Thermal

Combating Thermal Issues in Building Construction Utilizing Structural Steel

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Thermal

Course Description

Steel elements that bridge across the insulation in a building enclosure can cause significant heating and cooling energy loss in a building, adversely affecting a building's energy performance and the comfort and well being of inhabitants - but they don't have to. A number of effective mitigation techniques can be used to combat this issue and other systems are being developed. As buildings become tighter and more insulated, it becomes increasingly important to address thermal steel bridging. This presentation will explain the issues and present practical solution strategies. Topics to be addressed include the use of manufactured structural thermal break assemblies, proprietary support systems, thermal 'shims', isolation techniques, and others. The issue of the thermal capacity of buildings will also be explored from the perspective of system mass, exposed thermal area and the heat propagating properties of materials.

Learning Objectives

At the end of the this course, participants will be able to:

1. Understand the background of heating and cooling in building structures and the impact of energy use in structures for greater building sustainability and occupant health and comfort.

2. Gain background knowledge on thermal bridging: why it's important in building construction from the perspective of economics, occupant comfort and health, and lifetime structure longevity and sustainability.

3. Explore possible solutions to improved details in building construction that address typical challenge areas of structures, which can help mitigate thermal bridging, considering both cost and energy savings.

4. The issue of the thermal capacity of buildings will also be explored from the perspective of system mass, exposed thermal area and the heat propagating properties of materials – all areas which impact building sustainability and occupant comfort.

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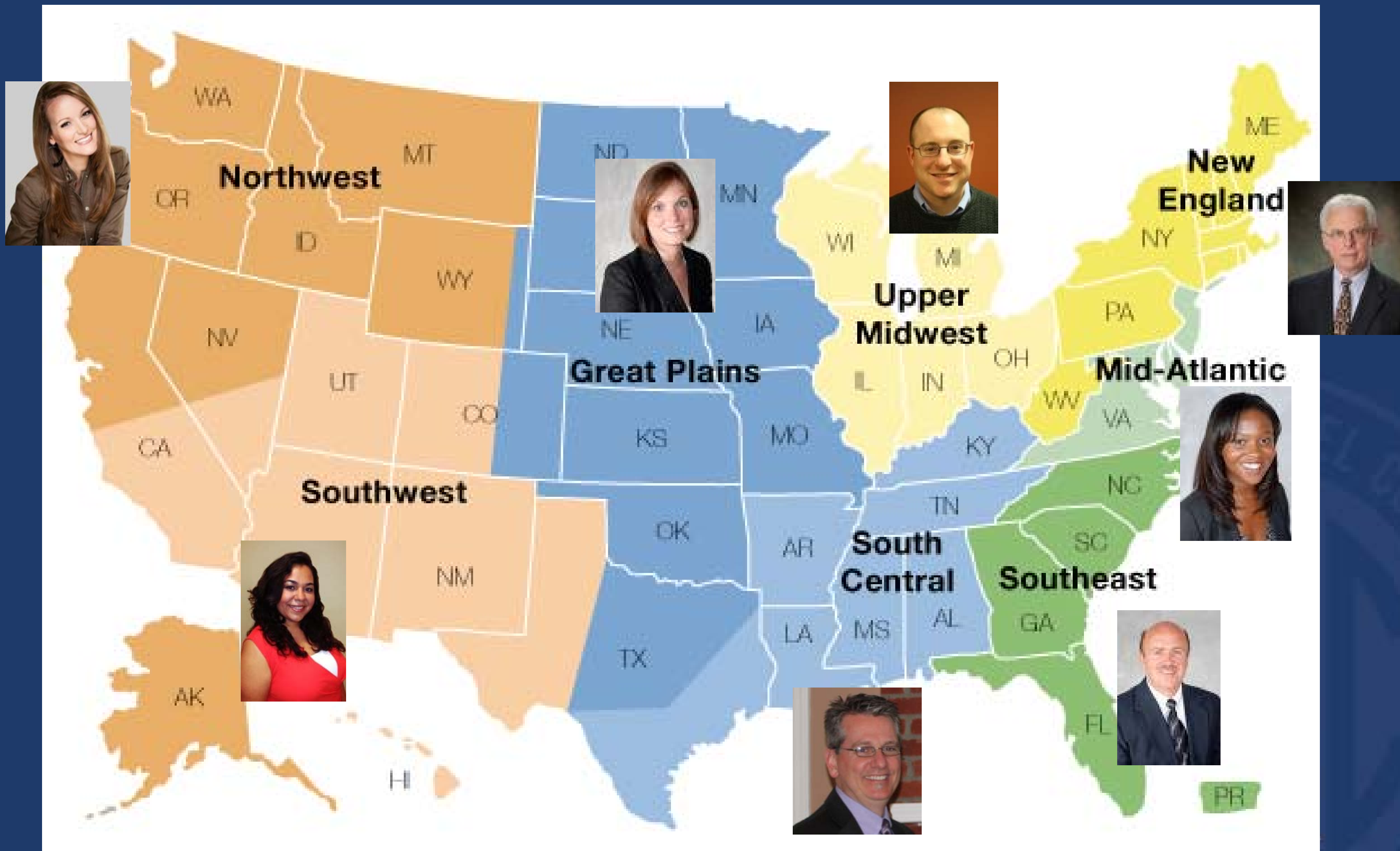

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Thermal Agenda

Thermal Bridging + Thermal Capacity

- Heating and Cooling Energy Use in Buildings
- Overview of Thermal Bridging
  - Solution Concepts
    - Nonconductive Thermal Shims
    - Intermittent Carbon Steel Supports
    - Intermittent Stainless Steel Supports
    - Material Separation
    - Manufactured Structural Thermal Break Assemblies
  - Recommendations
- Thermal Capacity
- What's Ahead?

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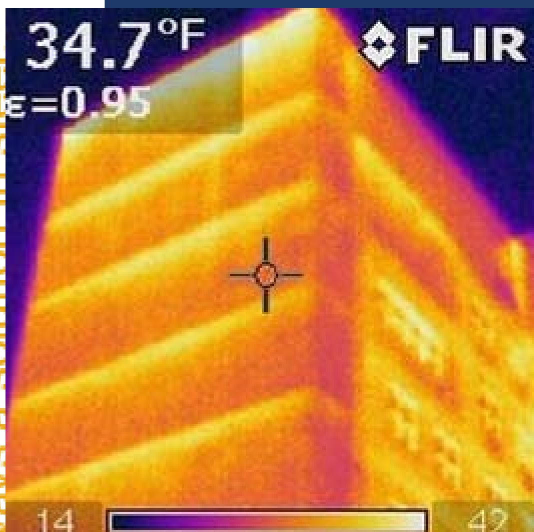
Thermal Bridging + Thermal Mass: Why Should I Care???



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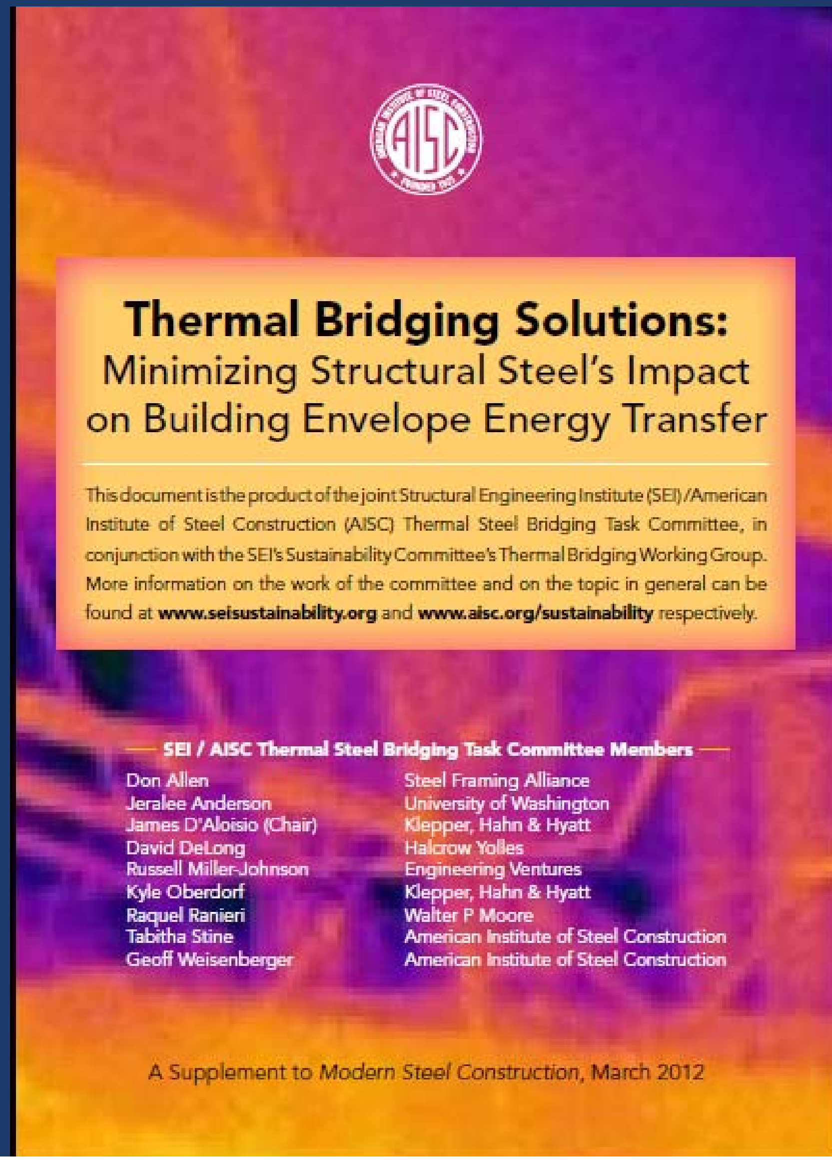
Thermal Bridging

New Publication!



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Heating and Cooling Energy Use in Buildings

Responsible for:
25% of energy use in commercial buildings
40% of energy use in residential buildings

Buildings consume approximately 40% of energy use in the United States.

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Thermal Bridging

Conductive heat transfer through thermally conductive materials across building envelope

Responsible for energy loss as well as potential for condensation, reduced occupant comfort

Occurs with structural steel, cold formed steel, concrete, masonry, and wood

Can be minimized if properly detailed

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Heat Transfer in Building Envelopes

Types of Heat Transfer:

- Conduction
- Convection
- Radiation

Heat Transfer in Building Envelopes

- *U-Factor – A material's thermal conductivity*
- *R-Value – A material's resistance to heat flow*

$$R = \frac{1}{U}$$

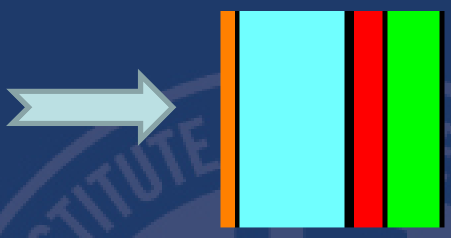
Heat Transfer in Building Envelopes

Common R-Values and U-Factors

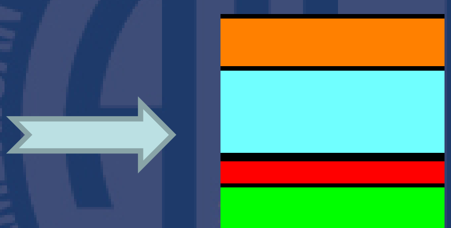
MATERIAL (per inch)	R-Value ft²·°F·h/Btu	U-Factor Btu/ft²·°F·h
Silica Aerogel	R-10	0.1
Expanded Polystyrene	R-3.8 to R-4.2	0.26 to 0.29
Cellulose	R-3.0 to 3.8	0.33 to 0.26
Hardwood (most)	R-0.71	1.4
Concrete, normal weight	R-0.08	12
Stainless Steel	R-0.009	110
Carbon Steel	R-0.0031	320

Heat Transfer in Building Envelopes

- *Conductive Heat Transfer Paths:*
  - *Series - Add up R-values along the path of heat flow*

