Build a Better House
The Shell

Maine Indoor Air Quality Council

1

Thank you, program sponsors...

2

The Goal

Energy and Cost Efficiency

Comfort

Healthy Indoor Environment

Futureproof



3

"Shell"

Envelope or Enclosure

Components and assemblies that physically separate the interior environment from the exterior

Requires "structure" to perform



4

Shell Components



For today...

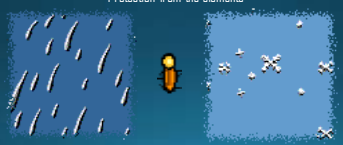
Walls

Roofs

5



The Purpose of the Building Shell...
Protection from the elements



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An effective shell must…



Control water & moisture *(IRC)*
Drainage plane, flashing, capillary break, VDR

Control air leakage *(IECC)*
Continuous air barrier

Control heat loss *(IECC)*
Continuous layer of insulation

Block pests and insects *(IRC)*
Integrated Pest Management

7

Futureproof means…

Prevent deterioration

Stimulate durability and adaptability

Extend service life, resilience

Fortify against extreme weather and shortages of energy and material

Local materials and labor

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Housing of Yesterday



Single component walls and roofs

Resisted moisture damage

Thermally inefficient

Unhealthy

Simple shapes

9

Housing of Today

Thermally efficient

Healthy

Multi-component walls and roofs

Must resist moisture damage

Complex shapes



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Walls are now multi-component…



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… as well as roofs



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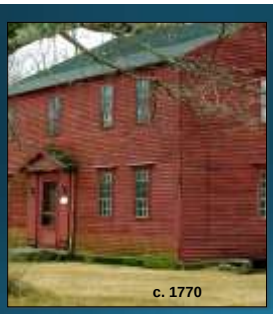

What changed?

Why?

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What…The ability to dry out

More complicated construction

More air tight and better insulated

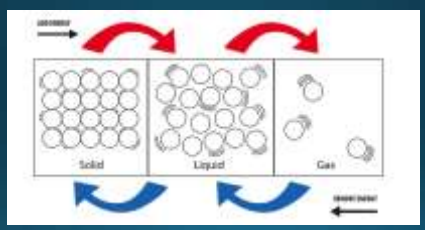
Harder to get wet

Less energy transfer through the wall

More difficult to dry

14

The Phases of Matter



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Surfaces





Shell components are joined together to form multi-surfaced structures

More surfaces equals more complication

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Building Science Basics

Bulk Water Management

Heat Flow Management

Air Flow Management

Vapor Management

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Bulk Water Management



Moisture flow is from warm to cold

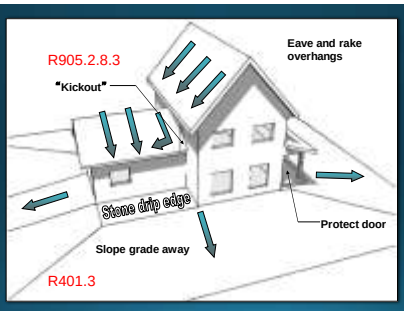
Moisture moves from more to less

Air carries moisture from high pressure areas to low pressure areas

Gravity pulls water down
Water wicks up

The Rules of Moisture Movement

18



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Common situation…





Common problem

20



Adding an overhang



21

Keep Out …

Wind driven rain

Cold dry air in winter

Humid air in summer

Retain…

Supplemental heat

Water vapor in winter

Solar gain when needed

22

Some definitions

Cladding (or siding)… a protective layer attached to the exterior of a building enclosure

First, but not primary, line of defense

Wet zone… the section of a wall system that is intended to be exposed to short and long term effects of bulk water penetration

Moisture tolerant

Dry zone… the section of a wall system that is not intended to be exposed to bulk water

Low moisture tolerance and little storage capacity

23

More definitions

Drainage plane… an element forming the dividing line between wet and dry zones

Water resistant and vapor permeable

Flashing… an element intended to collect and divert bulk water to the exterior of a building enclosure

Installed above any interruption to downward flow of water

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Cavity Wall



Rain Screen Walls
Water Managed Assemblies

Exterior cladding
Clapboards, vinyl, cement board

Air cavity
1/8" min. to break capillary action

Drainage layer
Building wrap, felt paper

Sheathing
Water resistant, airtight, structural(?)

