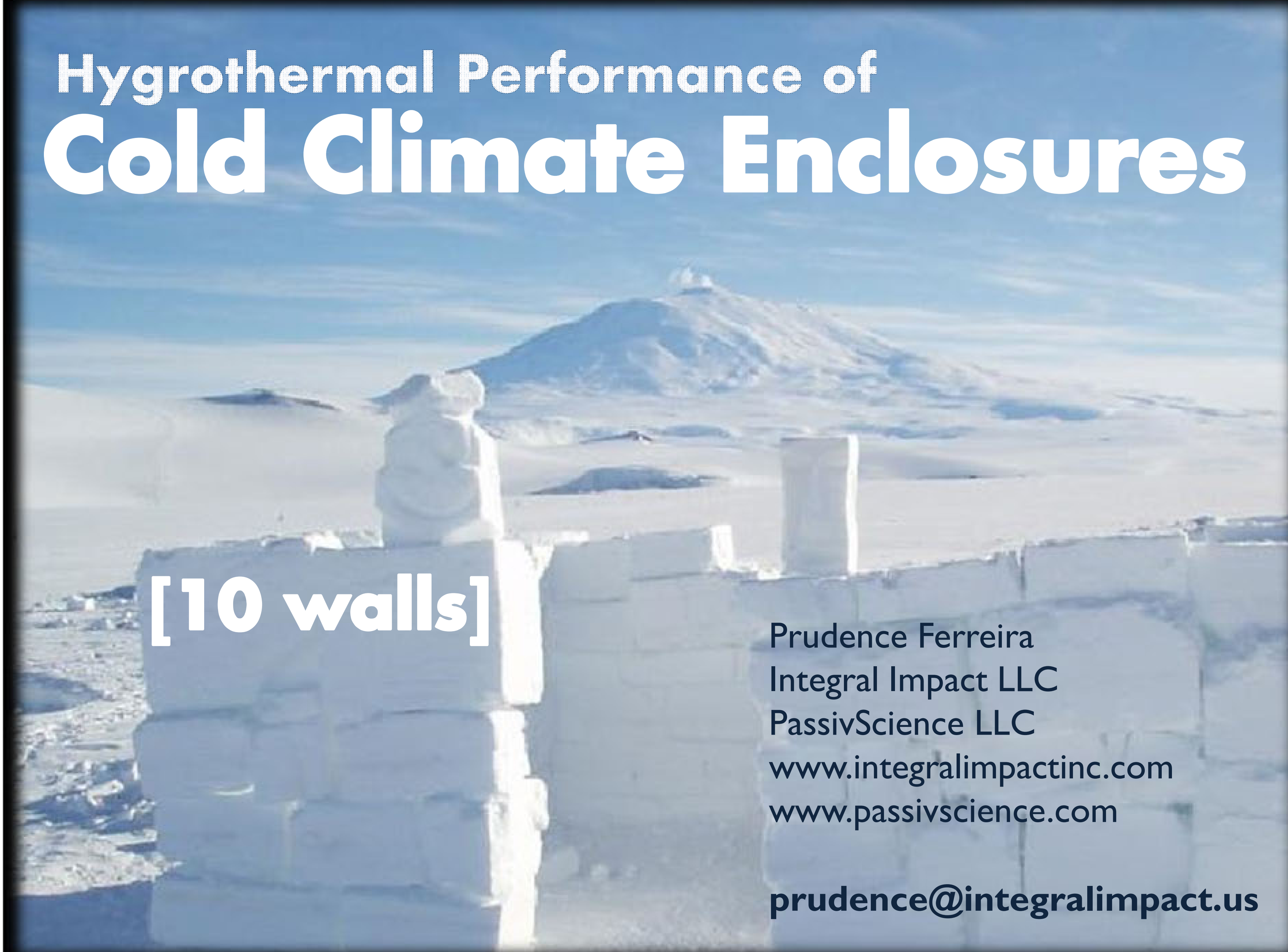

Hygrothermal Performance of
Cold Climate Enclosures

[10 walls]

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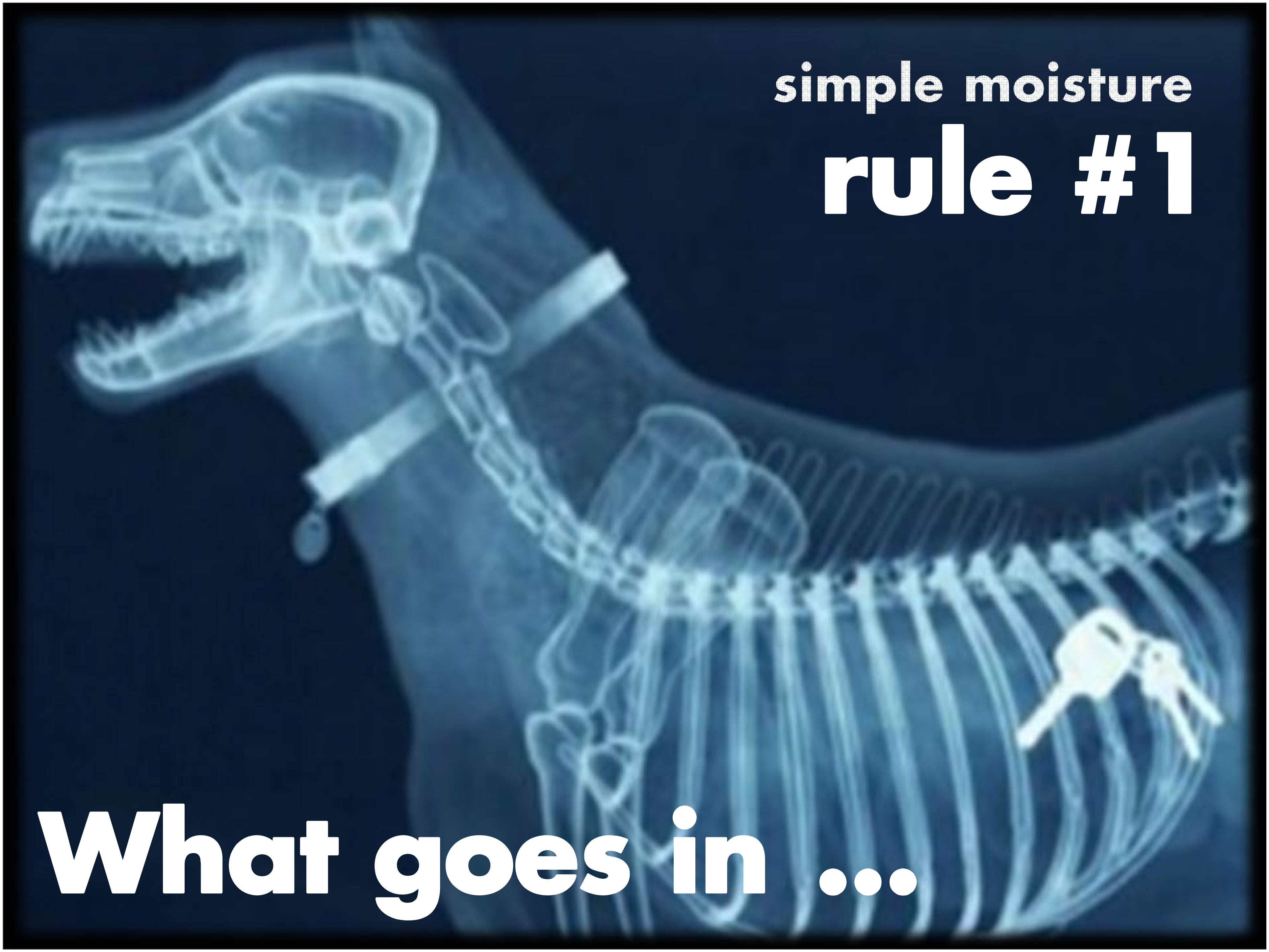
www.passivscience.com

prudence@integralimpact.us

Outlook

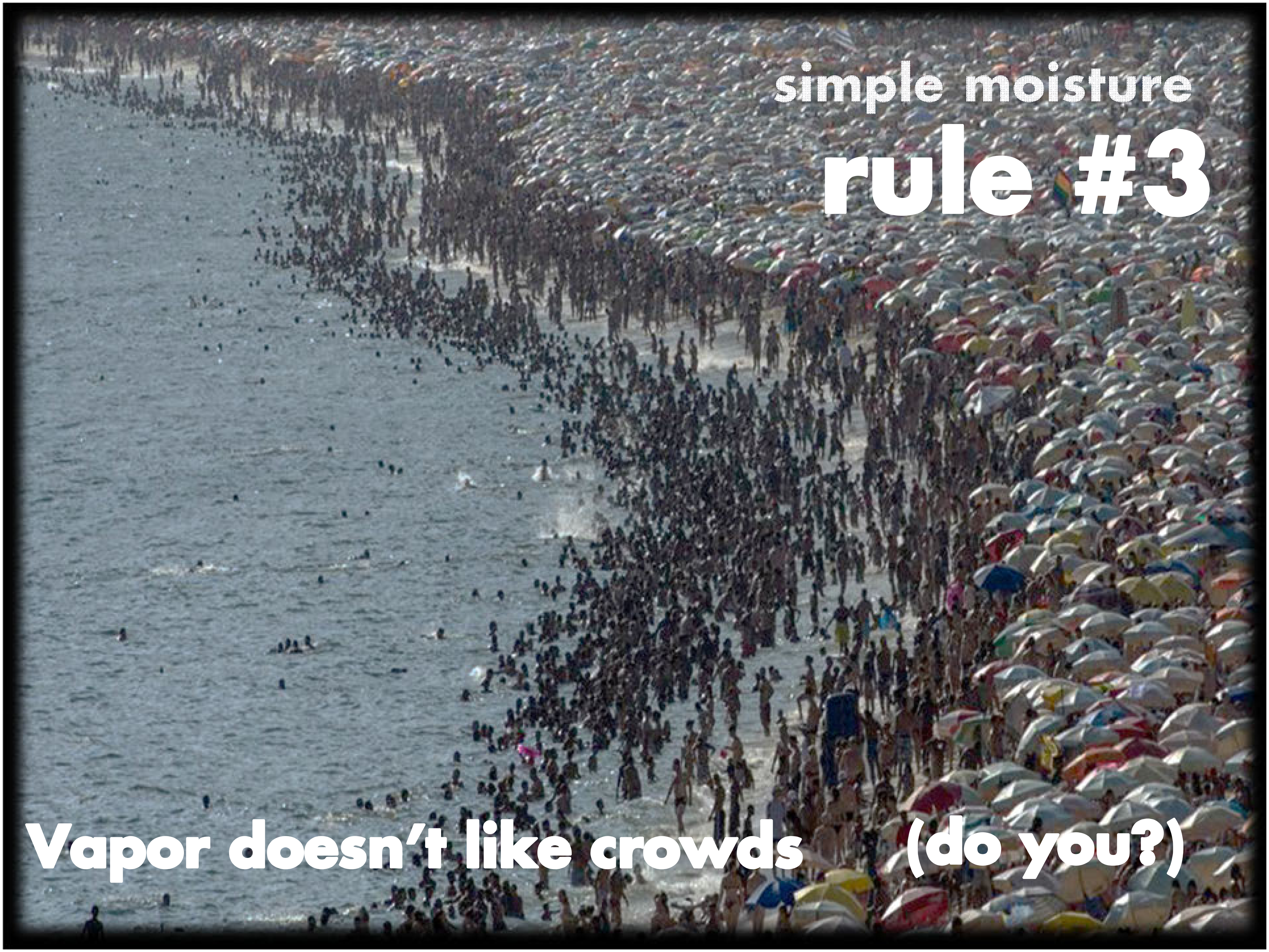
1. Cold Climate Building Science
2. Hygrothermal Risks
3. Assemblies + Inputs
4. Results Analysis + Conclusions

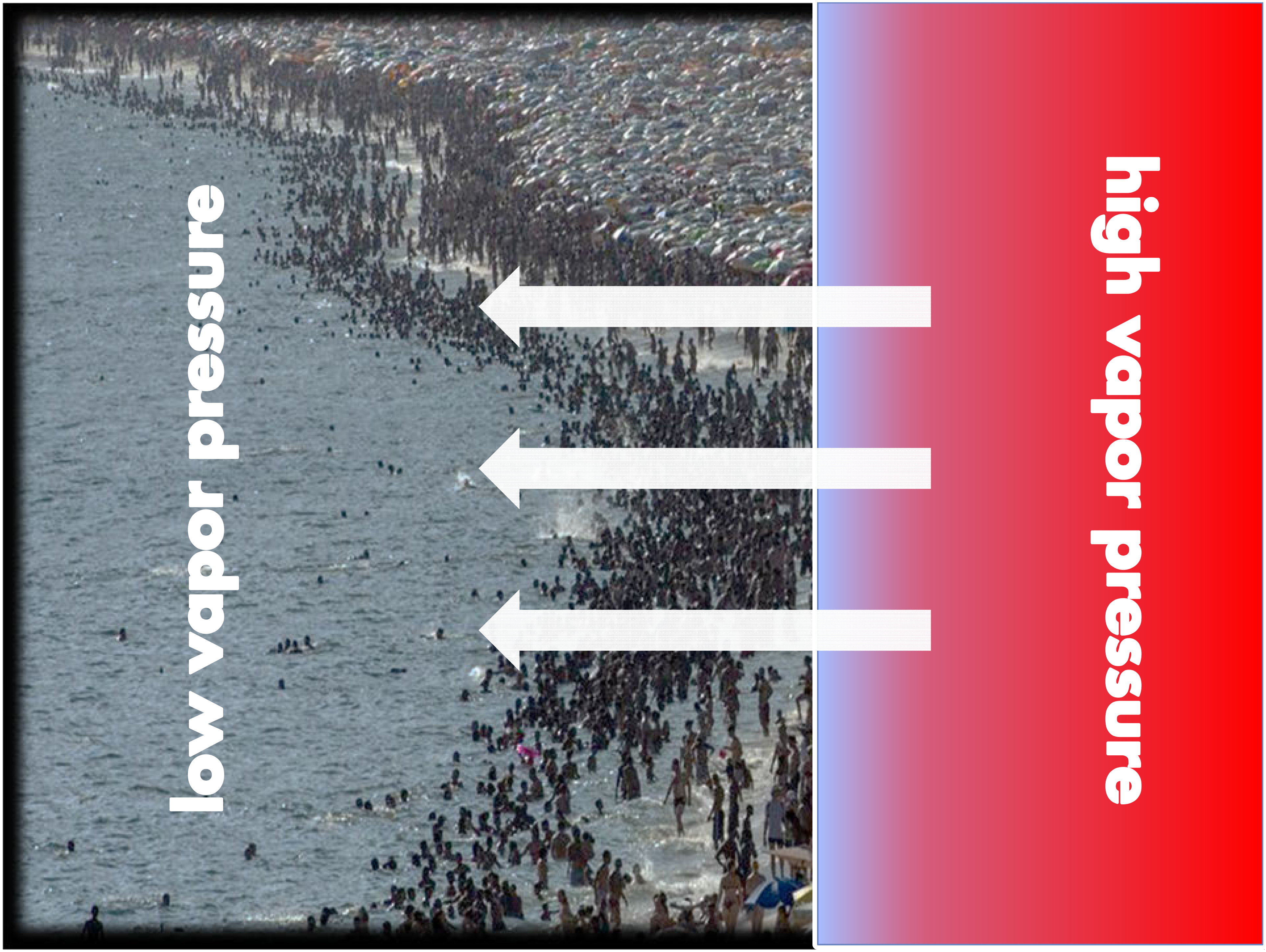

Building Science
Basics


simple moisture
rule #1
What goes in ...


simple moisture
rule #2
Warm air holds more moisture than...


simple moisture
rule #2
Ice hotel, Fairbanks, AK


simple moisture
rule #3
Vapor doesn't like crowds
(do you?)


low vapor pressure
high vapor pressure


simple moisture
rule #4
VS
Vapor is opportunistic


simple moisture
rule #4
Where air goes, vapor will follow...

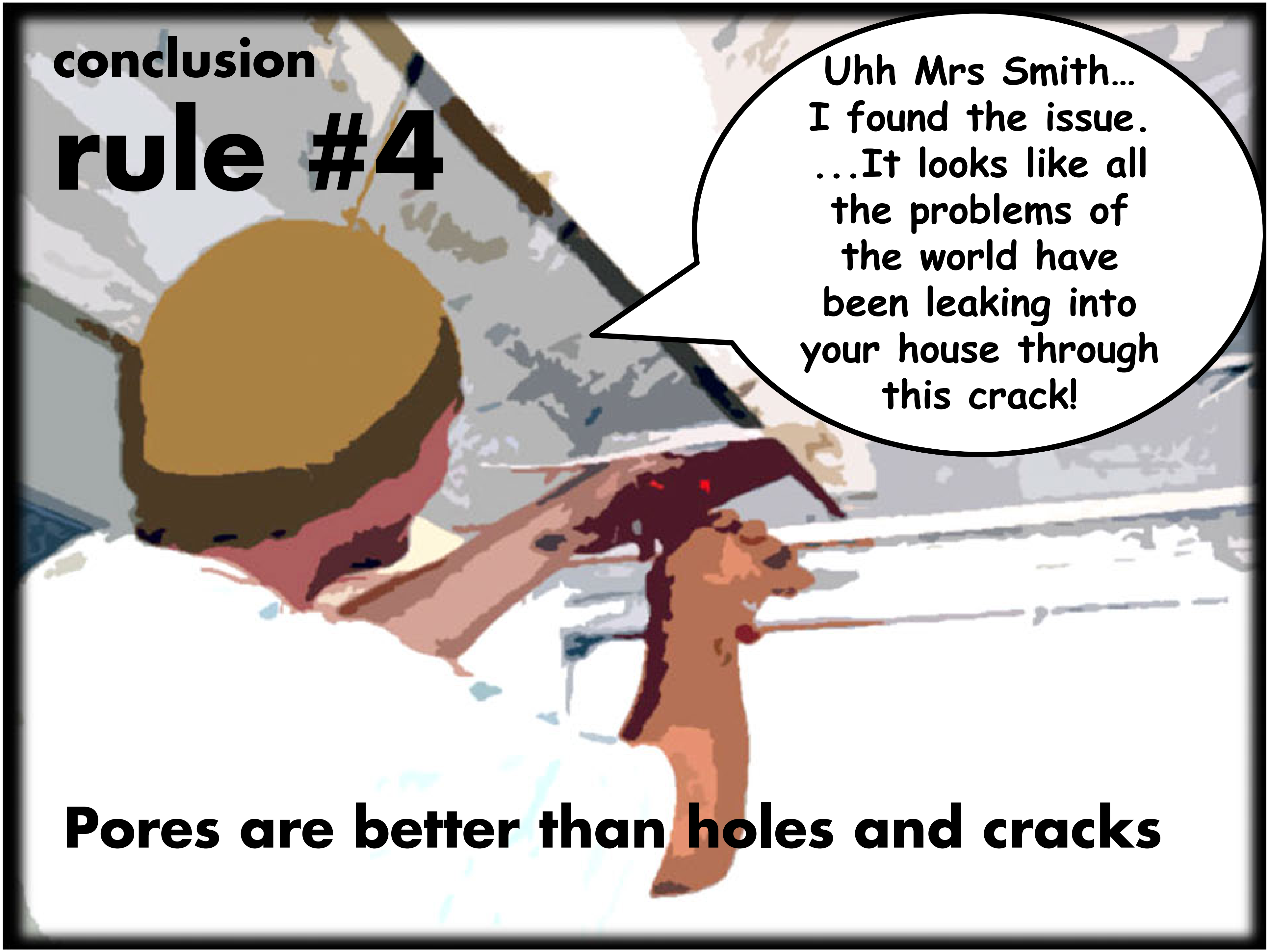

simple moisture
rule #4
exfiltration
@110F and 100% RH = ?? Quarts H2O
4 x 8 sheet drywall w/ 1.0 in² hole
One heating season @ 70F and 40% RH = 30 Quarts H2O

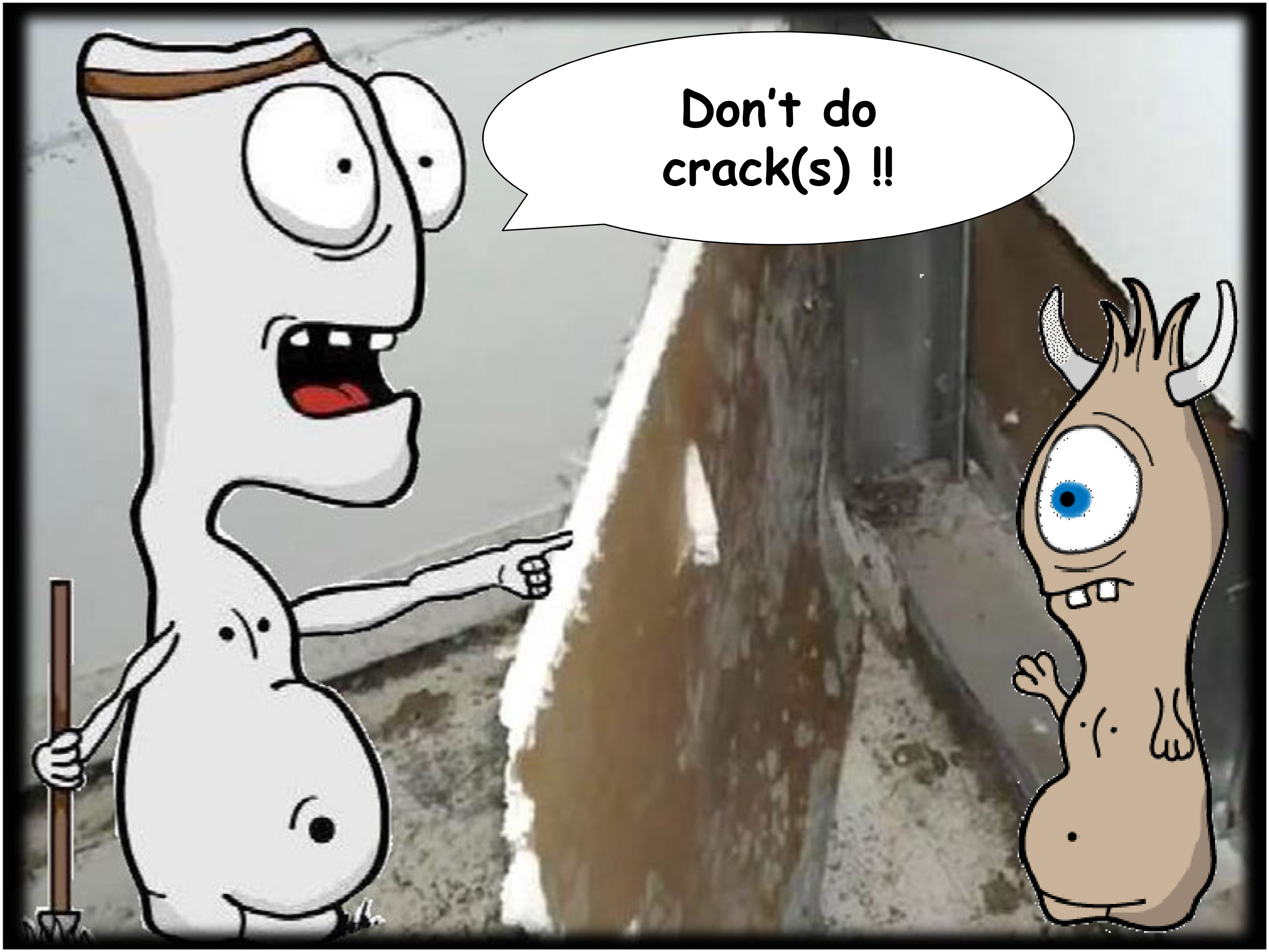
simple moisture

rule #4 diffusion

@110F and 100% RH = ?? Quarts H2O

One heating season @ 70F and 40% RH = 1/3Quart H2O


conclusion
rule #4
Uhh Mrs Smith...
I found the issue.
...It looks like all the problems of the world have been leaking into your house through this crack!
Pores are better than holes and cracks


Don’t do crack(s) !!

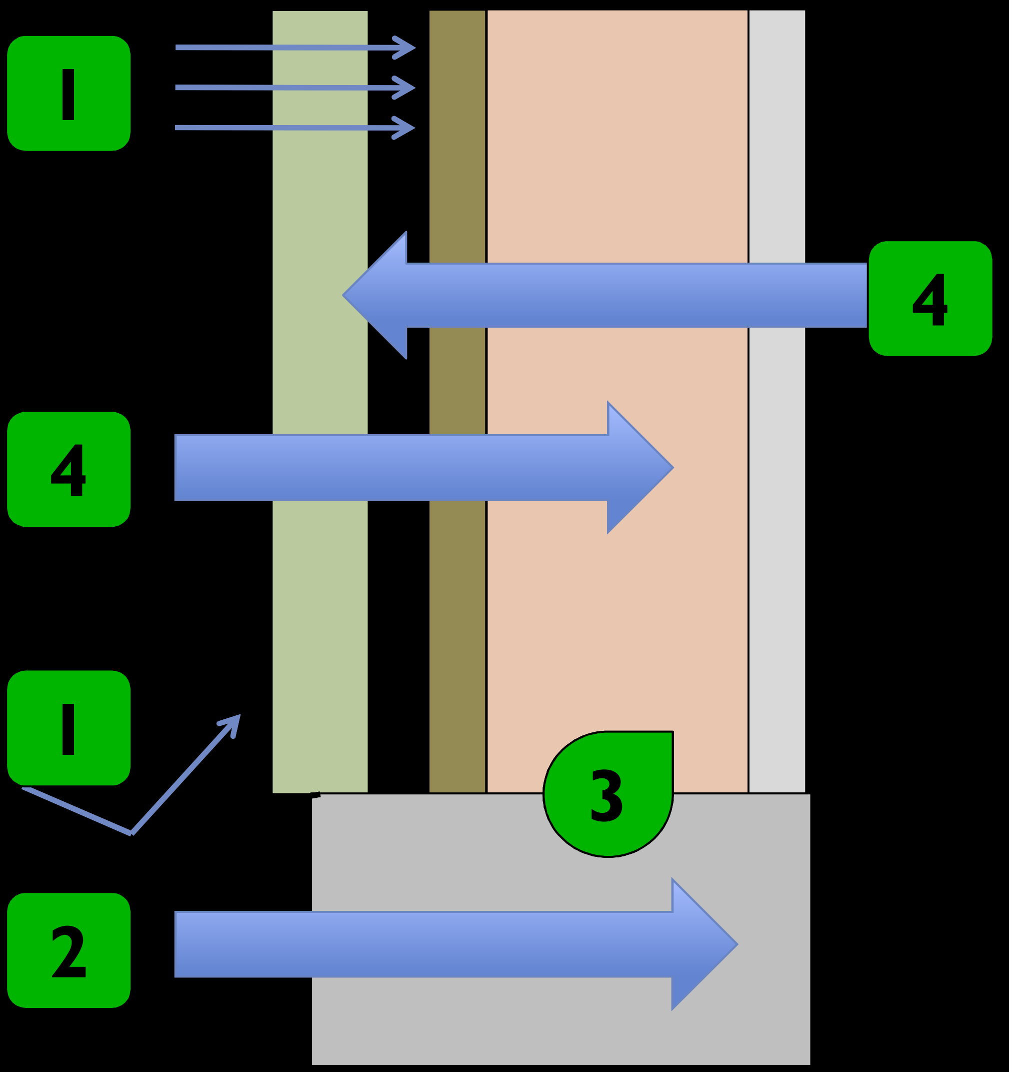
Wetting Mechanisms

1. Bulk water: absorption of driving rain and splash-back at grade

2. Bulk water: liquid and bound groundwater, driven by capillary suction, redistribution and gravity

3. Built-in and stored moisture, esp. in wood and concrete

4. Vapor transport via infiltration/exfiltration and/or diffusion



Wetting via Bulk Water

Capillary Liquid Transport is dependent on:

- **Material Properties** (Porosity and capillary diameter)
- **Moisture Content** (EMC - Liquid transport coefficients show a roughly exponential dependence on moisture content, the higher the moisture content, the more liquid transport occurs until EMC is reached by drying to inside)
- **Boundary Conditions** (RH and vapor pressure both outdoors and indoors)

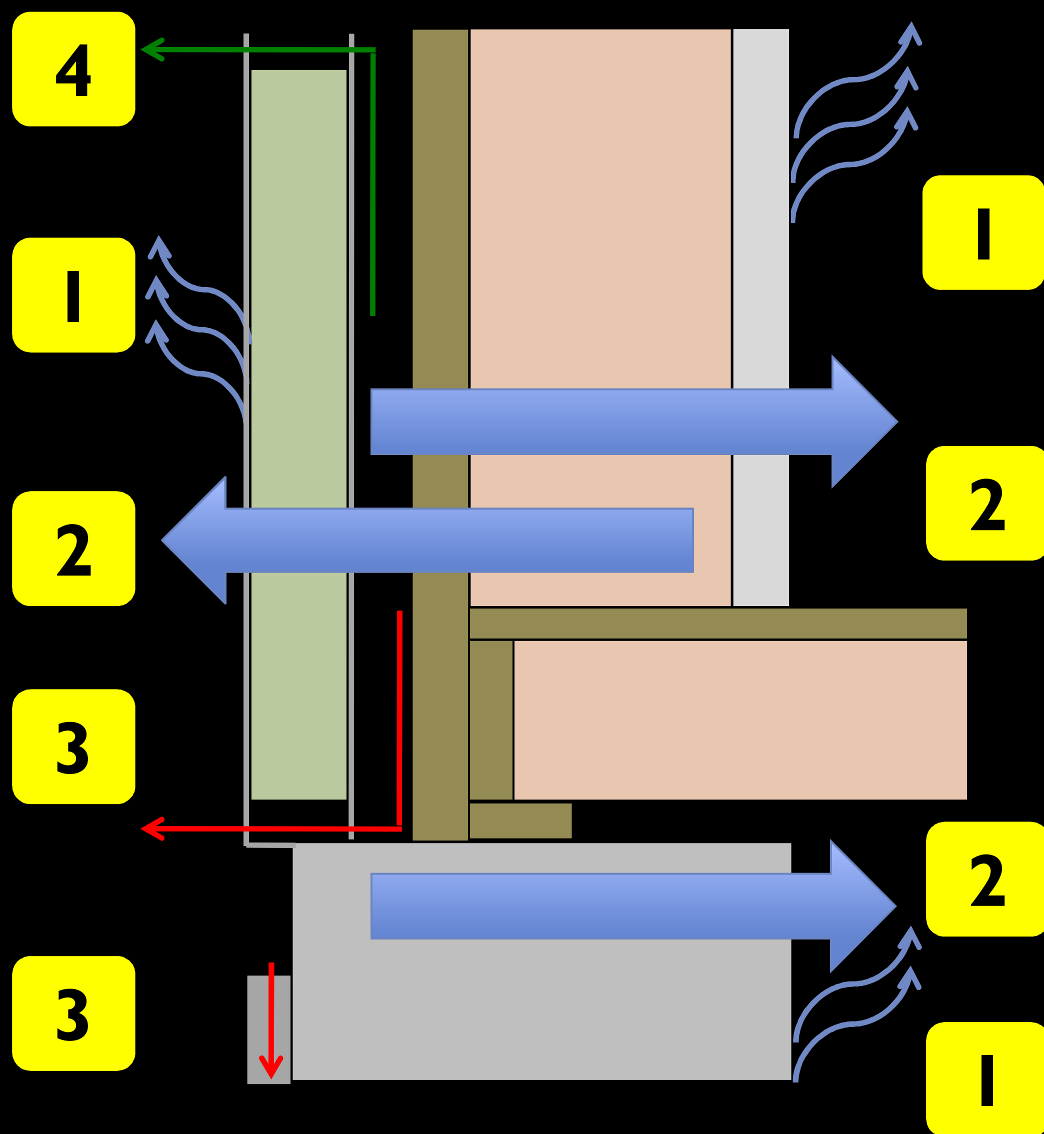
Drying Mechanisms

1. Evaporation: liquid water transported by capillary action to the inside or outside

2. Vapor transport via diffusion and/or effusion

3. Drainage of unabsorbed water, driven by gravity

4. Convection through intentional (or un-intentional) vented air cavities



Moisture Management

Minimize the use of materials that are prone to rot and mold.

Create assemblies that are vapor permeable to facilitate drying.

Waterproof and airseal to keep unwanted moisture and spores out of building assemblies.

Provide continuous balanced filtered mechanical ventilation to control indoor humidity and keep spores (and other allergens) out.

Prevent wetting and mold/fungus spore entry, promote drying.


Prevent
WETTING
Diffusion
Air Transport
Bulk H_2O
Promote
DRYING
Diffusion
Ventilation

Prevent Bulk Water Exposure

In wet/humid regions choose materials that are not prone to moisture damage.

