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BUILDING ENCLOSURE CONFERENCE 2023

Adventures in Hygrothermal Modeling

Keith A. Simon, FAIA
Terracon Consultants, Inc.

AIA Continuing Education Provider

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Adventures in Hygrothermal Modeling

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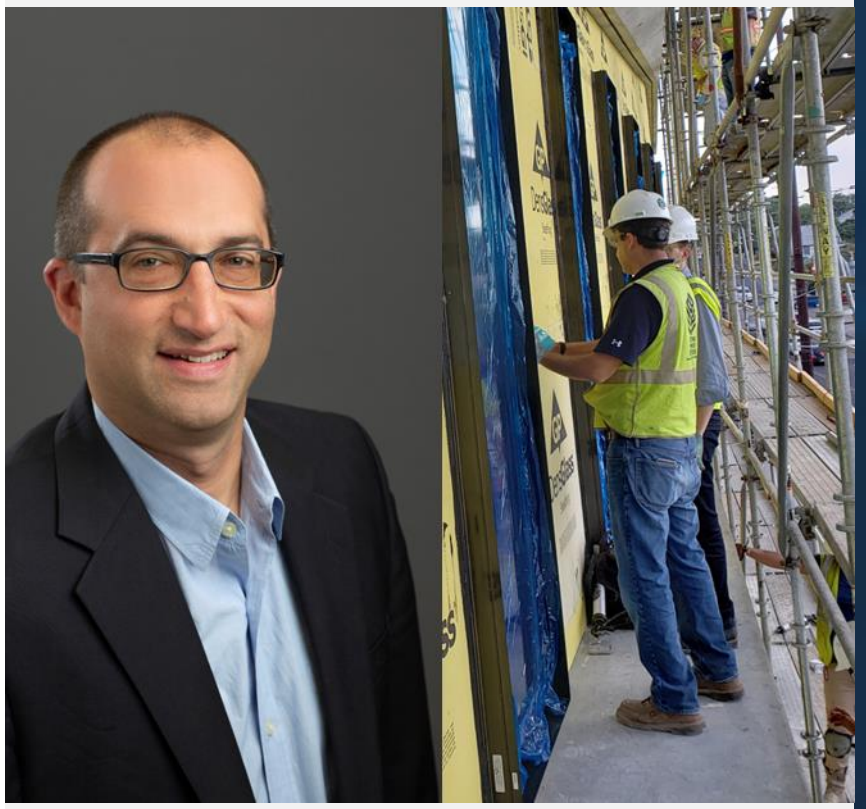

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Learning Objectives

1. Learn climate-specific design strategies for durable construction.
2. Learn to avoid common mistakes that can lead to mold, rot, mildew, corrosion and decay.
3. Understand how hygrothermal modeling can be used in the design process to ensure durability.
4. Learn how material properties (permeability, heat capacity, density, conductivity, and porosity) impact wall assemblies.

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building professionals
making quality sustainable

TMI
AIR BARRIER TESTING

FUNCTIONAL COATINGS by tesa®

siplast®

WALLcontrol™

NCFI POLYURETHANES

Henry®
A CARLISLE COMPANY

DOWSIL™
technologies by DOW

HB HOHMANN & BARNARD, INC.

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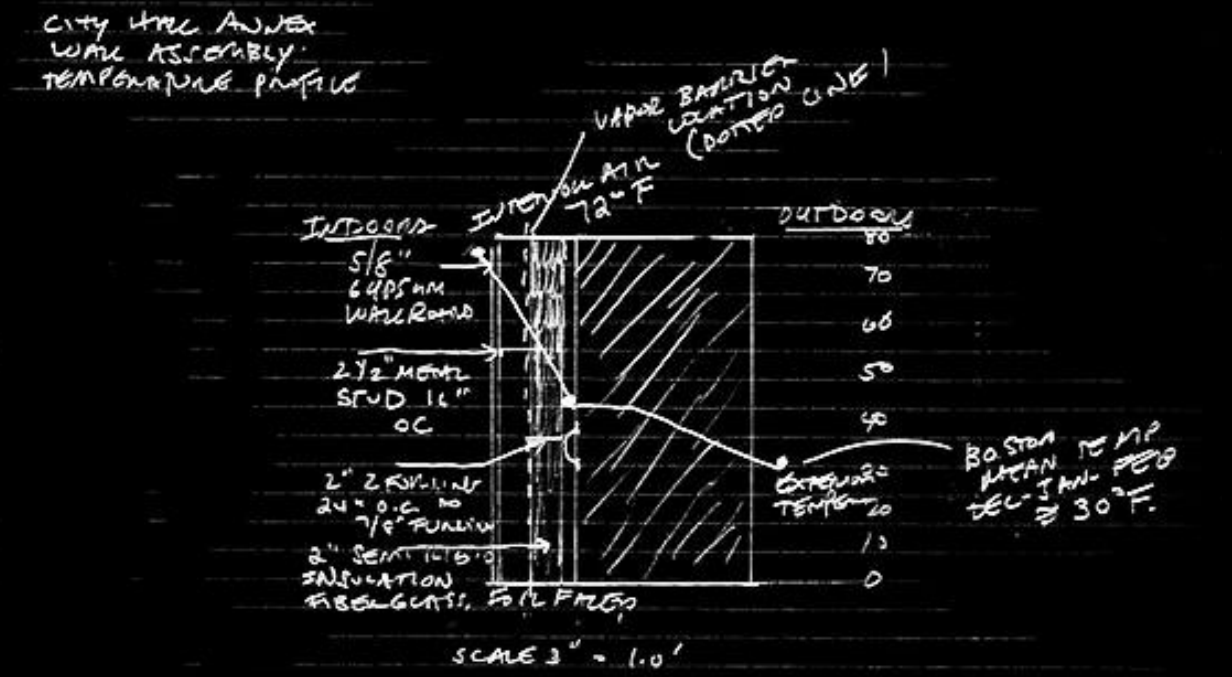
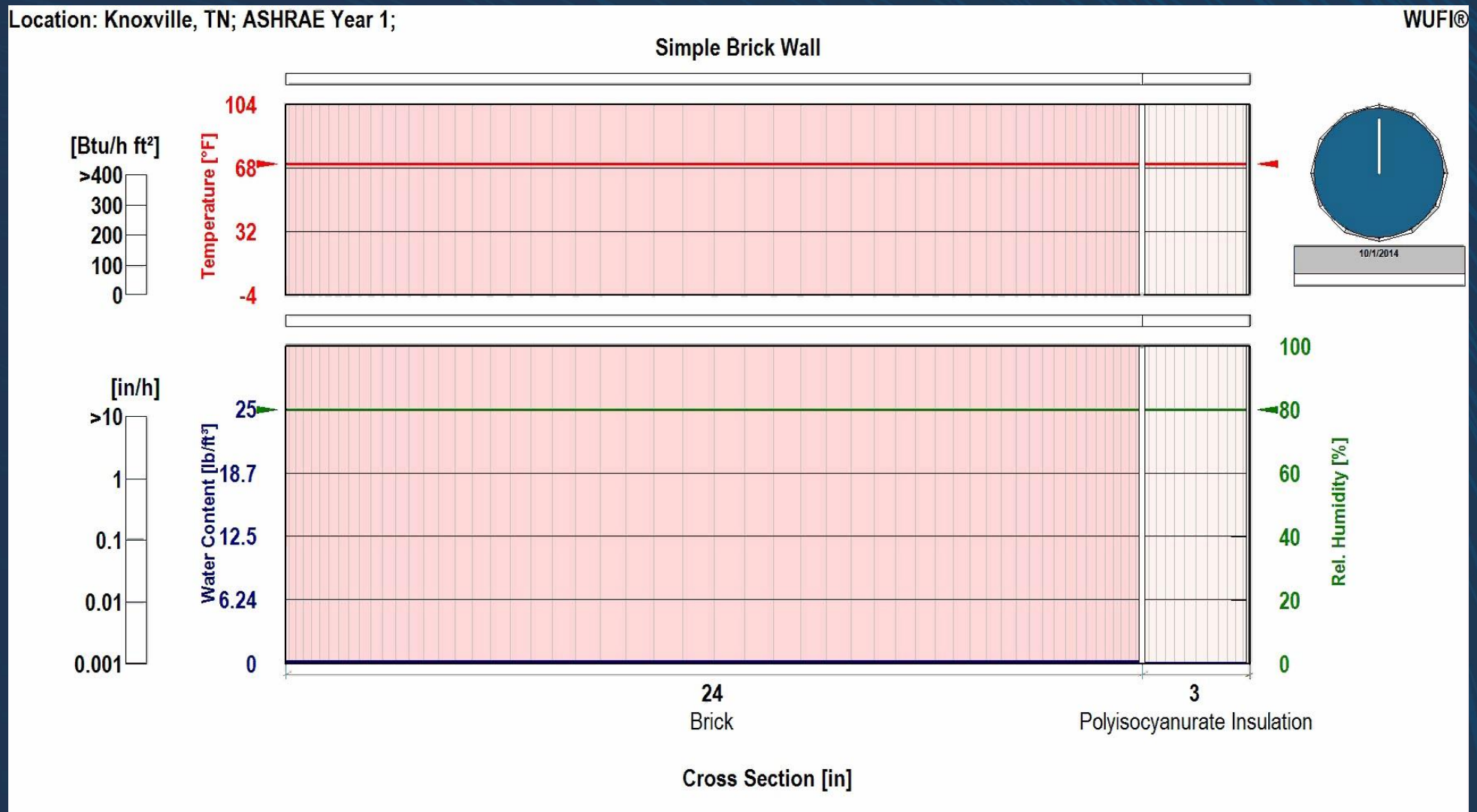
BE BUILDING ENCLOSURE

Dew Point Calculation?

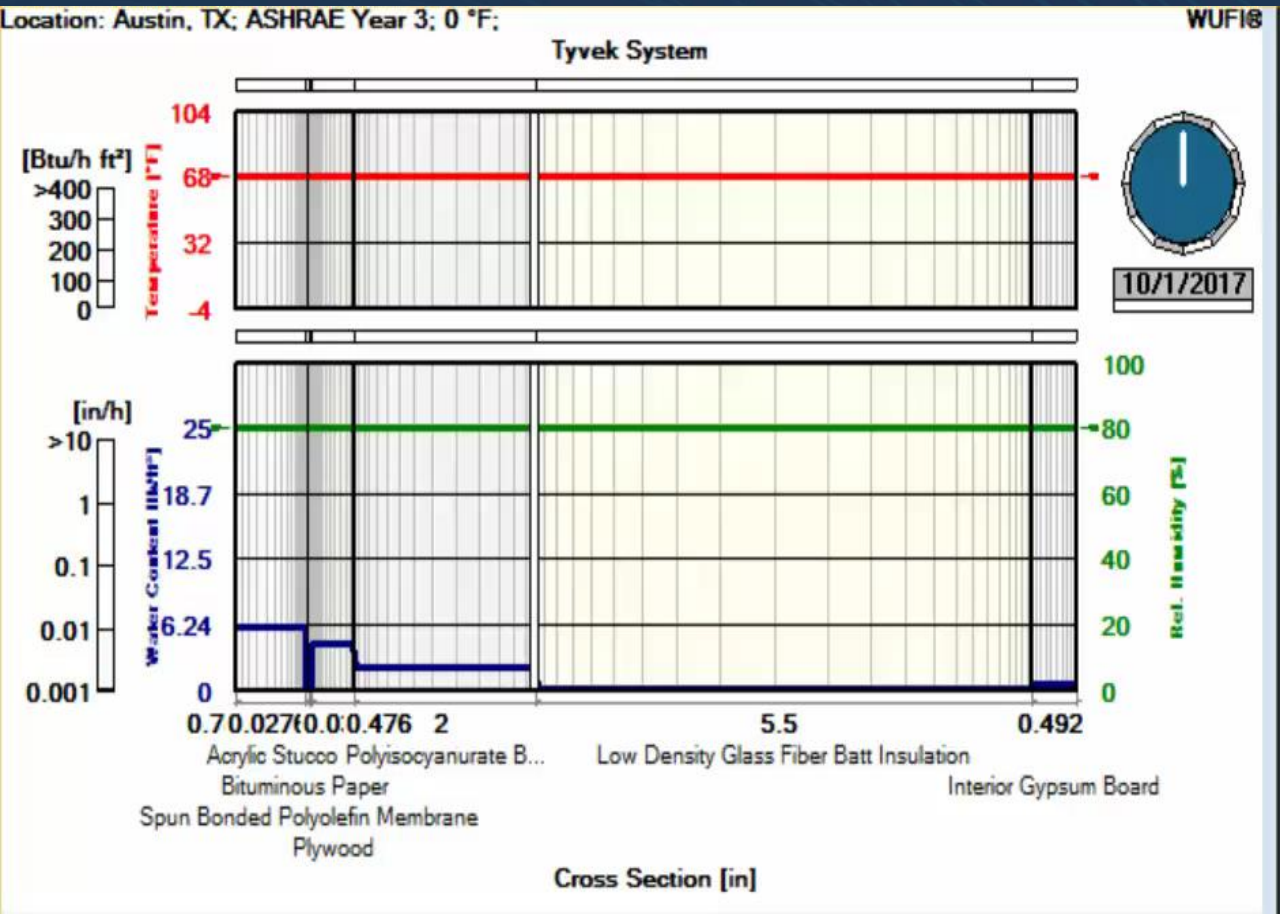


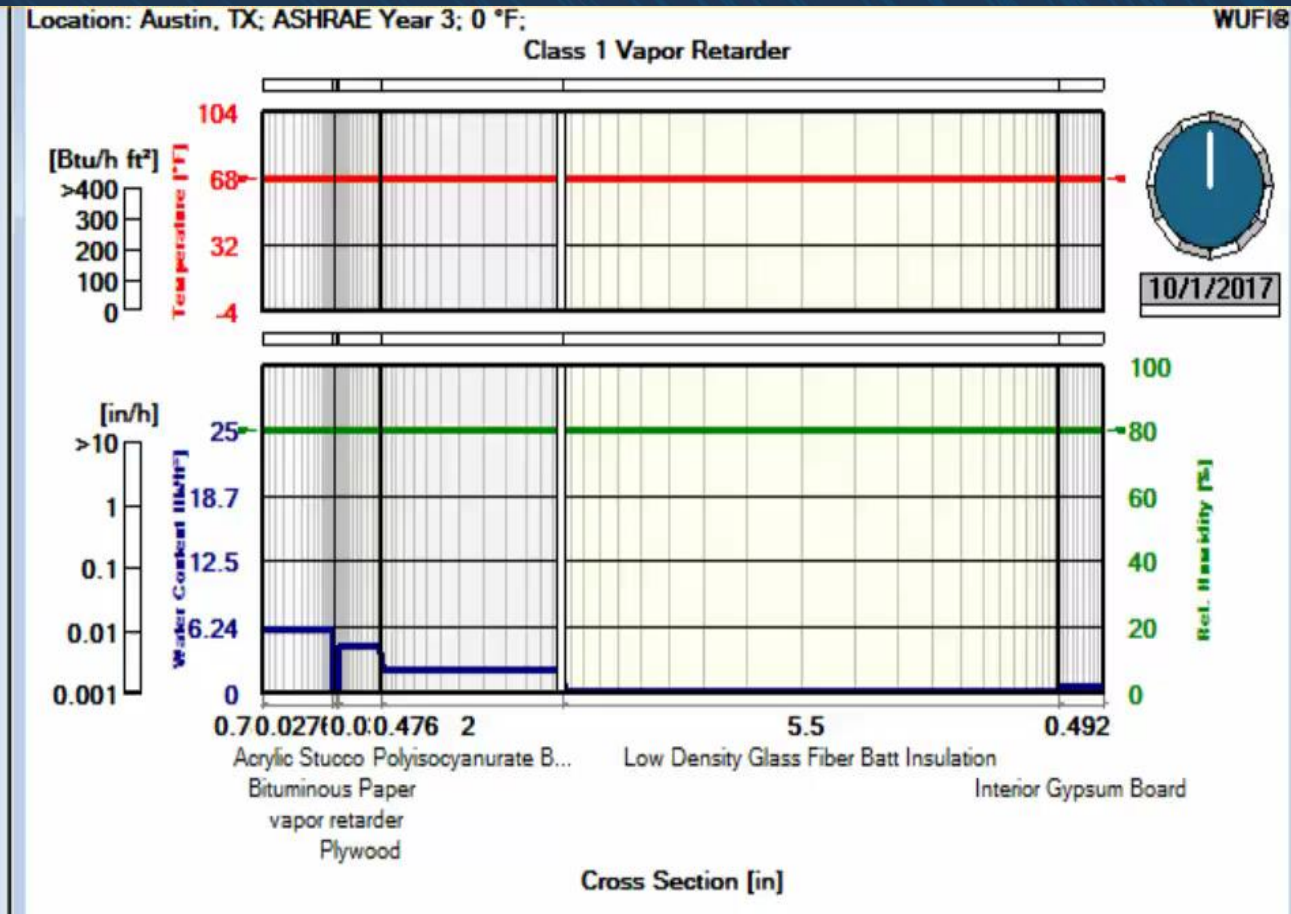
(5) ASSUMING INDOOR CONDITIONS AT 72°F and 35% RH THE DEW POINT FROM THE PSYCHROMETRIC CHART IS APPROXIMATE 40°F. ANY TEMPERATURE BELOW THE DEW POINT WILL CAUSE CONDENSATION IN THE WALL ASSEMBLY.

WUFI Pro 1d Simulation (Fraunhofer IBP)
Wärme Und Feuchte Instationär

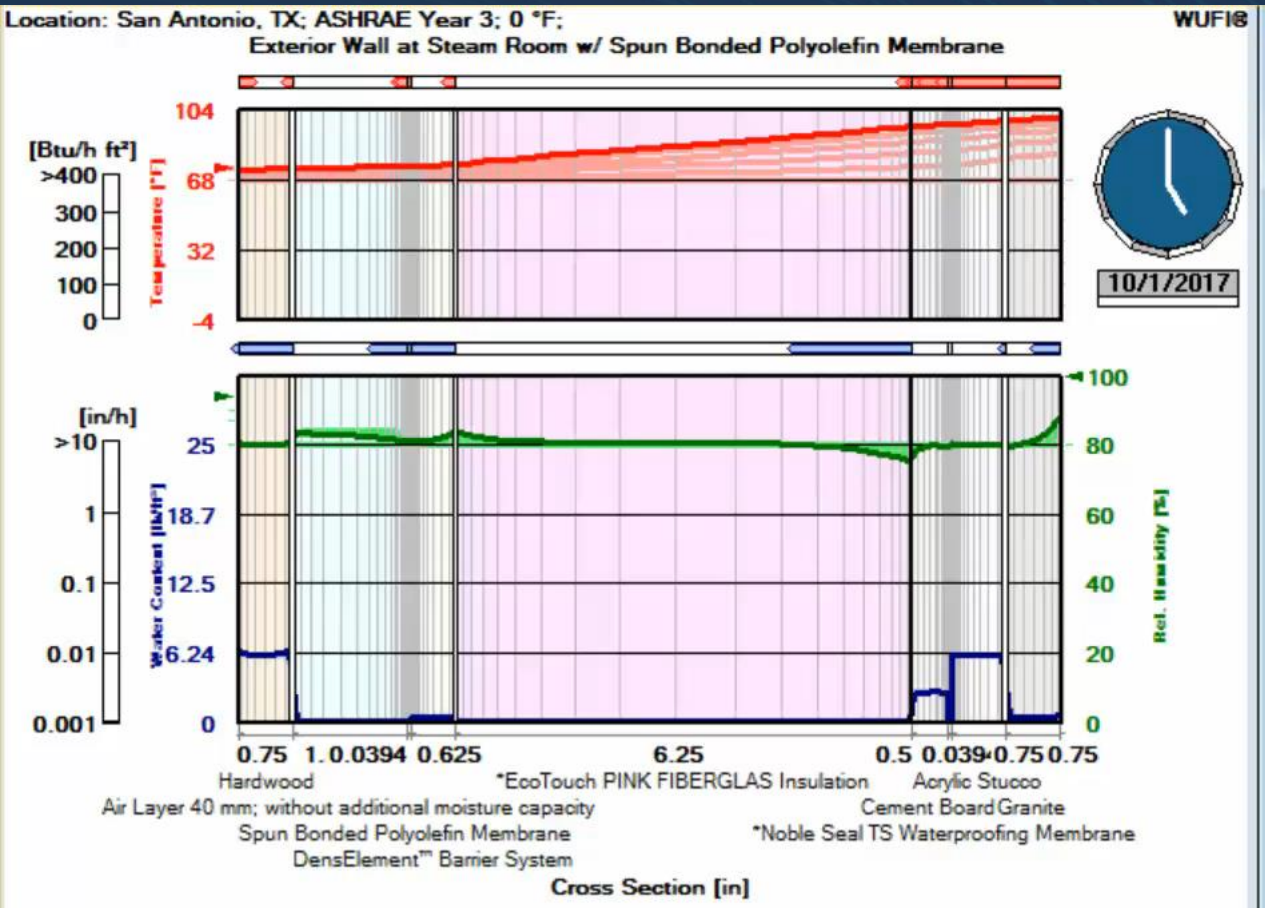


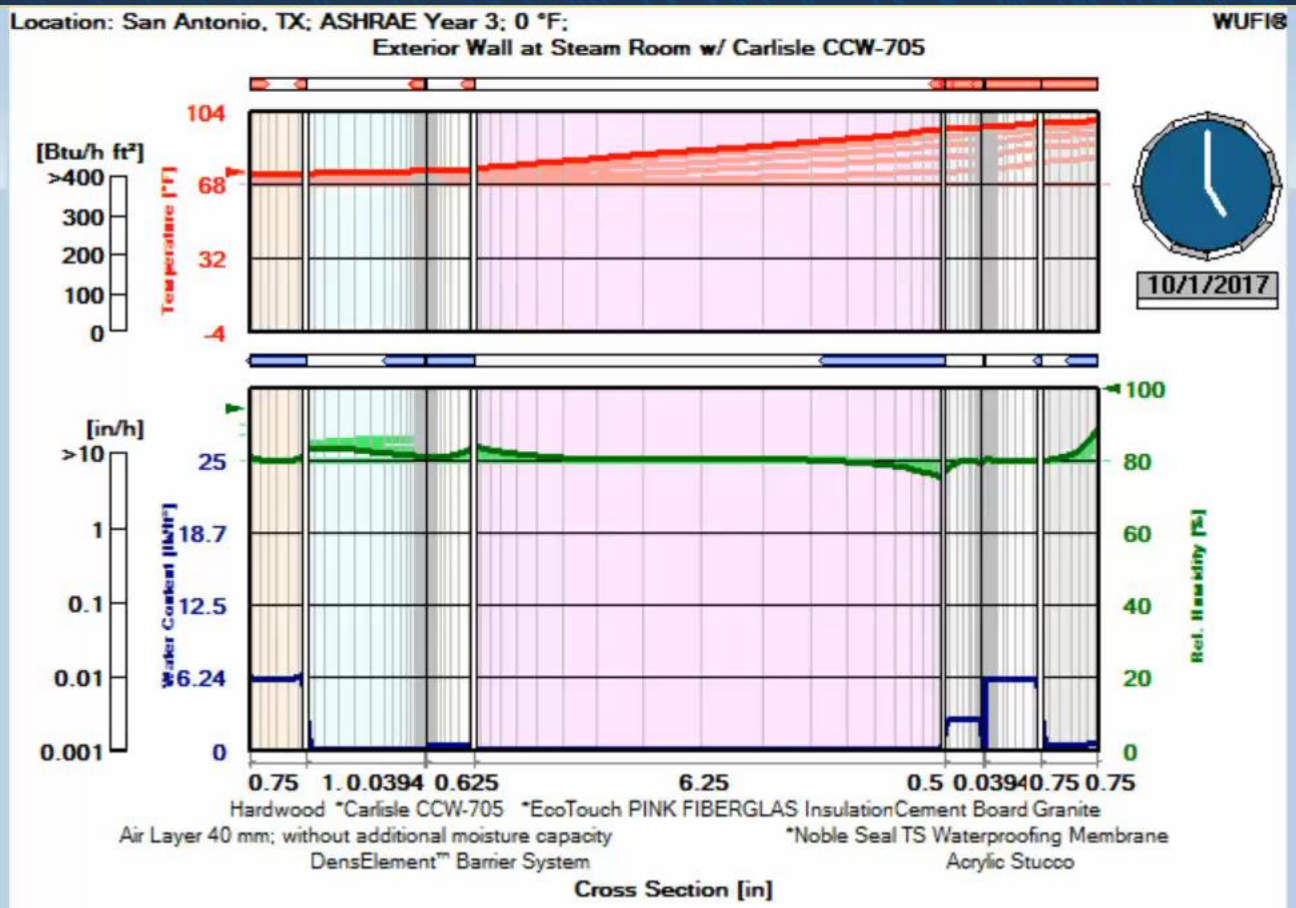
Simultaneous Simulations: Vapor Barrier – Good!