Air Space

Drainage space or cavity to avoid capillary movement
- **Home Slicker™ or air space**
- **Driwall™ Rainscreen 020-1**
- **Mortairvent™**

Cavity *Air Pressure* forces water down and out

Home Slicker™



Continuous airflow behind the cladding

©2021

Creating an air space with strips ripped from 2x4 stock



Cladding...the first line of defense

Most exterior claddings must have rain control plane behind them

Shingles
Clapboards
Vinyl Siding
Brick Veneer



Clapboards



Minimal overlap

No sidelap

Wind driven rain issues

Old Wood Clapboards

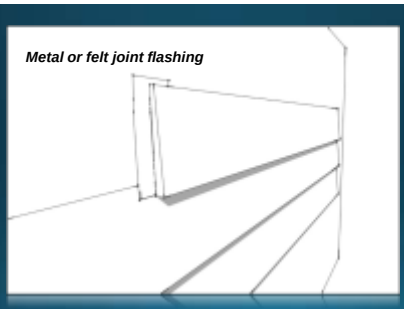


No drainage plane or rain screen

No insulation

Old growth wood

Note scarf joints



Loose installation requires drainage plane



Cement board siding

Concealed nailing

Longer lengths yield fewer butt joints

Good paint adhesion

Recommend rain screen and drainage plane





First generation cement board siding



Louisiana Pacific SmartSide™ lap siding

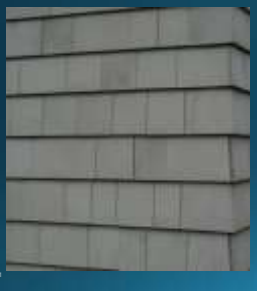
OSB based

16' lengths

Correct installation critical

37

Wood shingles



Concealed nailing

Triple coverage

Breathable

Long lasting

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Wall Sheathing



OSB, common and inexpensive

Susceptible to moisture
- Swells
- Flakes apart
- Supports mold growth

40

CDX plywood



41

CDX plywood vs. OSB

At 100% relative humidity…
OSB perm rating of 10
CDX perm rating of 30+

CDX dries three times faster than OSB!

42



Courtesy Huber

Zip™ wall sheathing

Perm rating of 12-16



Burnish the tape!

43

Exterior wind and water resistive barrier

Must be fastened properly

Joints must be overlapped and taped

Cover promptly



44



Fastening housewrap



45



Dupont™ Tyvek® DrainWrap™

46

Self adhering Housewrap

Blueskin VP100™





Grace Vycor en V-S™

47

Steve Konstantino

Performance Building Supply

48

Roofing underlayment

W. R. Grace Ice & Water Shield® or Certainteed Winterguard®
Does it prevent ice dams?
Does it prevent damage from ice dams?

