September 10th, 2019 – Christopher Hine

Reducing Thermal Bridging with Continuous Exterior Insulation

www.phrc.psu.edu

PennState College of Engineering | PENNSYLVANIA HOUSING RESEARCH CENTER

NARI CEU Approved

ICC PREFERRED EDUCATION PROVIDER

PHRC

Description

The desire to build more efficient buildings along with current energy codes 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. This webinar will take a look at how much of an effect thermal bridging has on energy efficiency, and then review how Chapter 11 in the 2015 IRC prescriptively requires the installation of continuous insulation in climate zone 6. We will conclude by taking a look into installation details along with specific code requirements for compliance.

2

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.
- Understand the energy efficiency requirements for meeting the prescriptive path to the 2015 IECC and 2015 IRC Chapter 11 for insulating with exterior rigid foam.
- Understand how the added insulation changes the dynamic of the "building science" within the wall assembly. This includes the movement of the dew point based on R-values and cavity insulation and associated potential risks of having the dew point located within the wall cavity.

3

Agenda

- What is thermal bridging and how does heat flow?
- Types of rigid foam sheathing
- Exterior foam and the energy efficiency
- Wall bracing with exterior insulation
- Foam and water-resistive barriers
- Critical framing details
- Building Science

4

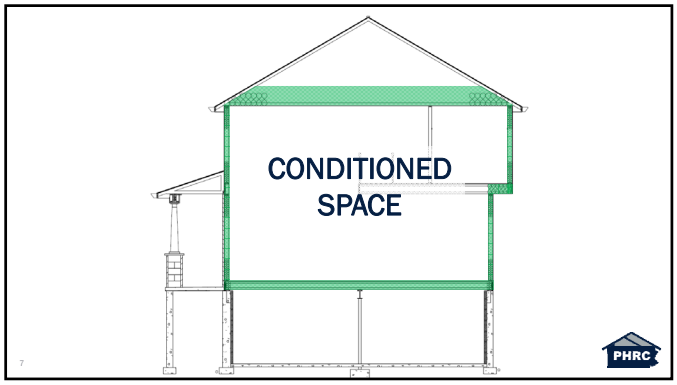
Movement of Heat

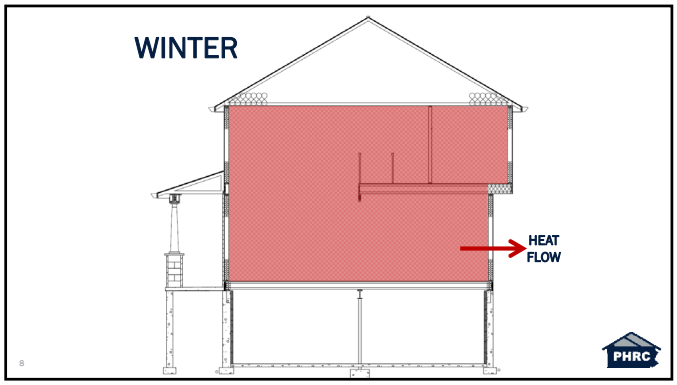
5

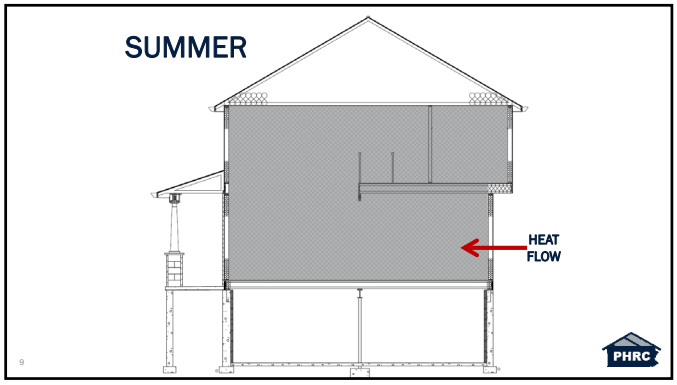
Heat Flow

- 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

6


CONDITIONED
SPACE
PHRC


WINTER
HEAT
FLOW
PHRC


SUMMER
HEAT
FLOW
PHRC

Conductive Heat Loss

- $Q = U \times A \times \Delta T$
  - Q = heat flow (Btu / hr)
  - U = thermal conductivity (U = 1 / R)
  - A = surface area (square feet)
  - ΔT = temperature difference across component (°F)

