MgO: No Sweat… Sweet!

Magnesium oxide exterior panels

August 5th, 2024

Westford Symposium

DUPONT™

Introductions

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Material Science
(PhD Chemical Engineering, Dow Mat Sci)
+
Building Science
(10 yrs Construction Product R&D, hands-on building, site visits and product trials)

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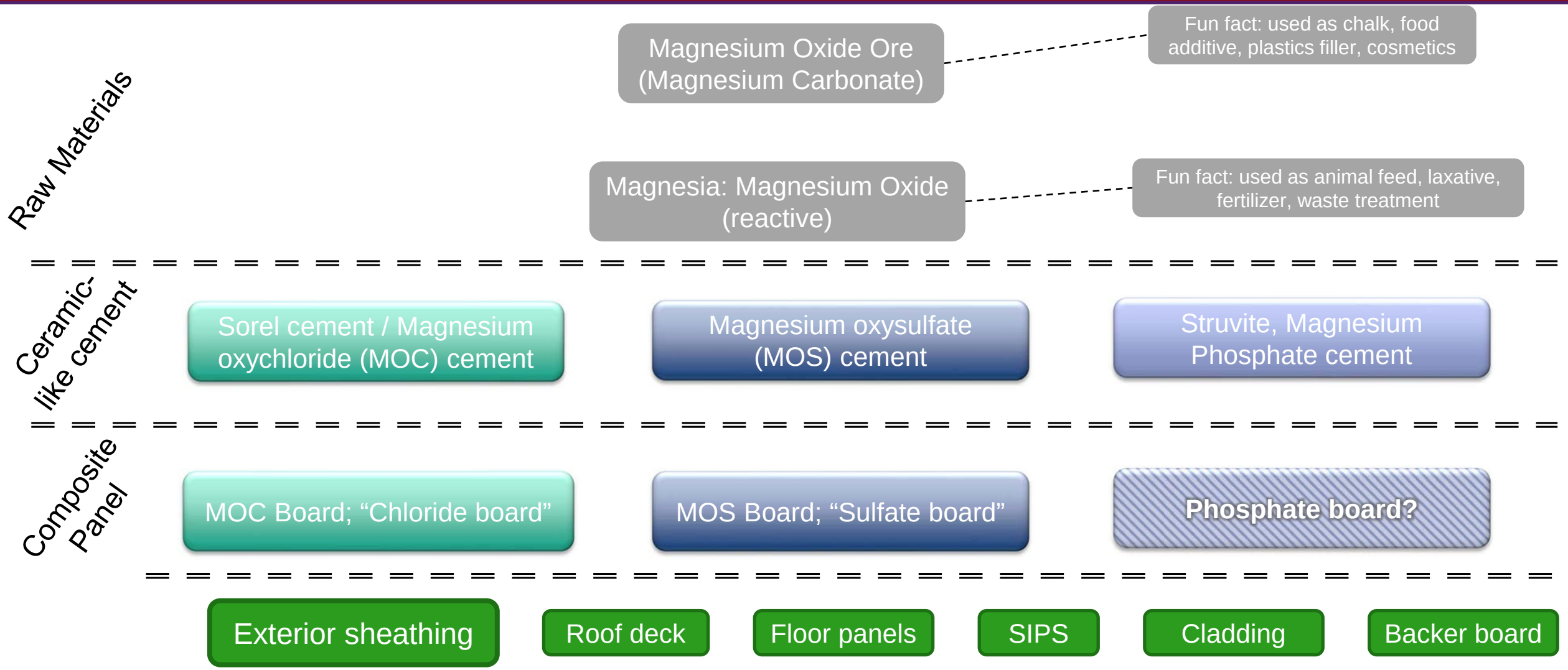
- Master of Applied Science - University of Waterloo
- Consultant in the field of applied Building Science, Forensics, and R&D
- Special Lecturer at the University of Waterloo School of Architecture
- FGIA/WDMA, SCEE, ASTM E06
- Personal: Three kids, gardening, cooking, smoking meat, and I like to build things - https://youtu.be/wOrxUQY766U

How to think about new materials like MgO?

What we'll cover today:

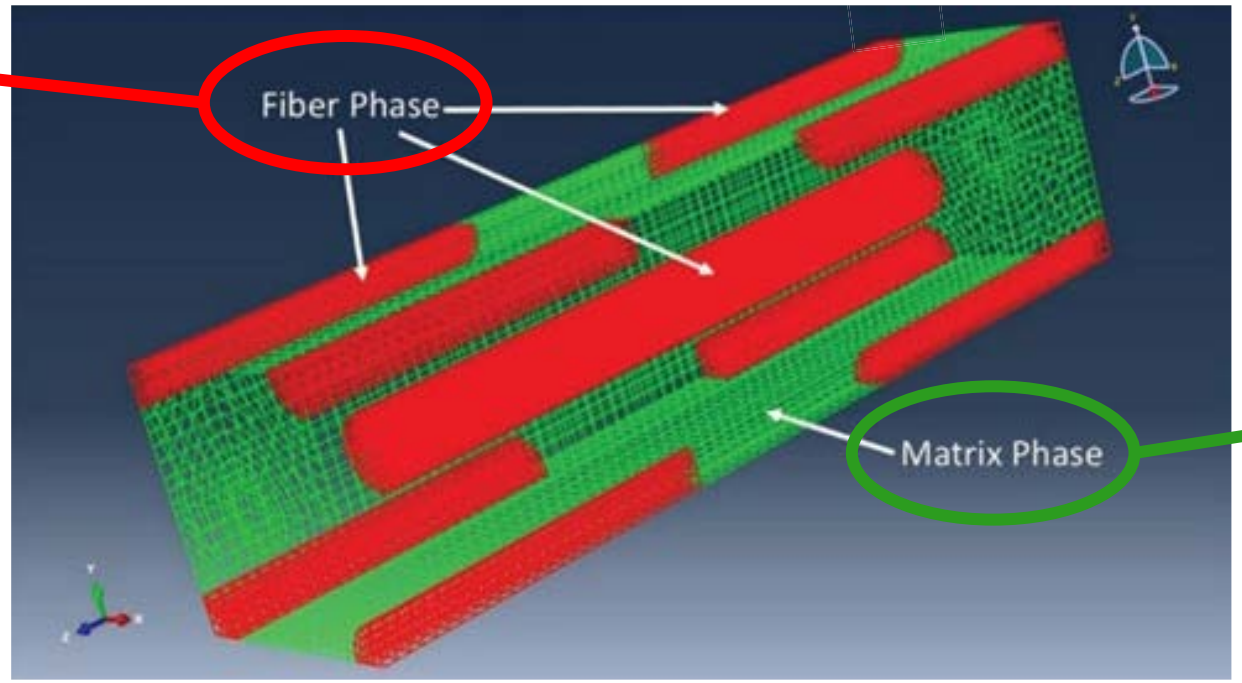
1. What's in an MgO Board?
2. Why is MgO Awesome? "The Promise"
3. Where has MgO gone wrong and how to mitigate risk? "The Box"
4. Quick dive into real world and accelerated testing

MgO Overview – Talk like an expert



Background – Composite Assemblies

Strength
Flexibility
Cohesion
Impact Resistance
Fastener holding

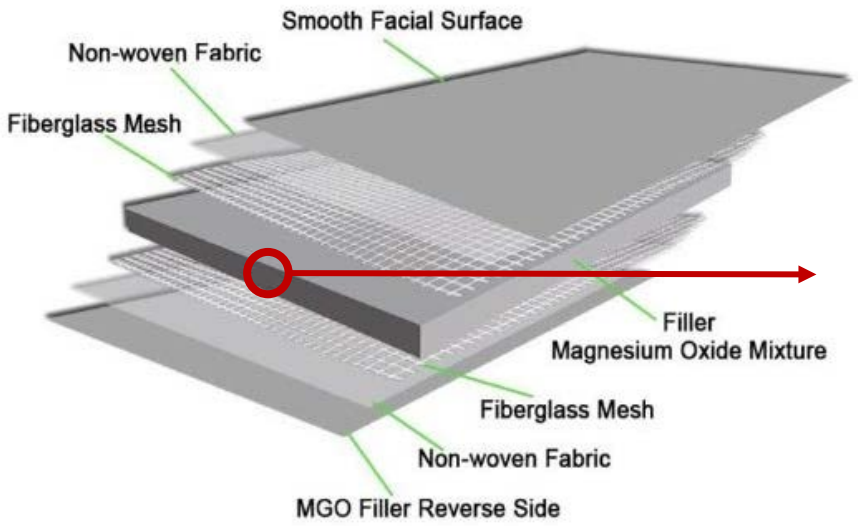


Durability
Weathering
Dimensional stability
Fire, water, microbial

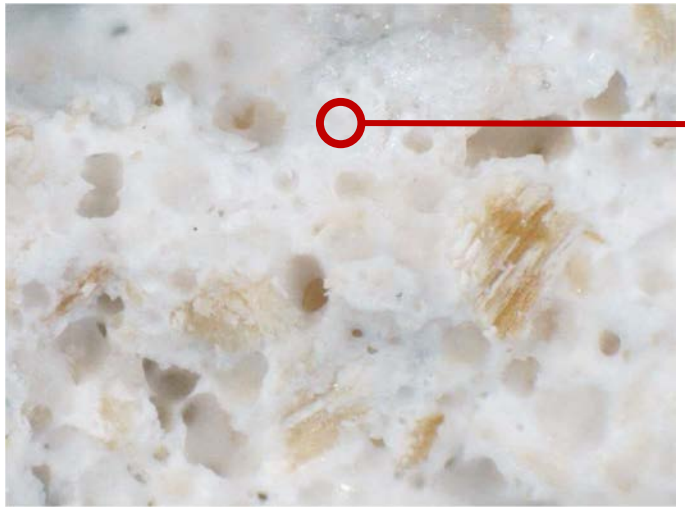
Combine best properties of both... but only with good adhesion and compatibility!

MgO Boards at all size scales…

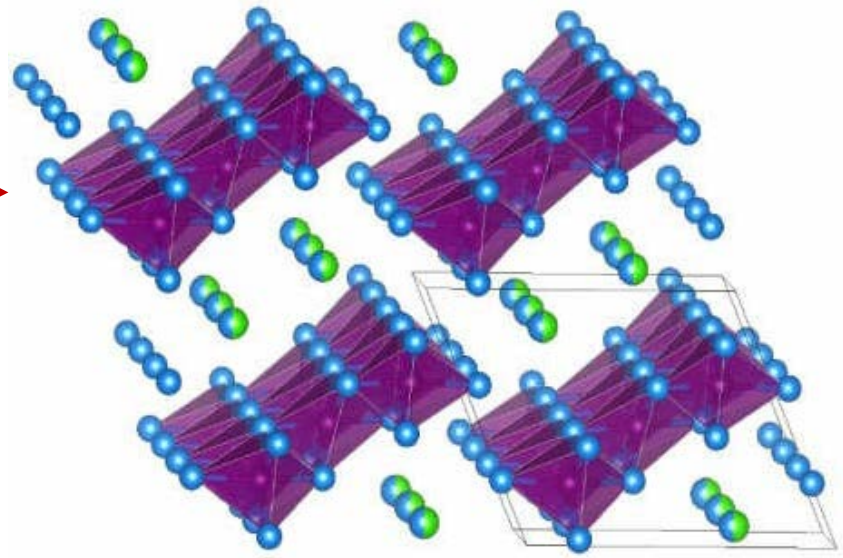
MgO Cement – Glass Fiber Composite Panel



Composite Cement



Inorganic Crystal



Carbon Dioxide Uptake by MOC-Based Materials - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Crystal-structures-of-Phase-3-left-and-Phase-5-right-Mg-atoms-are-located-in-the_fig1_340240893 [accessed 14 Jun, 2024]

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1X zoom: Benefits of Glass Fiber Reinforcement

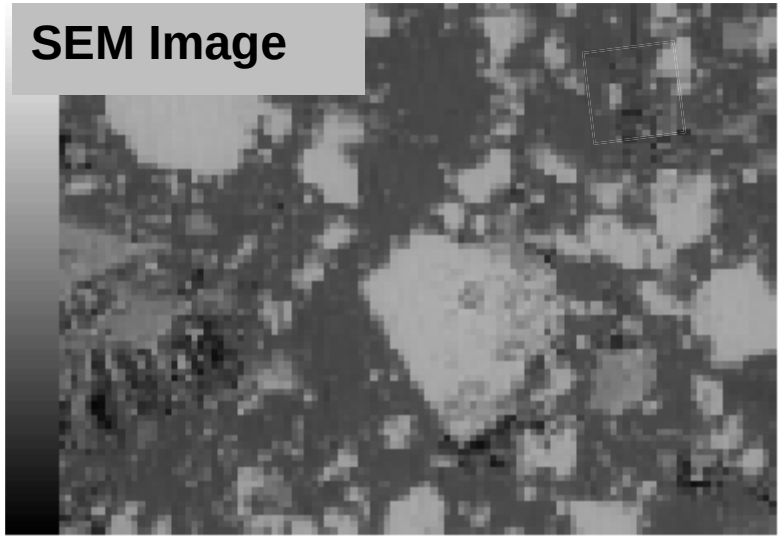
What makes it work

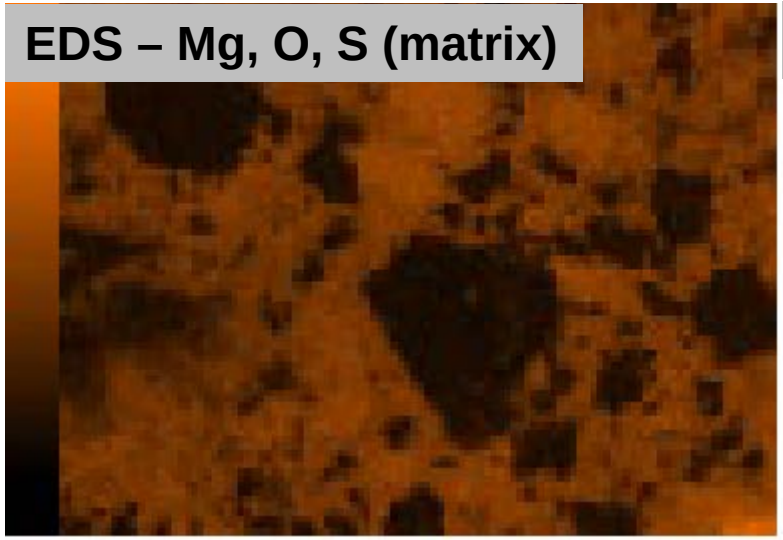
- Internal pH of 10-11, which won't degrade typical coated glass fibers
- Exhibits excellent binding ability to a variety of reinforcement fibers