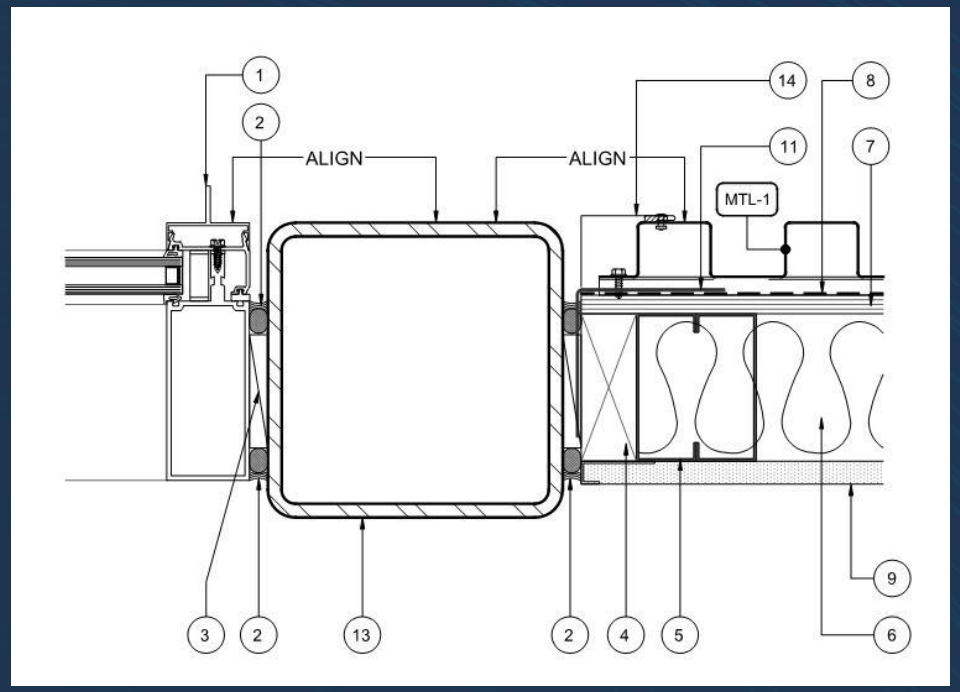


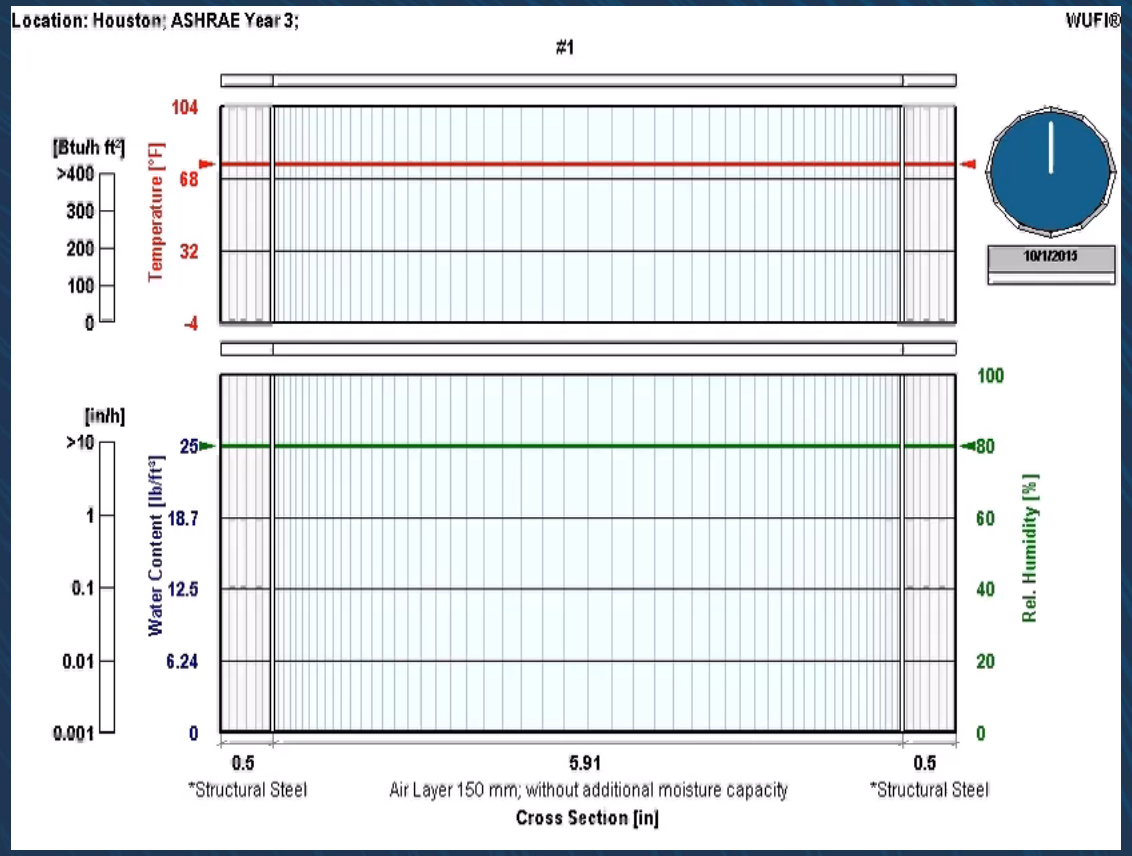
Simultaneous Simulations: Vapor Barrier – Bad!



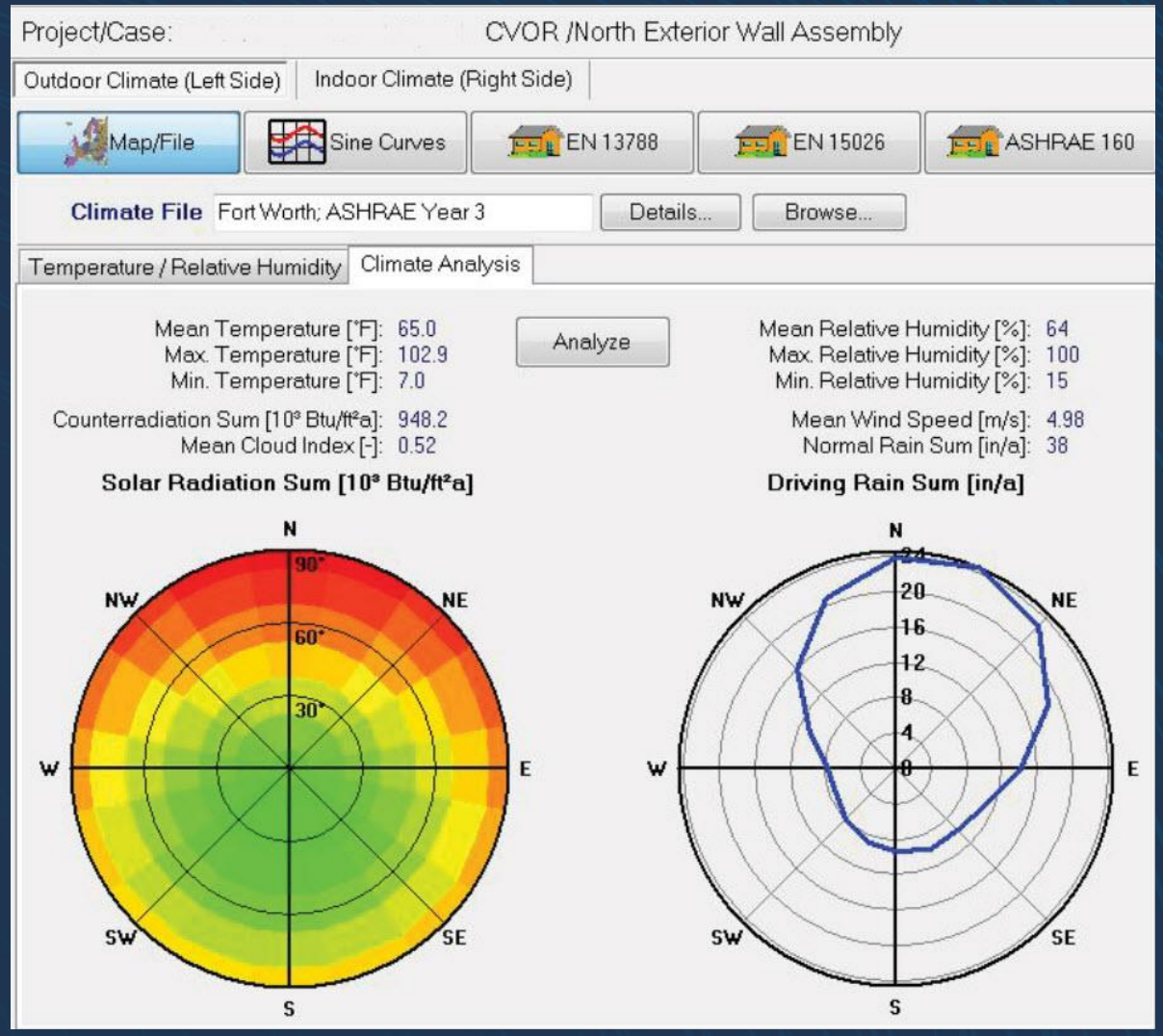


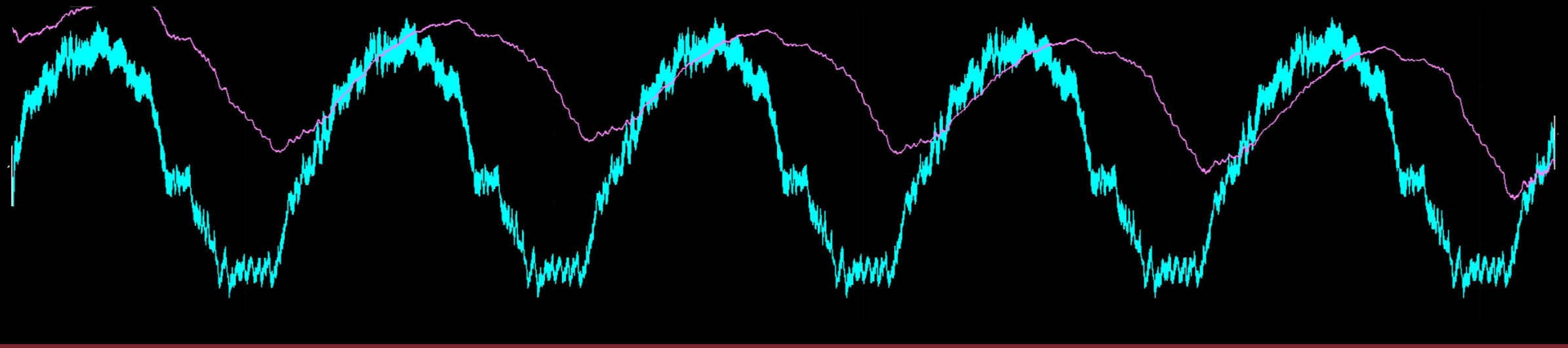
WUFI Pro 1d Simulation (Fraunhofer IBP)





Worst Case Scenario





Hygrothermal Analysis

How accurate is this stuff??

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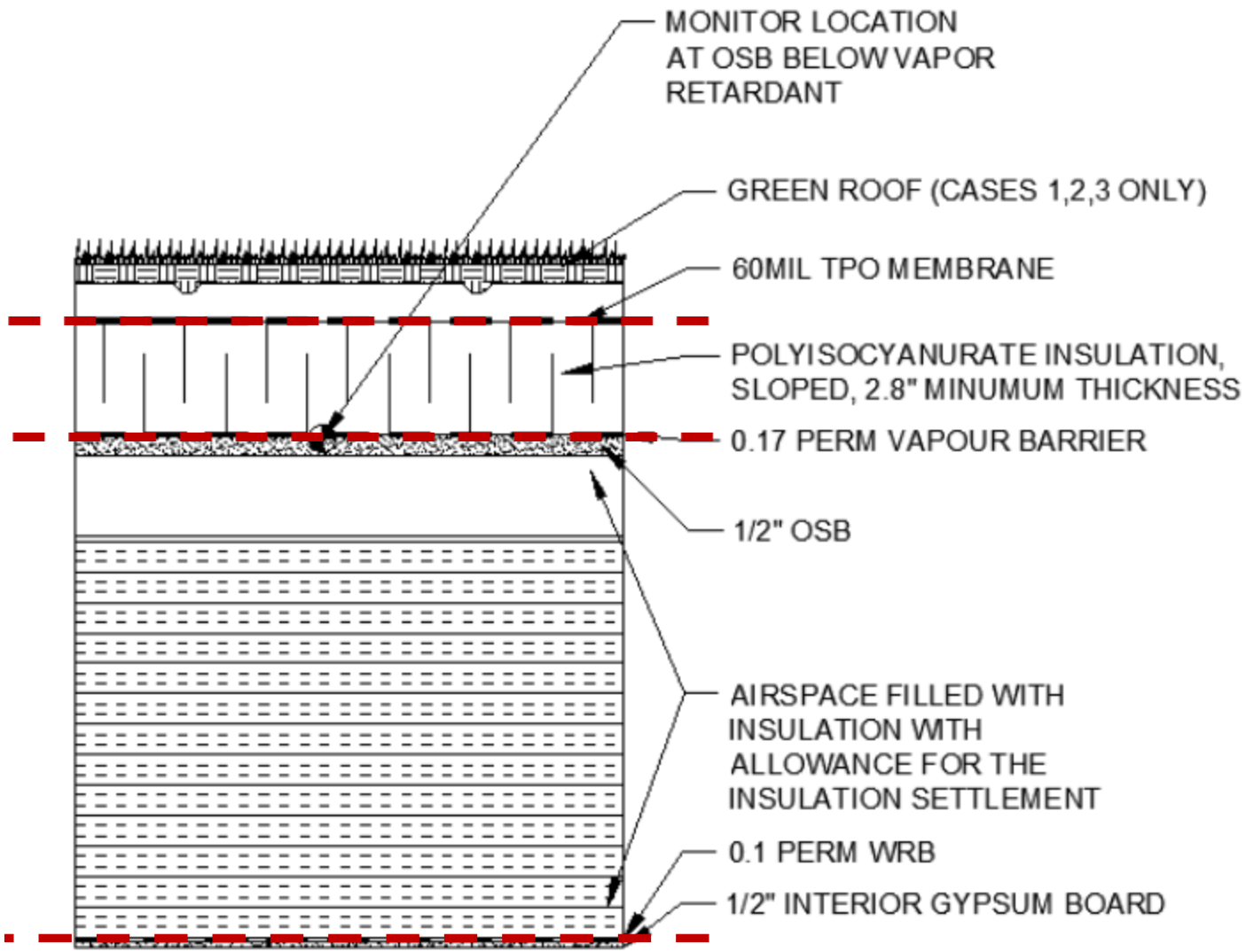


Figure 1 – Roof Structure

		Cases (green indicates "passing" cases)					
		1	**2**	**3**	**4**	**5**	**6**
Green Roof Assembly	6-7"	X	X	X			
TPO	60 mil	X	X	X	X	X	X
Polyiso	2.8"	X	X	X	X	X	X
Self-Adhered Vapor Barrier	0.017 perm	X	X	X	X	X	X
OSB	1/2"	X	X	X	X	X	X
Gap filled with Fiberglass Insulation	12" (10" ins, 2" air)	X			X		
	12" (6" ins, 6" air)		X			X	
	24" (22" ins, 2" air)			X			X
Poly Vapor Barrier	0.1 perm	X	X	X	X	X	X
Interior Gypsum Board	1/2"	X	X	X	X	X	X

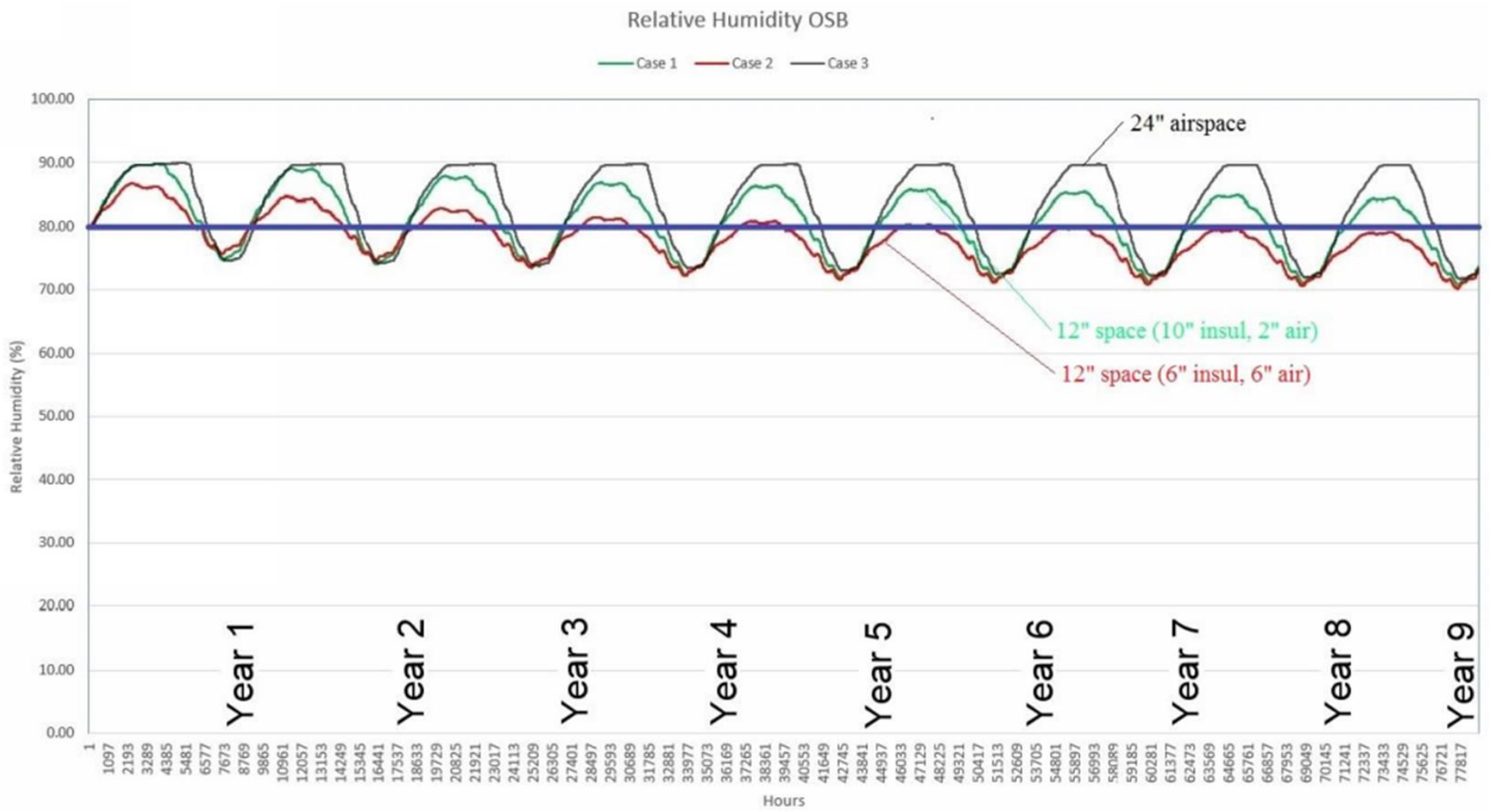
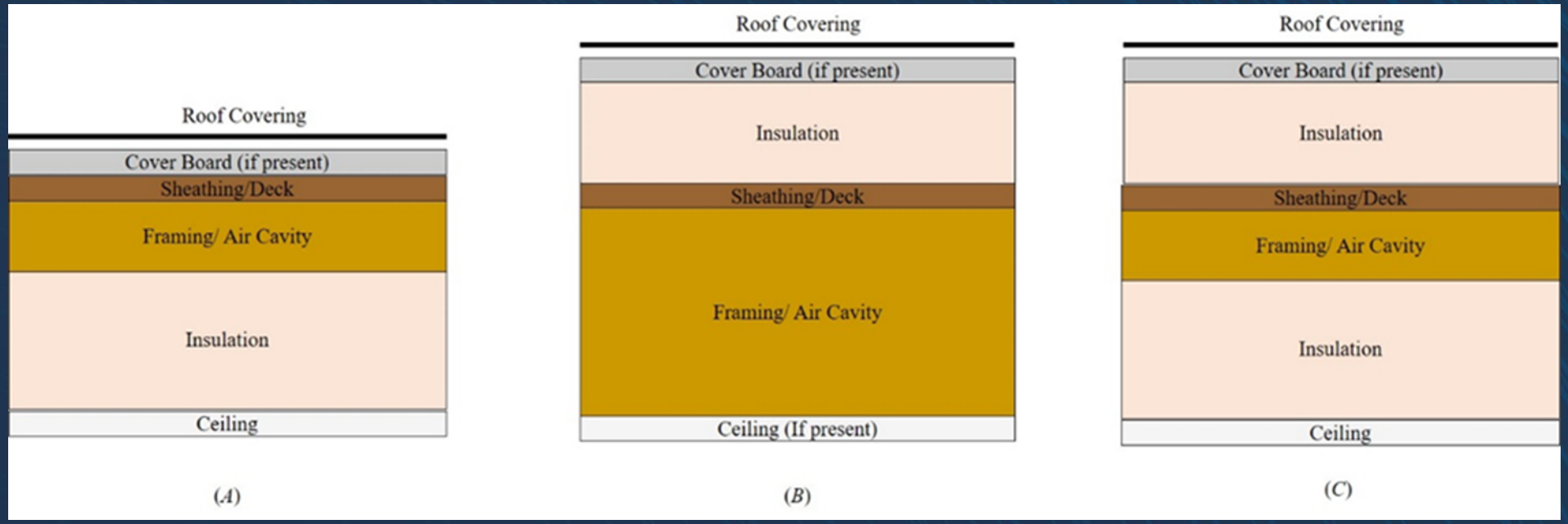
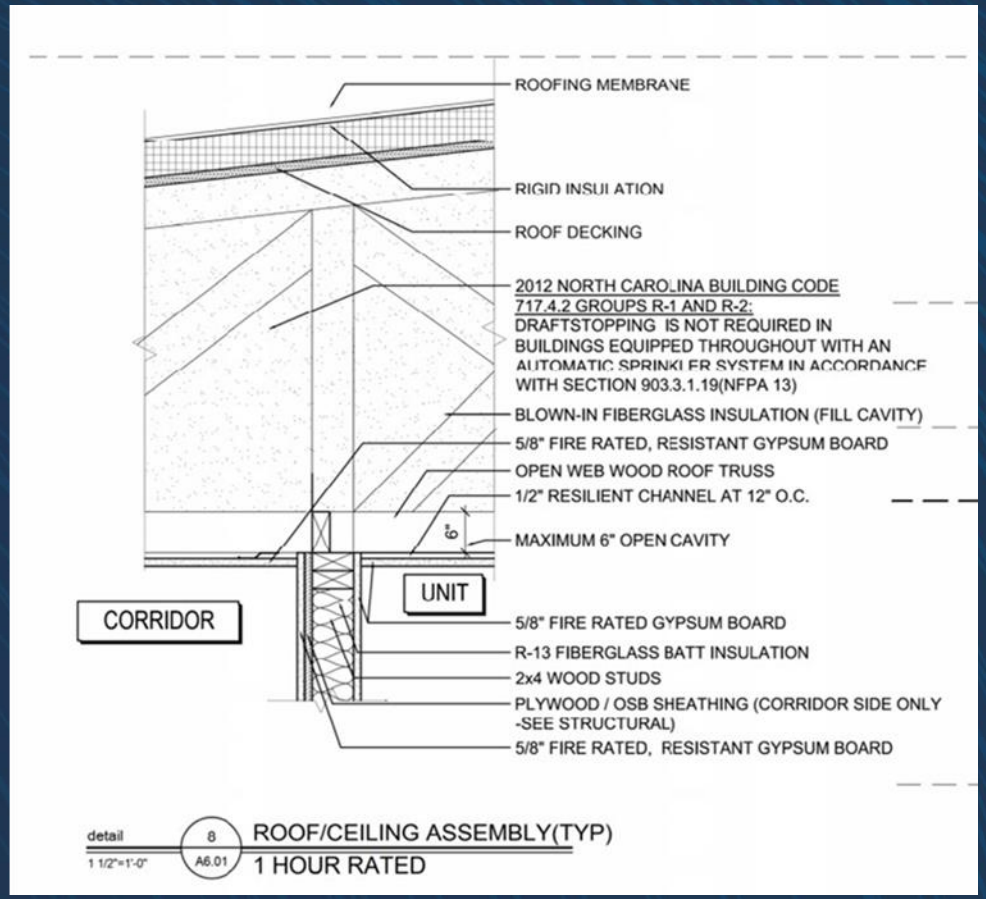


