PHRC Webinar Series | Tuesday, May 12, 2015 @ 1pm

Thermal Bridging in Residential Construction

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

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Description

- The desire to build more efficient buildings has driven the construction industry toward new and modified construction practices over the past two decades. As buildings have become more efficient, the strategies for reducing energy consumption have become more detailed and increasingly complex. In order to optimize the energy efficiency of standard platform light frame construction, builders and designers have been forced to address thermal bridging's role in the performance of residential structures. This webinar will take a look at how much of an effect thermal bridging has on energy efficiency, as well as the effectiveness of current strategies for reducing heat loss through these bridges.

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Learning Objectives

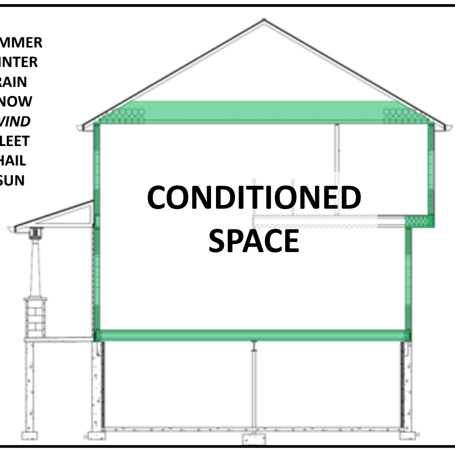
- **Understand the fundamental thermodynamic principles that allow for thermal bridges to occur in light frame platform construction.**
- **Identify current construction methods and assemblies that aim to reduce the effect that thermal bridging has on the efficiency and affordability of housing.**
- **Utilize various methods, including infrared thermography, to demonstrate the location and effect of thermal bridging in residential construction.**
- **Examine the role of building codes and above code programs in reducing operating costs for building occupants.**

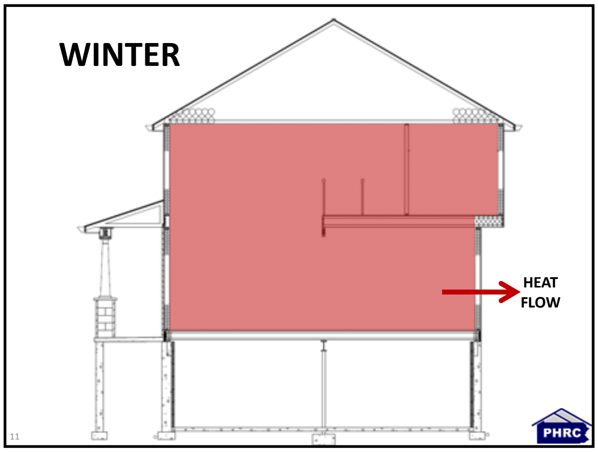
2009 IRC Definitions

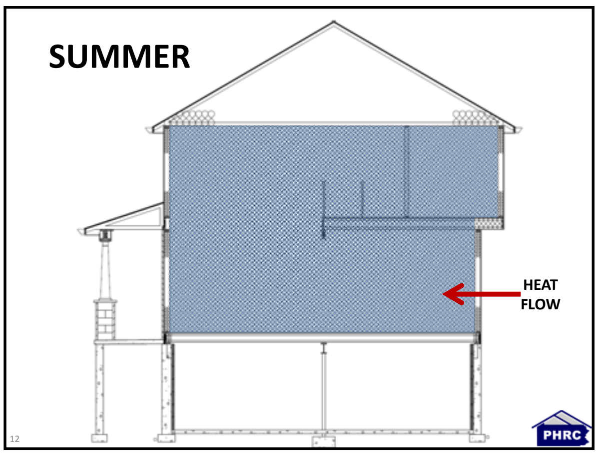
- ***Building Thermal Envelope*. The basement walls, exterior walls, floor, roof and any other building element that enclose conditioned spaces.**
  - Building Envelope
    vs
  - Building Enclosure
- ***Conditioned Space*. For energy purposes, space within a building that is provided with heating and/or cooling equipment or systems capable of maintaining, through design or heat loss/gain, 50°F (10°C) during the heating season and 85°F (29°C) during the cooling season, or communicates directly with a conditioned space.**