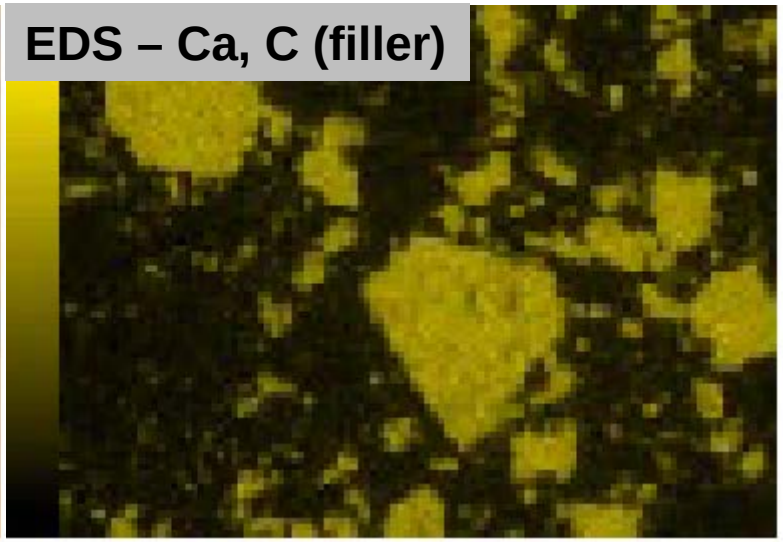
What do we get?

- Flex strength
- Fastener pull-out
- Crack resistance

10x Zoom: Fillers/Additives







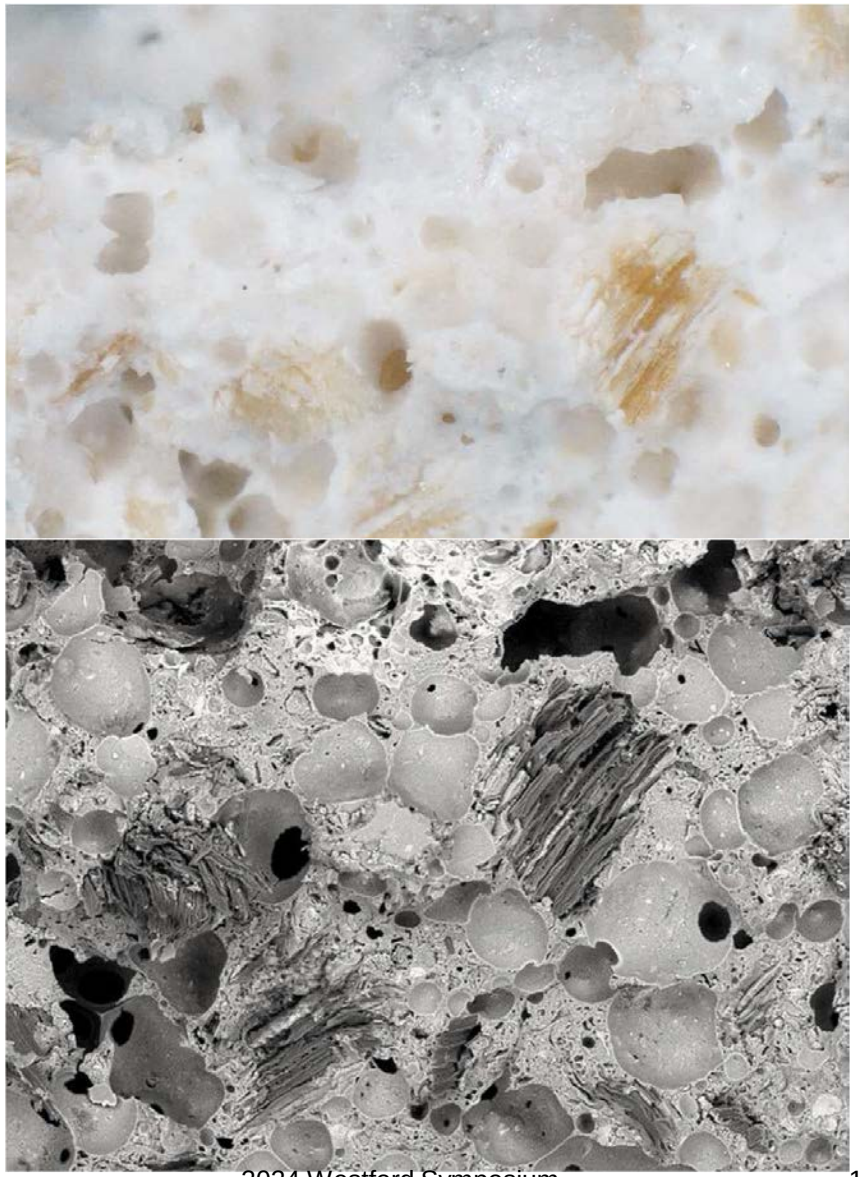
10x Zoom: Wood/Perlite with Cement Binder

What makes it work

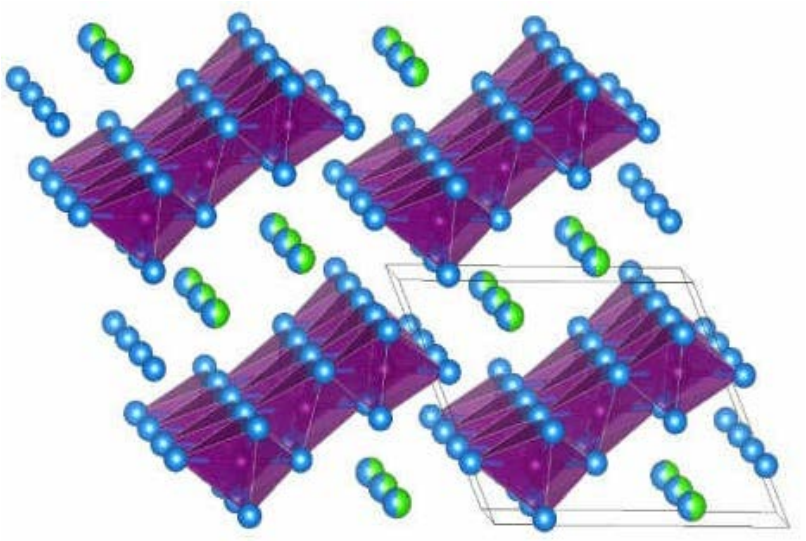
- Good adhesion and compatibility between fillers and matrix
- Toughness (wood), low density (wood and perlite)

What do we get?

- Easier handling
- Crack resistance
- Fastener holding
- Water permeability



1000X Zoom: What is the matrix structure?



Example: Magnesium oxychloride

5-1-8 crystal structure (Phase 5)

5 molecules $Mg(OH)_2$ —— 1 molecule $MgCl_2$

\ /

8 molecules H_2O

Crystal growth **self-assembly process** requires:

- Right **ratio** of ingredients
- Correct **temperature** (not too fast, not too slow)

"Current product performance"	MOC Phase 5	MOS Phase 5-1-7
High Strength	++	+
Strength retention (high temp)	++	+
Water resistance	+	++
No corrosion contribution	+	++

How the Sausage is Made

Mix

Pour

Stack

Cure (2 stage)

Store and Ship

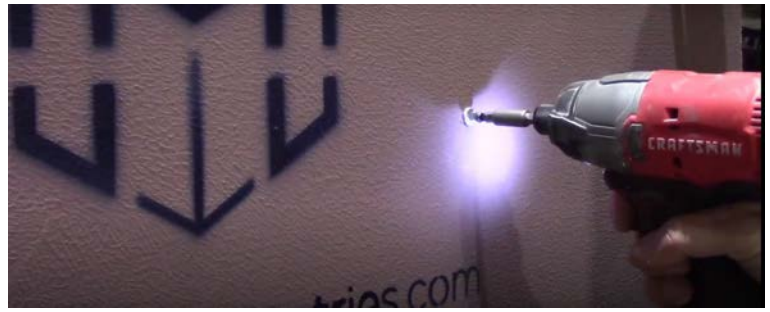
Mgo board machine, Deyi Machinery, video accessed 6/10/24

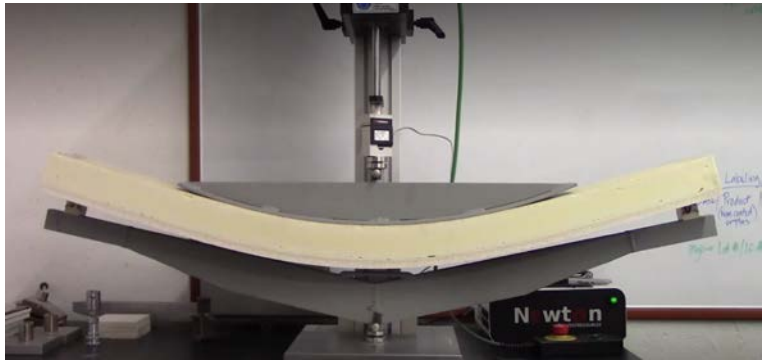
Sand and trim

Critical to Quality!!

Improved Since Early Boards

Connect the Dots: Material Science and Panel Performance





Material Science of MgO under Fire

ICC-ES ESL 1302 for Hourly Rated Walls

ICC-ES ESL 1442 for NFPA 285

During fire:

- Wood oxidizes (<5%)
- Water evaporates (~40%)
- Glass/MgO composite left behind

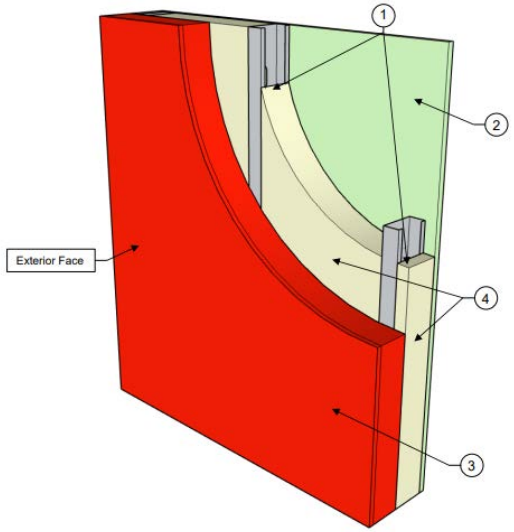
Example: DuPont Armorwall™ fire listings:

NFPA 285 (4 base walls, 4 insulation types, 21 cladding types, 4 rough opening treatment options)

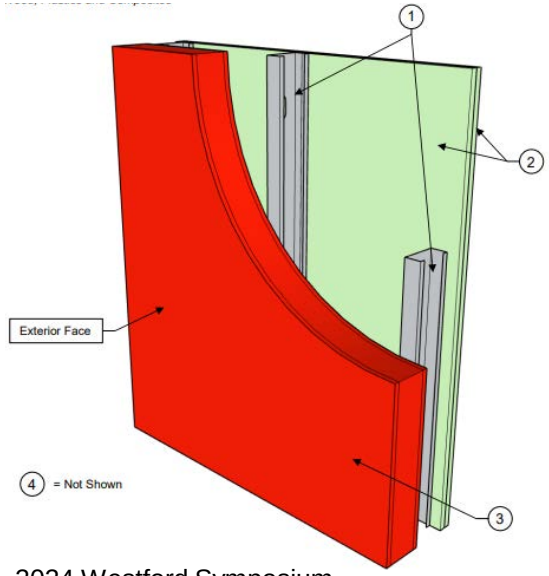
ASTM E119 (½-, 1-, and 2-hour rates assemblies)