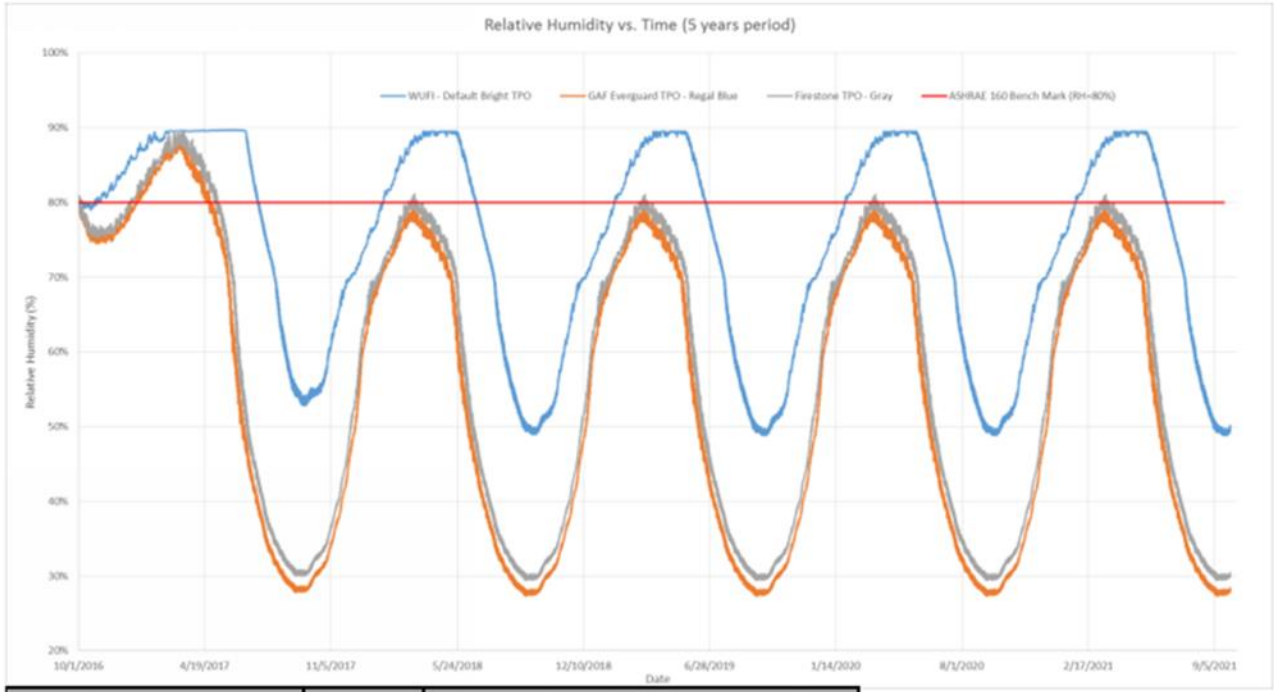
Figure 2: All cases include green roof

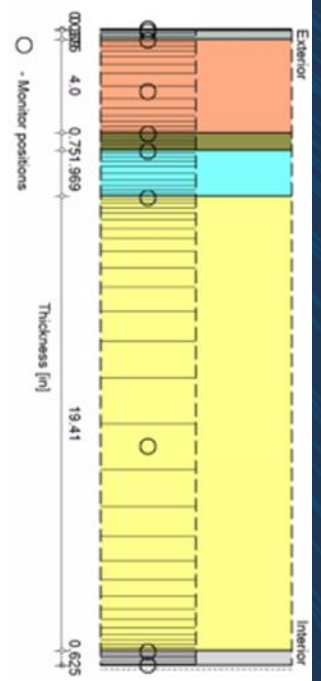

Roof Covering
Cover Board (if present)
Sheathing/Deck
Framing/ Air Cavity
Insulation
Ceiling
(A)
Roof Covering
Cover Board (if present)
Insulation
Sheathing/Deck
Framing/ Air Cavity
Ceiling (If present)
(B)
Roof Covering
Cover Board (if present)
Insulation
Sheathing/Deck
Framing/ Air Cavity
Insulation
Ceiling
(C)


ROOFING MEMBRANE
RIGID INSULATION
ROOF DECKING
2012 NORTH CAROLINA BUILDING CODE
717.4.2 GROUPS R-1 AND R-2:
DRAFTSTOPPING IS NOT REQUIRED IN
BUILDINGS EQUIPPED THROUGHOUT WITH AN
AUTOMATIC SPRINKLER SYSTEM IN ACCORDANCE
WITH SECTION 903.3.1.19(NFPA 13)
BLOWN-IN FIBERGLASS INSULATION (FILL CAVITY)
5/8" FIRE RATED, RESISTANT GYPSUM BOARD
OPEN WEB WOOD ROOF TRUSS
1/2" RESILIENT CHANNEL AT 12" O.C.
6"
MAXIMUM 6" OPEN CAVITY
UNIT
CORRIDOR
5/8" FIRE RATED GYPSUM BOARD
R-13 FIBERGLASS BATT INSULATION
2x4 WOOD STUDS
PLYWOOD / OSB SHEATHING (CORRIDOR SIDE ONLY
-SEE STRUCTURAL)
5/8" FIRE RATED, RESISTANT GYPSUM BOARD
detail
1 1/2"=1'-0"
8
A6.01
ROOF/CEILING ASSEMBLY(TYP)
1 HOUR RATED

NON-VENTED BLOWN IN INSULATION (Roof Membrane Color Comparisons)

Condition: 2 Bed Room Apartment per ASHRAE 160





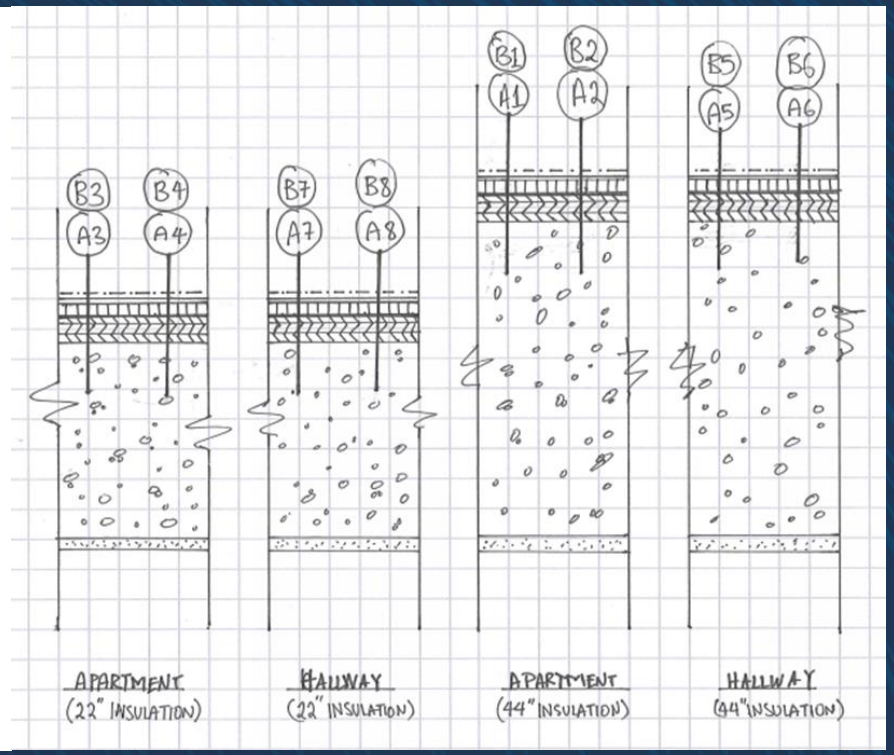
GAF Products	Absorptivity	Reflectivity	Thermal Emittance	Result
EverGuard TPO - White	0.24	0.76	0.83	FAIL
EverGuard TPO - Tan	0.35	0.65	0.84	FAIL
EverGuard TPO - Gray	0.6	0.4	0.86	Borderline PASS
EverGuard TPO - Regal Red	0.67	0.33	0.91	Borderline PASS
EverGuard TPO - Hartford Green	0.71	0.29	0.9	PASS
EverGuard TPO - Regal Blue	0.74	0.26	0.9	PASS
Firestone Products	Absorptivity	Reflectivity		Result
TPO White	0.32	0.68	0.83	FAIL
TPO Tan	0.45	0.55	0.84	FAIL
TPO Gray	0.66	0.34	0.88	PASS
WUFI TPO	Absorptivity	Reflectivity		Result
Bright	0.2	N/A	0.9	FAIL
Dark	0.8	N/A	0.9	PASS

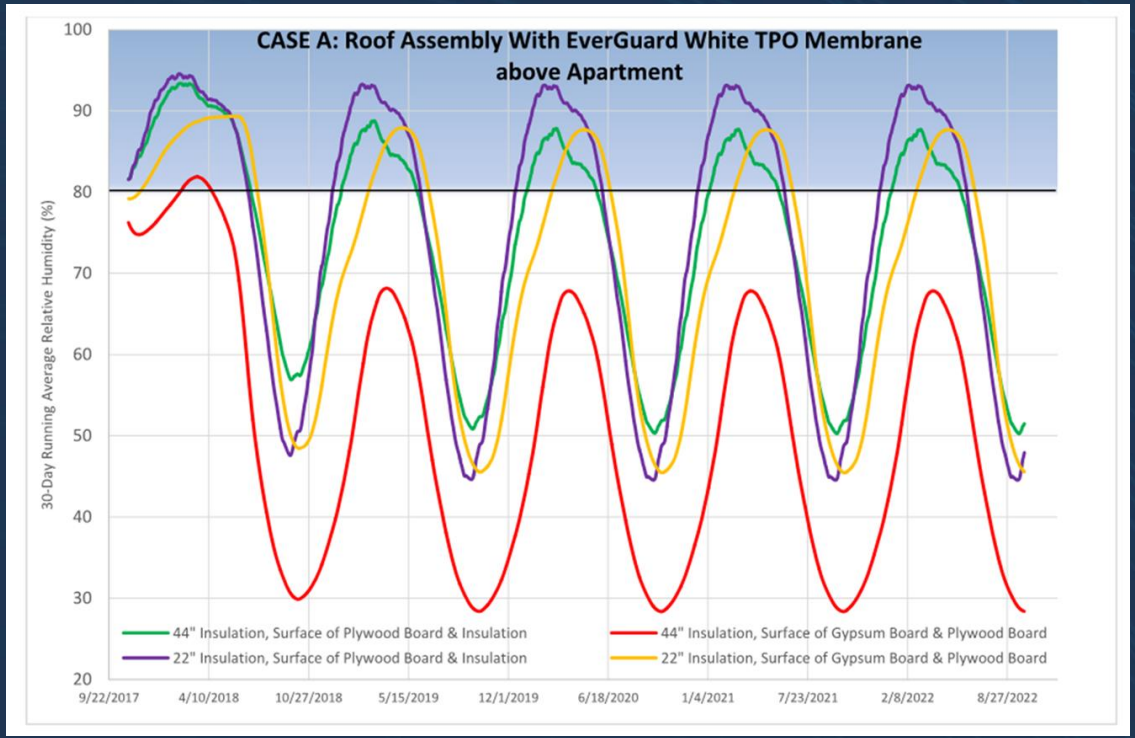
Materials:

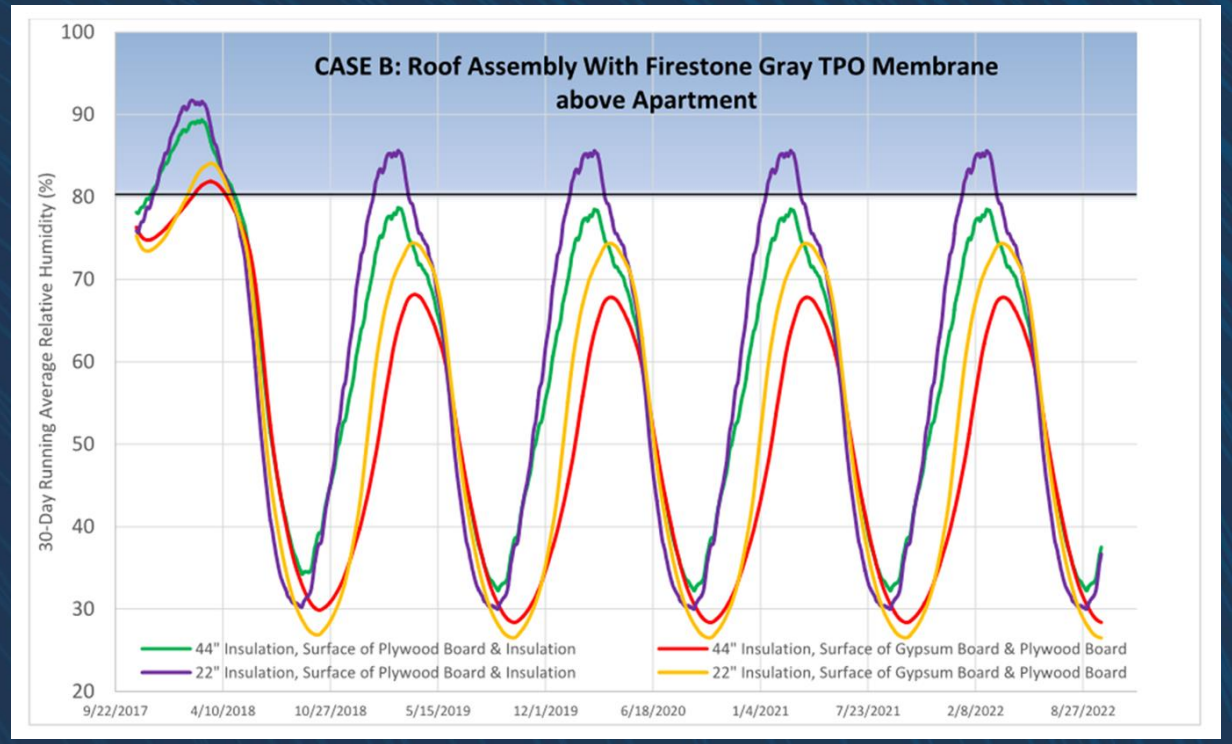
- vapor retarder (0.1perm)	0.039 in
- Gypsum Board (USA)	0.375 in
- Polyisocyanurate Insulation	4.0 in
- Plywood (USA)	0.75 in
- Air Layer 50 mm; without additional moisture capacity if city agrees to use 2013 NFPA code	1.969 in
- Low Density Glass Fibre Batt Insulation	19.41 in
- Interior Gypsum Board	0.625 in

			Insulation Thickness	Monitoring Point Location
Case A: EverGuard White TPO Membrane	Apartment	A1	44"	Between gypsum board & plywood decking
		A2	44"	Between plywood decking & Insulation
		A3	22"	Between gypsum board & plywood decking
		A4	22"	Between plywood decking & Insulation
	Hallway	A5	44"	Between gypsum board & plywood decking
		A6	44"	Between plywood decking & Insulation
		A7	22"	Between gypsum board & plywood decking
		A8	22"	Between plywood decking & Insulation
Case B: Firestone Gray TPO Membrane	Apartment	B1	44"	Between gypsum board & plywood decking
		B2	44"	Between plywood decking & Insulation
		B3	22"	Between gypsum board & plywood decking
		B4	22"	Between plywood decking & Insulation
	Hallway	B5	44"	Between gypsum board & plywood decking
		B6	44"	Between plywood decking & Insulation
		B7	22"	Between gypsum board & plywood decking
		B8	22"	Between plywood decking & Insulation

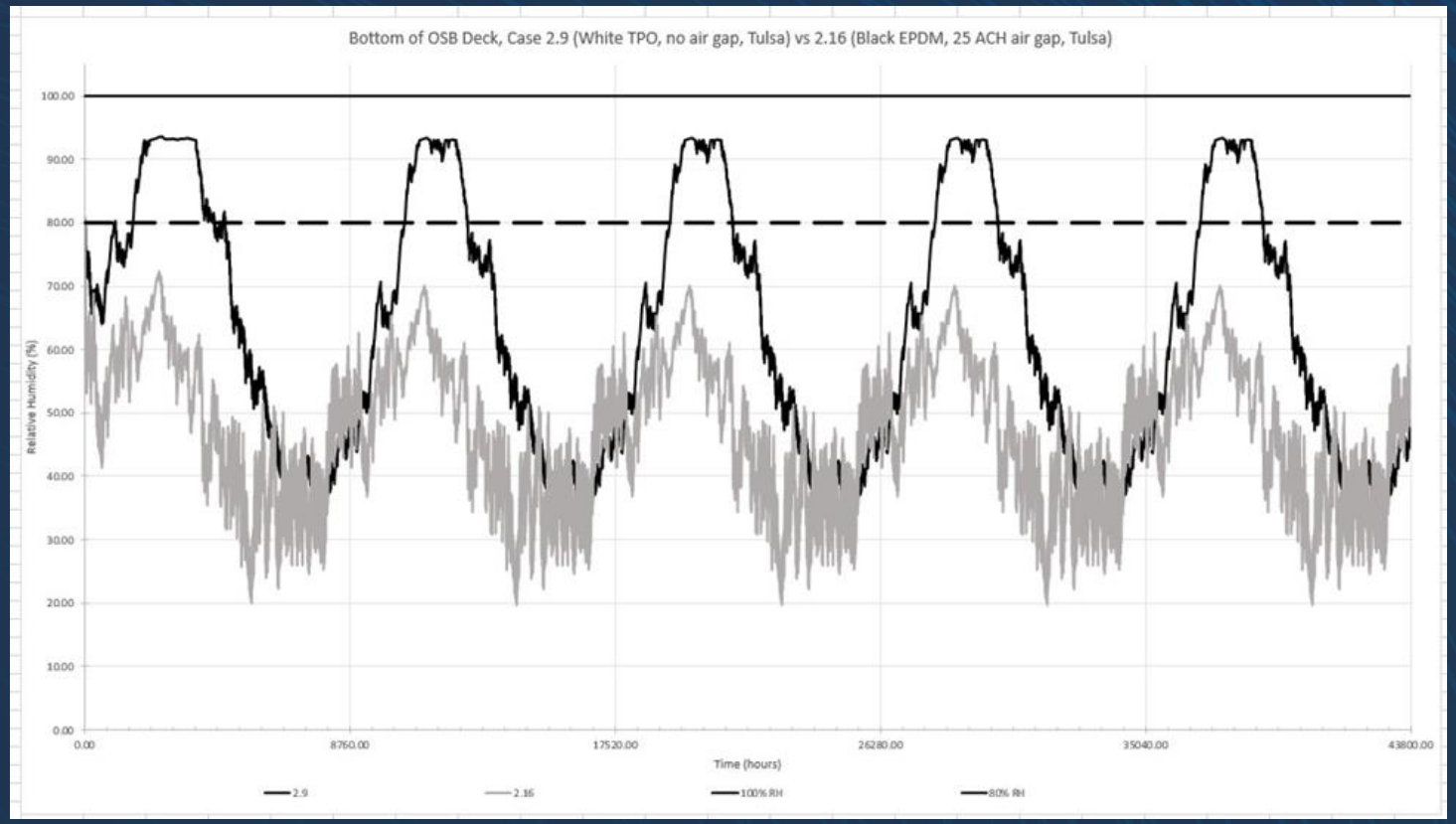
Table 1: Summary of Case A & B at different locations