2009 IRC Chapter 2

SUMMER
WINTER
RAIN
SNOW
WIND
SLEET
HAIL
SUN







Heat Flow

- **From hot to cold (high concentration to low concentration)**
- **Conduction**
  - Heat flow through a substance or material by direct contact
  - Conduction takes place within a single material or between materials in direct contact
- **Convection**
- **Radiation**

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Conductive Heat Loss

- **Q = U x A x ΔT**
  - Q = heat flow (Btu / hr)
  - U = thermal conductivity (U = 1 / R)
  - A = surface area (square feet)
  - ΔT = temperature difference across component (°F)

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Conductive Heat Loss

- **Can you stop heat flow?**

$$Q = U \times A \times \Delta T$$

  - Answer: **No**
    - Conductive heat flow can be managed, but not eliminated

      Therefore
    - Thermal bridging can be managed, but not eliminated

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Building Enclosure Functions

1. **Support (structural)**
2. **Control (heat, air, moisture, smoke, odor, sound, fire, insects, etc.)**
3. **Aesthetics (exterior and interior finishes)**
4. **Distribution of Services (MEP)**

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Managing Heat

- When a thermal gradient is present, heat flow cannot be stopped, but can be managed by installing thermal insulation
- Heat will always flow through path of least resistance
- How do we measure the insulating value of different materials?

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Thermal Properties

- Thermal resistance (R-Value)
  - Higher R-Value = better insulating value
- Thermal transmittance (U-Value)
- U-Value = 1 / (R-Value)
  - R-Value = Insulation
  - U-Value = Fenestration

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2009 IRC - R-Value

- ***R-Value, Thermal Resistance*****. The inverse of the time rate of heat flow through a building thermal envelope element from one of its bounding surfaces to the other for a unit temperature difference between the two surfaces, under steady state conditions, per unit area (h · ft2 · °F/Btu).**
  - ASTM C518-04: This test method covers the measurement of steady state thermal transmission through flat slab specimens using a heat flow meter apparatus.
    - Includes effects of conduction, convection, and radiation that occur within the specimen

2009 IRC Chapter 2

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Thermal Properties

- **R-Value = $\frac{\text{(Hour x Feet}^2\text{ x °F)}}{\text{Btu}}$**
  - R-20 insulation allows 1 Btu of energy to pass through one square foot of surface area in an hour's time when there is a temperature difference of 20°F between surfaces
  - R-40 insulation allows 1/2 Btu of energy to pass through one square foot of surface area in an hour's time when there is a temperature difference of 20°F between surfaces

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R-Values of Common Materials

Building Material	R-Value
Framing Lumber (SPF)	1.35 – 1.11 / inch
OSB (7/16")	0.62
Gypsum (1/2")	0.45
Cellulose	2.94 – 3.45 / inch
Fiberglass	3.33 – 3.82 / inch
Open Cell Spray Foam	3.5 / inch
Extruded Polystyrene (XPS)	5.0 / inch
Closed Cell Spray Foam	6.0 / inch

Source: 2009 ASHRAE Handbook – Fundamentals, www.spraypolyurethane.org

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TABLE N1102.1
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION U-FACTOR	SKYLIGHT[b] U-FACTOR	GLAZED FENESTRATION SHGC	CEILING R-VALUE	WOOD FRAME WALL R-VALUE	MASS WALL R-VALUE[k]	FLOOR R-VALUE	BASEMENT[c] WALL R-VALUE	SLAB[d] R-VALUE AND DEPTH	CRAWL SPACE[c] WALL R-VALUE
1	1.2	0.75	0.35[j]	30	13	3/4	13	0	0	0
2	0.65[i]	0.75	0.35[j]	30	13	4/6	13	0	0	0
3	0.50[i]	0.65	0.35[e,j]	30	13	5/8	19	5/13[f]	0	5/13
4 except Marine	0.35	0.60	NR	38	13	5/10	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.35	0.60	NR	38	20 or 13 + 5[h]	13/17	30[f]	10/13	10, 2 ft	10/13
6	0.35	0.60	NR	49	20 or 13 + 5[h]	15/19	30[g]	10/13	10, 4 ft	10/13
7 and 8	0.35	0.60	NR	49	21	19/21	30[g]	10/13	10, 4 ft	10/13