E84 Class A

1-hr UL Assembly



2-hr UL Assembly



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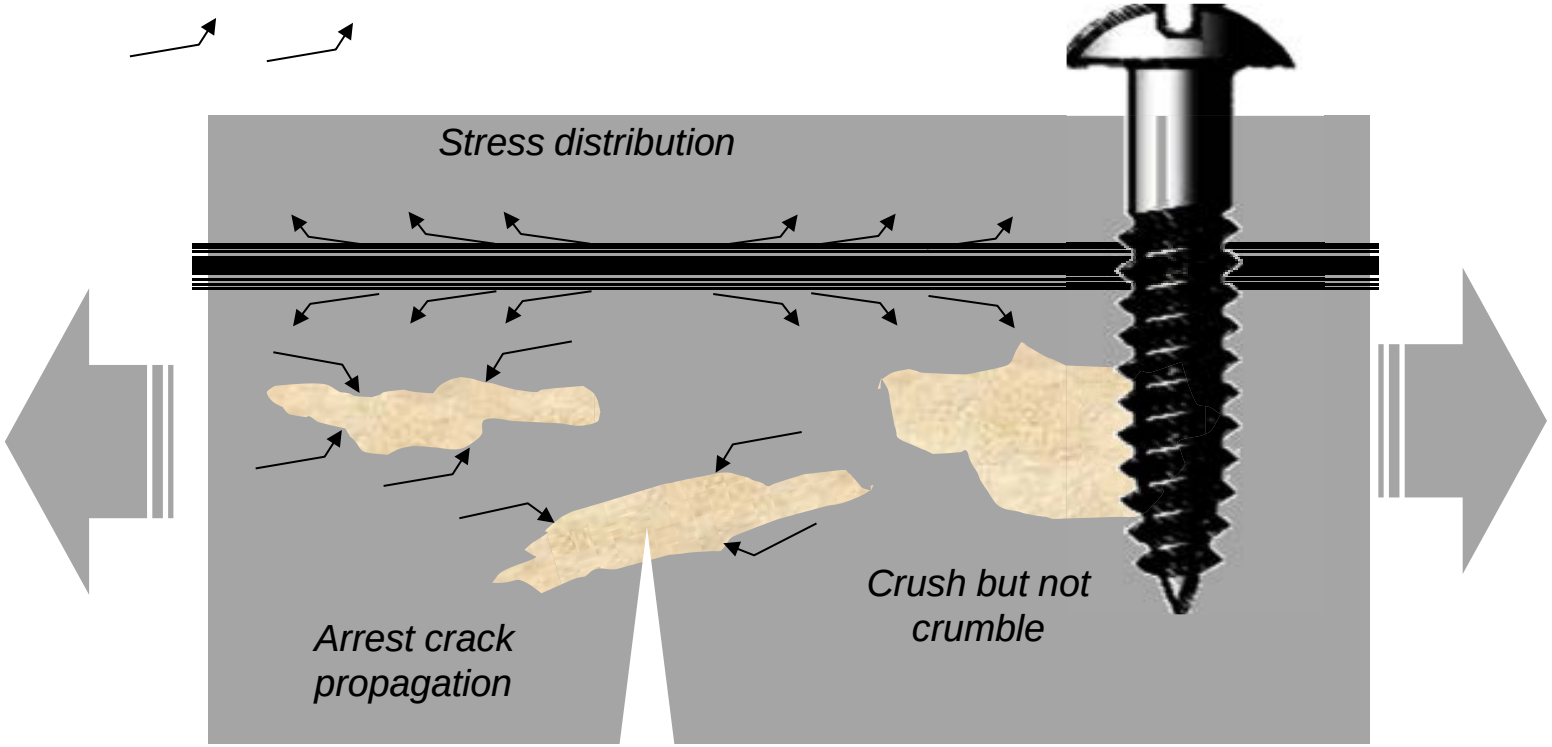
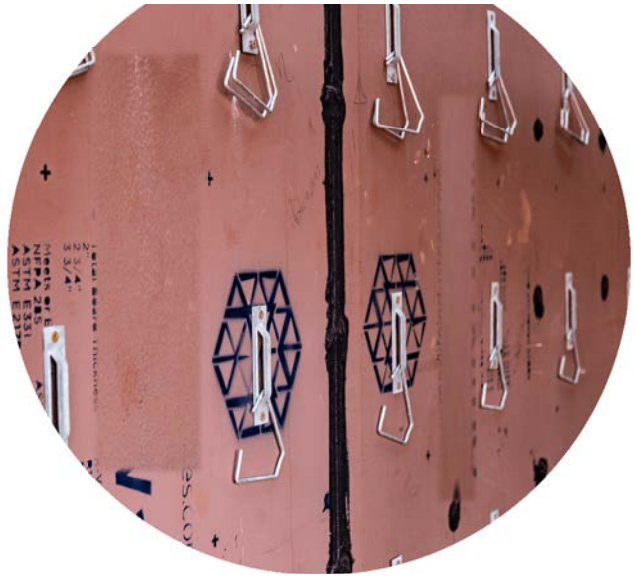
"ArmorWall™ is a trademark of DuPont de Nemours, Inc.

Board Performance- Strong but not Brittle



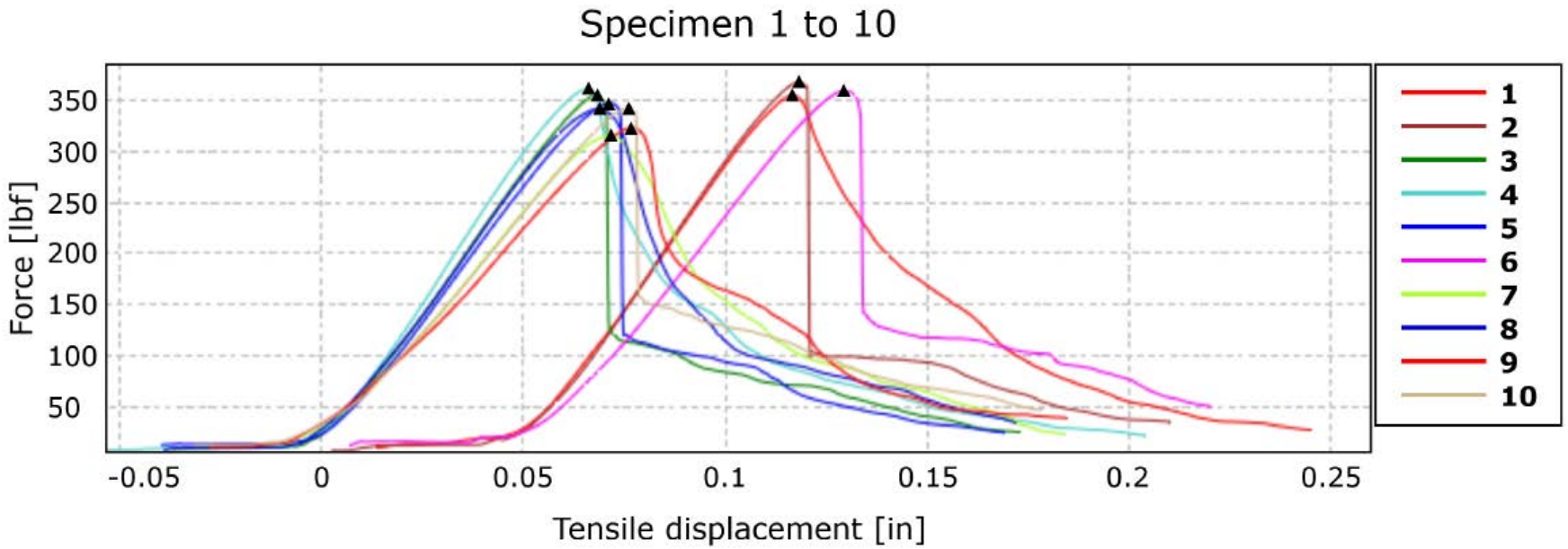
Direct attachment of cladding



Shear • Impact • Flex • Racking • Fastener

MOC cement has a compression strength of over 10,000 psi… ~50% higher than Portland cement!

Cladding Fastener Withdrawal



Cladding Attachment		
Fastener Shear in Sheathing Only	ASTM D1761	519 lbs
Fastener Pull Through	ASTM D1761	505.2 lbs
Fastener Withdrawal Capacity	ASTM D1761	284 lbs

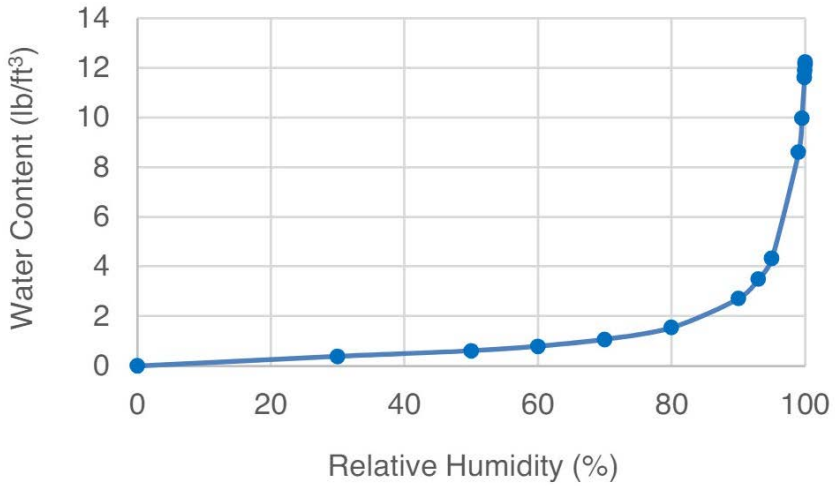
Board Performance: Water vapor

Move

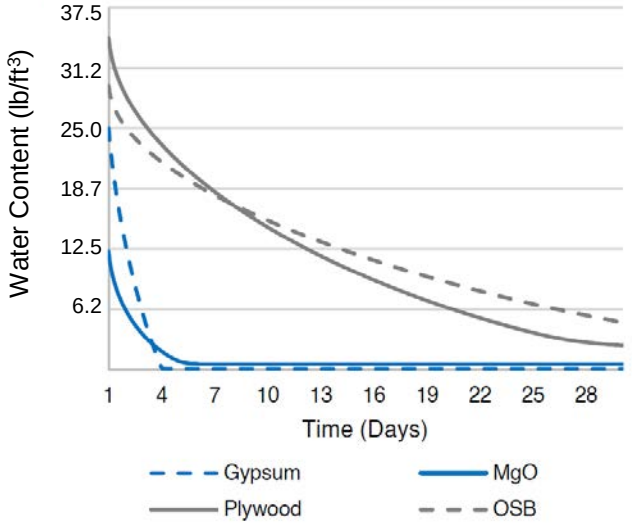
WRB coating: 1-30 perm

½” MgO : 10 Perm

Store



Release



Data credit: Built Environments Inc.

How?

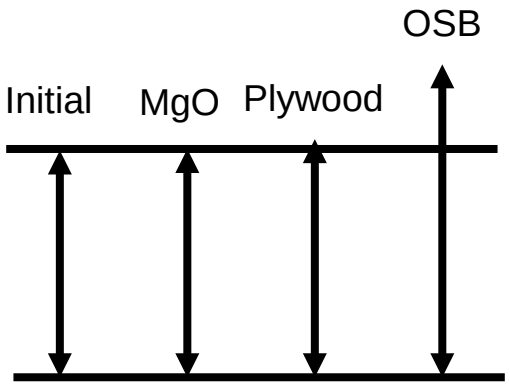
- Randomly oriented wood
- Interconnected pores
- Hygroscopic MgO cement crystals

Board Performance- Bulk Water

Lower water absorption than wood products

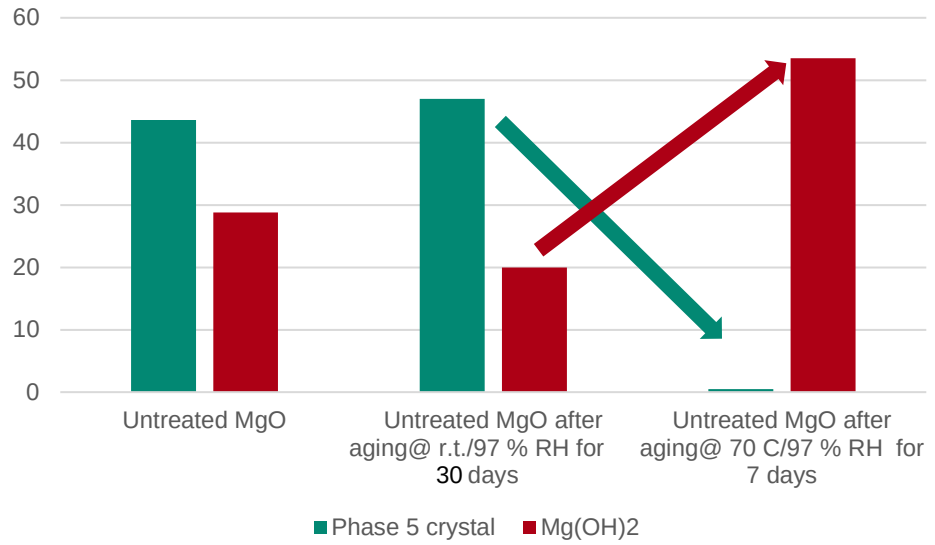
Dries quickly

Dimensionally stable



Relative thickness after 25 wet/dry cycles

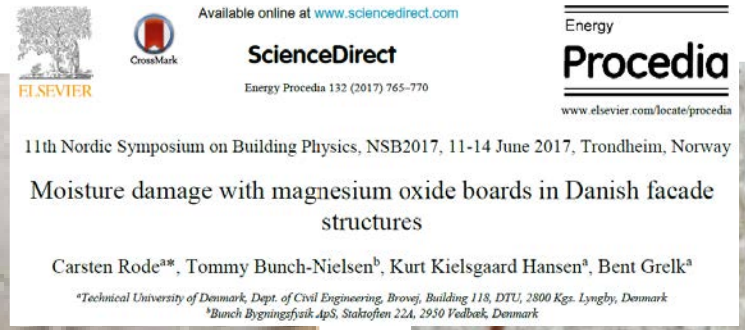
*Disclaimer: stable to bulk water… within limits!!