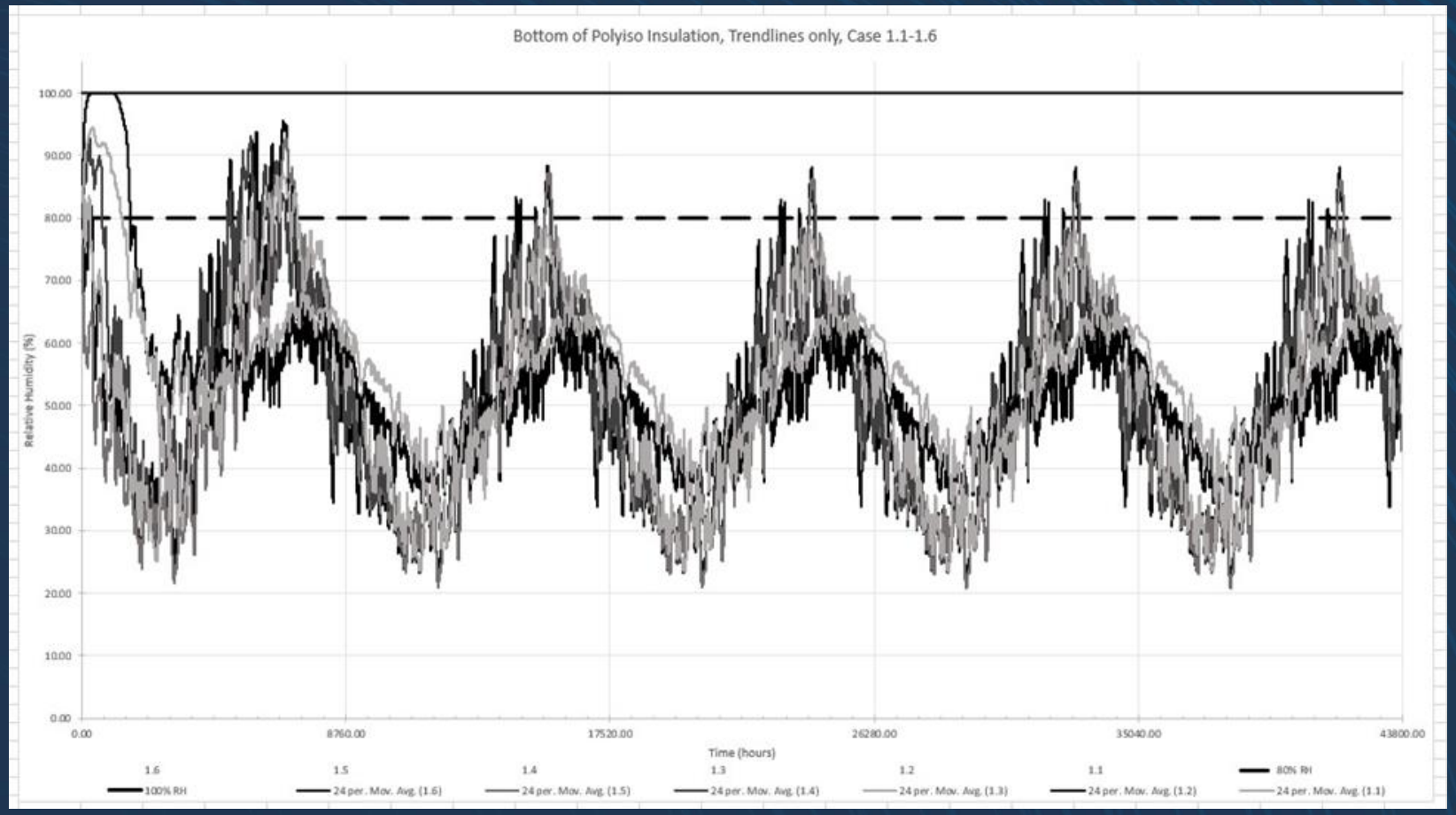

CASE A: Roof Assembly With EverGuard White TPO Membrane above Apartment
30-Day Running Average Relative Humidity (%)
100
90
80
70
60
50
40
30
20
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
1/4/2021
7/23/2021
2/8/2022
8/27/2022
44" Insulation, Surface of Plywood Board & Insulation
44" Insulation, Surface of Gypsum Board & Plywood Board
22" Insulation, Surface of Plywood Board & Insulation
22" Insulation, Surface of Gypsum Board & Plywood Board


CASE B: Roof Assembly With Firestone Gray TPO Membrane above Apartment
30-Day Running Average Relative Humidity (%)
100
90
80
70
60
50
40
30
20
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
1/4/2021
7/23/2021
2/8/2022
8/27/2022
44" Insulation, Surface of Plywood Board & Insulation
44" Insulation, Surface of Gypsum Board & Plywood Board
22" Insulation, Surface of Plywood Board & Insulation
22" Insulation, Surface of Gypsum Board & Plywood Board

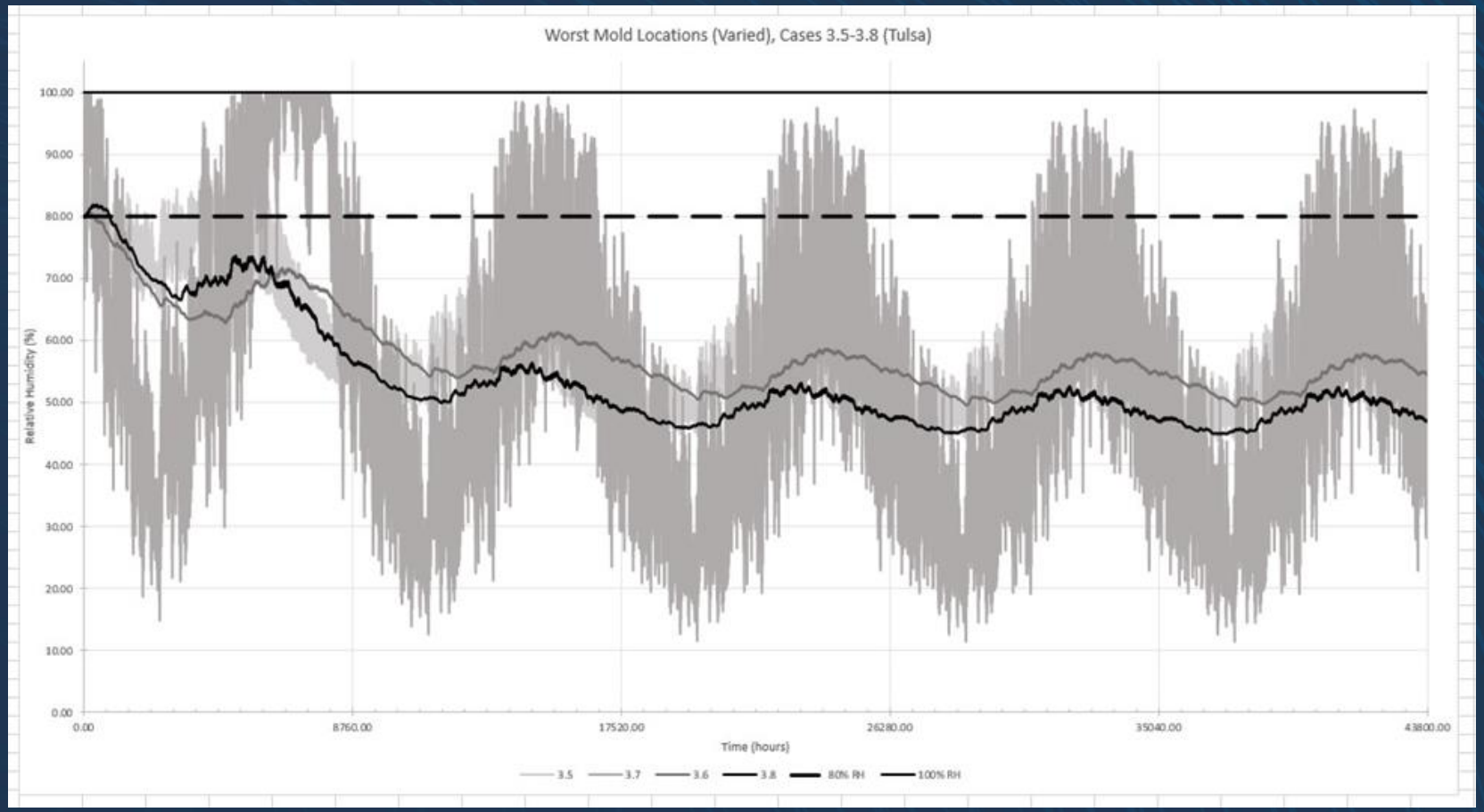
Comparison of White TPO versus Black EPDM Roof in Tulsa, OK

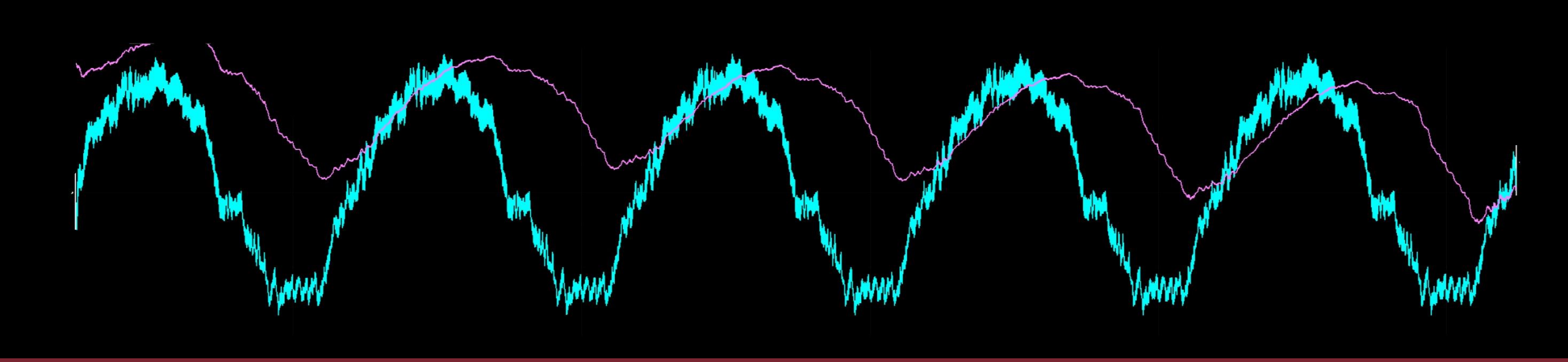


Comparison of Same Roof, all Insulation Above Deck in Miami, FL (1A), Tulsa, OK (3A), and Boulder, CO (5B)



Comparison of Same Roof with various deck ventilation quantities: Zero ACH, 5 ACH, and 25 ACH in Tulsa, OK





*“**Cool**” Roofing Cautions*

Additional vapor barriers may or may not be deleterious
Darker membrane would have helped
Careful with quantity of insulation below deck
Convection below deck helps if possible

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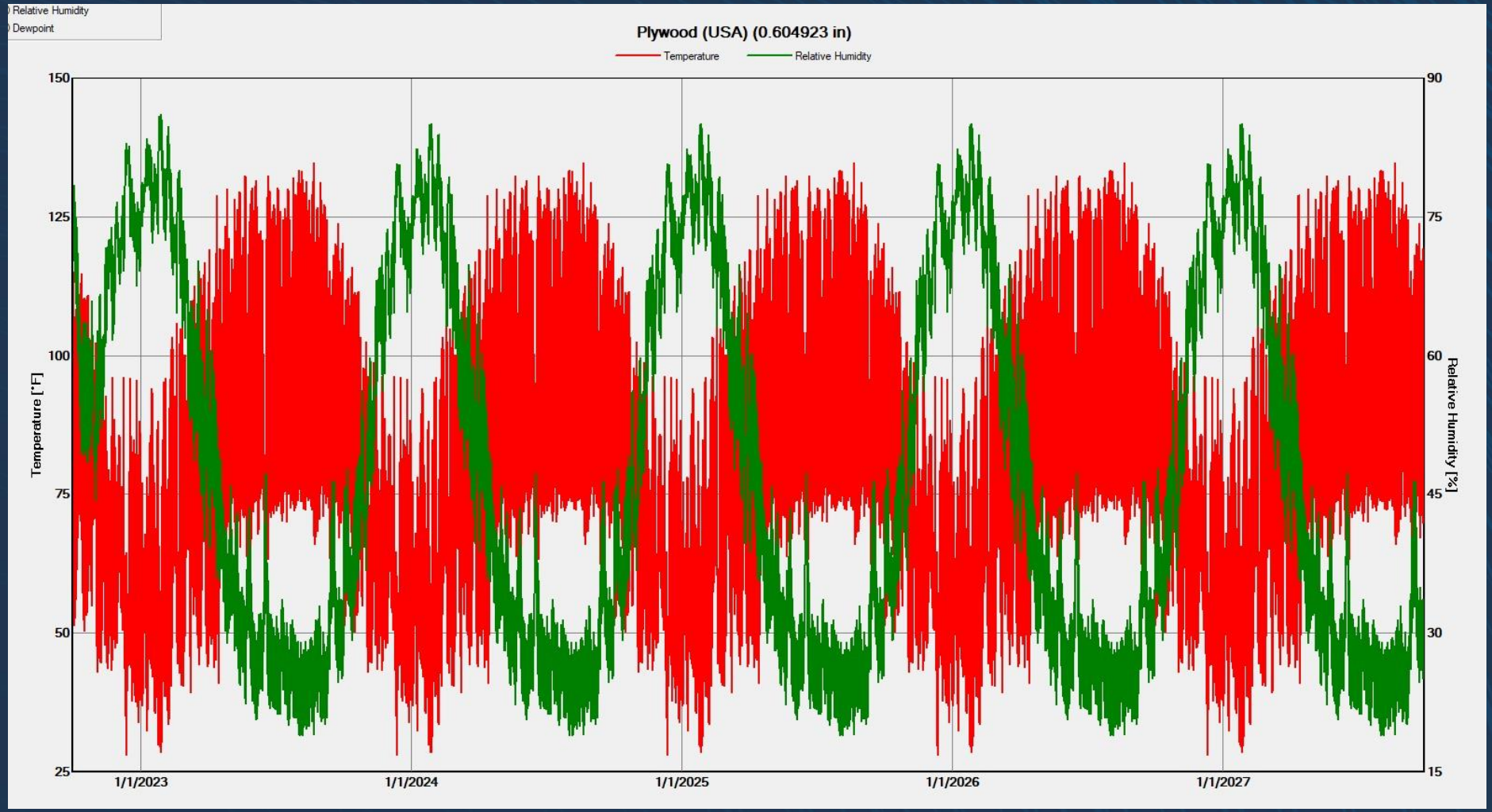
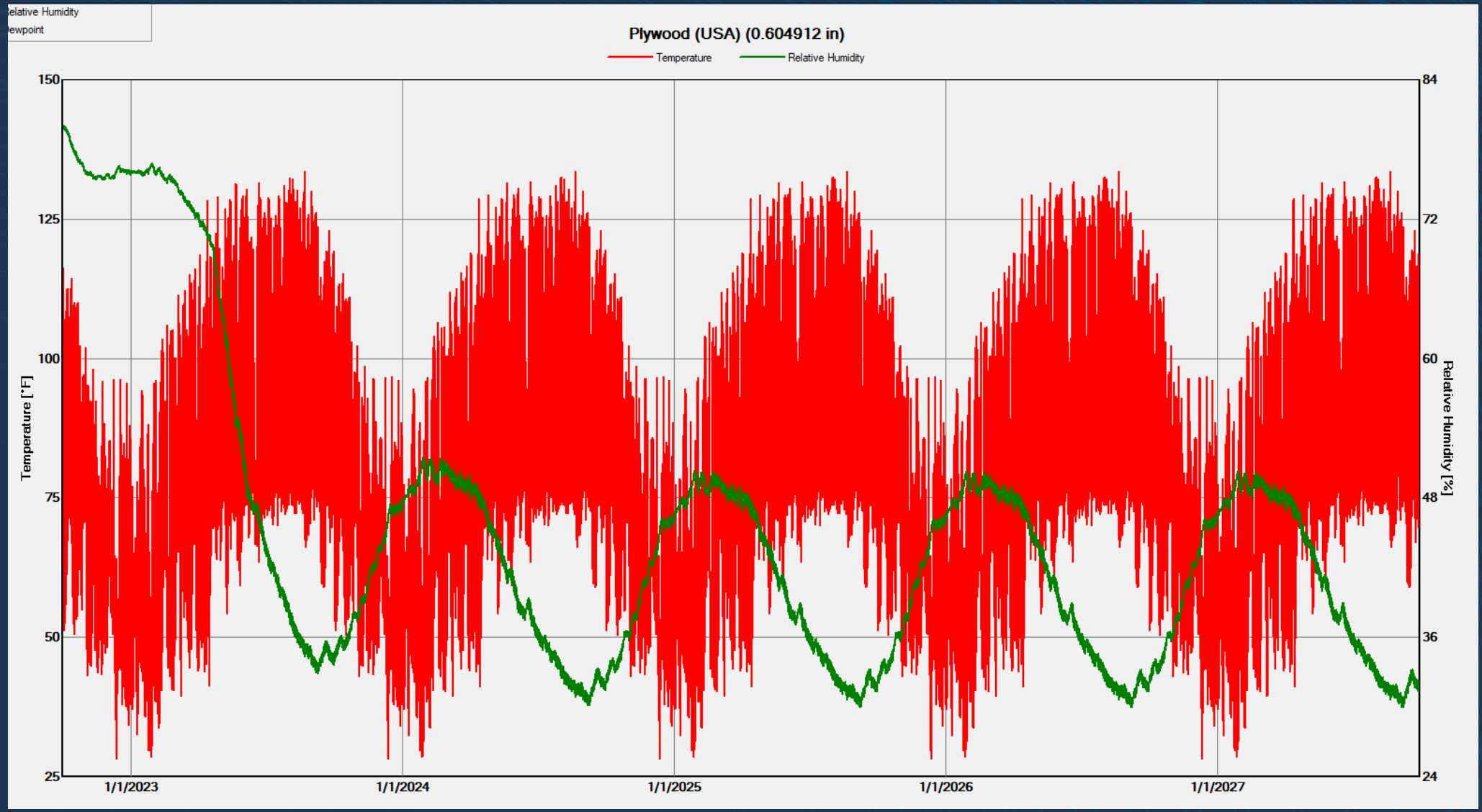
Roseburg

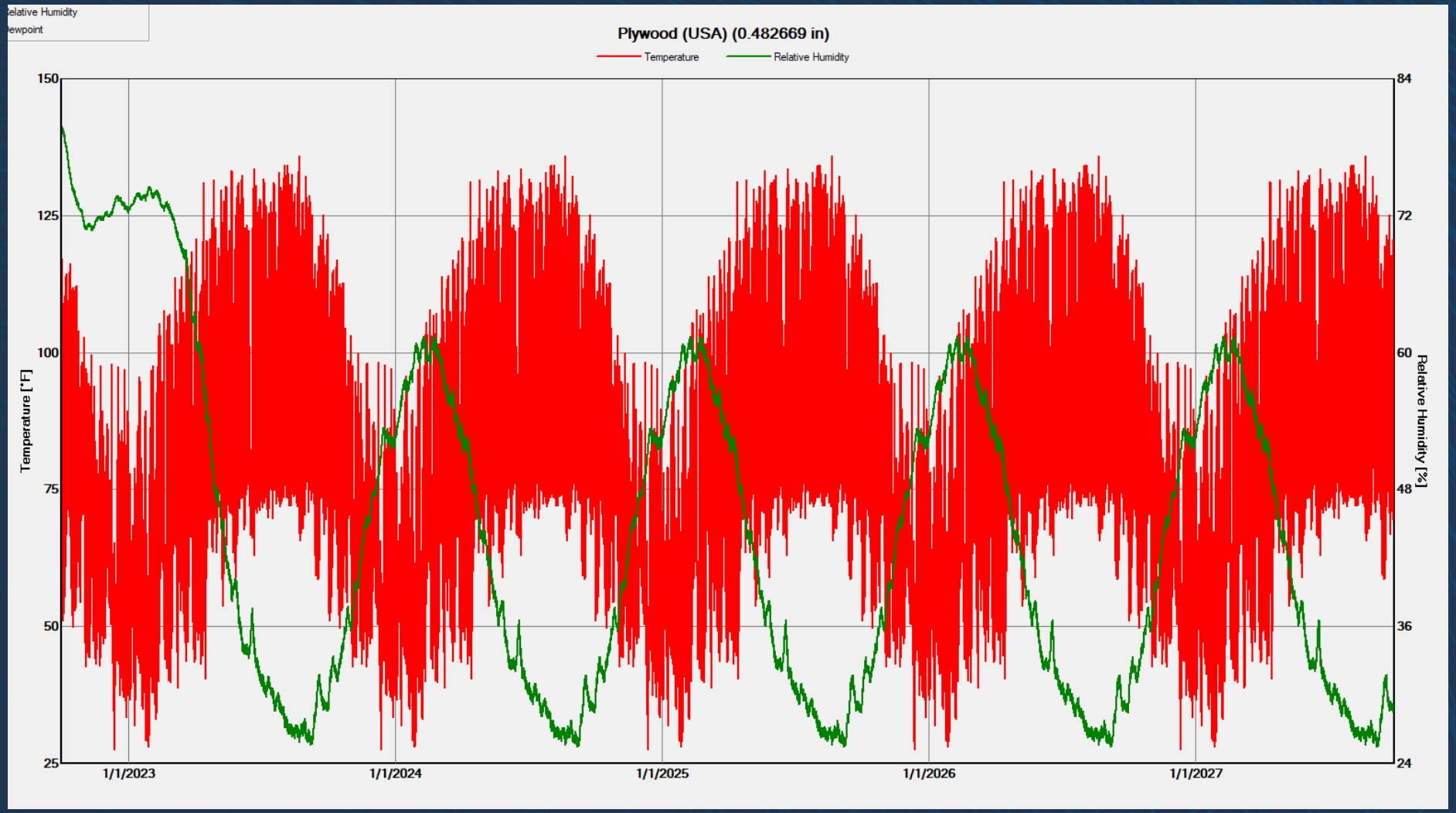
RH at Plywood Deck – 7” ocSPF

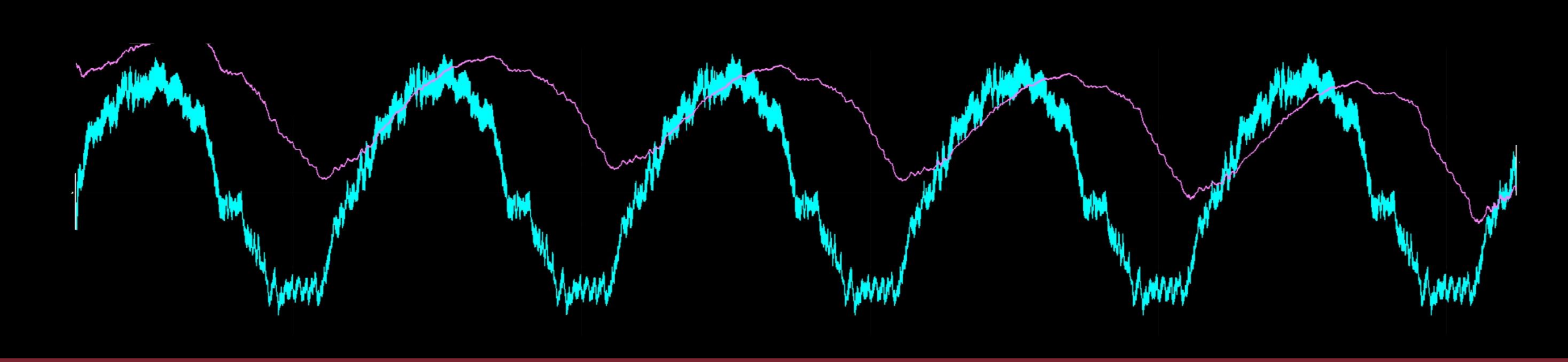


RH at Plywood Deck – 4” ccSPF



RH at Plywood Deck – 2” ccSPF + 3.5” ocSPF





Climate Zone 2A Dumb, Stupid Myths

Your walls have to “breathe”
Your house has to “breathe”
Never use a vapor barrier
Always use open-cell spray foam

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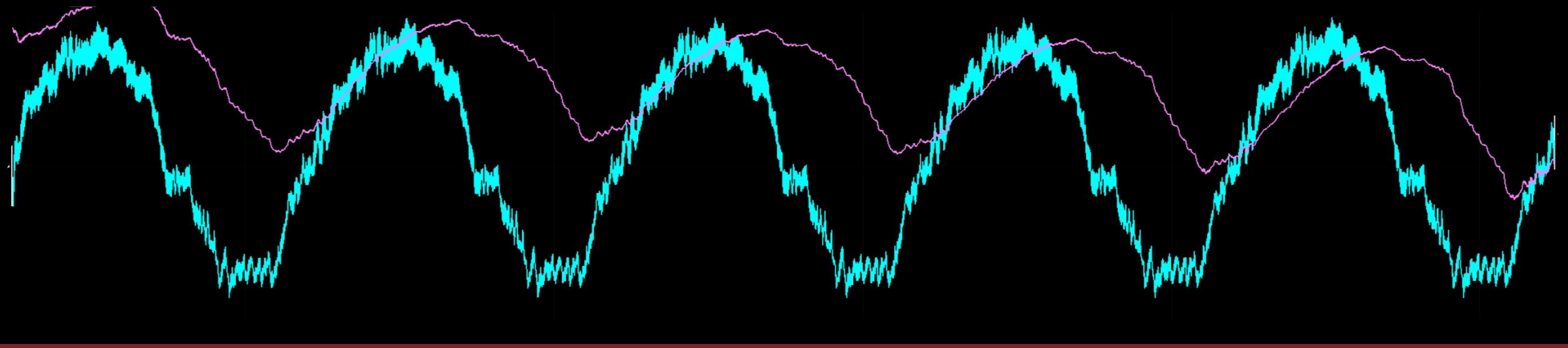

