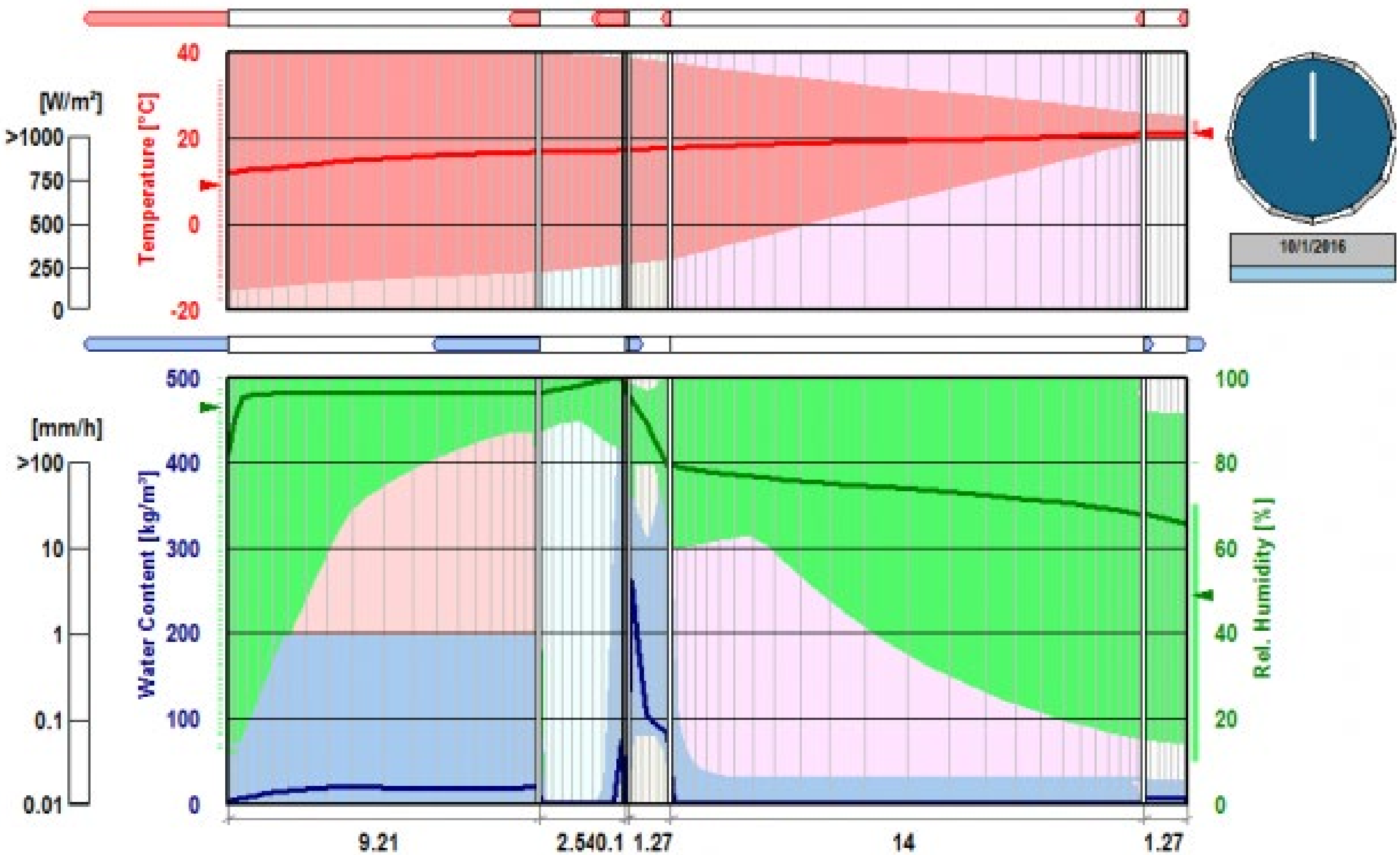
Moisture Risk and Heat Loss Analysis

For Wall Assemblies and Junctions



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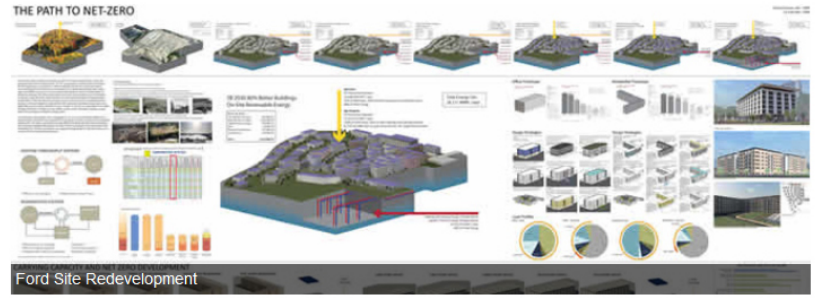
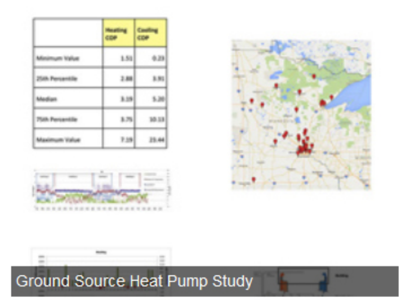
An Interview with Richard Graves



Ford Site Redevelopment

B3 Operations Manual

MNSHI Affordable Prototyping



Ground Source Heat Pump Study

The Rose

AREAS OF FOCUS

Energy and Climate Change: Provide tools, expertise, and research to support energy independence, security, and climate neutrality for the state, nation and planet.

Value and benefits of regenerative designs: Develop metrics to track the full range of value created by sustainable and regenerative designs.

The Water Cycle: Understand the water cycle and its relationship to the built environment in the provision, capture, use, reuse, and recharging of water in local and regional watersheds and global water cycle.

Equitable designs to provide sustainability for all: Investigate building solutions to provide sustainability to all communities.

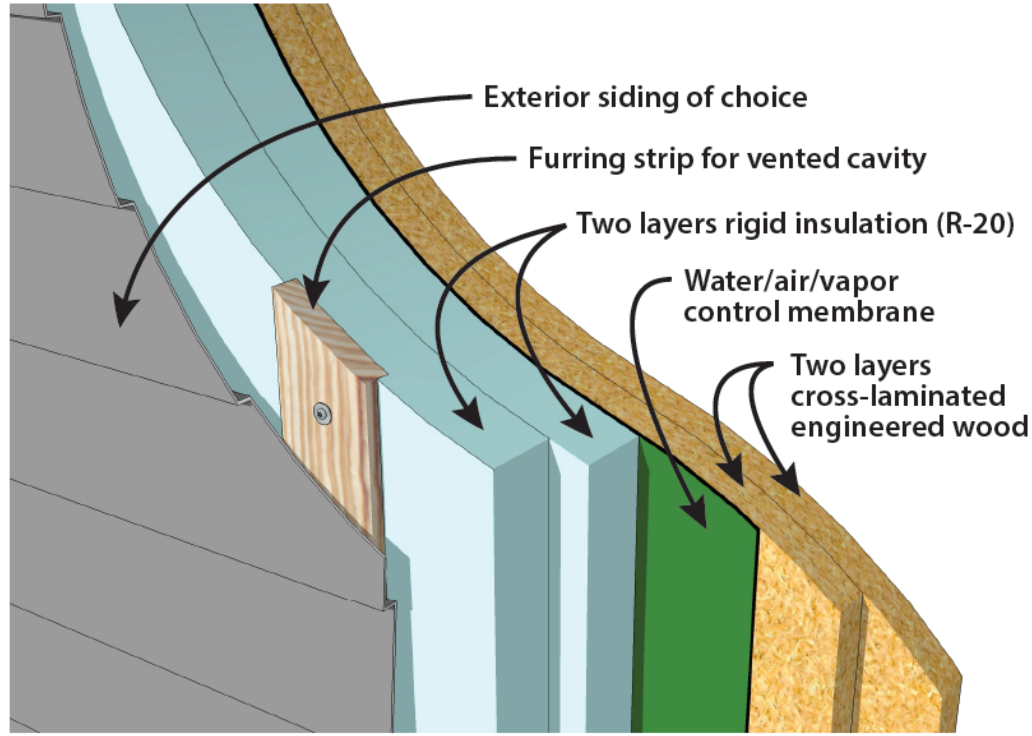
Sustainable Materials for a healthy built environment: A regenerative built environment will need a renewable source of materials that create healthy long-lasting environments.

Creating Regenerative and Resilient Communities: Our communities must become regenerative and resilient not only to be sustainable, but also to respond and adapt to stress and change in a dynamic global environment.

Affordable Housing – *Advanced Enclosure Systems*

Affordable, high-performance, moisture-managed building enclosure system

Assembly of a studless panel house.



Layers of the studless "SEP-ETMMS" wall assembly

Structure complete. *Water/air/vapor control membrane applied.* *Insulation, furring, and cladding installed.*

Moisture Risk & Heat Loss Analysis Workshop – Day 1

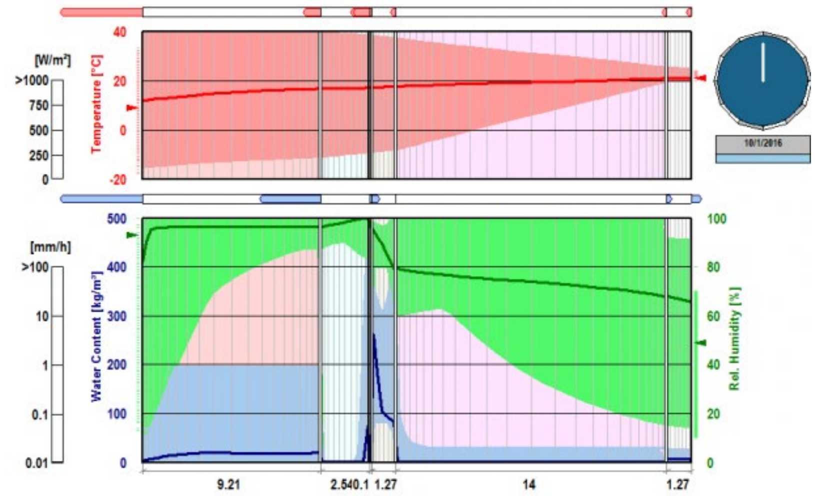
1. New B3 Requirements for I.2 Moisture and Water Control	
2. Building Science Review	
3. Qualitative Moisture Assessment	
4. Quantitative Moisture Analysis (Glaser, WUFI)	
5. Summary and Recap	…2:15
6. Working with Permeance & Permeability	0:30
7. Qualitative Moisture Assessment Practice	0:45
LUNCH BREAK	1:00
8. Glaser Analysis Walk-through and Practice	0:45
9. WUFI Analysis Walk-through and Practice	3:15

B3 Requirements - I.2 Moisture and Water Control

Intent: Ensure a moisture-safe building enclosure.

Requirements:

Part A Bulk Water
Part B Moisture Safe Design
Part C Moisture Safe Construction

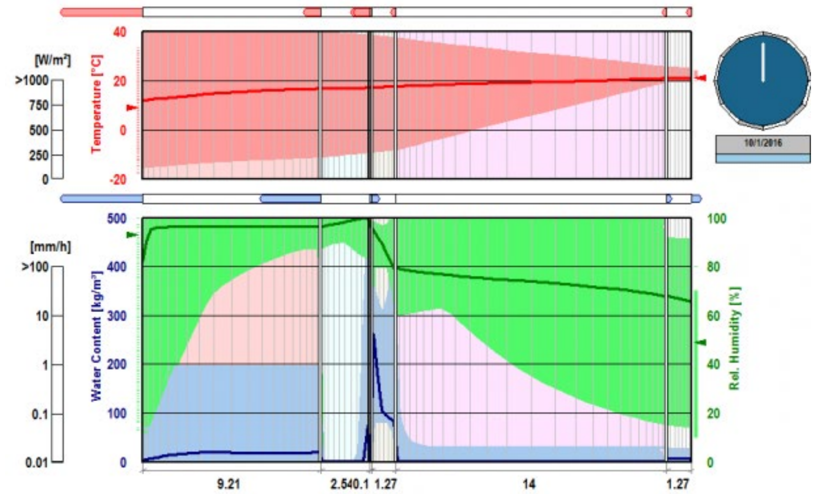


B3 Requirements - I.2 Moisture and Water Control

Intent: Ensure a moisture-safe building enclosure.

Requirements:

Part A Bulk Water => Based on previous guideline
1) Site grading - 5% slope for 10 ft
2) Downspout leaders, trench drains, etc direct water away from building
3) Irrigation systems – ensure no spray on building enclosure

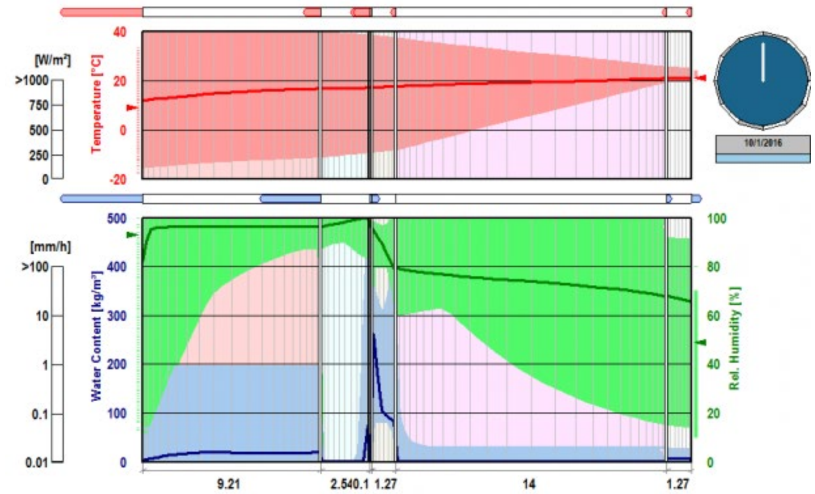


Part B Moisture Safe Design => <u>Significant new requirements for designers</u>

Part C Moisture Safe Construction => <u>Significant new requirements for contractors</u>

B3 Requirements - I.2 Moisture and Water Control

Intent: Ensure a moisture-safe building enclosure.



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1) Site grading - 5% slope for 10 ft
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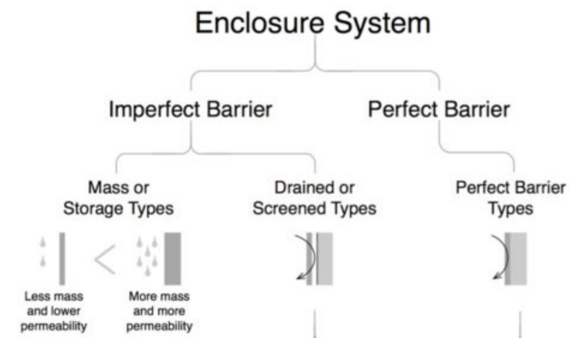
3) Irrigation systems – ensure no spray on building enclosure

Part B Moisture Safe Design => Significant new requirements for designers
1) Qualitative moisture assessment
2) Quantitative moisture assessment

Part C Moisture Safe Construction => Significant new requirements for contractors
1) Whole building airtightness test (or)
2) 3rd party building enclosure consultant

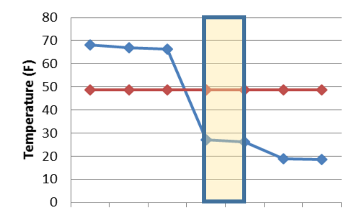
B3 Requirements - I.2 Moisture and Water Control

Part B Moisture Safe Design

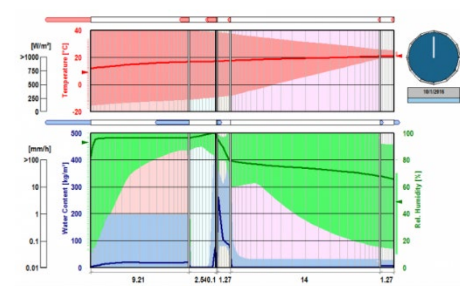


1) Qualitative moisture assessment (roof and wall)
   A thorough description of the design intent and placement of control layers for:
   - Bulk water, capillary wetting, and storage
   - Air leakage
   - Diffusion
   - Thermal transfer

   Description of sheathing drying direction, ratio of exterior/interior R-values, etc.



2) Quantitative moisture assessment (wall)
   - Glaser analysis (static dewpoint and vapor drive assessment)
     (or)
   - WUFI analysis (dynamic risk assessment)



B3 Requirements - I.2 Moisture and Water Control

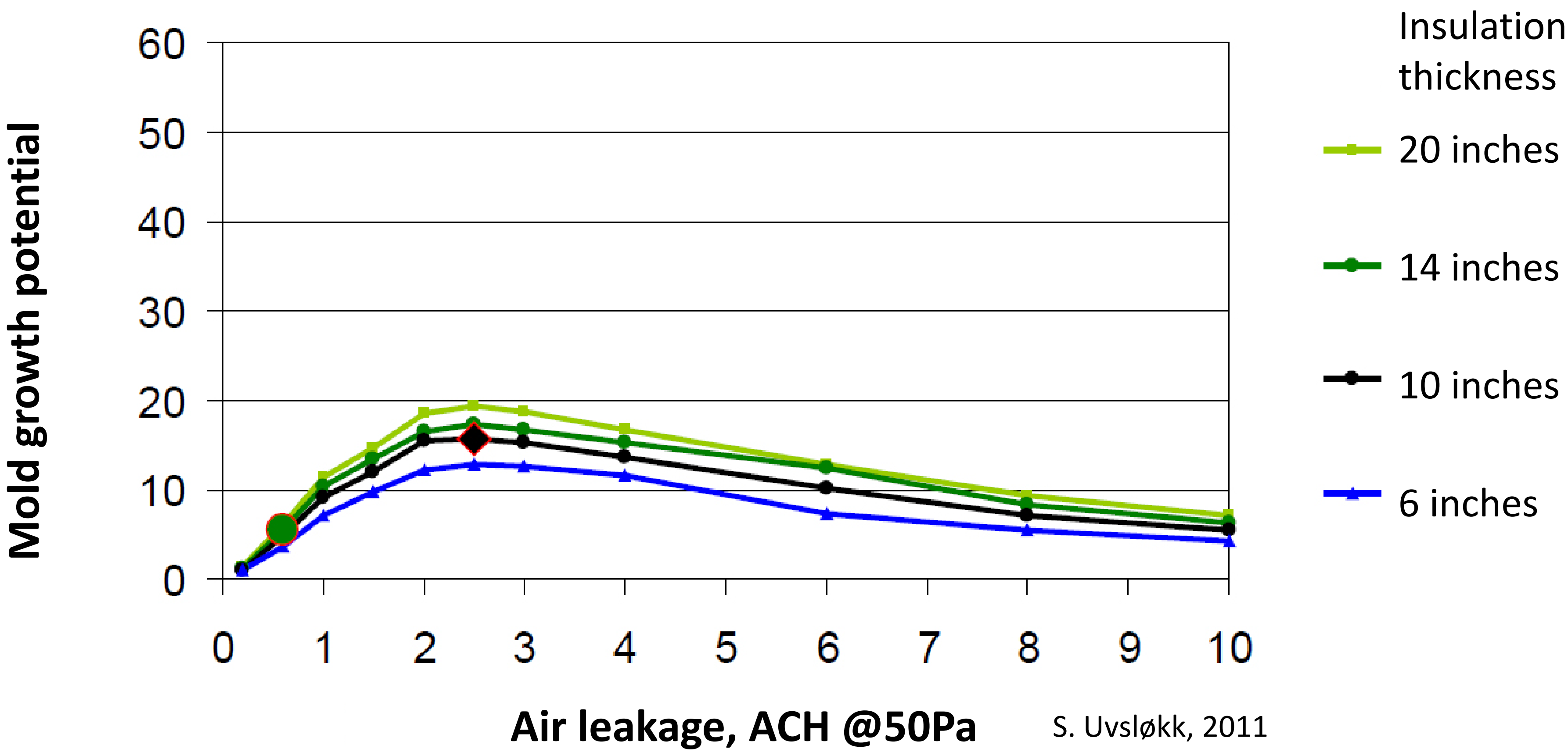
Part C Moisture Safe Construction (choose #1 or #2)

1) Whole building airtightness test
   Building thermal envelope must be tested according to ABAA Standard Method for Building Enclosure Airtightness Compliance Testing,
   - Maximum air leakage rate is 0.25 cfm/sf enclosure area at 75Pa
   - Non-destructive remediation steps are required for any enclosure above this level

2) 3rd party building enclosure consultant
   A 3rd party enclosure consultant shall be used during the design and construction phases with scope of work including at a minimum:
   - Regular meetings with design and construction teams
   - Review of all technical plans, specifications, shop drawings, and material submittals related to building enclosure
   - Coordination of preconstruction training for enclosure contractors focused on air and water barrier installation
   - Coordination of air and water leakage testing on windows installation
   - Field observation

B3 Requirements - I.2 Moisture and Water Control

Reason for significant new requirements: As we push the performance of the enclosure higher, mold growth risk can increase.



S. Uvsløkk, 2011

Section 1 – Building Science Review

What is the function of the building enclosure?

Section 1 – Building Science Review

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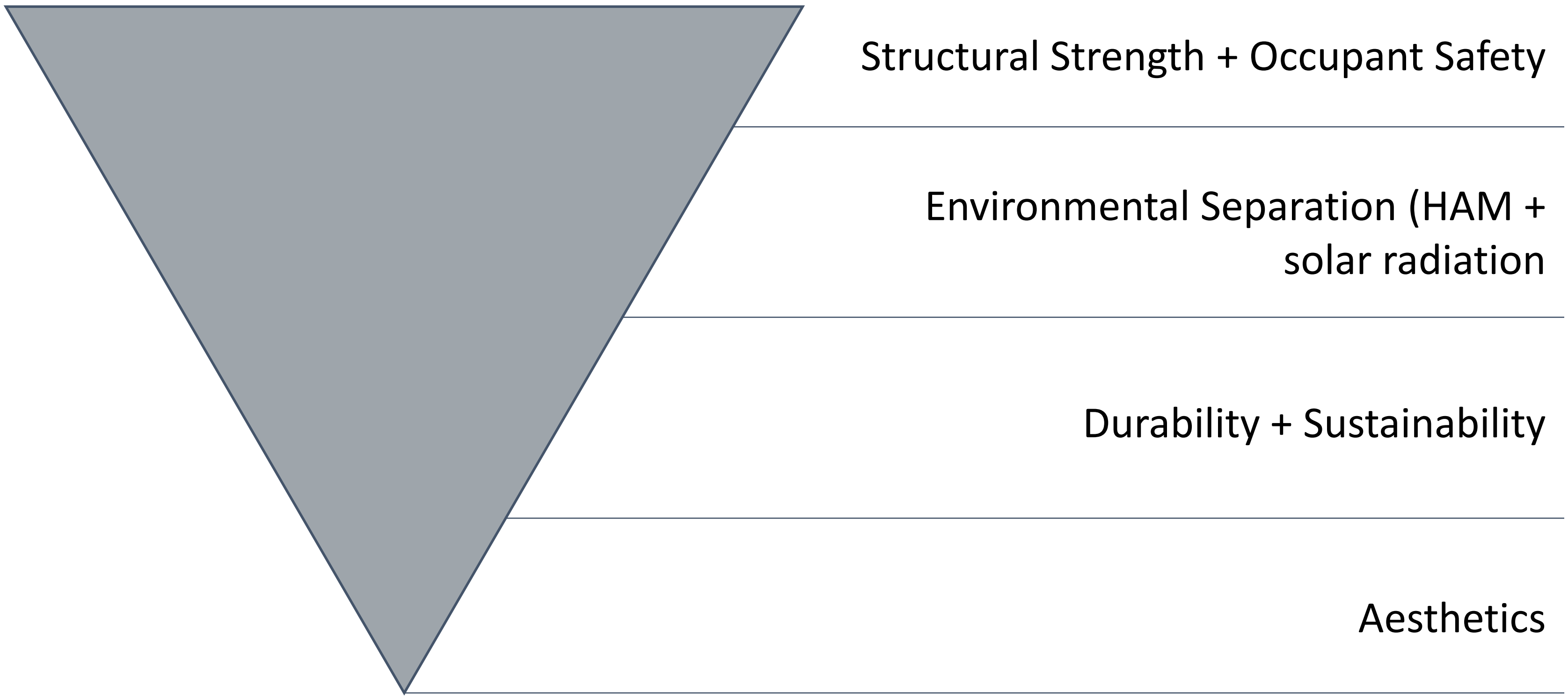


Section 1 – Building Science Review

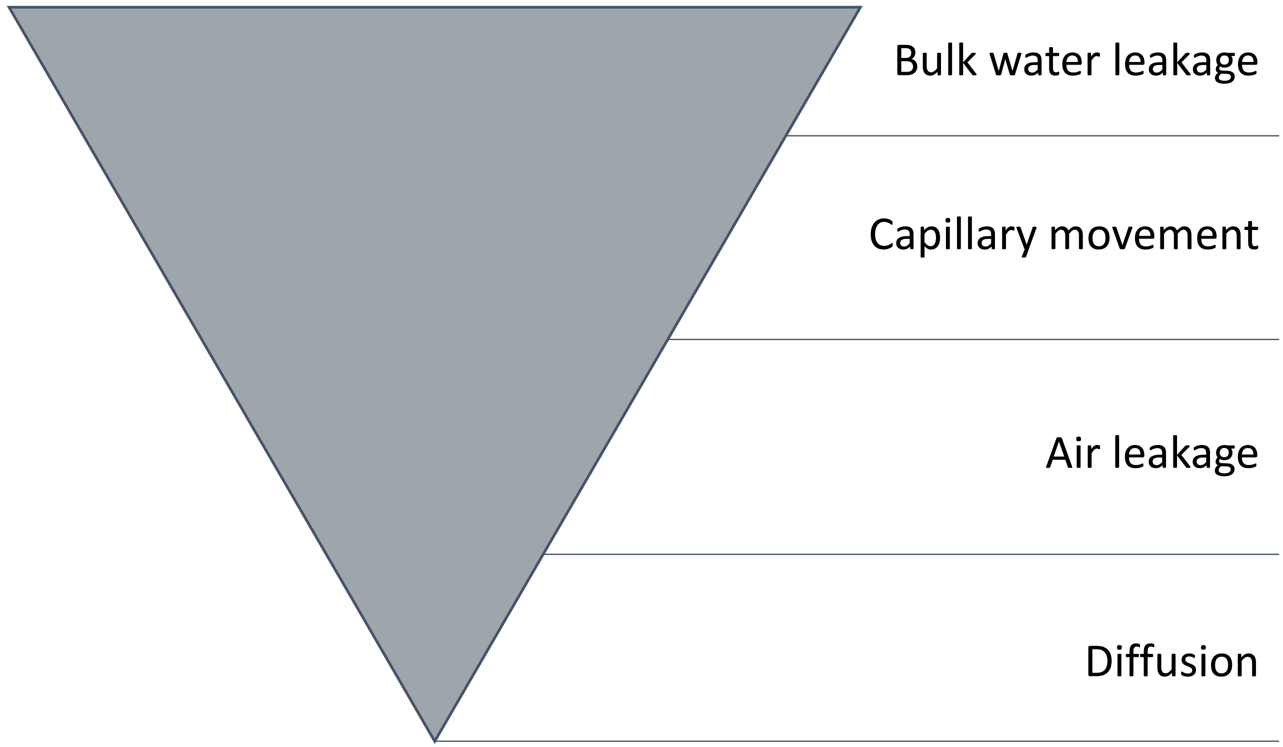
Moisture safety = balance between wetting, drying, and safe moisture storage

In general, drying potential of an envelope must be greater than its wetting potential over the course of a year.

