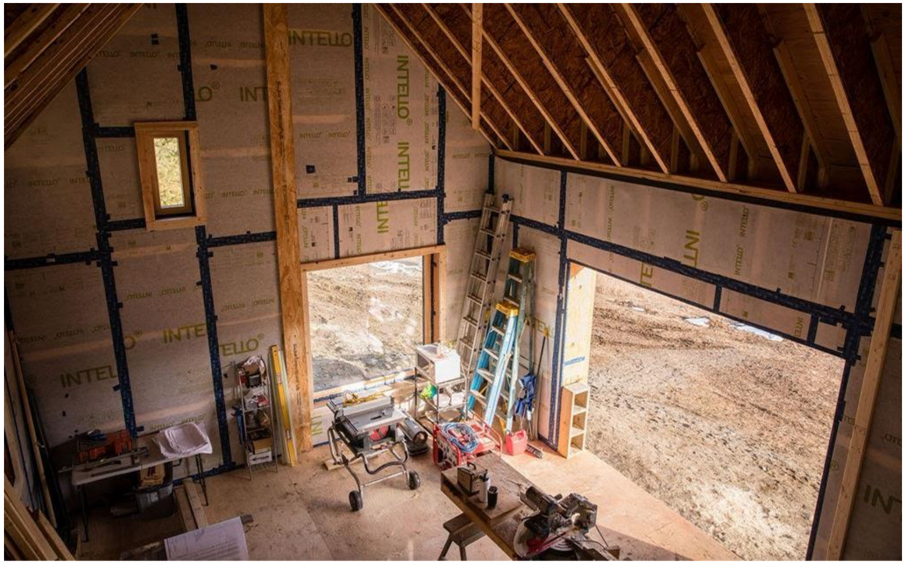
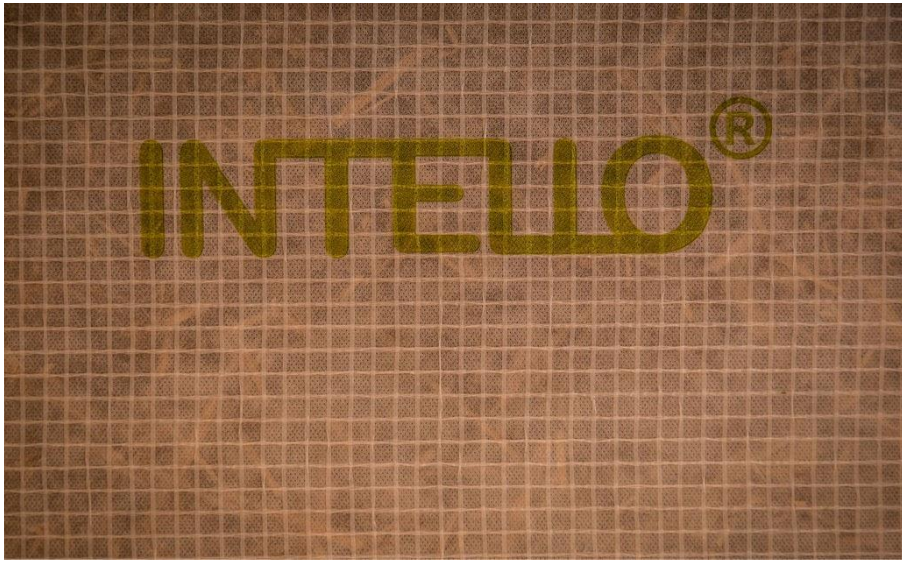




Designing Foam-Free Passive House Assemblies in Climate Zone 6 & 7

Floris Keverling Buisman
CEO - 475

- Master’s degree in Architecture + Real Estate Dev from the Delft University of Technology, Registered Architect in the Netherlands
- Served on NYC Building Code Committees
- Certified, consulted on and built several Passive House projects in New York and Vermont
- Adjunct professor at The City College of New York
- Certified WUFI ORNL Instructor
- Bicycle advocate

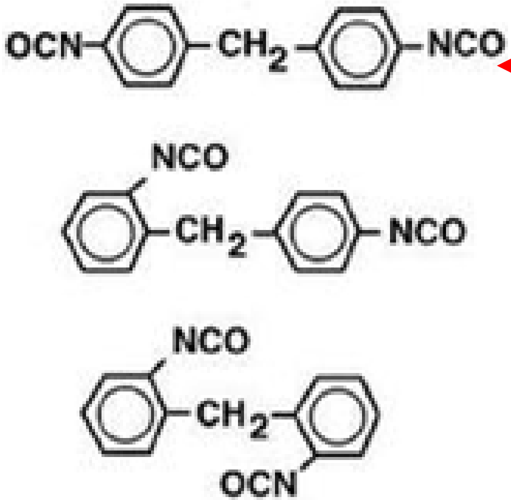
HIGH PERFORMANCE BUILDING SUPPLY
FOURSEVENFIVE.COM

What is High Performance?

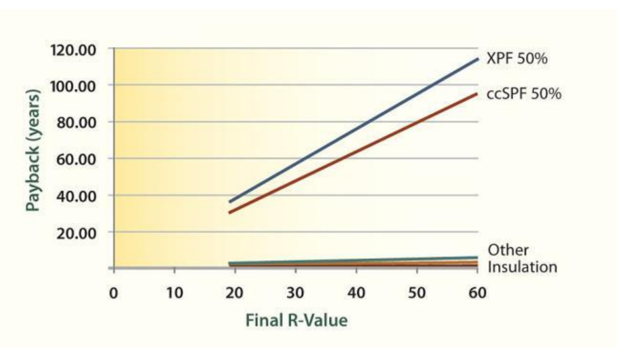
- Comfortable
- Healthy
- Energy efficient
- Resilient
- Affordable
- Beautiful

Credit: The Graduate, 1967,

Foam – Less is Best



Pure MDI's



Dangerous Toxic Ingredients

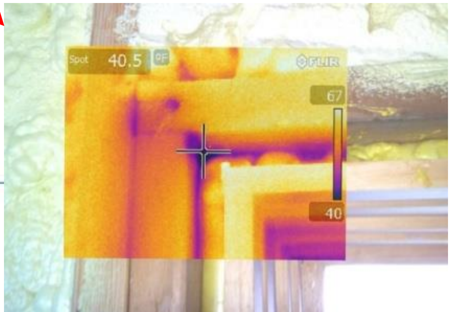
Unacceptable Fire Accelerant

This fire *started during installation due to an excessive exothermic reaction*

High Level of Embodied Energy & Global Warming Potential

Unreliable Performance

Reversible?



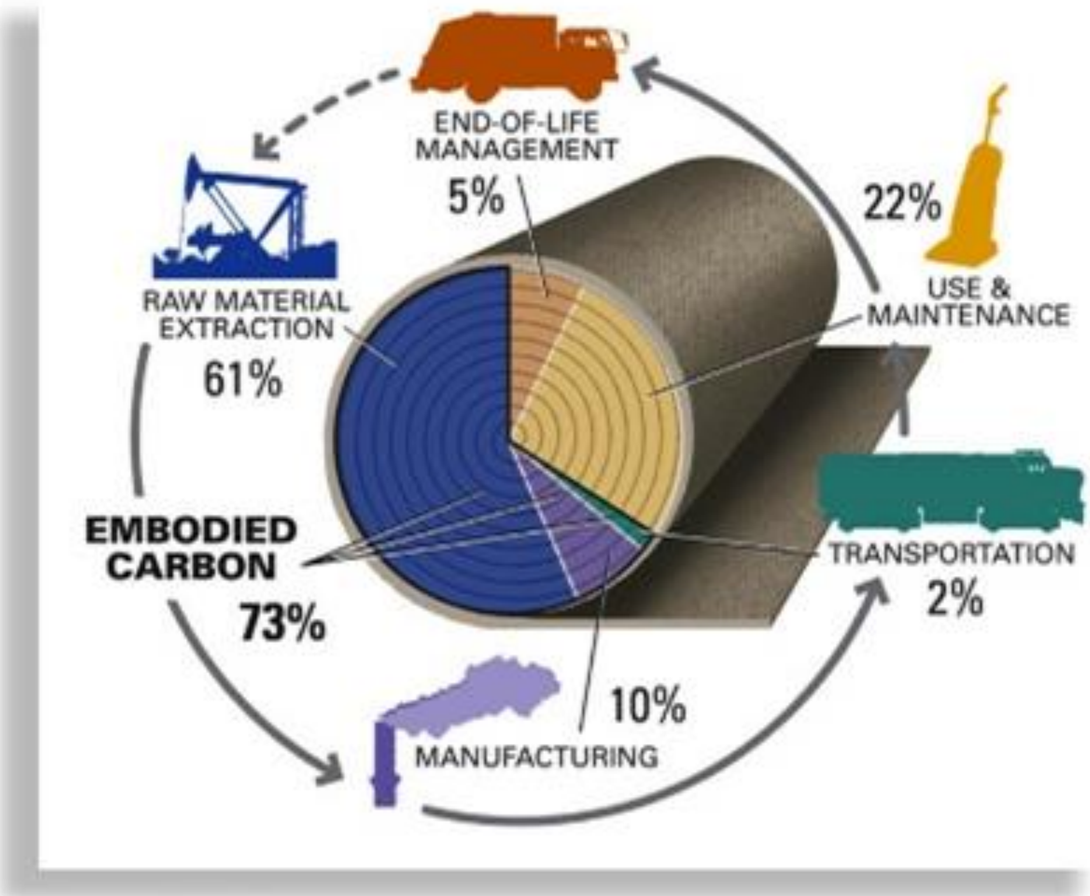
How to Mitigate Climate Change

Credit: Passive House Accelerator

"Global climate change is the challenge of our generation."

- Mayor **Bill de Blasio**, One City: Built to Last

Embodied Energy vs. Carbon Footprint

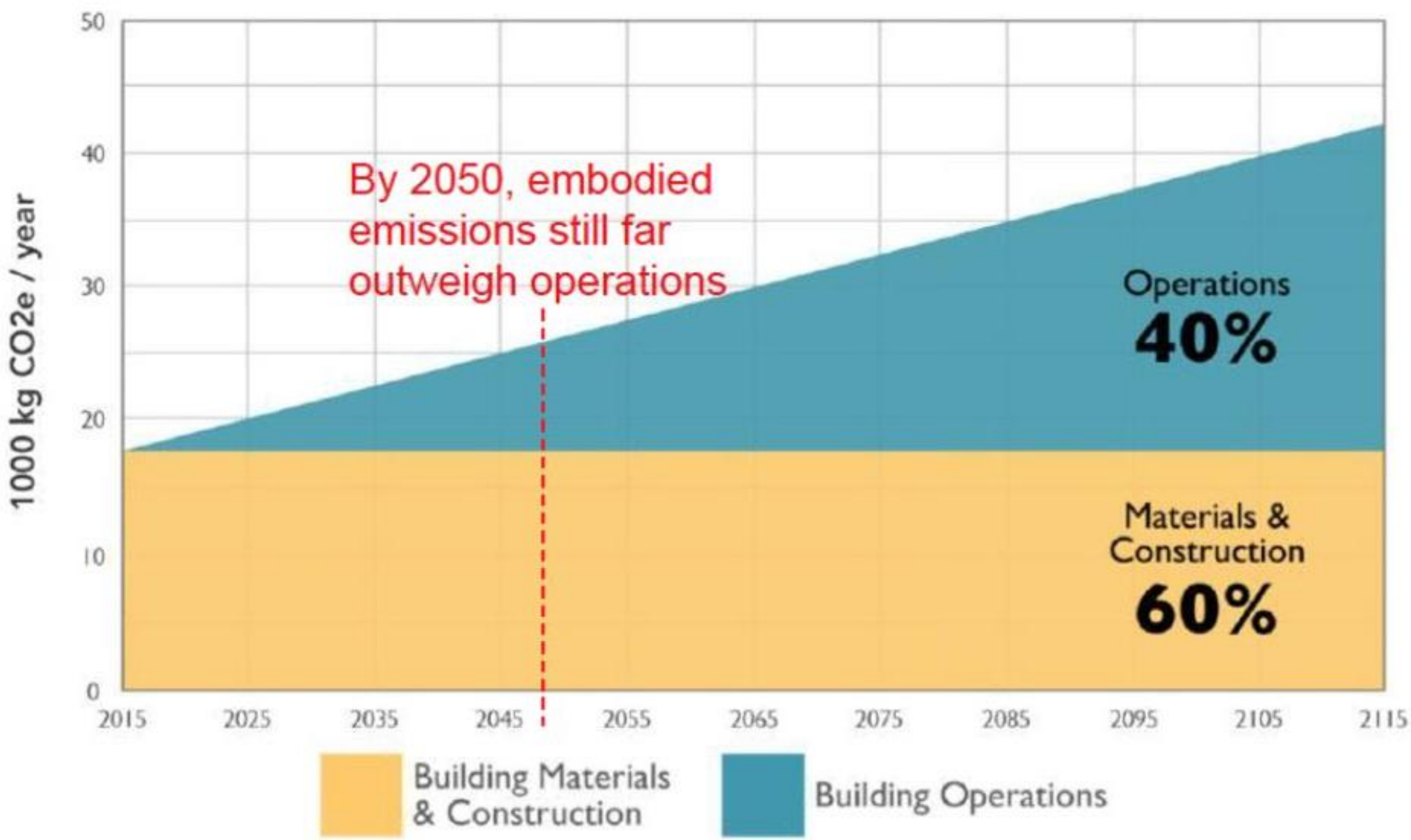


Source: Building Green

Embodied Energy = Sum of all energy needed to produce any product, as if that energy was incorporated or "embodied" into the product itself.

Carbon Footprint = Sum of all greenhouse gases emitted by the full life cycle of a product.

Why Embodied Carbon Matters



Carbon Emissions
(Typical High Performance Building)

Data Source: Embodied Carbon Benchmark Study, 2016; The Time Value of Carbon: Why reducing embodied carbon is critical to meet global climate goals, 2016

Components of High Performance

1. Robust enclosure
2. Quality daylighting
3. Less toxic and more sustainable.
4. Healthy indoor air quality
5. More predictable and durable
6. Low Energy – “Zero Energy Ready”

The Order of Importance

Enclosure Performance

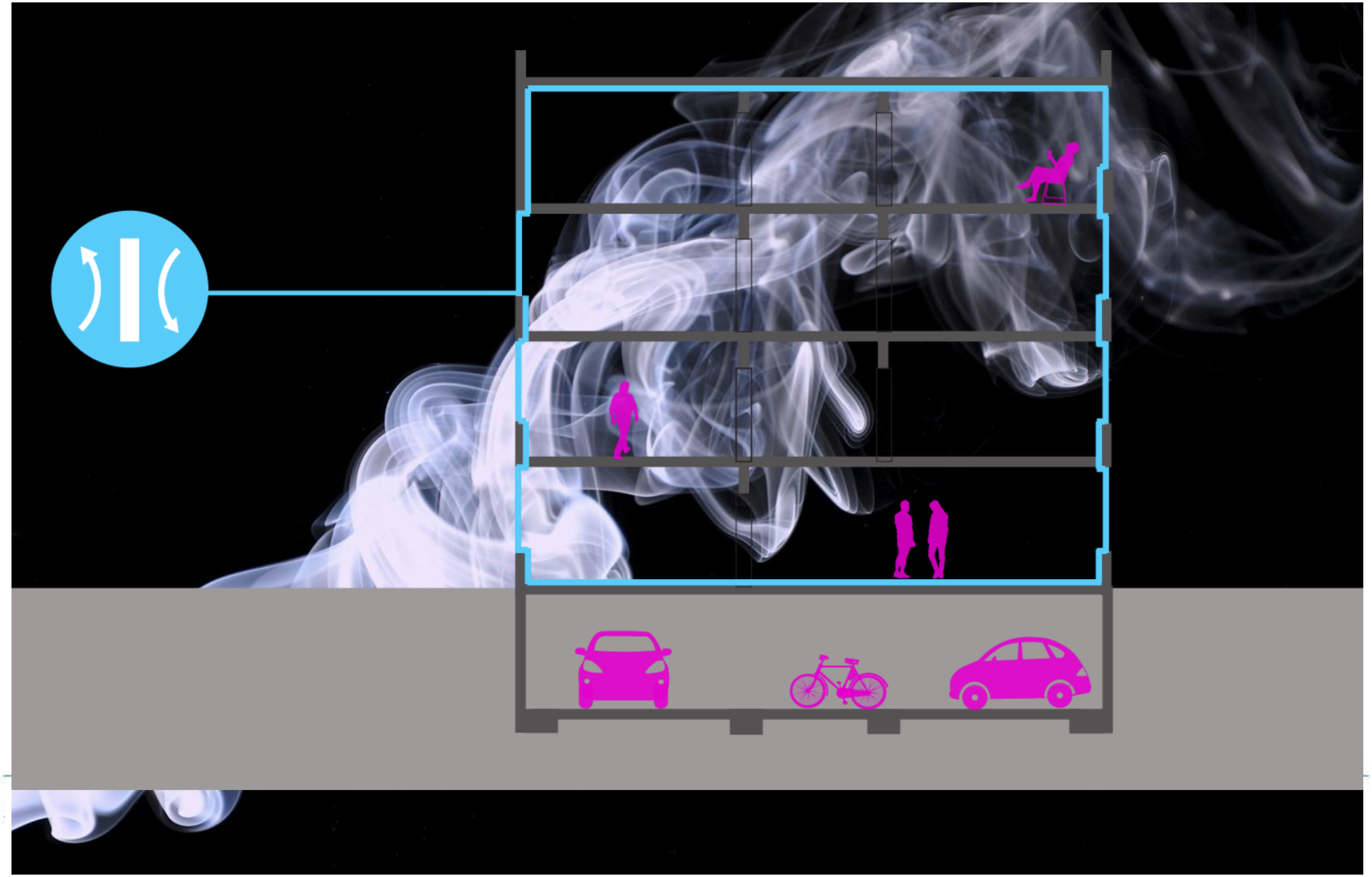
1. **WATER CONTROL**– shed it.
2. Ever greater **AIR CONTROL** – toward Passive House
3. More resilient **VAPOR CONTROL** – avoid mold
4. **THERMAL CONTROL** - toward thermal bridge free

WATER CONTROL – Shed it

Water Control

Or it will destroy your building…

AIR CONTROL



Why is airtightness so important?

It disproportionately affects fundamental aspects of building performance

Indoor Air Quality

Comfort

Durability

Energy Consumption

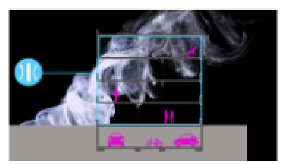
Joe Lstiburek:

"Air-sealing both sides of the wall is more important than the fluffing of the insulation in the cavity."

Building Science Camp 2012

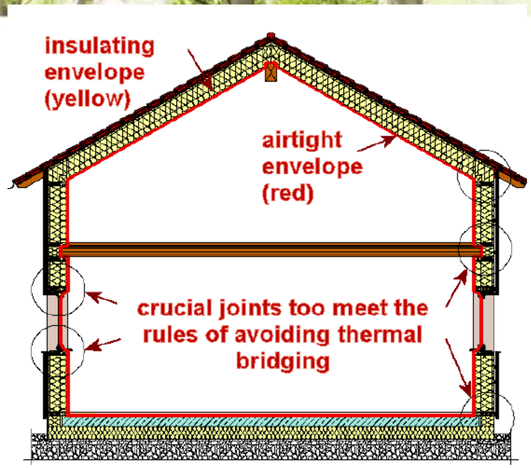
Order of importance

1. Water control
2. Air control
3. Vapor control
4. Thermal control



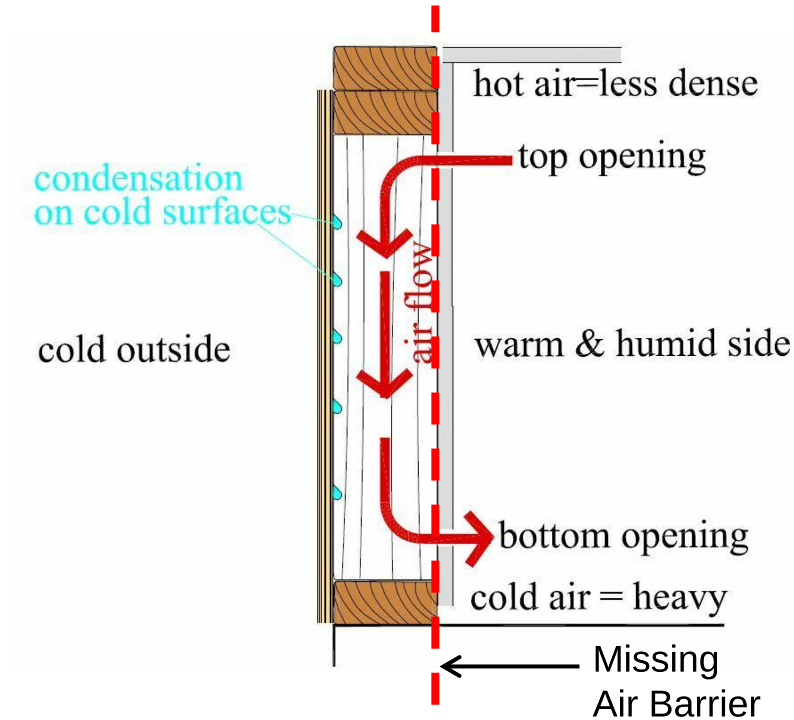
THE BLOWER DOOR DOESN'T LIE

Air Control

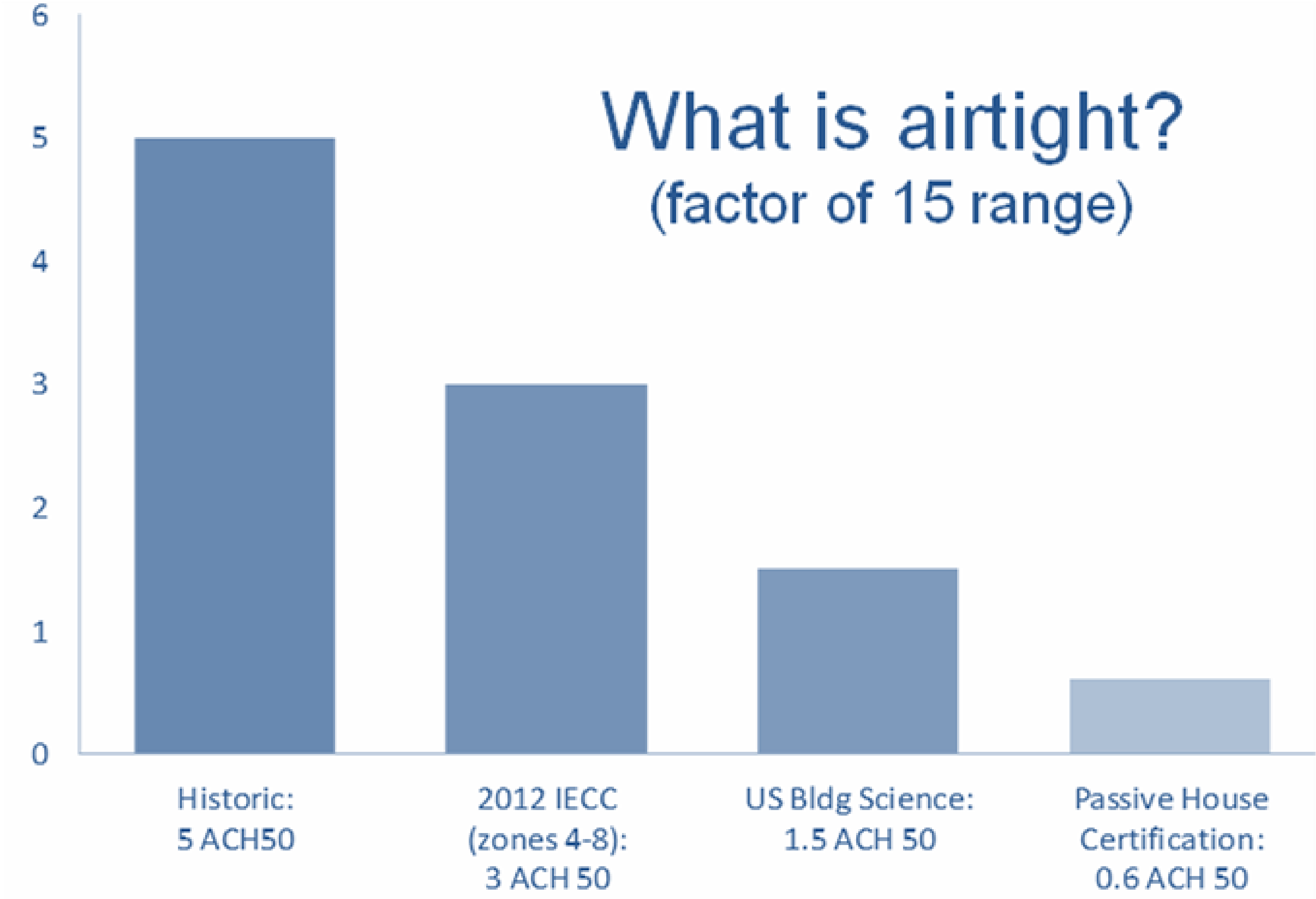


Ref http://passipedia.passiv.de/passipedia_en/

The Primary Air Barrier should be inboard of the insulation



475 HIGH PERFORMANCE BUILDING SUPPLY FOURSEVENFIVE.COM



Air Control Progression

Air Control:

Heating Load/Demand Correlation

Passive House verification

Building:	End-of-Terrace Passive House Kranichstein
Street:	
Postcode/City:	D-64289 Darmstadt
Country:	Germany/Hesse
Building Type:	Terraced House/Dwelling
Climate:	Standard Germany

Year of Construction:	1991	Interior Temperature:	20.0	°C
Number of Dwelling Units:	1	Internal Heat Gains:	2.1	W/m²
Enclosed Volume V_e:	665.0			
Number of Occupants:	4.5			

Specific building demands with reference to the treated floor area use: 0

				Requirements	Fulfilled?*
	Treated floor area	156.0	m²		
Space heating	Annual heating demand	14	kWh/(m²a)	15 kWh/(m²a)	yes
	Heating load	10	W/m²	10 W/m²	yes
Space cooling	Overall specific space cooling demand	1	kWh/(m²a)	20 kWh/(m²a)	yes
	Cooling load	9	W/m²	-	yes
	Frequency of overheating (> 25 °C)	0.6	%	-	-
Primary Energy	Space heating and cooling, dehumidification, household electricity.	61	kWh/(m²a)	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	34	kWh/(m²a)	-	-
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	-

Infiltration air change rate

Wind protection coefficient, e			-	0.07
Wind protection coefficient, f			-	15
Air Change Rate at Press. Test	n_{50}	1/h	-	0.22

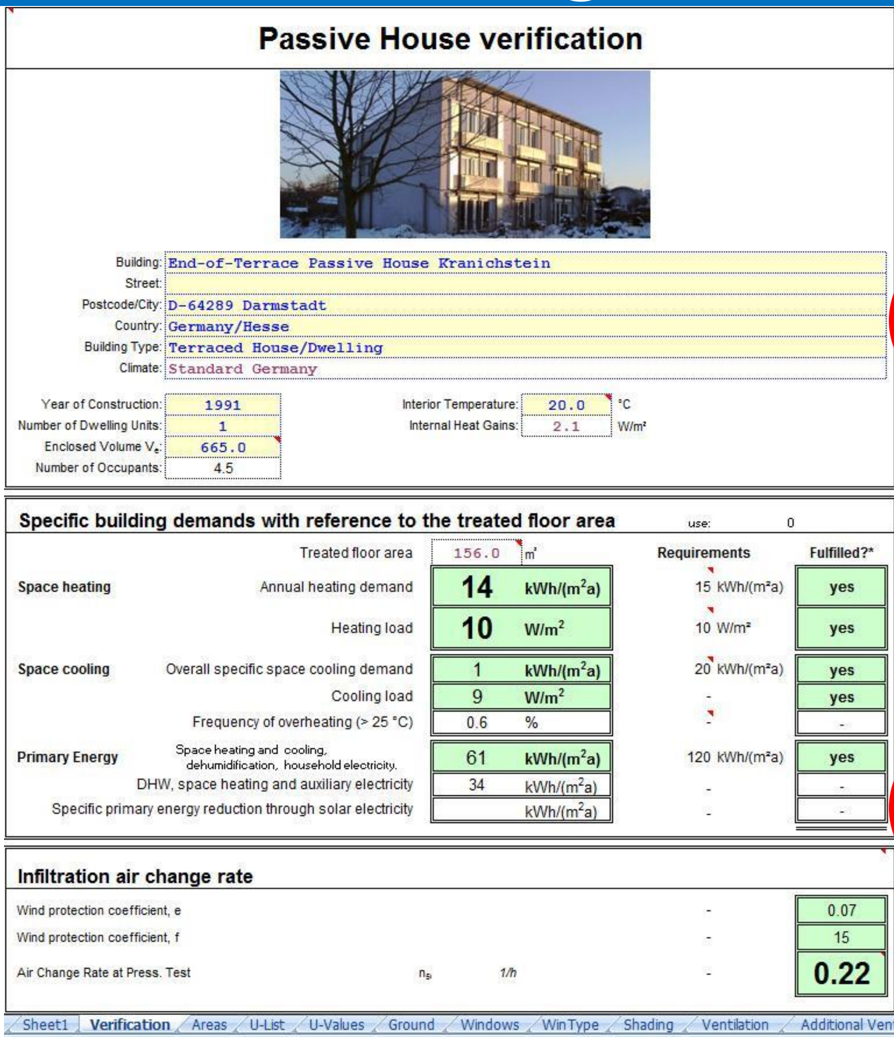
Sheet1 | Verification | Areas | U-List | U-Values | Ground | Windows | WinType | Shading | Ventilation | Additional Vent