In lab: high temp (70 C / 158 F) + water
=
No cement crystals and all hydrolyzed byproduct

So… what's the box?

Denmark Façade Failure



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Energy Procedia

www.elsevier.com/locate/procedia

11th Nordic Symposium on Building Physics, NSB2017, 11-14 June 2017, Trondheim, Norway

Moisture damage with magnesium oxide boards in Danish facade structures

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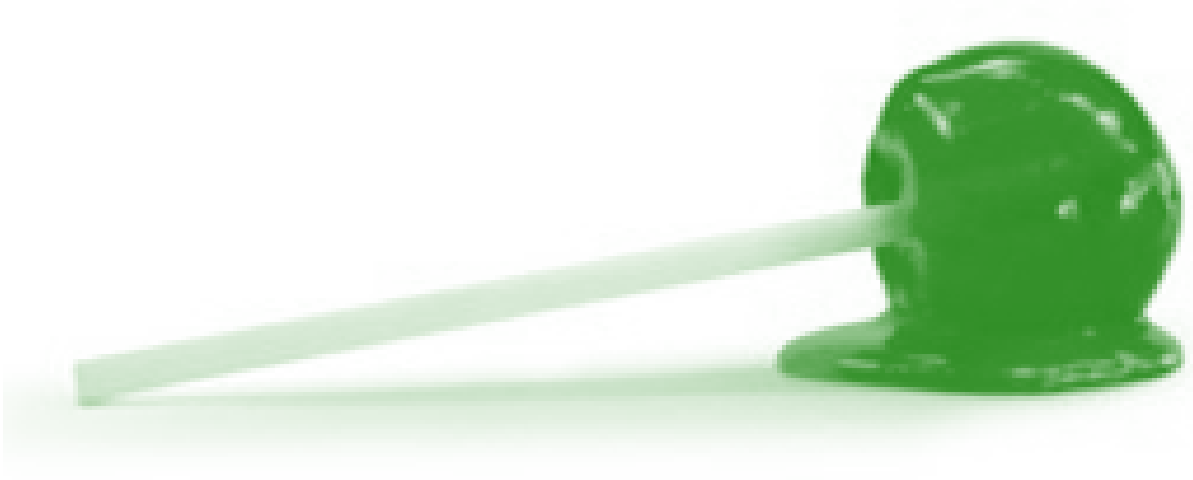
[a]Technical University of Denmark, Dept. of Civil Engineering, Brovej, Building 118, DTU, 2800 Kgs. Lyngby, Denmark
[b]Bunch Bygningsfysik ApS, Staktoften 22A, 2950 Vedbæk, Denmark

"Sweating"

Corrosion

MgO sweating… what in the world?



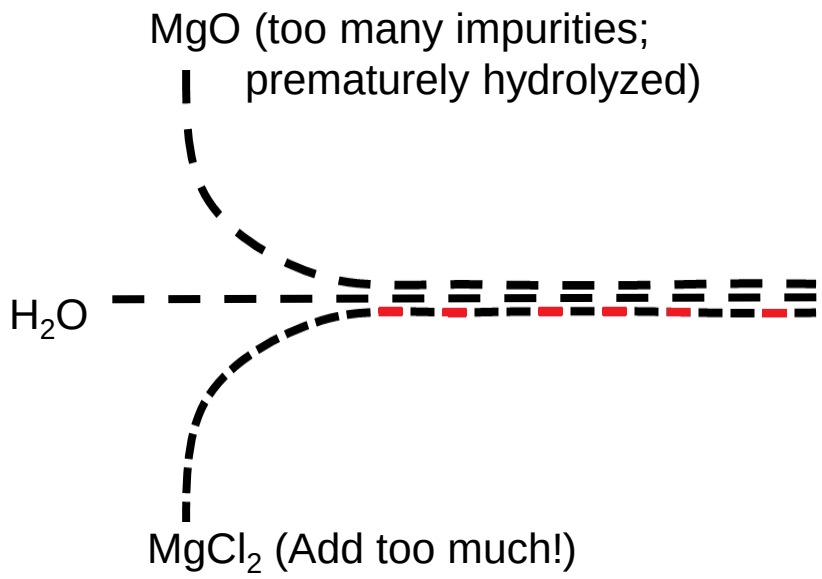
Concentrated Magnesium chloride solution droplets

Deliquescence: the process by which a substance absorbs moisture from the atmosphere until it dissolves in the absorbed water and forms a solution.

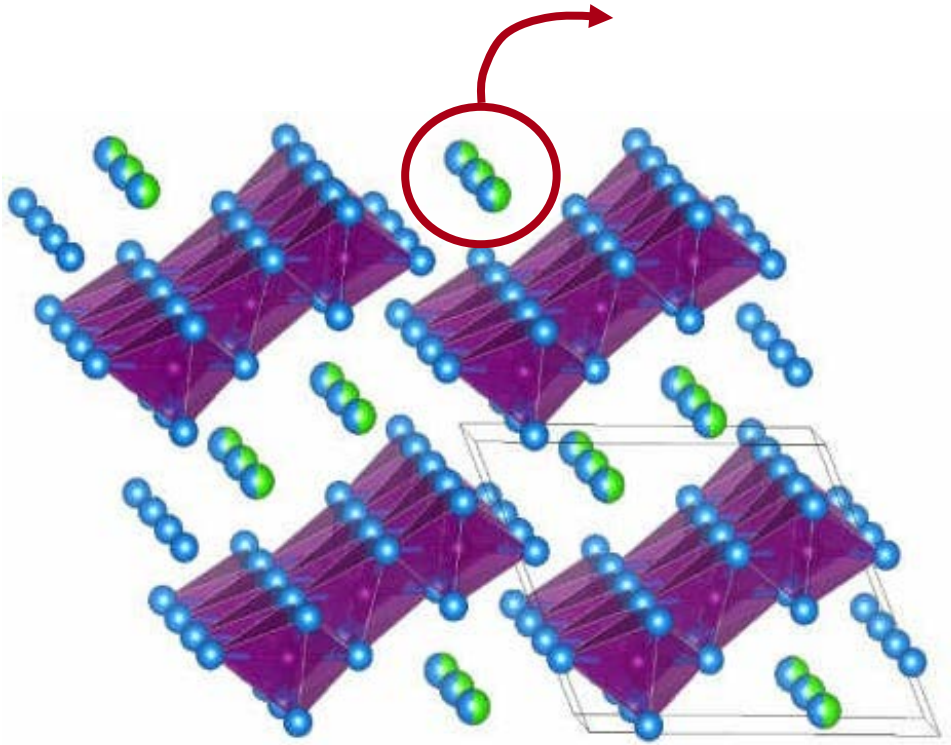
Chemistry Lesson: Where does extra Chloride come from?

Ingredient ratio

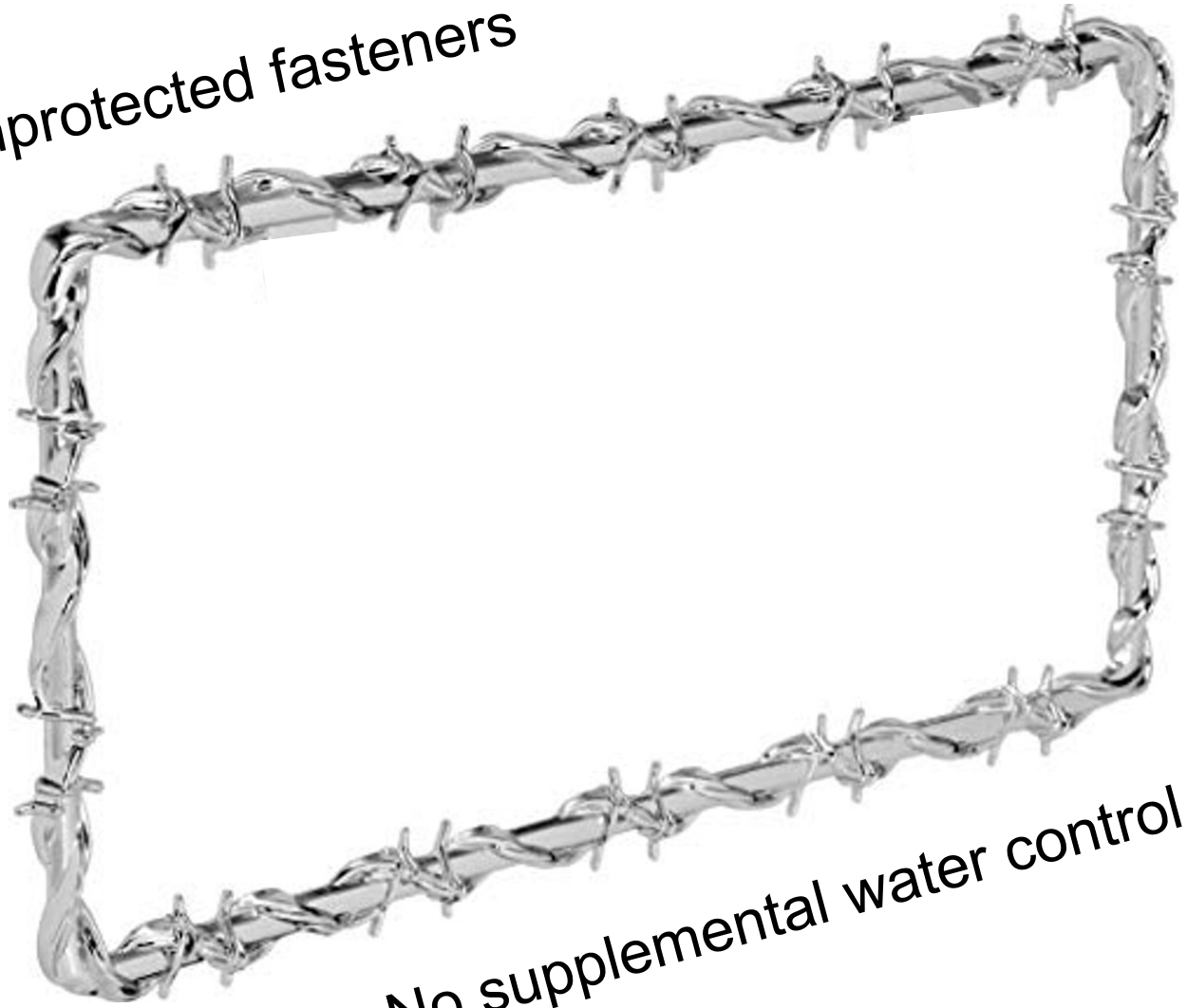
"Stoichiometry"



Poorly formed crystal falls apart



Outside the box…



Unprotected fasteners

Poor quality boards

High humidity at interior board surface

Air tightness

No supplemental water control layer

So where are we now?

1. High Quality Board
2. WRB
3. Interior vapor throttle
4. Protected and sealed fasteners

All need to be compatible!!! Look for composite panel rather than mix and match.

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Don’t put lipstick on a Pig – Start with a good MgO board

ASTM (XYZ)

ICC 1125

MgOBPA

ES ICC EVALUATION SERVICE®

www.icc-es.org | (800) 423-6587 | (562) 699-0543 *A Subsidiary of the International Code Council®*

ACCEPTANCE CRITERIA FOR FIBER-REINFORCED MAGNESIUM-OXIDE-BASED SHEETS

AC386

Approved October 2023

(Compliance Date - October 2025)

AC386 Section 3.1.1 – Flexural Strength	AC386 Section 3.1.7 – Nail-Head Pull Through
AC386 Section 3.1.2 – Freeze-Thaw Cycling	AC386 Section 3.1.8 – Falling Ball Impact
AC386 Section 3.1.3 – Dimensions and Tolerances	AC386 Section 3.1.9 – Shear Bond Strength
AC386 Section 3.1.4 – Moisture Movement	AC386 Section 3.1.10 - Humidified Deflection
AC386 Section 3.1.5 – Water Absorption	AC386 Section 3.1.11 – Flame Spread Characteristics
AC386 Section 3.1.6 – Compression Indentation	AC386 Section 3.1.12 – Corrosion Effects

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Behind the scenes: Elements of good QC

When you specify a board… do you trust their QC?

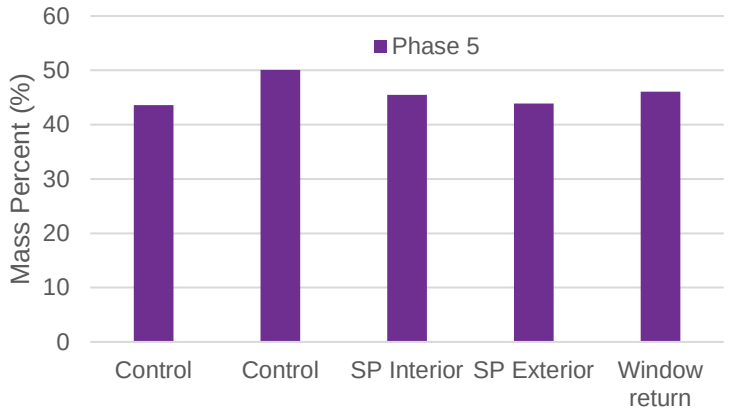
High Humidity – Does it sweat?

