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Moisture Movement and Condensation Control in Exterior Wall Assemblies

Karim Allana
Allana, Buick & Bers, Inc.

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Presentation Overview

- Introduction to moisture movement through facades
- Case Study #1 – 186-Unit Multi-Family Complex
- Case Study #2 – 60-Unit Multi-Family Complex
- Building Code Requirements
- Lessons Learned – Managing Moisture Movement and Condensation

Introduction

- Buildings are being designed to be more and more air tight and better insulated.
- Incidental water entering the assembly doesn’t easily dry
- Predicting moisture movement and “drying” is one of the most important factors effecting envelope performance today.
- Humidity and condensation control are directly linked to type of cladding, WRB, vapor barriers and mechanical ventilation.
- This seminar will focus on wall assemblies experiencing excessive water damage due to moisture diffusion and condensation.

Introduction

- Water damage from Condensation or moisture diffusion can occur with or without designed vapor permeable air barriers.
- This seminar discusses lessons learned from investigation and analysis of actual projects in California.
- We used data loggers and WUFI analysis to understand how buildings behave in real time versus design parameters and Code requirements.
- We will discuss mechanical ventilation and the role it plays in managing moisture movement through walls.
- We will also review code changes that now require ventilation for multi-family residential.

Case Study #1

186-Unit Multi-Family Complex
San Ramon, CA

Project Background

- 186-Unit Multi-Family Complex
- Located in San Ramon, CA
- Originally Built in 2011
- Consists of 5, 3-Story Buildings
- Construction
  - Type 5 construction
  - Wood Sheathing over Wood Framing
  - 2 Layers of 60-Minute WRB
  - 3-Coat Traditional Stucco System

Previous Attempt to Fix Exterior Wall

- There was an initial remediation attempt prior to ABBAE involvement.
- Reports of mold and moisture damage on the interior walls of 1 stack of 3 units in one of the Buildings.
- Water damage and biological growth were reportedly uniform across the backside of gypsum board and moisture damage on OSB.
- Damage ranged from heavy damage on the 1st floor to less damage on the 3rd floor.

Pre-ABBAE Remediation Effort

Building 1400

Samples of Initial Damage & Bio Growth

Pre-ABBAE Remediation Effort

- Management believed cement plaster was leaking.
- They hired a contractor to replace all the plaster in the unit stack.
- All the windows were re-flashed
- Approx. 1 year after the repair, same mold/damage developed on the same unit stack.
- 2nd time around, Management called us...

Typical Unit Stack

Water Intrusion Investigation

To Determine the Source(s) of Damaging Water Intrusion

Façade Assessment

- Phase I - visual assessment of the building exteriors and select unit interiors.
- Phase 2, Destructive Testing
- Phase 3, data loggers and WUFI modelling
- We were given access to 8 vacant units across 3 buildings.
- We observed mold or biological growth at 7 out of 8 of units.

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Building 1500, Unit 100 Interior

Mold Growth at SGL and Window Frames

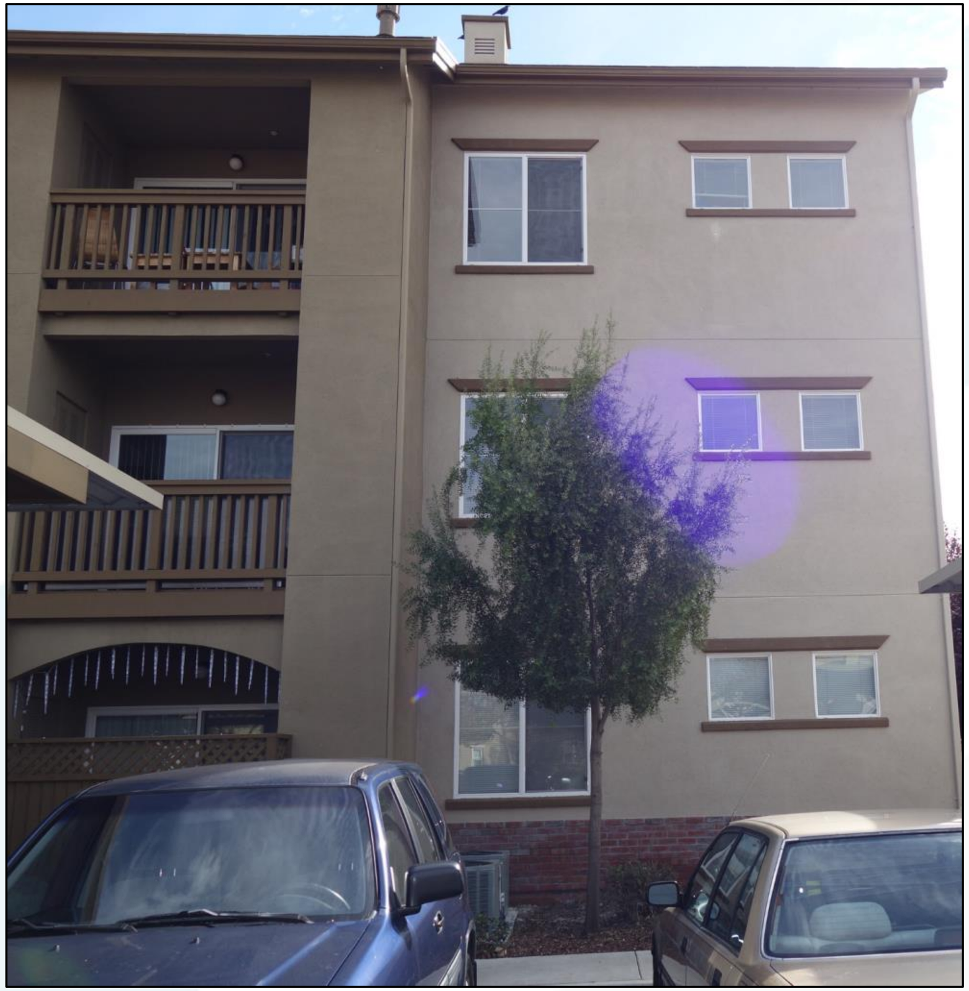
Active Condensation On Glass At a Window

Carpet Tack Strip Damage at Exterior Wall

High Interior Humidity & Moisture Reading

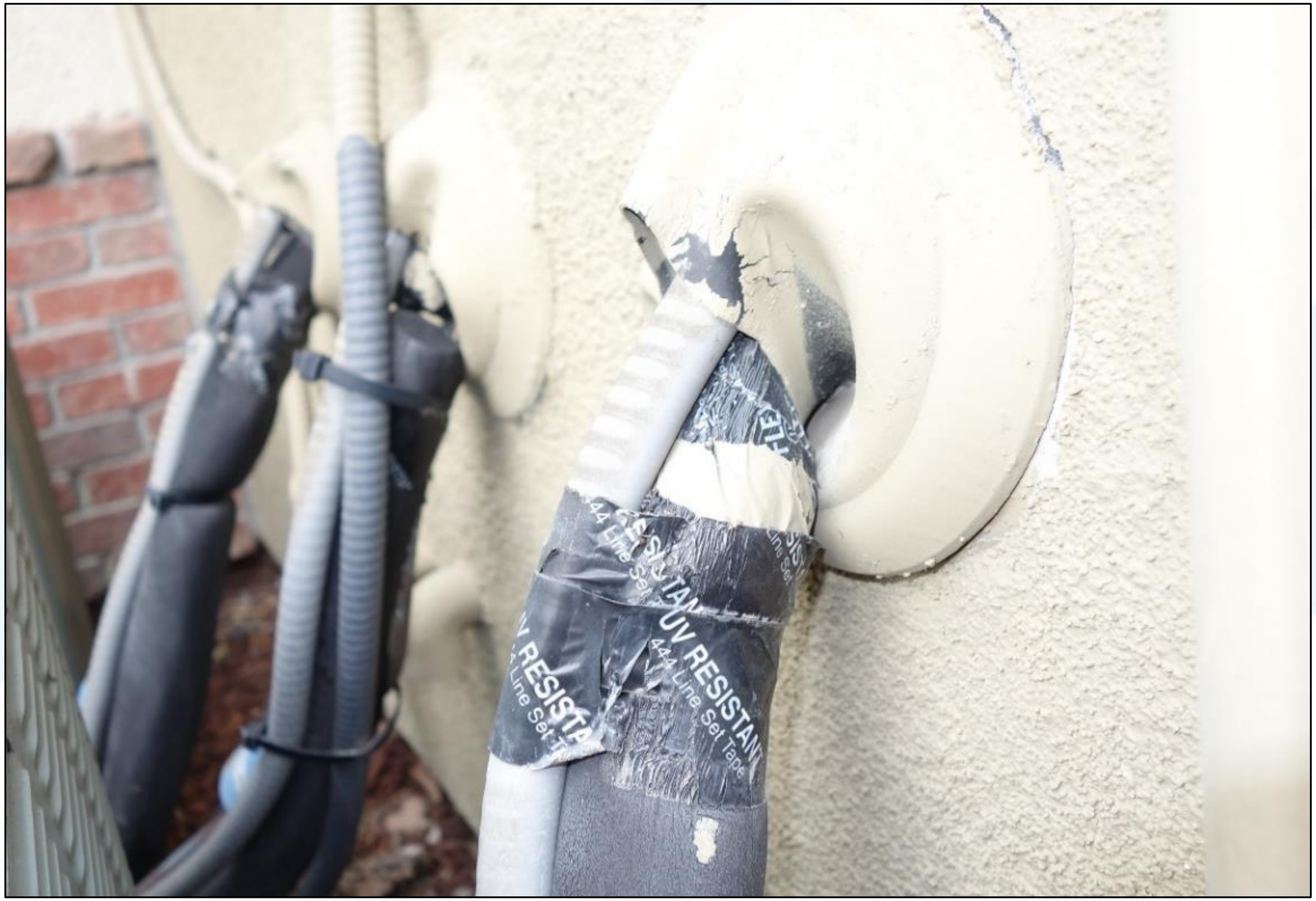
High interior moisture readings (despite unit being vacant)

Visual Investigation of Potential Leak Sources



Significant cracks in the 3 coat traditional plaster system

Potential Leak Sources at Exterior Walls



Poorly sealed penetrations

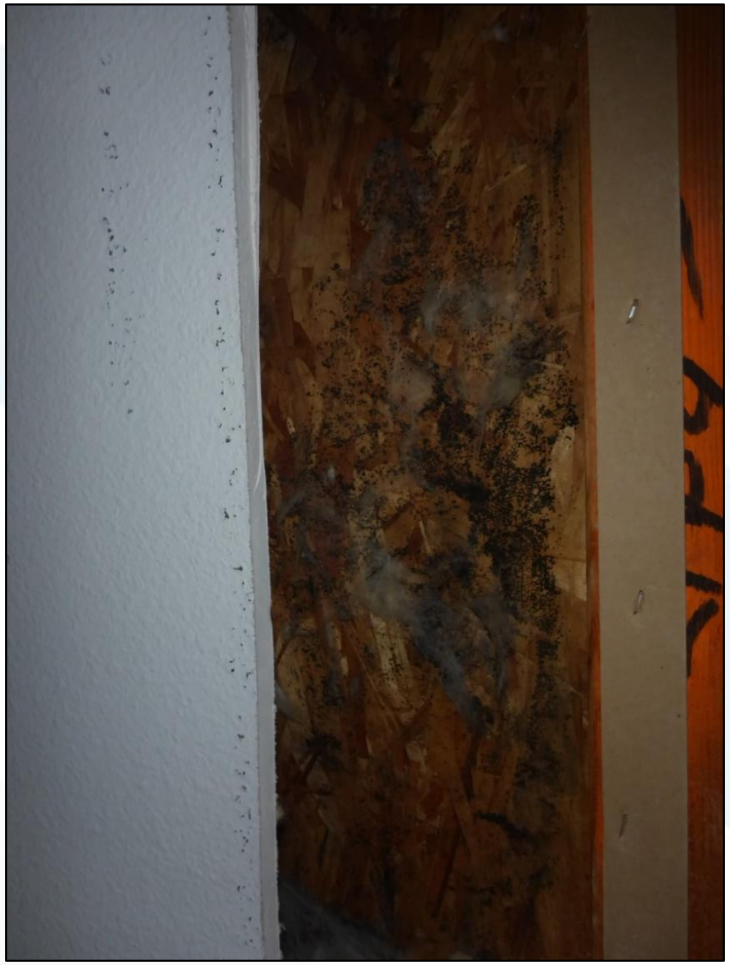
Exterior Sources Add Water "Leakage" on WRB

Pot shelves, foam trims and signs of efflorescence

Recommended Further Destructive Testing

- Management gave us a “vacant” unit to investigate.
- Based on observed interior/exterior damage, interior humidity levels, additional testing was required.
- We opened up gypsum board in the various units.
- We observed severe damage to the exterior oriented strand board (OSB) sheathing.
- Based on our observations, we identified several potential sources of wall and window leaks for testing.

Damage In Wall Cavity After Removing Drywall



Oddly, damage across the plywood was very uniform. Didn't seem to be specific to wall leaks.

2 Days of Extensive Water Testing

- Included extensive testing of the windows and wall assemblies.
- Windows were tested under ASTM E-1105 under differential pressure.
- Exterior stucco façade was tested with a spray rack for 2 hours with no differential pressure.
- <u>Results: </u>Very isolated water intrusion, not responsible for uniform and extensive damage

2 Days of Water Testing – No Significant Leaks

No Significant Interior Leaks from Water Testing

One “non-historic” glazing stop leak was observed during negative pressure testing of a window

No Significant Change In Wood Moisture from Testing

We tested wood moisture levels moisture levels before, during and after 2 hr. testing.

Interior moisture levels did not change significantly within the 6-8 hour testing period

If Not the Walls, then Foundation Slab?

- Since liquid water was not coming directly through the stucco walls (WRB), next potential source was the foundation slab.
- We performed concrete coring and calcium chloride testing of the interior unit slabs.
- We looked for water travelling under the slab and if there was an under-slab vapor barrier present.
- Calcium chloride tests indicated an elevated slab moisture vapor of between 3.7 and 5.7 pounds/1000 square feet.

Concrete Coring to Check for Under-slab Water

Water Under The Concrete Slab

The foundation wall was allowing water from the landscape irrigation system to migrate under the slab

Liquid water migrated on top of the vapor barrier during water testing

This under-slab water still does not explain the interior humidity levels

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Moisture Study For Diffusion Through Slab

DATA COLLECTED

Specimen A		Specimen B		Specimen C	
date	wt, grams	date	wt, grams	date	wt, grams
7/24/18 11:45	4866.86	7/24/18 11:45	4582.43	7/24/18 11:45	4783.50
7/27/18 10:28	4863.23	7/27/18 10:28	4580.58	7/27/18 10:28	4780.32
7/30/18 11:57	4860.04	7/30/18 11:58	4578.60	7/30/18 11:58	4777.27
8/2/18 10:16	4857.32	8/2/18 10:16	4576.74	8/2/18 10:16	4774.40
8/3/18 9:12	4856.50	8/3/18 9:12	4576.01	8/3/18 9:12	4773.48
8/6/18 13:41	4853.74	8/6/18 13:41	4573.85	8/6/18 13:41	4770.38
8/8/18 13:11	4852.12	8/8/18 13:11	4572.44	8/8/18 13:12	4768.48
8/10/18 14:26	4850.46	8/10/18 14:26	4571.07	8/10/18 14:27	4766.51
8/13/18 13:37	4848.21	8/13/18 13:38	4569.04	8/13/18 13:38	4763.65
8/15/18 9:39	4846.81	8/15/18 9:40	4567.79	8/15/18 9:40	4761.93

Destructive Testing – Signs of Wetting and Drying

Traditional cement plaster with 2 layers of Grade D paper shows wetting and drying

Study For Diffusion Through Plaster = 3.5 Perms

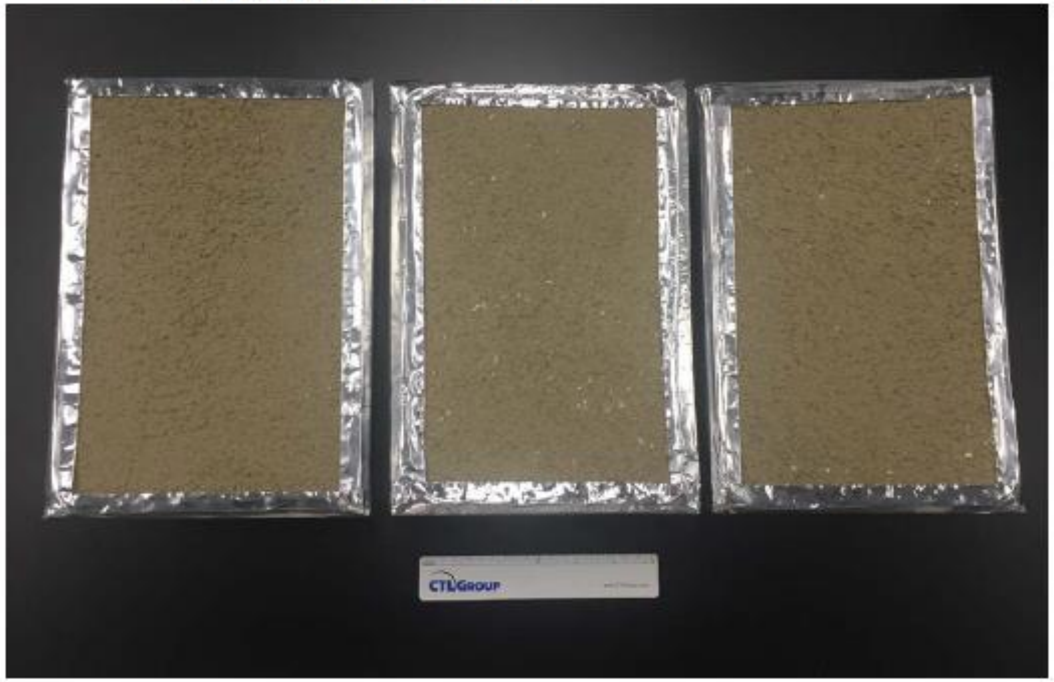
RESULTS

WS Stucco 3.5 perms (grains h^{-1} ft^{-2} in Hg^{-1})

SPECIMEN INFORMATION

Client ID	WS Stucco
CTLGroup ID	4718704
Material type	Stucco
Specimen thickness, in.	0.95-in.
Exposed area, in^2.	54.3
Balance	EP6102C s/n M028112
Last Calibration	23-Feb-18
Prepared by	M. Klaric

SPECIMEN PHOTOGRAPH



Not the Façade, Not the Slab… So Where?

- According to plans, there was ducted fresh air intake in mechanical system, so why the high interior humidity?
- Neither exterior walls or slab accounted for significant enough water intrusion to raise humidity levels, especially with designed HVAC exhaust/fresh air.
- We installed data loggers to track temperature, humidity and actual moisture levels in exterior sheathing during rains.
- 2 to 3 data loggers were installed in 3 units for comparison.
- Data loggers were installed inside the wall cavity and living space to measure relative humidity levels.

Using Data Loggers

To Track Temperature, Humidity and Actual Moisture Levels in Exterior Sheathing

Data Logger Results

WME = Wood Moisture Equivalent

Unit	Location	Temp (Daily Low)	Temp (Daily High)	% Int. Hum. (Daily Low)	% Int. Hum. (Daily High)	%WME (Daily Low)	%WME (Daily High)
1100-100 East	BD 1	66.9	77.7	48.9	71.1	10.6	12.6
1100-100	Hall	73.9	77.3	46.8	51.1	7.6	8
1100-100 West	Master	67.3	79.4	55	77.7	11.8	14.4
1400-100 South	BD 1	67.2	83.4	49	72.2	10.1	12.5
1400-100	Hall	72.3	79.7	44.8	52.8	6.5	7.4
1400-100 East	Master	66.8	81.9	57.1	76.2	10.1	12.1
1500-311	Hall	74	80.1	39.5	48.9	6.3	7.1
1500-311 South	Master	65.5	80.5	51	75.8	8.4	10.5
1800-202 East	BD 1	68.3	83.7	53.7	82.6	9.4	13.1
1800-202	Hall	75.4	80.1	53.1	56.5	8.3	8.7
1800-202 East	Master	63.1	88.1	43.3	73.8	6.4	8.6
1100-115	Hall	54.2	79.1	45.6	74.7	9.6	20
1100-115 East	Master	54.7	89.1	45	98.7	9.6	21.5
1100-115 East	Master Ceiling	54	87	45.8	80.3	10.1	20.1
1100-115 South	Master Closet	53.7	80.5	45.4	77.1	7.7	18.8
1500-100 North West	BD 1	54.4	76.9	45.8	68.7	10.1	18.6
1500-100	Hall	54.3	78.4	40	60.2	8	18.6
1500-100 North East	Living Room	53.8	79	39.5	66.1	8.8	18
1500-100 West	Master Closet	50.8	80.6	39.6	73.7	9.2	18.9

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WUFI Modeling - As-Designed Conditions

- WUFI stands for Wärme Und Feuchtetransport instationär (or Transient Heat and Moisture Transport).
- It is a software suite designed to realistically calculate heat and moisture transport through multi-layered building components.
- First we modeled the building exterior and ventilation as designed.
- Design included mechanical ventilation ducted to the forced air fan coil system used for heating and cooling.