Felt

RoofTopGuard® and others







Flashing

Redirects bulk water onto the exterior surface

Must flash all penetrations
to avoid wall wetting

Intentional holes should not be straight through wall,
water will follow air

Flashing details

Window flashing



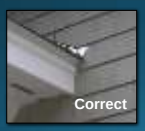
Deck flashing



Incorrect flashing







Failure to properly weave step flashing into horizontal cladding

Board sheathing soaked and insect-ridden…



End result

A very unhealthy situation

Water managed window installation



#1… "I" cut house wrap, cut head flap

From US Department of Energy

#2… Install back dam, slope sill





#3... caulk outside edges of head, side jambs

Install window plumb, level, square

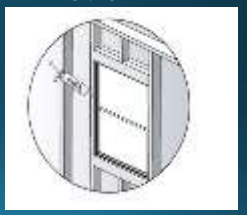
#4... Install jamb and head flashing





#5... Tape down house wrap head flap

#6... Air seal rough opening from inside



Window Pan Flashing



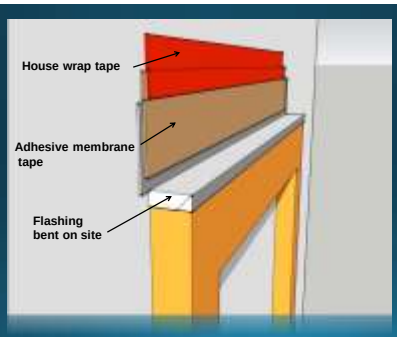




Door pan

Simple to bend on site

Invisible after trim and flooring installed







Prefabricated exterior window casing

61



62

Dealing with the previous situation



63



Window tape carried onto face of cladding

Lower window side flashing detail

Leave backing on lowermost tape until siding

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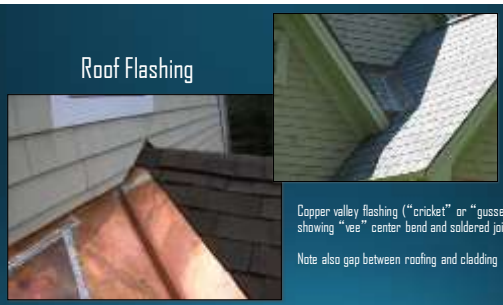
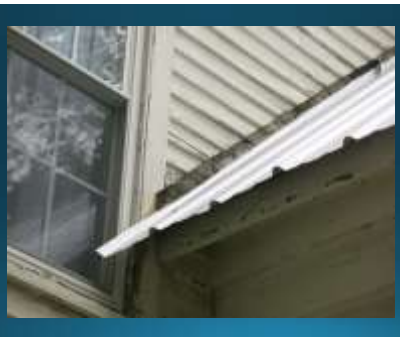
Roof Flashing



Copper valley flashing ("cricket" or "gusset") showing "vee" center bend and soldered joints

Note also gap between roofing and cladding

65



66



Chimney pan flashing or "through flashing"



Chimney flashing



Metal roof



Two methods of chimney flashing

Drip Edge

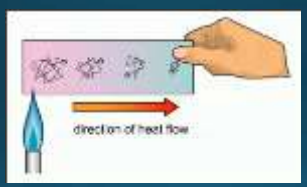


Note the overhanging shingles and the additional bend in the metal edge



15 minute break

Heat Flow Management



Heat will always flow from warmer to cooler, or more to less

With no external energy, molecular vibrations slow down until equilibrium is reached

Heat transfer mechanisms

Conduction… molecular excitation without molecular movement

Convection… fluid movement of excited molecules

Radiation… electromagnetic motion of charged particles



Heat Flow Management

Reduce conductive losses by placing resistive material
in the path of heat flow

Disrupt thermal contact

"Thermal Break"

73

Wall systems

Wall systems must..

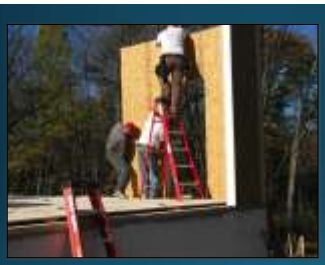
Transfer gravity loads to the foundation

Resist wracking from high winds

Minimize heat loss and water penetration

Be penetrated by windows and doors

74



No Stud Variants

Structural Insulated Panels

Redundancy?

75



No Stud Variation

Insulating Concrete Forms

76



77



No Stud House 2008

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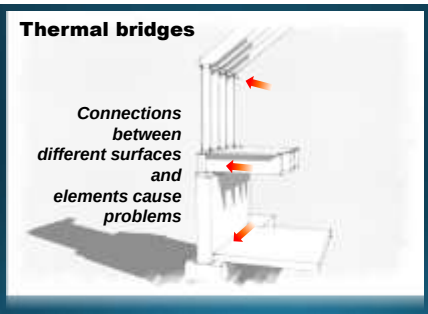
Thermal bridges

Connections between different surfaces and elements cause problems



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Single stud variations



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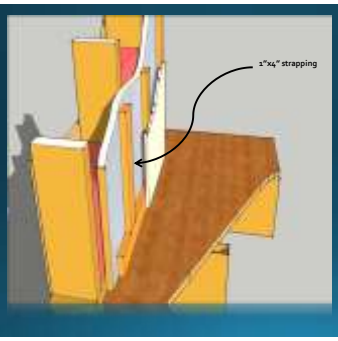


Modified Wall

- Little thermal bridging
- Interior isocyanurate with air space
- Cold framing/sheathing
- Radiant "bounce"
- Outlet difficulty

81

XPS Insulation

Interior or exterior

Controls conductive and convective losses

Miscuts can be foamed



82

Insulated sheathing

Low perm rating!



