High-Performance Wall Assemblies

Tuesday May 14, 2013

1:00 p.m.

Presented by:

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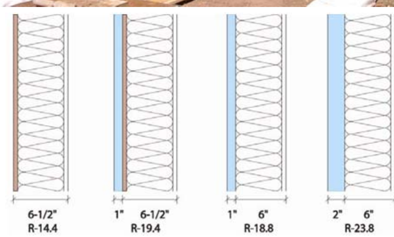
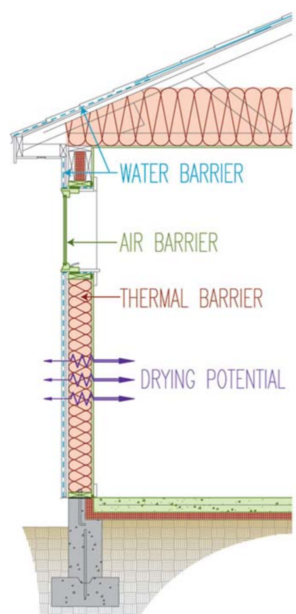


http://www.buildingscience.com

Presentation Objectives

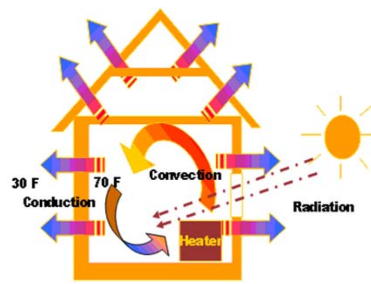
- Review the basic concept of heat transfer and definition of terms/parameters
- Illustrate calculation of U-factor and R-value for typical wall assemblies
- Discuss the basic concepts related to condensation in walls and ways to avoid or minimize moisture problems
- Introduce and present comparison of envelope walls with high R-values



http://www.buildinggreen.com; Steve Baczek Architect

Basic Concepts of Heat Transfer

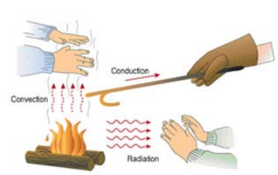
- We use insulation in walls as one approach to minimize heat flow across the envelope
- This in turn leads to:
  - Control of interior temperature
  - Occupant comfort
  - Reduction in condensation
  - Energy savings
- Heat transfer mechanisms:
  - Conduction
  - Convection
  - Radiation



https://www.e-education.psu.edu/egee102/node/2053

Definition of Conduction, Convection, Radiation

- Conduction: Heat transfer through solid material or between two materials at contact surfaces
- Convection: Heat transfer through gas or liquid when one part is heated (e.g., adjacent to hot solid surface) and expands/moves as density changes
- Radiation: heat transfer by electro-magnetic waves emitted from one surface traveling through a gas or vacuum and reaching another surface a distance apart

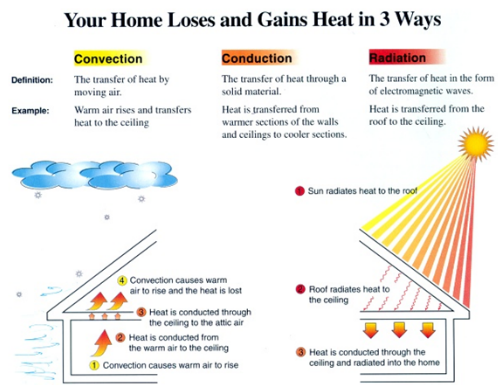


http://www.optotherm.com/infrared-heat.htm

Image courtesy of Waifer X via Flickr

Conversion of Heat Transfer Mechanisms

- Heat transfer mechanism can change from one to another mechanism
- Example:
  - Solar radiation heats the brick wall
  - Heat flows through wall by conduction
  - Interior gets warmed up by convection
  - Interior brick surface emits radiation and warms up other interior surfaces
- Insulation in walls is intended to control heat flow through conduction



http://www.houleinsulation.com/r-value.html

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Definition of Conductivity, Conductance, and thermal Resistance

- Conductivity k: Amount of heat flow across a unit area, though a unit thickness, for a unit temp. increase
  - SI Unit: W/m.k; US Unit: Btu-in./hr.ft^2.°F; 1 W/m.k = 0.144 Btu-in./hr.ft^2.°F
- Thermal Conductance C: Conductivity for a given thickness
  - SI Unit: W/m^2.k; US Unit: Btu/hr.ft^2.°F; 1 W/m^2.k = 5.678 Btu/hr.ft^2.°F
- Thermal Resistance R: Resistance of a layer to heat flow, 1/C
  - SI Unit, RSI: m2.k/W; US Unit, R: hr.ft^2.°F/Btu; 1 R (R-value) = 5.678 RSI
- Thermal Transmittance U: The ability of an envelope assembly to transfer heat by conduction, U-Factor=1/R_{total}