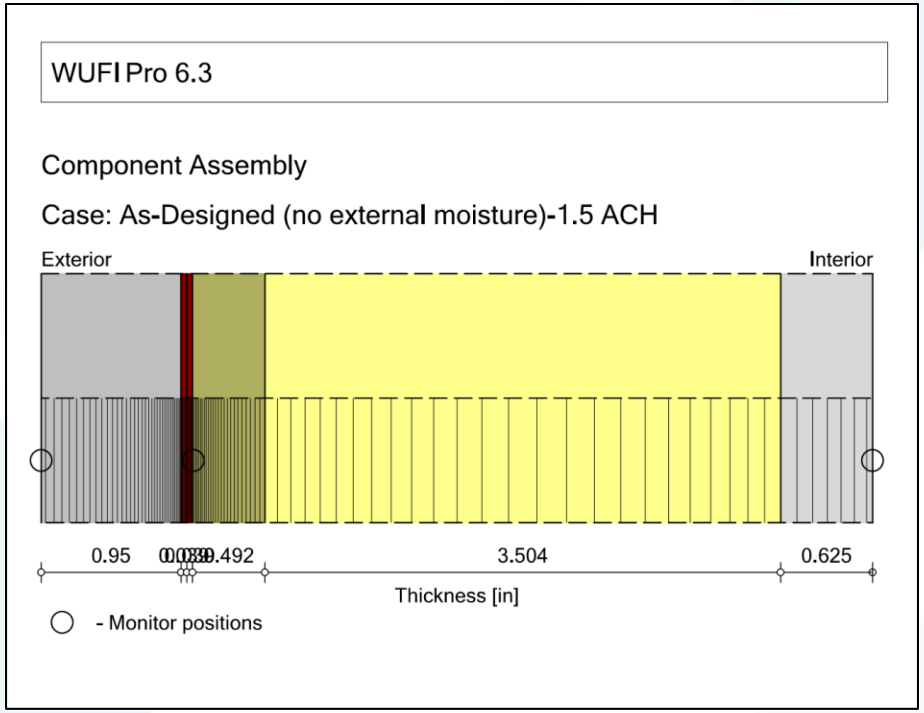
WUFI Model 1 – As-Designed Conditions

- This model uses the following parameters and generated the following results:

Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾” stucco (bright paint) • 60 min. building paper (2 layers) • ½” OSB • 3.5” fiberglass batt insulation (1.2 pcf) • 5/8” interior gypsum board (painted)	San Ramon, CA	0. 83 lbs/hr (2-bedroom residence per WUFI)	None	1.5 ACH

Mold Index	Sheathing Moisture Content
0	11%

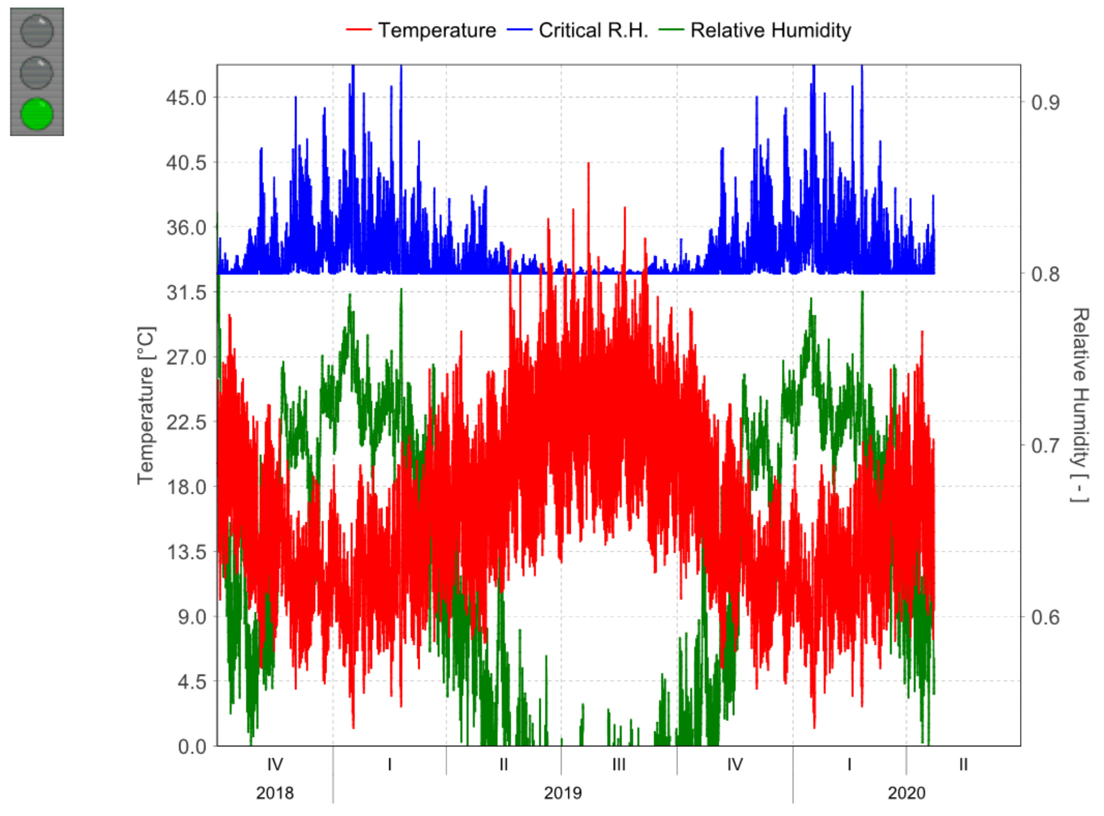
WUFI Model 1 – With ACH = 1.5



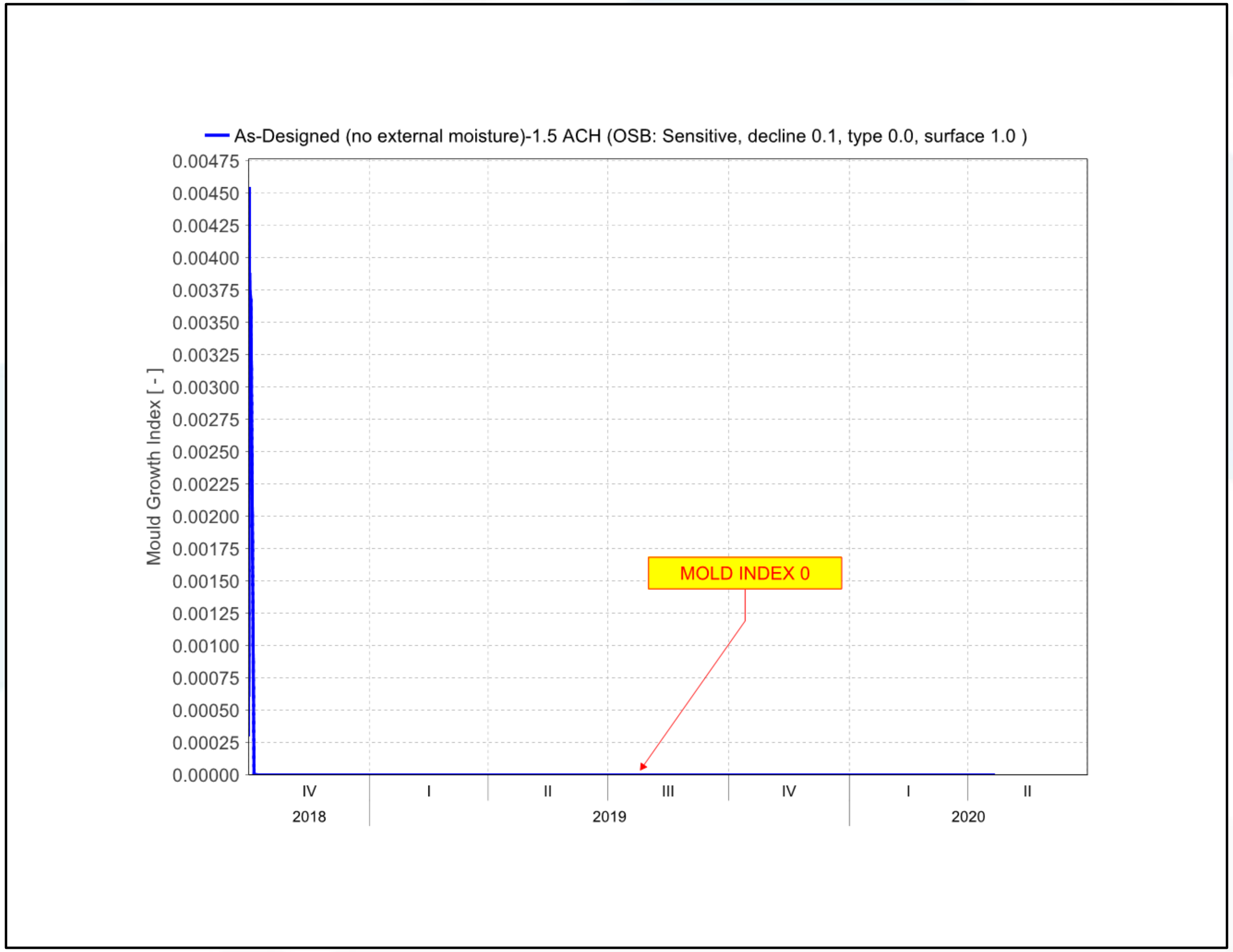
Materials:

- Portland Cement-Lime Mortar - Type S	0.95 in
- Asphalt Impregnated Paper (60 min Paper)	0.039 in
- Asphalt Impregnated Paper (60 min Paper)	0.039 in
- Oriented Strand Board	0.492 in
- *Low Density Glass Fiber Batt Insulation - unlocked	3.504 in
- Interior Gypsum Board	0.625 in

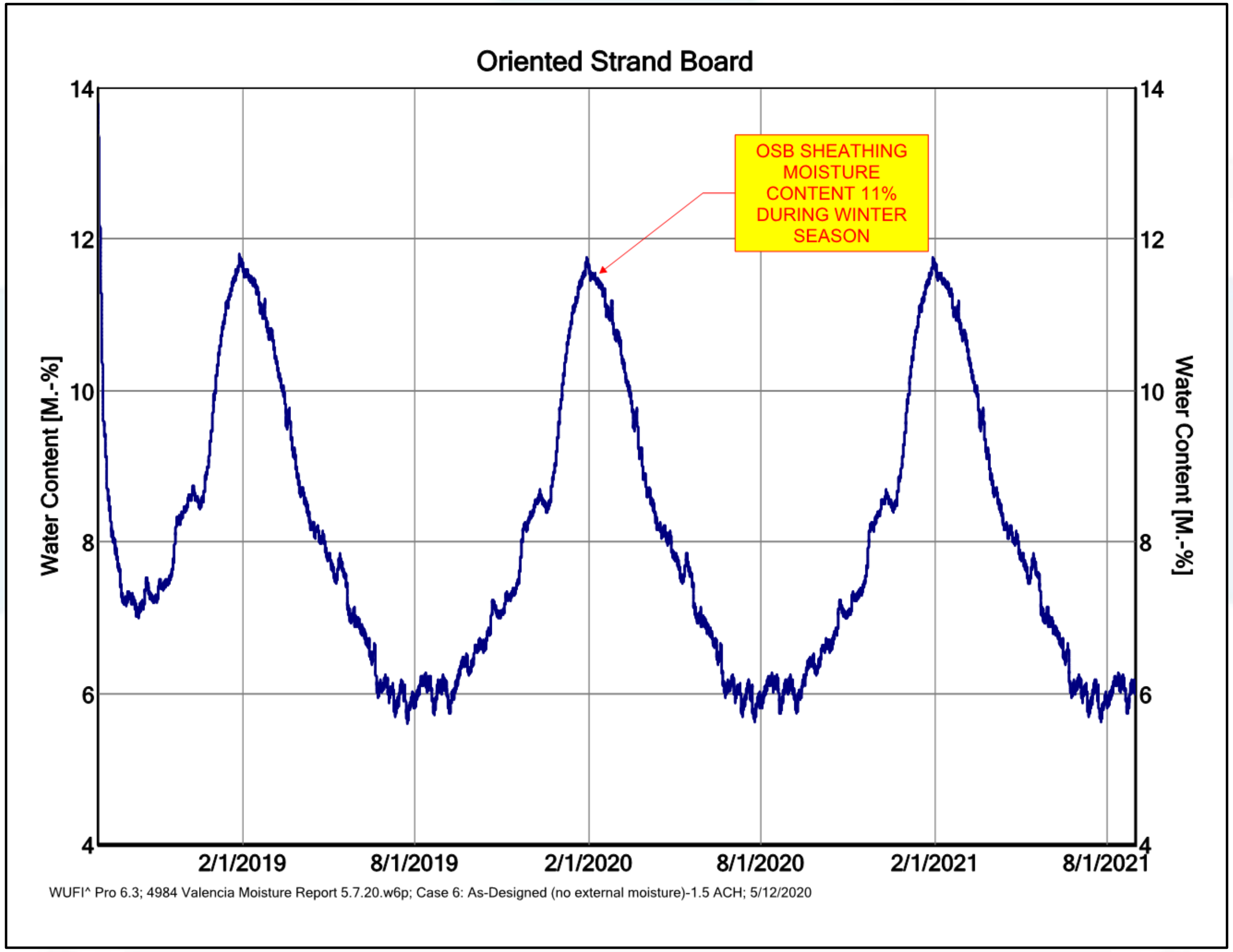
WUFI Model 1 – Mould (Mold) Index Low



WUFI Model 1 – Mould (Mold) Index



WUFI Model 1 – Sheathing Water Content (WME)



Data Logger Results and WUFI Modeling

- Data loggers showed high humidity and moisture levels in OSB.
- WUFI model 1, showed mold and high moisture levels were not possible (as designed)
- Base on data, we decided to du further modelling in WUFI
- We also used the data loggers to monitor changes in moisture and humidity in exterior OSB sheathing before and after rain events.
- Changes in humidity during a rain event allowed us to model how much “leakage” was occurring through the 3-coat plaster on WRB and soaking through the walls.
- We modeled the actual results and studied in WUFI.

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Moisture Diffusion Through Exterior Walls?

- There was no liquid passing through WRB on to interior finishes.
- However, moisture must have been diffusing through building the paper, through the exterior sheathing.
- Was there "leakage" was due to the WRB getting damp from cracks and openings through the stucco?
- Was damp WRB building paper acting like a wet towel against the OSB sheathing and the moisture gradually absorbing into the wall cavity?

Was the HVAC System Functioning Properly?

- HVAC investigation scope included:
  - Review of design drawings and specifications
  - On-site verification of the mechanical systems installed
  - Air flow measurement of:
    - Bathroom exhaust fans
    - Fan-coil unit outside air intakes
  - Blower door air barrier testing
- We knew the HVAC design had a fresh air intake duct connected to the fan coil unit.
- Were the exhaust fans and fresh air ducts working properly?

Mechanical System Per Design Documents

KEY NOTES:

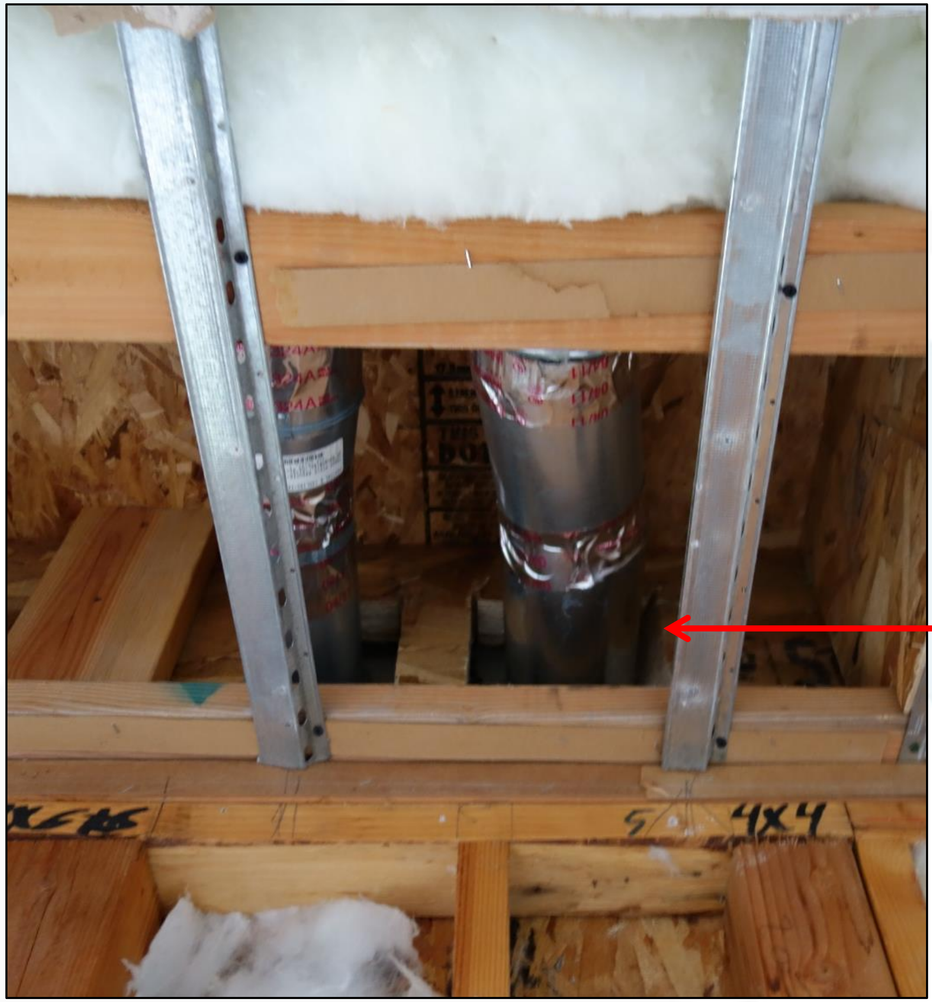
1. 6"Ø EXHAUST AIR DUCT THRU WALL TO WALL CAP. CAP SHOULD BE 3 FT (MIN.) AWAY FROM ANY OPENING.
2. 4"Ø DRYER VENT AIR DUCT THRU WALL TO WALL CAP. CAP SHOULD BE 3 FT (MIN.) AWAY FROM ANY OPENING. PROVIDE BOOSTER FAN FOR MORE THAN 34'-0" DRYER VENT TOTAL LENGTH. SEE DRAWINGS M-D2, DETAIL 1 FOR BOOSTER FAN SPECIFICATIONS AND M-D1, DETAIL 2 FOR DRYER VENT SIZING AND CALCULATIONS.
3. 6"Ø KITCHEN HOOD EXHAUST AIR. THRU WALL TO WALL CAP. CAP SHOULD BE 3 FT (MIN.) AWAY FROM ANY OPENING.
4. 120 CFM OUTSIDE AIR THRU 6"Ø GALVANIZED OSA THRU WALL OUTSIDE (FRESH) AIR INTAKES SHALL BE 10 FT AWAY FROM ANY EXHAUST OPENINGS OR SANITARY VENTS. FIELD VERIFY EXACT LOCATION.
5. ROUTE 3/4" CONDENSATE DRAIN TO LAVATORY TAILPIECE AND CONNECT AS REQUIRED BY CODE. ROUTE 3/4" OVERFLOW DRAIN TO VISIBLE LOCATION, COORDINATE WITH THE ARCHITECT.
6. THRU-THE WALL HEAT PUMP MOUNTED MIN 6" OFF THE FLOOR TO ALLOW INSTALLATION OF THE DRAIN CONNECTIONS.
SIZE REFRIGERANT LINES PER MANUFACTURER'S RECOMMENDATIONS BASED ON TONNAGE & TOTAL LENGTH BETWEEN THE HEAT PUMP AND THE FAN COIL UNIT. SEE ARCHITECTURAL DRAWINGS FOR EXACT LOCATION OF THRU-THE WALL HEAT PUMP.

EXHAUST FAN SCHEDULE

UNIT DESIGNATION		EF 1	EF 2	EF 3	EF 4
UNIT LOCATION		CEILING MOUNTED	CEILING MOUNTED	CEILING MOUNTED	CEILING MOUNTED
AREA SERVED		RESTROOM (MAINTEN. BLDG.)	RESIDENTIAL BATHROOM	RESTROOM (CLUBHOUSE)	RESTROOM (POOL BLDG.)
MANUFACTURER'S NAME		GREENHECK	BROAN	GREENHECK	GREENHECK
MODEL NUMBER		CSP-A110	QTXE110	CSP-A125	CSP-A200
DRIVE TYPE		DIRECT	DIRECT	DIRECT	DIRECT
CFM		50	100	125	250
STATIC PRESSURE IN W.G.		0.375	0.10	0.125	0.25
FAN RPM		950	-	1,100	900
SONES		1.5	5.5	1.5	1.5
MOTOR DATA	WATTS (HP)	51	300	55	48
	VOLTAGE	120	120	115	115
	PHASE	1	1	1	1
	HZ	60	60	60	60
WEIGHT (LBS)		16	20	16	25
REMARKS		1 2	1	1 2	1 2

1. PROVIDE INTERNAL GRILLE & BACKDRAFT DAMPER FOR EACH CEILING MOUNTED EXHAUST FAN.
2. INTERLOCKED WITH LIGHT ON/OFF SWITCH.