ACH50	Annual Heating Demand	Heating Load
0.22 ACH50	14 kWh/(m²a)	10 W/m²
0.60 ACH50	15.4 kWh/(m²a)	12 W/
1.50 ACH50	20 kW	
3.0		
		36 W/m²

Certified Passive House

Air Control:

Heating Load/Demand Correlation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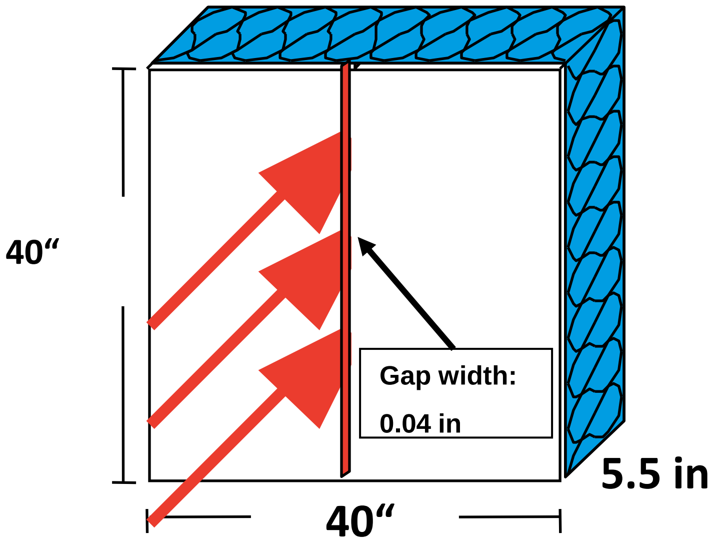
1.50 ACH50	20 kWh/(m²a)	17 W/m²
3.00 ACH50	27 kWh/(m²a)	25 W/m²
5.00 ACH50	38 kWh/(m²a)	36 W/m²

Wetting of the enclosure from inside

Moisture Load: Diffusion and Convection



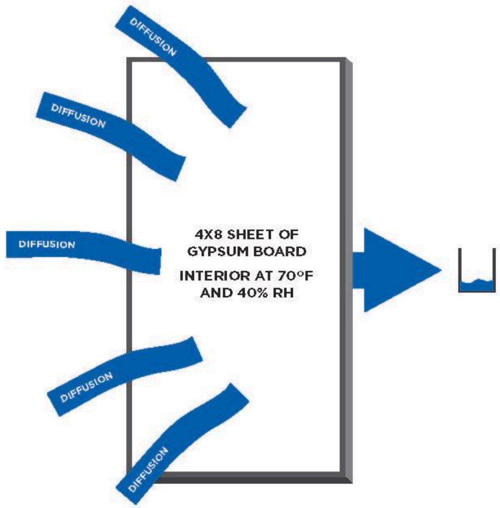
Difference of 1600x

Without gap: Diffusion 0.3 perms:
e.g. Intelligent vapor retarder: **0.017oz water/10 sqft x24h**

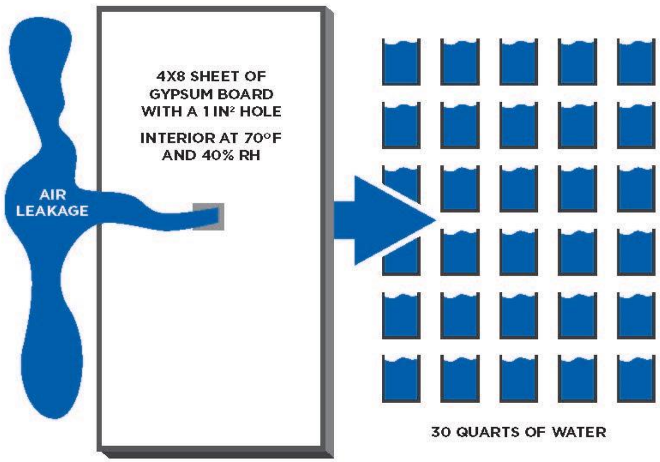
Without a gap: Diffusion 35 perms
e.g. Painted sheetrock: **5.3 oz water/ 10 sqft x24h**

With a 0.04 in gap: No vapor diffusion
Only vapor convection: **28.2 oz water/3,17 ft x 24h**

VAPOUR CONTROL



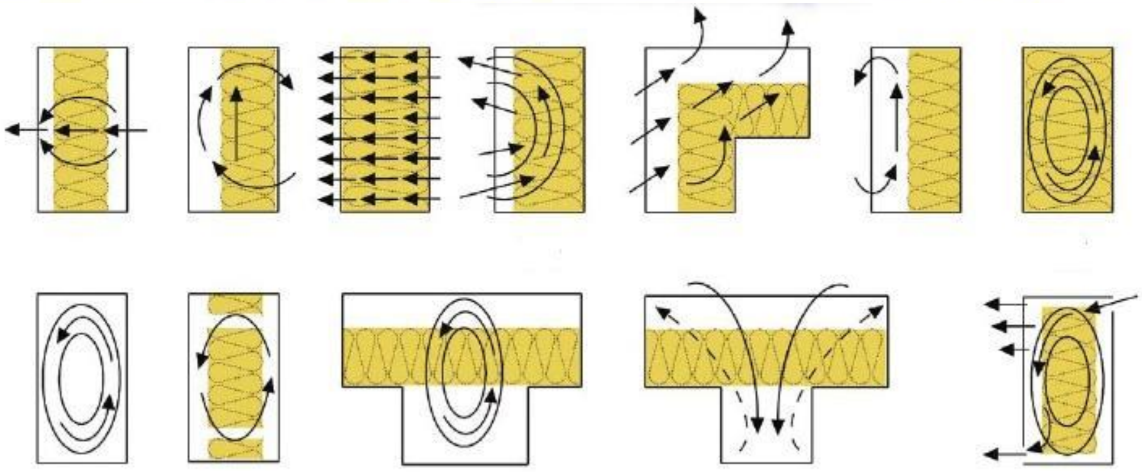
AIR CONTROL



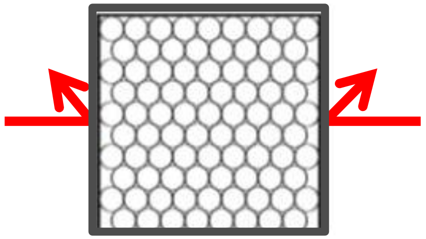
Disproportionately effects:

1. Indoor air quality: control the air to control the quality
2. Comfort: drafts are uncomfortable
3. **Air transported wetting: a bigger liability than diffusion wetting**
4. Heat loss & energy efficiency

Air Control Fundamentally Effective

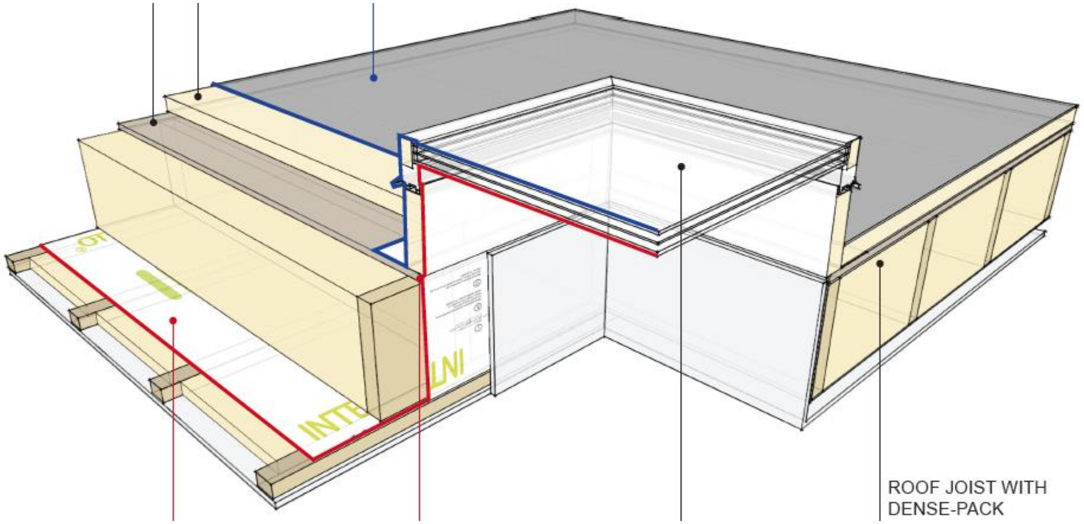


Mark Siddall

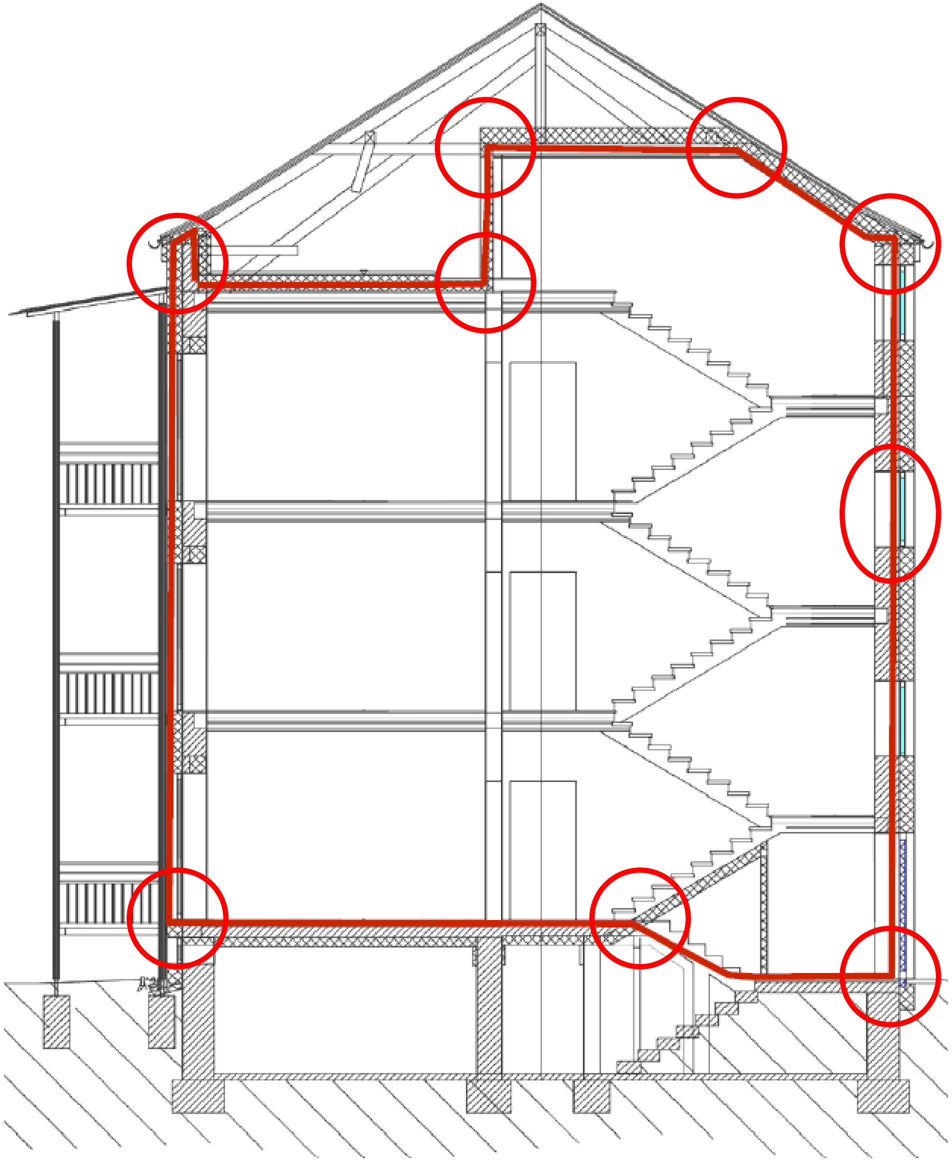


To optimize insulation **surround it** with airtightness on all 6 sides.

Primary Inboard
Secondary Outboard
(windtight)



Thermal bypass



1. Robust materials
2. Simplify the details
3. Consider the sequence
4. Seal penetrations
5. Repairable and verified
6. Protected

Continuity: In Design & Construction

ASTM E2357 Testing

ASTM E2357 Testing

Inboard:

- Primary Air Barrier
- Tightest PHI Certified Membrane System
- Vapor Control Layer

Outboard:

- Secondary Air Barrier
- ~~vapor open~~
- **FLATROOF membrane**

Air Control

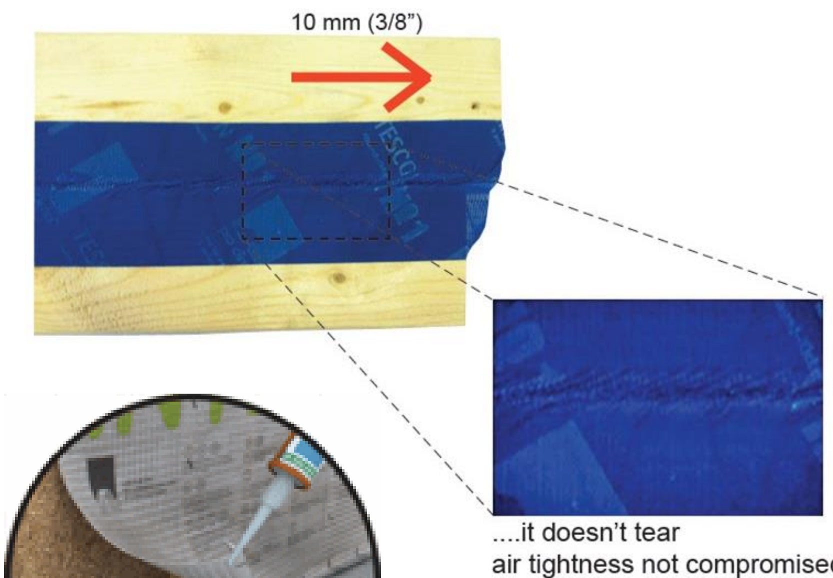
Robust Air Barriers? …. (Lab-) Tested?!

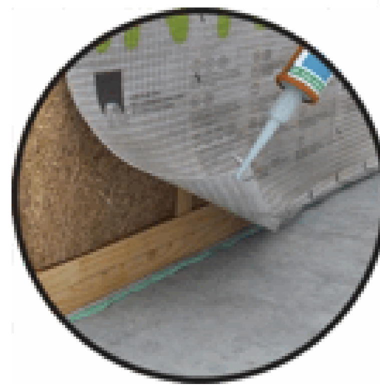
Foam is Not airtight or optimal

Traditional

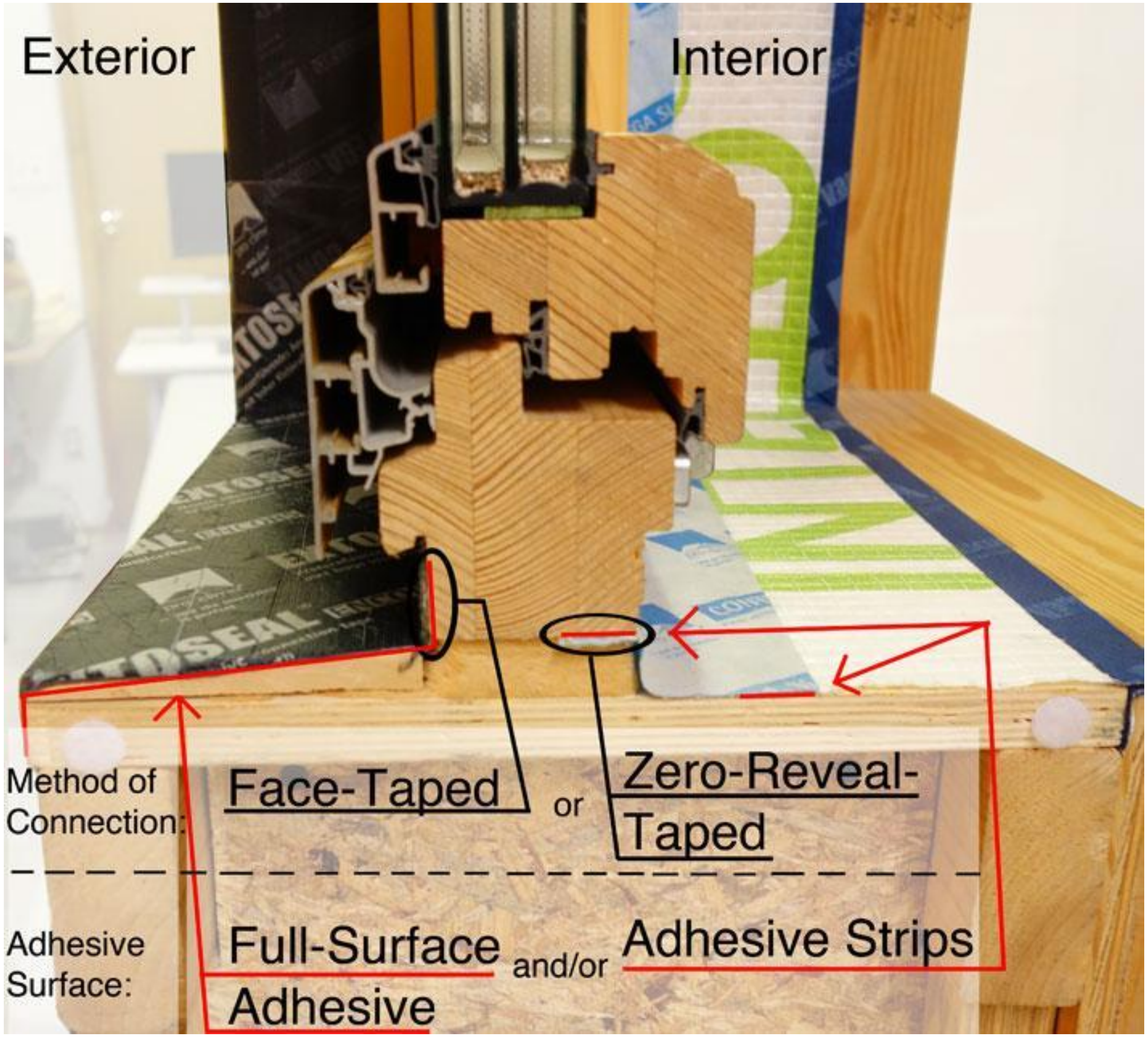
- Many sealants dry, embrittle and fail over time

New Approach





Robust Connections are Essential



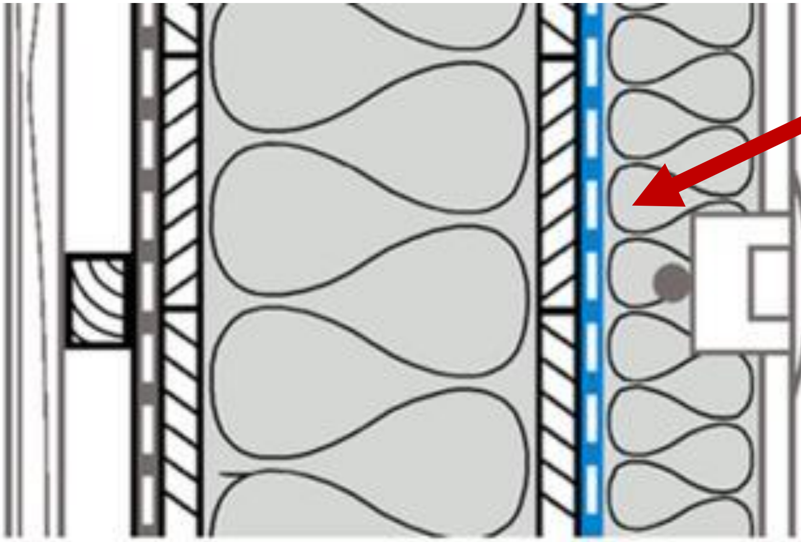
Window integration

Air Control

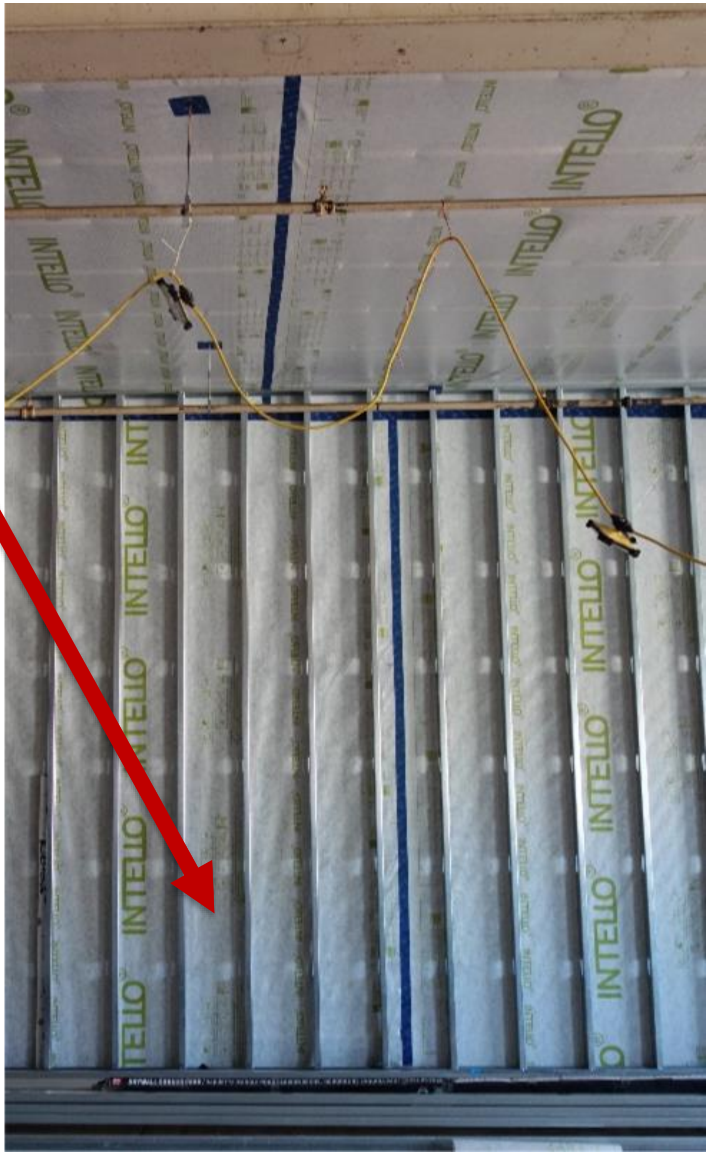
Allow for room to gasket properly

Credit: Ed May, BldgTYp

Wire and Pipe Penetration Sealing

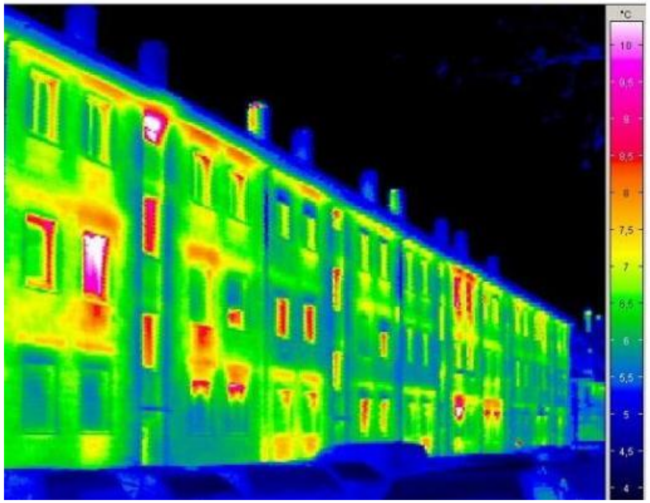


Service cavity protects airtight layer



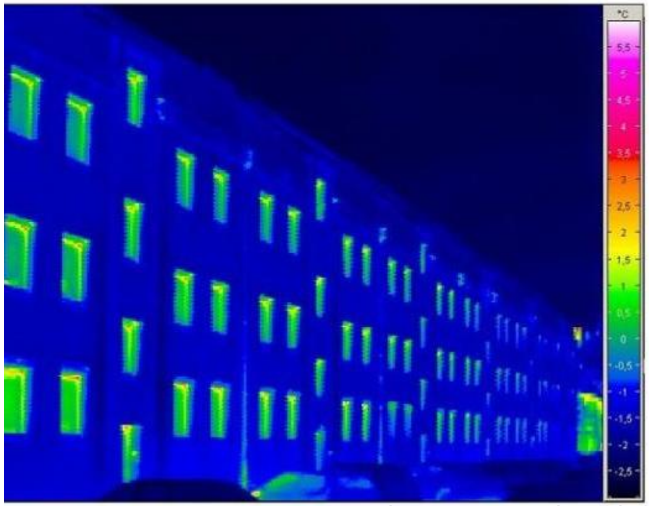
Service Cavity

VAPOR CONTROL



Passive House Institute (PHI)

Pinkbrownstone



Passive House Institute (PHI)

Poorly insulated buildings heat themselves dry.

Well built assemblies dry through vapor diffusion.

“Stuff happens so build a moisture tolerant design”

Smart Vapor Control

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Work with the Dominant Vapor Drive…

Go with the Flow

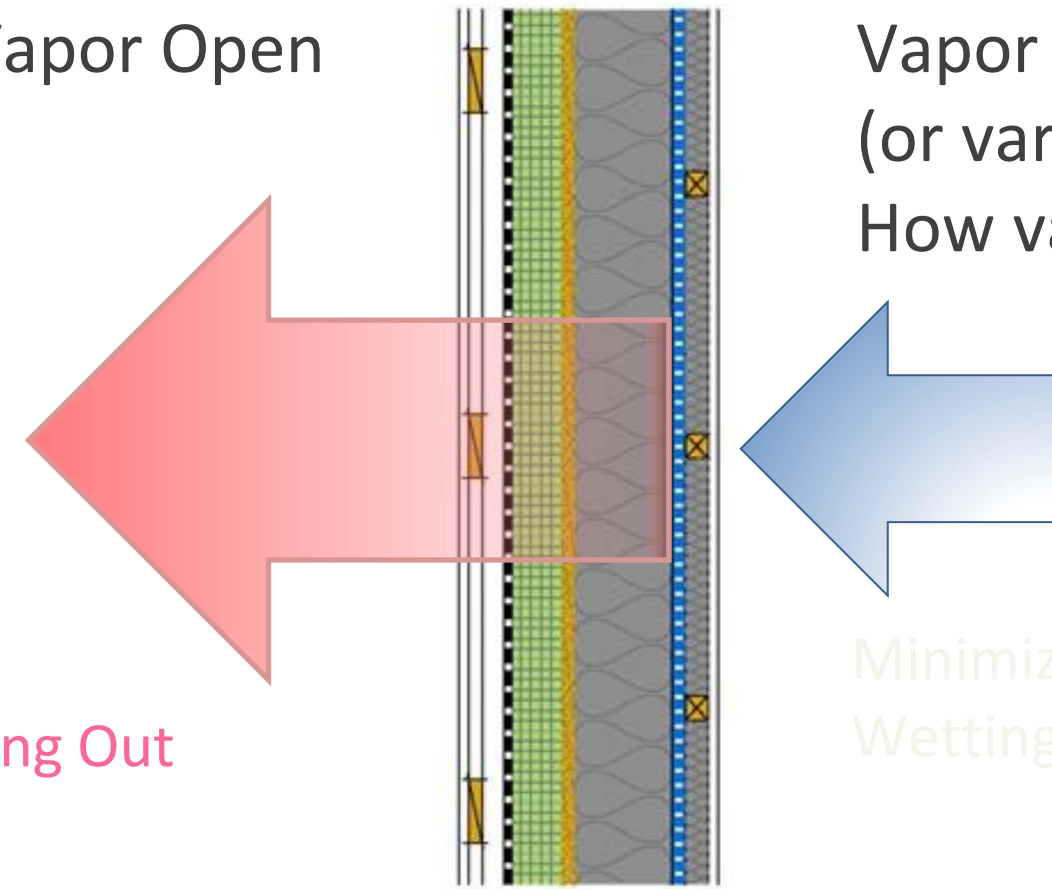
Outside

Winter

Inside

Vapor Open

Vapor Retarding
(or variable)
How variable?