a. R-values are minimums. U-factors and solar heat gain coefficient (SHGC) are maximums. R-19 batts compressed in to nominal 2 × 6 framing cavity such that the R-value is reduced by R-1 or more shall be marked with the compressed batt R-value in addition to the full thickness R-value.
b. The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration.
c. The first R-value applies to continuous insulation, the second to framing cavity insulation; either insulation meets the requirement.
d. R-5 shall be added to the required slab edge R-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less, in zones 1 through 3 for heated slabs.
e. There are no SHGC requirements in the Marine Zone.
f. Basement wall insulation is not required in warm-humid locations as defined by Figure N1101.2 and Table N1101.2.
g. Or insulation sufficient to fill the framing cavity, R-19 minimum.
h. "13+5" means R-13 cavity insulation plus R-5 insulated sheathing. If structural sheathing covers 25% or less of the exterior, R-5 sheathing is not required where structural sheathing is used. If structural sheathing covers more than 25% of exterior, structural sheathing shall be supplemented with insulated sheathing of at least R-2.
i. For impact-rated fenestration complying with Section R301.2.1.2, the maximum U-factor shall be 0.75 in zone 2 and 0.65 in zone 3.
j. For impact-resistant fenestration complying with Section R301.2.1.2 of the *International Residential Code*, the maximum SHGC shall be 0.40.
k. The second R-value applies when more than half the insulation is on the interior.

2009 IRC Table N1102.1

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Thermal Bridging

- **Material with lower R-Value allowing heat to pass through assembly with much higher overall R-Value**
- **Example: Wood stud wall**
  - Insulation (cavity) = R-21
  - 2x6 stud ~ R-6.88

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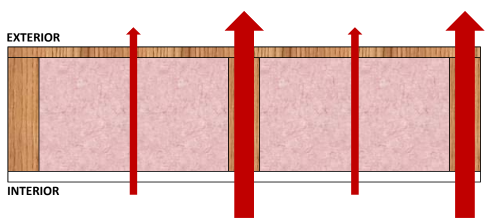
Thermal Bridging



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How Do We Visualize Thermal Bridging?

- **Simulations**
- **Infrared imagery**
  - Requires minimum thermal gradient (up to 50°F, can be less with higher performing equipment)
  - Can represent all mechanisms of heat flow (must use caution when interpreting infrared images)

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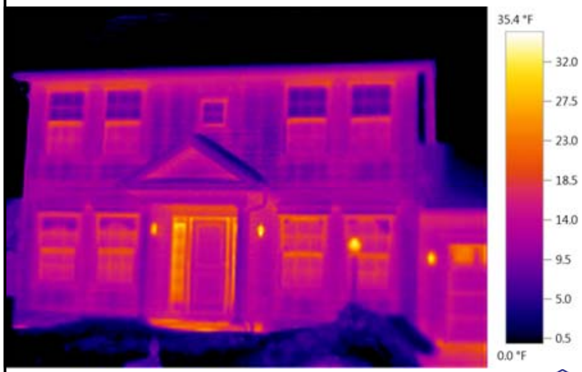
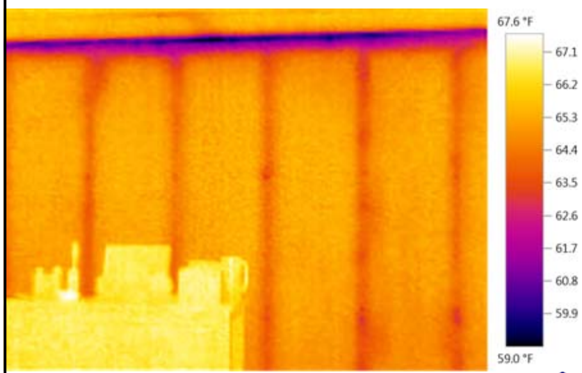