Existing HVAC Unit



Fresh Air Intake was missing

HVAC Investigation Results

- Installed indoor fan coil system did not comply with existing construction documents.
- The fresh air intake duct as designed by the mechanical engineer was not installed.
- Had the ducted fresh air inlets been per design, it would have resulted in a ventilation rate of 1.5 to 1.7 Air Changes per Hour (ACH).
- Actual Air Exchange Rate was 0.4 ACH

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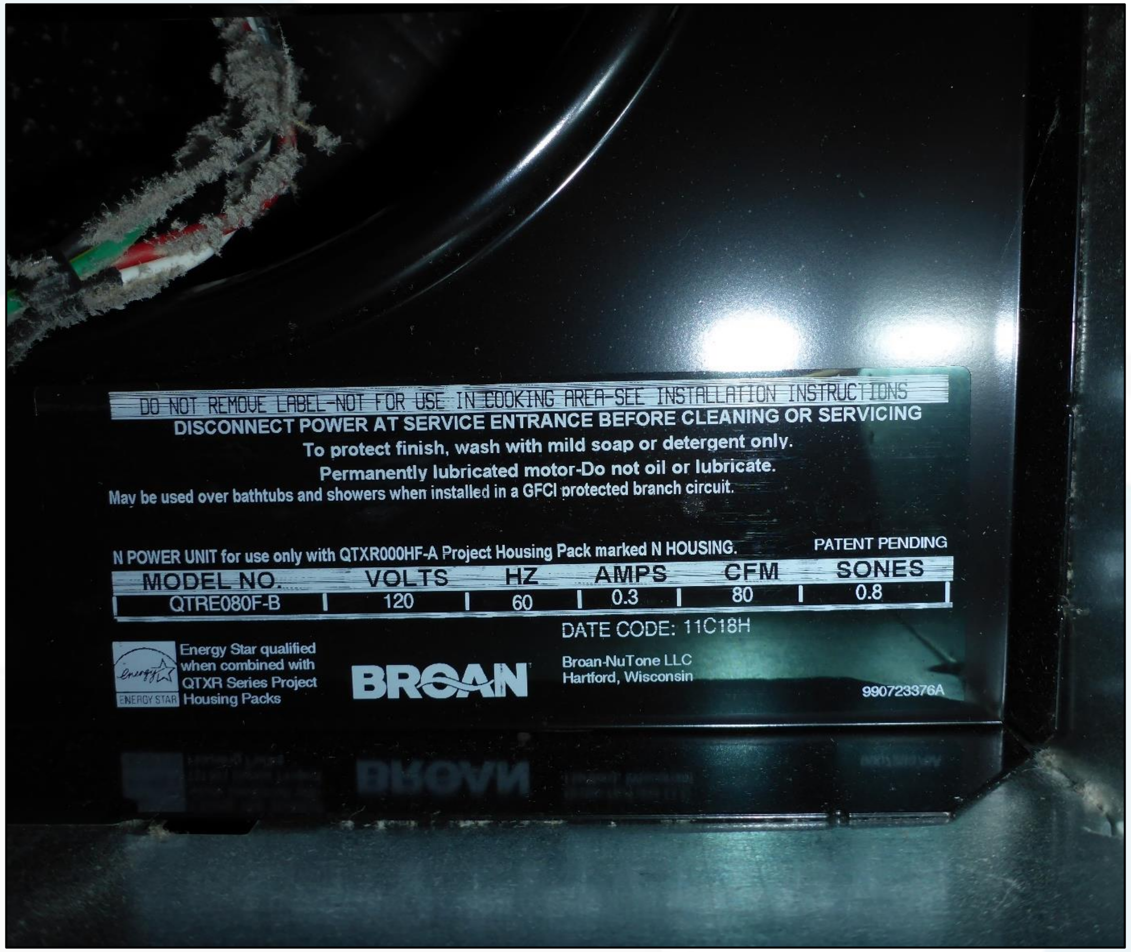
HVAC Investigation Results

- Bathroom exhaust fans were undersized and also did not match the specifications.
- Originally designed exhaust fans were specified to flow at 110 cfm (two exhaust fans per residential unit).
- Our calculations showed 1.5 air changes per hour (ACH) can be achieved in bathroom from designed 110 cfm fans (working 24/7).
- The 80 cfm units installed can only achieve 0.3 ACH (bathroom) when working 4 hours per day.

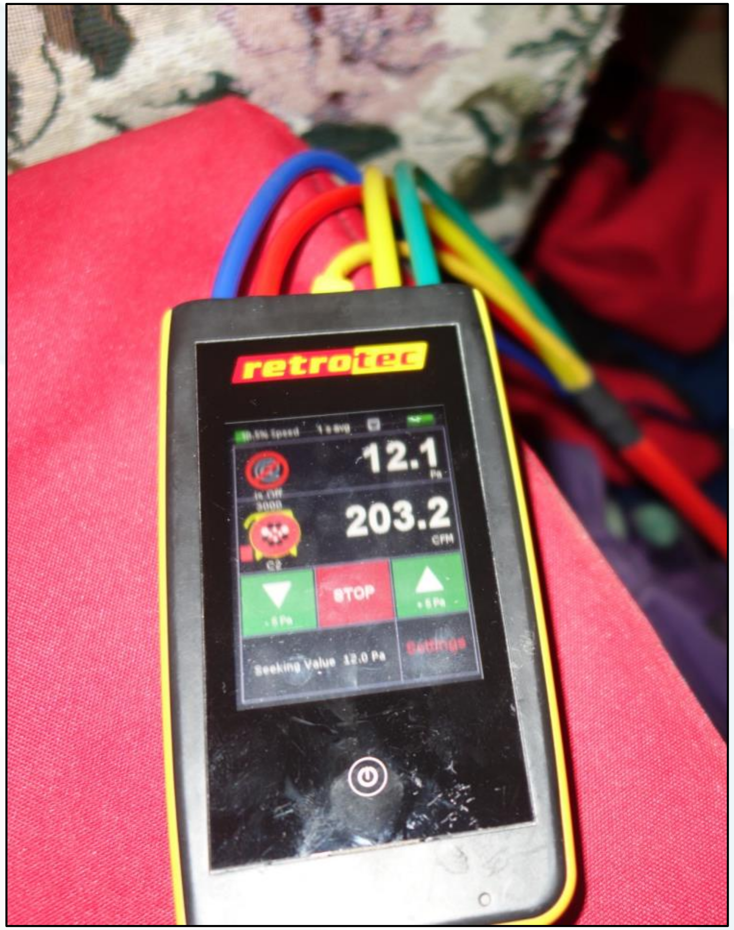
Bathroom Exhaust Fans Were Undersized



More WUFI Modeling

Replicating Actual Field Conditions with WUFI model

Air Leakage / Blower Door Testing



WUFI Model 2 – As-Built Condition

- This next model was based on the understanding that the mechanical ventilation designed for the project had not been properly installed.
- We used blower door to measure actual air leakage rates for WUFI modeling. Building was fairly air-tight
- We used air changes per hour based on bathroom and kitchen exhaust which are only on part of the day.
- This model also included interior source moisture to account for occupant activity and concrete slab.

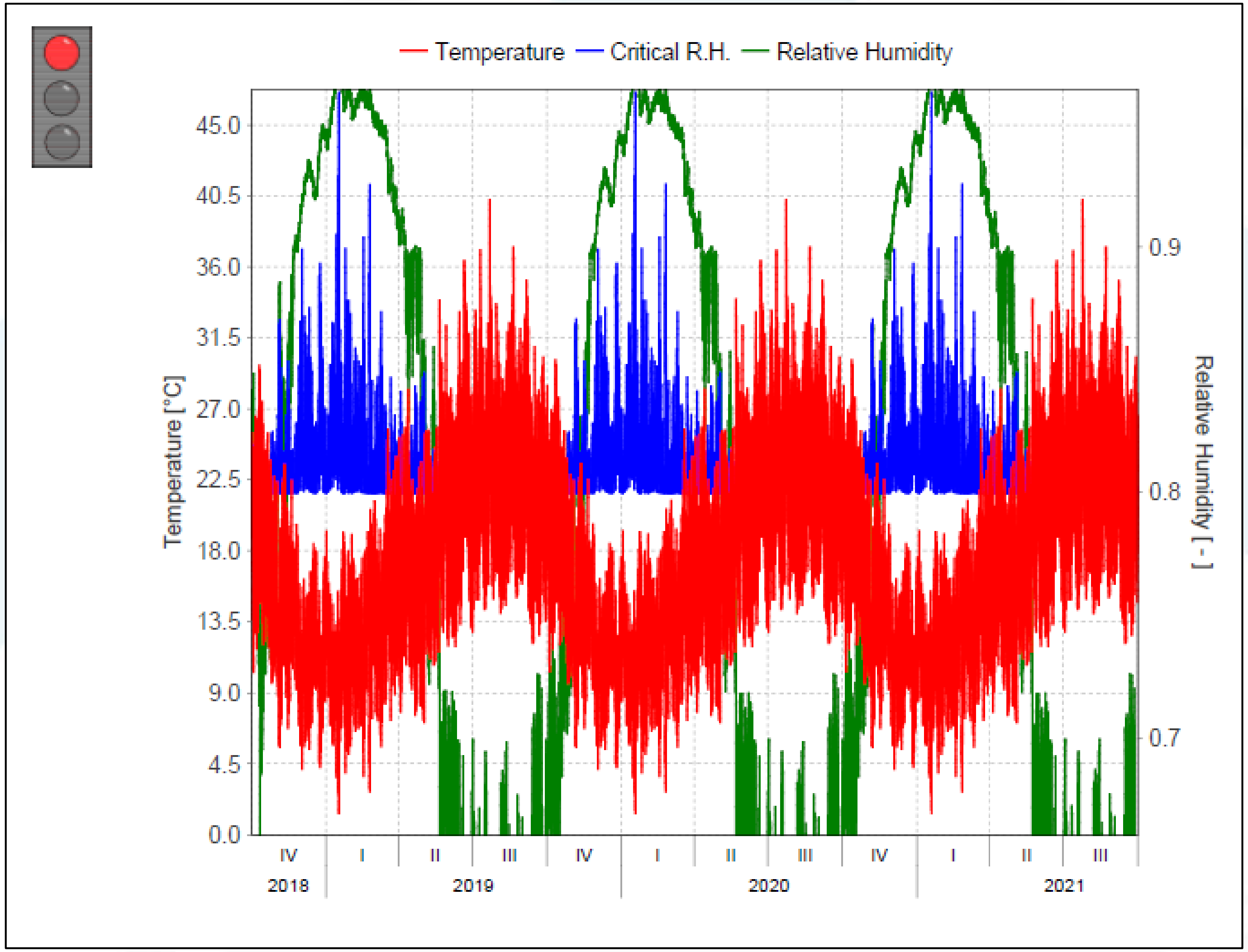
WUFI Model 2 – With ACH = 0.3

- This model uses the following parameters and generated the following outcomes:

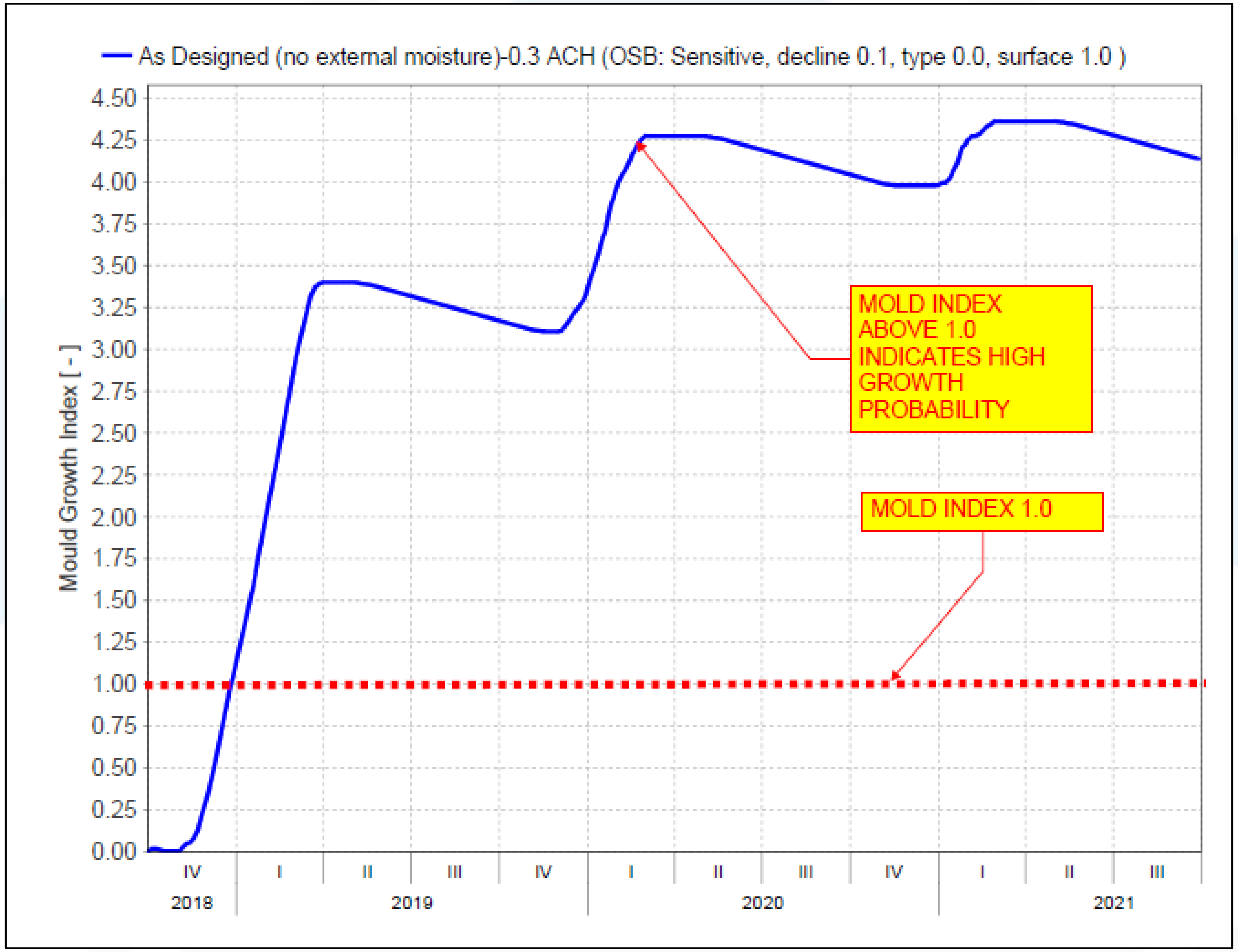
Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾” stucco (bright paint) • 60 min. building paper (2 layers) • ½” OSB • 3.5” fiberglass batt insulation (1.2 pcf) • 5/8” interior gypsum board (painted)	San Ramon, CA	0. 83 lbs/hr (2-bedroom residence per WUFI)	None	0.3 ACH

Mold Index	Sheathing Moisture Content
4.3	26%

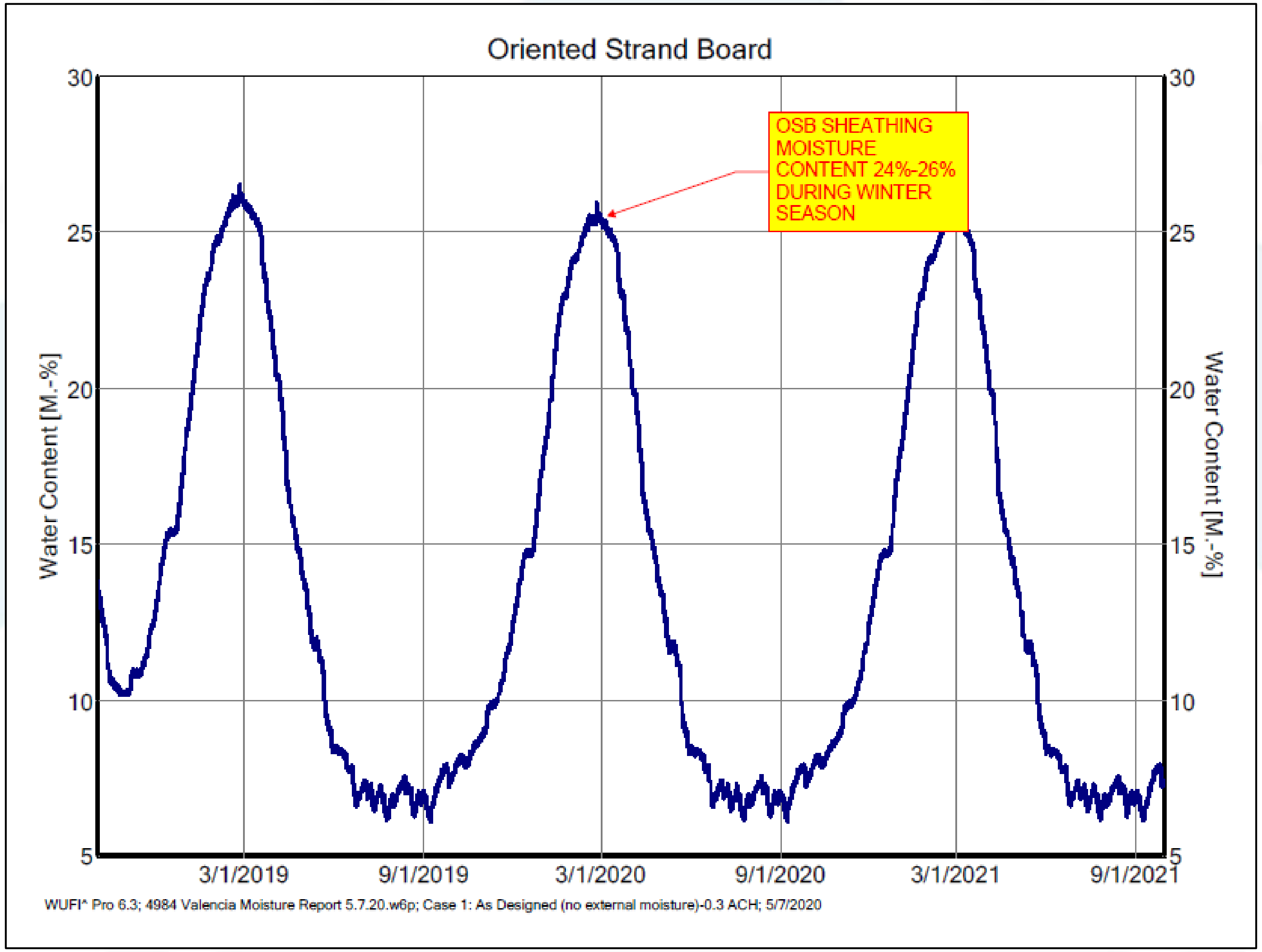
WUFI Model 2 – Mould (Mold) Index High



WUFI Model 2 – Mould (Mold) Index



WUFI Model 2 – Sheathing Water Content (WME)



WUFI Results – Just Excluding Fresh Air Intake

- WUFI results look good, but did not represent 32% WME at exterior OSB.
- Actual high WME in OSB was 32% tapering down below 19% after 7 weeks of no rain.
- To determine how much “wetting” the OSB was experiencing, we were able to monitor changes in moisture and humidity before and after rain events with data loggers.
- Changes in humidity during a rain event allowed us to model how much “leakage” was occurring through the exterior wall assembly.
- We were able to add the additional moisture source to the next WUFI model.

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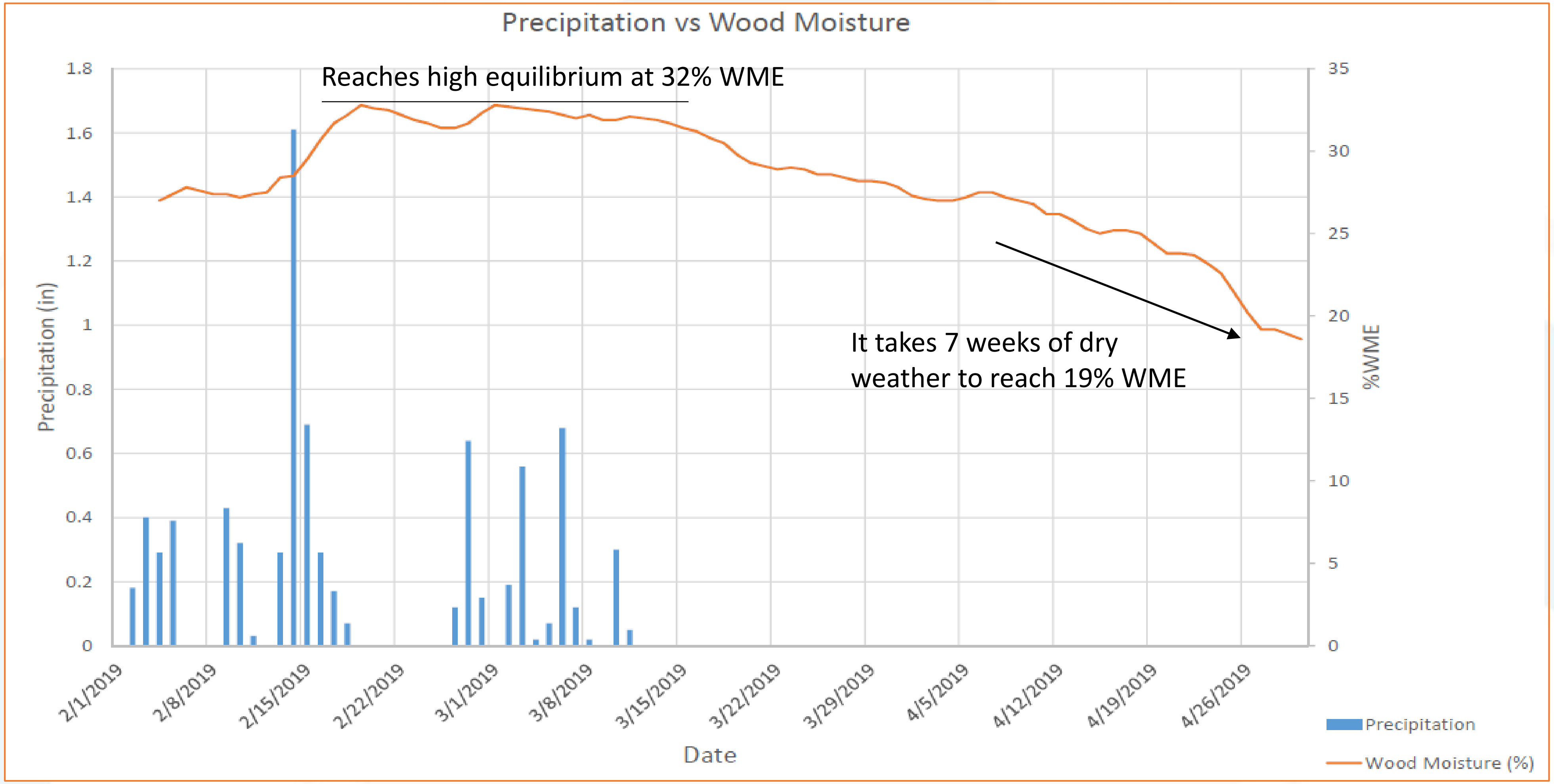
Data logger OSB Moisture Before/After Rain



WUFI Model 3 – To Match Data Logger Results

- For the next run, we added an exterior wall permeability (or water "leakage" rate) to replicate actual conditions.
- We adjusted water leakage rates until the WUFI results mirrored actual site conditions.
- Model showed high interior humidity and OSB RH.