Wetting may overcome drying at times, if there is storage capacity to hold the moisture until drying conditions return.

Section 1 – Building Science Review

arranged in order of significance - **Wetting pathways**



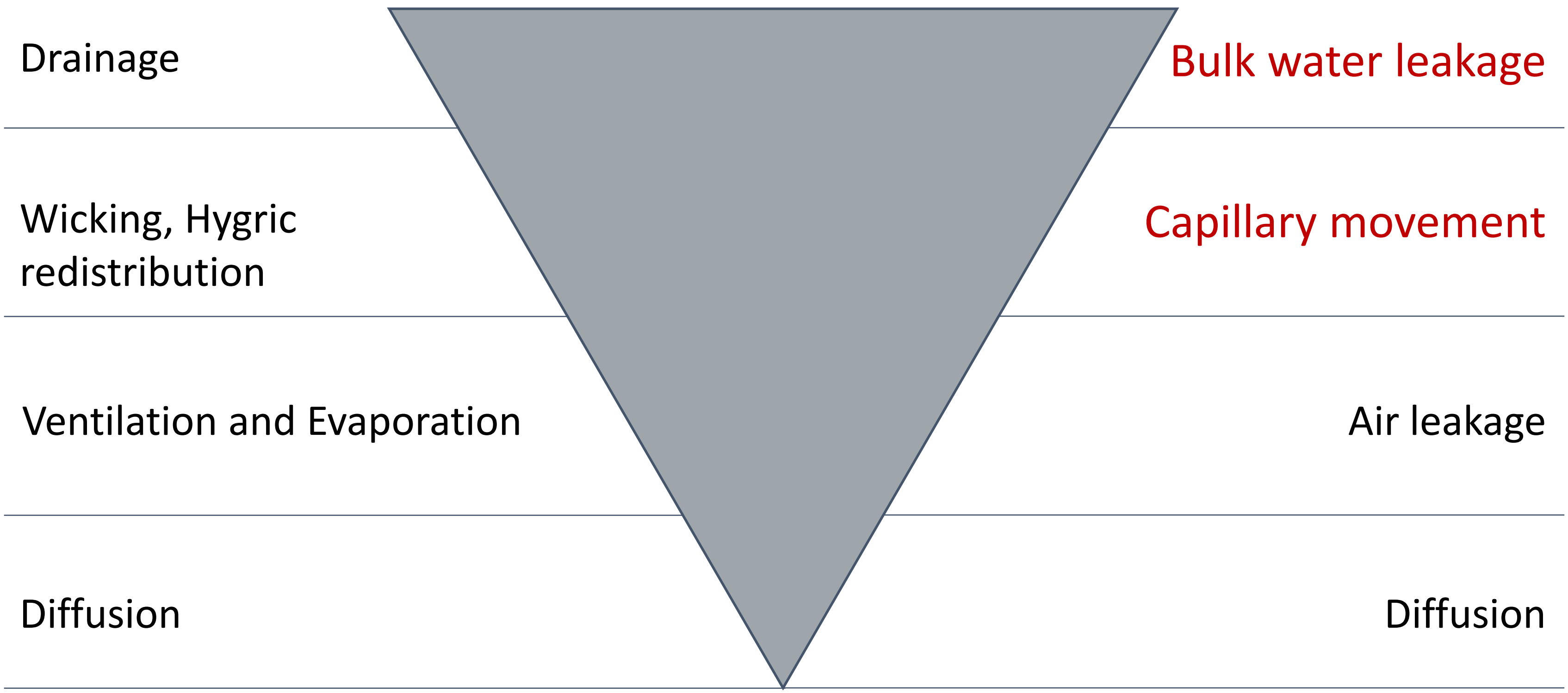
Section 1 – Building Science Review

Drying pathways – arranged in order of significance

Drainage	Bulk water leakage
Wicking, Hygric redistribution	Capillary movement
Ventilation and Evaporation	Air leakage
Diffusion	Diffusion

Section 1 – Building Science Review

How do we control these two in a modern wall?



Section 1 – Building Science Review

…Drainage cavity behind cladding, with ventilation

1) Allows any water leakage that does happen to drain out of the assembly.
2) Stops capillary moisture drive.
3) Ventilation aids evaporation and removes moisture.

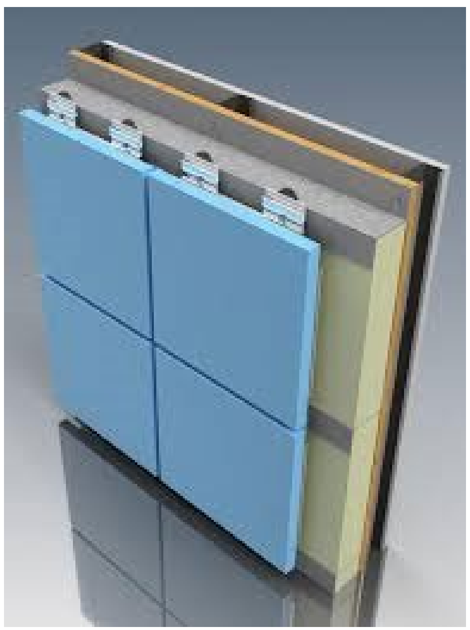


Image credit – CEI Composite Materials

Section 1 – Building Science Review

How do we control these two for a wall?

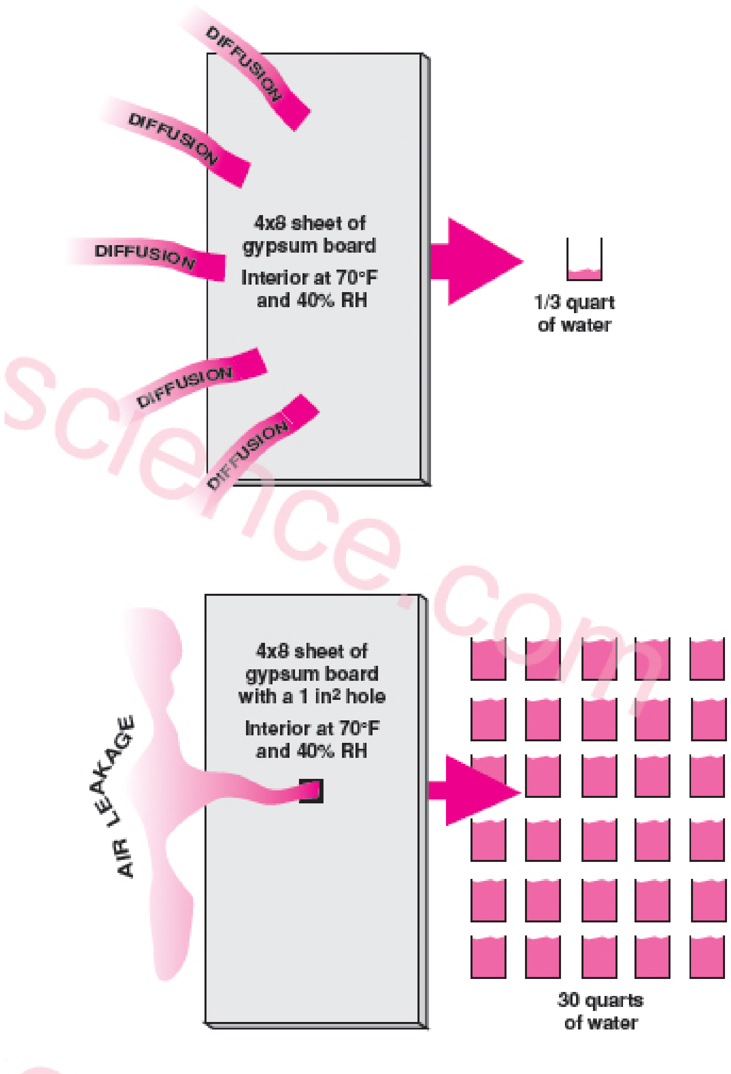
Drainage	Bulk water leakage
Wicking, Hygric redistribution	Capillary movement
Ventilation and Evaporation	Air leakage
Diffusion	Diffusion

Section 1 – Building Science Review

…Frequently 6 mil poly

1) Poly is most often used as both the vapor retarder AND air barrier
2) Not a durable product - frequently punctured
3) Difficult to install in an airtight manner
4) More impermeable than is really needed – can restrict diffusion drying

Section 1 – Building Science Review

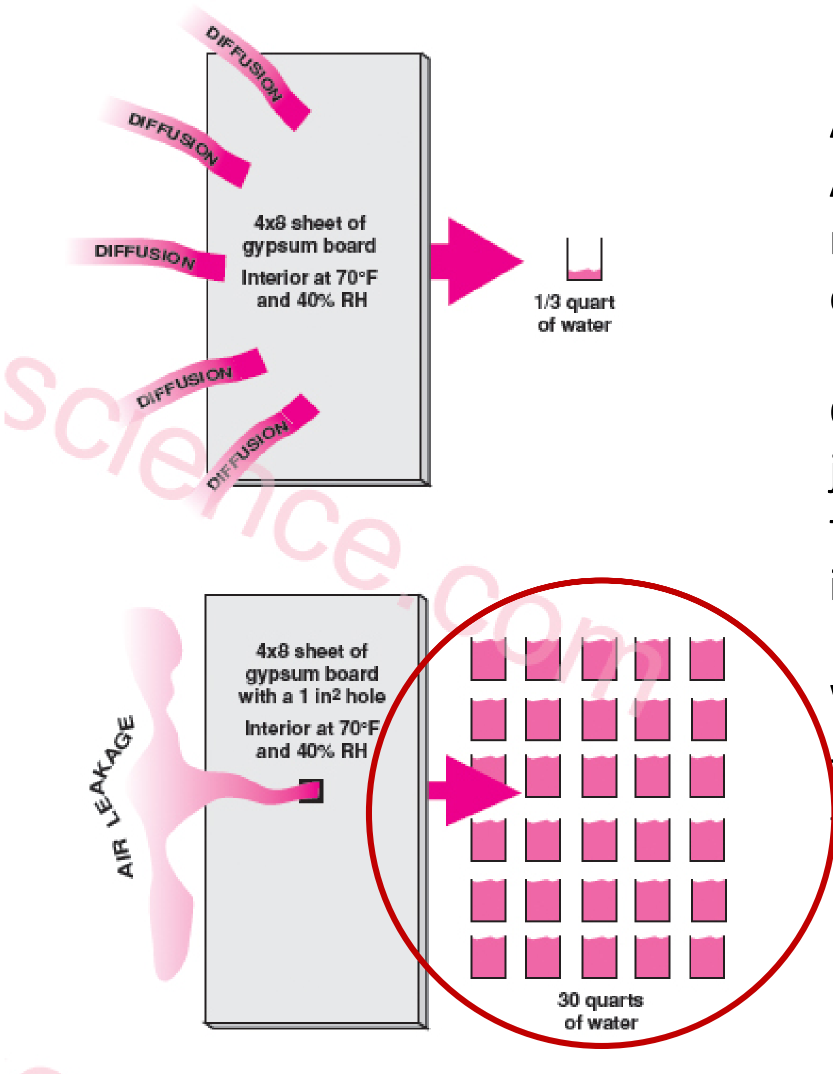


Air Leakage vs. Diffusion

Air leakage has the potential to introduce many times more water into a wall than diffusion.

Controlling air leakage is important not just for energy savings, but for the long term moisture durability of highly-insulated envelopes.

Section 1 – Building Science Review



Air Leakage vs. Diffusion

Air leakage has the potential to introduce many times more water into a wall than diffusion.

Controlling air leakage is important not just for energy savings, but for the long term moisture durability of highly-insulated envelopes.

Where does all this water go?

- Some escapes with the air
- In the winter, much of it "condenses" on the first cold surface, typically the sheathing.

Section 1 – Building Science Review

In reality, condensation only happens on the surface of "hygrophobic" materials like glass, metal, tile, etc.

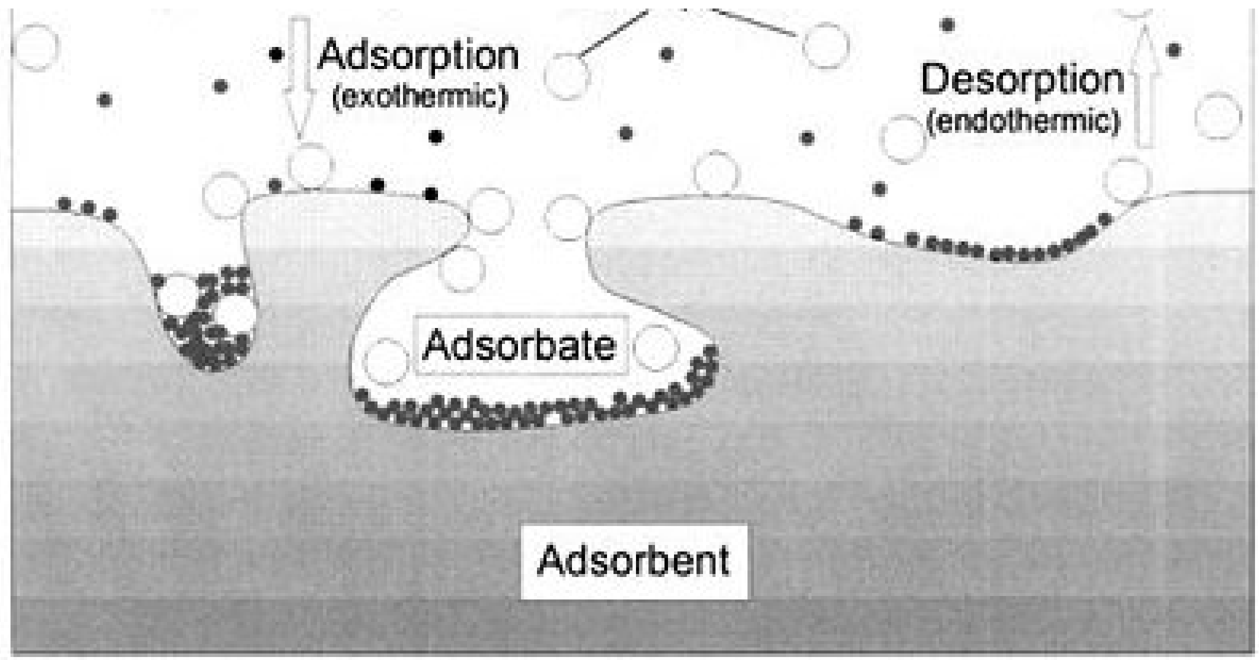
Actual condensation on wood building materials is rarely observed…

…but we will continue to use the term "condensation" since it implies the importance of maintaining the sheathing above the dew point.

Section 1 – Building Science Review

In fact, moisture is "adsorbed" by the surface of a hygrophilic material (such as wood), then is wicked deeper into the material until it becomes saturated.

Adsorption happens as a molecular layer of liquid forms on the surface and in the material's pores.

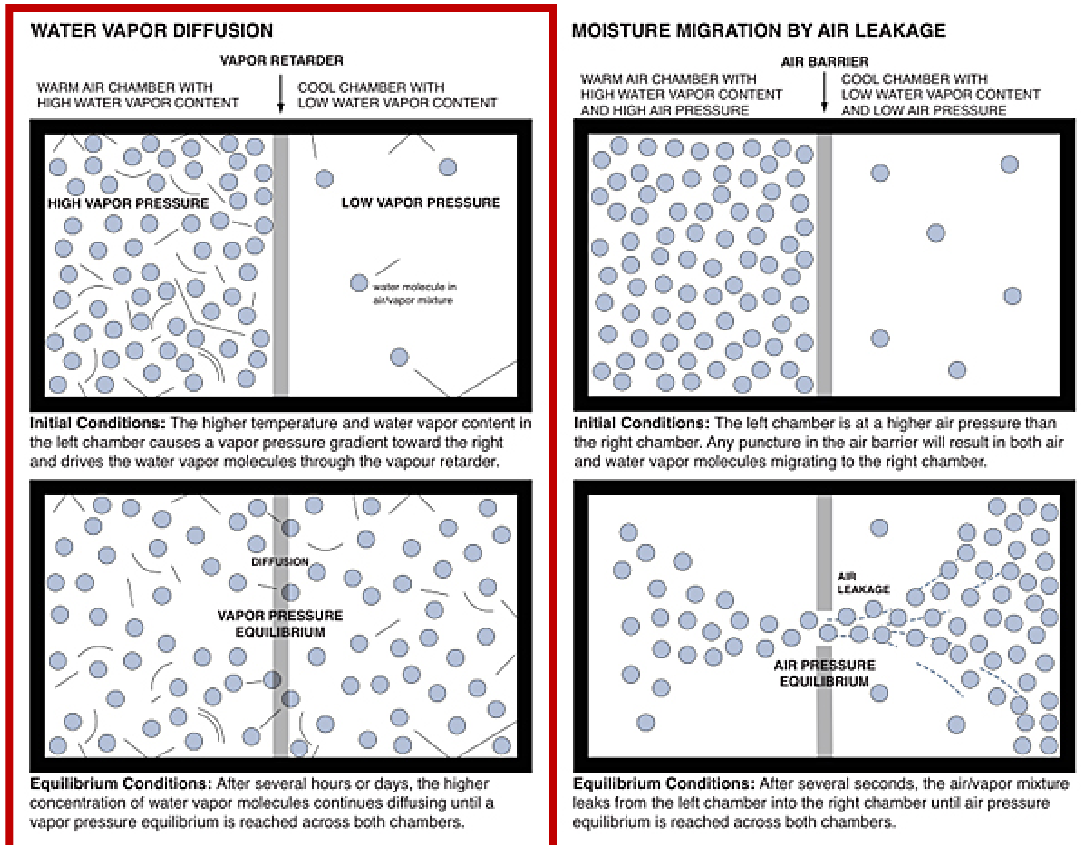


Section 1 – Building Science Review

After bulk water leakage, capillary movement, and air leakage are controlled, diffusion wetting and drying should be considered.

It can be the most confusing topic.

Diffusion is the transport of water vapor through a material, molecule by molecule, driven by difference in vapor pressure.



Whole Building Design Guide

Section 1 – Building Science Review

After bulk water leakage, capillary movement, and air leakage are controlled, diffusion wetting and drying should be considered.

Here are some basic rules for cold climates:

1) A class I or II warm side vapor retarder is required in most cases

Impermeable	Semi-impermeable	Semi-permeable
<--- Class I -------------------	Class II --------------------	Class III --->
(0.1 perm or less)	(> 0.1 perm to 1 perm)	(> 1 perm to 10 perms)
6 mil poly	vapor retarder paint	latex paint
metal foil	OSB (dry)	plywood (dry)
rubberized membranes	1 inch XPS foam	1 inch closed cell SPF
	Kraft paper	1 inch EPS foam
		roofing felt
		grade D bldg. paper (dry)

Section 1 – Building Science Review

Here are some basic rules for cold climates:

1) A class I or II warm side vapor retarder is required in most cases
2) Don’t create a “vapor sandwich”

Norwegian building code requires exterior layers of sheathing and insulation to be 10x more vapor permeable than the warm side vapor retarder. This is to encourage <u>outward drying</u> (which is probably the easiest approach in cold climates).

Section 1 – Building Science Review

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior XPS (pink or blue foam) be applied?

Section 1 – Building Science Review

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior XPS (pink or blue foam) be applied?

- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL

Section 1 – Building Science Review

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If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior EPS (white Styrofoam) be applied?

Section 1 – Building Science Review

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If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior EPS (white Styrofoam) be applied?

- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES

Section 1 – Building Science Review

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If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior foil-faced polyiso be applied?

Section 1 – Building Science Review

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- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly - FAILS!

Section 1 – Building Science Review

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can 1 inch of exterior mineral wool be applied?

- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly – FAILS!
- 1 inch of mineral wool (100 perms) is 1000x more vapor open- PASSES (easily)

Section 1 – Building Science Review

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can OSB be used as the exterior sheathing?

- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly – FAILS!
- 1 inch of mineral wool (100 perms) is 1000x more vapor open- PASSES

- OSB sheathing (1.0 perms) is exactly 10x more vapor open – PASSES

Section 1 – Building Science Review

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can fiberglass-faced gypsum board (like DensGlass Gold) sheathing be used?

- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly – FAILS!
- 1 inch of mineral wool (100 perms) is 1000x more vapor open- PASSES

- OSB sheathing (1.0 perms) is exactly 10x more vapor open – PASSES
- DensGlass Gold, fire-rated type X (18 perms) is 180x more vapor open – PASSES

Section 1 – Building Science Review

Testing the 10x guideline…

If 6 mil poly (0.1 perms) is used as the warm side vapor retarder, can OSB + exterior EPS be used together?

- 1 inch of exterior XPS (1.0 perms) is 10 x more vapor open – PASS/FAIL
- 1 inch of exterior EPS (3.0 perms) is 30x more vapor open - PASSES
- 1 inch of foil faced polyiso (0.05 perms) is less permeable than the poly – FAILS!
- 1 inch of mineral wool (100 perms) is 100x more vapor open- PASSES

- OSB sheathing (1.0 perms) is exactly 10x more vapor open – PASSES
- DensGlass Gold, fire-rated type X (18 perms) is 180x more vapor open – PASSES
- OSB sheathing + 1 inch of EPS (0.75 perms total) is 7.5x more vapor open - FAILS, but…

The addition of exterior rigid foam over sheathing is often a gray area that requires more analysis.

Section 1 – Building Science Review

If exterior foams are used:

1) An adequate amount should be used to meet R-value guidelines (keeps sheathing warm and helps prevent condensation in the wall cavity)
2) A more permeable warm-side vapor retarder should be used, class III, to allow the cavity to dry to the inside

Be advised:
In cold climates, a thin application of exterior foam puts the wall in “no-man’s land” – not enough exterior R-value to keep the sheathing warm and condensation free, but perhaps enough vapor resistance to create a cold side vapor retarder.