Prevent Capillary Suction

- Damp proofing – seal capillary pores
- Waterproof membranes (PE)
- Large pore gravel capillary break
- Drainage

Prevent Liquid Flow

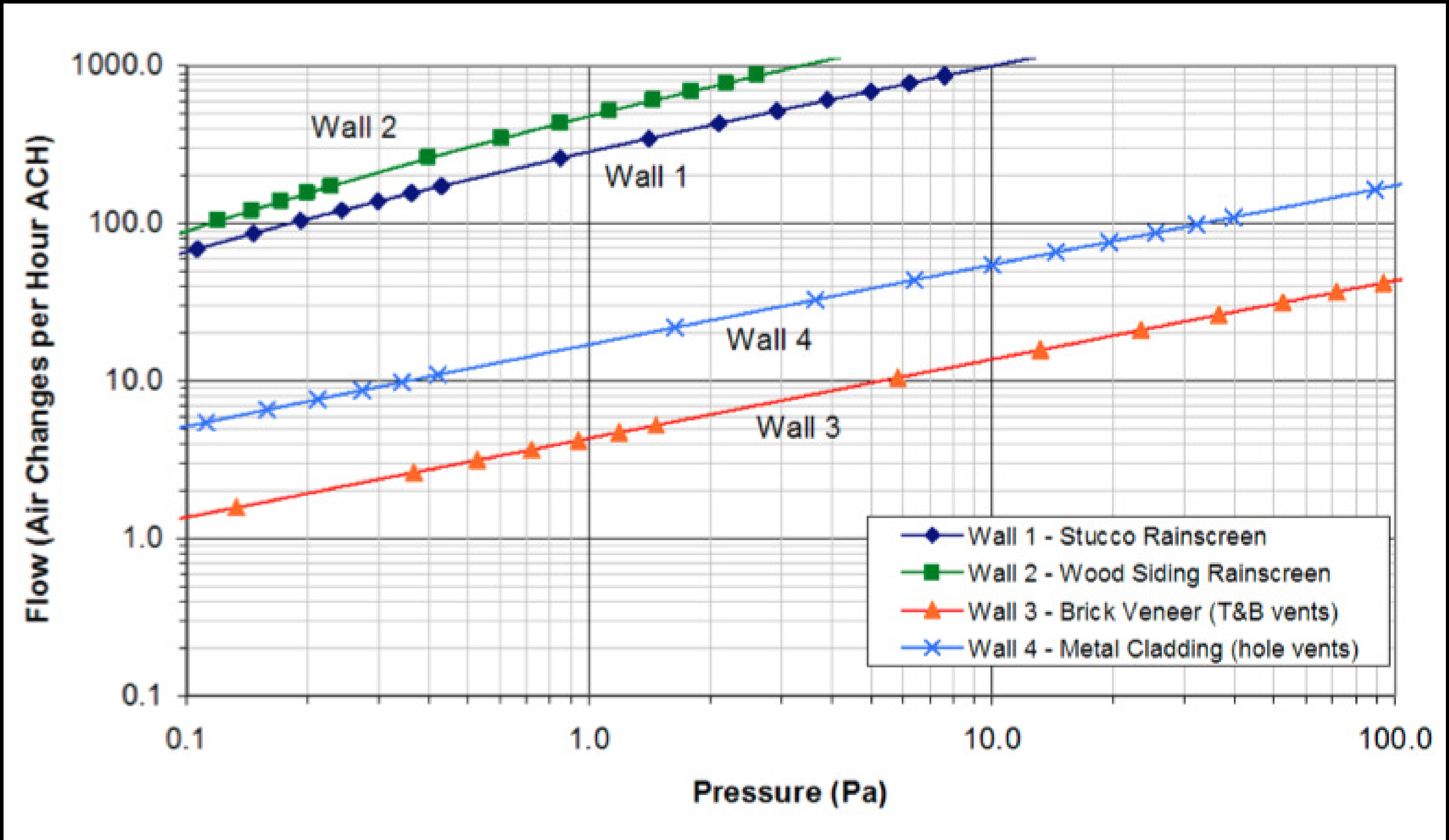
- Use water resistant barrier/drainage plane behind cladding
- Proper flashing of intersections + penetrations
- Drainage!

Techniques interchangeable for ALL regions

Promote Drying: Bulk Water

- Vented Wall – Vents at bottom of wall for drainage, limited air exchange
- Ventilated Wall – Vents at top and bottom of air cavity to promote air exchange
- Rainscreen - Cladding over a ventilated, drained and pressure relieved 3/8" - 5/8" cavity with fully flashed transitions

Promote Drying: Bulk Water



Ventilated Wall Claddings: Review, Field Performance, and Hygrothermal Modeling _ John Straube and Graham Finch

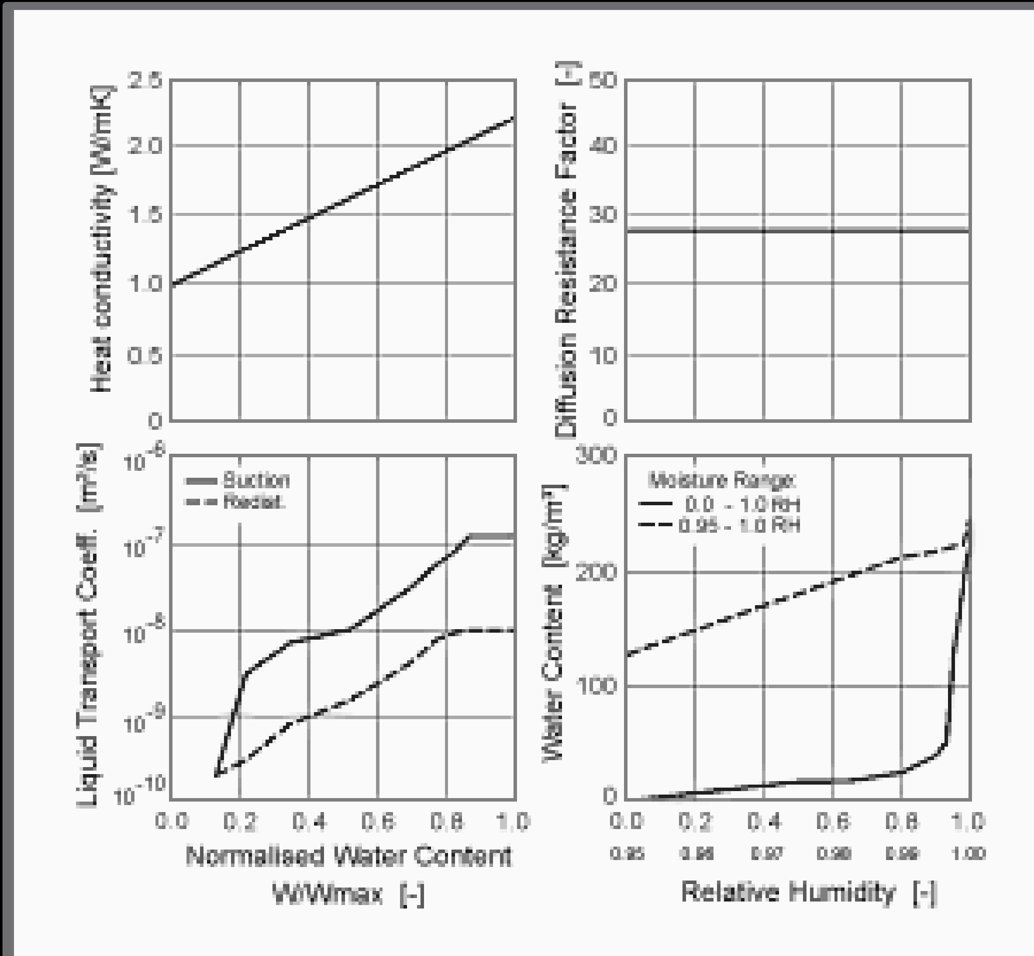
Built-in and Stored Moisture

Vulnerability to rot and mold varies depending on material constitution and ability to safely store moisture without degradation

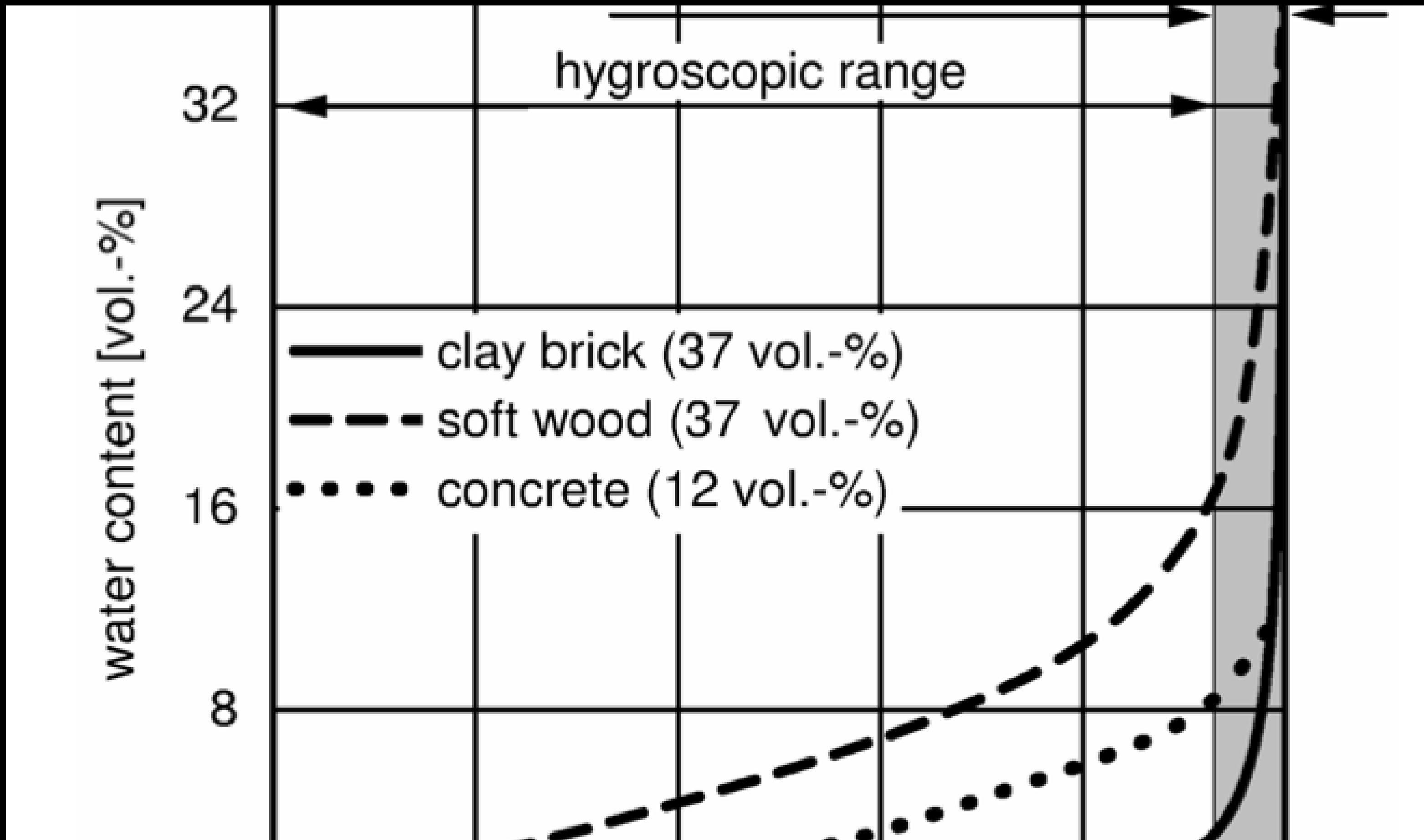
Material : Lime Silica Brick

Description:

Bulk density	[kg/m³]:	1900
Porosity	[m³/m³]:	0.29
Heat Capacity	[kJ/kgK]:	0.85
Heat Conductivity Dry	[W/mK]:	1.0
Moisture - related Supplement	[%/M.-%]:	8
Water Vapour Diffusion Resistance Factor Dry	[-]:	28
Free (Capillary) Water Saturation	[kg/m³]:	250.0



Built-in and Stored Moisture



Give it a drying path!

Built-in and Stored Moisture

A material's ability to store moisture depends on:

1. **RH:** If atmospheric RH is high, water content of a material can be higher

2. **Temperature:** Higher temperatures can result in increased ability of both air and materials to hold moisture and but also cause desorption/evaporation as materials heat up

3. **Material Properties and Behaviors**

Material Properties

Porosity: The measure of the distribution of minute spaces or holes in a material through which liquid or air may pass

Permeability: [perm in] Moisture transmission rate of a material, not dependent on thickness. Divide permeability by a layer thickness yields permeance, (*typ used for vapor transmission performance evaluation of bulk materials.)*

Vapor Diffusion Resistance: μ-value (Mu) Inverse of permeability;

- Ratio of the diffusion coefficients of water vapor in air and in the building material
- The factor by which the vapor diffusion in the material is impeded, as compared to diffusion in air.
- For very permeable materials, such as mineral wool, the μ-value is thus close to 1, whereas it increases for materials with greater diffusion resistance.

Material Behaviors

Permeance: [perms] Vapor transmission performance evaluation *typ used for thin materials. (ASTM E96).* States the diffusion openness of a specific construction layer *(object),* incorporates layer thickness

1 Perm: [a unit of permeance] : One perm is one grain of water vapor per hour flowing through one square foot of a layer, induced by a vapor pressure difference of one inch of mercury across the two surfaces.

VS

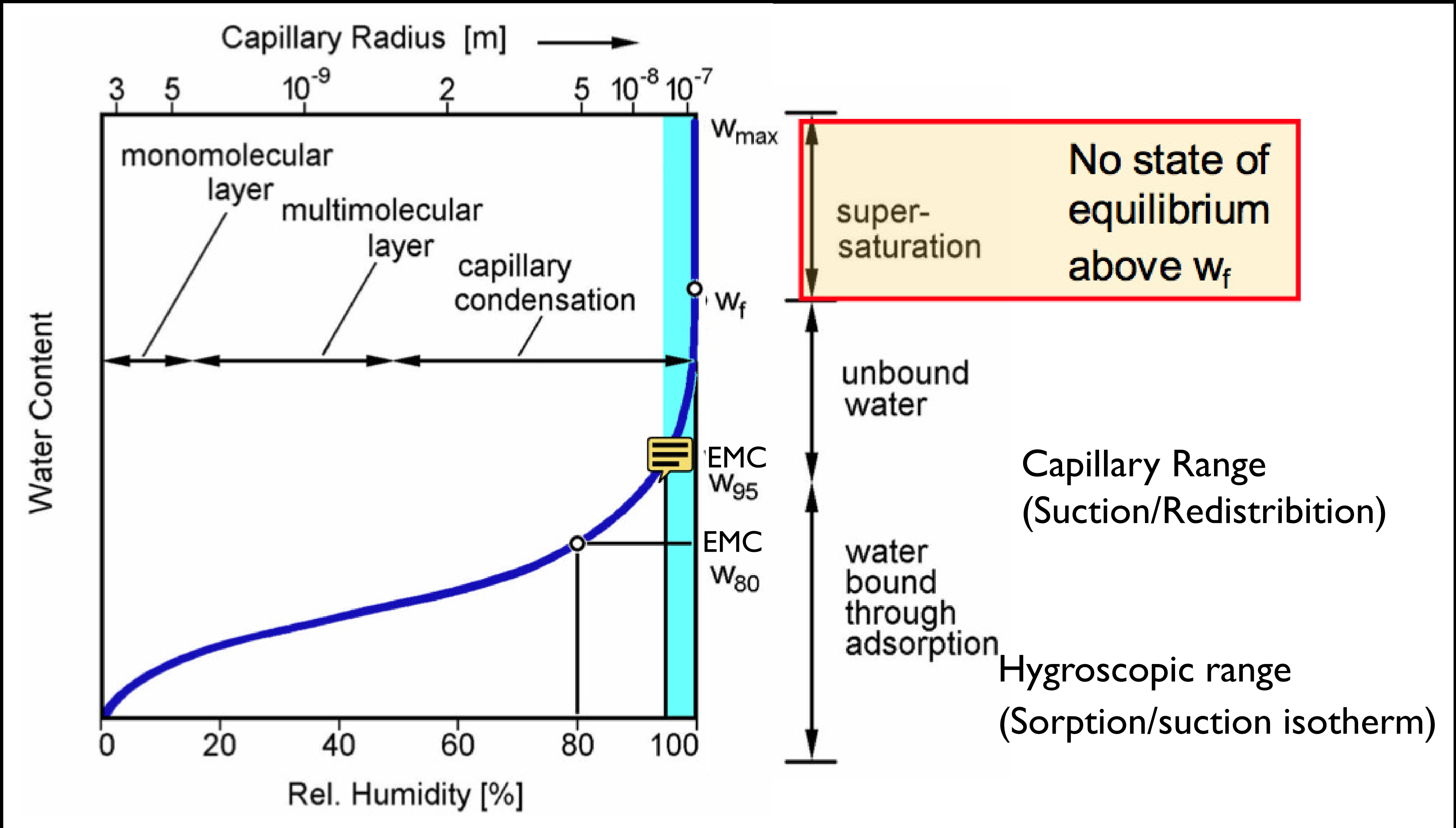
Permeability: [perm in] A material property that describes the moisture transmission rate of a material, not dependent on thickness.

Material Behavior

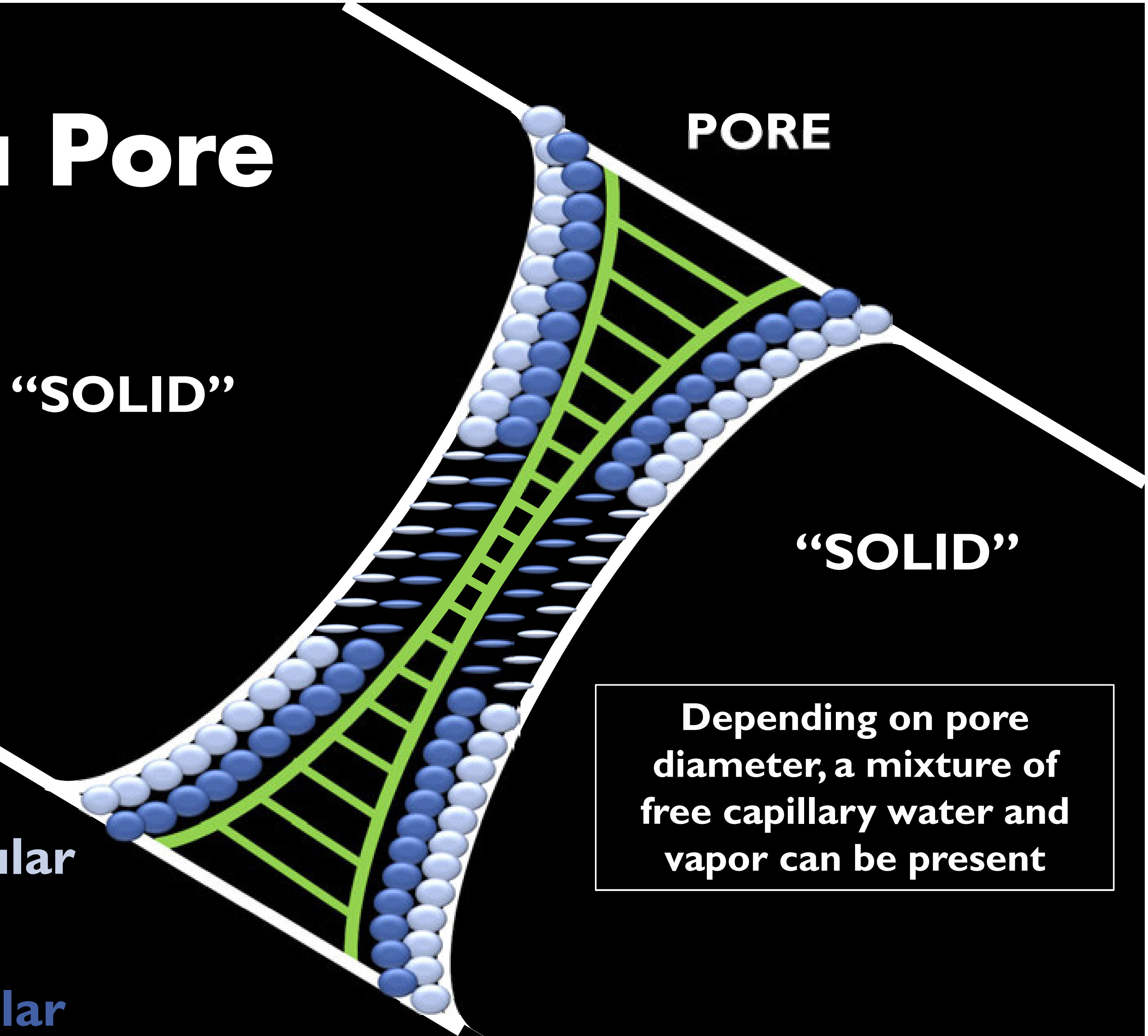
Moisture Storage Function: The max amount of water that can be stored in a material relative to atmospheric RH, and at what point capillary action initiates liquid transport via capillary conduction. Includes 3 important thresholds for building materials:

- **EMC@80% RH** is annual avg in most of world, above this is where you start to get issues
- **EMC@95%RH** = equilibrium moisture content:
- **W_f**= Water free saturation (max amount of H20 that can be stored in a material)

Moisture Storage Function

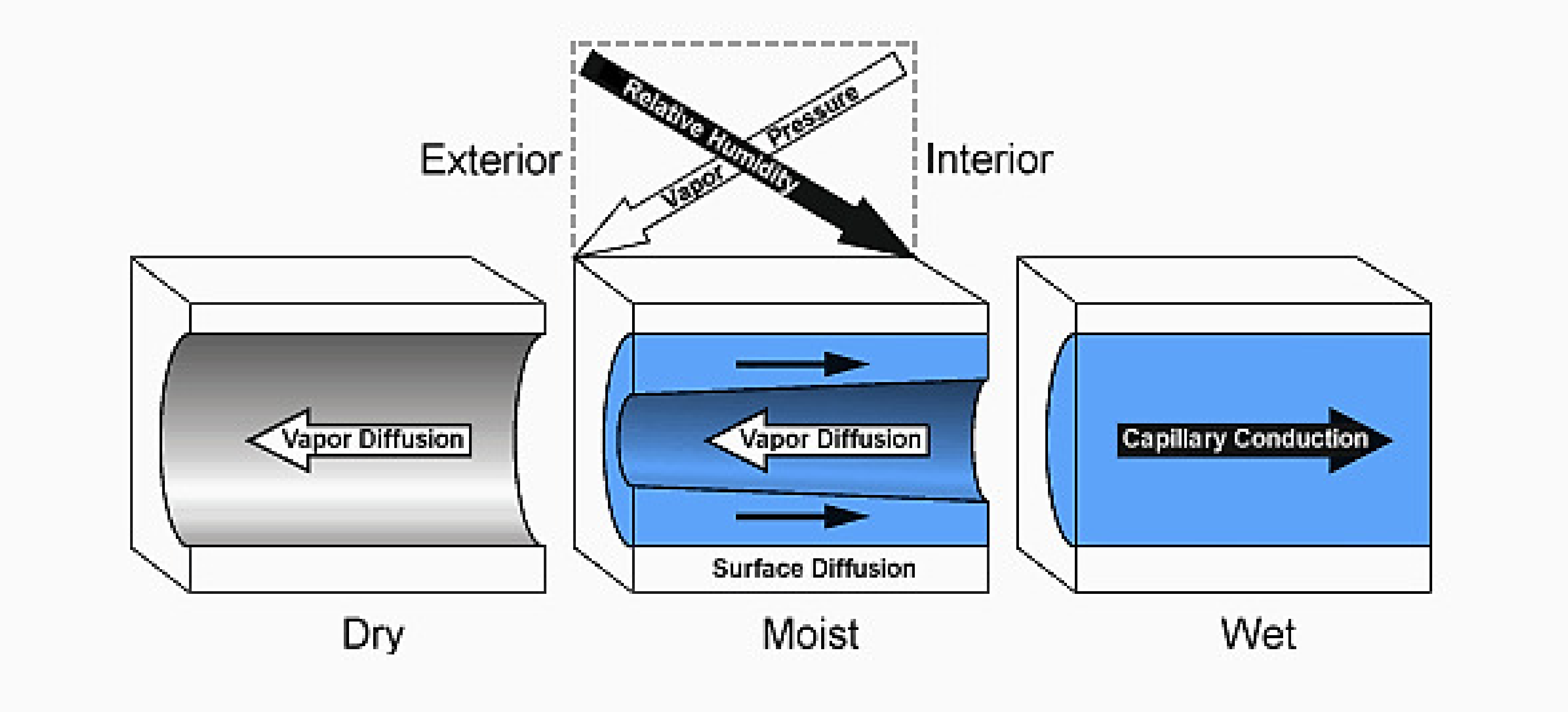


Life
Inside a Pore



1. RH increases
2. Mono-molecular
3. RH increases
4. Multi-molecular
5. Capillary pore diameter decreases + cap suction increases
6. Increased pressure in pore causes capillary condensation

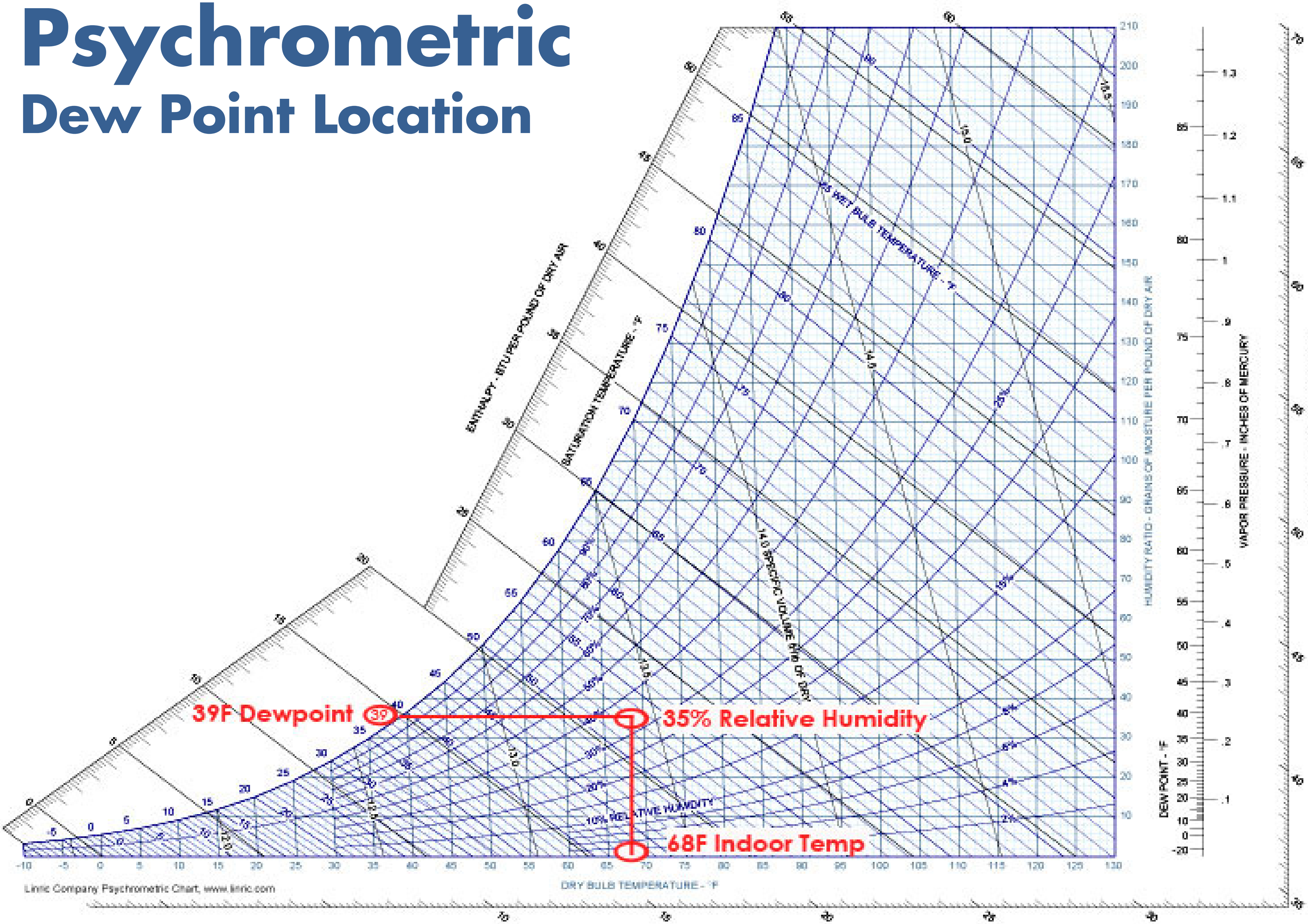
Coupled Heat + Moisture Transport is Complex



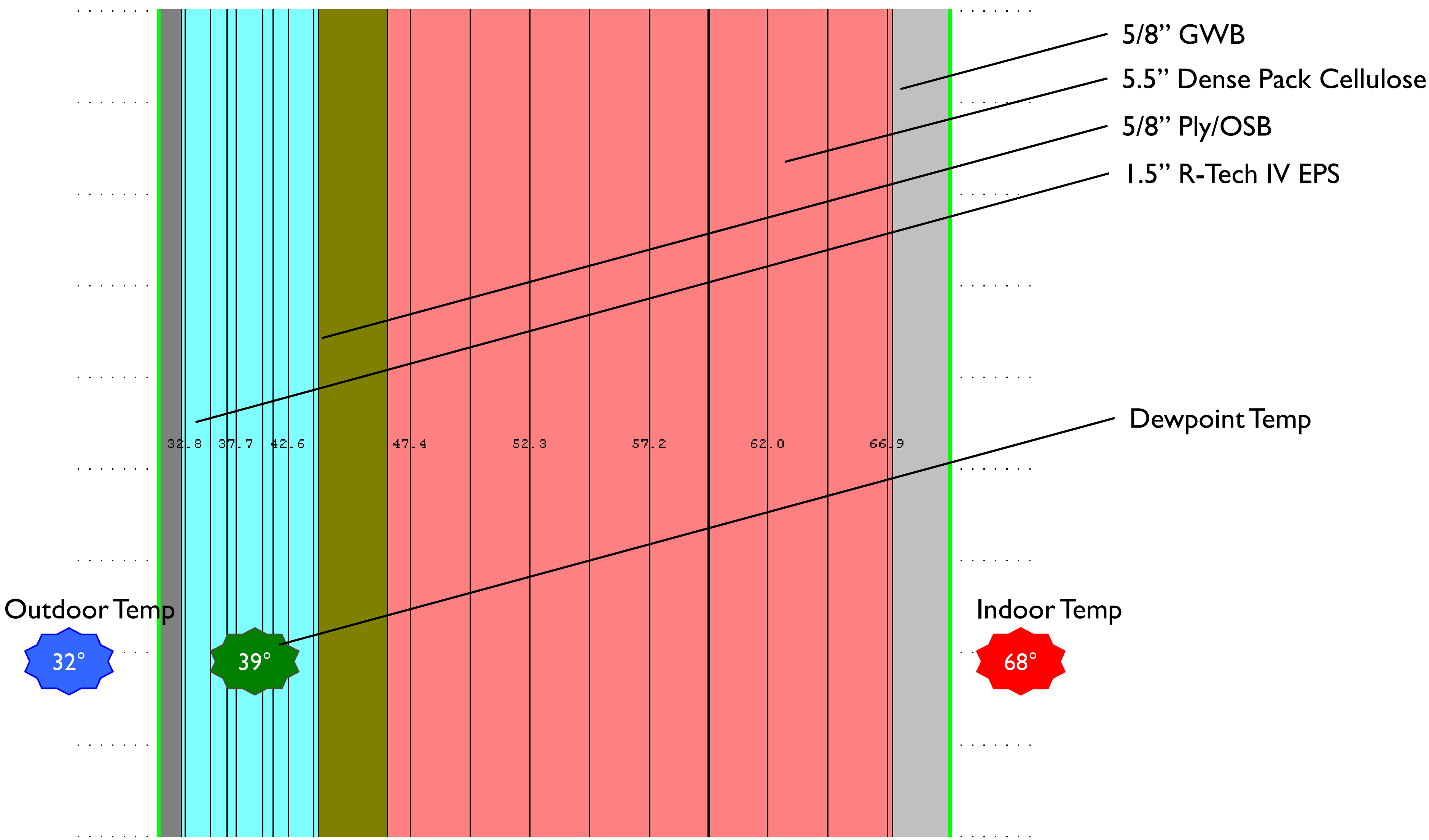
These hygrothermal phenomenon can occur simultaneously

Psychrometric

Dew Point Location

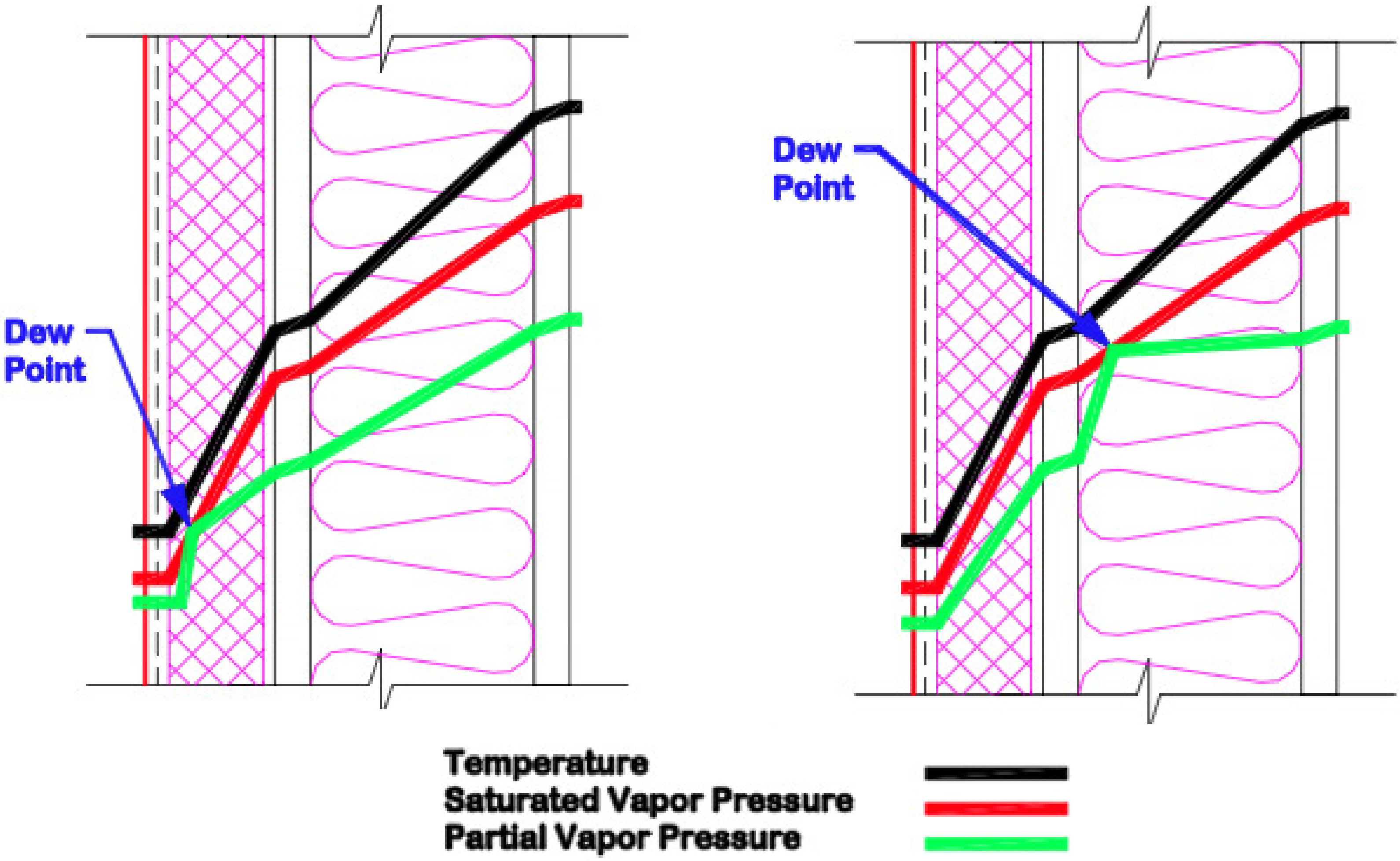


THERM Dew Point Location



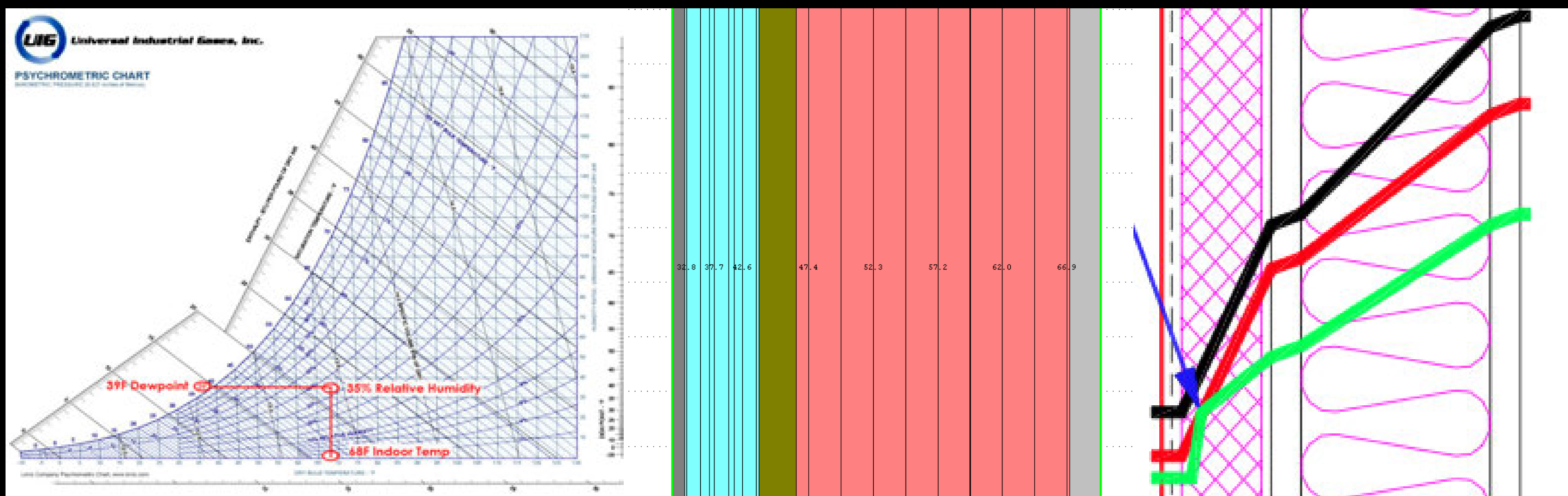
Glaser Method

Dew Point Location




Dirty Secrets
in YOUR walls?
Hygrothermal
Risks

Not Good Enough!



