High R Wall Systems for Deep Energy Reductions

BEY 5

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Building Science Corporation
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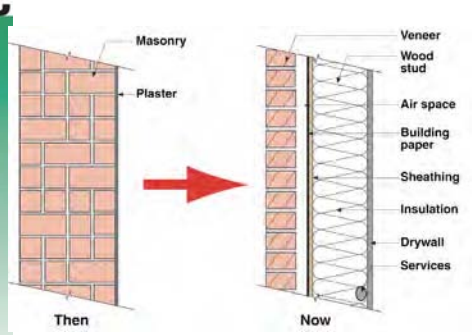
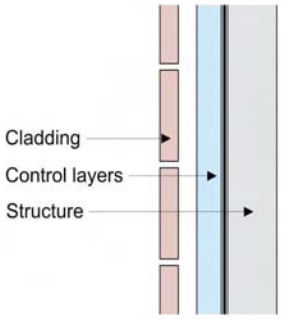
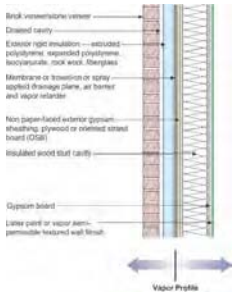
Building America
U.S. Department of Energy
Research Toward Zero Energy Homes



ENCLOSURE: SIMPLE LAYERS



THE BEST RESIDENTIAL WALL ASSEMBLY



- **Brick Face/ cavity/ impermeable membrane as drainage plane**
- **Impermeable foam as insulation**

Heat Flow

- Easiest to understand - transfer of energy
- Radiation
  - Solid body looses its heat energy to other solid body with less heat energy -MORE TO LESS
  - Can occur in a vacuum
  - Major factor in roof heat loss and heat gain
- Convection
  - Hot air rises creating convective loops -MORE TO LESS
  - Heat energy lost as loop reaches areas with less heat
  - Occurs through fluids (liquid or gas) air movement
- Conduction
  - Liquids and solids, touching other with less heat energy -MORE TO LESS
  - R values only deal with conduction, misleading

Thermally Efficient Assemblies

•Structure only where needed

•Insulating sheathing

•Blown insulations that fill the entire void

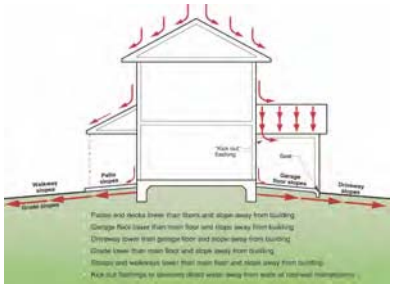
Air Flow

- Easy to understand
- Before you can control air you must enclose air
- Concept of building enclosures – no big holes
- Air barriers
- Air sealing

Moisture Flow
The Big Four of Moisture Control

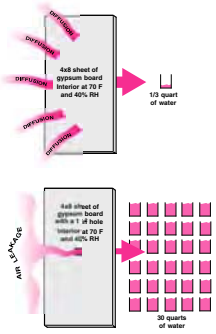
- Controlling rain entry
- Controlling ground water
- Controlling water vapor via air transport
- Controlling water vapor via vapor diffusion

Shed the water from the face of the building



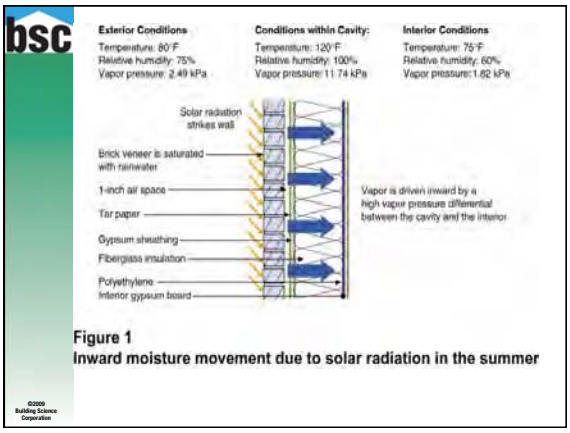
Moisture Movement through Air Leakage vs. Diffusion