To Vent or Not to Vent

(Soffits)

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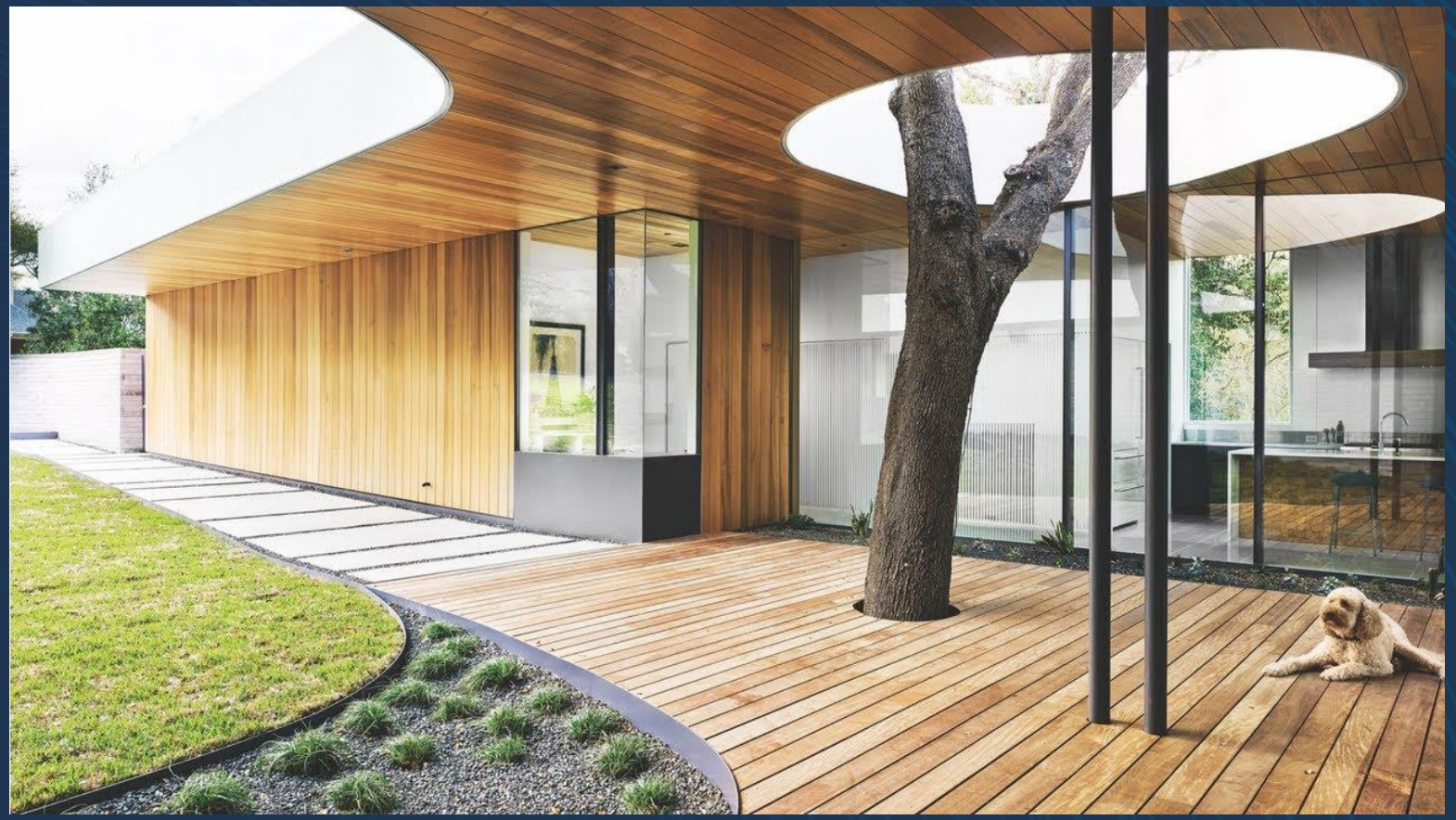
Austin, TX Residence
Alterstudio Architects



1202.2 Roof ventilation.

Roof assemblies shall be ventilated in accordance with this section or shall comply with Section 1202.3.

1202.2.1 Ventilated attics and rafter spaces.

Enclosed *attics* and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof framing members shall have cross ventilation for each separate space by ventilation openings protected against the entrance of rain and snow. Blocking and bridging shall be arranged so as not to interfere with the movement of air. An airspace of not less than 1 inch (25 mm) shall be provided between the insulation and the roof sheathing. The net free ventilating area shall be not less than $^1/_{150}$ of the area of the space ventilated. Ventilators shall be installed in accordance with manufacturer's installation instructions.

Exception: The net free cross-ventilation area shall be permitted to be reduced to $^1/_{300}$ provided both of the following conditions are met:

1. In Climate Zones 6, 7 and 8, a Class I or II vapor retarder is installed on the warm-in-winter side of the ceiling.
2. At least 40 percent and not more than 50 percent of the required venting area is provided by ventilators located in the upper portion of the *attic* or rafter space. Upper ventilators shall be located not more than 3 feet (914 mm) below the ridge or highest point of the space, measured vertically, with the balance of the *ventilation* provided by eave or cornice vents. Where the location of wall or roof framing members conflicts with the installation of upper ventilators, installation more than 3 feet (914 mm) below the ridge or highest point of the space shall be permitted.

1202.2.2 Openings into attic.

Exterior openings into the *attic* space of any building intended for human occupancy shall be protected to prevent the entry of birds, squirrels, rodents, snakes and other similar creatures. Openings for ventilation having a least dimension of not less than $^1/_{16}$ inch (1.6 mm) and not more than $^1/_4$ inch (6.4 mm) shall be permitted. Openings for ventilation having a least dimension larger than $^1/_4$ inch (6.4 mm) shall be provided with corrosion-resistant wire cloth screening, hardware cloth, perforated vinyl or similar material with openings having a least dimension of not less than $^1/_{16}$ inch (1.6 mm) and not more than $^1/_4$ inch (6.4 mm). Where combustion air is obtained from an *attic* area, it shall be in accordance with Chapter 7 of the *International Mechanical Code*.

1202.3 Unvented attic and unvented enclosed rafter assemblies. P CDP

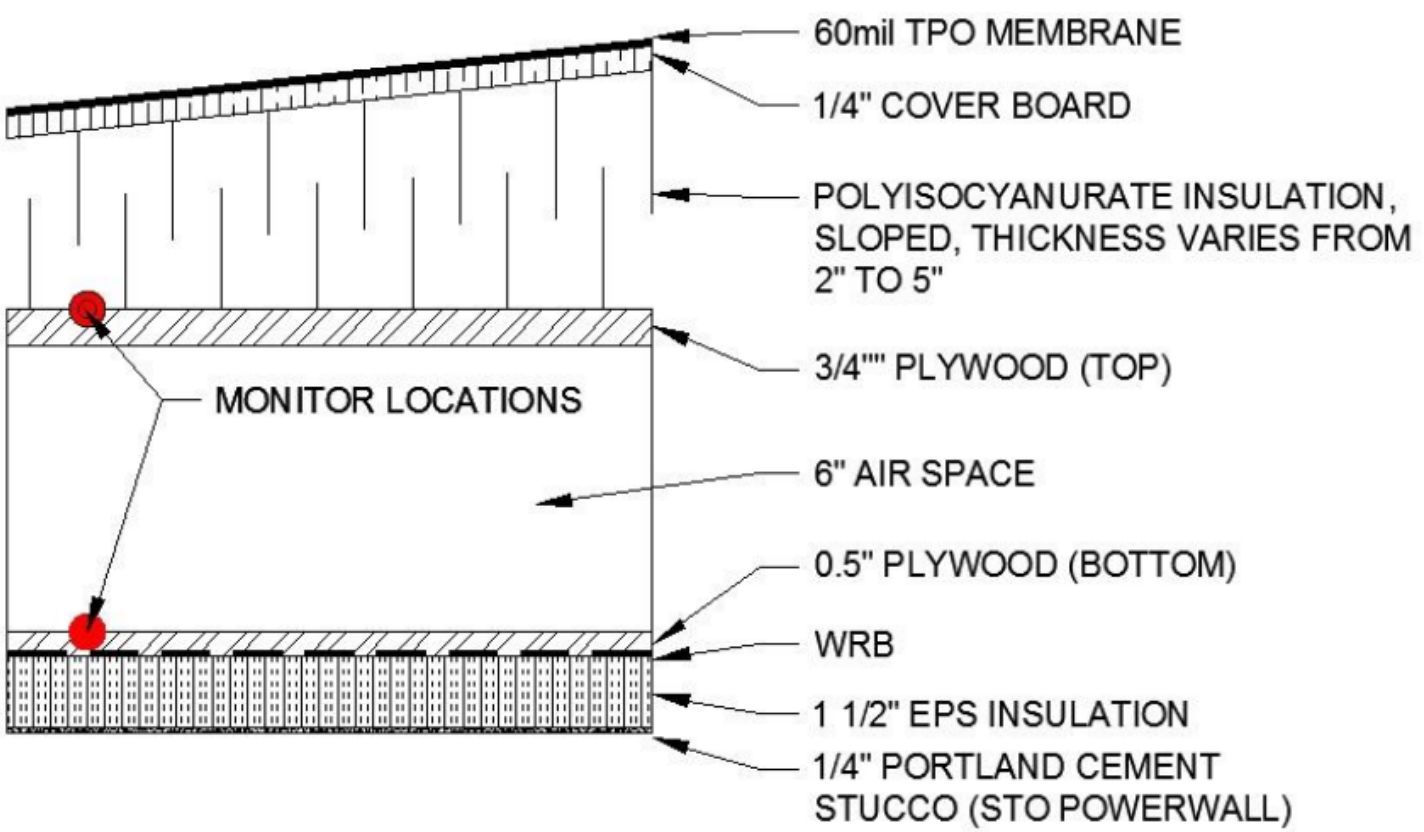
Unvented *attics* and unvented enclosed roof framing assemblies created by ceilings applied directly to the underside of the roof framing members/rafters and the structural roof sheathing at the top of the roof framing members shall be permitted where all of the following conditions are met:

1. The unvented *attic* space is completely within the *building thermal envelope*.
2. No interior Class I vapor retarders are installed on the ceiling side (*attic* floor) of the unvented *attic* assembly or on the ceiling side of the unvented enclosed roof framing assembly.
3. Where wood shingles or shakes are used, not less than a $^1/_4$-inch (6.4 mm) vented airspace separates the shingles or shakes and the roofing *underlayment* above the structural sheathing.
4. In Climate Zones 5, 6, 7 and 8, any *air-impermeable insulation* shall be a Class II vapor retarder or shall have a Class II vapor retarder coating or covering in direct contact with the underside of the insulation.
5. Insulation shall comply with either Item 5.1 or 5.2, and additionally Item 5.3.

5.1. Item 5.1.1, 5.1.2, 5.1.3 or 5.1.4 shall be met, depending on the air permeability of the insulation directly under the structural roof sheathing.

5.1.1. Where only *air-impermeable insulation* is provided, it shall be applied in direct contact with the underside of the structural roof sheathing.

5.1.2. Where air-permeable insulation is provided inside the building thermal envelope, it shall be installed in accordance with Item 5.1.1. In addition to the air-permeable insulation installed directly below


60mil TPO MEMBRANE
1/4" COVER BOARD
POLYISOCYANURATE INSULATION, SLOPED, THICKNESS VARIES FROM 2" TO 5"
3/4"" PLYWOOD (TOP)
MONITOR LOCATIONS
6" AIR SPACE
0.5" PLYWOOD (BOTTOM)
WRB
1 1/2" EPS INSULATION
1/4" PORTLAND CEMENT STUCCO (STO POWERWALL)

		Cases																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TPO	60mil	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gypsum board	1/4”	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Polyiso	2”	X	X	X	X	X	X	X	X	X									
	5”										X	X	X	X	X	X	X	X	X
Plywood	1/2”	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Airgap	0 ACH	X	X	X							X	X	X						
	5 ACH				X	X	X							X	X	X			
	25 ACH							X	X	X							X	X	X
Plywood	½”	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WRB	none	X			X			X			X			X			X		
	0.1 perm		X			X			X			X			X			X	
	10 perm			X			X			X			X			X			X
EPS	1 ½”	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Stucco	1/4”	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

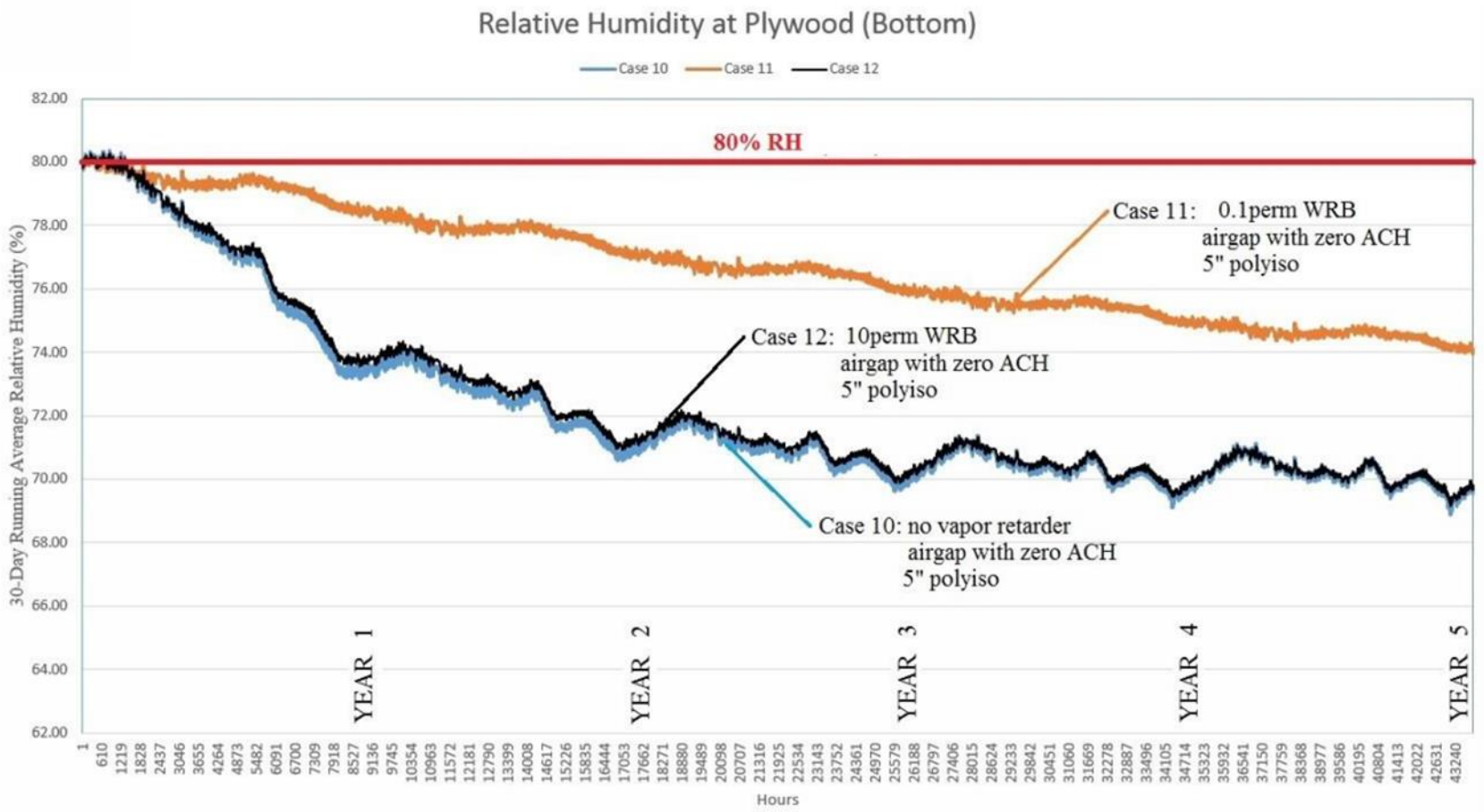


Figure 5 (zero ACH, 5" ISO)

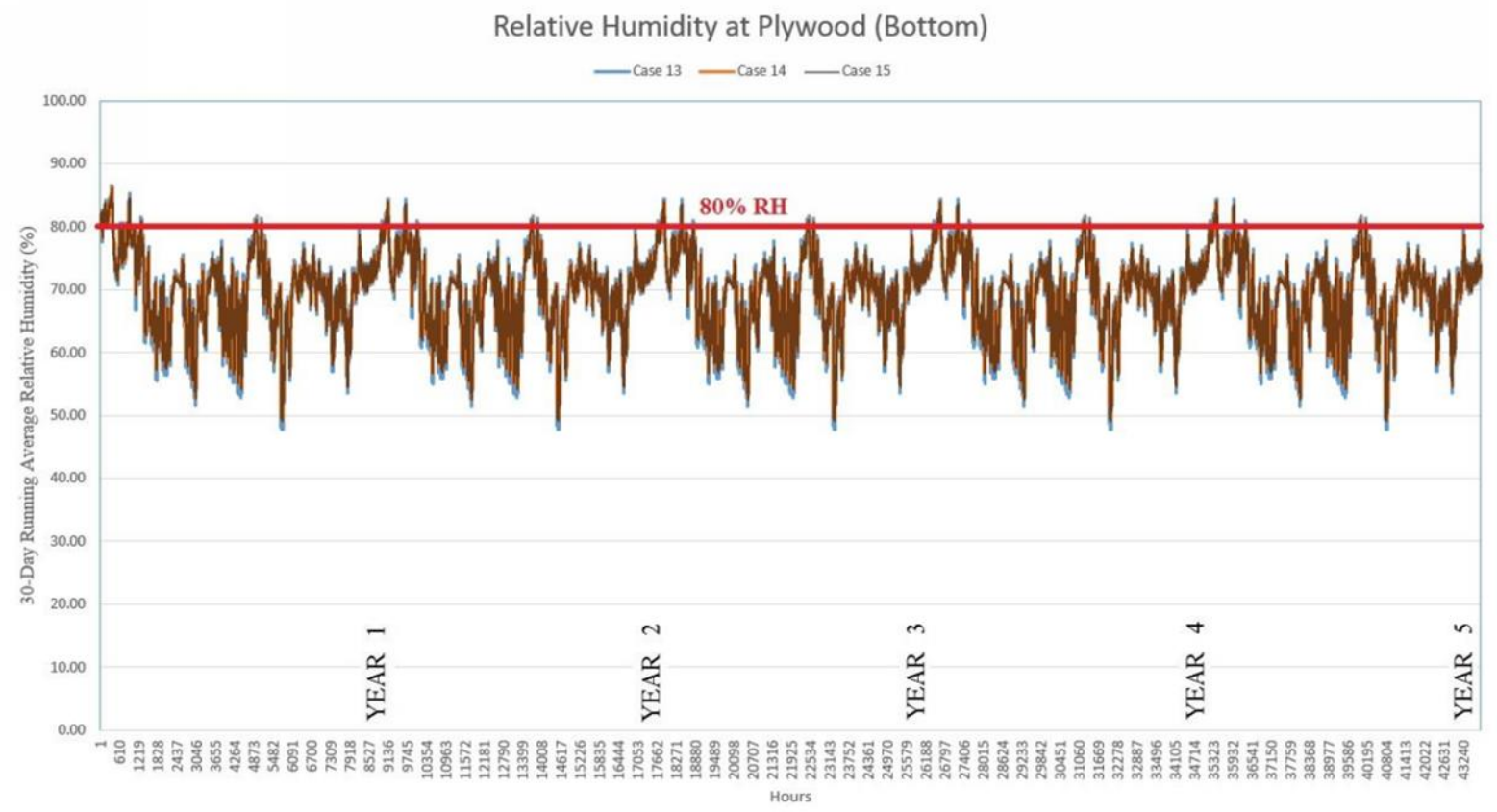


Figure 11 (5 ACH, 5" ISO)

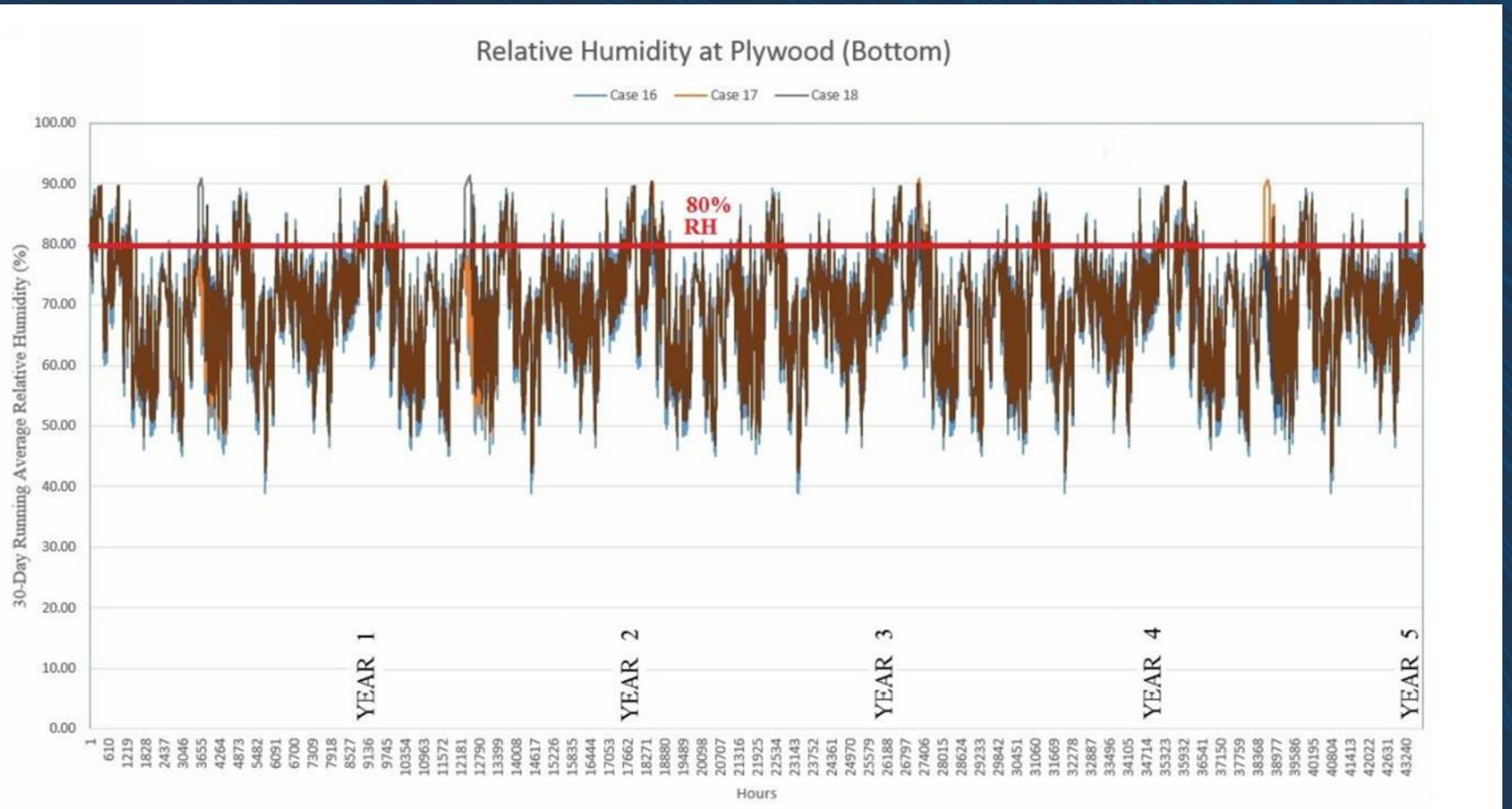
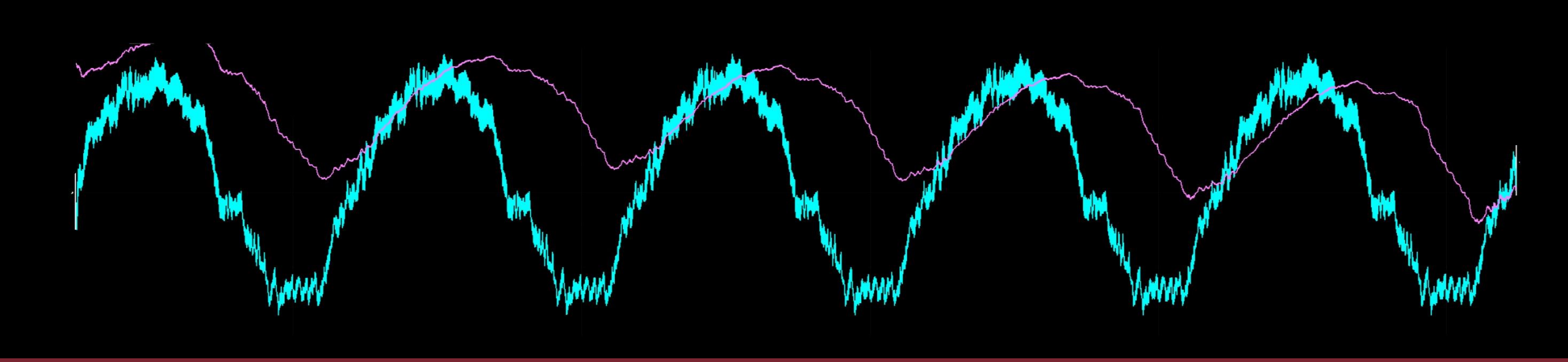