Minimize Potential
Wetting from Inside

Drying Out

Winter Drives Outward

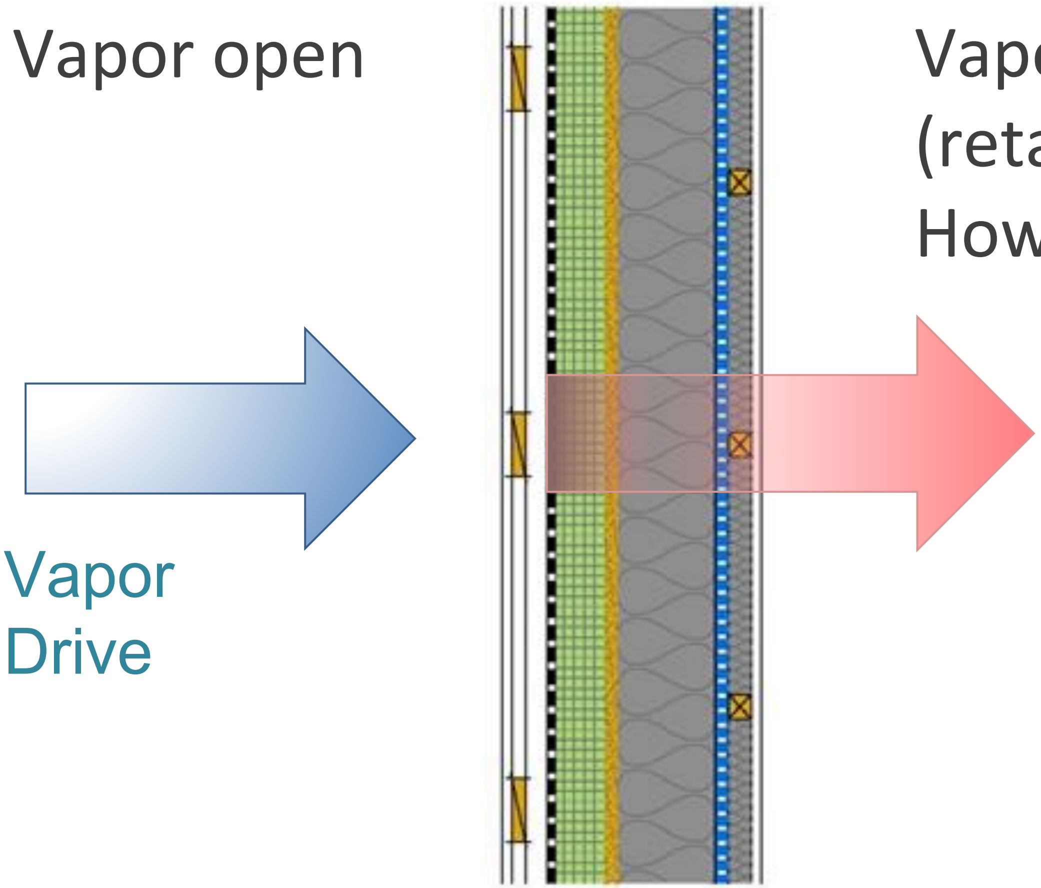
Outside

Summer

Inside

Vapor open

Vapor Open
(retarding/variable)
How variable?



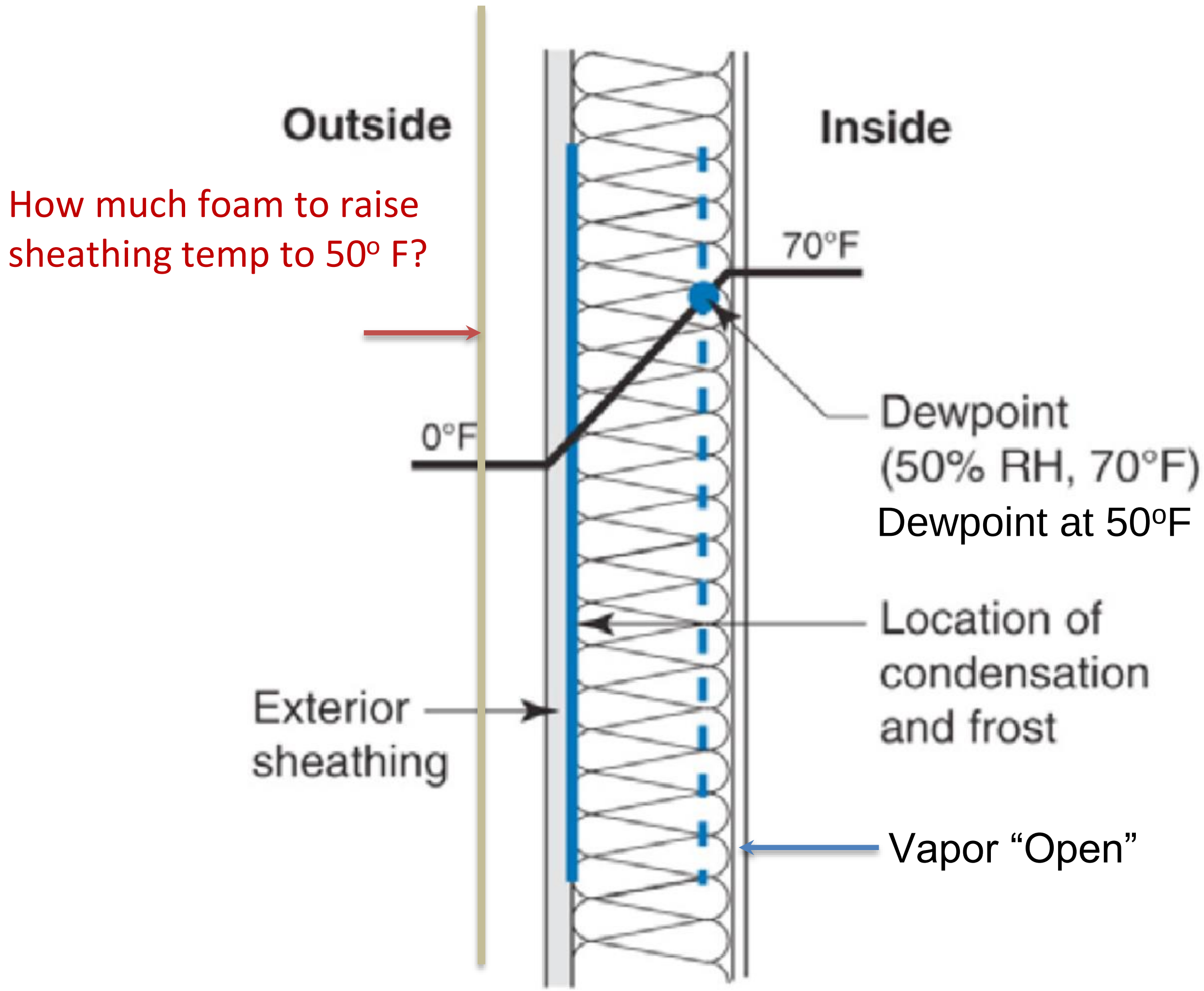
Vapor
Drive

Drying In

Summer Drives Inward

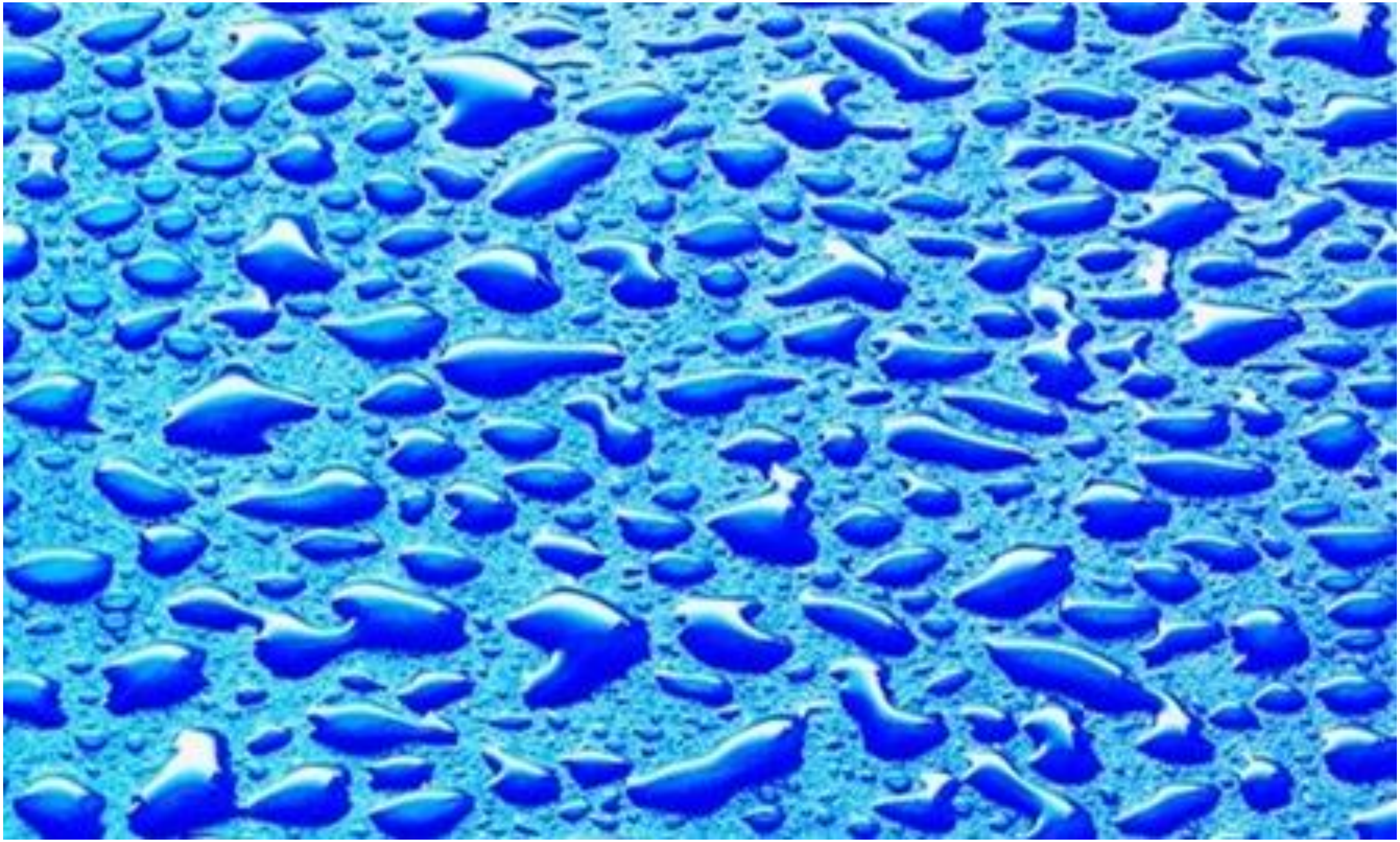
Credit: Synergy Companies Construction LLC

Why are we installing vapor dams?



Credit: Building Science Corp.
www.buildingscience.com

Foam is Addressing Dew Point



Foam is Hydrophobic and doesn't aid drying

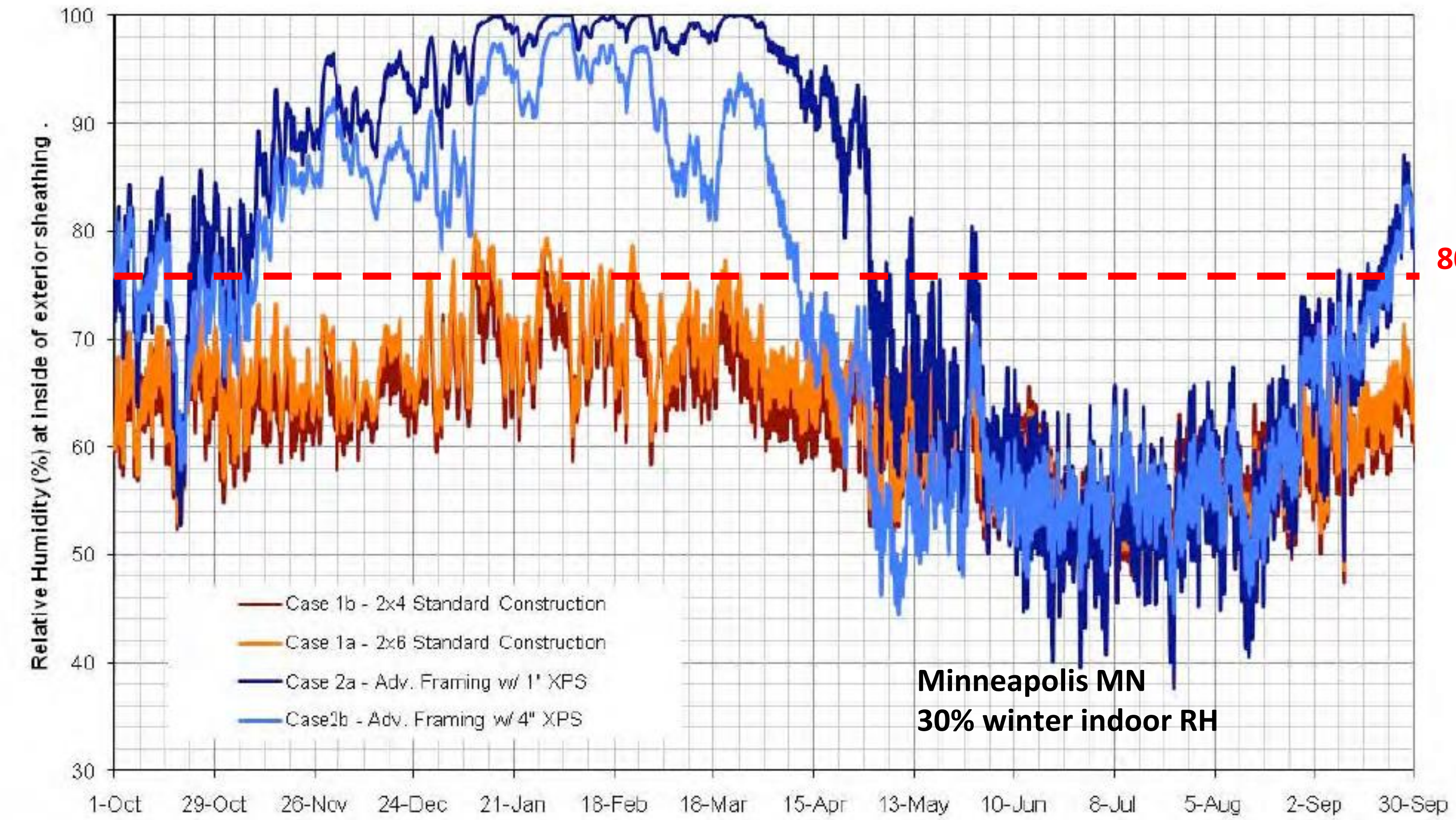


Figure 9 : Winter time sheathing relative humidity for Case 1 and Case 2

Credit: Building Science Corp, Building America Special Research Project: High R Walls Case Study Analysis

Foam can make wetness

Vapor Control

Foam makes enclosures more intolerant

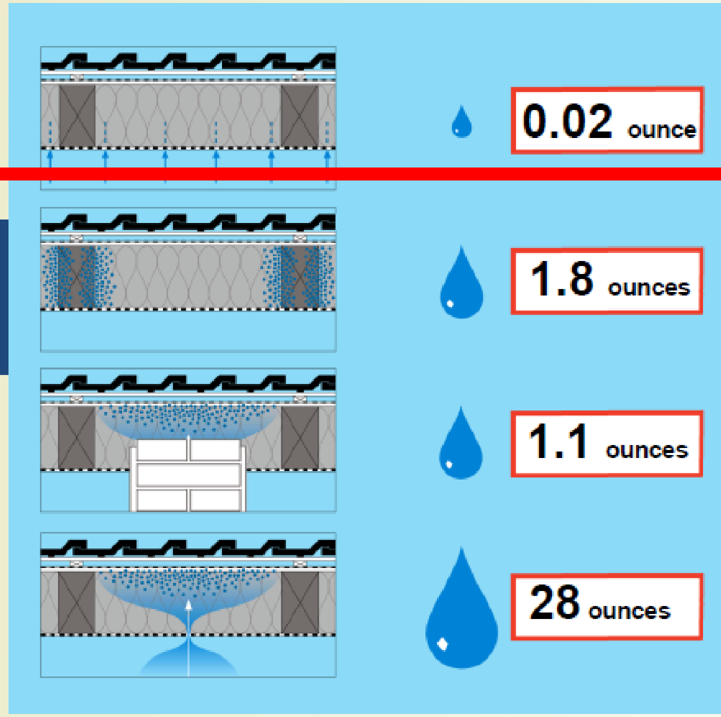
Vapor Control

Diffusion

Wet Construction

Flank diffusion

Convection 1 mm gap



In winter construction is exposed to moisture

Only Diffusion is calculated during the planning process

Conclusion:

There is no absolute protection against moisture

Note: Many sources of moisture

Credit: Ed May, http://bldgtypblog.blogspot.com/


Credit: Gutex woodfiber board insulation

Vapor Open Sheathing at Exterior

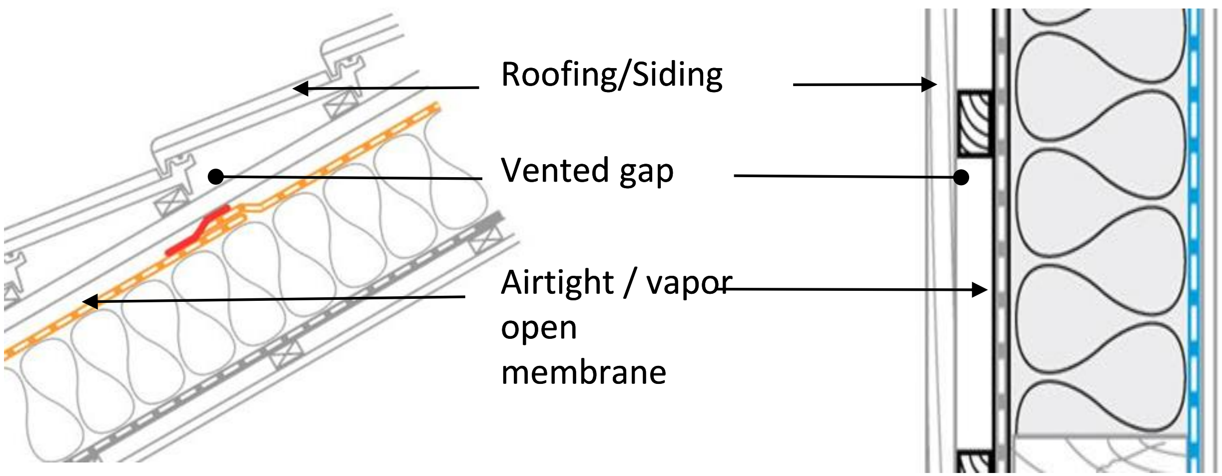
Vapor Control

Or No (exterior) Sheathing

Vapor Control


Credit: Three Tree Home Performance

Or No Sheathing at All!



(Roofs and Walls)

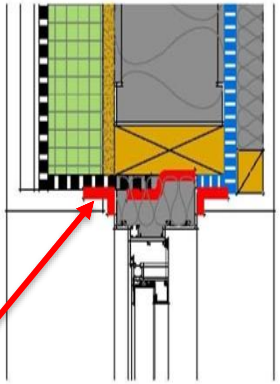
Back Vented Rain Screens

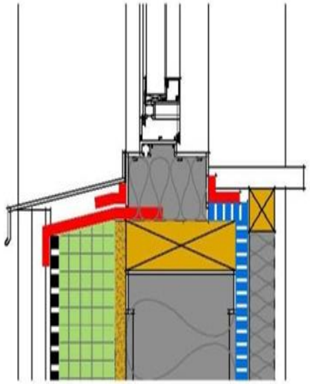
Traditional
Vapor barrier tape

At sill, high quality modified butyl-acrylic tape - is vapor closed
but doesn't lap over ext >1"
no vapor damming!

New Options
Vapor permeable tape

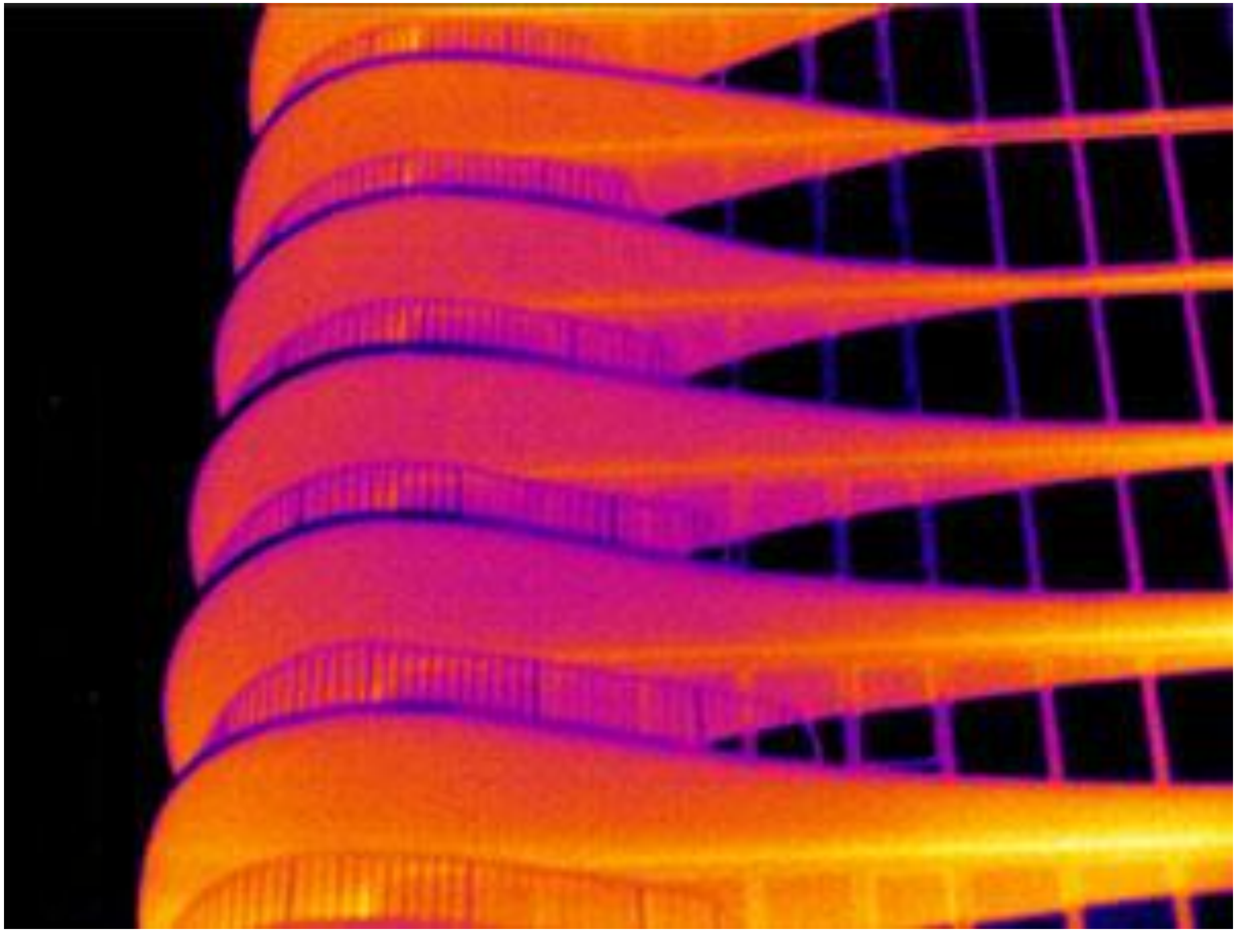
Vapor Open Tapes And Membranes





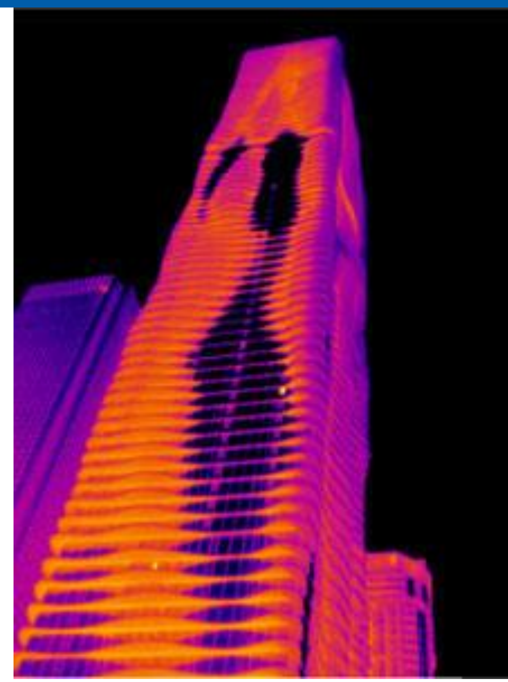
Don't Dam Moisture Around Openings

THERMAL CONTROL

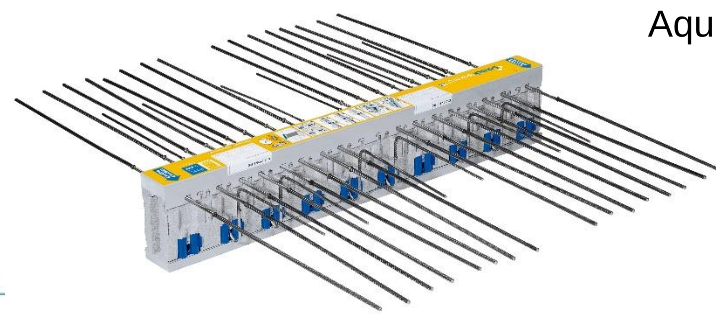


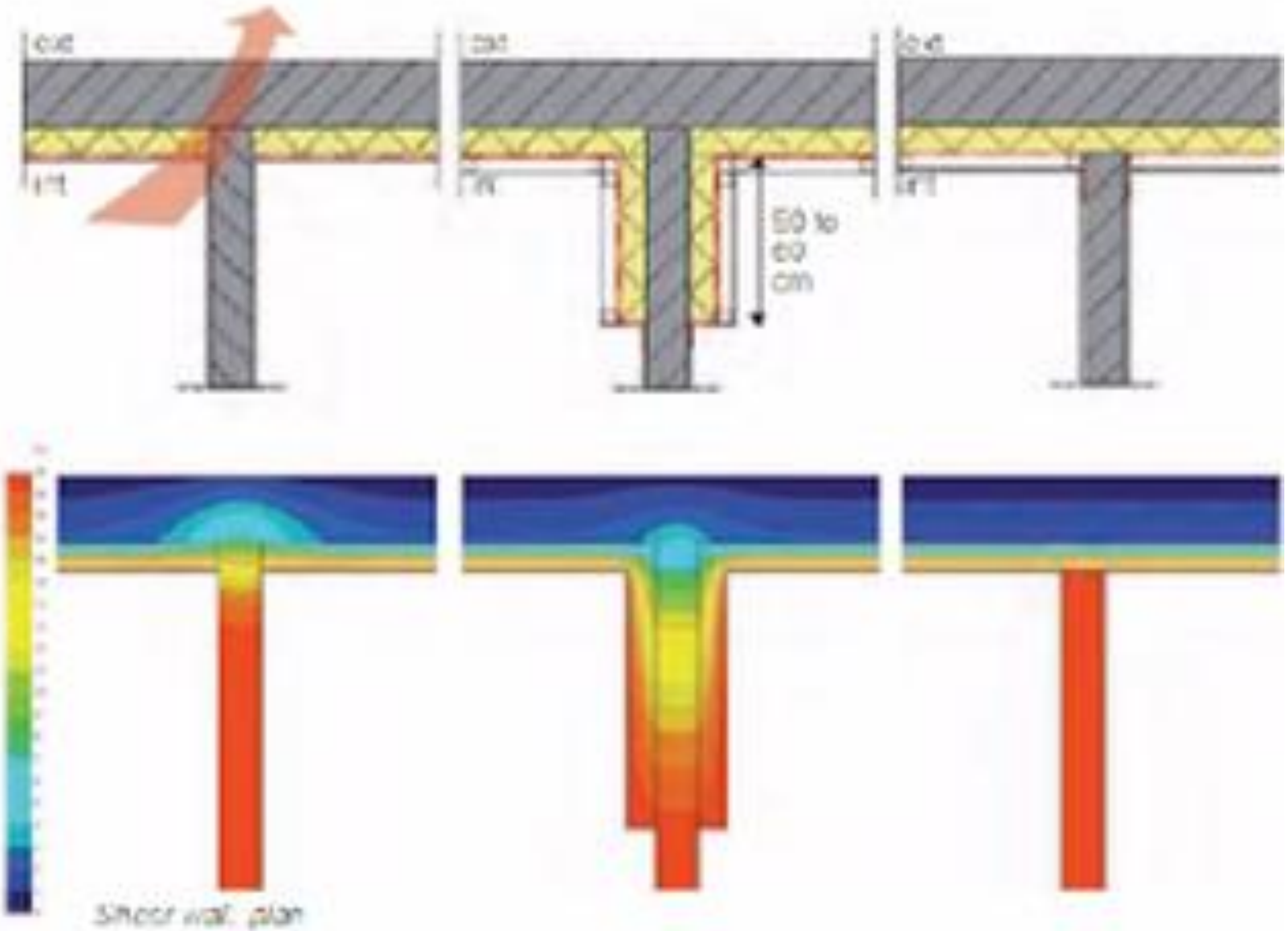
THERMAL CONTROL

- Enclosure
  - Continuous insulation
  - Thermal bridge free joints and penetrations
- THINK THERMOS