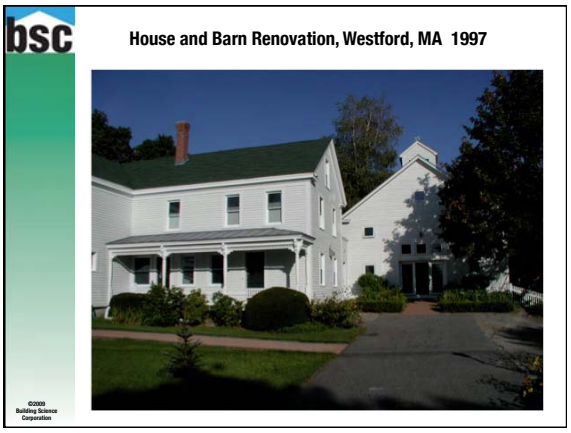
In most cold climates over an entire heating season, 1/3 quart of water can be collected by diffusion, 30 quarts of water can be collected by air leakage

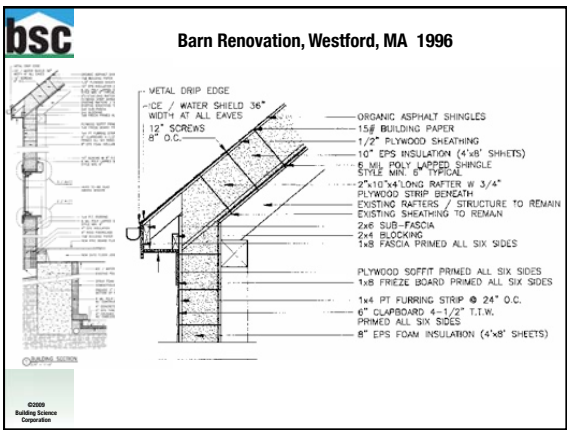


Vapor Diffusion Control

- **Diffusion**
  - **Migration of moisture by means of vapor pressure differential**
  - **Occurs in either direction based on climate conditions and interior levels of humidity**


Exterior Conditions
Temperature: 80°F
Relative humidity: 75%
Vapor pressure: 2.49 kPa
Conditions within Cavity:
Temperature: 120°F
Relative humidity: 100%
Vapor pressure: 11.74 kPa
Interior Conditions
Temperature: 75°F
Relative humidity: 60%
Vapor pressure: 1.62 kPa
Solar radiation strikes wall
Brick veneer is saturated with rainwater
1-inch air space
Tar paper
Gypsum sheathing
Fiberglass insulation
Polyethylene
Interior gypsum board
Vapor is driven inward by a high vapor pressure differential between the cavity and the interior
Figure 1
Inward moisture movement due to solar radiation in the summer


House and Barn Renovation, Westford, MA 1997


Barn Renovation, Westford, MA 1996
METAL DRIP EDGE
ICE / WATER SHIELD 36" WIDTH AT ALL EAVES
12" SCREWS 8" O.C.
ORGANIC ASPHALT SHINGLES
15# BUILDING PAPER
1/2" PLYWOOD SHEATHING
10" EPS INSULATION (4'x8' SHEETS)
6 MIL POLY LAPPED SHINGLE STYLE MIN. 6" TYPICAL
2"x10"x4'LONG RAFTER W 3/4" PLYWOOD STRIP BENEATH
EXISTING RAFTERS / STRUCTURE TO REMAIN
EXISTING SHEATHING TO REMAIN
2x6 SUB-FASCIA
2x4 BLOCKING
1x8 FASCIA PRIMED ALL SIX SIDES
PLYWOOD SOFFIT PRIMED ALL SIX SIDES
1x8 FRIEZE BOARD PRIMED ALL SIX SIDES
1x4 PT FURRING STRIP @ 24" O.C.
6" CLAPBOARD 4-1/2" T.T.W. PRIMED ALL SIX SIDES
8" EPS FOAM INSULATION (4'x8' SHEETS)