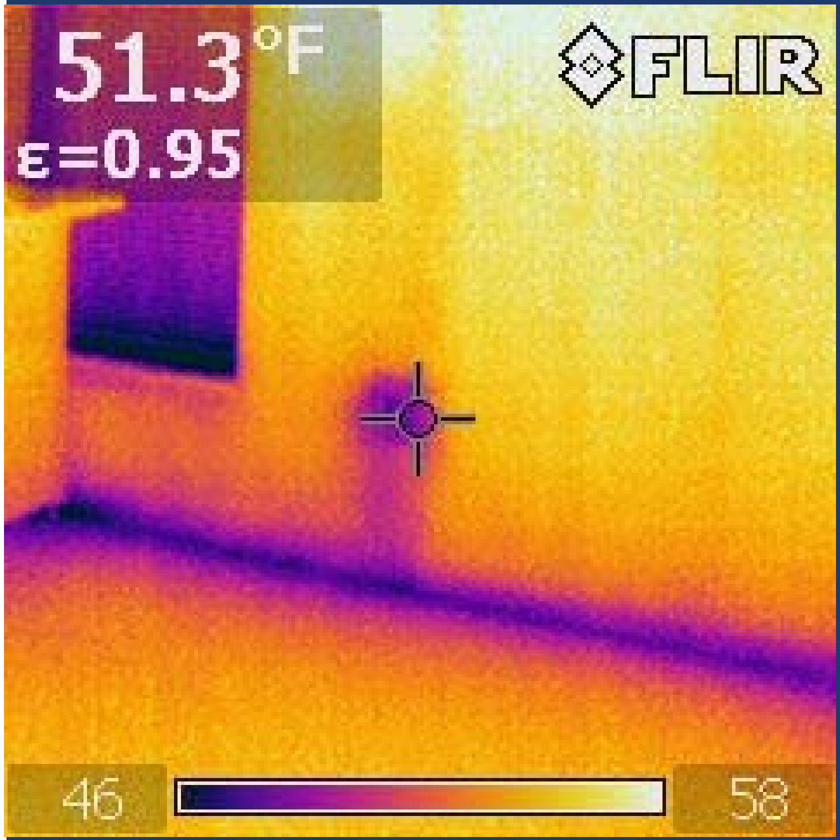


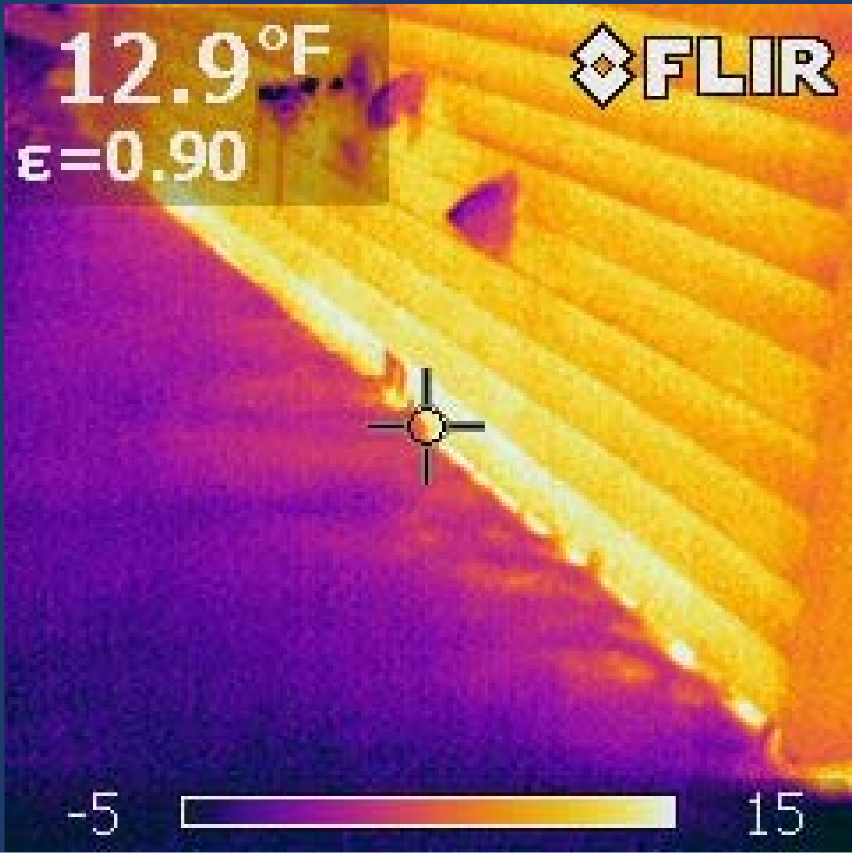
  - *Parallel - Heat chooses path of least resistance*



Thermal Bridging

Infrared Building Images





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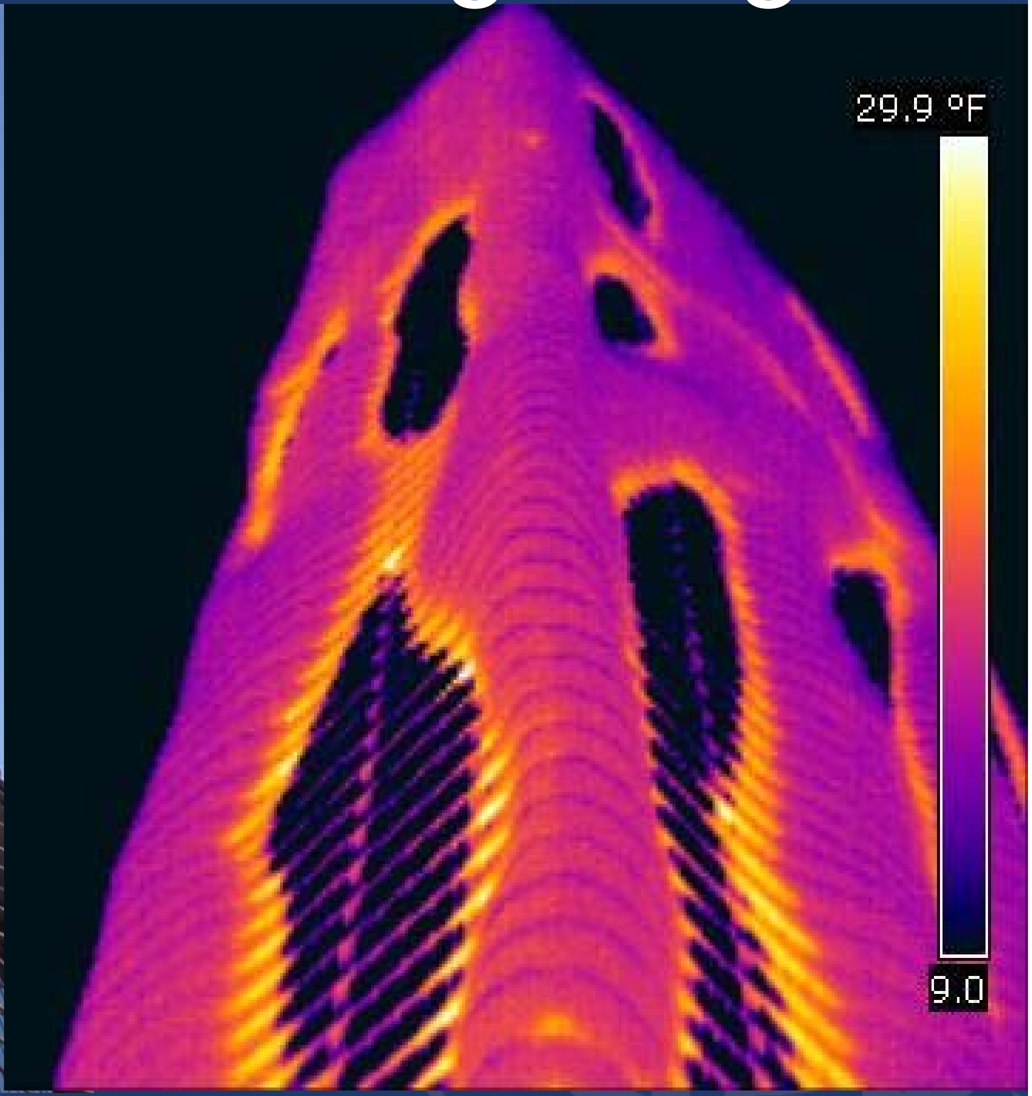
Thermal Bridging

Infrared Building Images



Thermal Bridging

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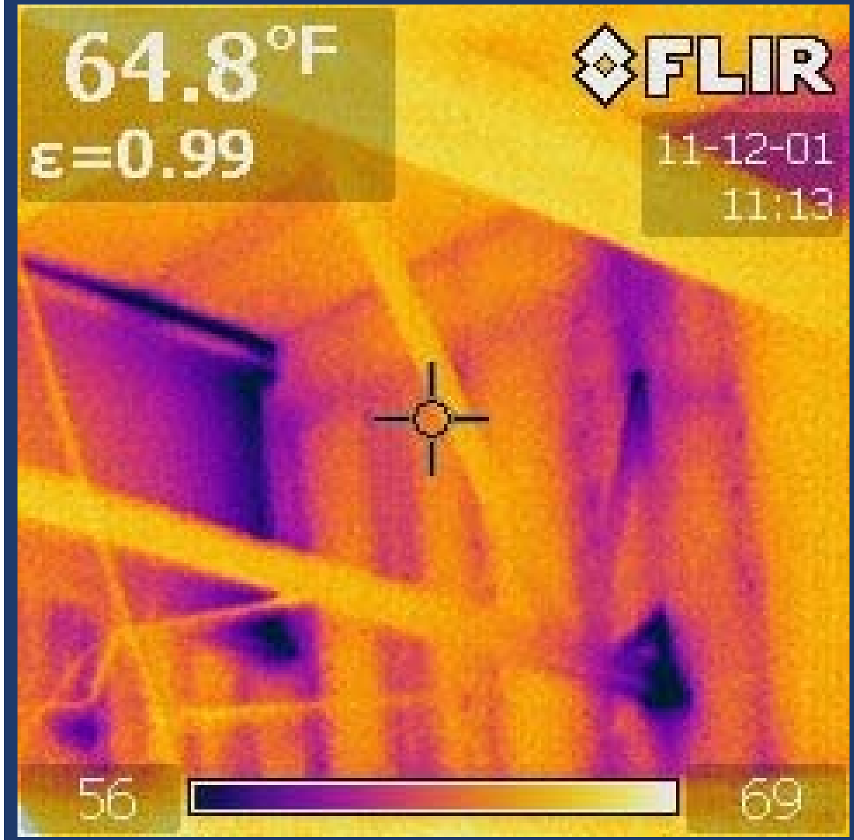

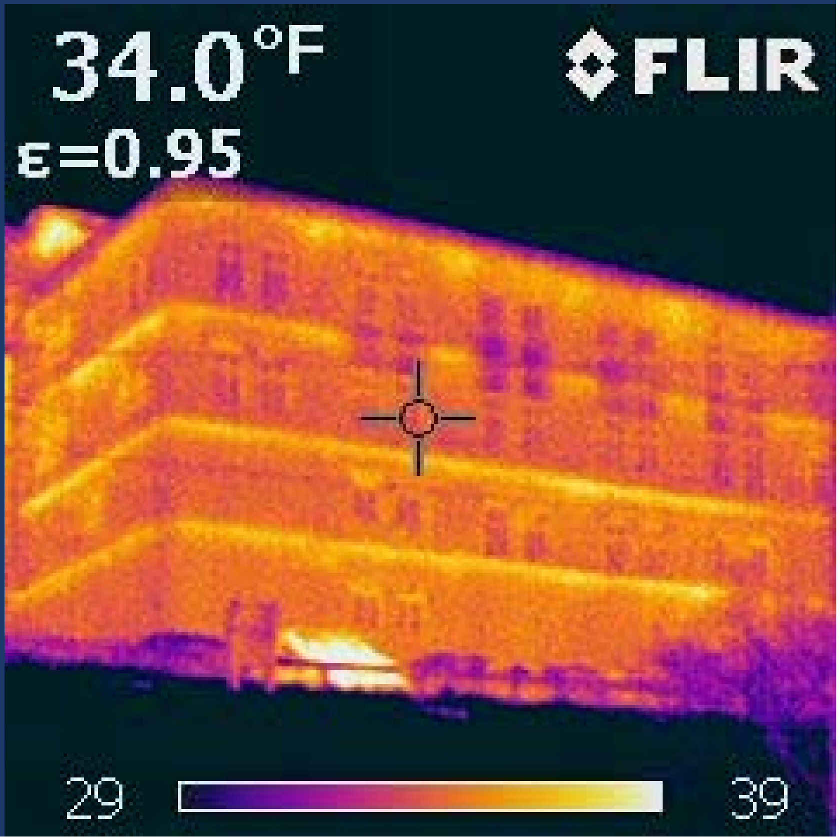

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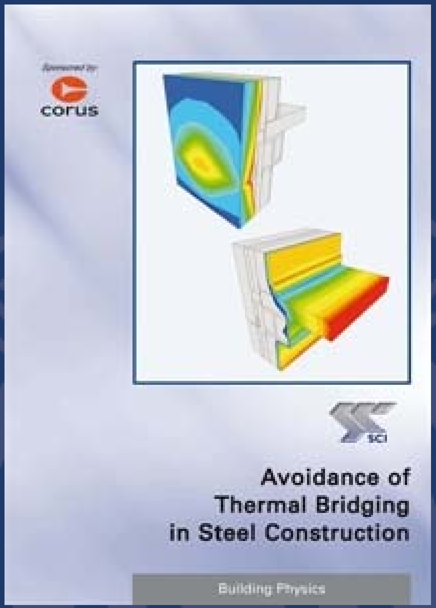
Other Countries and Thermal Bridging