Aqua Tower, Chicago

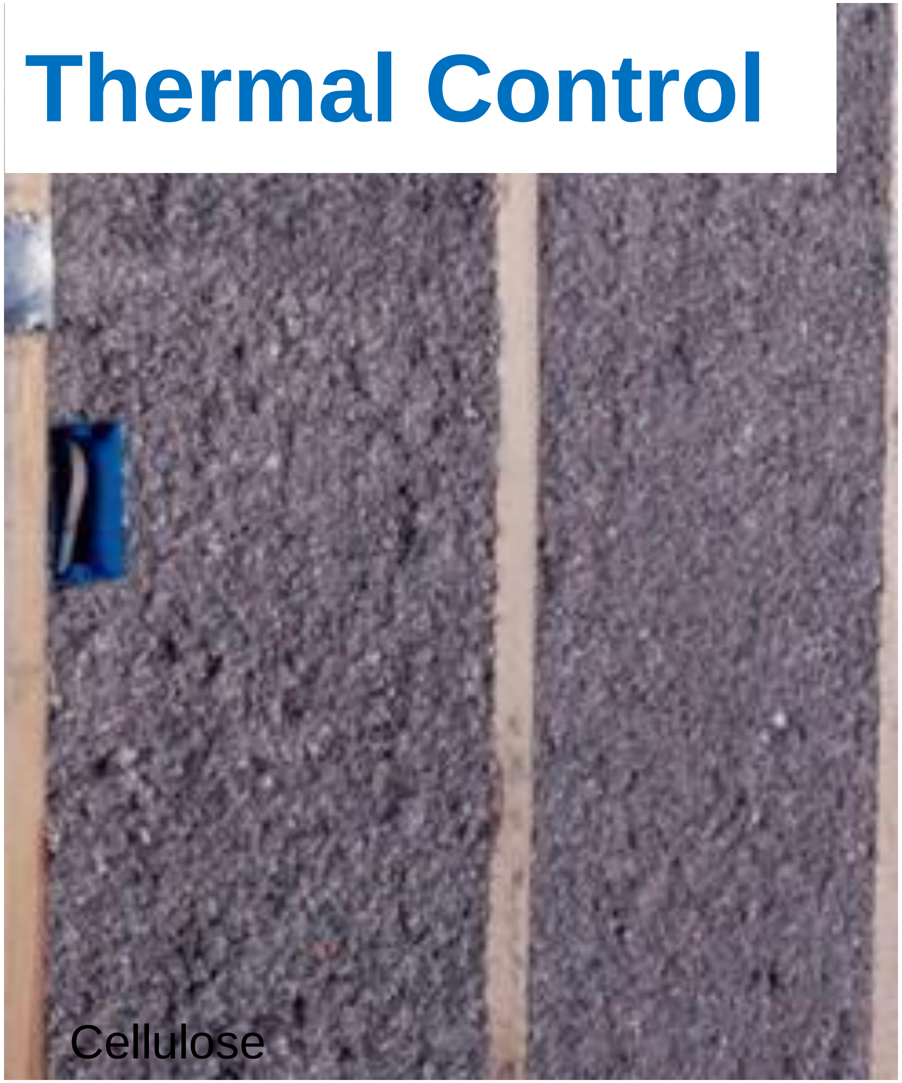




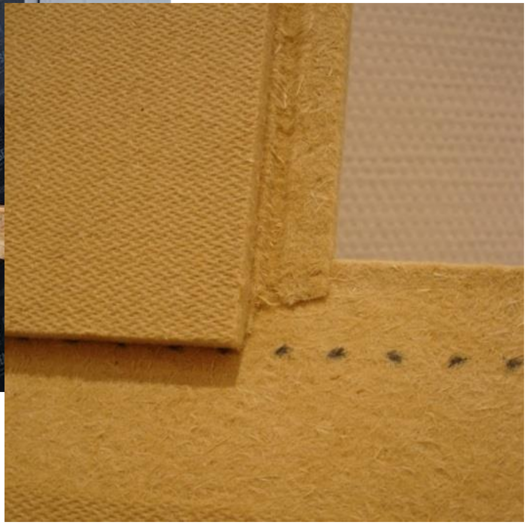
A2M, Passive + Architecture

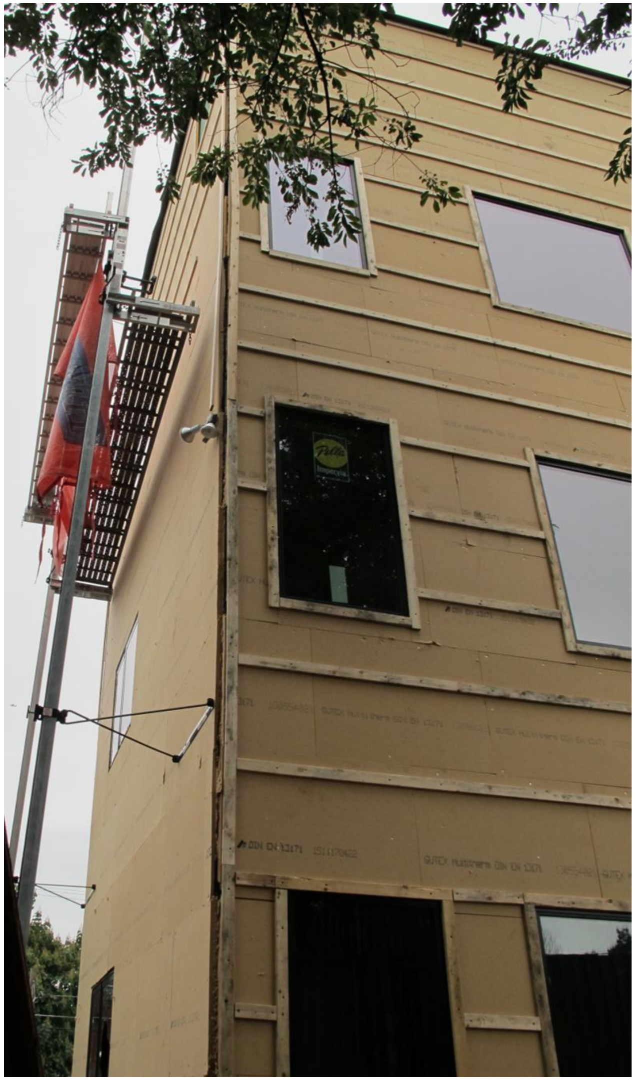
Thermal Breaks

Thermal Control

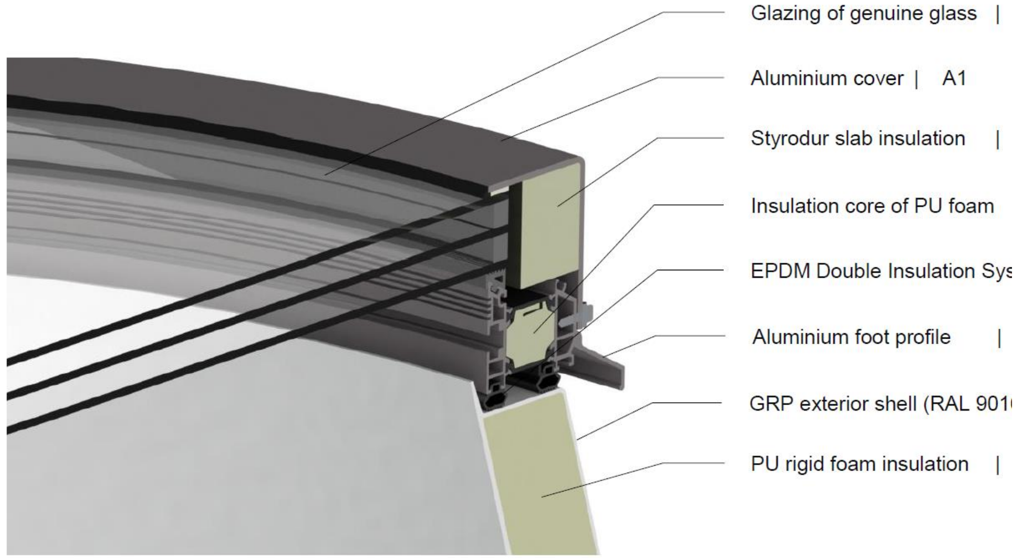


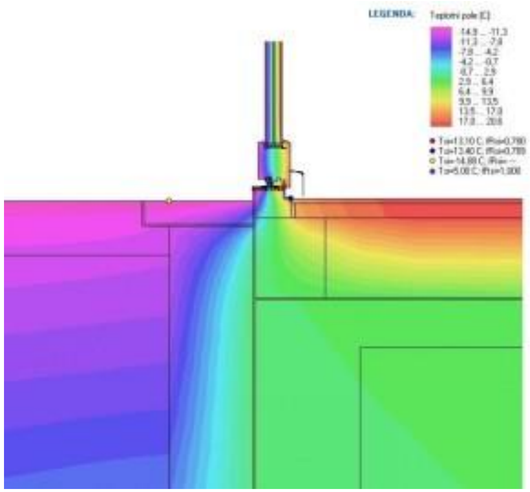
Consider an Insulation that Helps Drying





Outboard Vapor Open Insulation

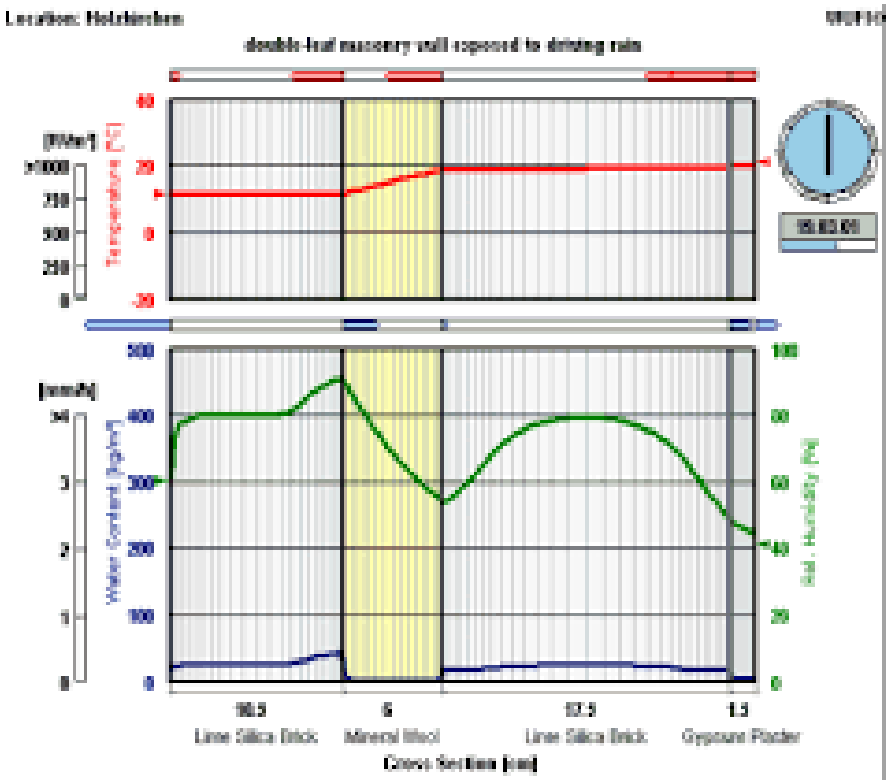




Thermal Breaks (…almost foam free)

About Using WUFI Pro

- A relative risk assessment not an absolute risk assessment
- Examining for high moisture risk at critical components
- 5-10 year analysis
- Using Moisture Content as proxy
  - <15%MC = safe/low risk OSB, plywood
  - <18%MC = acceptable risk for wood> OSB?
  - 20%MC = danger threshold, significant risk also for solid wood
  - >20%MC = rising risks
- Higher insulation values = Higher risks
- Don't design safety factors out of the wall: maintain drying reserves

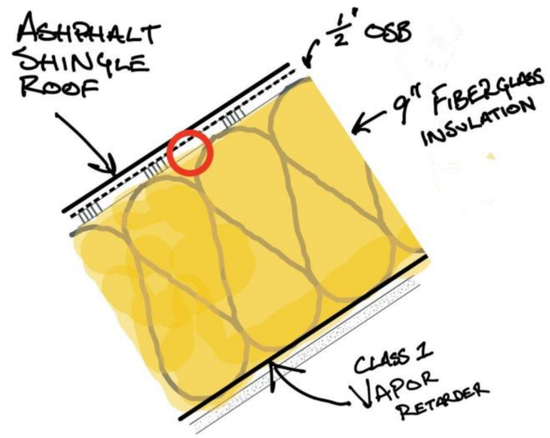


Moisture-Driven Damages

- Condensation
- Wood rot
- Corrosion
- Interstitial mold
- Freeze-thaw

Design Methods

Dewpoint vs Dynamic Method (ASHRAE 160)

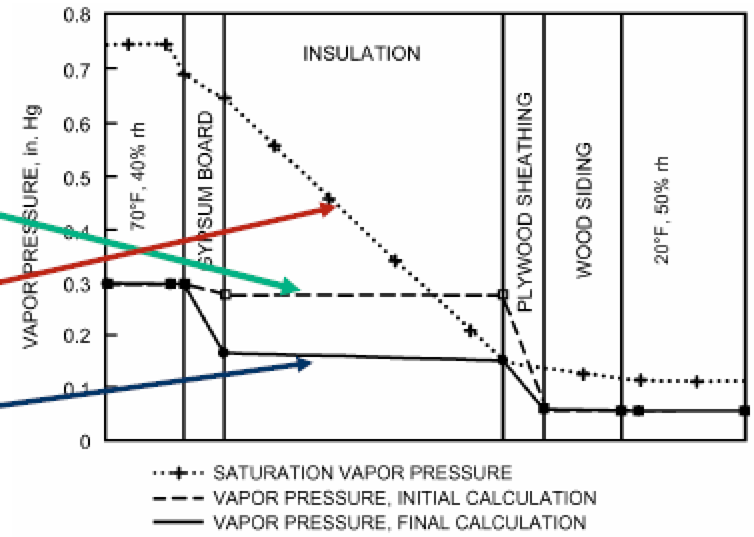


Winter time snap shot....

From steady-state to transient

Glaser / Dew Point Method

- Plot vapor pressure gradient for steady-state conditions
- Determine temperature gradient and plot saturation pressure gradient
- Adjust vapor pressure gradient so it does not cross saturation pressure and calculate from that influx and efflux of moisture



Problems

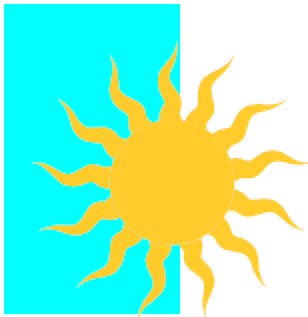
- no heat and moisture storage
- no liquid flow
- no coupling of heat and moisture transfer

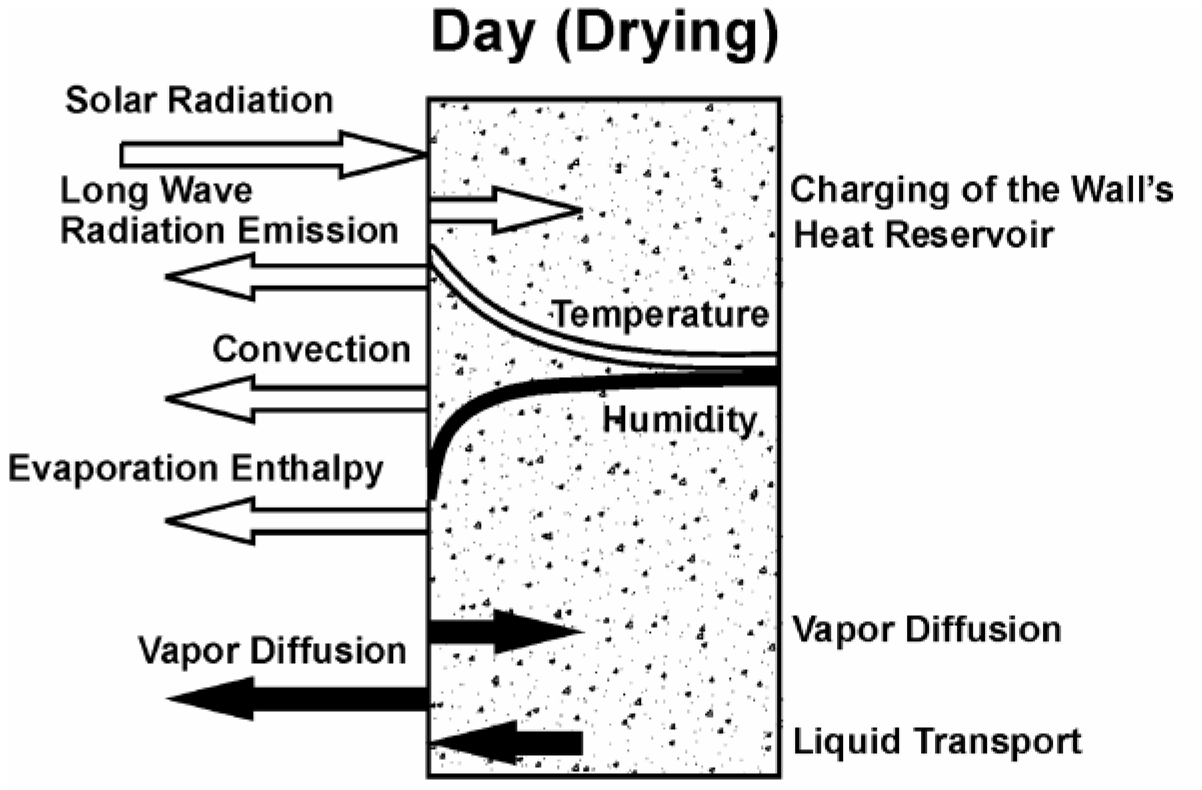
Inputs

Interior Conditions	Exterior Conditions	Interstitial Conditions
(Dynamic)	(Dewpoint vs Dynamic)	(Dynamic)
• Occupancy • ACH50 • Ventilation rate	• T (fixed vs hourly) • RH (fixed vs hourly) • Wind (none vs dynamic) • Rain (none vs dynamic)	Assumed embedded moisture after construction

Hourly calculations!

- From steady-state to transient

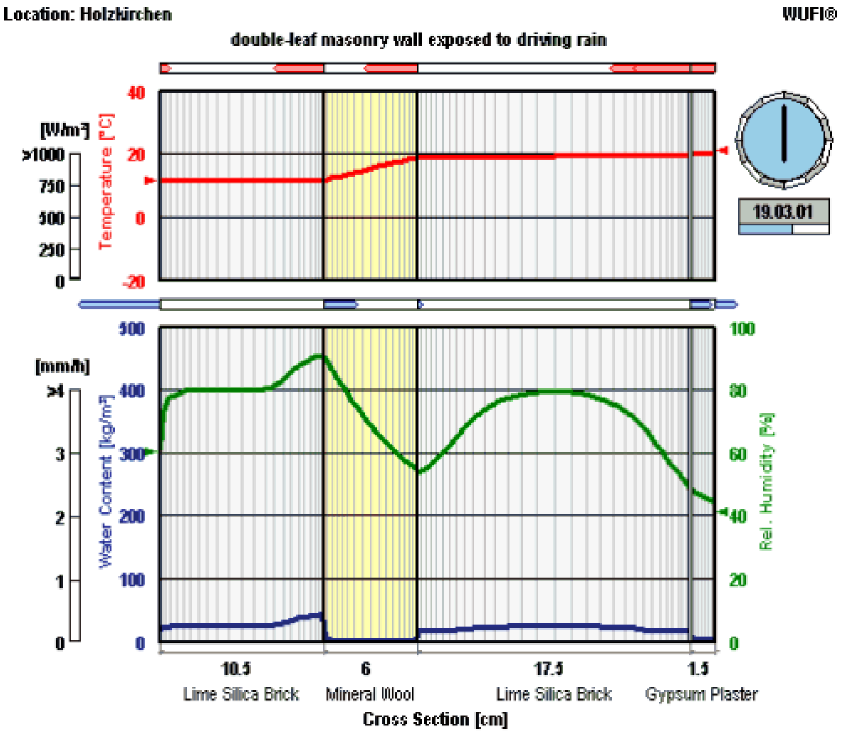




Heat, air and moisture transfer

WUFI: Wärme und **Feuchte instationär**

- The tool: WUFI Pro (6.3) with plug-ins
- Calculation/assement. To be confident in an assembly design
- Prevents risky assembly, guides design before construction or damages occur
- Code compliance: ASHREA 160p or DIN EN 15026:
  - "design using accepted engineering practice for hygrothermal analysis" as described in 1404.3 (walls) etc.



Performance assements

Takes time! Test huts

To validate

Computer model....

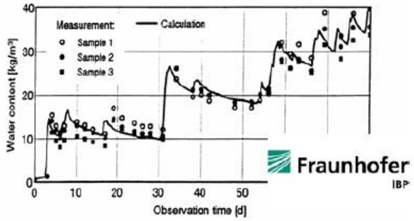
Previous Assessment

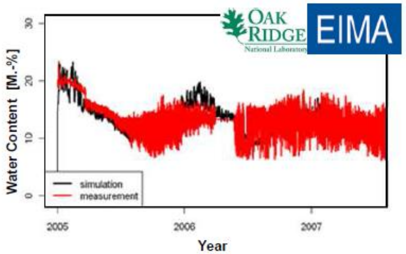
Field tests:

- Solution to climate dilemma
- Very time consuming
- Very expensive
- Search for alternative ways to investigate hygrothermal performance

Fraunhofer IBP, Germany

WUFI model validation

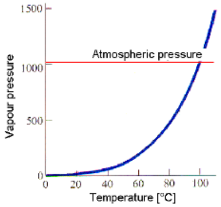


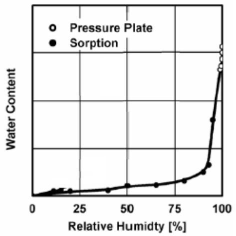


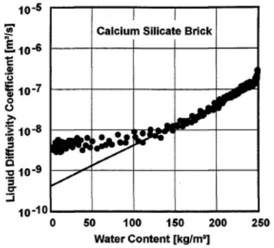
SmartSOL

Heat vs. Moisture

Hygrothermal material properties are highly non-linear.
(unlike thermal material properties)



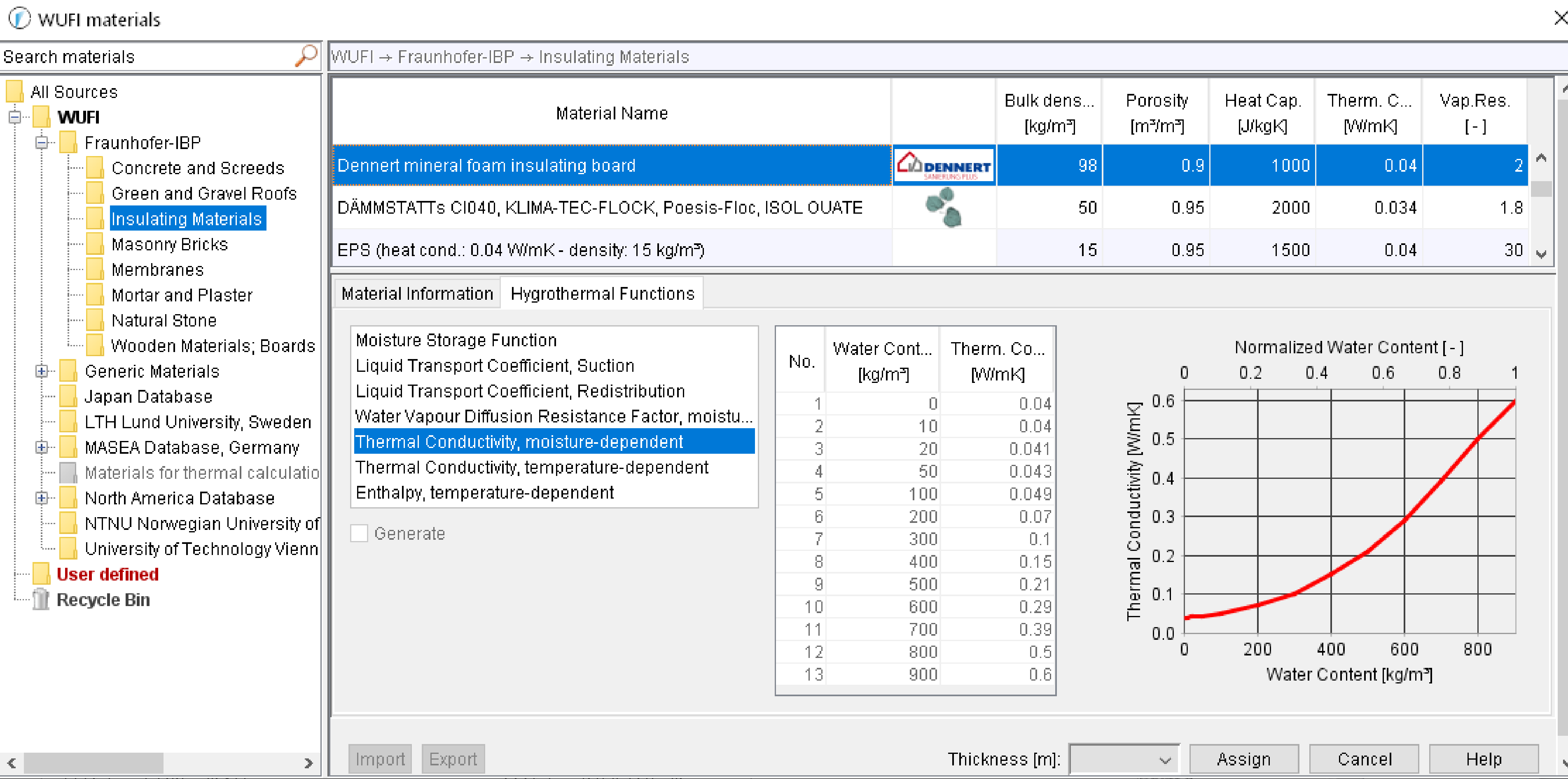




SmartSOL

Material values are not static

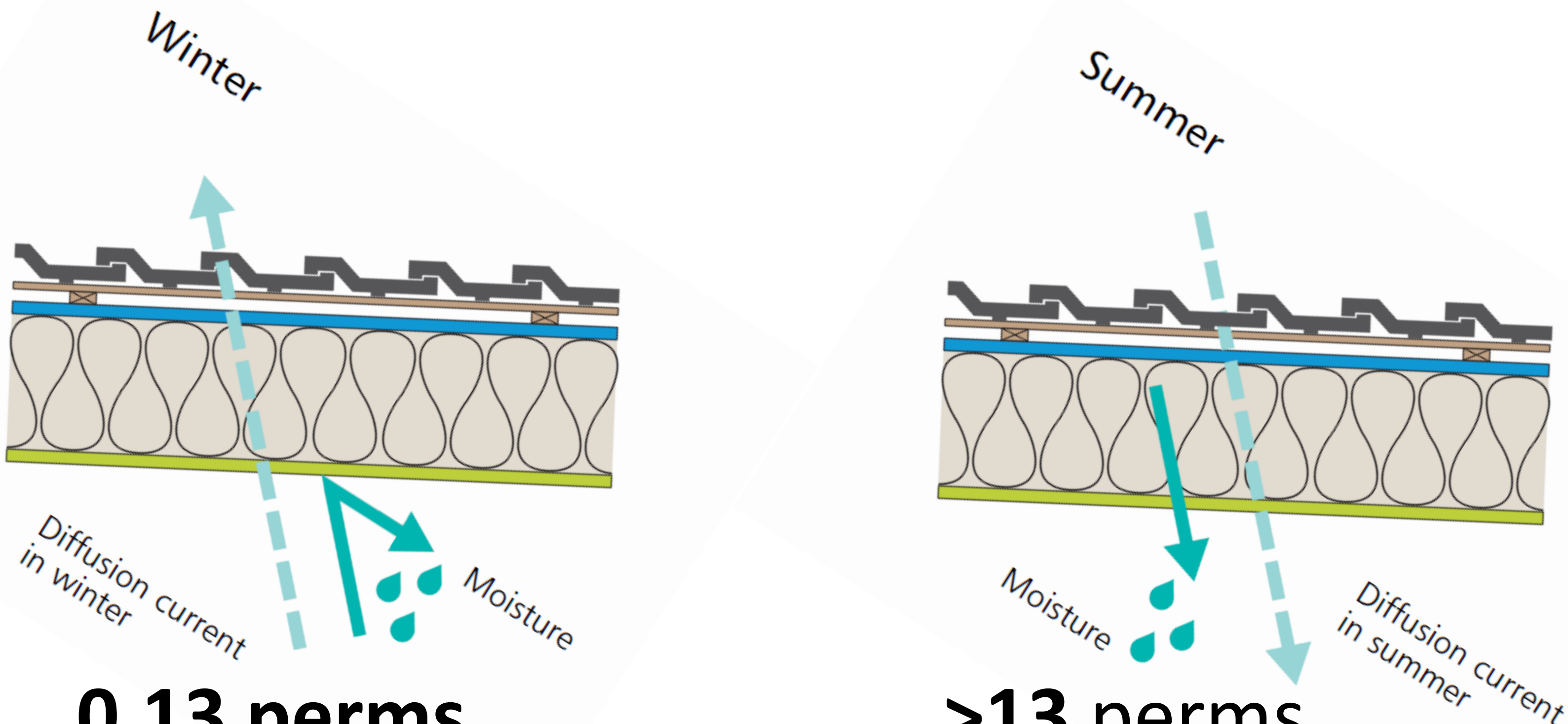
Fibrous ins can see R-value reduced by factor 10 (from 30 to 70% h2o)