1. *Continuous foam insulation*
1. *Engineered wood*
2. *Water resistive barrier*
3. *Continuous air barrier*
4. *Zip™ system tape*

83



1.5" insulated sheathing on 2x6 studs

84

Climate zone	Minimum R-value for exterior foam installed on an existing 2x4 wall	Minimum R-value for exterior foam installed on an existing 2x6 wall
Marine 4	2.5	3.75
5	5	7.5
6	7.5	11.25
7 and 8	10	15

Courtesy BuildingGreen, Inc

Minimum True R-values
for
exterior foam applications
IRC R702.7.1

w/Class III VDR

85

Modified Wall

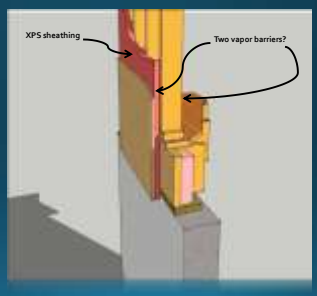
No thermal bridging

Dew point concerns

Warm framing

Cold sheathing

No outlet problem



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Single Stud House 2009

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Double Stud Wall

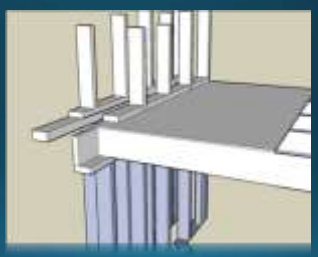
Two 2x4 walls, 3" space between

VB applied to outer face of inner wall

Outer 2/3 dense pack

Inner 1/3 HD batts

Minimal thermal bridging



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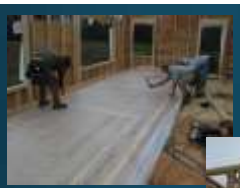
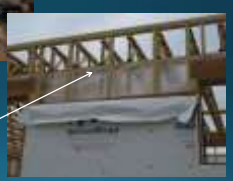
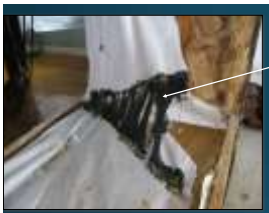


Double Stud Wall



Sheathing omitted for ease of joist band installation

89



Tremco™ acoustical sealant, 22 years old



Double wall VB after 22 years

90



Connecting walls together
at the second floor

Truss mending plates
@ 48" centers

91



Double Stud House 1982

92

"Wrap and Strap"



Dense Pack Cellulose and Roxul Batts
R-30

93



Acoustical sealant
at overlaps and
at penetration repairs



94



95



Avoid aligning horizontal elements

96



Block for outlets, cabinets

97



Wrap and Strap House 2018

98

Larsen™ Truss for major wall retrofit



99

Roof Systems

A roof system is a wall system laid on its side, except…

Stack effect more pronounced

Snow loads must be considered

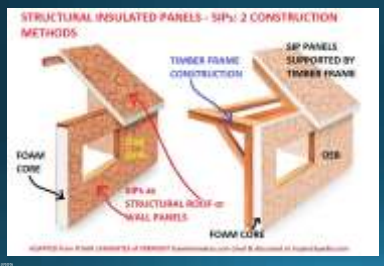
It is subjected to harsher sun and more persistent rain

Has far fewer penetrations

Maintenance is more difficult due to its greater height

100

Zero Rafter Roof



Redundancy?

101



Single Rafter Roof



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Double Rafter Roof



Supertruss™ ..22" depth

1982

103

"Supertruss" 2021



104



Site built "scissor trusses"

105



Another approach

106



Dealing with the problem ar

2 part spray foam must be properly applied

107



108

"R" values per inch

Material	Resistivity
Concrete…	0.08
Softwood…	1.41
Fiberglass…	3.5
DP cellulose...	4.0
XPS…	5.0
HCFC…	7.5
Dead air…	5.6
Water…	0.24
Vacuum…	40.0

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Heat Loss Calculation



Surface Heat Loss =AΔT/R

A = Surface Area
ΔT = Temperature Difference
R = Resistance

One can change one or all three of these meters

110

Fiberglass Insulation

Controls conductive losses

Air sealing necessary





111

Roxul™ Mineral Wool Insulation

Tight friction fit

Controls conduction and convection



112

Cellulose





Controls conductive and convective losses

Proper installation reduces settling

113



Dense packed cellulose

R-3.35/in

114

Rigid foil faced insulation



Controls conductive, convective, and radiant losses

Requires careful installation with taped seams, foamed penetrations



115

Insulation with air sealing and VB



116

Spray Foam Insulation



Courtesy Corbond

No convection

Dense, almost structural
Aerosol "Gorilla Glue"

VDR not needed?

"Green" ?