All European Union countries have new energy codes

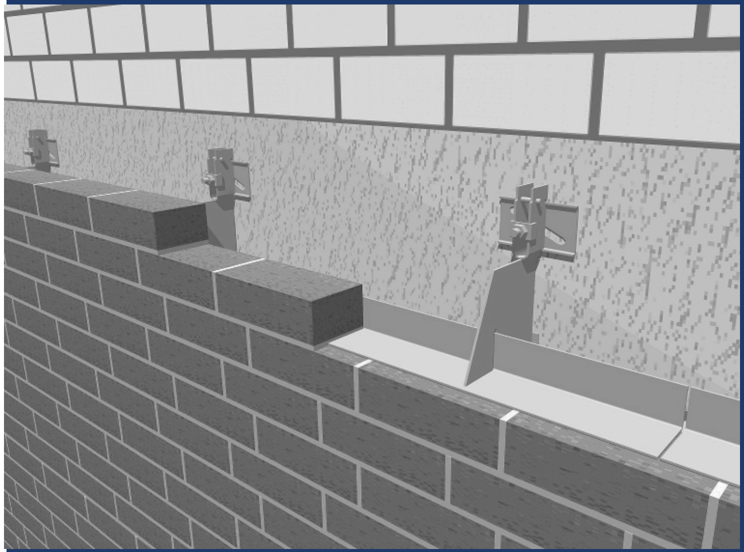
Based on limiting carbon emissions of buildings for Kyoto Protocol

Set limits of thermal bridging, varying with building types



structural STEEL

Other Countries and Thermal Bridging

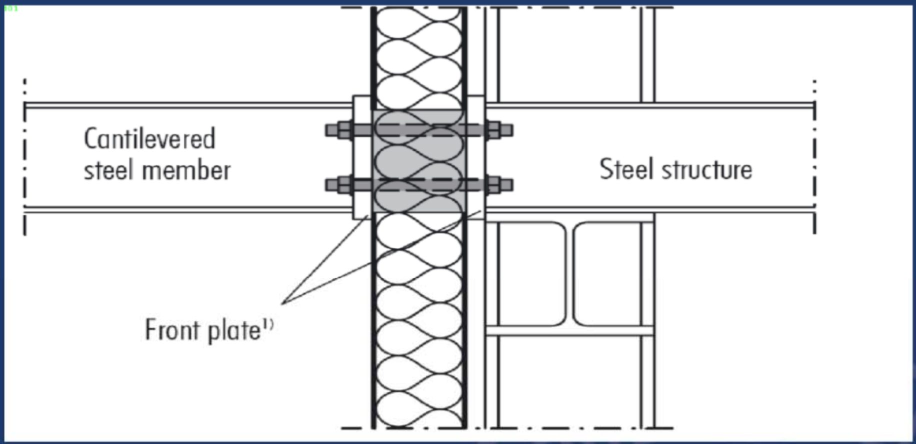


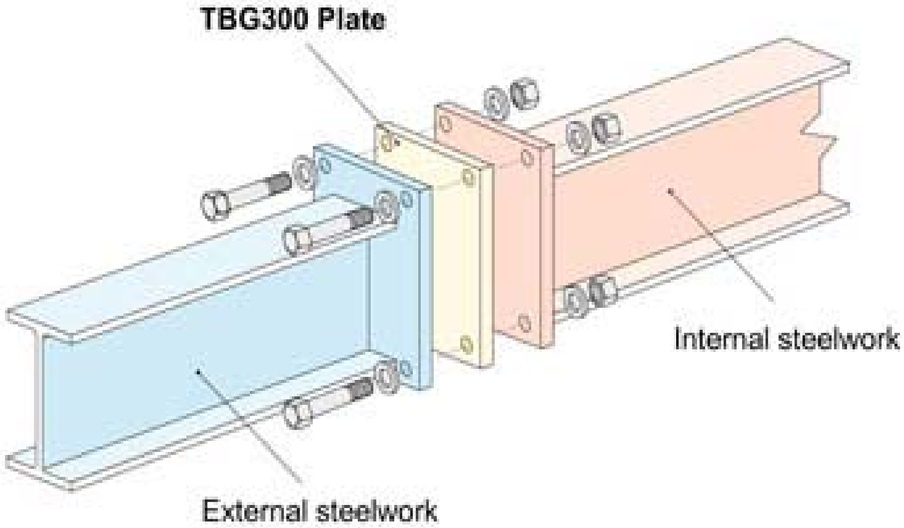
European Stainless Steel Relieving Angle Assembly

European Glass Fiber Reinforced Plastic Lintel

Thermal Bridging

Manufactured Structural Thermal Break Assemblies





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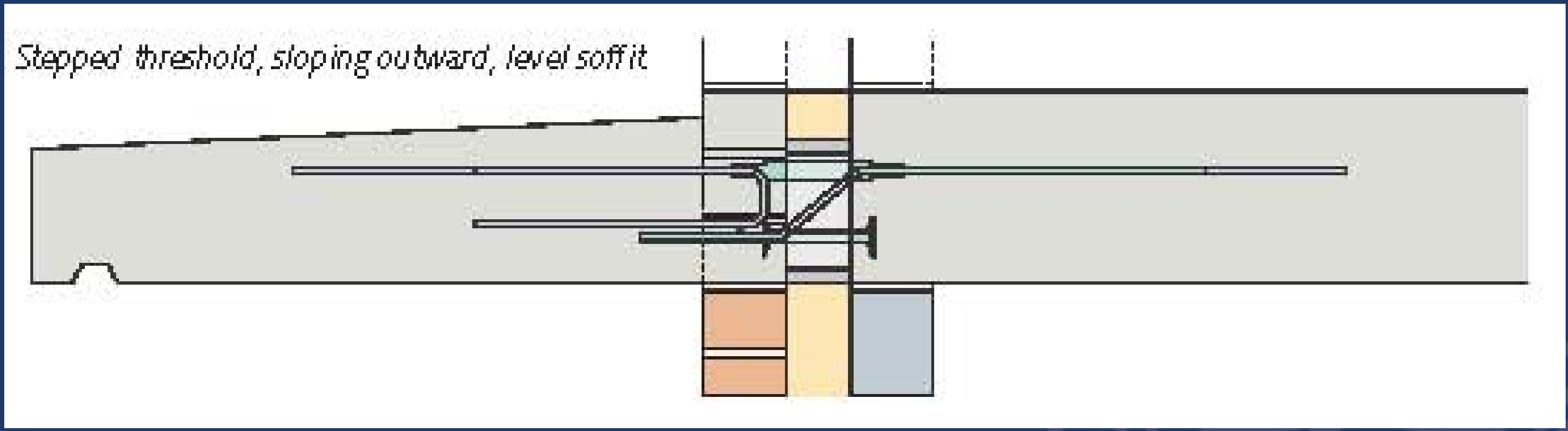
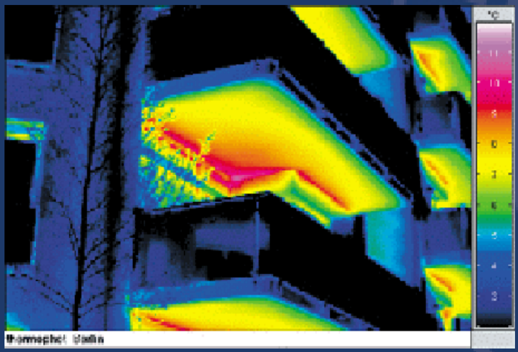
Manufactured Structural Thermal Break Assemblies





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Solution Concepts

Thermal Bridging

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	Condition	Improvement Strategy in Alternate Detail
Detail 1	Rooftop Grillage Posts	Non-Conductive Shims
Detail 2	Roof Edge Angle	Intermittent Carbon Steel Supports
Detail 3	Shelf Angle Support	Intermittent Stainless Steel Supports
Detail 4	Masonry Lintel	Material Separation
Detail 5	Cantilever Roof Canopy	Manufactured Structural Thermal Break Assembly

Using the energy modeling program TRACE 700, the entire building was modeled to determine the estimated average total building energy usage with all of the unmitigated thermal bridging details. The results are as follows:

Chicago:

$5,092 HVAC +

$5,954 other (lighting and plug loads) = $11,885

Phoenix:

$10,954 HVAC + $9,972 other = $20,927

The Phoenix costs are higher than Chicago costs as a result of air conditioning being less efficient than natural gas heating, and higher electricity costs in Phoenix than Chicago.

	Detail	Condition	Area Affected	Annual Building Heating & Cooling Cost	Annual Potential Energy Savings Realized Through Use of Alternative Detail		% Energy Improvement from Standard Detail to Alternate Detail	Potential Average Alternate Detail Implementation Cost Increase (-) or Savings (+) In Entire Structure (Material/ Fabrication/Erection)		Percent Cost Increase (-) or Savings (+) from Standard Detail to Alternate Detail
					Dollars	% Impact		Total Locations	Dollars	
Chicago	1	Rooftop Grillage Posts	7.74 sq. ft.		$1.00	0.01%	19%	12 posts	-$350	-14%
Chicago	2	Roof Edge Angle	957 sq. ft.		$130	1.10%	30%	230 ft.	$1,100	17%
Chicago	3	Shelf Angle Support	1,035 sq. ft.		$260	2.20%	77%	460 ft.	$400	1%
Chicago	4	Masonry Lintel	398 sq. ft.		$39	0.33%	26%	336 ft.	-$28,000	-98%
Chicago	5	Roof Canopy	9.25 sq. ft.		$1.30	0.01%	27%	7 beams	-$6,300	-137%
Chicago	**Total**			**$11,885**	**$431.30**	**3.60%**	**46%**			
Phoenix	1	Rooftop Grillage Posts	7.74 sq. ft.		$1.00	0.00%	17%	12 posts	-$350	-14%
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Phoenix	4	Masonry Lintel	398 sq. ft.		$43	0.20%	27%	336 ft.	-$28,000	-98%
Phoenix	5	Roof Canopy	9.25 sq. ft.		$1.60	0.00%	30%	7 beams	-$6,300	-137%
Phoenix	**Total**			**$20,927**	**$485.60**	**2.30%**	**47%**			