Section 1 – Building Science Review

If exterior foams are used:

Climate Zone	*Class III vapor retarders permitted for:*
Zone Marine 4	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over [exterior] gypsum [sheathing] Insulated [foam] sheathing with R-value ≥ R2.5 over 2x4 wall Insulated [foam] sheathing with R-value ≥ R3.75 over 2x6 wall
Zone 5	Vented cladding over OSB Vented cladding over plywood Vented cladding over fiberboard Vented cladding over [exterior] gypsum [sheathing] Insulated [foam] sheathing with R-value ≥ R5 over 2x4 wall Insulated [foam] sheathing with R-value ≥ R7.5 over 2x6 wall
Zone 6	Vented cladding over fiberboard Vented cladding over [exterior] gypsum [sheathing] Insulated [foam] sheathing with R-value ≥ R7.5 over 2x4 wall Insulated [foam] sheathing with R-value ≥ R11.25 over 2x6 wall
Zones 7 and 8	Insulated [foam] sheathing with R-value ≥ R10 over 2x4 wall Insulated [foam] sheathing with R-value ≥ R15 over 2x6 wall

IECC 2007, table 402.5.1

Center for Sustainable Building Research

Section 1 – Building Science Review

We've been talking about:
Control Layers

Water Barrier

Air Barrier

Vapor Retarder

Thermal Barrier

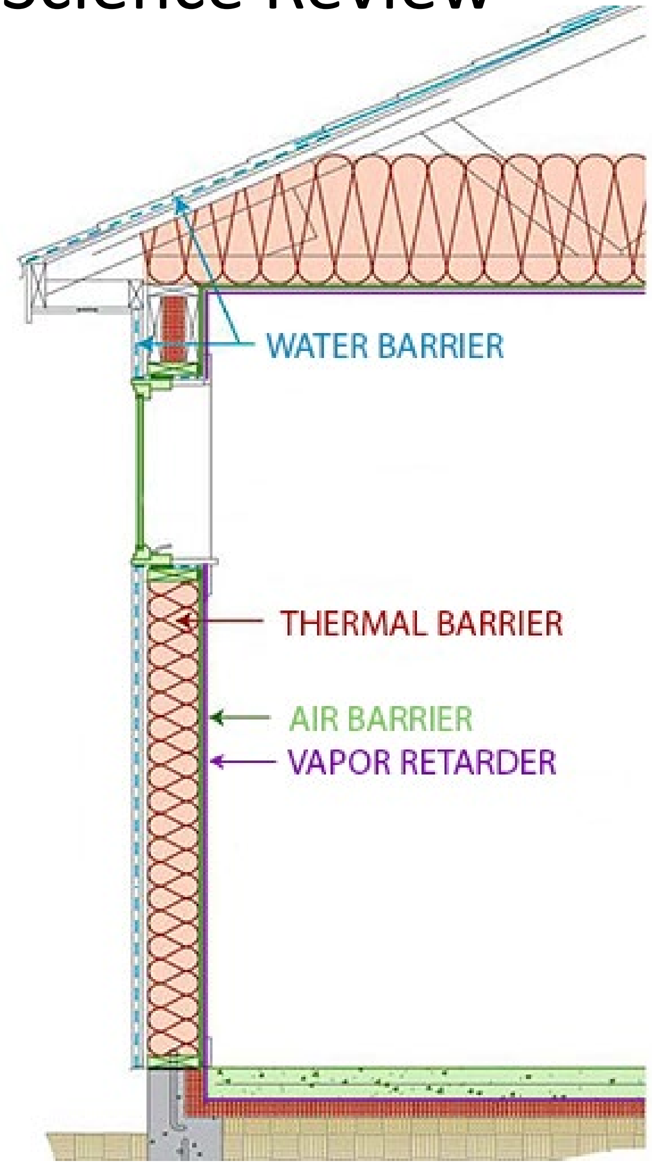

Image from Peter Yost

Section 1 – Building Science Review

We've been talking about:
Control Layers

Water Barrier – "physics first (slope, weatherlap, capillary break), chemistry second" (sealants, tapes, coatings). High *water* resistance is key, but *vapor* resistance is variable (e.g. Gore-tex)

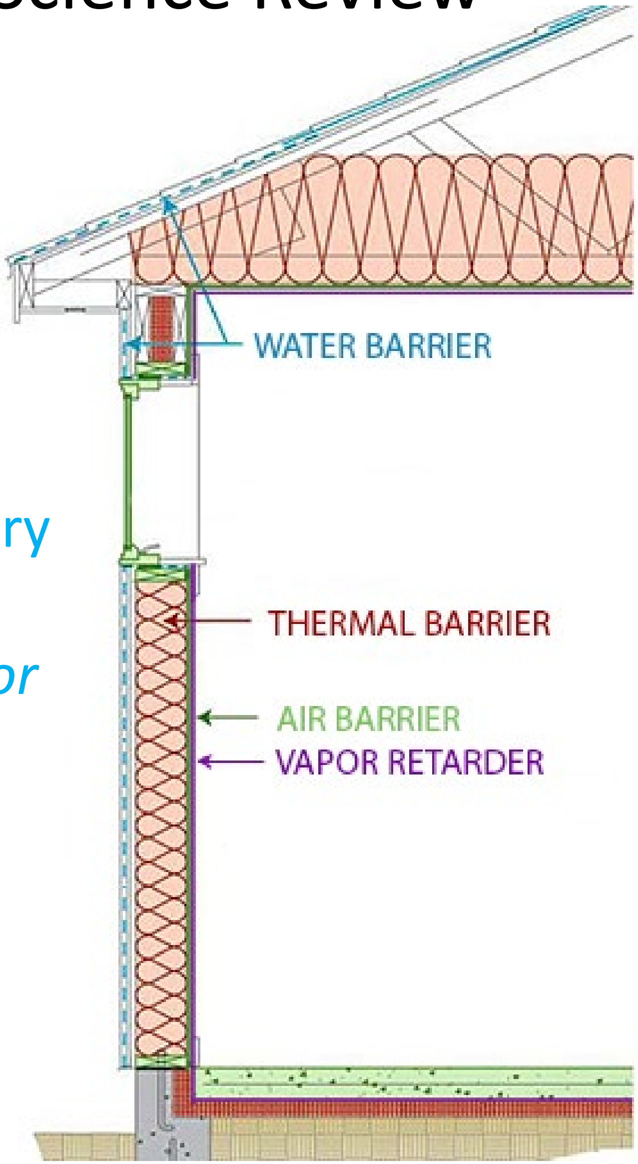

Image from Peter Yost

![CSBR Center for Sustainable Building Research]

Section 1 – Building Science Review

We've been talking about:
Control Layers

Air Barrier – Ability to resist air pressure is key. 100% continuity is vital. Vapor resistance can be variable. Think carefully about its location in the wall cross section and the possibility for air flow within the cavity.

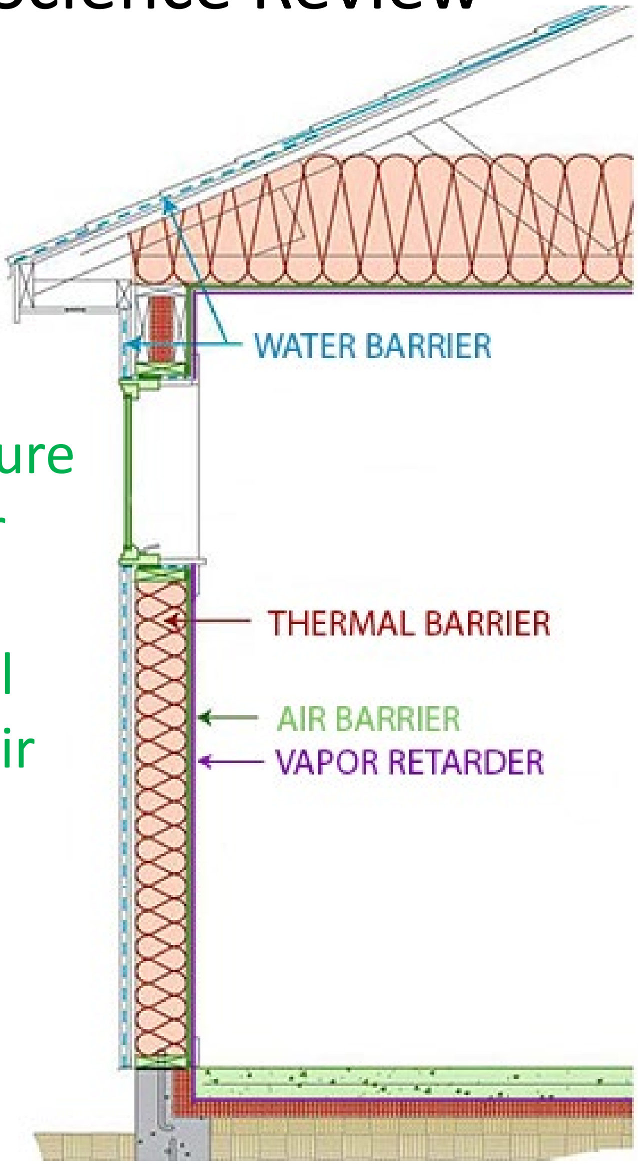

Image from Peter Yost

Section 1 – Building Science Review

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Control Layers

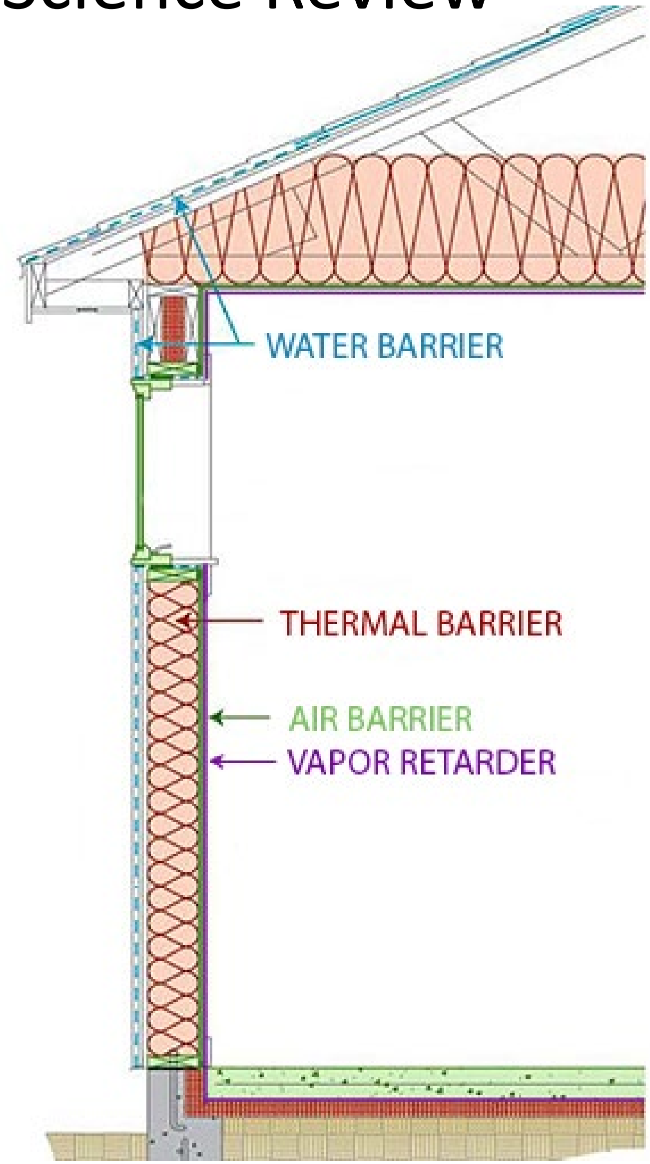


Image from Peter Yost

Vapor Retarder – Vapor resistance is still variable. Needs to be chosen according to climate (direction of vapor drive), location in the wall assembly, and design intent (e.g. desired drying direction).

Continuity is less important:
A 99% continuous vapor retarder is 99% effective.

Section 1 – Building Science Review

We've been talking about:
Control Layers

Thermal Barrier – Low thermal conductivity is key. Continuity is also important (no thermal bridges).

Ratio of exterior insulation to interior insulation plays a huge role in the moisture dynamics of the wall assembly.

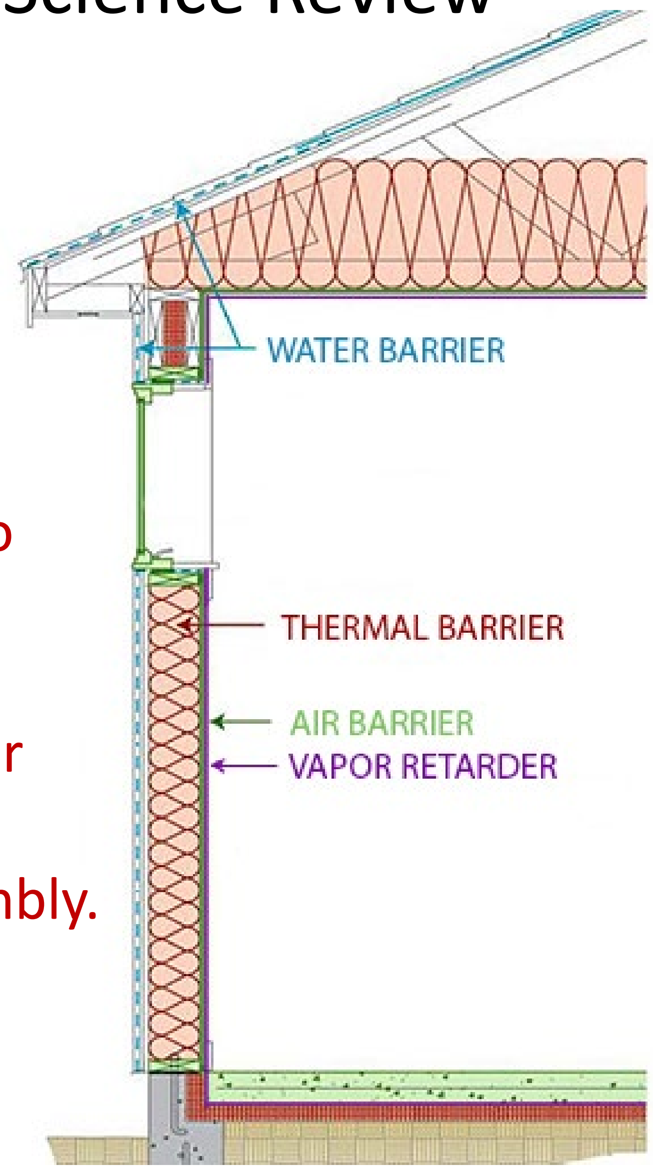


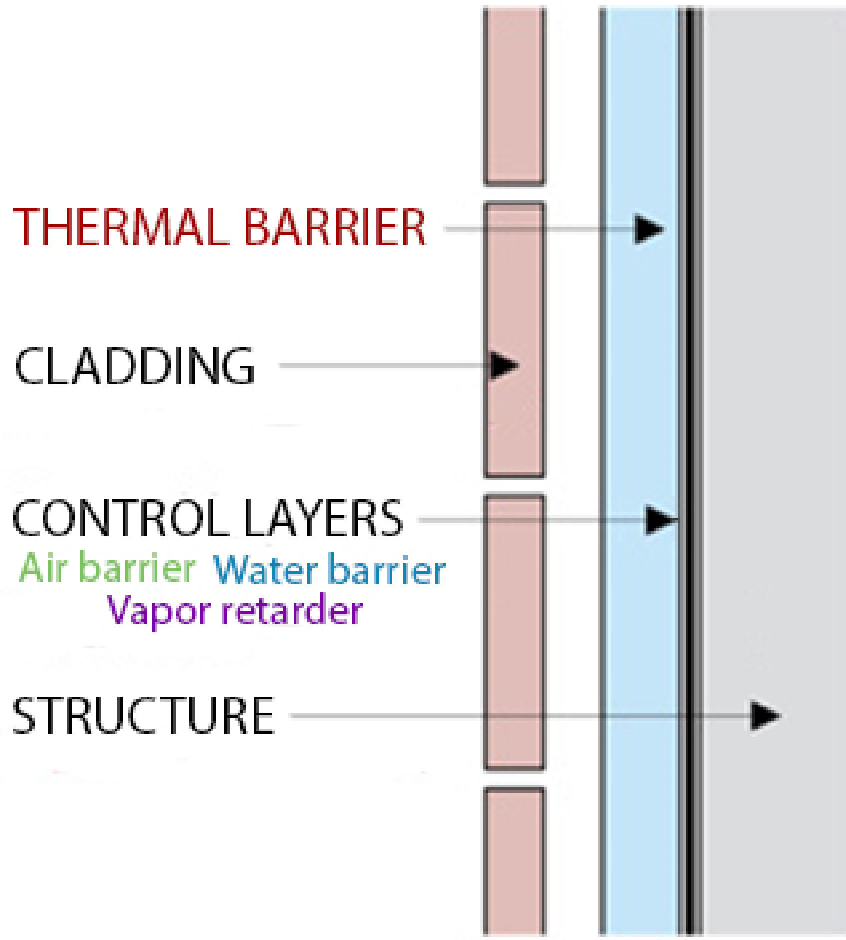
Image from Peter Yost

Section 1 – Building Science Review

The Perfect Wall – Wall design simplified!

1) All control layers to the exterior of the structure
2) Structure is kept warm and dry
3) Air barrier, water barrier, and vapor retarder can be combined into one layer
4) Those control layers are protected by the insulation and application is simplified
5) Works in any climate zone

Image from Building Science Corp.



Section 2 – Qualitative Moisture Assessment

How is the assembly *designed* to handle moisture?

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How is the assembly *designed* to handle moisture?

There are a few steps to a qualitative moisture assessment:

1) Describe how the assembly is designed to handle bulk water
2) Describe how the assembly is designed to control air leakage
3) Describe how the assembly is designed control diffusion
4) Describe how the assembly is designed to control heat flow
5) Describe how the assembly is designed to dry (drying direction)

Evaluate the design, constructability, and long-term durability

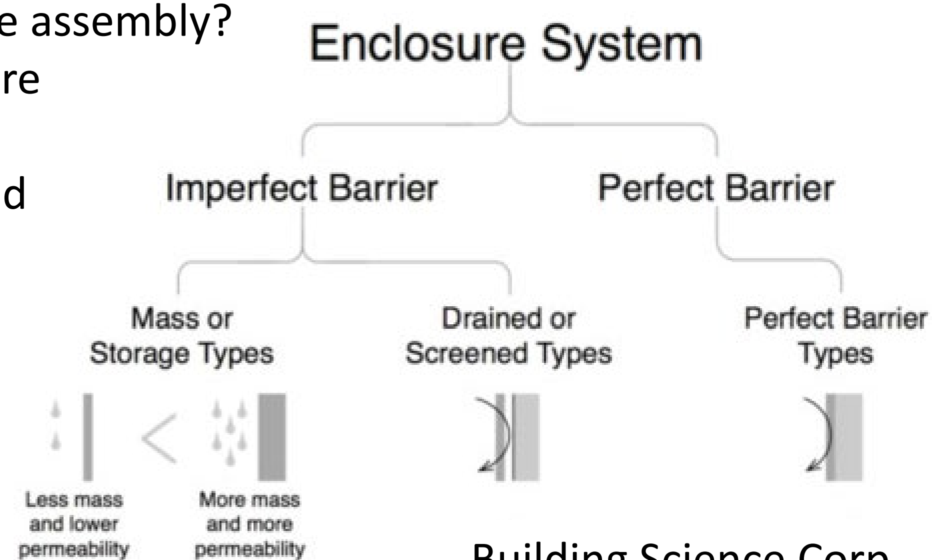
Section 2 – Qualitative Moisture Assessment

How is the assembly *designed* to handle moisture?

There are a few steps to a qualitative moisture assessment:

1) Describe how the assembly is designed to handle bulk water

- Identify the water control layer. Does it rely on perfection? (i.e. face-sealed cladding or caulk)
- Are there redundancies built into the assembly?
- Does the assembly have safe moisture storage potential?
- Is the water control layer durable and protected from damage functions (extreme temps, solar radiation, etc?)
- Is a drainage gap/capillary break provided?



Building Science Corp.

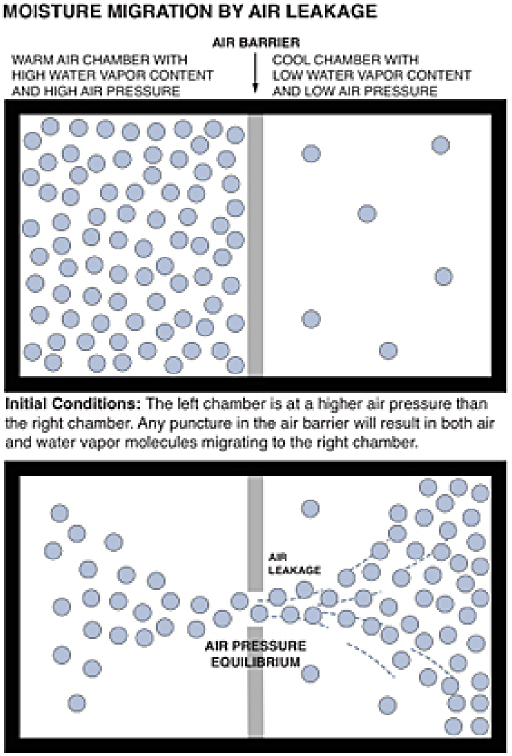
Section 2 – Qualitative Moisture Assessment

How is the assembly *designed* to handle moisture?

There are a few steps to a qualitative moisture assessment:

2) Describe how the assembly is designed to control air leakage

- Identify the air control layer. Can it be installed easily in a continuous fashion?
- Is the air barrier a durable (or fragile) material?
- Is the air barrier protected from damage functions?
- Is it located in the right place in the assembly?



Initial Conditions: The left chamber is at a higher air pressure than the right chamber. Any puncture in the air barrier will result in both air and water vapor molecules migrating to the right chamber.

Equilibrium Conditions: After several seconds, the air/vapor mixture leaks from the left chamber into the right chamber until air pressure equilibrium is reached across both chambers.

Center for Sustainable Building Research

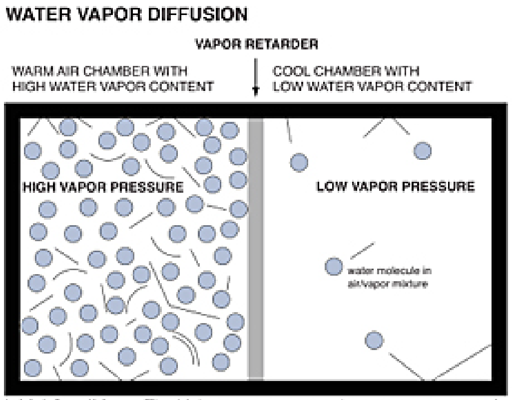
Section 2 – Qualitative Moisture Assessment

How is the assembly *designed* to handle moisture?

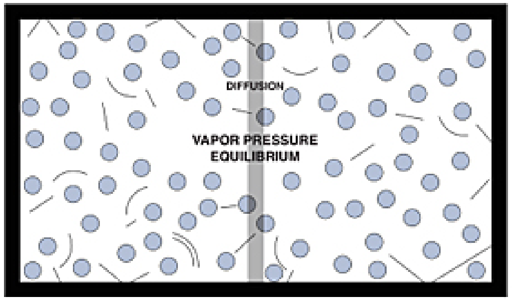
There are a few steps to a qualitative moisture assessment:

3) Describe how the assembly is designed control diffusion

- Identify the vapor control layer.
  For cold climates, is it on the warm side?
- Does the assembly avoid creating a vapor sandwich?
- Do interior layers of the assembly have an adequately high drying potential, or is the assembly very impermeable in both directions?



Initial Conditions: The higher temperature and water vapor content in the left chamber causes a vapor pressure gradient toward the right and drives the water vapor molecules through the vapour retarder.



Equilibrium Conditions: After several hours or days, the higher concentration of water vapor molecules continues diffusing until a vapor pressure equilibrium is reached across both chambers.

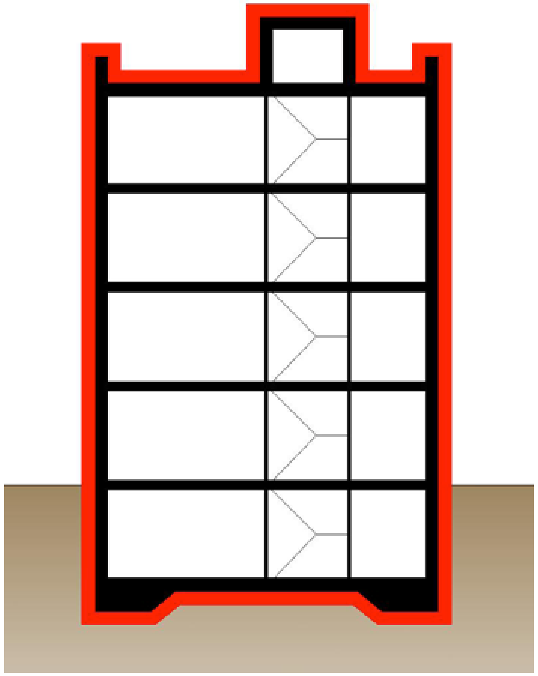
Section 2 – Qualitative Moisture Assessment

How is the assembly *designed* to handle moisture?

There are a few steps to a qualitative moisture assessment:

4) Describe how the assembly is designed to control heat flow

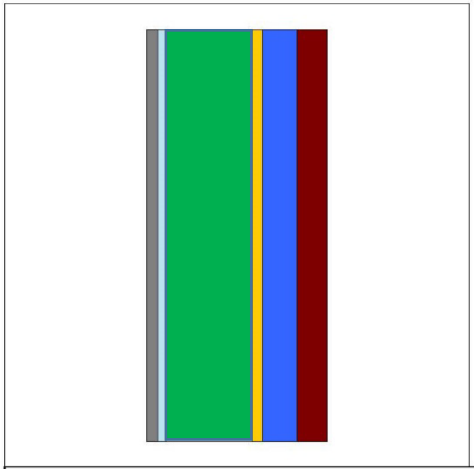
- Identify the thermal control layer.
  Is it continuous or are there uninsulated spots where condensation could occur?
- Does the insulation help protect control layers from damage functions?
- Does the insulation help keep the sheathing and structure warm and dry?