10

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

11

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

12

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
  - Lower U-Value = better insulating value

13

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

14

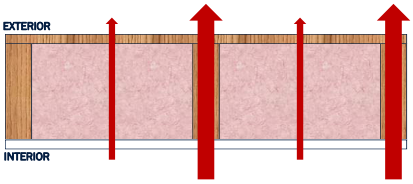
Source: 2009 ASHRAE Handbook - Fundamentals, www.spraypolyurethane.org

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

15

Thermal Bridging

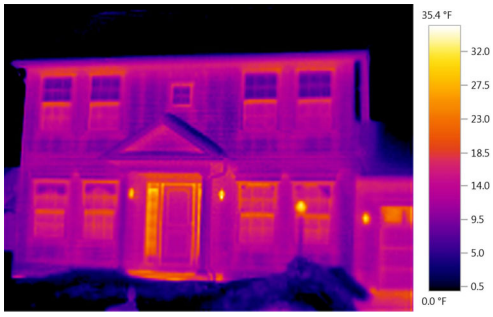


16

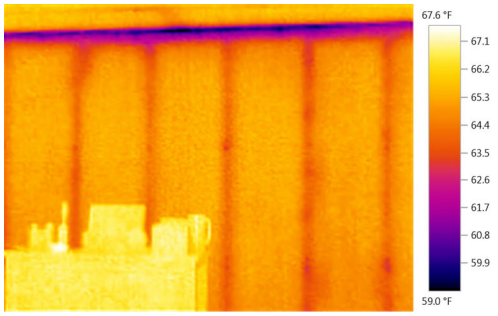
How Do We Visualize Thermal Bridging?

- 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)

17



18

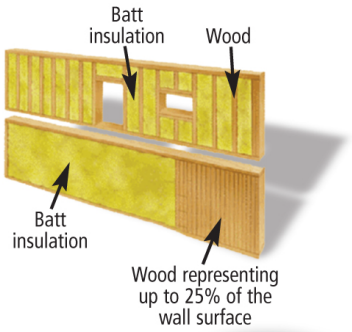


19

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%

20



21

Image courtesy of "Thermal Bridge Free Construction"; Sam Hagerman

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

22

TABLE N1102.1.2 (R402.1.2) INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION U-FACTOR[b]	SKYLIGHT[b] U-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING R-VALUE	WOOD FRAME WALL R-VALUE	MASS WALL R-VALUE[i]	FLOOR R-VALUE	BASEMENT[c] WALL R-VALUE	SLAB[d] R-VALUE & DEPTH	CRAWL SPACE[c] WALL R-VALUE
1	NR	0.75	0.25	30	13	3/4	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.65	0.25	38	20 or 13 + 5[h]	8/13	19	5/13[f]	0	5/13
4 except Marine	0.35	0.55	0.40	49	20 or 13 + 5[h]	8/13	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13 + 5[h]	13/17	30[g]	15/19	10, 2 ft	15/19
6	0.32	0.55	NR	49	20 or 13 + 5[h] or 15 or 19	15/20	30[g]	15/19	10, 4 ft	15/19
7 and 8	0.32	0.55	NR	49	20 or 13 + 5[h] or 15 or 19	19/21	30[g]	15/19	10, 4 ft	15/19

a. *R*-values are minimums. *U*-factors and SHGC are maximums. When insulation is installed in a cavity which is less than the label or design thickness of the insulation, the installed *R*-value of the insulation shall not be less than the *R*-value specified in the table.

b. The fenestration *U*-factor column excludes skylights. The SHGC column applies to all glazed fenestration.

Exception: Skylights may be excluded from glazed fenestration SHGC requirements in Climate Zones 1 through 3 where the SHGC for such skylights does not exceed 0.30.

c. "15/19" means R-15 continuous insulation on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. "15/19" shall be permitted to be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home. "10/13" means R-10 continuous insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.

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 N1101.10 and Table N1101.10.

g. Or insulation sufficient to fill the framing cavity. R-19 minimum.

h. The first value is cavity insulation, the second value is continuous insulation, so "13+5" means R-13 cavity insulation plus R-5 continuous insulation.

i. The second *R*-value applies when more than half the insulation is on the interior of the mass wall.

j. R-18 insulation to be permitted in place of R-20 requirement provided the wall framing factor is 20% or less or exterior walls with 24" o.c. nominal vertical stud spacing.

Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

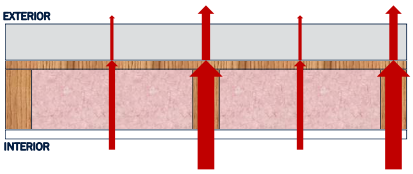
23

Exterior Foam Insulation

- Adding an insulating layer of exterior foam on the exterior of the wall framing provides a continuous thermal break
- 2015 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

24

Thermal Bridging w/Exterior Foam



25

Rigid Foam Sheathing

26

Three types of foam

- Expanded Polystyrene (EPS)
  - Insulfoam
  - R-Tech
  - Benchmark Foam
- Extruded Polystyrene (XPS)
  - STYROFOAM
  - FOAMULAR
  - GreenGuard
- Polyisocyanurate (ISO)
  - Thermax
  - Tuff-R
  - RMax

27

Expanded Polystyrene (EPS)

- **Common uses**
  - Insulated concrete forms
  - Insulated concrete block
  - SIPs
- **Typical thermal resistance:** R-4 per inch
- **Vapor permeability:** 5 perms (Class III vapor retarder
- **Durability**
  - Avoid prolonged exposure to UV
  - Requires care when cutting and handling (fragile edges)

28

Note: Vapor permeability varies with material thickness. Values listed are based on 1 inch.

Extruded Polystyrene (XPS)

- **Common uses**
  - Sheathing
  - Under-slab insulation
- **Typical thermal resistance:** R-5 per inch
- **Vapor permeability:** 1.1 perms (Class III vapor retarder)
- **Durability**
  - Avoid prolonged exposure to UV
  - Matrix is stronger than EPS beads. More forgiving on the jobsite.

29

Note: Vapor permeability varies with material thickness. Values listed are based on 1 inch.

Polyisocyanurate (ISO) (Polyiso)

- **Common uses**
  - Sheathing
- **Typical thermal resistance:** R-6.5 per inch
- **Vapor permeability:**
  - < 1.0 perms with fiberglass facing (Class II vapor retarder)
  - 0.03 perms with foil facing (Class I vapor retarder)
  - Class III vapor retarder on interior of wall assembly? R601.3.1
- **Durability**
  - Facing can be more resistant to UV
  - Matrix is stronger than EPS beads. More forgiving on the jobsite.

30

Note: Vapor permeability varies with material thickness. Values listed are based on 1 inch.

Exterior Foam and Energy Efficiency

31

The Energy Code

- 2015 International Energy Conservation Code
  - Chapter 4

- 2015 International Residential Code
  - Chapter 11

32

The Energy Code

- Three prescriptive options for wall insulation based on the 2015 ICC Codes (Climate zone 4 & 5)
  - Cavity insulation only (R-20)

    OR
  - Cavity plus continuous (R-13 + R-5)[h]
    - h. R-13 cavity insulation plus R-5 insulated sheathing
  - Equivalent *U*-factor (*U*-.060)

Table N1102.1.2
Table R402.1.2

Table N1102.1.4
Table R402.1.4

33

The Energy Code

- Three prescriptive options for wall insulation based on the 2015 ICC Codes (Climate zone 6)
  - Cavity plus continuous (R-20 + R-5)[h]
    OR
  - Cavity plus continuous (R-13 + R-10)[h]
    OR
  - Cavity plus continuous (R-18 + R-6.5)[h]
  - Equivalent *U*-factor (*U*-.045)

Table N1102.1.2
Table R402.1.2

Table N1102.1.4
Table R402.1.4

34

Total UA Alternative

- *N1102.1.5 (IECC R402.1.5)* If the total building thermal envelope UA (sum of U-factor times assembly area) is less than or equal to the total UA resulting from using the U-factors in Table N1102.1.4 (multiplied by the same assembly area as in the proposed building), the building shall be considered in compliance with Table N1102.1.2. The UA calculation shall be done using a method consistent with the ASHRAE Handbook of Fundamentals and shall include the thermal bridging effects of framing materials. The SHGC requirements shall be met in addition to UA compliance.