Barn Renovation, Westford, MA 1996


Barn Renovation, Westford, MA 1996


Barn Renovation, Westford, MA 1996

Barn Renovation, Westford, MA 1996

House Renovation, Westford, MA 1997

House Renovation, Westford, MA 1997

House Renovation, Westford, MA 1997

Duplex Renovation, Somerville, MA 2001

Duplex Renovation, Somerville, MA 2001

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Duplex Renovation, Somerville, MA 2001

Single Family Home Renovation, Concord, MA 2007

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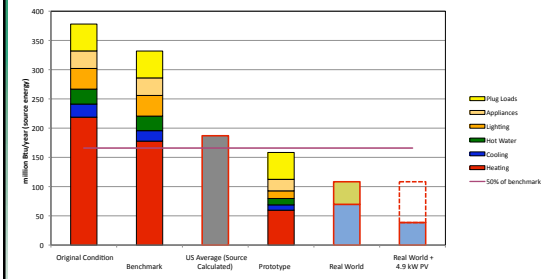


Duplex Exterior Retrofit – Arlington, MA, 2009

Duplex Exterior Retrofit – Arlington, MA, 2009

- Existing House
  - Duplex building (first floor unit; second/third floor unit)
  - ~3000 sf total both units
  - Very leaky (11.4 ACH 50)
  - Some existing wall insulation (retrofitted sidewalls)
  - Incomplete roof/ceiling insulation; some in poor repair
  - Single-glazed double hung wood windows (sashcord units) with storm windows
  - Single-pipe steam heating (x2 boilers) with tankless coil DHW
  - Homeowner renovating exterior: energy upgrades?

Duplex Exterior Retrofit – Arlington, MA, 2009

- Wall Retrofit
  - Two 2" layers of polyisocyanurate foam (R-26 continuous)
  - Corrugated housewrap as secondary drainage plane inboard of foam
  - ¾" strapping creates drained & ventilated cavity (and secures rigid foam board)
  - NuCedar polymer interlocking siding
  - Air barrier detailing
  - ~$4/sf installed upgrade cost for 4" foam (does not include residing of house)

Duplex Exterior Retrofit – Arlington, MA, 2009

Wind

- Single glazed + storm and double glazed windows
- Insert replacement windows chosen Low E Argon (donated)
- Pan flashed opening
- Integrated with drainage plane

Duplex Exterior Retrofit – Arlington, MA, 2009

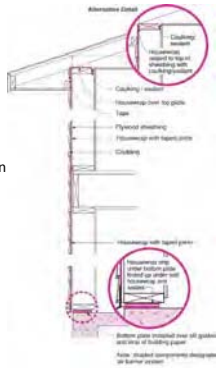
- Roof Retrofit
  - Current roof—existing risk of wintertime condensation damage
  - Risk increased: airtightness → higher interior RH → greater condensation potential
  - Two 3" layers polyisocyanurate chosen (+ plywood nail base)

Duplex Exterior Retrofit – Arlington, MA, 2009

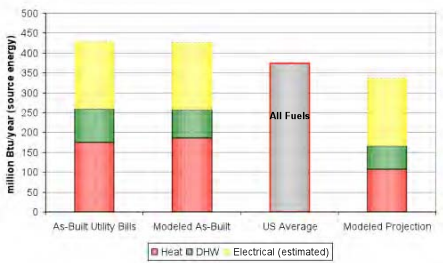
- Replacement Windows
  - Risk of water intrusion at windows
  - Complete flashing of existing window opening
  - Low-E/Argon insert frame units
  - Extension sills & jambs required
  - ~$35,000+ installed cost

Duplex Exterior Retrofit – Arlington, MA, 2009

- Exterior Air Barrier (Concept)
  - Shown here with housewrap on exterior as air barrier
  - Bottom of wall: sill plate inaccessible
  - Top of wall: connection between wall air barrier & ceiling air barrier (vented attic)
  - Penetrations/windows
  - How effective?—total air leakage to be tested