Section 2 – Qualitative Moisture Assessment

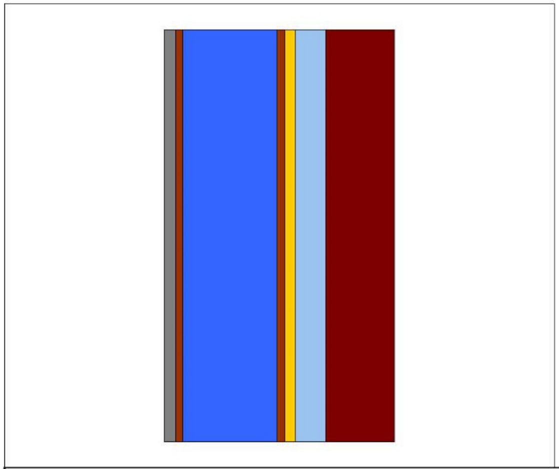
Introducing 3 (High Performance) Multifamily Wall Types:

2x6 w ccSPF and Enduramax



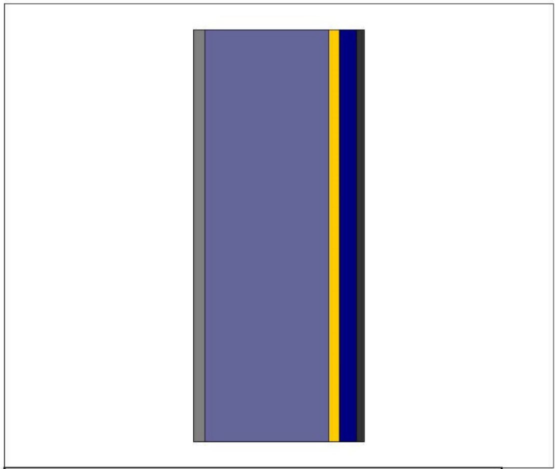
	Material	λ[W/(m·K)]	ε
■	Brick (R-0.1/inch)	1.312	0.900
■	Dens Glass Gold	0.161	0.900
■	EPS Type VIII (R-4/inch)	0.036	0.900
■	Gypsum board	0.161	0.900
■	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
■	ccSPF (R-6.7/inch)	0.021	0.900

6" SIP w brick



	Material	λ[W/(m·K)]	ε
■	Brick (R-0.1/inch)	1.312	0.900
■	Dens Glass Gold	0.161	0.900
■	EPS Type VIII (R-4/inch)	0.036	0.900
■	Gypsum board	0.161	0.900
■	Luftschicht, ruhend, horizontal, Dicke: 45 mm	0.250	
■	OSB	0.097	0.900

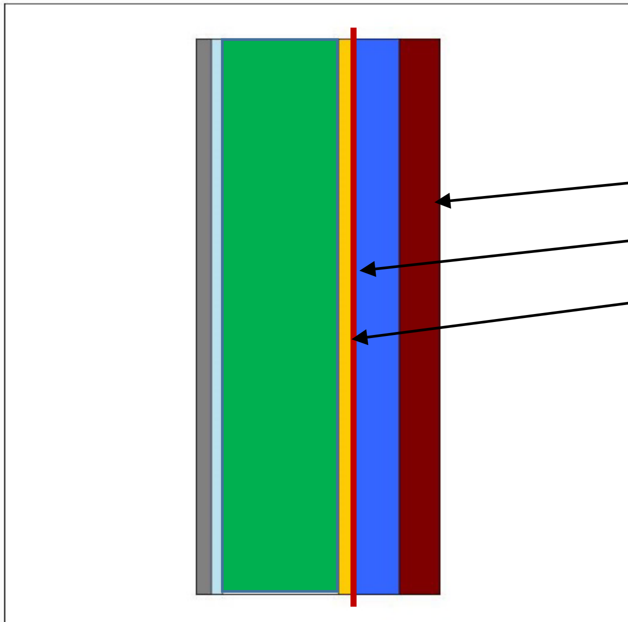
2x8 w cellulose and fiber cement



	Material	λ[W/(m·K)]	ε
■	Cellulose	0.040	0.900
■	Dens Glass Gold	0.161	0.900
■	Fiber cement - Hardie board	0.301	0.900
■	Gypsum board	0.161	0.900
■	XPS	0.029	0.900

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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■	Gypsum board	0.161	0.900
■	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
■	ccSPF (R-6.7/inch)	0.021	0.900

Water control: Drained and screened
- brick cladding sheds bulk water
- drainage gap built into backside of EPS
- WRB is liquid-applied 3M 2085VP

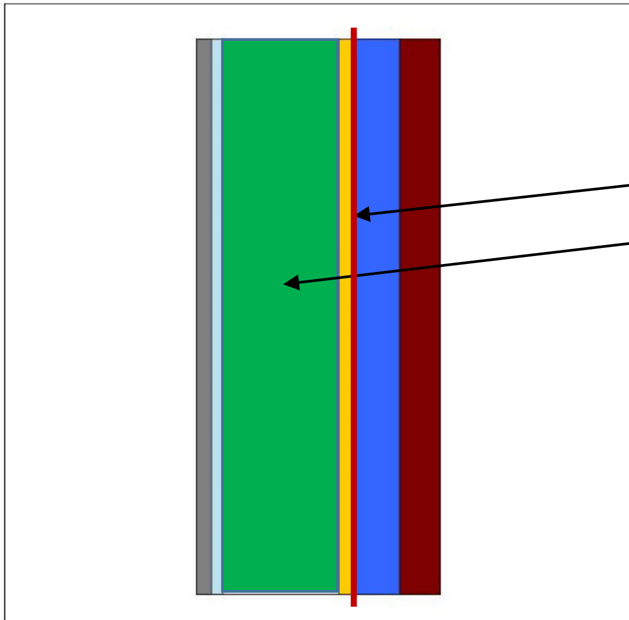
System has good redundancy
WRB is protected from damage functions
Drainage gap provides capillary break

But little water storage potential

Overall: ☺

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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	Gypsum board	0.161	0.900
	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
	ccSPF (R-6.7/inch)	0.021	0.900

Air control: ccSPF plus exterior air barrier

- liquid-applied 3M 2085VP
- closed cell spray foam in stud cavities

System has good redundancy

3M 2085 can be applied in continuous fashion and is well-protected

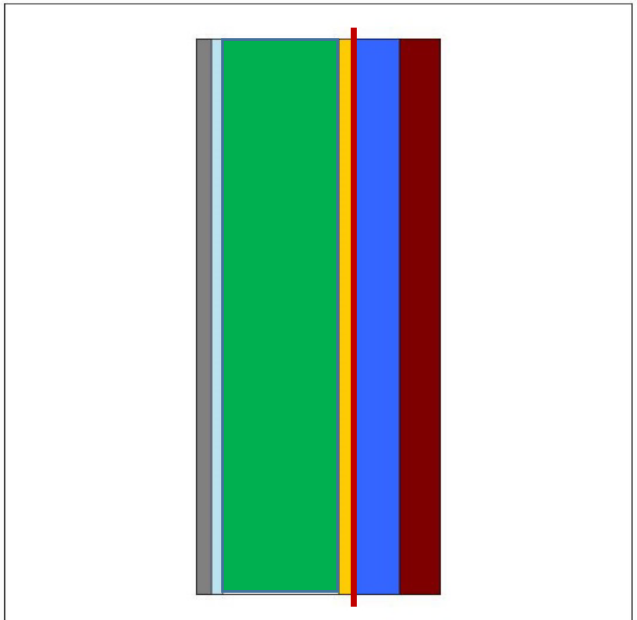
ccSPF is a very durable air barrier

Location of primary air barrier on exterior of sheathing works well *with air-impermeable cavity insulation*

Overall: ☺

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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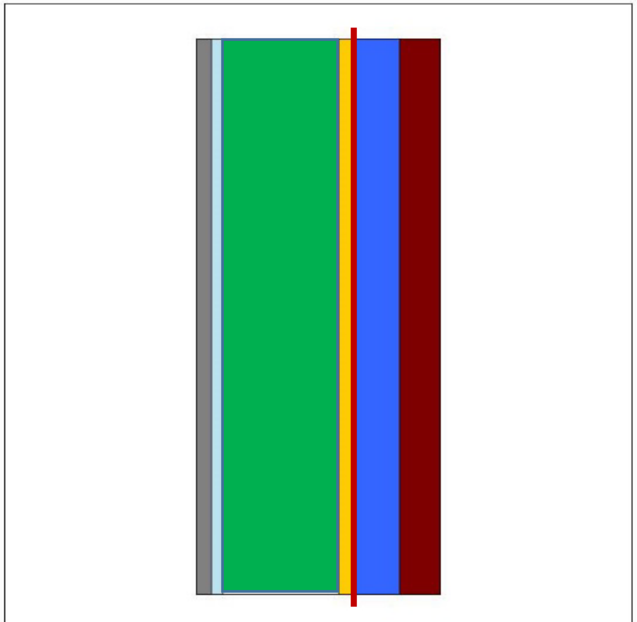
Gypsum board	0.161	0.900
Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
ccSPF (R-6.7/inch)	0.021	0.900

Drying Strategy/Direction:

Which way does the sheathing dry?

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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Gypsum board	0.161	0.900
Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
ccSPF (R-6.7/inch)	0.021	0.900

Drying Strategy/Direction:

Which way does the sheathing dry?

Primary vapor retarder is ccSPF at 0.3 perms

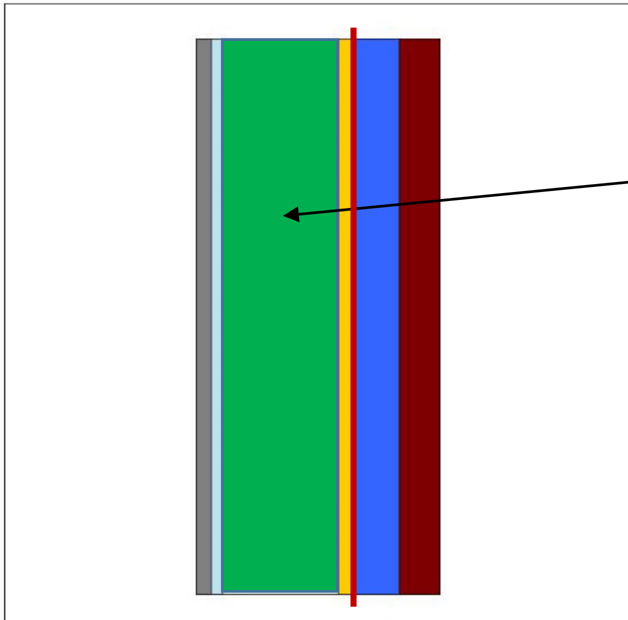
Exterior layers of gypsum sheathing and 3M 2085 are vapor open, but EPS + brick is only 3.5x more vapor open than the ccSPF (approx. 1 perm)

Exterior foam is not thick enough to move the sheathing "inside"

Sheathing primarily dries to the outside, but Enduramax product muddles this strategy somewhat. Overall: 😐

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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	EPS Type VIII (R-4/inch)	0.036	0.900
	Gypsum board	0.161	0.900
	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
	ccSPF (R-6.7/inch)	0.021	0.900

Vapor control: ccSPF
- closed cell spray foam in stud cavities

Vapor control is on warm side

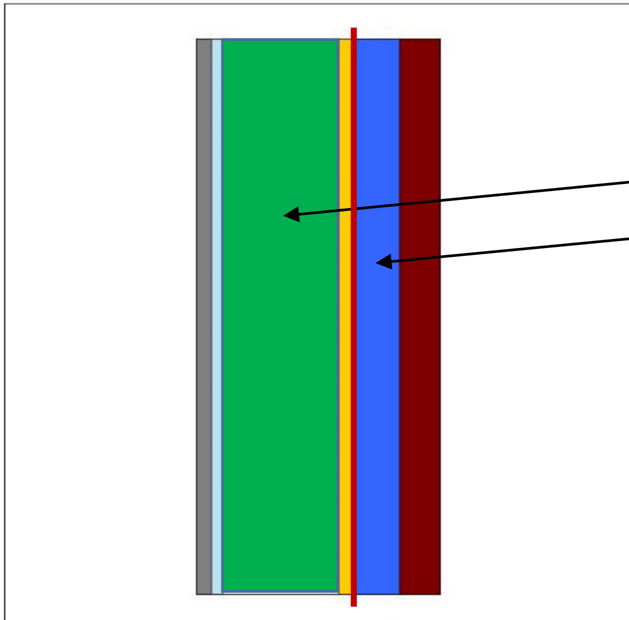
Exterior layers of gypsum sheathing and 3M 2085 are vapor open, but EPS + brick is only 3.5x more vapor open than the ccSPF

Sheathing is located between two semi-impermeable layers, but has some relief thanks to drainage gap

Overall: 😐

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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	EPS Type VIII (R-4/inch)	0.036	0.900
	Gypsum board	0.161	0.900
	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
	ccSPF (R-6.7/inch)	0.021	0.900

Thermal control: ccSPF plus Enduramax

- closed cell spray foam in stud cavities
- exterior EPS

Spray foam fills cavities completely and exterior EPS help eliminate cold spots/thermal breaks

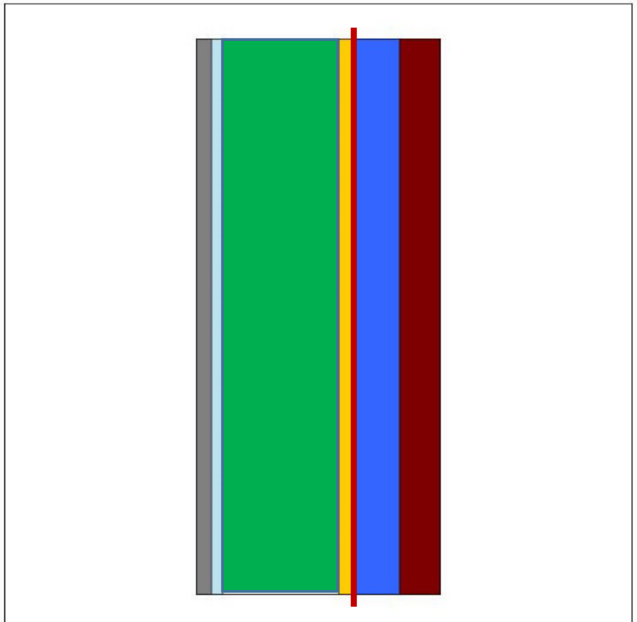
Exterior insulation helps protect primary air and water barrier

Exterior EPS (2 inches, R-8) is too thin to keep sheathing and structure above dew point during winter conditions

Overall: ☺/😐

Section 2 – Qualitative Moisture Assessment

2x6 with ccSPF and Enduramax



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	Gypsum board	0.161	0.900
	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
	ccSPF (R-6.7/inch)	0.021	0.900

Overall:

Water control: ☺

Air control: ☺

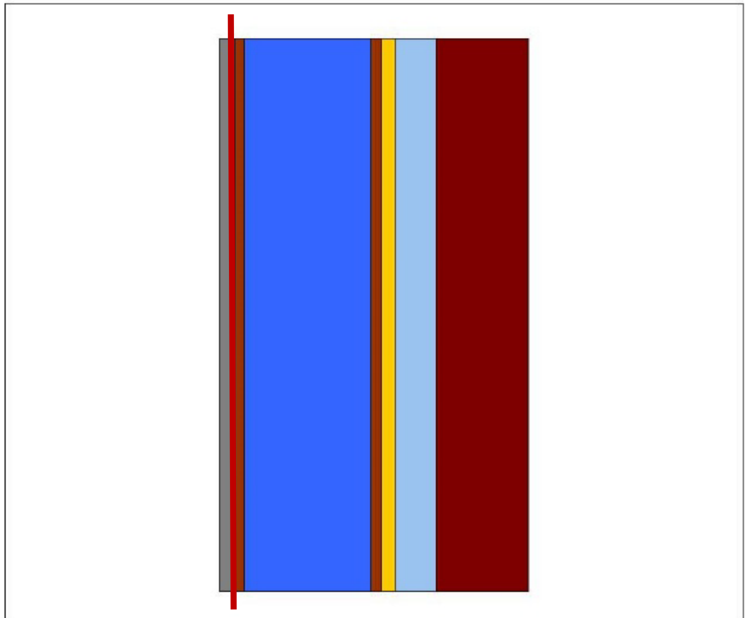
Vapor control: 😐

Thermal control: ☺/😐

Drying strategy: (outward drying) 😐

Section 2 – Qualitative Moisture Assessment

6 inch SIP with brick



	Material	λ[W/(m·K)]	ε
	Brick (R-0.1/inch)	1.312	0.900
	Dens Glass Gold	0.161	0.900
	EPS Type VIII (R-4/inch)	0.036	0.900
	Gypsum board	0.161	0.900
	Luftschicht, ruhend, horizontal, Dicke: 45 mm	0.250	
	OSB	0.097	0.900

Overall:

Water control: drained and screened

Air control: SIP panel w tape/spray foam

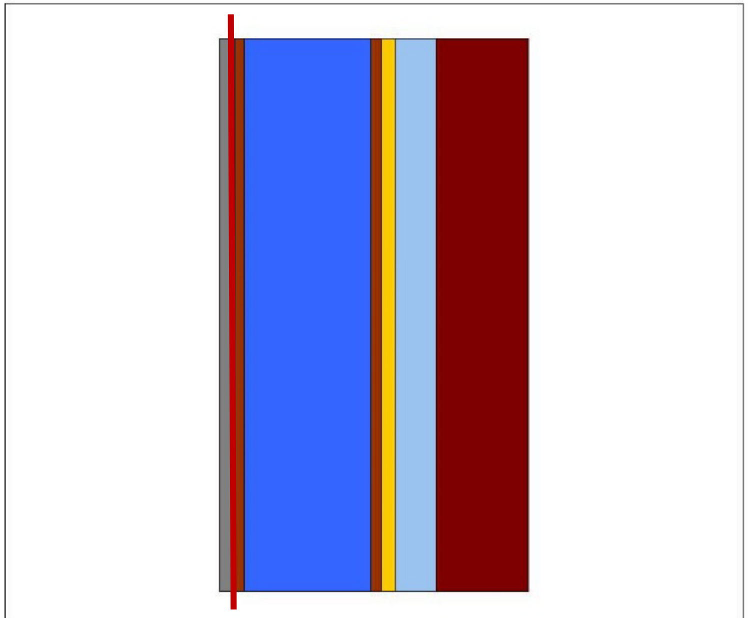
Vapor control: SIP panel (semi-impermeable and symmetric)

Thermal control: SIP panel (reduced thermal bridging)

Drying Strategy: Bi-directional drying

Section 2 – Qualitative Moisture Assessment

6 inch SIP with brick



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■	EPS Type VIII (R-4/inch)	0.036	0.900
■	Gypsum board	0.161	0.900
■	Luftschicht, ruhend, horizontal, Dicke: 45 mm	0.250	
■	OSB	0.097	0.900

Overall:

Water control: ☺

Air control: ☺

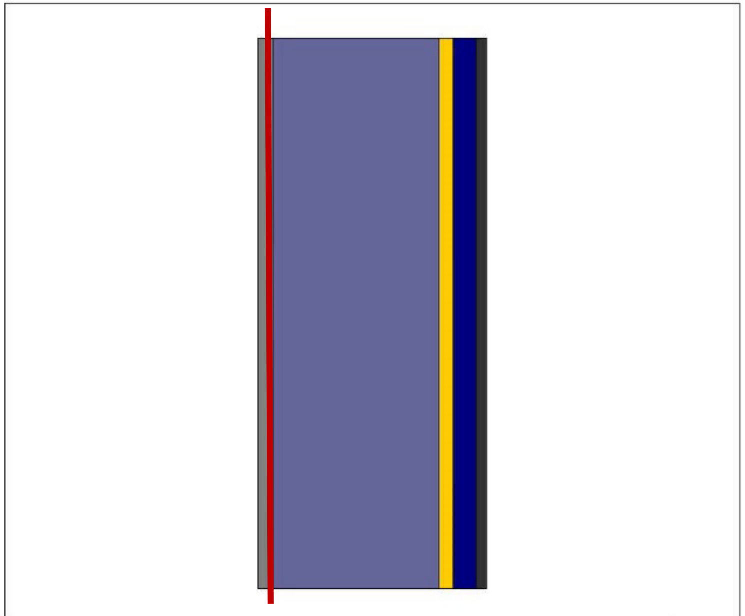
Vapor control: 😐

Thermal control: 😐

Drying strategy: (bi-directional drying) ☺

Section 2 – Qualitative Moisture Assessment

2x8 with cellulose and fiber cement



	Material	λ[W/(m·K)]	ε
	Cellulose	0.040	0.900
	Dens Glass Gold	0.161	0.900
	Fiber cement - Hardie board	0.301	0.900
	Gypsum board	0.161	0.900
	XPS	0.029	0.900

Overall:

Water control: no drainage gap, but cellulose has large moisture storage/redistribution potential

Air control: 6mil poly & dense pack cellulose

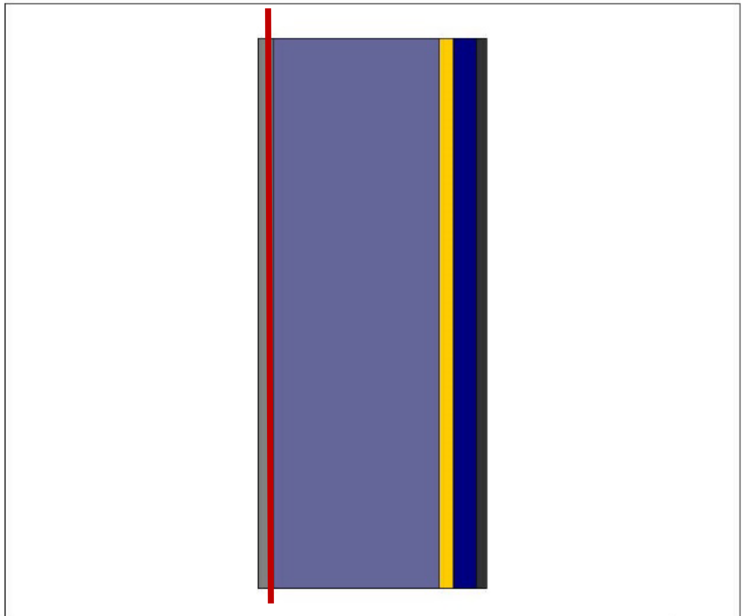
Vapor control: 6 mil poly and 1 inch exterior XPS (possible vapor sandwich)

Thermal control: exterior XPS (R-5) reduces thermal bridging but is too thin to keep sheathing above dew point

Drying Strategy: Outward drying

Section 2 – Qualitative Moisture Assessment

2x8 with cellulose and fiber cement



	Material	λ[W/(m·K)]	ε
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	Dens Glass Gold	0.161	0.900
	Fiber cement - Hardie board	0.301	0.900
	Gypsum board	0.161	0.900
	XPS	0.029	0.900

Overall:

Water control: 😐

Air control: ☹/☠

Vapor control: ☹

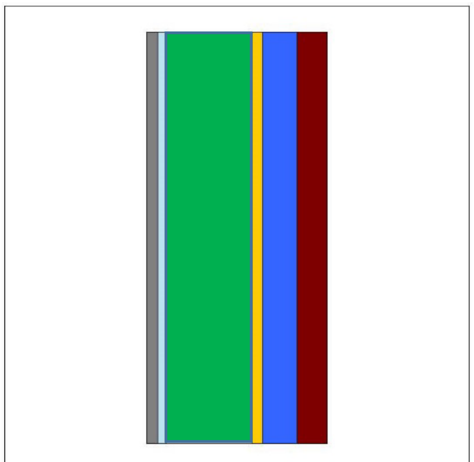
Thermal control: 😐

Drying strategy: (outward drying) 😐

Section 2 – Qualitative Moisture Assessment

Which wall is the least moisture safe?:

2x6 w ccSPF and Enduramax



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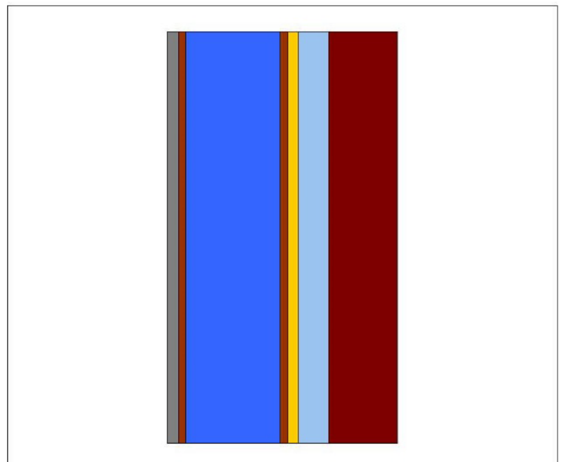
■	Dens Glass Gold	0.161	0.900
■	EPS Type VIII (R-4/inch)	0.036	0.900
■	Gypsum board	0.161	0.900
■	Luftschicht, ruhend, horizontal, Dicke: 13 mm	0.080	
■	ccSPF (R-6.7/inch)	0.021	0.900

6” SIP w brick



	Material	λ[W/(m·K)]	ε
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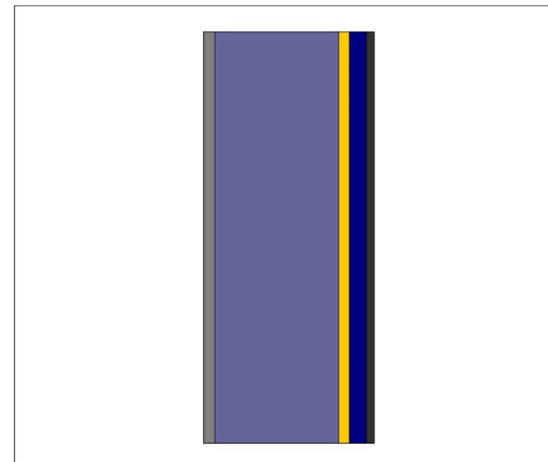
■	Dens Glass Gold	0.161	0.900
■	EPS Type VIII (R-4/inch)	0.036	0.900
■	Gypsum board	0.161	0.900
■	Luftschicht, ruhend, horizontal, Dicke: 45 mm	0.250	
■	OSB	0.097	0.900

2x8 w cellulose and fiber cement



	Material	λ[W/(m·K)]	ε
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■	Dens Glass Gold	0.161	0.900
■	Fiber cement - Hardie board	0.301	0.900
■	Gypsum board	0.161	0.900
■	XPS	0.029	0.900

Section 3 – Glaser Analysis

How is the assembly *designed* to handle condensation risk and diffusion?