Figure 13 (25 ACH, 5" ISO)



ASHRAE Hot and Humid Climate Zones Probably Don't Vent…

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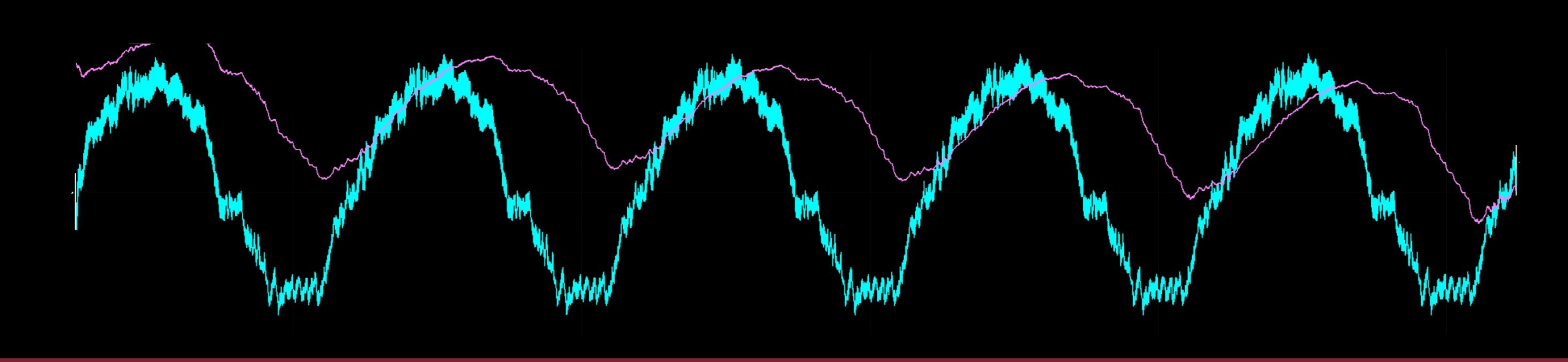

Vented roofs blow off more than unvented roofs. Vented roofs burn more than unvented roofs. Vented roofs are energy inefficient compared to unvented roofs. Vented roofs cause moisture problems south of the Mason-Dixon Line and east of Interstate 35 in Texas. Venting a roof in a hot-humid and mixed humid climate is a very, very bad idea.

- Joe Lstiburek, March 15, 2023 from ***Shakespeare Does Roofs***

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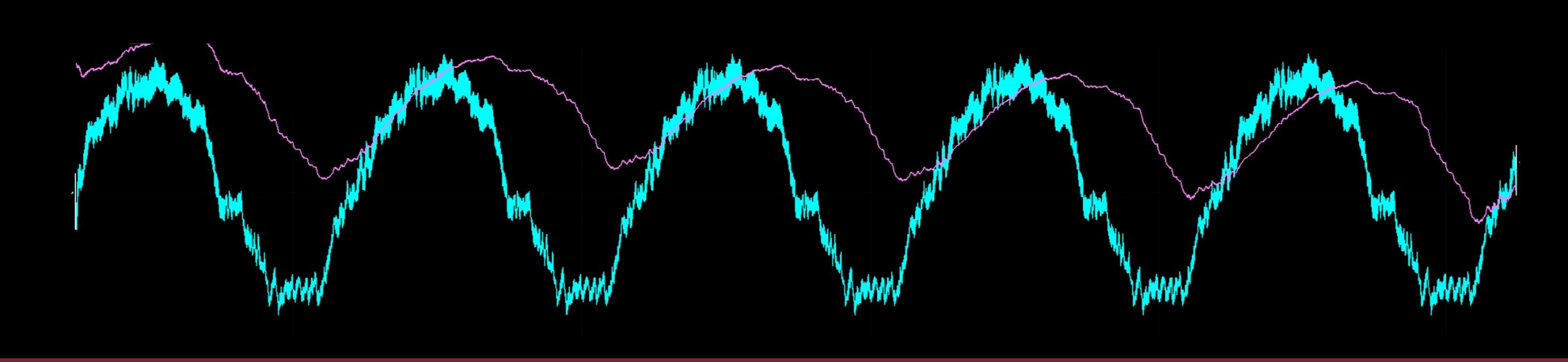

The Perfect Wall versus Zip R-Board

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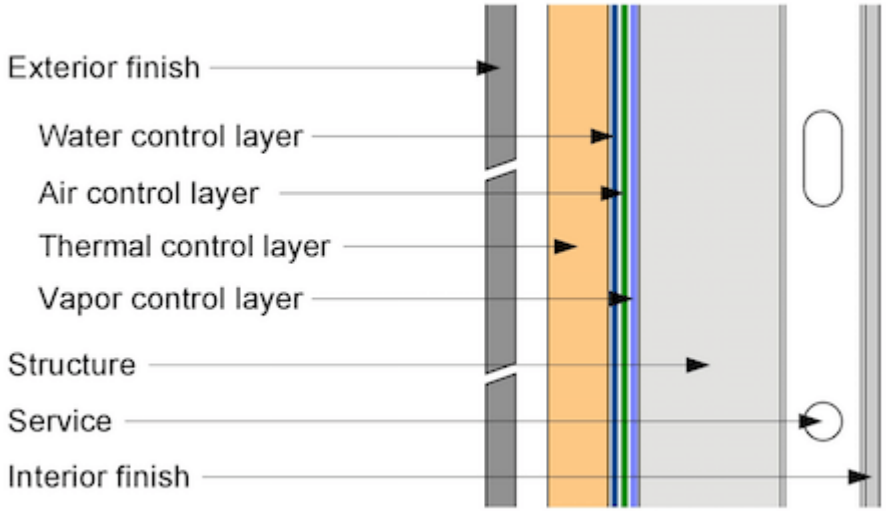
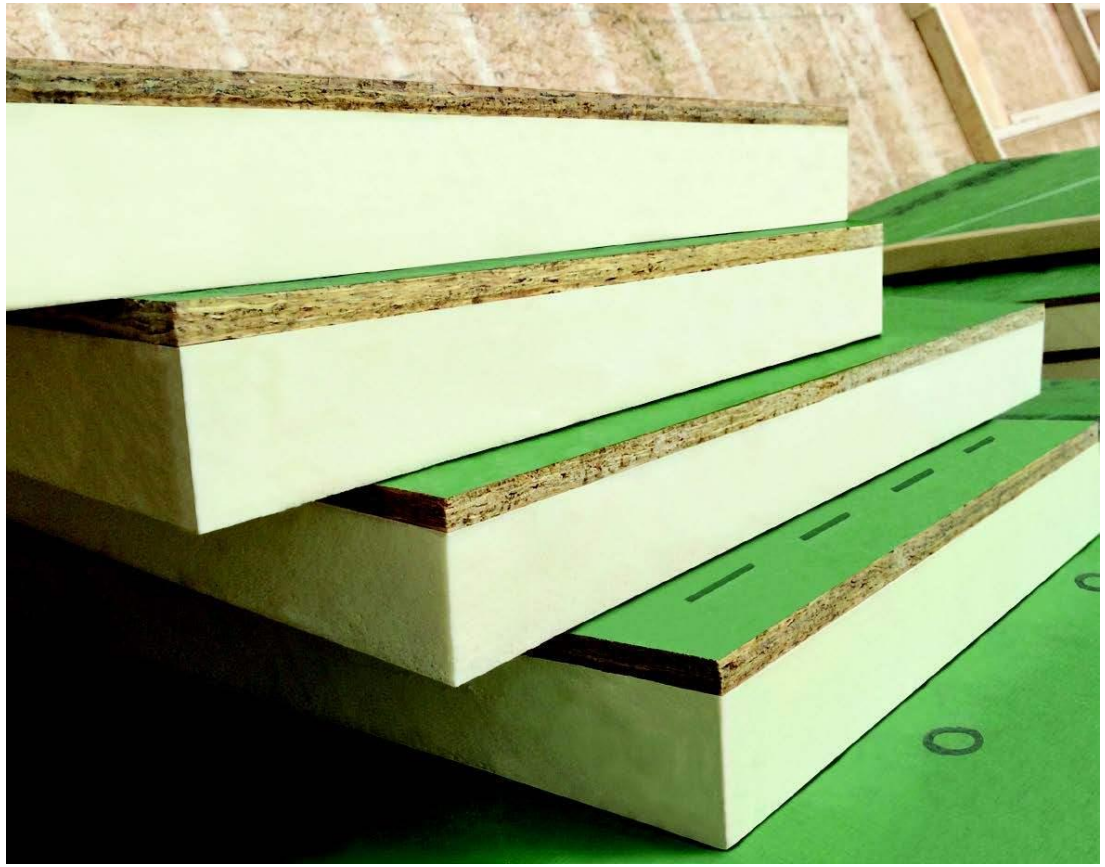


www.buildingscience.com

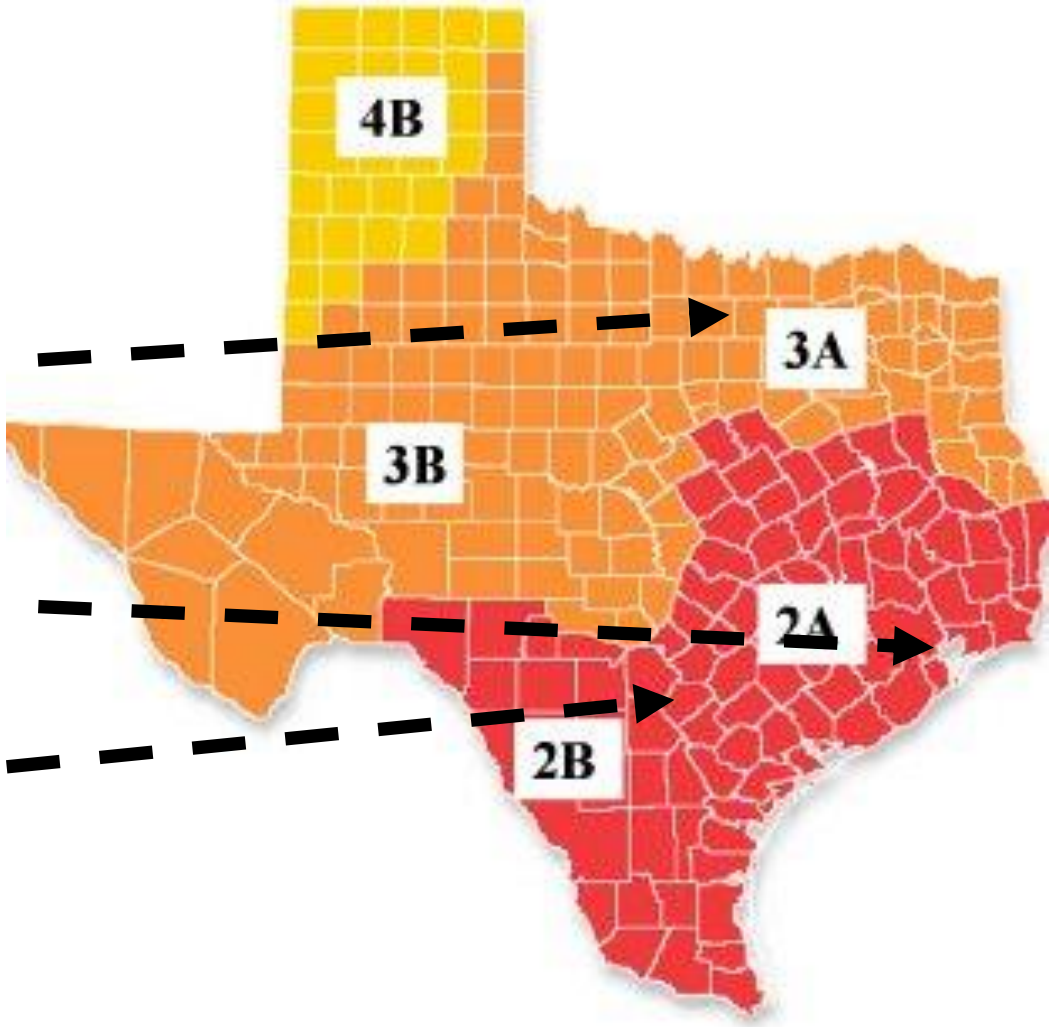


Branch Bank Buildings:

Ft. Worth

Houston

San Antonio



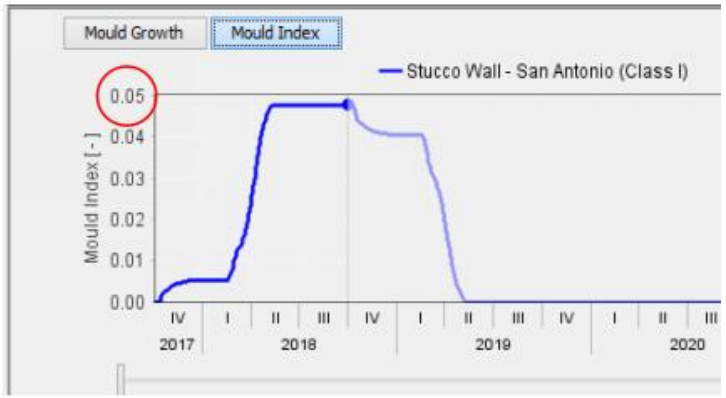
2 Assemblies x 3 Climates = 6 Simulations

Stucco Wall Assembly:

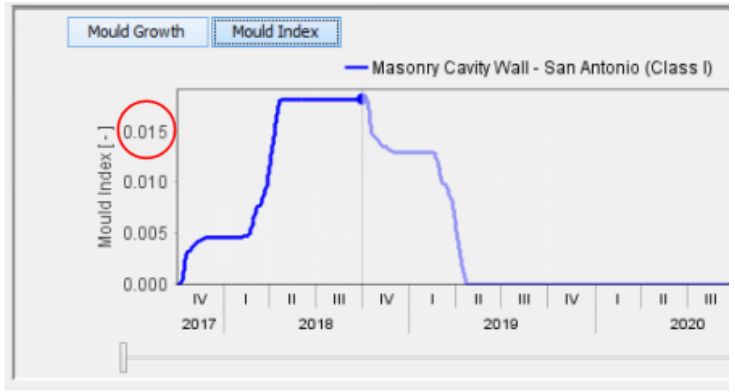
- 3 coat cement plaster on galvanized metal lath (.875" thickness)
- Drainage mat (10.5mm)
- Asphalt-saturated building paper
- Huber Zip R-sheathing w/ Zip tape (R-6 minimum)
- 6" cold formed metal stud framing with batt insulation in stud cavity (R-19, 6 ¼" thick)
- 5/8" type X gypsum board (5/8" thickness)

Masonry Cavity Wall:

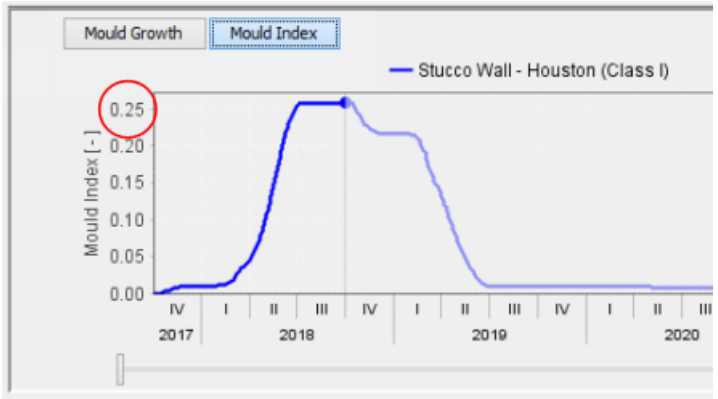
- 4" nominal brick or veneer limestone
- 1 ¼" air gap
- Huber Zip R-sheathing w/ Zip tape (R-6 minimum)
- 6" cold formed metal stud framing with batt insulation in stud cavity (R-19, 6 ¼" thick)
- 5/8" type X gypsum board (5/8" thickness)



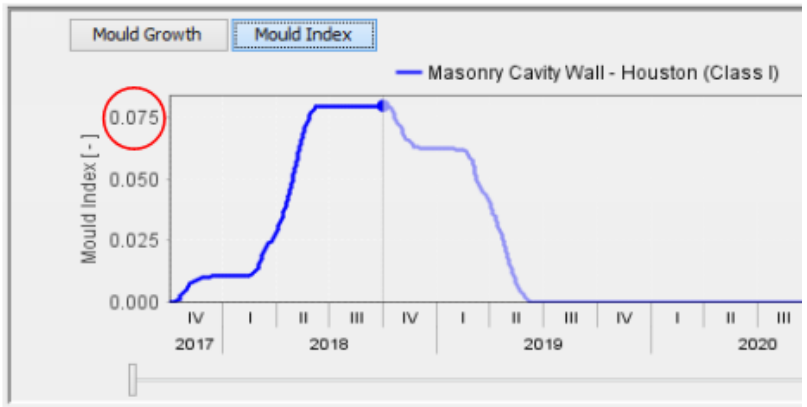
Stucco Wall: San Antonio



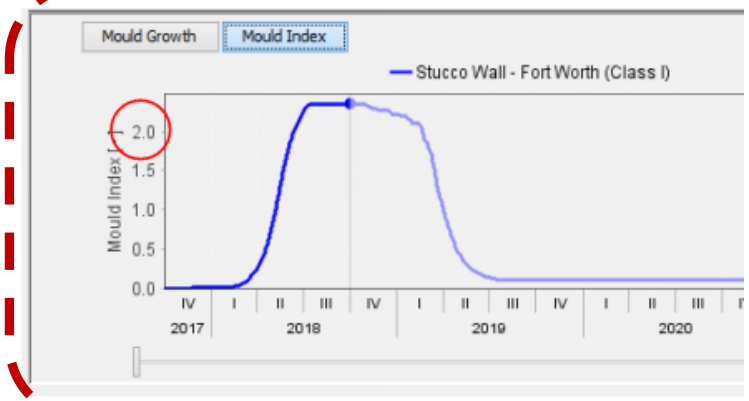
Masonry Wall: San Antonio



Stucco Wall: Houston

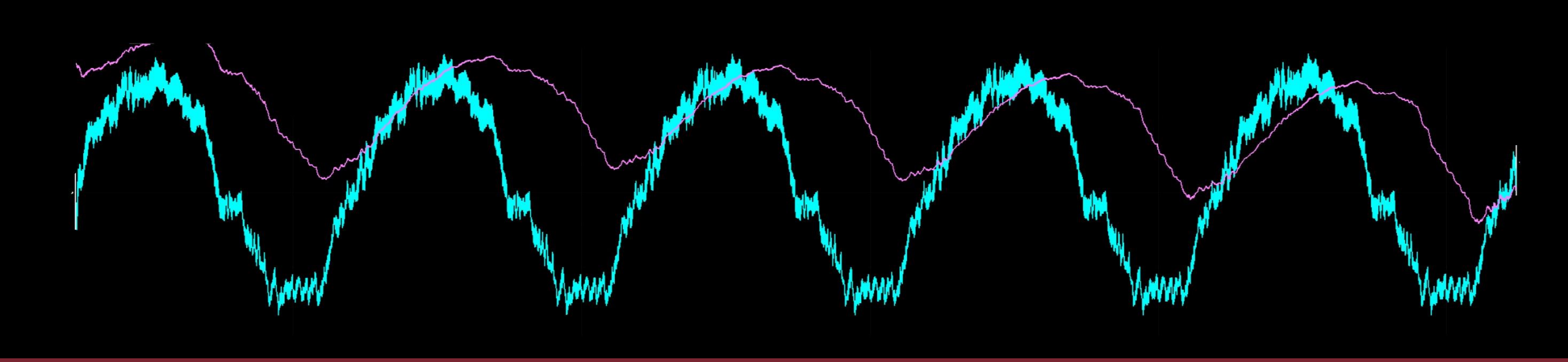


Masonry Wall: Houston



Stucco Wall: Ft. Worth

Masonry Wall: Ft. Worth



Perfect Wall always works (that's why it's called the perfect wall…)
Zip R-Board can be an easy way to high-performance, but is climate-specific
…may need to bump up insulation levels

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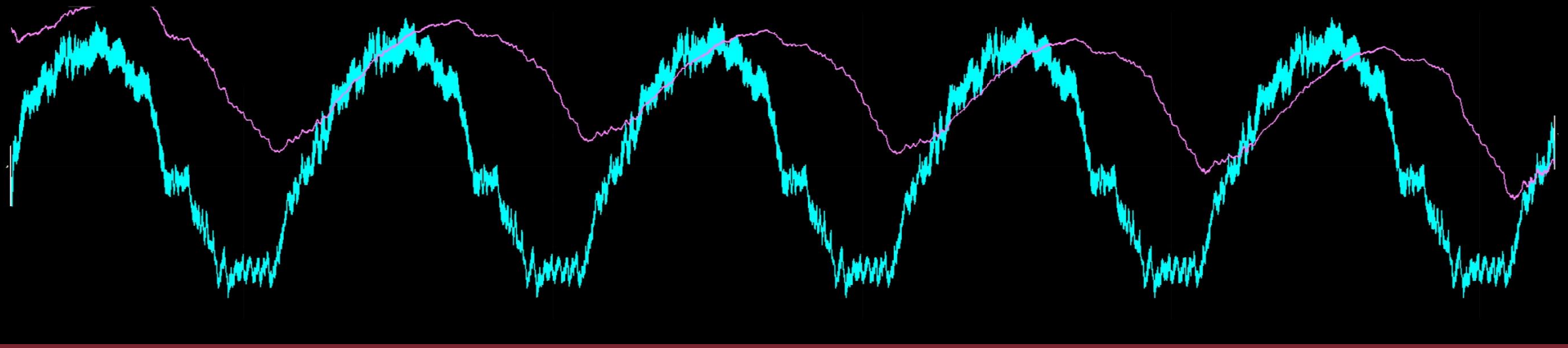

Forensics

Do I actually have a problem??