Messy if uncontrolled

Proper installation critical

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Heat Flow Management

Radiation

Dealing with MRT

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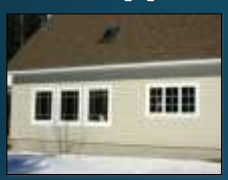
Managing Radiant Energy



Planned winter gain



Planned summer shading

119

The importance of Mean Radiant Temperature (MRT)

Operative temperature is what humans experience thermally in space

$T_o = (T_{mr} + T_{db})/2$

120

MRT is a
building enclosure performance element

Poorly designed buildings have
low MRT's in winter
and
high MRT's in summer

For instance, excessive fenestration

121

Radiant Floor Heat does not heat our bodies...

**It reduces the temperature difference between
our bodies
and the interior surfaces**

Metabolic heat is retained

Remember the rules of heat movement

122



***This* radiation
heats
our bodies**

123

**Relationship between
warm human body
and cold wall**

For every ΔT° , the human body radiates 9 additional watts of heat energy

With a ΔT° of 10° , radiated energy is equal to 90 watts

A ΔT° of 30° raises that radiated energy to 270 watts



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End of Session One

Up next...

Steve Konstantino

Performance Building Supply

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Build a Better House
The Shell Part Two

Maine Indoor Air Quality Council

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Thank you, program sponsors...



Heat Flow Management

Reduce convective loss by disrupting fluid

motion of molecules between a heated object

and the surrounding environment

"Air Seal"

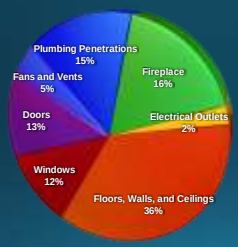
Air Flow Management



The Rules of Air Movement

Air always moves from high pressure to low pressure

"Stack Effect" Mechanical fans Wind



Where does the air leak most?

Insulation

Continuous layer of insulation
- Avoid thermal bridges
  - Ideally separate *structure* from exterior
  - Avoid surface/interstitial condensation

Don't let air flow through insulation
- *Air sealing required*

Detail to prevent pest infestation



Poor Insulation Performance

Airflow within assemblies

Convective loops around and through batt insulation caused by gaps and large temperature difference

Convective loops in batts or loose fill with one side open to cold air in attics

Prevent "Windwashing"



Need air tightness outside the insulation

- Sealed housewrap
- Flashed corners
- Sheathing sealed with tape
- Attic baffles/blocking
- High density cavity insulation
  foam, dense cellulose

133



Sheathing tape controls bulk water *and* air movement

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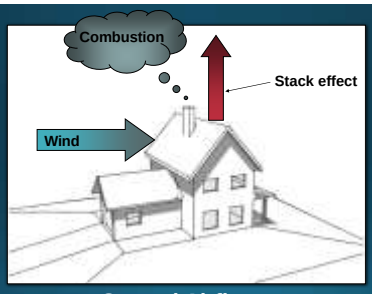

Control Airflow

135

Dust and dirt around the switch



136

Sealed
Floor Plate



137



Fiberglass
Air Filter

Air sealing is critical

138



139



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Air Leakage



141

Air Leakage Evaluation

ACH @ cfm50
- < 7 is not particularly tight
- < 3 achievable is a good job
- < 1 really good job!
- Passivhaus .6ACH @ cfm50

MSH Green minimum standard
- 0.25 cfm/SF @ 50 PA

IECC 402.4.2.1…less than 3 ACH



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Use Air Barriers

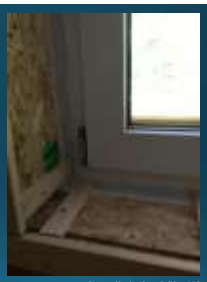
Inside... air tight drywall

Interstitial... smart membrane

Outside... taped sheathing

143





Courtesy Yandow Green Builders, LLC

Tape for Air Sealing Windows

144

Shawn Spear

Dupont Building Envelope specialist

145

The Rules of Vapor Transport

Water vapor will always move from areas of higher concentration to areas of lower concentration

Drivers include…

Vapor pressure differential

Permeability of membrane

Air movement

146

Dew Point

Temperature at which water vapor condenses into liquid water

High relative humidity values indicate the dew point temperature is close to the current air temperature

Dew point at 100%RH equals ambient temperature

147

Dew Point: What Happens Outdoors…





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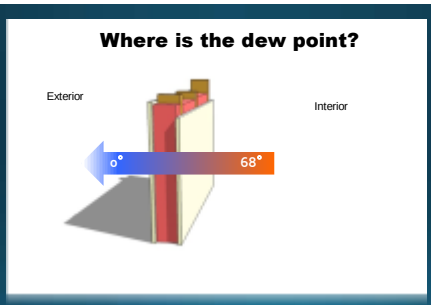
Where is the dew point?