Where R_{total} = the sum of the R-values of all layers making up the envelope, including air film on each face

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Four Main Types of Wall Insulations

- Fiberglass batt: flexible, R3.14-4.30/inch
- Blown cellulose: loose fiber/pellets, R3.8-3.9/inch
- Rigid foam sheets: stiff panels, Expanded polystyrene (EPS) R4.0/inch, Extruded polystyrene (XPS) R5.0/inch
- Spray foam: sprayed in place, stiff, Polyurethane (foamed in place) R6.25/inch
- Notes:
  - Can add two 3 ½ in. R11 fiberglass batt to get R22, but need 7 in. cavity thickness; cannot compress batt and linearly increase R-value
  - Batt insulation between studs does not eliminate heat loss due to air leakage
  - If gaps exist between batt insulation and sheathing, convection heat loss could occur where air is free to move

Thermal Bridging, Cold Spots

- By placing insulation in stud cavity, the overall R-value will be on the order of 20-40% less than the R-value of the insulation – this is the result of thermal bridging
- Thermal Bridge: A component that creates a “bridge” for heat to flow over and by-pass the insulation
- Thermal bridges cause cold spots that may lead to condensation, heat loss, discomfort, or durability/deterioration issue for the wall

Framing Factor, U-factor, R-value

- To account for thermal bridge, we need to first determine the percentage of the area of framing within the wall surface
- For example consider 2x4 studs at 16" o.c.; the percentage of the stud area would be 1.5"/16"=9.4%, say 10%. This means the framing factor is 10%. However, because there are top and bottom plates, when these are also considered, the framing factor will be larger
- Next, we determine a weighted average R by considering the R-value through the insulation and the R-value through the studs
- U-factor= %insulation/$R_{insulation}$ + %framing/$R_{framing}$
- R-value=1/U-factor
  - $R_{insulation}$ = R-value for envelope segment through insulation
  - $R_{framing}$ = R-value for envelope segment through framing

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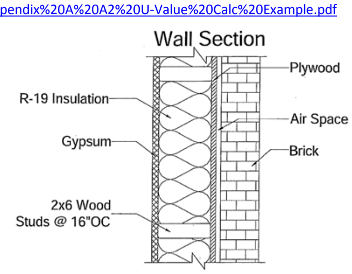
Example U-factor & R-value Calculations

Between Framing		At Framing	
Element	**R-value**	**Element**	**R-Value**
Inside Air Film	0.68	Inside Air Film	0.68
½" GWB	0.45	1/2" GWB	0.45
R-19 Insulation	19.00	2X6 Stud @ 16" O.C.	5.61
½" Plywood Sheathing	0.62	½" Plywood Sheathing	0.62
1/2" Air Space	0.90	1/2" Air Space	0.90
4" Brick	1.20	4" Brick	1.20
Outside Air Film	0.17	Outside Air Film	0.17
Total R-value	23.02	Total R-value	9.63
Framing Percentage			18%

http://www.wyoming.gov/loc/03302010_1/resources/Documents/design%20guidelines/Appendix%20A%20A2%20U-Value%20Calc%20Example.pdf

- U-factor= %insulation/Insulation R-value + %framing/Framing R-value
- U-factor=0.82/23.02 + 0.18/9.63 = 0.054
- R-value – 1/U-factor = 1/0.054 = 18.5



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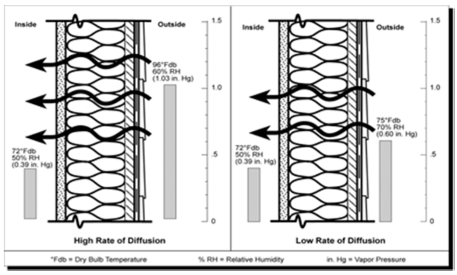
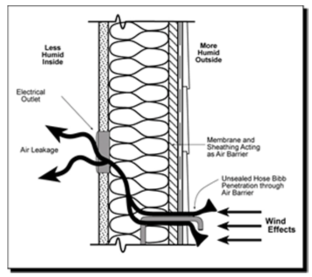
Understanding Condensation, Vapor Retarder, and Enclosure Configurations

- Mechanisms of Moisture Movement:
  - Water vapor moves from warmer side or higher air/vapor pressure side to colder side or lower air/vapor pressure side
  - Water vapor moves across the envelope either by air flow (e.g., air leakage) or by vapor diffusion through the material