Duplex Exterior Retrofit – Arlington, MA, 2009



- 43% heating energy savings projected
- 14% domestic hot water savings projected (only one unit)
- ~$1500/year savings heating ($3/gallon oil)
- $275/year savings domestic hot water ($1.65/therm gas)

Single Family Home Renovation, Bedford, MA 2009

Retrofit of Existing Farmhouse into a 2 Story Single Family Home with 3 Bedrooms and 2.5 Baths

The Farmhouse is located in a Cold Climate, Climate Zone 5A (5596 HDD, 5358 CDH)

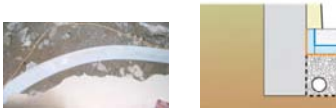
Existing Farmhouse

Single Family Home Renovation, Bedford, MA 2009

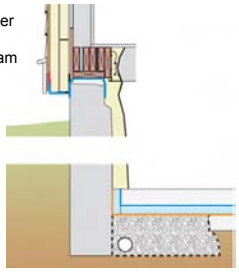
Single Family Home Renovation, Bedford, MA 2009

Basement Details

- Capillary Break installed under new sill beam
- 2"-3" High Density Spray Foam (~R13 – R19.5) applied to Rubble Stone Foundation
- Intumescent Paint fire protection for spray foam
- R-10 XPS under New Slab



Perimeter Drain



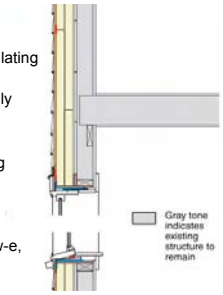
Basement Wall Section

Wall Details

- 4" Cellulose in Walls (R-14)
- 2" – 4" Foil-Faced Polyiso Insulating Sheathing (R-13 to R-26)
  - Joints staggered horizontally and vertically
  - All joints taped and sealed
- Wood furring strips, vinyl siding

High Performance Windows

- U = 0.31, SHGC = 0.32
- Double pane, vinyl-framed, low-e, argon fill

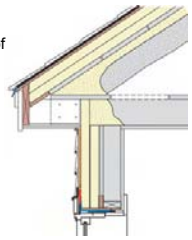


Typical Wall Section

- Window installation

Roof Details

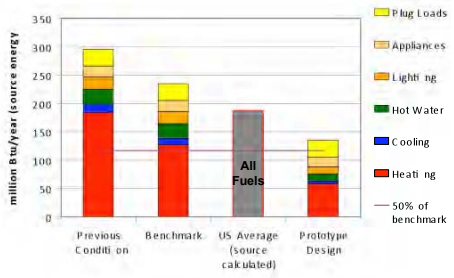
- High Density Spray Foam Air Seal at Roof Perimeter
- Spray Foam Flash Coat 1"-2" (~R6-12) to underside of Roof Sheathing and at Gable Walls
- Cellulose Netted and Blown 2"-4" (~R7-14) between Roof Rafters and Gable Framing
- 4" (R26) Foil-Face Polyiso Insulating Sheathing, in (2) Layers
  - Joints staggered horizontally and vertically
  - All joints taped and sealed
- Nail base, Ice and Water Membrane, Asphalt Shingles



Basement Wall Section

50

Projected Energy Use



Above grade walls

- Interior retrofit limits improvements to airtightness, rain control,thermal bridge
- Exterior allows excellent improvements and increased durability
- Windows should be done at the same time
- Installation cost $200+/- so get good windows, eg vinyl triple glazed for $30/sf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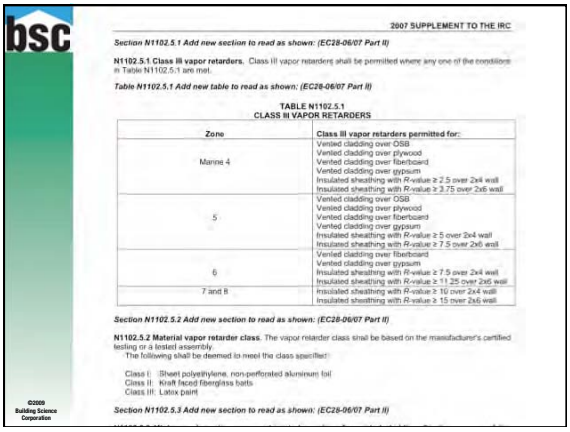
Windows