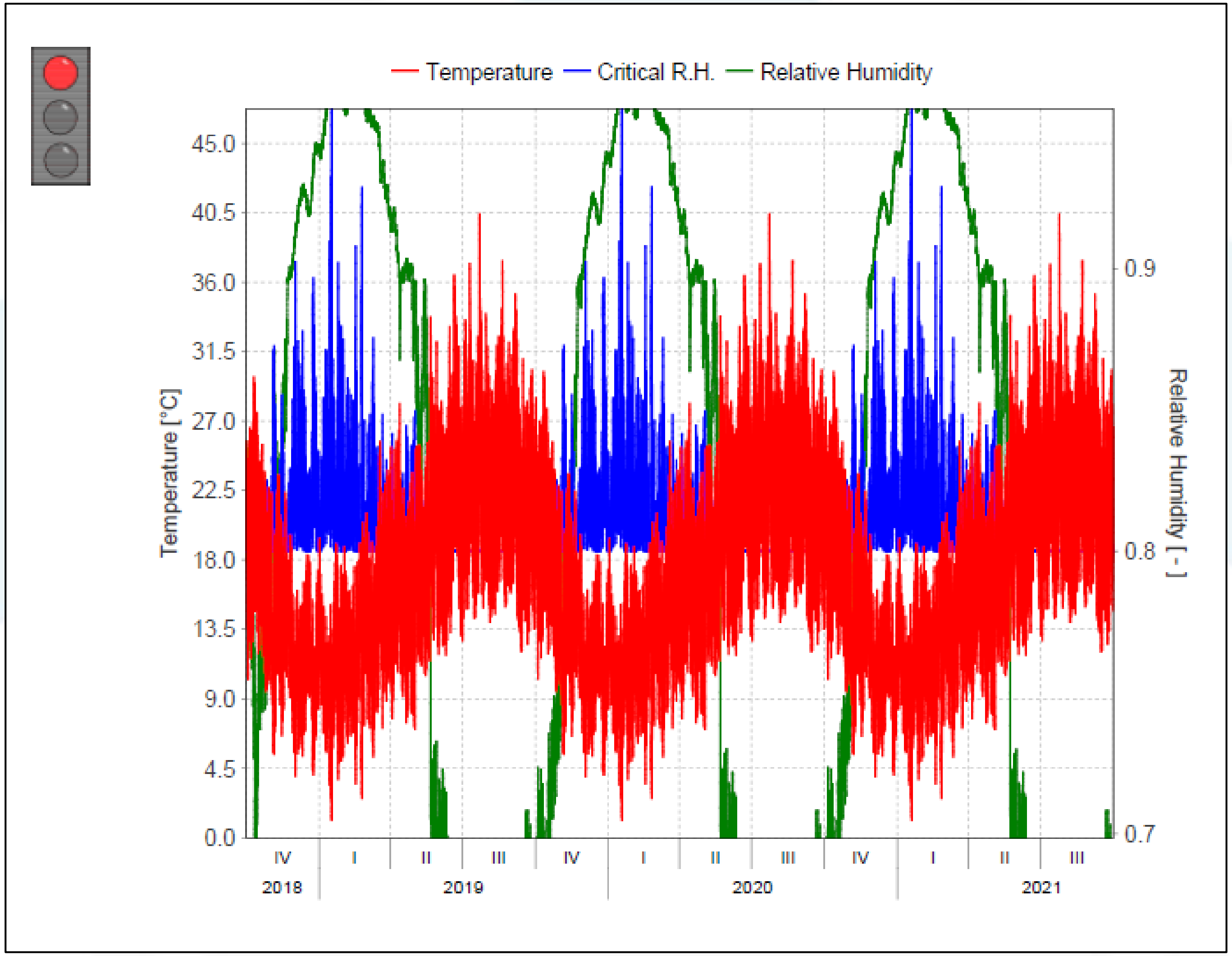
WUFI Model 3 – Actual Site Conditions

- This model uses the following parameters and generated the following outcomes:

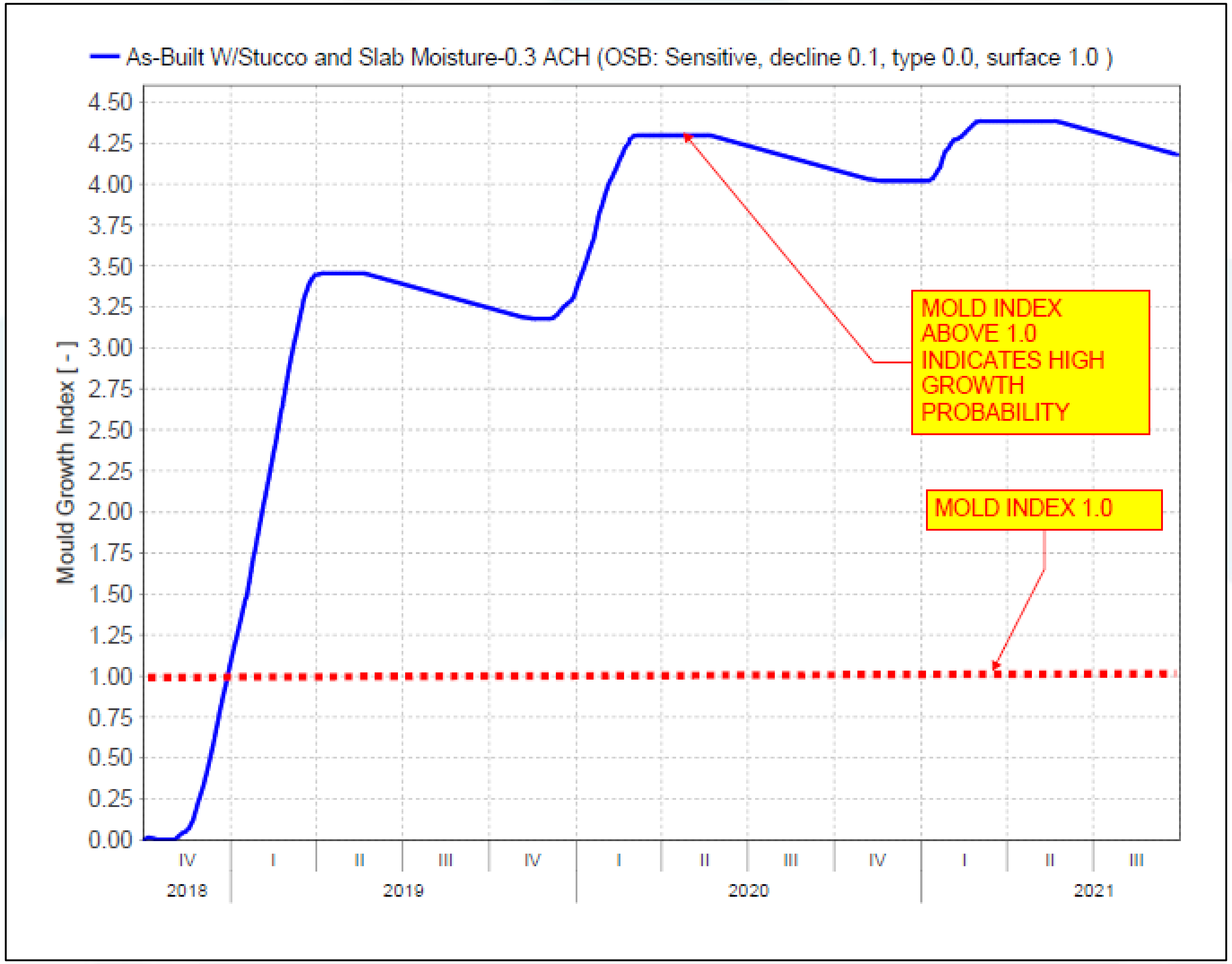
Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾” stucco (bright paint) • 60 min. building paper (2 layers) • ½” OSB • 3.5” fiberglass batt insulation (1.2 pcf) • 5/8” interior gypsum board (painted)	San Ramon, CA	0. 83 lbs/hr (2-bedroom residence per WUFI)	• 20% of driving rain at stucco • 2% of driving rain at building paper • 0.15 lb/sf moisture at floor slab	0.3 ACH

Mold Index	Sheathing Moisture Content
4.4	31%

WUFI Model 3 – Mould (Mold) Index



WUFI Model 3 – Sheathing Moisture Content (WME)



WUFI-3 Results – Matched Actual Site Conditions

- These results represent the final output from numerous incremental adjustments in exterior source moisture.
  - 20% of driving rain at stucco
  - 2% of driving rain at building paper
  - 0.15 lb/sf moisture emission at floor slab
  - ACH = 0.3
- The OSB moisture content for this model peaked at 32% during winter seasons.
- The mold index for this model peaked at over 4.2, indicating a high probability for mold growth.
- These results matched field conditions verified by the data loggers over time.

WUFI Model 4 – Ventilation Solutions

- Once we were confident that our WUFI model was replicating the real-life existing conditions, we began modeling corrective solutions.
- This model added exhaust and new fresh air intake components to mitigate excess humidity.
- The results of WUFI Run 3 is the final output from numerous incremental adjustments in the air changes per hour.

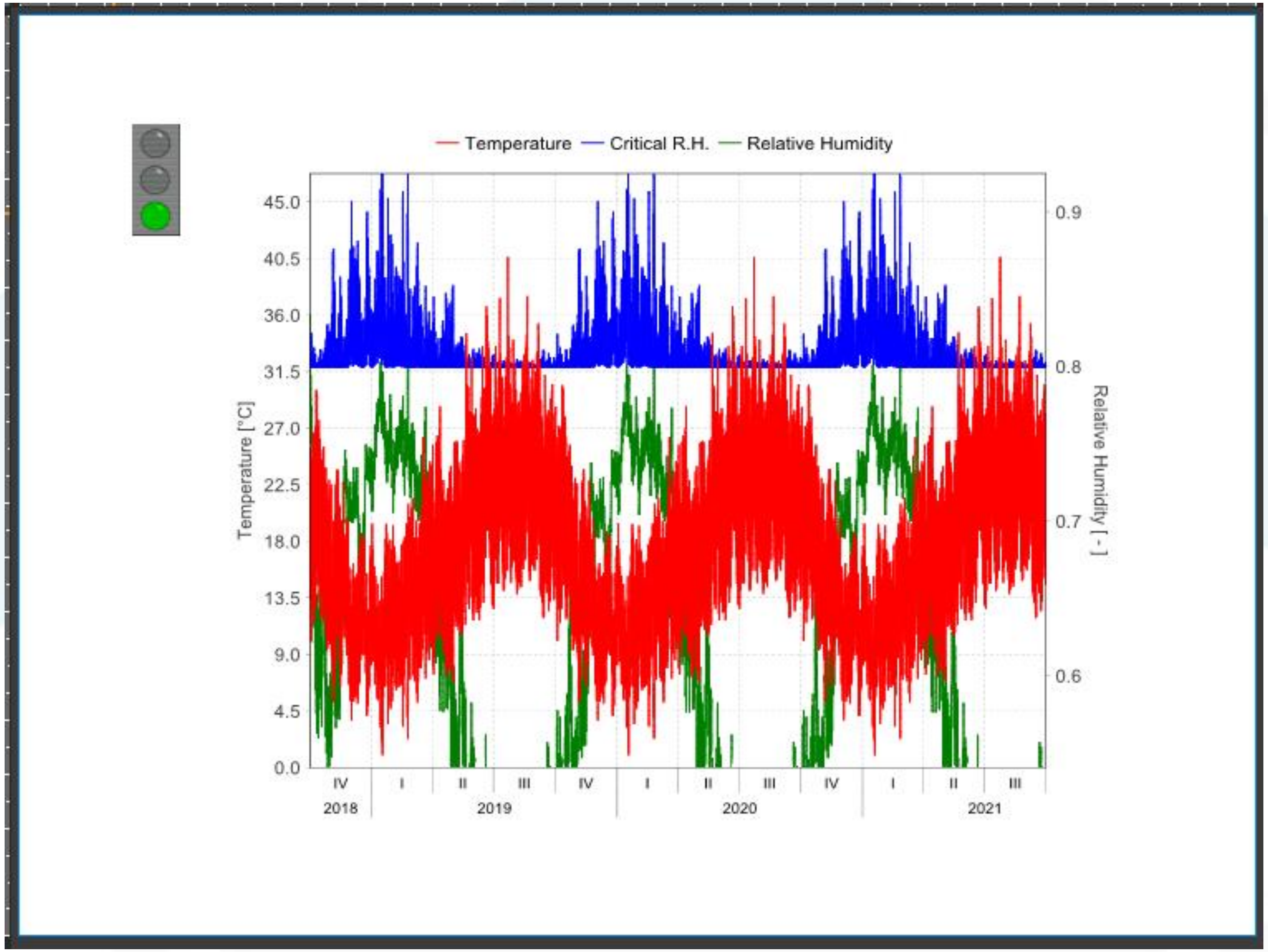
WUFI Model 4 – Ventilation Solutions

- This model uses the following parameters and generated the following outcomes:

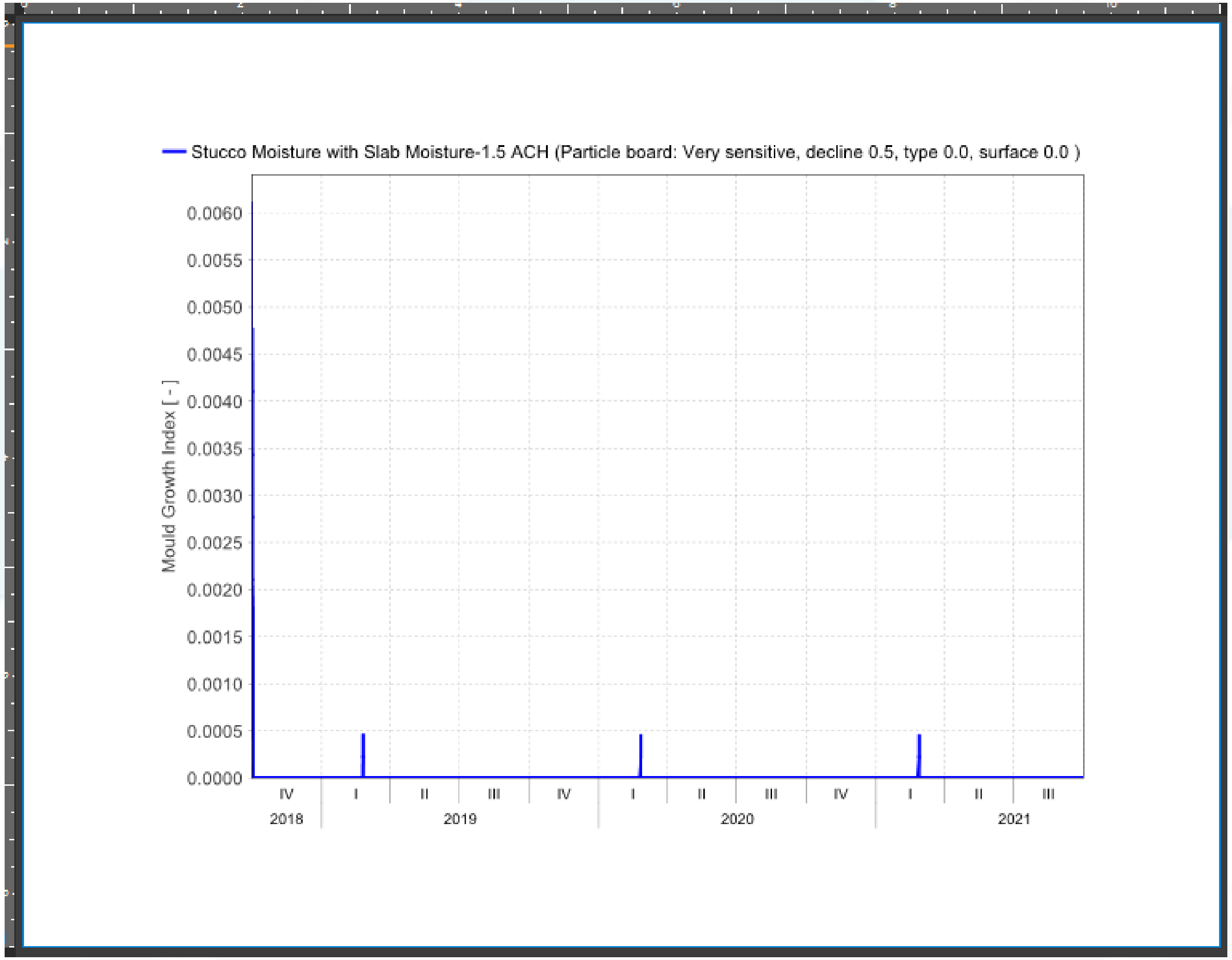
Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾" stucco (bright paint) • 60 min. building paper (2 layers) • ½" OSB • 3.5" fiberglass batt insulation (1.2 pcf) • 5/8" interior gypsum board (painted)	San Ramon, CA	0. 83 lbs/hr (2-bedroom residence per WUFI)	• 20% of driving rain at stucco • 2% of driving rain at building paper • 0.15 lb/sf moisture at floor slab	1.5 ACH

Mold Index	Sheathing Moisture Content
.0005	14%

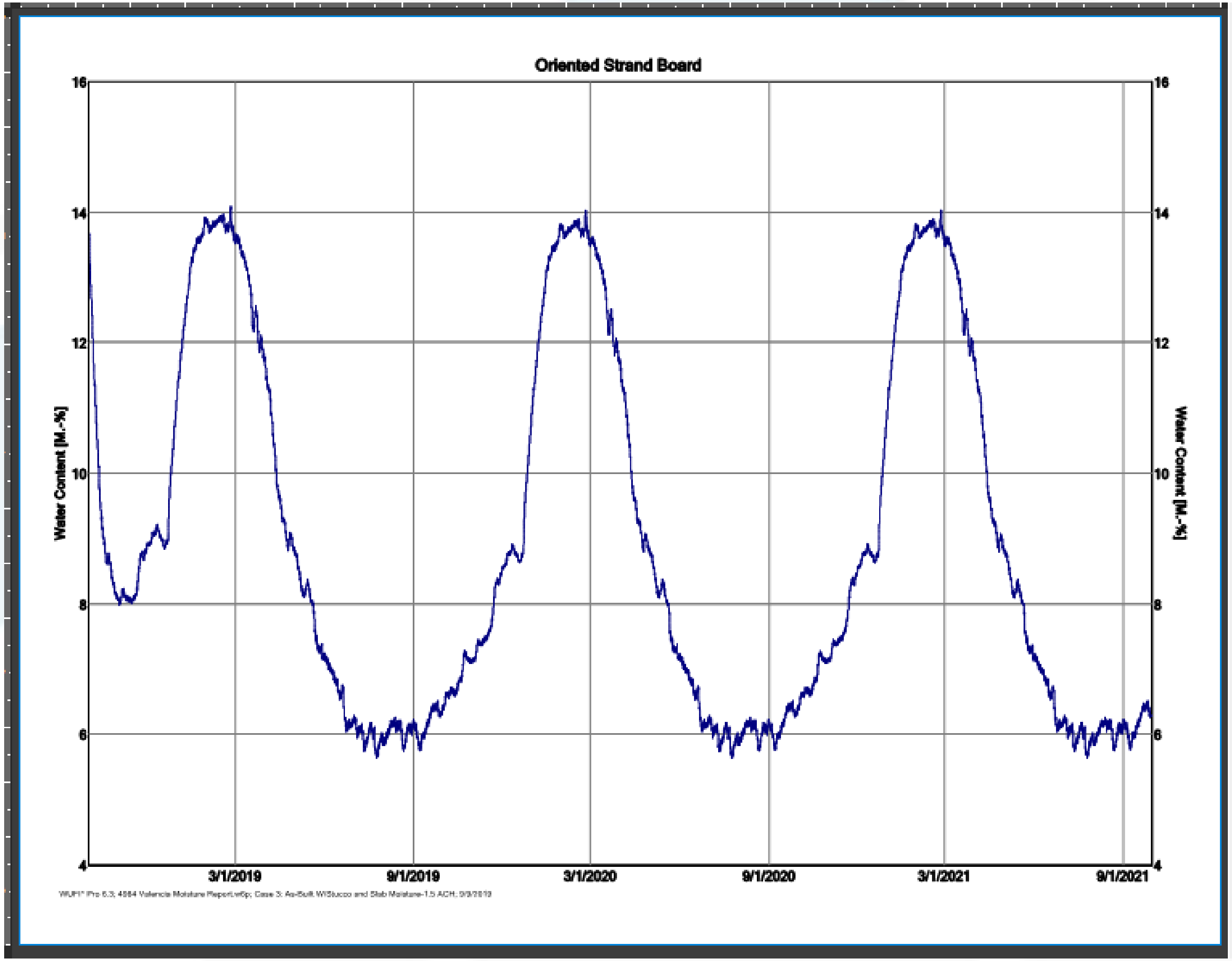
WUFI Model 4 – Mould (Mold) Index



WUFI Model 4 – Mould (Mold) Index



WUFI Model 4 – Sheathing Moisture Content



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WUFI Results – Ventilation Solutions

- This model indicates that with the higher ventilation 1.5 ACH, there is no probability for mold growth.
- The mold index for this model is 0.0005, well below the index 1.0 threshold.
- The OSB moisture content for this model peaked at a safe 14% during winter seasons.
- By maintaining residential unit ventilation at a min. of 1.5 ACH, there would be a significant reduction in moisture accumulation and related damage.