Vapor diffusion through a wall



Air leakage through the wall

http://www.wbdg.org/resources/moisturemanagement.php

Vapor Retarder and Air Barrier

- The function of vapor retarder is to control vapor diffusion – retard vapor transport through the material
- The function of air barrier is to control vapor movement via air flow
- In some cases, an barrier may have material properties that can also function as vapor retarder – example: building paper

http://www.nachi.org/vapor-barriers.htm

http://imi-illinois.blogspot.com/2012/04/
air-barrier-training-at-abaa-conference

http://www.energyvanguard.com/blog-building-science

Permeability, Perm

- The effectiveness of vapor retarders to retard vapor flow is expressed as permeability with unit referred to as "perm".
- Ranges and example vapor barriers:
  - Perm≤0.1: vapor impermeable (rubber, glass, metal..)
  - Perm>0.1, ≤1.0: Vapor semi-impermeable (oil-based paint, vinyl, XPS≥1"…)
  - Perm>1.0, ≤10: Vapor semi-permeable (OSB, EPS, XPS<1", latex-based paint…)
  - Perm>10: Vapor permeable (gypsum board, plaster, stucco, house wrap…)

http://www.jmhomeowner.com/insulation/install/vaporretarders.asp

http://www.buildinggreen.com/auth/article.cfm/2003/11/1/CertainTeed-MemBrain-First-Smart-Vapor-Retarder/

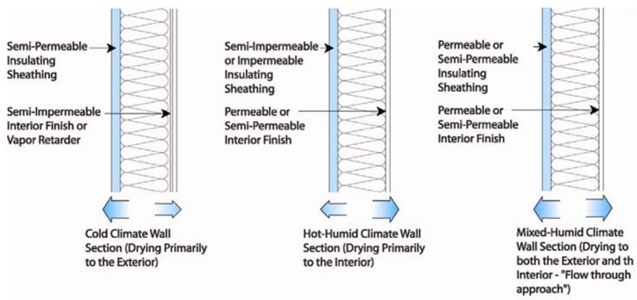
http://www.hpbmagazine.org/products/envelope/air-barriers

Classification of Vapor Retarders

- Class I Vapor Retarder: 0.1 perm or less
- Class II Vapor Retarder: >0.1 perm, ≤1.0 perm
- Class III Vapor Retarder: >1.0 perm, ≤10 perm
- Vapor Barrier = Class I Vapor Retarder
- Vapor Retarder vs. Air Barrier:
  - Air flow through a small hole can transport an order of magnitude more vapor compared to vapor diffusion through a drywall panel
  - Therefore, air barrier has a more important function compared to vapor retarder

Strategies to Control Vapor Transport

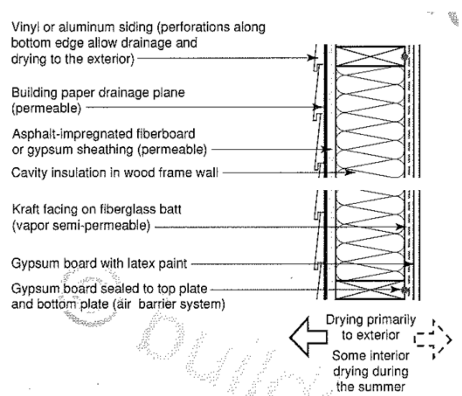
- The following strategies can be used:
  - Vapor retarders, Air barriers, Air pressure control
  - Control of interior moisture level (ventilation, dehumidifier)
- Overall strategy:
  - Reduce the chance of envelope to get wet (form condensation)
  - Build mechanisms for enclosure to dry to the interior or exterior if moisture accumulates



http://www.buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing

Wall Configuration for Cold Climates

- In cold climates moisture moves from warm interior to cold exterior so vapor retarder and air barrier is installed toward the interior warm surfaces
- Drying is toward the exterior, so permeable material is used as exterior sheathing



http://www.buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders

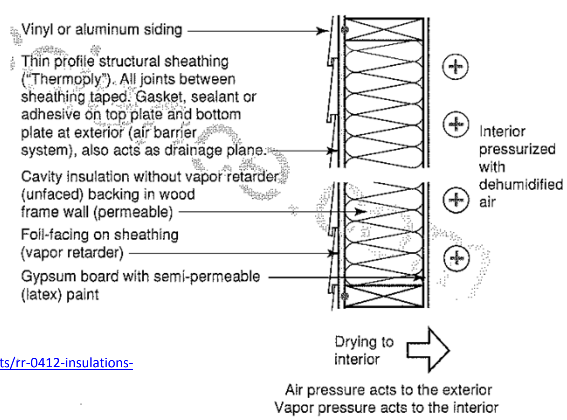
Classic Cold Climate Wall Assembly

- Vapor retarder to the interior (the kraft facing on the fiberglass batt)
- Air barrier to the interior
- Permeable exterior sheathing and permeable building paper drainage plane
- Ventilation provides air change (dilution) and also limits the interior moisture levels

Wall Configuration for Hot Climates

- In hot climates or cooling season, the vapor drive is from exterior to the interior; therefore for such dominant climates the air barrier and vapor retarder should be placed on the exterior side
- The envelope should be allowed to dry toward the interior, so permeable interior wall finishes should be used.
- One may use un-faced fiberglass batt insulation in the cavity
- Should not use oil-based paint on the drywall or vinyl wallpaper
- The interior should have positive air pressure with dehumidified air to control infiltration of exterior warm air