Thermal Bridging

Detail 1: Rooftop Grillage Posts, Non-Conductive Shims

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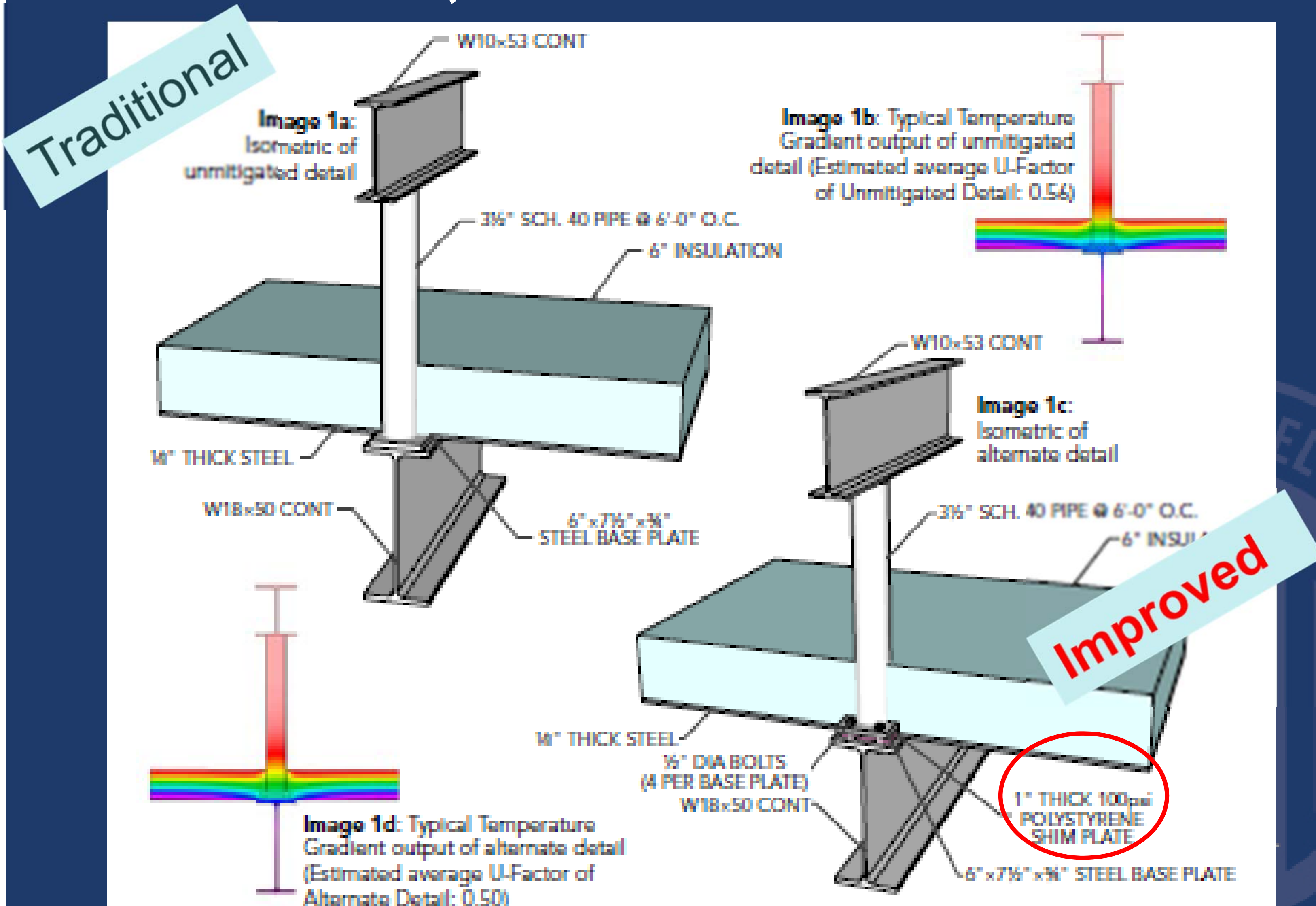

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Thermal Bridging

Detail 2: Roof Edge Angle: Intermittent Carbon Steel Supports

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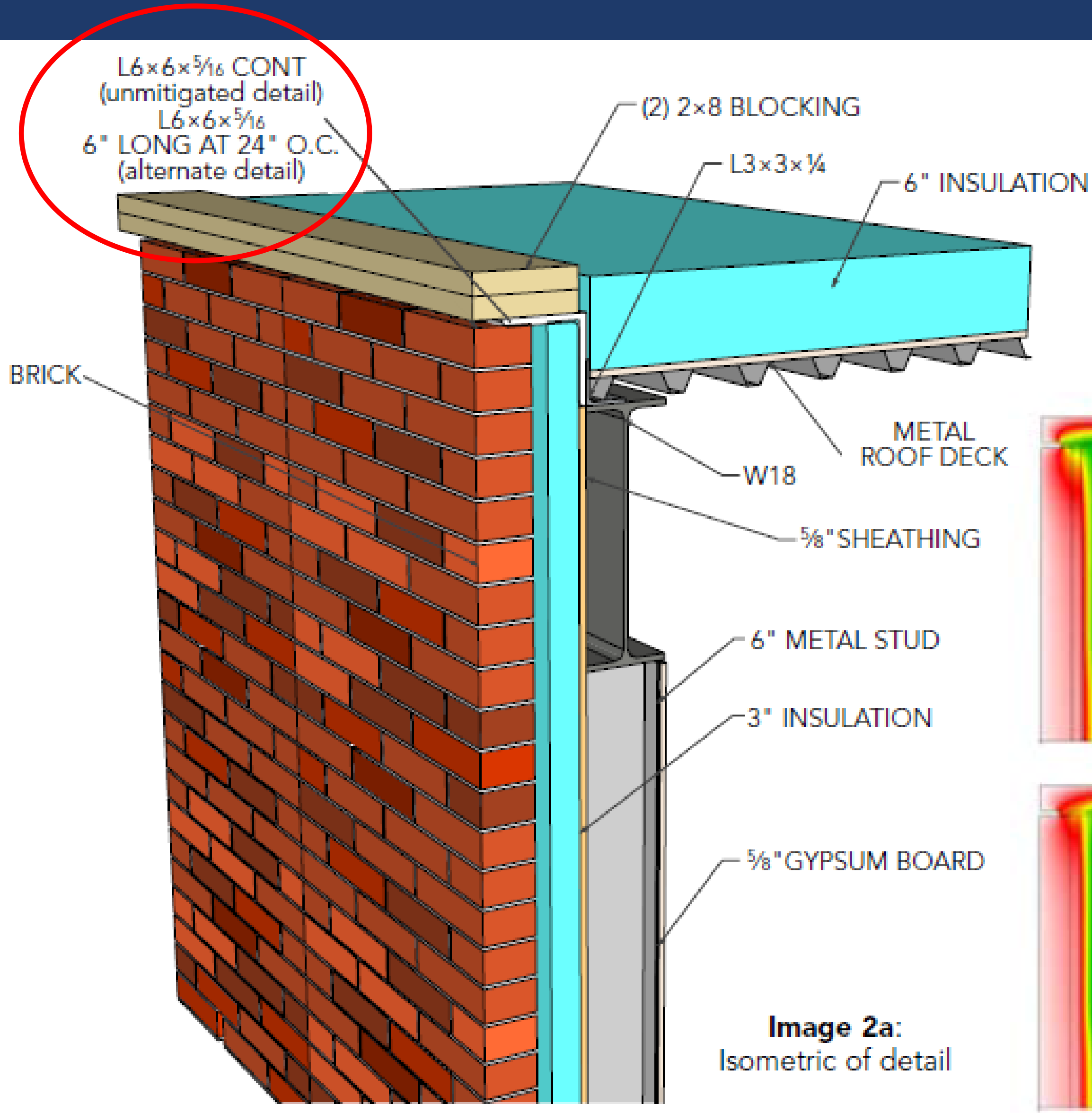

Image 2a: Isometric of detail

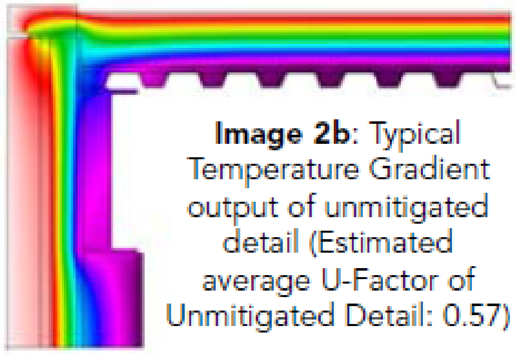

Image 2b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.57)

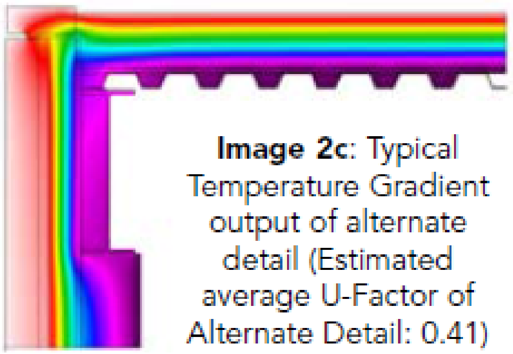

Image 2c: Typical Temperature Gradient output of alternate detail (Estimated average U-Factor of Alternate Detail: 0.41)

	Detail	Condition	Area Affected	Annual Building Heating & Cooling Cost	Annual Potential Energy Savings Realized Through Use of Alternative Detail		% Energy Improvement from Standard Detail to Alternate Detail	Potential Average Alternate Detail Implementation Cost Increase (-) or Savings (+) In Entire Structure (Material/ Fabrication/Erection)		Percent Cost Increase (-) or Savings (+) from Standard Detail to Alternate Detail
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Detail 3: Shelf Angle Support, Intermittent Stainless Steel Supports

Traditional

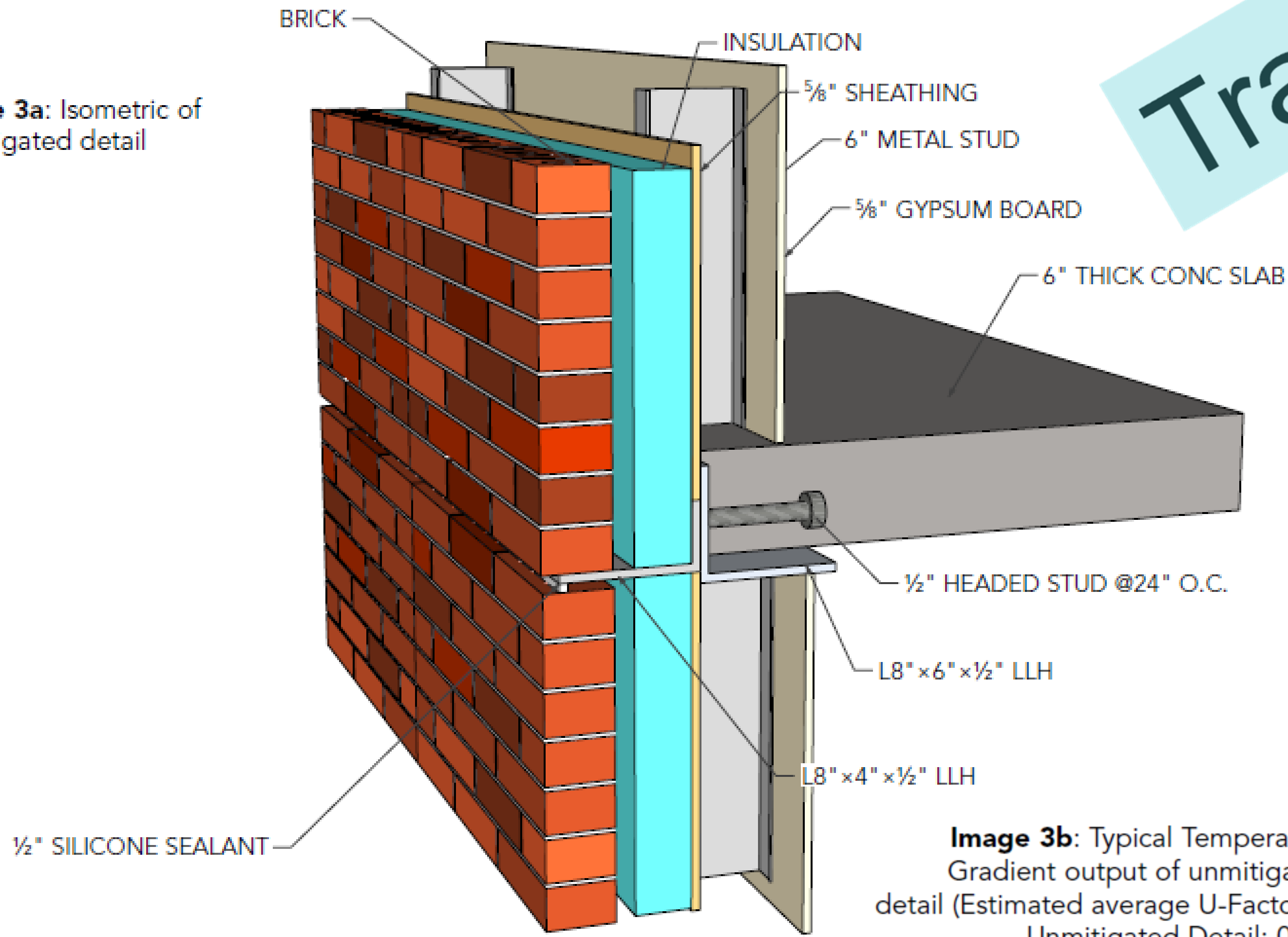

Image 3a: Isometric of unmitigated detail

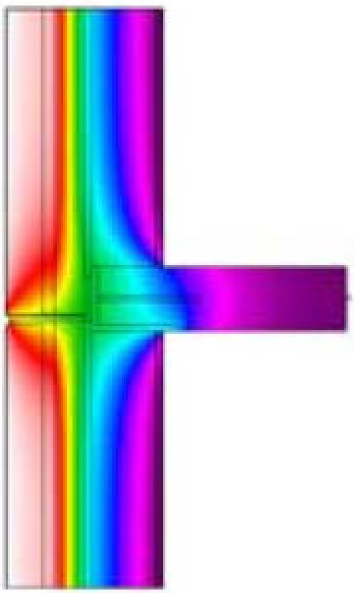

Image 3b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.44)