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Exterior XPS with insufficient thickness

Interior RH too high

Dew point reached

Exterior sheathing rotted in 5 years

Structural elements too!

150

Maine Uniform Building & Energy Code

IRC…Int' l Residential Code 2015

IBC…Int' l Building Code 2015

IECC…Int' l Energy Conservation Code 2015 or…

ASHRAE 90.1

IEBC…Int' l Existing Building Code

ASHRAE 62.1 and ASHRAE 62.2

ASTM E-1465



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Consider Climate Impact of Insulation Materials

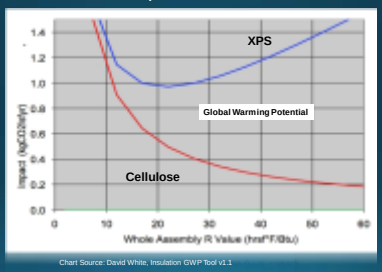

Chart Source: David White, Insulation GWP Tool v1.1

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Avoid thermal bypasses

Solid wood member bad
Uninsulated concrete worse
Uninsulated glass worse still
Through wall metal worst
Acts as a thermal radiator attempting to heat the outdoors
50% loss in system R value



153



154

IRC R702.7

Class I or II vapor diffusion retarder required on the interior of frame walls

Class III permitted in special circumstances
Vented cladding

Class I…Polyethylene or foil

Class II… Kraft faced batts

Class III… Paint

155



A small amount of water can pass through solid drywall via vapor diffusion.



Much more water—100 times as much—can pass through a 1-in. by 1-in. hole in drywall.

156

VB vs. VDR

There really is a difference between the two

Remember, diffusion is weak
VB is overkill

VDR deals with diffusion easily
Allows accidental moisture to escape

157

Vapor Management

Reduce *vapor diffusion* into assembly

Prevent *air leakage* into assembly

Plan on some moisture penetration into assembly

Allow for drying pathway

158

Water Proof and Vapor Permeable



Courtesy dupont.com/products

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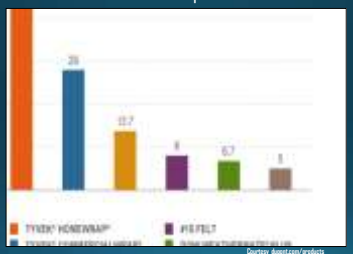
Water Proof and Vapor Permeable



Courtesy dupont.com/products

160

Product permeability

Perm Rating	Product	Use
40	Vinyl siding	VP
40	Brick veneer	VP
30	Building felt paper	VP
10?	CDX plywood	VSP
5	Housewrap	VSP
2	OSB sheathing	VSP
>1	EPS (Beadboard)	VSP
1	XPS (1" - thickness)	VSP
0.1 - 1	XPS (1" + thickness)	VSP
<0.1	Faced XPS	VI (Barrier)
<0.1	Foil or poly facing	VI (Barrier)

Courtesy Building Science Corporation

161

CDX plywood vs. OSB

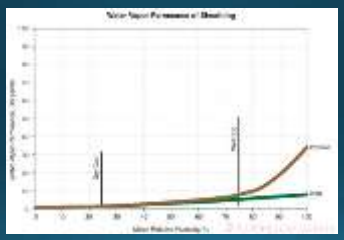
"Wood layers versus Wood McNuggets



Building Science Corp

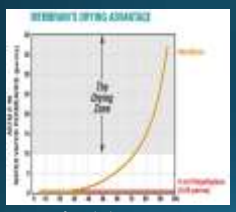
162

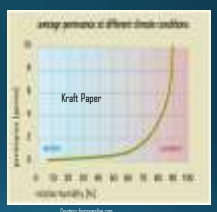
Vapor Diffusion Plywood vs OSB



163

Smart vapor diffusion retarders





164

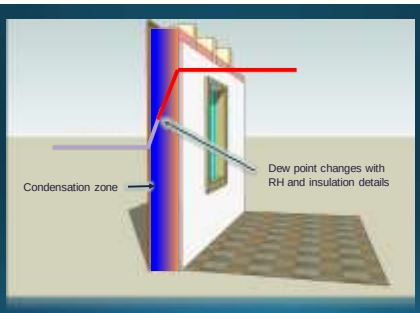
Damaging condensation occurs…

When humid exfiltrating air cools down

Diffusing water vapor hits cold surface

Air leakage is critical

165



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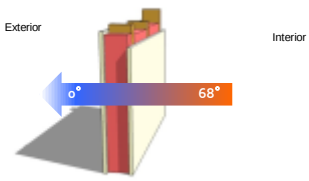
166