35.4 °F
32.0
27.5
23.0
18.5
14.0
9.5
5.0
0.5
0.0 °F

27


67.6 °F
67.1
66.2
65.3
64.4
63.5
62.6
61.7
60.8
59.9
59.0 °F

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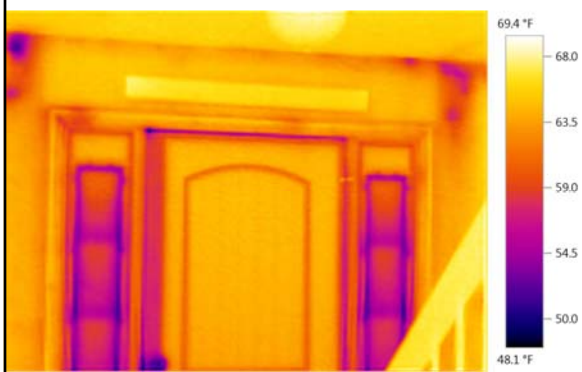
69.4 °F
68.0
63.5
59.0
54.5
50.0
48.1 °F

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Light-Frame Thermal Bridging

- **Wood studs serve as primary thermal bridge in low-rise light-frame construction**
  - Others: Slab edge, fenestration, mechanical penetrations, etc.
- **Framing factor defines the proportion of framing in an insulated wall system (includes studs, jacks, kings, headers, top / bottom plates)**
  - Typical framing factor = 25%

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Building Enclosure Functions

1. Support (structural)
2. Control (heat, air, moisture, smoke, odor, sound, fire, insects, etc.)
3. Aesthetics (exterior and interior finishes)
4. Distribution of Services (MEP)

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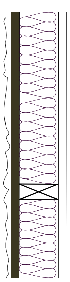
R-Value of Total Wall Assembly

2x6 wall @ 16" o.c.



Component	Cavity R-value	Frame R-value
Outside air film	0.17	0.17
Lap siding	0.62	0.62
7/16" OSB	0.62	0.62
Batt insulation	21	--
2x6 stud	--	6.88
Gypsum board	0.45	0.45
Inside air film	0.68	0.68
Total R-values	23.54	9.42
Total U-factor (1/R-value)	0.0425	0.1062

$U_{overall}$ = (0.0425x.75)+(0.1062x.25) = 0.0584

$R_{overall}$ = 1/0.0584 = **17.1**

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Data pulled from "Typical Thermal Properties of Common Building and Insulating Matererials": 2009 ASHRAE Handbook

U-Factor Compliance

TABLE N1102.1.2
EQUIVALENT U-FACTORS[a]

CLIMATE ZONE	FENESTRATION U-FACTOR	SKYLIGHT U-FACTOR	CEILING U-FACTOR	FRAME WALL U-FACTOR	MASS WALL U-FACTOR[b]	FLOOR U-FACTOR	BASEMENT WALL U-FACTOR	CRAWL SPACE WALL U-FACTOR
1	1.20	0.75	0.035	0.082	0.197	0.064	0.360	0.477
2	0.65	0.75	0.035	0.082	0.165	0.064	0.360	0.477
3	0.50	0.65	0.035	0.082	0.141	0.047	0.091[c]	0.136
4 except Marine	0.35	0.60	0.030	0.082	0.141	0.047	0.059	0.065
5 and Marine 4	0.35	0.60	0.030	0.060	0.082	0.033	0.059	0.065
6	0.35	0.60	0.026	0.060	0.060	0.033	0.059	0.065
7 and 8	0.35	0.60	0.026	0.057	0.057	0.033	0.059	0.065

a. Nonfenestration U-factors shall be obtained from measurement, calculation or an approved source.
b. When more than half the insulation is on the interior, the mass wall U-factors shall be a maximum of 0.17 in zone 1, 0.14 in zone 2, 0.12 in zone 3, 0.10 in zone 4 except Marine and the same as the frame wall U-factor in Marine zone 4 and in zones 5 through 8.
c. Basement wall U-factor of 0.360 in warm-humid climates as defined by Figure N1101.2 and Table N1101.2.

$R_{overall}$ = 1/0.0584 = **17.1**

2009 IRC Table N1102.1.2

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R-Value Computation

- ***402.1.2 R-value computation*. Insulation material used in layers, such as framing cavity insulation and insulating sheathing, shall be summed to compute the component R-value. The manufacturer's settled R-value shall be used for blown insulation. Computed R-values shall not include an R-value for other building materials or air films.**

2009 IECC Sect. 402.1.2

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How Do We Manage Thermal Bridging?