Thermal Bridging

Detail 3: Shelf Angle Support, Intermittent Stainless Steel Supports

Improved

Image 3c: Isometric of alternate detail

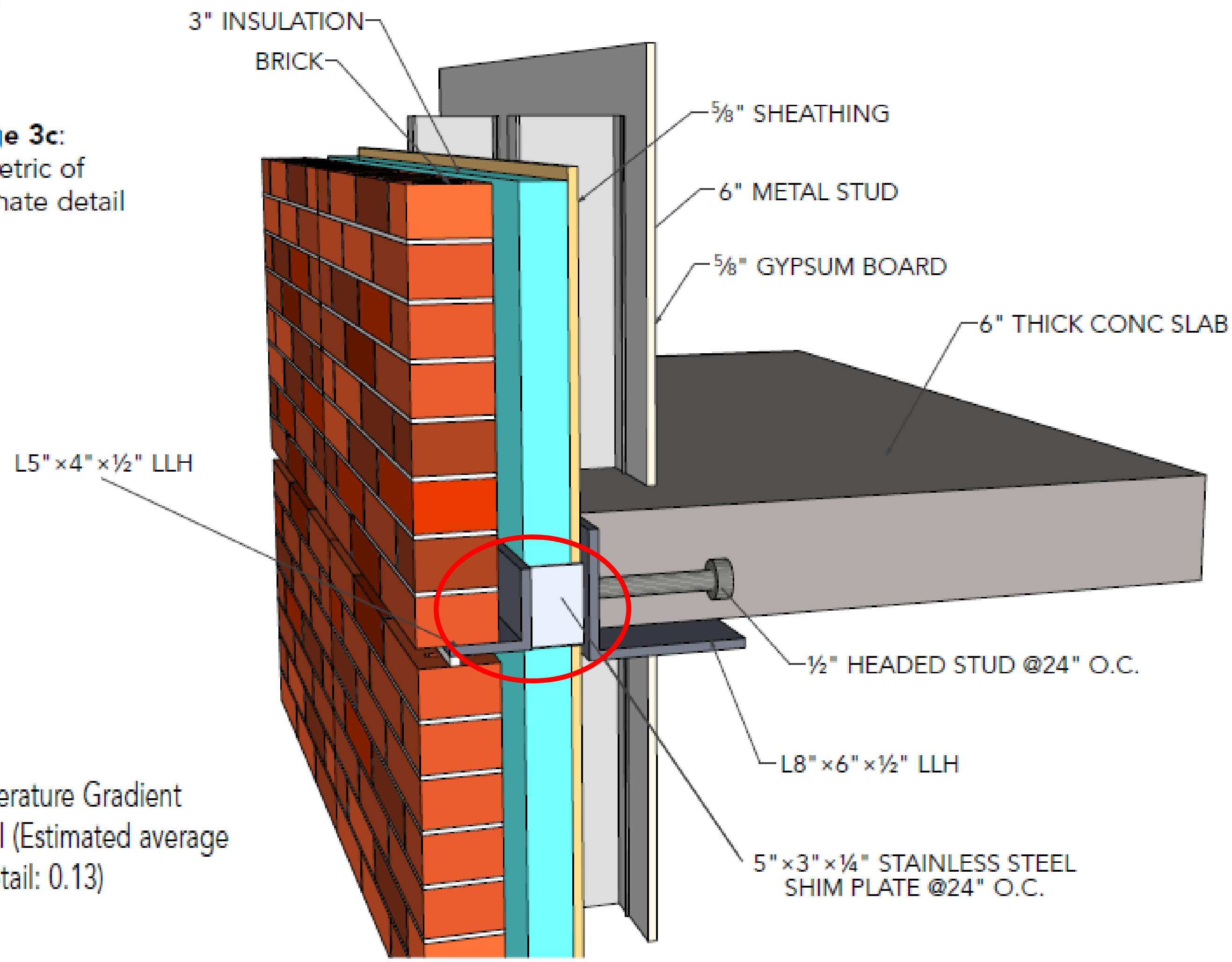

Image 3d: Typical Temperature Gradient output of alternate detail (Estimated average U-Factor of Alternate Detail: 0.13)

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Detail 4: Masonry Lintel, Material Separation

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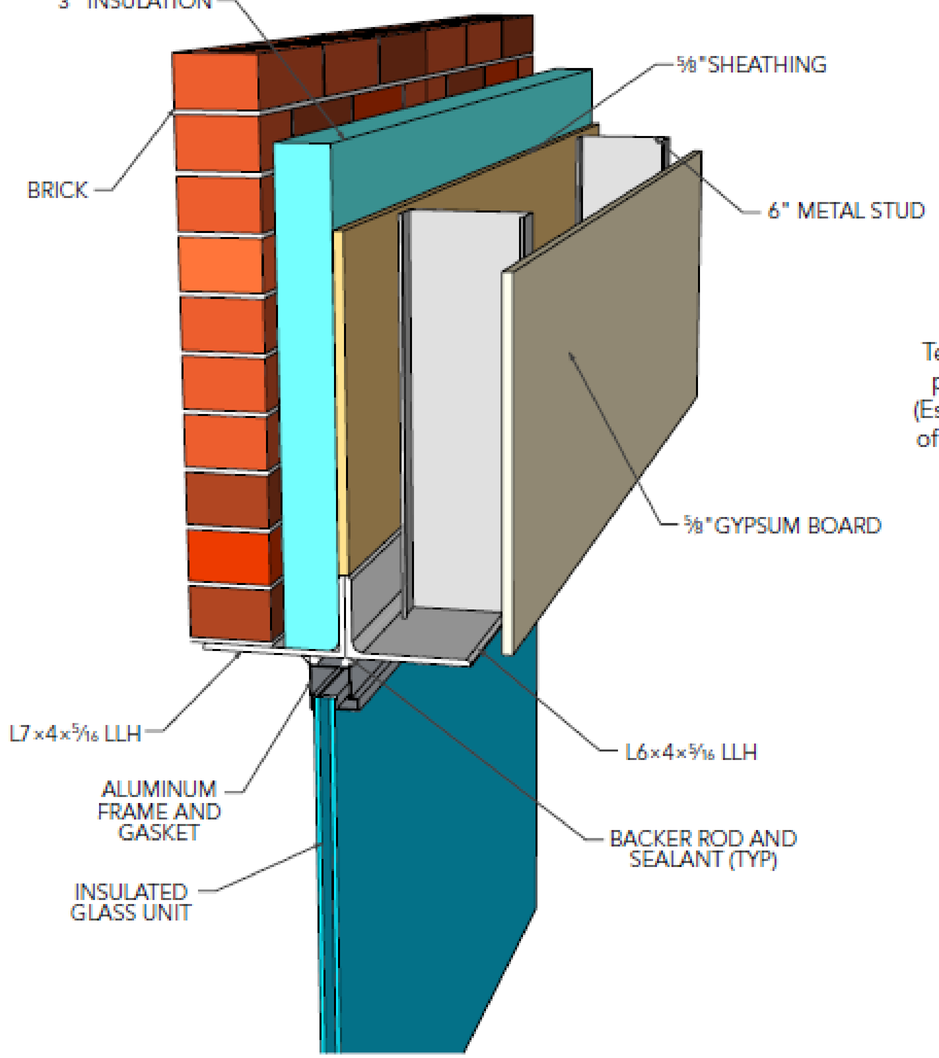
Traditional



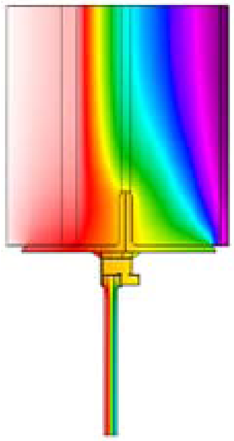


Image 4b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.62)

Thermal Bridging

Detail 4: Masonry Lintel, Material Separation

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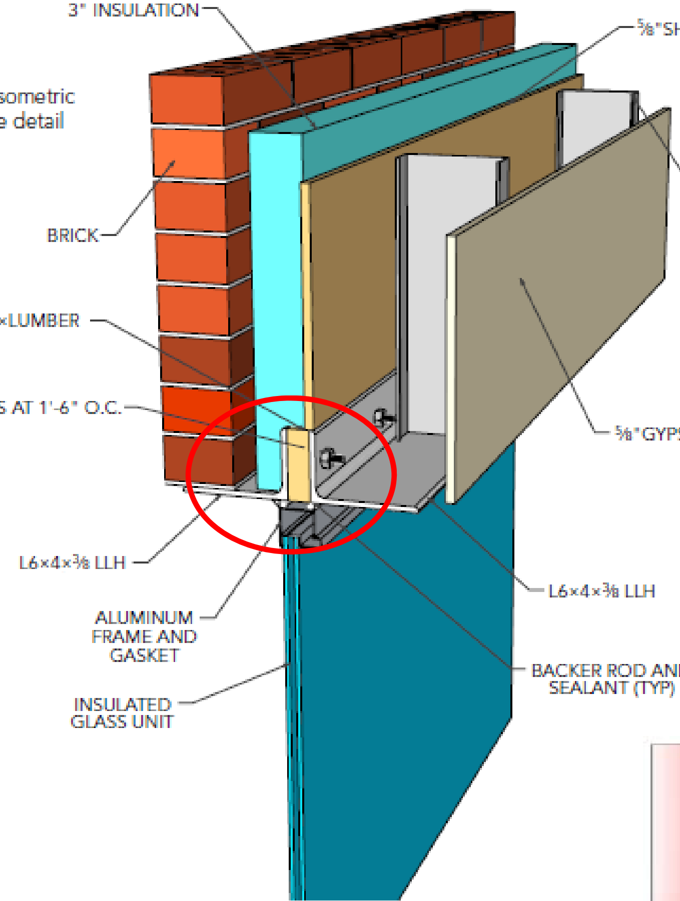
Improved

Image 4c: Isometric of alternate detail



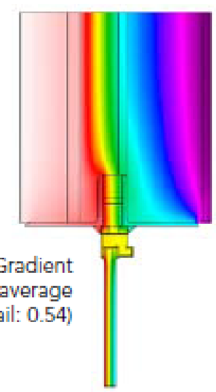


Image 4d: Typical Temperature Gradient output of alternate detail (Estimated average U-Factor of Alternate Detail: 0.54)