35

Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

U-Factor Compliance

TABLE N1102.1.4 (R402.1.4) EQUIVALENT *U*-FACTORS[a]

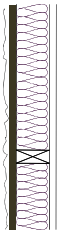
CLIMATE ZONE	FENESTRATION *U*-FACTOR	SKYLIGHT *U*-FACTOR	CEILING *U*-FACTOR	FRAME WALL *U*-FACTOR	MASS WALL *U*-FACTOR[b]	FLOOR *U*-FACTOR	BASEMENT WALL *U*-FACTOR	CRAWL SPACE WALL *U*-FACTOR
1	0.50	0.75	0.035	0.084	0.197	0.064	0.360	0.477
2	0.40	0.65	0.030	0.084	0.165	0.064	0.360	0.477
3	0.35	0.55	0.030	0.060	0.098	0.047	0.091[c]	0.136
4 except Marine	0.35	0.55	0.026	0.060	0.098	0.047	0.059	0.065
5 and Marine 4	0.32	0.55	0.026	0.060	0.082	0.033	0.050	0.055
6	0.32	0.55	0.026	0.045	0.060	0.033	0.050	0.055
7 and 8	0.32	0.55	0.026	0.045	0.057	0.028	0.050	0.055

36

Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

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**

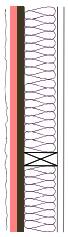
$U_{overall}$ = (0.0425x.75)+(0.1062x.25) = 0.0584
$R_{overall}$ = 1/0.0584 = **17.1**

37

Data pulled from "Typical Thermal Properties of Common Building and Insulating Materials"; 2009 ASHRAE Handbook

R-value of total wall assembly (CZ 4&5)

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**

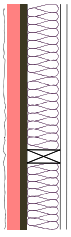
$U_{overall}$ = (0.0487x.75)+(0.0839x.25) = 0.0575
$R_{overall}$ = 1/0.0575 = **17.4**

38

Data pulled from "Typical Thermal Properties of Common Building and Insulating Materials"; 2009 ASHRAE Handbook

R-value of total wall assembly (CZ 6)

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	10	10
2x4 stud	--	4.38
Gypsum board	0.45	0.45
Inside air film	0.68	0.68
Total R-values	**25.54**	**16.92**
Total U-factor (1/R-value)	**0.0393**	**0.0591**

$U_{overall}$ = (0.0393x.75)+(0.0591x.25) = 0.0443
$R_{overall}$ = 1/0.0443 = **22.6**

39

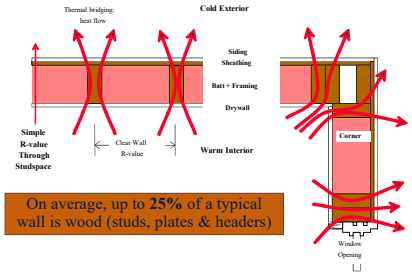
Data pulled from "Typical Thermal Properties of Common Building and Insulating Materials"; 2009 ASHRAE Handbook

Why?

- Total R-value for a 2x6 wall = **R-17.1**
- Total R-value for a 2x4 wall with R-5 exterior foam = **R-17.4**
- Total R-value for a 2x4 wall with R-10 exterior foam = **R-22.6**

40

Thermal Bridging



On average, up to **25%** of a typical wall is wood (studs, plates & headers)

41

Principle of Thermal Bridging

- Thermal Conductivity @ ~ 70° F
  - Wood (pine) = 0.14 (W/mK)
  - Fiberglass insulation = 0.04 (W/mK)
  - Air = 0.023 (W/mK)
- Therefore, wood has more than three times the thermal conductivity of fiberglass insulation

42

43

44

45

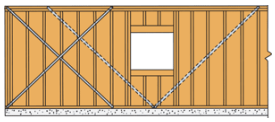
46

Wall Bracing with Foam

47

Options for Bracing with Foam

- Let in Bracing – LIB
  - May not be allowed depending on designed wall height



Images courtesy of www.stronglie.com

48

Options for Bracing with Foam

- Hybrid – Wood Structural Panel and Foam
  - R1102.2.7 – ***Walls with partial structural sheathing.*** *Where Section N1102.1.2 would require continuous insulation on exterior walls and structural sheathing covers 40 percent or less of the gross area of all exterior walls, the continuous insulation R-value shall be permitted to be reduced by an amount necessary to result in a consistent total sheathing thickness, but not more than R-3, on areas of the walls covered by structural sheathing. This reduction shall not apply to the U-factor alternative approach in Section N1102.1.4 and the total UA alternative in Section N1102.1.5.*