Recipe for Disaster....?

For our specials this evening sir we have a very fresh and fragrant mould … or nicely aged brown rot fungii with a generous side of structural damage…

Mould Menu

Stachybotrys chartarum

Aspergillis niger

Aspergillis fumigatis

Alternaria alternata

Fusarium oxysporum

Brown Rot Fungii Menu

Meruliporia incrassate

Coniophora puteana

Fibroporia vaillantii

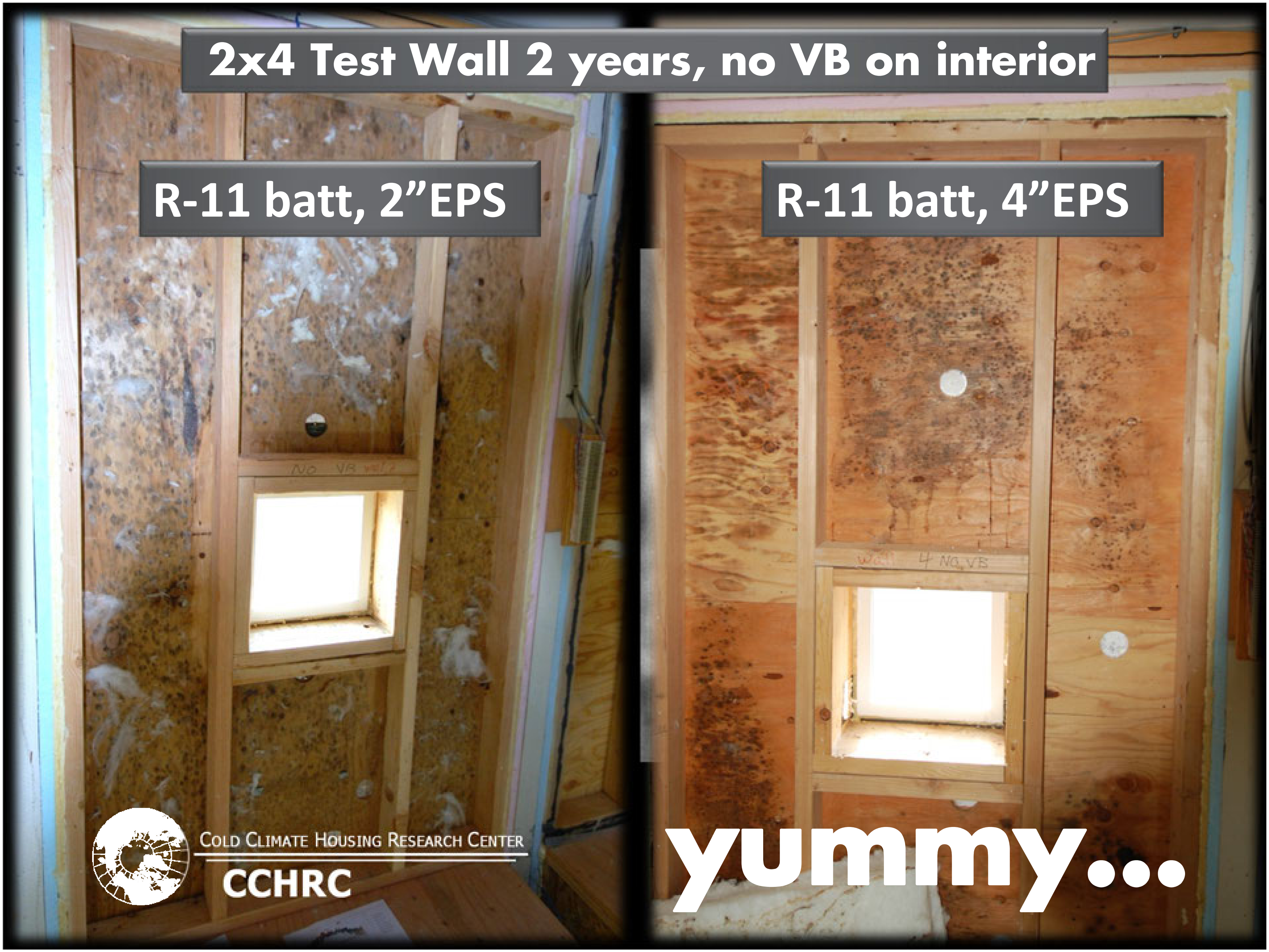
Antrodia vallantii

Serpula lacrymans


Mmmmh
Tasty!
Stachybotrys chartarum


Oooh
Yeah!
Serpula lacrymans


Soooo
Deelicious!
Meruliporia incrassate



2x4 Test Wall 2 years, no VB on interior
R-11 batt, 2"EPS
R-11 batt, 4"EPS
Cold Climate Housing Research Center
CCHRC
yummy...

Vapor Control Requirements - IRC

A Class II vapor control layer is required by the IRC on interior side of framed walls in climate zones:

- **7, 8 – Alaska**
- **6 – Minneapolis, Burlington**
- **5 – Boston, Chicago, Columbus, Denver, Boise**
- **4c – Seattle, Portland**

Exceptions:

- Basement walls or below-grade portion of any wall
- Wall construction that is not sensitive to moisture or freezing
- **Avoiding Class I vapor control layers in general in wall assemblies, except in special use occupancies in cold climates such as indoor pools and spas.

Vapor Retarder Classes

Class I:

0.1 perm or less

Class II:

1.0 perm or less and greater than 0.1 perm

Class III:

10 perm or less and greater than 1.0 perm

Vapor Retarder Classes

Class I: Polyethylene film, glass aluminum foil, sheet metal, oil based paints, vinyl finishes, foil-faced insulating sheathing

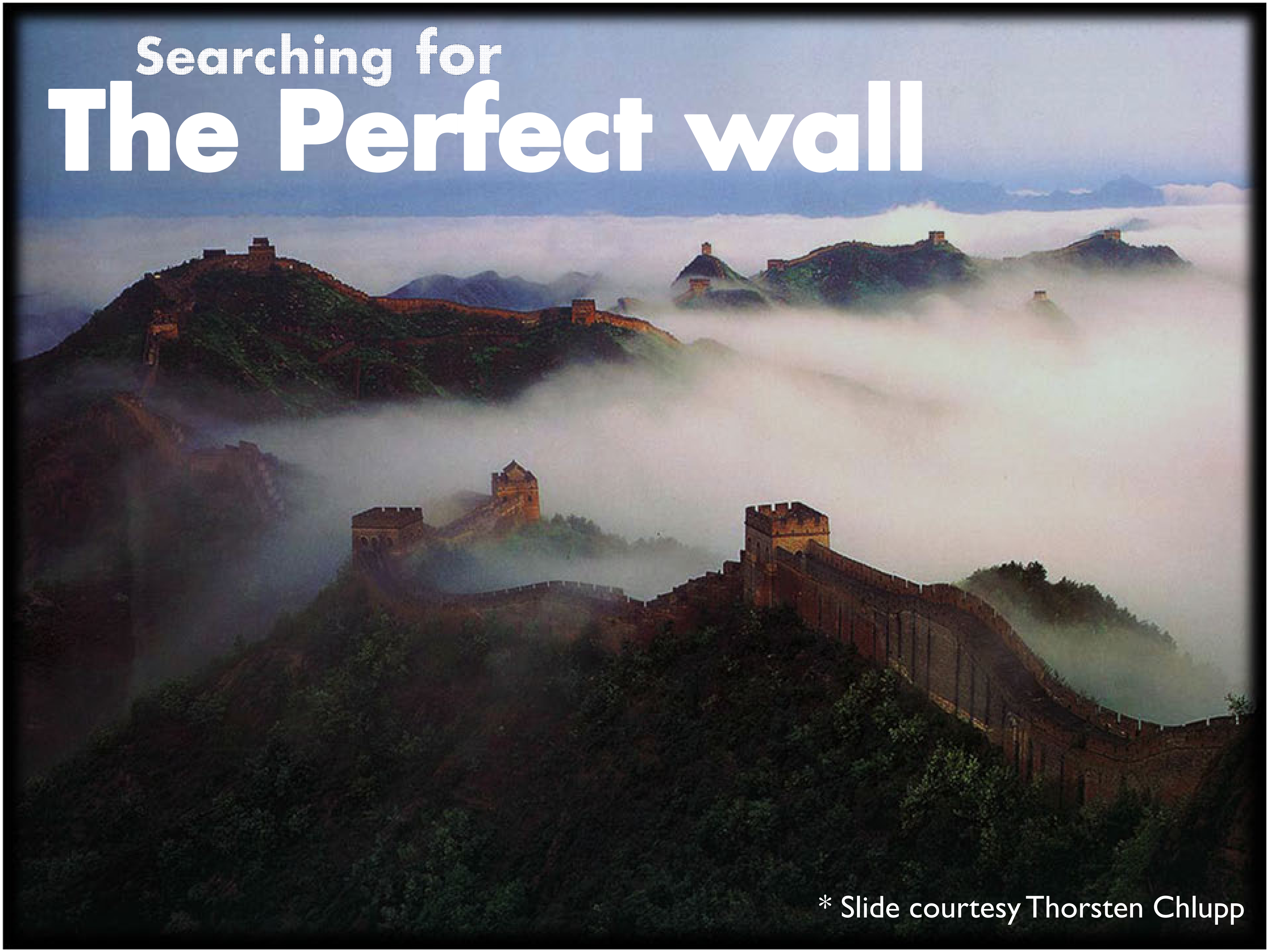
Class II:

Brick, EPS, XPS Fiber faced polyiso, asphalt-backed kraft paper facing, OSB, CDX Plywood

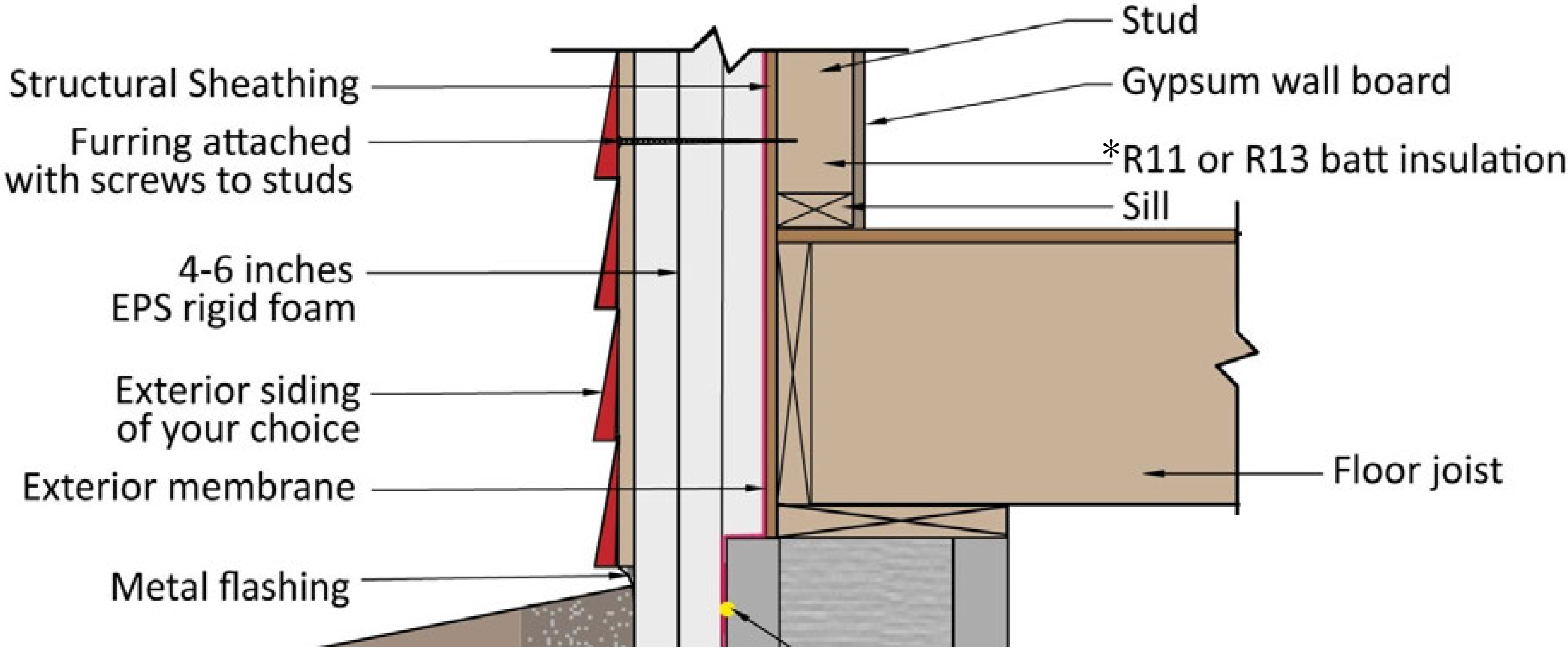
Class III: Plywood, most latex paint over gyp, various vapor retarder membranes greater than 1 and less than10 perms

Moisture Control Best Practices

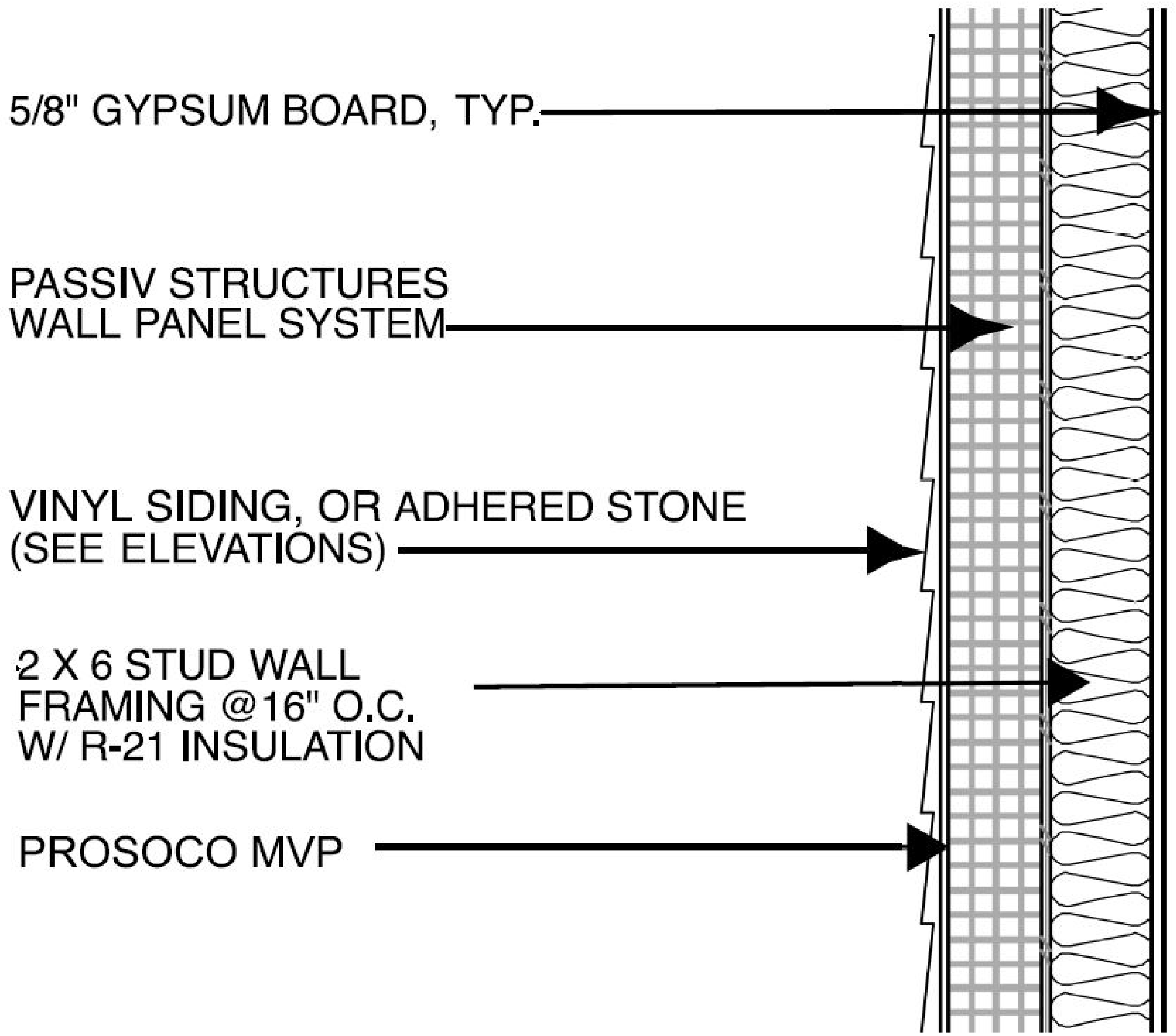
1. Avoid using vapor retarders where vapor permeable materials will provide satisfactory performance. Thereby encouraging drying mechanisms over wetting prevention mechanisms.
2. Avoid installation of vapor retarders on both sides of assemblies – i.e. "double vapor barriers" in order to facilitate assembly drying in at least one direction.
3. Aim for the use of diffusion open and hygroscopic materials over impermeable hydrophobic materials
4. Layer assemblies so that vapor retarding layers are close to the source of moisture and more sensitive, less durable materials are protected
5. Promote initial and ongoing drying and short-circuit accumulation by providing ventilation per ASHRAE 62.1, 62.2 or better


Searching for
The Perfect wall
* Slide courtesy Thorsten Chlupp

Residential Wall 1 - REMOTE



Residential Wall 2 – SIPS+



Residential Wall 3 – 1" Ext Foam

LATEX PAINT

5/8" INTERIOR GWB

2x6" FRAMED WALL WITH DP CELLULOSE

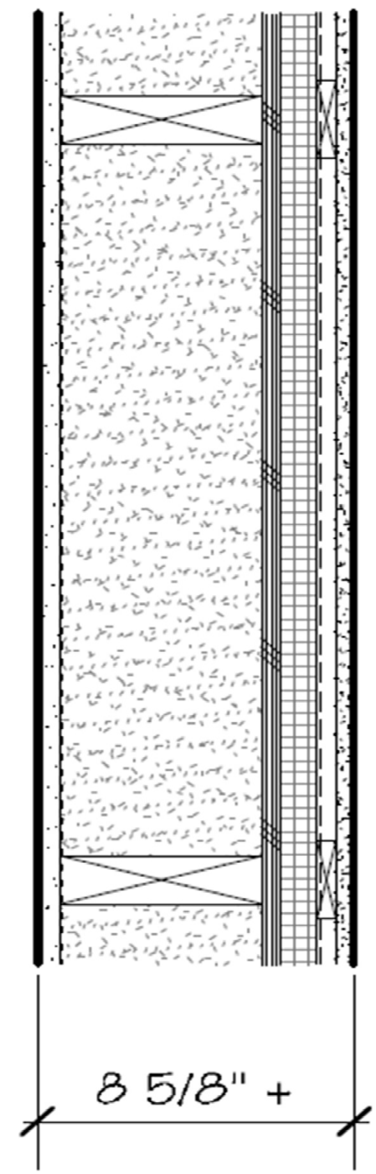
1/2" EXTERIOR PLYWOOD

BUILDING WRAP

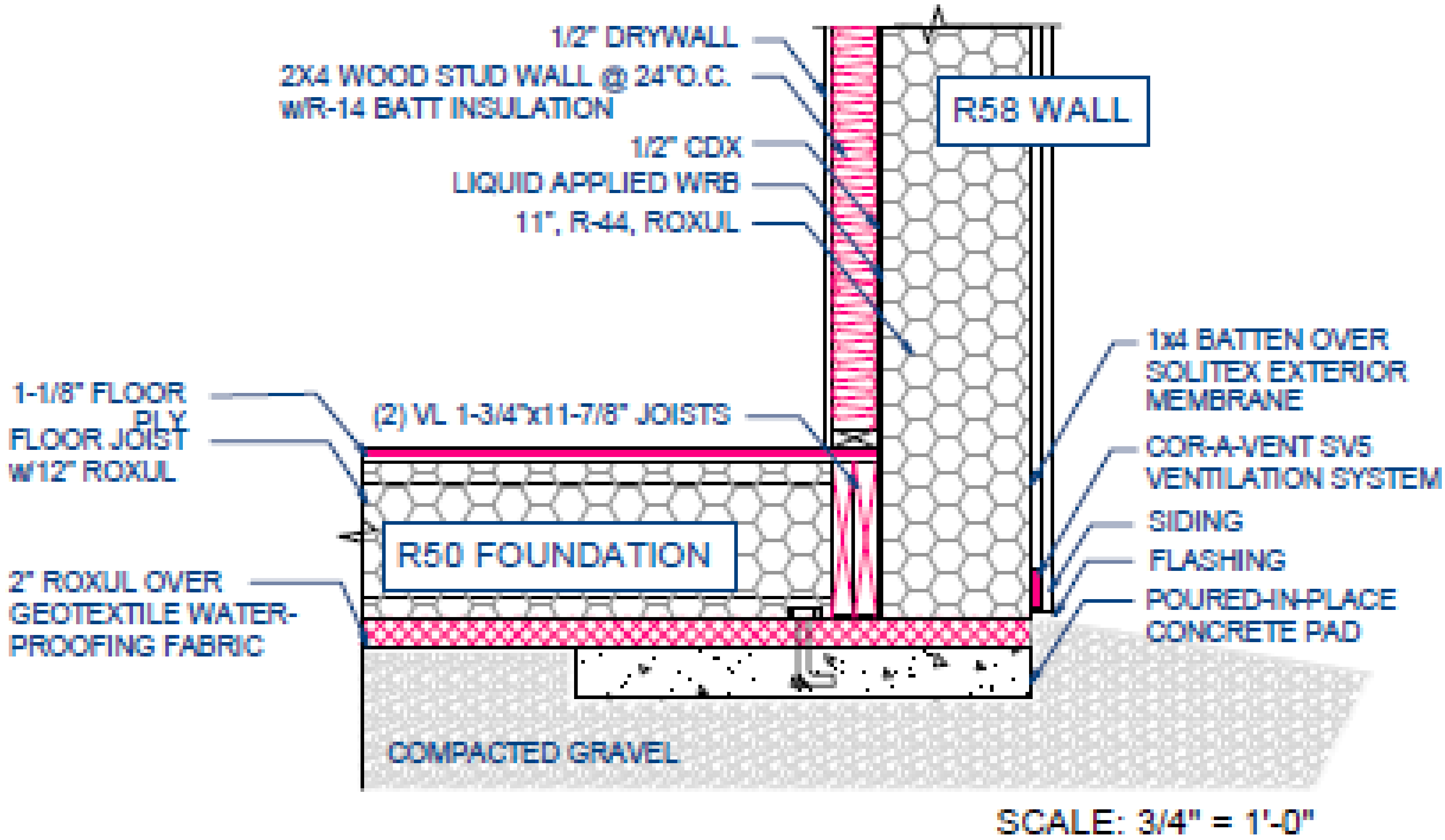
1" EXPANDED POLYSTYRENE (EPS)

3/8" AIR GAP BETWEEN PT STRAPPING

3/4" FIBER CEMENT SIDING



Residential Wall 4 – REMOTE-MW



ARCTIC WALL

LATEX PAINT

5/8" INTERIOR GWB

2x4 UTILITY CHASE WALL

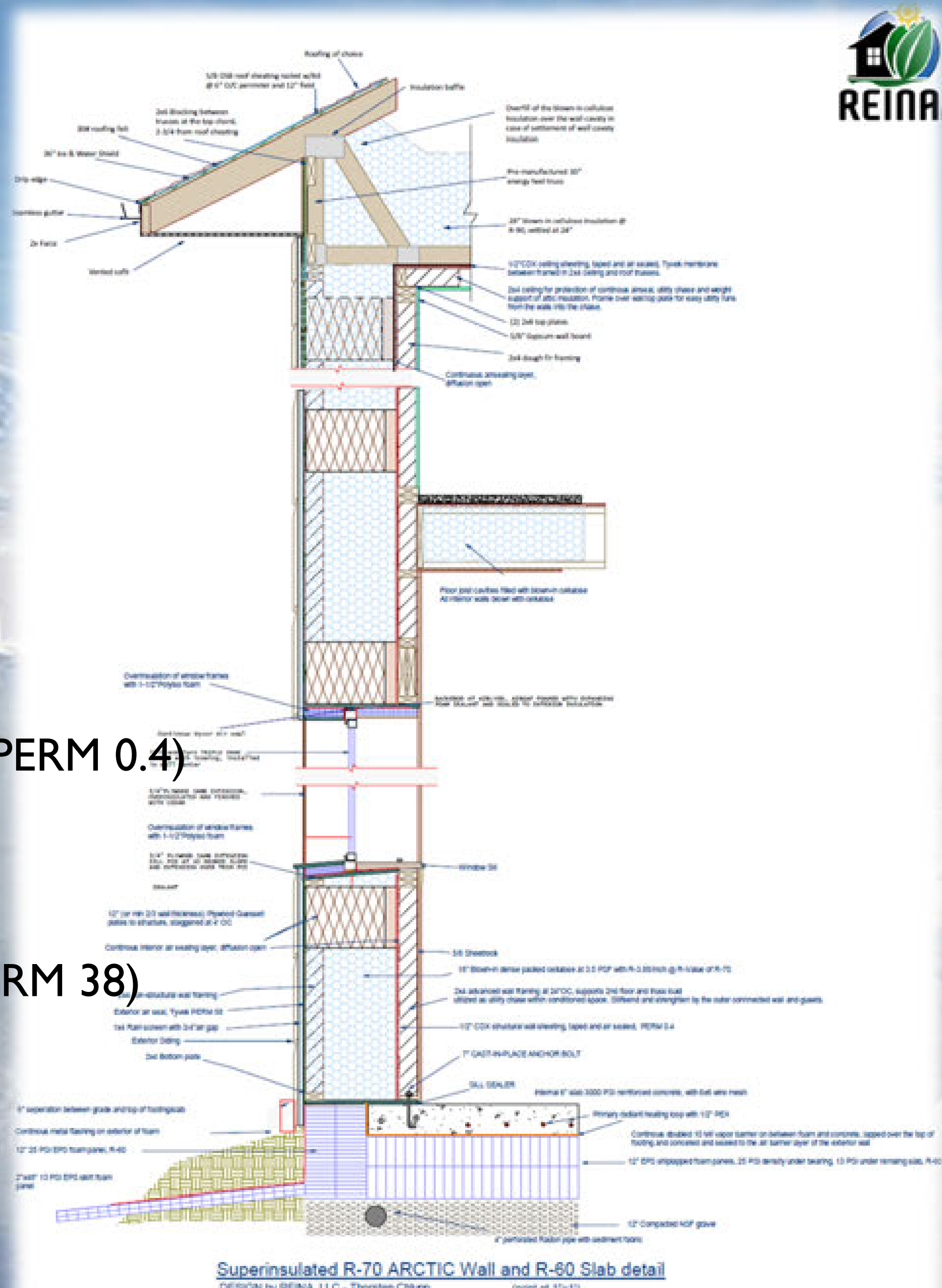
1/2" CDX STRUCTURAL SHEATHING (PERM 0.4)

18" CELLULOSE @ 3.5 lb/ft3

SOLITEX MENTO PLUS MEMBRANE (PERM 38)

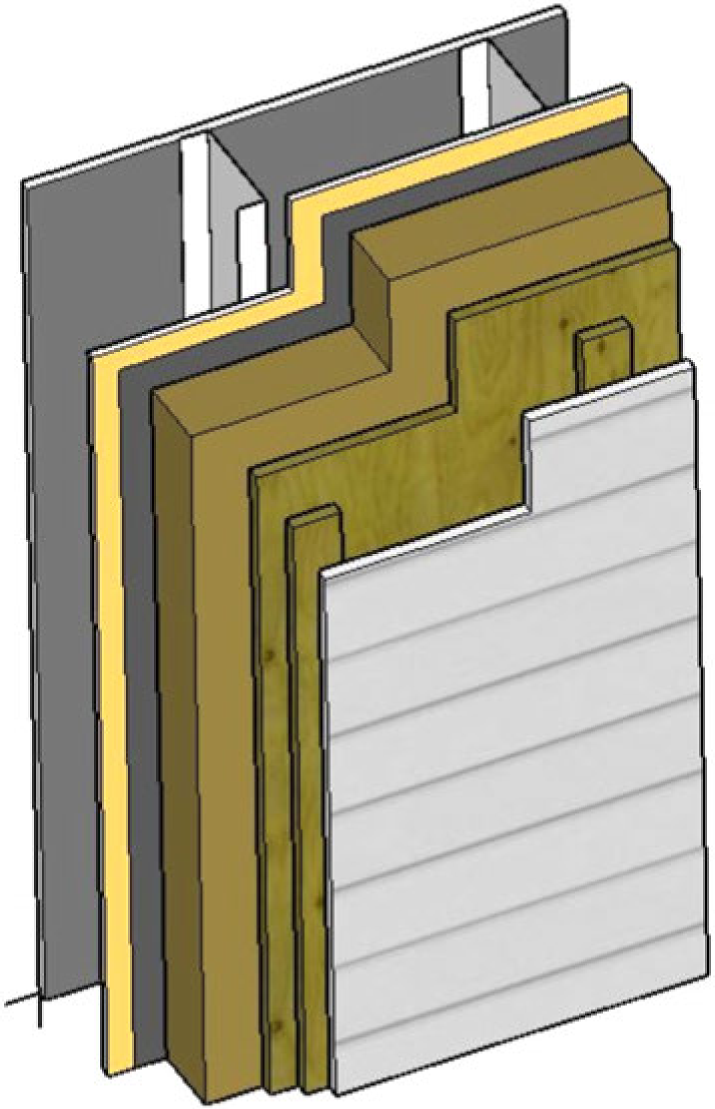
1x4 STRAPPING w/ ¾" AIR GAP

3/4" FIBER CEMENT SIDING



* Slide courtesy Thorsten Chlupp

Commercial Wall 1 – Ext MW



LATEX PAINT

5/8" INTERIOR GWB

6" STILL AIR LAYER BETWEEN METAL STUDS

5/8" EXTERIOR GYPSUM SHEATHING

VAPOR/AIR CONTROL LAYER (CLASS II min)