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Thermal Bridging

Detail 5: Cantilevered Roof Canopy Beam: MTBA

Image 5a: Isometric detail

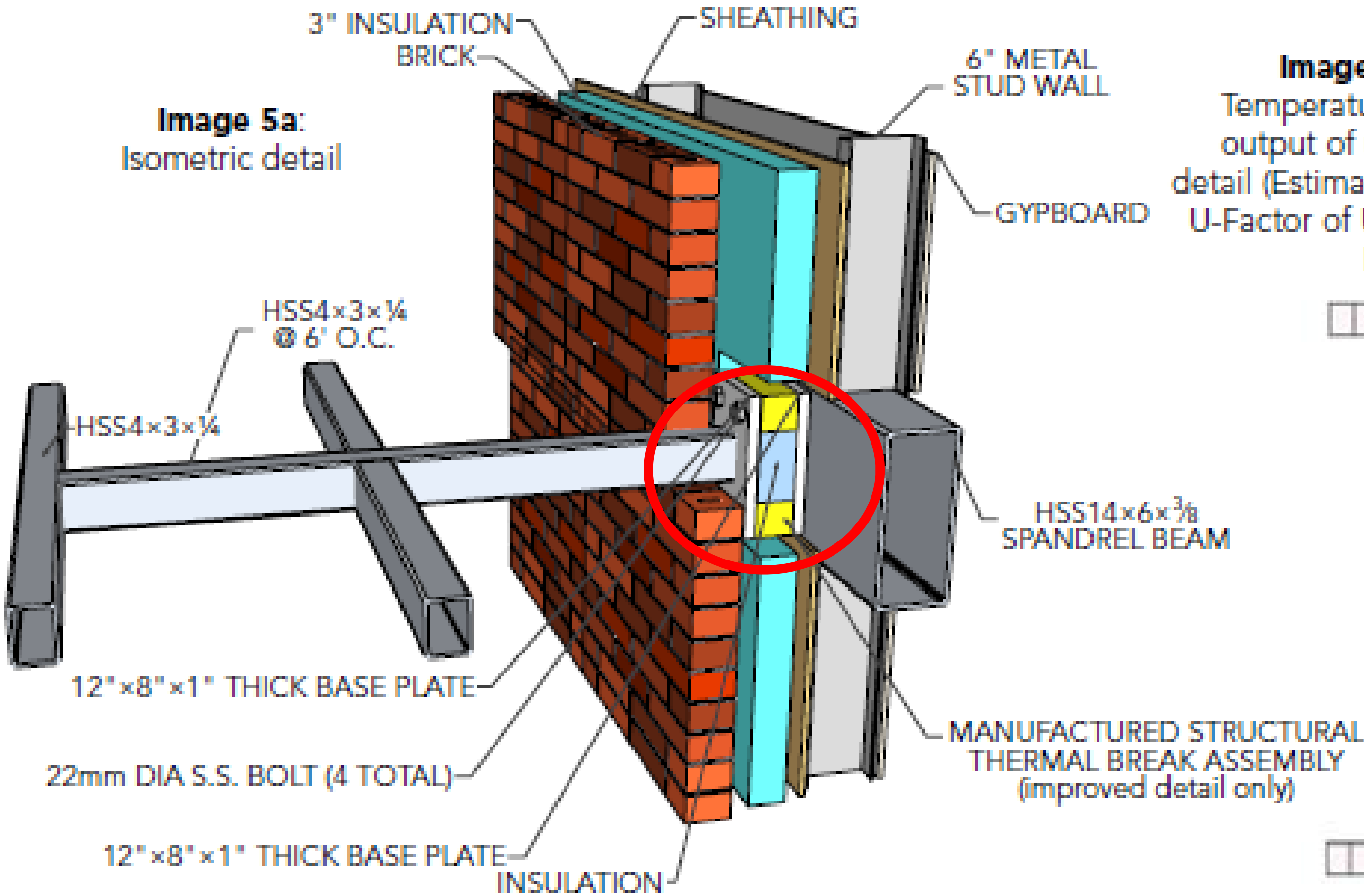
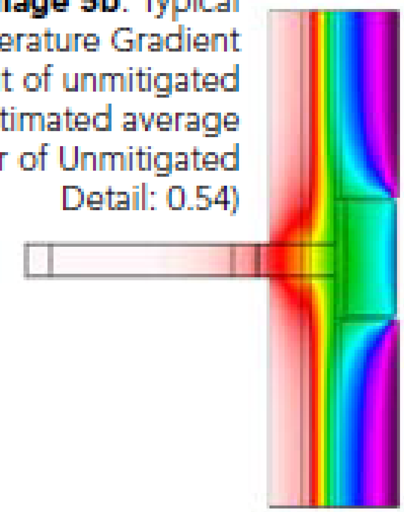


Image 5b: Typical Temperature Gradient output of unmitigated detail (Estimated average U-Factor of Unmitigated Detail: 0.54)



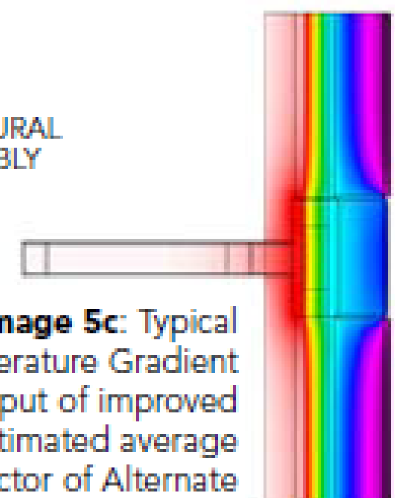


Image 5c: Typical Temperature Gradient output of improved detail (Estimated average U-Factor of Alternate Detail: 0.41)

	Detail	Condition	Area Affected	Annual Building Heating & Cooling Cost	Annual Potential Energy Savings Realized Through Use of Alternative Detail		% Energy Improvement from Standard Detail to Alternate Detail	Potential Average Alternate Detail Implementation Cost Increase (-) or Savings (+) In Entire Structure (Material/ Fabrication/Erection)		Percent Cost Increase (-) or Savings (+) from Standard Detail to Alternate Detail
					Dollars	% Impact		Total Locations	Dollars	
Chicago	1	Rooftop Grillage Posts	7.74 sq. ft.		$1.00	0.01%	19%	12 posts	-$350	-14%
	2	Roof Edge Angle	957 sq. ft.		$130	1.10%	30%	230 ft.	$1,100	17%
	3	Shelf Angle Support	1,035 sq. ft.		$260	2.20%	77%	460 ft.	$400	1%
	4	Masonry Lintel	398 sq. ft.		$39	0.33%	26%	336 ft.	-$28,000	-98%
	5	Roof Canopy	9.25 sq. ft.		$1.30	0.01%	27%	7 beams	-$6,300	-137%
	Total			**$11,885**	**$431.30**	**3.60%**	**46%**			
Phoenix	1	Rooftop Grillage Posts	7.74 sq. ft.		$1.00	0.00%	17%	12 posts	-$350	-14%
	2	Roof Edge Angle	957 sq. ft.		$150	0.70%	31%	230 ft.	$1,100	17%
	3	Shelf Angle Support	1,035 sq. ft.		$290	1.40%	76%	460 ft.	$400	1%
	4	Masonry Lintel	398 sq. ft.		$43	0.20%	27%	336 ft.	-$28,000	-98%
	5	Roof Canopy	9.25 sq. ft.		$1.60	0.00%	30%	7 beams	-$6,300	-137%
	Total			**$20,927**	**$485.60**	**2.30%**	**47%**			

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	Total			**$20,927**	**$485.60**	**2.30%**	**47%**			

Recommendations

Minimize thickness of bridging elements, where structurally possible

Minimize conditions of continuous bridging, substituting intermittent bridges

Use stainless steel when possible

Work to provide wraparound insulation when possible

Look for new information and research

Recommendations: Practical Things You Can Do

Based on the results of the analysis in the examples, the recommendations below should be considered:

1. Refer to the five examples of thermal bridging and mitigation strategies in the detailing of structural steel projects. Try to especially minimize conditions of continuous thermal bridging, such as at continuously supported steel brick shelves.
2. Pay particular attention to minimizing thermal bridging for buildings that fall into one or more of the following categories:
   - A. Buildings with a long estimated service life, such as institutional buildings, hospitals, etc.
   - B. Buildings in extremely warm or cold climates
   - C. Buildings where highly climate-controlled conditions exist, such as medical facilities and senior residence facilities
3. Consider the use of two-dimensional heat transfer modeling software to analyze unusual conditions where thermal bridging may occur in conditioned buildings.
4. Discuss the issue of building envelope energy performance with the other members of the design team, in order to develop coordinated strategies to minimize building energy loss through thermal bridging.
5. Confirm the structural integrity of any design solution for the project under design.
6. For informational purposes, take advantage of any opportunity to obtain feedback of the building envelope energy loss of buildings you have designed, using an infrared thermal camera.
7. Perform a full ROI analysis of proposed details before preparing construction documents and obtain the approval of the owner.

Mass versus Capacity

Thermal Mass or Thermal Capacity?

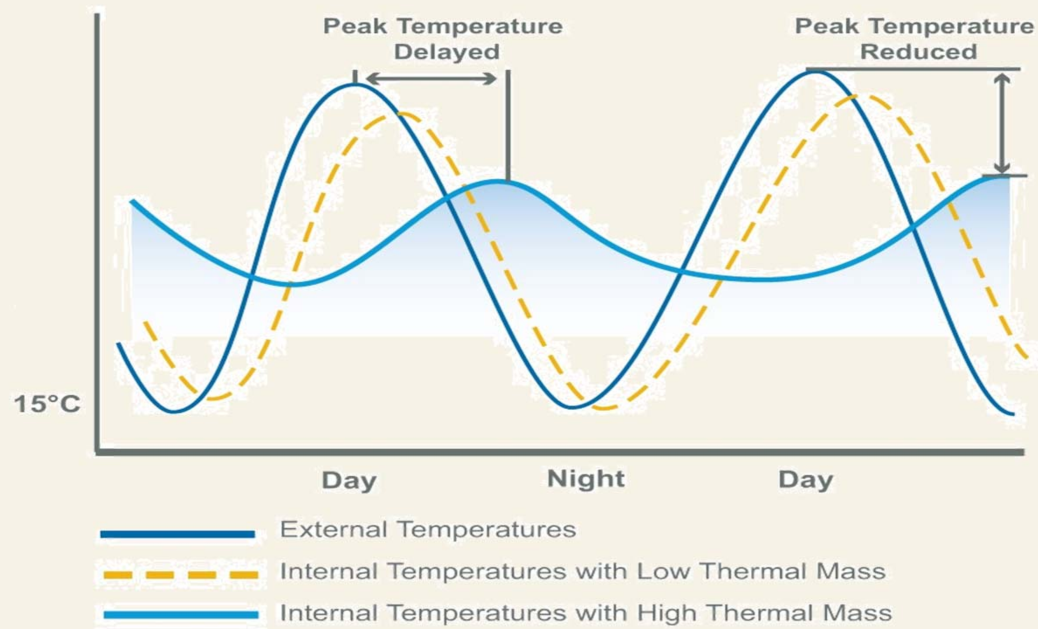
The measure of thermal mass is a material's ability to absorb, store and release heat. It is measured by the amount of thermal energy stored per unit of mass.

The measure of thermal capacity is a building's ability to absorb, store and release heat. It is measured by the amount of thermal energy stored per unit of building volume.

Thermal Capacity

What is thermal capacity?

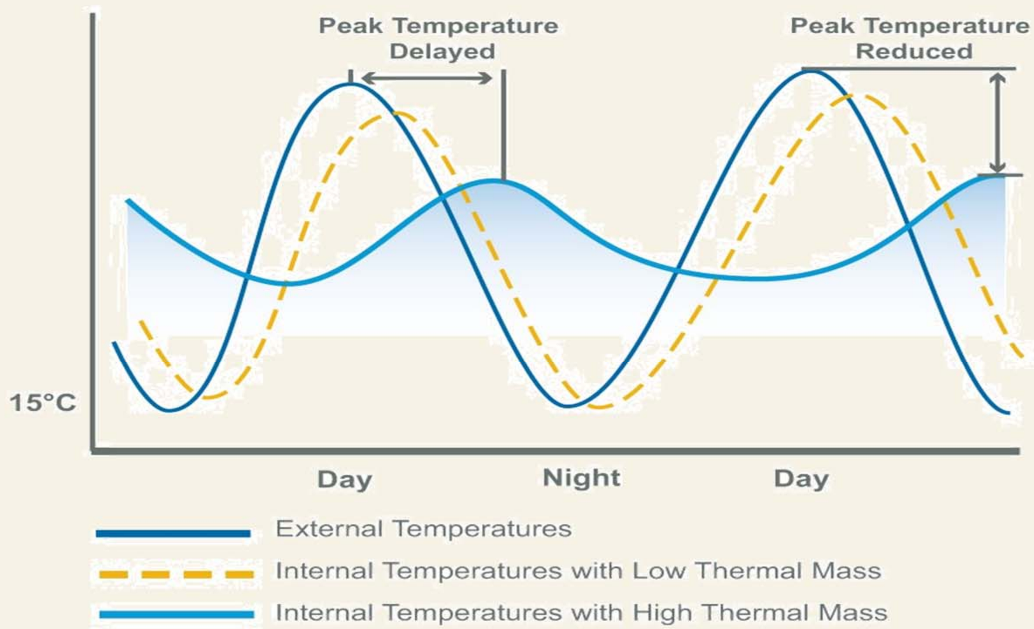
Thermal capacity is analogous to a flywheel. It allows a building to store excess thermal energy and then releases it over time.



Thermal Capacity

Why is it important?

Building elements can act as "shock absorbers" to dampen peak heating and cooling demands reducing energy consumption and operational costs.



Thermal Capacity

Overcoming the Myth of Thermal Mass

The Myth: The more mass the greater the thermal capacity of the building.

The Fact: Mass is only one factor in developing the thermal capacity of a building.