1. **Provide a thermal break**
   - Thermal Break Definition: An element of low conductivity placed between two conductive materials to limit heat flow
     - Source: DictionaryofConstruction.com
   - Exterior foam insulation
2. **Reduce the number of thermal bridge elements**
   - Advanced framing techniques

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k. The second R-value applies when more than half the insulation is on the interior.

2009 IRC Table N1102.1

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Exterior Foam Insulation

- **Adding an insulating layer of exterior foam on the exterior of the wall framing provides a continuous thermal break**
- **2009 IRC**
  - 13 + 5 option
  - Able to reduce amount of cavity insulation as the exterior foam contributes to the overall R-Value (for code compliance)
  - Must provide a minimum level of continuous insulation in order to mitigate condensation risk associated with foam permeability

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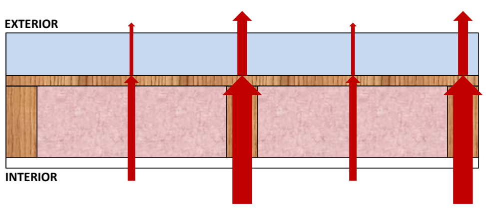
Thermal Bridging w/Exterior Foam



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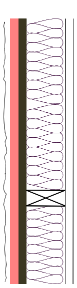
R-Value of Total Wall Assembly

2x4 wall @ 16" o.c. & foam



Component	Cavity R-value	Frame R-value
Outside air film	0.17	0.17
Lap siding	0.62	0.62
7/16" OSB	0.62	0.62
Batt insulation	13	--
Rigid Foam	5	5
2x4 stud	--	4.38
Gypsum board	0.45	0.45
Inside air film	0.68	0.68
Total R-values	20.54	11.92
Total U-factor (1/R-value)	0.0487	0.0839

$U_{overall}$ = (0.0487x.75)+(0.0839x.25) = 0.0575

$R_{overall}$ = 1/0.0575 = **17.4**

41 Data pulled from "Typical Thermal Properties of Common Building and Insulating Matererials": 2009 ASHRAE Handbook

U-Factor Compliance

TABLE N1102.1.2
EQUIVALENT U-FACTORS[a]

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a. Nonfenestration U-factors shall be obtained from measurement, calculation or an approved source.
b. When more than half the insulation is on the interior, the mass wall U-factors shall be a maximum of 0.17 in zone 1, 0.14 in zone 2, 0.12 in zone 3, 0.10 in zone 4 except Marine and the same as the frame wall U-factor in Marine zone 4 and in zones 5 through 8.
c. Basement wall U-factor of 0.360 in warm-humid climates as defined by Figure N1101.2 and Table N1101.2.

$R_{overall} = 1/0.0575 =$ **17.4**

2009 IRC Table N1102.1.2

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Exterior Foam – Key Considerations

- **Hygrothermal loading**
  - Double vapor retarder / barrier
- **Wall bracing**
- **Cladding attachment**
- **Water-resistive barrier placement**
  - Flashing

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Advanced Framing

Source: APA Advanced Framing Construction Guide (www.apawood.org)

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Advanced Framing Elements

- **A combination of the following framing techniques can reduce the framing factor by up to 10% (from 25% down to 15%)**
  - Single top-plate
  - Studs spaced @ 24" o.c. where allowable
  - Two-stud corners
  - Elimination of redundant framing at openings
  - Engineered headers

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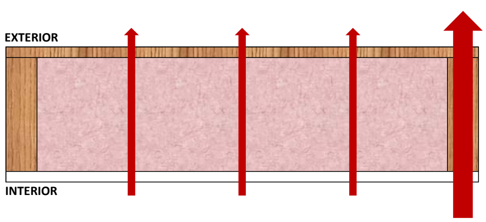
Thermal Bridging w/Advanced Framing



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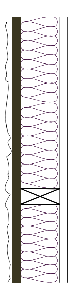
R-Value of Total Wall Assembly

2x6 wall @ 24" o.c.