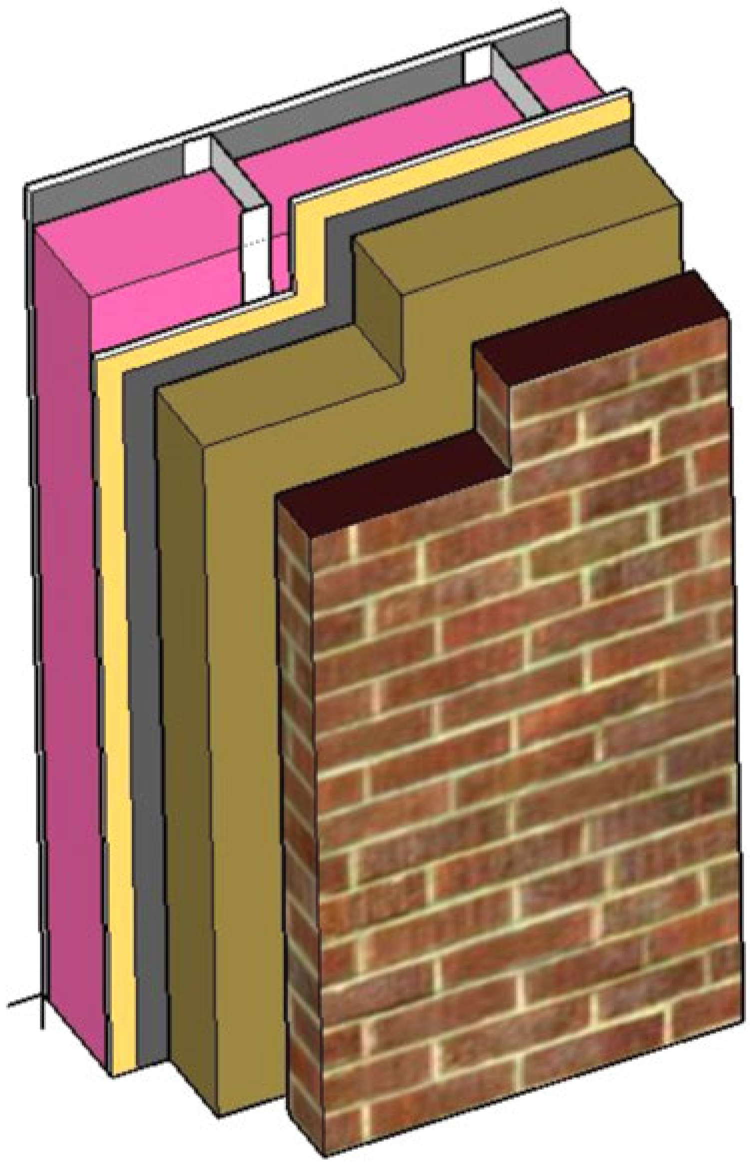
4" MINERAL WOOL

3/4" EXTERIOR PLYWOOD

1" AIR GAP BETWEEN PT STRAPPING

3/4" FIBER CEMENT SIDING

Com Wall 2 – Ext MW Brick



LATEX PAINT

5/8” INTERIOR GWB

6” FG BATTS BETWEEN METAL STUDS

5/8” EXTERIOR GYPSUM SHEATHING

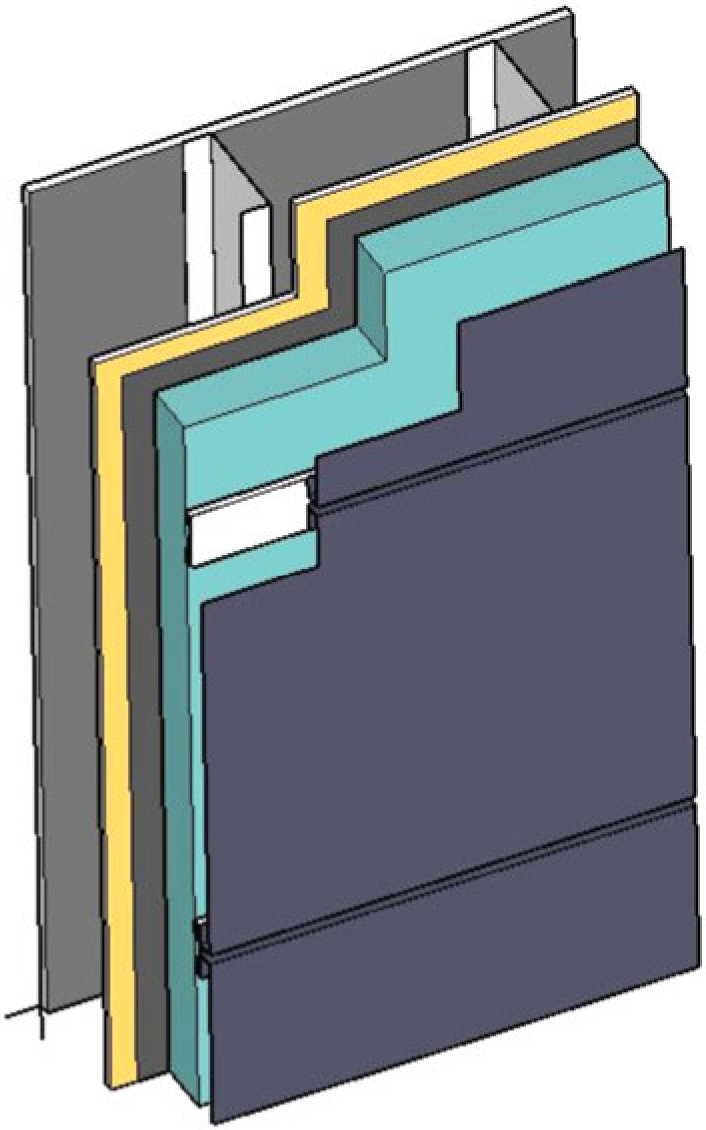
VAPOR/AIR CONTROL LAYER (CLASS II min)

5” MINERAL WOOL

1 3/8” AIR GAP

BRICK VENEER

Commercial Wall 3 – Ext XPS



LATEX PAINT

5/8" INTERIOR GWB

6" STILL AIR LAYER BETWEEN METAL STUDS

5/8" EXTERIOR GYPSUM SHEATHING

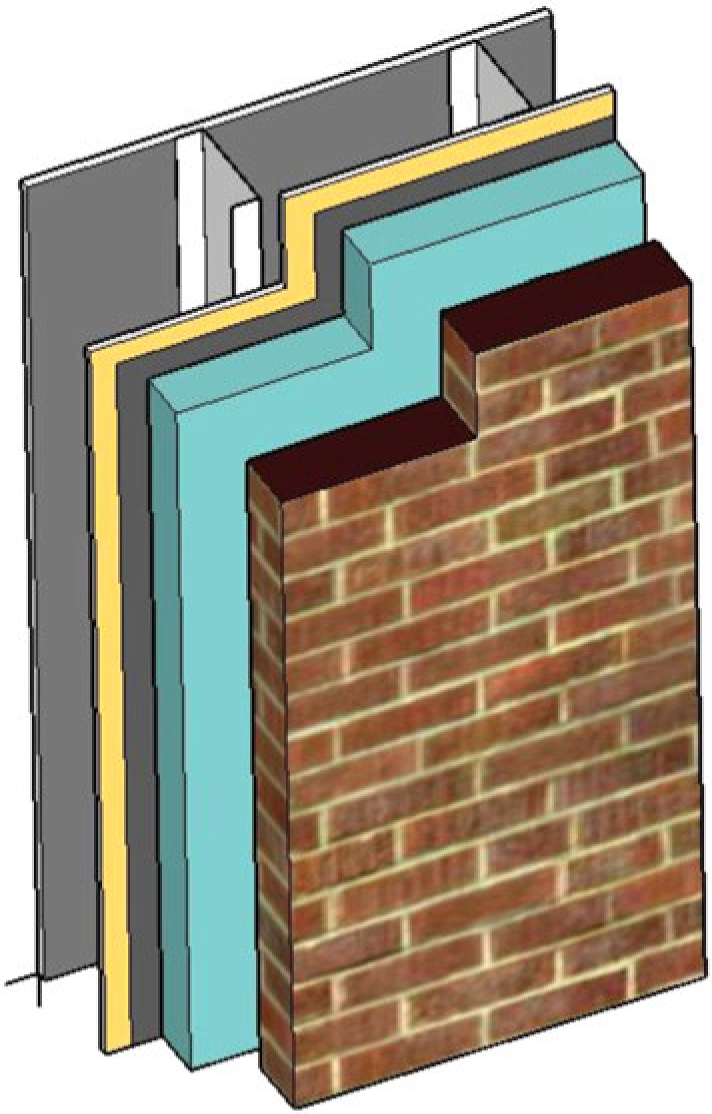
VAPOR/AIR CONTROL LAYER (CLASS II min)

3" EXTRUDED POLYSTYRENE (XPS)

1" AIR GAP BETWEEN VENTED MTL STRAPPING

METAL PANEL

Com Wall 4 – Ext XPS Brick



LATEX PAINT

5/8" INTERIOR GWB

6" STILL AIR BETWEEN METAL STUDS

5/8" EXTERIOR GYPSUM SHEATHING

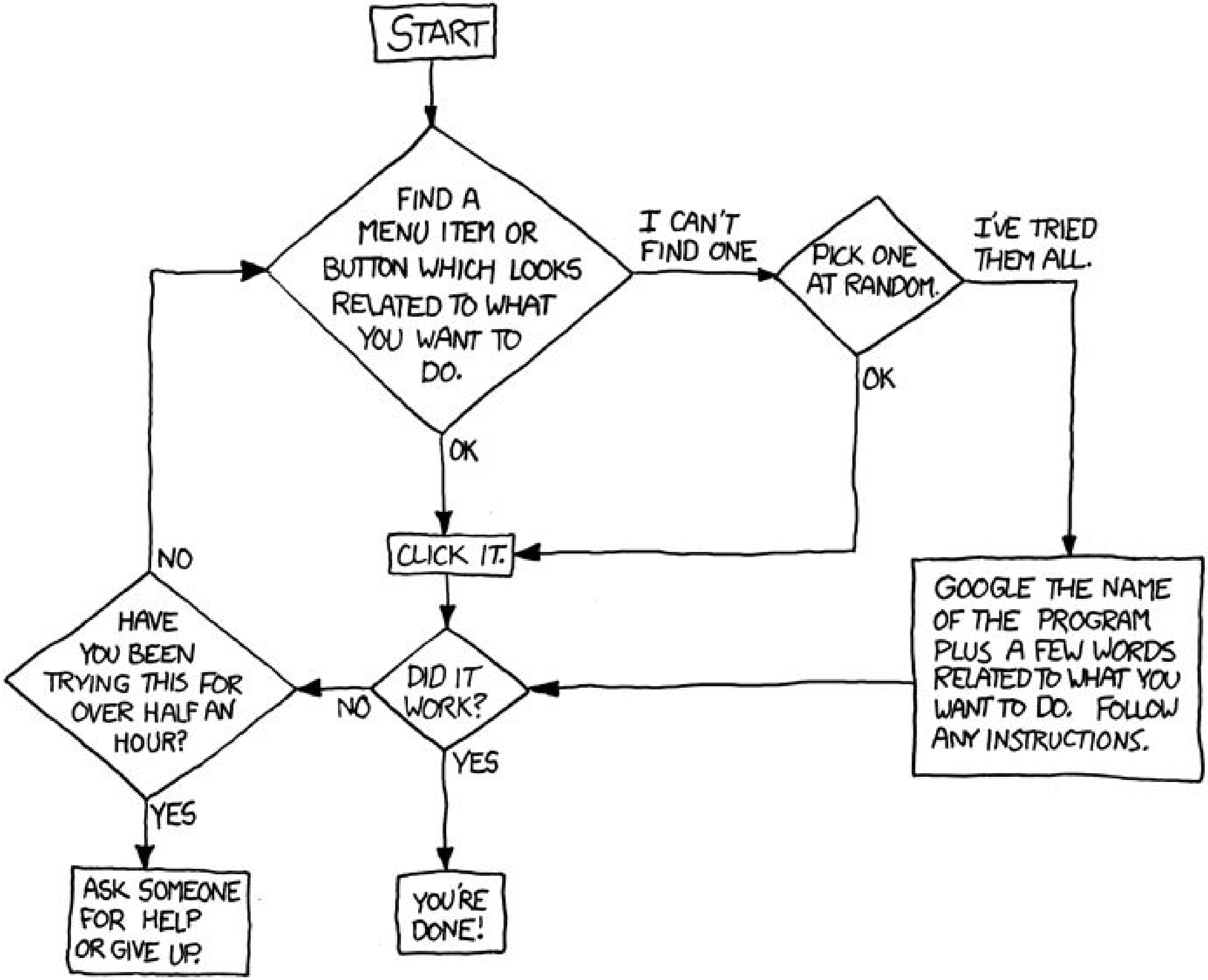
VAPOR/AIR CONTROL LAYER (CLASS II min)

3" EXTRUDED POLYSTYRENE (XPS)

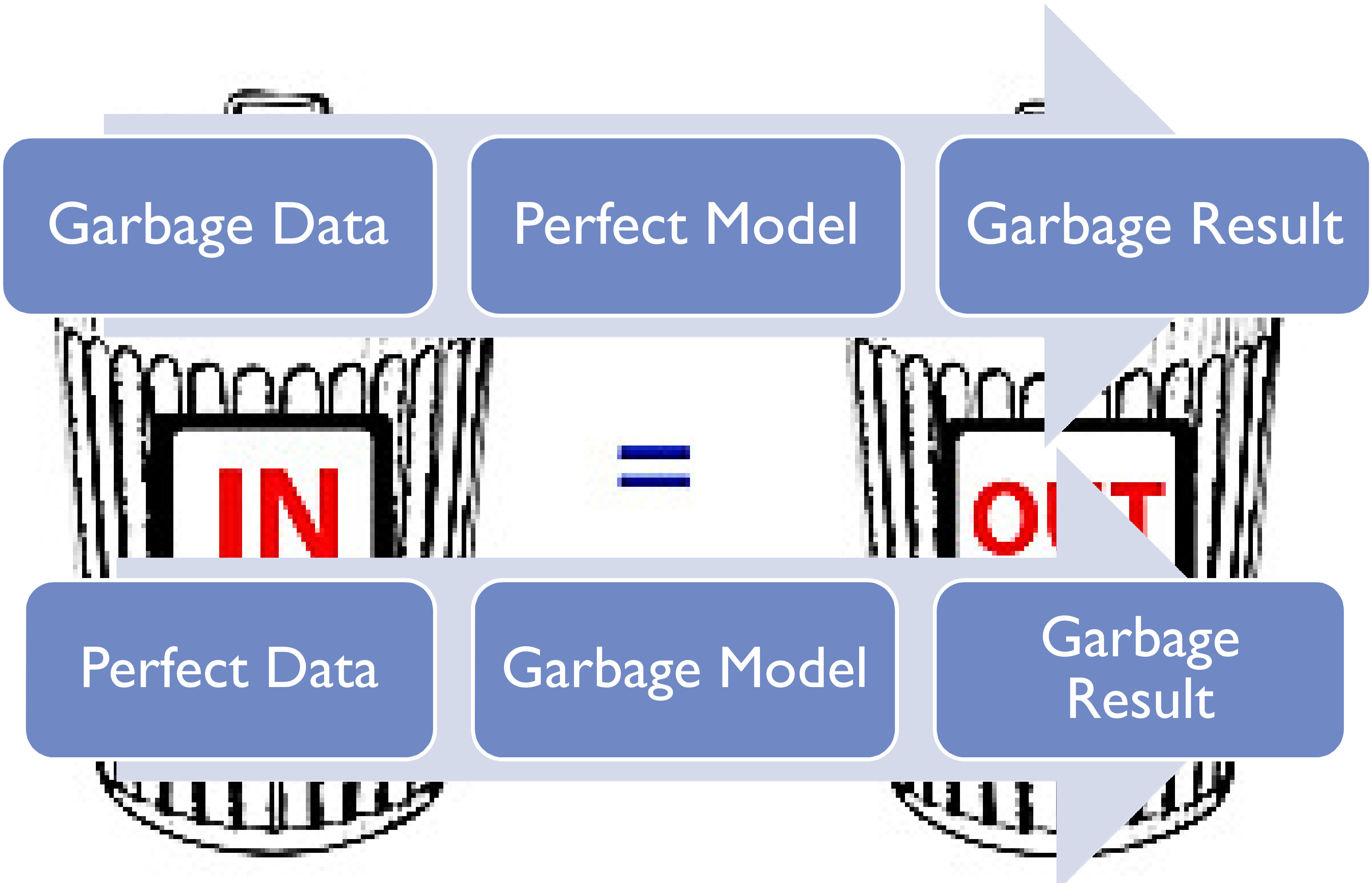
1 3/8" AIR GAP

BRICK VENEER

Create the Models!!



GIGO Paradigm



WUFI Weather Data

- Older WUFI ORNL data based on 10 percentile hot and cold year. Originally thought to be good way to calc hygrothermal effects – still must be used for 160P calcs until its updated.

- New data thanks to ASHRAE project 1325 (includes rain data). Year 1, Year 2 and Year 3 worst out of 30 years 1969-1990 for 100 locations

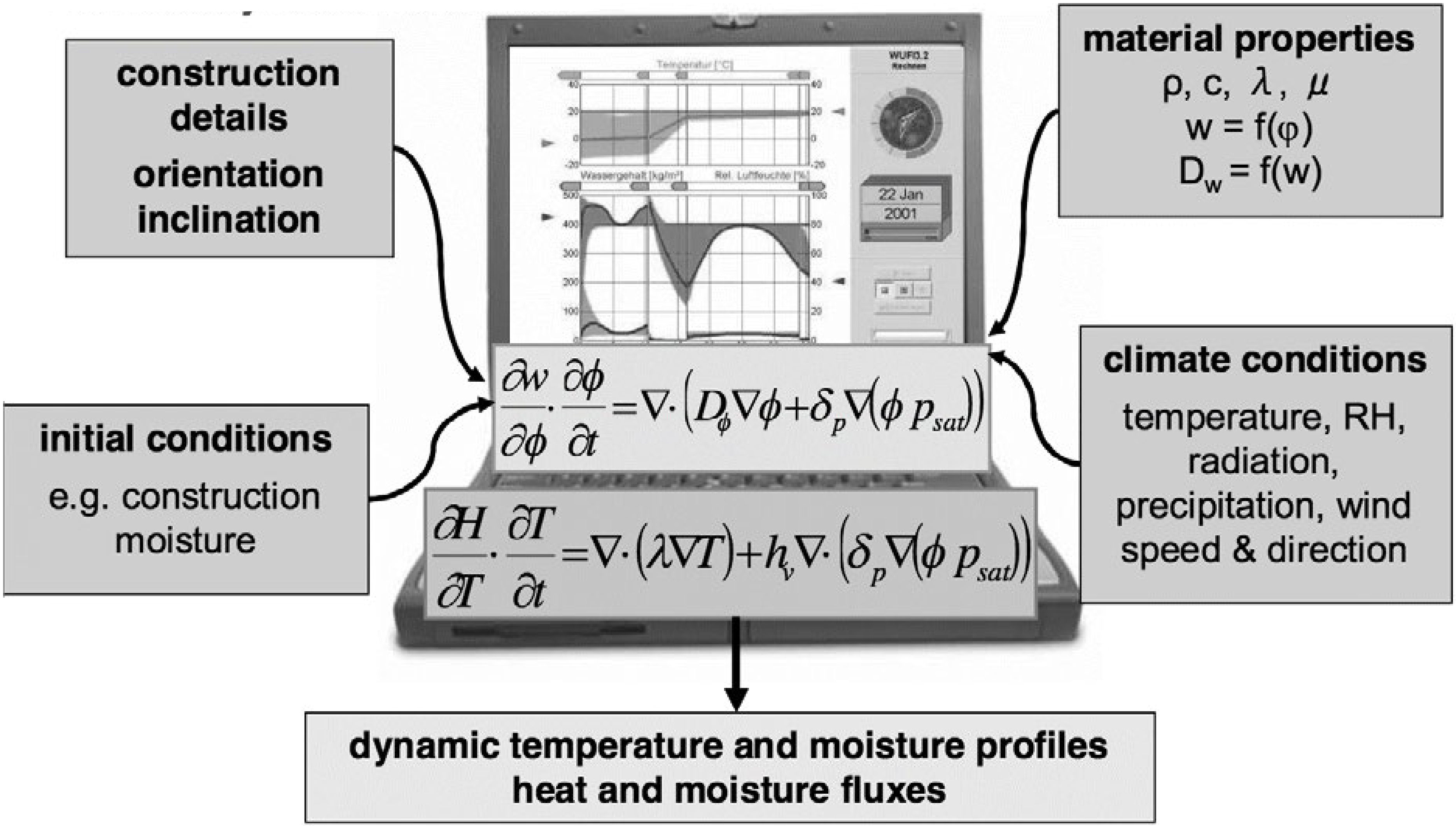
- Can also get a wac file for your location (Meteonorm)

ASHRAE 160P Purpose

Specify performance-based design criteria for predicting, mitigating or reducing moisture damage to building envelope, materials, components, systems and furnishings, depending on climate, construction type and HVAC operation. Criteria include:

1. Criteria for selecting analytic procedures
2. Criteria for inputs
3. Criteria for evaluation and use of outputs

Crunch the Numbers...



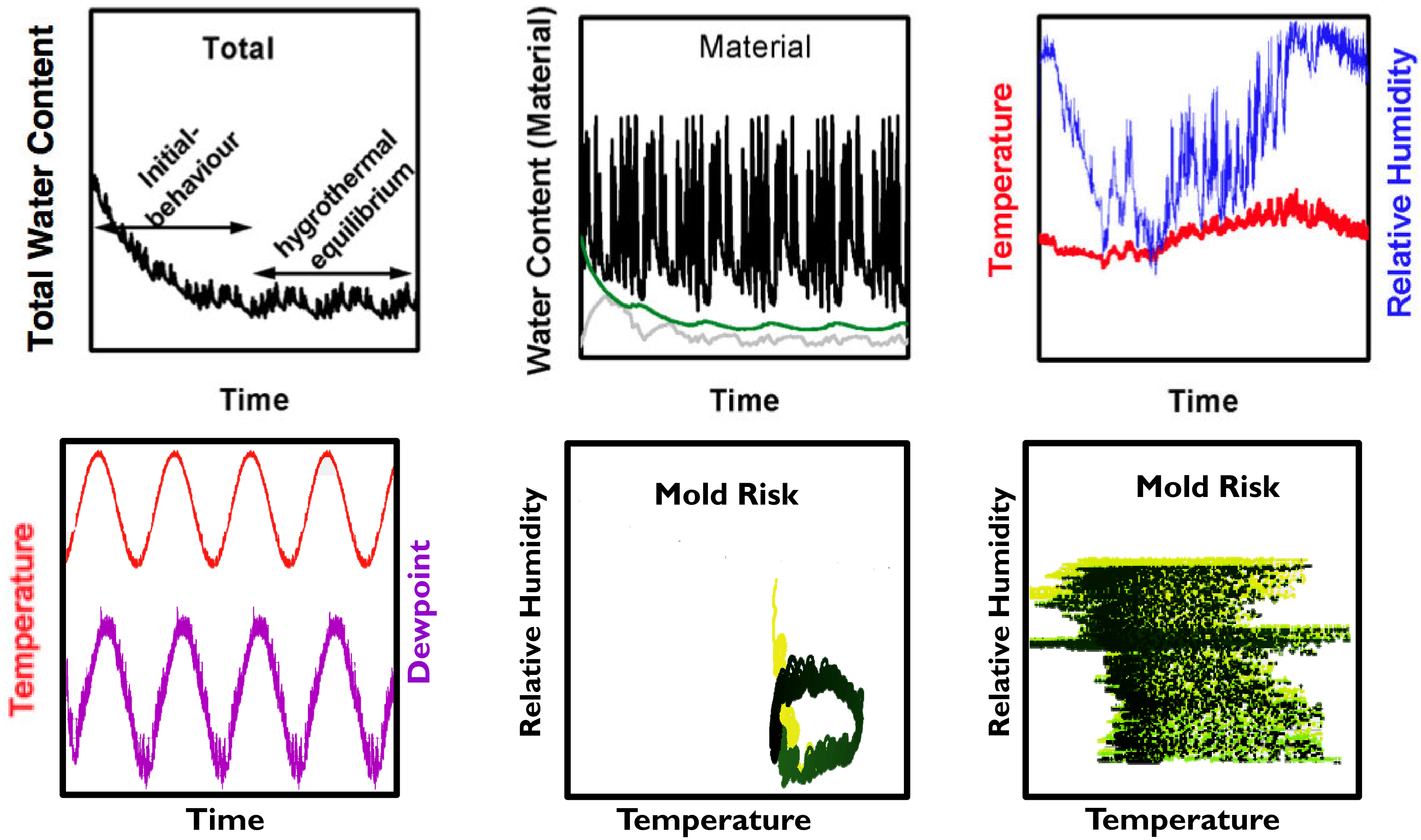
5x ASHRAE YR3 Burlington and ...

~~Woofie~~

Results

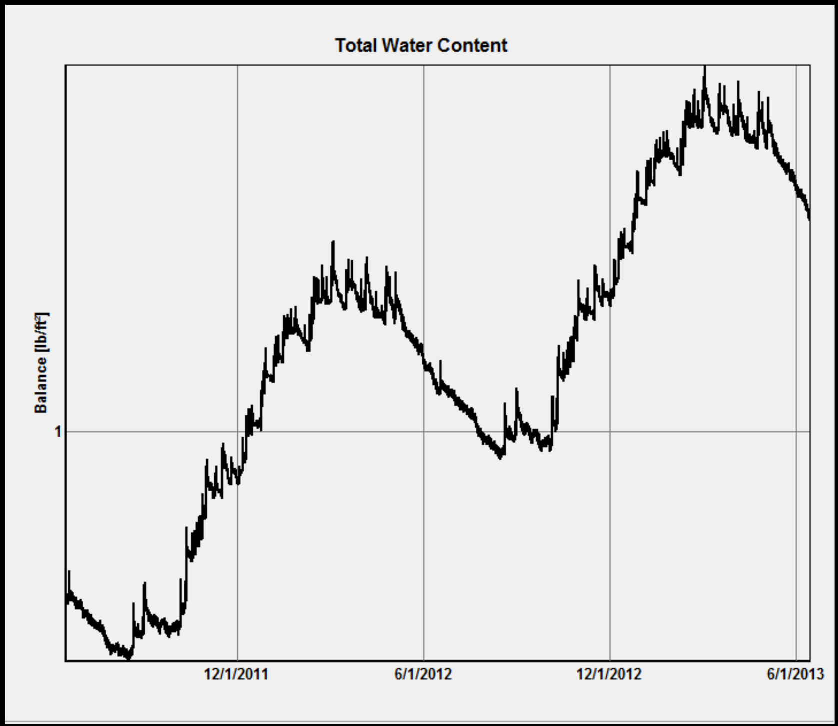
WUFI Results

WUFI Results Data

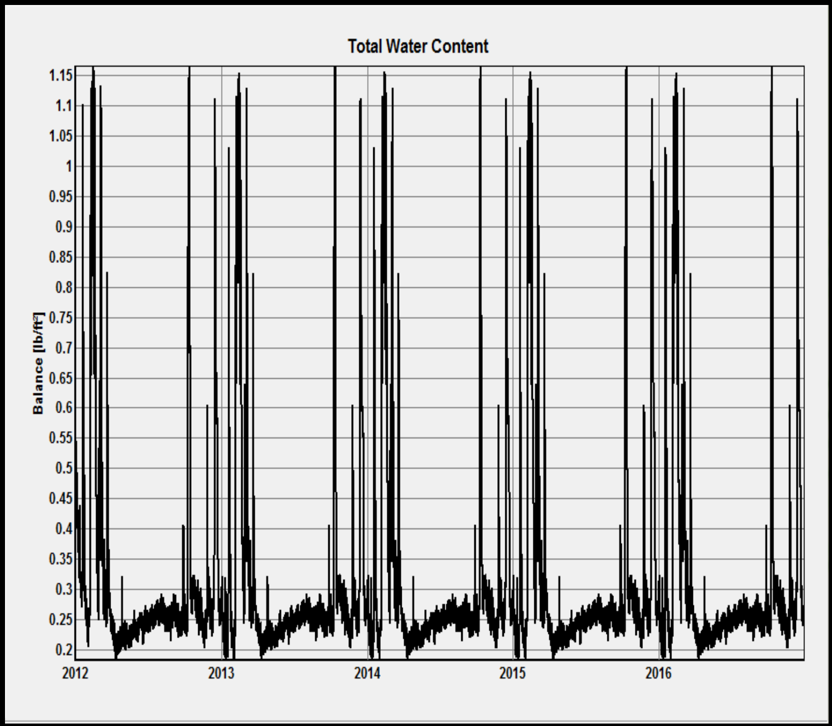


Total Water Content

BAD NEWS



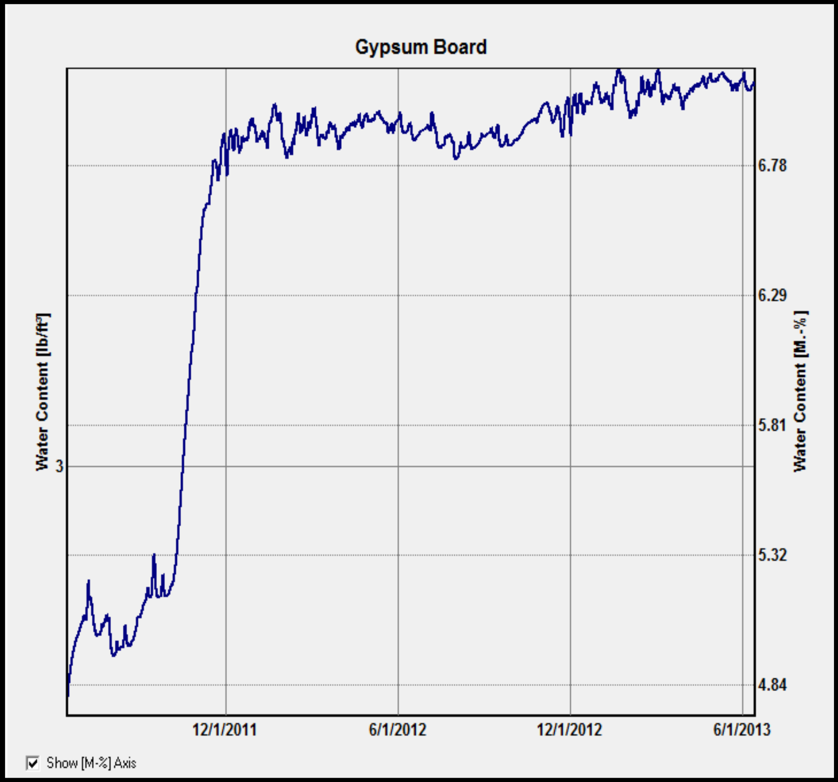
BETTER



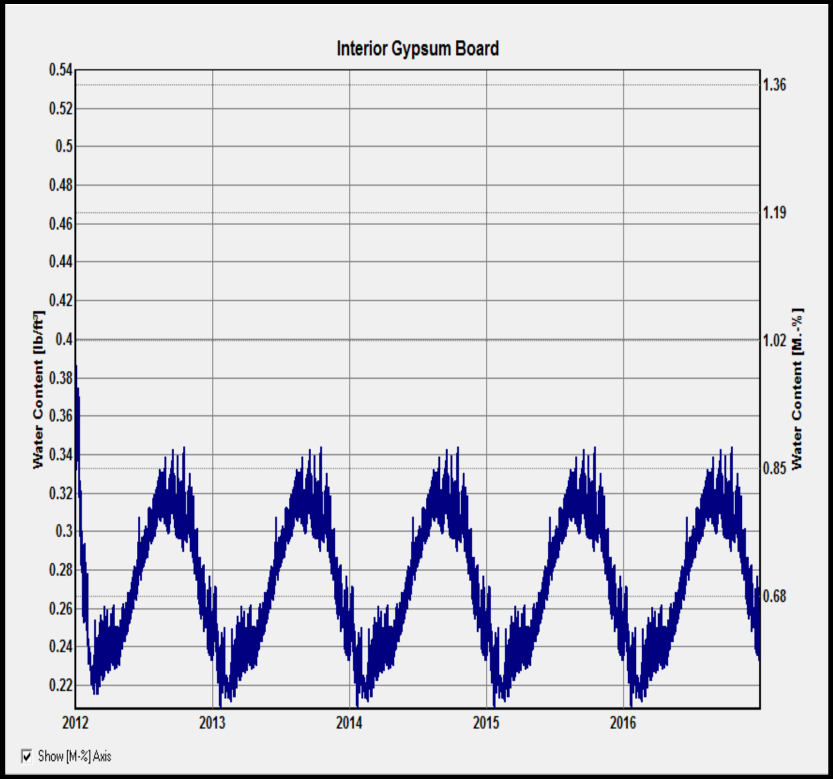
Total H2O content should show a regular pattern of seasonal fluctuation and should not increase over time

Water Content by Layer

BAD NEWS



BETTER



H2O content per construction layer should initially decrease and thereafter establish a regular pattern of seasonal fluctuation

Results Analysis Thresholds

Caution!

- Be careful when looking at moisture content graphs vs. RH graphs!