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WUFI Model 5 – Rain Screen Solution

- We modeled a rainscreen approach of controlling the moisture load into the unit, plus minor ventilation improvements.
- We added a rain screen to prevent the stucco cladding from becoming a moisture source.
- The rain-screen WUFI modeling is based on Modeling Enclosure Design - 2016 by Building Science Corp.
- For modeling, we also upgraded from OSB to exterior grade plywood.

WUFI Model 5 – Rain Screen Repair Solution

- This model uses the following parameters and generated the following outcomes:

Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾" stucco (bright paint) • 3/8" drain mat • 40 mil weather resistive barrier • ½" plywood exterior grade • 3.5" fiberglass batt • 5/8" interior gypsum board (painted)	San Ramon, CA	0. 83 lbs/hr (2-bedroom residence per WUFI)	• 20% of driving rain at stucco • 0.15 lb/sf moisture at floor slab	0.5 ACH

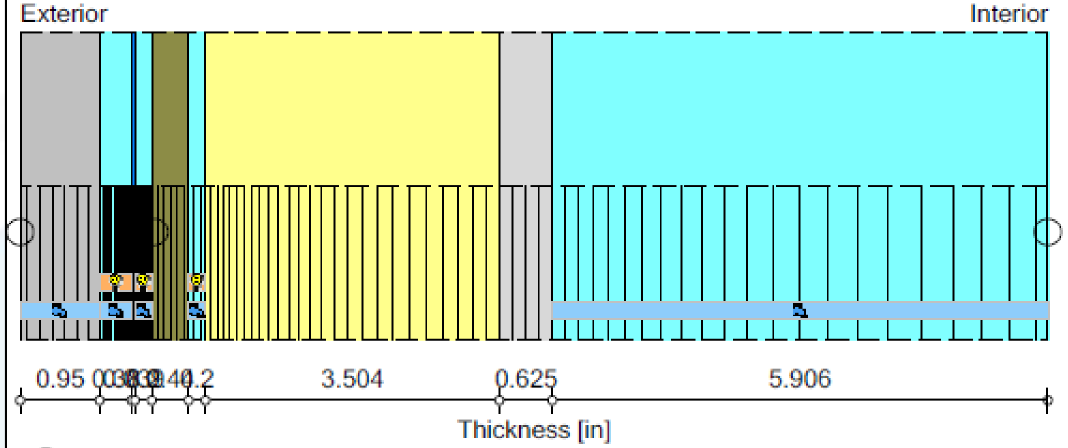
Mold Index	Sheathing Moisture Content
0.35	15%

WUFI Model 5 – Rain Screen Repair Solution

WUFI Pro 6.3

Component Assembly

Case: Rain Screen W/Stucco and Slab Moisture-0.5 ACH



- Monitor positions

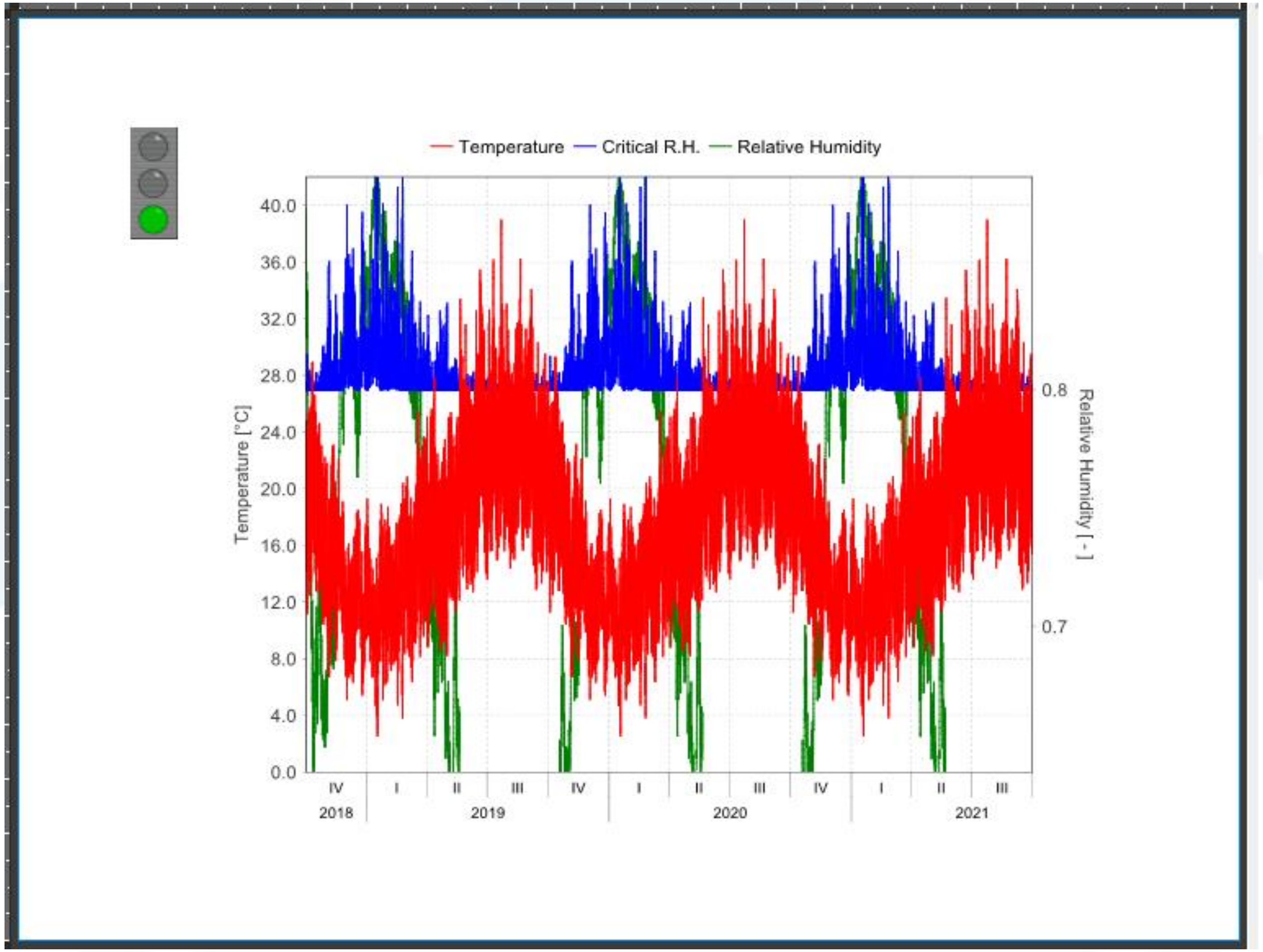
- Heat/Moisture source/sink positions

Materials:

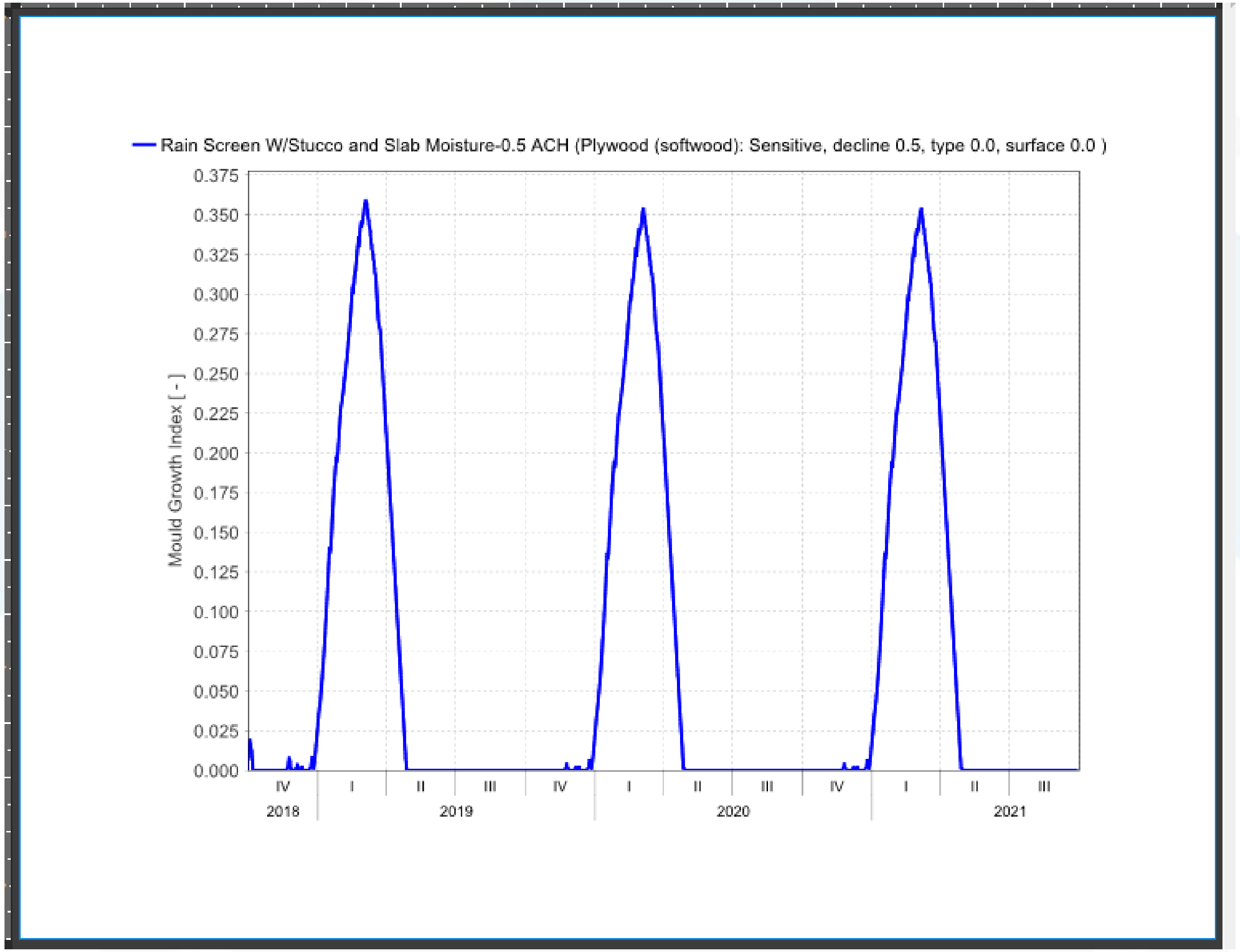
- Portland Cement-Lime Mortar - Type S	0.95 in
- Air Layer 10 mm; without additional moisture capacity	0.38 in
- *WRB - WrapShield SA (Vaproshield Data)	0.039 in
- Air Layer 10 mm; without additional moisture capacity	0.2 in
- Plywood, Exterior-Grade	0.44 in
- Air Layer 10 mm; without additional moisture capacity	0.2 in
- *Low Density Glass Fiber Batt Insulation - unlocked	3.504 in
- Interior Gypsum Board	0.625 in
- Air Layer 150 mm	5.906 in

Total Thickness: 12.244 in
R-Value: 12.85 h ft² °F/Btu
U-Value: 0.072 Btu/h ft²°F

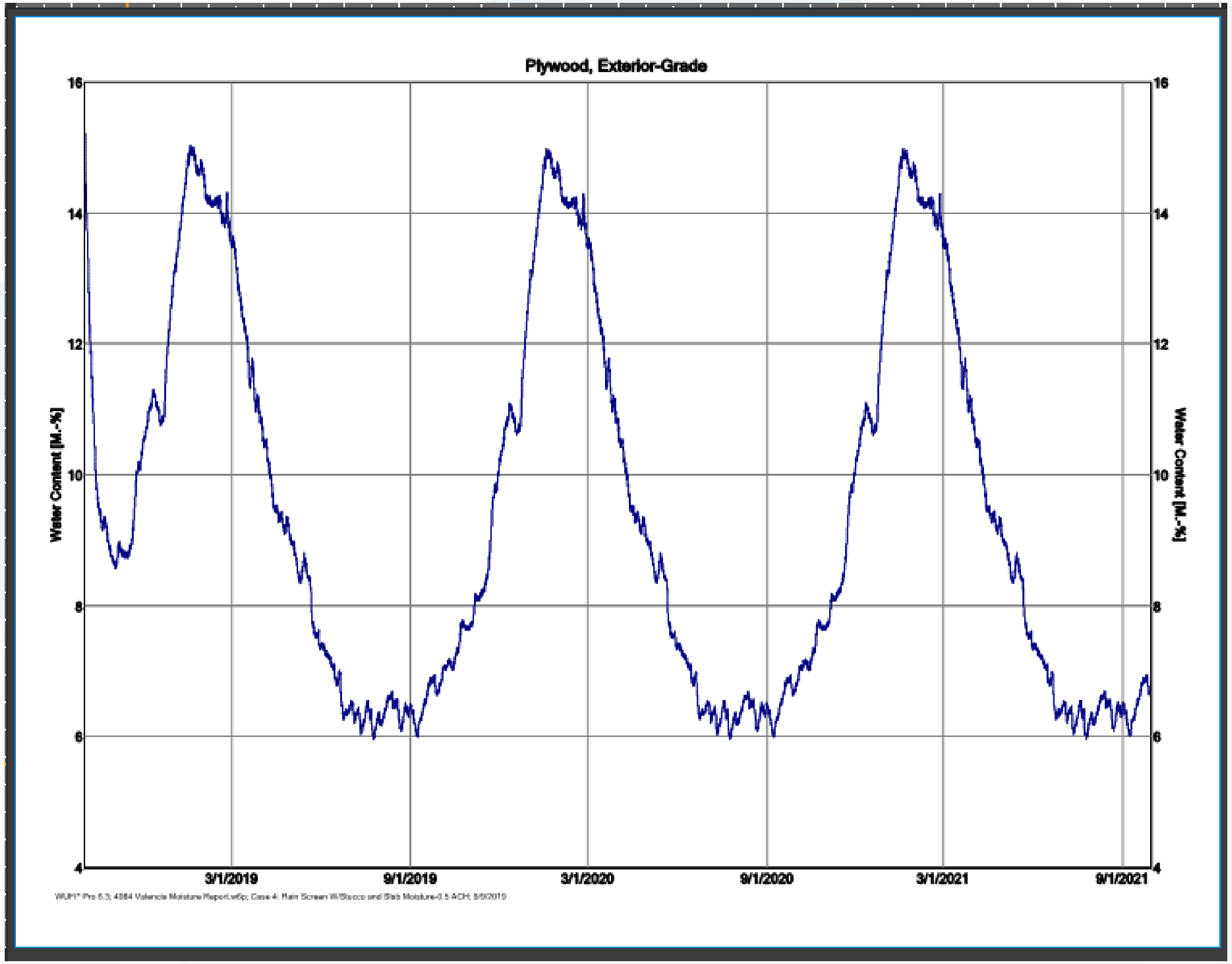
WUFI Model 5 – Mould (Mold) Index



WUFI Model 5 – Mould (Mold) Index



WUFI Model 5 – Sheathing Moisture Content



WUFI Results – Rain Screen Solution

- The mold index was 0.35, well below the 1.0 index threshold.
- The moisture content of the OSB sheathing moisture content maxed at 15% during the winter season.
- By adding a rain screen system, the ventilation requirements to manage moisture were dramatically reduced to 0.5 ACH, making this configuration more energy efficient. Changing bathroom exhaust to a more powerful model can do the trick
- Reservoir claddings must be installed in a rainscreen configuration over vapor permeable WRBs.

Case Study #2

60-Unit Multi-Family Complex
in Redwood City, CA

60-Unit Multi-Family Complex

Project Background

- 60-Unit Multi-Family Complex
- Located in Redwood City, CA
- Originally Built in 2006
- Consists of 2 3-Story Buildings
- Exterior Construction:
  - Wood Sheathing over Wood
  - Exterior Gypsum Board
  - Stucco or Panel Siding

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Water Intrusion Investigation

To Determine the Source(s) of Damaging Water Intrusion

Visual Interior and Exterior Survey

- We were retained in 2015 to investigation repeated water intrusion.
- Leaks were reported at 12 residential units and clubhouse locations.
- We performed a visual survey to review the windows, walls, and private balcony decks.
- Very minimal interior damage found .
- Damage was limited to damaged carpet tack strips under a few windows.
- Next step – invasive testing.

Typical Building Elevation

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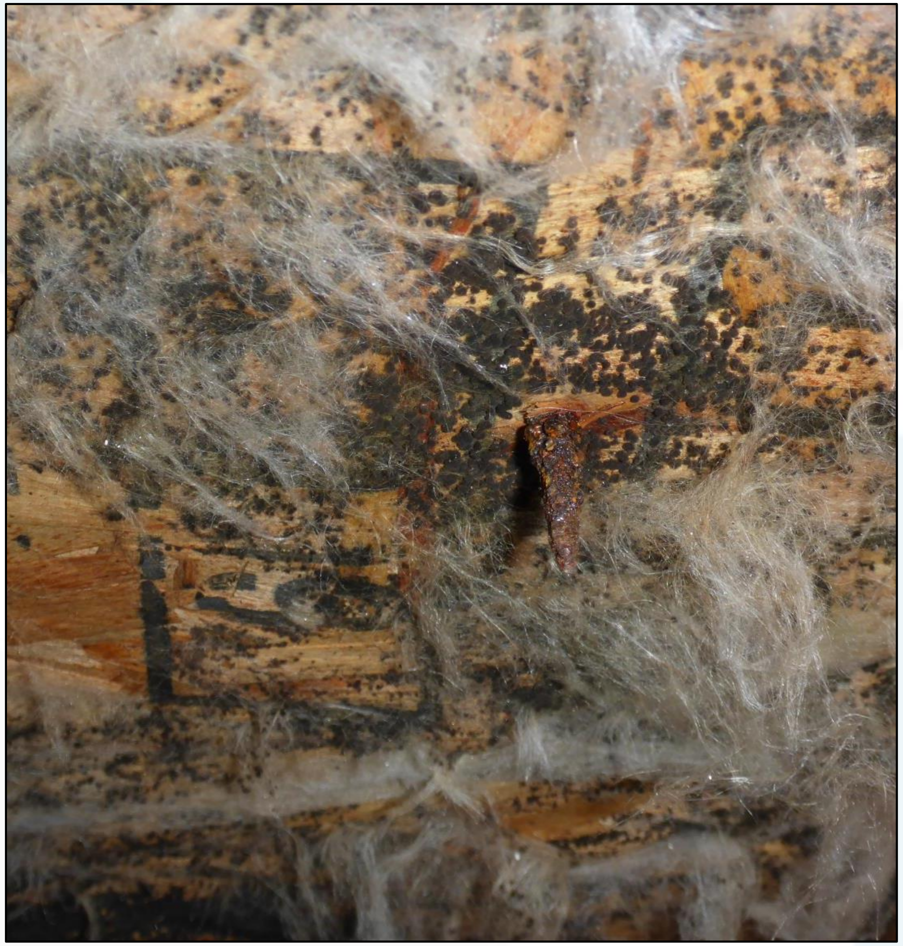
Typical Unit Interior

Invasive Testing – Windows and Stucco

- We removed the interior gypsum board and batt insulation.
- In one unit stack in particular, we observed dark staining and biological growth on the backside of the sheathing and insulation.
- We did not observe significant damage when the sheathing was removed.
- We DID observe severe damage once we removed the batt insulation.

Bio Growth on Backside of Wood Sheathing



ASTM E-1105 Water Testing – No Active Leaks

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Invasive Testing – Windows & Exterior Stucco

Destructive Testing – Exterior Walls

- We proceeded to remove layers of the wall assembly.
- We removed siding panels to exposed WRB over exterior gypsum board.
- Removal of the WRB exposed exterior gypsum board sheathing with fiberglass facer (low signs of damage).
- However the fasteners were rusted.
- While the sheathing survived years of wetting and drying cycles, the fasteners did not.

Rusted Fasteners from Soaked Gypsum Board

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Exterior Wood Sheathing & Framing Damage

Exterior Gypsum sheathing absorbs water and holds it up against OSB like a wet towel!

Wet Towel Effect – Intensified With Gypsum Sheathing

Moisture absorbed through gypsum sheathing in to WRB, soaking the OSB

Using Data Loggers

To Track Temperature, Humidity and Actual Moisture Levels in Exterior Sheathing

Where Did the Moisture Come From?

- We installed data loggers in several units to measure humidity, temperature, dew point and moisture in the wood sheathing.
- Data loggers information would verified if humidity and moisture levels changed fluctuated.