Wall Configuration for Hot Climates



http://www.buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders

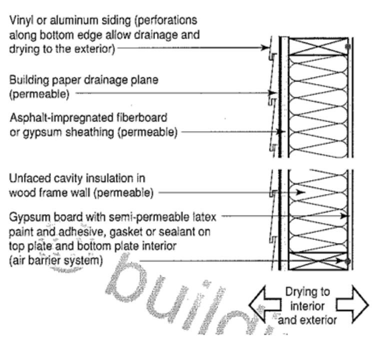
Classic Hot-Humid Climate Wall Assembly

- Vapor retarder to the exterior
- Air barrier to the exterior
- Pressurization of conditioned space
- Impermeable exterior sheathing also acts as drainage plane
- Permeable interior wall finish
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit the infiltration of exterior, hot, humid air
- Air conditioning also provides dehumidification (moisture removal) from interior

Wall Configuration for Mixed Climate

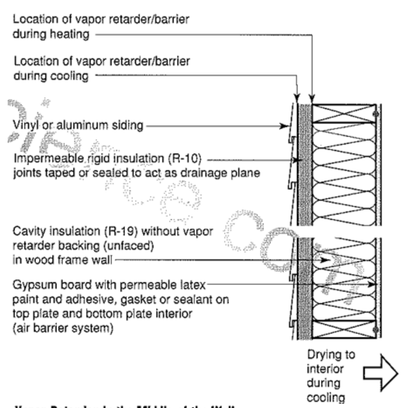
- In mixed climates, the enclosure should be allowed to dry to either the exterior, interior or both “flow through” wall.
- May have either cold climate or hot climate detail, but should regulate the interior air condition:
  - Use air pressure control during cooling
  - Use interior moisture control (ventilation during heating, dehumidification or air conditioning during cooling)
  - Rely on drying to the interior or exterior to get rid of the moisture accumulated
- For flow through design, use permeable material on both sides
- Using vapor retarder as exterior insulating sheathing (impermeable or semi-impermeable) – say foil-faced insulating sheathing; the air barrier can be toward the interior or exterior

Wall Configuration for Mixed Climate



Classic Flow-Through Wall Assembly
- Permeable interior surface and finish and permeable exterior sheathing and permeable building paper drainage plane
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit the infiltration of exterior moisture-laden air during cooling
- Ventilation provides air change (dilution) and also limits the interior moisture levels during heating
- Air conditioning/dehumidification limits the interior moisture levels during cooling

http://www.buildingscience.com/documents/reports/rr-0412-insulations-sheathings-and-vapor-retarders



Vapor Retarder In the Middle of the Wall
- Air barrier to the interior
- Permeable interior wall finish
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit the infiltration of exterior moisture-laden air during cooling
- Ventilation provides air change (dilution) and also limits the interior moisture levels during heating
- Air conditioning/dehumidification limits the interior moisture levels during cooling
- Impermeable exterior sheathing also acts as drainage plane

Introduction of Walls with High R-values

- There is demand for increased insulation in some clod climates (R-value larger than R18)
- In some envelope systems, use of higher insulation may increase the risk of condensation on the interior face of exterior sheathing because the sheathing will be colder
- Need to define how overall R-value is determined – the whole-wall R-value is defined to consider all the framing (studs, top and bottom plates, rim joists), wall to wall corners, wall to roof, wall to floor, wall to door, and wall to window connections as well.
- Study by Straube and Smegal (2009) *[Building America Special Research Project: High-R Wall Case Study Analysis – RR-0903, March 2009]* compares several high R-value walls based on thermal performance, moisture control, constructability and cost, and other considerations
- Computer programs Therm used for thermal analysis and WUFI used for hygro-thermal analysis of wood-frame systems – the walls were assumed for Minneapolis, MN IECC Climate 6

Materials and Properties Used

- Conventional framing assumed 2x4 studs at 16" o.c. with a framing factor of 25%
- Advanced framing is defined as 2x6 framing at 24" o.c. and single top plate and a framing factor of 16%
- The Therm analysis carried out for an interior temp. of 68°F and exterior temp. of -4°F.
- Cellulose and fiberglass batt assumed to have similar R-values per inch, however, installed R-value of cellulose will be higher because of the potential air gaps between batt insulation and sheathing, especially around plumbing, electrical, …