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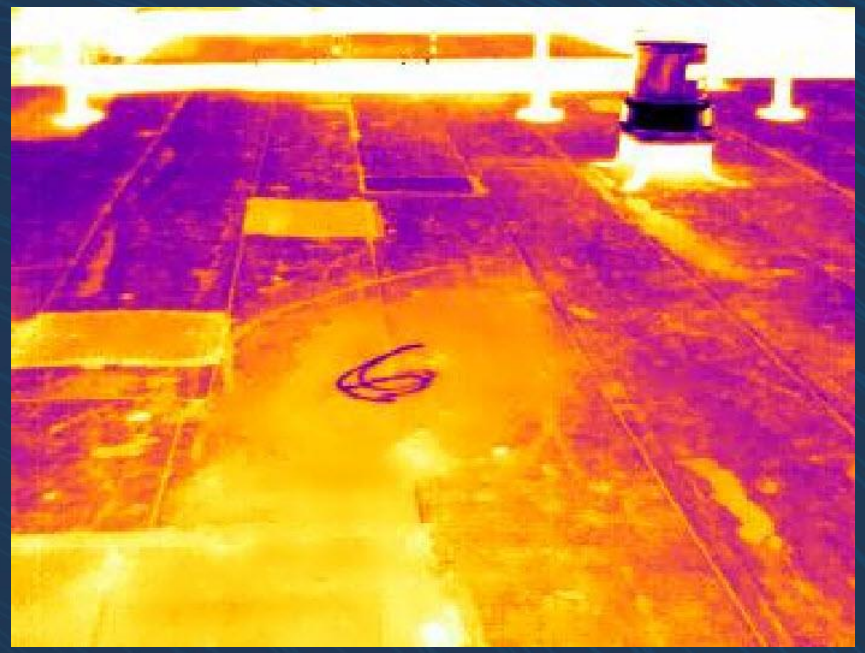
Roof Assembly

- 1 ply Firestone SBS FR Cap - White
- 1 ply Firestone SBS PolyBase
- ½-inch DensDeck Prime Roof Board
- Two layers 2-inch Firestone ISO 95+ GL polyisocyanurate insulation (insulation facers simulated with layers of #15 felt)
- 2-inch thick structural concrete supported by 24-inch concrete beams @ 5-foot OC (w/c = 0.5)

Calcium Chloride results 8/31/15

1N	8/28	8/31		
T	11:34	7:56	68 hrs	1.61 lbs
W	30 g	31g	1 gram	
2N	8/28	8/31		
T	11:34	8:21	68 hrs	3.2 lbs
W	29 g	31g	2 gram	
4N	8/28	8/31		
T	11:54	8:15	68 hrs	4.8 lbs
W	29 g	32g	3 gram	
5N	8/28	8/31		
T	12:01	8:27	68 hrs	6.49 lbs
W	28 g	32g	4 gram	
1S	8/28	8/31		
T	12:15	8:30	68 hrs	1.61 lbs
W	30 g	31g	1 gram	
2S	8/28	8/31		
T	1:08	8:33	67 hrs	6..49 lbs
W	29 g	33g	4 gram	
3S	8/28	8/31		
T	1:15	8:35	67 hrs	6.49 lbs
W	30 g	34g	1 gram	
4S	8/28	8/31		
T	1:21	8:51	67 hrs	6.49 lbs
W	29 g	33g	4 gram	
5S	8/28	8/31		
T	1:24	8.52	67 hrs	6.49 lbs
W	28 g	32g	1 gram	



Relative Humidity Probe Results

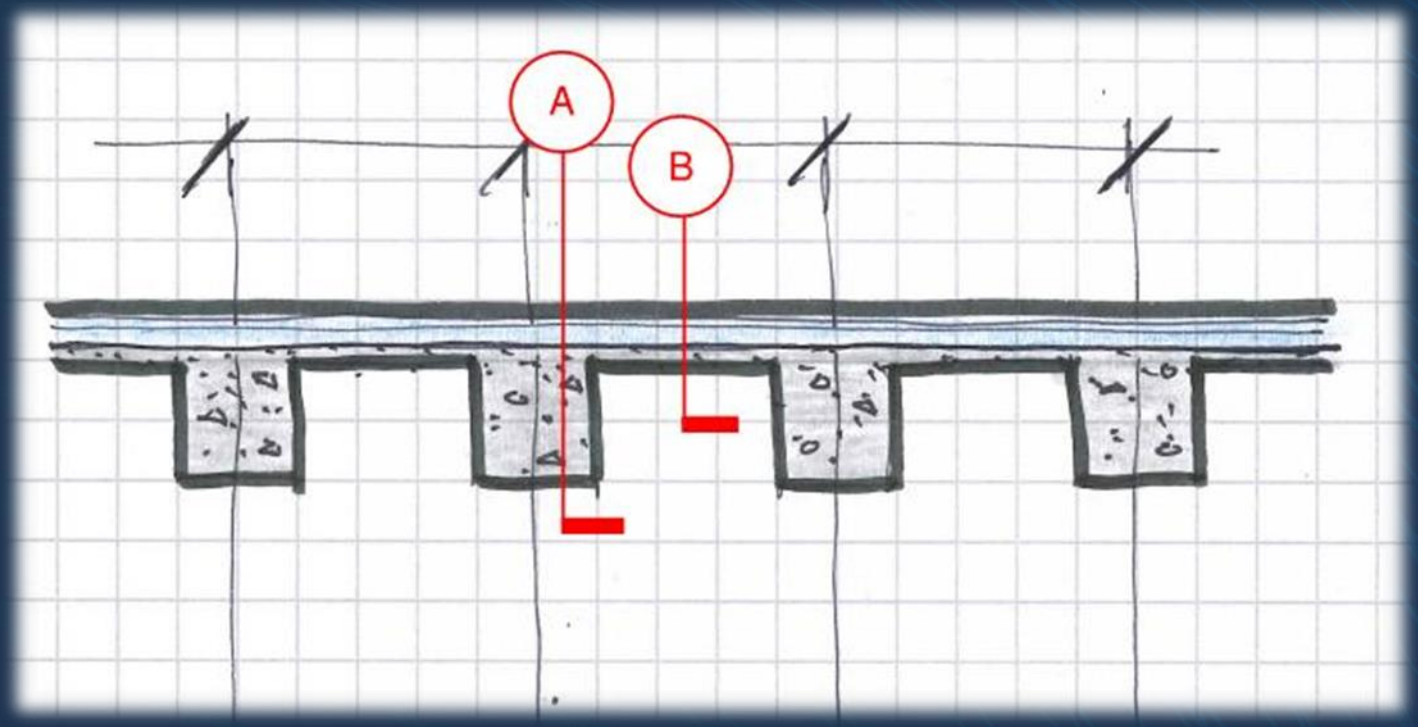
8/31/15

	Deck Surface	Slab Temp	Humidity
1S	75.6	70	78%
2S	74.4	76	75%
3S	77.2	79	85%
4S	77.4	78	81%
5S	75.4	77	78%
1N	75.6	79	79%
3N	77	74	71%
4N	73.2	77	82%
5N	78.2	79	78%

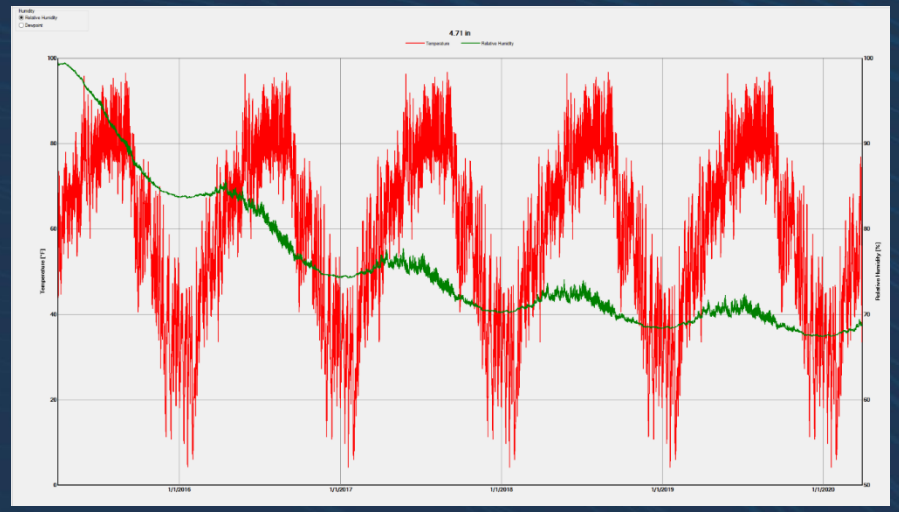
Roof Cores

Summary of Gravimetric Analysis						
	A	B	C	D	E	F
Core Number and Sample Name	TARE WEIGHT	TARE + SAMPLE	TARE + SAMPLE "DRIED"	WEIGHT OF ORIGINAL SAMPLE	WEIGHT OF DRIED SAMPLE	PERCENT MOISTURE BY DRY WEIGHT
C1-Dense Prime	None	None	None	654.8	650.5	0.66%
C1-ISO	None	None	None	79	78.6	0.50%
C2-Dense Prime	None	None	None	323.9	320.1	1.18%
C2-ISO	None	None	None	82.5	80	3.12%
C3-Dense Prime	None	None	None	266.7	264	1.02%
C3-ISO	None	None	None	160.1	158.7	0.88%
C4-Dense Prime	None	None	None	370.7	368.1	0.70%
C4-ISO	None	None	None	71.8	71.5	0.42%

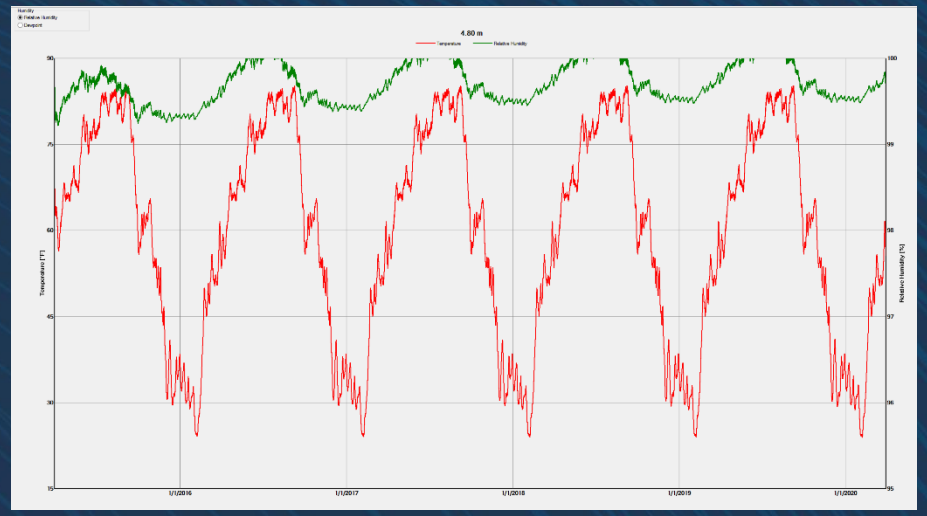
Concrete Variations



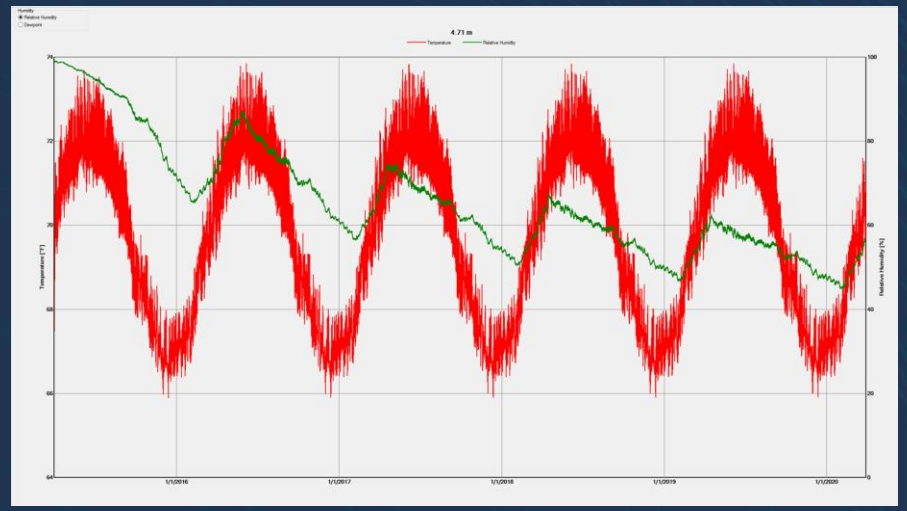
Not at Beam; **No A/C;** 100% RH



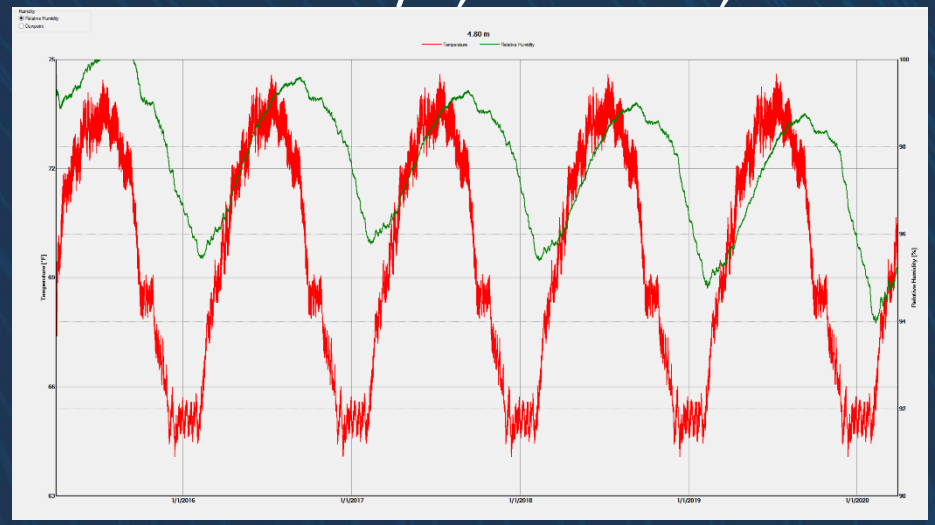
At Beam; No A/C; 100% RH



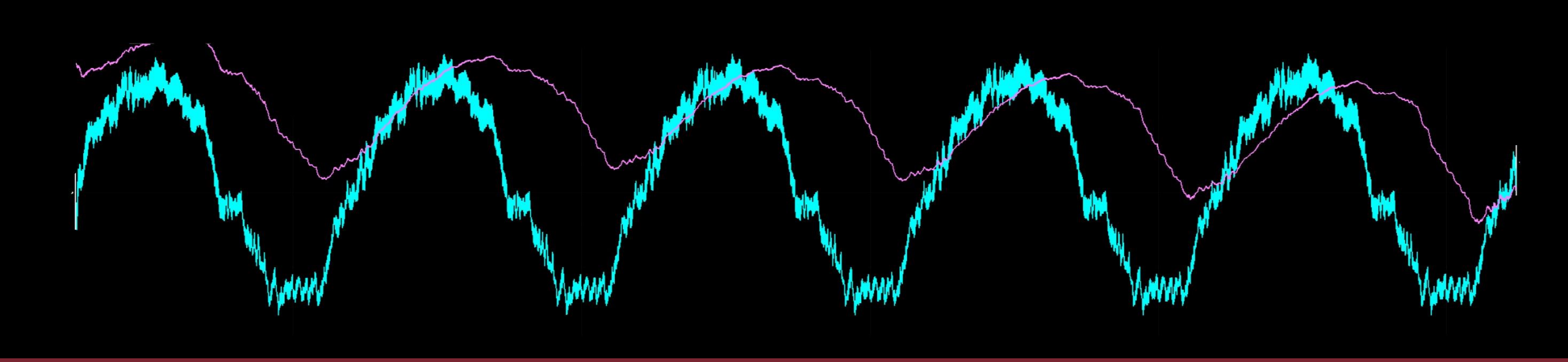
Not at Beam; **with A/C & Heating**



At Beam with A/C; 100% RH; **8” Conc**




Humidity
Relative Humidity
Dewpoint
4.80 m
Temperature
Relative Humidity
Temperature [°F]
Relative Humidity [%]
90
75
60
45
30
15
100
98
96
94
92
90
1/1/2016
1/1/2017
1/1/2018
1/1/2019
1/1/2020



Do I actually have a problem?
May need to follow up with more investigation.

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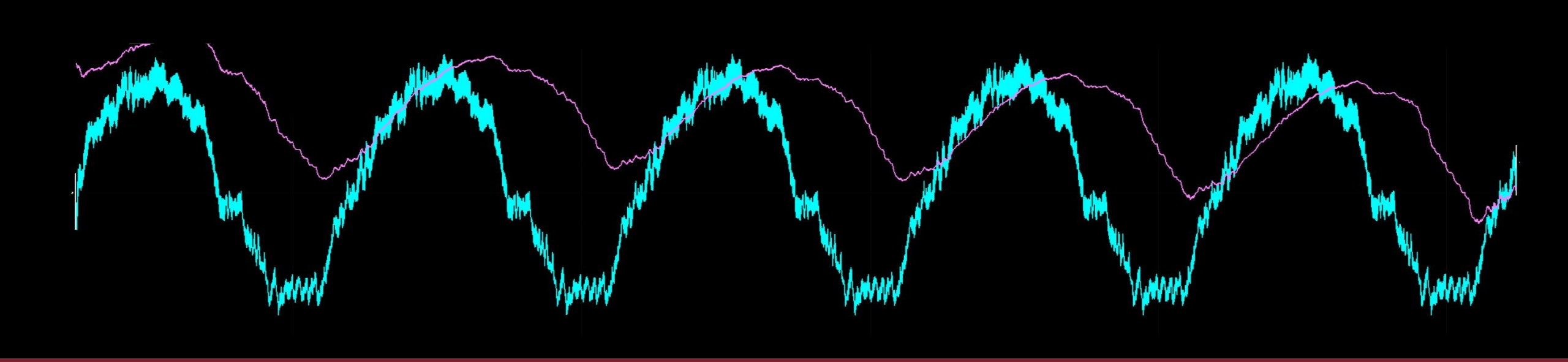