Where is the dew point? heating

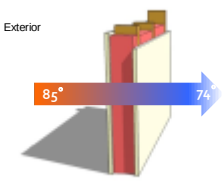


Temperature difference across a wall

©2021

167

Where is the dew point? cooling



Temperature difference across a wall

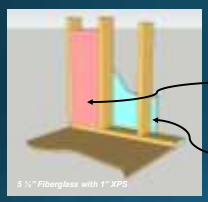
©2021

168

Temperature Calculation
within the wall

1. Determine total R-value
2. Determine ΔT across the wall
3. Starting from outside... $T_{interface} = T_{outside} + (\%\ of\ total\ R\ value \times \Delta T)$

169



Calculating interface temperatures

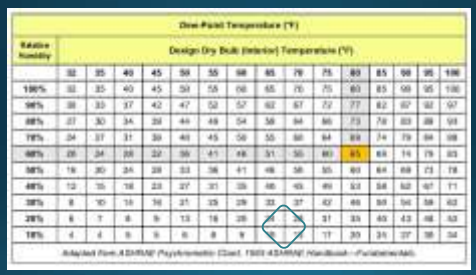
170

Total R value = R19 + R5 = R24

ΔT = 68º (68º interior, 0° exterior)

Step One	*Step Two*
XPS R-value % = 20.8%	*Fiberglass R-value % = 79.2%*
.208 x 68° = 14.14º	*.792 x 68° = 53.86º*
0º + 14.14° = 14.14º	*0º + 14.14° + 53.86º = 68º*

171



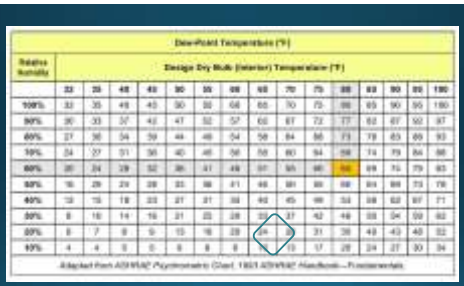
172

Total R value = R19 + R10 = R29

ΔT = 68º (68º interior, 0° exterior)

Step One	*Step Two*
XPS R-value % = 34.5%	Fiberglass R-value % = 65.5%
.345 x 68° = 23.46º	.655 x 68° = 44.54º
0º + 23.46° = 23.46º	0º + 23.46° + 44.54º = 68º

173



174

Climate zone	Minimum R-value for exterior foam installed on an existing 2x4 wall	Minimum R-value for exterior foam installed on an existing 2x6 wall
Marine 4	2.5	3.75
5	5	7.5
6	7.5	11.25
7 and 8	10	15

Courtesy SaddleCreek, Inc.

Minimum R-values
for
exterior foam applications

175



What temperature here?

Total R value = R11 + R7

ΔT = 68°

Step One

CCF R-value % = 38.9%

.389 x 68° = 26.45°

176

Dew-Point Temperature (°F)															
Relative Humidity	Design Dry Bulb (Interior) Temperature (°F)														
	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88
60%	20	24	28	32	36	41	46	51	55	60	65	69	74	79	83
50%	16	20	24	28	33	38	41	46	50	55	59	64	69	73	78
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71
30%	8	10	14	18	21	25	29	[illegible]	[illegible]	42	46	50	54	59	62
20%	5	7	8	9	13	16	20	[illegible]	[illegible]	31	35	40	43	48	52
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34

Adapted from ASHRAE Psychrometric Chart, 1993 ASHRAE Handbook—Fundamentals.

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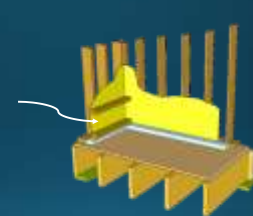
"Wrap and Strap" System

What temperature here?