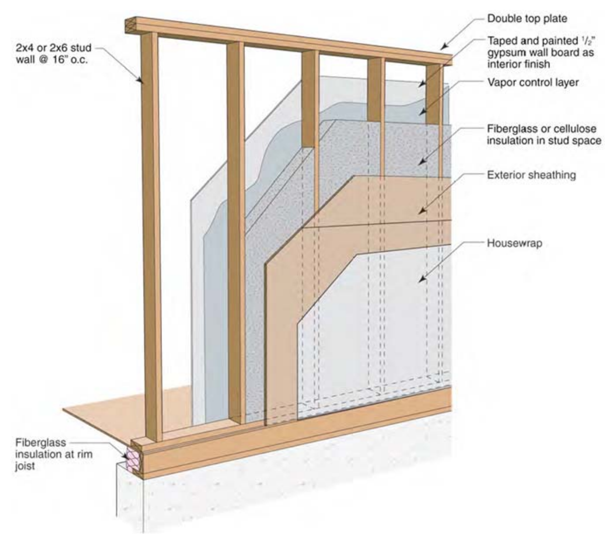
Material	Thermal Conductivity K (W/m.K)	R-value per inch R (hr. °F.ft²/Btu)
R8 Fiberglass Batt (2.5")	0.045	3.1
R13 Fiberglass Batt (3.5")	0.039	3.7
R19 Fiberglass Batt (5.5")	0.042	3.4
Extruded Polystyrene (XPS)	0.029	4.9
Expanded Polystyrene (EPS)	0.038	3.7
Framing Lumber	0.140	1.0
Cellulose Insulation	0.044	3.5
0.5 pcf Spray Foam	0.037	3.8
2.0 pcf Spray Foam	0.025	5.7
OSB	0.140	1.0

List of Wall Types & Whole Wall R-values

Wall No.	Wall Type	Description	Whole Wall R-value
1a	Conventional 2x4 framing	2x4, 16" o.c, R13 FG, OSB	10.0
1b	Conventional 2x6 framing	2x6, 16" o.c., R19 FG, OSB	13.7
2a	Advanced framing 1" XPS	2x6 AF, 24" o.c., R19 FG +1"R5 XPS	20.2
2b	Advanced framing 4" XPS	2x6 AF, 24" o.c., R19 FG + 4"R20 XPS	34.5
3	Int. 2x3 horiz. Strapping	2x6 AF, 24" o.c., 2x3 R19 + R8 FG	21.5
4	Double stud	Double stud wall 9.5" R34 cellulose	30.1
5	Truss wall	Truss wall 12" R43 cellulose	36.5
6	SIPs	SIPs 3.5" EPS, 11.25" EPS	14.1, 36.2
7	ICFs	ICFs 9" foam (5" EPS), 15" foam (5" EPS)	20.2, 20.6
8a	Advanced framing o.5 pcf SF	2x6 AF, 24" o.c, 5.5" 0.5 pcf R21 SPF, OSB	16.5
8b	Advanced framing 2.0 pcf SF	2x6 AF, 24" o.c, 5.5" 2.0 pcf R29 SPF, OSB	19.1
9	Hybrid system, HD 2.0 pcf Flash & Fill	2x6 AF, 24" o.c., 2" SPF, 3.5" cellulose	17.5
10	Double stud, 2" HD 2 pcf SF & fiber insul.	Double stud, 2" 2pcf SPF, 7.7" cellulose	32.4
11	Ext. HD 2 pcf offset framing SPF & insul.	Offset frame wall, ext. SPF	37.1
12	Ext. insulation finish sys (EIFS)	2x6 AF, 24" o.c., EIFS, 4" EPS	30.1

Case 1a, 1b: Conventional Framing

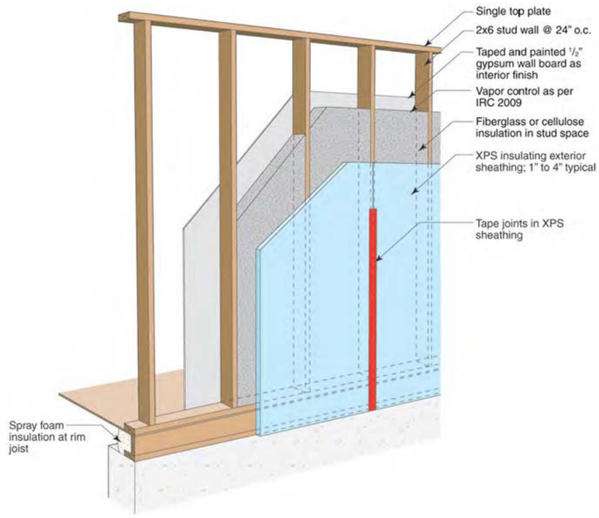
- There will be a difference in performance when is batt vs. cellulose is used
- All trades quite familiar with this construction
- R10-R13.7



http://www.buildingscience.com/documents/reports/rr-0903-building-america-special-research-project-high-r-walls

Case 2: Adv. Framing + Insulated Sheathing

- AF reduces the framing factor
- Single plate requires alignment of studs
- Exterior insulated sheathing reduces thermal bridging
- Cost will be greater for >2" thick XPS
- Details at doors and windows need adjustment
- R20.2-R34.5