- It makes a difference whether material is hygroscopic or hydrophobic in considering whether to regard water content or RH results as realistic indicators

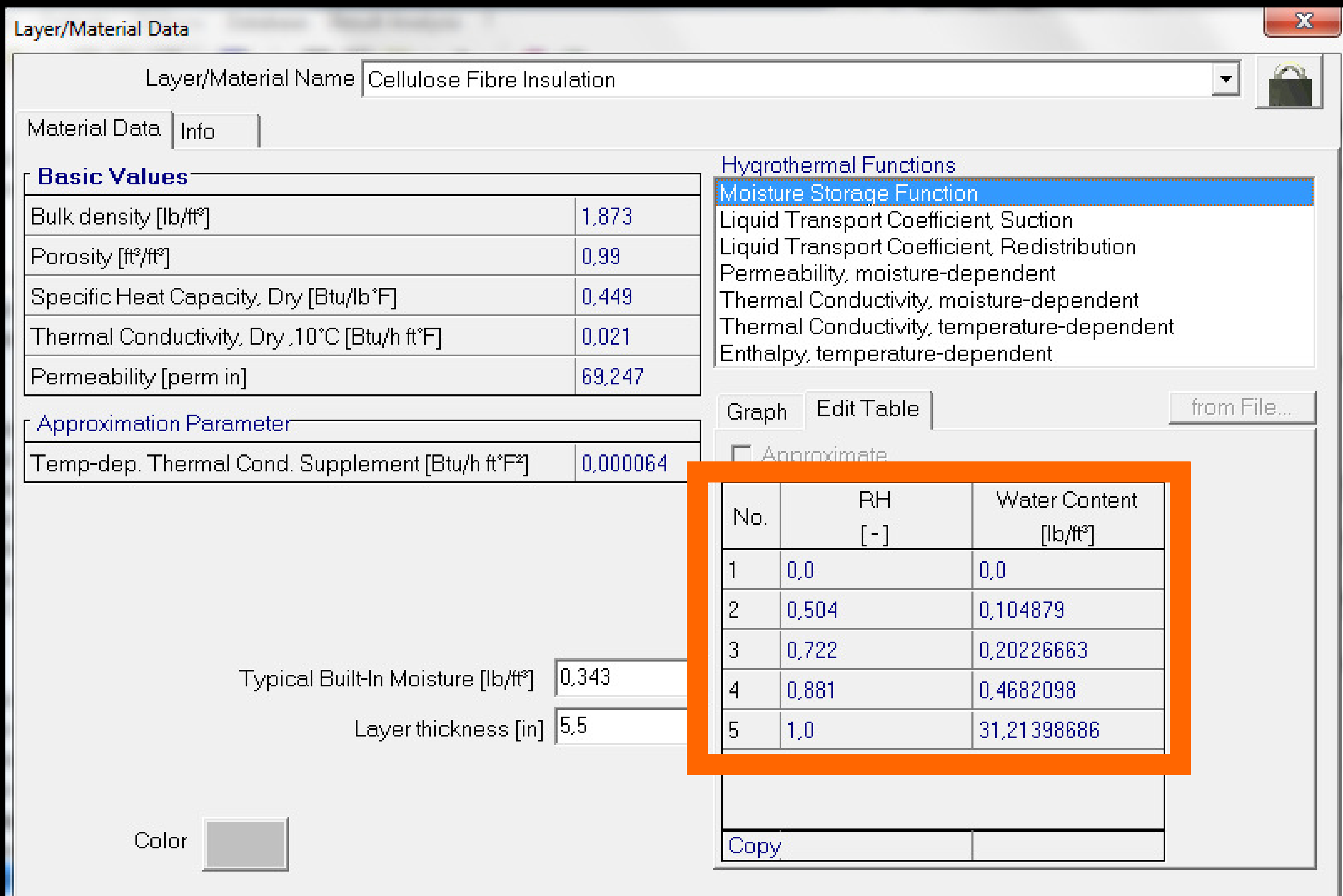
Spray Foam vs Fiberglass Water Content

- CCSF may have closed cells which greatly reduces vapor diffusion through the foam, but the polyurethane material making up the walls between the cells is not completely impermeable to vapor diffusion

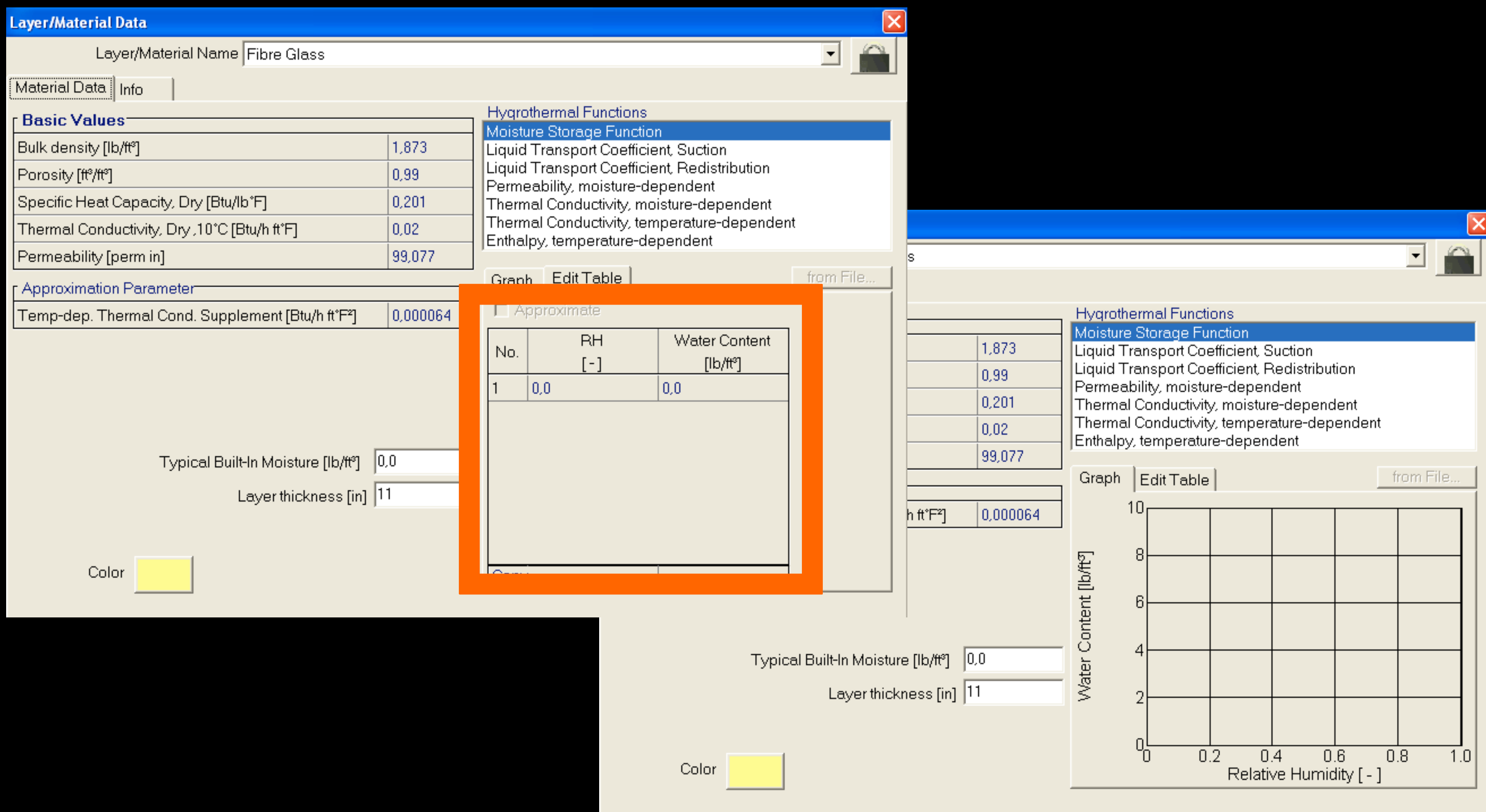
- The material database lists a mu-value of 89 for this foam, so you will have some moisture intruding into and through the foam layer by means of vapor diffusion.

- In fiberglass, by contrast, the cells are closed and the glass walls between the cells are practically completely vapor-tight. That's why no water content is to be expected in the cellular glass under any circumstances. Water content results from WUFI should be disregarded. Look at RH!

WUFI Material Properties



Moisture Storage Function for Hydrophobic Materials

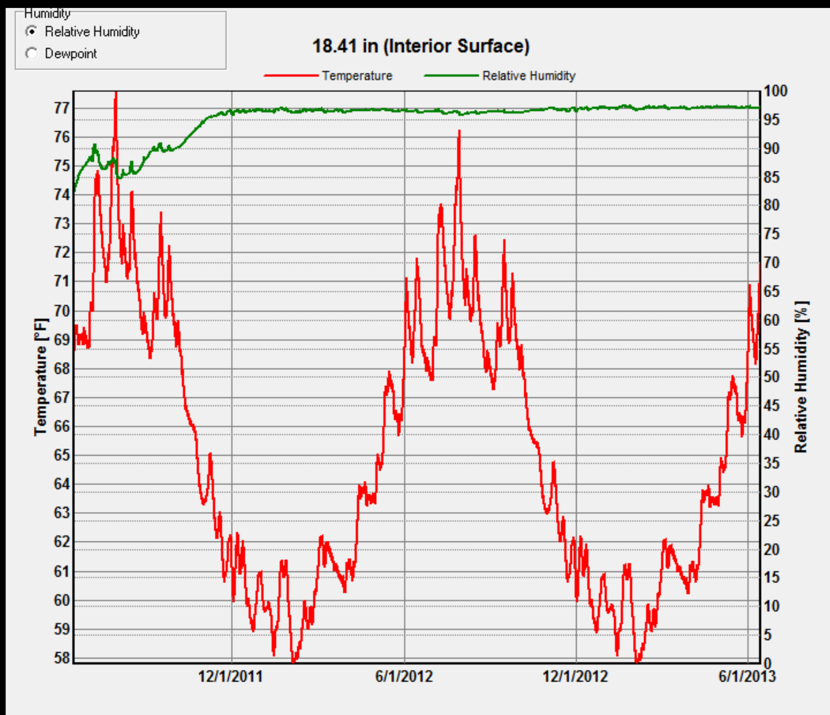


WUFI Sim Limitations

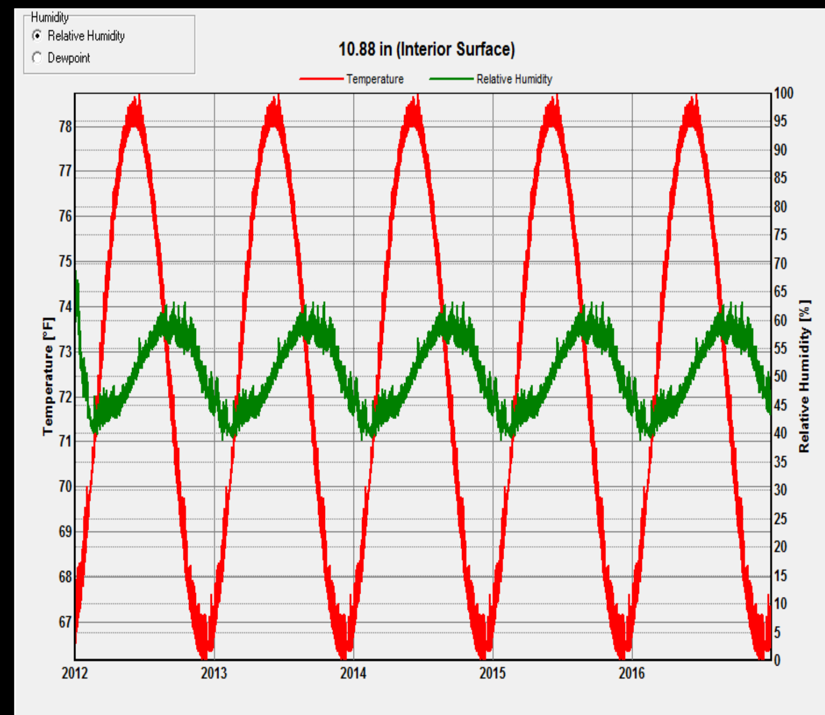
- Disregarded phenomena
  - Natural + Forced Convection
  - Stack Effect
  - Air Infiltration (user defines air-related moisture)
- Temperature-dependency of moisture storage function (all material properties measured at 75F per ASHRAE 1019)
- Property changes due to contamination (ie salt)
- Mold isopleth for interstitial surfaces doesn't take into account "reset" conditions that some species go through, nor lack of oxygen

Relative Humidity

BAD NEWS



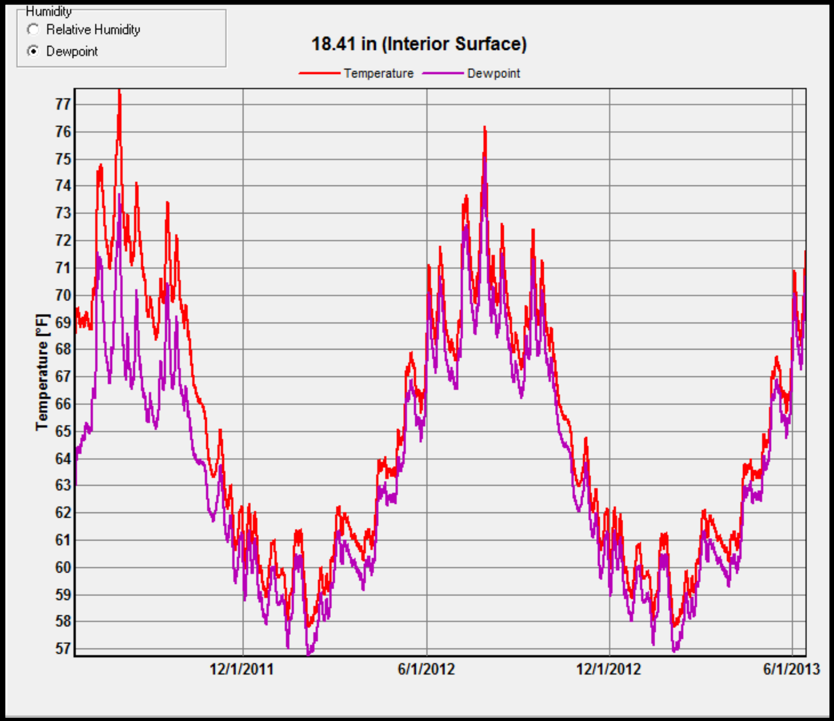
BETTER



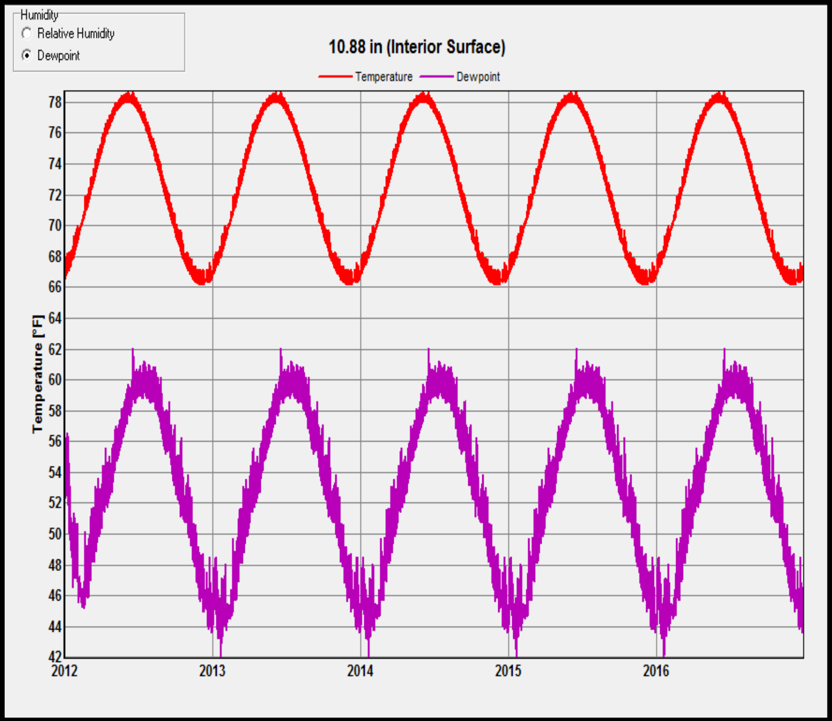
RH should also initially decrease and thereafter establish a regular pattern of seasonal fluctuation

Dewpoint

BAD NEWS



BETTER



Dewpoint should be well below temperature and show a regular pattern of seasonal fluctuation

Specific Risk Thresholds

Condensation

Mold

Wood Rot

Corrosion

Condensation Risk?

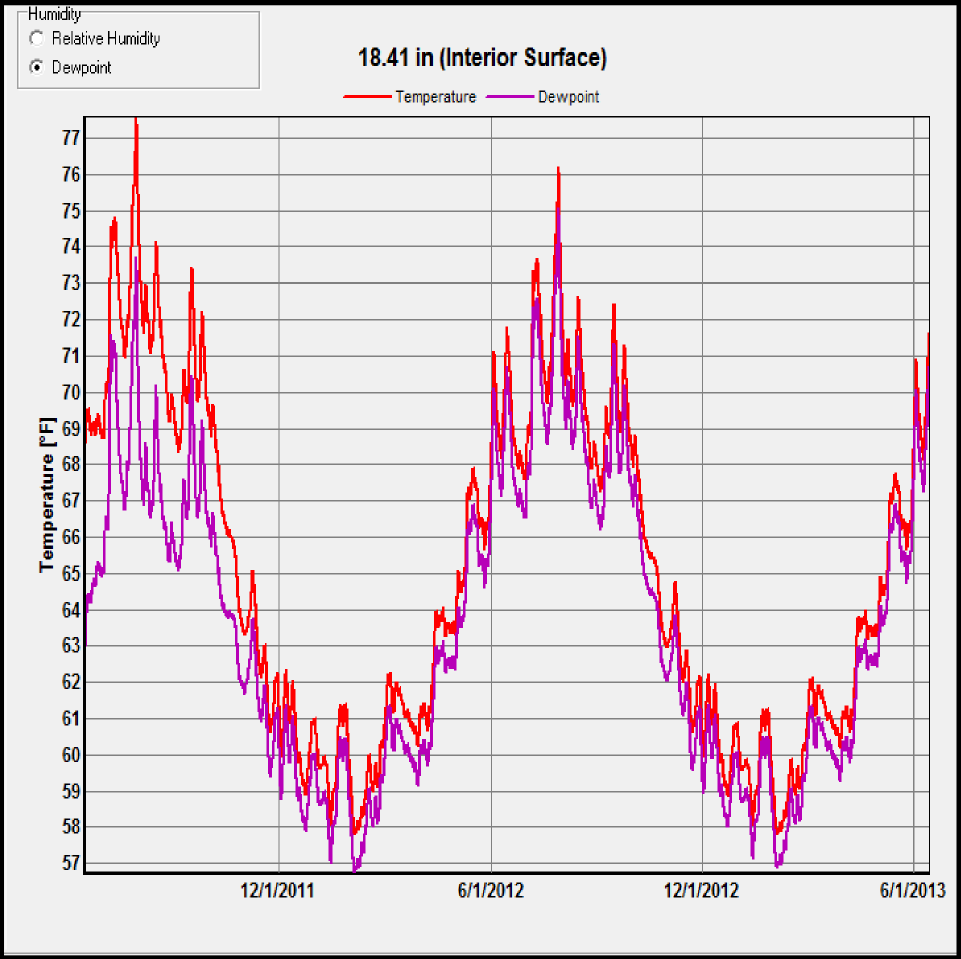
Does dewpoint occur in the assembly? If so in which construction layer?

Condensation will occur concurrent with dewpoint in porous materials. Condensation will occur on first surface outboard of dewpoint for non-porous materials

Are moisture sensitive materials exposed to condensation over an extended period, or cyclically?

Do materials in question have suitable moisture storage capacity or will material performance degrade?

Condensation Risk?



- Dewpoint is uncomfortably close to temperature.
- Condensation will likely occur in this porous layer
- Paper backing on gypsum drywall is vulnerable to moisture damage
- Paper backing has little moisture storage capacity
- Goal: Increase temperature by further insulating the assembly

Specific Risk Thresholds: Mold

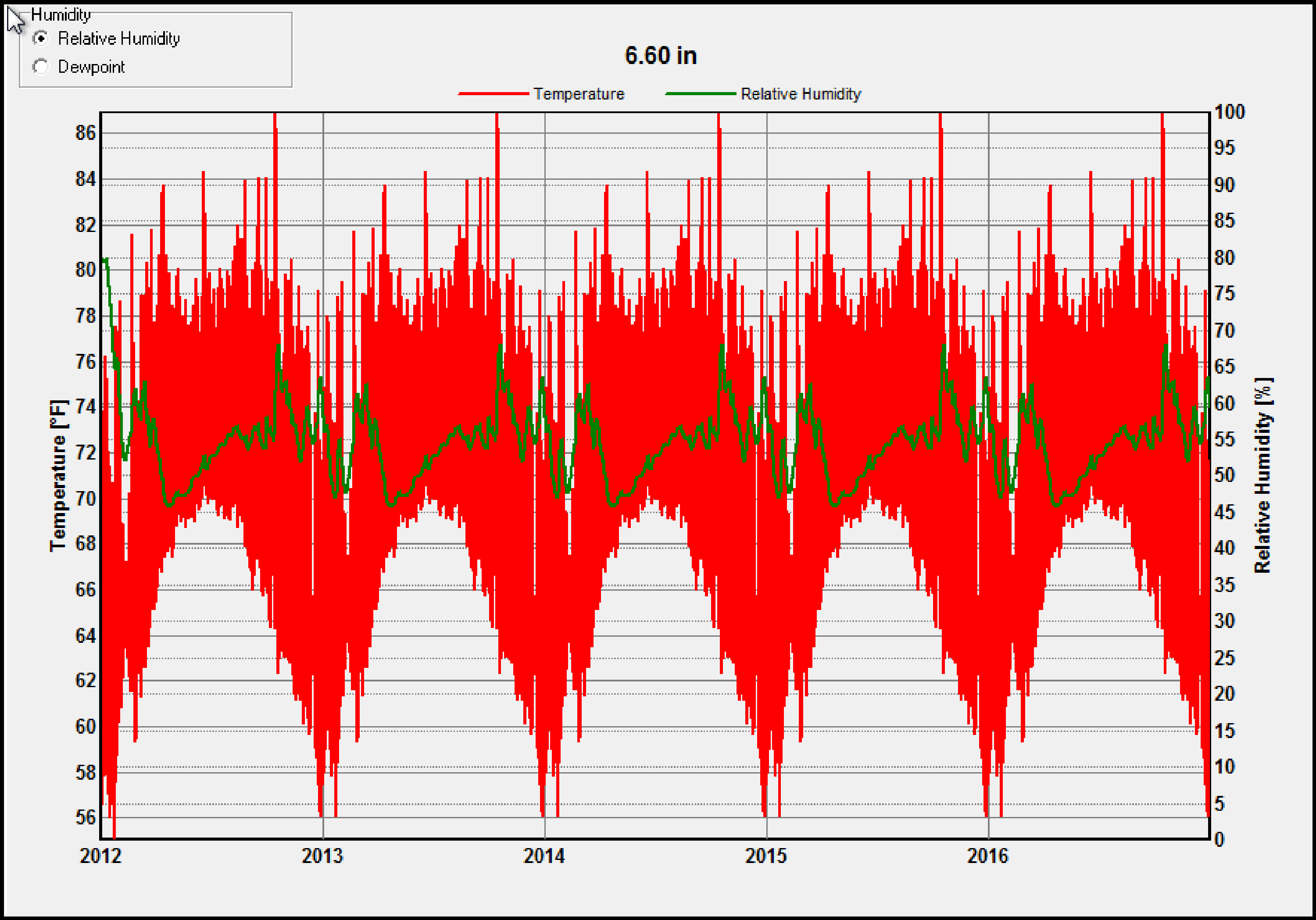
Spore presence MUST be assumed! But to germinate, fungi need the following conditions:

Nutrients: wood, paper, glues, paints, dust, dirt, soap

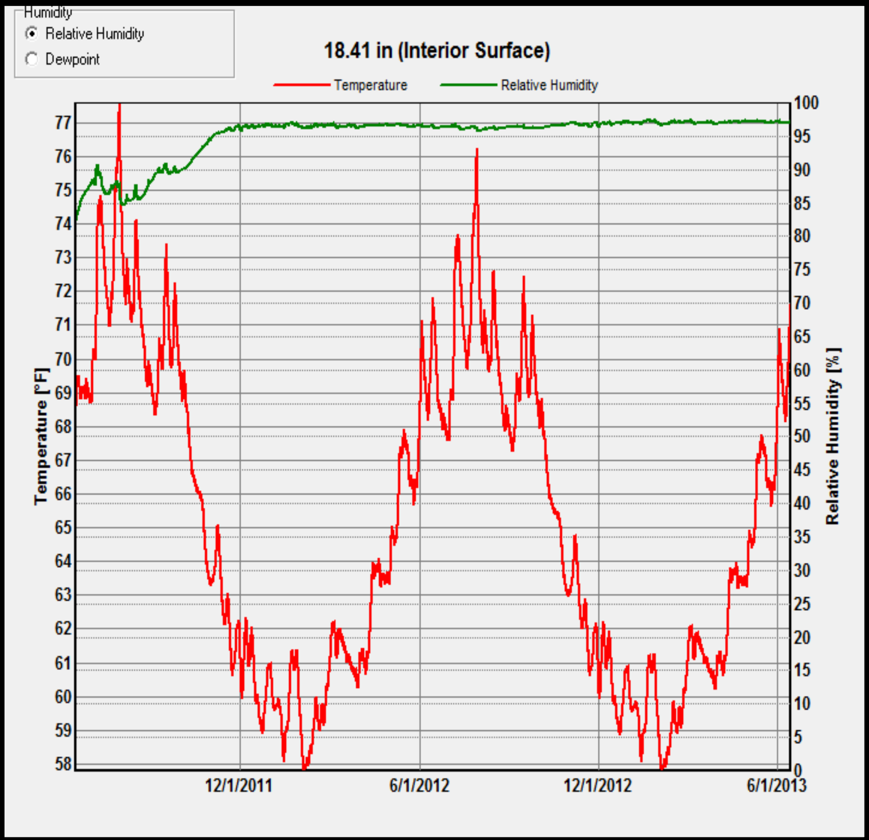
Favorable Temperature: 68°F -95°F is ideal, outside of 41°F-122°F growth stops

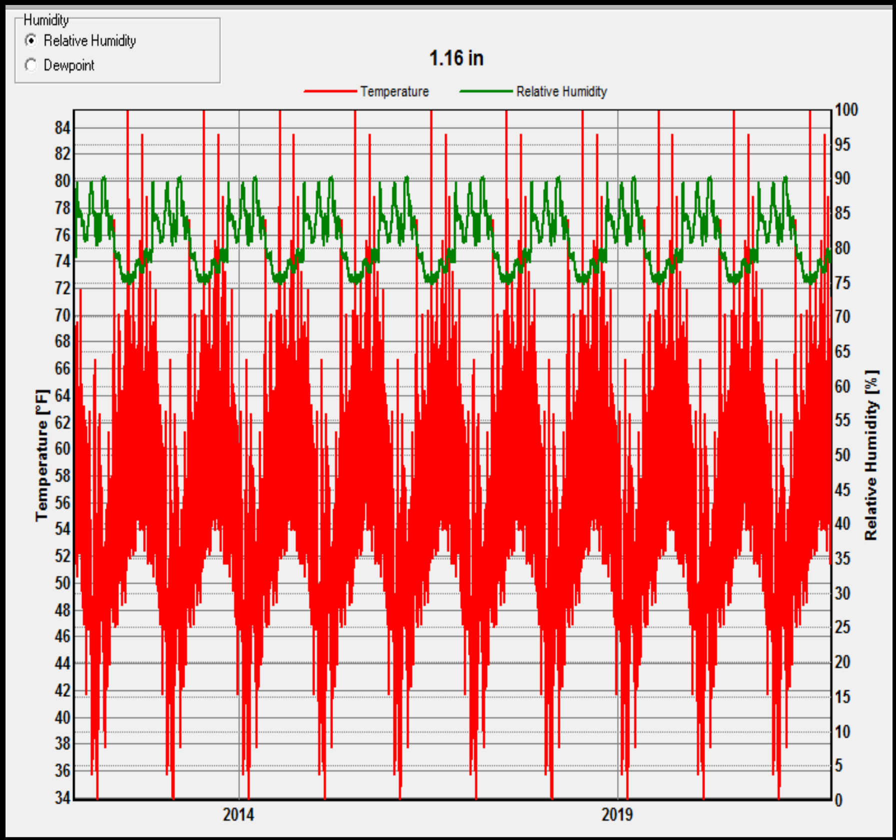
Moisture: Surface RH of 75-80%. Above 90-95% RH lack of oxygen stops fungal growth

Mold Risk?


Humidity
Relative Humidity
Dewpoint
6.60 in
Temperature
Relative Humidity
Temperature [°F]
Relative Humidity [%]
86
84
82
80
78
76
74
72
70
68
66
64
62
60
58
56
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
2012
2013
2014
2015
2016

Mold Risk Examples



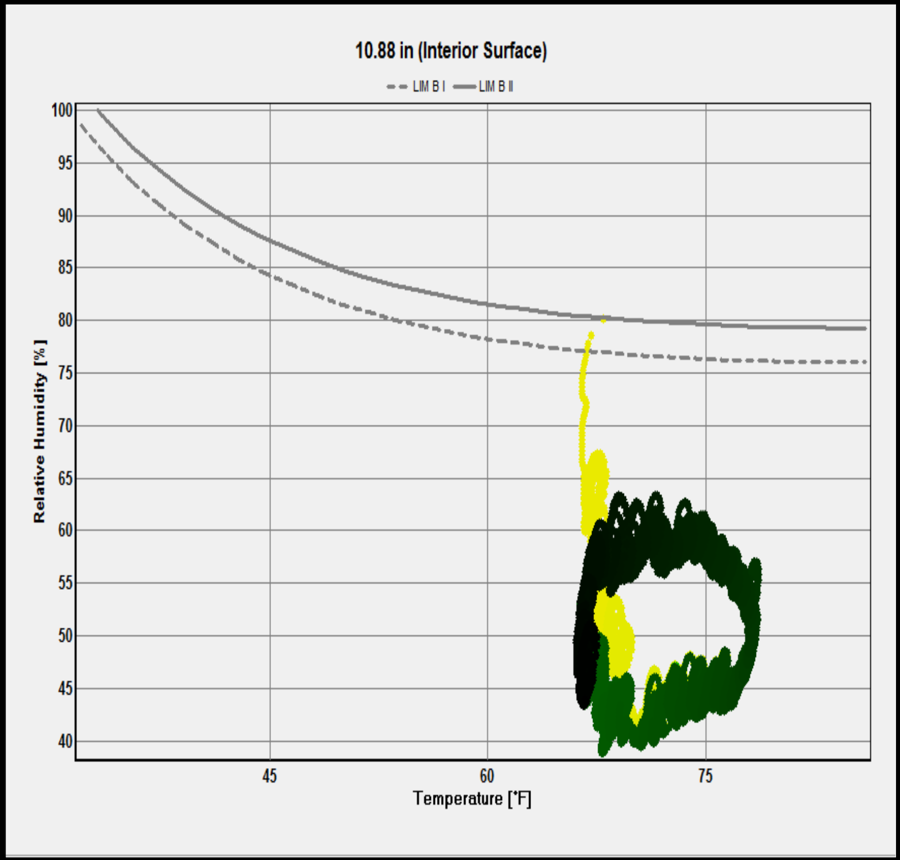


RH% is too high for mold to grow, but wood rot can still happen here

RH% is in the ideal range for mold to grow, and the right temperatures occur as well

**Check out IEA Annex 55 use Hannu Viitanen Mold growth model for more accurate assessment*

Mold Isopleth Distribution



Each point is a time-step (1 hr)

Changing colors represent passage of time

- Start of Calculation = Yellow
- Middle of Calculation = Green
- End of Calculation = Black

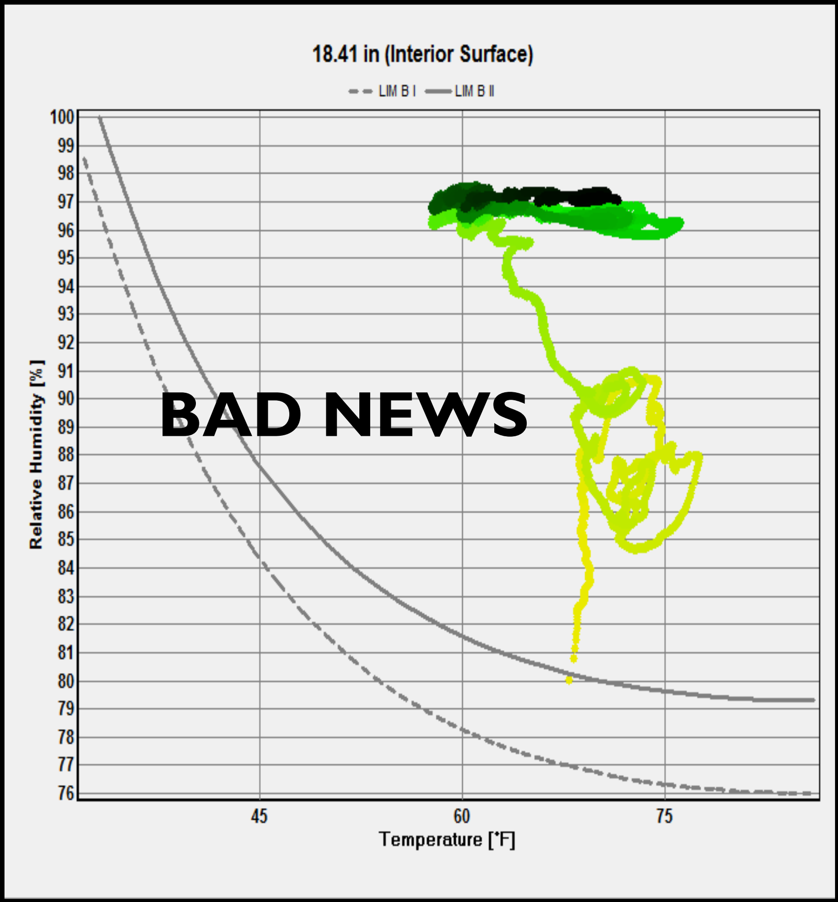
The dotted line is mold risk for cellulosic substrates