Intelligent vapor retarders:

prevent wetting and **promote drying**

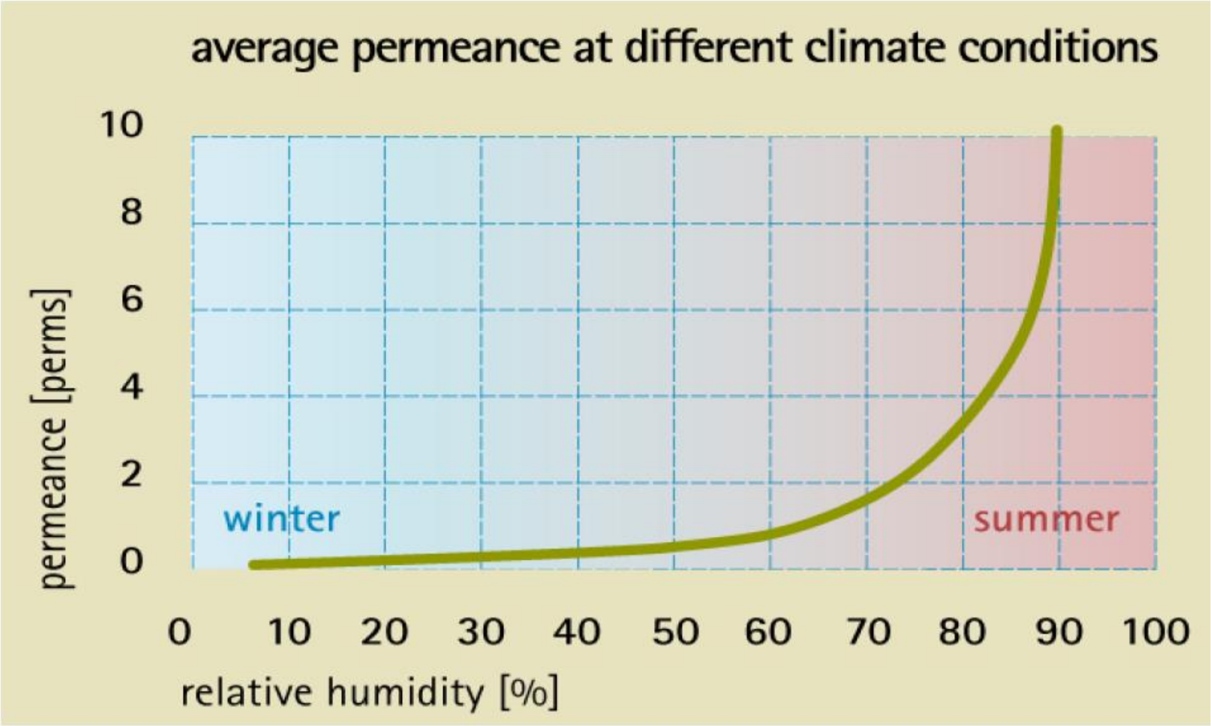
for **maximum protection (factor 100)**



0.13 perms **>13** perms

But when/how – where/why

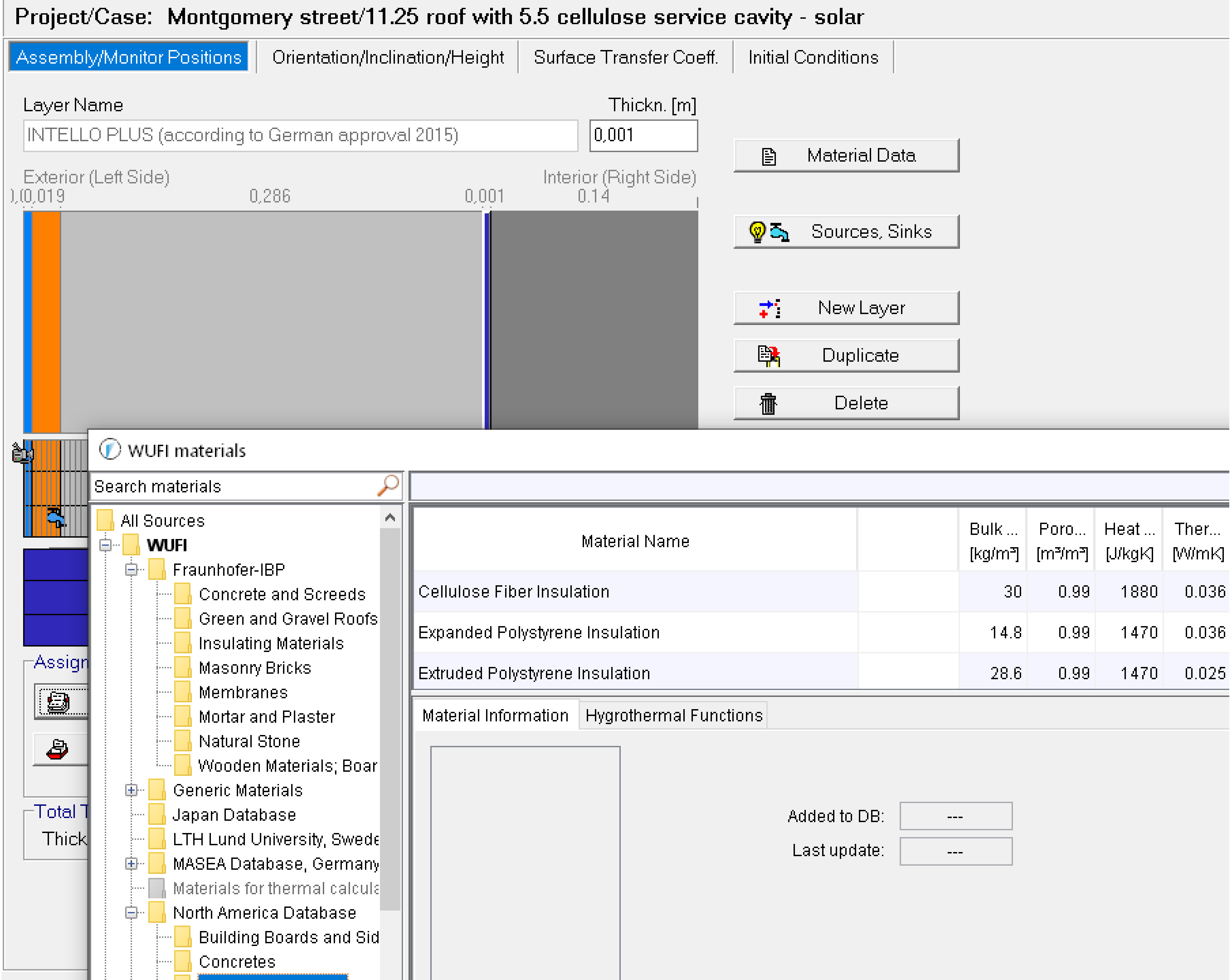
Vapor **Intelligent Membrane**



From vapor closed in winter to vapor open in summer

<2.2 perms till 70%RH – prevents during winter construction etc

Hydrosafe Smart Vapor Control


Project/Case: Montgomery street/11.25 roof with 5.5 cellulose service cavity - solar
Assembly/Monitor Positions
Orientation/Inclination/Height
Surface Transfer Coeff.
Initial Conditions
Layer Name
Thickn. [m]
INTELLO PLUS (according to German approval 2015)
0,001
Material Data
Exterior (Left Side)
Interior (Right Side)
0,019
0,286
0,001
0.14
Sources, Sinks
New Layer
Duplicate
Delete
WUFI materials
Search materials
All Sources
WUFI
Fraunhofer-IBP
Concrete and Screeds
Green and Gravel Roofs
Insulating Materials
Masonry Bricks
Membranes
Mortar and Plaster
Natural Stone
Wooden Materials; Boar
Generic Materials
Japan Database
LTH Lund University, Swede
MASEA Database, Germany
Materials for thermal calcula
North America Database
Building Boards and Sid
Concretes
Material Name
Bulk ... [kg/m³]
Poro... [m³/m³]
Heat ... [J/kgK]
Ther... [W/mK]
Cellulose Fiber Insulation 30 0.99 1880 0.036
Expanded Polystyrene Insulation 14.8 0.99 1470 0.036
Extruded Polystyrene Insulation 28.6 0.99 1470 0.025
Material Information
Hygrothermal Functions
Added to DB: ---
Last update: ---
Assign
Total T
Thick

It’s complicated

Layer/Material Data

Layer/Material Name: Densepack cellulose

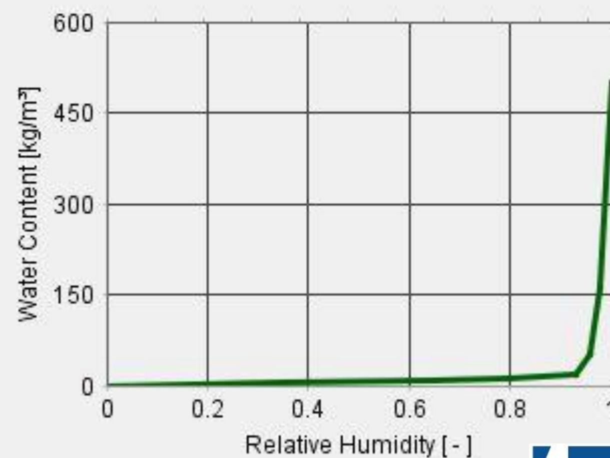
Bulk density [kg/m³]:	70	Typical Built-In Moisture [kg/m³]:	12
Porosity [m³/m³]:	0.95	Layer Thickness [m]:	0.14
Spec. Heat Capacity [J/kgK]:	2500	Thermal Conductivity, Design Value [W/mK]:	
Thermal Conductivity [W/mK]:	0.04	Color:	
Water Vapour Diffusion Resistance Factor [-]:	1.5		

Hygrothermal Functions | Material Information

- Moisture Storage Function
- Liquid Transport Coefficient, Suction
- Liquid Transport Coefficient, Redistribution
- Water Vapour Diffusion Resistance Factor, moistu...
- Thermal Conductivity, moisture-dependent
- Thermal Conductivity, temperature-dependent
- Enthalpy, temperature-dependent

☐ Approximate

No.	RH [-]	Water Cont... [kg/m³]
1	0	0
2	0.35	4.5
3	0.65	8
4	0.8	12
5	0.93	18
6	0.96	50
7	0.98	160
8	1	500



Paste into Database | Import | Export | OK | Cancel

Calculation of coupled transport

Coupled transport equations

- exponential increase of saturation pressure with temperature
- moisture depending thermal conductivity
- enthalpy flow by vapor diffusion with phase change

Heat transfer

$$\frac{\partial H}{\partial T} \cdot \frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) + h_v \nabla \cdot \left(\delta_p \nabla (\phi\ p_{sat})\right) + S_h$$

Moisture transfer

$$\frac{\partial w}{\partial \phi} \cdot \frac{\partial \phi}{\partial t} = \nabla \cdot \left(D_\phi \nabla \phi + \delta_p \nabla (\phi\ p_{sat})\right) + S_w$$

Coupled differential equations have to be solved numerically.

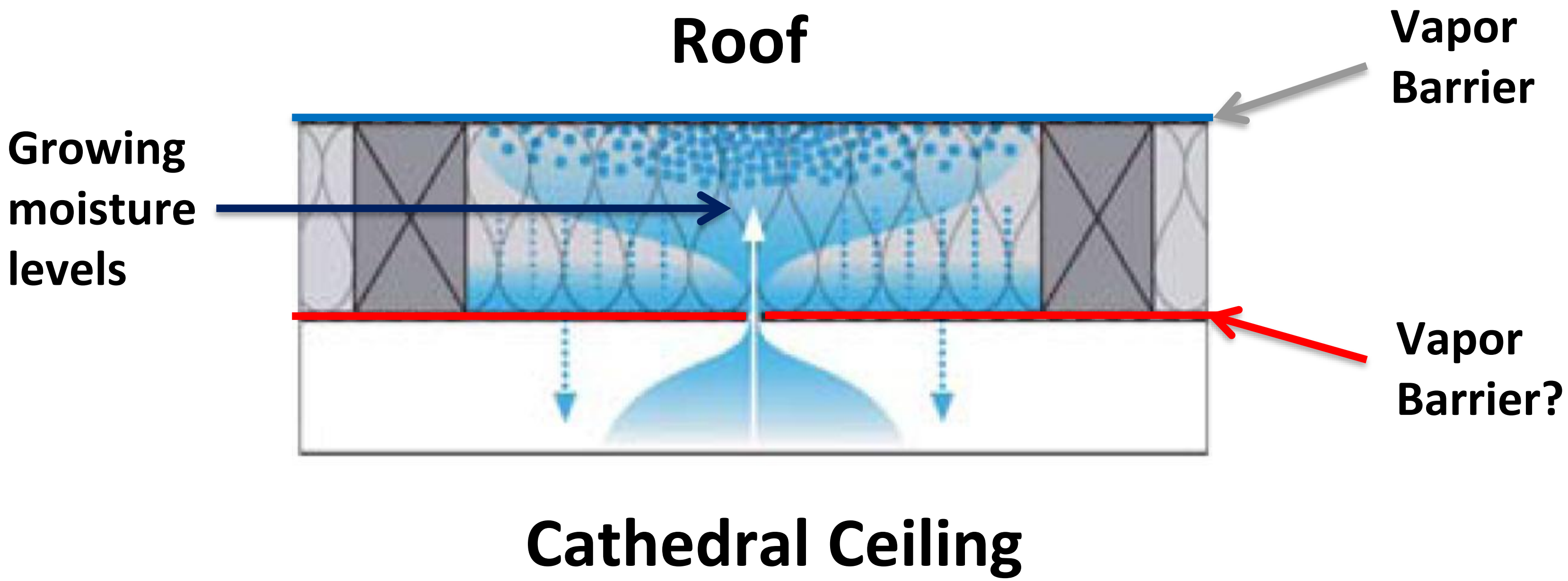
Actually a third Equation!


Outdoor Climate (Left Side)
Indoor Climate (Right Side)
From Map / File
EN 15026 / WTA 6-2
ISO 13788
ASHRAE 160
Sine Curves
New York City, NY; cold year
Set Climate...
Details...
Temperature / Relative Humidity
Climate Analysis
Temperature [°C]
Relative Humidity [%]
31-Dec 30-Jan 02-Mar 01-Apr 02-May 02-Jun 30-Jun 31-Jul 30-Aug 30-Sep 30-Oct 30-Nov 31-Dec
Additional Data Diagrams
Diffuse Solar Radiation
ISD [W/m²]
Data Info
Location: New York City, NY
Latitude [°]: 40.78 North
Longitude [°]: 73.97 West
Altitude [m]: 16
Time Zone: -5.0
Number of data lines: 8760
Description: . . .
Comment: . . .
Climate Elements
Temperature: TA
Relative Humidity: HREL
Short-Wave Radiation: ISGH, ISD
Long-Wave Radiation: ——
Wind: WS, WD
Rain: RN
Cloud Index: CI
Air Pressure: ——

Often roofs are vapor barriers,

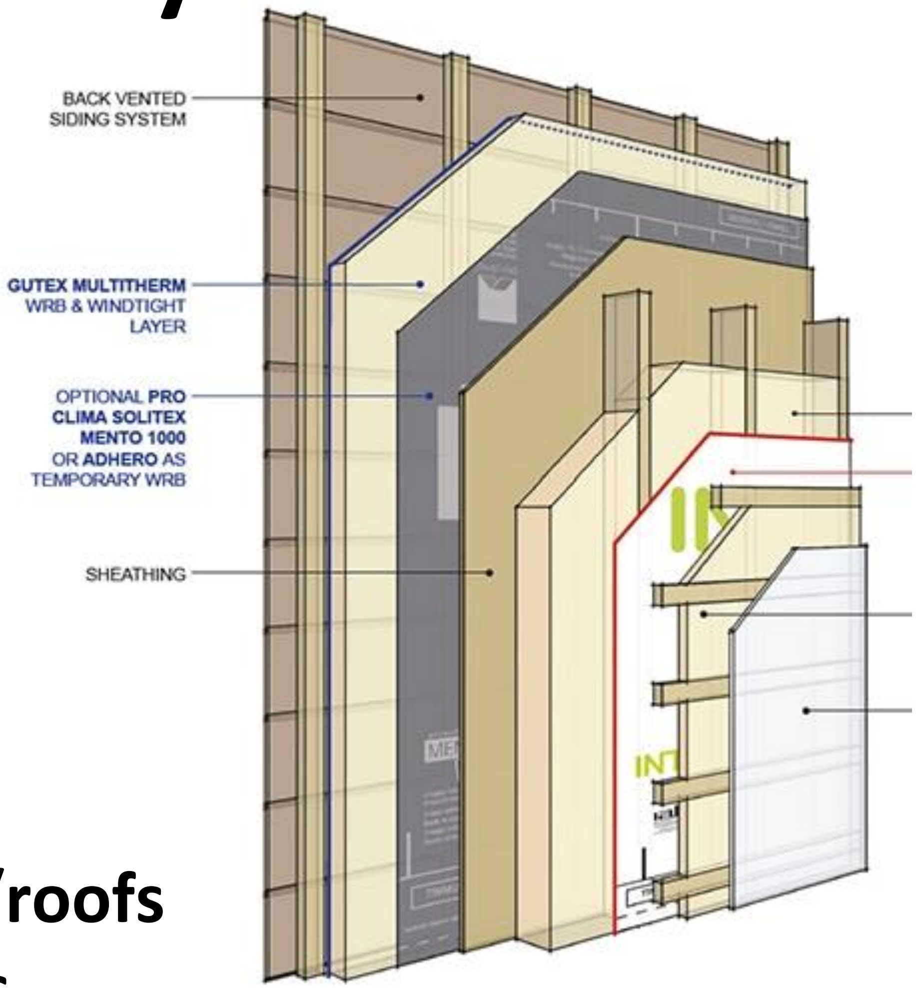
so don't make it **worse**

(even in mild climates (even in climate zone 4,3), watch out for radiant cooling)



Walls – can be "easy"

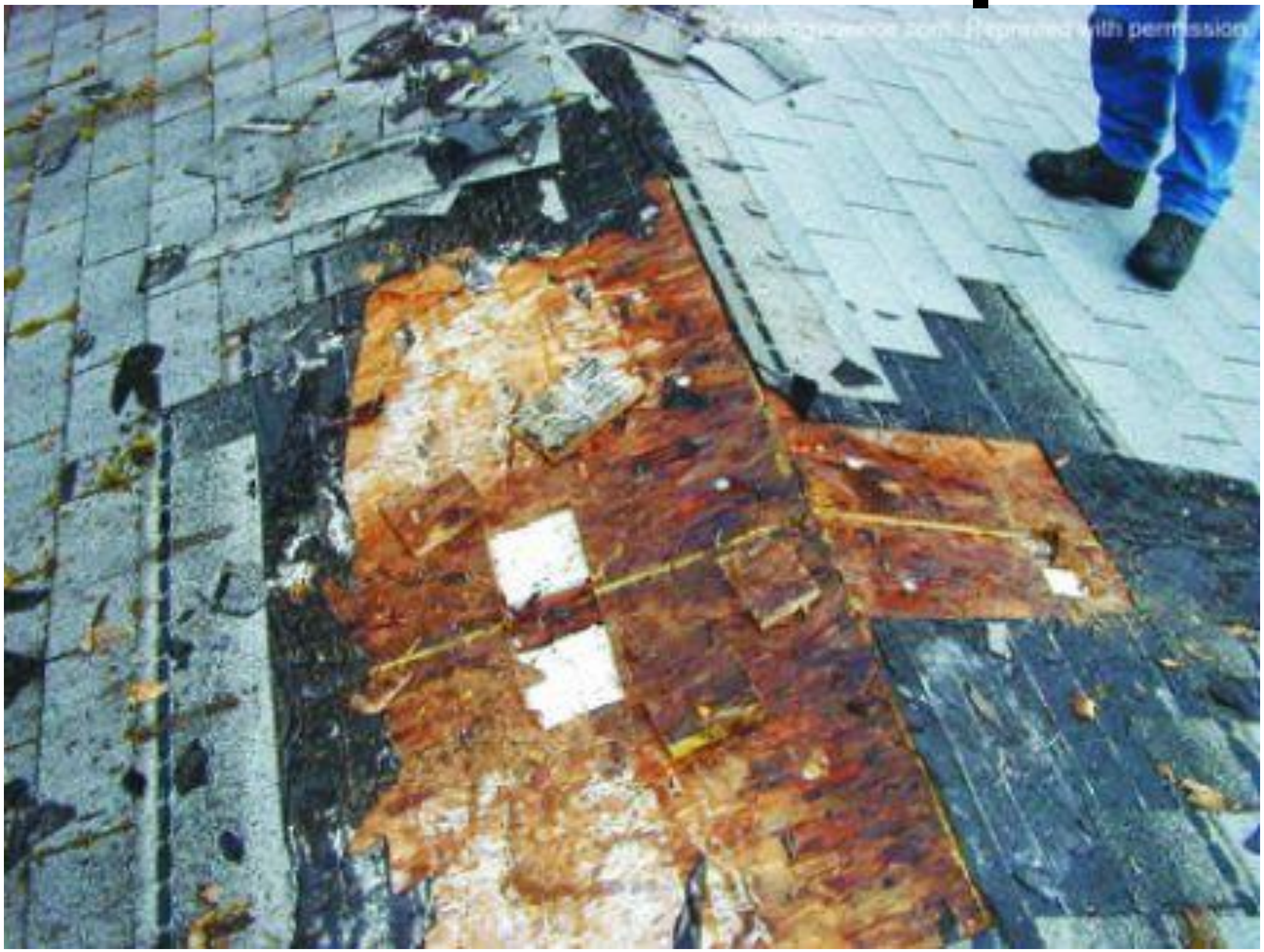
@TEstudioarch



Vented rain screened walls/roofs with PH interior airtightness

Better than PERFECT – 6 sides & dry both ways

Roofs are often vapor closed

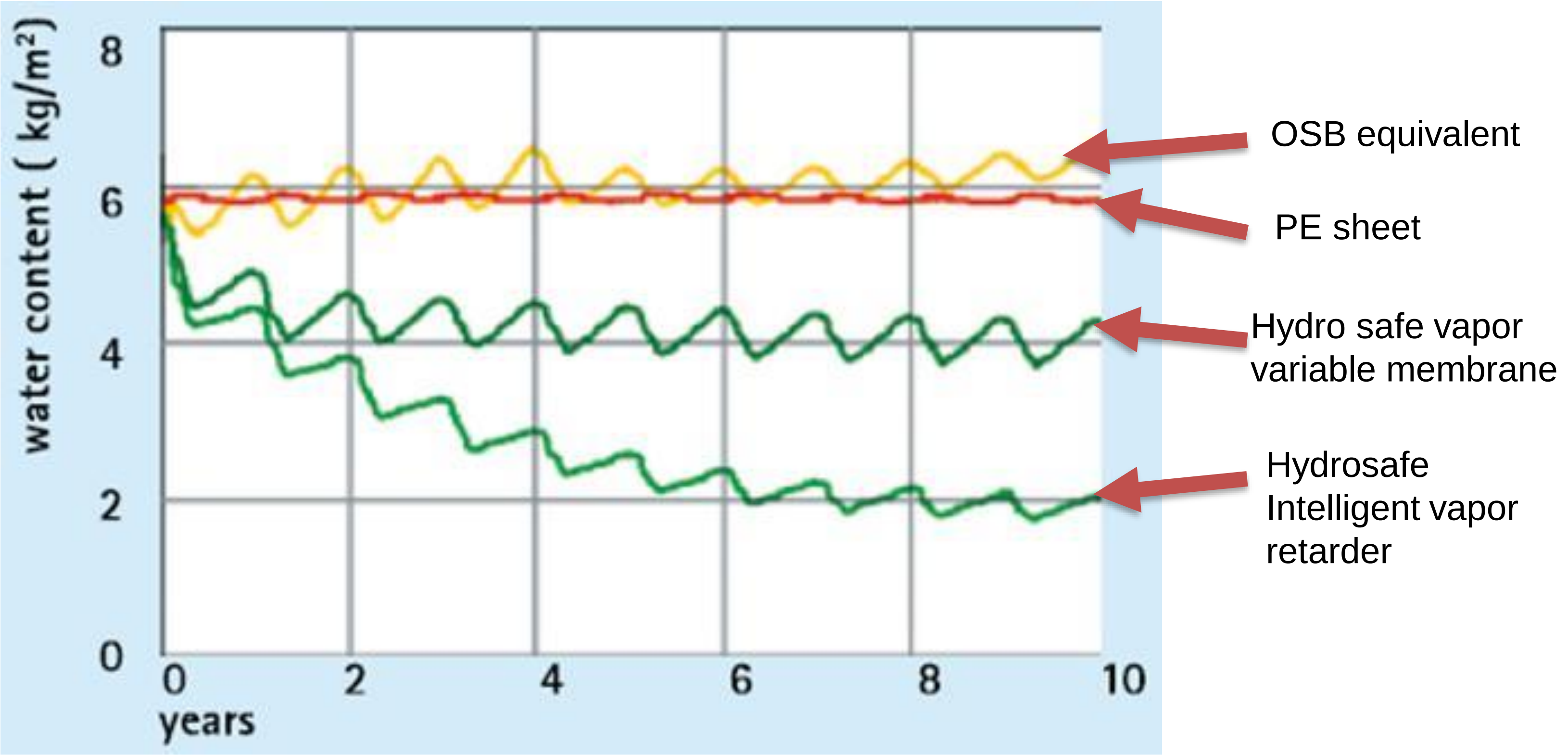


Credit: FineHomebuilding

Asphalt and flatroofs….prone to damage
Can't dry outwards…

Maximize drying potential

Study: Steep pitched, north facing roof at high altitude (a worst case scenario).



Credit: Pro Clima

Intelligent vapor retarder

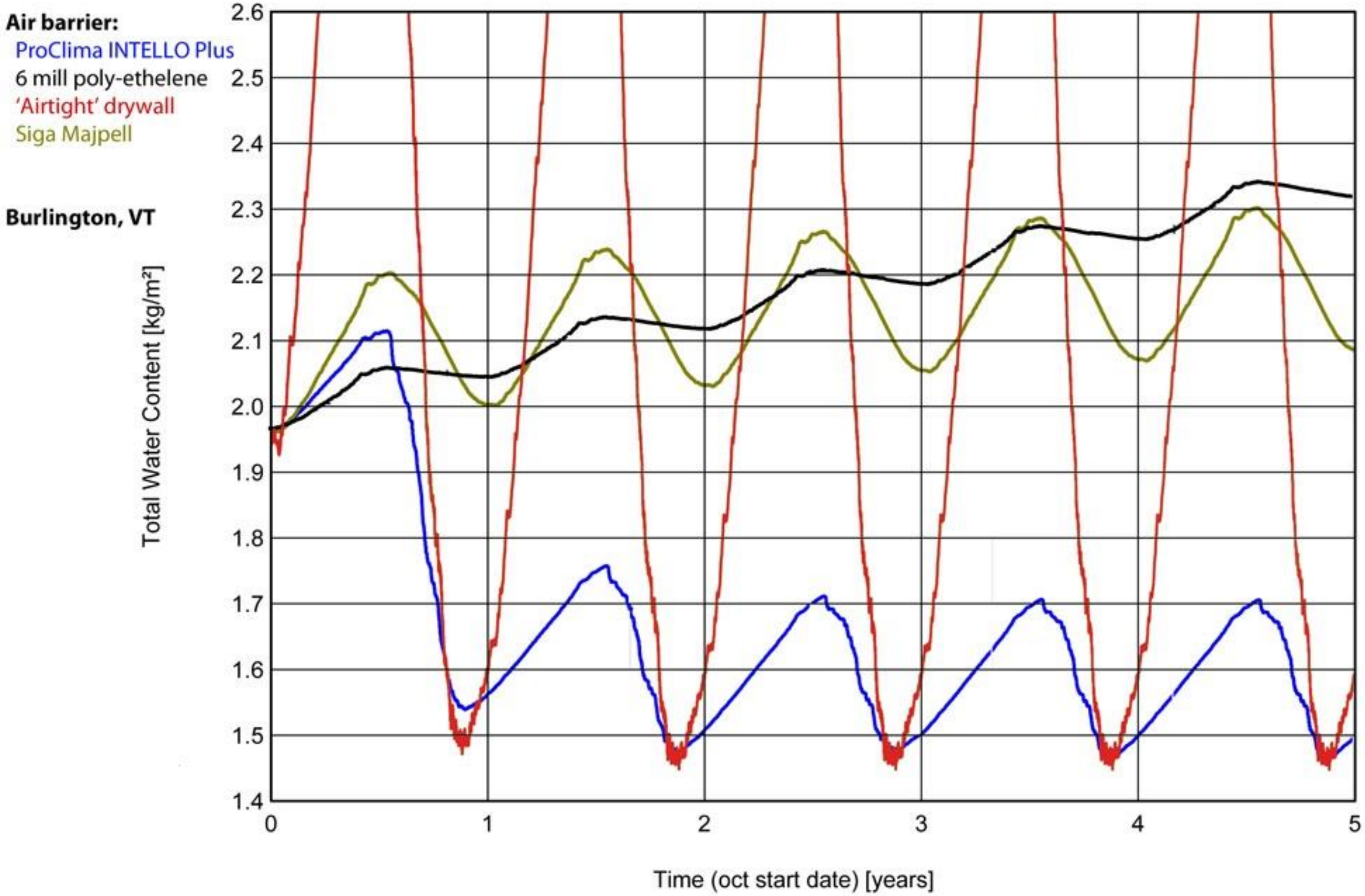
Ideally suited for:

1. Meeting Code for Class II vapor retarders.
2. Assemblies with significant vapor retarding or vapor closed outboard layers.
3. Historic Masonry Retrofits
4. Cellulous and fibrous insulation
5. Highly insulated assemblies
6. Where increased drying reserves are desired

What about ADA?