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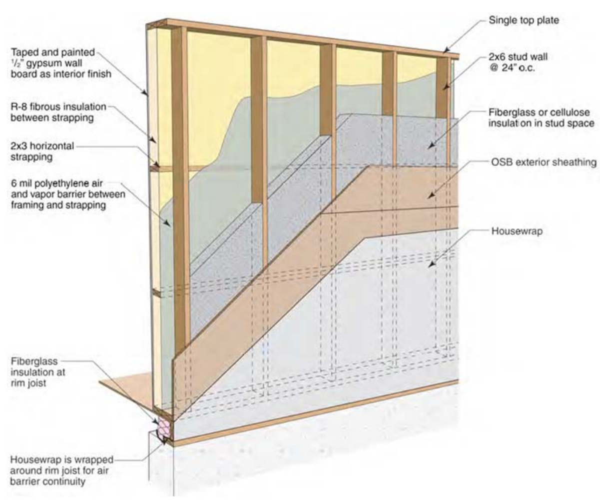
Case 3: Interior 2x3 with Horiz. Strapping

- Design tries to reduce thermal bridge by adding 2x3 horiz. Strapping on the interior side over the vapor retarder
- Horiz. Strapping is new to builders, would require training
- Details for windows need developed
- R21.5



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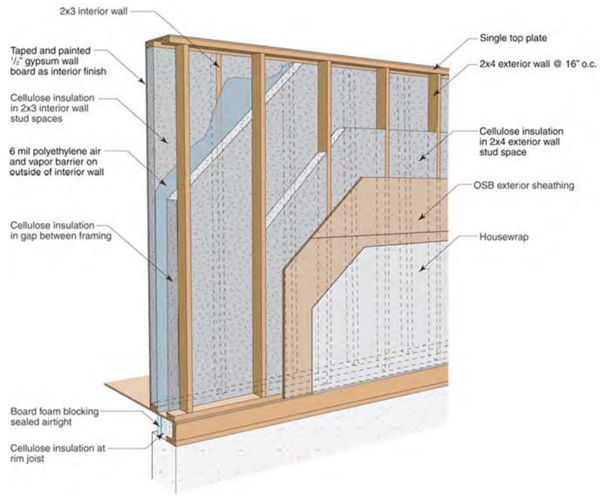
Case 4: Double Stud

- Normally used in multi-family designs to reduce noise and improve fire resistance
- Ext. framing is standard 2x4 at 16”
- Int. framing is non-load bearing at 24”
- Space in bet. Filled with cellulose insul.
- Builders need training
- R30.1



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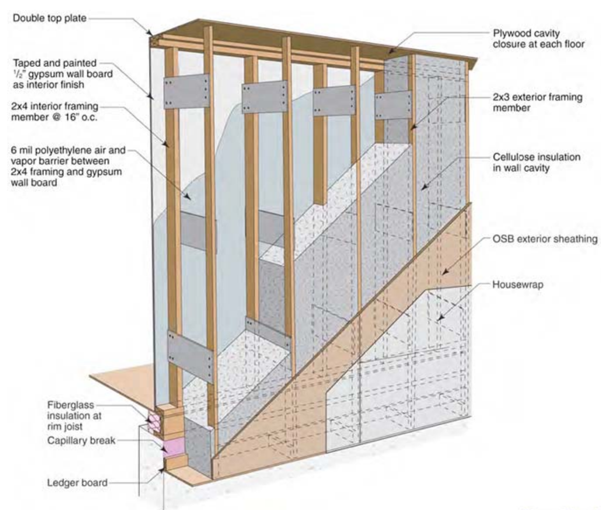
Case 5: Truss Wall

- Not a widely used system
- R36.5



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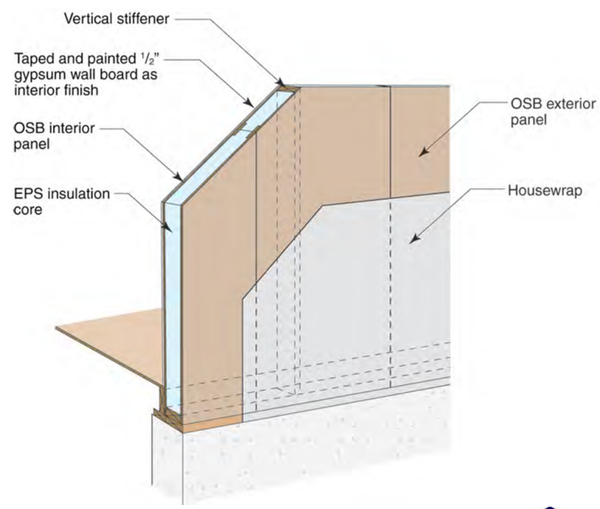
Case 6: Structural Insulated Panels (SIPs)