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Lap siding	0.62	0.62
7/16" OSB	0.62	0.62
Batt insulation	21	--
2x6 stud	--	6.88
Gypsum board	0.45	0.45
Inside air film	0.68	0.68
Total R-values	23.54	9.42
Total U-factor (1/R-value)	0.0425	0.1062

$U_{overall}$ = (0.0425x.85)+(0.1062x.15) = 0.0521

$R_{overall}$ = 1/0.0521 = **19.2**

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Data pulled from "Typical Thermal Properties of Common Building and Insulating Matereials": 2009 ASHRAE Handbook

U-Factor Compliance

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EQUIVALENT *U*-FACTORS[a]

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$R_{overall}$ = 1/0.0521 = **19.2**

2009 IRC Table N1102.1.2

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Two Different Strategies

- **Advanced Framing – Thermal Break**
  - Engineered headers
  - Ladder blocking @ intersecting partitions
- **Advanced Framing – Fewer Bridge Elements**
  - 24" o.c. stud spacing
  - Elimination of redundant elements at openings
  - Two-stud corners

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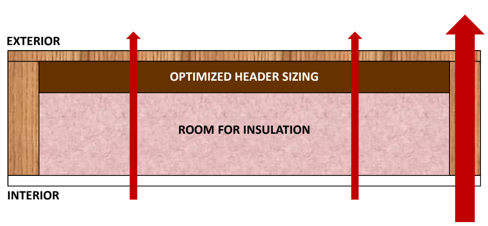
Advanced Framing – Thermal Break



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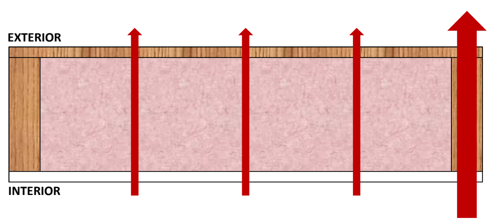
Advanced Framing – Fewer Elements



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Advanced Framing – Key Considerations

- **Wall bracing**
- **Cladding attachment**
- **Framing alignment**
- **Code limitations**
  - Stud spacing (2009 IRC Table R602.3(5))
  - Prescriptive design vs. engineered design

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2009 IRC Table R602.3(5)

TABLE R602.3(5)
SIZE, HEIGHT AND SPACING OF WOOD STUDS[a]

STUD SIZE (inches)	BEARING WALLS					NONBEARING WALLS	
	Laterally unsupported stud height[a] (feet)	Maximum spacing when supporting a roof-ceiling assembly or a habitable attic assembly, only (inches)	Maximum spacing when supporting one floor, plus a roof-ceiling assembly or a habitable attic assembly (inches)	Maximum spacing when supporting two floors, plus a roof-ceiling assembly or a habitable attic assembly (inches)	Maximum spacing when supporting one floor height[a] (feet)	Laterally unsupported stud height[a] (feet)	Maximum spacing (inches)
2 × 3[b]	—	—	—	—	—	10	16
2 × 4	10	24[c]	16[c]	—	24	14	24
3 × 4	10	24	24	16	24	14	24
2 × 5	10	24	24	—	24	16	24
2 × 6	10	24	24	16	24	20	24

2009 IRC Table R602.3(5)

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Summary

- **Thermal bridging is a natural consequence of low-rise light-frame construction**
  - Effects of thermal bridging can be reduced, but not eliminated
- **Two main methods for managing thermal bridging:**
  - Exterior rigid foam
  - Advanced framing
- **All methods for managing thermal bridging rely on proper detailing, attention to code requirements, and coordination with various trades**

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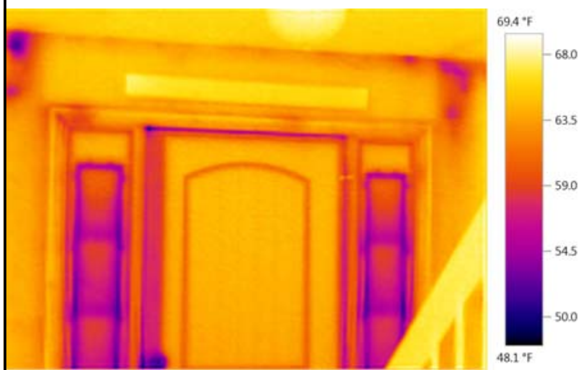

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Building Enclosure Functions

1. Support (structural)
2. Control (heat, air, moisture, smoke, odor, sound, fire, insects, etc.)
3. Aesthetics (exterior and interior finishes)
4. Distribution of Services (MEP)

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