Data Logger Results

Unit	Interior AH	%WME (Average, BDR Closed)	%WME (Average, LVR Closed)	%WME (Average, Hall Open)	Int. Temp	Significant Climate Event	Exterior AH (High)	Exterior AH (Low)
205	40	9.9	9.6	10.4	72	None	40	31
209	40	10.5	10.8	10.35	72			
212	40	10.6	10.3	10.15	72			
203	40	9.35	11.1	11.45	72			
208	40	11.75	11.6	11.65	72			
209	40	11.5	11.6	11.6	72			
205	65	14.1	15.05	9.7	71	After Rain	32	20
209	81	26.7	20.1	10.85	73			
212	54	8.65	9.4	7.85	85			
203	38	9.5	8	9.4	65			
208	58	8.8	8.8	8.55	74			
209	40	15.25	14.25	9.55	62			
205	56	14	13.4	10	69	Before Rain	58	45
209	60	23.6	17	10.7	67			
212	57	8.5	7.9	7.9	74			
203	48	9.7	7.8	9.1	68			
208	57	8.8	8.1	9.6	69			
209	45	14.1	11.6	9.6	64			
205	82	14.2	13.6	10.1	72	Rain Event	72	50
209	55	23.5	17	10.7	64			
212	62	8.4	7.9	8	75			
203	42	9.4	7.8	9.2	65			
208	60	8.8	7.9	9.8	62			
209	49	14	11.8	9.5	68			
205	76	14.4	14	10.3	72	After Rain	64	53
209	61	23.5	17.1	11.1	65			
212	67	8.8	7.8	8.1	77			
203	46	9.6	7.9	9.2	66			
208	71	9.2	8.2	9.9	76			
209	75	14.2	12	9.7	71			

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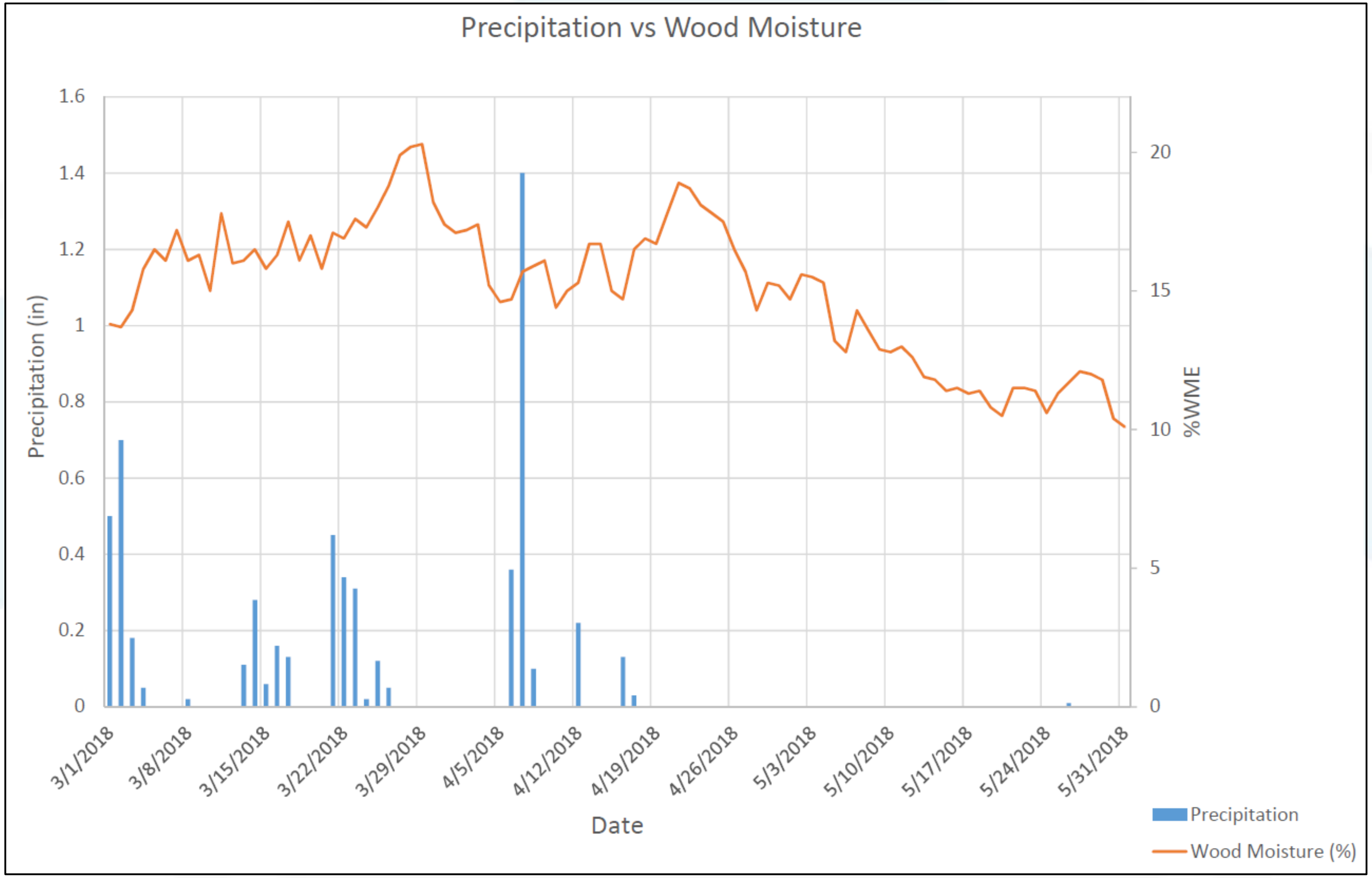
Data Logger Study



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Data Logger Results

- Data loggers did verify that humidity and moisture increased during heavy rains.
- There was higher moisture levels in units that were shaded for more of the day.
- The cumulative nature of multiple rain events during the winter increased interior unit humidity.
- This enabled mold and mildew growth.
- This project was not designed with central fresh air. Just 2 exhaust fans in bathroom and laundry room.
- We used WUFI modeling to establish expected performance.

WUFI Modeling – As-Designed Conditions

- This model uses the following parameters:
  - Bathroom exhaust fan 80 CFM at 4 hours per day
  - Laundry room Exhaust fan at 90 CFM 1 Hr per day (Avg)
  - Kitchen hood exhaust at 120 CFM 2 hours per day
  - No make-up air!

- Assume 80% efficiency due to no make-up air.

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WUFI Model 1- As-Designed Conditions

- This model uses the following parameters and generated the following results:

Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾” stucco (bright paint) • 60 min. building paper (2 layers) • ½” OSB • 3.5” fiberglass batt insulation (1.2 pcf) • 5/8” interior gypsum board (painted)	Redwood City, CA	0. 92 lbs/hr (3-bedroom residence per WUFI)	None	0.4 ACH

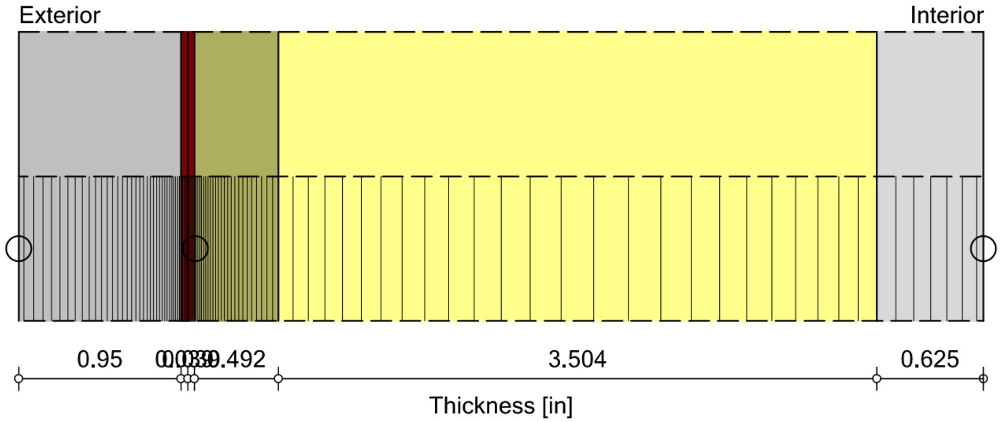
Mold Index	Sheathing Moisture Content
1.7	18%

WUFI Model 1 – As Designed Conditions

WUFI Pro 6.3

Component Assembly

Case: As Designed- Room 209 (no external moisture)-0.4 ACH



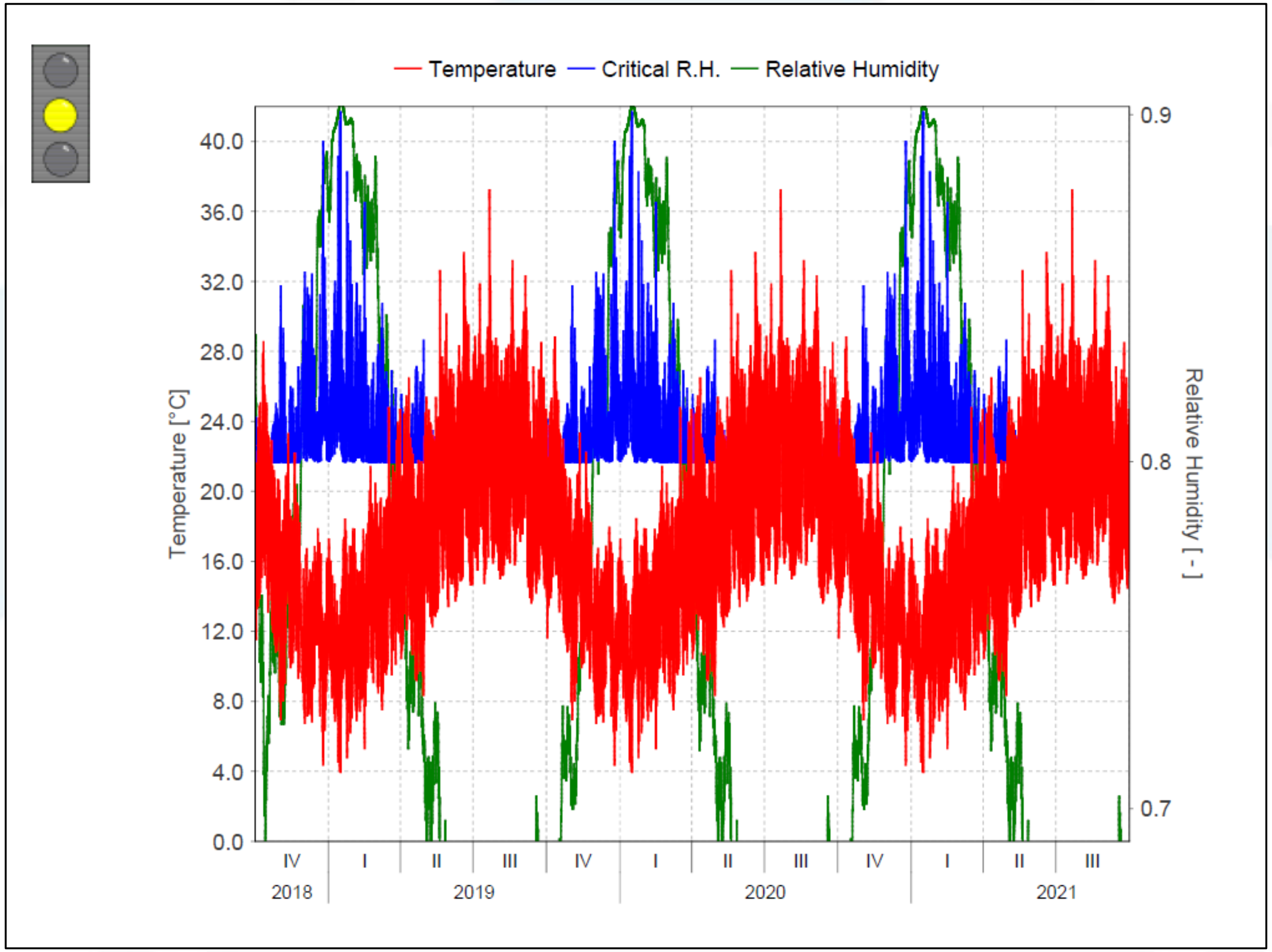
- Monitor positions

Materials:

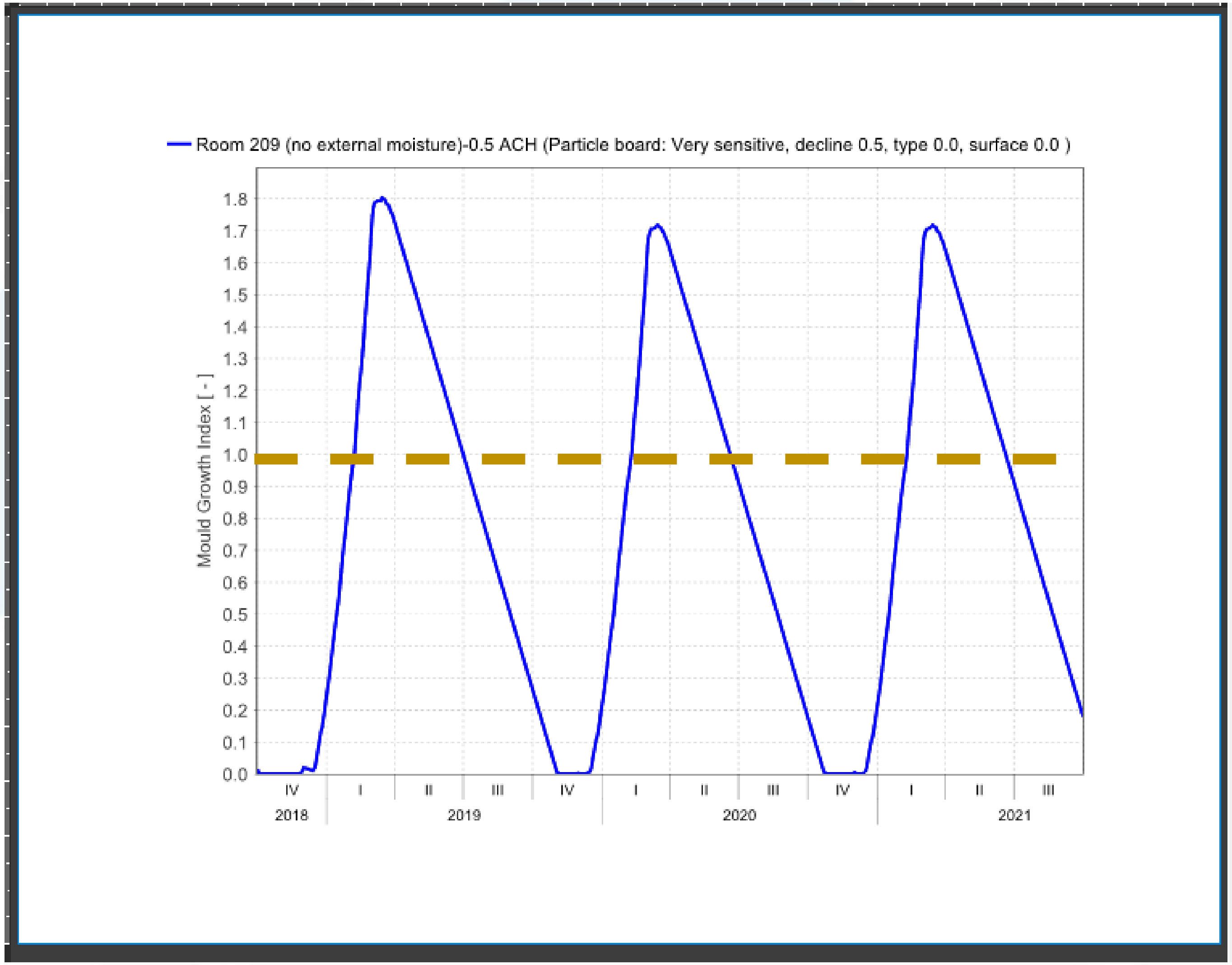
- Portland Cement-Lime Mortar - Type S	0.95 in
- Asphalt Impregnated Paper (60 min Paper)	0.039 in
- Asphalt Impregnated Paper (60 min Paper)	0.039 in
- Oriented Strand Board	0.492 in
- *Low Density Glass Fiber Batt Insulation - unlocked	3.504 in
- Interior Gypsum Board	0.625 in

Total Thickness: 5.65 in
R-Value: 10.59 h ft² °F/Btu
U-Value: 0.086 Btu/h ft²°F

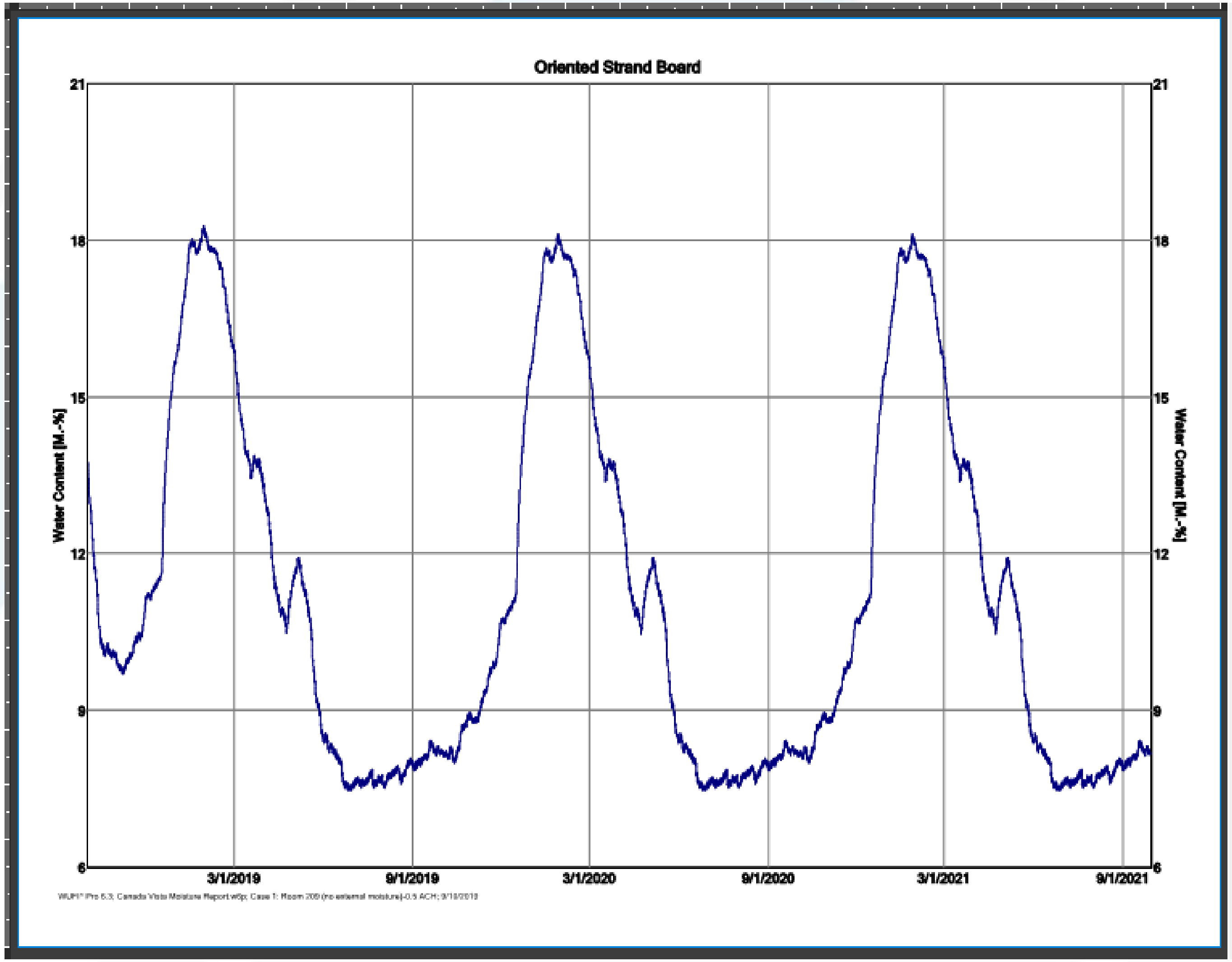
WUFI Model 1 – Mould (Mold) Index



WUFI Model 1 – Mould (Mold) Index



WUFI Model 1 – Sheathing Moisture Content



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WUFI Results – As Designed Conditions

- WUFI results were OSB at 18% WME – and mold index was higher than 1 indicating mold.
- Results (again) did not match field measurements of moisture and observed mold growth.
- Leakage rates for the wall must have been higher than design intent

More WUFI Modeling

Replicating Actual Field Conditions and Establishing Corrective Solutions

WUFI Model 2 – Matching Actual Site Conditions

- We used the parameters from the as-design run with modifications.
- We adjusted the porosity of the stucco and added leakage rate until the WUFI model mirrored the site conditions.
- Once actual conditions were established we were able to model corrective solutions.