Crush and soak– How much chloride does it release?

In the field… what are we seeing?

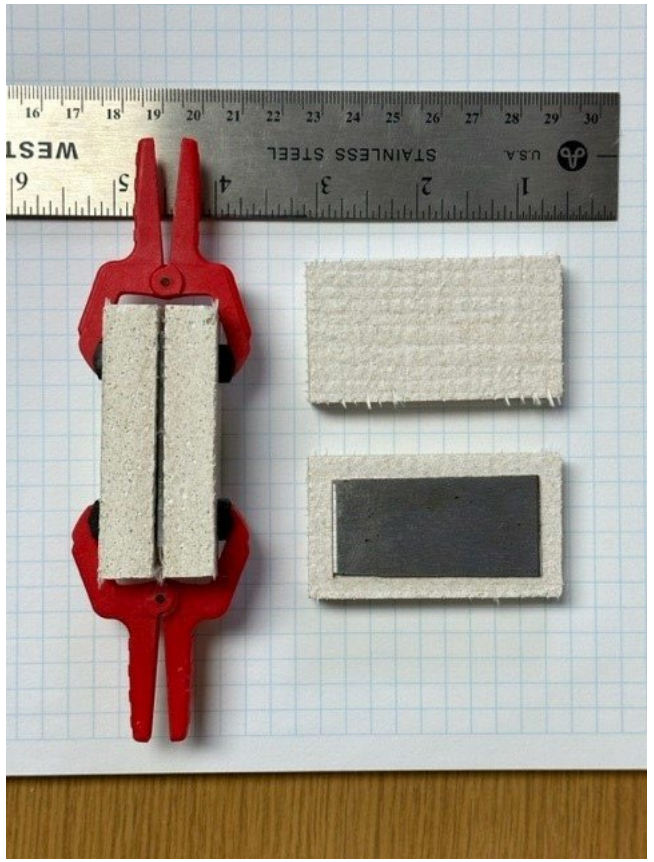
Site review and analysis (Portland, Maine):

- Exposed returns and SP panels for > 12 months. (Aug ‘21 - Aug ‘22)
- No corrosion of fasteners or studs in contact with MgO found during investigation
- Open stairwell, no roof covering – rain can hit interior of boards
- Both SP and ArmorBoard completely exposed on the interior



Beyond QC… How do we know it works?

Test Huts



Accelerated corrosion tests predict long-term failure risk

Australian research lab tests MgO samples for > 2 years at high RH

Test Hut Validation Research

August 5, 2024

Past Projects

DuPont RBETS – Florida (credit RDH)

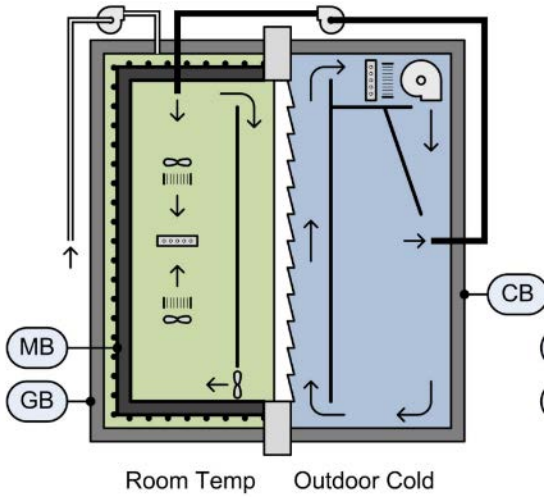
DuPont RBETS – Oregon (credit RDH)

Past Projects

Summer Camp Mockup

DuPont Florida Test Hut

Past Projects



Building Science Corporation – Thermal Metric (credit RDH)

Carleton University – CABER Facility – Guarded Hot Box and PSR (credit Carleton)

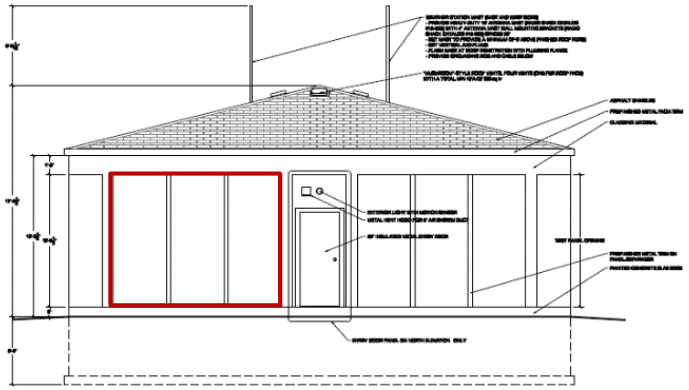
Toronto Metropolitan University – Building Physics Lab (credit TMU)

George Brown College – Climate Chamber (credit RDH)

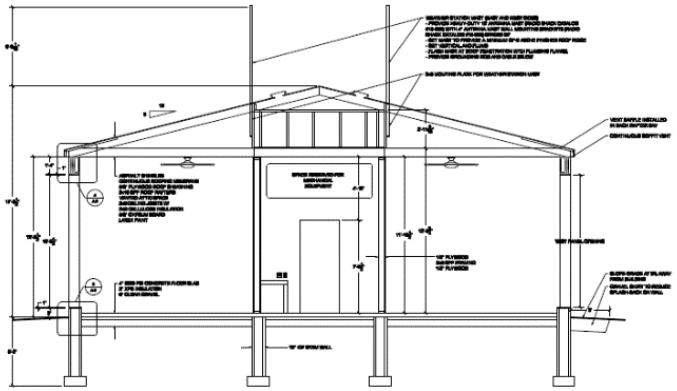
Midland Outdoor Exposure Facility

“Taj MaHut” – The pinnacle of building enclosure exposure facilities

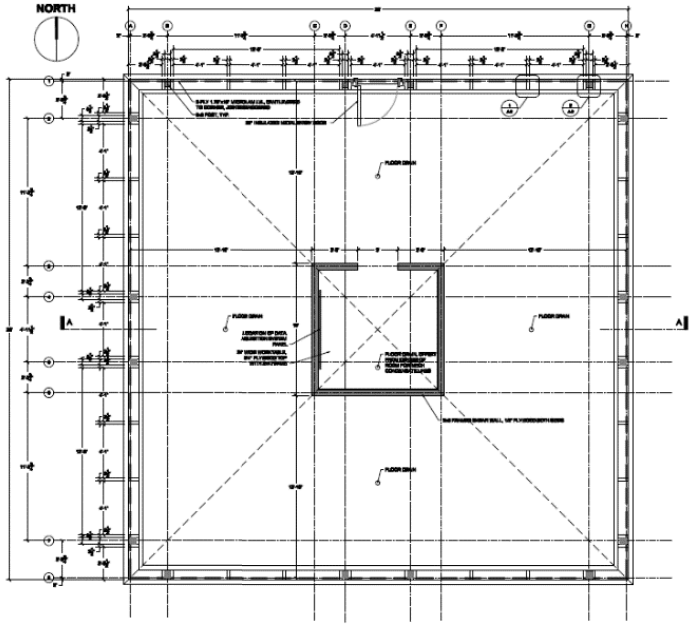
- 7 walls per orientation*
- 4’x10’ openings (or up to 12’x10’)
- Corner instrumentation
- Weather station
- Pressurization/Depressurization
- ~800 sensors (T/RH/MC/Flux)



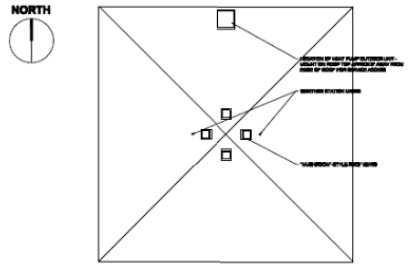
3 Typical Elevation



4 Building Section A-A



1 Floor Plan



2 ROOF PLAN

Past Projects

Dow – Midland, MI

Midland Outdoor Exposure Facility

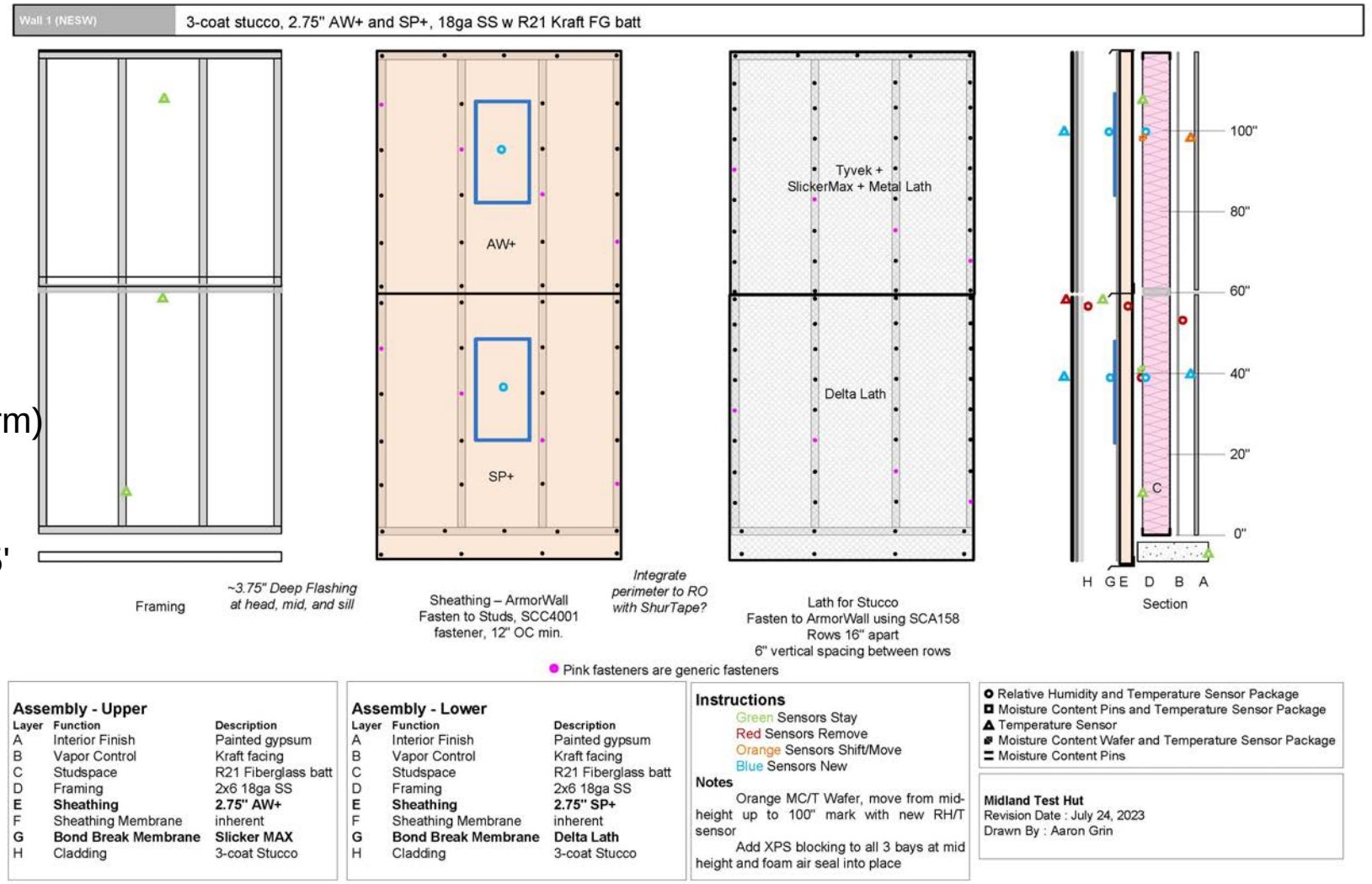
Finished Walls – Nov 2023

Wall Assembly 1

Test Wall – Split Upper/Lower

- 3 Coat stucco
- Slicker (open) and Delta Lath (low perm)
- ArmorWall Plus™ - 2.75" - Upper 5’
- ArmorWall SP Plus™ - 2.75"- Lower 5'
- Insulated 6in Steel Stud Wall