Section 3 – Glaser Analysis

Start with condensation risk:

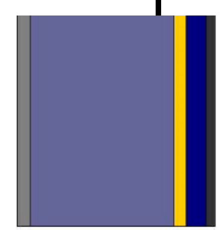
Calculate the temperature profile through a wall,
3 options for this:

1) Locate a calculator on line, search for “wall gradient calculator”
   http://cwc.ca/resources/wall-thermal-design/
2) Develop your own calculator
3) Use calculator that has been developed for the MN B3 program

Section 3 – Glaser Analysis

Calculate the temperature profile through a wall: #1 R-value of each layer

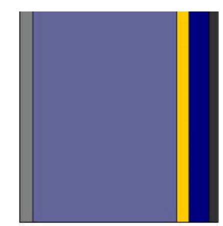
Wall Section Surfaces - R-value through insulation				
surfaces (from inside to outside)				fraction of total (additive
1	inside air film	R=	0.68	0.02
2	gypsum+latex paint+6mil poly	R=	0.56	0.04
3	cellulose	R=	26.83	0.83
4	DensGlas Gold + Tyvek	R=	0.56	0.85
5	XPS	R=	5.00	0.99
	0	R=	0.00	0.99
	0	R=	0.00	0.99
	0	R=	0.00	0.99
	0	R=	0.00	0.99
	0	R=	0.00	0.99
6	outside air film	R=	0.17	1.00
	total resistance value	R=	33.8	



Section 3 – Glaser Analysis

Calculate the temperature profile through a wall: #2 Temp at each surface

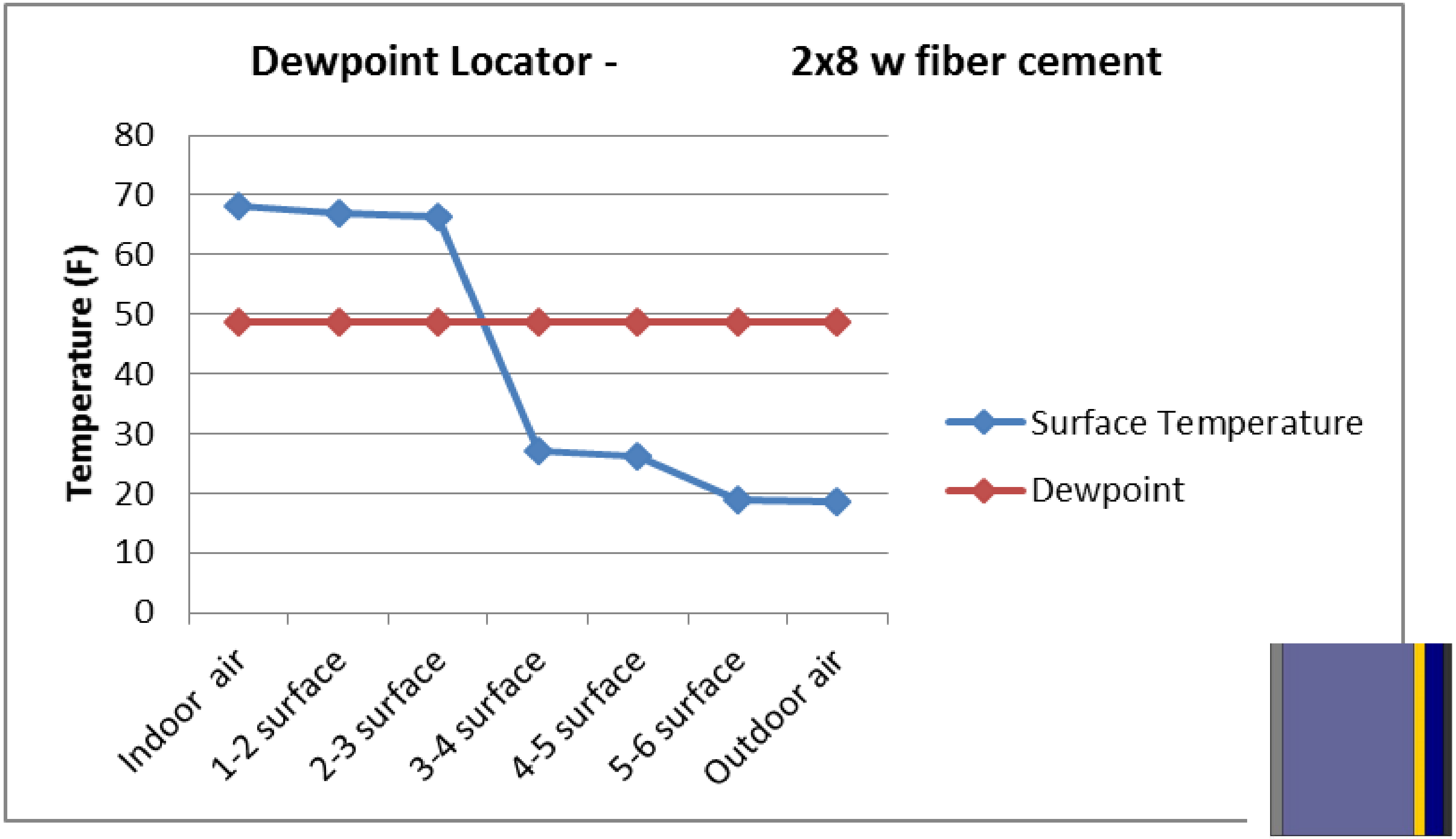
Temperature Profiles - Dewpoint Locator		
surfaces (from inside to outside)		winter (design)
	inside RH %	50%
	inside temperature	68
1	inside air film	67.0
2	gypsum+latex paint+6mil poly	66.2
3	cellulose	27.1
4	DensGlas Gold + Tyvek	26.2
5	XPS	18.9
6	outside air film	18.7
	outside temperature	18.7
	outside RH%	75%
	dewpoint temp	48.6



Typically, outside conditions are set to average winter temp and RH, estimate the likely average interior conditions (temp and RH)

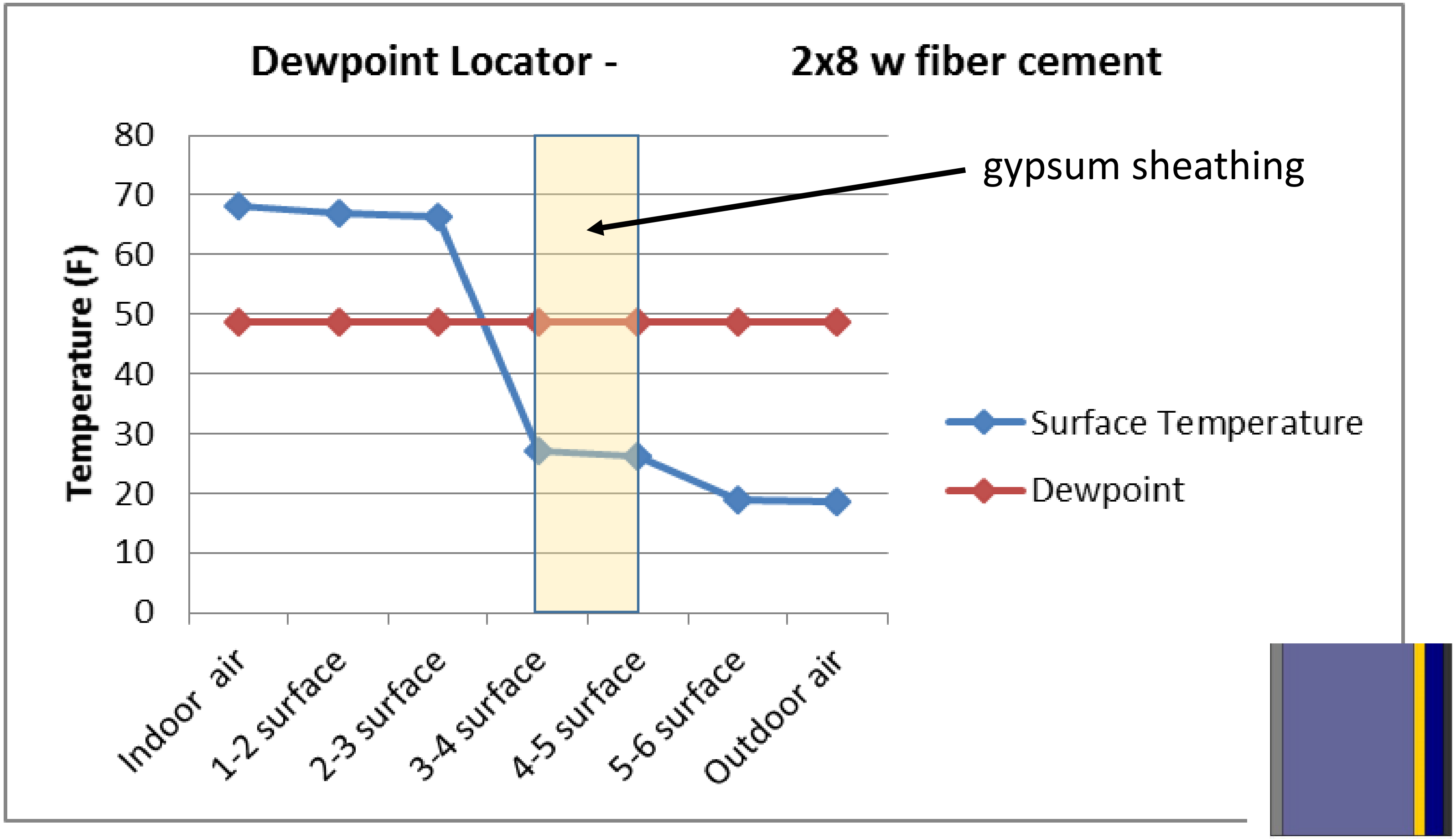
Section 3 – Glaser Analysis

Calculate the temperature profile through a wall: #3 Graph profile



Section 3 – Glaser Analysis

Where a surface temperature is below the dewpoint, there is risk of condensation



Section 3 – Glaser Analysis

The vapor profile is based on the temperature profile, but adds vapor resistance and pressure to each layer.

You need to know additional material properties:

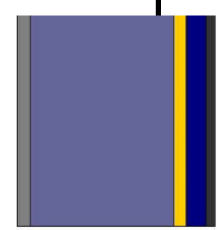
1) the permeance (perms) of all membranes
2) the permeability (perm in) of all thick materials and air layers

Everything exterior of a vented/ventilated air gap is typically removed. (Effects of many cladding systems cannot be included.)

Section 3 – Glaser Analysis

Calculate the vapor profile through a wall: #1 Vapor resistance of each layer

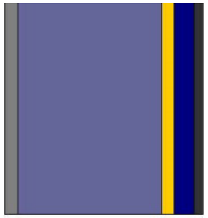
Wall Section Surfaces - vapor resistance, through insulation				
surfaces (from inside to outside)			resistance (reps)	fraction of total (additive
1	inside air film	R=	0.006	0.000
2	gypsum+latex paint+6mil poly	R=	16.796	0.940
3	cellulose	R=	0.063	0.943
4	DensGlas Gold + Tyvek	R=	0.104	0.949
5	XPS	R=	0.909	1.000
	0	R=	0.000	1.000
	0	R=	0.000	1.000
	0	R=	0.000	1.000
	0	R=	0.000	1.000
	0	R=	0.000	1.000
6	outside air film	R=	0.001	1.000
	total resistance value	R=	17.878	



Section 3 – Glaser Analysis

Calculate the vapor profile through a wall: #2 Vapor pressure at each surface

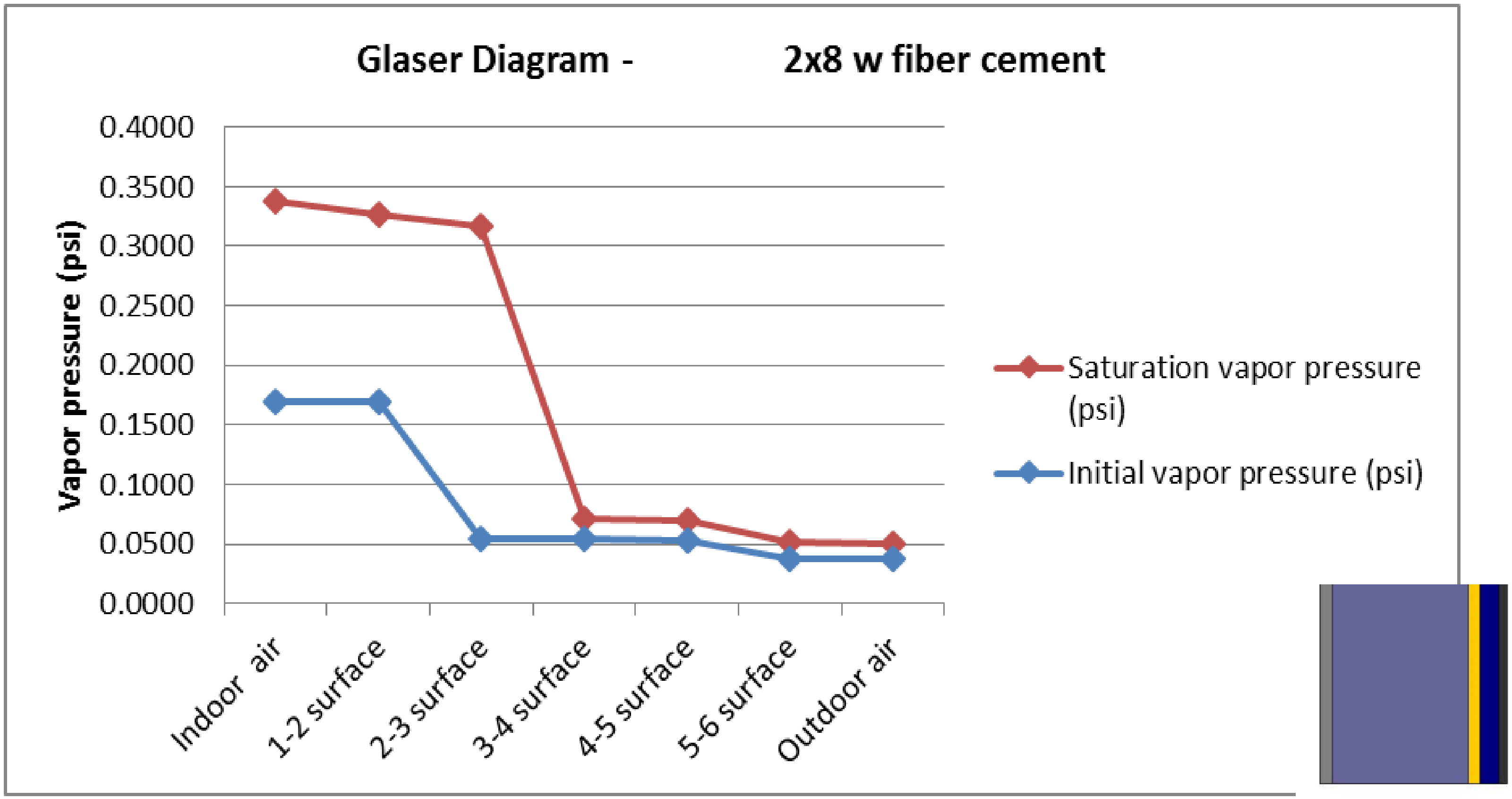
Vapor Pressure Profile - winter design conditions, through insulation				
surfaces (from inside to outside)	Temp	Saturation vapor pressure (psi)	RH	Initial vapor
Indoor air	68.0	0.3379	50%	0.1689
1-2 surface	67.0	0.3265		0.1689
2-3 surface	66.2	0.3173		0.0456
3-4 surface	27.1	0.0717		0.0451
4-5 surface	26.2	0.0693		0.0444
5-6 surface	18.9	0.0508		0.0377
Outdoor air	18.7	0.0503	75%	0.0377



Center for Sustainable Building Research

Section 3 – Glaser Analysis

Calculate the vapor profile through a wall: #3 Graph profile



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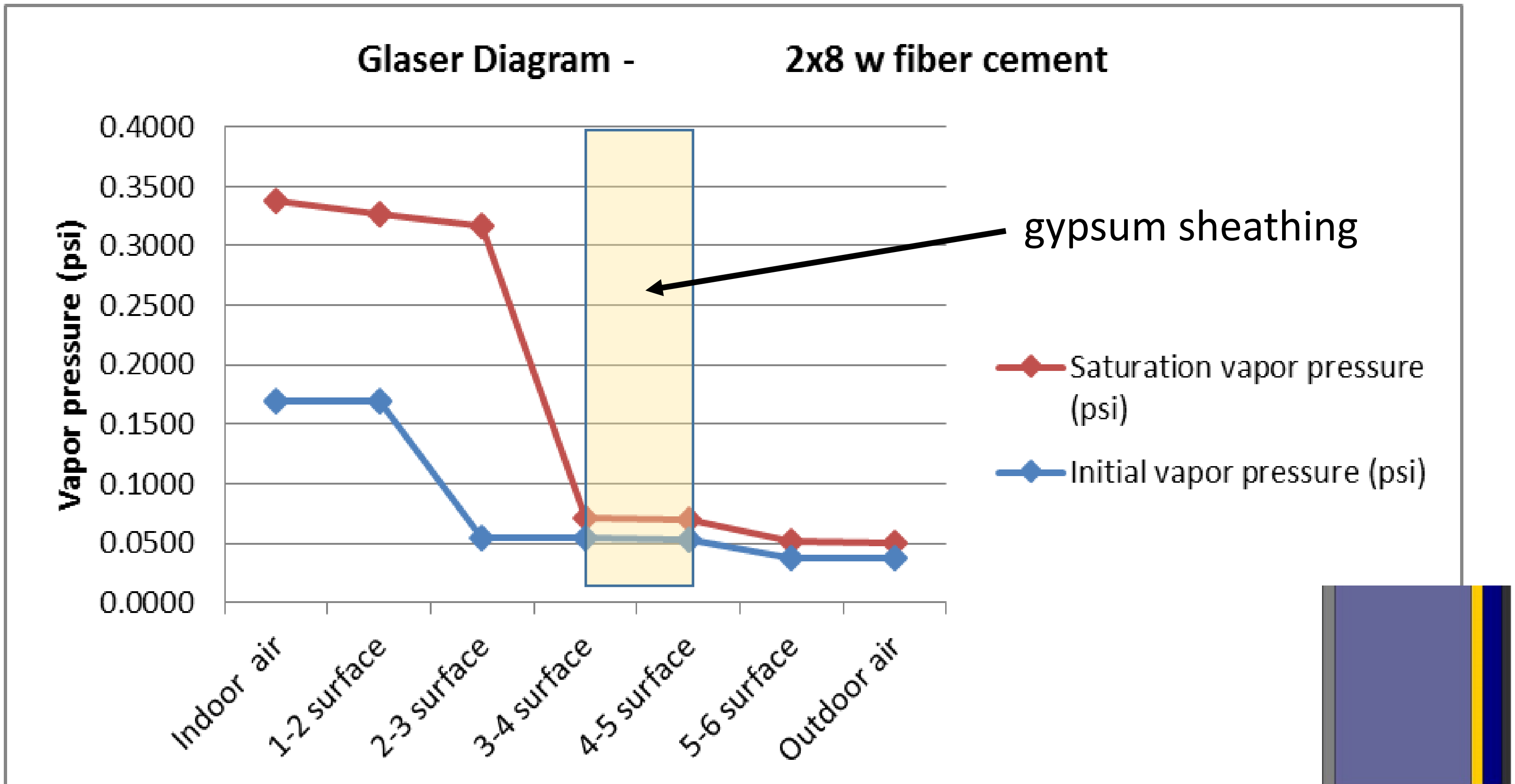
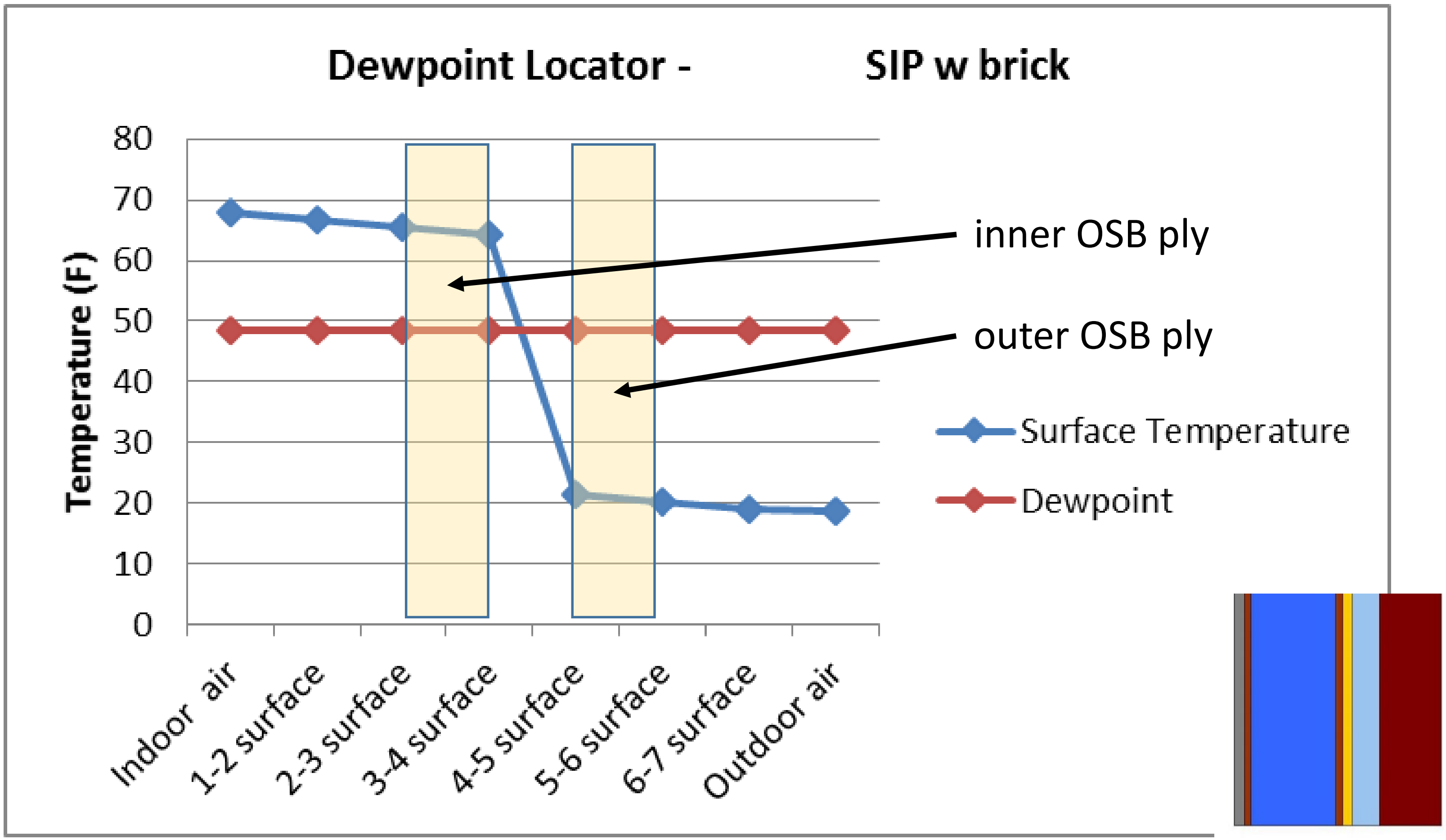
Section 3 – Glaser Analysis

Where the initial vapor pressure is above the saturation vapor pressure, moisture will climb towards 100% RH: little risk in this case



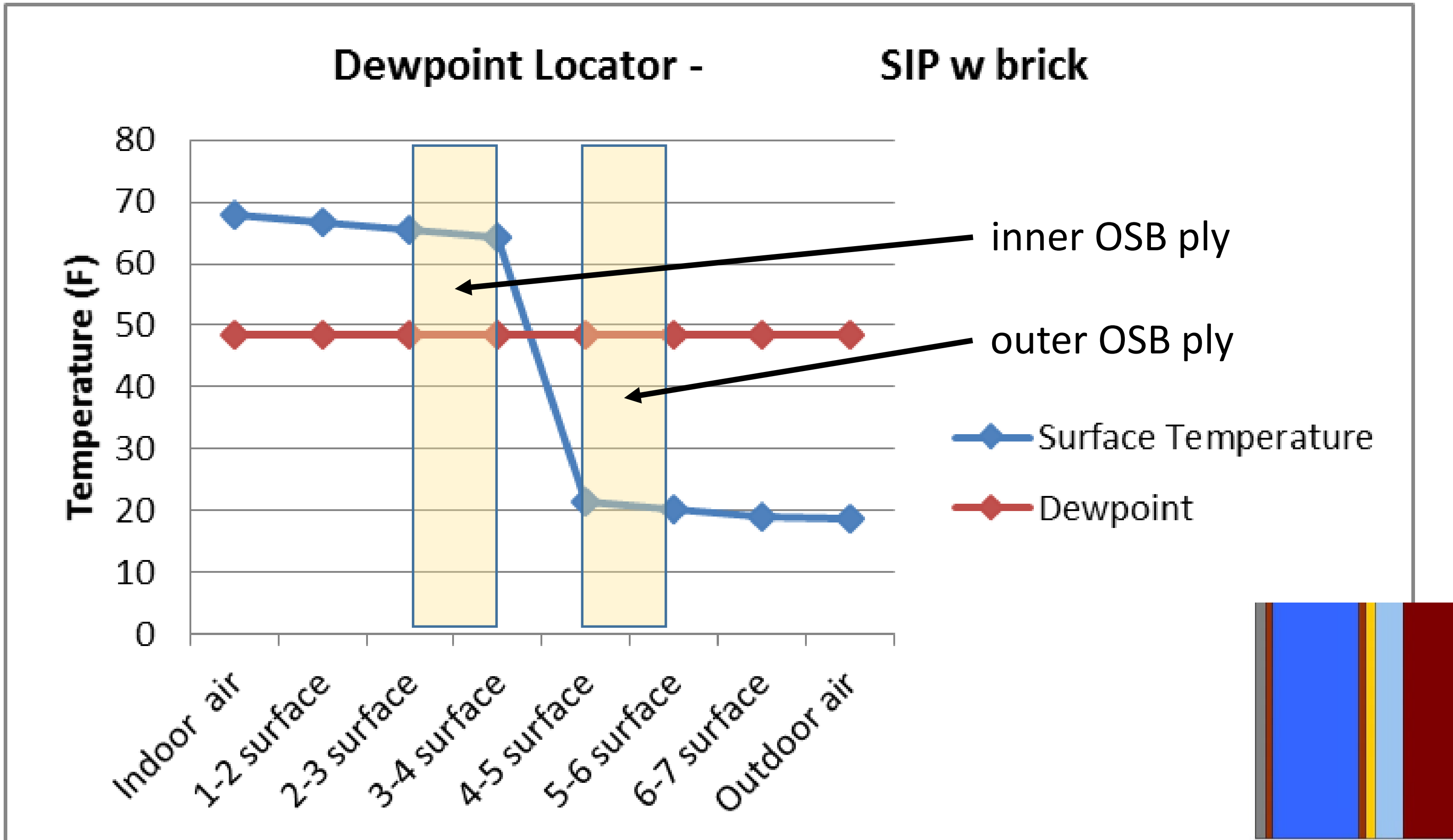
Section 3 – Glaser Analysis

Exterior ply of the SIP panel is below dewpoint – but what's the risk?