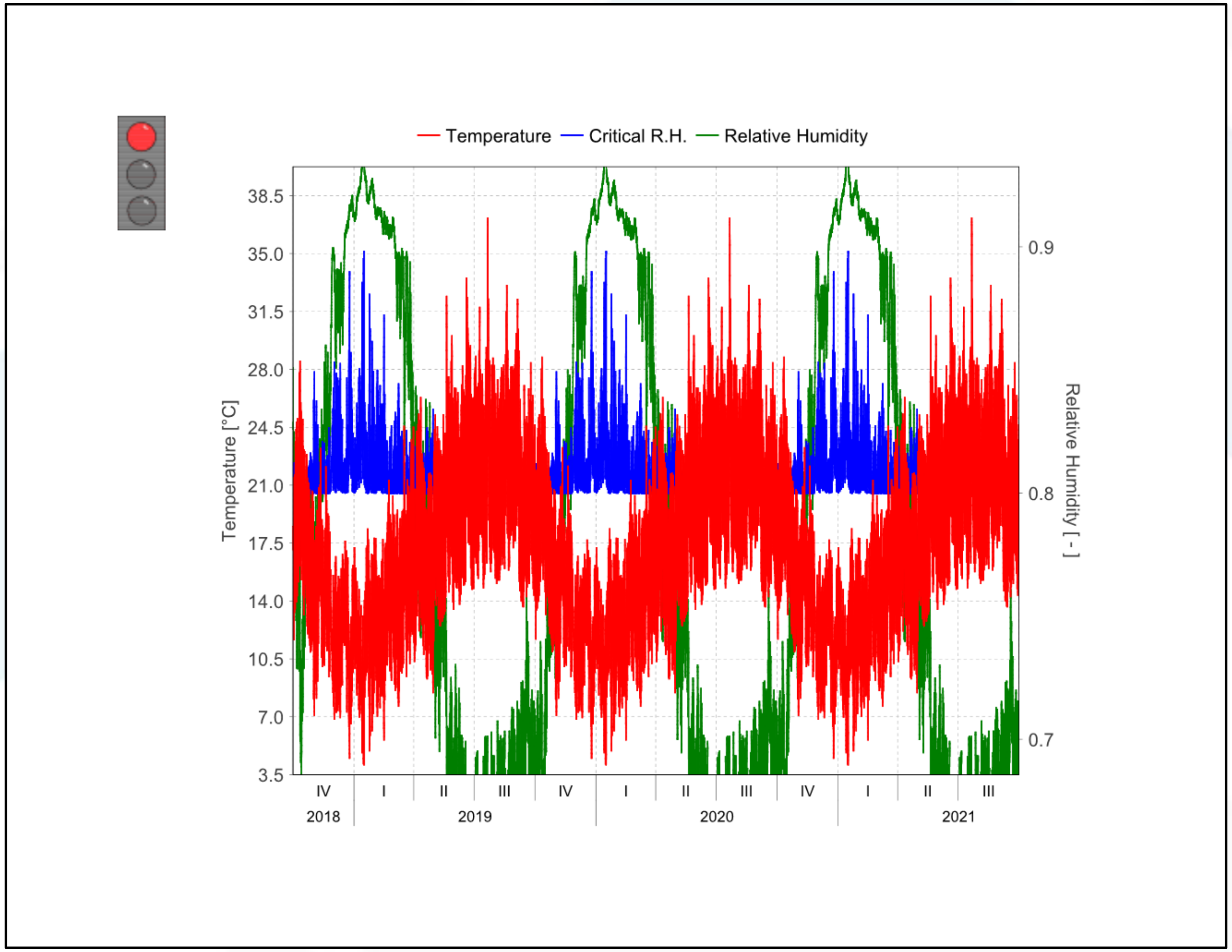
WUFI Model 2 – Actual Site Conditions

- This model added exterior source of moisture on the WRB:

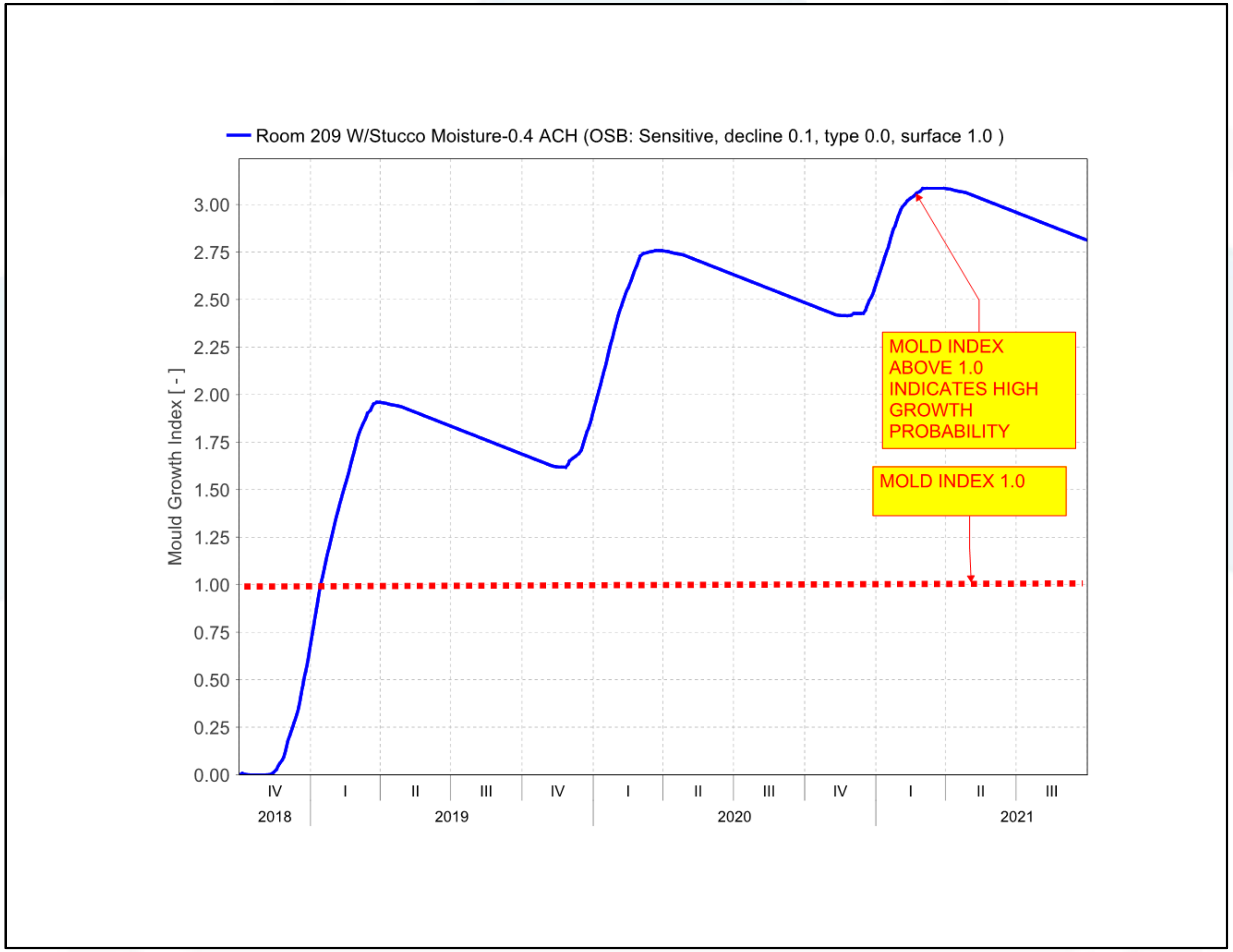
Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾” stucco (bright paint) • 60 min. building paper (2 layers) • ½” OSB • 3.5” fiberglass batt insulation (1.2 pcf) • 5/8” interior gypsum board (painted)	Redwood City, CA	0. 92 lbs/hr (3-bedroom residence per WUFI)	• 20% of driving rain at stucco • 2% of driving rain at building paper	0.4 ACH

Mold Index	Sheathing Moisture Content
3.25	22%

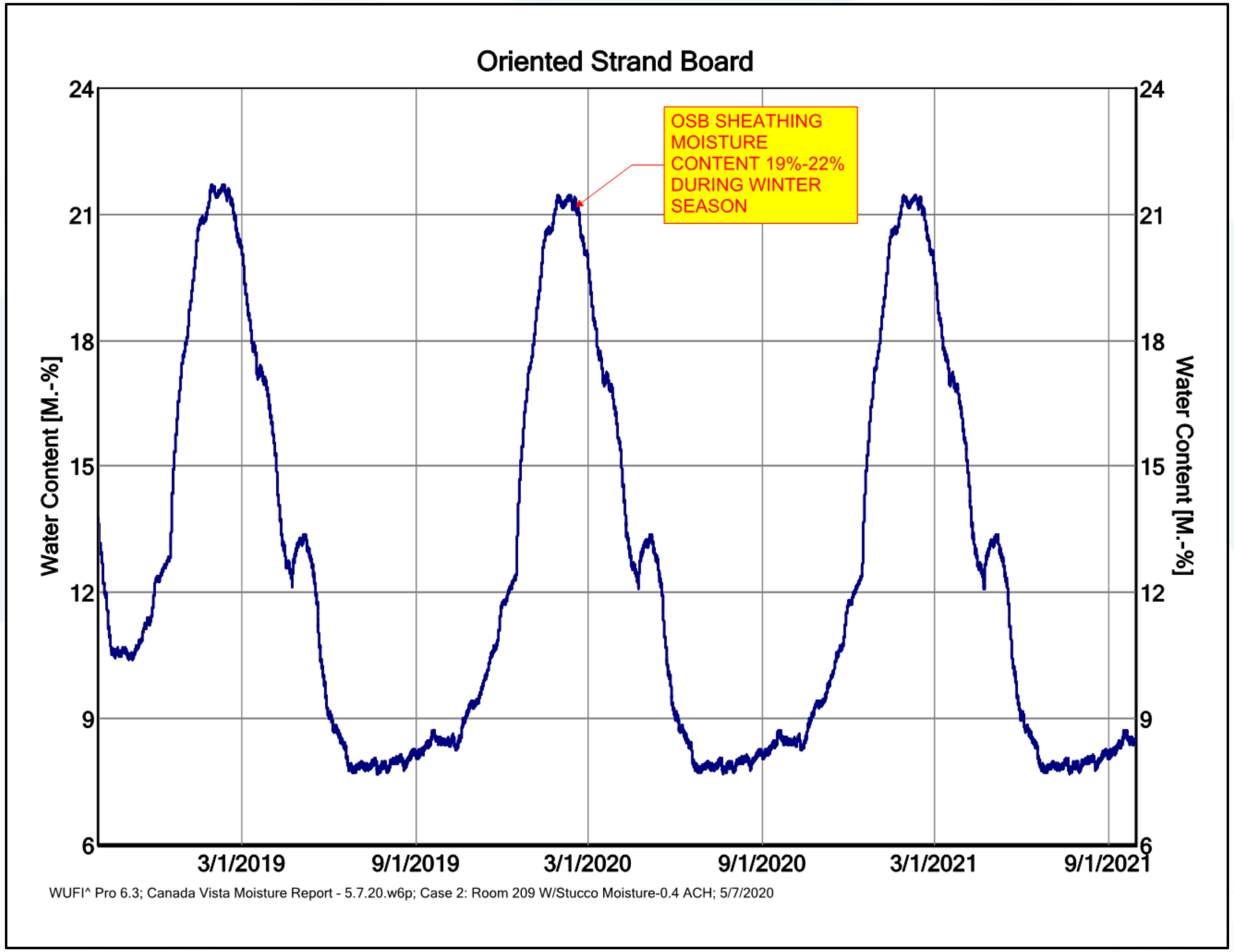
WUFI Model 2 – Mould (Mold) Index



WUFI Model 2 – Mould (Mold) Index



WUFI Model 2 – Sheathing Moisture Content



WUFI Model 2 Matching Actual Site Conditions

- The results represent the final output from numerous incremental adjustments in exterior source moisture.
- The OSB moisture content for this model peaked at 22% during winter seasons.
- The mold index for this model peaked at over 3.25, indicating a high probability for mold growth.
- These results matched field conditions verified by data loggers.

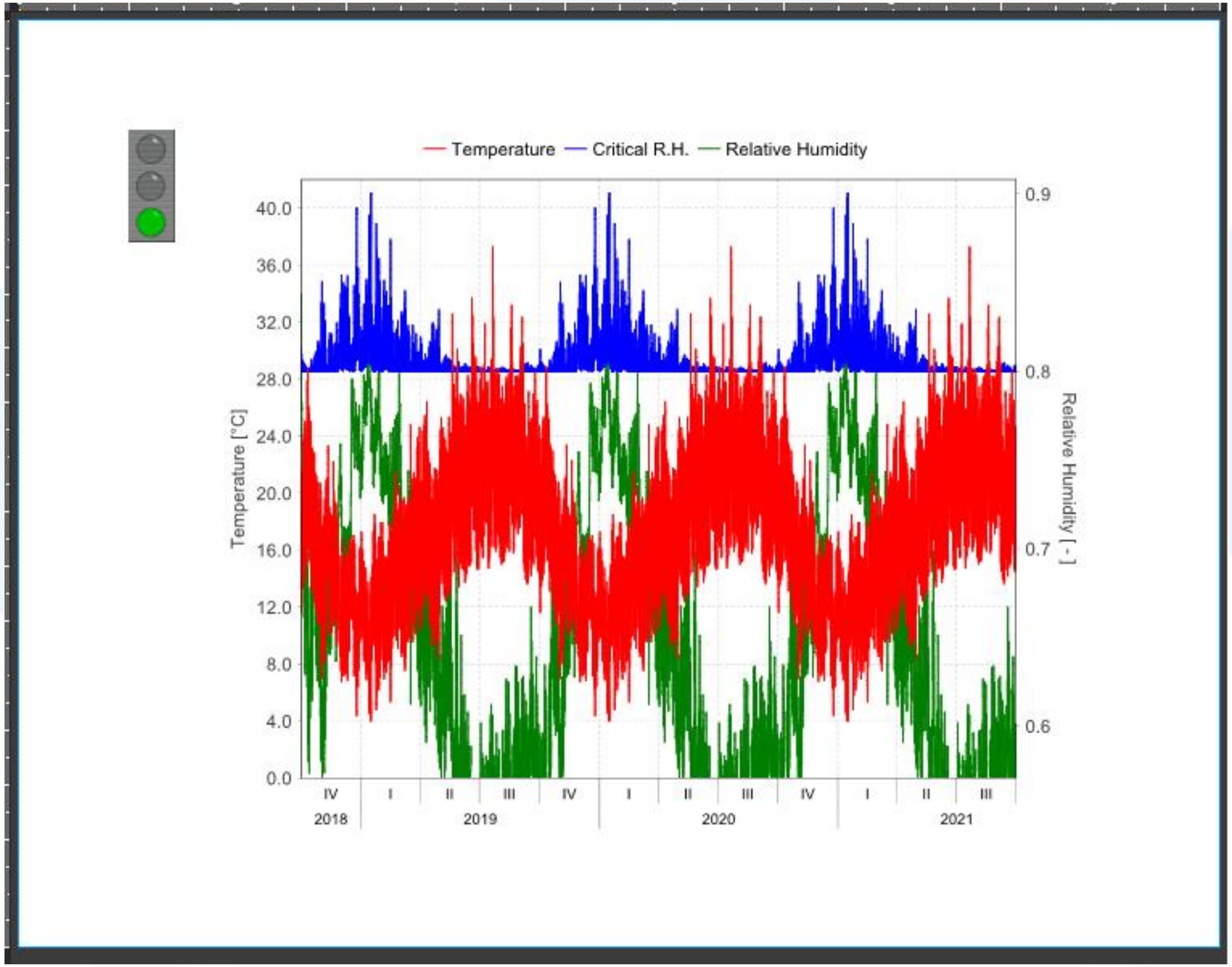
WUFI Model 3 – Ventilation Solutions

- This model uses the following parameters and generated the following results:

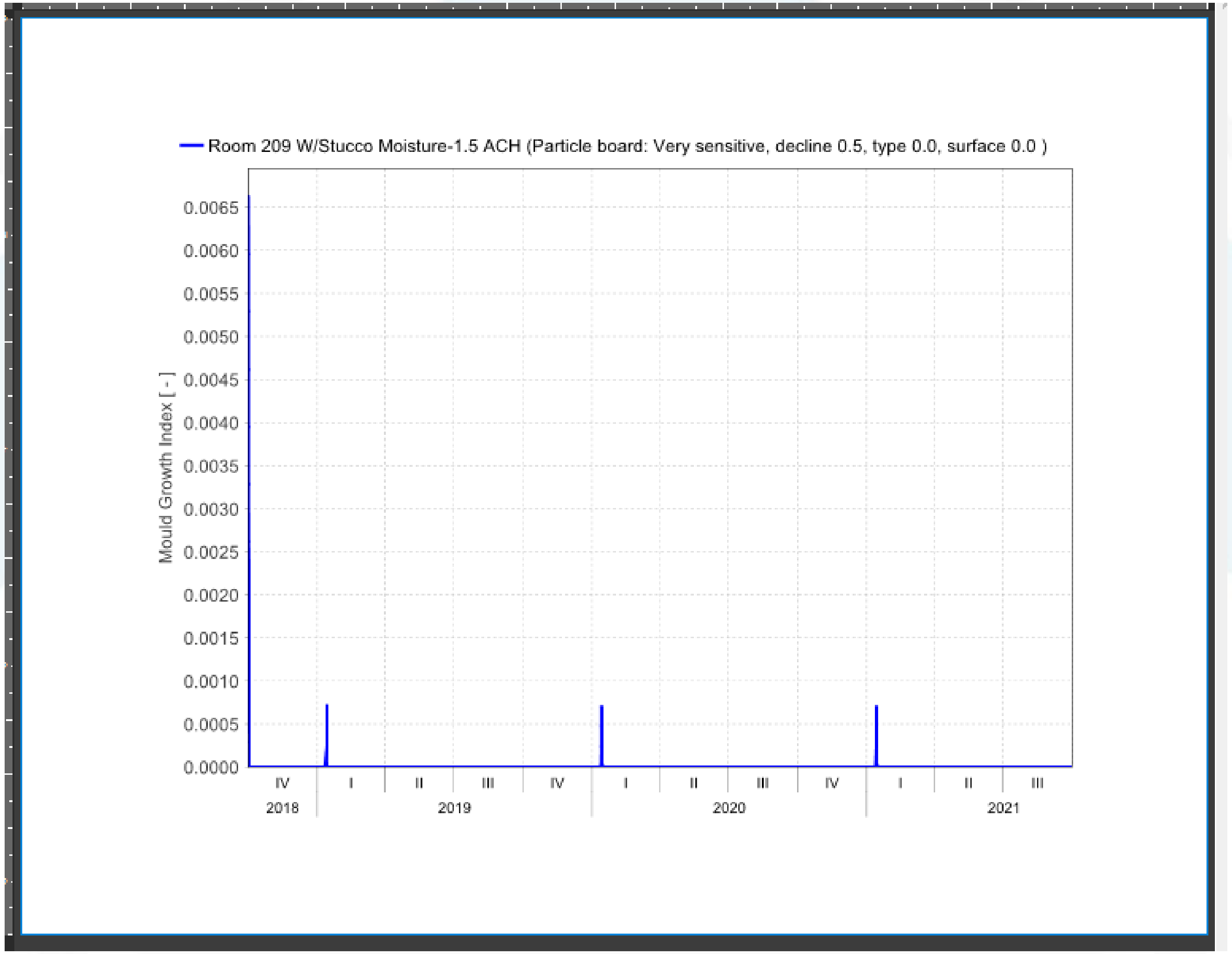
Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾” stucco (bright paint) • 60 min. building paper (2 layers) • ½” OSB • 3.5” fiberglass batt insulation (1.2 pcf) • 5/8” interior gypsum board (painted)	Redwood City, CA	0. 92 lbs/hr (3-bedroom residence per WUFI)	• 20% of driving rain at stucco • 2% of driving rain at building paper	1.5 ACH

Mold Index	Sheathing Moisture Content
0.0005	15%

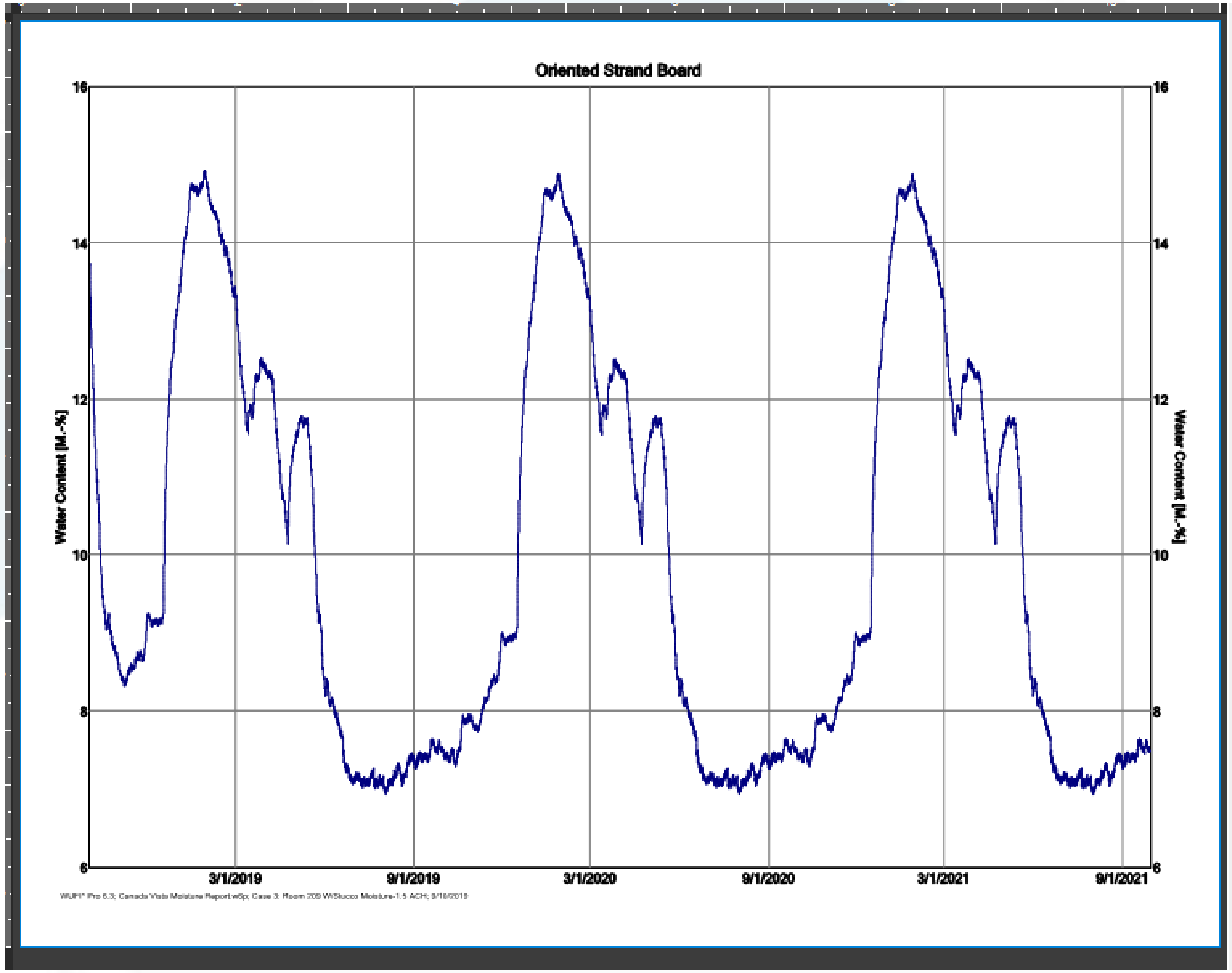
WUFI Model 3 – Mould (Mold) Index



WUFI Model 3 – Mould (Mold) Index



WUFI Model 3 – Sheathing Moisture Content



WUFI Model 3, Results – Ventilation Solutions

- The model indicated that with higher ventilation, there is no probability of mold growth.
- The mold index is 0.0005, well below the index 1.0 threshold.
- The OSB moisture content peaked at a safe 15% during winter seasons.
- By maintaining unit ventilation at a min. of 1.5 ACH, there would be a significant reduction in moisture accumulation and related damage.
- 1.5 ACH represents significant increase in energy consumption

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WUFI Model 4 – Rain Screen Solution

- Finally, we modeled a rain screen approach of controlling the moisture load into the unit.
- The stucco cladding was addressed in two corrective approaches.
  - 1 - By applying a WRB coating that reduces moisture absorption
  - 2 – Installing stucco in a rain-screen configuration.
- By adding a rain screen system, the ventilation requirements to manage moisture were dramatically reduced to 0.5 ACH, making this configuration more energy efficient.
- As with Case Study #1, we upgraded from OSB to exterior grade plywood for durability since we were already adding a rainscreen.