- Added Stressors
  - Intentional wetting at WRB layer

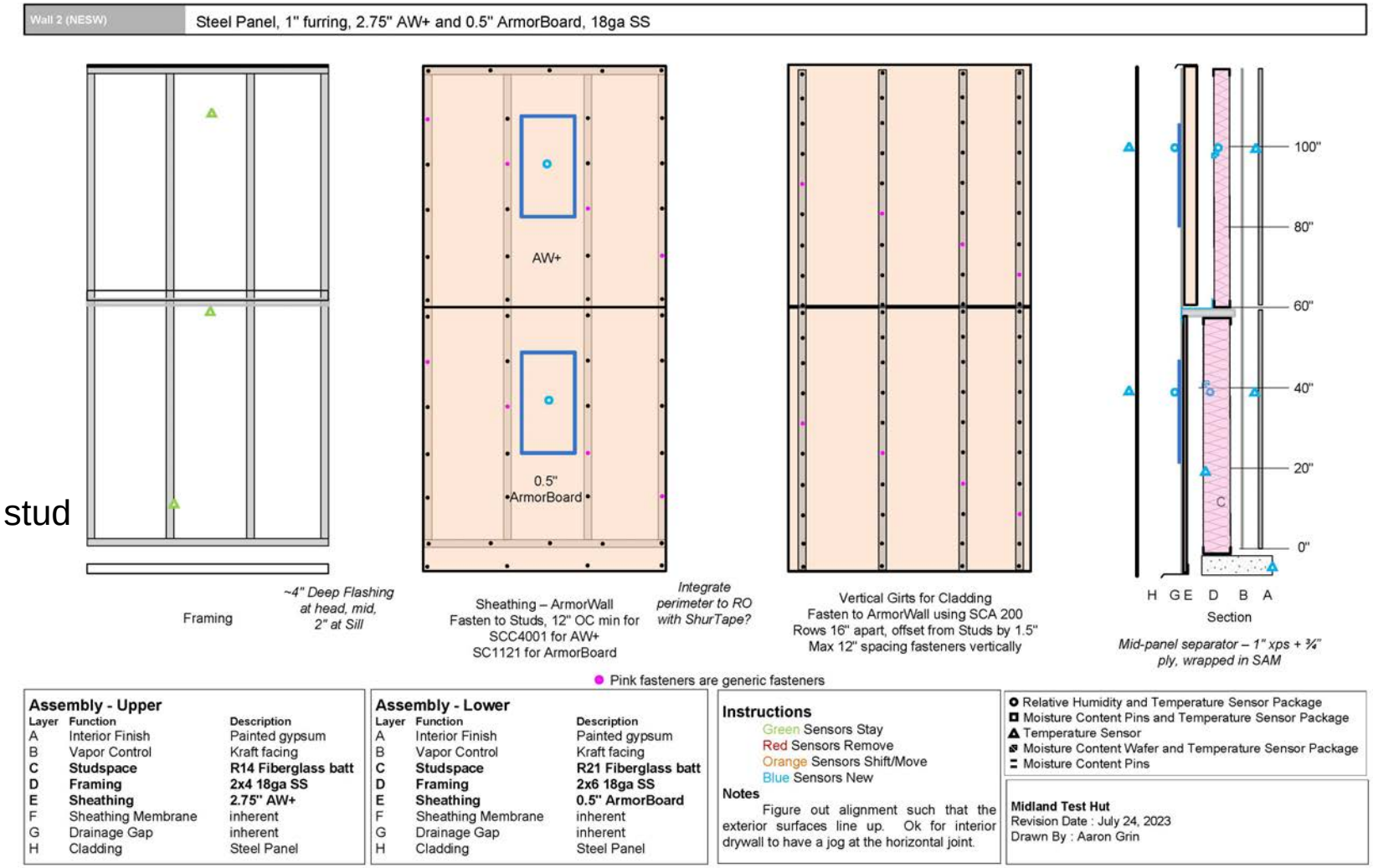


Wall Assembly 2

Test Wall – Split Upper/Lower

- Metal Panel Cladding
- Gap
- AW+ - 2.75"- on 4in insulated stud
- ArmorBoard™ - 0.5"- on 6in insulated stud

- Added Stressors
  - Intentional wetting at WRB layer
  - Air leakage into stud-bay

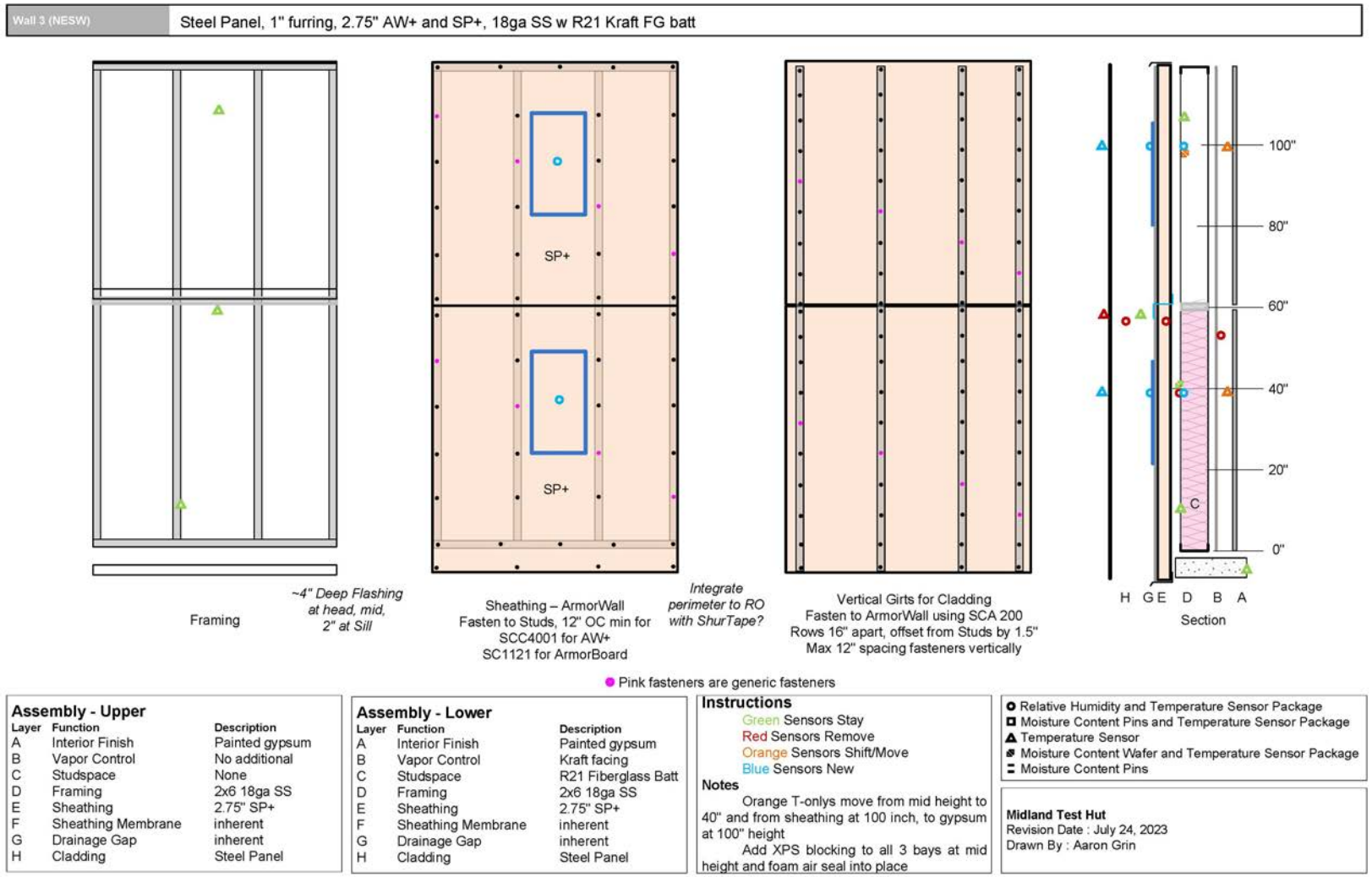


Wall Assembly 3

Test Wall – Split Upper/Lower

- Metal Panel Cladding
- Gap
- AW+ - 2.75“ – empty 6in steel stud
- AW+ - 2.75“ – insulated 6in steel stud

- Added Stressors
  - Intentional air leakage into stud-bay

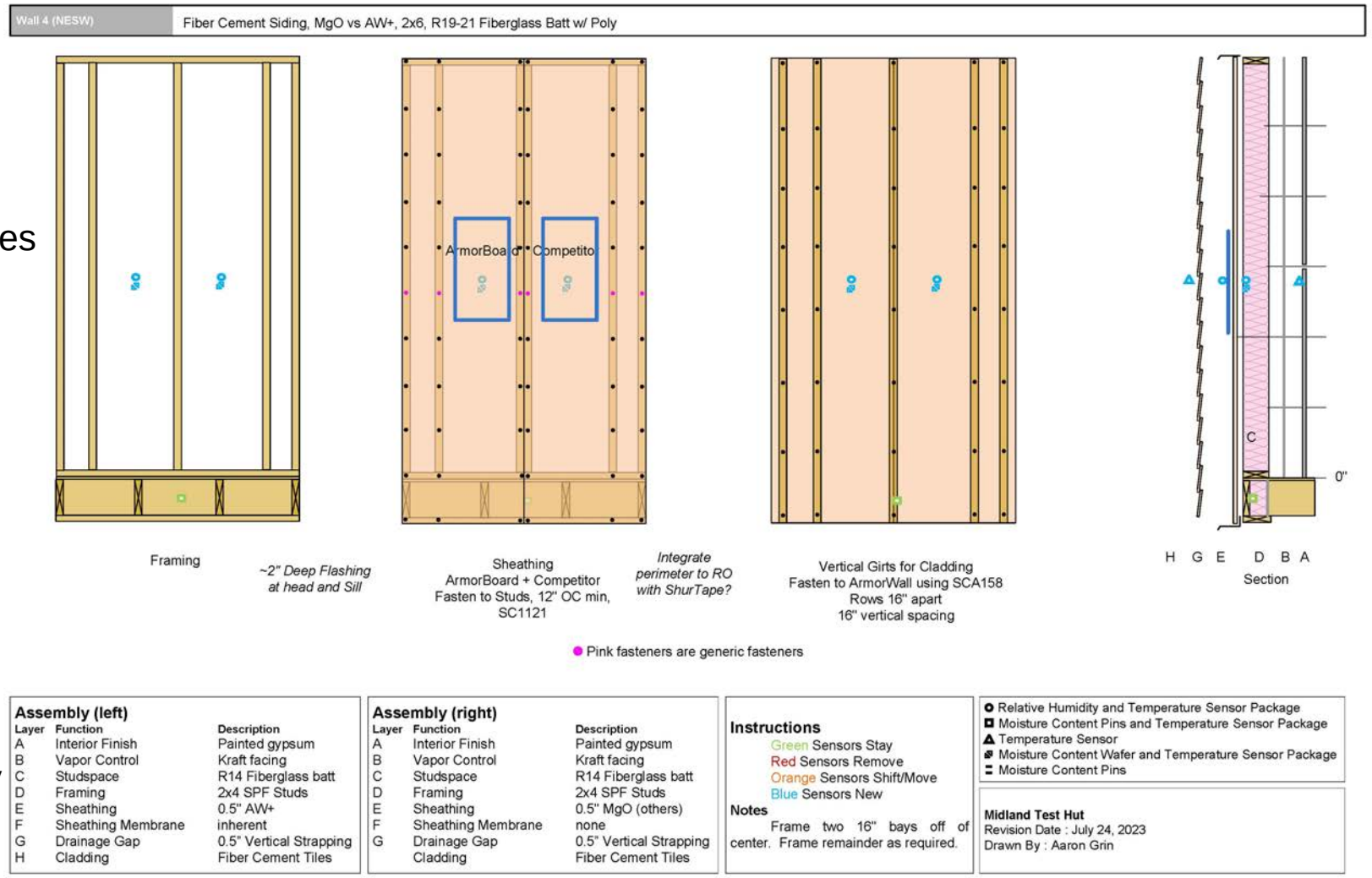


Wall 4 – Recreate Denmark MgO Wall

Test Wall – Split Left-Right

- Fiber Cement Cladding installed as Tiles
- 0.5in Gap
- Bare MgO 0.5“
- AB+ Coated MgO 0.5“
- Insulated 2x6 Cavities

- Added Stressors
  - Intentional wetting at WRB layer
  - Intentional air leakage into stud-bay



Test Hut Update

Test Hut Update

- Test Wall 1
  - *SlickerMax® (vapour open)*
  - *vs Delta Drain® (vapour barrier)*
  - Wetting Apparatus in Drainage Cavity
  - Surface Temperature Sensors
  - Cavity T and RH Sensors

DUPONT™

Test Hut Update

- Test Wall 2
  - *½” ArmorBoard on 2x6*
  - *2 ¾” AW+ on 2x4*
  - Wetting Apparatus in Drainage Cavity
  - Surface Temperature Sensors
  - Cavity T and RH Sensors