49

Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

Options for Bracing with Foam

- Wood Structural Panels – WSP
  - Foam over sheathing or sheathing over foam
    - Placement of WRB
    - Fastener length and structural properties

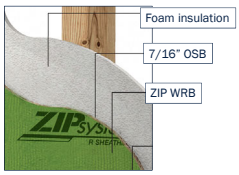
50

Options for Bracing with Foam

- Proprietary Systems
  - Huber Zip R-Sheathing
    - R-3.6 @ 1"
    - R-6.6 @ 1.5"

BOTH:
- Structural sheathing
- Water resistive barrier

Installation:
- Use compatible tape
- Follow MII for nailing



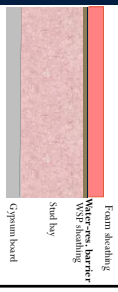
51

Foam and Water-Resistive Barriers

52

Water-Resistive Barrier Strategy 1

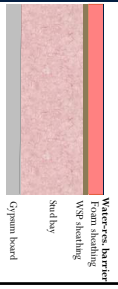
- WSP + WRB + Foam
  - Improved durability
    - WRB is supported by WSP
    - WRB is protected by foam
  - Recommended for areas with:
    - High exposure
    - High rainfall
  - Best for "innie" windows



53

Water-Resistive Barrier Strategy 2

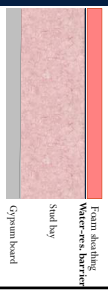
- WSP + Foam + WRB
  - Best for "outie" windows
  - More exposure to the elements
  - Longer fasteners required for housewrap



54

Water-Resistive Barrier Strategy 3

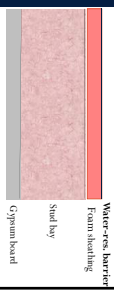
- **WRB under foam**
  - No structural sheathing
  - Housewrap stretched across stud
  - WRB is protected by foam
  - Care must be taken when installing WRB
  - Best for "innie" windows



55

Water-Resistive Barrier Strategy 4

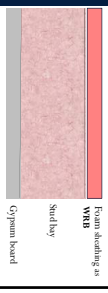
- **WRB over foam**
  - No structural sheathing
  - More exposure to the elements
  - Best for "outie" windows



56

Water-Resistive Barrier Strategy 5

- **Foam as WRB**
  - Check ES Report
  - All seams must be taped
  - Flashing details at openings are critical



57

Critical Framing Details

58

Inset Window Exterior Jamb Details (innie)

Images courtesy of the Cold Climate Housing Research Center

59

Inset Window Exterior Jamb Details (innie)

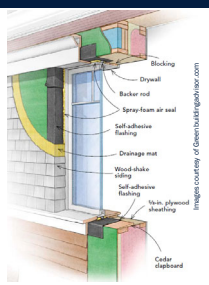
Azek | Stucco | Steel

Images courtesy of the Cold Climate Housing Research Center

60

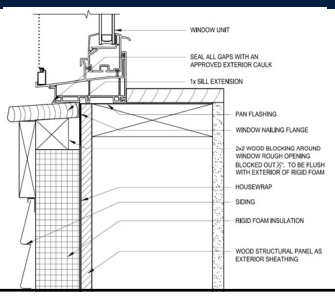
Window installation (innie)

- Example of an "innie" window installation. The window is set to the inside standard location.



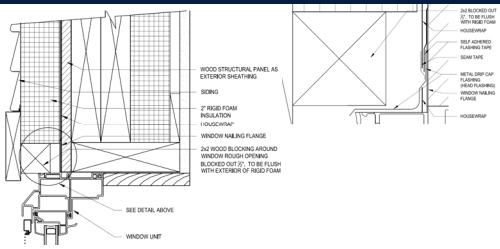
61

"Innie" window sill detail



62

"Innie" window head detail



63

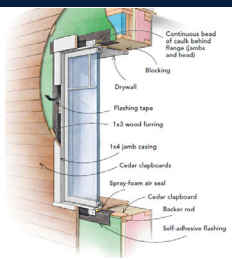
Outset Window Exterior/Interior Jamb Details (outie)

Images courtesy of Greenbuildingadvisor.com

64

Window installation (outie)

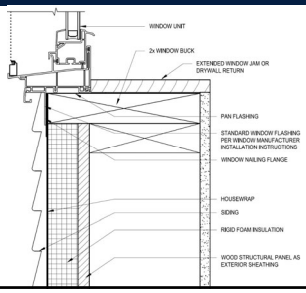
- Example of an "outie" window installation. The window is set to the outside standard location.