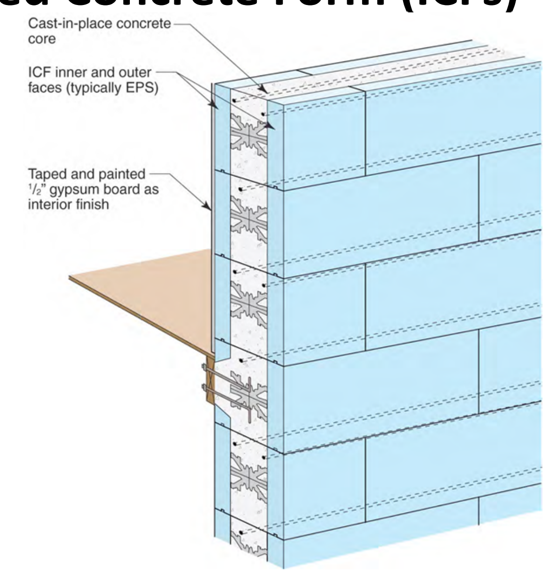
- Sandwich panel
- Continuous plane of insulation
- Thermal bridge at vertical connection of panels & top & bottom plates
- Builders need training
- R14.1-R36.2



http://www.buildingscience.com/documents/reports/rr-0903-building-america-special-research-project-high-r-walls

Case 7: Insulated Concrete Form (ICFs)

- More expensive than wood systems, but easy to construct
- R20.2-R20.6



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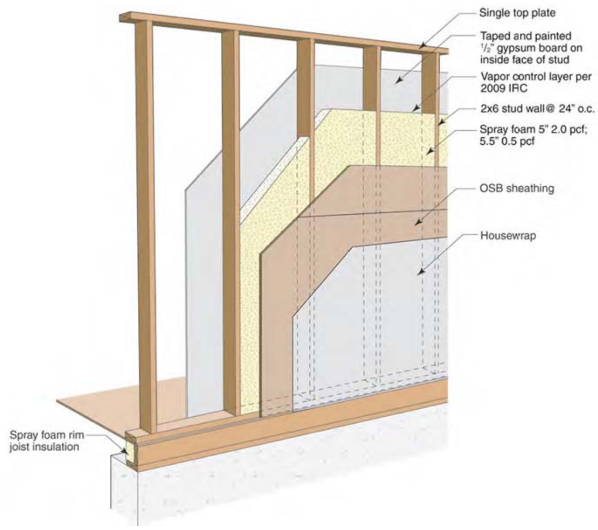
Case 8: Adv. Framing with Spray Foam

- System uses polyurethane spray foam in stud cavity instead of fiberglass batt or cellulose
- Better air barrier
- High density SF acts as air barrier and VB
- Low density SF acts only as air barrier (vapor diffusion)
- Easy to construct, but expensive
- R16.5-R19.1



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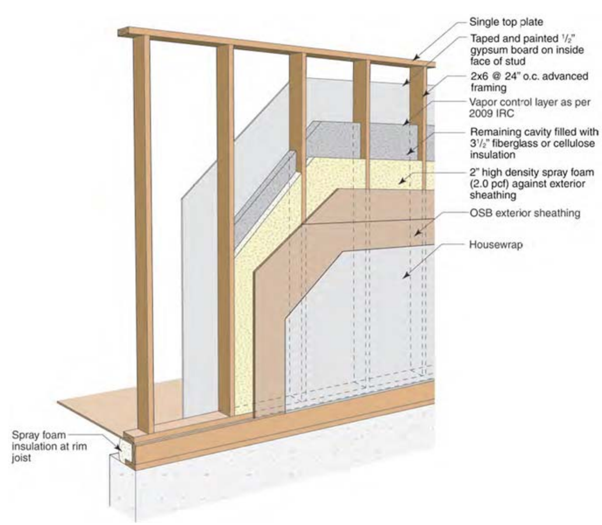
Case 9: Hybrid System 2" SPF + Fibrous Fill

- System uses both types of insulation
- Good air tightness
- Better thermal control than conventional but thermal bridge still there
- Cost is higher due to SPF
- R17.5



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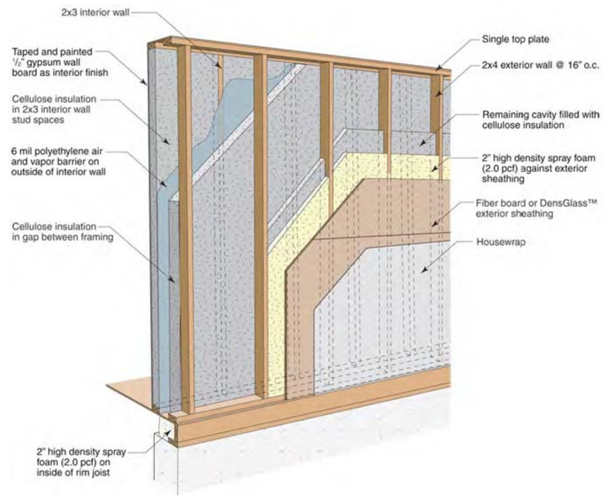
Case 10: Double Stud Wall with SPF