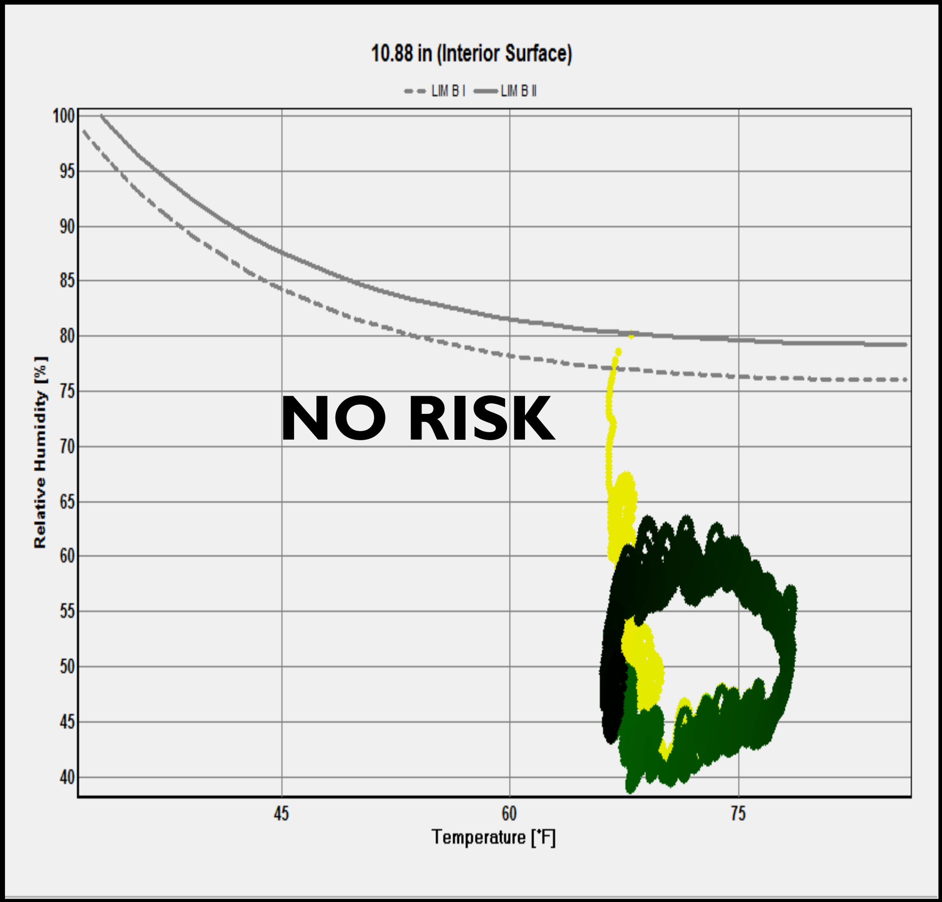
The solid line is mold risk for mineral substrates

Time steps below the lines represent no mold risk

Time steps between or above the lines represent high likelihood for mold

Mold Isopleth Distribution





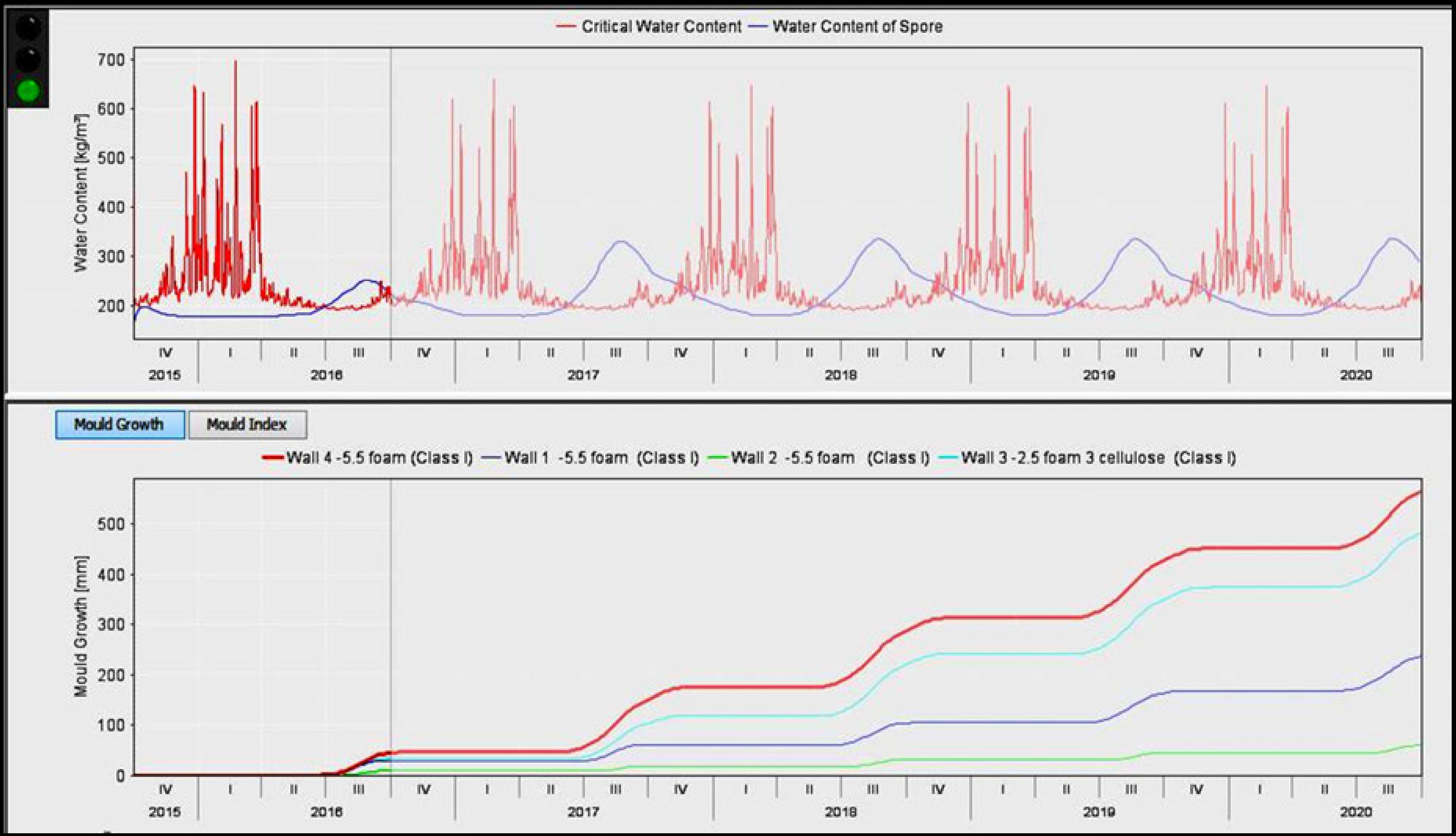
Scatter graph points should stay below curved mold risk lines

WUFI BIO Post-Proc

- Klaus Sedebauer's Thesis
- Mold Growth in mm or Mold Index
- Models hygrothermal behavior of a mold spore which consists of envelope and living material inside
- Envelope is like a membrane, when humid membrane opens and it can live and germinate, when dry membrane is closed to keep moisture inside
- When critical water content is reached, germination is complete
- Other models just say when a specific RH and temp are reached then there is risk, this goes further to model hygrothermal behavior or spore and ascertain where germination (growth occurs)

**Use IEA Annex 55 use Hannu Viitanen Mold growth model for more accurate assessment*

WUFI BIO Post-Proc

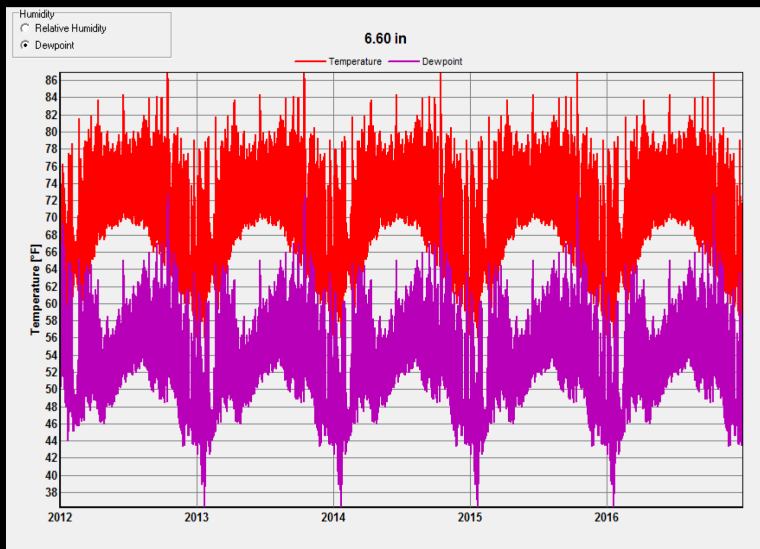


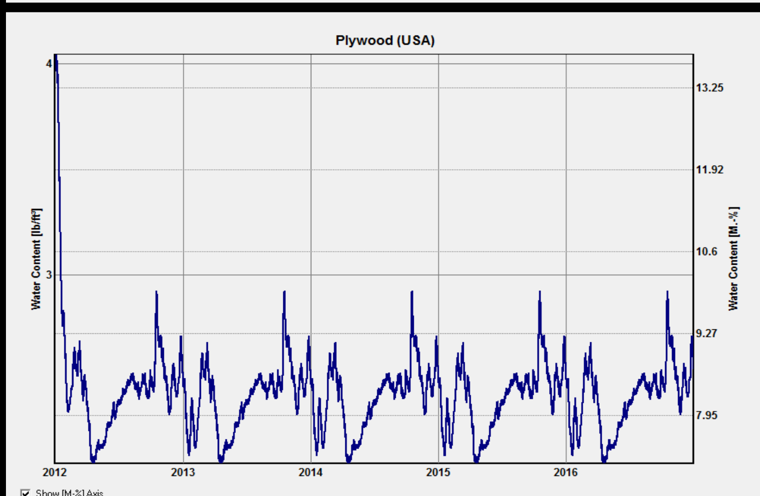
WUFI BIO Post-Proc

Mould index

Index:	Description:
0:	no growth
1:	some growth visible under microscope
2:	moderate growth visible under microscope, coverage more than 10%
3:	some growth detected visually, thin hyphae found under microscope
4:	visual coverage more than 10%
5:	coverage more than 50%
6:	tight coverage, 100%

Wood Decay





Wood Decay is due to fungal infections that require:

<u>Favorable Temperature</u>: > 50°F

<u>Moisture</u>: H20 content by weight > 20%-M

In example, temperature is often above 50°F

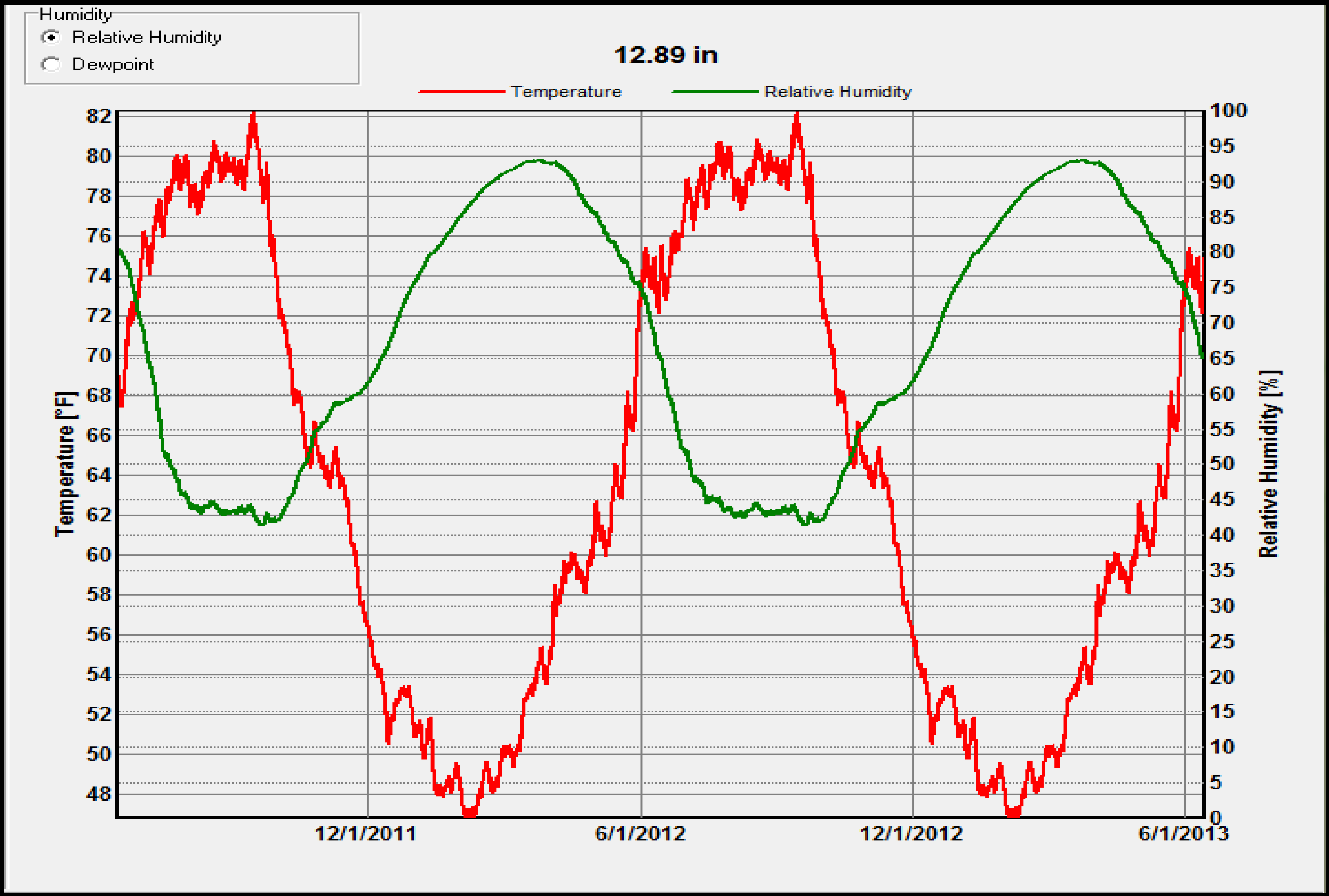
H2O Mass % is below 20%

Wood rot risk is absent unless H2O Mass% increases

Corrosion

- Corrosion – reinforced steel corrosion in carbonated concrete.
- Per 160P when lacking info - Surface RH of metal should not be above 80% RH for 30 day running average of hourly values
- This can vary with penetration percentage of driving rain behind insulation and permeability of exterior insulation.
- Mineral wool has net drying impact, EPS has problems once you get beyond 1% driving rain potential

Freeze-Thaw Risk Too?



Subflorescence of Salts

Source: Mineral building materials, deicing salts, marine salt and/or soil salts dissolved in water

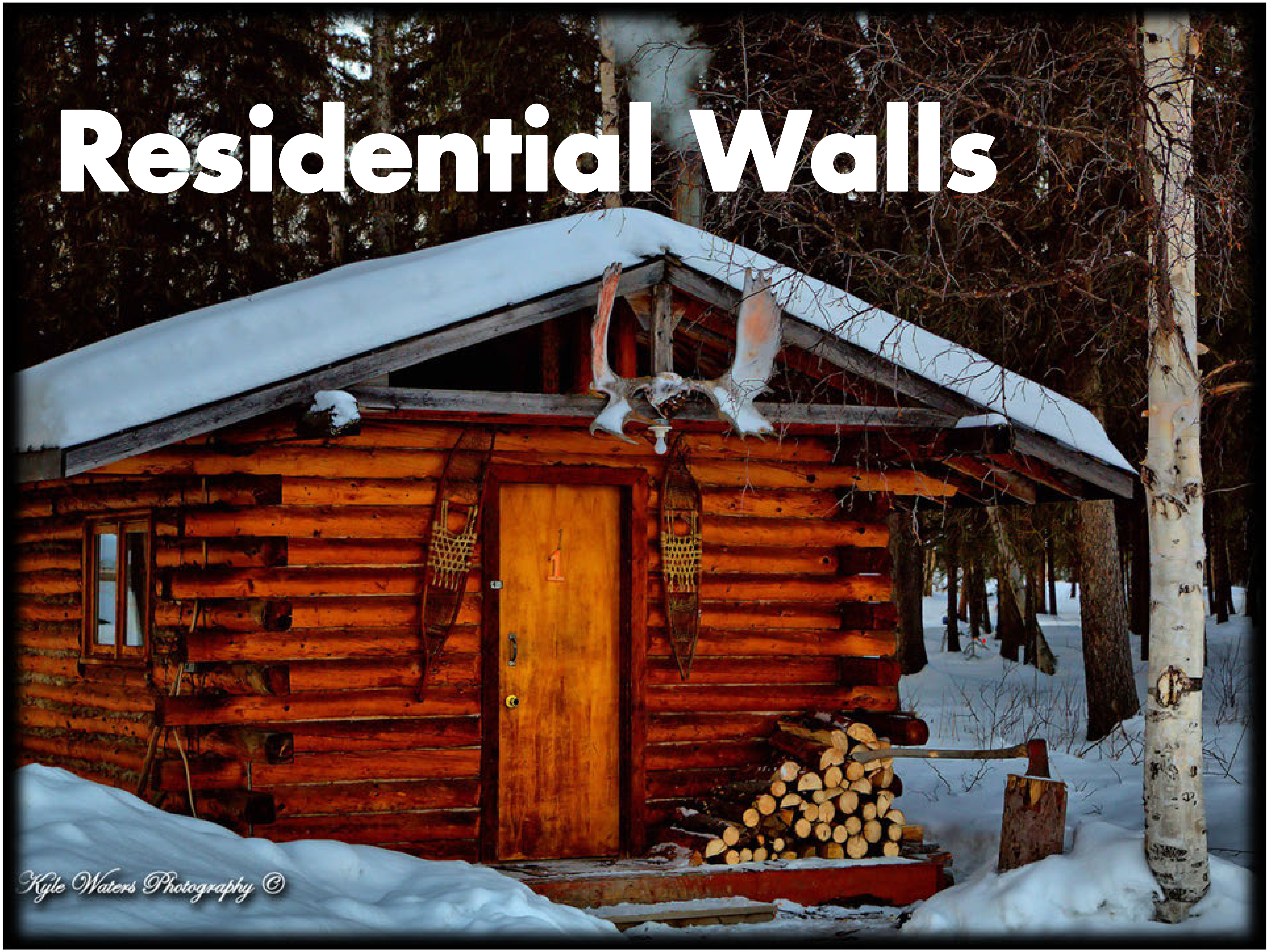
Action: Water evaporates, salt is left behind.

- Salt on exterior surface = efflorescence
- Salt within porous material = subflorescence

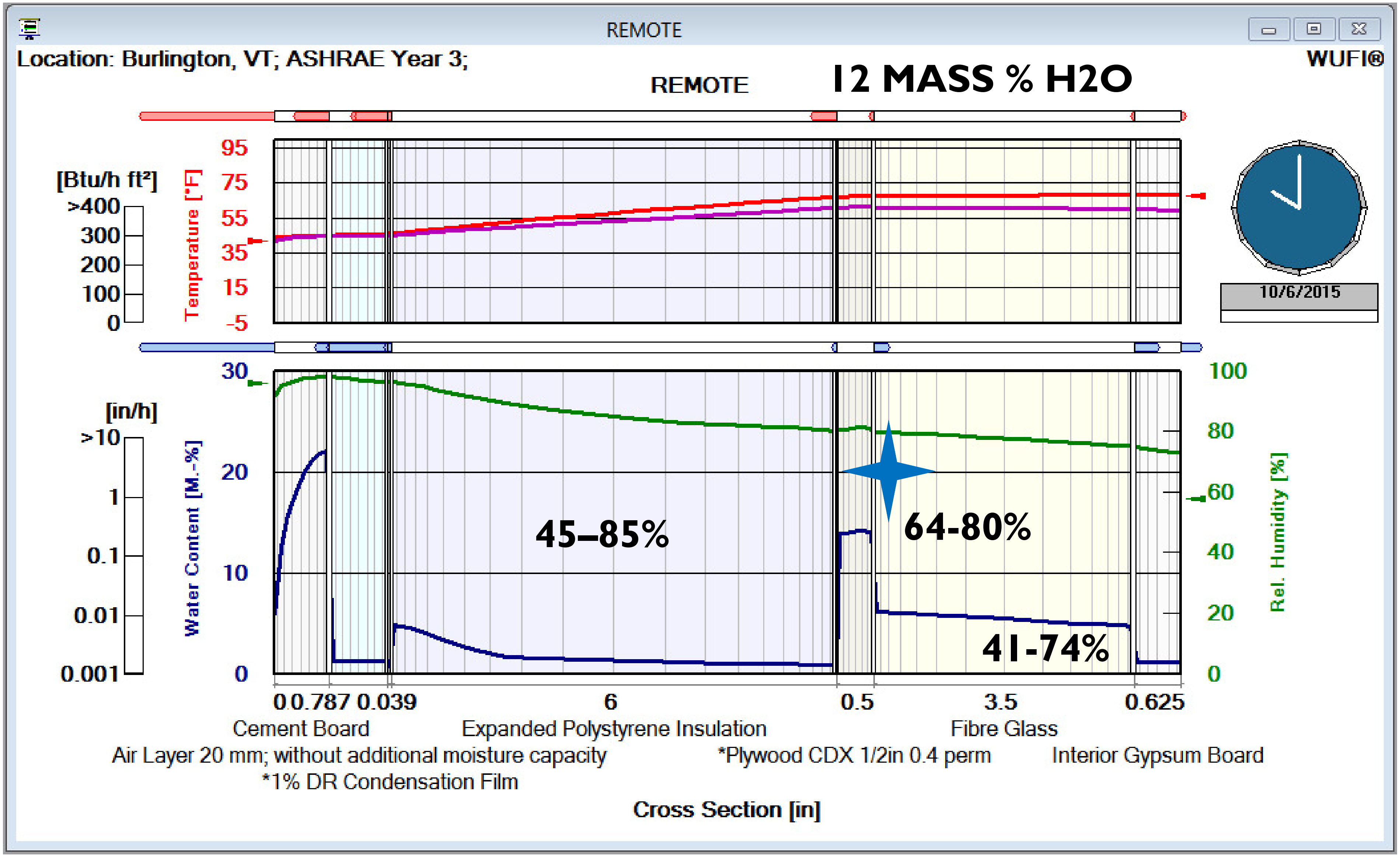
Results: Damage and vapor permeance reduction

- Damage looks similar to freeze/thaw
- Salts clog pores, moisture content inside assembly can increase causing failure, common in historic masonry

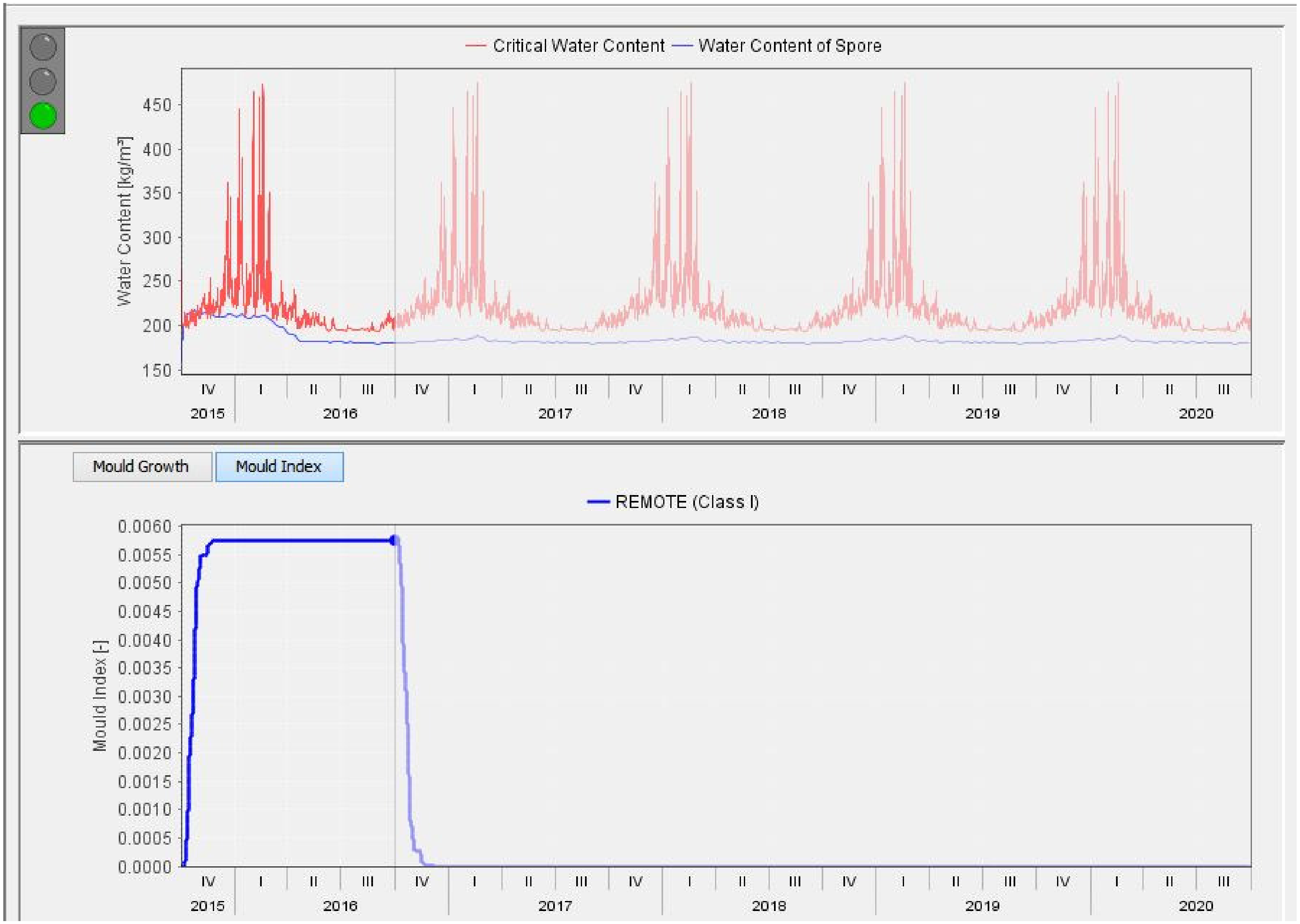

and the
winners are...