Factors Impacting the Thermal Capacity of a Building

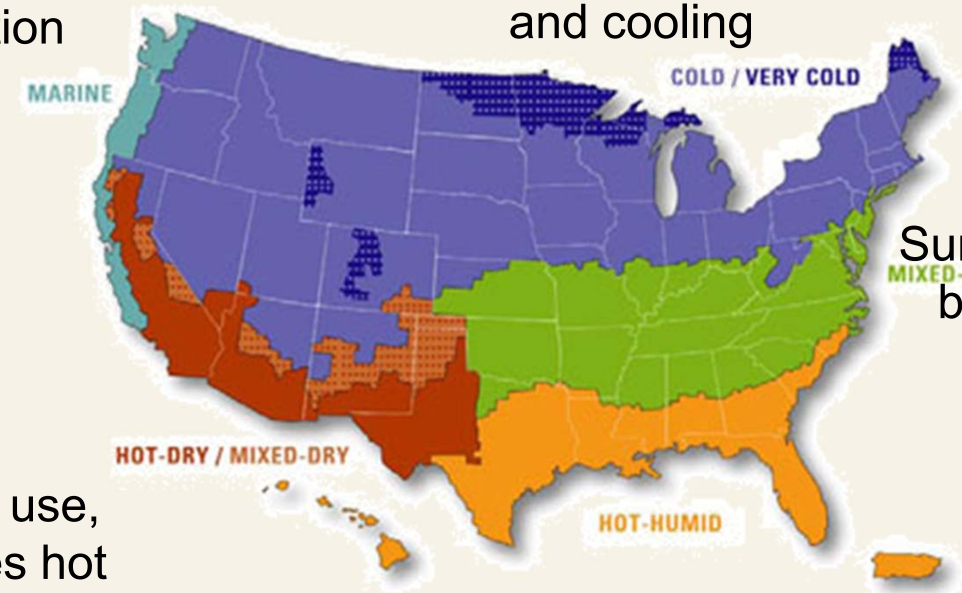
- The climate zone the building is located in
- The occupancy cycle of the building
- The selection of building materials
- The mass of the material
- The thickness of the material
- The exposed surface of the material
- The placement of the material
- The placement of finishes used in the building

Thermal Capacity

The Climate Zone of the Building

Little value due to limited temperature variation

Best use is to flatten the demand curve for mechanical heating and cooling



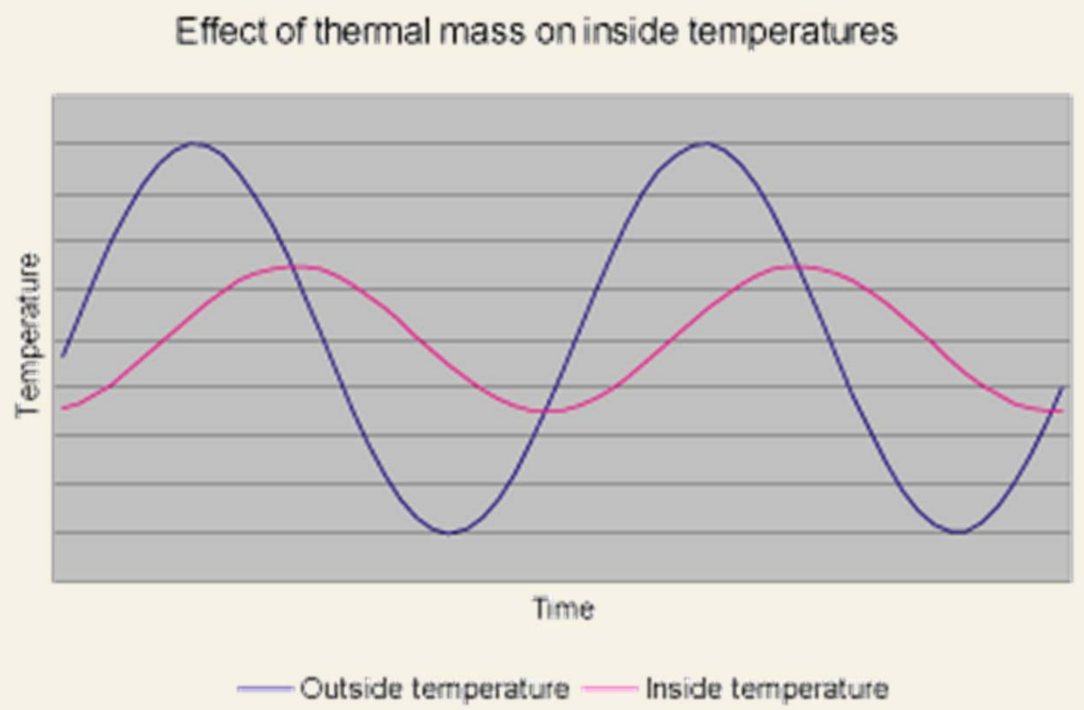
Summer benefits may be offset by winter losses

Classic use, mitigates hot days and cool nights based on solar gain

Most challenging and must be strategically located to prevent overheating

The Occupancy Cycle

The closer the occupancy cycle of building follows the temperature cycle of the day, the greater will be the impact of energy savings



The Selection of Building Materials

- Materials with a high density
- Materials with a low strength
- Materials with a low thermal conductivity
- Result favors high mass (not density) materials

The Mass of the Material

The more mass the more thermal energy a material can store.

$$Q = mC_p\Delta T$$

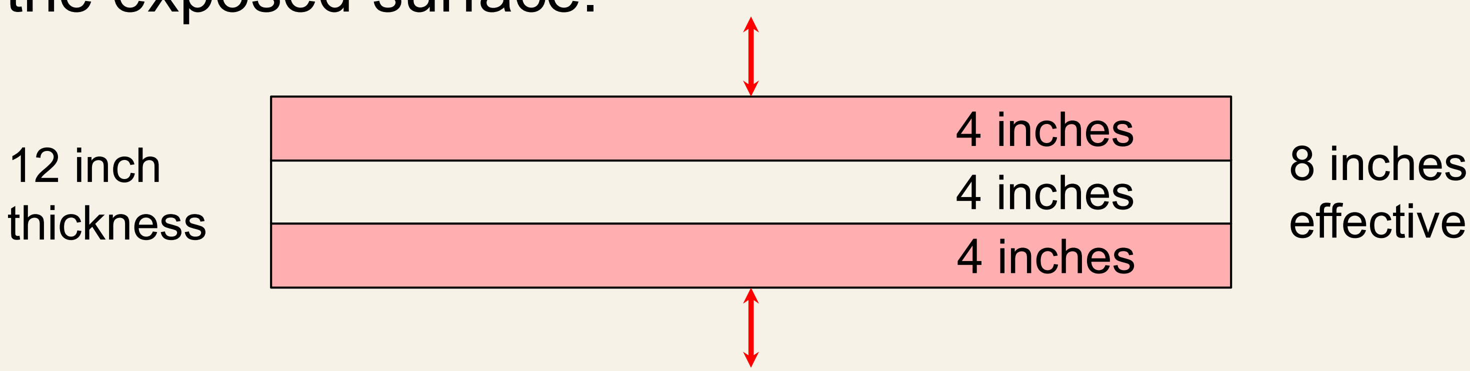
where:

- Q = thermal energy transferred
- m = mass of the body
- C_p = the isobaric heat capacity of the material
- ΔT = change in temperature

The Thickness of the Material

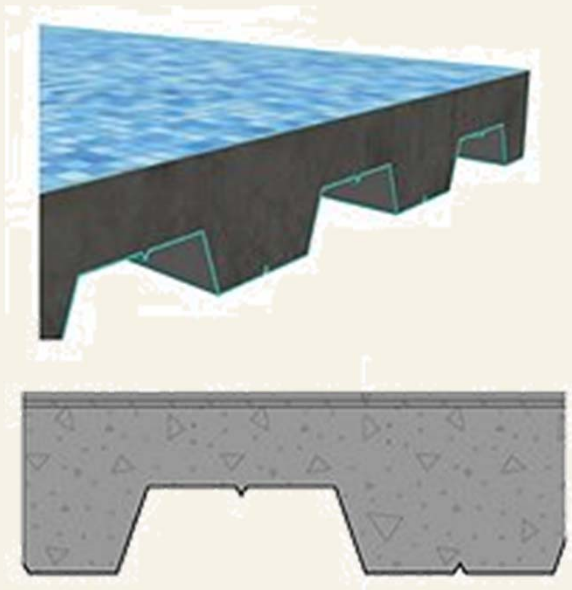
The absorption and release of heat energy takes place on a cyclical rather than absolute basis. The rate of heat energy penetration into the material is just as important as the mass of the material. The effective thermal mass of a material is limited by the depth to which the thermal energy can penetrate the material in a typical 24 hour cycle.

For concrete the limiting thickness is 4 inches from the exposed surface.



The Exposed Surface of the Material

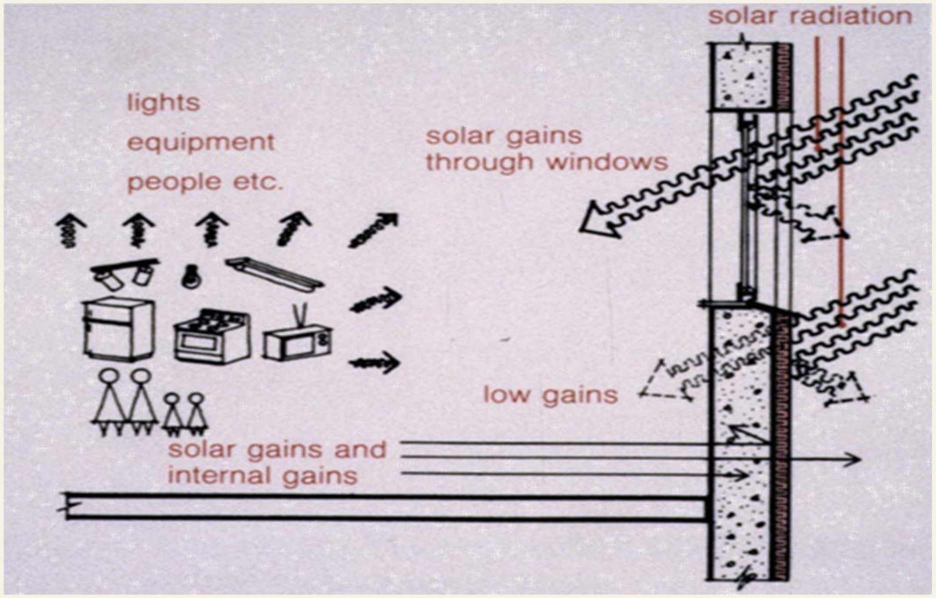
The corollary is that increasing the exposed surface area increases the thermal efficiency of the material.



Steel decking has a high rate of thermal transmission and does not adversely impact the energy transfer.

The Placement of the Material

- Exposure to solar heat sources, air movement and internal spaces is critical
- Materials located outside the insulated envelope of the building do not contribute to the thermal capacity of the building



The Exposed Surface of the Material

Isolating the surface of material with thermally resistive materials significantly limits the exchange of thermal energy. Avoid the use of:

- Carpeting
- Dropped ceilings with no free air flow (15% minimum openness recommended)
- Plastered walls
- Gypsum wall linings
- False floors

Ensuring thermal connectivity to air flow (convection) is critical.

How Much Mass Is Required?

Typically the mass of concrete in the floor and wall systems are adequate to develop the necessary thermal capacity of the building

National Renewable Energy Laboratory
Golden, Colorado

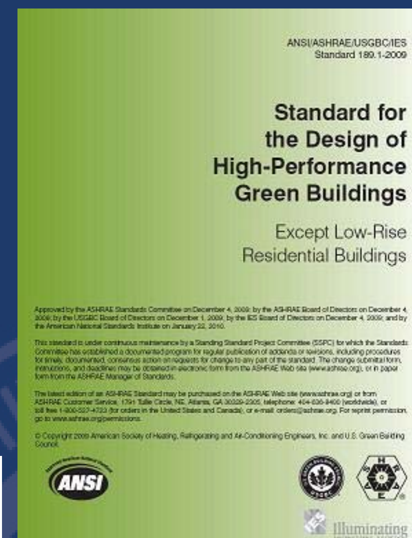
Taking Advantage of Thermal Capacity

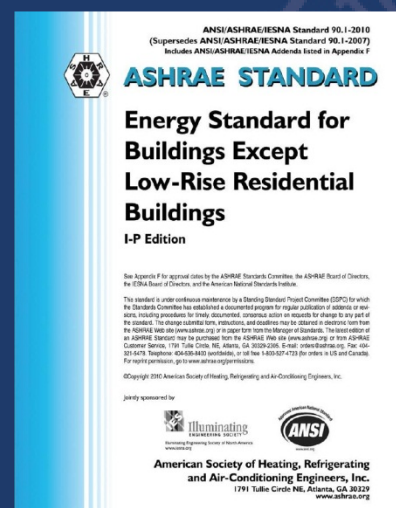
- Optimized design requires significant modeling and specialized passive systems if the goal is eliminate mechanical heating systems
- Improved building efficiency can be accomplished through design decisions:
  - Consider the climate zone
  - Evaluate the occupancy cycle
  - Don’t needlessly increase building mass
  - 4 inch thickness per exposed side
  - Increase surface area
  - Don’t isolate or insulate the concrete surfaces

Thermal Bridging

Codes and Standards

- IgCC
- ASHRAE





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What's Ahead?