Images courtesy of Greenbuildingadvisor.com

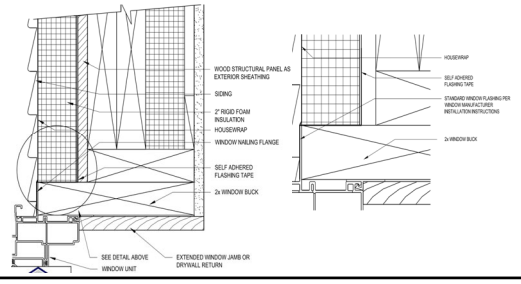
65

"Outie" window sill detail



66

"Outie" window head detail



67

Building Science

68

Exterior Insulation: Considerations

- Hygrothermal loading
  - Double vapor retarder / barrier
- Wall bracing
- Water-resistive barrier placement
  - Flashing
- Window & door installation

69

Drying Potential

- Assuming an assembly will get wet, will it be able to dry?
  - Through proper source control, occupant behavior, and assembly design, all building assemblies *must be designed so that they can **dry*** to the *interior, exterior, or both*.

70

2015 IRC Section R702.7 Vapor Retarders

- Class I or II vapor retarders are required on the interior side of framed walls in Zones 5, 6, 7, 8, and Marine 4
- Exceptions:
  - Basement walls
  - Below grade portion of any wall
  - Construction where moisture or its freezing will not damage materials

Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

2015 IRC Section R702.7.1 Class III Vapor Retarders

- Class III vapor retarders shall be permitted where any one of the conditions in Table R702.7.1 is met.
  - *By adding insulated sheathing, drying potential to exterior is reduced – Must maximize interior drying potential*

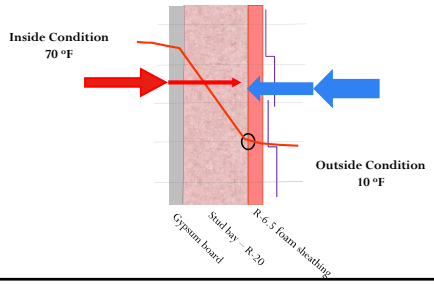
Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

2015 IRC Section R702.7.1 Class III Vapor Retarders

Climate Zone	Class III Vapor Retarders Permitted For:
4	Vented cladding over wood structural panels Vented cladding over fiberboard Vented cladding over gypsum Continuous insulation with R-value ≥ 2.5 over 2 x 4 wall Continuous insulation with R-value ≥ 3.75 over 2 x 6 wall
5	Vented cladding over wood structural panels Vented cladding over fiberboard Vented cladding over gypsum Continuous insulation with R-value ≥ 5 over 2 x 4 wall Continuous insulation with R-value ≥ 7.5 over 2 x 6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Continuous insulation with R-value ≥ 7.5 over 2 x 4 wall Continuous insulation with R-value ≥ 11.25 over 2 x 6 wall

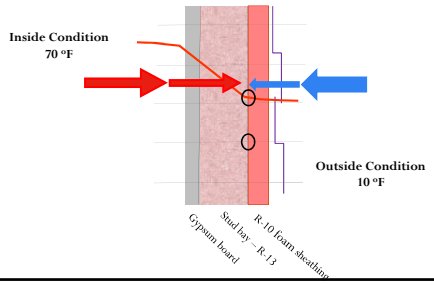
Source: International Code Council (ICC). (2014). 2015 International Residential Code, Country Club Hill, Ill.

How Does Insulation Placement Affect Face Temperature?



74

How Does Insulation Placement Affect Face Temperature?



75

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 (reducing the framing factor)
- All methods for managing thermal bridging rely on proper detailing, attention to code requirements, and coordination with various trades

76

Summary

- Identify the type of foam to be used
- Attach foam to framing per manufacturer's instructions
- Consider wall bracing options at the design phase
- Proper flashing at openings

77

Questions?

www.phrc.psu.edu

78

References

- International Code Council. (2014). 2015 International Energy Conservation Code, ICC, Country Club Hill, Ill.
- International Code Council. (2014). 2015 International Residential Code, ICC, Country Club Hill, Ill.
- International Code Council. (2008). 2009 International Residential Code, ICC, Country Club Hill, Ill.

79