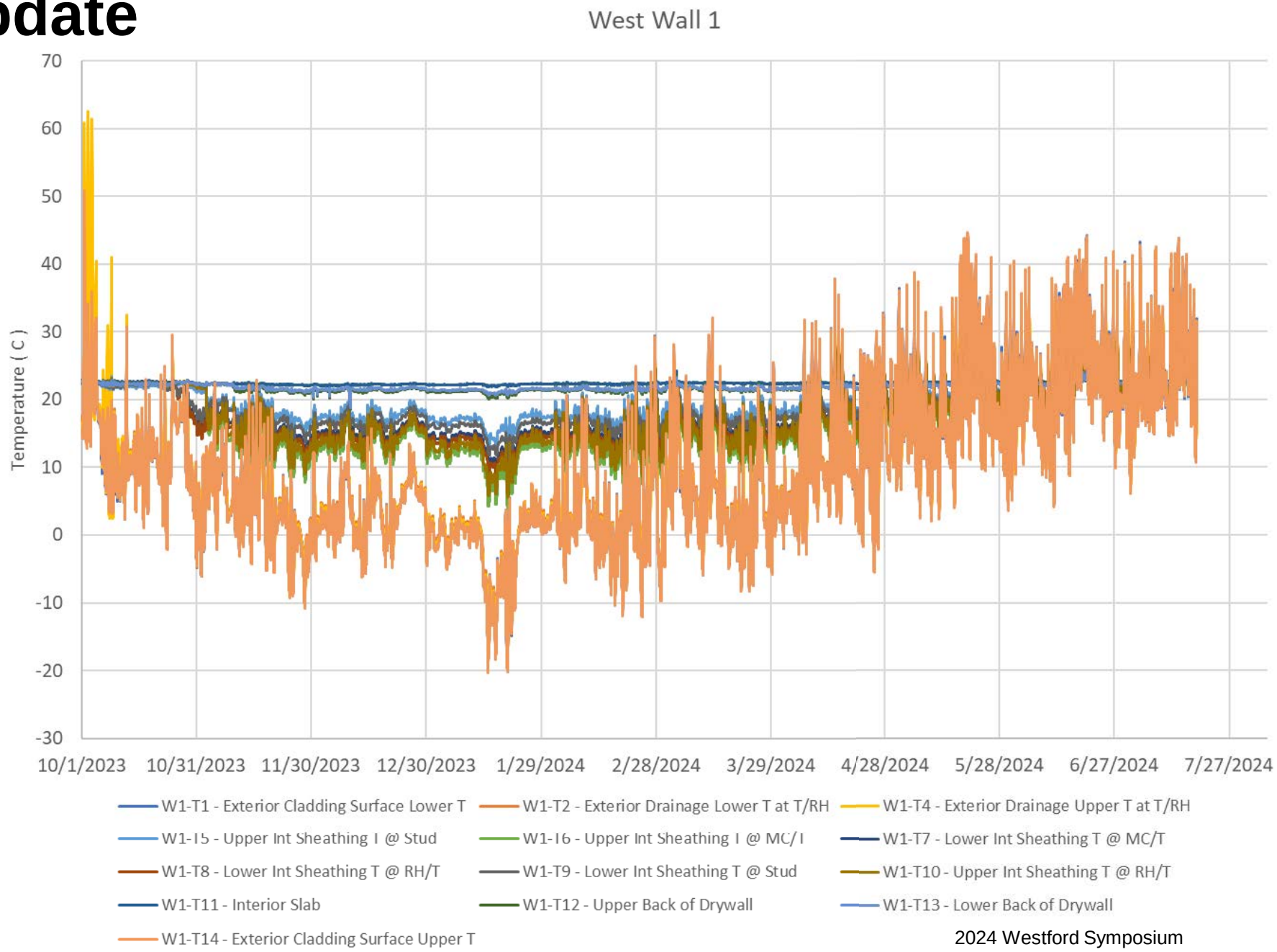
Test Hut Update

- Test Wall 3
  - *2 ¾” AW+ on 2x6 w and w/o Cavity insulation*
  - Wetting Apparatus in Drainage Cavity
  - Surface Temperature Sensors
  - Cavity T and RH Sensors

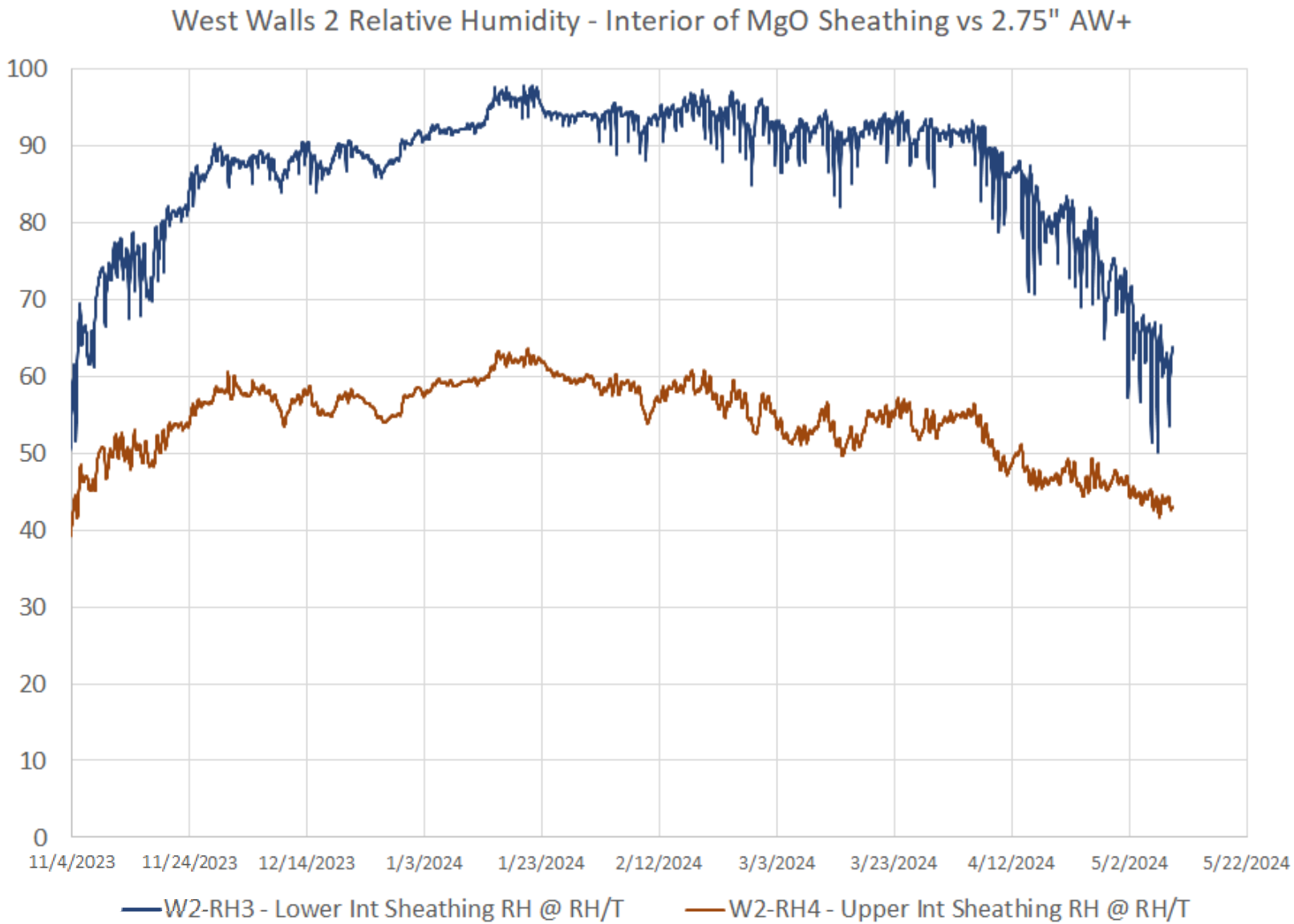
Test Hut Update

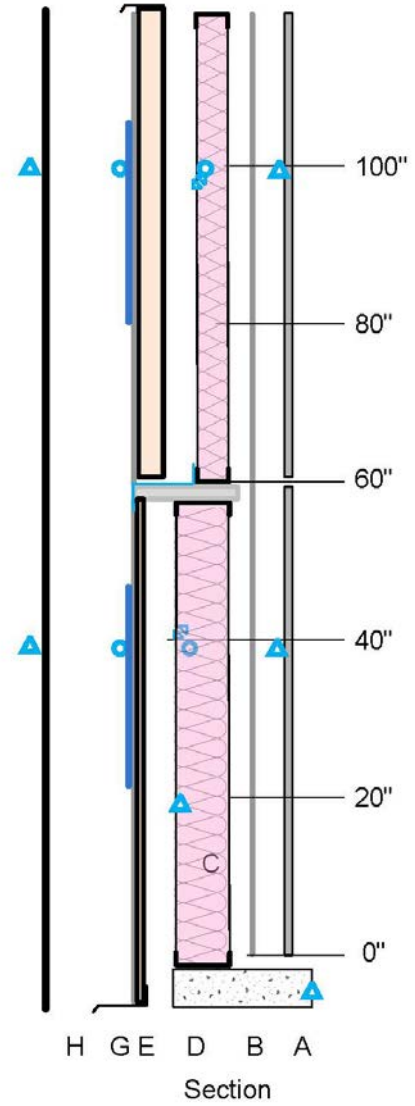
- Test Wall 4
  - *Bare MgO vs Coated on 2x4 wood*
  - Wetting Apparatus in Drainage Cavity
  - Surface Temperature Sensors
  - Cavity T and RH Sensors

Test Hut Update



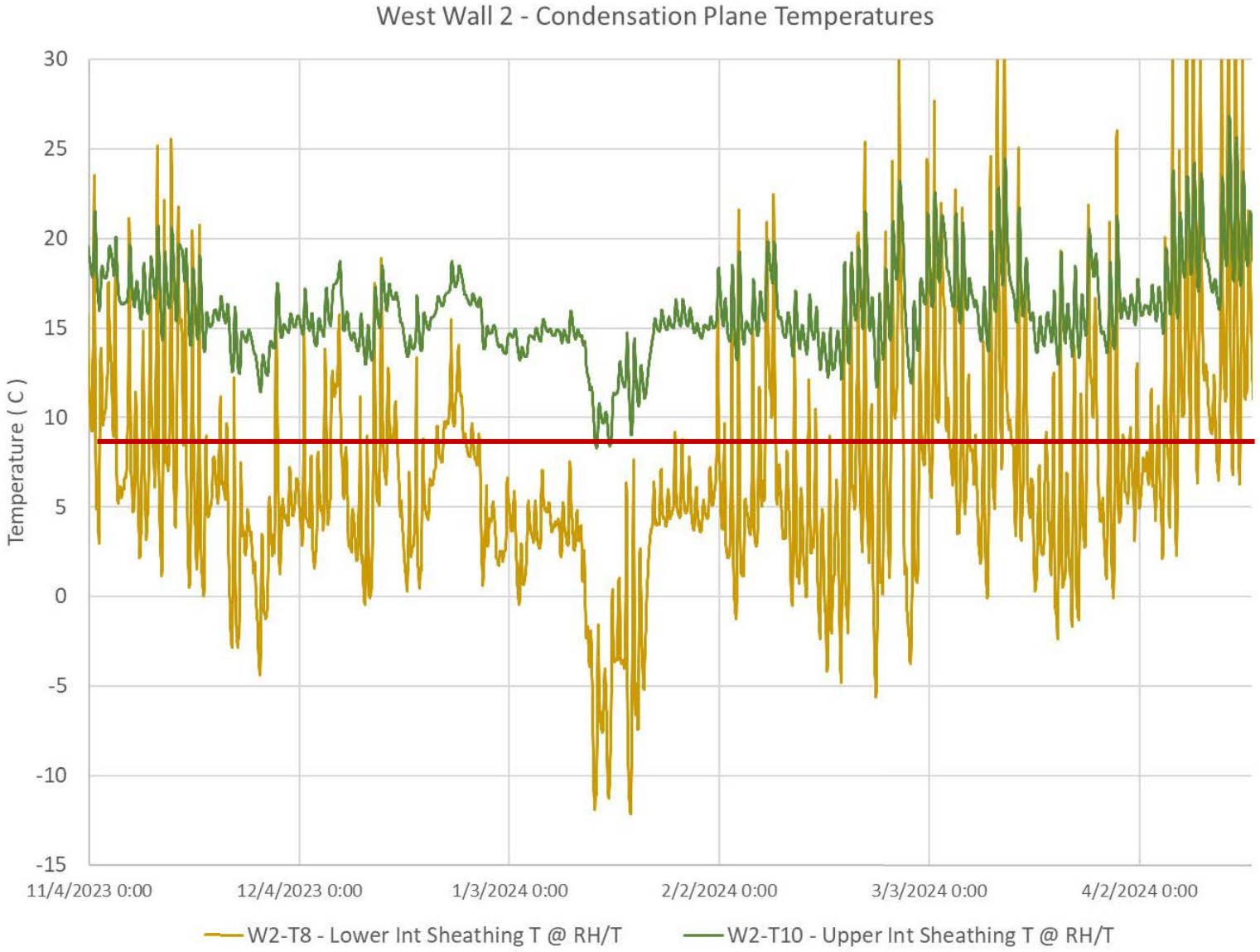
Wall Assembly 2 – Diffusion Analysis

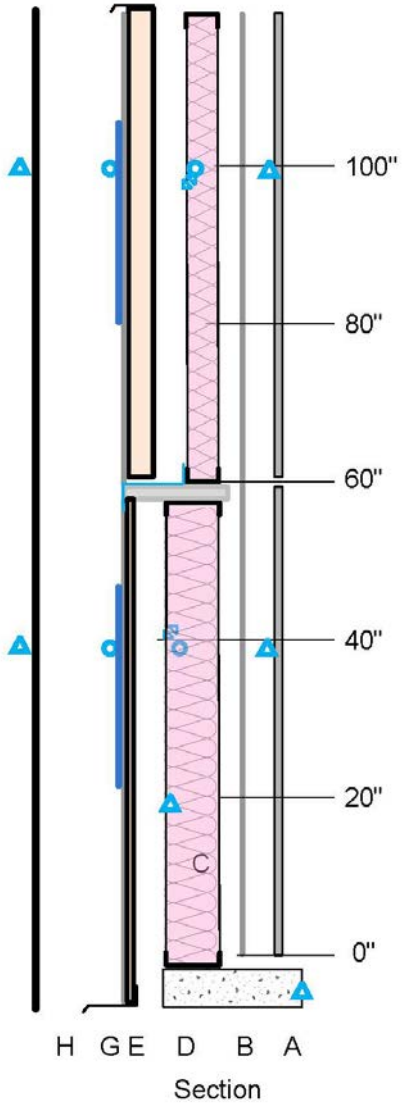




- Relative Humidity and Temperature Sensor Package
- Moisture Content Pins and Temperature Sensor Package
- Temperature Sensor
- Moisture Content Wafer and Temperature Sensor Package
- Moisture Content Pins