Unvented Sloped Roof w/ Fiberglass

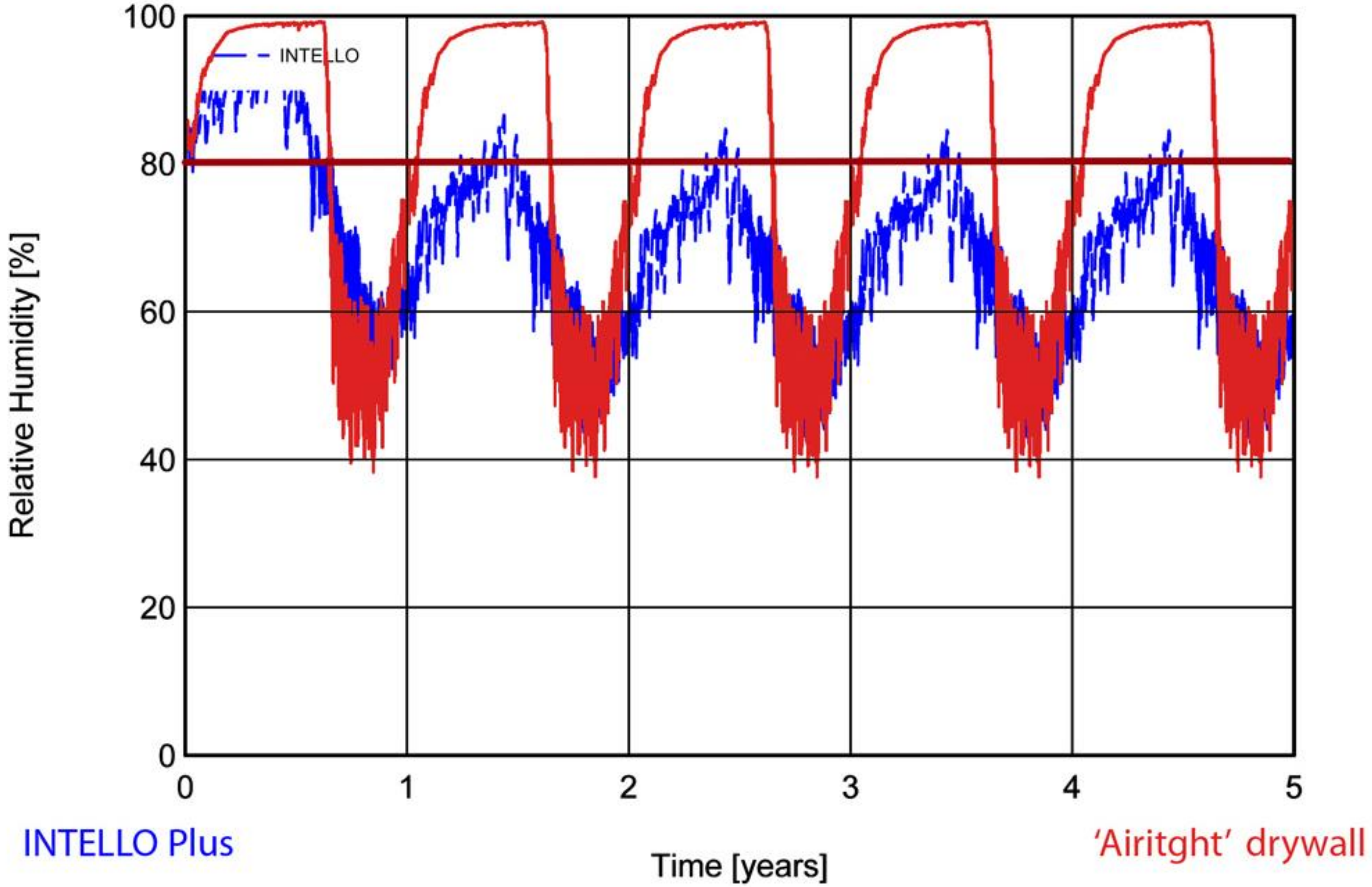
Study: 10:12 pitch, north facing roof at high altitude (a worst case scenario)



See blog post: ***Yes, Unvented Roof Assemblies Can Be Insulated With Fiberglass – A WUFI Post***

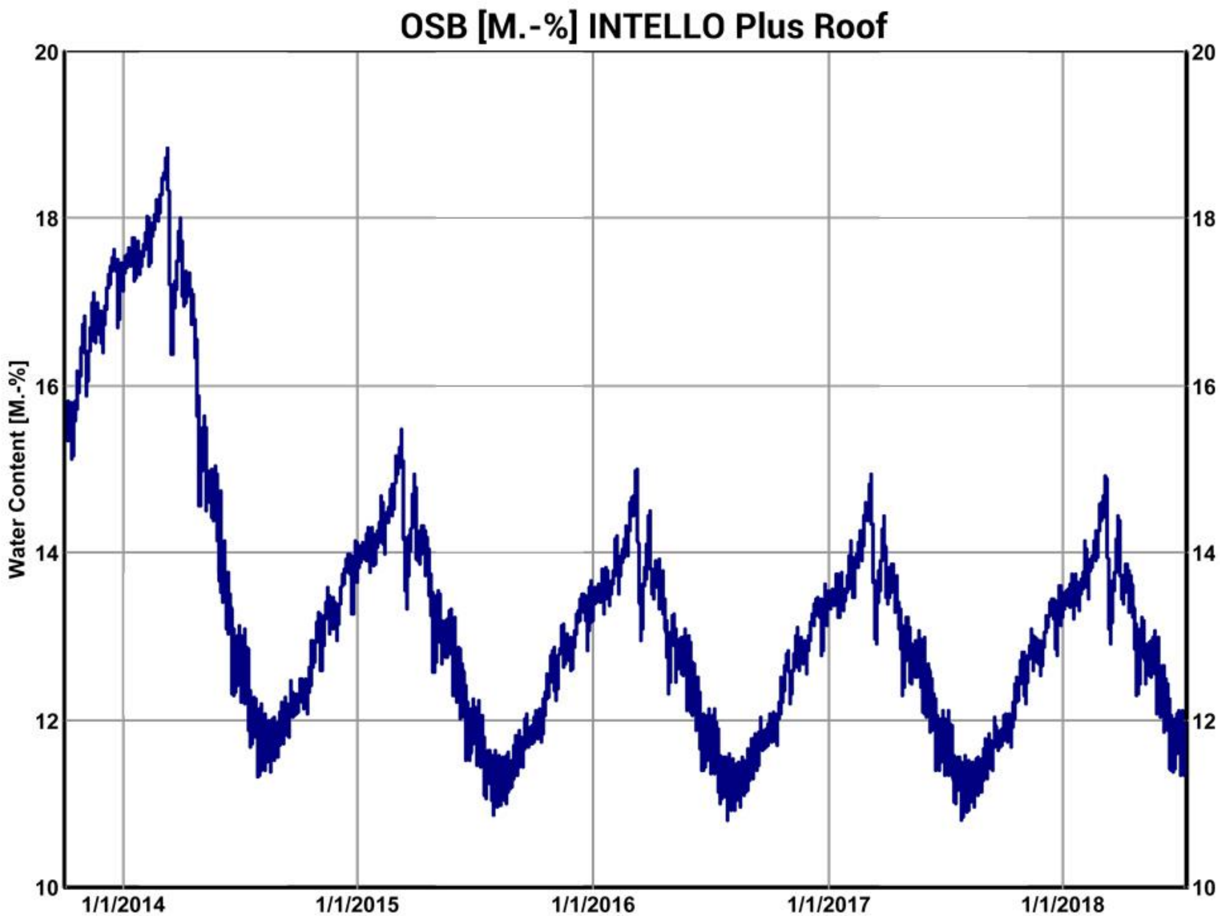
ADA vs Intelligence – what is save M%

Study: 10:12 pitch, north facing roof at high altitude (a worst case scenario)



ADA vs Intelligence – what is save M%

Study: 10:12 pitch, north facing roof at high altitude (a worst case scenario)



Roof WUFI model

Vapor closed materials meet hygroscopic materials in roof

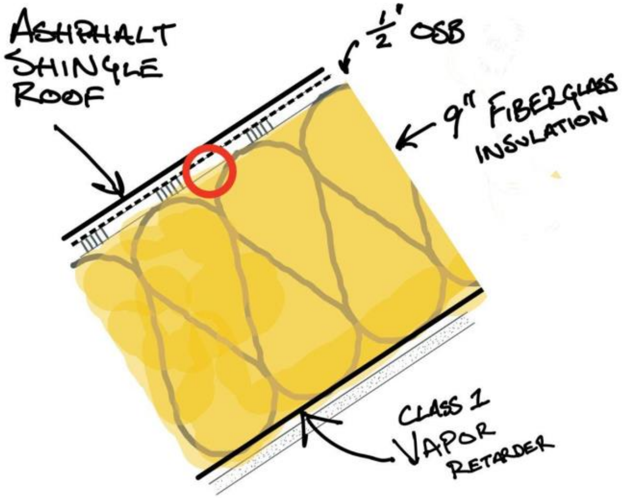
Minneapolis, MN

Climate Zone 6

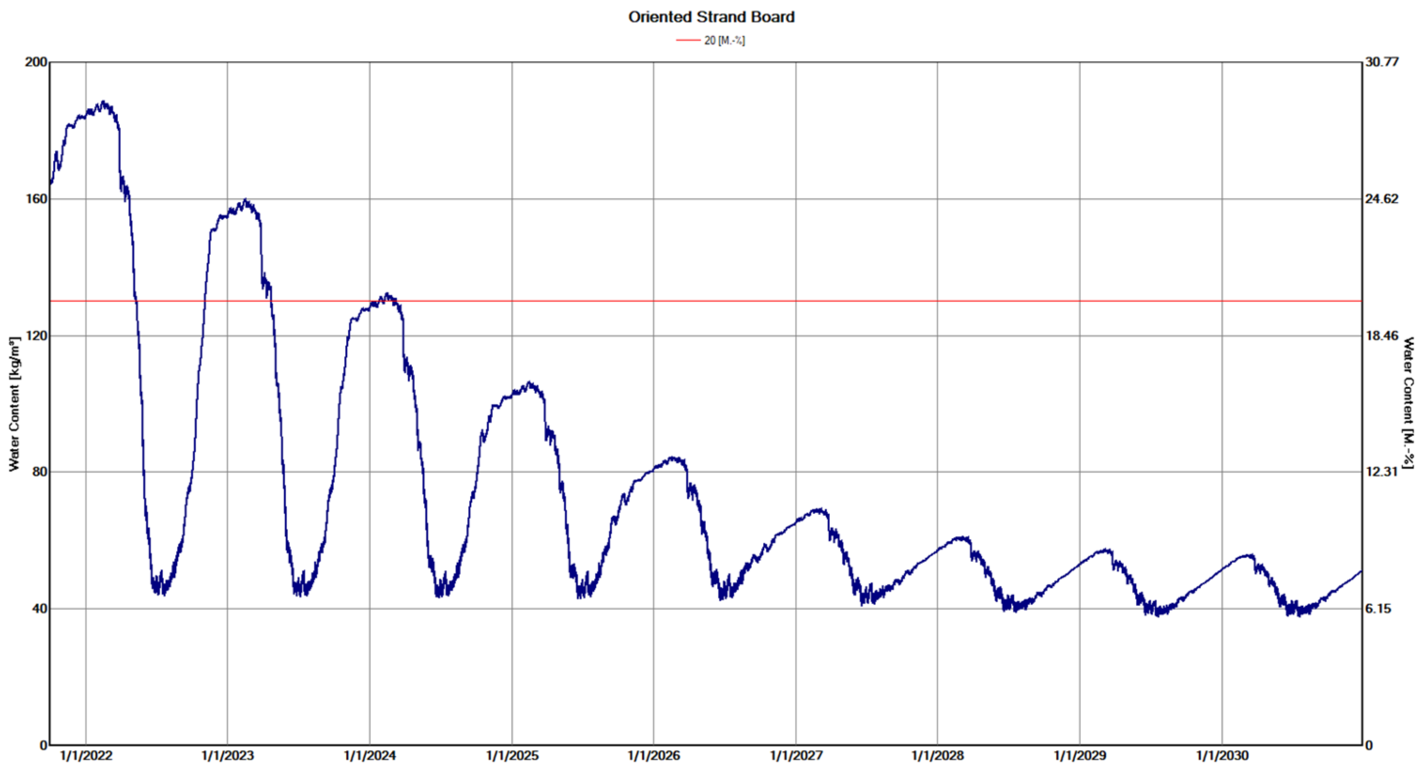
Follow ASHRAE 160 w/additional air leakage

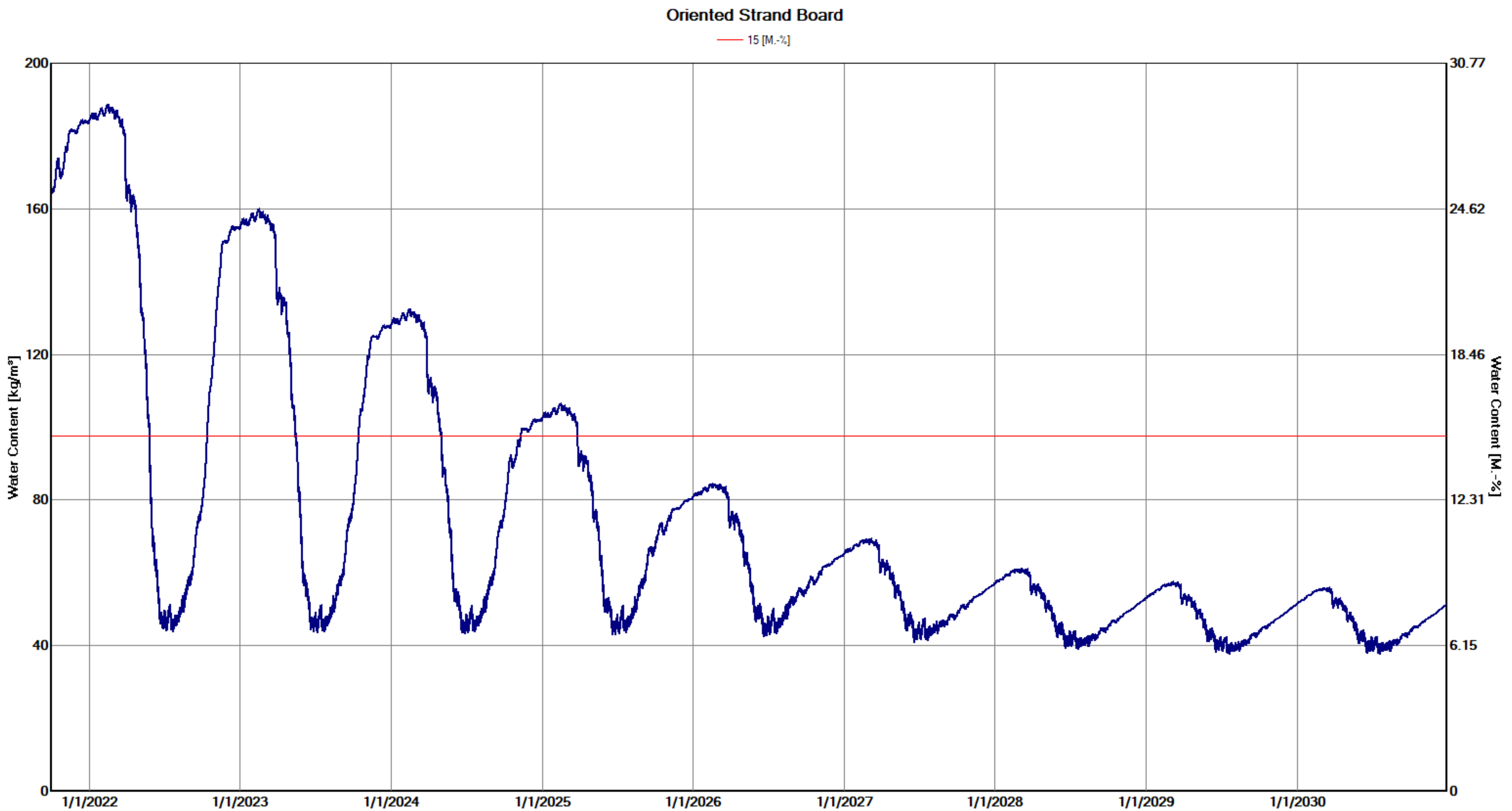
First Example - Asphalt Shingle Roof, ½” OSB, R31 Fiberglass (Not even code minimum!), PE airbarrier, Gypsum Board

Second Example - Asphalt Shingle Roof, ½” OSB, 2” Vented Air Space, SOLITEX MENTO 3000, ½ OSB, R51 Fiberglass, INTELLO PLUS, Service Cavity, Gypsum Board

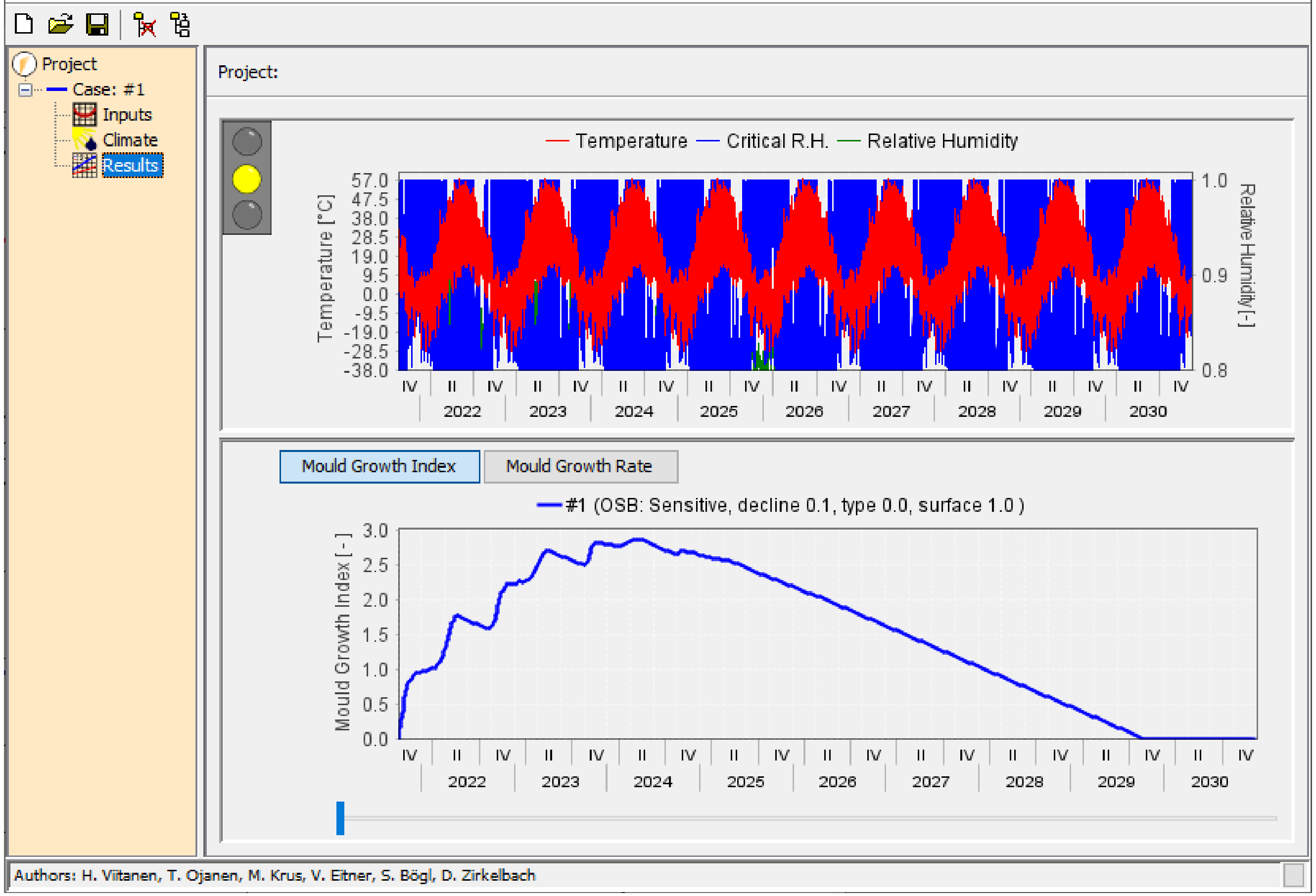


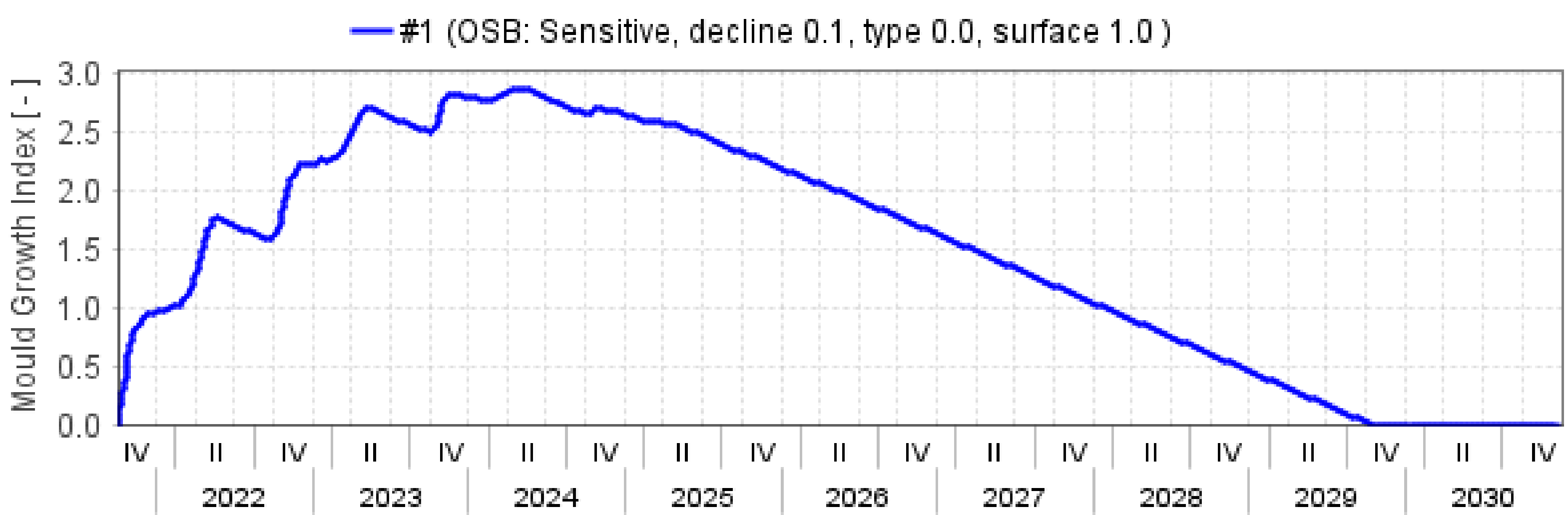
Build in construction moisture
DRIES TO SLOW!

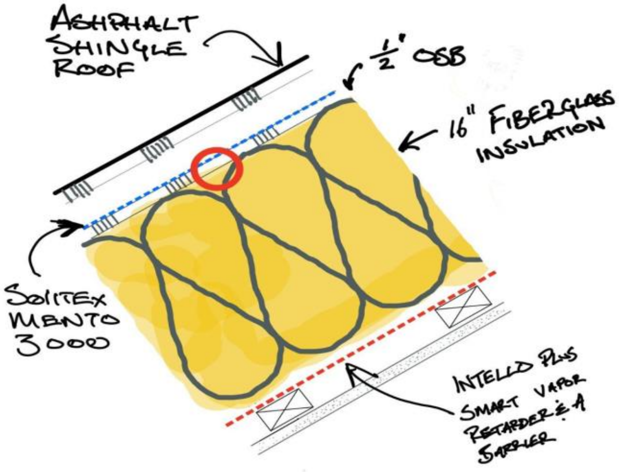


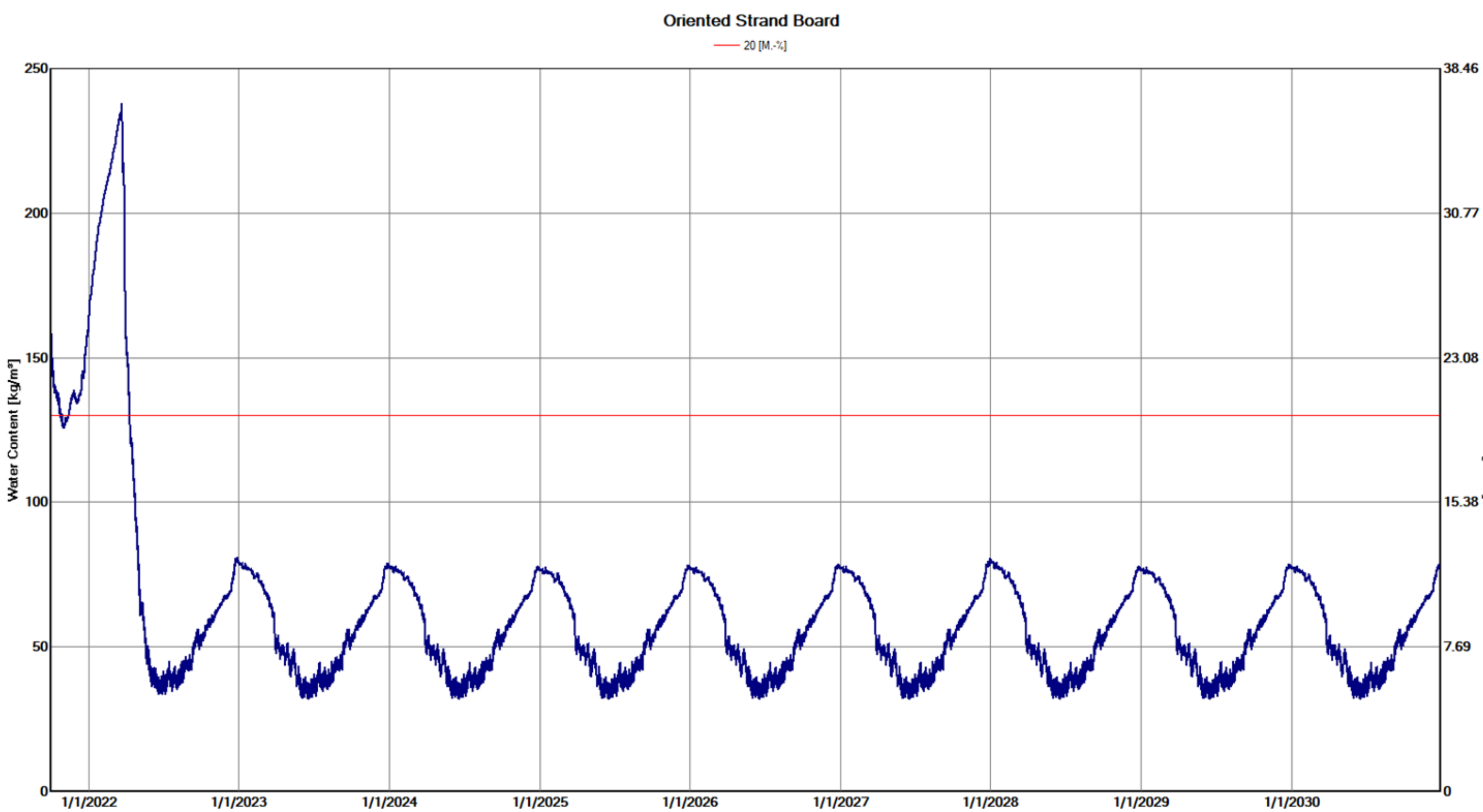


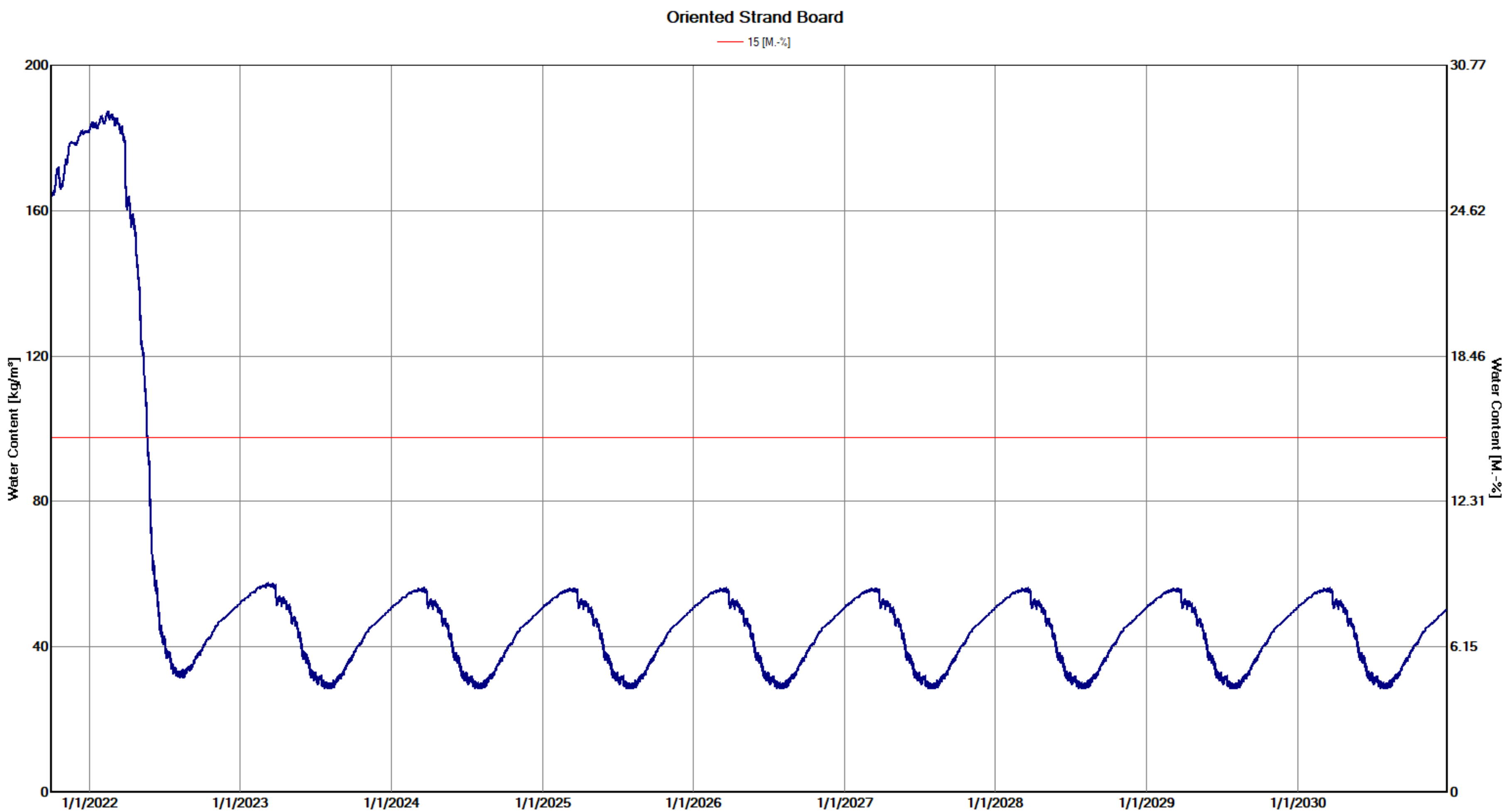
Oriented Strand Board
15 [M.-%]
Water Content [kg/m³]
Water Content [M.-%]
200
160
120
80
40
0
30.77
24.62
18.46
12.31
6.15
0
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030