*Is **HT** (high-temp rated) really important?*

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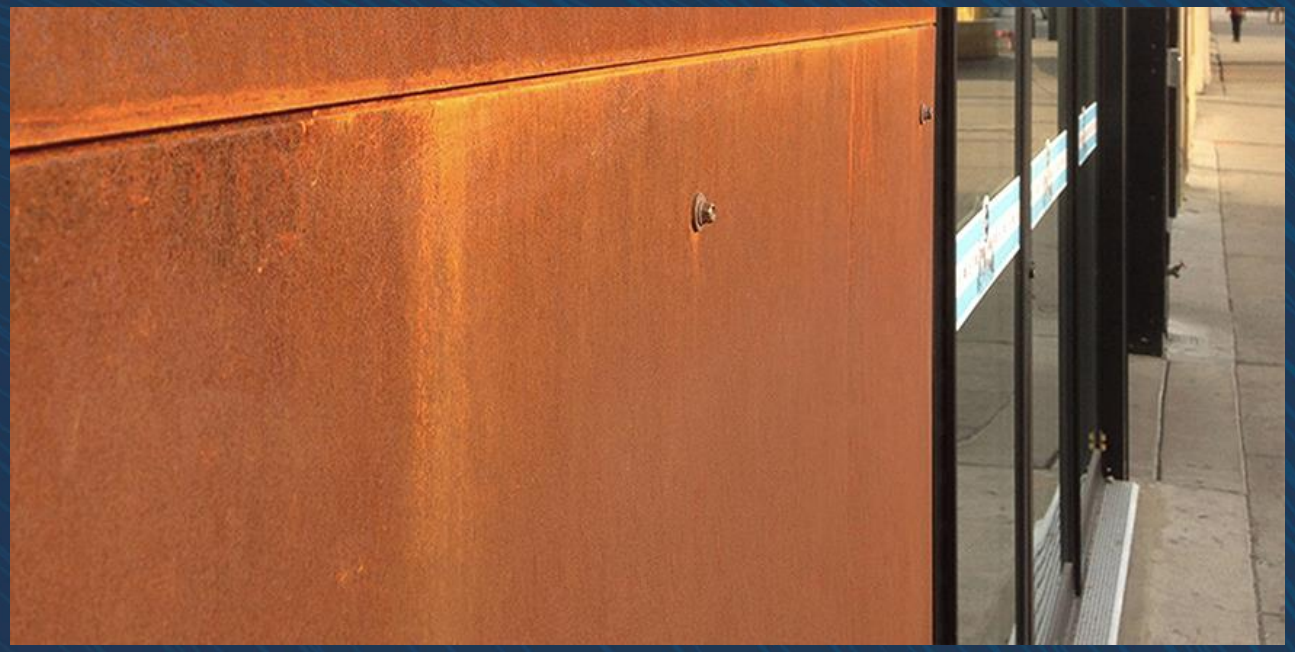
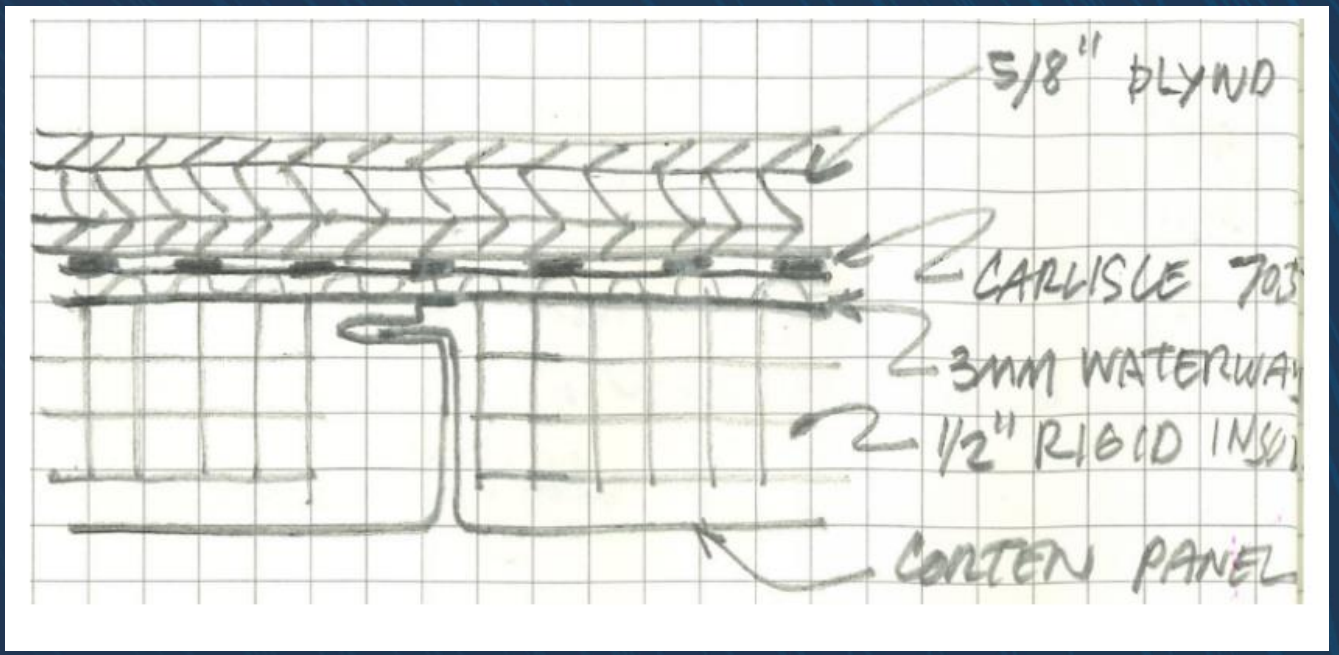
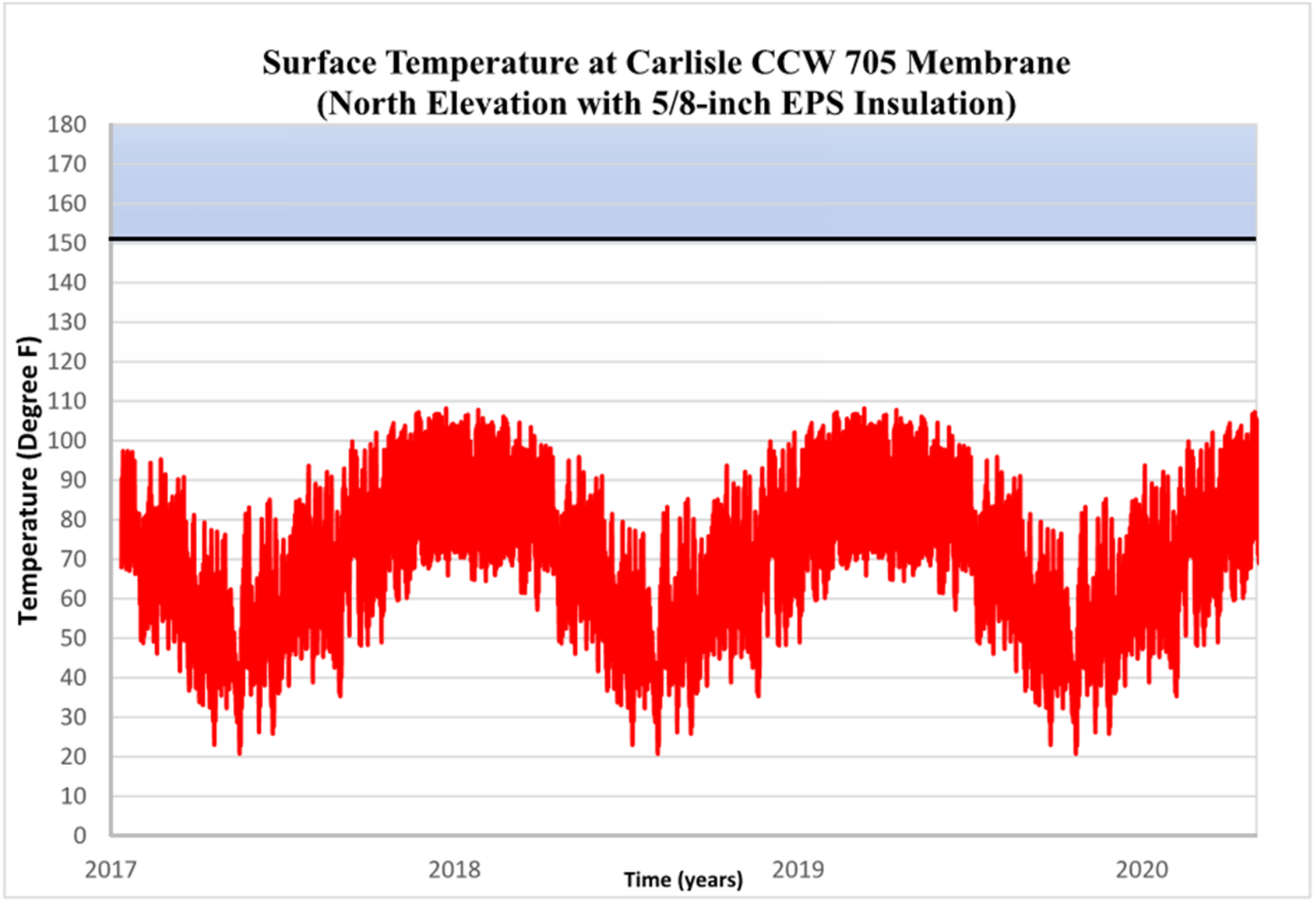
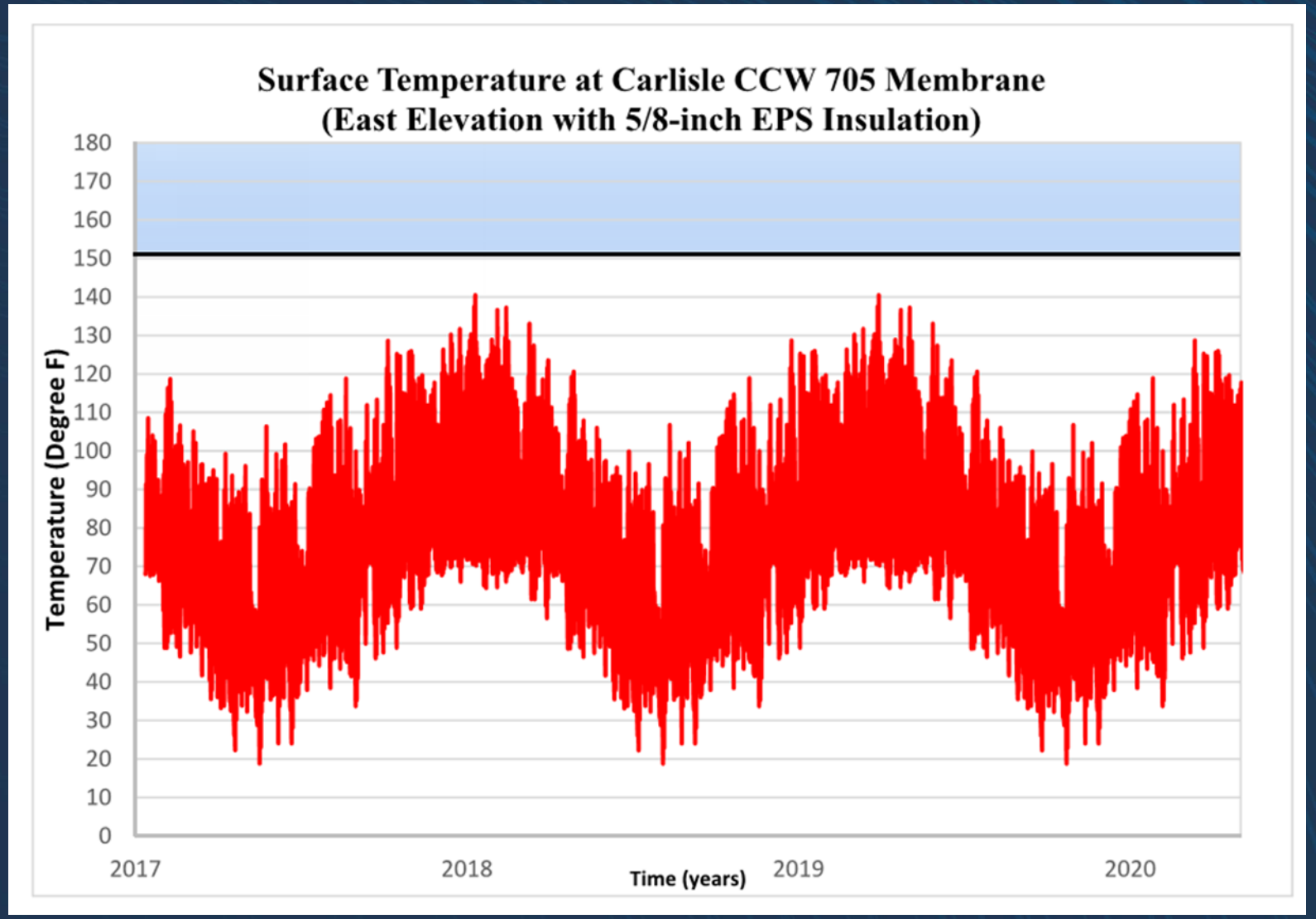
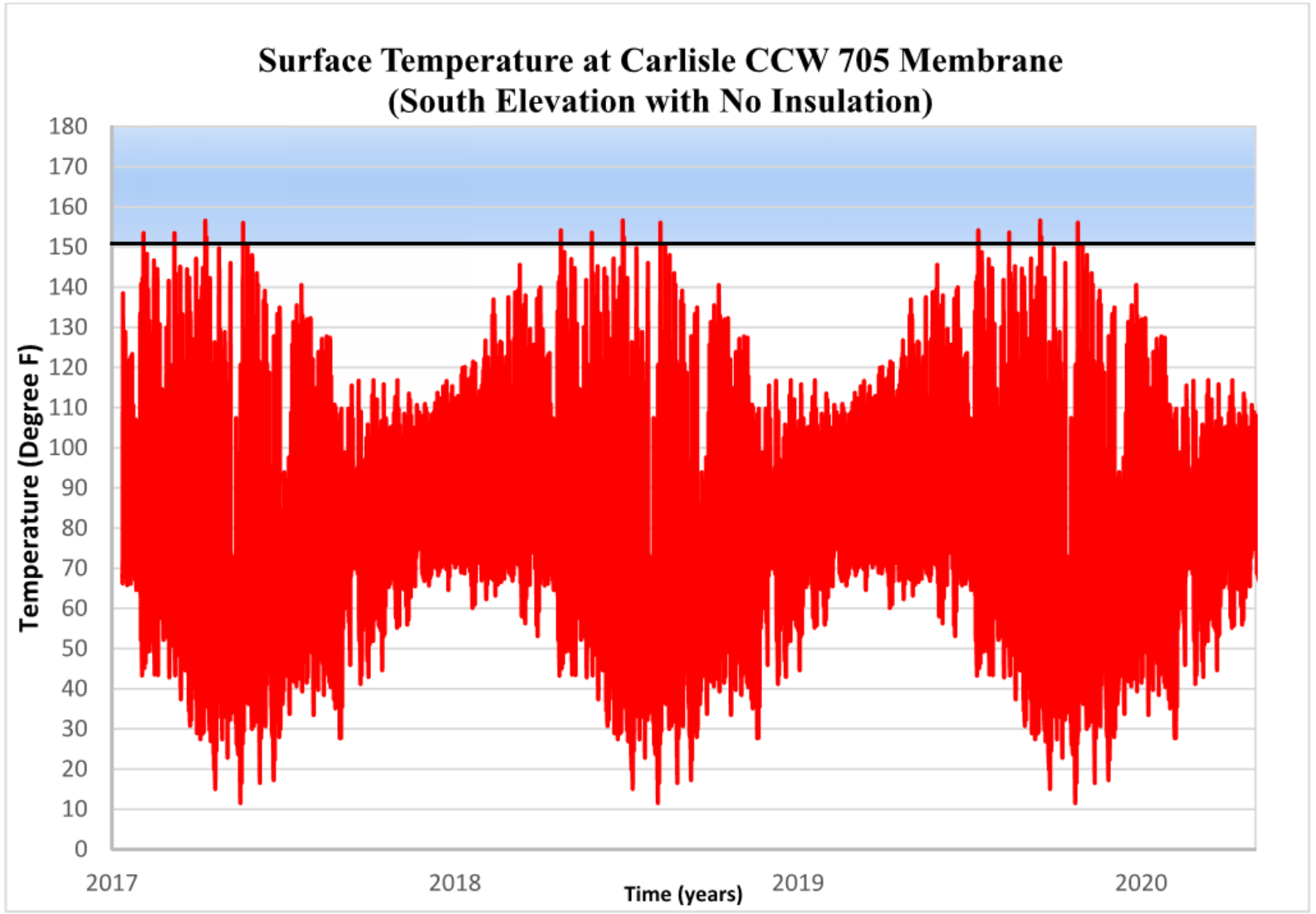
Miro Rivera Architects

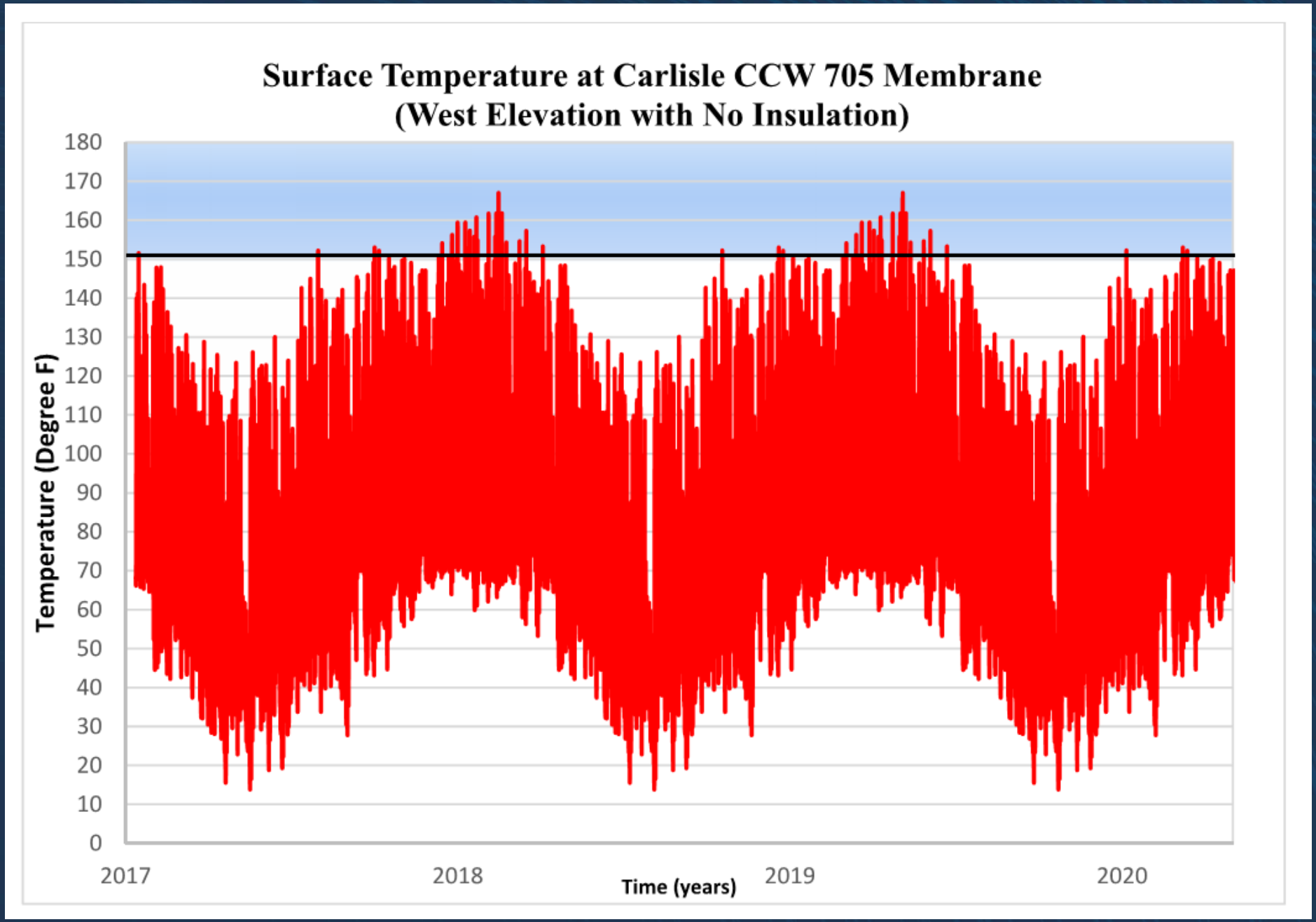


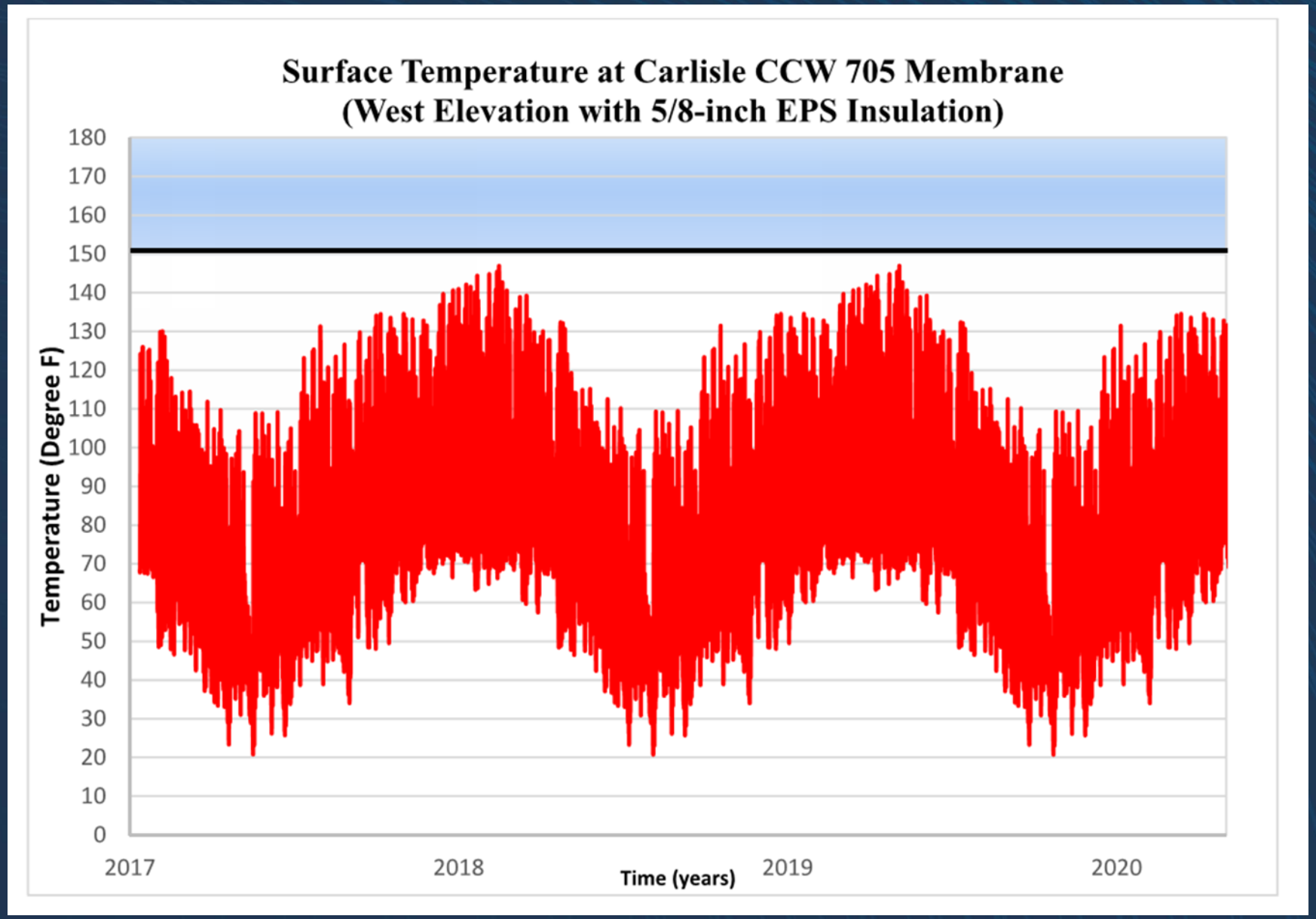


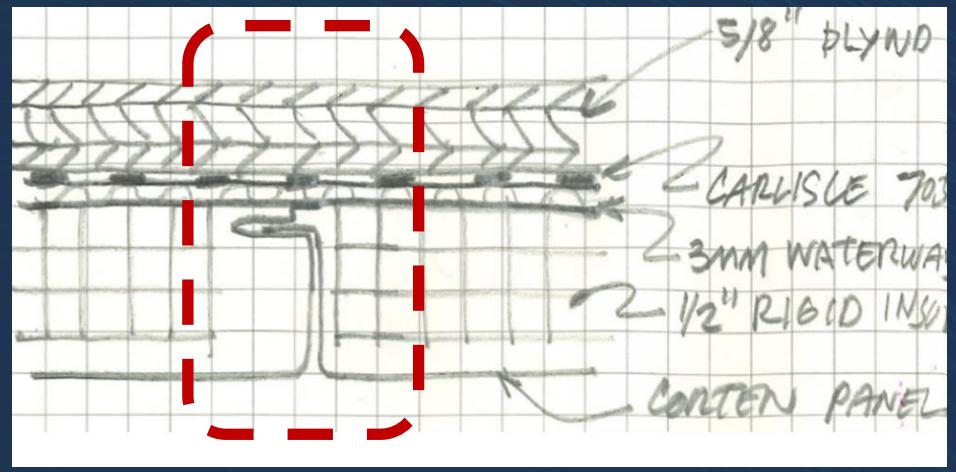

Surface Temperature at Carlisle CCW 705 Membrane
(North Elevation with 5/8-inch EPS Insulation)
Temperature (Degree F)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2017
2018
2019
2020
Time (years)


Surface Temperature at Carlisle CCW 705 Membrane
(East Elevation with 5/8-inch EPS Insulation)
Temperature (Degree F)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2017
2018
2019
2020
Time (years)

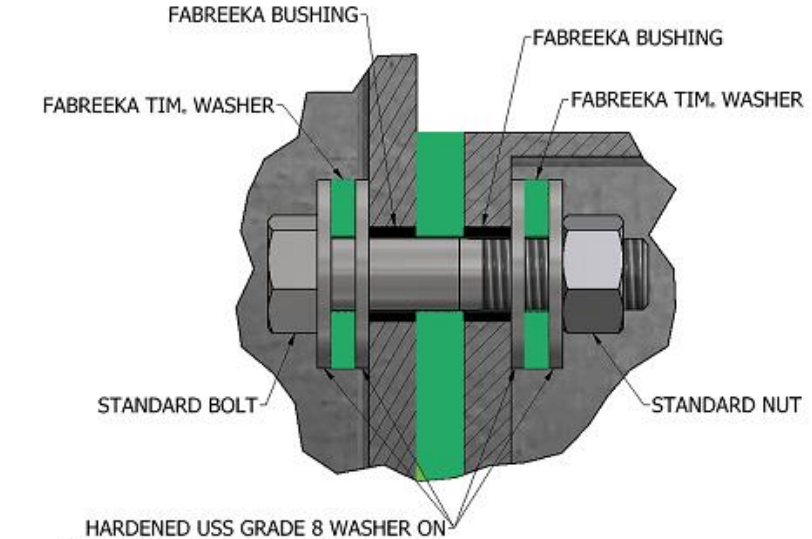

Surface Temperature at Carlisle CCW 705 Membrane
(South Elevation with No Insulation)
Temperature (Degree F)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2017
2018
2019
2020
Time (years)


Surface Temperature at Carlisle CCW 705 Membrane
(West Elevation with No Insulation)
Temperature (Degree F)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2017
2018
2019
2020
Time (years)


Surface Temperature at Carlisle CCW 705 Membrane
(West Elevation with 5/8-inch EPS Insulation)
Temperature (Degree F)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2017
2018
2019
2020
Time (years)



Connection example:



Keith A. Simon, FAIA

Keith.simon@terracon.com

512.800.4485