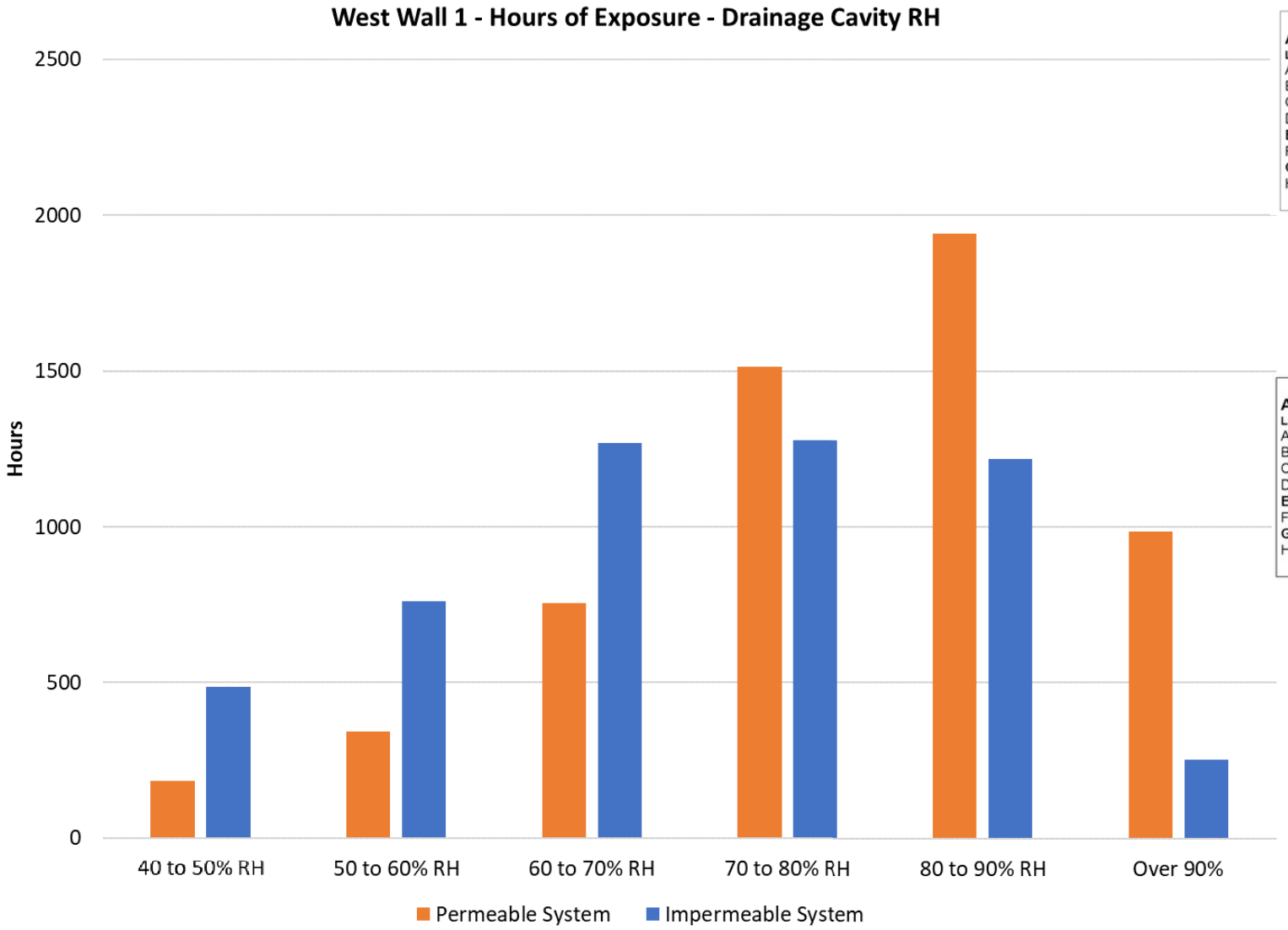
Wall Assembly 2 – Thermal Analysis





Relative Humidity and Temperature Sensor Package
Moisture Content Pins and Temperature Sensor Package
Temperature Sensor
Moisture Content Wafer and Temperature Sensor Package
Moisture Content Pins

Wall Assembly 1 – RH Analysis

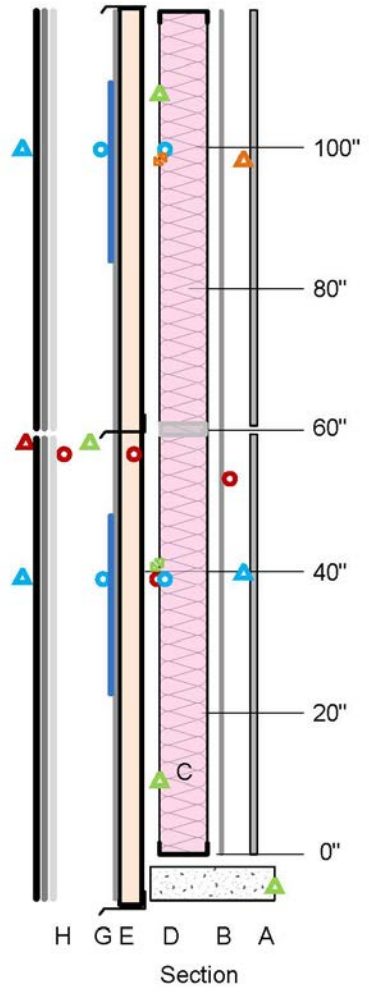


Assembly - Upper

Layer	Function	Description
A	Interior Finish	Painted gypsum
B	Vapor Control	Kraft facing
C	Studspace	R21 Fiberglass batt
D	Framing	2x6 18ga SS
E	**Sheathing**	**2.75" AW+**
F	Sheathing Membrane	inherent
G	**Bond Break Membrane**	**Slicker MAX**
H	Cladding	3-coat Stucco

Assembly - Lower

Layer	Function	Description
A	Interior Finish	Painted gypsum
B	Vapor Control	Kraft facing
C	Studspace	R21 Fiberglass batt
D	Framing	2x6 18ga SS
E	**Sheathing**	**2.75" SP+**
F	Sheathing Membrane	inherent
G	**Bond Break Membrane**	**Delta Lath**
H	Cladding	3-coat Stucco



- Relative Humidity and Temperature Sensor Package
- Moisture Content Pins and Temperature Sensor Package
- Temperature Sensor
- Moisture Content Wafer and Temperature Sensor Package
- Moisture Content Pins

2024-2026 Test Hut Plans

- Data Analysis
  - Lots to do
  - Extrapolation of WUFI® vs real-time data
  - Real-time data vs Carleton test hut data

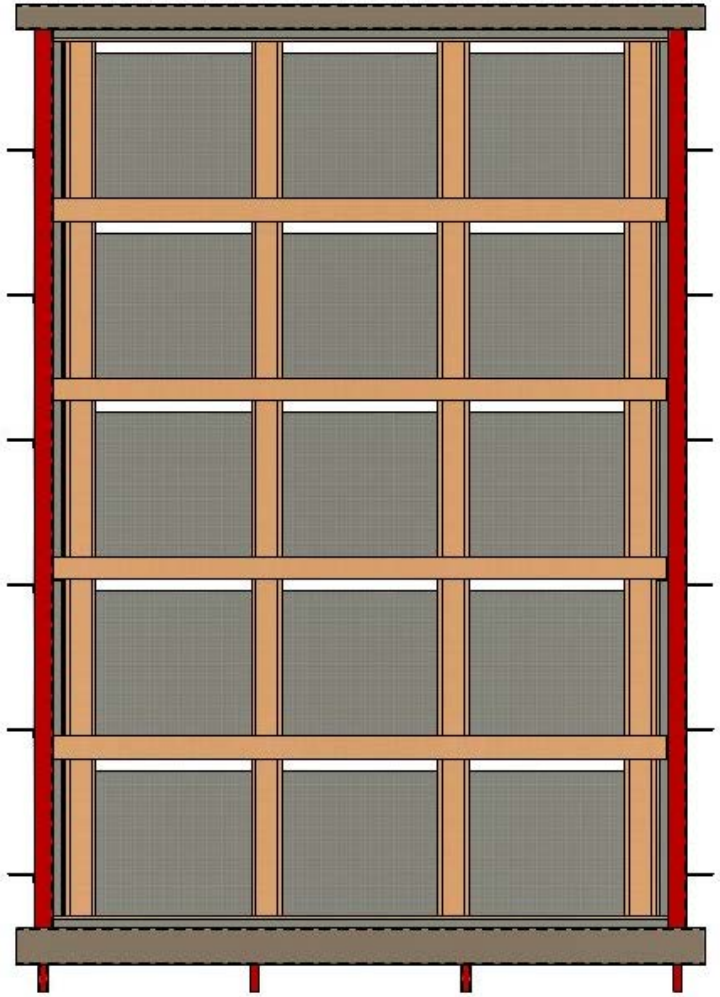
- Late 2024 or early 2025

  - Adding air leakage
  - Adding water leakage

- 2026 Wall Change Out and Destructive Analysis

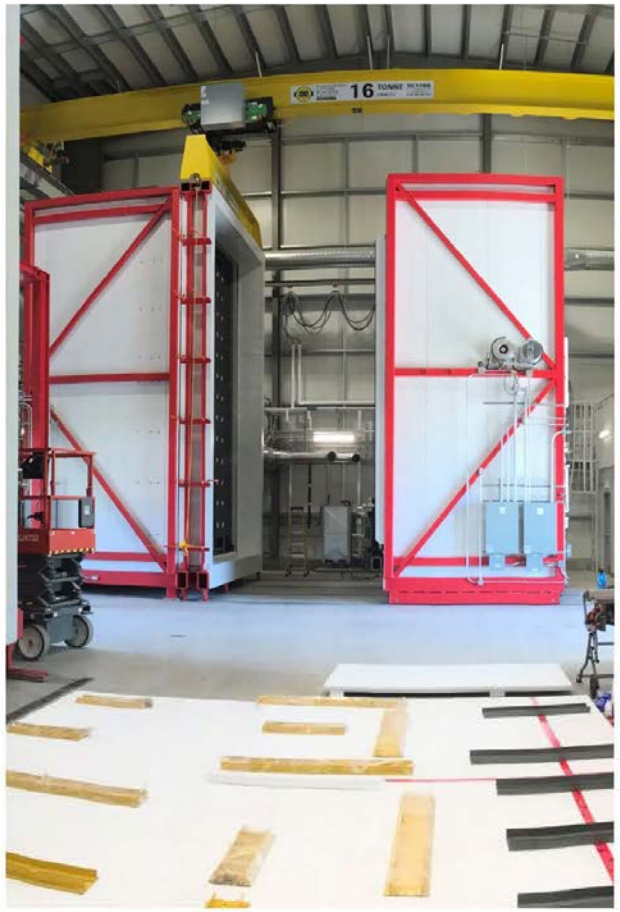
Short-Term, High-Value Climate Chamber Tests
Carleton CABER Facility – Ottawa, Ontario

- Specimens
  - Up to 15 – 4’ x 4’ samples – overall opening 16’ x 25’
  - Any wall makeup we want to test
- Test Plan
  - Many options
  - -22F (-30C) up to 120F (50C)
  - Full-scale pressurized spray rack
  - 20,000 watt Light Rack
  - Diurnal cycles possible
- Quantification (pre and post)
  - Visual review
  - MgO material property measurements
  - Structural testing – fastener withdrawal and bending



DUPONT™

Short-Term, High-Value Climate Chamber Tests
Carleton CABER Facility – Ottawa, Ontario



DUPONT™

Multi-Climate Field Exposure and Evaluation

Goal: **Expose AW products to field conditions and verify durability**

- Duration: 24 months – Collect samples every 6 months
- Monitor Temperature and Humidity in-situ
- Evaluate Walls at Time Zero (no exposure) and at 6, 12, 18 and 24 months of exposure in field

Mini Test Huts for AW Mock Wall Assessment

Mini Test Hut Locations

Tacoma, WA

Midland, MI

Miami, FL

Jyllinge, Denmark

Let’s Talk!

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References / Technical Resources

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Doggett et al, “Magnesium Oxide Panels: Emergence of a Modern Building Material” (https://built-environments.com/wp-content/uploads/2024/04/Magnesium-Oxide-Panels-Emergence-of-a-Modern-Building-Material_032524-3.pdf)

Doggett, “Hygrothermal Analysis of Magnesium Oxide as Structural Insulated Sheathing” (https://built-environments.com/wp-content/uploads/2024/02/Hygrothermal-Analysis-of-Magnesium-Oxide-as-Structural-Insulated-Sheathing.pdf)

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