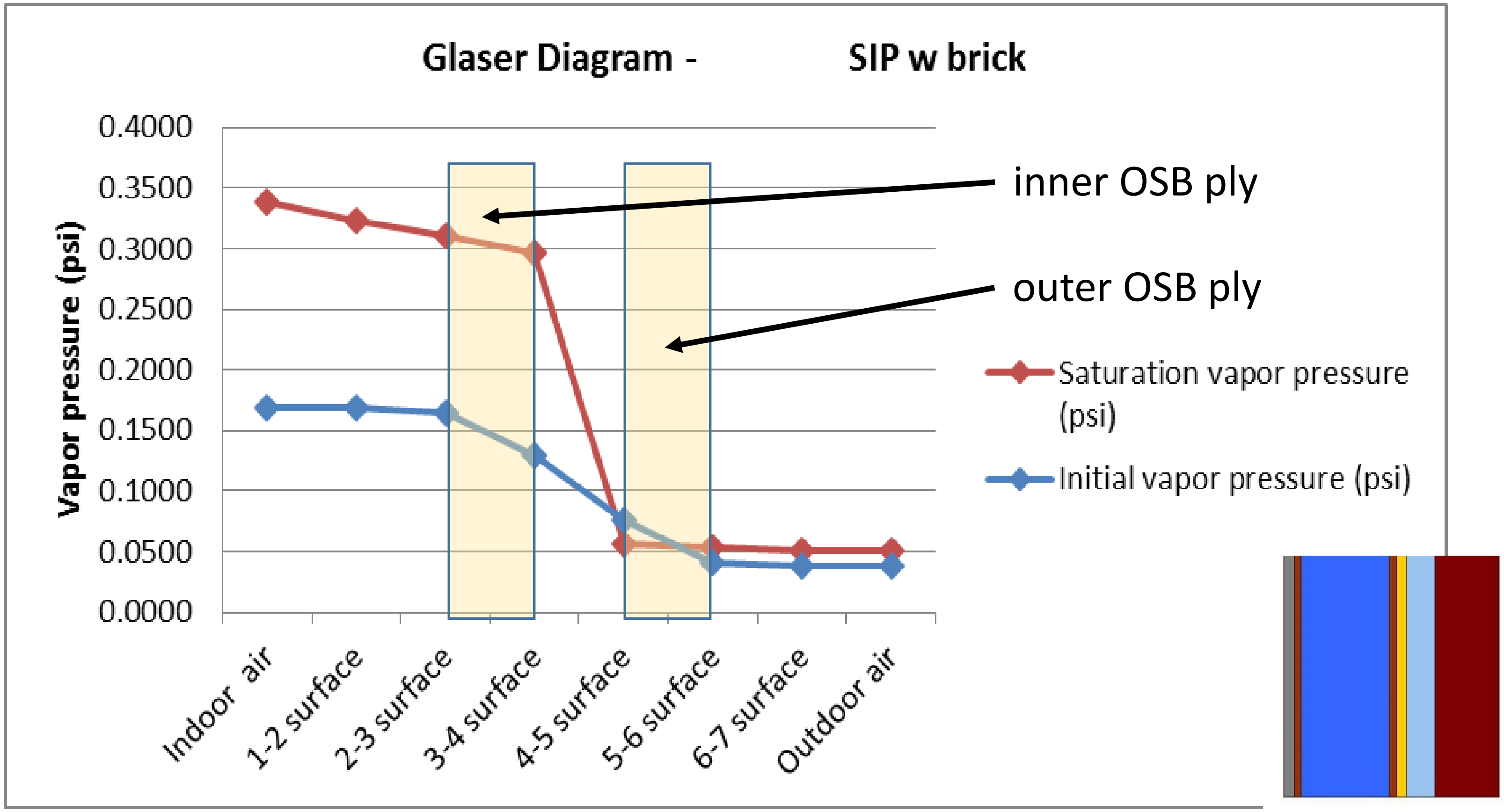
Section 3 – Glaser Analysis

Exterior ply of the SIP panel is below dewpoint – but what's the risk? – no cavity, no airflow, no available condensation plane in this case



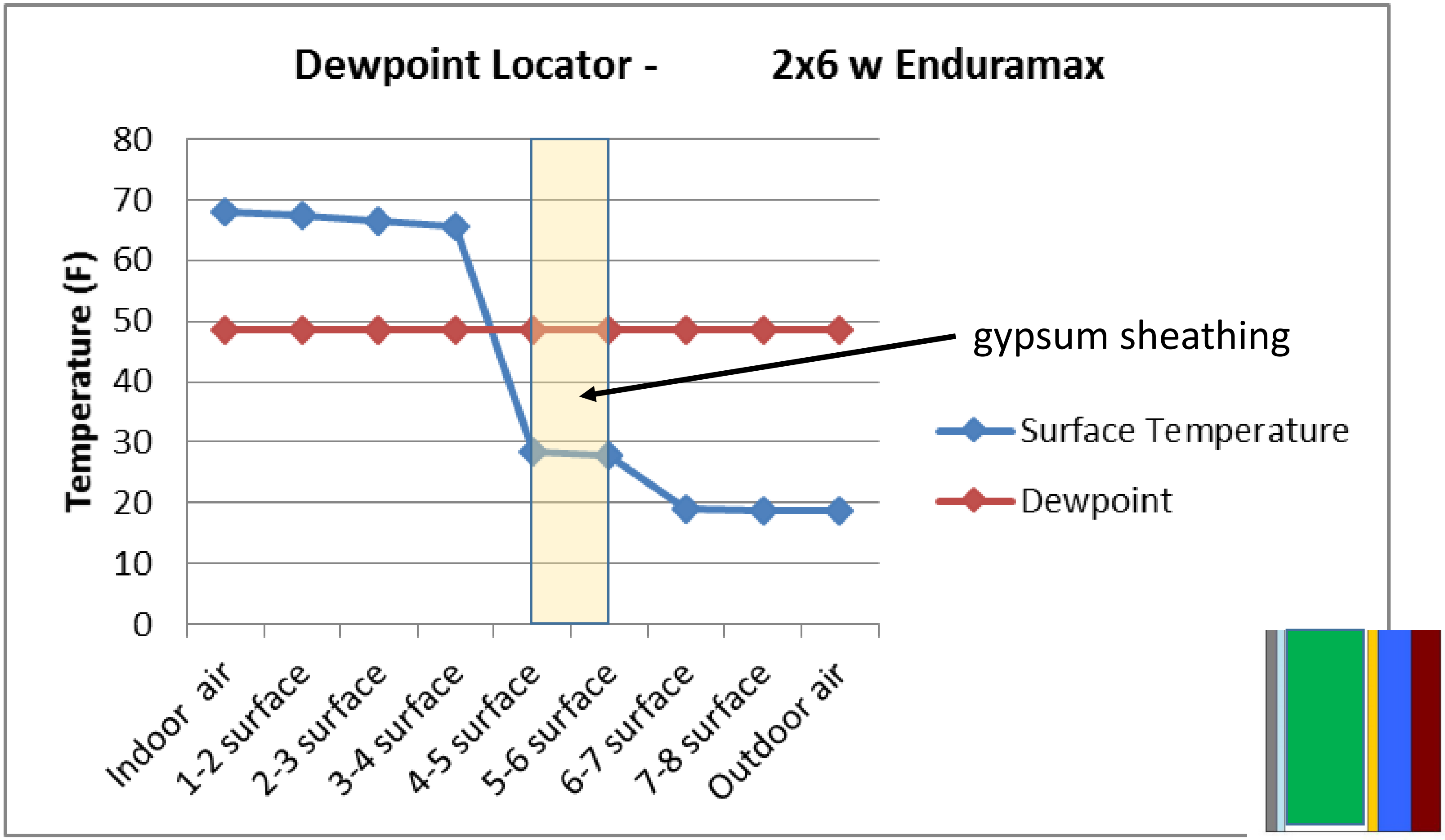
Section 3 – Glaser Analysis

Exterior ply of the SIP panel is above the saturation vapor pressure, moisture will climb towards 100% RH, elevated moisture risk



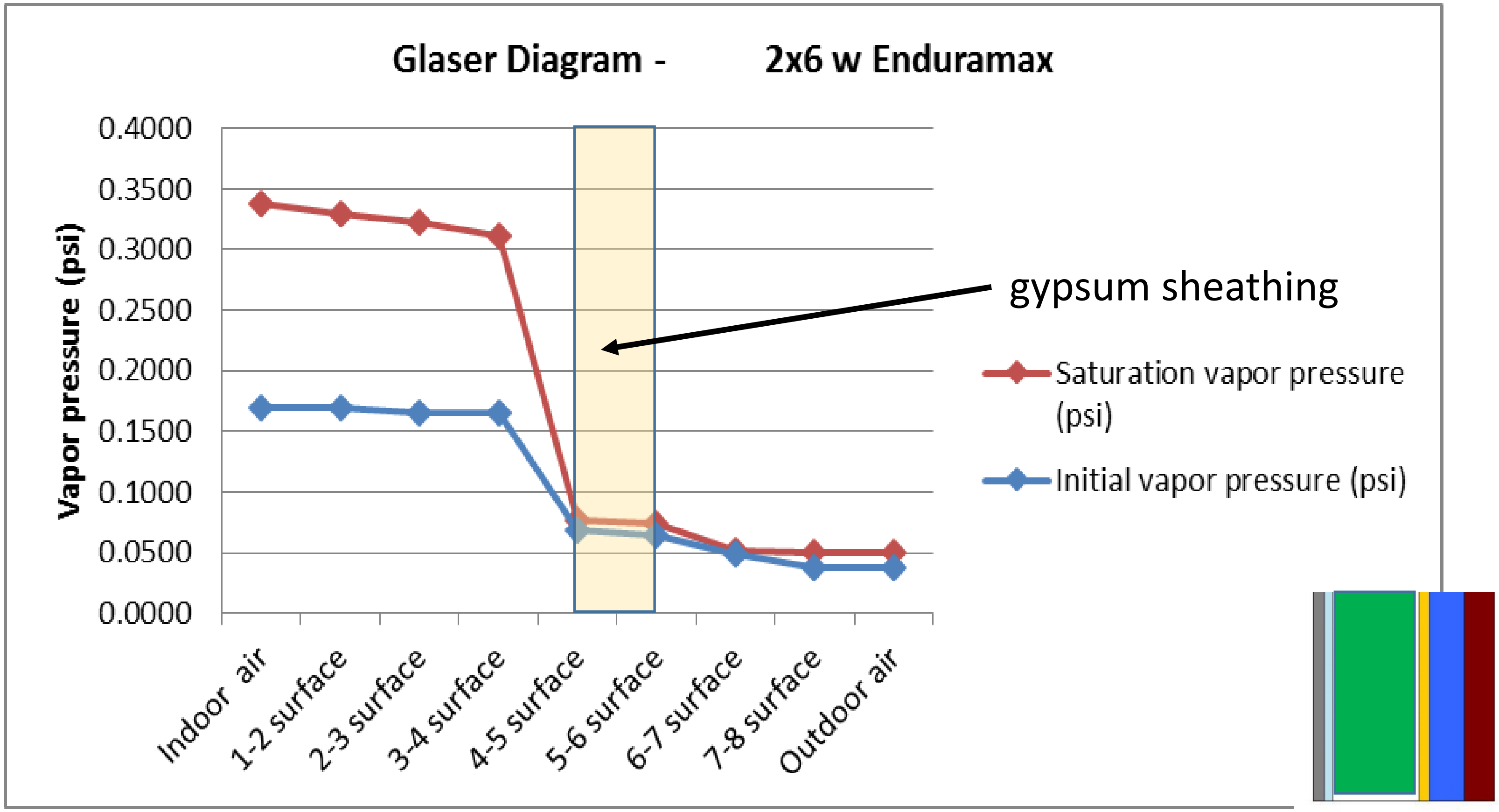
Section 3 – Glaser Analysis

Gypsum sheathing is below dewpoint – but what's the risk? Has a cavity that's filled with ccSPF, no available condensation plane in this case.



Section 3 – Glaser Analysis

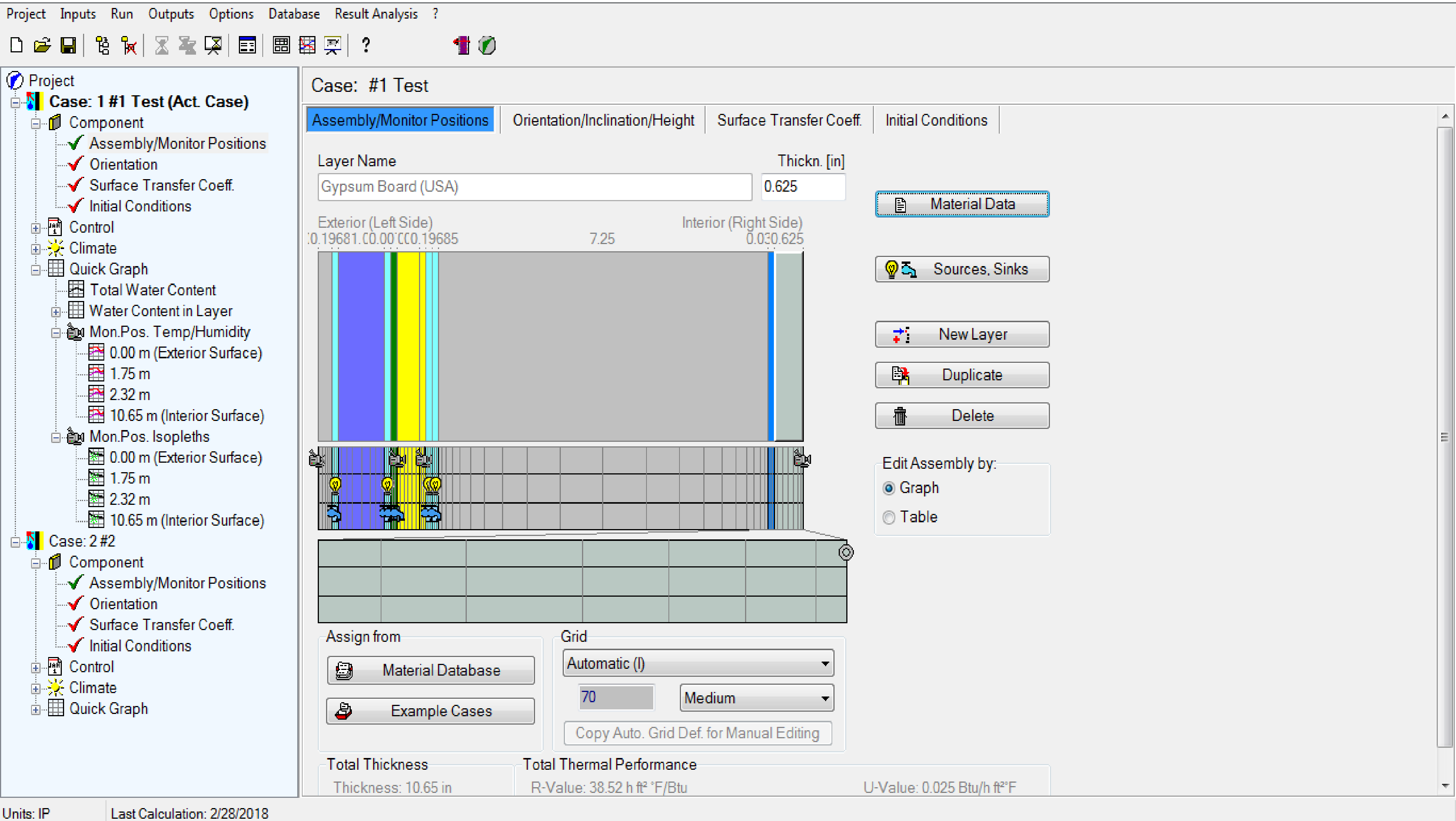
Gypsum sheathing is very close to the saturation vapor pressure. Possible elevated moisture risk.



Section 4 – WUFI Analysis

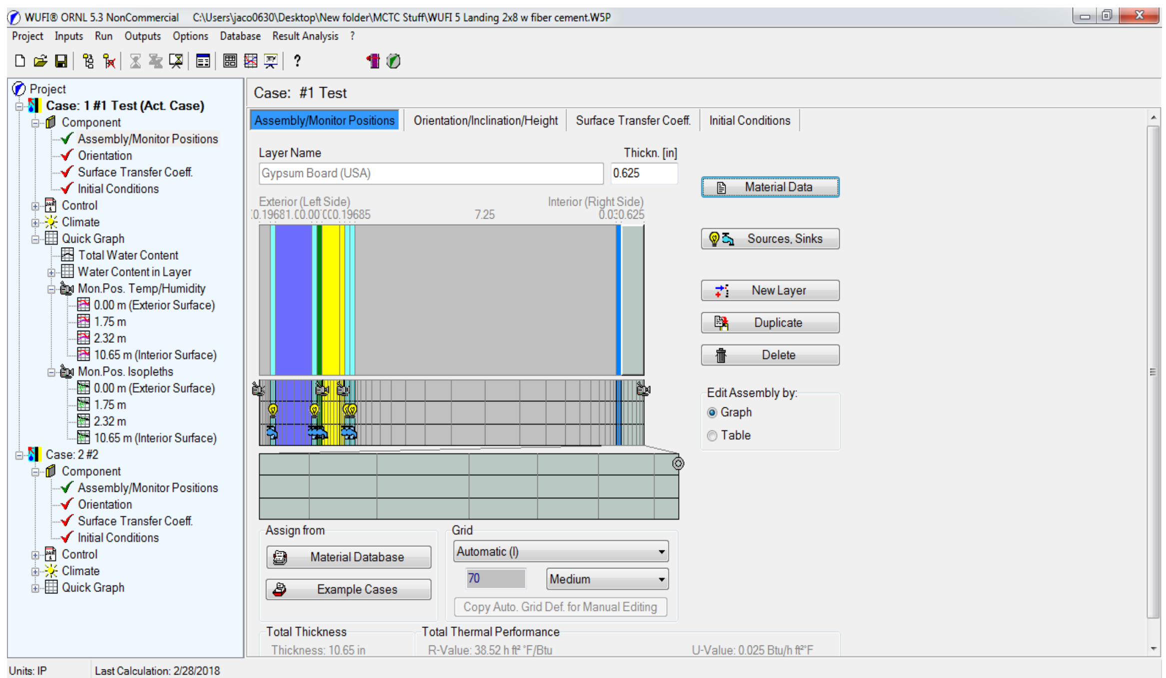
How is the assembly *predicted to perform* in terms of moisture?

Section 4 – WUFI Analysis



Section 4 – WUFI Analysis

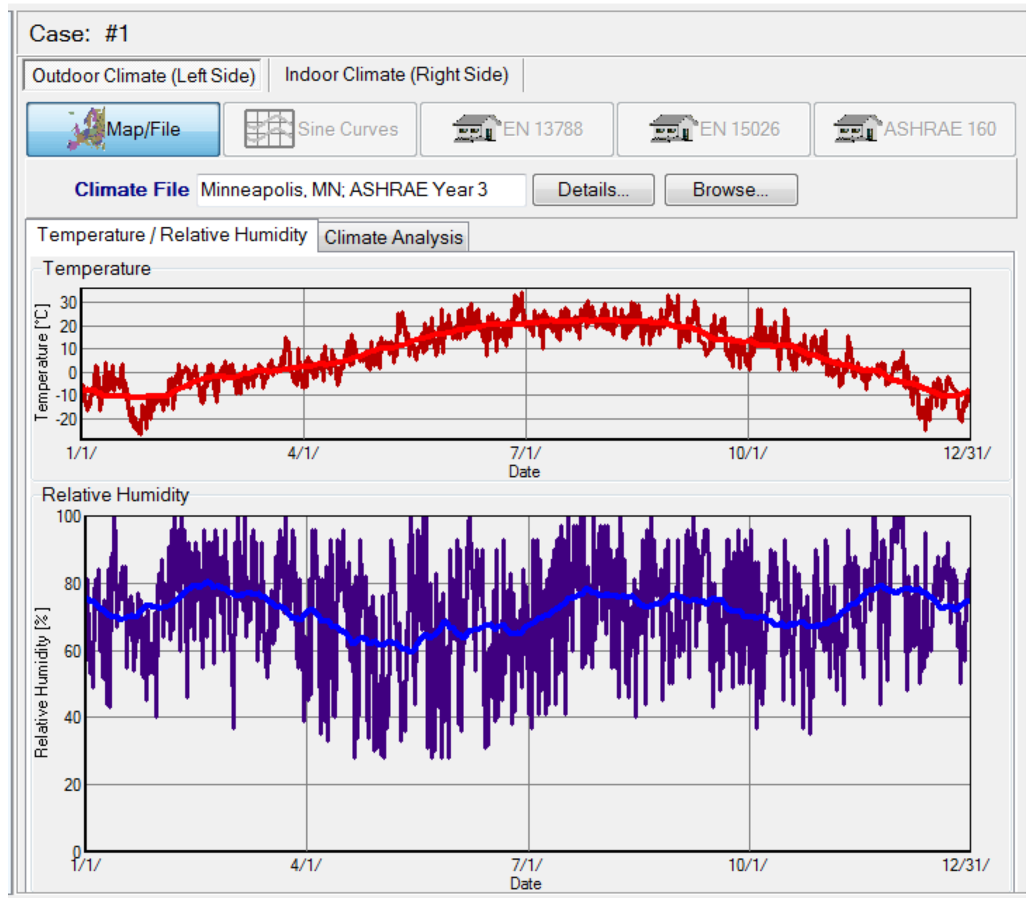
WUFI attempts to predict actual moisture levels in all layers of a wall (or roof) assembly by modeling almost all relevant forces and conditions dynamically, hour by hour.



Section 4 – WUFI Analysis

Hourly exterior environmental conditions including…

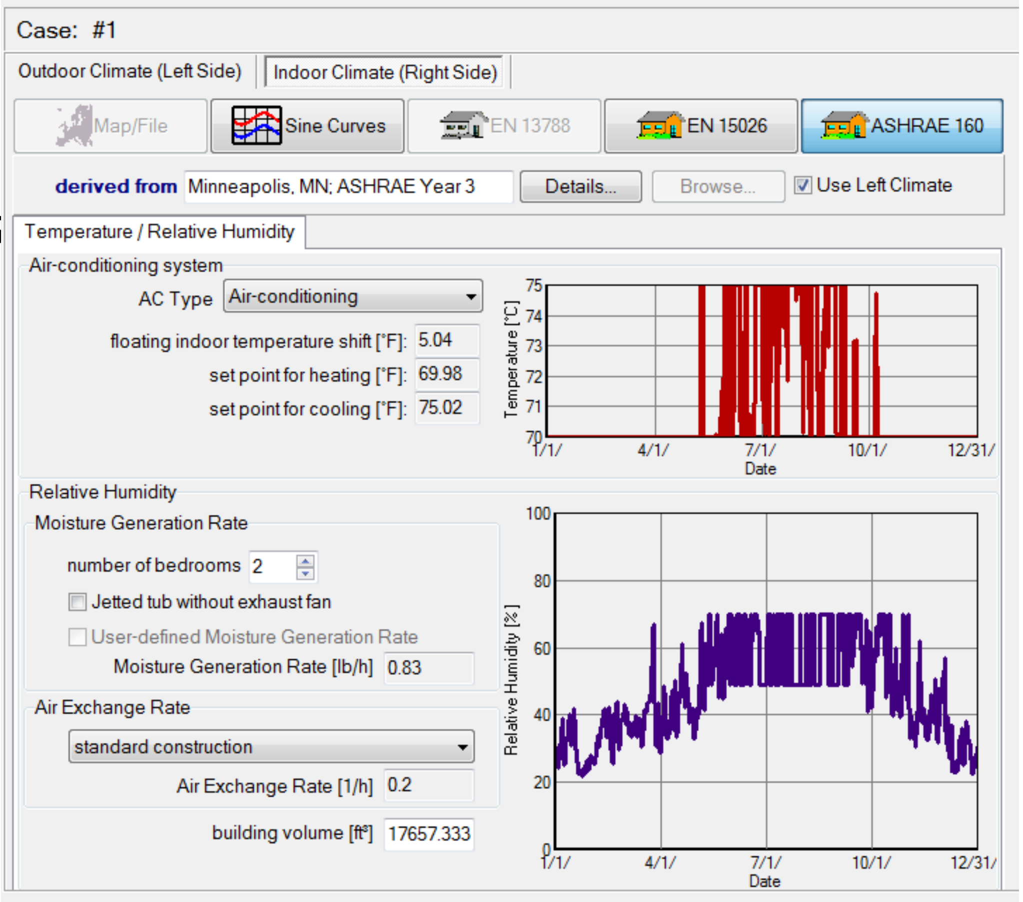
- Temperature
- Relative humidity
- Precipitation
- Solar radiation
- Wind