Steel Connection Assemblies with Fiberglass Reinforced Plastic "Shims" Research

Thermal Bridging Task Committee to Expand Purview to Include Concrete and Masonry

Exploring Improved Energy Modeling and Envelope Requirements

More Practitioner Experience

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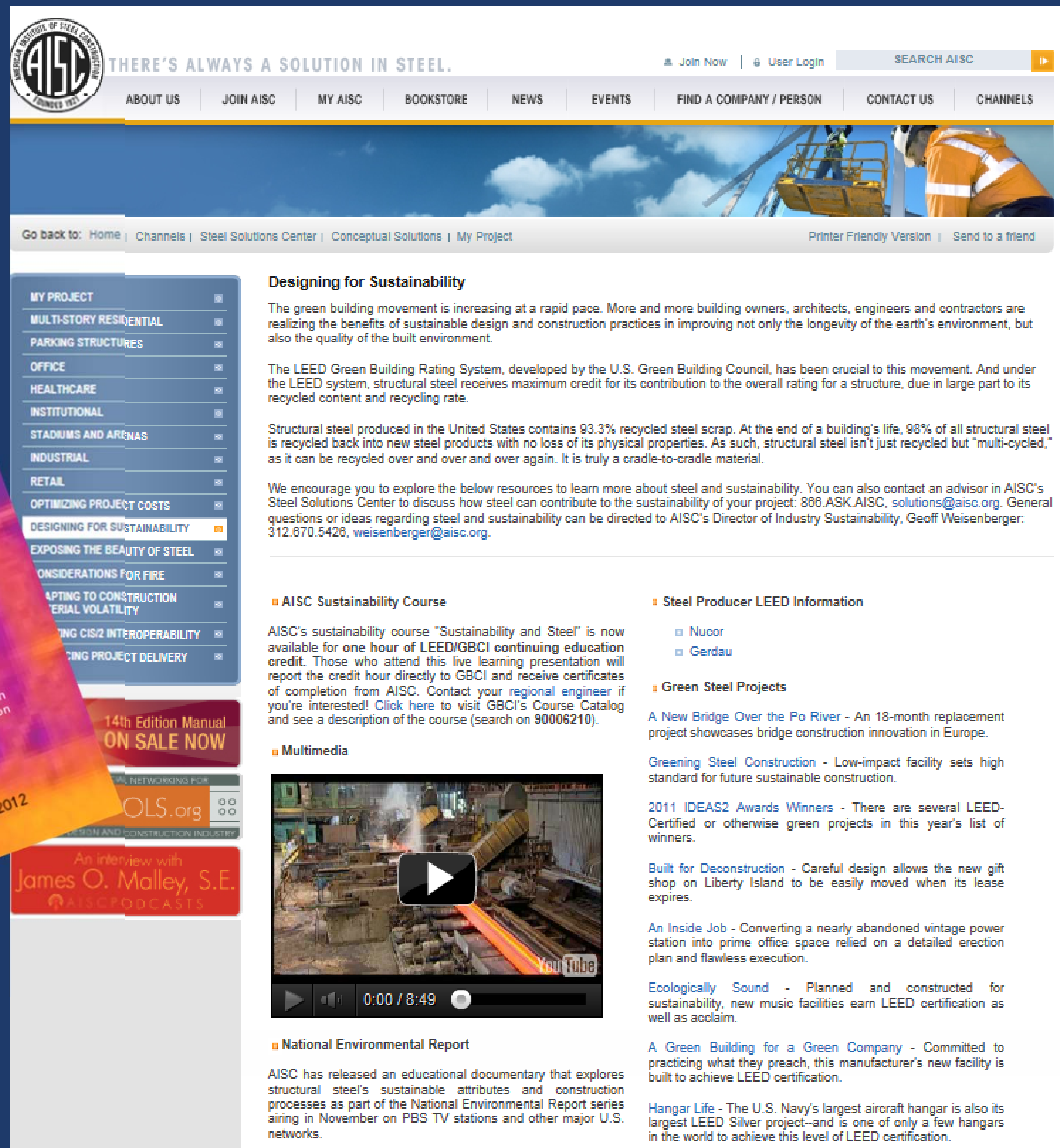
Sustainability



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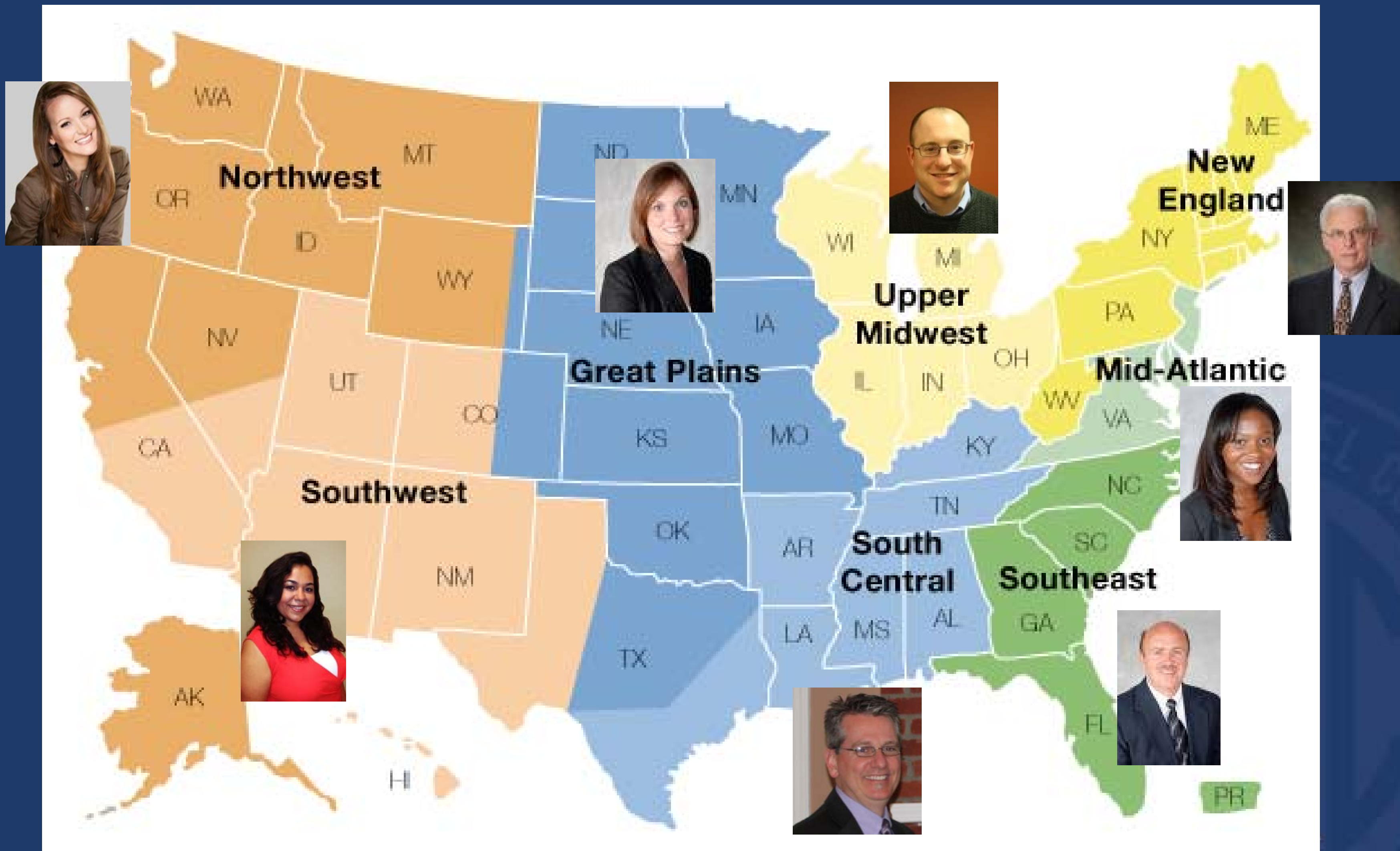

For more information or to contact your regional engineer, log on to www.aisc.org/myregion

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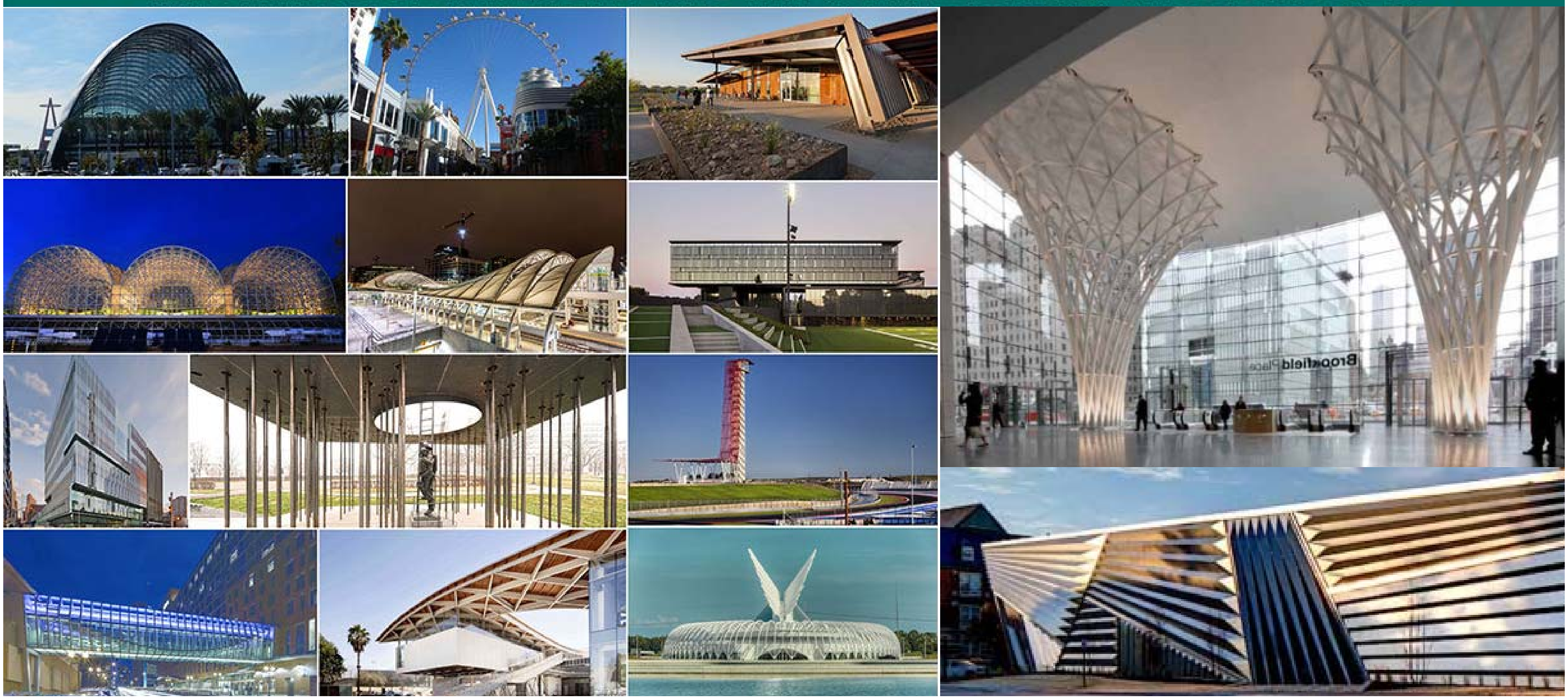

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