Dense packed cellulose both cavities

178

Total R value = R22 + R14 = R36

ΔT = 68º (68º interior, 0° exterior)

Step One

Ext. cavity R-value % = 61.1%

.611 x 68° = 41.55º

0º + 41.55° = 41.55º

Step Two

Int. cavity R-value % = 38.9%

.389 x 68° = 26.45º

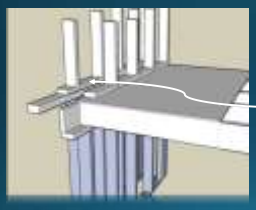
0º + 41.55° + 26.45º = 68º

179

Dew-Point Temperature (°F)															
Relative Humidity	Design Dry Bulb (Interior) Temperature (°F)														
	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88
60%	20	24	28	32	36	41	46	51	55	60	65	69	74	79	83
50%	16	20	24	28	33	38	41	46	50	55	59	64	69	73	78
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71
30%	8	10	14	18	21	25	29	35	37	42	46	50	54	59	62
20%	5	7	8	9	13	16	20	24	28	31	35	40	43	48	52
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34

Adapted from ASHRAE Psychrometric Chart, 1993 ASHRAE Handbook—Fundamentals.

180



Double Wall System

What temperature here?

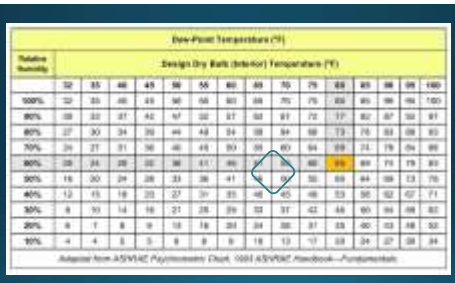
181

Total R value = R26 + R11 = R37

ΔT = 68º (68º interior, 0° exterior)

Step One	*Step Two*
Ext. cavity R-value % = 70.3%	Int. cavity R-value % = 29.7%
.703 x 68° = 47.8º	.297 x 68° = 20.2º
0º + 47.8° = 47.8º	0º + 47.8° + 20.2º = 68º

182



183

Assess Assembly

Permeability of each component
Least vapor permeable component
Extent and direction of vapor drive
Moisture storage and potential drying

Class I Vapor Retarder (vapor barrier): less than or equal to 0.1 perms

Class II Vapor Retarder: less than or equal to 1 perm and greater than 0.1 perms

Vapor III Vapor Retarder: greater than 1 perm but less than 10 perms

184

Building Thermal Envelope
Section R402.4.1 – Air Leakage

Requires BOTH:
- ✓Whole-house pressure test
- ✓Field verification of items listed in Table R402.5.1.1

Air Leakage Rate	Climate Zone	Test Pressure
≤ 5 ACH	1-2	50 Pascals
≤ 3 ACH	3-8	50 Pascals

Testing occurs after all building envelope penetrations

185

Air leakage site



Kraft paper face is a VDR

186

Ice Dams

Air leakage from below

Rare in a properly sealed well insulated home



187


Courtesy Building Science Corporation

Air leakage problems

188

Air Leakage From Occupied Space Into Attic



Courtesy Cornelius Associates

189

Recessed Lights Are Holes in the VDR air & vapor movement



Courtesy greenbuildingadvisor

Assess Assembly:

1. Permeability of each component
2. Least vapor permeable component
3. Extent and direction of vapor drive
4. Moisture storage and potential drying

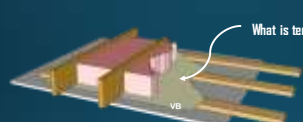
Class I Vapor Retarder (vapor barrier): less than or equal to 0.1 perms

Class II Vapor Retarder: less than or equal to 1 perm and greater than 0.1 perms

Vapor III Vapor Retarder: greater than 1 perm but less than 10 perms

190

Attic insulation of the 1970's



Gypsum ceiling = R .45

Air space = R 4.2

Fiberglass = R 19

Total R value = 23.65

Why old time builders avoided vapor barriers at ceiling

191

Total R value = 23.65

$\Delta T = 68^o$ (68° interior, 0° exterior)

Temperature of membrane at joist bay	*Temperature at joist*
Fiberglass R value = 19/23.65 x 100 = 80.33%	7.5/12.15 x 100 = 61.7%
.803 x 68° = 54.6°	.617 x 68 = 41.9°

192



Myers Inspection

193



194

Unvented roof



Mechanical systems located in attic

195

Hot roof and shingles

Check with shingle supplier regarding warranty

Certainteed and GAF will honor warranties, with restrictions

Strict adherence to local codes required

196

Roof retrofit



197

Deep snow accumulation



In snowy areas, unvented roofs can fail

- Added insulation value of snow layer brings roof surface to melting temperature

198



199

Building tight, moisture resistant shells is one part of the equation…

Proper ventilation and a warm, dry basement are also important

200

Up next…

Mark Toth

RST Thermal/Renewaire

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