Section 4 – WUFI Analysis

Hourly interior environmental conditions including…

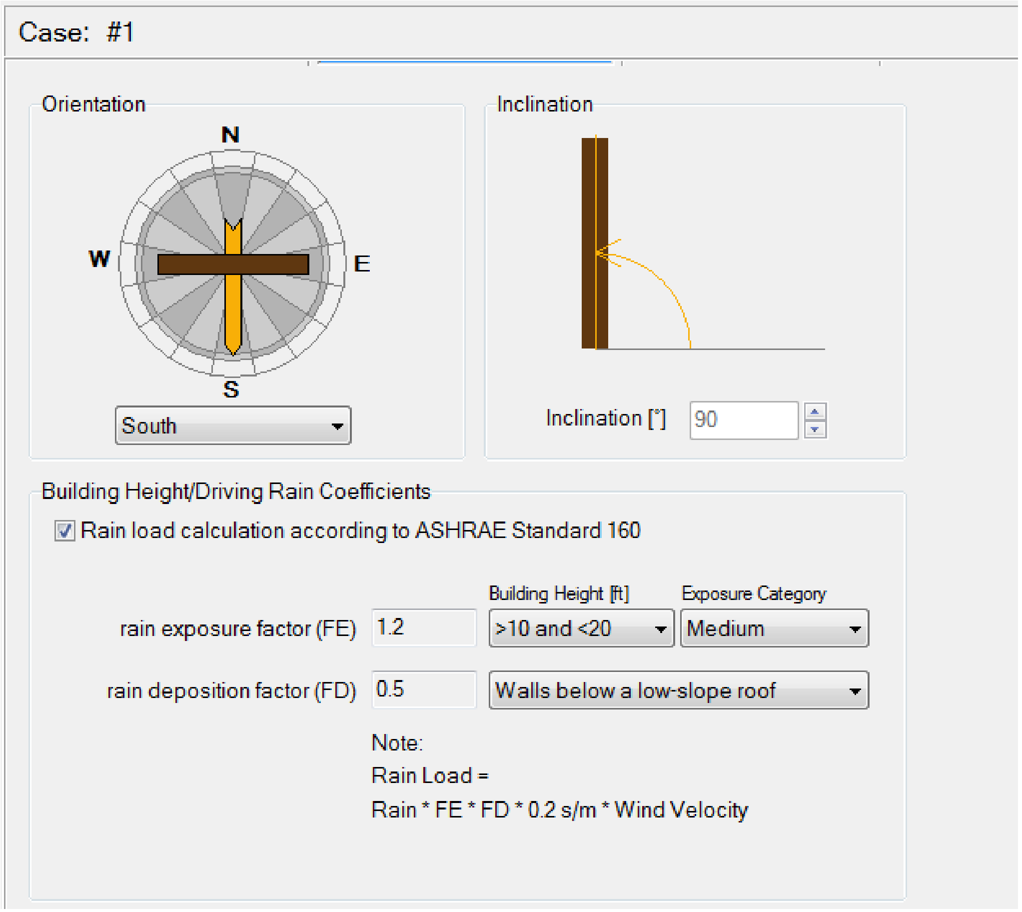
- Temperature
- Relative humidity
- Internal heat gains
- Internal moisture gains
- HVAC equipment
- Setpoints/schedules
- Ventilation rates
- Air leakage rates



Section 4 – WUFI Analysis

Building Conditions

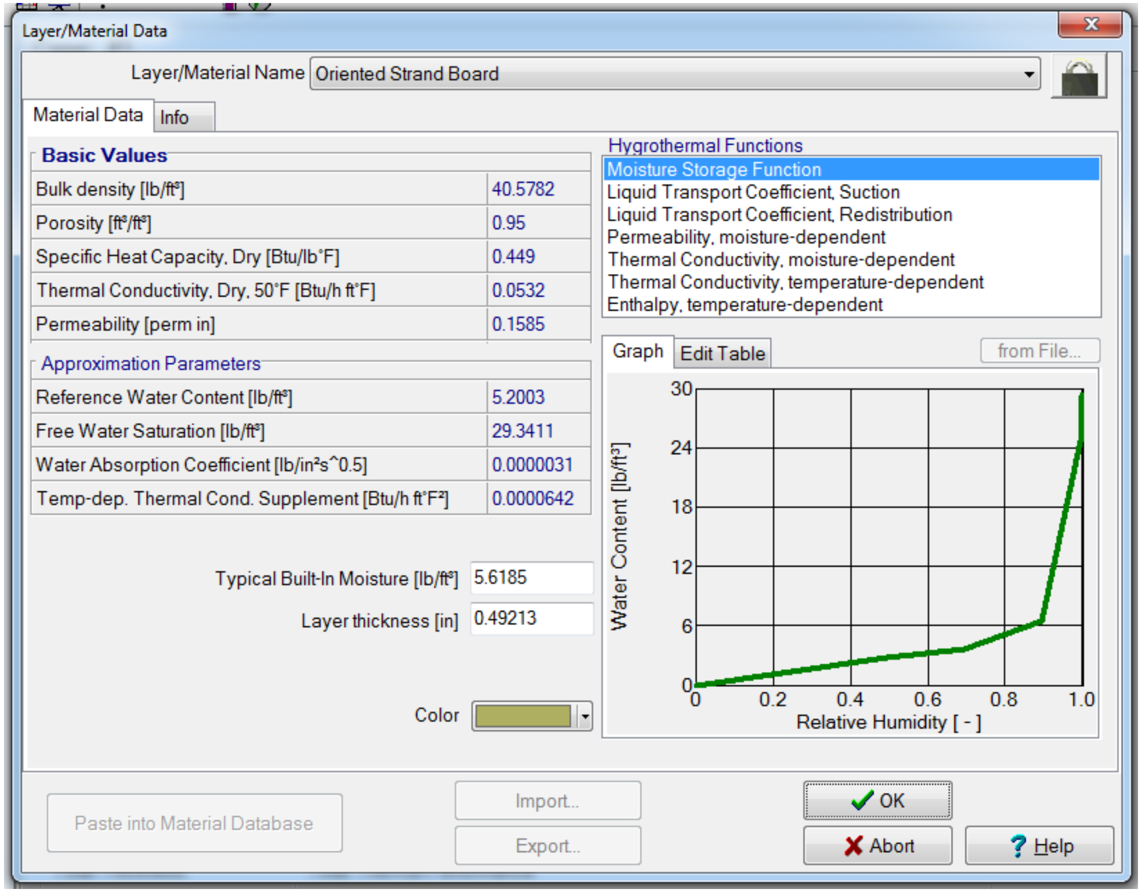
- Orientation
- Inclination
- Height
- Rain exposure
- Shading



Section 4 – WUFI Analysis

Material Properties – stored in large database of stock materials

- Density
- Heat conductivity
- Heat capacity
- Permeability
- Moisture storage
- Capillarity
- Others…



Section 4 – WUFI Analysis

Moisture dynamics possible to model

- Bulk water leakage
- Capillary drive
- Air leakage
- Diffusion
- Moisture storage
- Initial moisture conditions (wet building materials)
- Surface treatments (different moisture adsorption characteristics, colors, permeability, etc)

Dynamics not possible to model

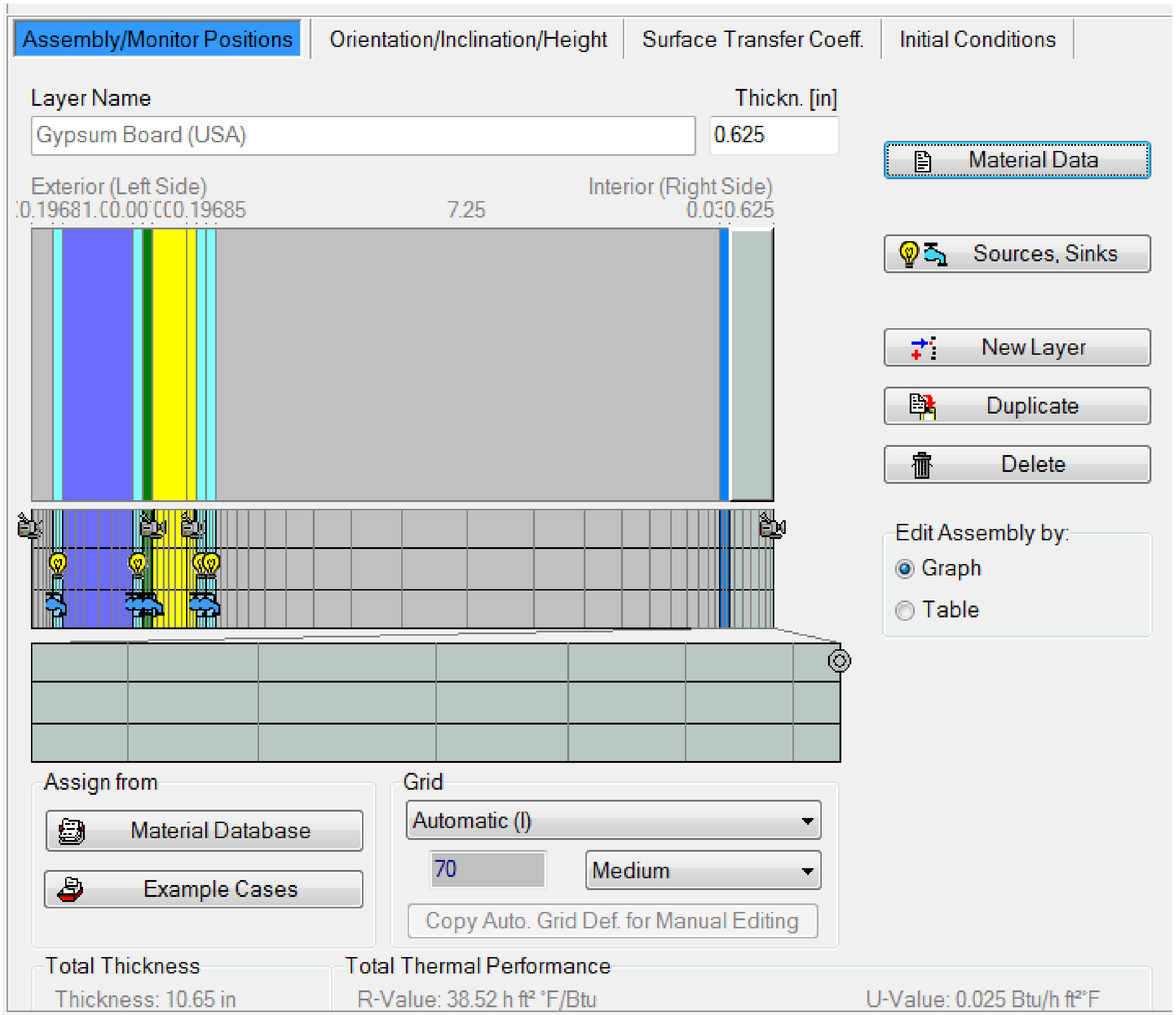
- Convection
- 2D moisture flow (only clear wall sections are modeled)

Section 4 – WUFI Analysis

Air leakage rates specified in special air layers

Water leakage rates specified within certain material layers

“Monitors” set in critical layers to track conditions



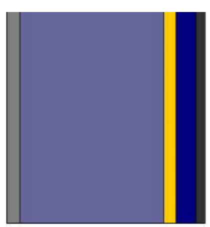
Section 4 – WUFI Analysis

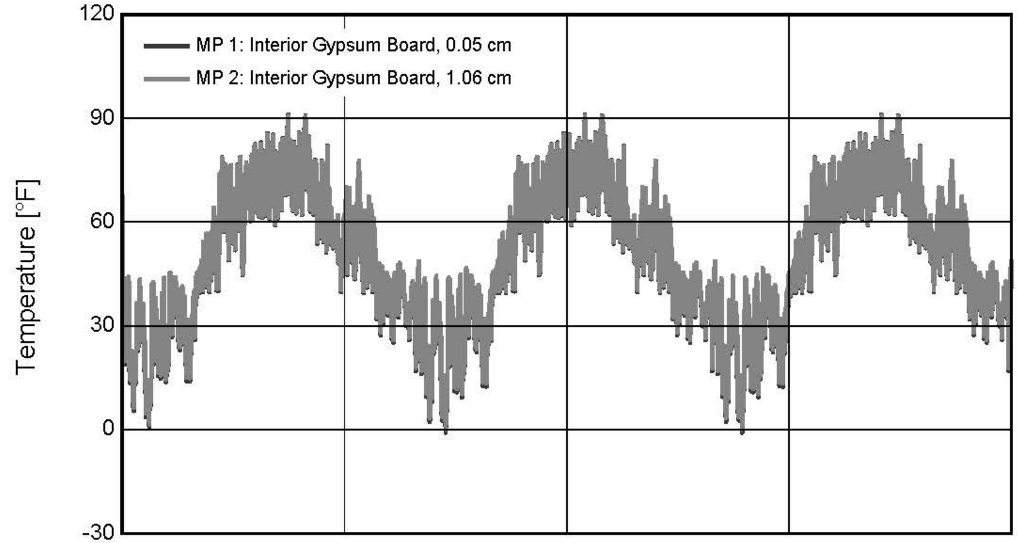
There are many ways to analyze WUFI results.

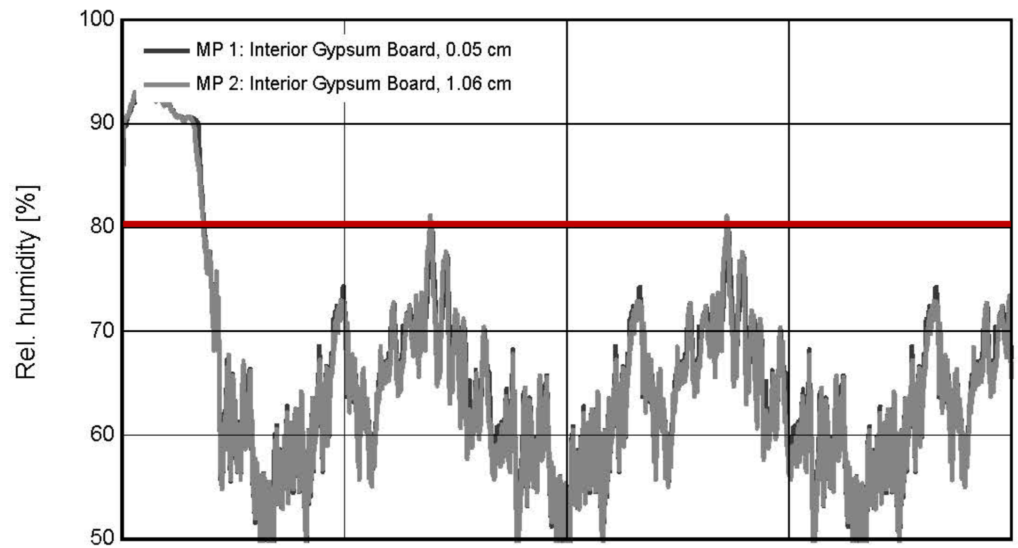
MC >/= 18% is problematic for wood-based materials.

“Sustained” RH >/= 80% can initiate mold growth, but temp must be > 32°F

3 years of results typical, to see trends





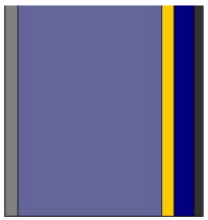


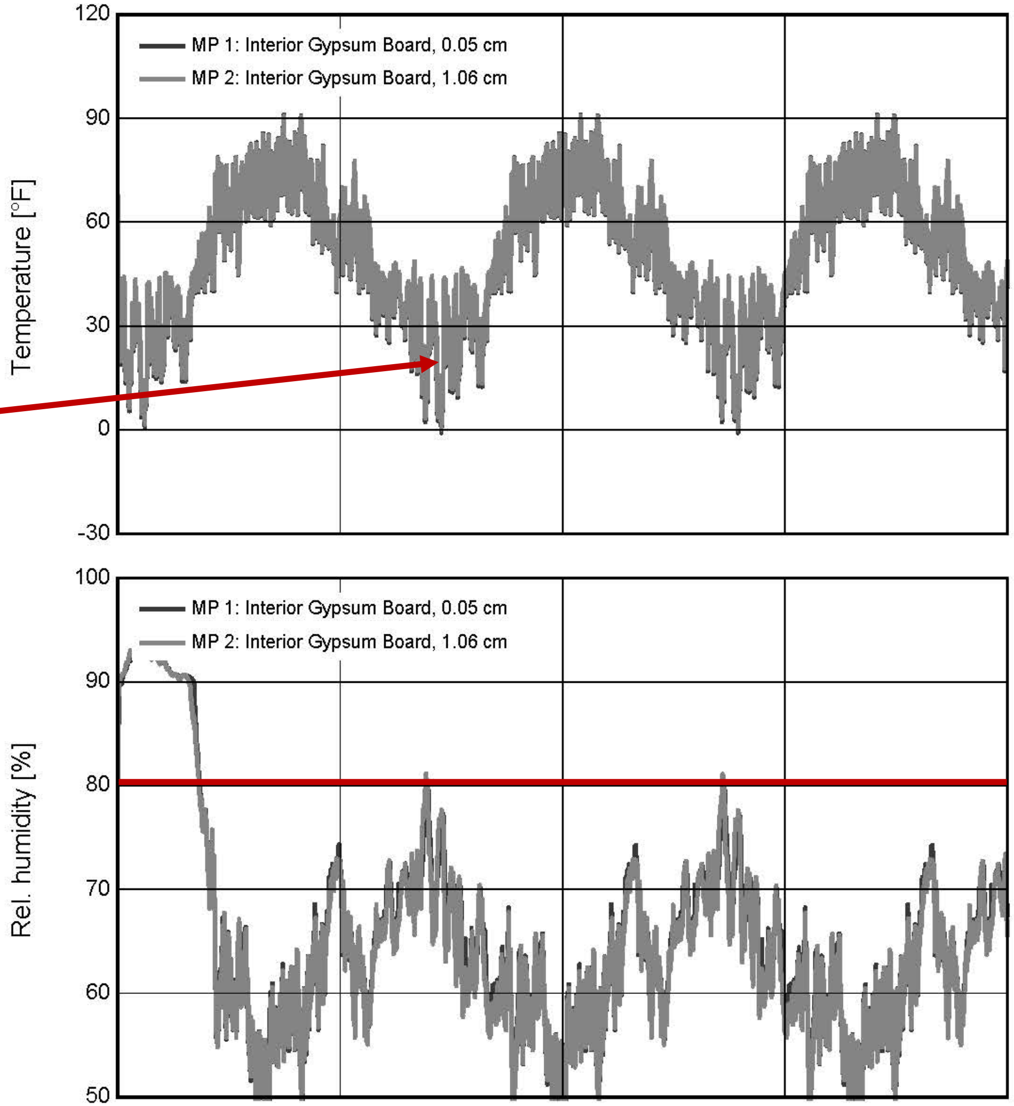
Section 4 – WUFI Analysis

For 2x8 w cellulose and fiber cement:

Despite exterior XPS, temps in sheathing are still frequently below freezing.

RH spikes in winter (sign of a wall that dries to the outside), but appears to be safely below 80% RH





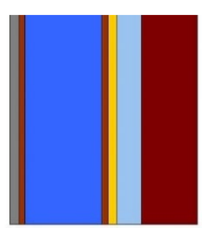
Section 4 – WUFI Analysis

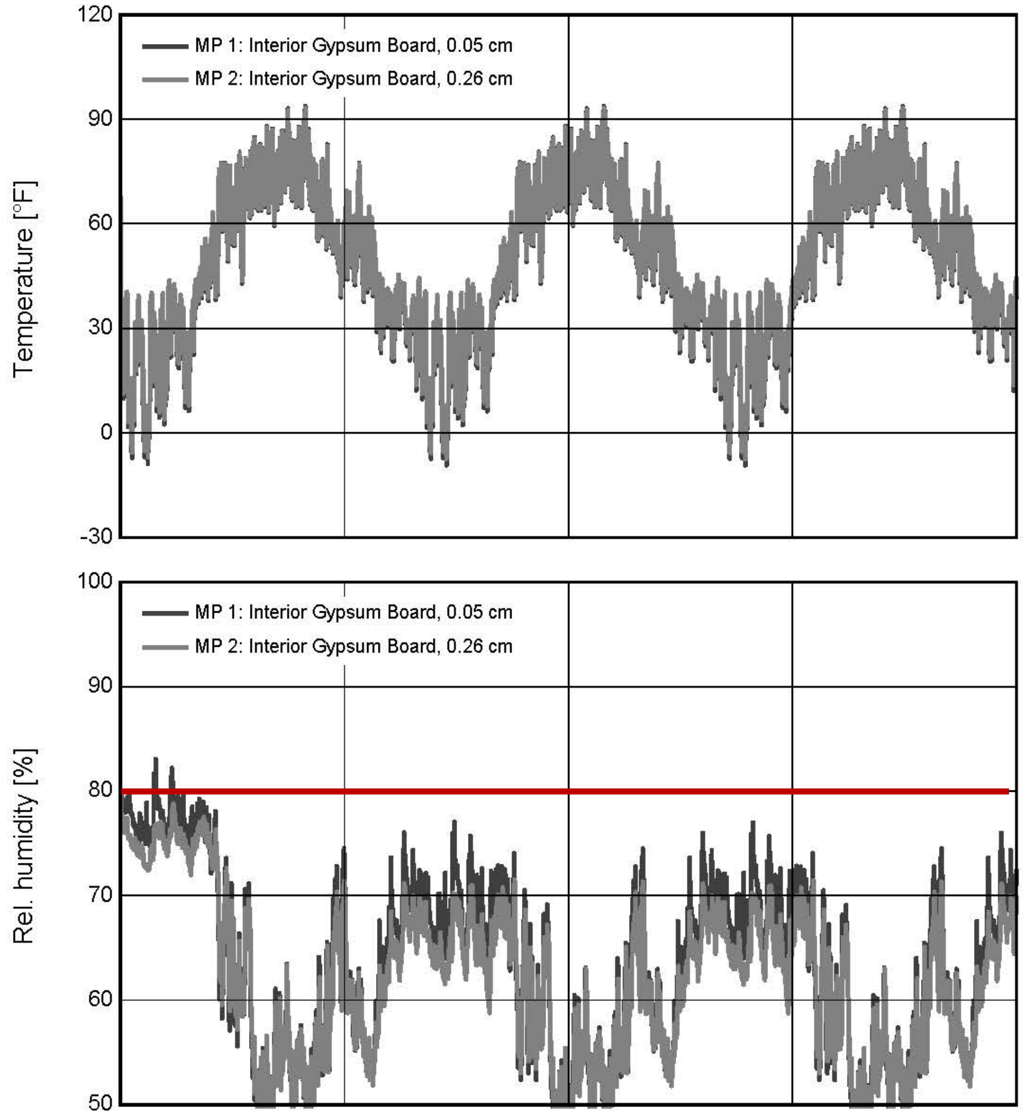
For 6" SIP w brick:

Sheathing is colder w/out exterior foam, but…

RH is actually lower in sheathing thanks to vented cavity and lack of semi-impermeable XPS

(Recall, Glaser predicted worse performance)





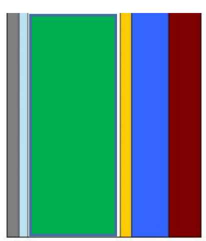
Section 4 – WUFI Analysis

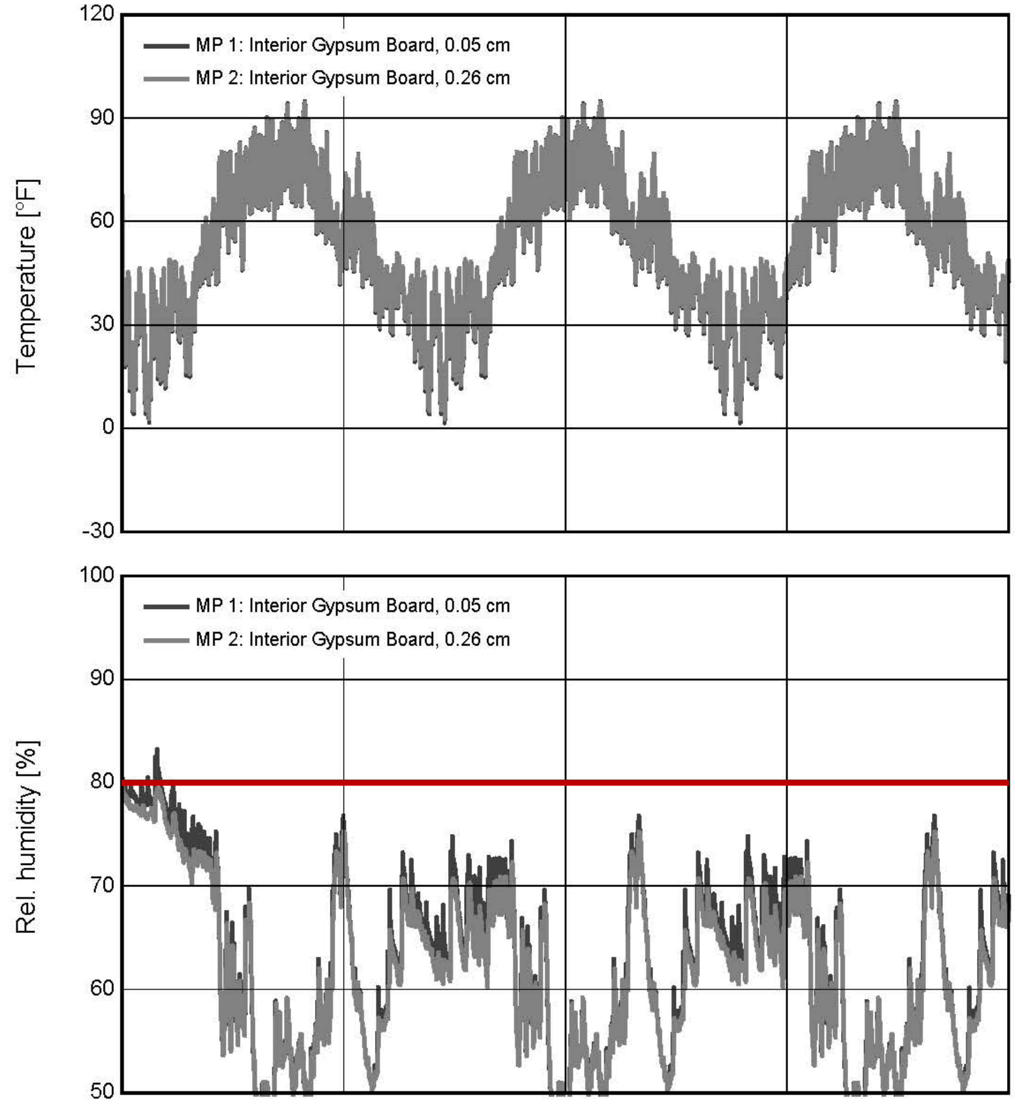
For 2x6 w ccSPF and Enduramax:

Sheathing is warmer thanks to exterior EPS (R-8)

RH is quite similar, slightly better than SIP

(Recall, Glaser predicted better performance than SIP too)





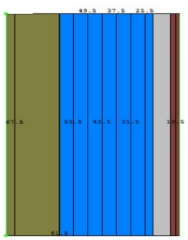
Section 4 – WUFI Analysis

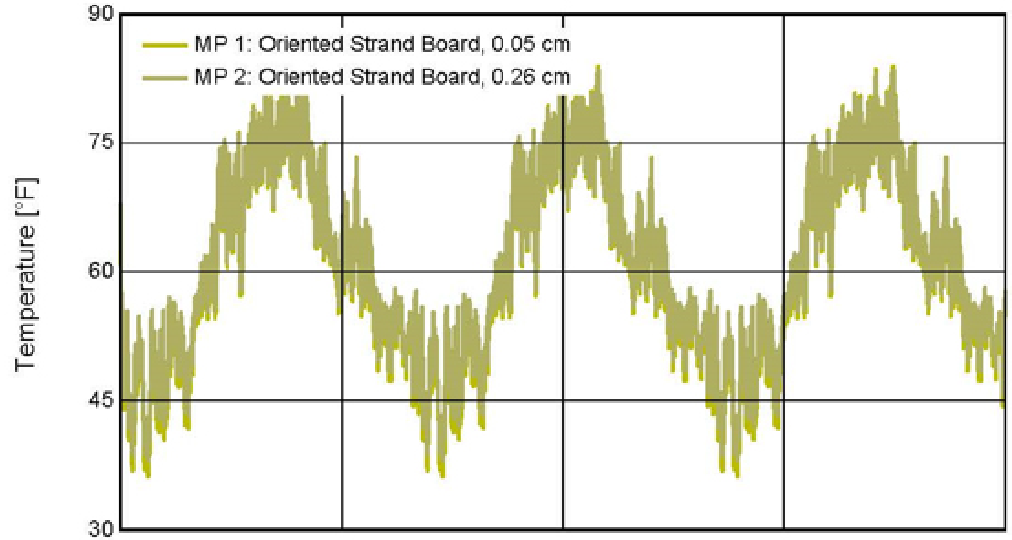
For a wall with 50% of R-value on the exterior (in climate zone 6):

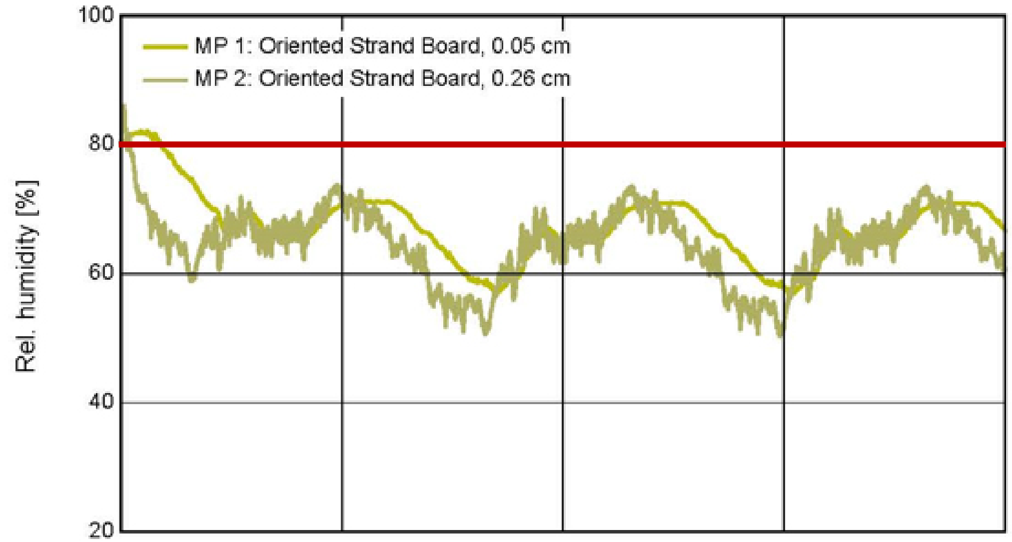
Sheathing is almost always above 40F (roughly, the dewpoint)

Sheathing now dries to the inside – driest period is during the winter

The sheathing's moisture level is now governed by interior conditions







Section 5 – 2D Thermal Analysis

How are intersections and details designed to limit condensation risk and heat loss?