Project
Case: #1
Inputs
Climate
Results
Project:
Temperature
Critical R.H.
Relative Humidity
Temperature [°C]
Relative Humidity [-]
57.0
47.5
38.0
28.5
19.0
9.5
0.0
-9.5
-19.0
-28.5
-38.0
1.0
0.9
0.8
2022
2023
2024
2025
2026
2027
2028
2029
2030
Mould Growth Index
Mould Growth Rate
#1 (OSB: Sensitive, decline 0.1, type 0.0, surface 1.0)
Mould Growth Index [-]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Authors: H. Viitanen, T. Ojanen, M. Krus, V. Eitner, S. Bögl, D. Zirkelbach

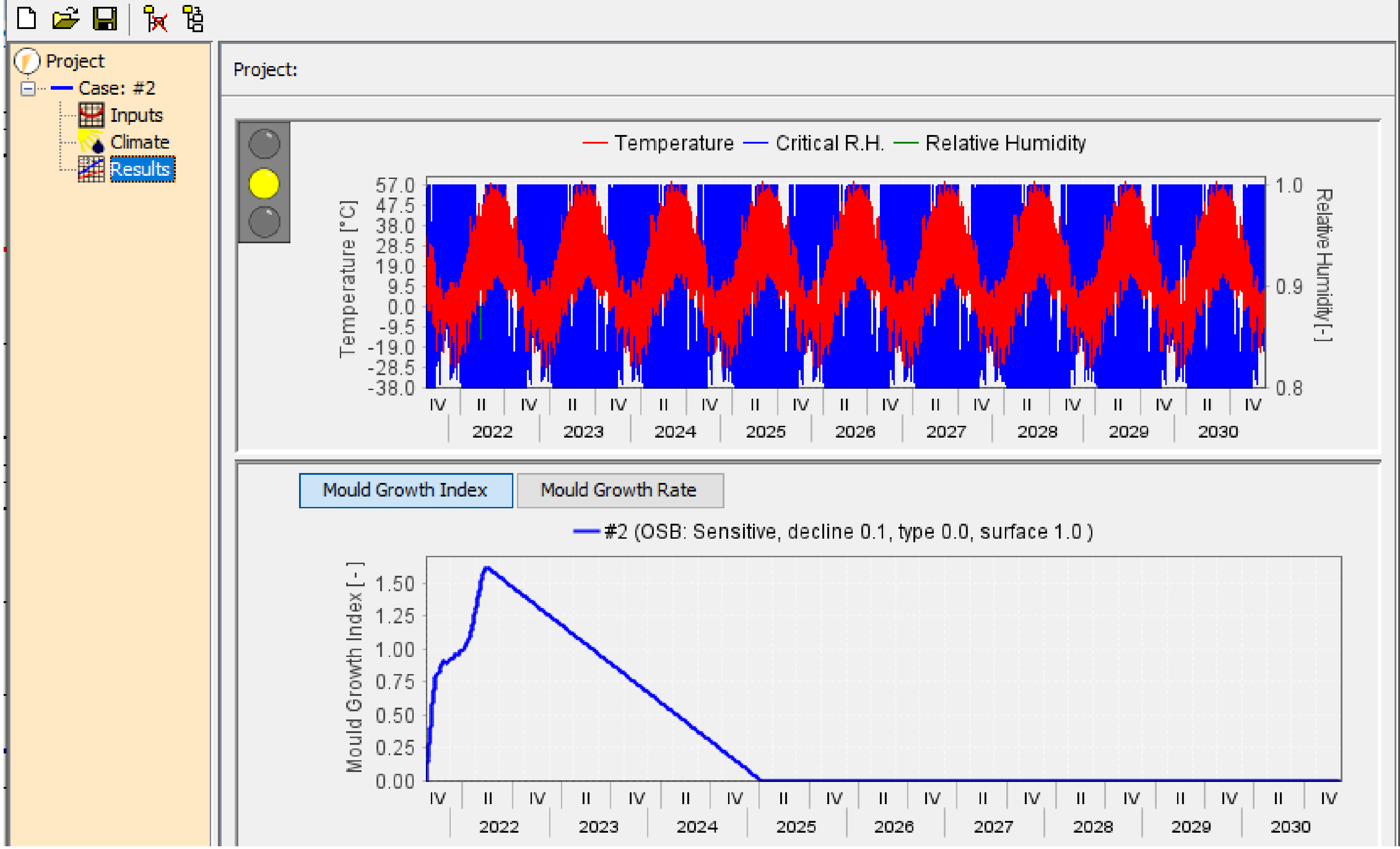

#1 (OSB: Sensitive, decline 0.1, type 0.0, surface 1.0)
Mould Growth Index [-]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
IV
II
2022
2023
2024
2025
2026
2027
2028
2029
2030

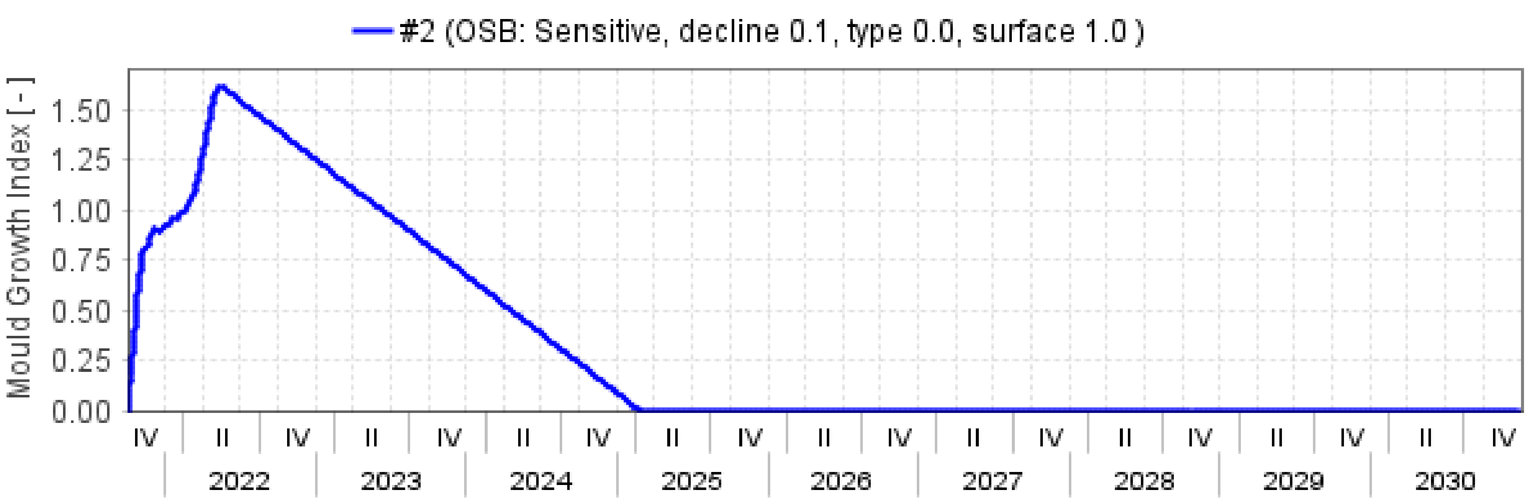

ASHPHALT SHINGLE ROOF
1/2" OSB
16" FIBERGLASS INSULATION
SOLITEX MENTO 3000
INTELLO PLUS SMART VAPOR RETARDER & A BARRIER


Oriented Strand Board
20 [M.-%]
Water Content [kg/m³]
Water Content [M.-%]
250
200
150
100
50
0
38.46
30.77
23.08
15.38
7.69
0
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030



Oriented Strand Board
15 [M.-%]
200
160
120
80
40
0
Water Content [kg/m³]
30.77
24.62
18.46
12.31
6.15
0
Water Content [M.-%]
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030


Project
Case: #2
Inputs
Climate
Results
Project:
Temperature
Critical R.H.
Relative Humidity
Temperature [°C]
57.0
47.5
38.0
28.5
19.0
9.5
0.0
-9.5
-19.0
-28.5
-38.0
Relative Humidity [-]
1.0
0.9
0.8
2022
2023
2024
2025
2026
2027
2028
2029
2030
Mould Growth Index
Mould Growth Rate
#2 (OSB: Sensitive, decline 0.1, type 0.0, surface 1.0)
Mould Growth Index [-]
1.50
1.25
1.00
0.75
0.50
0.25
0.00


#2 (OSB: Sensitive, decline 0.1, type 0.0, surface 1.0)
Mould Growth Index [-]
1.50
1.25
1.00
0.75
0.50
0.25
0.00
IV
II
2022
2023
2024
2025
2026
2027
2028
2029
2030

Real world verification - Good Energy Haus

Minneapolis, MN

Climate Zone 6 - Passive House

Airtightness: 0.4ACH60

Foam free wall and roof

HERS index: 8

Certificate

Certified Passive House Plus

Herz & Lang GmbH
Die Planer für energieeffizientes Bauen
Ritzensonnenhalb 5a
87480 Weitnau, Germany

Authorised by: Passive House Institute

Dr. Wolfgang Feist
64283 Darmstadt
Germany

[illegible] Residence

1520 Lexington Pkwy North, 55117 Saint Paul, USA

Certified Passive House
Passive House Institute
| classic | **plus** | premium |

Client	[illegible]
Architect	TE Studio, Ltd. 901 23rd Ave. NE 55418 Minneapolis, United States of America
Building Services	TE Studio, Ltd. 901 23rd Ave. NE 55418 Minneapolis, United States of America
Energy Consultant	TE Studio, Ltd. 901 23rd Ave NE 55418 Minneapolis, United States of America

Passive House buildings offer excellent thermal comfort and very good air quality all year round. Due to their high energy efficiency, energy costs as well as greenhouse gas emissions are extremely low.

The design of the above-mentioned building meets the criteria defined by the Passive House Institute for the 'Passive House Plus' standard:

Building quality		This building		Criteria	Alternative criteria
Heating					
Heating demand	[kWh/(m²a)]	15	≤	15	-
Heating load	[W/m²]	22	≤	-	10
Cooling					
Cooling + dehumidification demand	[kWh/(m²a)]	7	≤	15	15
Cooling load	[W/m²]	10	≤	-	10
Frequency of overheating (> 25 °C)	[%]	-	≤	-	
Frequency of excessively high humidity	[%]	1	≤	10	
Airtightness					
Pressurization test result (n_{50})	[1/h]	0.4	≤	0.6	
Non-renewable primary energy (PE)					
PE demand	[kWh/(m²a)]	94	≤	-	
Renewable primary energy (PER)					
PER-demand	[kWh/(m²a)]	44	≤	45	44
Generation (reference to ground area)	[kWh/(m²a)]	72	≥	60	59

The associated certification booklet contains more characteristic values for this building.

Weitnau, 10. October 2019
Certifier: Florian Lang, Herz & Lang GmbH

www.passivehouse.com 24675_HUL_PH_20191009_FL

Real world verification - Good Energy Haus

Real world verification - Good Energy Haus

Wall R-50?

Corr metal rainscreen

hor battens

3 layer monolithic WRB

Cellulose

airtight sheathing - taped

2x4 wall w fiber insul

gypsum wall board

NO WUFI needed -
proven vented assembly

Can dry out easily

and in if needed (slowly)

Real world verification - Good Energy Haus

Roof R-77

-flatroof (TPO)

-tapered foam

-¾" plywood sheathin

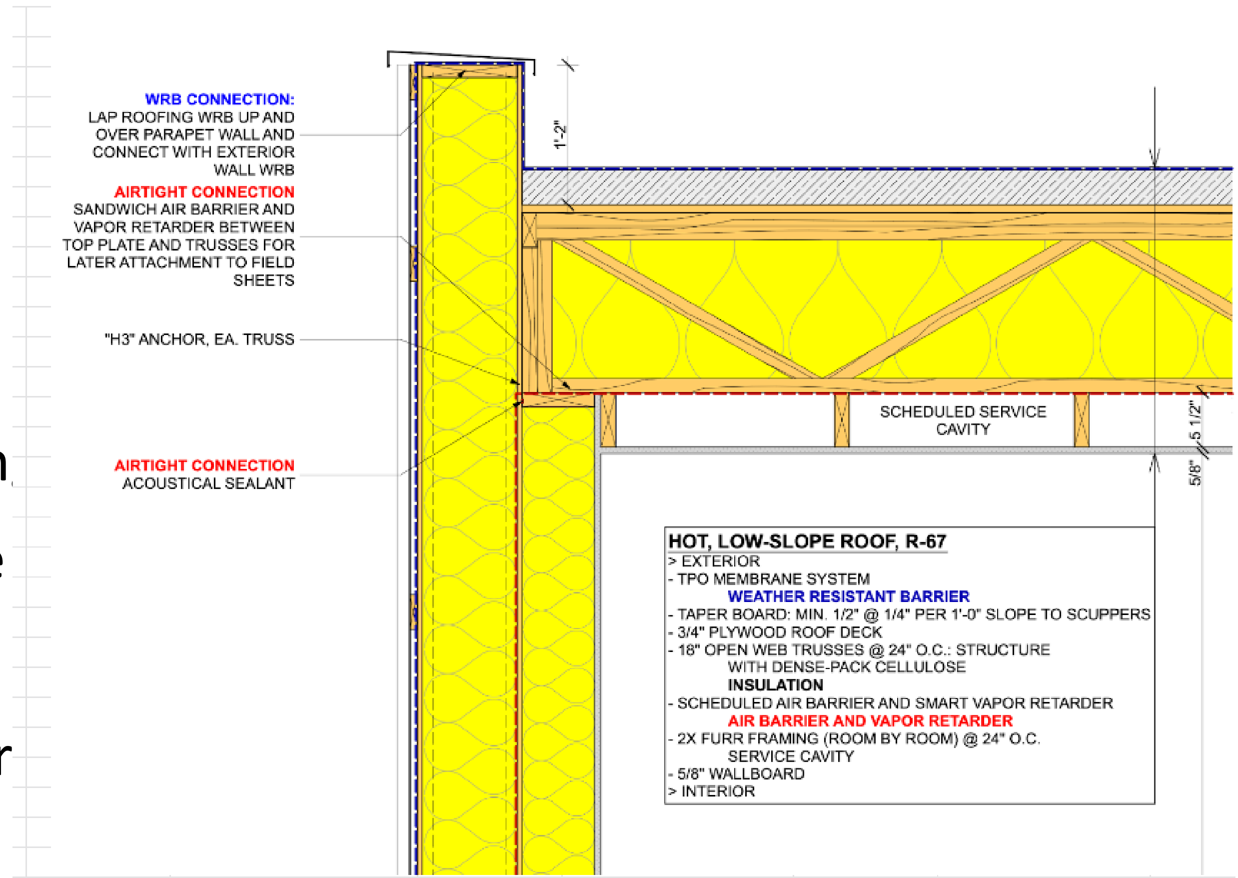
-16" truss w Cellulose

- Reinforced -

intelligent vapor retar

-2x4 service cavity

- gypsum wall board



Note: Final insulation value is R-77! The 67 is a typo on the detail drawing

Real world verification - Good Energy Haus

Roof R-77 - airtight details:

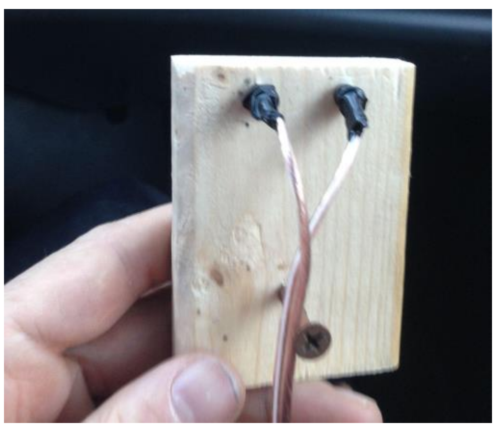
Real world verification - Good Energy Haus

Moisture monitoring:

DATE	READING	OUTSIDE TEMP (C)	OUTSIDE REL HUM	INSIDE TEMP (C)	INSIDE REL HUM
12/13/2021	14.30%	-5	84.00%	22	39.00%
12/18/2021	14.2	-3	74	22	37
12/30/2021	14.7	-8	79	21	35
1/2/2022	14.1	-11	62	23	34
1/17/2022	15.8	-4	83	21	38
1/31/2022	15.8	-6	79	21	38

Upward trend in winter is ok, as long as it only happens in year 1,2

Stays below 18-20M% and summers below 15M%



Passive House Verification

Real world verification - Whitchurch house

Middlesex, VT

Climate Zone 6 - Passive House

Airtightness: 0.28ACH60

Timber frame with

Foam free flatroof

and walls

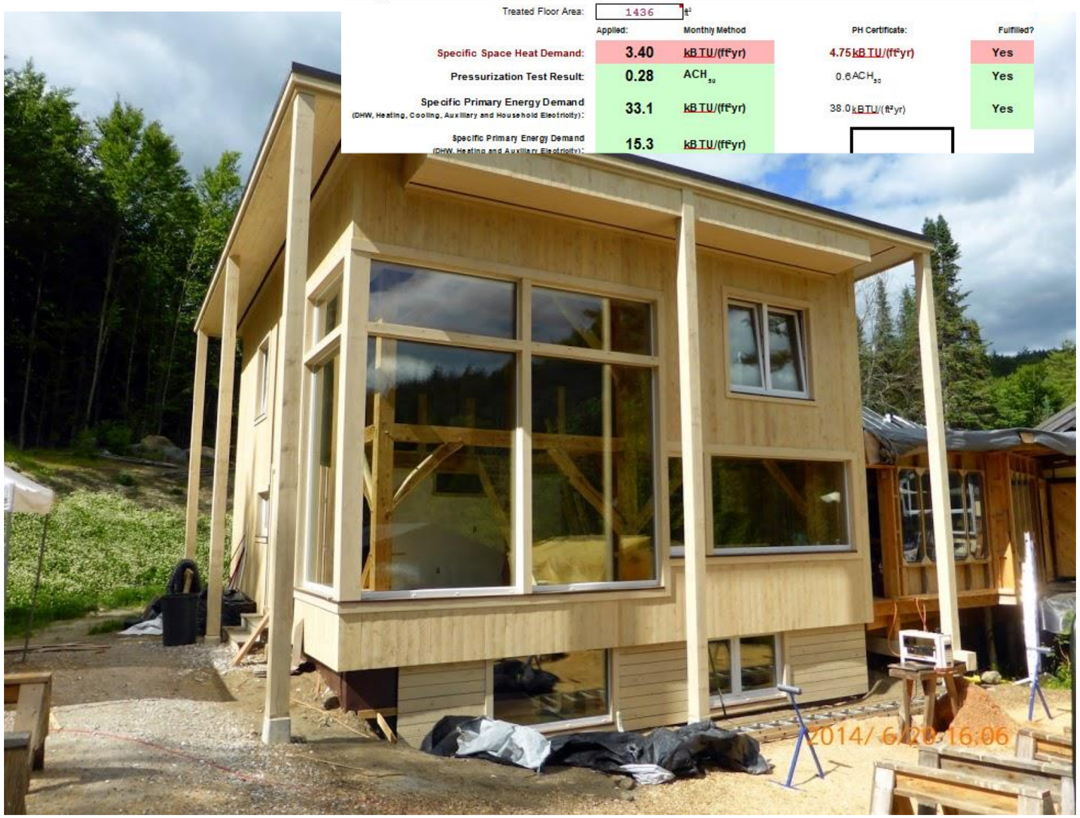
Building:	Whitchurch Passive House Cottage
Location and Climate:	Montpelier, VT
Street Address:	Brook Rd
City, State, Zip:	Middlesex
Country:	USA
Building Type:	Timber Frame
Home Owner(s) / Client(s):	Greg and Barb Whitchurch
Street Address:	Brook Rd
City, State, Zip:	Middlesex, VT
Architect:	Greg Whitchurch, Chris Miksic, Indigo Ruth-Davis
Street:	405 Camp Rd. PO box 32
City, State, Zip:	Calais, Vermont 05648
Mechanical System:	CERV, by Build Equinox
Street Address:	
City, State, Zip:	

Year of Construction:	2013				
Number of Dwelling Units:	1		Interior Temperature:	68.0	°F
Gross Enclosed Volume V_e:	21130	ft³	Internal Heat Gains:	0.7	BTU/hr.ft²
Number of Occupants:	3.8				

Energy Demands with Reference to the Treated Floor Area

Treated Floor Area: 1436 ft²

	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	3.40	kBTU/(ft²yr)	4.75 kBTU/(ft²yr)	Yes
Pressurization Test Result:	0.28	ACH_{50}	0.6 ACH_{50}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	33.1	kBTU/(ft²yr)	38.0 kBTU/(ft²yr)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	15.3	kBTU/(ft²yr)		



Real world verification - Whitchurch house

Walls - R50

Vented rainscreen

16” I-joist

w cellulose behind MENTO PLUS

Paper based smart vapor retarder (reinforced)

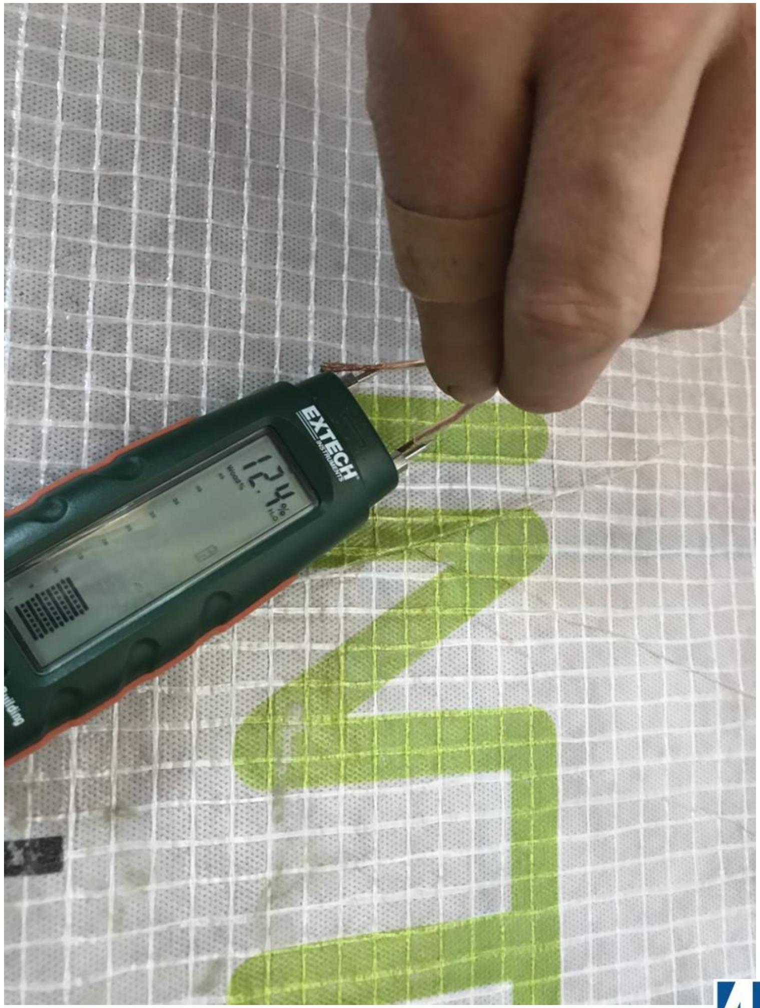
t&G sheathing (interior)

NO WUFI needed -
proven vented assembly

Can dry out easily

and in if needed (slowly)

Unvented Flat Roof w/ cellulose



Real world verification - Whitchurch house

Monitored wall:

North wall

13-16M%

South < 12.5%

acceptable

for wood

A	AR	AS	AT	AU	AV	AX	AY	BA	BB
Pix	Walls:		Outer	Edge	(TJI brand microlam)	Walls:	pine block**	Walls:	(3/4" fir ply)
		outer		flanges		outer	DPC	window	bucks
Date // Location/ Parameter	North 2nd: Moisture %	South 2nd: Moisture %	South 2nd: Moisture %	North 1st: Moisture %	Bath 1st: Moisture %	North 1st: Moisture %	Bath 1st: Moisture %	North 1st: Moisture %	Bath 1st: Moisture %
11/5/2013	?	?	?	?	?	?	?	?	?
11/6/2013	?	x	?	?	?	?	?	?	?
6/23/2014	?	12.4	?	16.5	11.2	11.8	13.3	16.2	18.3
10/13/2014	?	11.8	?	16.7 bounce	16.8	13.0	13.5	14.8 bounce	14.8
11/5/2014	?	12.1	?	17.6	17.3	13.5	14.2	14.2	15.7
12/5/2014	?	10.4	?	13.7	13.8	12.0	12.4	12.1	12.4
12/26/2014	?	11.4	?	16.3	16.3	13.2	14.1	13.3	14.1
1/16/2015	?	10.4	?	14.2	14.3	12.7	13.5	12.4	13.0
1/31/2015	?	9.3	?	12.9	13.0	11.7	12.3	11.2	11.7
2/17/2015	?	10.2	?	12.7	13.0	12.1	13.0	11.5	11.9
3/5/2015	?	10.6	?	14.7	14.6	13.3	14.7	12.9	13.2
3/17/2015	?	11.2	?	16.1	16.9	14.2	16.5	13.6	14.1
4/3/2015	?	11.1	?	15.8	17.3	13.6	15.9	13.8	14.6
4/16/2015	?	10.9	?	15.3	17.8	13.0	15.8	13.6	14.5
6/8/2015	?	10.7	?	15.0	15.1	11.5	11.6	13.7	14.3
8/23/2015	?	12.6	?	17.3	17.5	12.9	13.1	14.1	15.6
11/13/2015	?	10.8	?	16.2	15.6	13.1	13.1	13.1	13.8
12/17/2015	?	10.5	?	16.1	15.6	13.1	13.1	12.9	13.5
2/4/2016	?	11.3	?	16.4	15.9	13.8	14.4	13.1	13.8
4/7/2016	?	10.5	?	15.3	15.0	12.6	12.9	13.0	13.8
7/18/2016	?	12.1	?	17.1	16.5	12.3	12.0	14.5	14.5
12/14/2016	?	10.5	?	15.2	14.1	12.9	12.9	12.1	12.5
1/6/2017	?	10.1	?	14.2	13.4	11.9	12.1	11.5	11.8
1/15/2017	?	9.8	?	14.0	13.5	12.3	12.6	11.6	12.0
4/4/2017	?	10.1	?	15.0	14.2	12.2	12.7	12.4	12.7
4/25/2017	?	10.2	?	14.1	14.2	11.7	12.1	12.4	13.1
7/16/2017	?	12.1	?	17.0	17.1	12.7	12.9	13.5	15.4
4/27/2018	?	10.3	?	14.6	14.5	11.8	12.0	12.9	13.6
10/24/2018	?	10.5	?	14.6	14.4	12.0	12.1	11.6	12.4
5/10/2021		10.3		13.4	13.3	10.3	10.4	12.2	12.4
12/11/2021		9.7		13.0	13.3	11.2	11.8	10.9	11.5

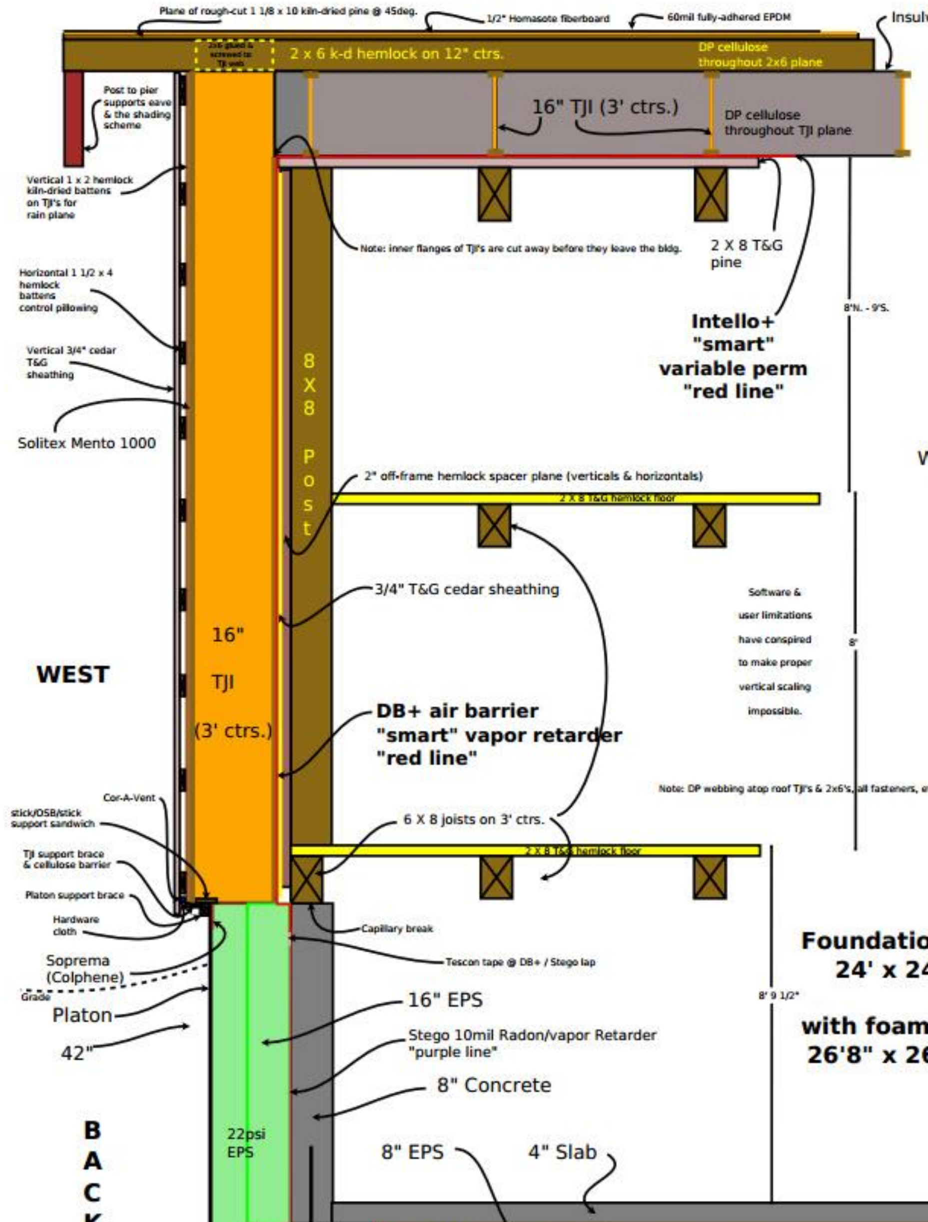
Real world verification - Whitchurch house