Residential Walls
Kyle Waters Photography ©

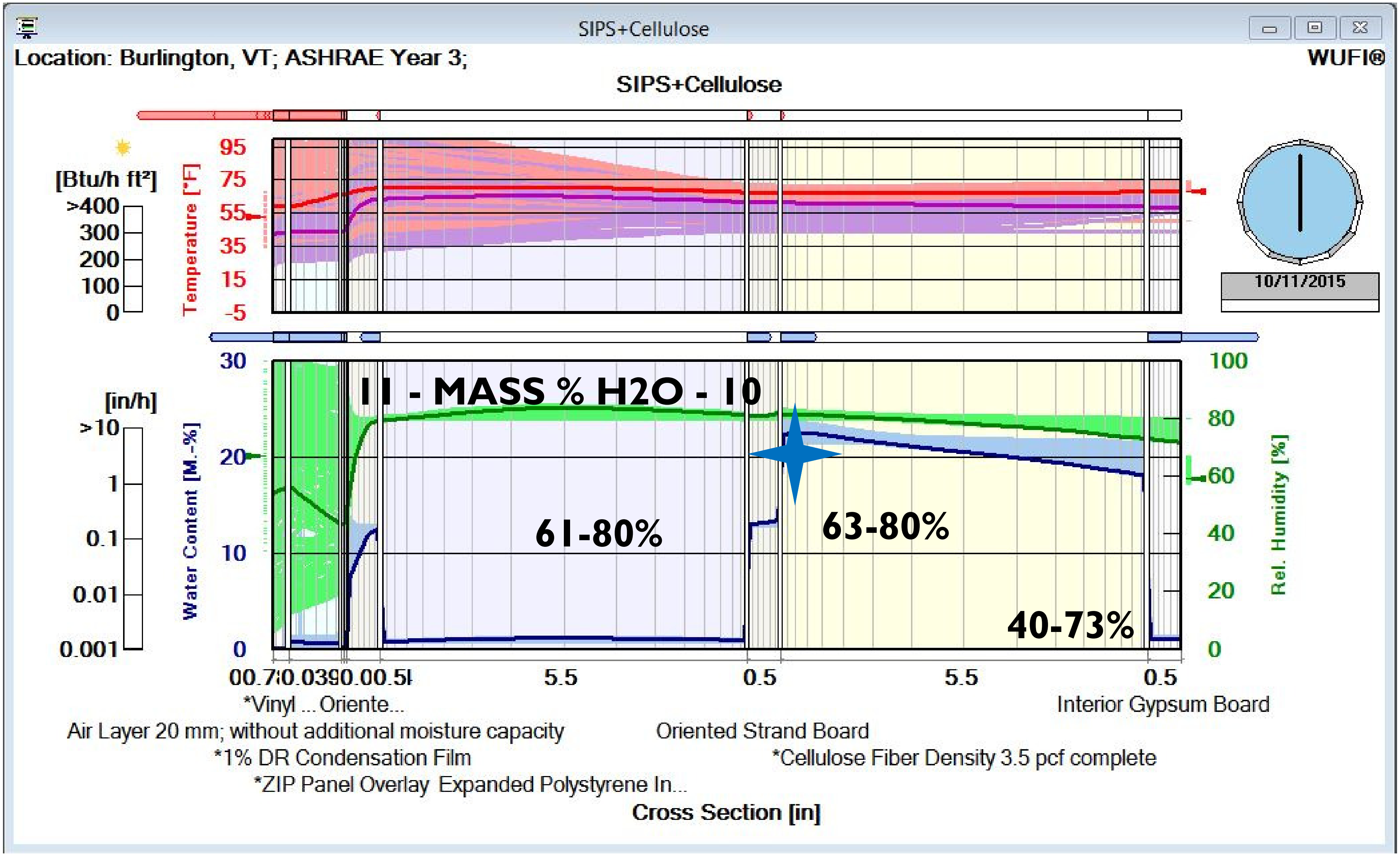
Residential Wall 1 - REMOTE



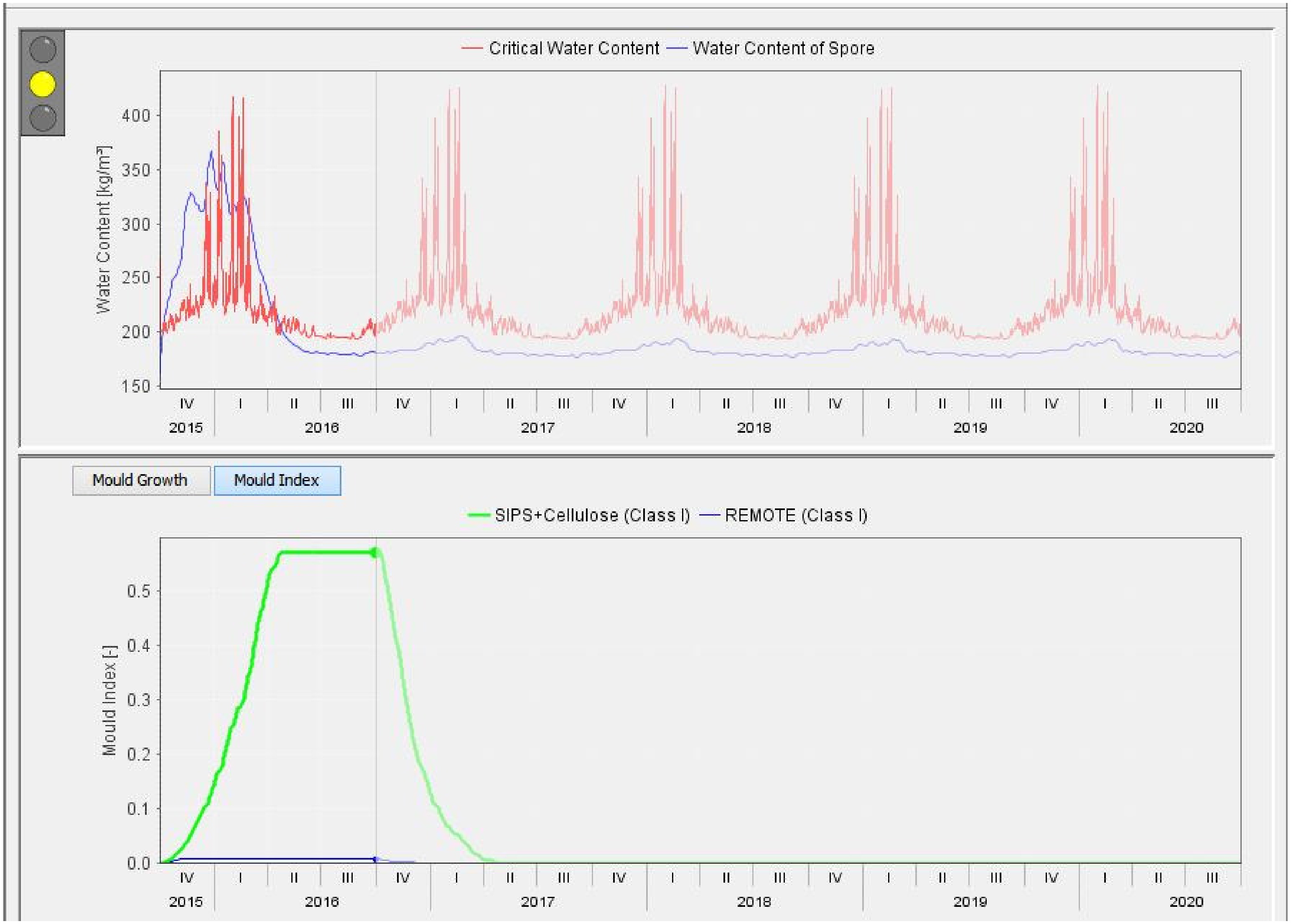
Residential Wall 1 - REMOTE



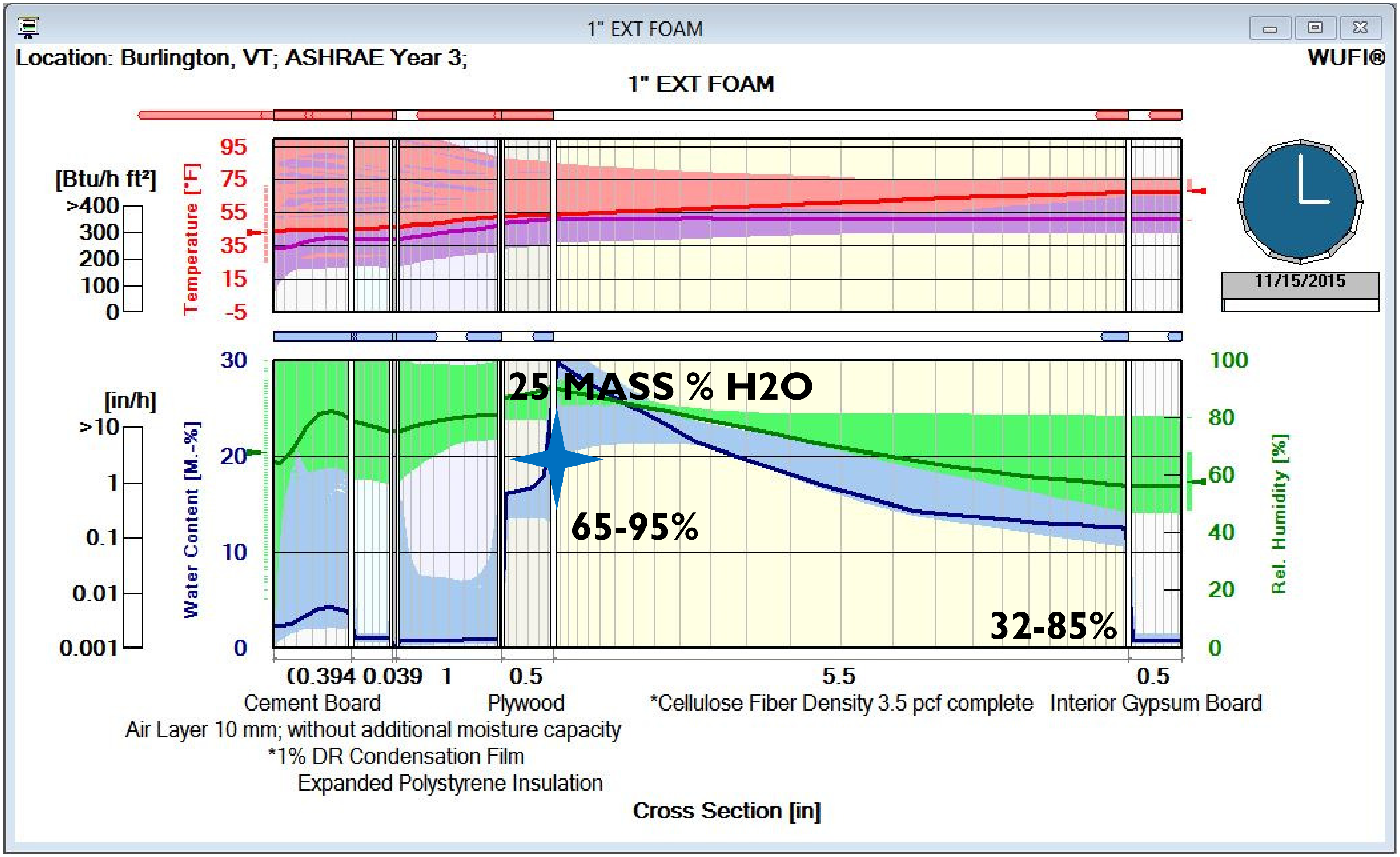
Residential Wall 2 – SIPS+



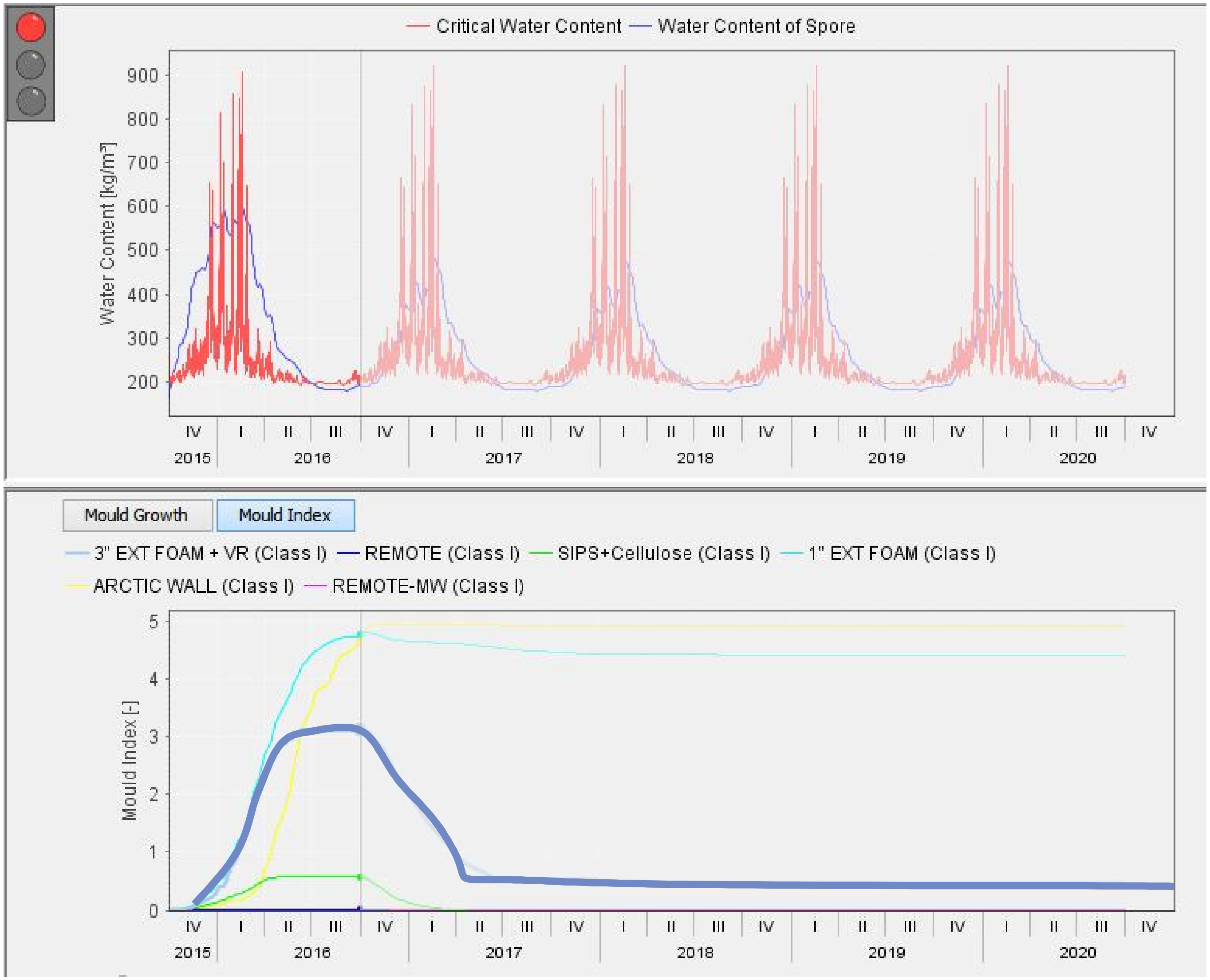
Residential Wall 2 – SIPS+



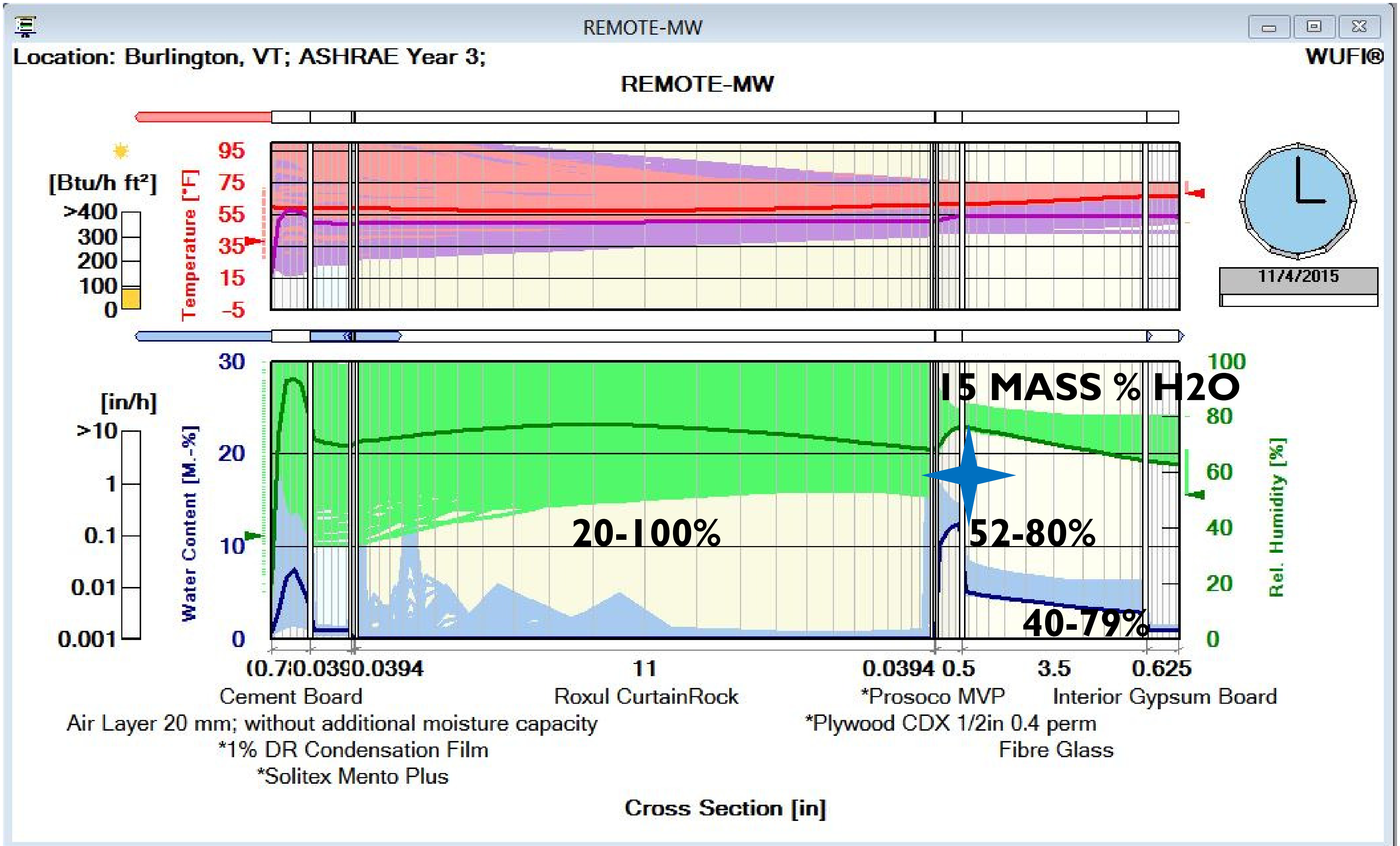
Res Wall 3 – 1"EPS+Cellulose ⚠



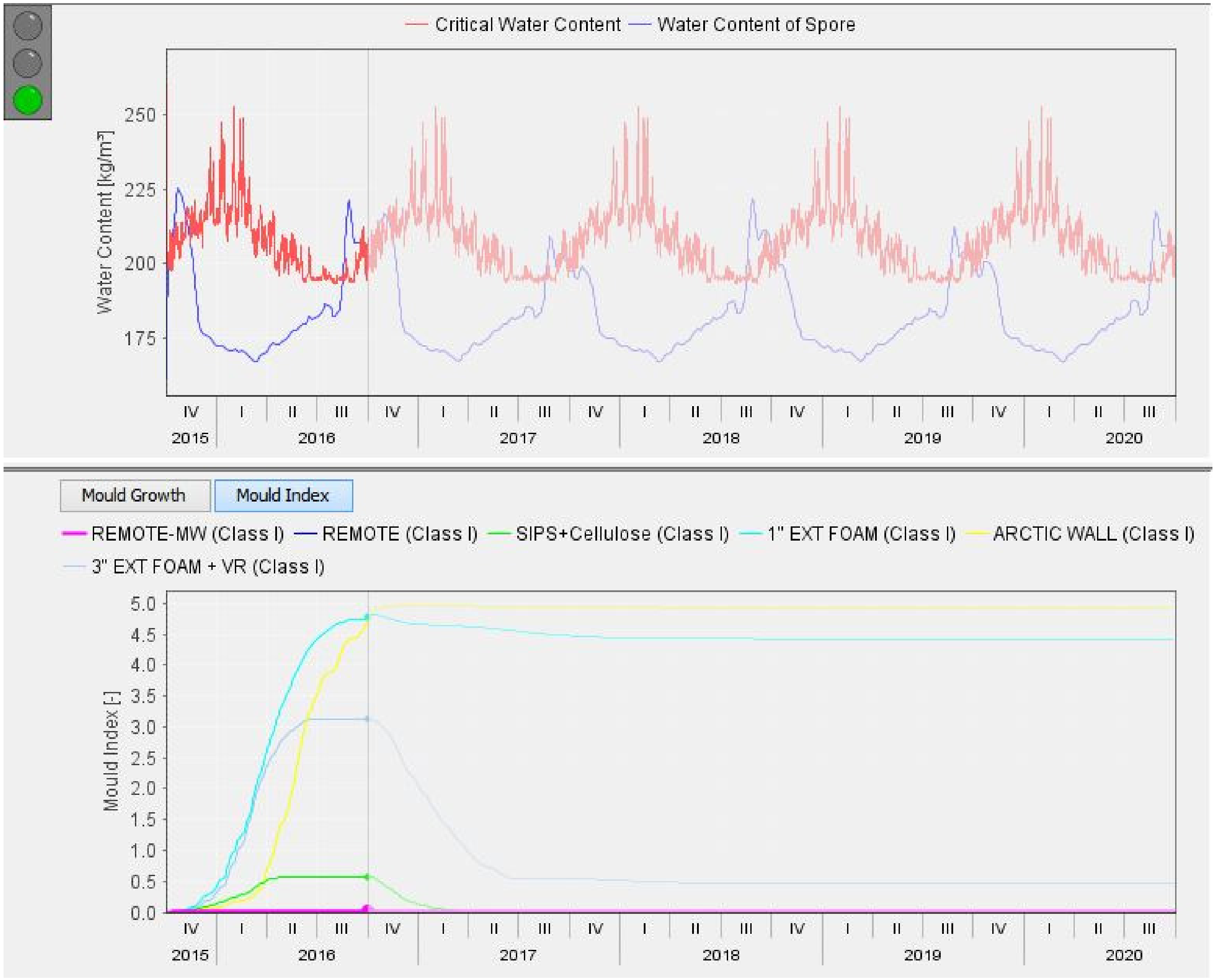
Res Wall 3v2 – 3"EPS+Cell



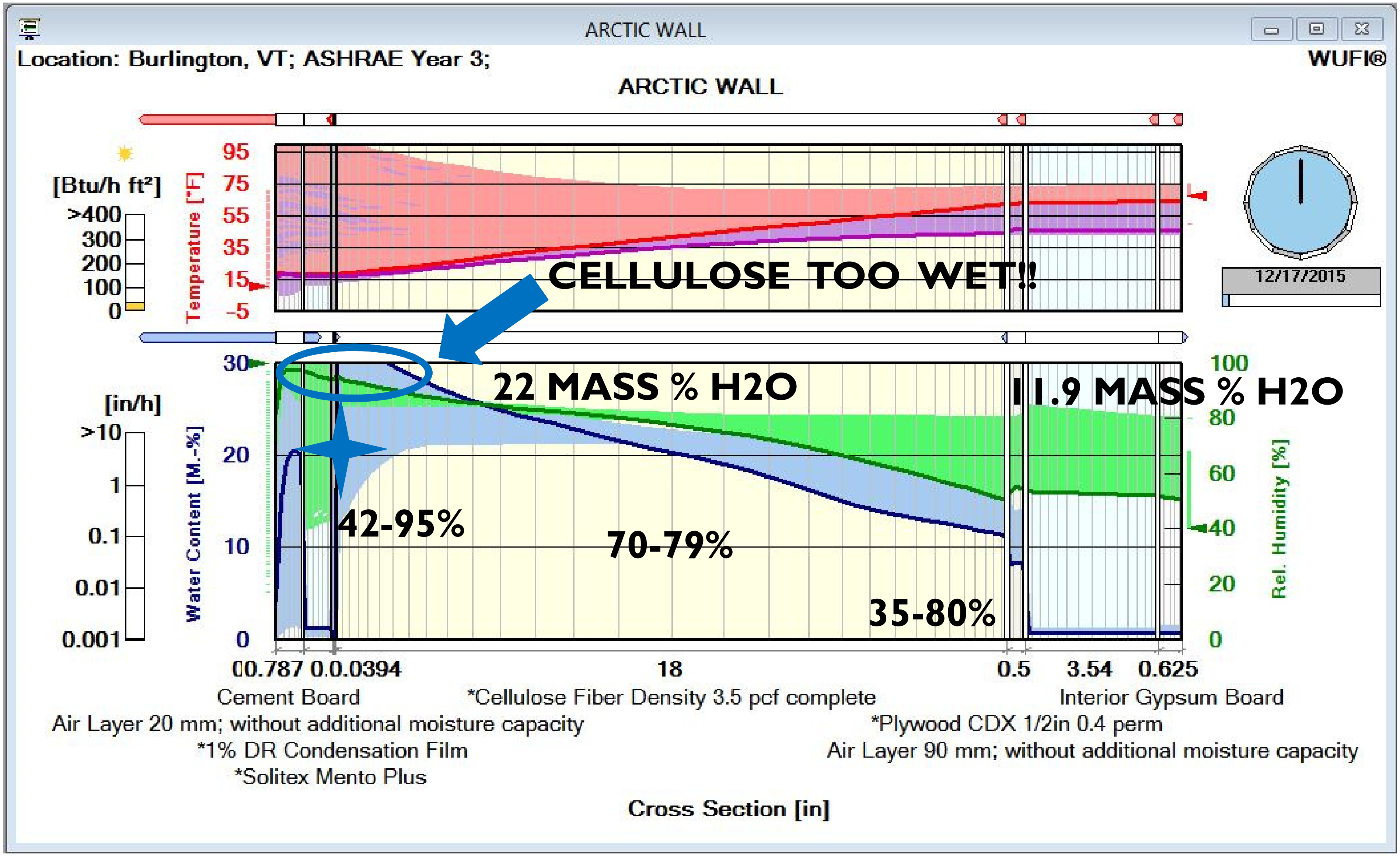
Residential Wall 4 – REMOTE MW



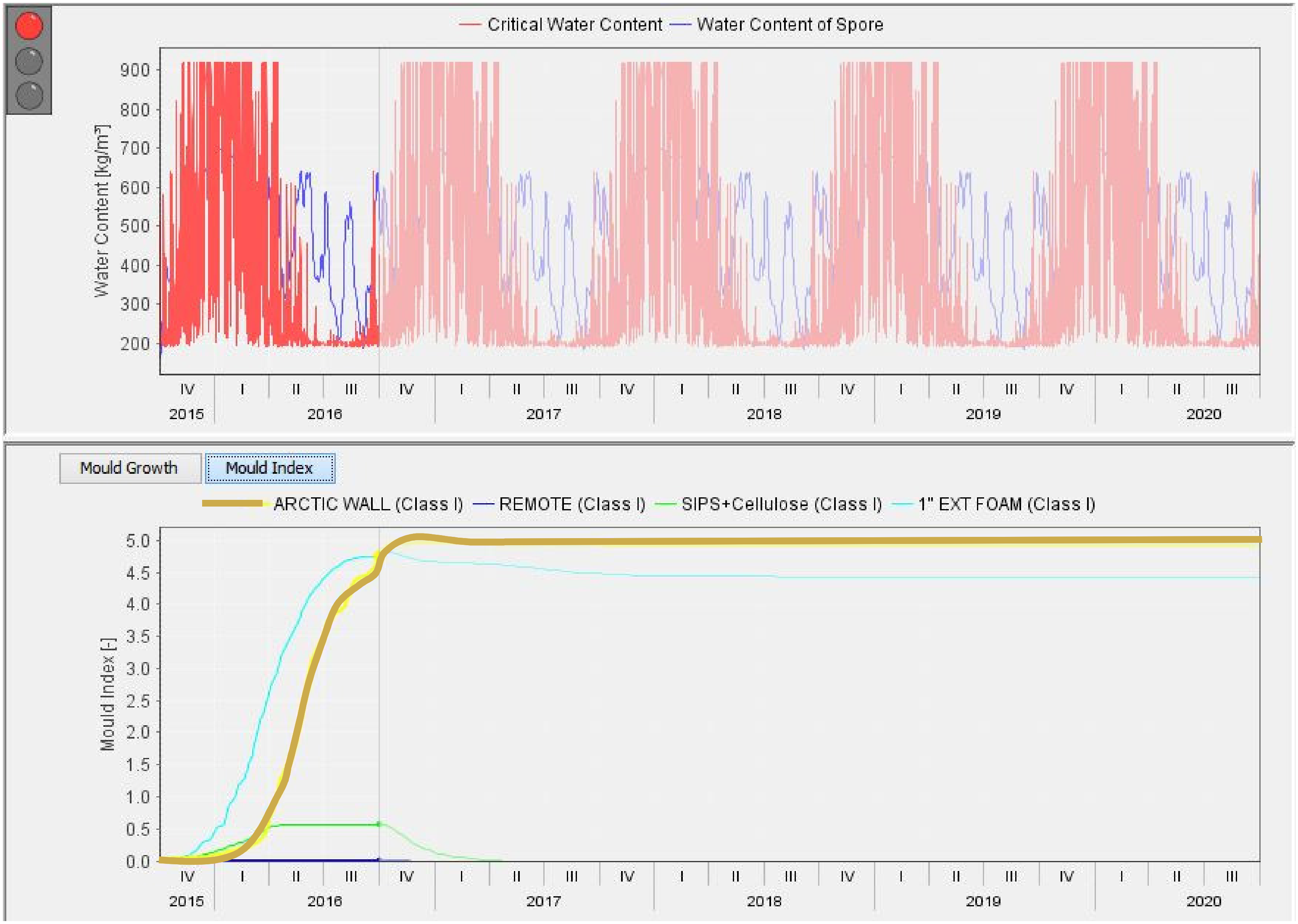
Residential Wall 4 – REMOTE MW



Residential Wall 5 – ARCTIC WALL ⚠

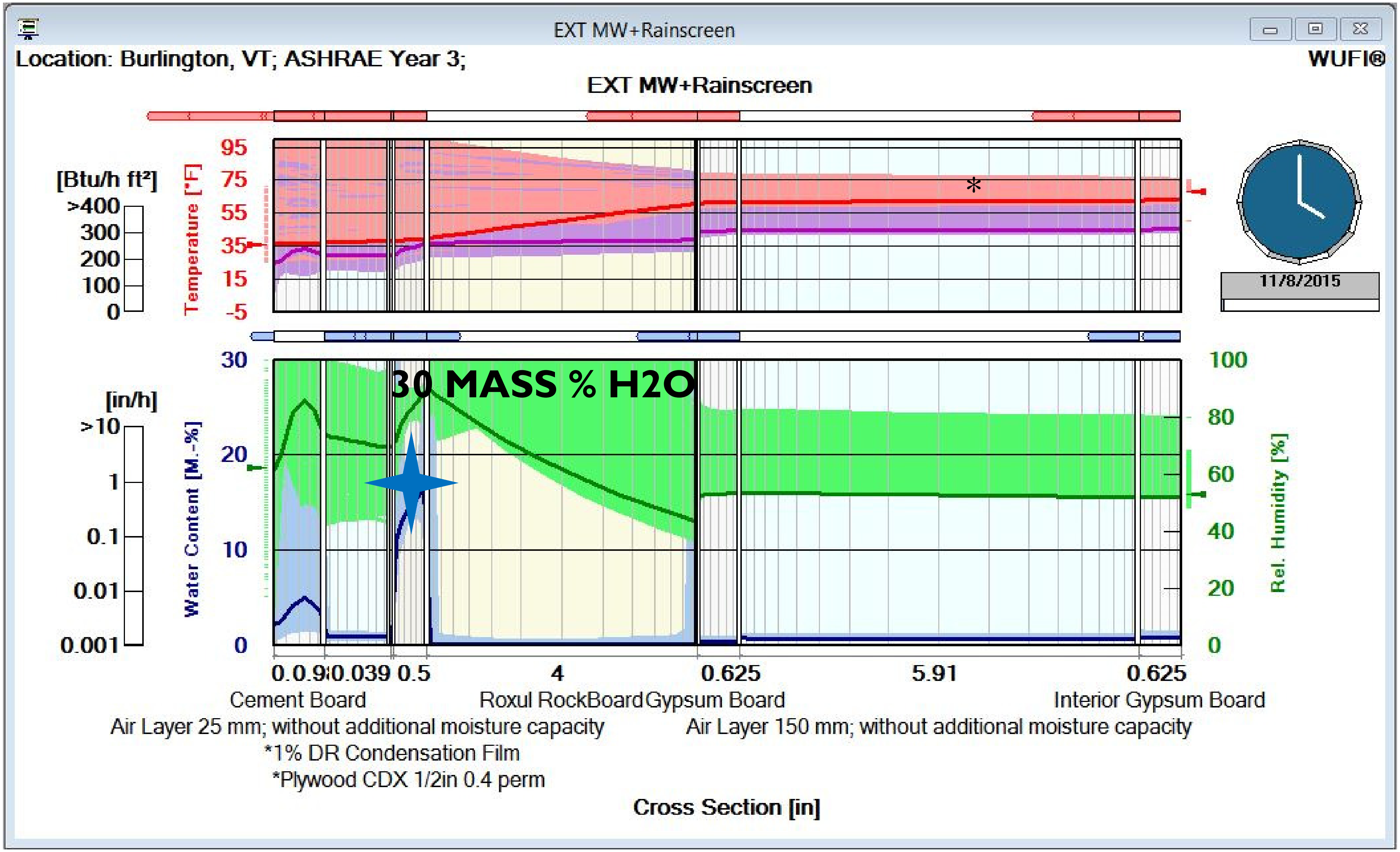


Residential Wall 5 – ARCTIC WALL ⚠

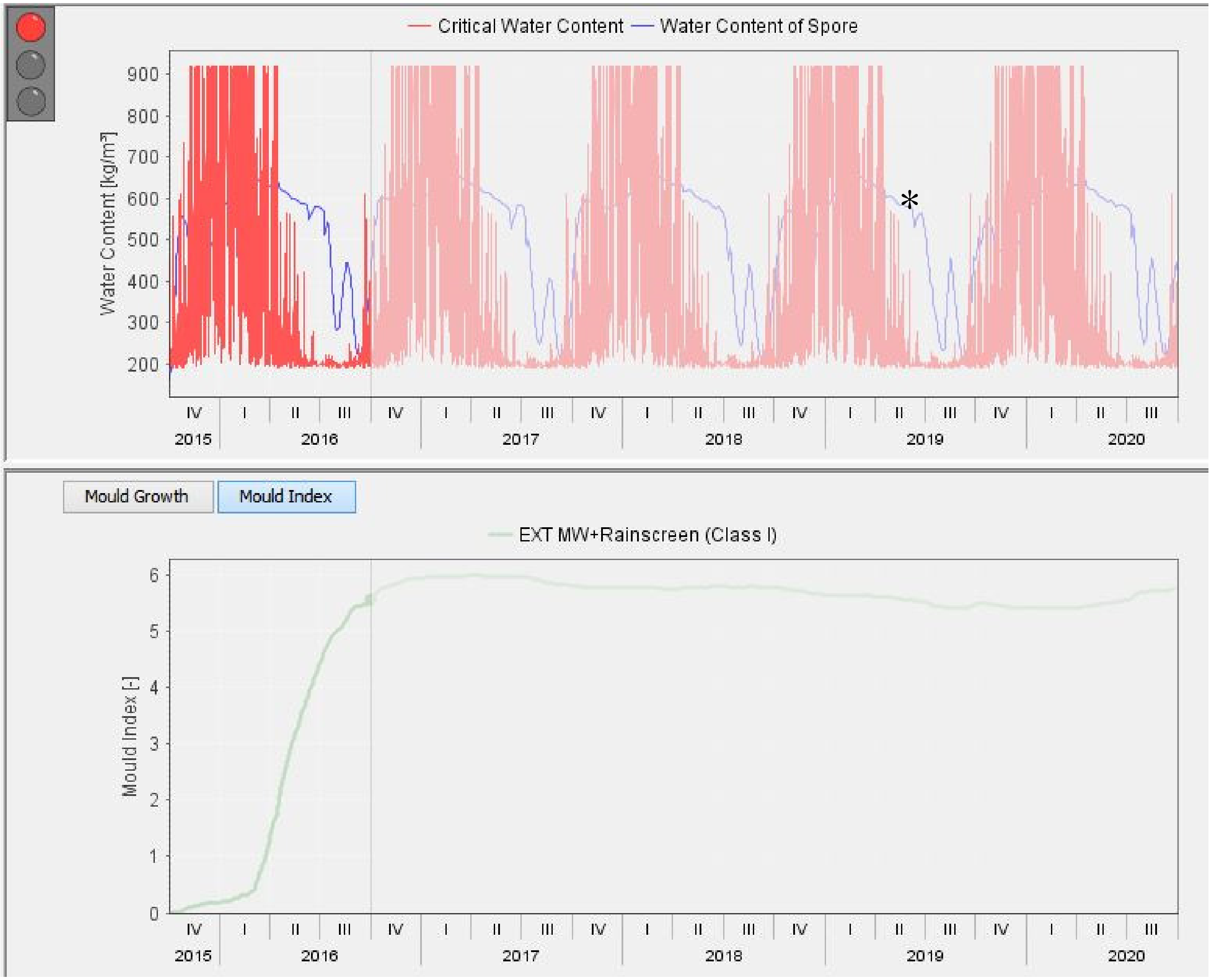



Commercial Walls

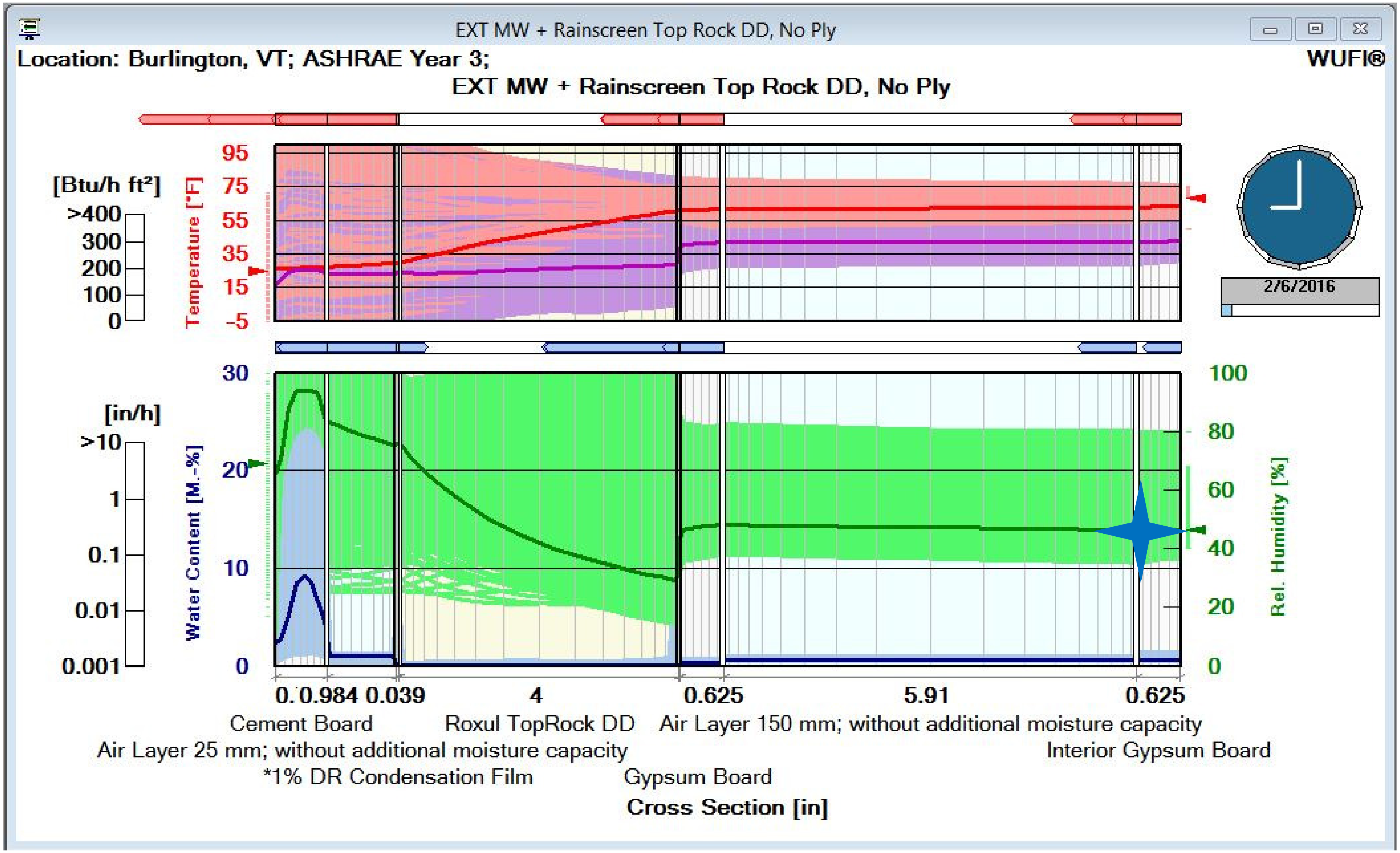
Com Wall 1 – Ext Min Wool



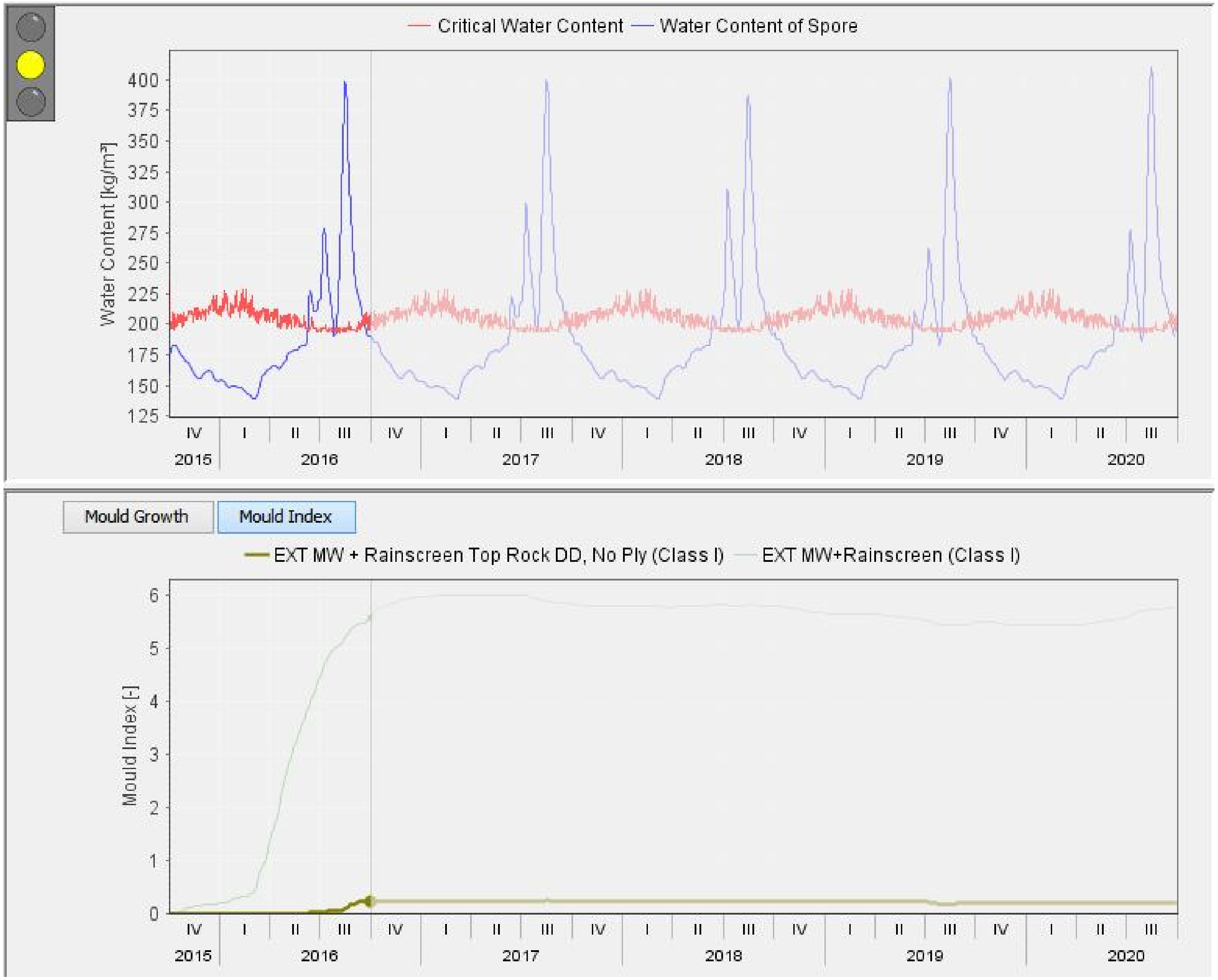
Com Wall 1 – Ext Min Wool



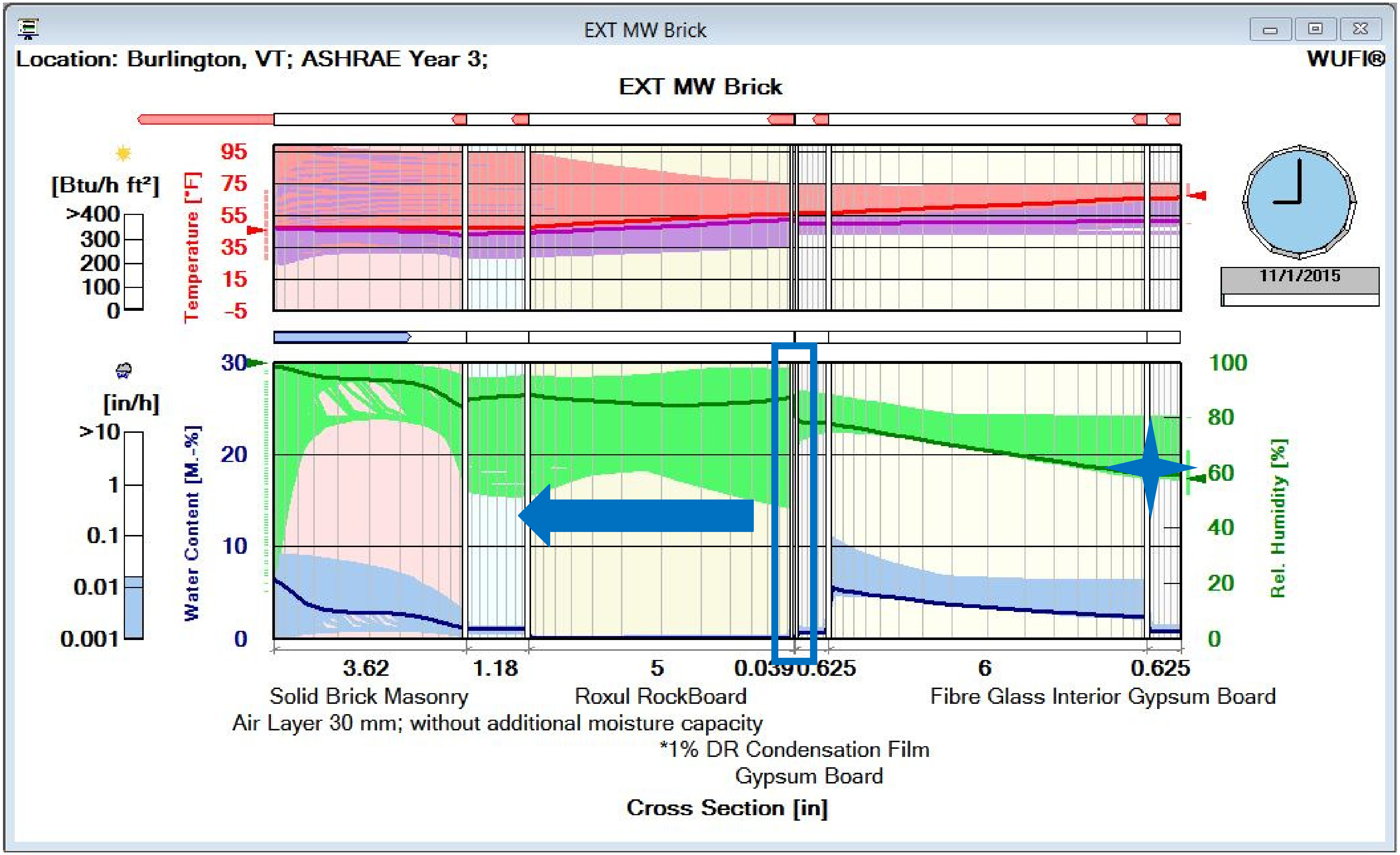
Com Wall 1v2 – NO Ply



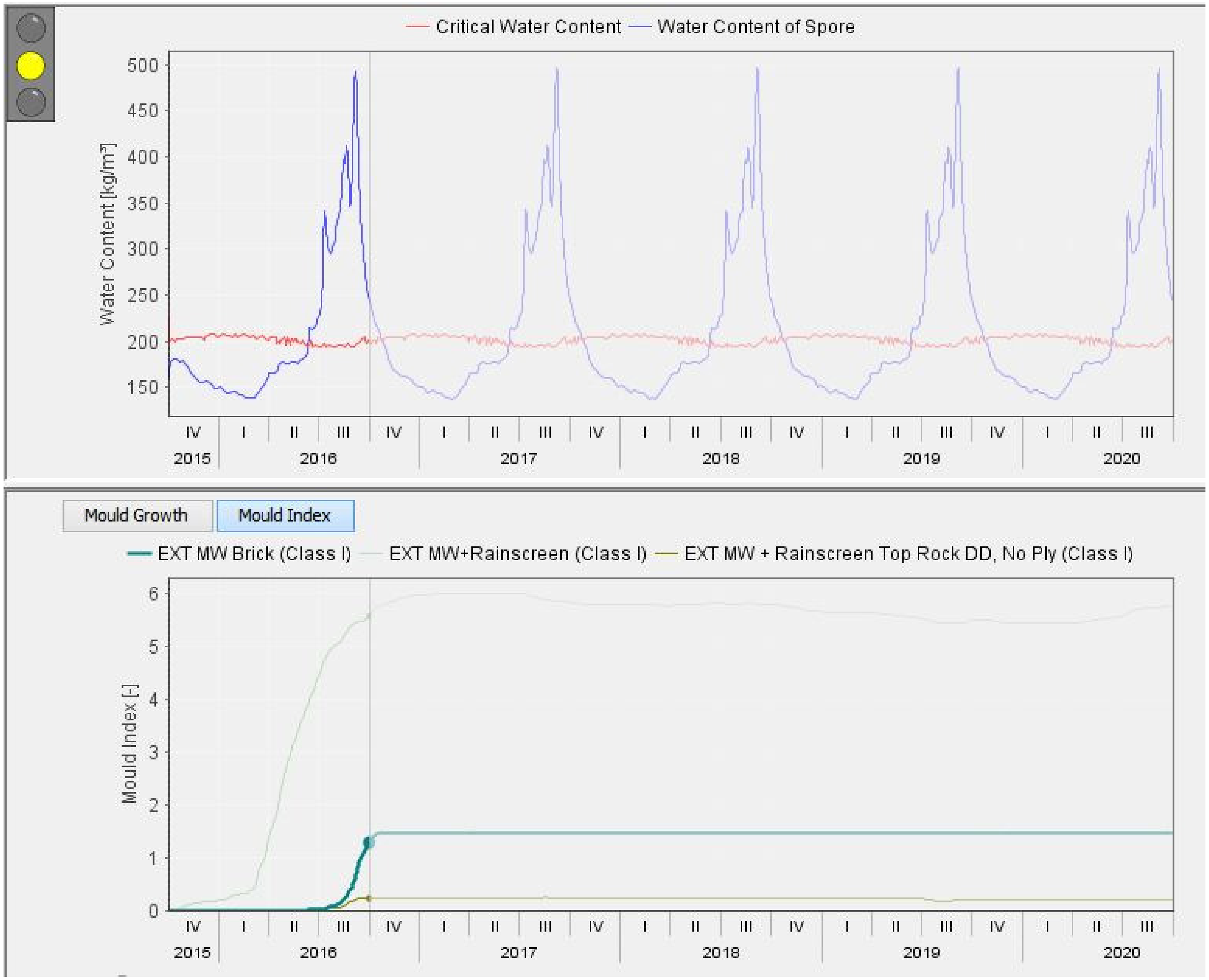