Section 5 – 2D Thermal Analysis

How are intersections and details designed to limit condensation risk and heat loss?

2D Thermal modeling can provide analysis for:

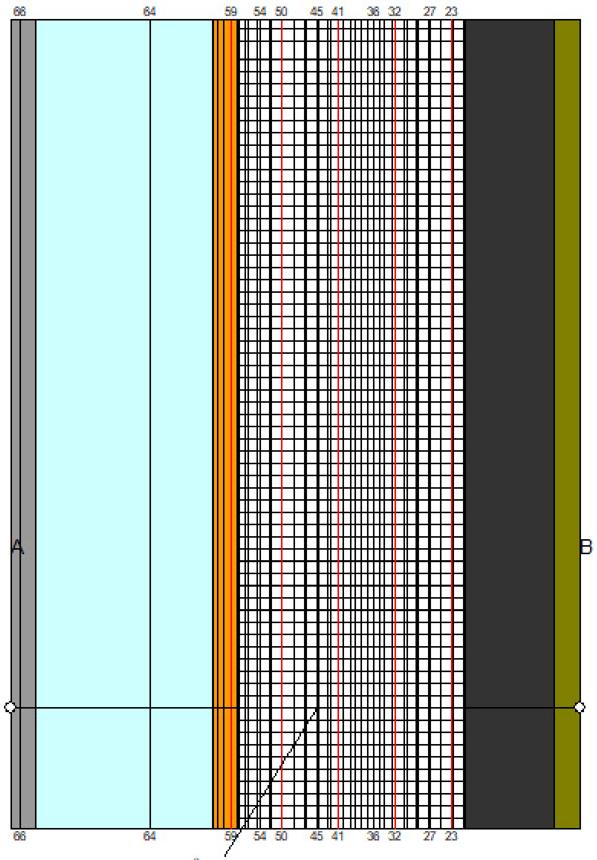
1) True R-values of wall assemblies – more detail tomorrow
2) Heat loss of linear thermal bridges – more detail tomorrow
3) Condensation risk at complex junctions – more detail tomorrow

Section 5 – 2D Thermal Analysis

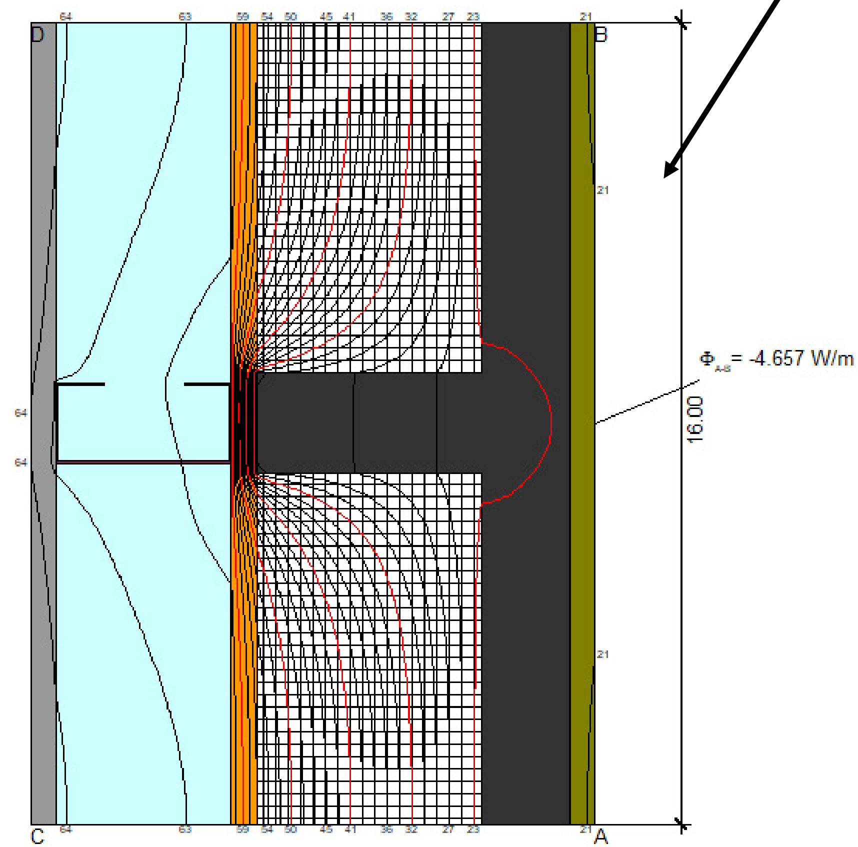
1) True R-values

Clear wall: R-24.4

Account for studs: R-13.6



$U = 0.041\ \mathrm{Btu/(h \cdot ft^2 \cdot F)}$



$$U_{A\text{-}B} = \frac{4.657}{27.389 \cdot 0.406} = 0.418\ \mathrm{W/(m^2 \cdot K)} = 0.0737\ \mathrm{Btu/(h \cdot ft^2 \cdot F)}$$

Section 5 – 2D Thermal Analysis

2) Linear Thermal Bridges

We can investigate heat loss from linear thermal bridges:

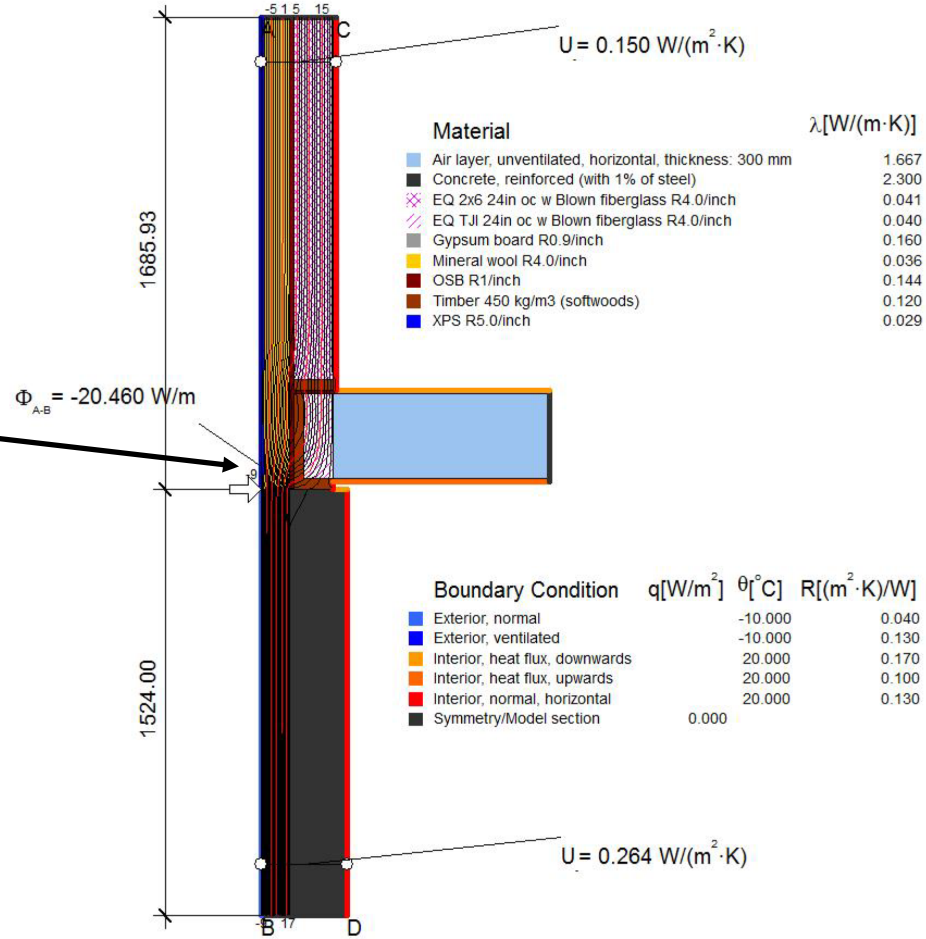
Where do these occur?

- Material and wall transitions
- Penetrations through insulation (flashing, furring, shelf angles)
- Assembly junctions (roof to wall, wall to floor, etc)
- Geometric effects (corners, misalignment of insulation layers)

Section 5 – 2D Thermal Analysis

2) Linear Thermal Bridges

The Psi value measures the heat flow impact of the extra framing, insulation alignment, and change of materials at the junction.



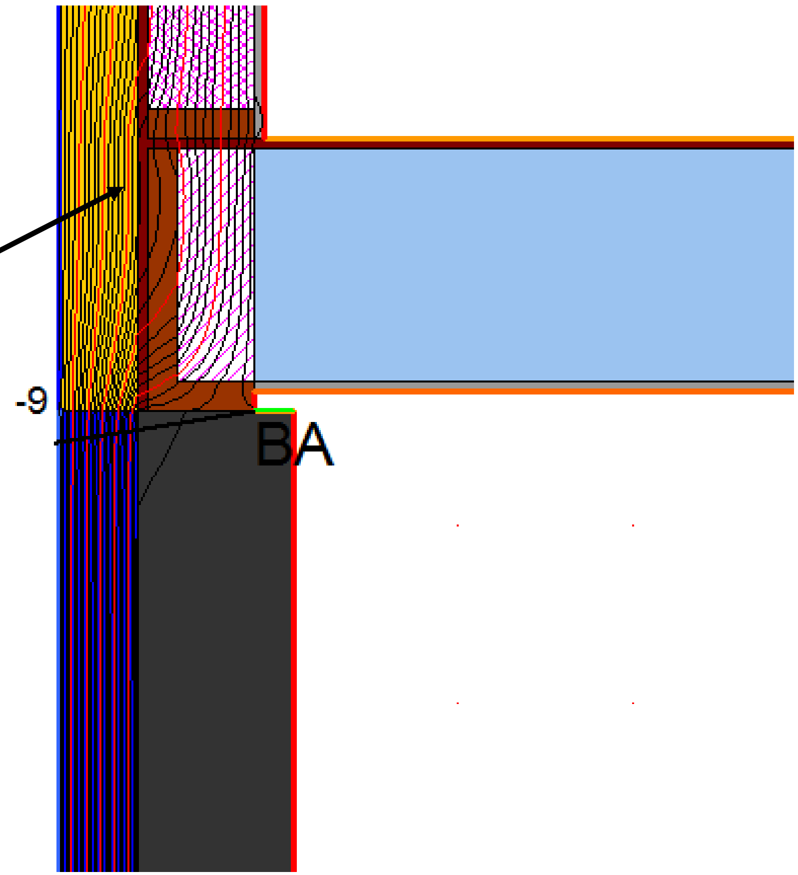
$$\Psi_{A\text{-}E\text{-}B} = \frac{\Phi}{\Delta T} - U_1 \cdot b_1 - U_2 \cdot b_2 = \frac{20.460}{30.000} - 0.150 \cdot 1.686 - 0.264 \cdot 1.524 = 0.026\ \mathrm{W/(m \cdot K)}$$

Section 5 – 2D Thermal Analysis

3) Condensation Risk Analysis

The dewpoint can also be located within the assembly (usually determined for average winter conditions).

Indoor air at 70°F and 35% RH = **40°F** dewpoint

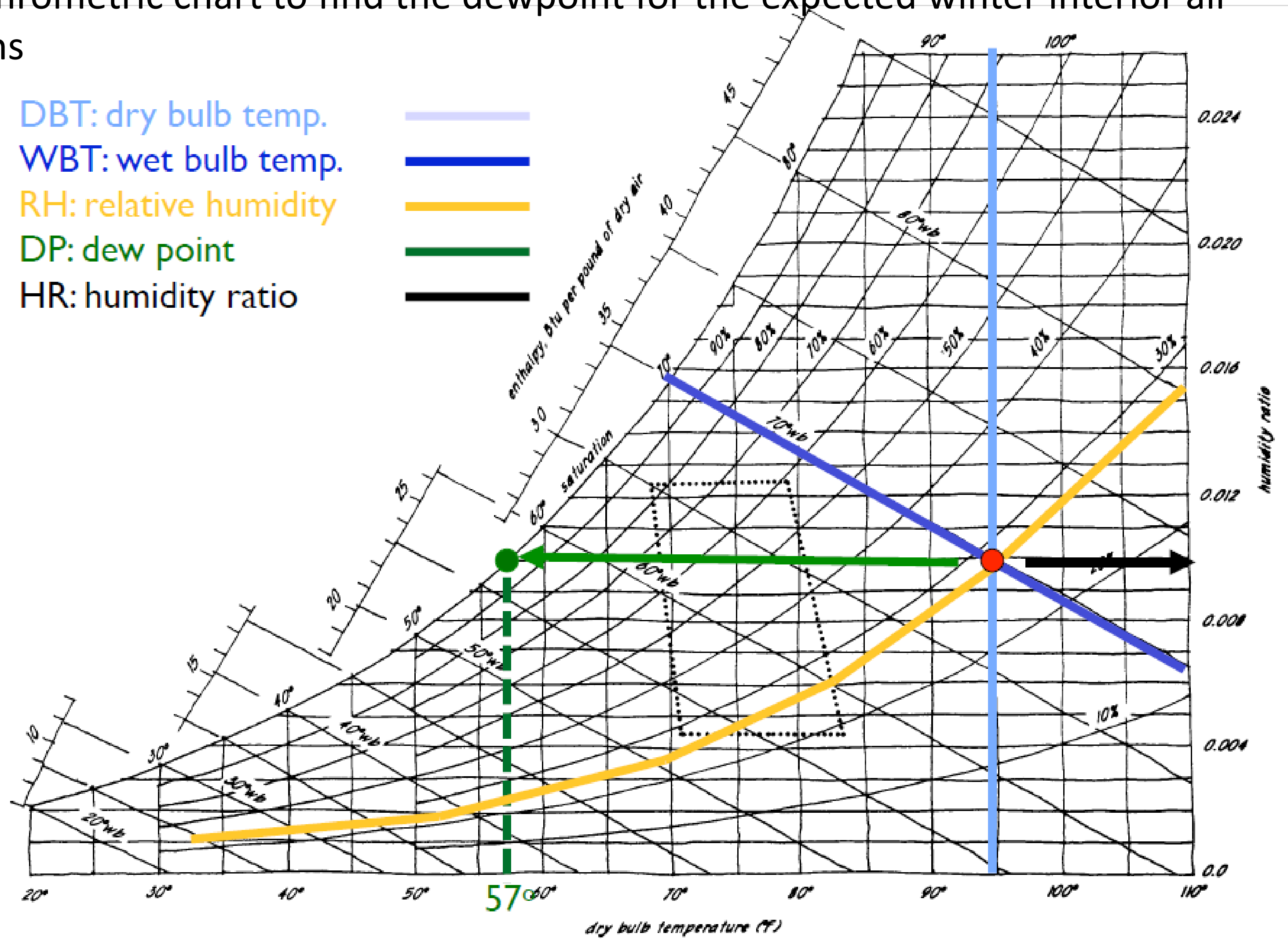


Is the sheathing above the dewpoint?
Is the rim board?

Section 5 – 2D Thermal Analysis

Use psychrometric chart to find the dewpoint for the expected winter interior air conditions

DBT: dry bulb temp.
WBT: wet bulb temp.
RH: relative humidity
DP: dew point
HR: humidity ratio



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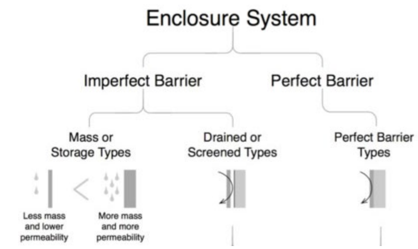
Section 5 – 2D Thermal Analysis

Available 2D Heat Flow Simulation Tools

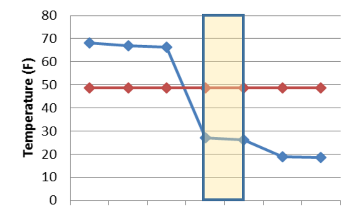
1) THERM – free, has a large user base, but difficult to use
2) Flixo – a “modern” version of THERM with built-in tools, easy drawing interface, and automatic reporting capabilities. $344 - $1,960 (1yr subscription)
3) HT Flux – similar to Flixo, more difficult to use, but added functionality with dynamic boundary conditions and 2D glaser analysis for advanced users.
4) Psi-Therm, Heat2, others

The 4 Types of Moisture Risk Analysis

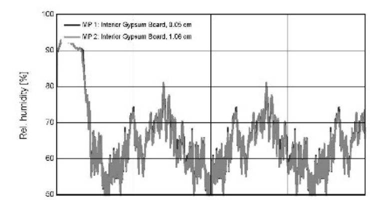
1) Qualitative moisture assessment



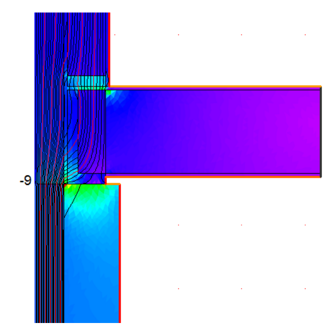
2) Static diffusion and condensation risk assessment (Glaser analysis)



3) Dynamic simulated hygrothermal performance (WUFI analysis)

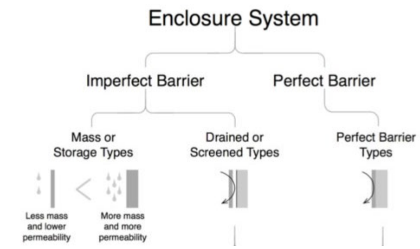


4) 2D thermal modeling/detail analysis (Flixo/THERM)

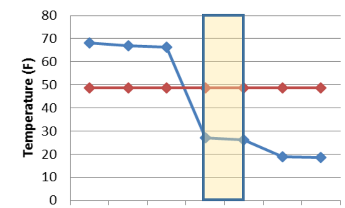


The 4 Types of Moisture Risk Analysis

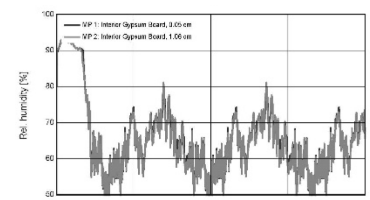
1) Qualitative moisture assessment



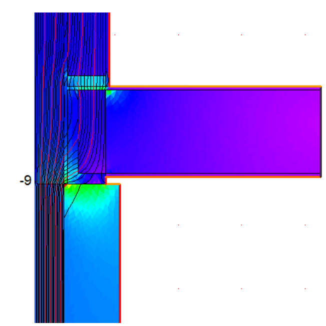
2) Static diffusion and condensation risk assessment (Glaser analysis)



3) Dynamic simulated hygrothermal performance (WUFI analysis)



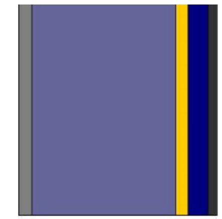
4) 2D thermal modeling/detail analysis (Flixo/THERM) Not required in B3



Center for Sustainable Building Research

The 4 Types of Moisture Risk Analysis

1) Summary – 2x8 w cellulose and fiber cement

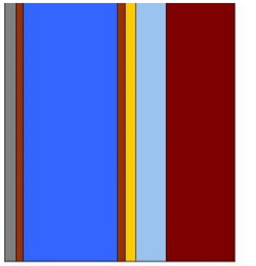


	Qualitative	Glaser	WUFI
Water control:	😐	-	😐
Air control/condensation:	☹/☠	☹	😐
Vapor control:	☹	☺	😐
Thermal control:	😐	-	-

Different tools provide different answers. Judgement is needed.

The 4 Types of Moisture Risk Analysis

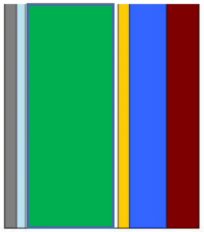
1) Summary – 6” SIP with brick



	Qualitative	Glaser	WUFI
Water control:	☺	-	☺
Air control/condensation:	☺	☹	☺
Vapor control:	😐	☹	☺
Thermal control:	😐	-	-

Different tools provide different answers. Judgement is needed.

The 4 Types of Moisture Risk Analysis



1) Summary – 2x6 with ccSPF and Enduramax

	Qualitative	Glaser	WUFI
Water control:	☺	-	☺
Air control/condensation:	☺	☹	☺
Vapor control:	😐	😐	☺
Thermal control:	☺/😐	-	-

Different tools provide different answers. Judgement is needed.

The 4 Types of Moisture Risk Analysis

1) Qualitative moisture assessment

- 👍 Encourages thoughtful analysis of all elements impacting moisture performance, and understanding of design intent (regarding moisture)
- 👍 Adds important considerations of material durability, constructability, and field experience (otherwise missed by models).
- 👎 Rarely provides definitive answers.

The 4 Types of Moisture Risk Analysis

2) Static diffusion and condensation risk assessment (Glaser analysis)

- Offers simple comparisons between wall assemblies that can be used quickly during design phase to identify and reduce condensation and diffusion risks. It is a quick design tool.
- Only considers behavior at one set of conditions (a given temp and RH)
- Does not incorporate many important elements related to moisture behavior – water leakage, air leakage, and capillary drive
- Cannot model impacts of vented/ventilated cladding systems
- Does not predict ultimate moisture levels, safety, or failure

The 4 Types of Moisture Risk Analysis

3) Dynamic simulated hygrothermal performance

- 👍 Attempts to predict actual moisture levels through all layers of wall and roof assemblies, affording greater certainty regarding success or failure
- 👍 Can model almost the complete range of moisture drive mechanisms including rain, solar gains, bulk water leakage, air leakage, capillary drive, diffusion, and storage.
- 👍 Dynamic, hour by hour modeling for a variety of climates can help pinpoint reasons and times of failures.
- 👎 Basic simulations are easy to run, but accuracy requires knowledgeable, experienced users and more time to refine material properties.
- 👎 There is still debate about the ultimate accuracy of WUFI, especially for cavity walls with possible air flow and roofs

The 4 Types of Moisture Risk Analysis

4) 2D Thermal modeling (Not required for B3)

- Analyzes heat loss and condensation risk at locations that aren't considered with Glaser or WUFI analysis.
- These locations can often be the most critical, hard to manage locations in the enclosure in terms of moisture risk, heat loss, and thermal comfort.
- Thermal bridge heat loss can be an important component of energy modeling (accounting for 20 – 70% of total heat loss through walls)
- THERM and Flixo only offer static modeling of *temperature* conditions. Therefore, only dewpoint/condensation risk and heat loss are considered.

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