2013 - First foam free roof

w PE sign off (code requirement)

- EPDM roof (black)
- White pine 1x's
- 16" I-joists filled w cellulose (3' o.c.)
- Intelligent/smart vapor retarder on

2x6 Hemlock interior

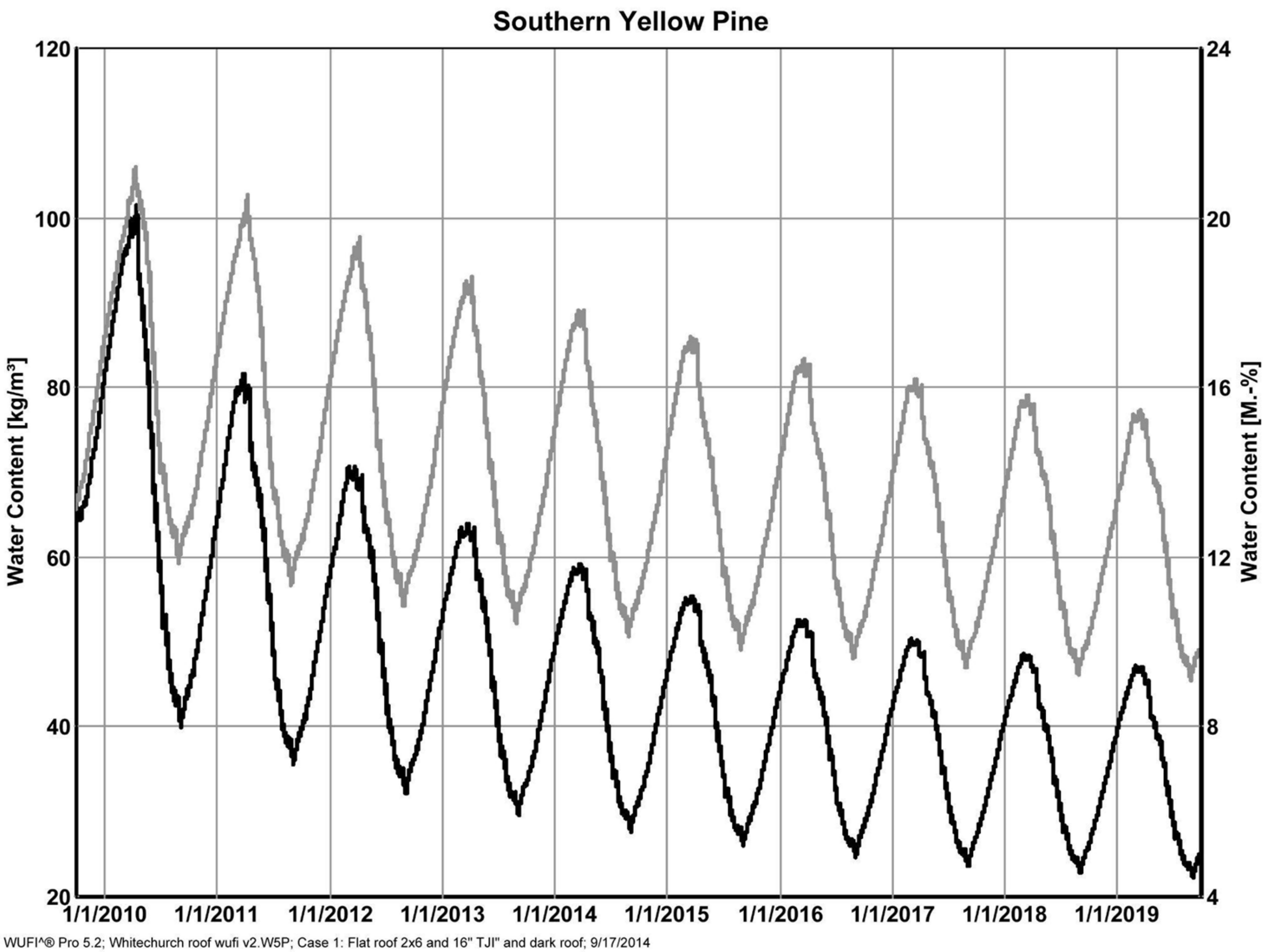


Real world verification - Whitchurch house

Real world verification - Whitchurch house

Dark vs light roof (in WUFI Pro):

10 Golden roofs for FOAM FREE FLATROOFS



Real world verification - Whitchurch house

Monitored results:

Below 10M%

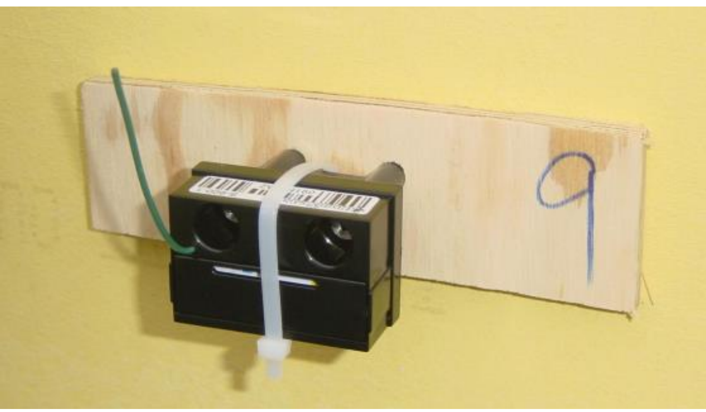
nice and dry!

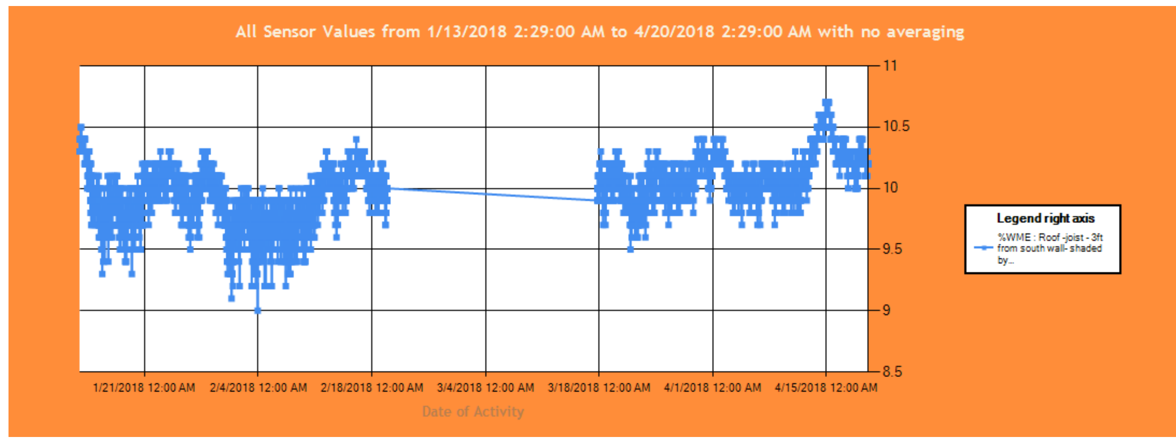
A	J	K	L	N	O	P
Pix	Middle	Layer		*Roof:*	Outer	
	eastern	hemlock			pine	deck
Date // Location/ Parameter	Ctr.: Moisture %	N.E.: Moisture VDC	N.E.: Moisture %	Ctr. Deck: Moisture %	Ctr.: Moisture %	N.E. Deck: Moisture %
11/5/2013	?	0.057	?	?	?	?
11/6/2013	?	?	?	?	?	?
6/23/2014	11.2	?	11.8	9.3	?	9.2
10/13/2014	9.4	?	9.0	8.4 (bounce)	?	9.2
11/5/2014	9.6	?	9.1	8.4	?	9.1
12/5/2014	8.5	?	8.0	7.5	?	8.0
12/26/2014	9.1	?	8.6	8.0	?	8.6
1/16/2015	8.4	?	8.0	7.9	?	8.1
1/31/2015	8.7	?	8.2	8.2	?	8.6
2/17/2015	9.0	?	8.2	8.3	?	9.0
3/5/2015	9.1	?	8.4	8.6	?	9.3
3/17/2015	9.2	?	9.0	9.0	?	10.0
4/3/2015	9.3	?	9.0	9.1	?	10.1
4/16/2015	10.0	?	9.6	12.6	?	10.6
6/8/2015	10.6	?	10.1	8.7	?	8.1
8/23/2015	10.6	?	9.3	9.2	?	8.5
11/13/2015	9.3	?	7.7	7.9	?	7.4
12/17/2015	9.2	?	8.0	8.1	?	7.4
2/4/2016	9.0	?	8.0	8.1	?	7.3
4/7/2016	9.9	?	8.6	9.2	?	7.9
7/18/2016	10.9	?	9.5	8.9	?	8.3
12/14/2016	8.4	?	7.6	7.7	?	7.3
1/6/2017	8.3	?	7.7	7.5	?	7.5
1/15/2017	7.9	?	7.7	7.7	?	7.5
4/4/2017	8.6	?	7.8	8.1	?	7.5
4/25/2017	9.5	?	8.3	9.1	?	7.7
7/16/2017	10.0	?	8.9	9.1	?	8.6
4/27/2018	9.4	?	8.4	8.6	?	7.8
10/24/2018	8.0	?	7.5	7.4	?	7.3
5/10/2021	9.0		8.3	8.4		8.0
12/11/2021	7.2		7.2	7.2		6.8

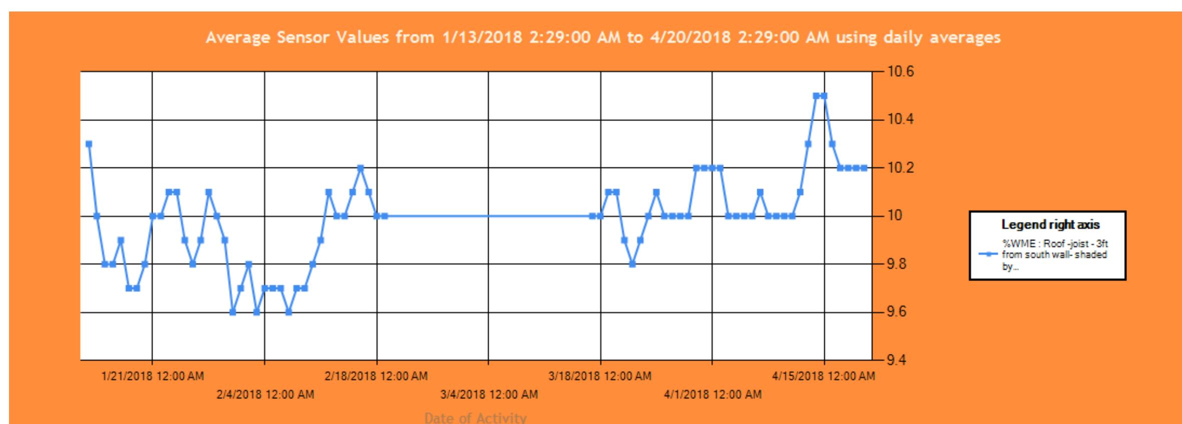
Moisture monitoring

Omnisense
- Accurate remote temp, RH and M%

- Cell or WIFI gateways



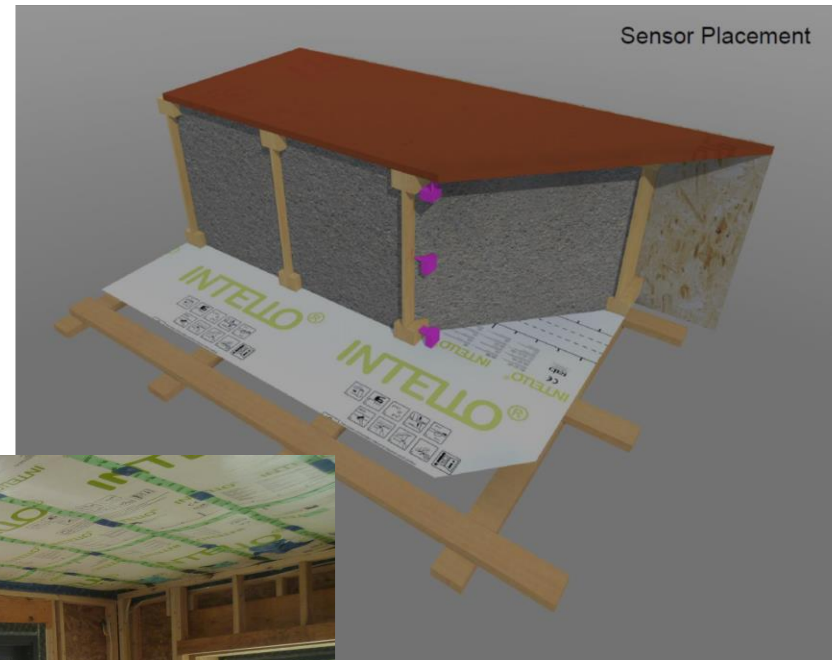




Unvented Flat Roof #1

Area of Flat Roof

Naomi Beal Photography



Grey house - Ecocor.us

Vapor closed Roof data…

The trajectory is down and increased reserves.
This is inline with WUFI Pro modelling

Source:Ecocor.us

Straw Bale

Vapor closed materials meet hygroscopic materials

Boulder, CO

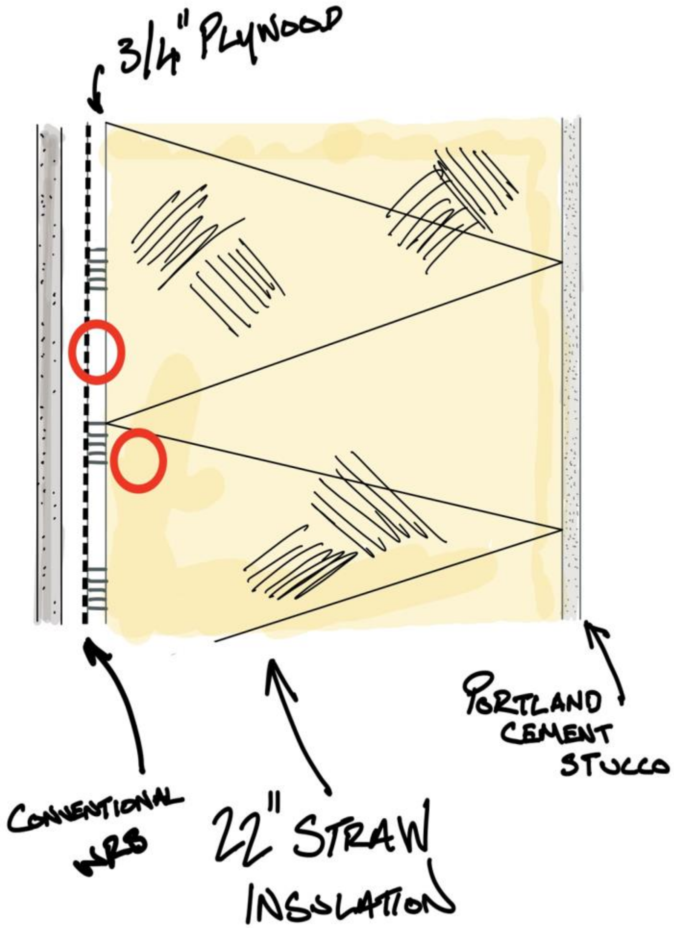
Climate Zone 5

Follow ASHRAE 160 w/additional air leakage

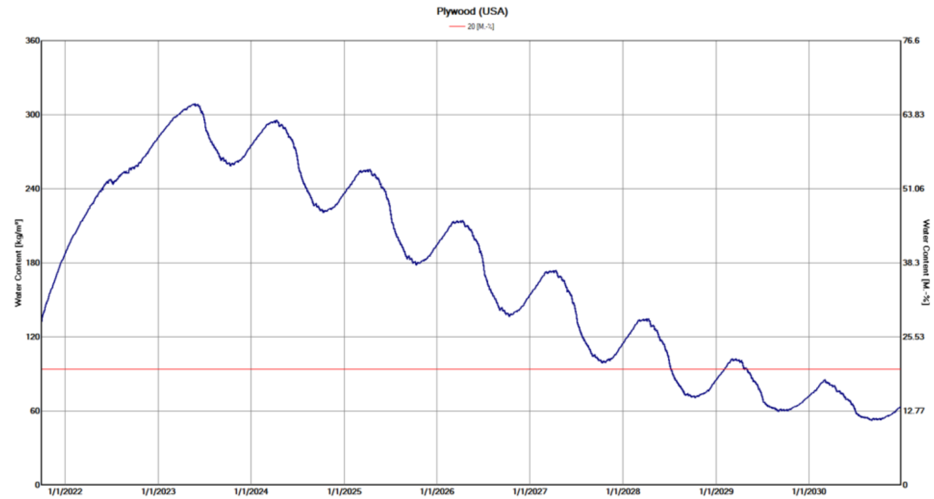
First Example - Portland cement stucco, 22” straw bale insulation @R2 per inch, ¾” plywood, Vapor closed WRB, Vented Cavity, Siding

Second Example - Clay stucco, 22” straw bale insulation @R2 per inch, ¾” plywood, SOLITEX MENTO 1000, Vented Cavity, Siding

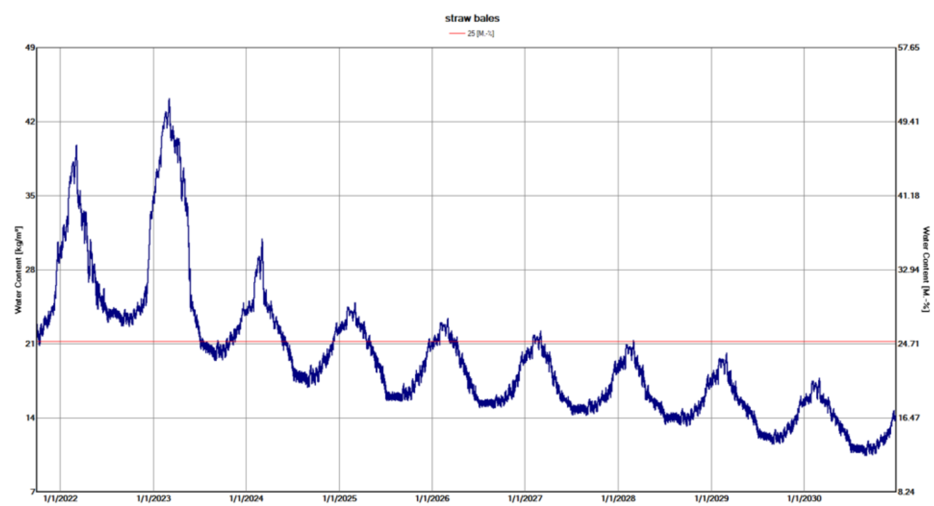
Note - M% of straw should not surpass 25M% of mass as per Wihan, J. 2007. Humidity in straw bale walls and its effect on decomposition of straw. PhD thesis of University of East London School of Computing and Technology.



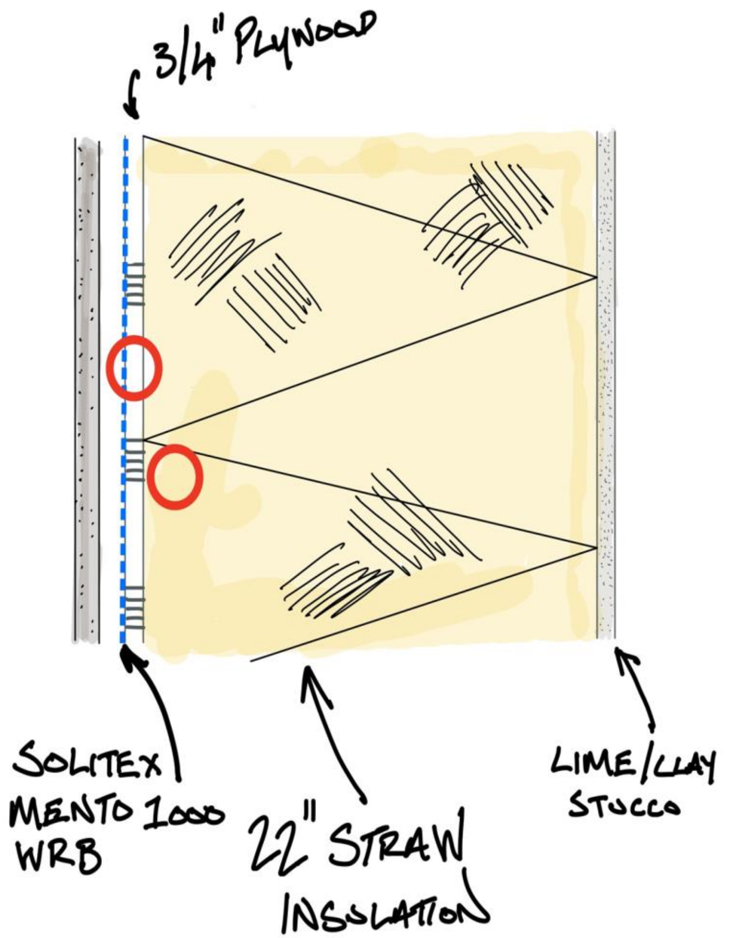
3/4" PLYWOOD
CONVENTIONAL WRB
22" STRAW INSULATION
PORTLAND CEMENT STUCCO

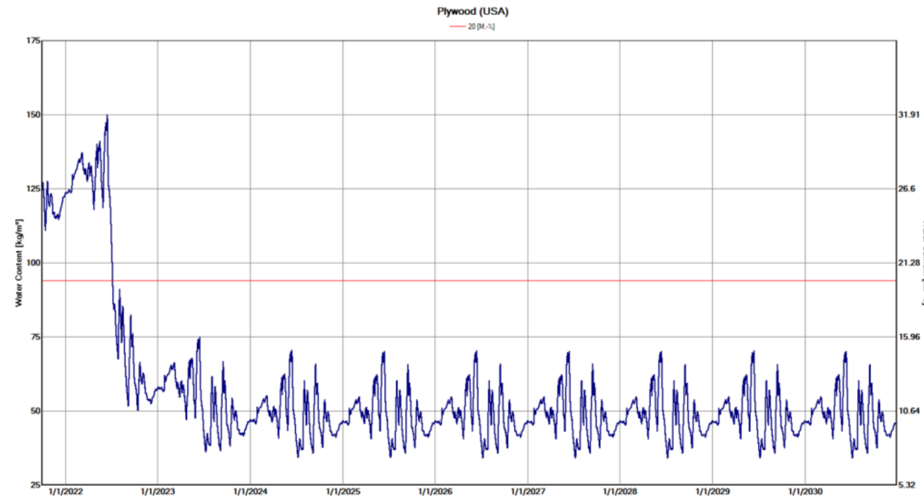


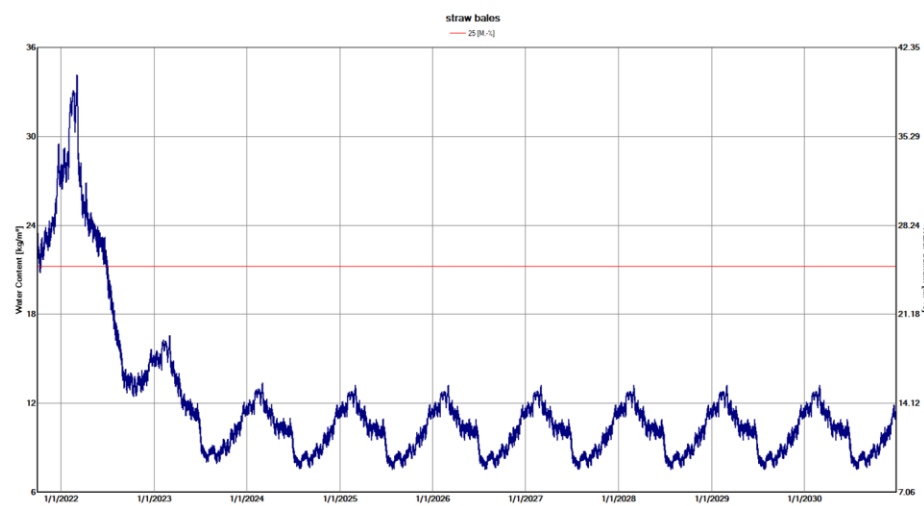
Plywood (USA)
20 [M.-%]
Water Content [kg/m³]
Water Content [M.-%]
360
300
240
180
120
60
0
76.6
63.83
51.06
38.3
25.53
12.77
0
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030



straw bales
25 [M.-%]
Water Content [kg/m³]
Water Content [M.-%]
49
42
35
28
21
14
7
57.65
49.41
41.18
32.94
24.71
16.47
8.24
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030


3/4" PLYWOOD
SOLITEX MENTO 1000 WRB
22" STRAW INSULATION
LIME/CLAY STUCCO


Plywood (USA)
20 [M.-%]
Water Content [kg/m³]
Water Content [M.-%]
175
150
125
100
75
50
25
31.91
26.6
21.28
15.96
10.64
5.32
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030


straw bales
25 [M.-%]
Water Content [kg/m³]
Water Content [M.-%]
36
30
24
18
12
6
42.35
35.29
28.24
21.18
14.12
7.06
1/1/2022
1/1/2023
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030

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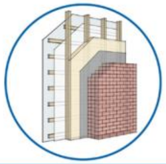
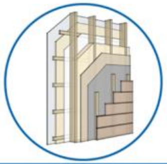


MASONRY RETROFIT

- Masonry Retrofit ebook (PDF - Page Layout)



WOOD RETROFIT

- Wood Retrofit ebook (PDF - Page Layout)

2x FRAMING

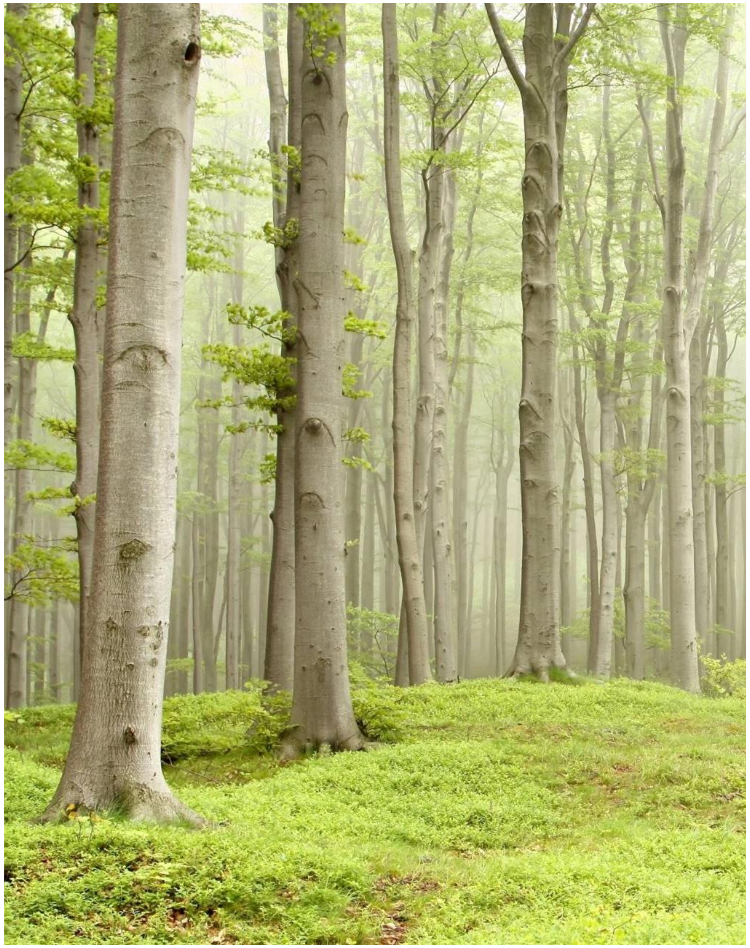
- 2x Framing ebook (PDF - Page Layout)

Our free e-books
Project support
WUFI modelling

How to put it all together

475
HIGH PERFORMANCE BUILDING SUPPLY
FOURSEVENFIVE.COM

SUMMARY



Make it tight. Make it right.

- **Make continuous control layers** with properly placed high performance materials and readily get great airtightness and smart vapor control.

- **Minimize (or eliminate) the use of plastic foams** and make a more durable and sustainable assembly.

- **Always blower door** your buildings - make them as tight as you can.

- **Protect your control layers** with sacrificial finishes.