- Important choice!
- Need better rain control
- Improved R-value of course

Exterior Covering Unventilated[2]	Sheathing	Allowable Interior Vapor Resistance Requirements by Class			
		Climate Zone			
		Marine 4	5	6	7
	OSB	Class I, II	Class I, II	Class I, II	Class I, II
	Plywood	Class I, II	Class I, II	Class I, II	Class I, II
	Gypsum[4]	Class I, II	Class I, II	Class I, II	Class I, II
	Insulating Sheathing[3]	Class I, II, III (R-2.5 or greater)[3]	Class I, II, III (R-5 or greater)[3]	Class I, II, III (R-7.5 or greater)[3]	Class I, II, III (R-10 or greater)[3]
	Fiberboard	Class I, II	Class I, II	Class I, II	Class I, II
	Other	Class I, II	Class I, II	Class I, II	Class I, II

Notes:
(2) When insulating sheathing is installed over other sheathing, requirements for insulating sheathing shall govern
(3) Insulating sheathing R-values shown in parenthesis are for 2x4 wall construction. 2x6 walls require insulating sheathing R-values to be increased 50%.
(4) When insulating sheathing has a vapor permeance of greater than Class III, requirements for gypsum sheathing shall govern
When insulating sheathing having a vapor permeance of greater than Class III is installed over other sheathing, requirements for insulating sheathing shall govern
(5) Stucco
Brick/Stone/Masonry Veneer
Wood/Wood Based/Fiber Cement
Panel



2007 SUPPLEMENT TO THE IRC

Section N1102.5.1 Add new section to read as shown: (EC28-06/07 Part II)

N1102.5.1 Class III vapor retarders. Class III vapor retarders shall be permitted where any one of the conditions in Table N1102.5.1 are met.

Table N1102.5.1 Add new table to read as shown: (EC28-06/07 Part II)

TABLE N1102.5.1
CLASS III VAPOR RETARDERS

Zone	Class III vapor retarders permitted for:
Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 2.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 3.75 over 2x6 wall
5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 5 over 2x4 wall Insulated sheathing with *R*-value ≥ 7.5 over 2x6 wall
6	Vented cladding over fiberboard Vented cladding over gypsum Insulated sheathing with *R*-value ≥ 7.5 over 2x4 wall Insulated sheathing with *R*-value ≥ 11.25 over 2x6 wall
7 and 8	Insulated sheathing with *R*-value ≥ 10 over 2x4 wall Insulated sheathing with *R*-value ≥ 15 over 2x6 wall

Section N1102.5.2 Add new section to read as shown: (EC28-06/07 Part II)

N1102.5.2 Material vapor retarder class. The vapor retarder class shall be based on the manufacturer's certified testing or a tested assembly.
The following shall be deemed to meet the class specified:

Class I: Sheet polyethylene, non-perforated aluminum foil
Class II: Kraft faced fiberglass batts
Class III: Latex paint

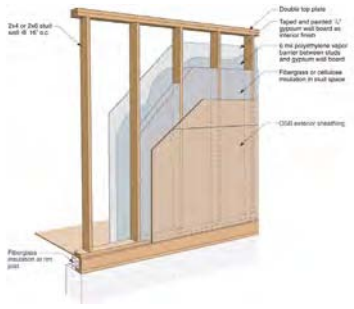
Section N1102.5.3 Add new section to read as shown: (EC28-06/07 Part II)

HIGH R-VALUE WALL CASE STUDIES

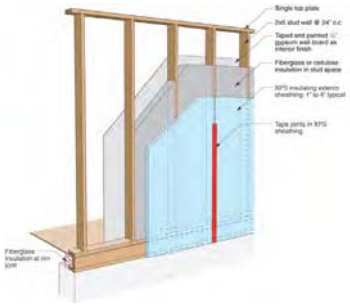
Overview of the High R Case Study Project