Com Wall 1v2 – NO Ply



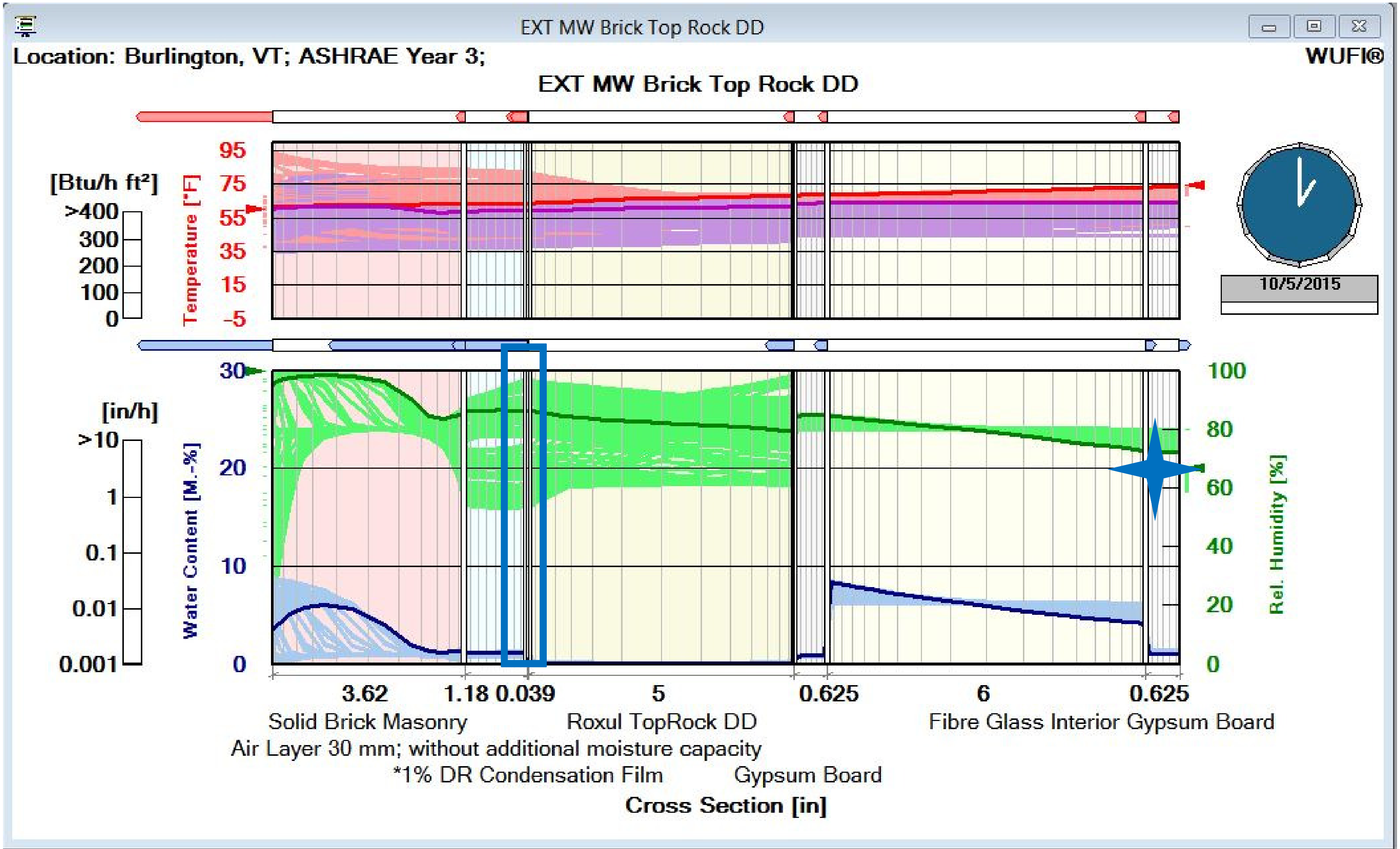
Com Wall 2 – Ext MW Brick



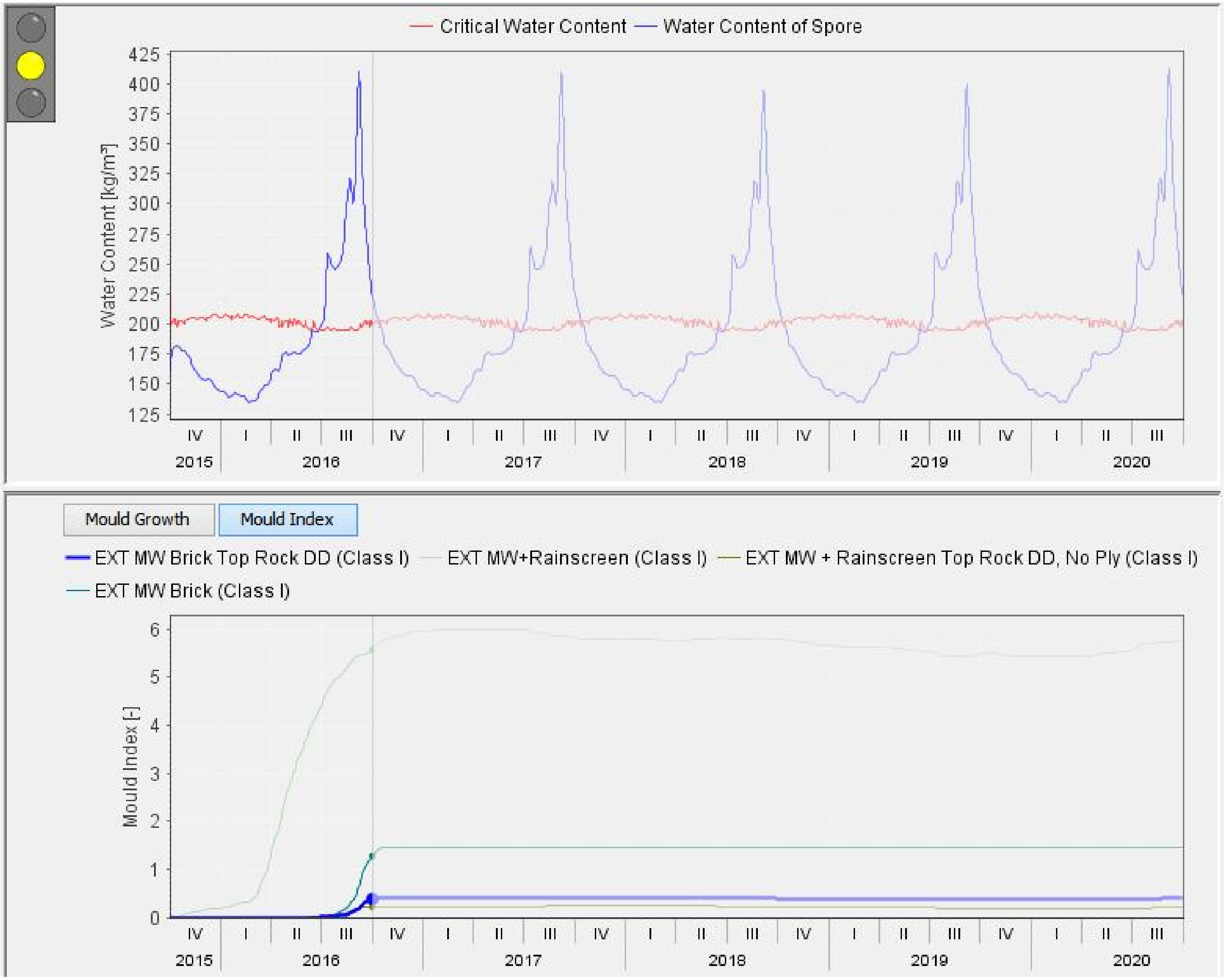
Com Wall 2 – Ext MW Brick



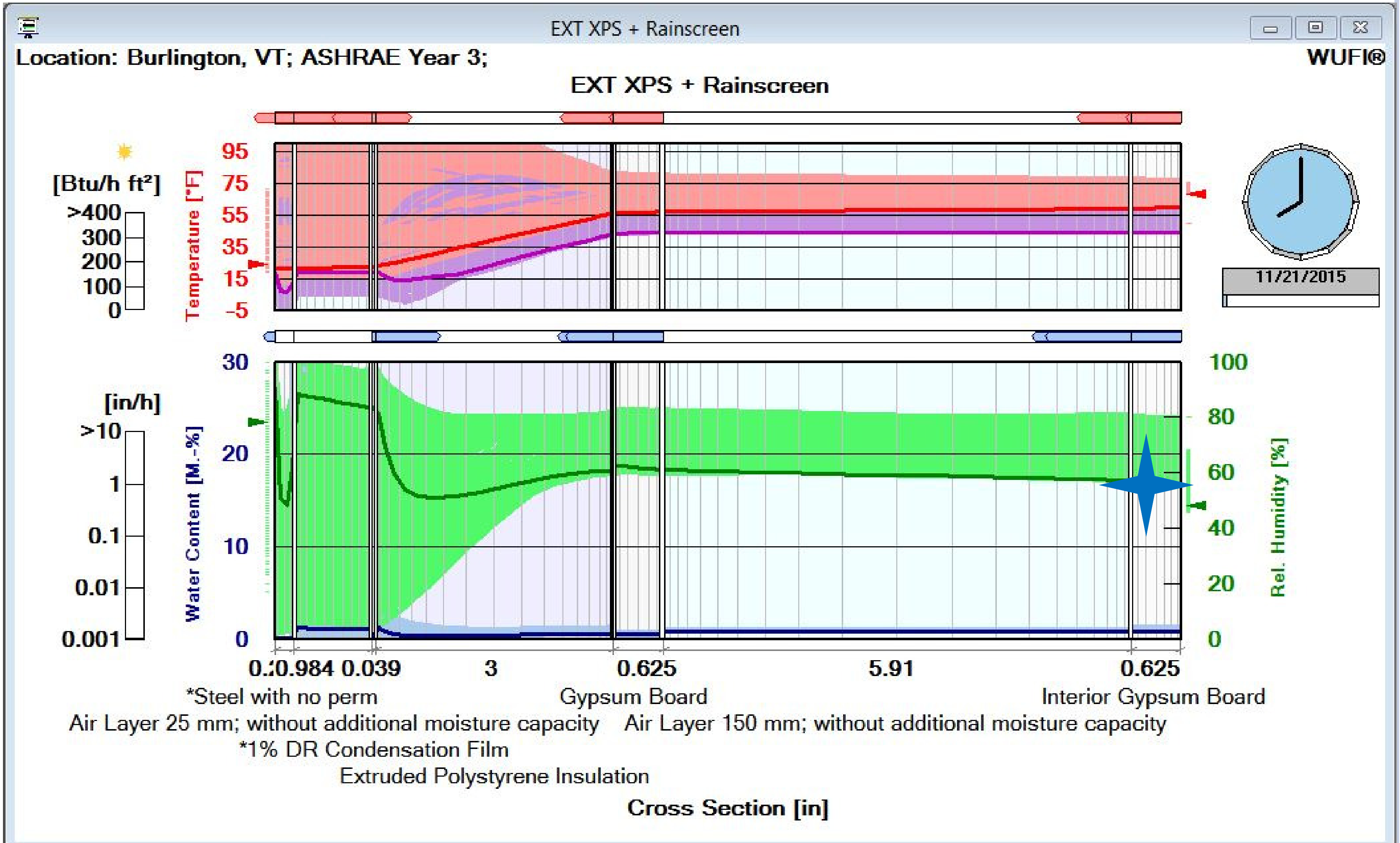
Com Wall 2v2 – Ext MW Brick



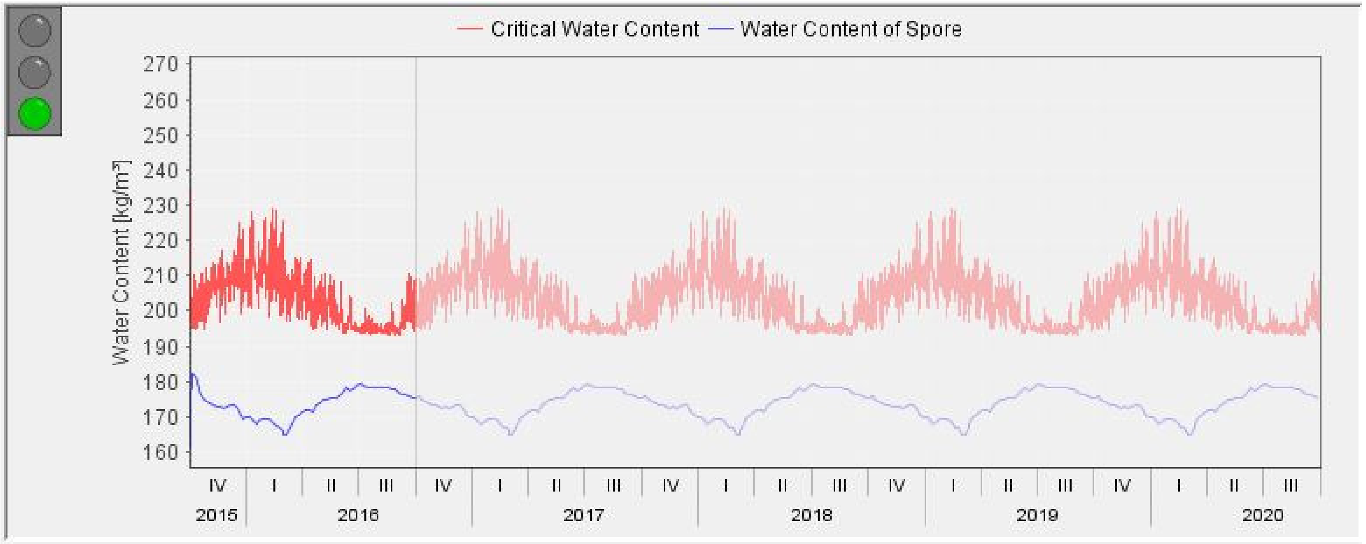
Com Wall 2v2 – Ext MW Brick

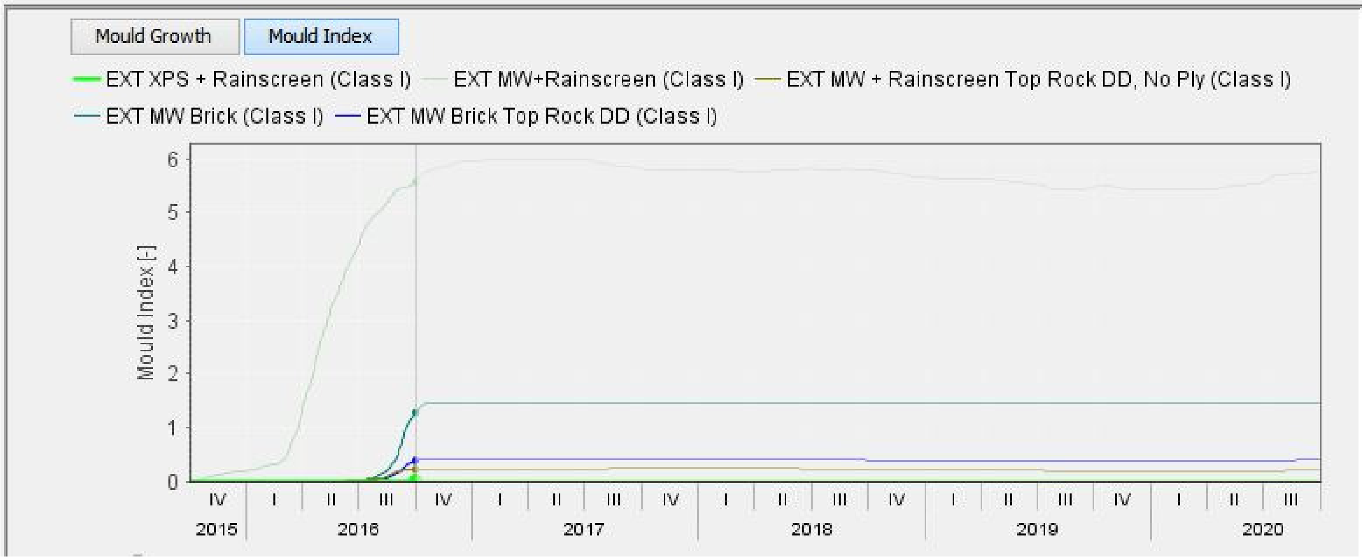


Com Wall 2 – Ext XPS

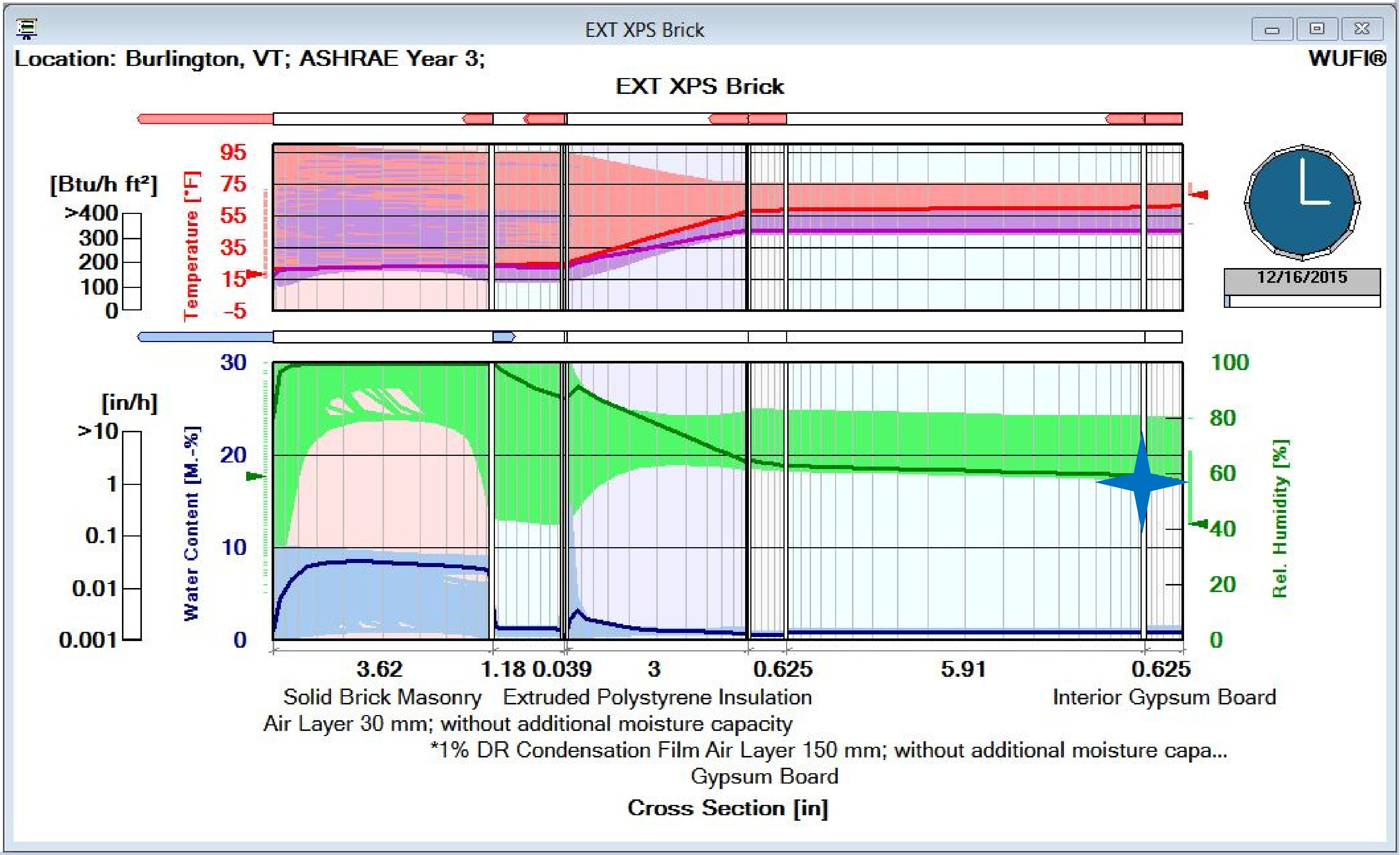


Com Wall 2 – Ext XPS

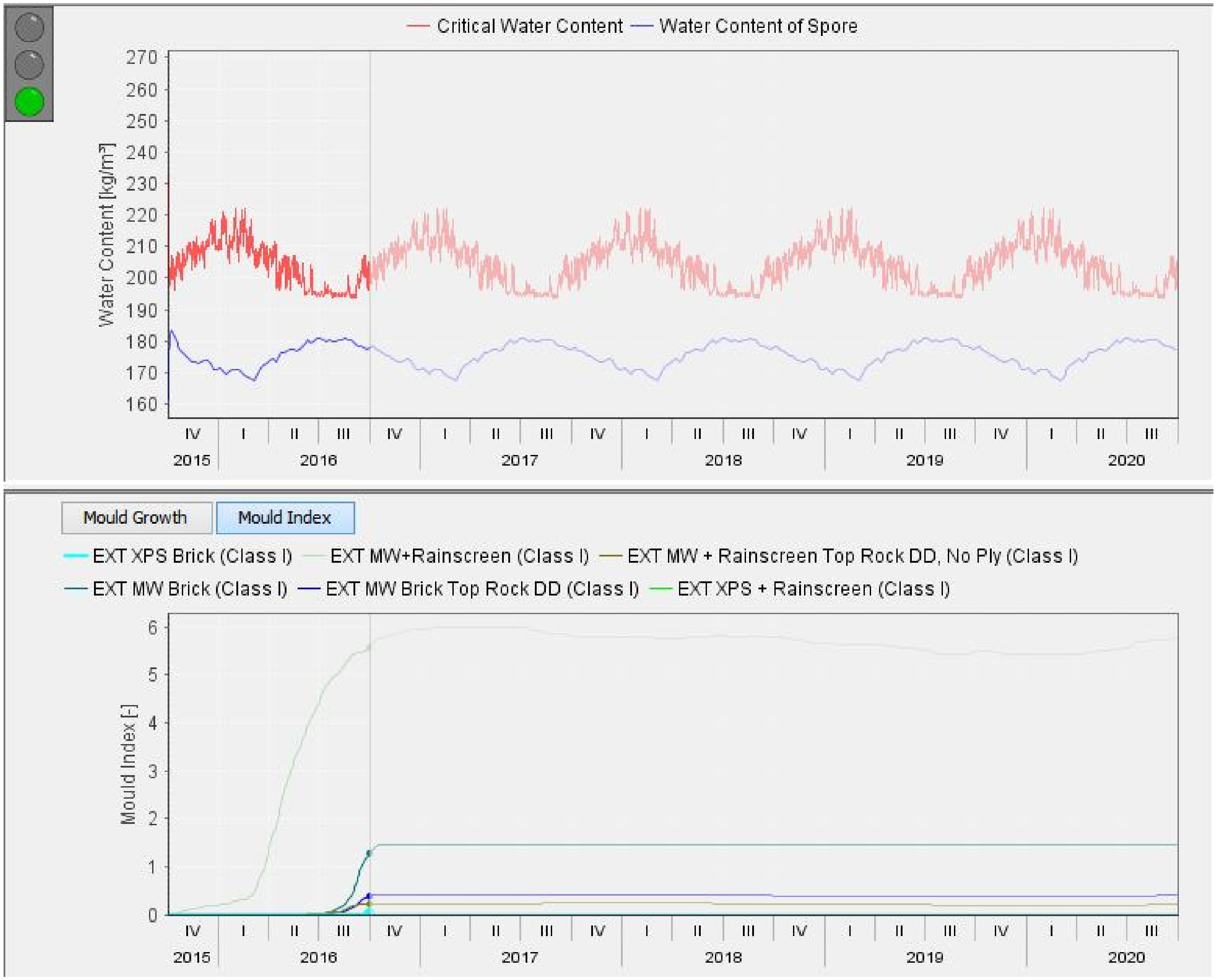




Com Wall 2 – Ext XPS Brick



Com Wall 2 – Ext XPS Brick



Conclusions …

- There are plenty of walls that work from a durability standpoint… Embodied energy? Local?
- Really need min 2"ext foam to avoid sheathing rot risk and outer cavity mold risk (watch that dewpoint!)
- Cellulose can work, just need to make sure its dry in outer layers of cavity
- Little too wet for 100% diffusion open wood framed walls. Need that class II VR (1 PERM).


For More Info/Analysis
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* Fairbanks HQ - Courtesy Thorsten Chlupp ☺