- System improves over double stud wall without SPF
- High density SPF applied over ext. sheathing
- Need more framing material
- Cost is high
- R32.4



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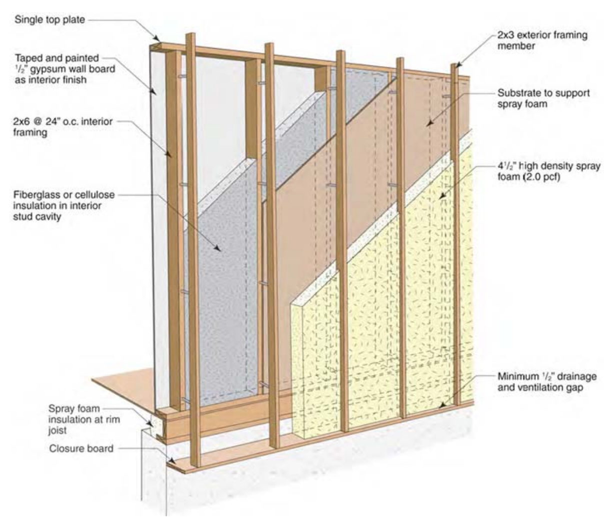
Case 11: Offset frame Wall with Ext. SPF

- This is a retrofit solution built over existing ext. wall
- Ext. frame is attached existing OSB substrate
- Expensive because of SPF
- Gets better thermal performance
- R37.1



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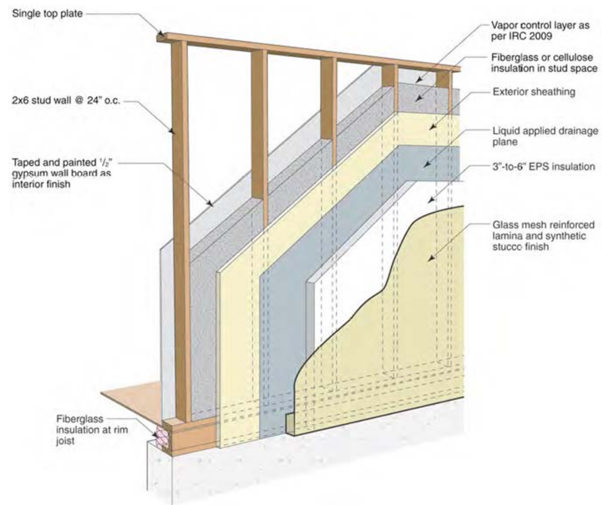
Case 12: Exterior Insulation Finish System

- This is an acceptable option for most climates
- Ext. insul. Applied over ext. sheathing
- Effective and durable if drainage and water management done correctly
- Because of stucco use, more expensive
- R30.1



http://www.buildingscience.com/documents/reports/rr-0903-building-america-special-research-project-high-r-walls

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Comparison of High R-value walls

- Walls can be grouped based on whole wall R-values: R<20, R approx. = 20, & R>30
- Walls compared based on
  - Thermal control
  - Durability
  - Buildability
  - Cost
  - Material Use
- Cases 2, 8, and 12 score the highest (20)
- Next Cases 9, 11 (19)
- Then 7, 10 (18)
- Followed by 1, 3, 6 (17)
- Finally, 4, and 5 (15)

	Thermal Control	Durability (wetting/drying)	Buildability	Cost	Material Use	Total
Criteria Weighting	1	1	1	1	1	
Case 1: Standard Construction	1	3	5	5	3	17
Case 2: Advanced Framing with Insulated Shtg	4	4	4	4	4	20
Case 3: Interior Strapping	3	3	3	4	4	17
Case 4: Double Stud	4	3	3	3	2	15
Case 5: Truss Wall	4	3	2	3	3	15
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: Offset Framing (ext. Spray foam insul.)	5	5	4	3	2	19
Case 12: EIFS with fibrous fill in space	5	5	4	3	3	20

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Summary and Conclusions

- There are several wall types with higher than R-20 that are not too expensive compared to conventional walls
- The locations of air barrier and vapor retarder are very important for wall performance
- The importance and function of air barrier to reduce condensation should be better realized
- Thermal bridging should be carefully considered in design as accurately as possible
- Use of software can significantly help in design of enclosure systems

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Thank you!
Questions

Next month's webinar:

Residential Multifamily Design for ENERGY STAR V3.0

Tuesday, June 11, 1:00 PM

Register at: **www.engr.psu.edu/phrc/Training/Webinars.htm**

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