- Examines thermal and moisture control, durability, buildability, cost, and material use
- Focused on Cold Climate (using Minneapolis as representative)
- Reviewed 12 wall assemblies including standard construction and "High R" walls

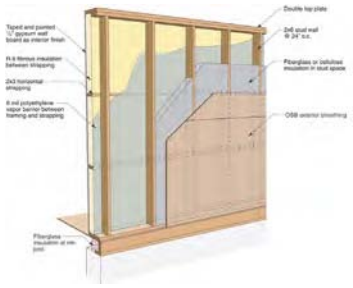
Case 1: Standard Construction Practice



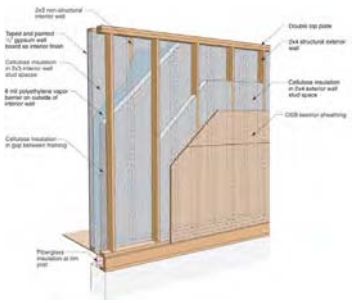
Case 2: Advanced framing + Insulating Sheathing



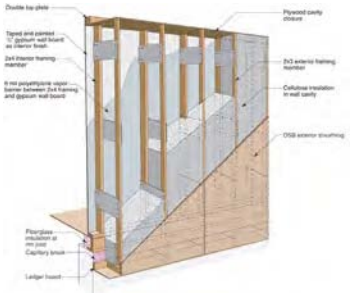
Case 3: Interior 2x3 horizontal strapping



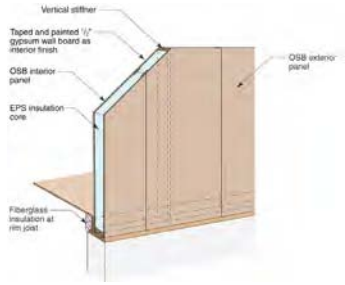
Case 4: Double Stud



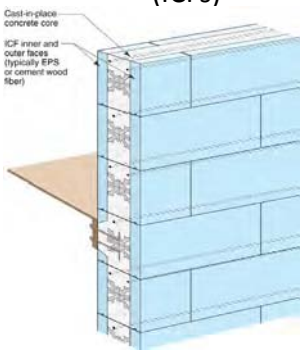
Case 5: Larsen Truss



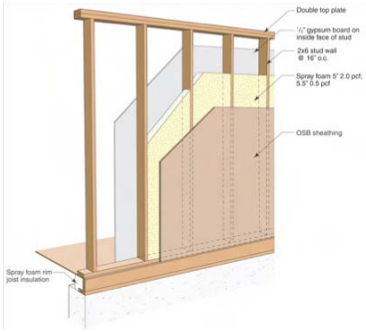
Case 6: Structural Insulated Panel Systems



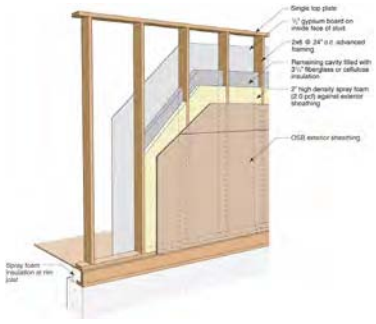
Case 7: Insulated Concrete Forms (ICFs)



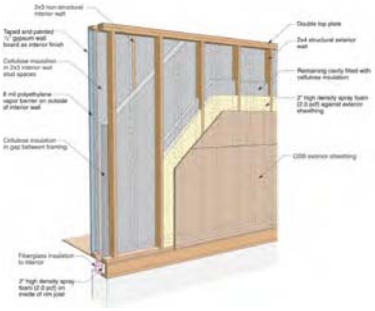
Case 8: Standard with Spray Foam



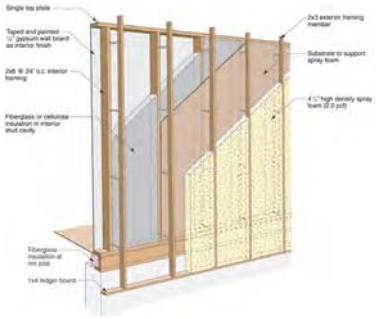
Case 9: Hybrid – "Flash and Fill"



