermal Bridging Guide



Spaced Shelf Angle		
	SI (W/m·K)	**IP** (BTU/hr·ft°F)
Ψ	0.31	0.18

Alternative shelf angle

MORRISON HERSHFIELD

https://www.bchydro.com/powersmart/business/programs/new-construction.html