WUFI Model 4 – Rain Screen Solution

- This model uses the following parameters and generated the following results:

Construction	Climate Zone	Interior Source Moisture	Exterior Source Moisture	Mechanical Ventilation Rate
• ¾" stucco (bright paint) • 3/8" drain mat • 40 mil weather resistive barrier • ½" plywood exterior grade • 3.5" fiberglass batt insulation (1.2 pcf) • 5/8" interior gypsum board (painted)	Redwood City, CA	0. 92 lbs/hr (3-bedroom residence per WUFI)	• 20% of driving rain at stucco • 2% of driving rain at building paper	0.5 ACH

Mold Index	Sheathing Moisture Content
0.425	15.5%

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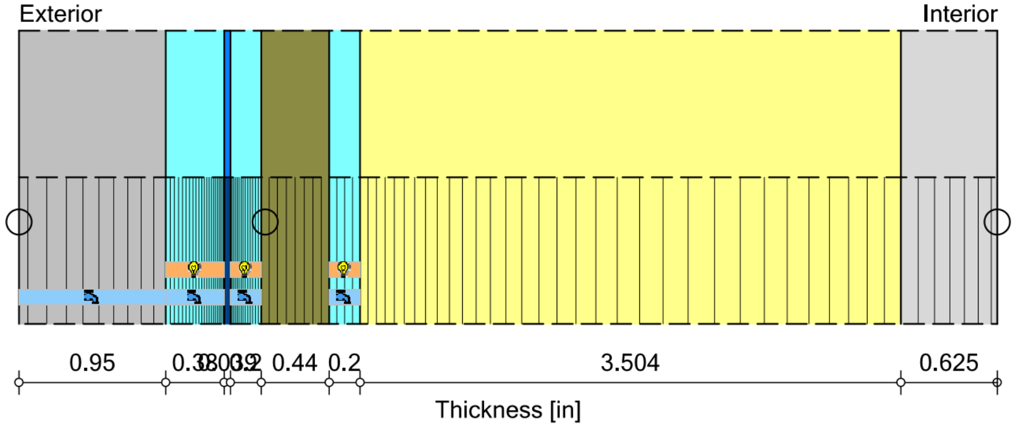
WUFI Model 4 – Rain Screen Solution

WUFI Pro 6.3

Component Assembly

Case: Rain Screen W/Stucco Moisture-0.5 ACH



- Monitor positions

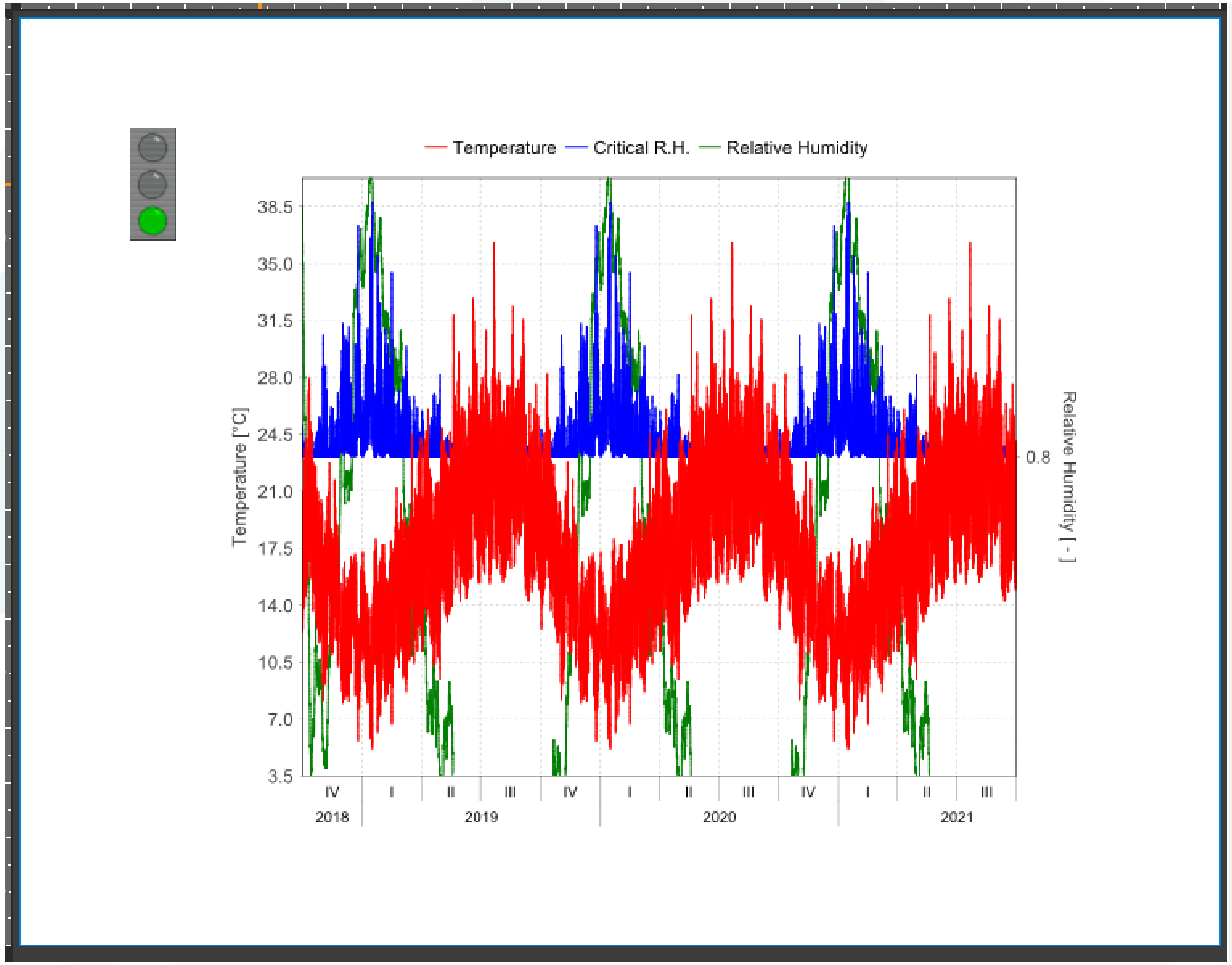
- Heat/Moisture source/sink positions

Materials:

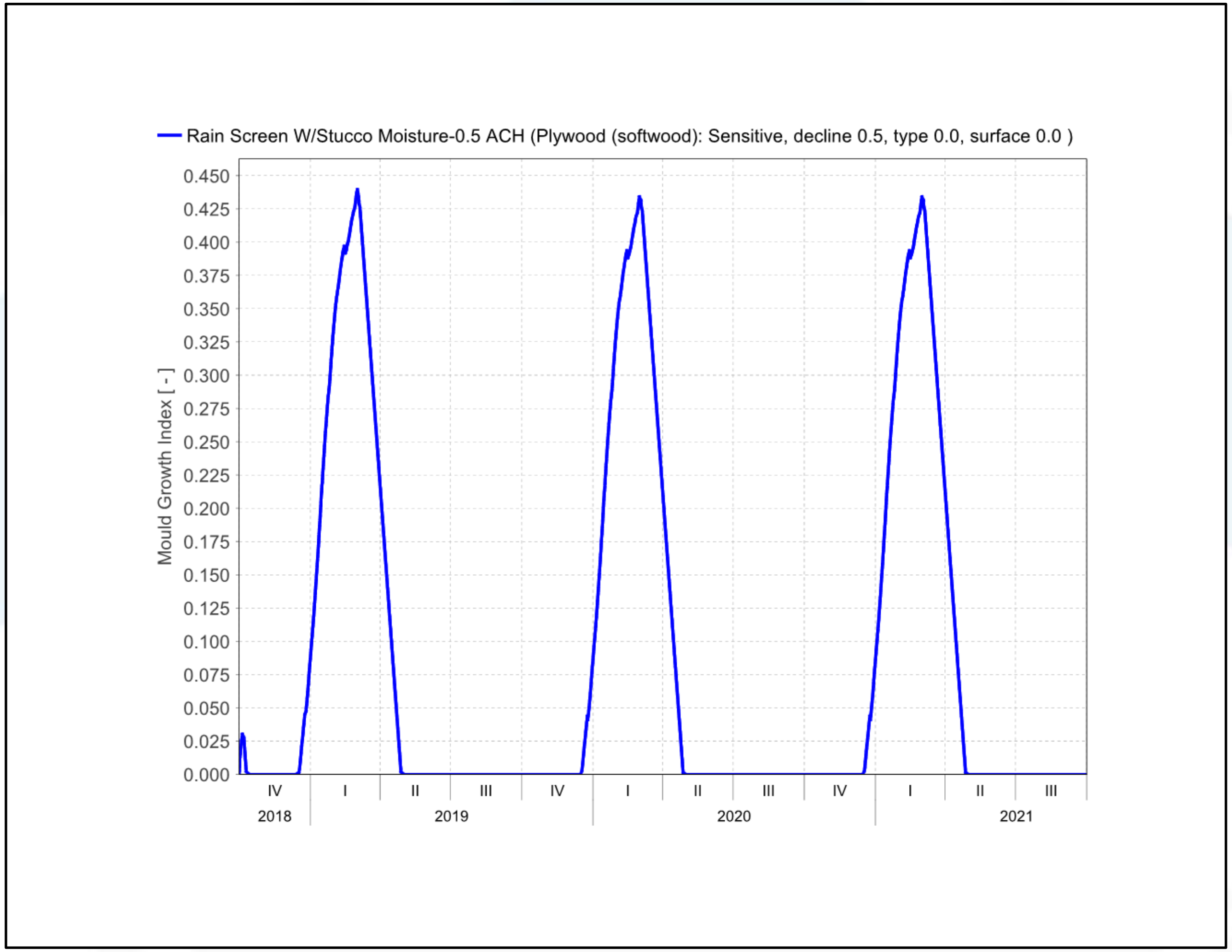
- Portland Cement-Lime Mortar - Type S	0.95 in
- Air Layer 10 mm; without additional moisture capacity	0.38 in
- *WRB - WrapShield SA (Vaproshield Data)	0.039 in
- Air Layer 10 mm; without additional moisture capacity	0.2 in
- Plywood, Exterior-Grade	0.44 in
- Air Layer 10 mm; without additional moisture capacity	0.2 in
- *Low Density Glass Fiber Batt Insulation - unlocked	3.504 in
- Interior Gypsum Board	0.625 in

Total Thickness: 6.338 in
R-Value: 11.95 h ft² °F/Btu
U-Value: 0.077 Btu/h ft²°F

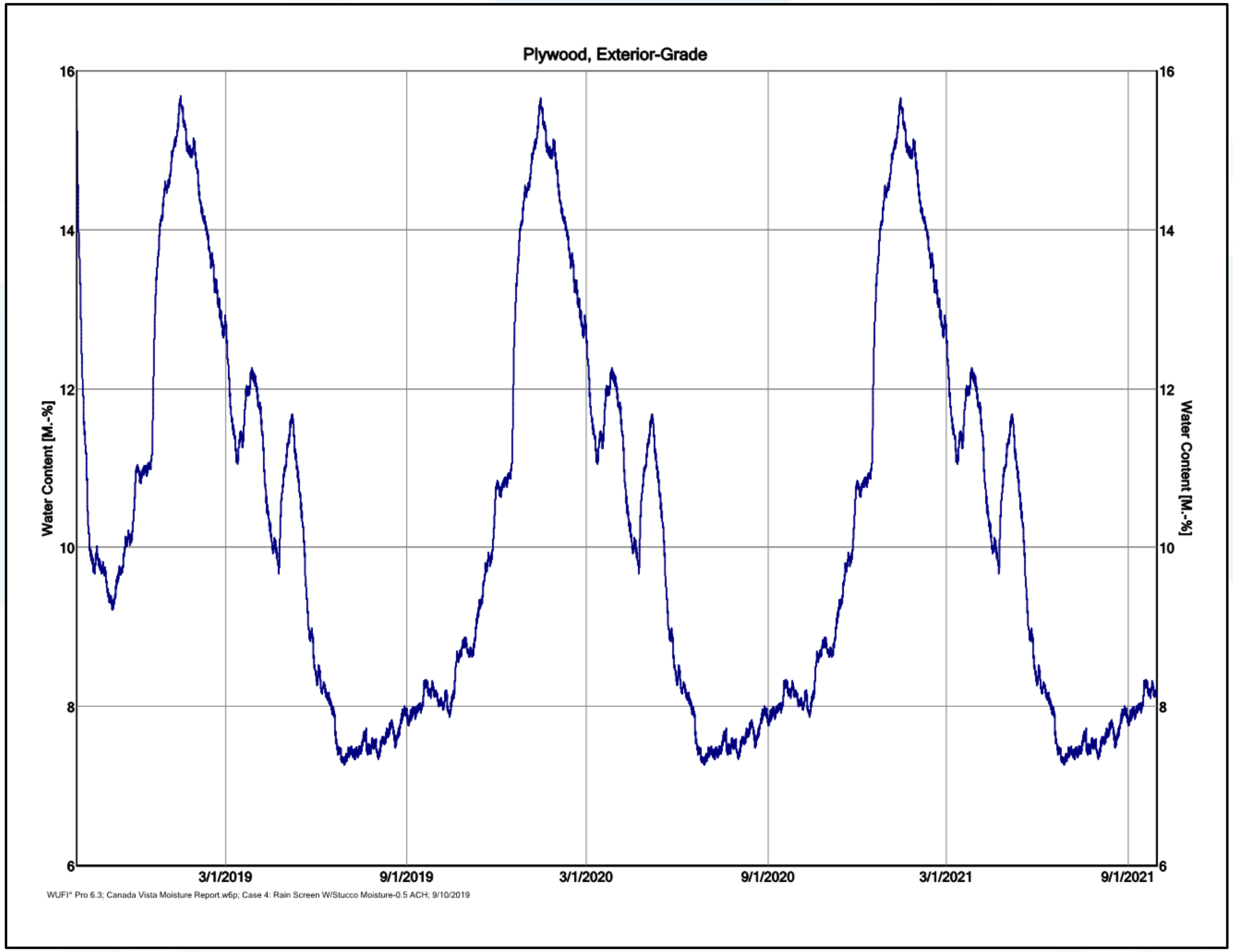
WUFI Model 4 – Mould (Mold) Index



WUFI Model 4 – Mould (Mold) Index



WUFI Model 4 – Sheathing Moisture Content



WUFI Results – Rain Screen Solution

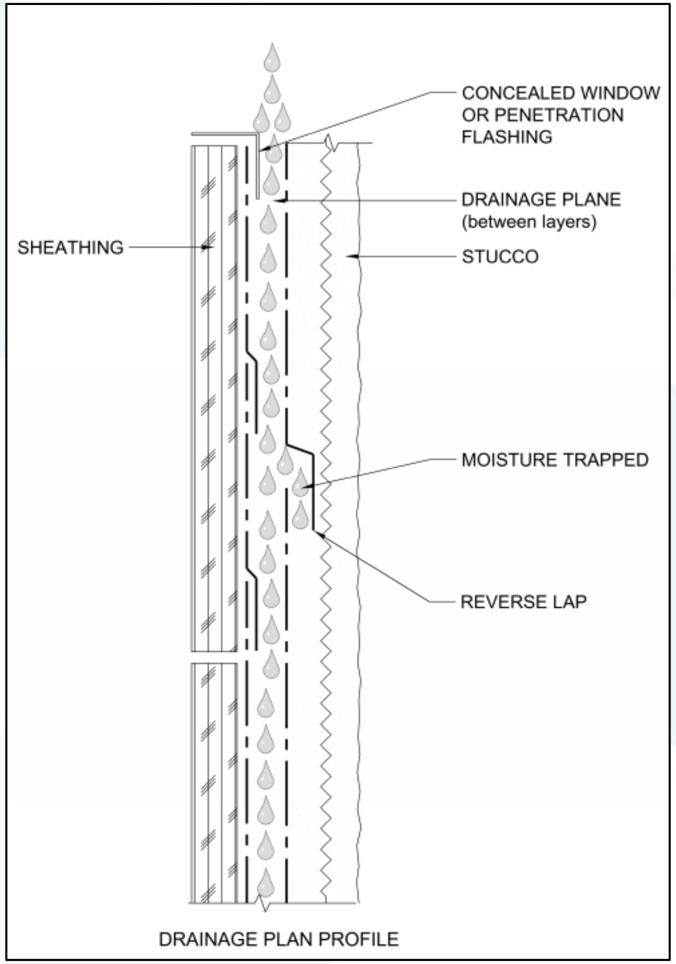
- The mold index was 0.425, well below the 1.0 index threshold.
- The moisture content of the OSB sheathing moisture content was 15.5% during the winter season.
- Reservoir claddings must be installed in a rainscreen configuration over vapor permeable WRBs.
- Rain Screen has more tolerance for incidental leakage through stucco and siding.

Building Code Requirements

- Designing to building code does not always prevent condensation and incidental moisture.
- Code does not take into account "20%" leakage rates in cladding.
- The International Building Code (IBC) requires vapor permeable water-resistive barriers be installed over wood sheathing in 2 independent layers.
- Furthermore, layers must be installed such that each layer provides a separate continuous plane.
- Any flashing intended to drain to the water-resistive barrier is directed between the layers.

Building Code Requirements

- This creates reverse laps within the WRB.
- This also creates more opportunities for trapped water within the wall system.
- Water will collect where the WRB bonds directly to the plaster.
- Water is also held between layers at crinkles, folds, creases, and puckers, of the WRB.



Is Code Requirement For Ventilation Adequate?

- Based on our forensic research of the modeled case studies, residential ventilation code requirements did not provide sufficient protection for the structural impacts of moisture.
- The 2020 CA Building Code that addresses residential ventilation is based on ASHRAE 62.2.
- The required ventilation rate is: 7.5 cfm per person + 0.1 x house floor area.
- Based on this calculation, the residential units simulated in this study would require a minimum ventilation rate of 0.3 [ACH].
- The analysis shows that with traditional stucco/siding over building paper, exterior wall would require ventilation at a minimum of 1.5 [ACH].
- However, Rain Screen system can get away with 0.5 ACH.

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Lessons Learned

Lessons Learned

- Claddings installed compactly over WRBs and sheathing – as allowed by Code – can lead to excessive moisture trapped in the walls.
- Water absorbed by reservoir claddings transfers through each layer of the assembly and 2%+ of wind driven rain winds up on WRB.
- This is compounded with highly absorptive cladding with significant moisture storage capacity (e.g. gypsum sheathing and stucco.)
- Traditional ventilation requirements are not adequate to handle trapped water in traditional cladding over WRB.

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Lessons Learned – Managing Ventilation

- CBC does not require including moisture load from the building enclosure for ventilation calculations.
- If the proposed design allows significant moisture gain not properly addressed with ventilation, or rainscreen, high moisture, humidity, and biological growth can be expected.
- There is an increased need for less incidental leakage in the exterior wall assembly or rainscreen.
- Furthermore, increasing ventilation (beyond code minimum) can reduce mold however, it will increase energy consumption.

Lessons Learned – Rainscreen

- Installing the cladding in a rainscreen or drainage configuration enhances drainage of bulk water.
- Ventilation will allow airflow behind the cladding that accelerates drying.
- Efficient ventilation requires combining the potential for air movement with vents at both the top and bottom of the wall.
- The stack effect and wind pressure differentials will effectively move air through the air space.
- With Rain Screen, ventilation rates of 0.4-0.5 ACH may be adequate.

Thank You!

Karim Allana, PE, RRC, RWC

Speaker Evaluations

Please complete
the Speaker Evaluations
by clicking here:
https://tinyurl.com/IIBECeval

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