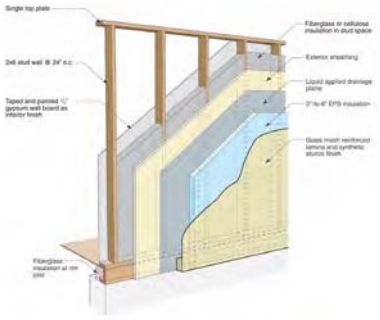
Case 10: Double Stud with Spray Foam



Case 11: Larsen Truss with Exterior Spray Foam



Case 12: Exterior Insulation Finish System



These are High R-value Walls

Case	Description	R-value Whole Wall	Rim Joist	R-value Clear Wall	Top Plate	Fraction Framing
1bii	2x4, 16"oc, R13FG + OSB (25%ff)	10.0	9.8	10.1	9.8	25%
1b	2x4 OVE, 24"oc, R13FG + OSB	11.1	9.8	11.5	9.8	16%
1aii	2x6, 16"oc, R19FG + OSB (25%ff)	13.7	12.3	14.1	12.5	25%
6a	SIPs (3.5" EPS)	14.1	12.3	14.5	10.6	
1a	2x6 OVE, 24"oc, R19FG + OSB	15.2	12.3	16.1	12.5	16%
7a	ICF - 8" foam ICF (4" EPS)	16.4		16.4		
8b	2x6 OVE, 24" o.c., 5.5" R21 0.5 pcf SPF, OSB	16.5	13.1	17.2	16.6	16%
7c	ICF - 14" cement woodfiber ICF with Rockwool	17.4		17.4		
9	2x6 OVE, 24"oc, 2" SPF and 3.5" fibrous fill	17.5	13.2	18.4	17.7	16%
8a	2x6 OVE, 24" o.c., 5" 2 pcf R29 SPF, OSB	19.1	13.6	20.3	19.5	16%
2a	2x6 OVE, 24"oc R19FG + 1" R5 XPS	20.2	18.5	20.6	20.3	16%
7b	ICF - 15" foam ICF (5" EPS)	20.6		20.6		
3	2x6 OVE, 24"oc, 2x4 R19+R8.6ci	21.5	13.4	23.5	18.4	16%
4	Double stud wall 9.5" R34 cellulose	30.1	14.3	33.5	28.8	
10	2x6 OVE, 24"oc, EIFS - 4" EPS	30.1	25.8	31.4	11.1	16%
4b	Double stud with 2" 2.0 pcf foam, 10" FG	32.4	15.9	36.2	28.5	
2b	2x6 OVE, 24"oc, R19FG + 4" R20 XPS	34.5	29.0	35.6	15.4	16%
6b	SIPs (11.25" EPS)	36.2	14	41.9	28.2	
5	Larsen Truss 12" R43 cellulose	36.5	18.6	40.5	34.8	
11	modified Larsen Truss with ext. spray foam	37.1	18.8	40.8	41.9	16%

Comparison Chart

	Thermal Control	Durability (wetti ng/drying	Buildability	Cost	Material Use	Total
Criteria Weighti ng	1	1	1	1	1	
Case 1: Standard Constructi on	1	3	5	5	4	18
Case 2: Advanced Framing	4	4	4	4	4	20
Case 3: Interior Strapping	3	3	3	4	3	16
Case 4: Double Stud	4	3	3	3	2	15
Case 5: Larsen Truss	4	3	2	3	2	14
Case 6: SIPs	4	4	3	3	3	17
Case 7: ICF	4	5	4	2	3	18
Case 8: Sprayfoam	5	5	4	2	4	20
Case 9: Flash and Fill (2" spuf and cell.)	4	4	4	3	4	19
Case10: Double stud with 2" spray foam and cell.	5	4	3	3	3	18
Case 11: Larsen Truss (ext. Spray foam insul.)	5	5	4	3	2	19
Case 12: EIFS with fibrous fill in space	5	5	4	3	3	20